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#0025

NATIONAL INTELLIGENCE SURVEY

ANTARCTICA

SECTION 22

OCEANOGRAPHY AND COASTS

CENTRAL INTELLIGENCE AGENCY
Washington, D. C.

#0025

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Date: 2 December 1957

MEMORANDUM FOR: All Recipients of NIS Publications

SUBJECT: Corrections to NIS 69 (Antarctica) Section 22 (Coasts and Landing Beaches)

1. All recipients of the NIS are requested to make the following changes in NIS 69 (Antarctica) Section 22 (Coasts and Landing Beaches), dated January 1956:

Page 22-13, left column

Line 20 from bottom, for "about 90%" read "about 70% to 80%"

Line 19 from bottom, for "between 55° and 60°S." read "at about 55°S."

Line 14 from bottom, for "and at 50°S." read "and more than 60% of the time at 50°S."

Page 22-13, right column

Lines 12 through 15 from top, delete "A belt" through "is intended" and substitute: "The belt of maximum occurrence of rough-to-high seas appears to have moved northward during this season. In general, isolines to the south of this area have been drawn to conform to this pattern."

Line 17 from bottom, for "is" read "continues"

Line 16 from bottom, for "of the Area" read "in winter" and delete "or autumn"

Lines 15 and 14 from bottom, delete the lines

Line 12 from bottom, delete "at all longitudes"

Page 22-14, left column

Delete lines 6 through 9 from top and substitute: "In the South Pacific the belt of rough-to-high seas has moved southward and has frequencies of about 60% along its major (east - west) axis."

Line 11 from top, for "80%" read "70%"

Line 12 from top, for "52°" read "50°"

2. The enclosed revisions of Figures 22-62 through 22-65 replace those contained in the published Section.

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K. A. KNOWLES

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This Section was prepared for the NIS by the Office of Naval Intelligence with the Navy Hydrographic Office contributing the data on oceanographic conditions.

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22. *Oceanography and Coasts*

A. General

1. Summary

The continent of Antarctica, almost twice the size of the United States, is unlike other continents in that it is separated from surrounding land masses by miles of open sea. The nearest land mass, South America, lies about 560 n. miles* away. Antarctica lies about 1,700 n. miles from Australia and 2,100 n. miles from Africa. The intervening sea areas are often rough, windy, and cold. The coasts of Antarctica, which total about 14,000 miles in length, are in general inhospitable. Nevertheless, at least 61 Antarctic expeditions have landed on at least 81 different landing places on and near the Antarctic continent (FIGURE 22–76). Most of the landings were made on or near the Palmer Peninsula south of South America, and in the Ross Sea area south of New Zealand, the two most approachable areas of Antarctica. With the exception of the landings effected by the U.S.S. *Atka* expedition of 1954–55, the landings made after 1950 are not covered in this Section; several photographs from "Operation DEEPFREEZE," which were received during publication of this Section, have been included.

The approaches to Antarctica are usually obstructed by a broad belt of pack ice** that lies as far as 1,000 n. miles offshore. In general, the belt extends northward to about 65°S. in the Pacific Ocean and eastern part of the Indian Ocean, and northward to about 56°S. in the Atlantic Ocean and western part of the Indian Ocean. During the summer months the belt of pack ice retreats southward and is usually backed by a broad belt of open water, but in some areas the pack disappears. In the southward approach to the belt of open water it has been found that during the summer the belt of pack ice to the north may be traversed or by-passed more easily along certain meridians. These favorable avenues of approach are along the Greenwich meridian, between the 70°E. and 90°E. meridians, and along the 180° meridian. The approach from the north to the west coast of the Palmer Peninsula also is seldom obstructed by pack ice during the summer months.

In addition to the previously mentioned belt of pack ice and the belt of open water to the south, many coasts are immediately bordered by ice that may extend several hundred miles seaward but usually extends perhaps 20 to 80 n. miles offshore. Most of this is pack ice, though some areas may consist of shelf ice and glacier ice tongues. The ease with which the pack ice may be penetrated by an icebreaker varies from time to time and from place to place. The occurrence and density of pack ice along coastal areas and in sea areas exhibit varying degrees of annual regularity. Some areas are consistently encumbered year after year, and other areas are only occasionally encumbered. Near the mainland the pack ice usually grades into sea ice, which often can be landed upon. Also, near the mainland it is not uncommon to find broad leads of open water. In most waters around Antarctica, depths are comparatively great. Aside from the ice, the chief navigational danger lies in the possibility of running aground on uncharted rocks in the vicinity of islands and islets. Most of these areas are poorly charted and depths differ greatly within short distances.

The uncertainty of pack-ice conditions off many coasts prevents definite evaluation of landing possibilities. Also, with the advent of more powerful icebreakers, coasts that formerly were considered to be unapproachable may soon be accessible. The weather of Antarctica is a highly variable, though most formidable, obstacle to landings. Some areas are subject to prolonged periods of violent winds and sudden blizzards that reduce visibility to zero. A phenomenon restricted to polar areas is the cloudy-bright "white-day" or "white-out," a weather condition in which no object casts a shadow, the horizon becomes indistinguishable, and only very dark objects can be seen.

Some stretches of the coast of Antarctica have in the past been unapproachable throughout the year on account of the dense pack ice. Such areas include most of the south and west coasts of the Weddell Sea, which lies east of the Palmer Peninsula. Other unapproachable coasts are the coast between the Palmer Peninsula and the Ross Sea, most of the coast between 152°E. and 170°E., the coast between about 115°E. and 139°E., and be-

* In text, distances are in statute miles unless nautical miles is specifically indicated by "n.," as "14 n. miles."

** Selected ice terms used in this Section are defined in Subsection A, 4.

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tween about 30°E. and 50°E. Some stretches of coast are almost always approachable during the summer. These areas include the west coast of the Palmer Peninsula, the South Orkney and South Shetland Islands, and the Ross Sea area. Many stretches of the remaining coast of Antarctica lying east of the Weddell Sea and west of the Ross Sea can usually be approached during the summer. These areas include the coast between 140°E. and 143°E., between 89°E. and 95°E., and most of the coast between 58°E. and 81°E., as well as the ice cliffs bordering New Schwabenland astride the Greenwich meridian.

Tides are diurnal (one high water and one low water each day) in the southern Atlantic and Pacific Ocean areas, but are mixed (two unequal high waters and/or two unequal low waters each tidal day) in the southern Indian Ocean area. In general, tidal currents tend to flood in a counterclockwise direction around the continent and ebb in the reverse direction. South of about 65°S., waves are usually from the northeast and winds are generally from the east and northeast, resulting in a current setting to the southwest. North of 65°S., high waves that generally progress eastward occur during all seasons and the prevailing westerly winds produce a surface current that sets to the east or northeast.

Most coasts of Antarctica are covered by great depths of snow and ice that extend seaward beyond the shoreline and terminate in vertical ice cliffs approaching 200 feet in height. Where the sheet of snow and ice extends many miles out to sea it is called shelf ice. Along the coasts where the ice cliff stands nearly on the shoreline, cliffs or headlands of bare rock interrupt the vertical ice cliff. On the back side of the headlands, or where the ice edge has retreated inland, the edge of the ice sheet commonly terminates against a low ridge or bank of rocks and rock fragments called a moraine. In some of the Antarctic areas such as the South Orkney Islands, the South Shetland Islands, part of the Palmer Peninsula, and the west coast of the Ross Sea, hills and mountains are free of snow and ice during the summer except for glaciers. Most low shores, however, are still guarded during the summer by vertical ice cliffs, and only the steepest shores are usually free of snow and ice. Antarctic terrain that is free of snow and ice is composed of bedrock, either bare or covered by morainal material, and is essentially devoid of soil and vegetation.

On Antarctica, beaches as normally defined in the SECTION 22 of the NIS are rare. Landings in this Area are usually made on sea ice, on shelf ice, or on shores of morainal material or bedrock. The simplest and most common landing is made directly from ship to sea ice, with the ship tying up alongside the sea ice, which forms a natural ice wharf standing perhaps 2 to 4 or more feet above sea level. The chief disadvantage of a sea-ice landing is that a firm and safe base still has not been achieved and there may be pressure ridges, open leads, tidal cracks, or vertical ice cliffs between the landing place and the objective. Landing can also be made directly on shelf ice, which stands many feet higher than sea ice, provided the vessel can penetrate to the shelf. The major difficulty in making a boat landing on an island or on the mainland is the steep slope of most shores, which makes egress from the landing site difficult and prevents secure beaching of the boat. Also, all heavy cargo must be lightered ashore. A comparatively recent innovation in landing on Antarctica has been the utilization of both fixed-wing aircraft and helicopters.

Information on landings in the Antarctic area was derived mainly from the *List of Expeditions* prepared in 1955 by the Board on Geographic Names. This list, which is complete through expeditions originating in 1950, is incorporated in the *Antarctica* gazetteer published in 1956. Additional sources of information were the official reports of the U.S. Navy "Operation WINDMILL" of 1947–48 and the expedition of the icebreaker U.S.S. *Atka* in 1954–55. The chief sources of information on the coasts and hydrography in the Antarctic area were the USHO charts available in December 1955, and the USHO *Sailing Directions for Antarctica*, 1943, H.O. Pub. No. 138, corrected through July 30, 1955. Other sources included Roscoe's "Contributions to the Study of Antarctic Surface Features by Photogeographic Methods," and a report on the Scott Expedition of 1910–13, which included helpful maps and survey notes.

In general, the maps and charts of Antarctica are lacking in detail, and the portrayal of the coastal configuration is highly generalized. Some local areas, however, are almost completely uncharted, whereas others are charted in great detail. On account of the wide differences in chart coverage and the small scale of the landing place map (FIGURE 22–76), all distances, coordinates, and elevations given in the text were taken from what were considered to be the most reliable sources, and may be slightly at variance with the landing place map.

In this Section, oceanographic coverage extends north to 50°S. latitude and coast and landing places coverage extends north to 60°S. latitude. The additional coverage for oceanography is to include consideration of the Antarctic Convergence Zone. To facilitate describing the coasts the Area is divided into four coastal sectors which are numbered counterclockwise around the continent. Coastal Sector 1 consists of the Palmer Peninsula and nearby islands, the South Orkney Islands, and

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the South Shetland Islands. Coastal Sector 2 consists of the coast between the Palmer Peninsula and the Ross Sea, including Peter I Island to the north. Coastal Sector 3 consists of the coasts of the Ross Sea. Coastal Sector 4, by far the largest coastal sector, extends counterclockwise from the Ross Sea to the base of the Palmer Peninsula. The coastal description of each sector proceeds in a counterclockwise direction.

2. Maps and Charts

The base for the landing place map (FIGURE 22–76) is USHO Chart 2562. Other USHO charts, the new 6000 series, cover Antarctica at a scale of 1:1,500,000 except for the coast between about 35°E. and 165°E. The charts covering the gap are at present under preparation and will be available soon.

Complete coverage of Antarctica is available in British Admiralty charts. Many of these are at a small scale and out of date; others, however, are at larger scales and afford very good coverage. The U.S. Hydrographic Office has reproduced a number of Norwegian charts, at a scale of 1:250,000, that were compiled from air photos and are now part of the USHO 16321 series. Similarly, a few large-scale Argentine charts have been reproduced as the USHO 16430 series. Other coverage consists of the three U.S. Department of Interior 1:1,000,000 provisional charts of the Wilkes Land, the so-called Blodgett series; and four French nautical charts and four topographic maps of the Adélie Coast. Other charts are those made by the American Geographical Society at a scale of 1:3,000,000; the German charts of the Kosack series at a scale of 1:4,000,000; and the World Aeronautical Charts at scales of 1:1,000,000, 1:3,000,000, and 1:5,000,000, each series covering the entire coast of Antarctica.

3. Landing places

Because of the unpredictability of the ice conditions near or on most coasts of the Antarctic area, and the lack of information, no attempt has been made to select, evaluate, or fully describe landing places. As an alternative the site of each landing made by Antarctic expeditions through 1950 and the expedition of the U.S.S. *Atka* in 1954–55 is shown on a landing place map (FIGURE 22–76). The landing places indicated on the map include landings made from ship to shore by boat or aircraft, and landings made from ship to sea or bay ice and thence to the shore on foot or by vehicle. Also included are landings made by aircraft from ice close by the ship to the ice close by an island or the mainland and thence on foot or by vehicle to the shore. Not considered as landing places are points reached by cross-country movement or by aircraft from other landing places. The fact that a landing has been made in an area is indicative of the favorable conditions that may prevail there. Common features of nearly all Antarctic landings have been the relative difficulty and small scale of each operation.

4. Glossary

The following ice terms have been used in describing the coasts and oceanography of Antarctica:

TERM	MEANING
bay ice	young, flat ice of sufficient thickness to impede navigation. In the Antarctic this term also has been used at times for heavy landfloes.
berg	*iceberg.*
bergy bit	a medium-sized fragment of glacier ice, heavy floe, or hummocky *pack ice,* washed clear of snow and floating or aground. A typical *bergy bit* is about the size of a small cottage.
brash	small fragments of *sea ice* less than 6 feet in diameter.
calving	the breaking away of a mass of ice from an *iceberg, glacier,* or *shelf ice* formation.
continental ice	ice which inundates a large land mass; the surface contours of the land are not revealed on the upper surface of the ice.
crevasse	a fissure or rift in *glacier, shelf ice,* or *land ice* formation due to temperature changes or motion of the ice.
fast ice	all types of ice, either broken or unbroken, attached to the shore, beached, stranded in shoal water, or attached to the bottom of shoal areas.
floe	term used for referring to fragments of ice with no specified size intended.
glacier berg	an *iceberg* usually bluish or greenish in color, smaller than a *tabular iceberg,* with little or no snow cover and often containing many crevasses.
glacier	a flow of *land ice* from an area of accumulation.
growler	a small fragment of ice awash, smaller than a *bergy bit,* usually of glacial origin, and generally greenish in color.
highland ice	a comparatively thin but continuous ice sheet overlying any flat or undulating land surface and conforming to a considerable extent to the irregularities of the land upon which it rests.
iceberg	a mass of *land ice* that has broken away from its parent formation on the coast, and either floats in the sea or is stranded on a shoal.

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TERM	MEANING
ice cliff	the cliff-like front of a *glacier* or of *shelf ice* where it meets the sea.
icepack	any large area of floating ice driven closely together.
ice shelf	a thick formation with level surface extending seaward from the land to which it is attached.
land ice	any ice formed on land masses, as an icecap or *glacier*.
lead	a long, narrow, but navigable water passage in *pack ice*.
moraine	a ridge of rock debris deposited by a *glacier*.
nunatak	an isolated hill or mountain of bare rock rising above the surrounding ice sheet.
pack ice	any large area of floating ice driven closely together.
pack	*icepack* or *pack ice*.
pancake	pieces of newly formed ice usually between 1 and 6 feet in diameter with raised rims and circular appearance.
piedmont ice	an ice sheet formed by the coalescence of ice spreading out from two or more wall-sided or valley *glaciers* over a comparatively level plain at the base of the mountain slopes down which the *glaciers* descend.
pressure ice	*sea ice* having the surface roughened by the action of wind, current, tide, and temperature changes. *Pressure ice* refers to a disturbed growth and development.
pressure ridge	*pressure ice* in the form of a ridge.
ramp	an accumulation of snow that forms an inclined plane between land or *land ice* elements and *sea ice* or *shelf ice*.
sludge	an accumulation of small pieces of soft ice mixed with slush; has a slight hardness.
sea ice	ice formed by the freezing of sea water.
shelf ice	a thick formation with level surface extending seaward from the land to which it is attached.
tabular berg	a mass of ice calved from *shelf ice*, with a flat upper surface and with at least the upper portion formed from stratified snow or more or less loose, granular ice in transition from snow to glacier ice; color changes with weathering, from original dazzling white to blue.
tide crack	a crack in *sea ice*, usually parallel to the shore, caused by the rising and falling tide.

B. Oceanography

1. General

This subsection includes oceanography for offshore and nearshore waters and geology for submarine areas and the entire continent of Antarctica. Since most of the nearshore region of NIS 69 is covered by ice, the oceanographic topics are primarily concerned with the offshore ice-free regions. In order to include discussion of the Antarctic Convergence Zone, which is a natural oceanographic boundary for the waters of this Area, the northern limit of the subsection is extended to approximately 50°S. latitude, which embraces the southern tip of South America and many of the oceanic islands and island groups not included in other Sections of this NIS.

The polar continent is roughly circular and almost entirely covered by a mantle of ice. Beaches and landing sites are sparse and the coast is characterized by frequent and almost vertical ice cliffs. Surrounding the continent and extending far seaward is an immense field of pack ice, which restricts access to the continent to the brief summer period.

In the open water region north of the pack the prevailing winds influence the direction and magnitude of the surface currents and waves. The major belt of winds is the westerlies, which generally lie north of about 65°S. In this belt rough-to-high sea and swell is common the year round; direction of both waves and currents is from the west.

South of the prevailing westerlies waves and currents are primarily from the east under the influence of the Polar easterlies.

2. Tides

a. GENERAL — Tidal observations on the Antarctic continent are not sufficient to provide an adequate description of the tides along most of the coast. The information illustrated on FIGURES 22–1, 22–2, and 22–3 is based primarily on data from the stations shown on the tide range chart (FIGURE 22–3), along with additional data from the islands and land areas to the north. As new data become available in the future, changes in these charts may be necessary.

Both mixed tides (two markedly unequal high waters and/or two markedly unequal low waters each tidal day) and diurnal tides (one high water and one low water each tidal day) occur along the Antarctic coastline (FIGURE 22–1). Tide curves for each of these types of tide are illustrated in FIGURE 22–4.

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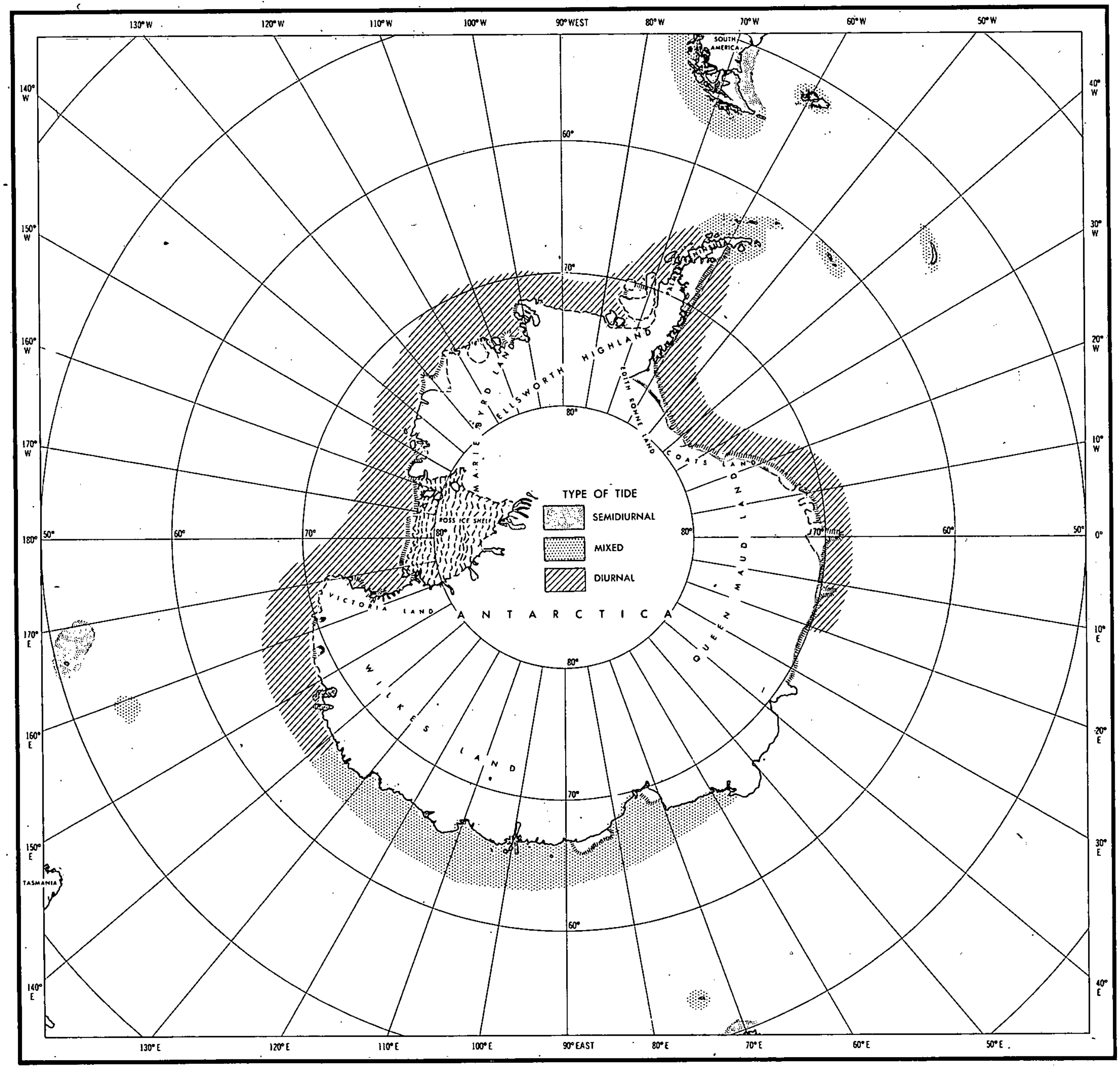

FIGURE 22–1. TYPE OF TIDE

In the vicinity of Ross Island (*14*),* the tide is diurnal or nearly so for the entire month, while off Adélie Coast (*5*) and Palmer Peninsula the tide is completely diurnal only near the time of maximum north or south lunar declination and quadrature. On the Adélie Coast the inequality is in the high water, whereas off Palmer Peninsula the inequality is in both the high and low waters. North of about 65°S., the tide becomes mixed with the inequality in the low water. Northward from the South Shetland and South Orkney Islands to South Georgia, the tide gradually changes from mixed to nearly semidiurnal, as it also does in the regions around Heard and Macquarie Islands. Westward of about 138°E., the tide is mixed with the inequality in the high water, probably becoming diurnal again somewhere between 70° and 10°E.

The progression of the high water of the principal lunar semidiurnal tide (M_2) is presented in the cotidal chart (FIGURE 22–2). Numerals represent the sequence of progression, time of high water of the partial (M_2) tide, and the approximate time of observable high water in all but the diurnal regions. Two nodal points of amphidromic systems are within the limits of this Area. The first, in a

* Italic numbers in parentheses following place names refer to locations shown on FIGURE 22–75.

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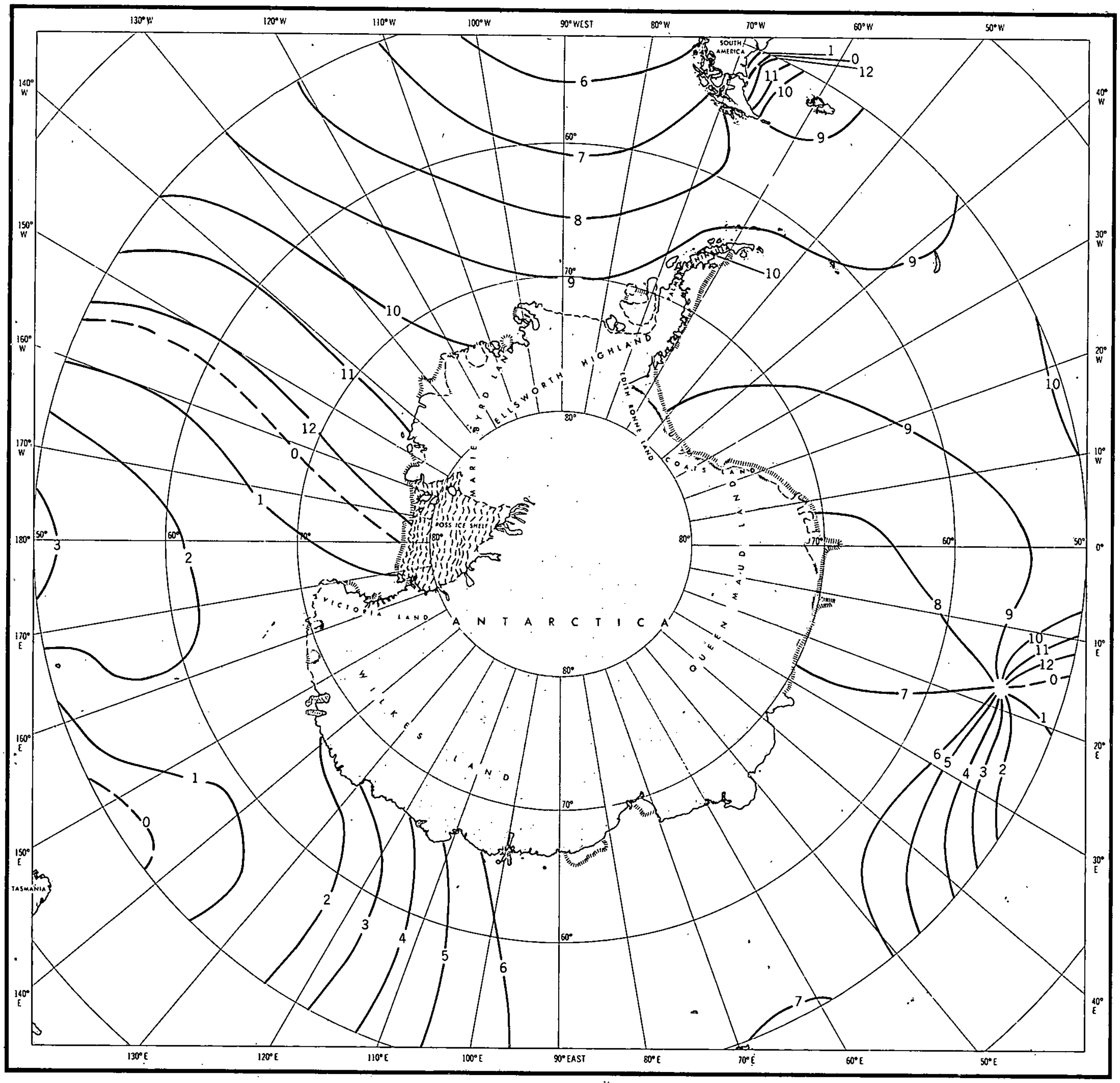

FIGURE 22–2. COTIDAL CHART. Numerals indicate time of high water of the principal lunar semidiurnal tide (M_2) in solar hours after upper and lower lunar transit of the Greenwich meridian at full and change of the moon.

clockwise amphidromic system, is at about 17°E. The second is a degenerate nodal point, somewhere to the south of Ross Island. This partially accounts for the strong diurnal tide in that region.

Tide ranges are shown in FIGURE 22–3. The largest ranges in the mixed and semidiurnal tide regions normally will occur near the time of new and full moon. In the diurnal portions, ranges usually will be largest near the time of maximum north or south declination of the moon. Insofar as tide ranges in the open ocean are unknown, the corange lines on FIGURE 22–3 indicate probable ranges.

It has been observed in the Arctic that a solid cover of stationary ice will materially alter tidal phenomena. With complete ice coverage, especially shorefast ice, high water has been retarded nearly 4 hours, and the range of the tide decreased 4 to 5 times. However, along the edge of shelf ice there will be no apparent tide since the ice shelf is a floating mass that rises and falls with the tides. This situation has been noted at Queen Maud Land and along the Ross Ice Shelf.

Fluctuations of water level ascribed to winds may be of particular importance in certain regions of the Antarctic. For example, high water marks

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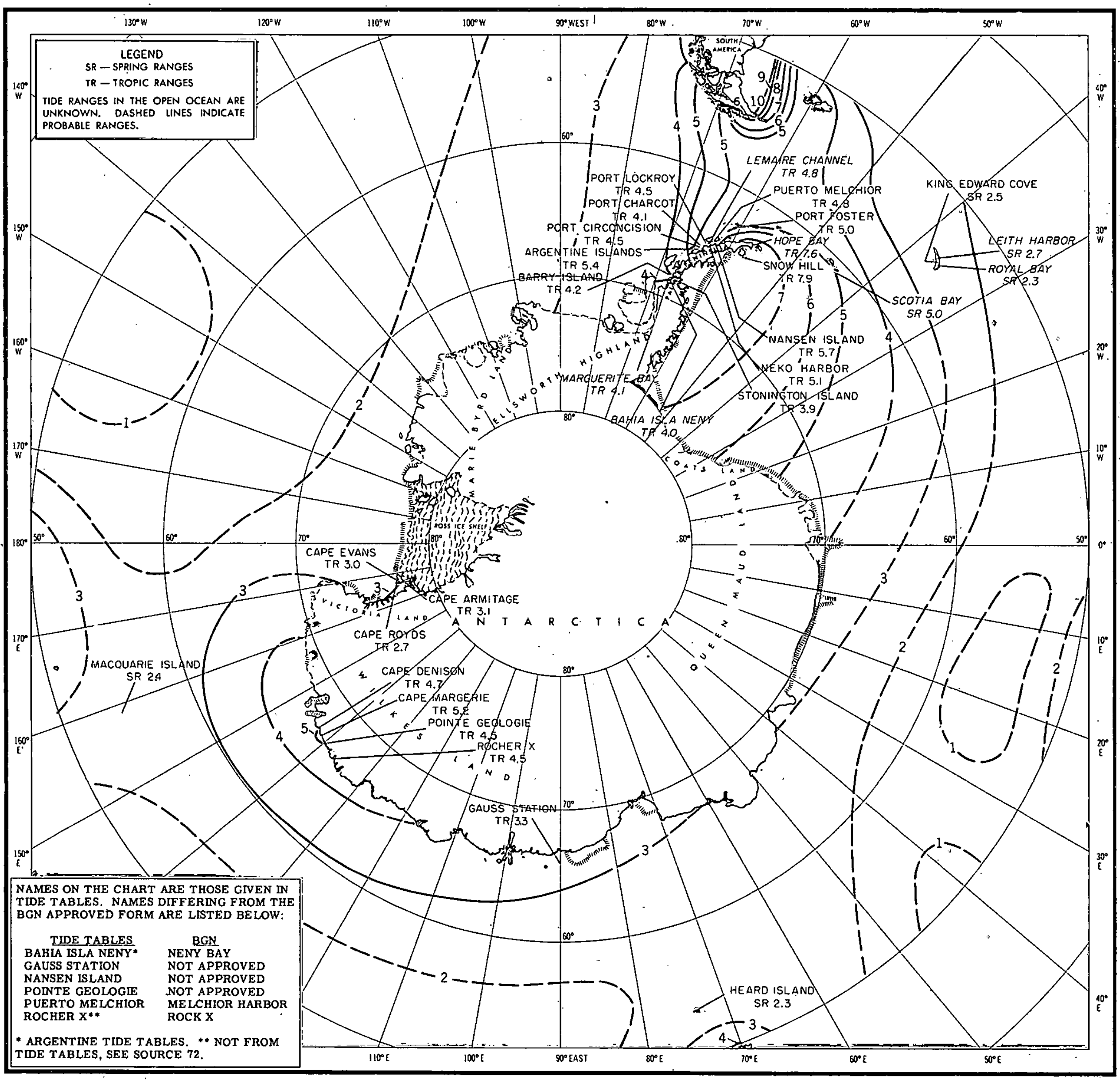

FIGURE 22–3. TIDE RANGES (FEET), 1955

12 to 14 feet above normal high water have been reported in the South Shetland Islands. However, for most of Antarctica the strongest winds are the offshore winds which tend to lower the water level rather than raise it.

