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Coastal-Change and Glaciological Map of the Larsen Ice Shelf Area, Antarctica: 1940–2005

By Jane G. Ferrigno, Alison J. Cook, Amy M. Mathie, Richard S. Williams, Jr., Charles Swithinbank, Kevin M. Foley, Adrian J. Fox, Janet W. Thomson, and Jörn Sievers

Pamphlet to accompany
Geologic Investigations Series Map I–2600–B

2008

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
Mark D. Myers, Director

U.S. Geological Survey, Reston, Virginia: 2008

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Suggested citation:
Ferrigno, J.G., Cook, A.J., Mathie, A.M., Williams, R.S., Jr., Swithinbank, Charles, Foley, K.M., Fox, A.J., Thomson, J.W., and Sievers, Jörn, 2008, Coastal-change and glaciological map of the Larsen Ice Shelf area, Antarctica: 1940–2005: U.S. Geological Survey Geologic Investigations Series Map I–2600–B, 1 map sheet, 28-p. text.

ISBN 978-1-4113-1910-3

Printed on recycled paper

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Conversion Factors

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer	0.6214	mile (mi)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic kilometer (km^3)	0.2399	cubic mile (mi^3)

Coastal-Change and Glaciological Map of the Larsen Ice Shelf Area, Antarctica: 1940–2005

By Jane G. Ferrigno,[1] Alison J. Cook,[2] Amy M. Mathie,[3] Richard S. Williams, Jr.,[4] Charles Swithinbank,[5] Kevin M. Foley,[1] Adrian J. Fox,[2] Janet W. Thomson,[6] and Jörn Sievers[7]

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. Antarctica is Earth's largest reservoir of glacial ice. Melting of the West Antarctic part alone of the Antarctic ice sheet would cause a sea-level rise of approximately 6 meters (m), and 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). The mass balance (the net volumetric gain or loss) of the Antarctic ice sheet is highly complex, responding differently to different climatic and other 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 known to be 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 that the thinning may be accelerating. Joughin and Tulaczyk (2002), on the basis of ice-flow velocities derived from analysis of synthetic aperture radar data, 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 (2004b) infer a 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 positive on the basis of the change in satellite-altimetry measurements made between 1992 and 2003. On the basis of satellite measurements of Earth's gravity from 2002 to 2005, Velicogna and Wahr (2006) concluded that the mass balance of the Antarctic ice sheet decreased during the period of measurement and that the West Antarctic ice sheet accounted for most of the loss of ice.

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 cryospheric 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, aerial photography, 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 1:1,000,000-scale and one 1:5,000,000-scale USGS Geologic Investigations Series Maps (I–2600) (Williams and others, 1995; Ferrigno and others, 2002; and Williams and Ferrigno, 2005) (available online at http://www.glaciers.er.usgs.gov).

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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 of1:1,000,000-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) 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 the1:1,000,000-scale maps. Each 1:1,000,000-scale map, apart from the three sheets covering the Antarctic Peninsula, extends to the southernmost nunatak within each map area or to the southernmost extent of Landsat images (about lat 81.5º 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.

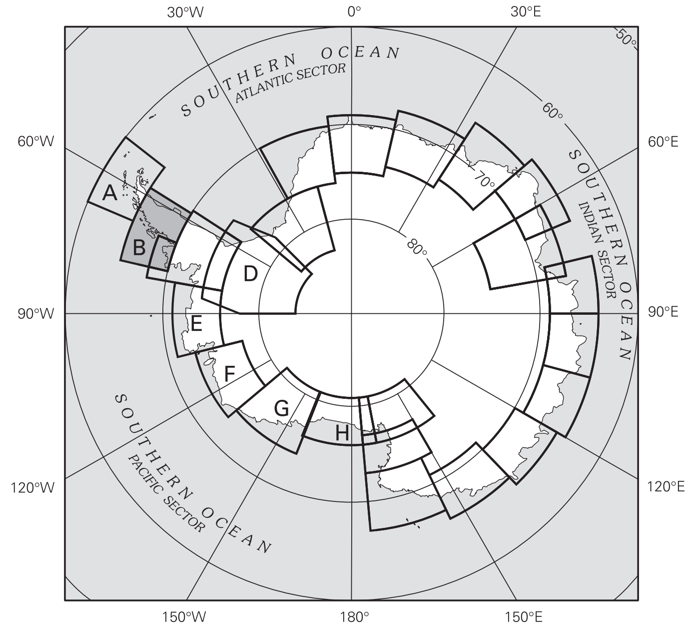

Figure 1. Index map of the planned coastal-change and glaciological maps of Antarctica at 1:1,000,000 scale. The Larsen Ice Shelf area map is shaded. Maps published to date are indicated by letter and described in table 6. They are available printed and online; see table 6 for the URLs.

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. In addition to Landsat and other satellite imagery, this map, as well as the other two Antarctic Peninsula maps [Trinity Peninsula area and South Shetland Islands (map I–2600–A) 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 vertical and (or) oblique aerial photographs acquired from 1940 to 2001 (table 1), maps from 1948 to 1985 (table 2), and manuscripts and publications (References Cited). (Table 2 follows the References Cited; see p. 20.)

The Landsat 4 and 5 TM image base used for the Larsen Ice Shelf area map is derived from images of the Antarctic Peninsula that were digitally mosaicked and georeferenced

Table 1. Vertical and (or) oblique aerial photographs used in analysis of ice-front change for the coastal-change and glaciological map of the Larsen Ice Shelf area.

[Abbreviations used: BAS, British Antarctic Survey; FIDASE, Falkland Islands and Dependencies Aerial Survey Expedition; IfAG, Institut für Angewandte Geodäsie; RARE, Ronne Antarctic Research Expedition; USA TMA, United States of America, Trimetrogon Antarctica]

Date	Source	Scale
1940, 1966, 1968–69	USA TMA vertical and oblique	1:38,000 (vertical)
1947	RARE vertical and oblique	1:18,000, 1:20,000 (vertical)
1956–57	FIDASE vertical	1:26,000, 1:27,000
1962–63, 1986–87, 1989, 1991–96, 1998, 2001	BAS vertical	1:10,000, 1:10,400, 1:11,000, 1:12,600, 1:20,000, 1:24,000, 1:25,000, 1:44,000
1972–74, 1976, 1990	British Royal Navy vertical	1:12,000, 1:20,000
1989	IfAG vertical	1:70,000

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 one Landsat 7 ETM+ scene to complete the coverage of Charcot Island. The coverage areas of the Landsat 1, 2, and 3 MSS images, Landsat 4 and 5 TM images, and Landsat 7 ETM+ images used in the compilation of the printed map are shown on the index maps on the accompanying map. Below the index maps, information about each image is listed.

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

The early Landsat scenes were acquired during the period 1972 to 1979. The Landsat 4 and 5 MSS and TM images date from 1986 to 1991. The Landsat 7 ETM+ images used in the completion of the mosaic and in the analysis of coastline change were digital and dated from 2000 to 2002. 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, RADARSAT images (1997) from the Canadian Space Agency radar satellite, NOAA (National Oceanographic and Atmospheric Administration) Advanced Very High Resolution Radiometer (AVHRR) images (1998, 1999), Moderate Resolution Imaging Spectroradiometer (MODIS) (2002, 2004, and 2005) images, and an image (2002) from the European Space Agency's (ESA) Envisat Advanced Synthetic Aperture Radar (ASAR).

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 use each source most effectively; these methodologies are discussed in the following section. Relative accuracy assigned to each data source is shown in the table below and described more fully in the Coastline Accuracies section. The large amount of information produced as a result of the abundance of data sources and the extensive analysis is generally too complex to portray properly 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:8080/add/

Relative accuracy assigned to each data source.

Source material	Relative accuracy (reliability) compared to IfAG mosaic (1, most accurate)
IfAG mosaic	1
Landsat 1–5 images	1, 2, or 3
Landsat 7 ETM+ images	1 or 2
Vertical aerial photographs	1, 2, or 3
Oblique aerial photographs	2 or 3
Maps and publications	3
Corona satellite photograph	1
European Space Agency Envisat ASAR image	2
Kosmos KATE-200 photographic mosaic	2
RADARSAT images	2 or 3
NOAA images	3
MODIS images	2

IfAG Mosaic

The IfAG Landsat TM image mosaic (30-m pixel resolution) was used as the image base onto which the coastlines were mapped for each of the three USGS-BAS 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 compiled 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 image 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 aerial photographs such as the Falkland Islands and Dependencies Aerial Survey Expedition (FIDASE) photographs (table 1), and with the Antarctic Digital Database (ADD) coastline (British Antarctic Survey and others, 1993; ADD Consortium, 2007).

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 1, 2, and 3 MSS 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 2 or 3.

Landsat 7 ETM+ Images

The Landsat 7 ETM+ images (30-m pixel resolution) were imported digitally and reprojected. Where necessary, an image was registered and rectified. Once correctly positioned, the ice-coast areas (grounded or floating) 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 their reliability was generally high. When it was possible to digitize the ice front or ice wall accurately from the photographs, the ice front or wall was assigned a reliability of 1. In other cases, for example where the photograph was grainy or where features were obscured to a greater or lesser degree by clouds, the information was given a reliability 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, and in these cases it was possible to give a reliability of 1 or 2.

Maps and Publications

Many paper maps and written documents dating back to 1953 show or describe the icebound coast (see table 2 and References Cited). Although such early sources of data are sometimes 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. We were able to determine the position of the ice front on some maps when they were used in conjunction with aerial photographs. Other maps were published at a large enough scale (for example, 1:100,000) to make them usable, and they were assigned a reliability of 3.

Corona Satellite Photograph

One Corona photograph was used to locate the position of the Larsen “B” Ice Shelf front in 1963. This photograph was scanned and georegistered, so that the ice front could be drawn with high accuracy (reliability of 1).