Tidal predictions for some of the stations shown on FIGURE 22–3 can be obtained either from the U.S. Coast and Geodetic Survey publications *Tide Tables, East Coast, North and South America* and *Tide Tables, Central and Western Pacific Ocean and Indian Ocean,* or the British Admiralty publication *The Admiralty Tide and Tidal Stream Tables, Atlantic and Indian Oceans.*

b. TIDAL CURRENTS — Tidal currents are the horizontal components of water movement ascribed to the influence of astronomical tide-producing forces. The duration of the tidal current in a particular direction normally depends upon the relative magnitude of the diurnal and semidiurnal component of the tide. This relation changes from place to place, as well as with change of phase and declination of the moon. When diurnal components predominate, the current may be expected to run in either direction (flood or ebb) for about 12 hours. When the tides are semidiurnal, the flood and ebb currents will each set for periods of about 6 hours. When the tide is mixed, the tidal

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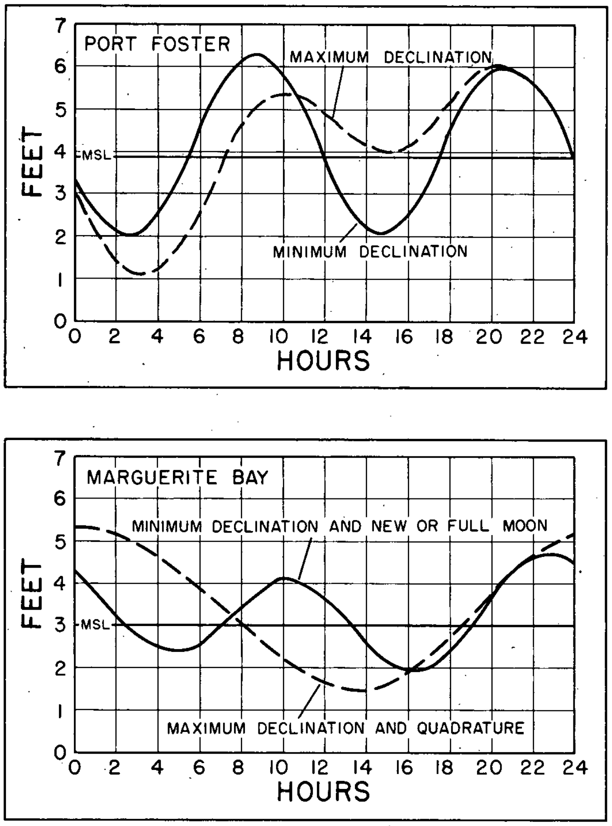

FIGURE 22–4. TIDE CURVES FOR ANTARCTIC STATIONS

current is characterized by a conspicuous difference in duration and velocity between the two floods or two ebbs.

Tidal current data for the Antarctic are practically nonexistent except for a few scattered observations for the Palmer Peninsula region, the Ross Sea region, and at the offshore islands. Elsewhere, tidal currents (FIGURE 22–5) are derived from the hypothetical progression of the semidiurnal and diurnal components of the tide. As a general rule, tidal currents tend to flood in the direction of the tidal progression, with speeds varying in proportion to the tidal range. In nearshore areas tidal currents set toward the land, entering bays and inlets; in constricted passages they may be of considerable importance. In the open water of this Area tidal currents are generally weak and rotary, and merely accelerate or reduce the prevailing current speeds.

In general, tidal currents tend to flood in a counterclockwise direction, following the trend of the coast around the Antarctic continent, and ebb in the reverse direction. The direction of flow is diverted in the larger bights, such as the Ross and Weddell Seas, and locally by bays and seaward ice projections. For example, on the eastern side of Palmer Peninsula in the vicinity of Lockyer Island (*44*) the tidal currents have been observed to flood strongly to the south and ebb to the north. At Paradise Harbor (*28*) on the western side of Palmer Peninsula, tidal currents have been observed to flood to the north-northeast with a maximum speed of approximately 0.6 knot at midtide level and ebb to the south-southwest with speeds of approximately 0.4 knot.

In the vicinity of the South Shetland Islands, generally one flood and one ebb occur every 24 hours. However, owing to the mixed type of tide, tidal currents are very irregular. Winds may also have a marked effect upon the tidal currents, not only by affecting the period and velocity but also by raising the tides beyond normal levels. In moderate weather, tidal currents probably run eastward and westward within about 6 miles from land. Outside this distance the current has been found to run with the wind at a rate of 1 knot. In the northern entrance to Yankee Harbor (*32*), tidal currents sometimes may attain a velocity of 5 or 6 knots. At Clothier Harbor (*30*), Robert Island (*31*), the current outside has been observed to start to run to the west at three-quarters flood in the harbor.

In the South Orkney Islands swift currents and tide rips have been observed in the straits and narrow channels. Large numbers of icebergs carried through the straits and channels by the tidal currents often restrict navigation. Reports indicate a current of 4.0 knots during flood tide in the narrow channel between Spine Islet (*40*) and Coronation Island (*42*), and a strong current has been observed between Spine Islet and Larsen Islands (*41*). In Washington (*38*) and Lewthwaite (*39*) Straits, east of Coronation Island, a current of about 3.5 knots has been observed.

In the vicinity of Coulman Island (*10*) in the Ross Sea the tidal currents appear to run north and south, 12 hours each way, the north-setting current being the stronger. Heavy drift ice usually is found in the channel between Coulman Island and Cape Jones (*9*) because of tidal currents and the prevailing southeasterly winds. Between Beaufort Island (*13*) and Cape Bird (*12*) a strong current sets westward, which at times reaches a velocity of 3.0 knots. Normally the strength of this current, but not its direction, is affected by the tides. Tidal currents greatly influence the breakout of the fast ice in McMurdo Sound (*11*).

Tidal current observations off the Antarctic ice barrier in the vicinity of Norsel Bay (*46*) show current averages of less than 0.1 knot setting toward the west-southwest; that is, the current is directed approximately parallel to the main direction of the coastline.

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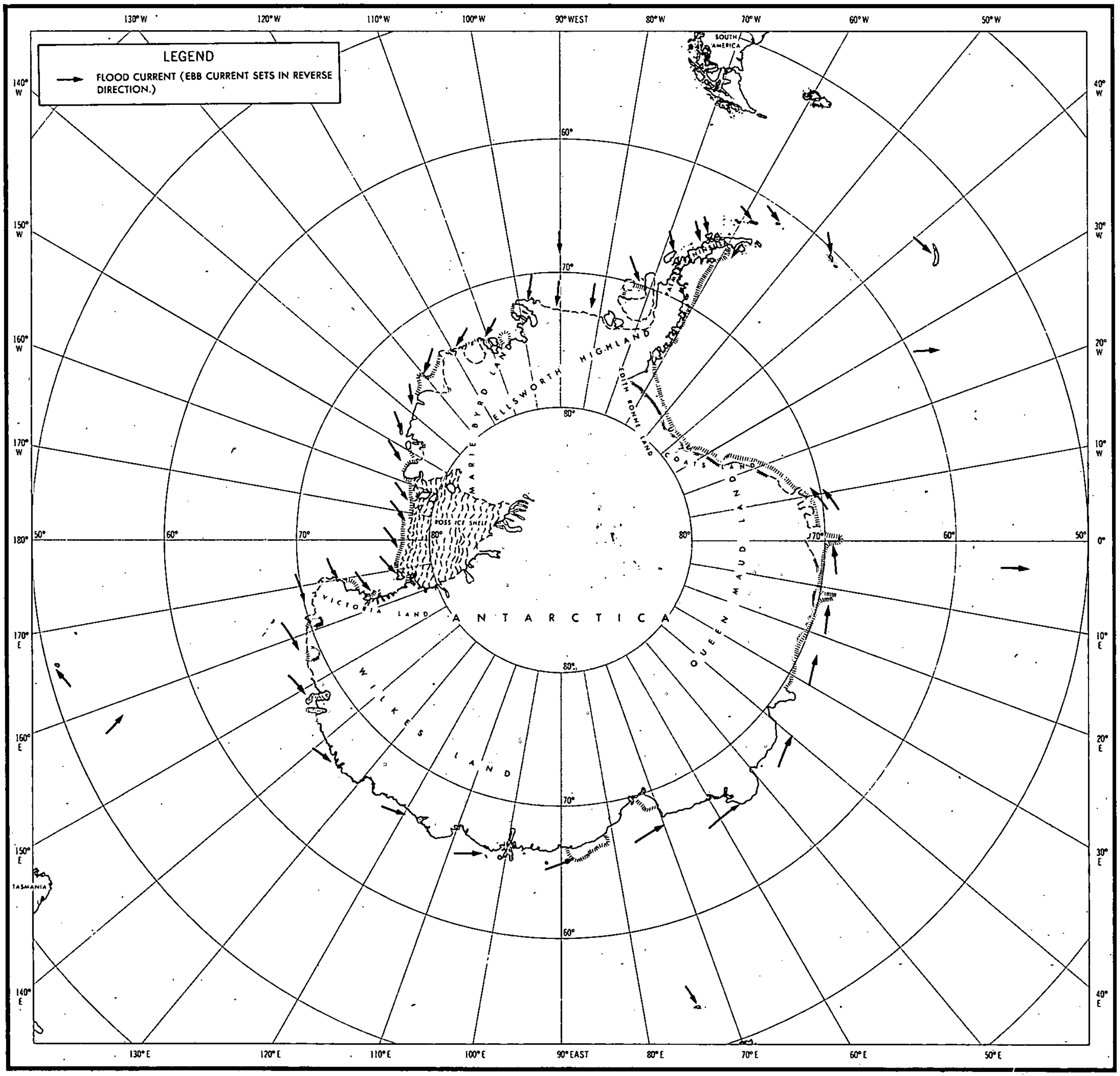

FIGURE 22–5. TIDAL CURRENTS

3. General circulation

a. SURFACE CIRCULATION

(1) *General* — The major currents in this Area are the West Wind Drift and the East Wind Drift, which lie in regions dominated by westerly and easterly winds, respectively. Between these two drifts lies the Antarctic Divergence. The West Wind Drift is circumpolar, but the East Wind Drift is interrupted by the Palmer Peninsula, where it is deflected northward into the region of westerly winds. Local deviations from generalized current directions and speeds shown on FIGURE 22–6 should be expected, since there is relatively little detailed information on the currents of this Area.

(2) *East Wind Drift* — This current results from the dominantly easterly winds (*Polar easterlies*) that blow around the periphery of the Antarctic continent. Originating from the Antarctic Divergence, a zone of upwelling which marks the boundary between the prevailing easterly winds and prevailing westerly winds, the East Wind Drift sets generally southwestward and terminates in a zone of sinking which surrounds most of the Antarctic continent. However, it is entirely possible that during summer melt water from ice on the

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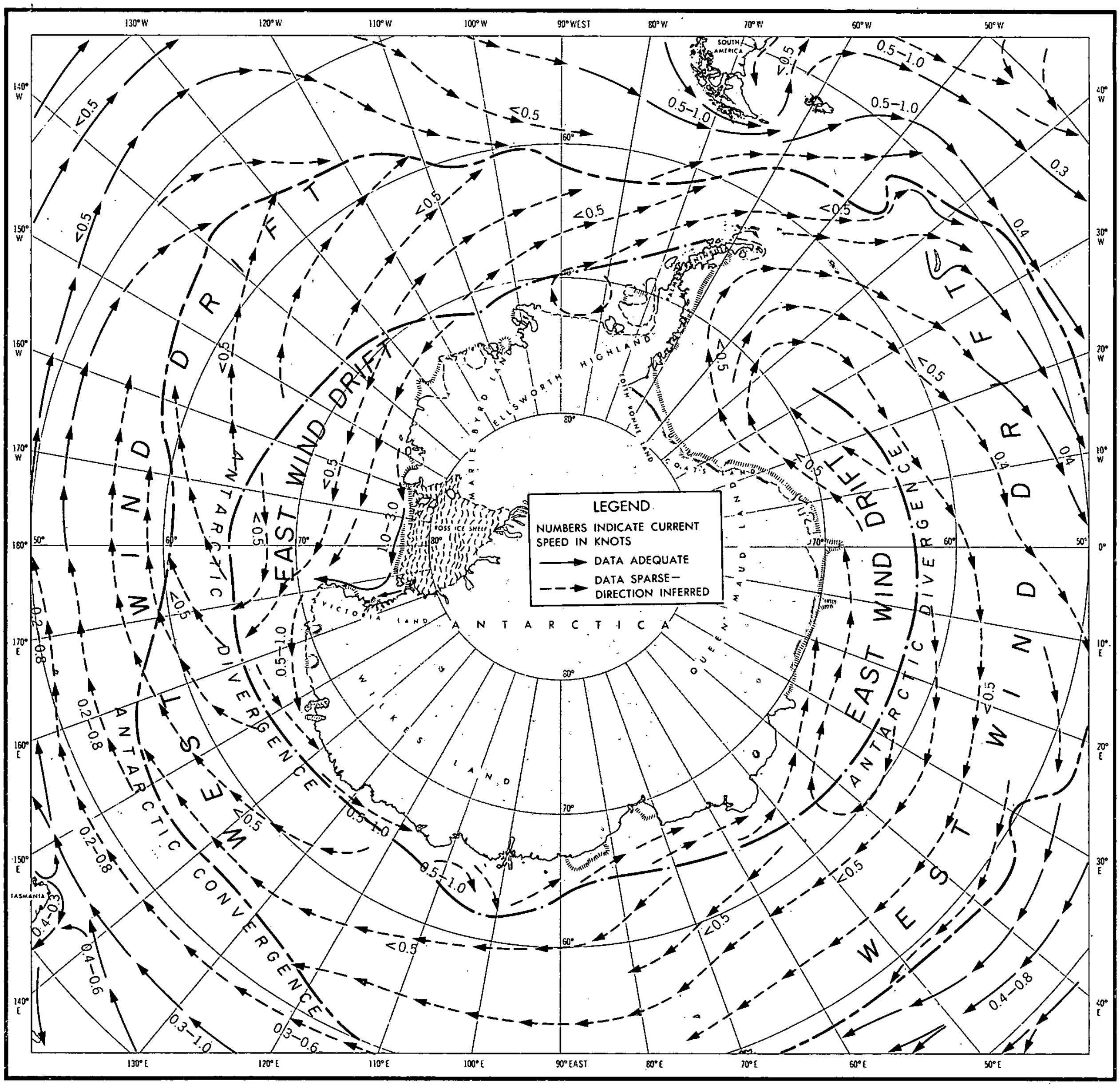

FIGURE 22–6. GENERAL SURFACE CIRCULATION

continent and on the sea may cause surface layers to have a northwesterly set, thereby scattering floating ice northward. In the winter the region of the East Wind Drift is covered by ice, which reduces still further the number of observations of this current. If the current still flows in winter, it would tend to bind floating ice to the continent.

The eddies and deviations resulting from variations in bottom topography and land masses cause an interchange of water between the East and West Wind Drifts. Notable examples of this interchange are the northward deviation of the East Wind Drift by the Palmer Peninsula, in which the bulk of the current is diverted into the West Wind Drift, and the large eddy motion in the vicinity of 60°S., 40°E., where a portion of the West Wind Drift is returned to the East Wind Drift. There are indications that several other eddy movements exist between these two currents.

(3) *West Wind Drift* — This current lies in a circumpolar belt dominated by prevailing westerly winds, and is characterized by generally slow drifts and northeasterly sets. It is bounded on the south by the Antarctic Divergence and on the north either by the Subtropical Convergence or by an undefined current convergence. The Antarctic Convergence divides the West Wind Drift into Antarctic and subantarctic zones. The Ant-

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arctic zone is distinguished by cold waters, northeasterly sets, and probably several large-scale eddy interchanges of water with the East Wind Drift. Conversely, the subantarctic zone has warmer waters, generally more easterly sets, and occasional southeasterly sets at its southern boundary, which may cause its surface waters to overlap the Antarctic Convergence.

In the Antarctic zone the main factors which tend to increase current speeds are strong winter winds and summer melt water. Their occurrence at opposite seasons results in a confused distribution of overall seasonal changes of current speeds.

b. SUBSURFACE CIRCULATION

(1) *General* — The subsurface currents of this Area generally set in the same direction as surface currents. They are deflected by land masses and bottom topography. Details on the set and speed of this circumpolar circulation are lacking, but speeds of the major east-setting current probably diminish with depth. FIGURE 22–7 shows the theoretical decrease of speed with depth that has been calculated for the West Wind Drift at 57°S. South of the Antarctic Convergence the east and west currents involve three water masses having their own north or south components by which they communicate with the major oceanic basins. Though, in most cases, mixing causes boundaries between water masses to grade into ill-defined transitional zones, the relationship of these water masses and their north or south components is shown in FIGURE 22–8. It should be understood that the minor north or south current components have no appreciable effect on the main easterly or westerly currents except where these become very weak, as at great depth.

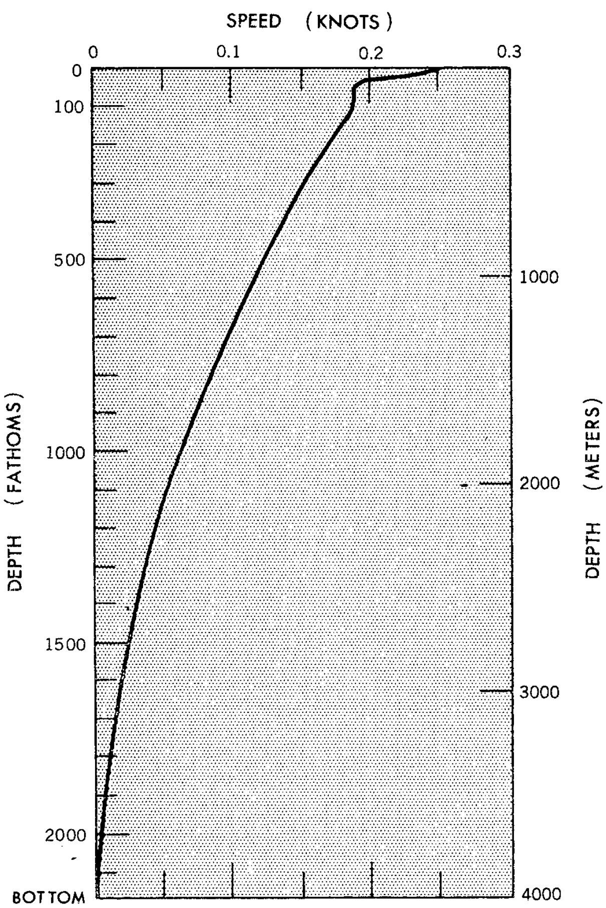

FIGURE 22–7. THEORETICAL SPEED WITH DEPTH OF THE DOMINANTLY EAST-SETTING CURRENT AT LATITUDE 57°S.

(2) *Antarctic Surface Water*—This shallow water mass includes the surface waters south of the Antarctic Convergence. Because of upwelling, this water mass has a minimum thickness at the Antarctic Divergence. As it moves northeastward, under the influence of prevailing westerly winds and supported by the denser underlying Deep Warm Water, the layer of Antarctic Surface Water thickens progressively to an average maximum thickness at the Antarctic Convergence, where it sinks with considerable mixing to become the Antarctic Intermediate Water. South of the Antarctic Divergence, the Antarctic Surface Water moves southwestward, again supported by Deep Warm Water, and progressively thickens as it moves. This Antarctic Surface Water terminates at the edge of the continent where it sinks. Under summer conditions, the formation of a low salinity, high temperature layer in the upper portion of the Antarctic Surface Water results in a two-layer system in which the individual members may have independent movements.

(3) *Deep Warm Water* — Originating mainly in the equatorial regions of the Atlantic, this water drifts slowly southward into the Antarctic circulation and, although it is caught up in the relatively faster eastward circulation existing under the West Wind Drift, it maintains a southerly component, rises steeply over the Antarctic Bottom Water, and merges with the strongly east-setting Antarctic Circumpolar Water. This water mass is partially or wholly excluded from shallow-shelf seas, such as the southern portion of the Weddell Sea, and from basins protected by submarine ridges, such as the Scotia basins and other small basins. South of the Antarctic Divergence, it probably participates in a general westerly circulation under portions of the East Wind Drift that are well developed, as well as in the large-scale eddies circulating between the East Wind Drift and the West Wind Drift. This Deep Warm Water stops short of the continental slope and dissipates its volume by mixing with overlying and underlying

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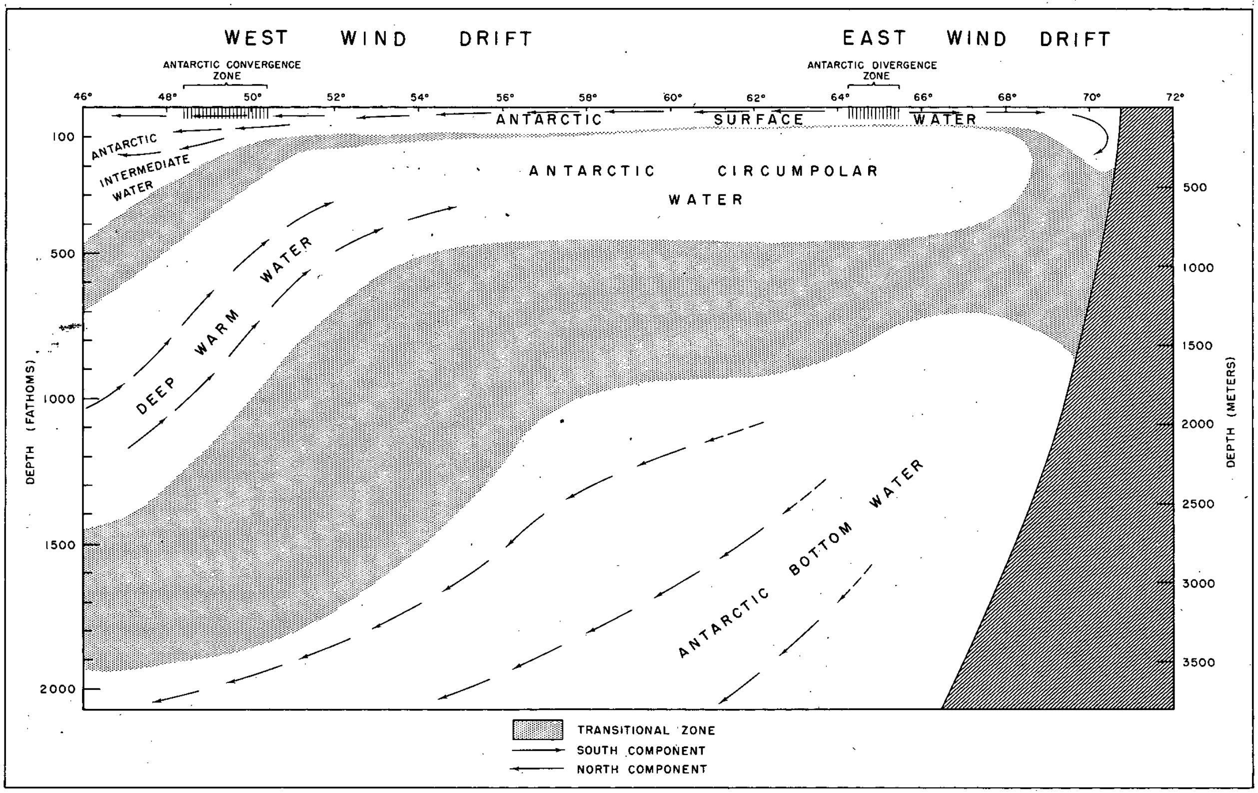

FIGURE 22–8. SCHEMATIC SECTION TYPICAL OF THE SOUTH ATLANTIC SHOWING MINOR COMPONENTS IN THE DOMINANTLY EAST- AND WEST-SETTING SUBSURFACE WATER MASSES

water masses which return the waters to adjacent oceanic basins.

(4) *Antarctic Bottom Water* — This water mass originates as very cold and saline water formed at the surface of the southwestern and western parts of the Weddell Sea. Sinking beneath all other water masses in the Area, this water then flows eastward successively through the Antarctic basins and completes its circumpolar path through Drake Passage. The presence of well developed north components in this east-setting water mass is shown by the strong flow of Antarctic Bottom Water into all the basins adjoining the Antarctic basins. The path taken by this water mass is controlled to a great extent by bottom topography.

4. Sea and swell

a. GENERAL — The marine portion of this NIS Area consists of a very large expanse of open water encircling a vast icefield with the south geographic pole its approximate center. The outer limit of the ice is almost circular with the radius considerably greater in winter than in summer. Over the South Pacific the mean winds north of about 70°S. are westerly, whereas south of this latitude they are generally easterly. Over the other two ocean areas the mean winds are westerly north of about 65°S. and easterly south of this latitude. Since the winds in this Area are both strong and persistent throughout the year, and since there are no land barriers to the westerlies, high waves occur during all seasons.

Sea and swell data in this Area are very sparse, especially over the Indian Ocean in all seasons, and are more sparse in winter than in summer. The overall pattern, however, indicates that waves are a little higher in winter than in summer.

FIGURES 22–62 through 22–69 present sea and swell roses for the four seasons, giving the relative frequencies of selected wave-height categories by direction, together with the number of observations making up each rose. The bar graph associated with each rose gives the total relative frequency for each height category. Isolines of the relative frequencies of rough-to-high seas ($\geqq$5 feet in height) and of high swell (>12 feet in height) are presented in these figures with an inset indicating the degree of their reliability.

In all seasons, the sea roses are closely correlated with wind roses of the Area (see SECTION 23, Climate). Westerly components are predominant north of 60°S. and easterly and northerly components south of 70°S. In the intermediate latitude

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band westerly and easterly seas occur with about equal frequency, corresponding to the zone of transition between westerly and easterly winds. The swell roses show a similar though less pronounced correlation, the greater variability in direction of swell resulting from the greater effect of migratory cyclones on swell than on sea, together with the propensity of swell to continue outward from the region of generation. When swell proceeds across a zone of transition from one region of predominating winds to another, greater seasonal variability of swell occurs in the second region.

Winds of Beaufort force 5 blowing over a fetch of only 20 miles will produce seas of 5 feet; therefore, the maximum occurrence of rough-to-high seas will be found in the belt of least occurrence of winds of Beaufort force ≧3 shown on the wind maps of SECTION 23.

Although fetches are essentially unlimited in the westerlies except off the east coast of South America, and a Beaufort force 6 will generate seas almost 14 feet in height, wind speeds of at least Beaufort force 7 are needed to produce swell greater than 12 feet (assuming some slight decay before observation). Therefore, the maximum occurrence of high swell will be found in the belt of maximum occurrence of winds of Beaufort force ≧8 shown in SECTION 23.

b. OPEN WATER DISTRIBUTION BY SEASON

(1) *Summer* — Although sea and swell data are more plentiful in summer (January, February, March) than in any other season, they can be classified as good only in the vicinity of South America.

With respect to the three oceanic regions within this Area, rough-to-high seas are most frequent on the average in the South Pacific, occurring as a maximum about ~~90%~~ 70% to 80% of the time south of New Zealand ~~between 55° and 60°S.~~ at about 55°S, 60% to 70% of the time at 60°S. over the central portion of the ocean, and 40% to 60% of the time in Drake Passage. In the Indian Ocean rough-to-high seas occur more than 70% of the time at about 57°S. over the central and extreme eastern portions, and ~~at 50°S.~~ * in the extreme western portion. In the South Atlantic rough-to-high seas occur 50% to 60% of the time at 50°S. in the eastern portion and about 40% of the time over the central portion at the same latitude. In the western portion they occur most frequently (40% to 50% of the time) between 55° and 60°S. In all these regions the frequency of rough-to-high seas decreases southward.

High swell in the South Pacific occurs with a maximum frequency of 60% to 70% of the time between 55° and 60°S. In the Indian Ocean high swell occurs with a maximum frequency of 30% to 40% of the time between 55° and 60°S. In the South Atlantic high swell occurs generally less than 30% of the time.

(2) *Autumn* — The data for autumn (April, May, June) apparently are biased toward the warmer portion of the season. Because of the scarcity of data for this season over certain regions, isolines have been extended in places partly on the basis of the summer pattern and partly on the basis of the pattern at lower latitudes where the data are more abundant.

In the South Pacific south of 60°S. the data are too sparse to permit analysis. ~~A belt of maximum occurrence of rough-to-high seas is depicted to conform to the summer pattern, but no indication of magnitude is intended.~~ * The pattern of rough-to-high seas over the Indian Ocean is very similar to the summer pattern, whereas the frequencies of occurrence of rough-to-high seas are somewhat higher over the South Atlantic in autumn.

In the South Pacific the frequency of high swell has diminished slightly by autumn, and the belt of maximum frequency has moved northward to about 50°S. The pattern shown for the Indian Ocean is purely the result of extrapolation. In the South Atlantic high swell appears to be approximately as frequent in autumn as in summer.

(3) *Winter* — By the beginning of winter (July, August, September) the northward extension of the ice has reduced the open water area considerably, the reduction being greatest in the South Atlantic. In the South Atlantic it appears that rough-to-high seas occur most frequently at about 50°S. at all longitudes except in the extreme western portion where, in the vicinity of Drake Passage, they occur as a maximum about 50% of the time. In the central portion at about 50°S. they occur as a maximum more than 80% of the time.

In the South Pacific, the main belt of maximum occurrence of westerly rough-to-high seas ~~is~~ continues farther north ~~of the Area~~ in winter than in summer ~~or autumn~~. ~~Absence of data precludes the ascertainment of a possible secondary westerly belt at high latitudes.~~ Rough-to-high seas occur as a maximum 70% to 80% of the time at 50°S. ~~at all longitudes~~ except in the extreme eastern and western portions where they occur somewhat less frequently.

High swell in the South Atlantic portion of the Area occurs 30% to 40% of the time in the eastern portion, 10% to 20% of the time in the western portion, and (based on sparse data) less than 10% of the time in most of the central portion. In the South Pacific high swell occurs as a maximum about 50% of the time at 50°S. and at nearly all longitudes, decreasing in frequency southward to the ice limits.

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* And more than 60% of the time at 50°S.

* The belt of maximum occurrence of rough-to-high seas appears to have moved northward during this season. In general, isolines to the south of this area have been drawn to conform to this pattern.

See 22 ii for revisions

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In the Indian Ocean, there are no data available either for sea or swell.

(4) *Spring* — In spring (October, November, December) as in autumn, the data are biased toward the warmer portion of the season.

~~In the South Pacific there are two areas of maximum rough-to-high seas, one in the central portion at 50°S. and a second southeast of New Zealand between 50° and 55°S.; both show about 80%.~~

In the Indian Ocean rough-to-high seas occur south of Australia more than ~~80%~~ 70% of the time at 50° ~~52°~~ to 54°S., in the central portion about 60% of the time at 50°S., and in the western portion about 40% of the time at 50°S. Rough-to-high seas decrease in frequency southward to the ice.

Over the eastern and central portions of the South Atlantic, rough-to-high seas occur 40% to 50% of the time at 50°S., decreasing in frequency southward. Northeast of Drake Passage rough-to-high seas occur with a frequency of more than 40%.

High swell appears to be most frequent in the South Pacific, with a belt of maximum occurrence of 40% to 50% in the eastern portion between 50° and 55°S. A similar belt of 60% to 70% occurs in the central portion at about 55°S., decreasing to 30% to 40% in the western portion. In the Indian and South Atlantic Oceans high swell generally occurs less than 30% of the time, the higher frequencies occurring at the lower latitudes.

c. SOUTH OF THE ICE LIMITS — The previous information has dealt with the open water north of the outer edge of the ice.