European Space Agency Envisat ASAR Image

One Envisat ASAR image was used to monitor the ice front of Larsen Ice Shelf. It was assigned a reliability of 2.

Kosmos KATE-200 Photographic Mosaic

A satellite photographic mosaic 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.

Other Satellite Images

NOAA images having a resolution of 1 km were given an accuracy of 3. The MODIS (250-m pixel resolution) images were given a reliability of 2 when compared to the IfAG mosaic.

Coastline Accuracies

Reliability 1 (within 60 m)
Accurately digitized from:

- Vertical aerial photographs that have adequate rock-outcrop features for positioning.
- Landsat TM and Landsat 7 ETM+ digital satellite images (good-quality georeferenced imagery).
- Corona photograph (after georegistration).

Reliability 2 (within 150 m)
Interpreted from:

- Vertical aerial photographs that are grainy or in which 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.
- Digital MODIS and Envisat ASAR images having pixel resolutions of 250 m and 25 m, respectively.

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.

Glaciological Features

The Larsen Ice Shelf area map covers the part of the Antarctic Peninsula and adjacent islands, including Adelaide Island and the northern part of Alexander Island, that extends from lat 65º to 70º S., and from long 57º to 78º W. Larsen Ice Shelf is named for Capt. C.A. Larsen, noted Norwegian explorer whose voyages along the east coast of the Antarctic Peninsula in his ship, *Jason*, during 1892–93 marked the beginning of commercial whaling operations in the Antarctic. Larsen led numerous whaling expeditions until his death in 1925. Ten geographic features in the Antarctic have been named in his honor, more than for any other individual.

The map shows the southern part of Graham Land, including Bowman, Fallières, Foyn, Graham, Loubet, Oscar II, Wilkins, and a small part of Danco and Rymill Coasts. All land except for small areas of exposed rock is covered by glacier ice and permanent snow. The most noticeable glaciological feature in the map area is Larsen Ice Shelf on the eastern side of the Antarctic Peninsula. Larsen Ice Shelf is fed by numerous outlet glaciers flowing from the upland areas of the Antarctic Peninsula to the west. In the 1970s, 1980s, and most of the 1990s, the front of the ice shelf extended in an irregular line from Robertson Island to Ewing Island. However, during the late 1990s and early 2000s, major change occurred, and a large part of the northern section of Larsen Ice Shelf (the part from Robertson Island to Jason Peninsula called Larsen B by Vaughan and Doake, 1996) disintegrated.

The coastline of the western side of the Antarctic Peninsula and the adjacent islands appears to be composed mainly of grounded ice walls interspersed with the floating ice fronts of a few noteworthy ice shelves and numerous small (by Antarctic standards) named and unnamed glaciers. On the early photographs and satellite images, Müller, Jones, Wordie, and the northern parts of George VI and Wilkins Ice Shelves were visible in the map area. However, by the early 2000s, Jones and Wordie Ice Shelves had essentially disappeared, Müller Ice Shelf was reduced in size, and George VI and Wilkins Ice Shelves had retreated south of the map boundary (see map I–2600–C).

On the map there are 231 named present and former glaciers and related glaciological features as defined in various scientific glossaries (Armstrong and others, 1973, 1977; Neuendorf and others, 2005), including 190 on the mainland, 8 on Adelaide Island, and 33 on Alexander and Rothschild Islands (table 3).

Glacier Inventory

Producing a sophisticated glacier inventory of the entire continent of Antarctica according to the requirements of the World Glacier Monitoring Service (Müller and others, 1977, 1978), as part of its ongoing “World Glacier Inventory” program, has been impossible with the present state of glaciological knowledge about Antarctica (Swithinbank, 1980). As recently as 2008, the World Glacier Inventory Web site hosted by the National Snow and Ice Data Center (NSIDC) did not include Antarctic data. However, as more remotely sensed data become available and as more scientific interest is focused on Antarctica, more glacier inventories will 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 the northern end of the Antarctic Peninsula on James Ross Island by Rabassa and others (1982). Braun and others (2001) 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), and Rau and others (2004) carried out a thorough GIS inventory of 900 individual glaciers and glaciological features in the northern part of the Antarctic Peninsula.

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 published maps, the USGS Geographic Names Information System (GNIS) database, and the SCAR Composite Gazetteer of Antarctica, we compiled a list of 231 named glaciers and related glaciological features within the Larsen Ice Shelf area map. Coastal-change measurements were made at 102 locations on these named ice fronts. In addition, measurements were made at 72 unnamed glaciers and ice fronts that are described by nearby geographic features and have been given a latitude/longitude identifier (table 4).

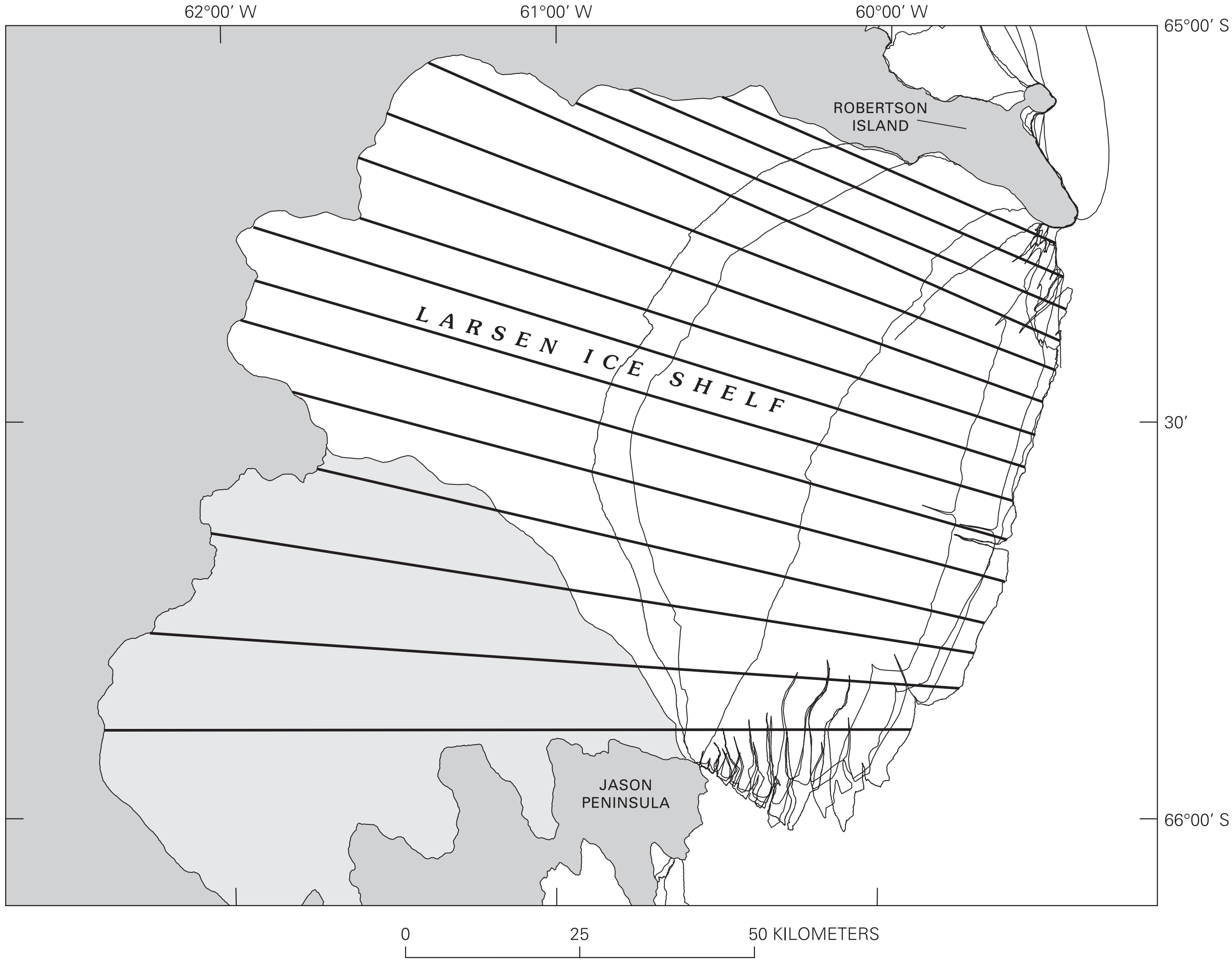

Figure 2. Sample lines drawn for analysis of ice-front change in Larsen "B" Ice Shelf.

Analysis

Methodology for Coastal-Change Analysis

As would be expected, the floating ice fronts, iceberg tongues, and glacier tongues are the most dynamic and changeable features in the coastal regions of Antarctica. The positions of the dynamic ice fronts in this map area as observed on the three sets of Landsat imagery, the aerial photographs, other satellite imagery, and historical data sources, were mapped and annotated with the date for each position. This made it possible to accurately date and analyze changes that have occurred. The drawback of this methodology, regardless of the number 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 occur between observations may be missed.

A total of 7,264 individual measurements of ice-front location using all source data were made on 174 named and unnamed glaciers, ice shelves, and other fluctuating ice-front areas along the glacier-ice coast within the map area. Sample lines—lines extending from the ice front to an established base line—were drawn on each of the 174 ice fronts to measure 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 or larger 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 final results 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, as was the maximum, minimum, and average advance or retreat between each observation. The number of months for each time period was determined and the change per year in meters was calculated.