The ice limit shown for each season is indicative of the general latitude at which the icepack would be encountered by a vessel bound toward Antarctica. The isolines of relative frequency of rough-to-high seas and of high swell in the vicinity of the ice limits are of limited reliability. Though it is known that the mean speeds of the westerlies decrease southward toward the ice and the region of easterlies, the inadequacy of the data in the vicinity of the ice limits permits little accuracy in the drawing of isolines depicting the effect of the easterlies in generating waves.

To some extent, through turbulent mixing, wave action hinders formation of ice, or through mechanical attrition expedites its dissolution. Conversely, the presence of ice hinders the formation of waves or brings about their ultimate decay. Even so, wave action, especially swell, does penetrate the boundaries of the icepack, the extent of penetration depending on the concentration of the pack. The consequent erratic motion of large masses of ice can be a serious hazard to ships navigating in such a region.

The north – south extent of the icepack varies from place to place, from season to season, and from year to year. In summer the ice is closely packed around the coast, whereas in winter the icepack is more open and scattered. Therefore, in the colder months extensive bodies of open water are occasionally found between the ice shelf and the outer edge of the pack. Although no quantitative estimates are possible at present, the presence of this open water together with the storms associated with the polar outbreaks indicate that rough-to-high seas and some high swell are to be found south of the outer edge of the pack in the colder months of the year. This is also true to a certain extent in the Ross Sea and Weddell Sea areas in summer. Though the storms are less frequent and less intense in this season, the configuration of the Antarctic continent in these regions is such as to facilitate the formation of a widely scattered pack, which permits the creation of occasional extensive areas of open water.

d. LOCAL EFFECTS — Foehn and katabatic winds occasionally affect the marine areas off mountainous islands and off the mountainous coasts of Antarctica, often reaching sea level with hurricane force. They are therefore capable of generating local seas in open coastal waters, and of temporarily converting a local icepack area into one of open water with seas hazardous to ships.

As an example of what might be expected off a mountainous island, consider a wind of one of these types reaching open water with a speed of 60 knots. Though the wind fans out and loses momentum as it proceeds seaward, seas of 6 feet or higher could be generated within 10 miles of the coast.

5. Sea water characteristics

a. PHYSICAL PROPERTIES

(1) *Introduction* — The main factors affecting the distribution of physical properties in the waters of the Antarctic are the currents, the prevailing cold polar climate, the presence of large quantities of sea ice, and the upwelling of deep water.

Antarctic Surface Water, cold and dense, and of relatively low salinity, surrounds the Antarctic continent and prevails at shallow depths throughout the Area. The distribution of physical properties in this surface water is remarkably constant at all longitudes. This mainly reflects two influences: the continuous transport of surface water around the Antarctic continent by the East Wind Drift and the West Wind Drift, and the constancy of the Antarctic climatic regime. Very little surface water enters the Area from the warmer climates to the north.

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* In the South Pacific the belt of rough-to-high seas has moved southward and has frequencies of about 60% along its major (east-west) axis.

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Antarctic Surface Water is bounded everywhere in the north by the Antarctic Convergence (FIGURE 22–9). At this convergence the cold and dense Antarctic Surface Water sinks beneath the warmer and lighter Subtropical Surface Water to the north. The convergence is marked by sharp changes in physical properties, particularly temperature and density.

Southward from the Antarctic Convergence changes in the physical properties of the surface water are relatively small. Temperatures decrease southward to below 32° F., whereas density and salinity generally increase slightly.

Beneath the cold surface water generally warmer and more saline Antarctic Circumpolar Water prevails throughout most of the Area. This water mass, which derives its heat content from its origins in the equatorial latitudes, here rises from great depth to within a few hundred feet of the surface, partly to replace the surface waters sinking at the convergence (see FIGURE 22–8). Because of its higher salinity, it is denser than the surface waters, despite being warmer. In the southern Weddell Sea and in parts of the Ross Sea, Circumpolar Water is missing; consequently, colder surface waters there extend to great depths.

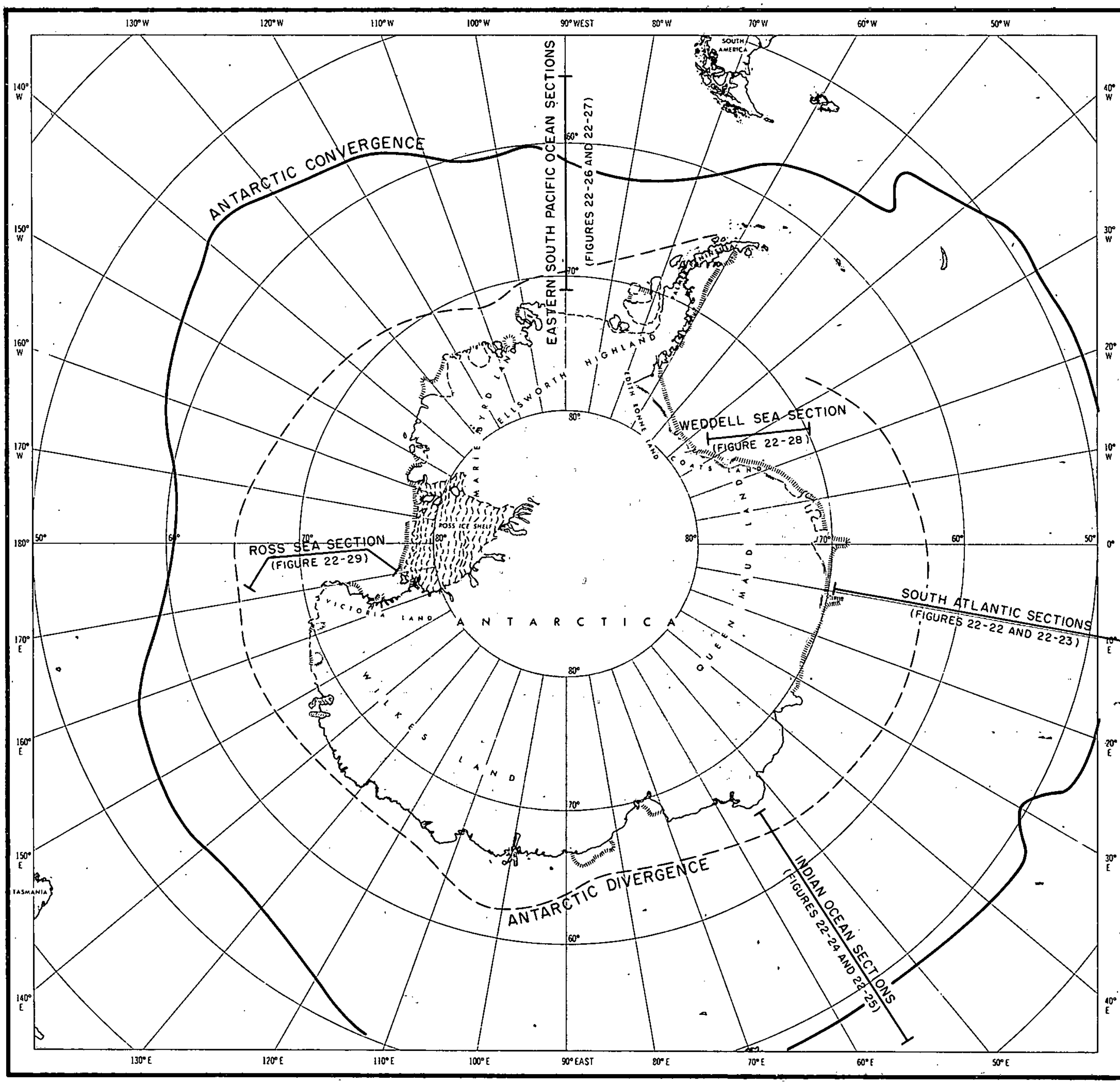

FIGURE 22–9. MEAN POSITION OF THE ANTARCTIC CONVERGENCE AND THE ANTARCTIC DIVERGENCE; LOCATIONS OF VERTICAL SECTIONS

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Seasonal changes in physical properties are usually small, except near melting ice, and are confined to the uppermost part of the Antarctic Surface Water, reflecting the short and cool Antarctic summer season. By midsummer a slightly warmer, lighter, and less saline surface layer of summer water prevails over much of the Area. This is separated from the colder winter water beneath by a poorly developed seasonal thermocline and density layer (a layer of relatively sharp temperature and density change with depth).

Seasonal melting and a retreat of the pack ice affect the surface distribution of physical properties in the southern part of the Area, especially south of the extreme winter pack-ice limit.

Near melting ice, thin surface layers of very low-salinity, light water of variable temperature are frequently present. Subsequent mixing with surrounding and underlying water tends to obliterate these melt waters, reducing the salinity and density of the surface waters over wide regions. These regions become increasingly more widespread as summer progresses, but their exact location and extent are highly variable.

The discussion of physical properties is confined in general to depths less than 1,000 feet, in the area between the Antarctic Convergence and the continent. The discussion is divided into two parts: 1) the upper mixed layer, within which the physical properties show little or no change, and 2) the underlying waters, in which properties may change considerably with depth.

(2) *Temperature*

(a) DISTRIBUTION OF TEMPERATURE IN THE MIXED SURFACE WATER

1) Winter — South of the Antarctic Convergence temperatures in the mixed isothermal (no temperature change with depth) surface layer are less than 37.5° F., decreasing evenly southward to less than 30° F. near the pack-ice limit (FIGURE 22–10). At the convergence, a southward temperature drop ranging from 2° to 6° F. takes place within a distance of 10 to 40 miles. To the north of the convergence winter surface temperatures are generally more than 40° F.

In general the temperatures immediately to the south of the Antarctic Convergence are somewhat higher in the Atlantic and Indian Oceans (37° F. or less), where the convergence lies farther to the north, than in most of the Pacific region (35° F. or less). The position of the convergence as well as the temperature decrease across the convergence may vary from month to month. The convergence may move as much as 100 miles from its mean position within a short time. At times the convergence may meander, forming loops and eddies. A north – south passage may thus encounter the convergence several times in succession within a hundred miles distance.

Frequently, large masses of warmer water may intrude southward into the cold Antarctic Water; at such times also several alternating zones of warm and cold water may be present rather than a single temperature drop.

Temperatures in the mixed surface water at the ice edge are slightly less than 29° F., or near the freezing temperature of sea water over most of the Area. In places, however, especially in the South Atlantic, the pack ice may drift northward, under the influence of winds, from the freezing zone into water as warm as 31° F. Thus, locally, somewhat warmer temperatures may occur at the ice edge. However, during cold years in which a generally heavy development of ice occurs, near-freezing surface temperatures (29° F. or less) probably will extend well northward of their mean positions inferred in FIGURE 22–10. Beneath the pack ice, temperature of the mixed water does not exceed 29° F.

In average winters the lowest surface temperatures will occur in September and October; the seasonally cold temperatures prevailing in the Area from July to November or December reflect the long Antarctic winter (FIGURE 22–11).

The mixed isothermal winter surface water extends from the surface to depths ranging from 250 to 450 feet over most of the Area, with an average depth of about 350 feet. Immediately to the south of the Antarctic Convergence, the isothermal water extends to considerable depth, generally more than 400 feet and in places as much as 1,000 feet. It reaches its shallowest development, as little as 250 feet, at the Antarctic Divergence (see FIGURE 22–9) which in winter lies to the south of the pack-ice limit and may be ice covered. In the Atlantic and the westernmost Indian Ocean, the average depth to which the mixed surface layer extends is generally somewhat less (250 to 350 feet) than in the western Indian Ocean and parts of the Pacific (300 to 450 feet).

2) Summer — In summer a layer of warmed surface water (hereafter referred to as summer water) extends above the cold winter layer throughout the Area (FIGURES 22–12, 22–23, 22–25, and 22–27). The seasonal warm layer begins to develop in spring, when surface heating results in warmer water at the surface. Further heating and wind mixing deepens the warmer surface layer, which is separated from the colder winter water beneath by a thin seasonal thermocline. As the ice limit recedes southward during spring and early summer, exposing more and more win-

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ter water to surface warming, the seasonal warm layer extends southward.

Temperatures in the summer surface layer decrease from north to south. By February, when surface layer temperatures are highest, temperatures range from less than 40° F. just south of the Antarctic Convergence to less than 30° F. near the pack limit of ice shelves. Most of the Area has surface temperatures between 37.5° and 32.5° F. The temperature drop southward across the Antarctic Convergence is similar to that of winter; however, the actual temperatures reflect the seasonal warming, ranging from about 45° to 40° F. in the Atlantic and Indian Oceans and from 42.5° to 37.5° F. in the Pacific Ocean and the Scotia Sea (*37A*).

The relatively small temperature increase (less than 5° F.) from winter to summer is due to a combination of several factors: 1) the low angle of incidence of the sun's rays and frequent cloud cover reduce insolation; 2) a northward component of flow north of the Antarctic Divergence transports colder water from the south; 3) the southernmost parts of the Area are protected from heating in spring and early summer by the prevailing ice cover and large quantities of drifting ice fields and bergs, the net effect of which is to depress the surface temperatures.

An extensive tongue of low temperatures, generally less than 35° F. and in places less than 32.5° F., extends from the Weddell Sea across the Atlantic and into the western Indian Ocean. This cold tongue reflects mainly the presence of large quantities of ice drifting out of the Weddell Sea in summer and being carried eastward past Bouvet Island (Bouvetøya) with the West Wind Drift (FIGURE 22–12). A sharp drop in surface temperatures, generally from more than 37° F. to less than 35° F., occurs between warmer waters to the north and the cool-water tongue, while somewhat warmer temperatures again prevail to the south.

Throughout the southern part of the Area, the summer temperature structure is complicated locally by the presence of ice. Large quantities of ice drifting into summer water may result in a thin layer of cold water at the surface. Near melting ice, a thin (10 to 30 feet) surface layer of melt water, in the absence of strong winds, may be warmed to temperatures of more than 40° F., which is generally considerably warmer than the summer water. However, with strong winds these layers will be destroyed quickly by mixing. Along landfast and shelf ice, and in the vicinity of large tabular icebergs, surface temperatures usually will be very low (29° to 30° F.) even in summer.

The depth to which the warmed and generally near-isothermal summer waters extend is rather variable, ranging from less than 50 to more than 250 feet. The average depth is 100 to 150 feet over most of the Area (see FIGURE 22–34). In general it is deepest, 150 to more than 300 feet, in the northern part of the Area, near the Antarctic Convergence and shallowest, 50 to 150 feet, in the vicinity of the Antarctic Divergence where the underlying winter water is also very shallow. To the south of the divergence it deepens again. In the vicinity of the continent or shelf ice, the surface water, which at these high latitudes is cold even in summer, extends to depths generally more than 400 feet and in places to more than 1,000 feet. These unusually great depths of mixed water reflect the influence of the prevailing easterly winds, which push the surface water against the continent, where it sinks. Along shelf ice, cooling and convection of the surface waters contribute to the sinking.

In much of the Weddell and Ross Seas, especially the southern and western parts, the mixed water (generally marked by temperatures of less than 29° F.) extends to great depths, exceeding 1,000 feet in places (FIGURES 22–28 and 22–29). Only in midsummer is a thin warm surface layer with temperatures of 30° to 32° F. present.

The warmer summer water is generally shallower than average along the northeastern sides of islands lying within the zone of the West Wind Drift. Locally, shallow sectors also occur in the vicinity of melting pack ice.

Beneath the summer surface water lies a thin seasonal thermocline which separates it from the colder winter water (FIGURES 22–23, 22–25, and 22–27). The temperature drop across the thermocline is generally less than 4° F., occurring within a vertical distance of 50 to 150 feet. In the southernmost part of the Area, where the temperature difference between summer and winter water is very small, the drop may amount to less than 1° F. in places, and where surfaces are cooled by the presence of ice, the thermocline may be missing altogether. The seasonal thermocline is especially well developed where the cold winter waters, under the influence of bottom topography, have a strong northward component of flow beneath the warmer summer water. This occurs generally to the north of the Shackleton Ice Shelf (*4*), near the Balleny Islands, and near Peter I Island (*24*). The thermocline is strengthened also in the Scotia Sea (*37A*), where colder surface water from the Weddell Sea tends to sink beneath warmer water from the Bellingshausen Sea (*25*). Within the

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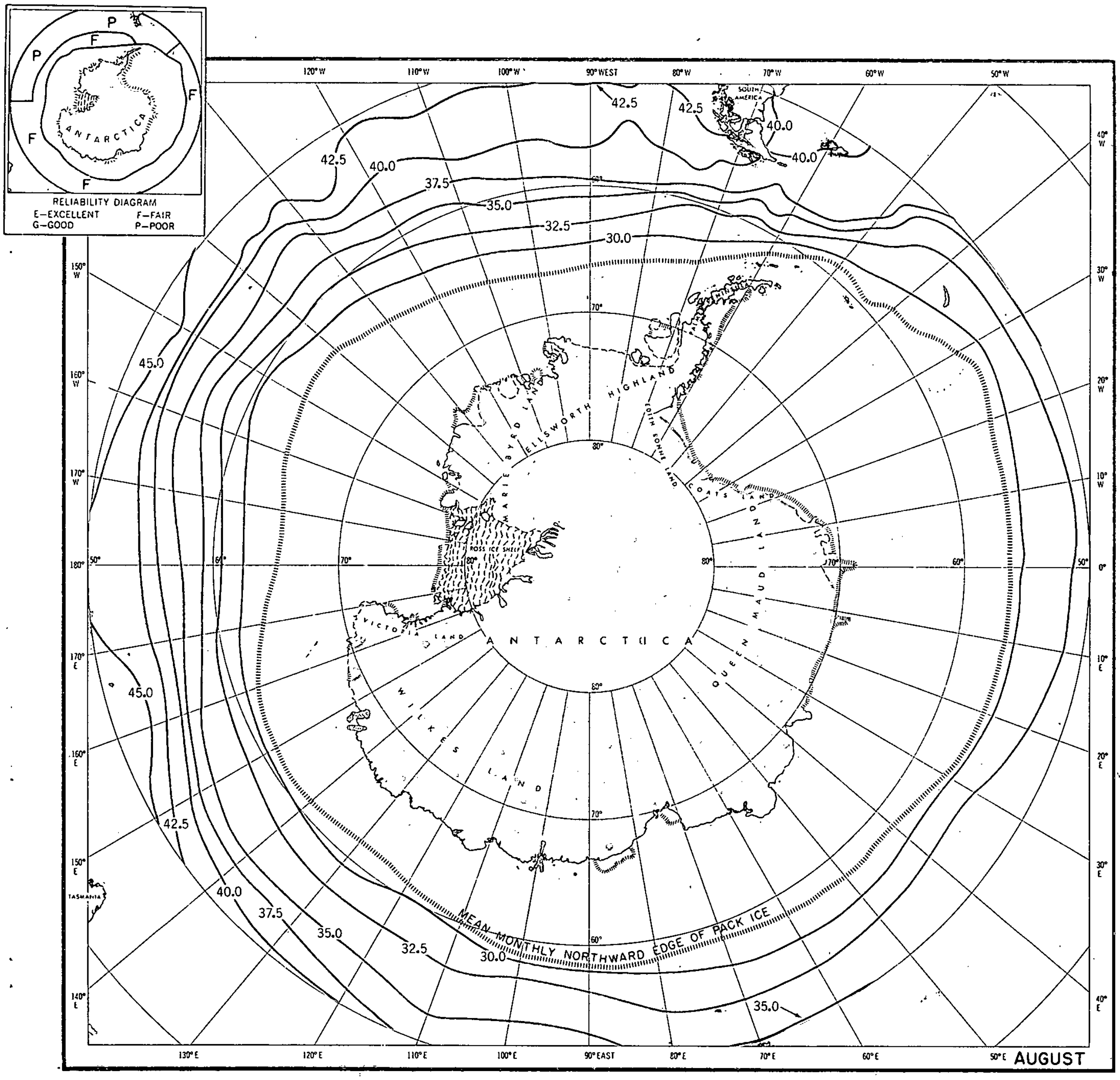

FIGURE 22–10. AVERAGE SURFACE TEMPERATURE (° F.), AUGUST

cold tongue emanating from the Weddell Sea, the seasonal thermocline is usually poorly developed.

In early autumn, cooling of the surface waters, convective mixing, and the advance of the ice limit result in a return to winter conditions (FIGURE 22–13).

A comparison of summer surface temperatures by latitudes is given in FIGURE 22–14, which shows the deviation from mean summer temperatures computed by latitude. At corresponding latitudes the summer surface temperatures in the Atlantic and Indian Oceans regions are as much as 13° F. cooler than in the Pacific. The greatest longitudinal variation occurs between 50° and 57°S. South of 65°S., surface temperatures vary little with longitude.

FIGURE 22–15 shows the deviation from mean summer temperatures computed along lines of equal distance from the continent. It indicates the longitudes at which approaches to the continent are in relatively warm or cold surface waters. Thus, at a distance of 1,000 miles from the continent, the summer surface temperature at 10°E. is 14° F. cooler than at 150°E. In general, approaches to the continent would be in relatively warm waters, for most of the distance, between 115° and 175°E. and in Drake Passage. In the Atlantic Ocean and the Ross Sea, approaches

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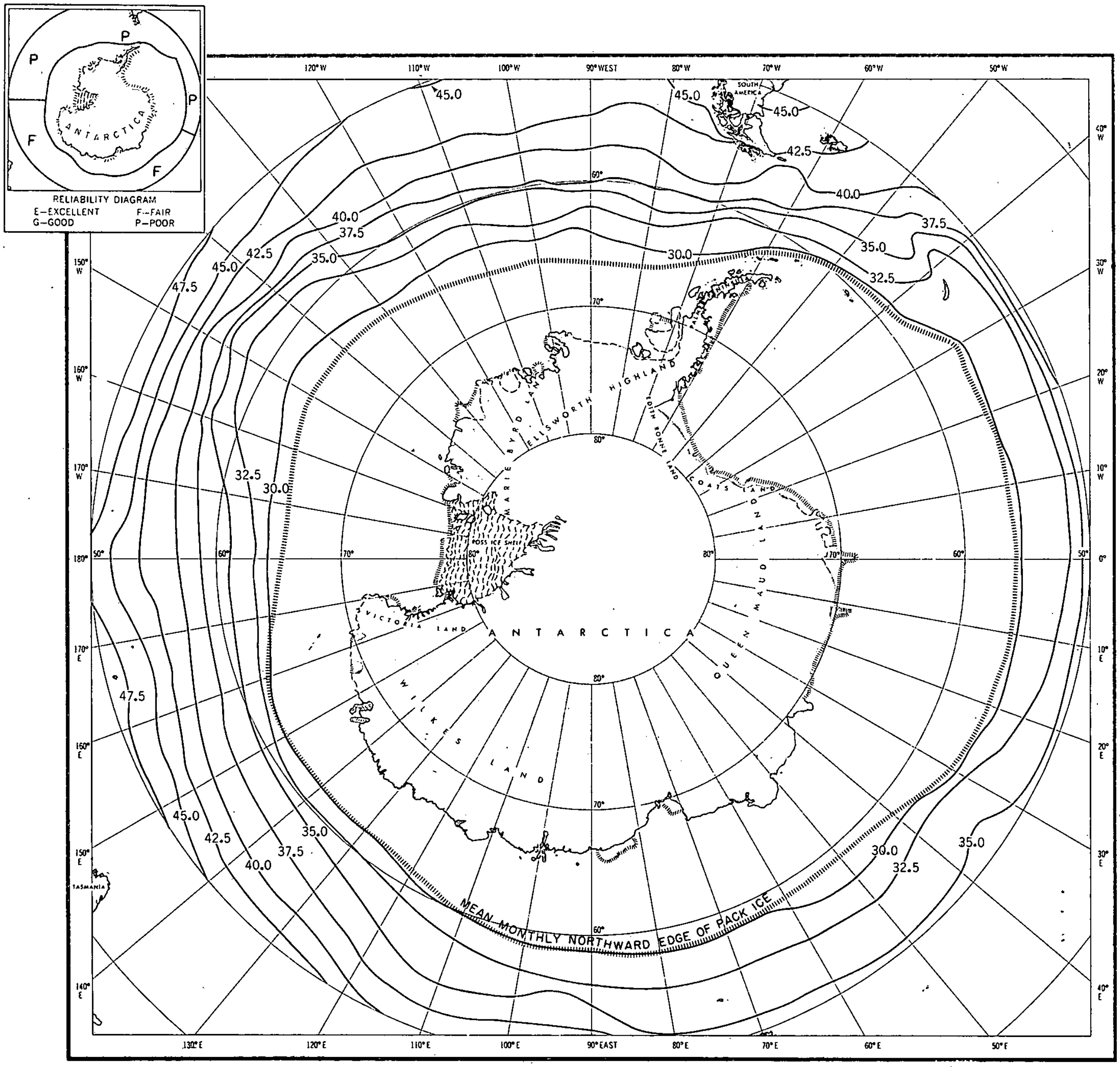

FIGURE 22–11. AVERAGE SURFACE TEMPERATURE (° F.), NOVEMBER

would traverse considerably cooler water for most of the distance. With increasing proximity to the continent, the temperature differences around the continent diminish. The maximum variation in temperature occurs at 900 to 1,000 miles from the continent.

(b) DISTRIBUTION OF TEMPERATURE FROM THE MIXED SURFACE WATER TO DEPTH OF 1,000 FEET — Throughout the Antarctic, relatively warm water prevails beneath the cold mixed surface waters (FIGURES 22–22 through 22–27). This deep warm water, with a layer of water transitional between the surface and deep waters, is referred to as Antarctic Circumpolar Water (see FIGURE 22–8). To the north of the Antarctic Convergence, it lies at great depth, but in this Area it rises to within a few hundred feet of the surface. It reaches its shallowest depths, from 250 to 600 feet, at the Antarctic Divergence, and then toward the continent deepens considerably. It is the rise of this warm but relatively dense water that limits the depth of the cold winter water, which otherwise in the cold stormy Antarctic climate would extend to considerably greater depth.

Within a short distance to the south of the convergence, the rise of this warm water is evidenced by temperatures near 35° F. at 1,000 feet. Farther south, temperatures in this water range from 32°

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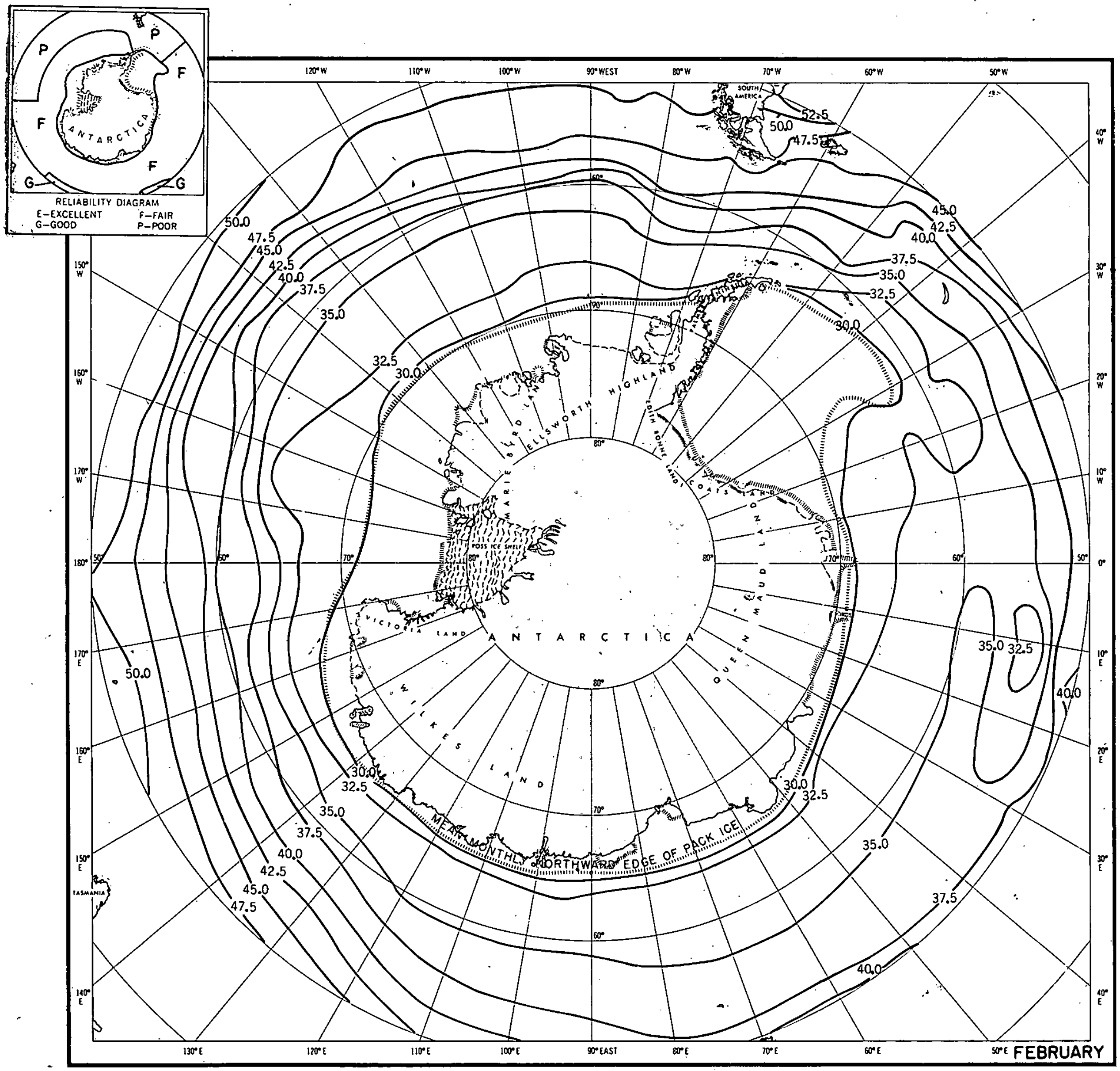

FIGURE 22–12. AVERAGE SURFACE TEMPERATURE (° F.), FEBRUARY

to 35° F. The temperature increase from the winter water to the warm water beneath amounts to about 3° F. on the average. Near the Antarctic Divergence, where the winter water is very cold and the warm water lies at its shallowest depth, an increase of as much as 4° F. may occur within less than 30 feet.