Discussion of Observed Coastal Changes

After the coastal changes were digitally mapped, it became evident that the magnitude of the change on an annual to decadal basis is often not discernible at 1:1,000,000 scale, the scale of the printed map. We selected coastal-change information to show on the printed map that is of high interest and visible at the map scale. The entire set of mapped changes is included in a digital dataset available at the SCAR ADD Web site hosted by BAS at http://www.add.scar.org:8080/add/

The most dramatic changes that have occurred on the Larsen Ice Shelf area map are (1) the calving of an immense iceberg from Larsen "C" Ice Shelf [8], possibly in early 1986 and originally thought to be 9,000 km^2 (Ferrigno and Gould, 1987) but probably more than 6,000 km^2, on the basis of ice-front positions shown on this map; (2) the rapid retreat of the northern part of Larsen "B" Ice Shelf between 1986 and 2000; and (3) the subsequent rapid disintegration of the remaining northern part of Larsen "B" Ice Shelf in 2002. Although not as noticeable at the scale of the map, other changes also have taken place in the map area, including the retreat and disappearance of Wordie Ice Shelf probably beginning in 1966 (Doake and Vaughan, 1991), the virtual disappearance of Jones Ice Shelf from the early 1970s to 2001 (Morris and others, 2002; Fox and Vaughan, 2005), and the retreat of Müller Ice Shelf (Ward, 1995). In addition, George VI Ice Shelf retreated to its present position south of the boundary of the map between the 1960s and the 1990s (Lucchitta and Rosanova, 1998), and Wilkins Ice Shelf did the same in the 1990s (Vaughan and others, 1993; Lucchitta and Rosanova, 1998; NSIDC [http://nsidc.org/iceshelves/larsenb1999/wilkins.html]). Both George VI and Wilkins Ice Shelves are discussed more thoroughly in the coastal-change and glaciological map of the Palmer Land area (I–2600–C). The overall trend of the changing ice fronts has been retreat, and the more dramatic ice-shelf breakups have been seen first in the northern part of the Antarctic Peninsula and migrating southward.

The retreat of ice shelves, a possible precursor to the deglaciation of West Antarctica predicted by Mercer (1978), has been tied to the significant and consistent warming trend of the peninsula area, documented by King (1994) and others. According to a review by Vaughan and others (2003), the Antarctic Peninsula warming rate of 3.7±1.6°C per century is an order of magnitude larger than the global mean warming rate of 0.6±0.2°C. Many researchers have observed, described, monitored, and analyzed the ongoing changes in the Antarctic Peninsula using field work, a large variety of remotely sensed data, and mathematical modeling, and have discussed the probable mechanics of the retreat. Others have discussed the retreat and the stability or viability of the remaining ice shelves. Beginning with Doake and Vaughan's study of the retreat of Wordie Ice Shelf in 1991, the overall peninsula area has been studied by Vaughan and Doake (1996), Hindmarsh (1996), Hulbe (1997), Rott and others (1998), Skvarca and others (1998, 1999b), Scambos and others (2000, 2003, 2004), Domack and others (2001, 2005), Vaughan and others (2001, 2003), Fahnestock and others (2002), Morris and Vaughan (2003), Skvarca and De Angelis (2003), Cook and others (2005), Rignot and others (2004a), and Ferrigno and others (2006), among others.

Most research has focused on the dramatic changes of the larger ice shelves and their tributary glaciers, but substantial change has been occurring in many smaller ice fronts of this map shown by the 7,264 individual measurements we made on 174 changing ice coastlines using source data from 1940 to 2005. The measurements showed an overall advance on the majority of the smaller ice fronts and glaciers from the 1940s to about 1960, followed by retreat in the 1960s and 1970s. Beginning in the 1990s, retreat was more pronounced and became quite rapid in the late 1990s. Of the 174 measured coast areas, 143 (82 percent) experienced net retreat, often substantial, ranging from hundreds of meters to kilometers. Only 31 (18 percent) (indicated on the map by purple dots) did not have net retreat or had overall average advance, usually only slight to moderate, generally tens of meters. When the figures for all measured ice fronts in the Larsen Ice Shelf area map are compared with those for all measured glaciers throughout the Antarctic Peninsula (Cook and others, 2005), the entire peninsula has a somewhat higher percentage of glacier-ice fronts showing overall retreat (87 percent). This may reflect the more dominant pattern of retreat in the northern part of the peninsula as shown on the Trinity Peninsula area map (I–2600–A) (Ferrigno and others, 2006). Although the 31 cryospheric coastlines that showed net advance are found throughout the map area, it is worth noting that 55 percent (17) are located along the Graham and Danco Coasts in the northwestern part of the peninsula on this map.

Although the Trinity Peninsula area map (Ferrigno and others, 2006) has a somewhat larger percentage of cryospheric coastlines that show overall retreat, this map has a much larger percentage of active ice fronts—ice fronts that have advanced or retreated an average of more than 75 m a^{-1} during some measured time interval. The Trinity Peninsula area map has 46 out of 211 measured locations that were considered active on that basis (22 percent). This map has 93 of 174 measured ice fronts (53 percent) that changed that quickly or faster on average during some measured time interval. Of the 93 ice fronts, 10 are ice shelves that are known to change rapidly by calving and disintegration; the other 83 are not as well known. Of the 83 ice fronts, 66 had an average change during some time interval >100 m a^{-1}, 44 of these >200 m a^{-1}, 25 of these >300 m a^{-1}, 15 of these >400 m a^{-1}, and 7 of these >500 m a^{-1}. The seven locations with the greatest average change during some measured interval were northeastern Adelaide Island, Murphy Glacier, Palestrina Glacier, Snowshoe Glacier, Widdowson Glacier, the unnamed glacier north of Mount Reeves, and the unnamed ice shelf near the Rhyolite Islands.

Some of the measurements of rapid change occur in only one time period for each glacier. However, many ice fronts

[8] Larsen "C" is the part of Larsen Ice Shelf between Jason Peninsula and Gipps Ice Rise as described by Vaughan and Doake, 1996.

have had more than one active phase. When there are multiple periods of rapid change, there is often both rapid advance and rapid retreat. We decided to highlight on the map the 54 measured ice fronts that had an average change >200 m a^{-1} during some time interval since the 1940s. These 54 ice fronts constitute 31 percent of the total measured ice fronts, a percentage greater than those considered to be active on the Trinity Peninsula area map. These locations are shown on the map with red, green, or orange dots. These statistics are based on the measured change for each ice front averaged across the entire ice front. If one were to examine the individual measurements for each ice front, the number of ice fronts having average change >75 m a^{-1} during some time period would increase to 120 (69 percent of the total) and there would be a greater range of change values. The maximum change measured in the map area (other than on ice shelves) occurred on the ice front of northeastern Adelaide Island, where average retreat of more than 2,500 m a^{-1} was measured between 1969 and 1973 at two sample points.

In brief, substantial coastal change is occurring on all parts of the Antarctic Peninsula. Although the changes occurring in the eastern part of the Peninsula are more dramatic and more noticeable, the changes occurring in the western part are equally important and also have the potential of affecting the mass balance of the entire Antarctic Peninsula.

Wordie Ice Shelf

Wordie Ice Shelf, previously quite extensive, located on the western side of the Antarctic Peninsula and centered at approximately lat 69°15´ S., long 67°15´ W., has retreated during the last 40 years and disappeared, except for a few small remnants. Its retreat, noted and described by Doake and Vaughan (1991), inaugurated the increase in scientific interest concerning the changes in the peninsula ice shelves. Historical studies showed that Wordie Ice Shelf filled all of Wordie Bay in 1936 (D.G. Vaughan, BAS, written commun., 1996) when first described by the British Graham Land Expedition. Data from 1948–58 showed that the southern front of the ice shelf extended westward to the Bugge Islands, while the northern front remained fairly stationary (D.G. Vaughan, written commun., 1996). Our measurements, based on airborne and satellite remotely sensed data, begin with 1947 aerial photography and indicate consistent advance from 1947 to 1966 along the ice-shelf front (tables 5*A*, *B*). From 1966 to 1974, our measurements show slight average annual advance on the northern front ranging from 200 to 400 m a^{-1}, and average annual retreat along the southern front ranging from 400 m to 2 km a^{-1}. From 1974 to 1979, retreat occurred along the entire front, averaging from about 200 m a^{-1} to 2,500 m a^{-1}, except in the vicinity of Napier Ice Rise, which appeared to be a "pinning point" for this part of the ice shelf in the 1970s. In 1979 Linchpin Ice Rise was recognized and named for its role in maintaining the position of the ice front at that time. In the 10 years between 1979 and 1989, slight to moderate retreat was seen in the most northern and southern parts of the ice shelf. However, in the central part of the ice shelf, the retreat was much more pronounced, ranging from an average of more than 1,200 m a^{-1} to almost 1,800 m a^{-1} (table 5*A*). Doake and Vaughan (1991) noted that the retreat in the central part of the ice shelf brought the ice front back to the grounding line, essentially dividing the ice shelf in two. They estimated that the area of Wordie Ice Shelf was ~2,000 km^2 in 1966 but only ~700 km^2 in 1989, on the basis of aerial photography and Landsat images. From 1989 to 1992, retreat was seen to continue in the areas where aerial photographic coverage existed (tables 5*A*, *B*). In contrast, from 1992 to 1997, most parts of the ice front advanced, with the greatest advance occurring where the outlet glaciers that formerly fed and formed Wordie Ice Shelf were located (table 5*A* and map inset). This advance was considered to be the natural result of the removal of the buttressing ice shelf. Retreat continued from 1997 to 1999 and from 1999 to 2001 (table 5*A*), with average change as much as 12 km a^{-1}, leaving only a few tiny remnants of the ice shelf. From 2001 to 2004, the floating tongue of Carlson Glacier and some lingering shelf ice in the northern part of the area disappeared; essentially Wordie Ice Shelf had become Wordie Bay.