In the Atlantic and the westernmost Indian Ocean, this temperature increase begins at fairly shallow depths, 300 to 450 feet for most of the distance between the Antarctic Convergence and the Antarctic Divergence (FIGURES 22–22 and 22–23). An extensive tongue of cooler water emanating from the Weddell Sea and extending to 30° to 45°E. results in temperatures as low as 32.5° F. within the body of the warmer water, with warmer temperatures to the north and south; within this tongue the positive temperature gradient between the winter water and the warmer water is very weak, amounting to less than 1° F. In the Indian Ocean east of about 45°E., in the region to the north of the Antarctic Divergence, the positive gradient lies generally at a depth of 300 to 600 feet, since here the deep warmer water rises more gradually from depth (FIGURES 22–24 and 22–25). In the Pacific Ocean and in Drake Passage, where the Convergence and the Divergence lie rather close together, the rise of warm water is particularly

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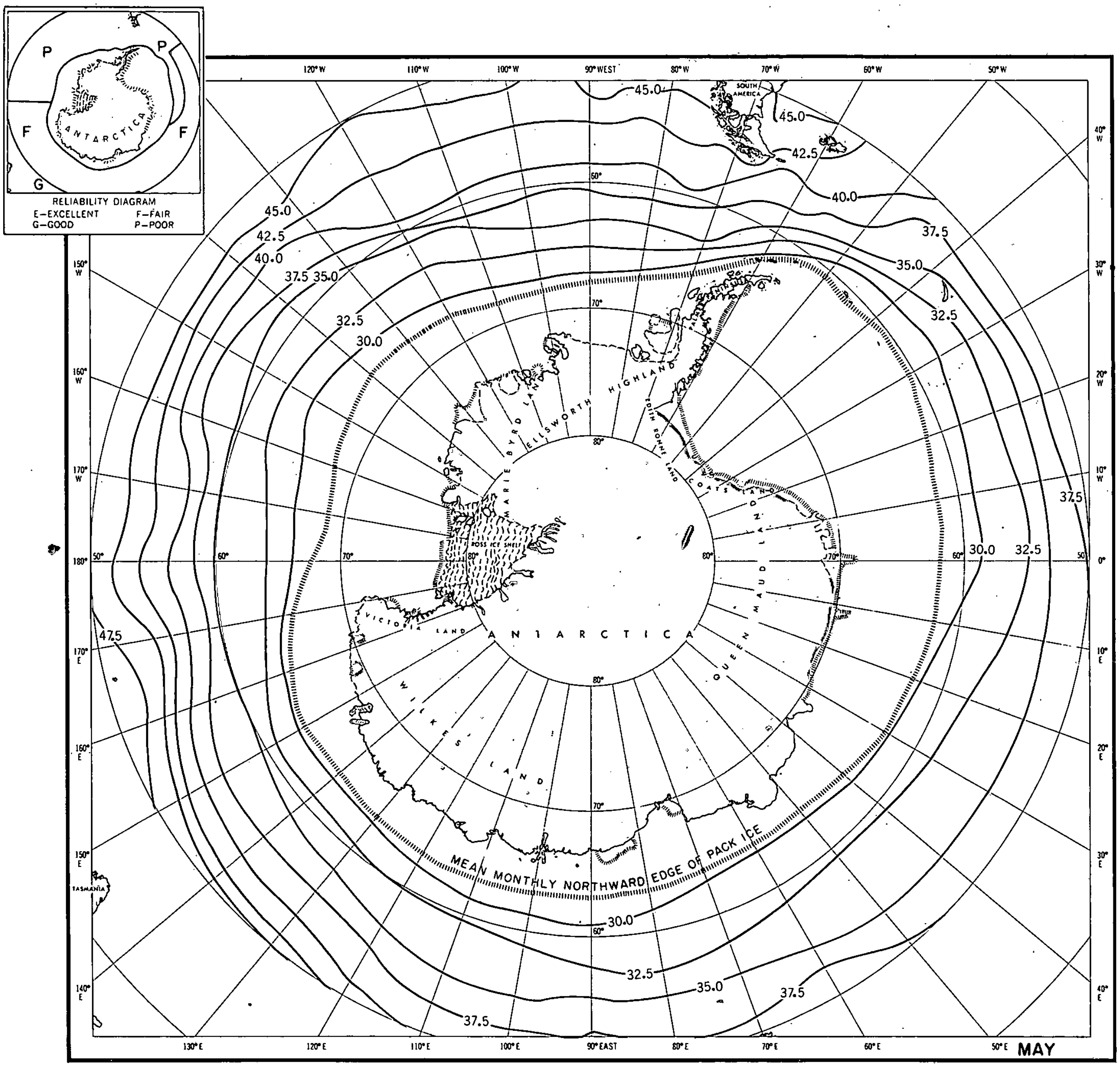

FIGURE 22–13. AVERAGE SURFACE TEMPERATURE (° F.), MAY

marked (FIGURES 22–26 and 22–27). A tongue of slightly lower temperatures within the warm water also is present to the north of the Ross Sea, but is far less extensive than the tongue from the Weddell Sea.

To the south of the Antarctic Divergence, the upper boundary of the Circumpolar Water deepens, reaching depths ranging from 500 to more than 1,000 feet near the continent.

The deep warm water is missing in the southern Weddell Sea and in parts of the Ross Sea. There the cold winter waters prevail at all depths, and no positive gradient is present.

Internal waves may cause fluctuations in the depth at which the warm water is generally encountered; changes as much as 150 feet within a few hours have been recorded.

(3) *Salinity*

(a) DISTRIBUTION OF SALINITY IN THE MIXED SURFACE WATER

1) Winter — In the layer of mixed surface water salinity increases evenly southward from less than 34.00‰ (parts per thousand) at the Antarctic Convergence to more than 34.15‰ at the pack-ice edge (FIGURE 22–16). The low salinities prevailing in the vicinity of the convergence reflect the relatively high prevailing rate of precipitation

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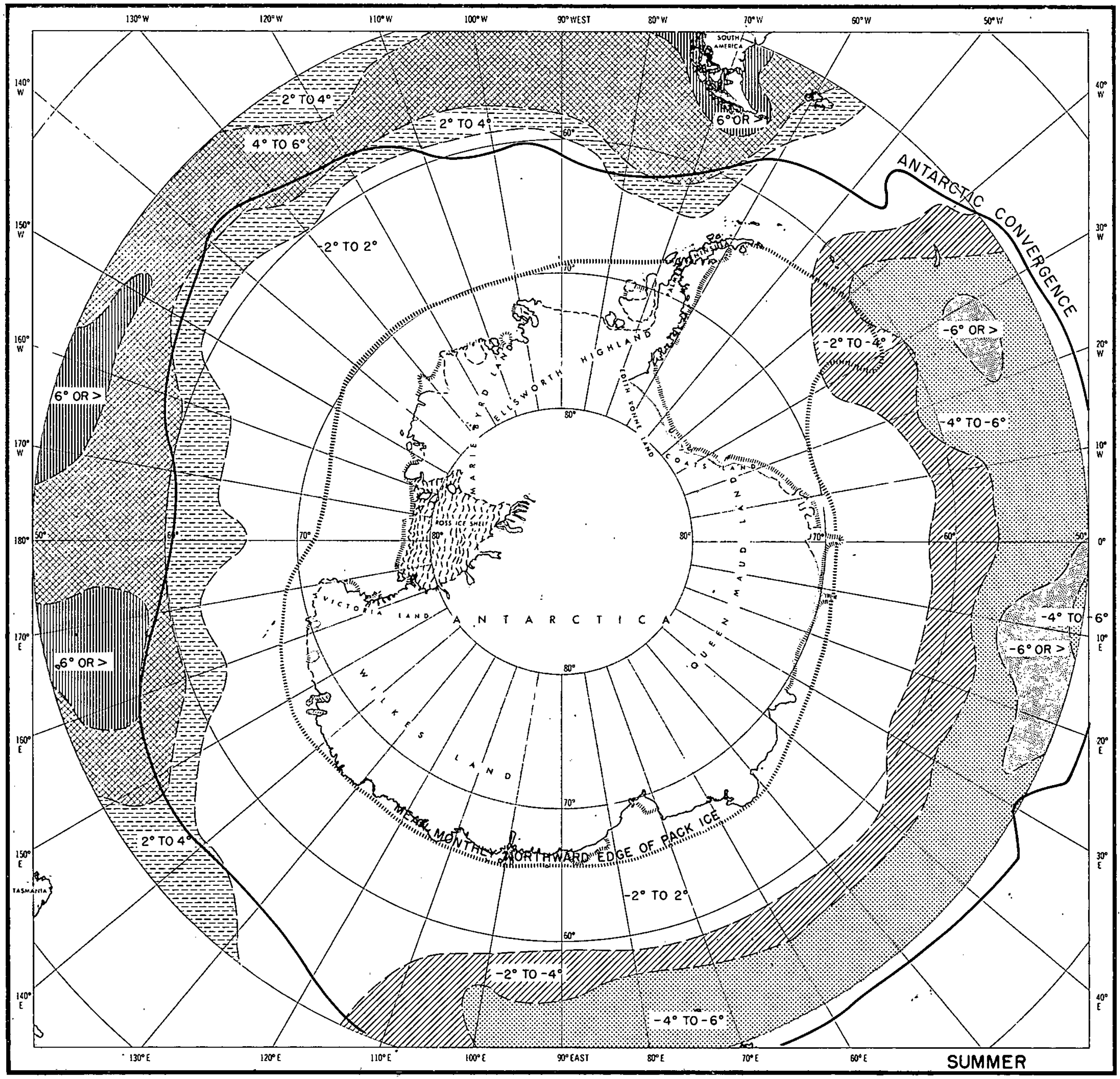

FIGURE 22–14. DEVIATION FROM THE MEAN TEMPERATURE BY LATITUDE, SUMMER. Approximate anomaly of surface temperature (° F.) based on the mean February temperatures for lines of latitude spaced 2½° apart.

and the low rate of evaporation. The increasing salinities farther to the south reflect mainly the mixing with the more saline water prevailing at depth.

At the pack-ice edge in late winter, the surface waters are to some extent enriched by the addition of salts from the freezing process, and salinity within about 20 miles of the pack ice may be as much as 34.45‰. In early winter, however, when the cumulative effect of the freezing process is not yet apparent, salinities near the ice edge may be rather low, in places less than 34.00‰. Lower salinities also may prevail at the ice edge in many places, especially in the Atlantic, where the ice has drifted northward into less saline water with temperatures above freezing. Beneath the pack ice in the mixed surface water salinities probably range from 34.40‰ to 34.45‰ throughout most of the Area by late winter. In the southernmost Weddell Sea and in the southern Ross Sea, where the freezing process continues for many months, salinities beneath the ice may be as high as 34.90‰.

The isohaline (no salinity change with depth) mixed winter surface water extends to about the same depths as the isothermal winter surface water described in the discussion on temperature distri-

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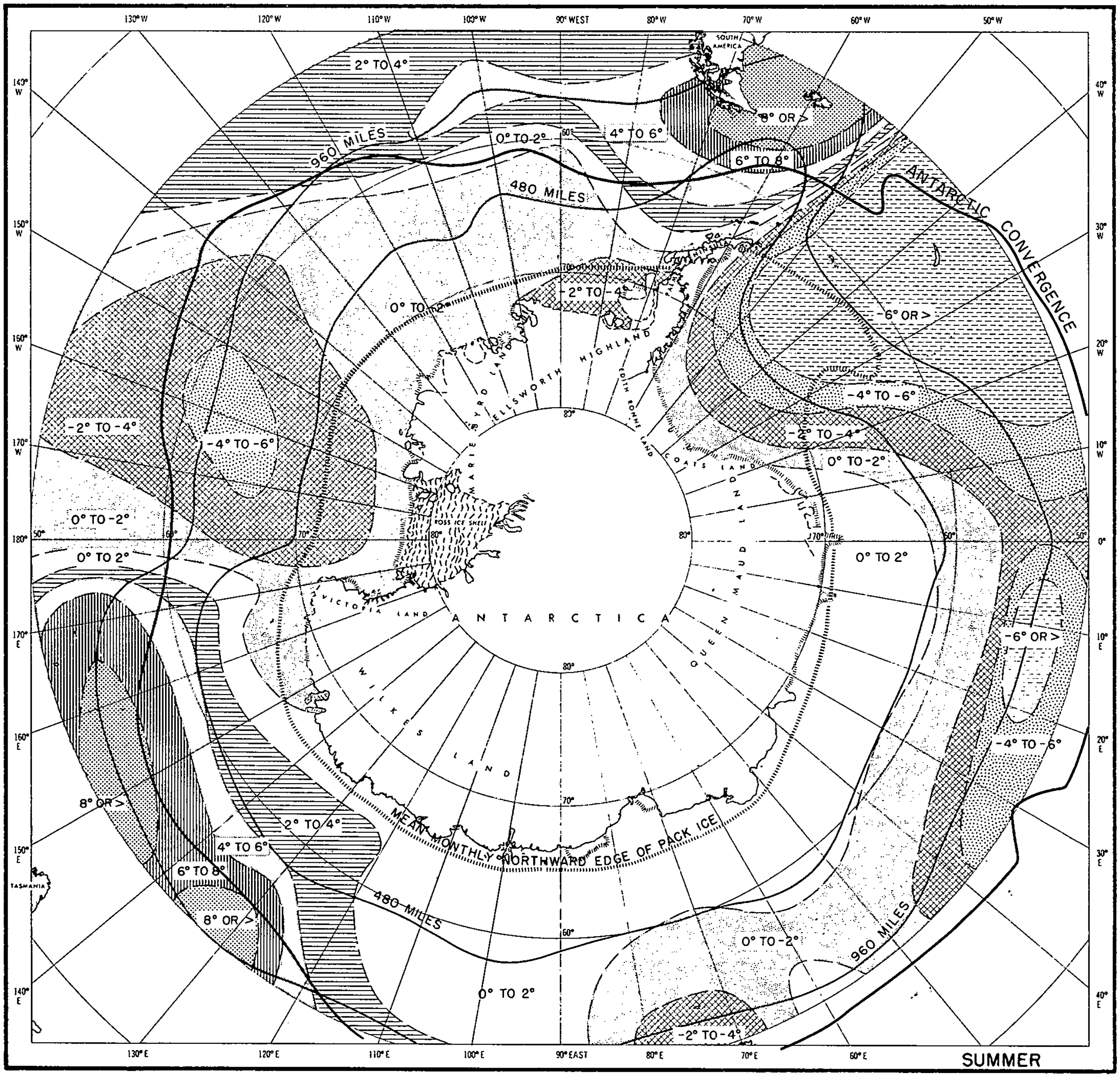

FIGURE 22–15. DEVIATION FROM THE MEAN TEMPERATURE ALONG LINES EQUIDISTANT FROM THE CONTINENT, SUMMER. Approximate anomaly of surface temperature (° F.) based on the mean February temperatures for lines spaced at intervals of 240 miles from the continent.

bution. An exception is the region immediately to the south of the Antarctic Convergence: here the waters may be nearly isothermal to depths of as much as 1,000 feet but because of mixing processes with the underlying water, the salinity generally increases between depths of 600 to 1,000 feet, to values as high as 34.25‰ in the Atlantic and 34.10‰ to 34.20‰ in the Indian and Pacific Oceans.

2) Summer — In the northern part of the Area salinity changes only little throughout the year (FIGURE 22–17). In the southern part of the Area during spring and summer the melting of ice results in a highly variable distribution of surface salinity. By summer, salinity in the southern part of the Area ranges from 32.00‰ to 34.50‰, with most commonly occurring salinities ranging from 33.50‰ to 34.10‰ (FIGURE 22–17). Melted or partially melted fields of pack ice produce extensive local areas of low salinity, 33.50‰ to 33.80‰, which extend generally to the depth of the seasonal thermocline. Such layers of melt water are separated from the more saline winter water beneath by a strong positive salinity gradient, with increases as much as 0.80‰ within 50 feet of depth.

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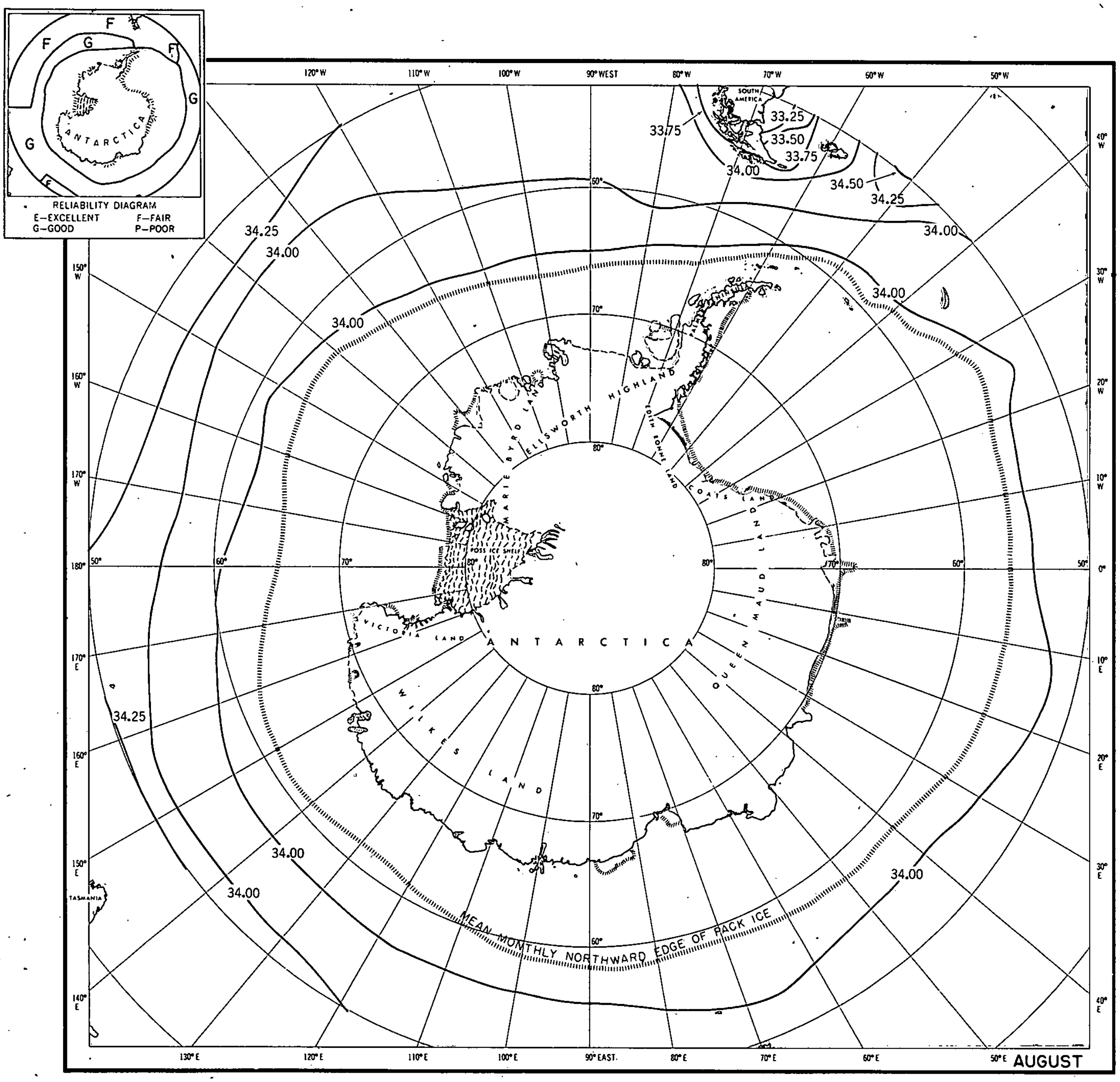

FIGURE 22–16. AVERAGE SURFACE SALINITY (PARTS PER THOUSAND), AUGUST

In the immediate vicinity of melting pack ice, shallow (10 to 50 feet deep) surface layers, with salinities as low as 32.00‰, frequently may be present. Very thin (less than 15 feet) layers of near-fresh water may be present near tabular icebergs during relative calms. Shallow lenses of very low salinity due to surface runoff also may be present in places along the shores of the continent.

In early summer in the southernmost part of the Area, when the melting ice has not reached its maximum, high salinities (34.00‰ to 34.25‰) predominate in the surface layer. In the Ross Sea and especially in the Weddell Sea, salinities as high as 34.40‰ extending to considerable depth have been observed in summer, even in the vicinity of ice; however, there are also present extensive but shallow low-salinity lenses of melt water. In the eastern Atlantic a tongue of higher salinities (34.05‰ to 34.15‰) persists to the east of Bouvet Island, probably the result of the addition to the surface layer of more saline water welling up from depth at the so-called Bouvet Divergence.

South of the Antarctic Divergence, there is a deepening both of the saline winter water and, in places, of the overlying less saline summer water. Near the continental shores and shelf-ice edges the winter water, marked by salinities increasing with depth from about 34.30‰ to 34.50‰, may extend

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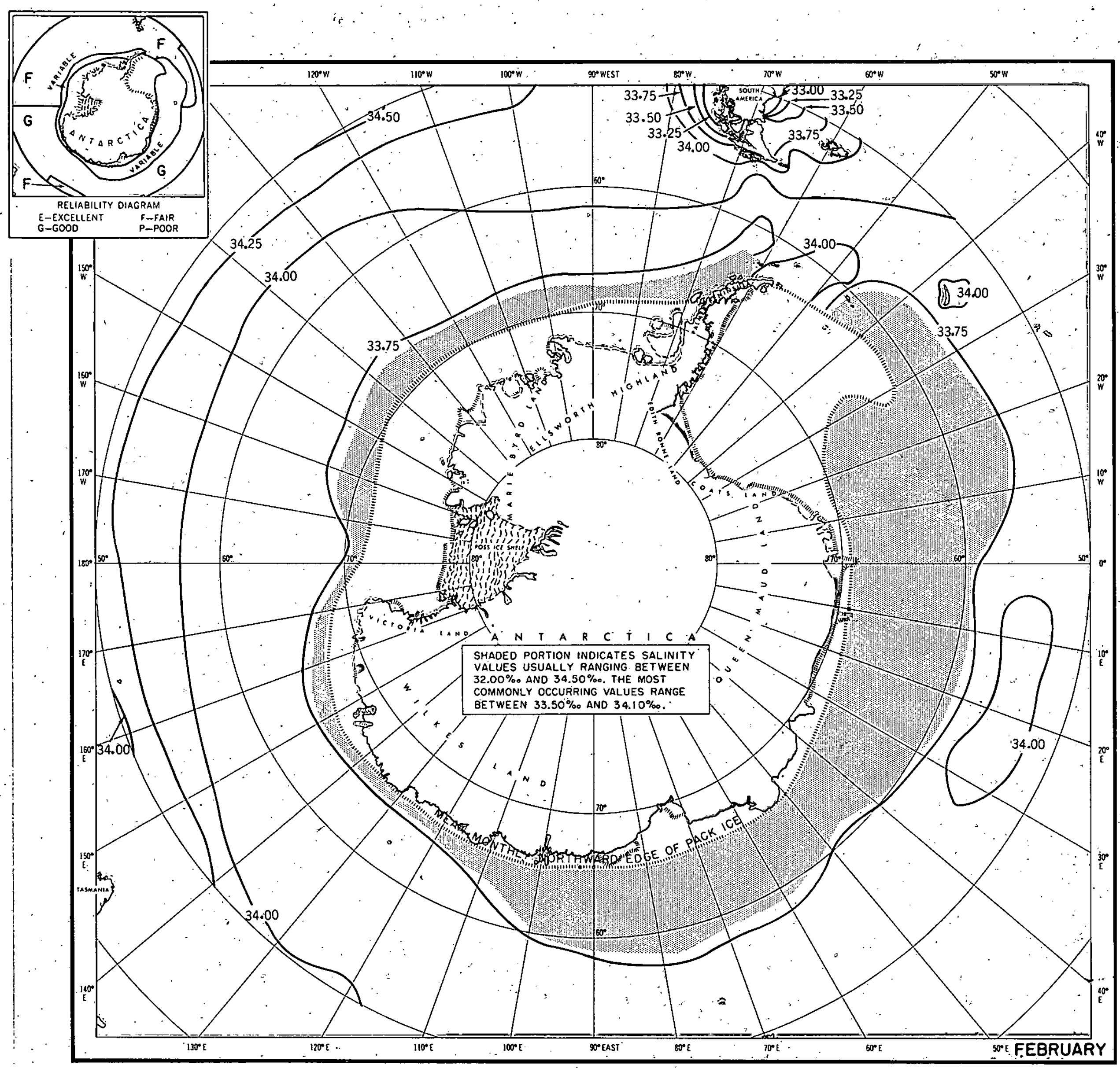

FIGURE 22–17. AVERAGE SURFACE SALINITY (PARTS PER THOUSAND), FEBRUARY

to more than 1,000 feet. The depth of the less saline overlying summer water is quite variable, but may be as great as 350 feet in places. Locally along the Ross Ice Shelf, the less saline summer water, with salinities ranging from 34.10‰ to 34.30‰, may extend in places to more than 1,000 feet, reflecting strong convective mixing along the barrier.

(b) DISTRIBUTION OF SALINITY FROM THE MIXED SURFACE WATER TO DEPTH OF 1,000 FEET — Antarctic Circumpolar Water, relatively saline water marked by salinities exceeding 34.55‰, prevails at depth beneath the mixed winter water throughout most of the Area (FIGURES 22–22 through 22–27). It rises from great depth to the south of the Antarctic Convergence, and at the Antarctic Divergence its characteristically high salinity is evident within 250 to 600 feet of the surface. Within the Circumpolar Water, the salinity increases gradually within a few hundred feet of depth to a maximum of 34.75‰.

In the Atlantic Ocean and the westernmost Indian Ocean, the deep saline water is present beneath depths of 300 to 450 feet for most of the distance between the Antarctic Divergence and the Antarctic Convergence (FIGURES 22–22 and 22–23).

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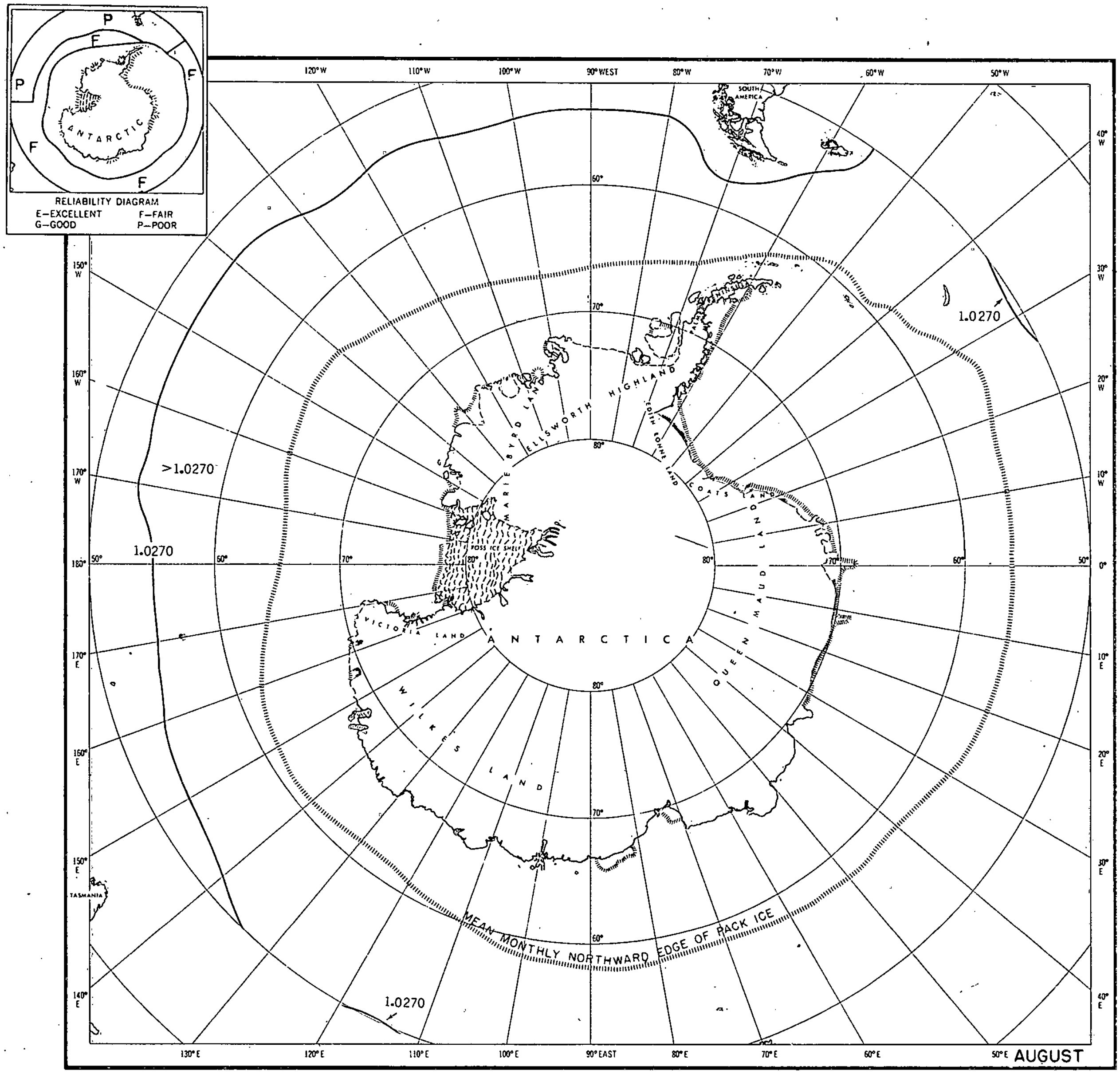

FIGURE 22–18. AVERAGE SURFACE DENSITY, AUGUST

A marked positive salinity gradient at about the same depth as the positive temperature gradient separates the winter water from the underlying deep water; the average salinity increase amounts to about 0.30‰ within an average depth interval of 150 feet.

In the Indian Ocean between about 40° and 140°E., the warm deep saline water remains at greater depths, generally slightly more than 1,000 feet, rising abruptly to within 300 to 600 feet at the Antarctic Divergence (FIGURES 22–24 and 22–25). Consequently, in a wide belt ranging from 5° to 8° of latitude, between the convergence and the divergence, the salinity at 1,000 feet ranges between 34.25‰ and 34.50‰. The positive salinity gradient, between the winter water and the saline Circumpolar Water, is quite weak over most of the Indian Ocean, except at the Antarctic Divergence.

In the Pacific Ocean and Drake Passage, where the convergence and the divergence lie closer together, the deep saline water is present at depths less than 1,000 feet within 1° to 3° of latitude to the south of the Antarctic Convergence, reaching depths of about 250 to 350 feet at the Antarctic Divergence (FIGURES 22–26 and 22–27). In the Bellingshausen Sea the average depth at the divergence probably is somewhat greater.

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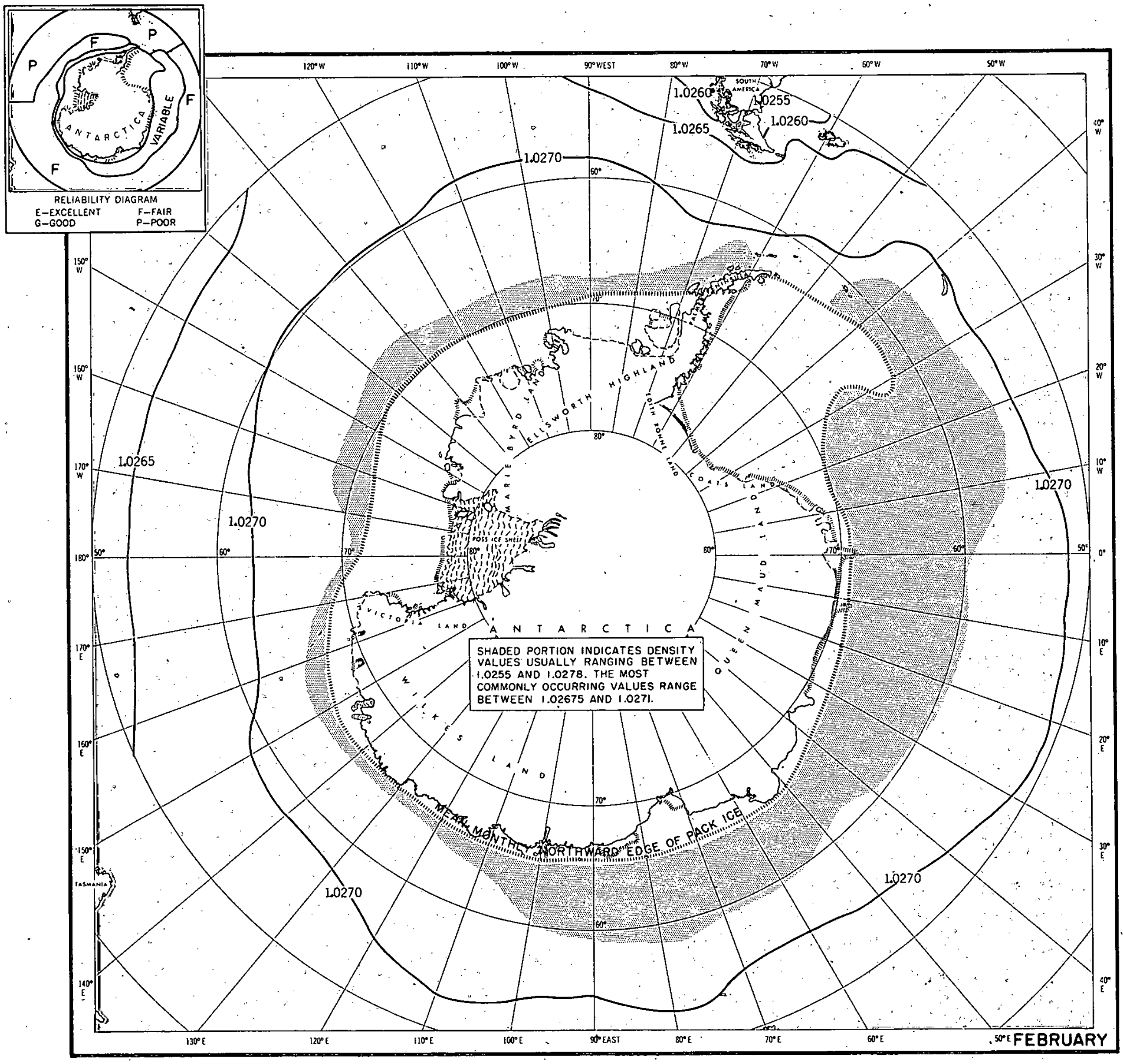

FIGURE 22–19. AVERAGE SURFACE DENSITY, FEBRUARY

Because the Circumpolar Water originates mainly in the Atlantic Ocean its salinity is highest in these longitudes, and it decreases slightly by mixing in its clockwise movement around the continent; its average salinity in the Pacific Ocean and the Scotia Sea (*37A*) is about 0.05‰ lower than in the Atlantic.