One of the side effects of the retreat of Wordie Ice Shelf is the loss of several ice rises that had been an integral part of the ice shelf. With the retreat of Wordie Ice Shelf, Napier and Buffer Ice Rises became islands, and their names were modified by the U.S. Advisory Committee on Antarctic Names on 29 November 2005. Linchpin and Miller Ice Rises should be considered historical names, because there is no visible trace of the former ice rises. Reynolds, Wade, and Coker Ice Rises appear to be islands on the latest satellite imagery.

Considering the increased velocity of the tributary glaciers in the Larsen embayment following the disappearance of the buttressing ice shelf, scientists took a closer look at the glaciers flowing into Wordie Ice Shelf/Bay to determine if there was any measurable increase in the velocity. Doake and Vaughan (1991) were not able to determine any velocity change, did not see change in the flowlines of tributary glaciers, and did not think there had been much effect inland at that time. More recently, Rignot and others (2005), using satellite interferometry (InSAR) data and airborne ice-thickness data, compared velocity data acquired 50 km upstream of the grounding line; they concluded that Fleming Glacier was flowing 50 percent faster in 2002 than in 1975, prior to most of the ice-shelf retreat. They also concluded that the tributary glaciers are both thinning and discharging a considerable amount of ice mass—approximately 6.8±0.3 km^3 a^{-1}.

Larsen Ice Shelf

The earliest year of observation of Larsen Ice Shelf recorded on the map is 1963. During the period between 1963 and 1986, the Larsen "B" ice front gradually advanced, extending seaward of Robertson Island and Jason Peninsula. Between 1986 and 1997, the ice front calved back as much as 30 km to a more stable position, essentially in a semi-straight line from Robertson Island to Jason Peninsula. After the

Table 5*A*. Average annual change of the ice front of Wordie Ice Shelf 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. Location numbers refer to site of sample lines drawn in Wordie Ice Shelf area, similar to lines shown in figure 2. The numbering sequence begins at the northern end of the ice shelf. For more detailed information, see complete digital file at http://www.add.scar.org:8080/add/]

Date	1947	1966	1974	1979	1989	1992	1997	1999	2001
Reliability[1]	2	3	2	2	1	1	2/3	3	1
Location									
1.	#	+419	-186	-1,355	-108	-48	-16	-1,693	+81
2.	#	+479	+394	-2,564	-32	-192	-249	-909	+385
3.	#	+505	+222	-735	-390	-2,094	-244	-94	-973
4.	#	+367	+413	-954	-208	-2,220	+2,085	-8,798	-1,275
5.	#	+375	+313	-1,258	0		+2,712	-11,171	+392
6.	#	+429	+246	-554	-551		+12	-12,075	+256
7.	#	+433	+254	-616	-600		+155	-11,844	-1,180
8.	#	+422	+201	-671		-610	+308	-1,143	-9,033
9.	#	+443	+209	-732	-627		+333	+711	-10,412
10.	#	+498	+ 78	-683	-665		+170		-6,471
11.	#	+517	-3	-561	-1,701		+1,627		-6,284
12.	#	+637	-416	-1,116	-1,687		+2,114		-6,491
13.	#	+605	-686	-1,093	-1,435	-7	+3,977		-5,809
14.	#	+445	-1,007	-687	-1,788	+472	+2,071		-3,588
15.	#	+457	-1,205	-609	-1,702		+1,336		-3,774
16.	#	+597	-1,648	-402	-1,487		+663		-1,985
17.	#	+475	-1,604	-4	-1,244		+721		-3,936
18.	#	+388	-1,688	-219	-79		-373		-2,584
19.	#	+306	-1,705	-1,124	+4	-2,047	+3,683		-5,411
20.	#	+266	-1,939	-953	-10	-15	+2,232		-3,453
21.	#	+197	-2,151	-1	-3	-2			+4
22.	#	+7	-811		-2	+2			-4

[1] For explanation, see Coastline Accuracies section of pamphlet.

Table 5*B*. Source materials for coastal-change measurements of Wordie Ice Shelf.

[Reliability ranking is explained in the Coastline Accuracies section of this pamphlet. Abbreviations used: RARE, Ronne Antarctic Research Expedition; USA TMA, United States of America, Trimetrogon Antarctica; MSS, Multispectral Scanner; TM, Thematic Mapper; BAS, British Antarctic Survey; AVHRR, Advanced Very High Resolution Radiometer; ETM+, Enhanced Thematic Mapper Plus]

Date	Type	Reliability	Identification
21 Nov 1947	Aerial photography	2	RARE 1:20,000 (vertical)
Nov/Dec 1966	Aerial photography	3	USA TMA 1835 1:38,000 (vertical)
6 Jan 1974	Satellite image	2	Landsat 1 MSS (1532-12325; Path 233, Row 109)
3 Feb 1979	Satellite image	2	Landsat 3 MSS (30335-12253; Path 233, Row 109)
20 Feb 1989	Satellite image	1	Landsat 4 TM (42411–12441; Path 218, Row 109)
27 Dec 1992	Aerial photography	1	BAS 1:20,000 scale
1 Oct 1997	Satellite image	3	RADARSAT
29 Jan 1999	Satellite image	3	AVHRR BAS Aries
4 Jan 2001	Satellite image	1	Landsat 7 ETM+ (LE718109000100451)
28 Jan 2001	Aerial photography	1	BAS 1:20,000 scale

complete disintegration of Larsen “A” Ice Shelf in 1995 (see map I–2600–A [Ferrigno and others, 2006]), many researchers intensively monitored and analyzed the characteristics and stability of Larsen “B” Ice Shelf (Rott and others, 1996, 1998, 2002; Doake and others, 1998; Rack and others, 1999, 2000; Skvarca and others, 1999a, 2004; Bindschadler and others, 2002; and Shepherd and others, 2003). From 1997 to 2000, the Larsen “B” ice front retreated as much as another 30 km, much of which occurred between February 1998 and March 1999 (T.A. Scambos, 1999, written commun.). This retreat calved an area of more than 2,300 km^2, and the total 1986-to-2000 retreat involved the loss of more than 4,550 km^2 of ice shelf. Then, during a 35-day period from 31 January to 7 March 2002, there was a sudden and complete disintegration of northern Larsen “B” Ice Shelf that brought the ice front back to the grounding line. The total loss of ice from this event was 3,250 km^2 (T.A. Scambos, written commun., 21 March 2002; Scambos and others, 2003). Since 2002, the ice front (the former grounding line) of northern Larsen “B”, north of Cape Disappointment, has retreated farther, the remaining southern part of Larsen “B” Ice Shelf has calved an additional almost 500 km^2 of ice, and melt ponds can be seen on the surface where Leppard and Flask Glaciers enter the shelf. Scambos and others (2000) discussed the role of meltwater ponding on the surface of the ice shelf that is often one of the first visible signs of impending breakup; the supraglacier-meltwater pond formation also accelerates the breakup by contributing to the process of rapid disintegration.

Although ice fronts of glaciers and ice shelves commonly fluctuate in response to surrounding conditions, the collapse of Larsen “B” Ice Shelf is unprecedented in respect to both area and time. The ice shelf has been in place for at least the last 11,000 years (Domack and others, 2005). According to Domack and others (2005), the collapse is most likely due to long-term thinning and recent prolonged warming in the Antarctic Peninsula region.

Originally, there was some debate about whether the disappearance of buttressing ice shelves would have an effect on the glaciers flowing into the ice shelves. But observations on both Larsen “A” (Bindschadler and others, 1994; Rack and others, 1999; Rott and others, 2002; De Angelis and Skvarca, 2003) and Larsen “B” Ice Shelves (De Angelis and Skvarca, 2003; Scambos and Bohlander, 2003; Rack and Rott, 2004; Rignot and others, 2004a; Scambos and others, 2004) have shown a significant increase in the velocity of former tributary glaciers and a marked lowering of the glacier surface in response to the velocity increase. See the section on Outlet-Glacier, Ice-Stream, and Ice-Shelf Velocities below for more discussion of ice-velocity measurements in the area.

Additional evidence of the changing conditions in the area can be seen by inspecting recent satellite imagery of the surrounding land areas. More rock outcrops and much less snow and ice cover appear to be present than can be seen in satellite imagery of earlier years, possibly indicative of warmer conditions in the areas around the ice shelf.

Jones Ice Shelf

Jones Ice Shelf, previously centered at lat 67°30´ S., long 67° W., was first visited and surveyed in 1949 (Fox and Vaughan, 2005). At that time, it covered Jones Channel between Arrowsmith Peninsula and Blaiklock Island (fig. 3) and was a little less than 25 km^2 in area. By 2001, it was only a tiny remnant, and by 2003, it had disappeared. Its retreat was described by Fox and Vaughan (2005) on the basis of analysis of aerial photography and satellite imagery.

Jones Ice Shelf is the smallest of the named ice shelves on the map, but it is worthy of more discussion, because along with Müller Ice Shelf it had been one of the most northerly substantial ice shelves on the western side of the Antarctic Peninsula (Fox and Vaughan, 2005). Its retreat illustrates the migration of the climatic limit of viability for ice shelves proposed by Mercer (1978) and examined by Vaughan and others (2001) and Morris and Vaughan (2003). Jones Ice Shelf, fed primarily by Heim Glacier, had a roughly stable area from 1947 to 1969 (Fox and Vaughan, 2005). In contrast to most ice shelves, it had two ice fronts, one to the east and one to the west. From 1969 to 2001, the eastern part of Jones Ice Shelf retreated in a linear manner. The western part behaved quite differently, remaining pinned to a small ice rise until about 1991, then retreating very rapidly until 2001 (fig. 3). The different pattern of retreat of the two ice fronts suggests that the geometry of the embayment is as important to retreat as climate (Fox and Vaughan, 2005).