In the southern and western parts of the Weddell Sea and in parts of the Ross Sea, the deep saline water is missing. The highly saline water (up to 34.90‰) found locally at depth in these seas (FIGURES 22–28 and 22–29) represents surface water which has sunk after having been enriched with salts by the freezing process in winter.

(4) *Density*

(a) DISTRIBUTION OF DENSITY IN THE MIXED SURFACE WATER

1) Winter — In the mixed surface water, density ranges from 1.0270 to 1.0275, increasing gradually southward over most of the Area (FIGURE 22–18). Across the Antarctic Convergence, which bounds the heavy Antarctic Surface Water in the north, a southward density increase of 0.0001 to 0.0003 takes place within 20 to 60 miles. In the Atlantic and western Indian Oceans, the density immediately to the south of the convergence is characteristically 1.0270. Farther eastward it increases slightly, reflecting the slightly

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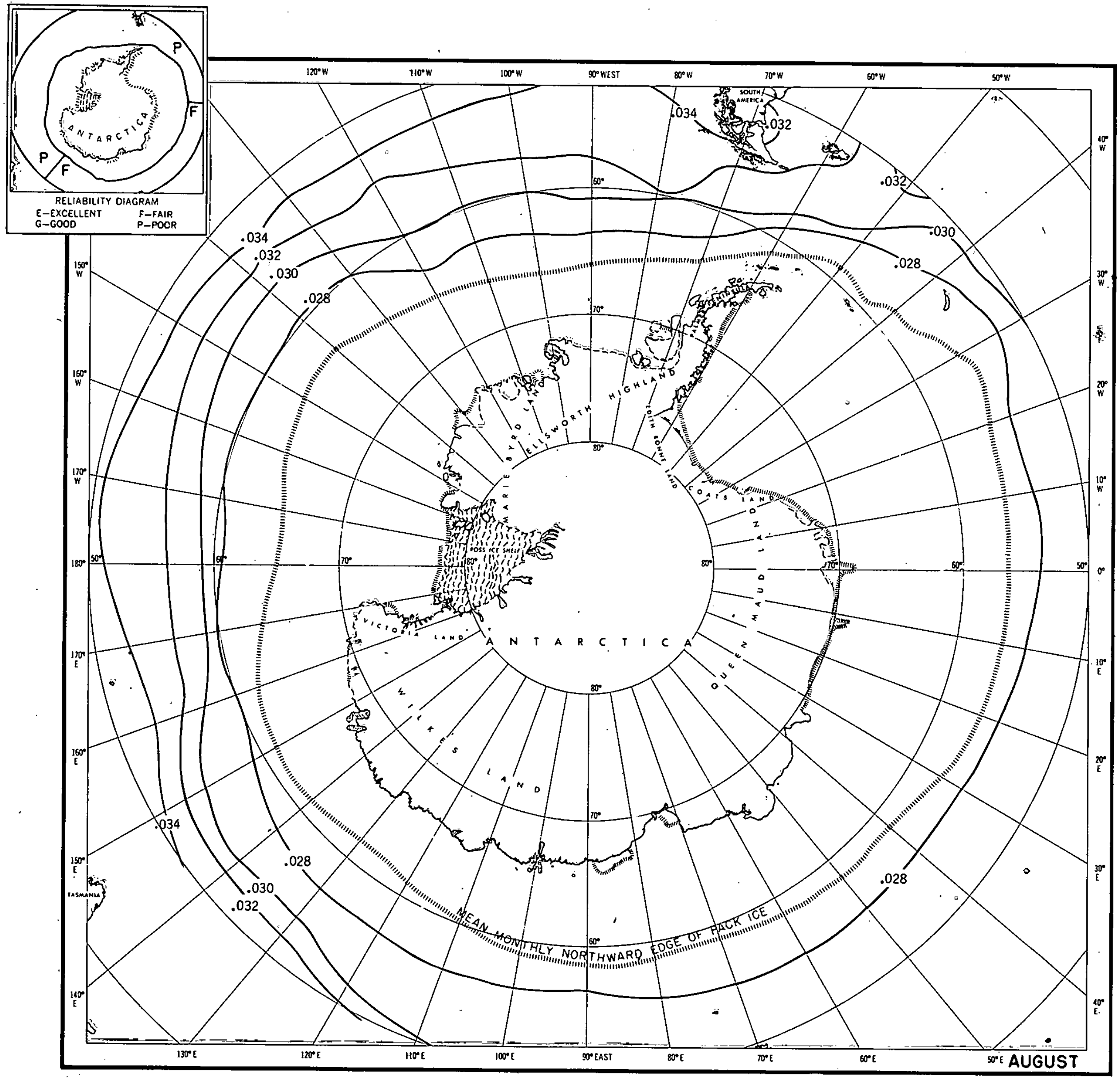

FIGURE 22–20. AVERAGE SURFACE ELECTRICAL CONDUCTIVITY (MHO/CM.), AUGUST

lower temperatures and slightly higher salinities. In the Pacific, density near 1.0271 prevails along the northern edge of the winter Antarctic Surface Water. In the cold and more saline water near the ice edge, densities range from 1.0273 to 1.0275. Beneath the pack ice density likewise is quite high, reaching 1.0275 to 1.0277 by the end of winter. Throughout the Area, the depth of the near-isopycnal (comparatively uniform density with depth) winter Antarctic Surface Water is approximately the same as the depth of the isothermal mixed water except near the Antarctic Convergence, where density generally increases slightly between 600 and 1,000 feet as a result of salinity increases.

2) Summer — During spring and summer a layer of slightly lighter surface water develops above the heavy winter water (FIGURE 22–19). On the average, surface densities by midsummer are about 0.0002 lower than in winter. In the northern part of the Area the seasonal decrease in density results primarily from the seasonally warmer temperatures; in the southern part of the Area, where temperatures are very low, the decrease is primarily due to the seasonally lower salinity. At very low temperatures, salinity changes have a much stronger effect on density

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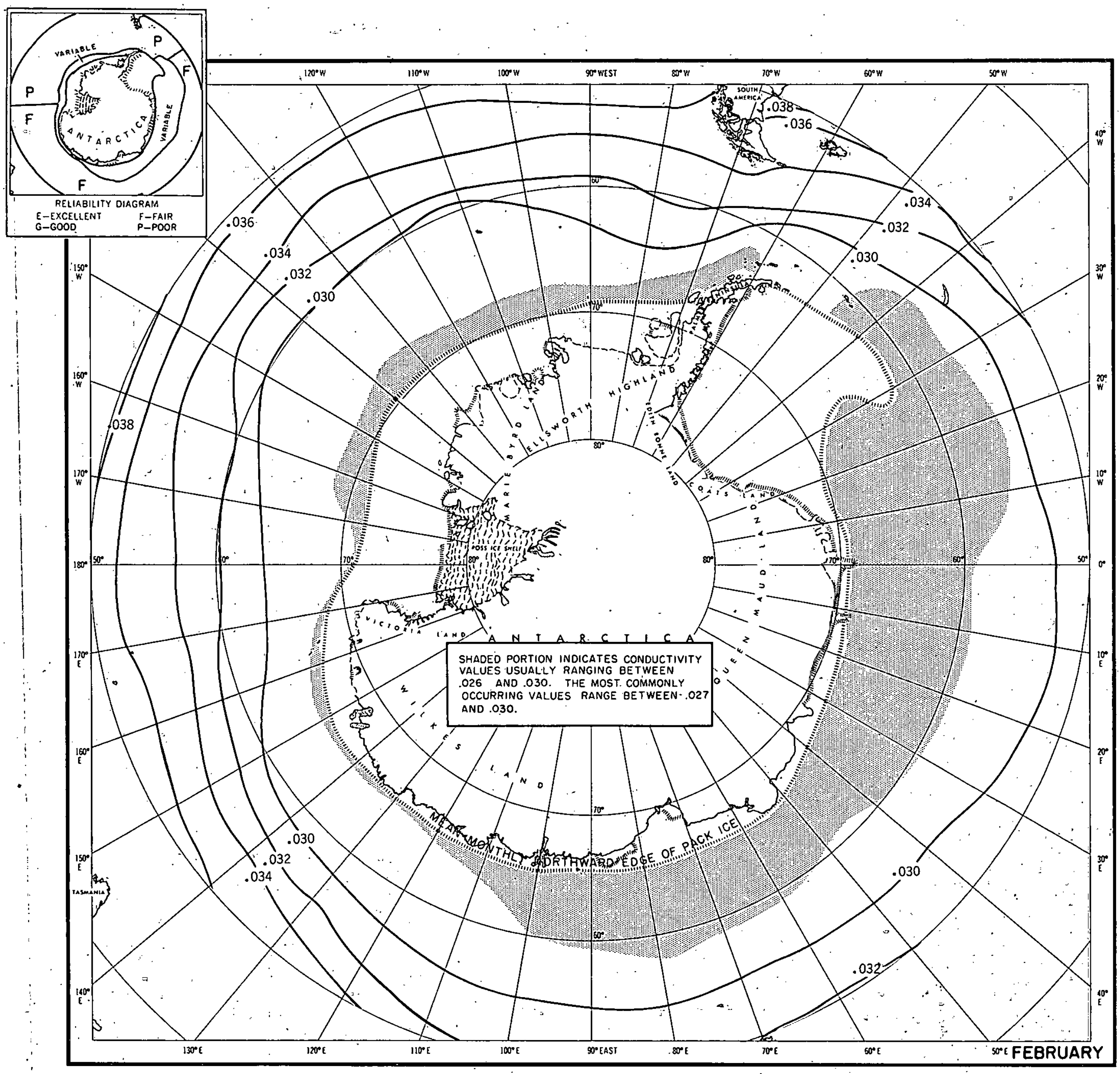

FIGURE 22–21. AVERAGE SURFACE ELECTRICAL CONDUCTIVITY (MHO/CM.), FEBRUARY

than do changes in temperature. The average density of the surface layer increases southward slightly, from less than 1.0270 at the convergence in the Atlantic and Indian Oceans and from about 1.0270 in the Pacific to average values near 1.0271 in the central latitudes of the Area. In the Atlantic a tongue of denser water from the Weddell Sea, marked by densities of more than 1.0272, extends past Bouvet Island to about 30°E. in the Indian Ocean.

In the south, densities are quite variable. Extensive widely scattered regions of low-salinity ice-melt water are marked by low densities ranging generally from 1.0267 to 1.0271. Locally, melting ice may result in very light water with densities as low as 1.0255. These regions are especially common in the Atlantic. In open water, densities generally range from 1.0271 to 1.0274.

The low-density, near-isopycnal summer water extends to about the same depth as the isothermal warm summer water. The very light water lenses due to ice melting are, however, usually very shallow, extending only to depths of 10 to 50 feet. To the south of the Antarctic Divergence, the relatively light surface water may deepen in places to as much as 1,000 feet near the continent.

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Throughout most of the Area the lighter summer water is separated from the denser winter water at depth by a thin, but generally sharp, density layer (FIGURES 22–23, 22–25, and 22–27). It will be strongest beneath the Antarctic Divergence and beneath the light ice-melt water. Vertical density increases through the seasonal density layer range from 0.0002 in the northern part of the Area and beneath ice-free water, to as much as 0.001 beneath ice-melt water in the southern part of the Area. The thickness of the layer ranges from 25 to about 150 feet. The seasonal layer may be very poorly developed in places near the continent in the southern Ross and Weddell Seas, and beneath the tongue of dense water emanating from the Weddell Sea, since in these sectors the difference between the summer and winter densities is small.

(b) DISTRIBUTION OF DENSITY FROM THE MIXED SURFACE WATER TO DEPTH OF 1,000 FEET — Beneath the mixed winter surface water, the denser deep Antarctic Circumpolar Water prevails throughout most of the Area (FIGURES 22–22 through 22–27). Despite being warmer, this water is heavier than the overlying winter water because of its high salinity; it is marked by densities of about 1.0276 to 1.0278. Within the Antarctic Circumpolar Water, density increases only very slightly with depth.

In the Atlantic and westernmost Indian Oceans, the dense Antarctic Circumpolar Water is present at shallow (300 to 450 feet) depth over most of the distance between the Antarctic Convergence and the Antarctic Divergence (FIGURES 22–22 and 22–23). Its relatively high density (1.0277 to 1.0278) reflects the presence of denser water from the Weddell Sea and very saline deep water from the Atlantic. In the Atlantic, Antarctic Circumpolar Water actually consists of the very dense tongue of Weddell Sea Water flanked to the north and to the south by slightly lighter deep water from the Atlantic. This deep water rises from great depth just to the south of the Antarctic Convergence and flows eastward along with the heavy water from the Weddell Sea, which lies just to the south of it. In the Indian Ocean between longitudes 30°E. and 45°E., the easternmost extent of the Weddell Sea tongue, much of this water, now mixed, turns southward and returns westward in the southernmost part of the Area with the East Wind Drift. After re-entering the Weddell Sea, this returned water gains in density by being chilled and subsequently forms the eastward-flowing cold dense tongue of Weddell Sea Water.

In a narrow zone immediately to the south of the convergence, where the Circumpolar Water still lies at depth greater than 1,000 feet, the transition from the winter mixed water is gradual and weak, the density increase amounting to about 0.0003 to a depth of 1,000 feet. Farther south, with the rise of the Circumpolar Water, the transition is marked by a sharp density increase of 0.0001 to 0.0003 within a short vertical distance. In the southernmost latitudes the increase is generally small, but still sharp, because of the prevailing high density of the winter water.

In the Indian Ocean between about 45° and 130°E., the main rise of the Atlantic Circumpolar Water from depth takes place much farther south than in the Atlantic, due to the absence of the Weddell Sea tongue of dense water. Hence the characteristic high densities of the Circumpolar Water are evident only at shallow depths only in the vicinity of the Antarctic Divergence (FIGURES 22–24 and 22–25). Over most of the distance between the divergence and the convergence, densities increase very gradually beneath the mixed winter water. Values at 1,000 feet range from 1.0272 to 1.0275, an increase of less than 0.0002 from the surface densities. At the Antarctic Divergence the dense water rises to within 300 to 600 feet of the surface, being separated from the overlying winter water by a small but sharp density gradient. The highest density in the Circumpolar Water in the Indian Ocean (about 1.0278) generally occurs near the Antarctic Divergence.

Farther east, in the Pacific Ocean and Drake Passage, where the Antarctic Convergence and the Antarctic Divergence lie fairly close together, the rise of the dense deep Circumpolar Water takes place within 2° or 3° of latitude south of the convergence (FIGURES 22–26 and 22–27). Immediately south of the convergence, the density increase beneath the mixed winter water is very small; at times near-isopycnal water may extend from the surface to depths of more than 1,000 feet.

At the divergence the depth of the upper part of the Circumpolar Water ranges from 300 to 600 feet, the greater depths being more likely in the Bellingshausen Sea (*25*).

To the north of the Ross Sea, the density of the Circumpolar Water is somewhat higher (1.0278), owing to the addition of some heavier Ross Sea water. Farther east the density decreases slightly, and in Drake Passage the density in the Circumpolar Water does not exceed 1.0277, reflecting the influence of the mixing processes with less saline waters during its long eastward passage around the continent.

To the south of the Antarctic Divergence throughout most of the Area, the upper limit of the dense Circumpolar Water deepens. In places near the continent, where it may lie at a depth of more than 1,000 feet, isopycnal water or a weak density gradient prevails. Thus, the average density of the water column between the surface and

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the 1,000-foot depth is greatest at the Antarctic Divergence and somewhat less to the south.

The dense Circumpolar Water is missing in the southern part of the Weddell Sea and in parts of the Ross Sea. In places in these regions where the bottom is shallow, some very dense water, nevertheless, may be present at depth (FIGURES 22–28 and 22–29). This water, with density as high as 1.0280, is a result of the freezing process in winter.

(5) *Electrical conductivity* — Electrical conductivity is relatively poor throughout this Area, reflecting the prevailing low surface temperature. In winter, conductivity decreases southward from about 0.030 mho/cm. (reciprocal ohms per centimeter) at the Antarctic Convergence to less than 0.028 mho/cm. near the ice edge (FIGURE 22–20). In summer, conductivity in the northern parts of the Area is about 0.002 mho/cm. higher than in winter, reflecting the seasonally slightly warmer temperatures (FIGURE 22–21). To the south, conductivity is variable because of the presence of extensive local regions of low-salinity ice-melt water; conductivity generally will range from 0.027 to 0.030 mho/cm., with the lower values occurring in regions where melting ice has diluted the surface water. Very low conductivities may exist in the vicinity of tabular icebergs, which at times give rise to a thin layer of nearly fresh water.

(6) *Buoyancy* — To the south of the Antarctic Convergence no well-developed or predictable layer suitable for balancing or running in trim exists at any time. In both summer and winter pumping conditions predominate over most of this Area at all depths.

(a) WINTER — In winter throughout the Area, a ballast reduction ranging from 10,000 to 13,000 pounds is required to dive in trim from the surface to 1,000-foot depth. Proportionally smaller reduction would be necessary to dive to intermediate depths (FIGURES 22–22, 22–24, and 22–26). These winter conditions probably prevail from May through November. While running submerged at fixed depth, no sudden changes in buoyancy conditions will occur except in the vicinity of the Antarctic Convergence. There, when crossing the convergence submerged, the submarine would move from the lighter water in the north to the heavier Antarctic Surface Water to the south within a short distance, and it might be necessary to adjust ballast to remain in trim at a fixed depth. In going south across the convergence the submarine would become relatively too light and while crossing north relatively too heavy. The necessary ballast adjustment probably would not exceed 1,500 pounds. The convergence often may be marked by several alternating zones of light and heavy water, making depth control difficult. These horizontal changes are most pronounced in the upper 200 to 500 feet. Diving in trim at a fixed position near the convergence, however, would necessitate the same amount of pumping per depth as elsewhere in the Area.

(b) SUMMER — In summer, when a surface layer of lighter water is present throughout most of the Area, the ballast reduction necessary to dive in trim to depths beneath the seasonal thermocline is somewhat less than in winter (FIGURES 22–23, 22–25, and 22–27). In general, ballast reduction within the isothermal water (which over most of the Area extends to depths ranging from 50 to more than 250 feet) amounts to about 1,400 pounds per 100-foot depth increase. In the northern part of the Area the thermocline generally is too weak to result in a balancing layer, and pumping is required to dive through it. In much of the southern part of the Area, where the thermocline is augmented by a positive salinity gradient, ballast adjustment necessary to dive through the thermocline from the surface ranges from about 2,000 pounds pump to about 1,500 pounds flood. A flooding layer, which is usually less than 100 feet thick, is most likely to be present in places where the seasonal thermocline is at depths less than 150 feet, such as near the Antarctic Divergence. To dive to a depth of 500 feet in summer, that is, generally beneath the seasonal thermocline, ballast reductions are necessary ranging from 2,500 pounds where a flooding layer prevails to 5,000 pounds where no flooding layer is present.

Throughout the southern part of the Area, local and erratically distributed flooding layers are present in summer, because of the presence of low-salinity, light melt water (FIGURES 22–23 and 22–27). They generally will be at depths ranging from 50 to 150 feet. Flooding necessary to dive through these ephemeral balancing layers would amount at most to 2,500 or 3,000 pounds. Ballast adjustments necessary to dive to greater depths from the surface would be correspondingly less than elsewhere. The occurrence of such layers cannot be predicted, except that they are more likely to occur near melting pack-ice fields and in the absence of heavy storms.

(7) *Color and transparency* — Data on color and transparency are very sparse in this Area. Transparency is probably low because of the high plankton content of the surface water. Estimated average transparency is 50 feet; over most of the Area, transparency is probably more than 23 feet and less than 90. Low values are probably near pack ice.

The color of the Antarctic Surface Water is usually blue gray, blue green, or green. Near pack ice the water is usually green. During the time of initial freezing, the sea may appear grayish or leaden in color. *(Text continued on page 22-40)*

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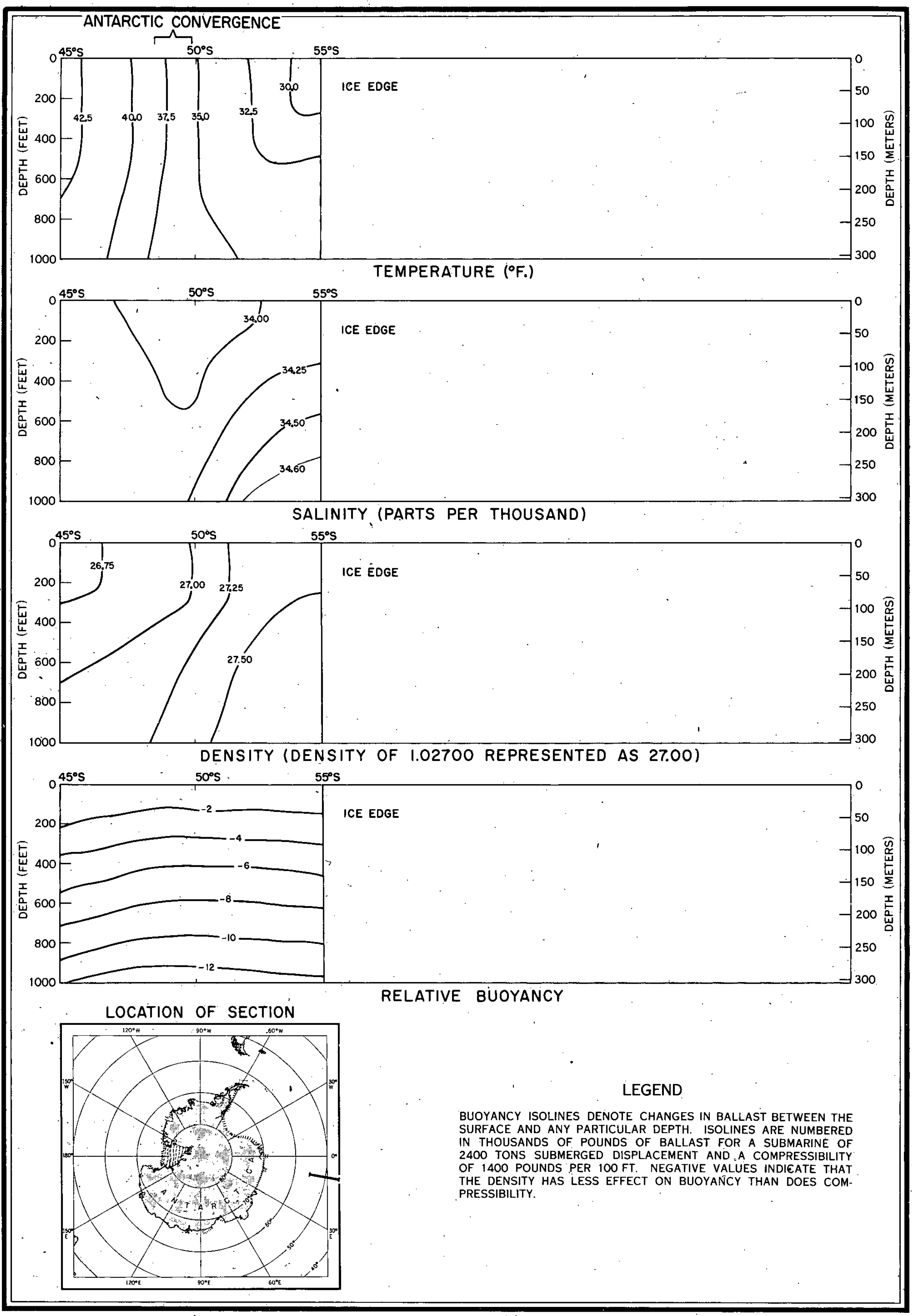

FIGURE 22–22. COMPOSITE VERTICAL SECTION IN THE SOUTH ATLANTIC OCEAN, WINTER

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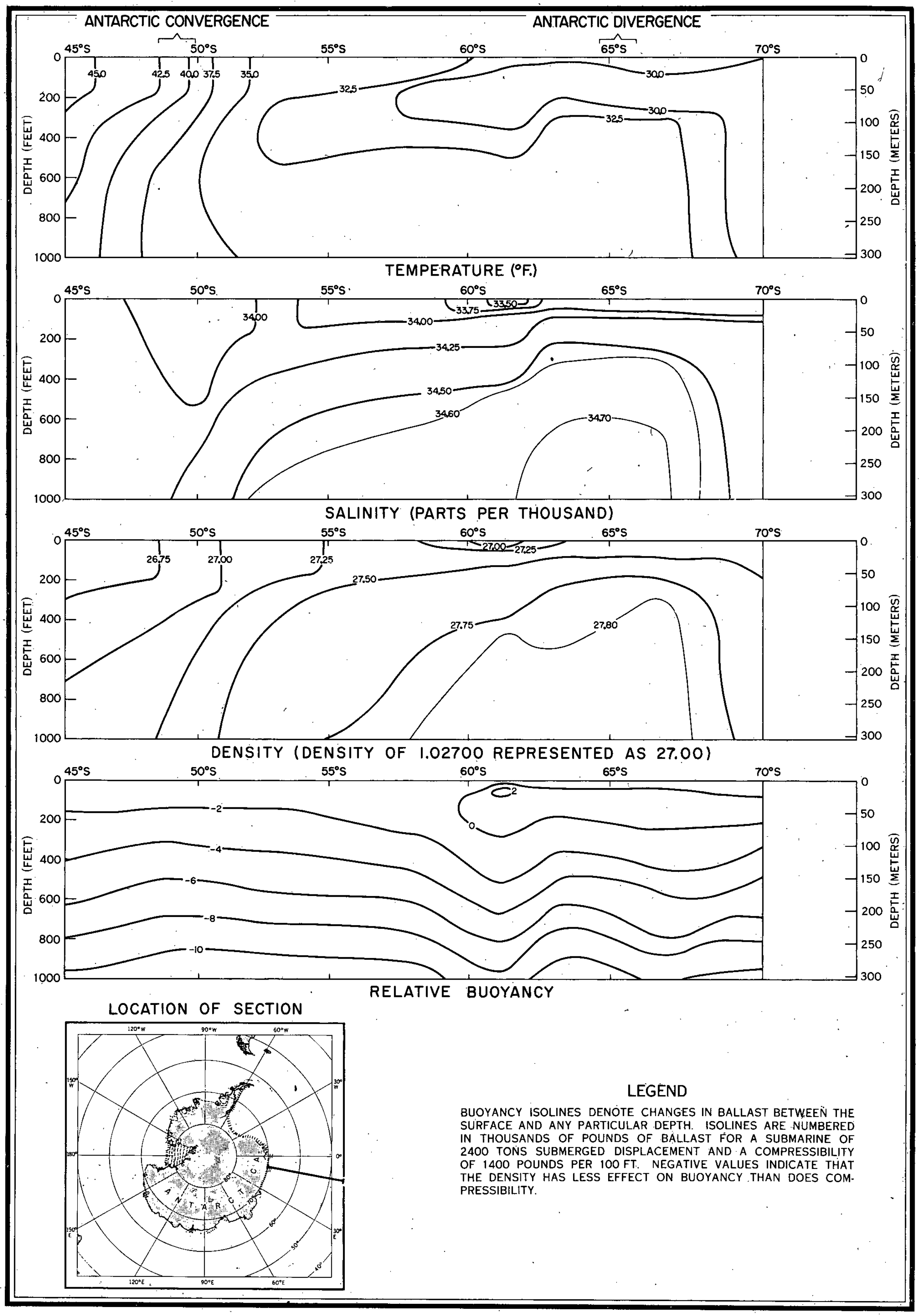

FIGURE 22–23. COMPOSITE VERTICAL SECTION IN THE SOUTH ATLANTIC OCEAN, SUMMER

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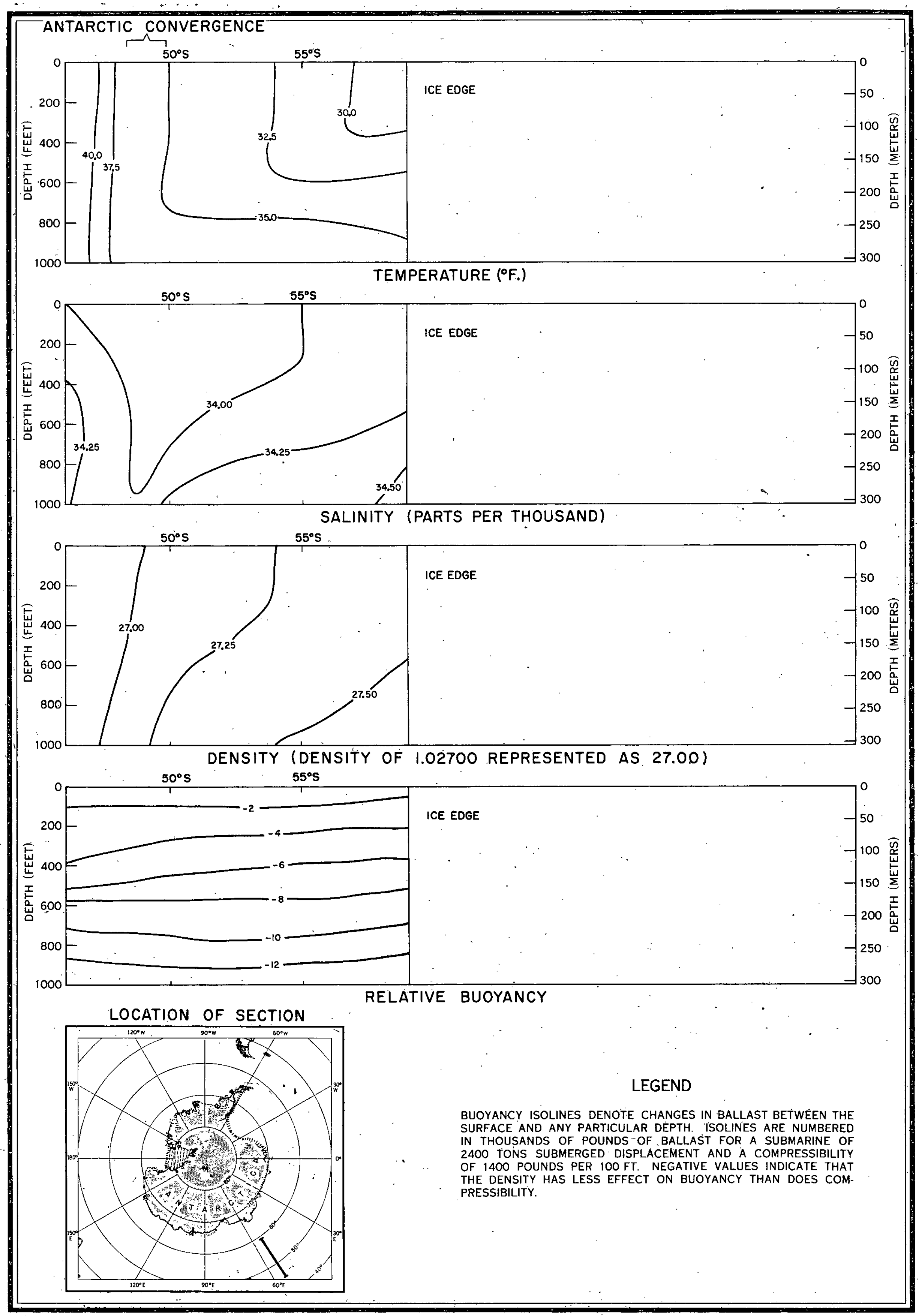