Other observations revealed changing ice conditions that may reflect changing climatic conditions in the area. Splettstoesser (1992) reported the disappearance of the ice ramp connecting Northeast Glacier to Stonington Island in Marguerite Bay. Fox and Cooper (1998) noted the reduction in the areal extent of small snow and ice masses in the Marguerite Bay area on the basis of inspection of aerial photography. Smith and others (1998) reported lowering of the ice ramp at Rothera Point, on Adelaide Island, from repeated ground surveys.

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

Only a few ice-velocity measurements were made in this map area prior to 2000. In 1972, C.S.M. Doake surveyed Fleming Glacier at a site 50 km upstream from the grounding line where the velocity was ~200 m a^{-1} (Doake and Vaughan, 1991). Most of the ice-velocity measurements in the area have been made recently as part of the studies of ice-shelf retreat and the resulting changes in tributary glaciers. Doake and Vaughan (1991) used satellite images from 1974, 1979, 1986, 1988, and 1989 to derive velocities at the front of Wordie Ice Shelf. They found three distinct ice-flow regions. The ice in the northern part of the ice shelf, flowing from Hariot Glacier, was moving ~200 m a^{-1} between 1986 and 1989. The ice tongue from the northern part of Forster Ice Piedmont, supplied by Airy, Seller, and Fleming Glaciers, was flowing ~1,800 m a^{-1} between 1986 and 1988 and increased in veloc-

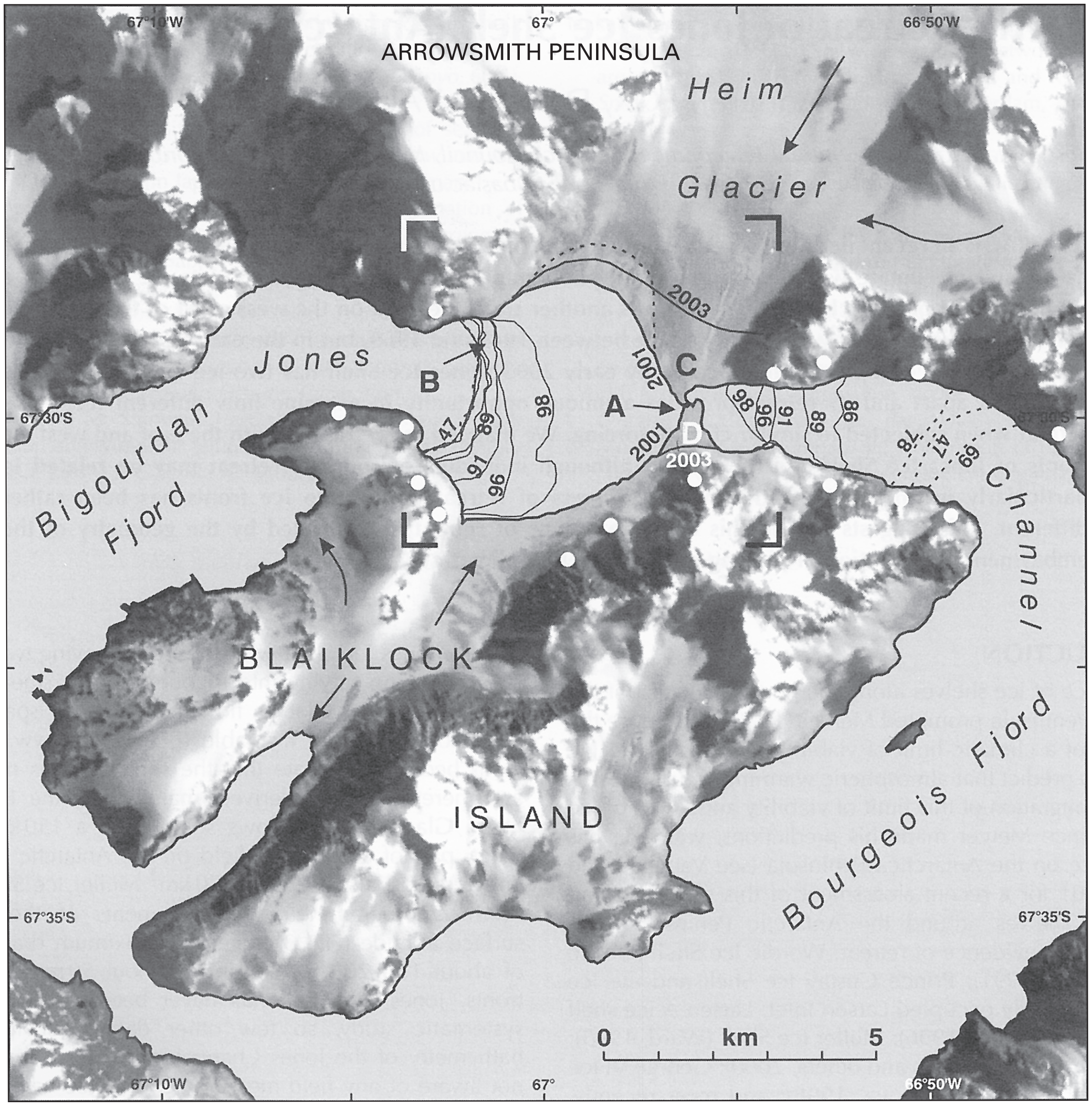

Figure 3. Positions of the east and west ice fronts of Jones Ice Shelf, derived from vertical and oblique aerial photography and Landsat TM and MSS imagery. The boundary between the east and west parts of the ice shelf is a line between C and D. Because of scale limitations, not all the ice-front positions shown here are portrayed on the map. Reprinted from the Journal of Glaciology (Fox and Vaughan, 2005) and used with permission of the authors and the International Glaciological Society.

ity to 2,000 m a^{-1} in 1988 and 1989. The ice in the southern part of the ice shelf, flowing primarily from Prospect Glacier, moved ~600 m a^{-1} from 1974 to 1979, and ~1,000 m a^{-1} in 1988 and 1989.

Rignot and others (2005) used European Remote Sensing (ERS) satellite ERS-1 and -2 interferometry and speckle tracking on RADARSAT data to measure ice velocity in the Wordie Ice Shelf/Bay area. They determined essentially no acceleration on the grounded ice between 1995 and 2004, but a 50 percent increase in velocity, from ~200 to ~300 m a^{-1}, between 1974 and 1996 on the Fleming Glacier where Doake had carried out ground surveys in 1972.

During joint field campaigns in 1997 and 1999, the Glaciology Division of the Instituto Antártico Argentino and Innsbruck University's Institute for Meteorology and Geophysics carried out static differential global positioning system (GPS) measurements on Larsen "B" Ice Shelf (Rott and others, 1998; Skvarca and others, 1999a). Their measurements showed an average ice velocity of 24.6 m a^{-1} on the northernmost part of Larsen "B", 320 m a^{-1} in the southern area of Larsen "B", and a range of 400 to 445 m a^{-1}, increasing near the ice front, in the middle part of Larsen "B".

Scambos and others (2004) used Landsat 7 images from January 2000 to February 2003 and ICESat (Ice, Cloud, and land Elevation Satellite) laser altimetry data from February, March, and September 2003 to measure a twofold to sixfold increase in velocity of four glaciers flowing into the location of the former Larsen "B" Ice Shelf and to record a lowering of Hektoria Glacier by 38 m during a six-month period, beginning one year after the breakup of Larsen "B". As would be expected, the greatest velocity increase was in the lower reaches of the glaciers. They reported that, in the lower reaches, Crane Glacier had increased from ~550 m a^{-1} in 2001 to almost 1,500 m a^{-1} in 2003, Green Glacier had increased from ~350 m a^{-1} in 2001 to almost 1,500 m a^{-1} in 2003, and Hektoria Glacier had increased from ~350 m a^{-1} in 2001 to more than 1,800 m a^{-1} in 2003. Jorum Glacier also increased in velocity, but less dramatically.

Rignot and others (2004a) used radar interferometry (InSAR) data from ERS and RADARSAT from 1996 to 2003 to determine the velocity increase in both Larsen Ice Shelf and former tributary glaciers after the breakup of Larsen "B". They found a 20 percent increase (100 m; from 500 to 600 m a^{-1}) in the velocity of Larsen Ice Shelf between 1996 and 2000. They also found that Hektoria, Green, and Evans Glaciers had accelerated eightfold at the grounding line (from ~275 to ~2,200 m a^{-1}) between October 2000 and October 2003, and that Crane Glacier had accelerated twofold by October 2003 (from >500 to >1,000 m a^{-1}) and threefold by late 2003 (>1,500 m a^{-1}). They computed thinning rates of tens of meters per year and noted that the calving fronts of some glaciers were situated inland of their 1996 grounding lines.

Both Rignot and others (2004a) and Scambos and others (2004) confirm the role of the buttressing ice shelf by noting that Flask and Leppard Glaciers, still buttressed by the remnant of Larsen "B" Ice Shelf, show little to no change in velocity or elevation. The implications of the acceleration of former tributary glaciers are substantial mass loss to the Antarctic Peninsula (27 km^3 a^{-1} in the Larsen embayment area according to Rignot and others [2004a]) and a contribution to the rise in global sea level.

Map Revisions and Comparisons

As discussed in the Sources section and the Analytical and Other Methodologies section, the Larsen Ice Shelf area map was compiled from analysis of geographic and glaciologic features on Landsat 1–5 images and Landsat 7 ETM+ 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 (generated from aerial photographs and reconnaissance ground surveys) and the modern, satellite-derived sources. Significant retreat of the glaciers in the Larsen Ice Shelf map area during the last few decades created the need for new maps to show change. This map documents changes at 1:1,000,000 scale. A new satellite-image map of Adelaide Island and Arrowsmith Peninsula was published by BAS and BKG in 2001, and BAS has plans for other new maps in the region.

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 (2000–2002), and other satellite imagery and historical data of the Larsen Ice Shelf area made it possible to identify and describe glaciological features, document coastal change, and look for trends in the changing cryospheric coastline. The analysis resulted in this map and a digital database and was a cooperative endeavor between the USGS and BAS.