FIGURE 22-24. COMPOSITE VERTICAL SECTION IN THE INDIAN OCEAN, WINTER

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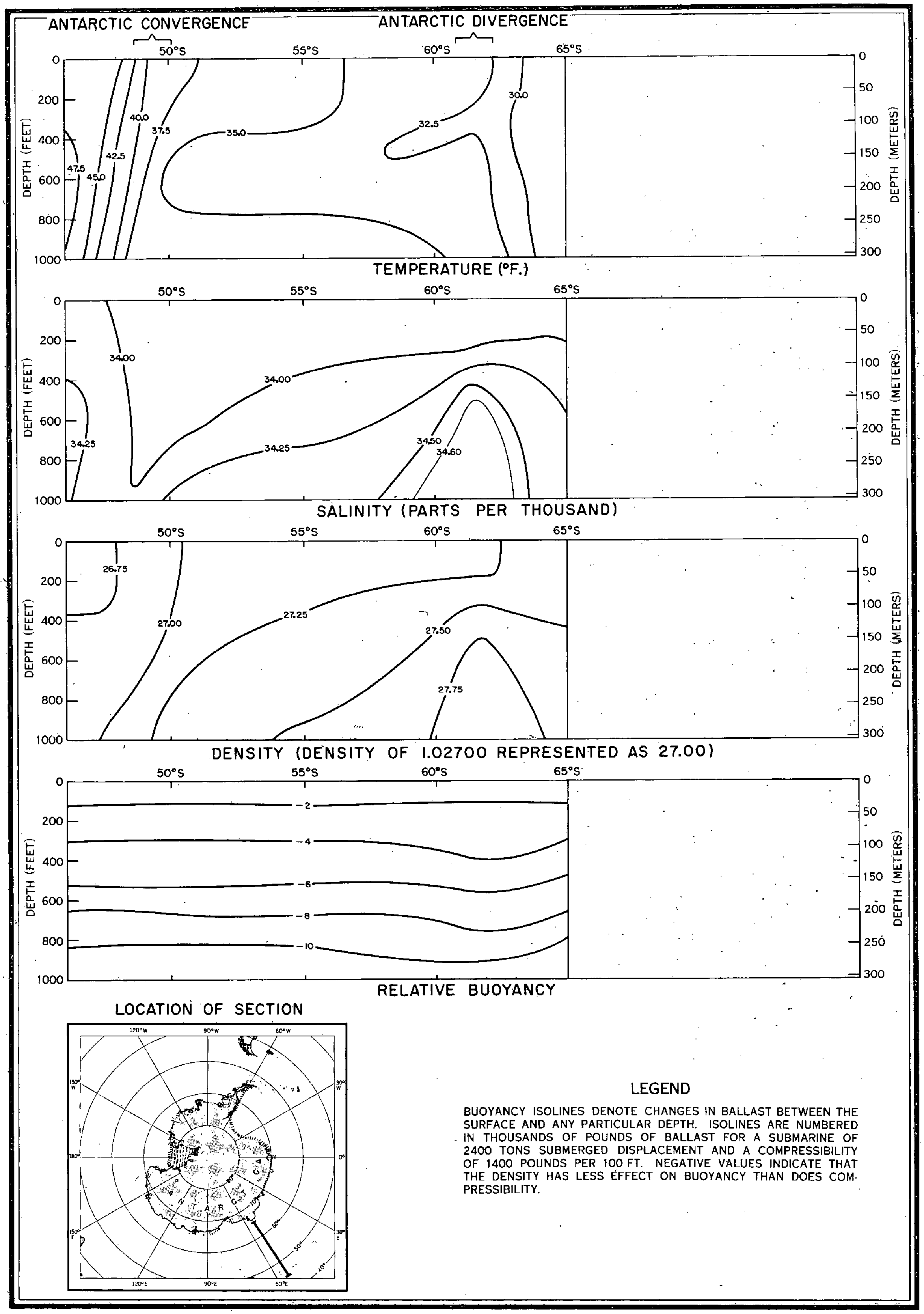

Figure 22–25. Composite vertical section in the Indian Ocean, summer.

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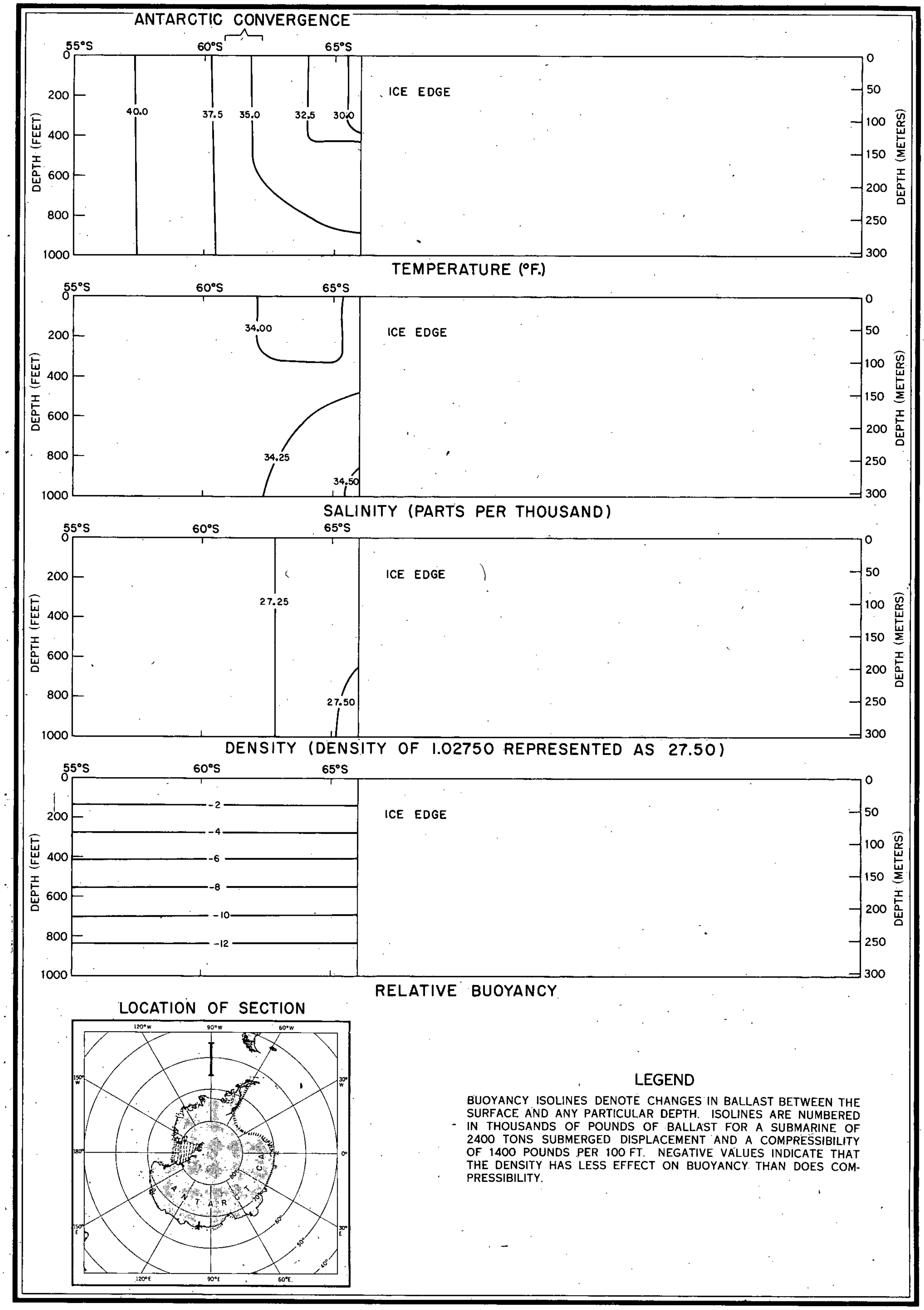

FIGURE 22–26. COMPOSITE VERTICAL SECTION IN THE EASTERN SOUTH PACIFIC OCEAN, WINTER

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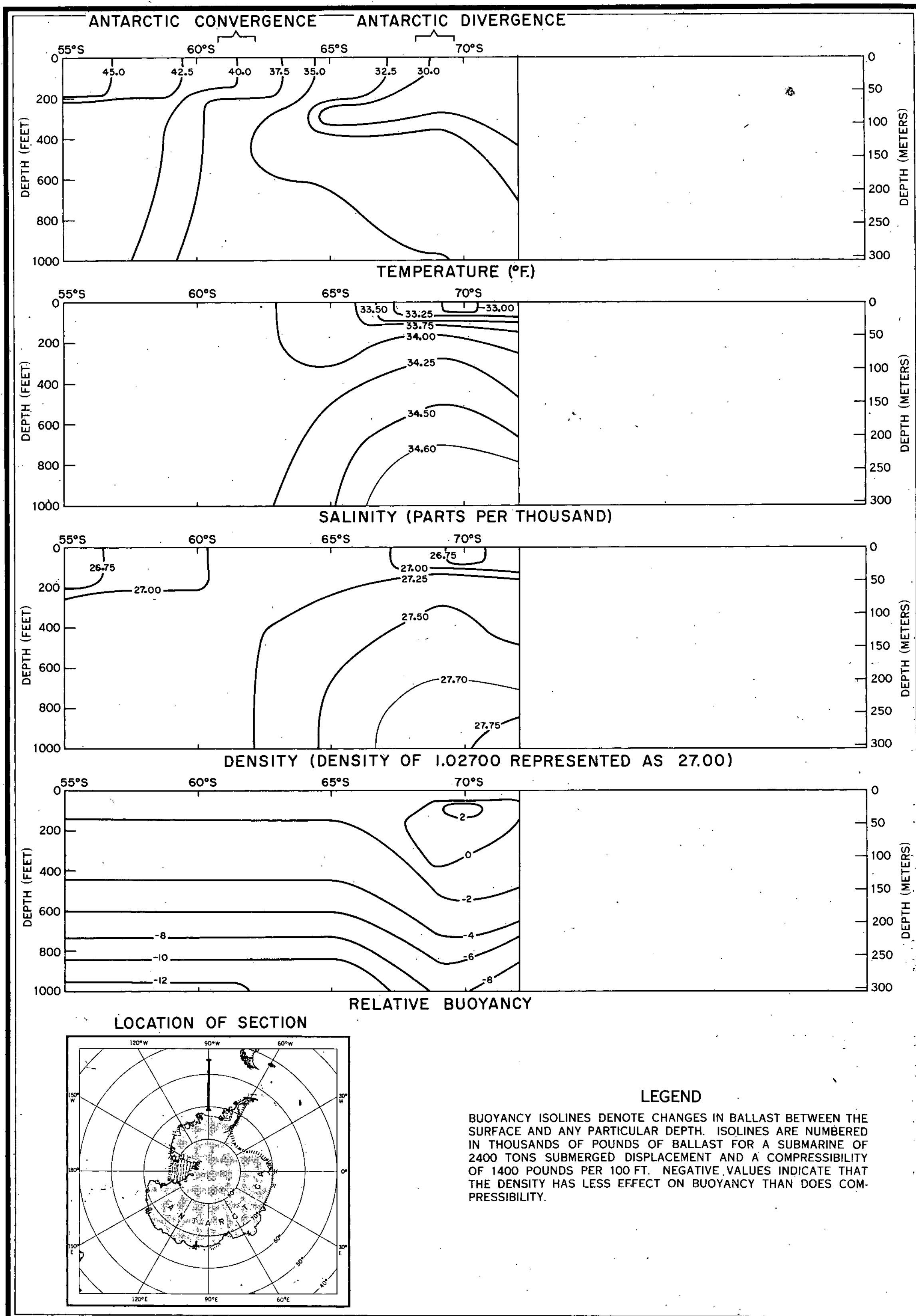

FIGURE 22–27. COMPOSITE VERTICAL SECTION IN THE EASTERN SOUTH PACIFIC OCEAN, SUMMER

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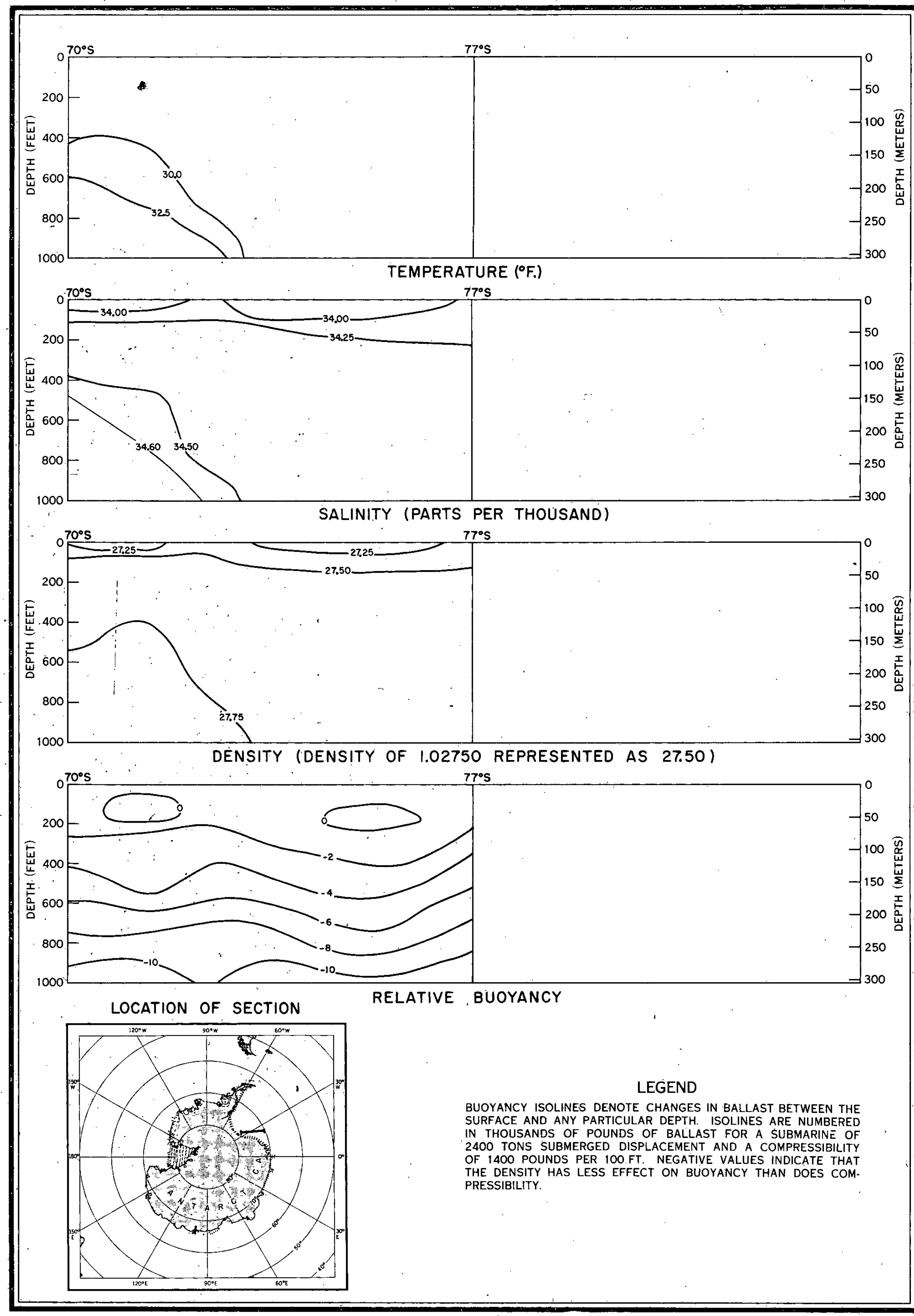

FIGURE 22–28. REPRESENTATIVE VERTICAL SECTION IN THE WEDDELL SEA

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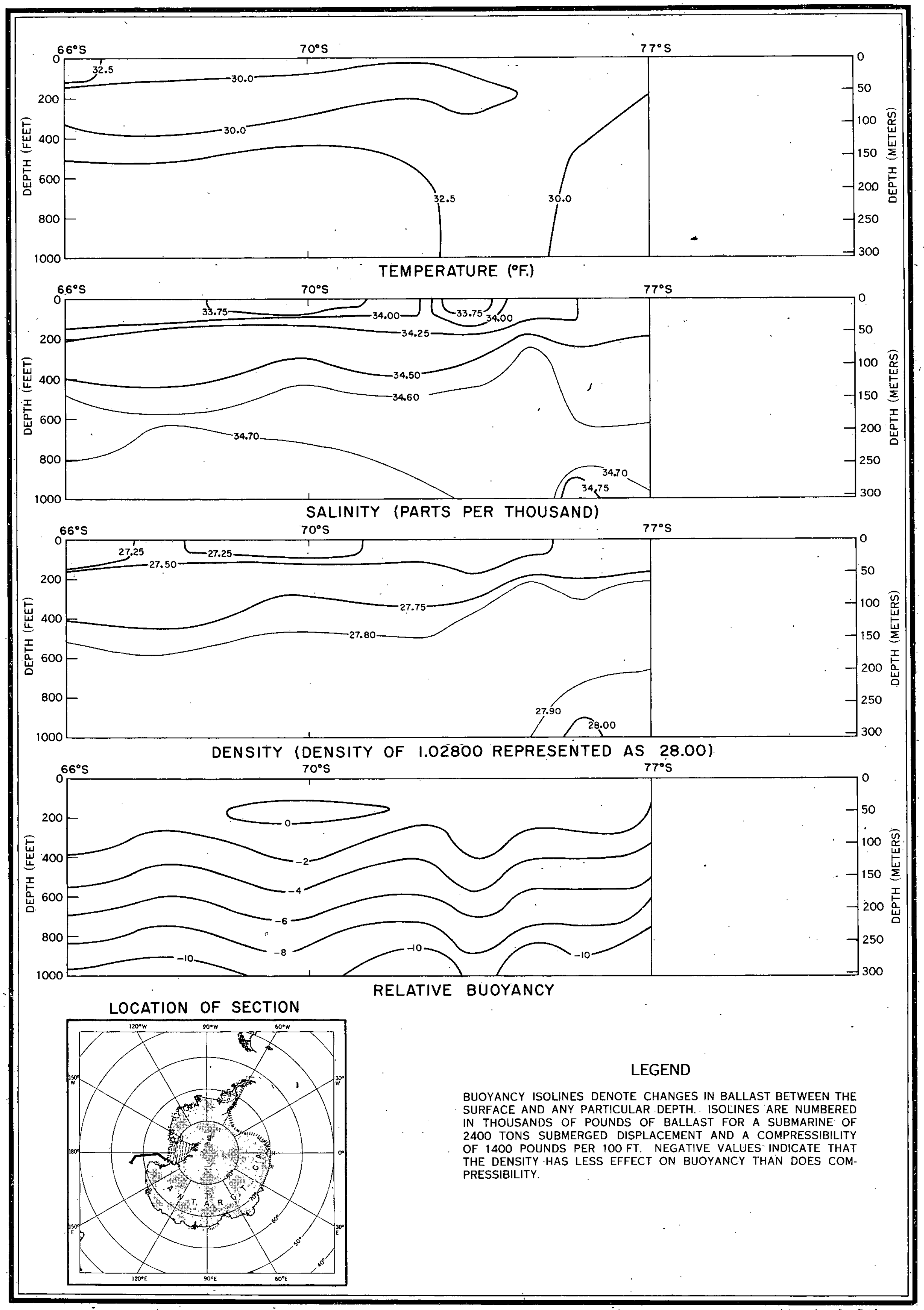

FIGURE 22–29. REPRESENTATIVE VERTICAL SECTION IN THE ROSS SEA

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b. ICE

(1) *General* — Probably the greatest single factor influencing any operation in the Antarctic is the pack ice (FIGURE 22–58B). During winter it completely surrounds the continent, forming an almost impassable barrier that extends on the average as far north as 56°S. in the Atlantic sector and to approximately 65°S. in the Pacific sector. Pack ice may be defined as any large area of floating ice driven closely together. It may include ice formed in the open sea, remnants of fast ice formed near the coastline of the continent, and seaborne detritus of land ice derived from the continent and the islands. The important characteristic of Antarctic pack ice which distinguishes it from that of the Arctic is the extreme heterogeneity of any particular field of pack: in one locality the ice may range from huge bergs and floes, many miles long and broad, to the ice crystals produced by supercooling of the sea. In the Arctic, in contrast, the pack of a particular field of ice is more generally homogeneous, consisting of only one type.

The pack-ice edge varies latitudinally with season. It seldom exists as a straight east – west line, but follows a rather tortuous course with embayments and promontories extending for many miles into and out of the pack. Owing to the prevailing southeasterly winds, the pack has a definite drift toward the north and west. As a consequence of the westerly movement, a great piling up of pack ice occurs in the western part of the Weddell Sea. This westward drift likewise will cause a considerable piling up of ice on the eastern sides of ice tongues projecting from the continent.

Another distinct feature of the ice in the Area is the tabular bergs (FIGURES 22–60A and 22–61B). Formed by the calving of portions of shelf ice, these generally are immense pieces of ice which may be as long as 100 miles and as high as 200 feet above the waterline. The ice shelves from which these bergs are derived are in themselves an outstanding feature of the Antarctic area (FIGURE 22–58A); these great ice masses, sometimes many hundreds of miles in extent (for example, the Ross Ice Shelf), present sheer walls of ice which bar access to the continent from the sea.

In general, ice conditions in the waters surrounding Antarctica at any particular point are almost impossible to predict. For example, at the entrance to the Ross Sea, the summer band of pack ice with open water to the south may fluctuate in width from year to year from as much as 400 miles to as little as 1 mile. Glacier tongues and bays reported over many years of Antarctic exploration have completely disappeared. For example, the Bay of Whales (*16*), long reported by expeditions into the Ross Sea sector (FIGURE 22–52A), was found to have disappeared by summer 1955, its whole west side having broken off, carrying with it a portion of Little America IV.

(2) *Pack ice* — Mean limits of the pack ice by months are shown in FIGURES 22–31 and 22–32. These limits are based on observations from whaling vessels, voyages of the research ship H.M.S. *Discovery*, and numerous other expeditions to Antarctica. Because these are only mean limits, the charts should be used with caution since the actual position of the northernmost edge of the pack varies from year to year. It should also be noted that portions of these lines represent interpolations, particularly for winter, when data are very limited. Open water areas south of the mean limits are not shown, since these vary greatly. Many of the observations of the pack ice were made while skirting the pack, no entrance being attempted.

(a) ADVANCE OF THE ICE EDGE — Freezing begins in late March or early April and progresses very rapidly through June (FIGURE 22–31). The ice edge moves northward, reaching its maximum extent in September and October. This northward advance is attributable to two factors, one south of the main body of pack and the other at its northern edge. First, the pack is being fed constantly from the reservoir of land-ice formations and sheets of fast ice formed in place; this contribution of ice moves into and with the main body of pack to the north and west. Second, in addition to the accession from the south and the subsequent movement of the pack, the ice edge advances through freezing of the open sea to the north.

The initial indication of freezing of the sea is the formation of ice crystals in the form of thin plates of ice lying horizontally on the surface of the water. These increase in number until the sea is covered by a slush of a thick, soupy consistency. The slush generally does not exceed a thickness of 12 inches and causes the sea to assume a grayish or leaden color. Under these conditions, a ship may experience clogging of intakes through accumulation of this type of ice. If the sea remains perfectly calm, a smooth sheet of ice is formed (FIGURE 22–60B). If the sea is affected by swell at the time of freezing, the ice sheet is sufficiently plastic to give with the undulations. However, as the ice sheet thickens it becomes more and more brittle until finally the whole mass may be broken up. The resulting pieces are rocked by the swell and in their constant collision with each other assume the form of pancake ice (FIGURE 22–59A). Some of these smaller pieces may unite to form larger floes, which in turn acquire the pancake appearance. If the ice remains in place, the water freezes between the pancakes, and a continuous ice sheet is formed.

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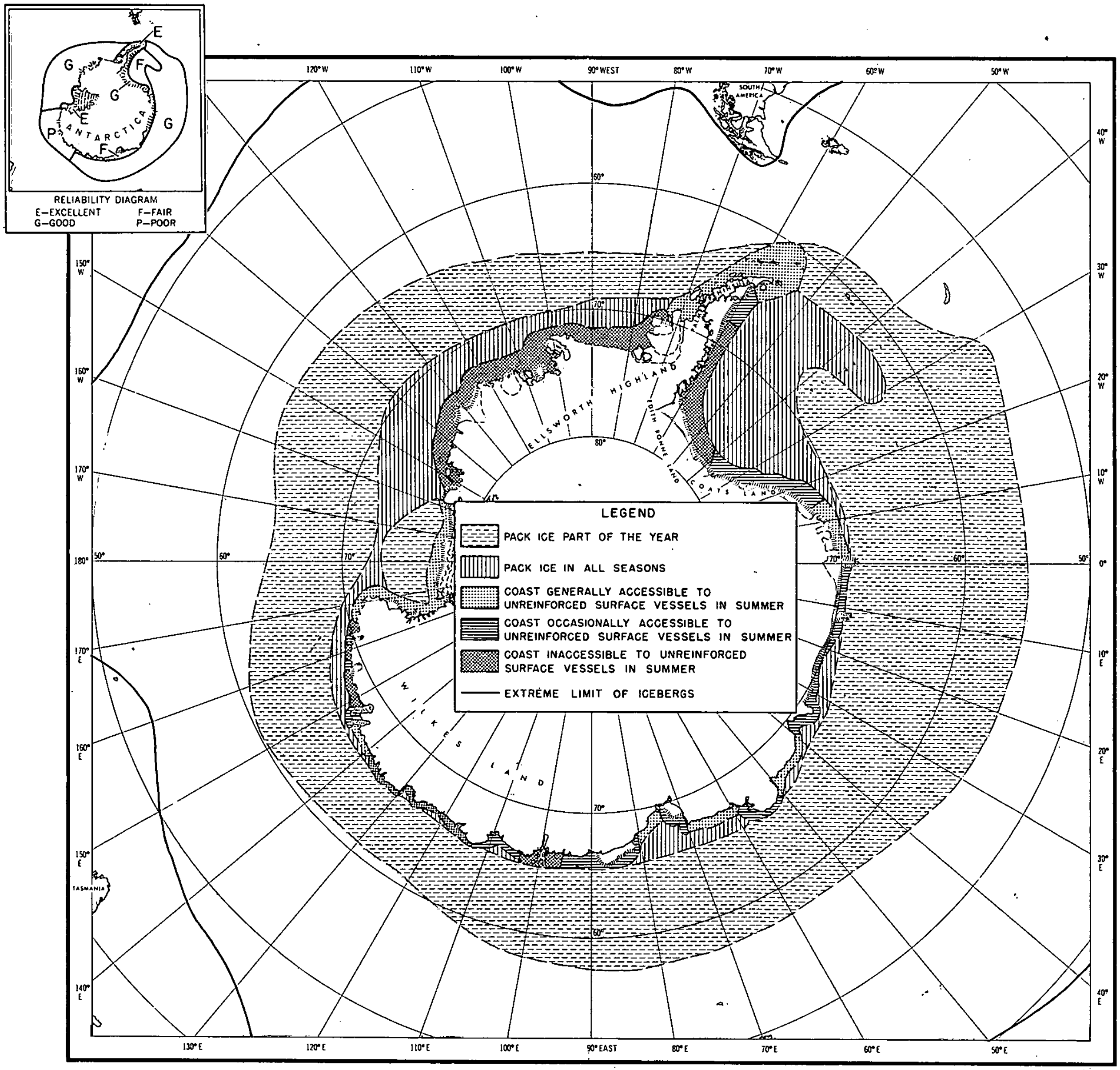

FIGURE 22–30. ACCESSIBILITY OF ANTARCTIC COASTS; EXTREME LIMIT OF ICEBERGS

The pack is being augmented constantly by the addition of precipitation in the form of snow and hoar frost. New ice also forms along the edges of cracks and pools.

The nature of the ice edge in winter varies with local winds and seas. Four conditions may exist: 1) With periods of calm, ice crystals or sludge will be found to the north of the heavier pancake ice, though not normally north of the 29.3° F. isotherm; 2) when there is a strong and persistent southerly wind, new ice probably will form in the calm water in the lee of the heavier ice; 3) in winds with a northerly component, new ice does not form readily and much of the newly formed ice crystals, sludge, and pancake on the fringe of the main body will melt, causing an apparent retreat of the ice edge; 4) with wind blowing directly from the west, the scum of ice crystals may disappear, but the sludge ice will persist to the north of the pack in a moderately wide belt.

At its maximum extent in September – October, the ice edge lies farthest from the continent in the Atlantic and western Indian sectors. It is probably closest to the continent in the vicinity of the Palmer Peninsula and in the eastern Indian Ocean sector.