The Larsen Ice Shelf area map covers the part of the Antarctic Peninsula that extends from lat 65º to 70º S. and from long 57º to 78º W. All land except for small areas of exposed rock is covered by glacier ice and permanent snow.

The main glaciological feature in the map area on the eastern side of the Antarctic Peninsula is Larsen Ice Shelf. The coastline of the western side of the Antarctic Peninsula and the adjacent islands is composed mainly of grounded ice walls interspersed with the floating ice fronts of a few noteworthy ice shelves and numerous small (by Antarctic standards) named and unnamed glaciers. There are 231 named glaciological features: 190 on the mainland, 8 on Adelaide Island, and 33 on Alexander and Rothschild Islands. There are 72 unnamed glaciers and ice fronts where measurable coastal change has occurred.

Changes that have taken place in the Larsen Ice Shelf map area include the retreat and disappearance of Wordie Ice Shelf, the disappearance of Jones Ice Shelf, and the retreat of Müller Ice Shelf, but the most dramatic changes that have occurred are (1) the calving of an immense—larger than 6,000 km^2—iceberg from Larsen "C" Ice Shelf, possibly in early 1986, (2) the rapid retreat of the northern part of Larsen "B" Ice Shelf between 1986 and 2000, and (3) the subsequent rapid disintegration of the remaining northern part of Larsen "B" in 2002.

A total of 7,264 individual measurements of ice-front location were made on 174 glaciers, ice shelves, and other changing ice coastlines using data from 1940 to 2005. The measurements showed an overall advance on the majority of the smaller ice fronts and glaciers from the 1940s to about 1960, followed by retreat in the 1960s and 1970s. Beginning in the 1990s, retreat was more pronounced and became more rapid in the late 1990s. Of the 174 measured coastlines, 142 (82 percent) showed average overall retreat, often substantial, ranging from hundreds of meters to kilometers. Observations by many scientists have shown a substantial increase in the velocity of tributary glaciers and a lowering of the glacier surface after the disappearance of adjacent ice shelves, confirming the buttressing role of the ice shelves. The map portrays one of the most rapidly changing areas on Earth, and the changes in the map area are widely regarded as among the most profound, unambiguous examples of the effects of global warming on Earth (T.A. Scambos, 2006, written commun.).

Acknowledgments

We would like to acknowledge the outstanding support provided for the preparation of this map by numerous individuals. Christopher G. Rapley, former Director, BAS, is thanked for his enthusiastic support of the project. Other BAS staff also helped considerably; David G. Vaughan provided satellite imagery and advice, and Olivier Cottray and Nicholas McWilliam assisted with image processing. Charles Swithinbank's participation in the project was made possible by the much-appreciated support of Jerry C. Comati, Chief, Environmental Sciences Branch, U.S. Army Research, Development, and Standardization Group (London, United Kingdom) of the U.S. Army Materiel Command. We are indebted to Dann S. Blackwood, USGS (Woods Hole, Mass.) and the late Lewis V. Thompson, USGS (Reston, Va.) for assistance with custom photographic processing of Landsat images. Mark Fahnestock, Ted Scambos, and John Splettstoesser gave very helpful reviews. Funding for the project was provided by the USGS commitment to the multi-Federal agency U.S. Climate Change Science Program, the U.S. part of the International Geosphere-Biosphere Programme.

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Appendix—Tables 2, 3, 4, and 6

Table 2. Maps used as source materials for the coastal-change and glaciological map of the Larsen Ice Shelf area.

[Abbreviations of areas covered: Adelaide, Adelaide Island; Black, Black Coast; Churchill, Churchill Peninsula; Detroit, Detroit Plateau; Graham, Graham Land; Hearst, Hearst Island; Larsen_B, Larsen "B" Ice Shelf; Larsen_C, Larsen "C" Ice Shelf; Loubet, Loubet Coast; Marg_Bay, Marguerite Bay; Oscar II, Oscar II Coast; Robertson, Robertson Island; SW_Alex, SW Alexander Island; Wilkins, Wilkins Coast; Wordie, Wordie Ice Shelf. Other abbreviations: BAT, British Antarctic Territory; BGLE, British Graham Land Expedition 1934–37; DCS, Great Britain Directorate of Colonial Surveys; 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; RARE, Ronne Antarctic Research Expedition 1947–48; USAAF, United States Army Air Force; 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
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).
Larsen_B, Larsen_C, Churchill Oscar II	Pub.	DCS	1949	DCS 701	1st (Provis.)	1:500,000	PM/GB/02/C/01/D	FID – South Shetlands and Graham Land; Sheet D	Compiled from unpub. 1:200,000 FIDS surveys (1947); BGLE map (1938); Admiralty Chart no. 3175 (1940).
Wilkins, SW_Alex, Marg_Bay	Pub.	DCS	1949	DCS 9	1st (Provis.)	1:500,000	PM/GB/02/C/01/F	FID – South Shetlands and Graham Land; Sheet F	Compiled from Admiralty Chart no. 3175 (1940) and BGLE unpub. maps (1934–37).
Wilkins, SW_Alex, Marg_Bay	Pub.	DCS	1950	DCS 701	1st (Provis.)	1:500,000	PM/GB/02/C/01/G	FID – South Shetlands and Graham Land; Sheet G	Compiled from Admiralty Chart no. 3175 (1940) and BGLE unpub. maps (1934–37).
Larsen_B, Larsen_C, Hearst	Pub.	DCS	1949	DCS 701	1st (Provis.)	1:500,000	PM/GB/02/C/01/H	FID – South Shetlands and Graham Land; Sheet H	Compiled from unpub. 1:200,000 surveys by FIDS (1947–48).
Wilkins, SW_Alex, Marg_Bay	Pub.	DCS	1948	DCS 9	1st (Provis.)	1:500,000	PM/GB/02/C/01/J	FID – South Shetlands and Graham Land; Sheet J	Compiled from U.S. Hydrographic Office Chart (1946); USAAF Chart (1943).
Wilkins, SW_Alex, Marg_Bay	Pub.	DCS	1948	DCS 9	1st (Provis.)	1:500,000	PM/GB/02/C/01/K	FID – South Shetlands and Graham Land; Sheet K	Compiled from U.S. Hydrographic Office Chart (1946); USAAF Chart (1943).

Table 2. Maps used as source materials for the coastal-change and glaciological map of the Larsen Ice Shelf area.— Continued

[Abbreviations of areas covered: Adelaide, Adelaide Island; Black, Black Coast; Churchill, Churchill Peninsula; Detroit, Detroit Plateau; Graham, Graham Land; Hearst, Hearst Island; Larsen_B, Larsen "B" Ice Shelf; Larsen_C, Larsen "C" Ice Shelf; Loubet, Loubet Coast; Marg_Bay, Marguerite Bay; Oscar II, Oscar II Coast; Robertson, Robertson Island; SW_Alex, SW Alexander Island; Wilkins, Wilkins Coast; Wordie, Wordie Ice Shelf. Other abbreviations: BAT, British Antarctic Territory; BGLE, British Graham Land Expedition 1934–37; DCS, Great Britain Directorate of Colonial Surveys; 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; RARE, Ronne Antarctic Research Expedition 1947–48; USAAF, United States Army Air Force; 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
Loubet	Pub.	DCS	1954	DCS 601	1st	1:200,000	PM/GB/02/ D/01/6766	FID – Sheet 67 66; Loubet Coast	Survey traverses by Blaiklock, K.V. (1948–50); Mason, D.P. (1946–48) and Freeman, R.L. (1946–48).
Adelaide	Pub.	DCS	1954	DCS 601	1st	1:200,000	PM/GB/02/ D/01/6768	FID – Sheet 67 68; Adelaide Island	Survey traverses by Blaiklock, K.V. (1948–50), Charcot 2d expedition (1908–10), and Admiralty Chart no. 3571 (1952).
Graham	Pub.	DCS	1955	DCS 601	1st	1:200,000	PM/GB/02/ D/01/6664	FID – Sheet 66 64; Darbel Bay	Selected FIDS traverses (1934–37) and sketched from the air by A. Stephenson, BGLE (1934–37).
Larsen_B, Larsen_C	Pub.	DCS	1955	DCS 601	1st	1:200,000	PM/GB/02/ D/01/6660	FID – Sheet 66 60; Jason Peninsula	Surveyed by Stratton, D.G. (1952–54).
Hearst, Black	Pub.	DCS	1955	DCS 601	1st	1:200,000	PM/GB/02/ D/01/6960	FID – Sheet 69 60; Ewing Island	Joint FIDS and RARE party (1947–48).
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.
Graham	Pub.	DOS	1959	DOS 610 Series D501	1st	1:200,000	PM/GB/02/ D/01/6564	FID – Sheet W 65 64; Grandidier Channel	Based on FIDASE aerial photography (1956–57).