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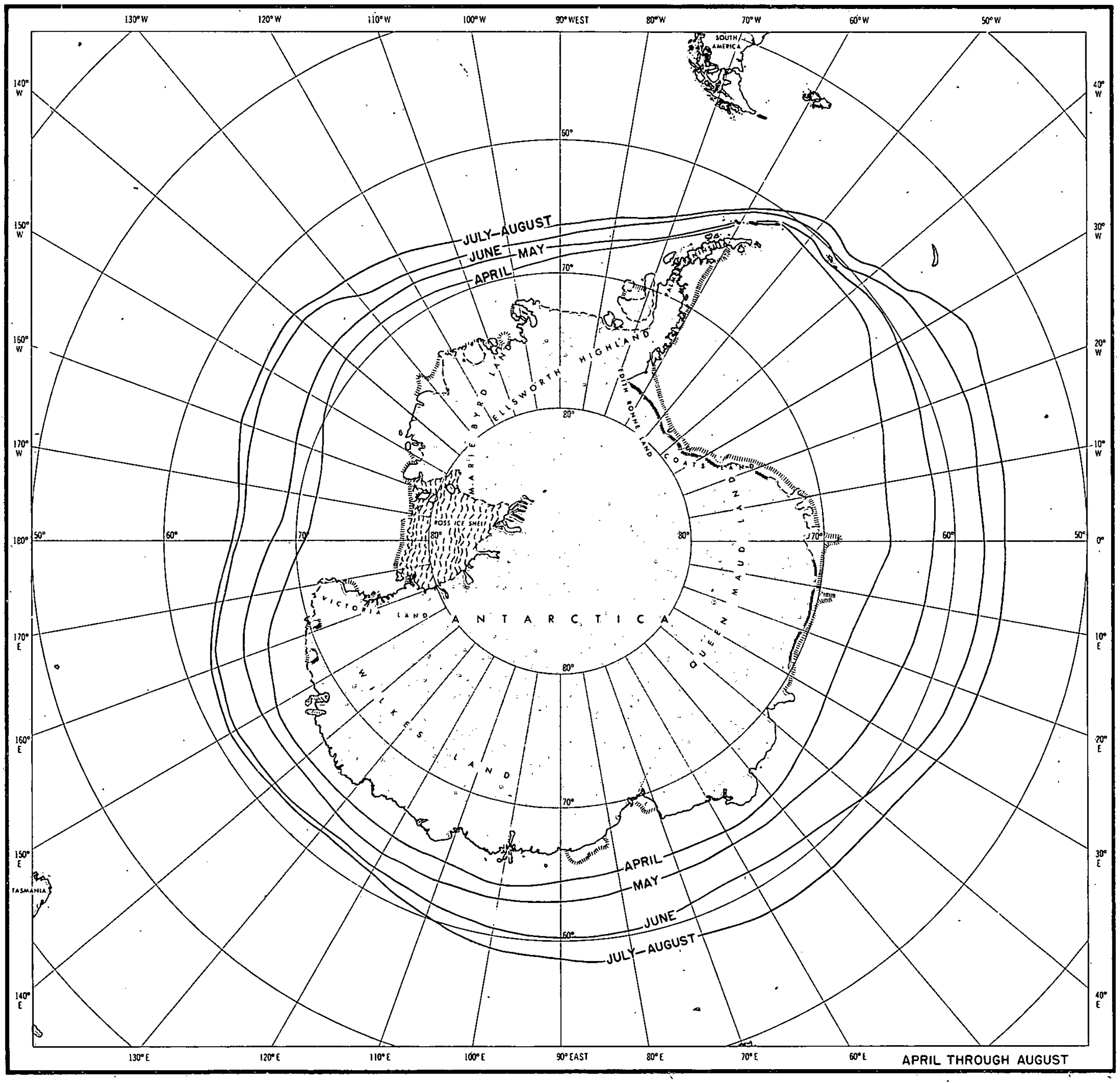

FIGURE 22–31. MEAN LIMITS OF PACK ICE, APRIL THROUGH AUGUST

(b) RETREAT OF THE ICE EDGE — The ice edge begins its retreat southward in November (FIGURE 22–32). There appears to be little melting between November and December except in the region east of the Weddell Sea, where the current causes a tonguelike extension of pack ice toward the east. In this region a vessel approaching Antarctica along the Greenwich meridian in December of an average year may encounter a broad belt of pack ice from about 55° to about 61°S., reach open water south of this, and then at about 65°S. encounter pack which extends to the continent. The greatest recession of the pack ice occurs from December to January. Little melting occurs between February and March. The tongue of ice from the Weddell Sea probably never disappears completely in summer, although its extent is diminished considerably. The pack ice is at its minimum in March and lies close to the continent except in the Weddell Sea and the region from 80°W. to 180°.

The mean position of the ice edge as shown on the charts does not necessarily imply that the entire portion from the limit line to the continent is completely icebound, because open water often is found south of the pack limit in summer and possibly in winter. For example, most of the Ross Sea is open in February – March, the amount of

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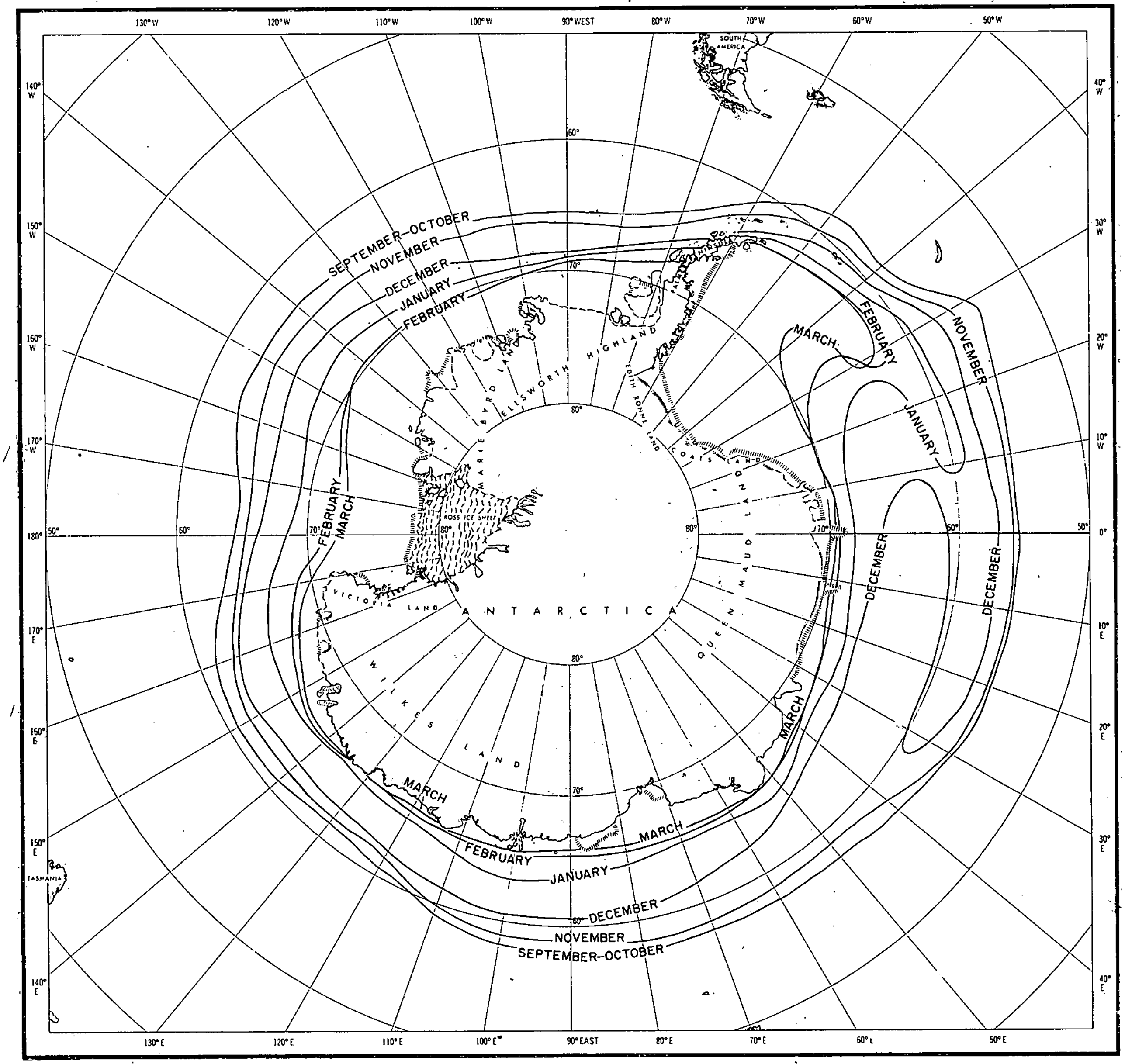

FIGURE 22-32. MEAN LIMITS OF PACK ICE, SEPTEMBER THROUGH MARCH

open portion depending on the width of the belt of pack ice lying at the entrance. Melting of the pack ice in the Ross Sea sector is probably very rapid, one observation having the disappearance of about 250 miles of pack in a little over 3 weeks. In contrast, however, the Weddell Sea is probably never completely ice free in summer, owing to the backing up of the westwardly drifting ice. In the Pacific sector there is generally little retreat of the pack, practically the entire area from Cape Colbeck (*20*) to the Bellingshausen Sea (*25*) being impenetrable because of the consolidated pack. South of about 71°S., the Bellingshausen Sea is probably never free of ice.

(c) SPECIAL CONSIDERATIONS OF THE PACK — The pack usually does not grade from isolated streams of ice to close pack. Such conditions may be found, but ordinarily the ice is first seen as a solid white line on the horizon, soon barring further progress. As evident from the discussion preceding, conditions and ice types found at the ice edge vary from season to season and with the locality. In spring and summer small floes and brash commonly are met, although much larger floes are to be found a short distance within the pack beyond the action of swell (FIGURES 22-59B and 22-61A). In autumn and winter the outer fringe of the pack often consists of ice scum or

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crystals grading into pancake ice and more substantial floes. Thickness of the ice varies in different localities. Floes which have drifted from the Weddell Sea tend to be hummocked, overridden, and very thick. In parts of the Pacific sector, where it appears that the ice may grow in place for considerable periods, immensely thick floes are to be found.

Several features of the pack which are of operational significance may be cited. Antarctic pack ice generally is covered with more snow than that of the Arctic. This snow provides a cushioning effect, tending at times to hold a ship when the thickness of the ice does not warrant it. In 1955 the U. S. S. *Atka* found that there were times when because of heavy snow on top of the ice it was brought to a standstill in ice 4 to 6 feet thick which otherwise would not have hindered an icebreaker to any great extent. As long as a ship remains underway it is fairly easy to penetrate this ice, but once it stops the snow adheres to the sides.

Antarctic ice appears to be less buoyant than that of the Arctic. It will submerge to a greater depth and remain submerged for a slightly longer time before rising to the surface. This longer submergence time conceivably could cause damage to screws by sudden emergence of ice after it has been broken by the ship.

Navigating in the pack along most of the coast of Antarctica is potentially dangerous, since sudden changes in wind can lead to complications. The greatest danger from pack exists in an enclosed space. For example, a narrow strait or deep bay into which the wind blows directly is the worst of all locations. The regions to windward of prominent points in the coastline can be equally dangerous, since a sudden change or increase of wind may cause a ship to be carried into shore or beset in a matter of minutes.

Pack ice which extends more than 3 feet below the surface is undercut at the waterline, sometimes as much as 5 feet in the thicker floes. The U. S. S. *Sennett* found that when operating in this type of ice the stern of a submarine should be trimmed down so that the propeller guards are at least a foot and a half below the surface of the water. This protects the propellers from damage by pushing the pack clear. The *Sennett* also noted that when it passed through a lead in a pressure ridge, it had to be kept under way at all times, because once it became dead in the water the ice closed in quickly and rode up over the tank tops forcing the submarine down.

(3) *Icebergs* — The maximum northward extent of icebergs is shown in FIGURE 22–30. Bergs are present nearly everywhere in the Antarctic, both within the pack and in open waters north and south of the pack belt. They are detected easily by sonar and radar and therefore are not as serious a threat as they once were.

Navigating in open water where icebergs are present poses very few problems, since with sonar and radar warning they can be avoided. In the pack, however, they are potentially dangerous. Since they may extend to considerable depth and move with the subsurface current, it is not uncommon to see them drifting contrary to the movement of the pack, in which they can build up considerable pressure. Occasionally, icebergs give the illusion of contrary movement because they move more slowly than the pack, which surges past them.

Probably the most dangerous features of icebergs are the submarine rams, or spurs, which lie below the waterline. These are formed in tabular and glacial bergs alike. Not only is there danger in striking one of these rams while navigating close to a berg, but the rams are subject to calving and may be buoyed up to the surface, producing a serious hazard even for large vessels.

Open lanes to leeward of a berg are a common phenomenon in the pack. Sea and swell also are effectively reduced in the open water to the lee of bergs. They should offer, therefore, an excellent location to effect transfer of materiel from one ship to another. However, some danger does exist. A sudden change in wind will alter the direction of movement of the surface water and ice, closing up the previously open lanes. In open water the greatest danger exists from the calving of portions of the bergs as well as of their rams; therefore, they should be given wide berth.

(4) *Accessibility of coast* — FIGURE 22–30 gives some idea of those waters of Antarctica which are usually navigable and the parts of the coast which are most likely to be inaccessible to unreinforced surface vessels. The least accessible portions of the coast are in the sectors from approximately 74°W. to 155°W. and the western shore of the Weddell Sea. The portion from 115°E. to 139°E. is probably inaccessible owing to the concentration of glaciers in the region. In these areas it is doubtful if a complete breakup ever occurs.

In some places the coast is almost always accessible in summer. The best known of these are the western and a small portion of the eastern coasts of the Palmer Peninsula, and almost all of the coast in the Ross Sea sector. This does not mean that there is ice-free water all the way to this coast; for example, entrance to the Ross Sea near the 180° meridian may require traversing from 1 mile to 400 miles of pack ice.

Practically everywhere near the coast of Antarctica some pack ice may be expected in all seasons. The outer limit of the area where pack ice is found only part of the year (FIGURE 22–30) coin-

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cides with the September – October mean limit of pack ice as shown on FIGURE 22–32. Even though some regions are shown as being accessible only occasionally in summer the coast is not necessarily icebound. If the pack can be traversed, it may be found that the waters in some of the coastal bays and around some of the islands will be open.

Because ice conditions in Antarctica are so variable from year to year, it is difficult to choose sites that would be suitable as bases of operations. In a survey conducted by the U.S. Navy in the summer season of 1954–1955, several sites were surveyed as possible bases for the 1957–1958 International Geophysical Year. Three sites were suggested: Kainan Bay (*18*) in the Ross Sea, Atka Bay (*47*), and Admiral Richard E. Byrd Bay (*48*) on the Princess Martha Coast (*45*). These were found to be suitable in most respects, and a detailed account of conditions in these bays will be found in Commander Service Squadron Four Report of U.S. Navy Antarctic Expedition, 1954–55, conducted by the U. S. S. *Atka* (AGB–3). Locations surveyed, but not found suitable, were Discovery Inlet (*15*), Okuma Bay (*19*), Sulzberger Bay (*21*), and Norsel Bay (*46*).

Bases located on shelf ice normally cannot be considered permanent, owing to periodic breakoffs of large portions of the shelf. For example, on the Ross Ice Shelf a large segment of Little America IV was removed by pressure or calving, and Little Americas II and III were placed adjacent to open water. The Bay of Whales (*16*), known for over a century and a shore base for five expeditions, has been subject to similar change. Past observations indicated that the western shore of the bay moved northward while the eastern side had a relative westward movement, resulting in a progressive narrowing of the entrance. During Operation HIGHJUMP in the summer season 1946–1947, the bay mouth was approximately 400 yards wide (FIGURE 22–52A); a year later the mouth had narrowed to less than 200 yards. At the time of the 1955 visit of the U.S.S. *Atka* a considerable breakoff of the west shelf ice changed the bay completely, making it almost unrecognizable.

c. SOUND CONDITIONS

(1) *Sonar*

(a) GENERAL — The expression "sonar conditions" is used in this subsection to describe the probable effectiveness of sonar based on oceanographic factors which influence underwater sound transmission. The factors include the variations of temperature, salinity, and pressure with depth, the depth of the mixed (isothermal) layer, and ambient noise. With the exception of ambient noise, these factors limit the horizontal range of the sound beam by refraction. Temperature and pressure are of greatest importance to calculations of sound velocities in the open ocean where salinity variations are comparatively small, and close approximations of ranges can be made from a knowledge of temperature alone for ordinary submarine operating depths.

FIGURE 22–33 illustrates, by means of idealized sound ray diagrams, the refraction associated with the two temperature structures most common to Antarctic waters in summer. Pattern NOP is characterized by an isothermal layer above a negative gradient with a temperature reversal at depth. As the sound beam approaches the colder water, some of the rays are refracted upward and remain within the isothermal layer, while those greater than a critical angle are refracted initially through the thermocline, but when the temperature gradient becomes positive these downward rays are refracted upward. Thus, to the depth of the bottom of the positive gradient, the water is completely insonified (permeated with sound). Pattern MIKE is characterized by an isothermal layer above a negative gradient with no reversal at depth. Here the rays refracted downward through the thermocline never return to the surface, and a shadow zone is formed from which very weak or no echoes will return.

The environmental factors contributing to sonar effectiveness are expressed singly or collectively as percentages of ideal conditions. Ideal conditions are assumed to exist when: 1) the layer depth (depth of the isothermal layer) is at least 450 feet; 2) the temperature difference between the surface and 30 feet does not exceed 0.1° F.; and 3) the wind force is no greater than Beaufort 1.

(b) AREA 69

1) General — The analysis of sonar conditions in Antarctic waters has been limited largely to summer, since the paucity of data precludes more than a cursory treatment of other seasons. Summer conditions may vary considerably, in some years being best developed in late January and rapidly deteriorating in early March, in other years extending into late March after attaining highest development in middle to late February. Because of this annual variability, data for only January and February have been used to evaluate average summer conditions. Listening range charts for this Area are not presented, due to insufficient data.

The ice limits superimposed on the sonar charts cover only those nearshore waters which usually are inaccessible. It should be noted that mean pack-ice limits for the summer months extend much farther north.

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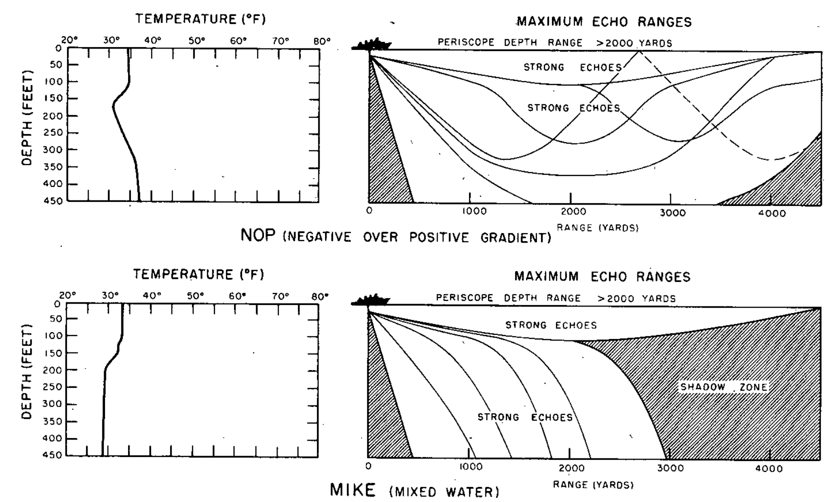

ESTIMATED PERISCOPE DEPTH RANGE

WHEN THE PATTERN IS:	THE PERISCOPE DEPTH RANGE IS:
NOP	EQUAL TO THE SURFACE RANGE
MIKE	2/3 TO 3/4 THE SURFACE RANGE

FIGURE 22–33. SOUND REFRACTION PATTERNS ASSOCIATED WITH TYPICAL ANTARCTIC TEMPERATURE GRADIENTS

The thermal structures most common to the Area in summer are typified by the two patterns illustrated in FIGURE 22–33. A positive temperature gradient (NOP pattern) at depths varying from 150 to 1,000 feet is indigenous to that part of the Area between the Antarctic Convergence and the Antarctic Divergence (see FIGURE 22–9). South of the divergence, MIKE pattern is found. The seasonal thermocline, restricted to depths averaging only about 100 feet, prevails throughout most of the Area. Exceptions are parts of the Weddell, Bellingshausen, and Ross Seas, where isothermal layers to more than 450 feet persist throughout the year.

Owing to the comparatively warmer water at depth surrounding Antarctica, upward refraction is the predominant characteristic of sound propagation in these waters. In regions of melting ice, a secondary positive gradient between 50 and 100 feet further enhances upward refraction. Where a positive gradient occurs at shallow depths, surface ranges will be shortened and, conjointly with sea states greater than 1, reverberation bursts may seriously obstruct target recognition.

In addition to shallow positive temperature gradients, very sharp salinity gradients, both vertical and horizontal, associated with ice-melt regions effectively decrease surface ranges.

Despite the poor reliability of sonar predictions in the regions dominated by ice, operational use of sonar for navigation appears both feasible and highly desirable. Operation HIGHJUMP reported sonar superior to radar during periods of low visibility. Bergy bits and growlers were contacted with 100% recognition at ranges from 500 to 1,800 yards with supersonic sonar, and icebergs at 4,000 yards. Ranges of such magnitude, however, cannot be obtained on submarines or even on larger surface ships, as their target strength is appreciably less than that of large ice objects. FIGURE 22–36 gives maximum echo ranges for high-frequency sonar on submarines surfaced or at periscope depth. Ranges on ice targets may be as much as 300% greater, dependent on size. The range chart is intended to supplement the presentation of percent probability of ideal echo ranging conditions (FIGURE 22–35) for operational use, and is considered more accurate wherever ice may prevail. In computing the given ranges, sea state was disregarded, since seas are effectively damped by ice; the parameters considered were layer depth, target strength, water temperature, spherical spreading, and the average figure of merit for destroyers at 15 knots equipped with QHB_a sonar.

Ambient noise is very low in ice areas where seas are minimal. Although the noise level increases farther north, it is generally of secondary

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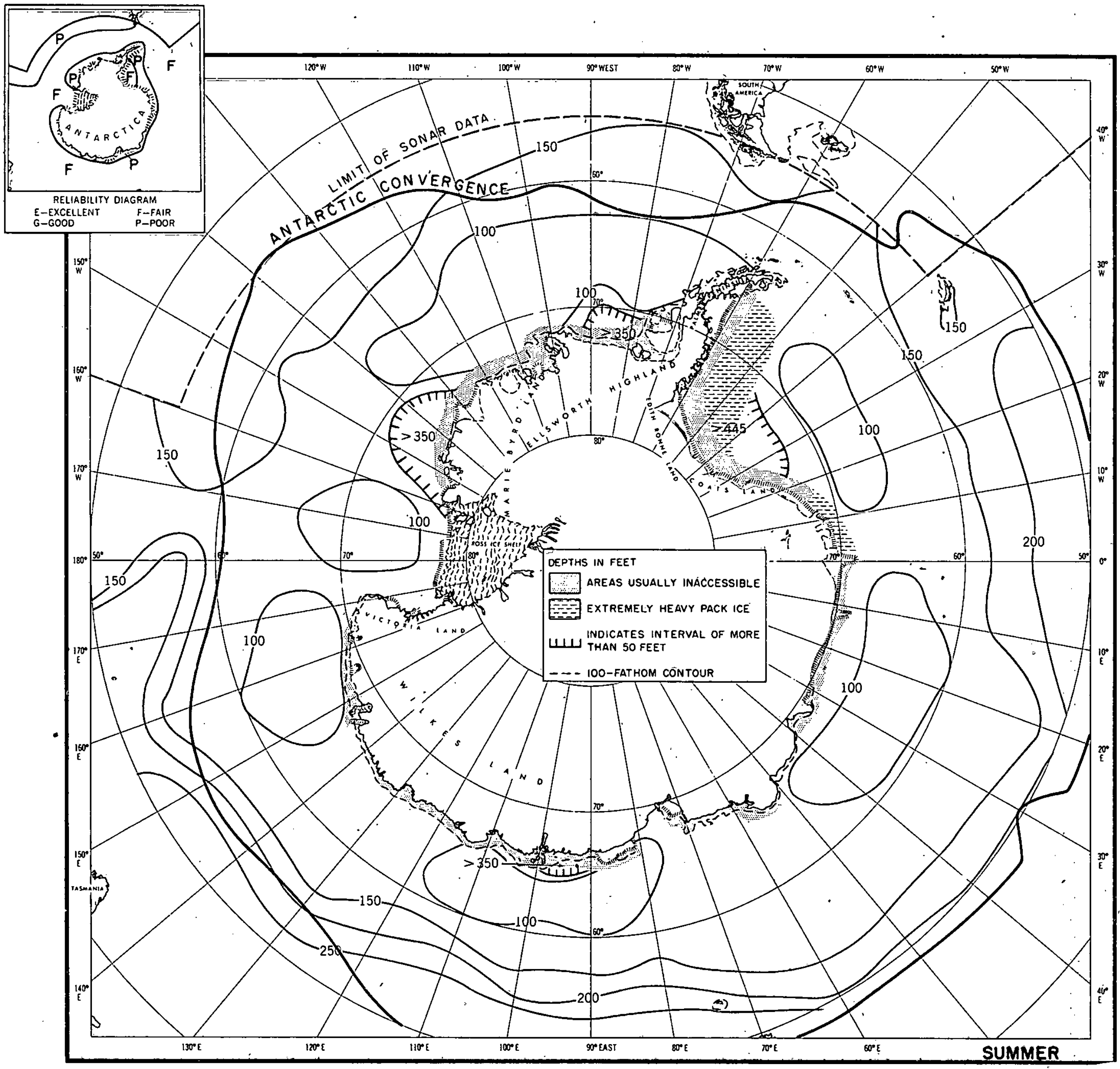

FIGURE 22–34. AVERAGE LAYER DEPTH (FEET), SUMMER

importance to sonar operations in summer, when the depth of the mixed layer is the limiting factor. However, winds of force 8 to 12 occur between 5% and 10% of the time, and during storms echo ranging is restricted primarily by high noise and quenching. The high incidence of sonic mammals (whales and seals) in the Area may occasion false echoes. A distinct doppler associated with whales serves to distinguish them from ice targets. However, good echoes, persistent and without doppler, are produced by blow wakes, which also can cause complete quenching if proximal. Whale concentrations are greatest between 40°W. and 100°E. in the Atlantic and Indian Oceans, and north of Cape Adare (7) between 170°E. and 180° in the Pacific. Their southerly limits vary with the edge of the pack ice. Killer whales haunt the fringes of the pack where seals are numerous, particularly in the Weddell Sea.

2) Layer Depth — South of 60°S., the depth of the mixed layer in summer seldom exceeds 150 feet, and there are large regions where the layer is less than 100 feet deep (FIGURE 22–34). These regions of least layer depth are apparently stable features of the Area. They occur where the thermocline has been strengthened by cold outflow from the continental shelf sinking beneath comparatively warmer water to the north, thus con-

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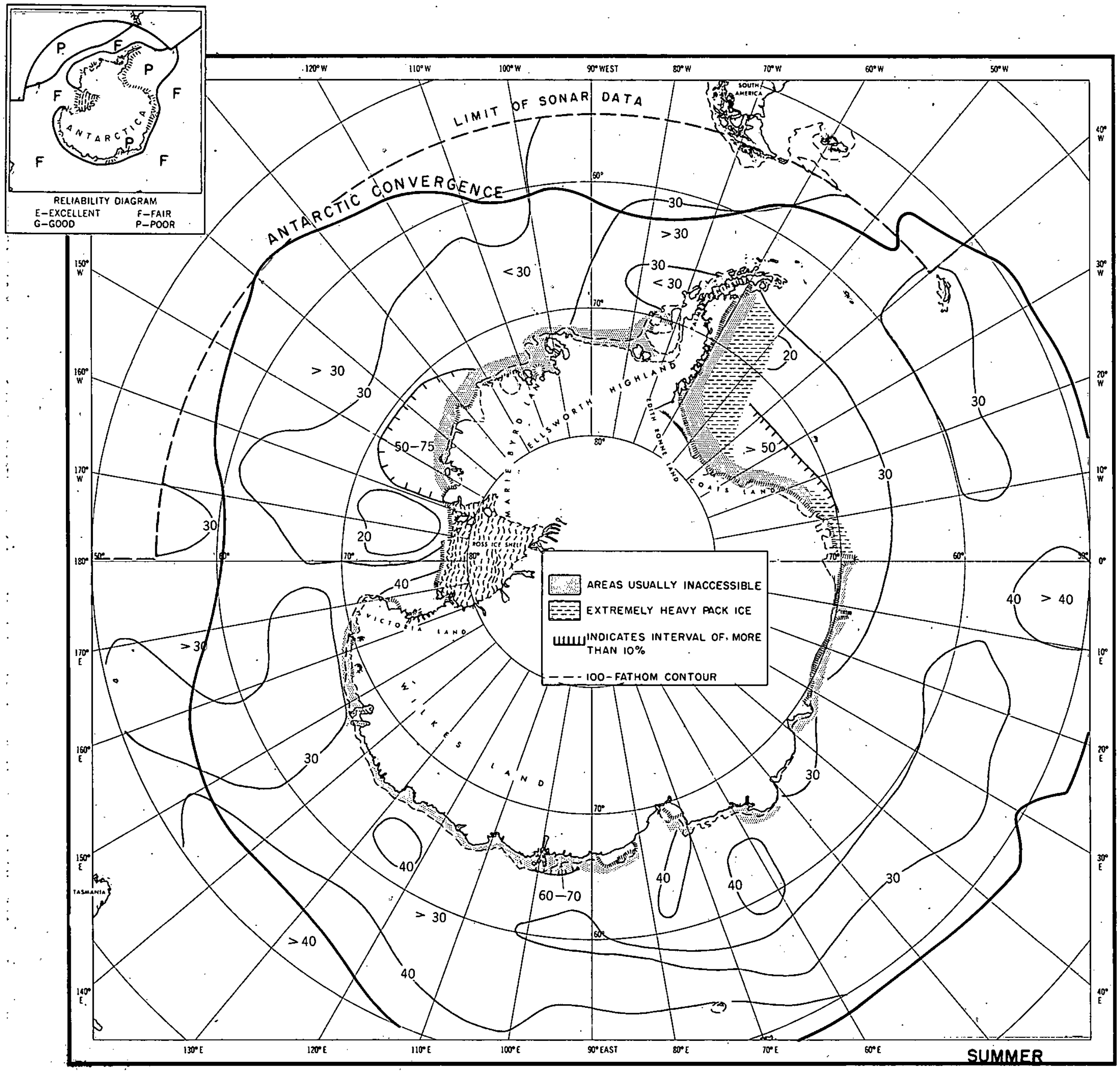

FIGURE 22–35. PERCENT PROBABILITY OF IDEAL ECHO RANGING CONDITIONS, SUMMER

fining the effects of insolation to a shallow layer. Accordingly, slightly warmer surface water should be associated with least layer depths. (The contour interval masks this relationship on the surface temperature chart, FIGURE 22–12.) The areas of shallowest layers also coincide almost exactly with the regions of greatest storm intensity. In the western part of the Ross Sea, and in the Weddell and Bellingshausen Seas, isothermal water extends to more than 450 feet at all times.

First evidences of the seasonal thermocline normally appear in November or December, when layer depths of 20 to 40 feet are common; with continued surface heating in summer, the thermal gradient becomes stronger. In mid-March or as late as mid-April, increasingly strong winds together with waning sunlight weaken the thermocline, and the layer deepens to about 300 to 350 feet. In winter, no negative temperature gradient is present at any depth less than 450 feet south of the Antarctic Convergence.