Table 2. Maps used as source materials for the coastal-change and glaciological map of the Larsen Ice Shelf area. — Continued

[Abbreviations of areas covered: Adelaide, Adelaide Island; Black, Black Coast; Churchill, Churchill Peninsula; Detroit, Detroit Plateau; Graham, Graham Land; Hearst, Hearst Island; Larsen_B, Larsen "B" Ice Shelf; Larsen_C, Larsen "C" Ice Shelf; Loubet, Loubet Coast; Marg_Bay, Marguerite Bay; Oscar II, Oscar II Coast; Robertson, Robertson Island; SW_Alex, SW Alexander Island; Wilkins, Wilkins Coast; Wordie, Wordie Ice Shelf. Other abbreviations: BAT, British Antarctic Territory; BGLE, British Graham Land Expedition 1934–37; DCS, Great Britain Directorate of Colonial Surveys; 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; RARE, Ronne Antarctic Research Expedition 1947–48; USAAF, United States Army Air Force; 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
Robertson	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).
Marg_Bay	Pub.	DOS	1963	DOS 610 Series D501	1st	1:200,000	PM/GB/02/ D/01/6968	BAT – Sheet W 69 68; Marg. Bay and George VI ice front	Compiled from RARE aerial photography (1947–48).
Wilkins, SW_Alex	Pub.	DOS	1963	DOS 610 Series D501	2d	1:200,000	PM/GB/02/ D/01/6866	BAT – Sheet W 68 66; Graham Land	Compiled from RARE aerial photography (1947–48).
Wordie	Pub.	DOS	1963	DOS 610 Series D501	2d	1:200,000	PM/GB/02/ D/01/ 6966 (2)	BAT – Sheet W 69 66; Graham Land	Compiled from RARE aerial photography (1947–48).
Detroit	Unpub.		1979			1:250,000	ES2/ EW1000A /217	Robertson Island	Compiled by Harris, J.S.; coastline date is 1977.
Larsen_B, Larsen_C, Hearst	Pub.	USGS Dept. of the Interior	1979	Antarctica Sketch Map		1:500,000	PM/US/02/ C/02	Palmer Land (North Part)	Compiled from U.S. Navy Tricamera aerial photography (1966–69).
SW_Alex	Unpub.		1985			1:236,000	K9603/1/ Pu25	Ronne Entrance East Part	U.K. Hydrographic chart (shows ice front of George VI Sound and Stange Sound in 1985).

Table 3.—Inventory of named glaciers and glaciological features on the coastal-change and glaciological map of the Larsen Ice Shelf area.

[Bold italic type indicates that glacier or glaciological feature has fluctuated an average of more than 200 m a^{-1} during some time period since the 1940s]

Geographic Place-name	Glaciological Description
Adelaide Island	
Fuchs Ice Piedmont	ice piedmont
Horton Glacier	outlet glacier
Hurley Glacier	outlet glacier
Shambles Glacier	outlet glacier
Sheldon Glacier	outlet glacier
Sloman Glacier	outlet glacier
Turner Glacier	outlet glacier
Wormald Ice Piedmont	ice piedmont
Alexander and Rothschild Islands	
Bartók Glacier	valley glacier
Bishop Glacier	outlet glacier
Bongrain Ice Piedmont	ice piedmont
Clarsach Glacier	valley glacier
Coulter Glacier	outlet glacier
Delius Glacier	valley glacier
Foreman Glacier	valley glacier
Frachat Glacier	outlet glacier
Geelan Ice Piedmont	ice piedmont
Gerontius Glacier	valley glacier
Gilbert Glacier	glacier
Hampton Glacier	outlet glacier
Lennon Glacier	outlet glacier
McManus Glacier	valley glacier
Mikado Glacier	valley glacier
Moran Glacier	outlet glacier
Mozart Ice Piedmont	ice piedmont
Nichols Snowfield	snowfield
Palestrina Glacier	outlet glacier
Paulus Glacier	valley glacier
Roberts Ice Piedmont	ice piedmont
Rosselin Glacier	valley glacier
Sedgwick Glacier	outlet glacier
Sibelius Glacier	glacier
Siegfried Glacier	outlet glacier
Sullivan Glacier	valley glacier
Toynbee Glacier	outlet glacier
Tumble Glacier	outlet glacier
Wager Glacier	outlet glacier

Geographic Place-name	Glaciological Description
Alexander and Rothschild Islands—Continued	
Wagner Ice Piedmont	ice piedmont
Walter Glacier	outlet glacier
Wilkins Ice Shelf	ice shelf
Wubbold Glacier	outlet glacier
Bowman Coast	
Ahlmann Glacier	outlet glacier
Aphrodite Glacier	outlet glacier
Apollo Glacier	outlet glacier
Bills Gulch	outlet glacier
Chamberlin Glacier	outlet glacier
Cole Glacier	outlet glacier
Cronus Glacier	glacier
Daspit Glacier	outlet glacier
Demorest Glacier	outlet glacier
Earnshaw Glacier	outlet glacier
Flint Glacier	outlet glacier
Franca Glacier	outlet glacier
Getman Ice Piedmont	ice piedmont
Gibbs Glacier	outlet glacier
Hermes Glacier	glacier
Lammers Glacier	outlet glacier
Lewis Glacier	outlet glacier
Maitland Glacier	outlet glacier
Matthes Glacier	outlet glacier
Mercator Ice Piedmont	ice piedmont
Pan Glacier	outlet glacier
Renaud Glacier	outlet glacier
Robillard Glacier	outlet glacier
Sumner Glacier	valley glacier
Tofani Glacier	outlet glacier
Traffic Circle	confluence of glaciers
Weyerhaeuser Glacier	outlet glacier
Wyatt Glacier	outlet glacier
Danco and Graham Coasts	
Archer Glacier (Danco Coast)	outlet glacier
Belgica Glacier	valley glacier
Bilgeri Glacier	outlet glacier
Birley Glacier	outlet glacier

Table 3.—Inventory of named glaciers and glaciological features on the coastal-change and glaciological map of the Larsen Ice Shelf area.—Continued

[Bold italic type indicates that glacier or glaciological feature has fluctuated an average of more than 200 m a^{-1} during some time period since the 1940s]

Geographic Place-name	Glaciological Description
Danco and Graham Coasts—Continued	
Bolton Glacier (Danco Coast)	outlet glacier
Bradford Glacier	valley glacier
Bussey Glacier	outlet glacier
Cadman Glacier	outlet glacier
Carbutt Glacier (Danco Coast)	valley glacier
Caulfeild Glacier	valley glacier
Comrie Glacier	outlet glacier
Daguerre Glacier (Danco Coast)	valley glacier
Doyle Glacier	outlet glacier
Funk Glacier	outlet glacier
Goodwin Glacier (Danco Coast)	outlet glacier
Hamblin Glacier	valley glacier
Hoek Glacier	outlet glacier
Hotine Glacier	outlet glacier
Hugi Glacier	outlet glacier
Lawrie Glacier	outlet glacier
Leay Glacier	outlet glacier
Lever Glacier	outlet glacier
Lind Glacier	outlet glacier
Luke Glacier	outlet glacier
Niépce Glacier (Danco Coast)	outlet glacier
Otlet Glacier	outlet glacier
Pollard Glacier	outlet glacier
Rickmers Glacier	glacier
Sayce Glacier (Danco Coast)	outlet glacier
Simler Snowfield	snowfield
Sohm Glacier	valley glacier
Somers Glacier	valley glacier
Talbot Glacier (Danco Coast)	outlet glacier
Trooz Glacier	outlet glacier
Weir Glacier	outlet glacier
Widmark Ice Piedmont (also Loubet Coast)	ice piedmont
Wiggins Glacier	outlet glacier
Fallières Coast	
Airy Glacier	outlet glacier
Bader Glacier	outlet glacier
Barnes Glacier	outlet glacier
Fallières Coast—Continued	
Bertrand Ice Piedmont	ice piedmont
Bucher Glacier	outlet glacier
Buffer Ice Rise	Now an island
Carlson Glacier	outlet glacier
Centurion Glacier	outlet glacier
Clarke Glacier	outlet glacier
Coker Ice Rise	Now an island
Dee Ice Piedmont	ice piedmont
Fleming Glacier	outlet glacier
Forbes Glacier	outlet glacier
Forster Ice Piedmont	ice piedmont
Hariot Glacier	outlet glacier
Linchpin Ice Rise (historical)	Not visible
Martin Glacier	outlet glacier
McClary Glacier	outlet glacier
McMorrin Glacier	outlet glacier
Meridian Glacier	valley glacier
Miller Ice Rise (historical)	Not visible
Moider Glacier	outlet glacier
Napier Ice Rise (now Island)	Now an island
Nemo Glacier	outlet glacier
Neny Glacier	outlet glacier
Northeast Glacier	outlet glacier
Nueve de Julio Glacier	outlet glacier
Perutz Glacier	outlet glacier
Prospect Glacier	outlet glacier
Remus Glacier	outlet glacier
Reynolds Ice Rise	Now an island
Romulus Glacier	outlet glacier
Rotz Glacier	glacier
Seller Glacier	outlet glacier
Shoesmith Glacier	outlet glacier
Sirocco Glacier	outlet glacier
Snowshoe Glacier	outlet glacier
Swithinbank Glacier	outlet glacier
Todd Glacier	outlet glacier
Uspallata Glacier	outlet glacier
Wade Ice Rise	Now an island
Wordie Ice Shelf	ice shelf

Table 3.—Inventory of named glaciers and glaciological features on the coastal-change and glaciological map of the Larsen Ice Shelf area.—Continued

[Bold italic type indicates that glacier or glaciological feature has fluctuated an average of more than 200 m a^{-1} during some time period since the 1940s]

Geographic Place-name	Glaciological Description
Foyn Coast	
Aagaard Glacier	outlet glacier
Alberts Glacier	outlet glacier
Anderson Glacier	outlet glacier
Attlee Glacier	outlet glacier
Balch Glacier	outlet glacier
Beaglehole Glacier	glacier
Bevin Glacier	outlet glacier
Breitfuss Glacier	outlet glacier
Cumpston Glacier	outlet glacier
Eden Glacier	outlet glacier
Fricker Glacier	outlet glacier
Friederichsen Glacier	outlet glacier
Gould Glacier	outlet glacier
Hess Glacier	outlet glacier
Mitterling Glacier	glacier
Morrison Glacier	outlet glacier
Quartermain Glacier	outlet glacier
Sleipnir Glacier	outlet glacier
George VI Sound (Rymill Coast)	
Eureka Glacier	ice stream
George VI Ice Shelf	ice shelf
Warren Ice Piedmont	ice piedmont
Zephyr Glacier	outlet glacier
Zonda Glacier	outlet glacier
Bowman, Foyn, Oscar II, and Wilkins Coasts	
Larsen Ice Shelf	ice shelf
Loubet Coast	
Antevs Glacier	outlet glacier
Avsyuk Glacier	outlet glacier
Brückner Glacier	outlet glacier
Byway Glacier	valley glacier
Cardell Glacier	outlet glacier
Drummond Glacier	outlet glacier
Erskine Glacier	outlet glacier
Field Glacier	outlet glacier
Finsterwalder Glacier	valley glacier
Forel Glacier	outlet glacier

Geographic Place-name	Glaciological Description
Loubet Coast—Continued	
Haefeli Glacier	valley glacier
Heim Glacier	outlet glacier
Hopkins Glacier	outlet glacier
Humphreys Ice Rise	ice rise/island
Jones Ice Shelf	ice shelf
Klebelsberg Glacier	valley glacier
Lliboutry Glacier	outlet glacier
McCance Glacier	outlet glacier
Müller Ice Shelf	ice shelf
Murphy Glacier	outlet glacier
Nye Glacier	outlet glacier
Reid Glacier	outlet glacier
Saussure Glacier	outlet glacier
Sharp Glacier	outlet glacier
Sölch Glacier	outlet glacier
Somigliana Glacier	outlet glacier
Stefan Ice Piedmont	ice piedmont
Vallot Glacier	outlet glacier
Ward Glacier	outlet glacier
Widdowson Glacier	outlet glacier
Wilkinson Glacier	outlet glacier
Oscar II Coast	
Ambergris Glacier	valley glacier
Bawden Ice Rise	ice rise
Crane Glacier	outlet glacier
Evans Glacier	glacier
Flask Glacier	outlet glacier
Fleece Glacier	valley glacier
Green Glacier	outlet glacier
Hektoria Glacier	glacier
Jeroboam Glacier	glacier
Jorum Glacier	glacier
Leppard Glacier	glacier
Mapple Glacier	glacier
Medea Dome	ice dome
Melville Glacier	glacier

Table 3.—Inventory of named glaciers and glaciological features on the coastal-change and glaciological map of the Larsen Ice Shelf area.—Continued

[Bold italic type indicates that glacier or glaciological feature has fluctuated an average of more than 200 m a^{-1} during some time period since the 1940s]

Geographic Place-name	Glaciological Description
Oscar II Coast—Continued	
Pequod Glacier	glacier
Punchbowl Glacier	glacier
Rachel Glacier	glacier
Starbuck Glacier	glacier
Stubb Glacier	glacier
Wilkins Coast	
Anthony Glacier	outlet glacier
Athene Glacier	outlet glacier
Wilkins Coast—Continued	
Bingham Glacier	outlet glacier
Casey Glacier	outlet glacier
Cordini Glacier	outlet glacier
Gipps Ice Rise	ice rise
Grimley Glacier	outlet glacier
Lurabee Glacier	outlet glacier
Sunfix Glacier	valley glacier

Table 4.—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 Larsen Ice Shelf area.

[Bold italic type indicates that the glacier or ice front has fluctuated an average of more than 200 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:8080/add/)

(N.B. The glaciers and ice fronts listed on this table are not formally named. They are described by an adjacent geographic feature, and this description should not be considered an official geographic place-name.)

	Location and Geographic Location Code[1]	Geographic Description
Adelaide Island		
1.	AN76646S6750W	S. Visser Hill ice front
2.	***AN76654S6801W***	***NE. Adelaide Island glacier***
3.	***AN76703S6759W***	***N. Mount Reeves glacier***
4.	AN76704S6753W	W. Landauer Point glacier
5.	AN76708S6747W	N. Mount Bodys glacier
6.	***AN76713S6751W***	***Barlas Channel a glacier***
7.	***AN76712S6749W***	***Barlas Channel b glacier***
8.	AN76714S6754W	S. Mothes Point glacier
9.	AN76715S6758W	Bahía Bandera glacier
Alexander Island		
1.	AN76953S6917W	E. Mount King glacier
2.	AN76945S6920W	N. Marr Bluff glacier
3.	***AN76942S6920W***	***S. Damocles Point glacier***
4.	***AN76936S6924W***	***N. Damocles Point glacier***
5.	AN76928S6933W	E. Mount Spivey ice front
6.	AN76924S6938W	E. Mount Nicholas glacier
7.	AN76912S7005W	E. Mount Calais glacier
Alexander Island—Continued		
8.	AN76915S7204W	W. Havre Mountains a glacier
9.	AN76920S7158W	W. Havre Mountains b glacier
Biscoe Islands		
1.	AN76612S6646W	West Lavoisier Island ice front
George VI Sound (Rymill Coast)		
1.	***AN76939S6826W***	***Rhyolite Islands ice shelf***
2.	***AN76947S6826W***	***Niznik Island ice shelf***
Antarctic Peninsula		
Fallières Coast		
1.	AN76736S6734W	E. Perplex Ridge ice front
2.	AN76744S6641W	Dogs Leg Fjord glacier
3.	AN76744S6650W	S. Dogs Leg Fjord glacier
4.	AN76756S6707W	E. Camp Point ice front
5.	AN76847S6704W	W. Boudin [Baudin] Peaks glacier
6.	AN76849S6710W	E. Query Island glacier
7.	***AN76919S6810W***	***E. Mount Guernsey a ice front***
8.	AN76920S6804W	E. Mount Guernsey b ice front

Table 4.—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 Larsen Ice Shelf area.—Continued

[Bold italic type indicates that the glacier or ice front has fluctuated an average of more than 200 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:8080/add/)]

(N.B. The glaciers and ice fronts listed on this table are not formally named. They are described by an adjacent geographic feature, and this description should not be considered an official geographic place-name.)

	Location and Geographic Location Code[1]	Geographic Description
Antarctic Peninsula—Continued		
Fallières Coast—Continued		
9.	AN76924S6817W	West Bay a glacier
10.	AN76922S6816W	West Bay b glacier
11.	AN76923S6838W	W. Brindle Cliffs ice front
Danco and Graham Coasts		
1.	AN76506S6334W	Azure Cove glacier
2.	AN76505S6340W	Crab Cove ice front
3.	AN76526S6400W	S. Kramer Rocks glacier
4.	AN76528S6353W	W. Bachstrom Point a glacier
5.	AN76528S6350W	W. Bachstrom Point b glacier
6.	AN76528S6346W	E. Bachstrom Point glacier
7.	AN76535S6359W	Beascochea Bay a glacier
8.	AN76536S6355W	Beascochea Bay b glacier
9.	AN76538S6405W	E. Eijkman Point glacier
10.	AN76541S6413W	Leroux Bay a glacier
11.	AN76542S6408W	Leroux Bay b glacier
12.	AN76542S6406W	Leroux Bay c glacier
13.	AN76538S6418W	Paragon Point glacier
14.	***AN76543S6422W***	***Lizard Island glacier***
15.	AN76553S6433W	N. Duyvis Point glacier
16.	AN76600S6430W	Barilari Bay glacier
17.	AN76559S6449W	W. Huitfeldt Point glacier
18.	***AN76555S6453W***	***Sphinx Island ice shelf***
19.	***AN76557S6502W***	***S. Loqui Point glacier***
Antarctic Peninsula—Continued		
Danco and Graham Coasts—Continued		
20.	AN76609S6518W	E. Lens Peak glacier
21.	***AN76611S6521W***	***E. Conway Island glacier***
22.	***AN76611S6530W***	***W. Conway Island glacier***
23.	AN76608S6537W	S. Black Head ice front
Loubet Coast		
1.	AN76632S6539W	W. Mount Bain glacier
2.	AN76638S6604W	N. Protector Heights glacier
3.	AN76635S6615W	Punta Paloma glacier
4.	AN76658S6632W	S. Orford Cliff glacier
5.	AN76713S6639W	Lallemand Fjord a glacier
6.	AN76718S6635W	Lallemand Fjord b glacier
7.	AN76721S6633W	Lallemand Fjord c glacier
8.	AN76648S6729W	Liard Island ice front
9.	AN76706S6726W	Shumskiy Cove a glacier
10.	AN76706S6720W	Shumskiy Cove b glacier
11.	AN76706S6738W	Hansen Island ice front
12.	AN76724S6734W	W. Haslam Heights a ice front
13.	AN76725S6736W	W. Haslam Heights b ice front
14.	AN76731S6721W	W. of Reid Glacier ice front
Wilkins Sound		
1.	AN76949S7442W	E. Charcot Island a ice shelf
2.	AN76952S7432W	E. Charcot Island b ice shelf
3.	***AN76949S7517W***	***W. Charcot Island ice shelf***

[1] The 72 unnamed glaciers and ice fronts that have been identified on source data 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.

Table 6. 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	References (see References Cited)	URL for online access
A	I–2600–A	Trinity Peninsula and South Shetland Islands	Ferrigno and others (2006)	http://pubs.usgs.gov/imap/2600/A
B	I–2600–B	Larsen Ice Shelf	This report	http://pubs.usgs.gov/imap/2600/B
D	I–2600–D	Ronne Ice Shelf	Ferrigno and others (2005)	http://pubs.usgs.gov/imap/2600/D
E	I–2600–E	Eights Coast	Swithinbank and others (2004)	http://pubs.usgs.gov/imap/2600/E
F	I–2600–F (2d ed.)	Bakutis Coast	Swithinbank and others (2003b)	http://pubs.usgs.gov/imap/2600/F
G	I–2600–G	Saunders Coast	Swithinbank and others (2003a)	http://pubs.usgs.gov/imap/2600/G
H	I–2600–H	Northern Ross Ice Shelf	Ferrigno and others (2007)	http://pubs.usgs.gov/imap/i-2600-h