3) Echo Ranging — FIGURE 22–35 gives the percent probability of ideal echo ranging conditions for the Area in summer. The depth of the mixed layer is the primary factor limiting ranges. However, in the northwestern Weddell Sea and the central Ross Sea, semipermanent *lows* are of great importance. The prevailing easterlies are pre-

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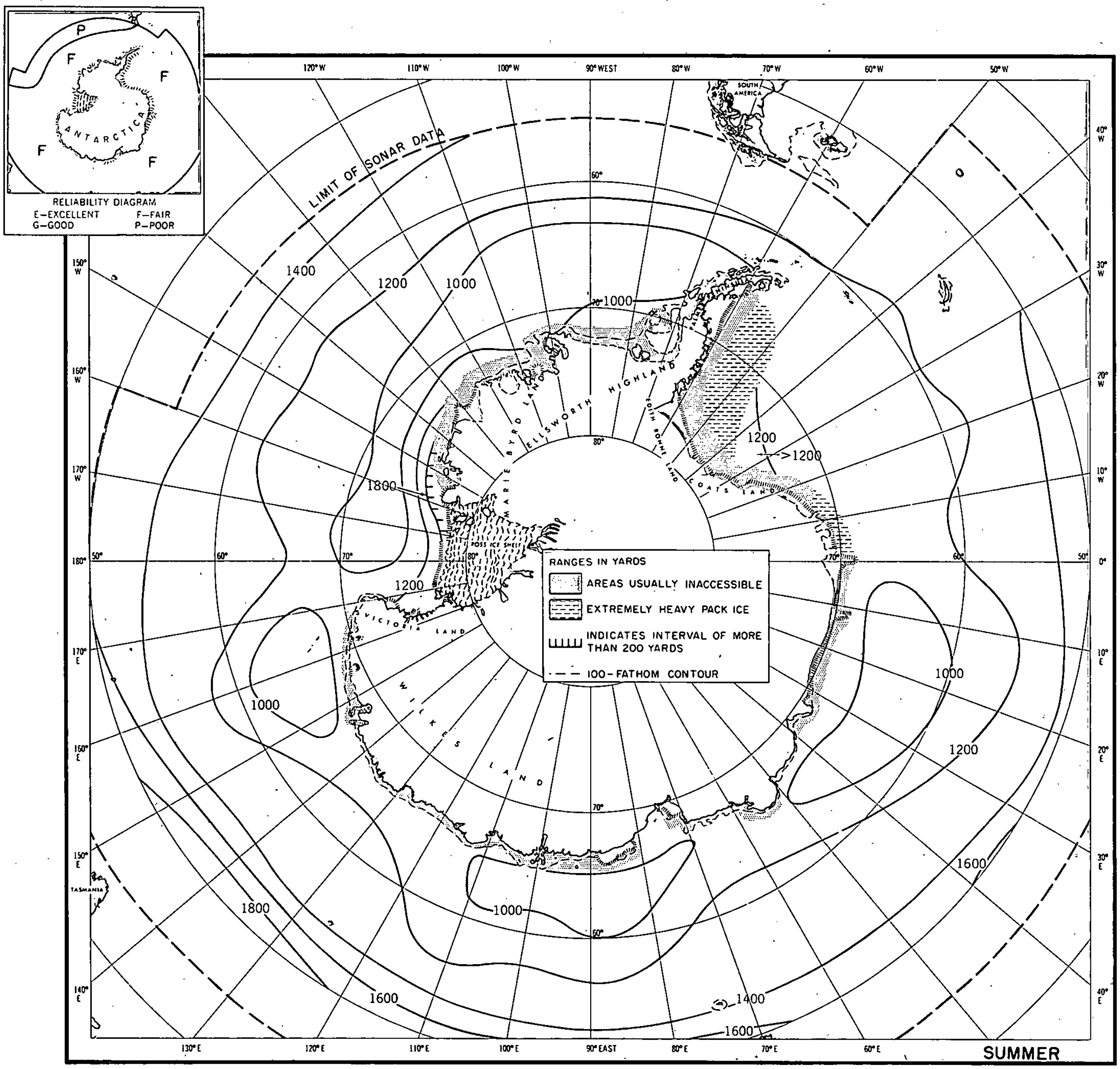

FIGURE 22–36. MAXIMUM SURFACE ECHO RANGES (YARDS) ON SUBMARINE WITH 25.5-KILOCYCLE SONAR (QHBa)

dominantly light to moderate in summer, and although local gravity winds cause storms of great intensity, their effects seldom extend beyond 15 miles to sea.

Conditions average about 30% ideal in the greater part of the Area, being slightly better than average in the Indian Ocean and poorer in the Pacific. Very sharp transitions from poor to excellent echo ranging conditions occur in the Weddell and Bellingshausen Seas, and in a large coastal region extending from Little America (*17*) to Cape Dart (*22*). In MacKenzie Bay (*2*) and the Davis Sea (*3*), conditions are poorer but average about 50% ideal or better. Where conditions are least favorable (less than 20% ideal), as in the northwestern Weddell Sea and the central Ross Sea, the semipermanent *lows* limit improvement.

Echo ranging conditions probably are best in November, when the layer is still deep and the frequency of high winds averages around 5%, lowest for the year. Observations from the region south of South Georgia and the Ross Sea support this inference, but data are not sufficient to present full areal charts for the month. By late April, despite isothermal layers to 350 feet or more, echo ranging will be hampered considerably by quenching and ambient noise, since the percentage of winds of force 8 to 12 approaches an annual maxi-

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mum, and low sea states in open water are infrequent. So little of the Area is ice free in winter that echo ranging has not been considered for that season. It is expected, however, that the average percent probabilities of ideal echo ranging conditions will be slightly better in all other seasons than in summer, although it is doubtful that they exceed 40% of ideal in the Area as a whole.

(2) *Sofar* — The region south of the Antarctic Convergence is characterized by a shallow sound channel which is the result of the summer thermocline. Autumn cooling and high winds destroy the thermocline; accordingly, no sound channel exists during the greater part of the year.

No deep sound channel is found south of the convergence. The shallow seasonal channel in the Area may be continuous with the permanent deep sound channel to the north, depending on the structural variability of the convergence itself. Continuity is more probable in the Atlantic Ocean where the northward slope of the convergence is generally more gentle than in the Pacific or Indian Oceans where the slope is steeper. Because a continuous channel is provisional, FIGURE 22–70 includes only the depths of the seasonal channel south of the convergence and the southern limits of the permanent channel where known.

In general, the channel shoals from a depth of about 400 feet south of the convergence to about 150 feet near the Antarctic continent, the axial velocity decreasing from approximately 4,770 feet per second at the convergence to about 4,715 ft./sec. near the continent. Very close to shore, and in the Ross and Weddell Seas, the channel axis deepens slightly and the minimum velocity increases to 4,725 ft./sec. Channel depth and axial velocity are directly related: shallowest depths and least velocities occur together, as do greatest depths and highest velocities. The depth of the sound channel in summer together with the positions of the vertical sections of sound velocity is shown in FIGURE 22–70.

Minor but definite longitudinal variation occurs in the depth and velocity of the sound channel in this Area. The variation depends primarily upon the quantity of colder or warmer water, relative to the mean, present in or introduced into the locale under consideration.

For example, the effect of cold Weddell Sea Water on the velocity structure of the Atlantic Ocean south of the convergence during summer is shown by vertical section A of FIGURE 22–70. The maximum channel depth (350 feet) and axial velocity (4,746 ft./sec.) are found at the northernmost station of this section, while at 61°S., the channel shoals rapidly to 200 feet and velocity decreases to a minimum of 4,712 ft./sec., owing to the introduction of Weddell Sea Water. South of this latitude, the velocity increases somewhat, to 4,717 ft./sec. near the continent.

In contrast to this cold-water section, vertical section B, also south of the convergence but in the Indian Ocean, shows the effect of warmer water on the channel structure. From north to south, the sound channel depth varies from 600 to 300 feet, while the axial velocity decreases from 4,768 to 4,717 ft./sec., never attaining the minimum of the cold water section.

Where the convergence closely approaches the Antarctic continent, the resultant effect on channel depth and axial velocity can be inferred from the South Pacific – Ross Sea vertical section (C). North of the convergence, channel depths of the order of 1,000 feet are found, with axial velocities greater than 4,800 ft./sec., while to the south the channel depth is 200 feet and the axial velocity 4,738 ft./sec. Stations on either side of the convergence indicate a transitional channel structure with an average depth of 300 feet and velocity of 4,755 ft./sec. Both depth and velocity diminish southward to 150 feet and 4,720 ft./sec., respectively, at the seaward limit of the Ross Sea. In the Ross Sea, the channel deepens to 250 feet and velocity increases to a constant value of 4,725 ft./sec. A parallel situation exists in the Weddell Sea.

The effects associated with the convergence are also apparent in the Drake Passage – Bellingshausen Sea vertical section (D). North of the convergence in Drake Passage, a 400-foot sound channel with velocities greater than 4,800 ft./sec. is found. To the south are the typical channel depths of 300 to 150 feet and velocities from 4,727 to 4,720 ft./sec., decreasing southward. Traversing the convergence the channel averages 350 feet in depth with an axial velocity of about 4,775 ft./sec.

FIGURE 22–70, supplementing vertical section C, shows detailed velocity structure in the Ross Sea. The complexity of the structure reflects the intrusion at depth of the warmer water transported by the East Wind Drift. Entering the Ross Sea along its eastern coast, this warmer water is assimilated rapidly, as is indicated by the decrease in velocity from 4,757 to 4,732 ft./sec. at 600 feet. High-salinity pockets at depth further complicate the picture. The combined effects of the seasonal thermocline, warm water intrusion, and high salinities result in a conglomeration of sound channels, ordinarily disconnected and highly transitional.

In general, velocities south of the convergence average 50 ft./sec. less than velocities to the north. This anomalous situation will be important to depth determinations by echo sounders, which are calibrated for an average sound velocity of 4,800 ft./sec.

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The seasonal thermocline, and consequently the sound channel, are destroyed by cooling of the surface water and mixing by high winds early in autumn. Following this, and throughout most of the year, the greater part of the Area is covered by sea ice, so that no thermocline or channel develops until the ice breakup and initial warming in late spring.

6. Geology

a. STRUCTURE — The outline of the Antarctic continent is roughly defined by the Antarctic Circle. Other than the deep indentations of the Ross and Weddell Seas, the only break in a nearly circular outline is the Palmer Peninsula, which trends into a submarine and insular ridge extending as the Scotia Arc toward South America.

The Antarctic has both a radial and a peripheral arrangement of marine structural features, as will be seen from FIGURE 22–71. Surrounding the continent is a peripheral zone of deep oceanic basins, and beyond this, 300 to 900 miles north of the Antarctic continent, midway between it and the other continents of the Southern Hemisphere, there is a ring of suboceanic ridges and rises. In contrast to these is the almost meridional orientation of structures such as Macquarie Rise and the Palmer Peninsula.

A significant feature of the Antarctic continent is its great elevation: its average height above sea level is 6,000 feet, compared with 2,000 feet for the average height of all other continents. In this respect the two polar regions of the earth are in direct contrast. Within the Arctic Circle there is a relatively thin, permanently frozen sheet of sea ice overlying a deep oceanic basin that exceeds 2,000 fathoms in depth, whereas within the Antarctic Circle there is a land mass capped by an immense steep-sided ice plateau estimated at 8,000 to 10,000 feet in elevation.

The continent is divided roughly into eastern and western portions by a depression extending between the Weddell Sea and the Ross Sea. Very little is known about the rocks underlying the ice in the interior of the great ice plateau of the eastern section, but it is thought that they may consist essentially of horizontal rocks overlying a pre-Cambrian complex. The plateau is bordered, on the periphery between 20°W. and 110°E., by a series of mountain ranges with peaks as high as 14,000 feet. The coastal area between 110°E. and 155°E. has peaks to 6,000 feet in height, and there is a mountainous area of unknown elevation in the region 72°S. to 78°S. and 110°E. to 140°E.

The greatest mountain range in eastern Antarctica extends southward from Cape Adare (7) along the western side of the Ross Sea, passes to the northwest of the South Pole in the 180° to 90°W. quadrant, and is thought then to continue toward the Weddell Sea. This great range has been carved from a horst, 1,500 miles long and more than 100 miles wide, composed of a series of block-fault mountains (FIGURE 22–37). These mountains prevent the ice from spilling over into the depressed areas separating the eastern and western portions of Antarctica. At right angles to its main trend, however, the horst is cut by small grabens which afford exits for a small portion of the ice of the plateau. For the most part, this horst is composed of flat-lying sedimentary rocks which have been intruded by igneous materials. Volcanoes are associated with the horst faults.

The depression extending from the Ross Sea to the Weddell Sea has been described as a graben or a downwarped area. It is still conjectural as to how much of this region lies below sea level, but it is generally conceded that the Ross and the Weddell Seas are not joined by a strait dividing Antarctica into two subcontinents.

The western sector of Antarctica and the adjacent Scotia Arc contain two principal structural zones: the Cordilleran Belt and the Platform Belt.

The Cordilleran or Alpide Fold Belt comprises Scotia Ridge and the west side of the Palmer Peninsula, and probably extends into Marie Byrd Land. This belt is composed of a multiple chain of folds consisting of Mesozoic and Paleozoic geosynclinal sediments intruded by extensive granodiorite and gabbro rocks. Recent volcanoes are associated with this belt.

The Platform Belt, which comprises the east side of the Palmer Peninsula and probably extends to Marie Byrd Land, contains late Mesozoic and Tertiary sediments which are slightly folded, but locally faulted and cut by plateau basalts of Tertiary Age. No active or Recent volcanoes are found in this belt.

Generally, it is accepted that the islands of the Scotia Arc and the Palmer Peninsula are related structurally to the Andes. However the relationship between the structures of Antarctica and those of New Zealand, Tasmania, and Australia is conjectural.

b. BATHYMETRY

(1) *General* — The nearly circular Antarctic continent is bounded by peripheral and radial features (FIGURE 22–71). The basins are peripheral in nature and are separated by radial submarine ridges and rises that point like connecting links toward the other continents. Beyond the ring of deep-sea basins, there is a second peripheral ring of rises.

(2) *Continental and island shelves* — The continental shelf around Antarctica is the deepest in the world, the break in slope occurring at depths

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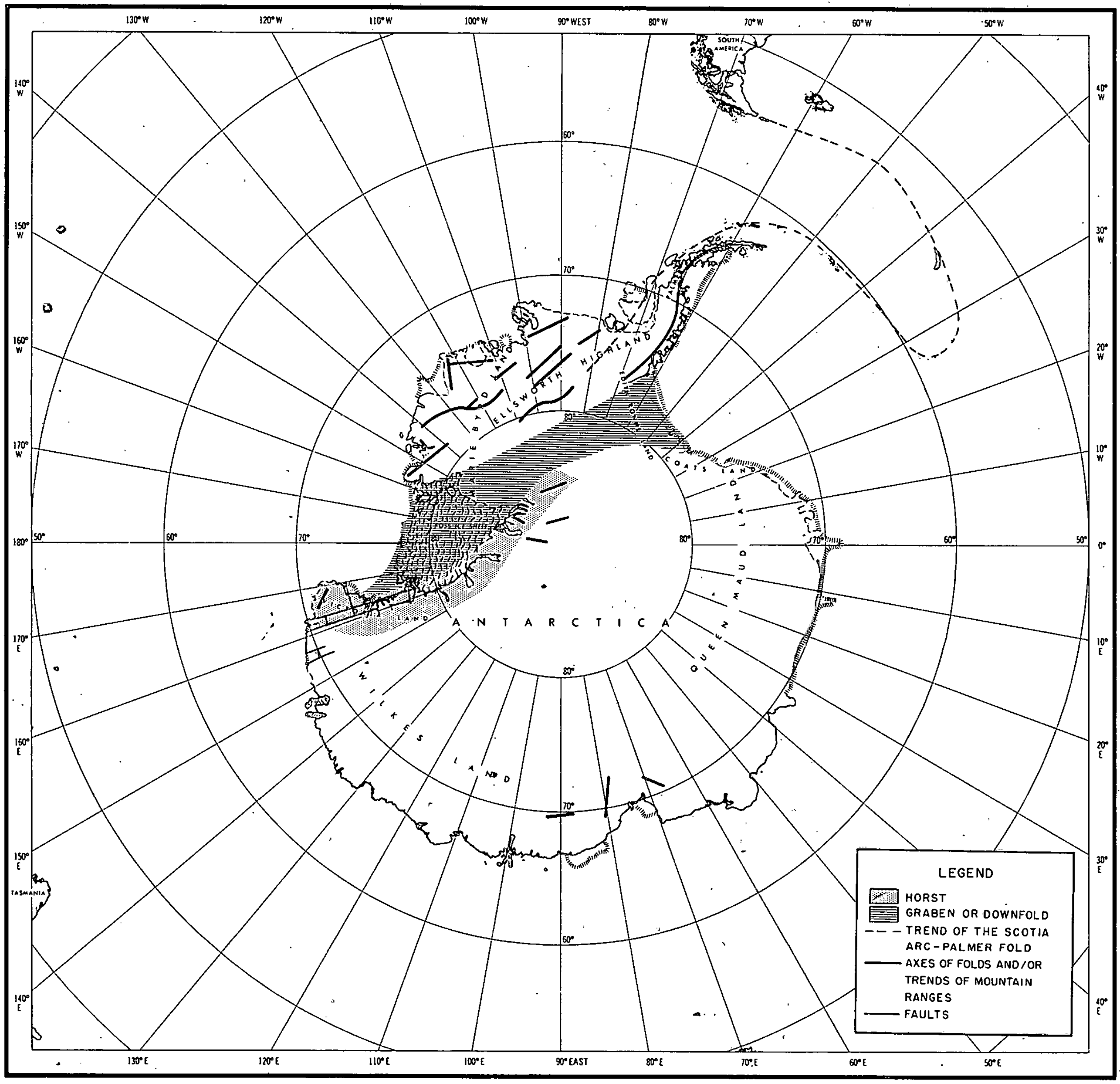

FIGURE 22–37. STRUCTURAL TRENDS

between 230 and 280 fathoms (FIGURE 22–72). The shelf varies in width from less than 20 to about 300 miles. It appears to be widest in the Ross Sea and the Weddell Sea regions and narrowest off certain parts of eastern Antarctica. Two broad embayments, the Ross Sea and Weddell Sea, are not deep gulfs but shelf seas which indent the coast 700 miles and 300 miles, respectively, from the outer edge of the continental shelf. Toward its outer edge, the shelf rises locally in a series of elongate terminal moraines which appear frequently and seem to outline the former maximum extension of the icecap. These mounds on the sea floor frequently are farther than 100 miles from the real land front and are hundreds of feet high. Basins appear in various places on the shelf; some of these reach depths exceeding 600 fathoms. These depressions, if actual and not due to faulty soundings, probably are a result of glaciation.

The oceanic island shelves are generally very narrow, with the shelf edge located at 100 fathoms or less. South Georgia and the South Orkney Islands are exceptions, with the shelf edge at approximately 145 fathoms and 200 fathoms or more, respectively. The reason for this difference is not evident, although the South Orkney Islands appear to follow the deep trend set by the continental shelf along the Palmer Peninsula.

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In contrast to the deep shelf of the Antarctic continent, the shelf edge along the southern tip of South America lies near 100 fathoms or slightly shoaler. Off eastern South America, it is wide and quite irregular, particularly in the vicinity of the Falkland Islands, where it is more than 400 miles wide. At Isla de los Estados (*33*) it narrows to less than 10 miles, broadens westward to 60 miles, and again narrows northward along the west coast of the continent. This west coast is a highly glaciated region with a very narrow and irregular shelf, which is cut into short segments by deep fiords, some of which are almost 1,000 fathoms deep.

Discussion of the bathymetric characteristics of other portions of the Antarctic periphery will be found in NIS 104–VII, 106–III, 106–II, and 105–XII.

(3) *Continental and island slopes* — Profiles of the continental slope of Antarctica show it to be relatively smooth and gentle, particularly in the Indian Ocean portion. Here it has a concave form with gradients ranging from 2° near the top to about ¼° at the bottom where the slope fades into the abyssal sea floor 150 miles from the continent. Some irregularities occur even here, with indications of an occasional submarine canyon and seamount or seaknoll. In other sectors of the continental slope around Antarctica, numerous seamounts and indications of submarine canyons are to be found. West of South America the gradient averages about 6°, but the slope is quite irregular. East of South America the continental slope is quite steep but is broken by a double ridge that extends east from the southern tip of the continent.

The island slopes are generally much steeper than the continental slopes in this Area. West of the South Sandwich Islands the gradient is about 8° to the 1,500-fathom curve; there it becomes much more gentle. On the east and north sides of these islands, the slope descends into the South Sandwich Trench with a gradient of about 6° to the 2,000-fathom curve, where it steepens to about 9° and continues to the bottom of the trench. A small terrace occurs at about 1,000 fathoms on this slope, but it is not evident to the south and west of the islands. The island slopes are quite regular and unbroken except for the canyons off South Georgia.

(4) *Submarine canyons* — The submarine canyons off the coast of Antarctica have not been identified or delineated accurately. Their very existence is subject to speculation. The indications of these features may be due to difficulties encountered in navigating and piloting through broken ice fields and along unsurveyed coasts where numerous course changes are required. If canyons are actually present, they may display either the V-shaped cross section typical of submarine canyons, or the U-shaped cross section typical of glaciated fiords. In the latter type there may be shoaling at the outer limits because of terminal moraine deposits which mark the seaward limit of the glacier. George VI Sound (*26*) is considered to be a structurally controlled submarine canyon. Indications of several submarine canyons may be found off the west and south coasts of South America. The only submarine canyons known to exist off the islands of the Area are on the north and south sides of South Georgia.

(5) *Seamounts and seaknolls* — Seamounts and seaknolls are found abundantly throughout the Area; they appear to be most common along the crests of the ridges and rises (FIGURE 22–71). A lesser number are found on the continental slope and scattered throughout the various basins. Banzare, Gribb, Iselin, Barth, and Maud Seamounts all lie upon the radial structures that extend from the continent; Spiess Seamount is on the outer peripheral ring of rises surrounding the continent. The Pacific – Antarctic Ridge ("Easter Island Cordillera") has a great number of seamounts and seaknolls concentrated just north and east of Balleny Basin. Another concentration of these features is found on the rise extending into the Pacific – Antarctic Basin ("Bellingshausen Basin") from Antarctica in the vicinity of the Amundsen Sea (*23*). The seamounts shown in the basins commonly occur along extensions of ridges and rises or upon a slight rise of the ocean floor.

(6) *Ridges, rises, and plateaus* — The ridges and rises in the Area tend to form two intersecting patterns: the first is a radial pattern pointing from Antarctica in a northerly direction; the second is a peripheral pattern at a distance varying from 300 to 900 miles from the continent. The best-defined ridge in the Area is the Scotia Ridge (FIGURE 22–71). This arcuate ridge which is steep, high, and sharp extends eastward from the tip of South America through Burdwood Plateau, Shag Rocks (*35*), South Georgia, and Clerke Rocks (*36*) to the South Sandwich Islands. Here the ridge turns south along the islands, then westward through the South Orkney and South Shetland Islands to the Palmer Peninsula. Burdwood Plateau, near the South American terminus of this complex sigmoid ridge, is shoaler than 100 fathoms for a distance of over 200 miles. In this vicinity and eastward to Shag Rocks the arc appears to be double, being divided by a broad trough. The northern ridge of the arc includes the Falkland Islands and extends eastward to a point about 100 miles due north of Shag Rocks. The southern ridge includes Burdwood Plateau and extends the length of the arc.

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The Central Indian Rise continues south of the ridge through Bangore and Gribb Seamounts and provides a deep sill between the basins on either side. It is surmounted by the Kerguelen–Gaussberg Ridge, which does not extend south to Antarctica. Macquarie Rise, extending south from Australia, is also surmounted by a ridge (South Tasmanian Ridge) that does not reach Antarctica. The narrowest rise in the Area is the Southwestern Auckland Rise, which extends south from the New Zealand Plateau. Also extending south from this plateau is the Campbell Rise, which terminates in Emerald Basin. The Pacific-Antarctic Ridge as contoured on FIGURE 22–71 appears to be rather simple in this Area, probably because of the sparseness of available data. It is apparently a system of submarine mountain ranges comparable to some of the large cordilleras on the continents. Soundings reveal a flat bottom on either side with no indication of a foredeep, and a general absence of concave sides. About 80 miles north of the ridge an unsubstantiated escarpment has been reported; this feature rises from a depth of nearly 3,000 fathoms to a sharp peak at 1,180 fathoms and has the appearance of a north-facing tilted fault block. The fault face has a straight profile with a declivity of 63°. The gentler south slope also is straight, but with a gradient of only 11°. This asymmetrical scarp appears to have a foredeep.

Slight, almost imperceptible rises separate the Pacific–Antarctic Basin from West Scotia Basin, and West Scotia Basin from East Scotia Basin. Although on FIGURES 22–71 and 22–72 South Georgia Rise appears to be a part of the Atlantic-Indian Rise, actually these are two separate features which merge near Spiess Seamount in a vast uplift of the ocean floor which involves several other ridges and rises north of the Area. The South Madagascar Ridge is an ill-defined ridge which, if accurately contoured, is a borderline feature bearing resemblance to both ridge and rise, but lack of data makes it impossible to resolve the various possibilities of its structural appearance. A submarine spur extending north from Riiser-Larsen Peninsula (*1*) has been reported to be an escarpment of considerable magnitude extending 300 miles from Antarctica. The escarpment has a 44° gradient on the east side, dropping from 1,100 fathoms to at least 2,700 fathoms with a suggestion of a minor foredeep.

(7) *Trenches and troughs* — The only trench in this Area is the South Sandwich Trench, which is also the only trench in the South Atlantic Ocean. This trench lies parallel to that portion of the Scotia Ridge which is in the vicinity of the South Sandwich Islands. Arcuate in form, it has a recorded depth of 4,518 fathoms. It is part of the cordilleran belt which is thought to extend from the Andes of South America through the Scotia Ridge to Antarctica. The southern extent of the trench is questionable because of the paucity of data. The northern limit appears to lie on the slope of the South Georgia Rise, but it may be related genetically to the wide and relatively shoal trough lying between the northern and southern ridges of the Scotia Ridge. A small terrace on the landward side occurs at about 1,000 fathoms on this slope, but it is not repeated on the seaward side of the trench.

A number of glacial troughs are found on the west coast of South America. These troughs extend into the numerous fiords along the coast, and depths in excess of 600 fathoms are to be found far inland. The submarine canyons previously mentioned on the coast of Antarctica may be similar to these features.

(8) *Basins* — Profiles taken with echo sounders aboard ships crossing the peripheral basins show them to be relatively smooth and featureless. However, the continuity of the basins is interrupted by ridges and rises as well as by a number of seamounts. The basins as shown on FIGURE 22–71 are elongated in an east–west direction, forming an almost continuous ring around Antarctica. Many of the sills separating the basins are insignificant in relief and, in some cases, poorly defined. The major basins such as the Southwestern Pacific, Bellingshausen, Atlantic–Indian Antarctic (or "Valdivia"), and Indian–Antarctic Basins have been sounded very sparsely, but the average depth appears to be just over 2,500 fathoms. In only a few places do the depths reach 3,000 fathoms.

A number of small basins are found on the continental shelf of Antarctica. These basins have a small lateral extent, but attain depths which exceed 600 fathoms.

c. BOTTOM SEDIMENTS — FIGURE 22–73 illustrates the bottom sediment pattern in the sampled portions of the Antarctic region. In general, nearshore information is extremely limited, being confined principally to locations visited by exploratory and scientific expeditions. Much of the data has been obtained by ships caught in the pack ice. Areas of easy accessibility, such as the Palmer Peninsula and the sector southward from New Zealand, have been given the most attention.

Approximately 50% of the bottom sediment data shown on FIGURE 22–73 were extracted from reports of scientific expeditions which explored small restricted regions. The remainder of the data was obtained from nautical charts. More detailed information is available but cannot be shown on a chart of this scale.

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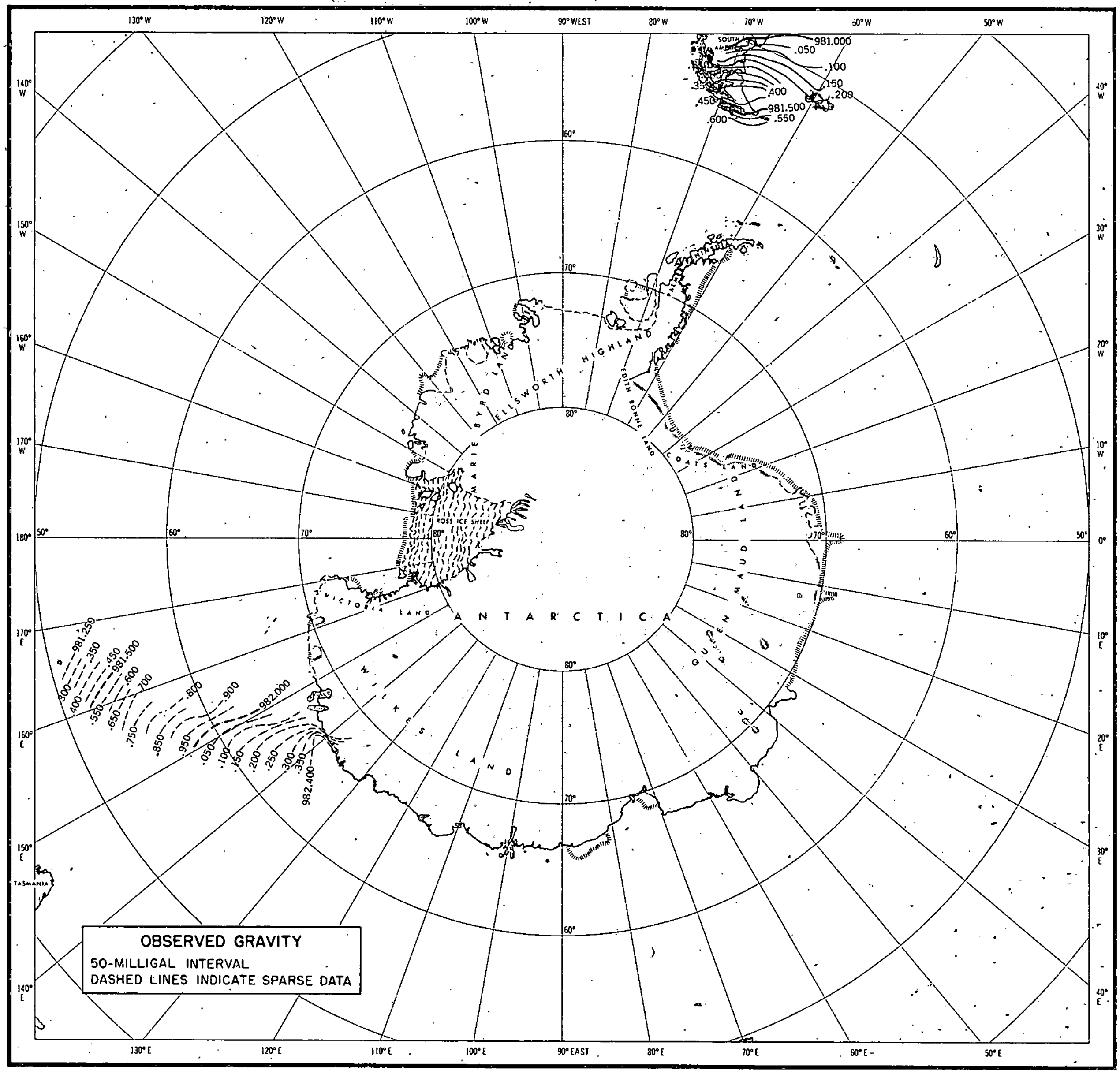

FIGURE 22–38. OBSERVED GRAVITY

Dredge samples taken in the Weddell and Scotia Seas indicate that bottom sediments in this sector may contain a higher sand and gravel fraction than is shown on FIGURE 22–73. This may be true in other sectors as well.

Data obtained from detailed charts of specific localities indicate that large rock areas exist in most of the nearshore and shallow water sectors.

d. GEOPHYSICS

(1) *Gravity* — Gravity data for the Area are very sparse. The contours shown (FIGURES 22–38 and 22–39) from Auckland Island to the Adélie Coast (*5*) are based on values interpolated from a single line of six observations. Except for the region off South America, data are insufficient to interpret the gravity field. No attempt is made to correlate available data with the geology.

(2) *Seismicity*

(a) EARTHQUAKES — FIGURE 22–40 shows the locations of the epicenters of 186 recorded shocks as given in *Source 54,* and 14 additional shocks listed in *Source 154.* The scale of this figure is such that a symbol may represent more than one epicenter.

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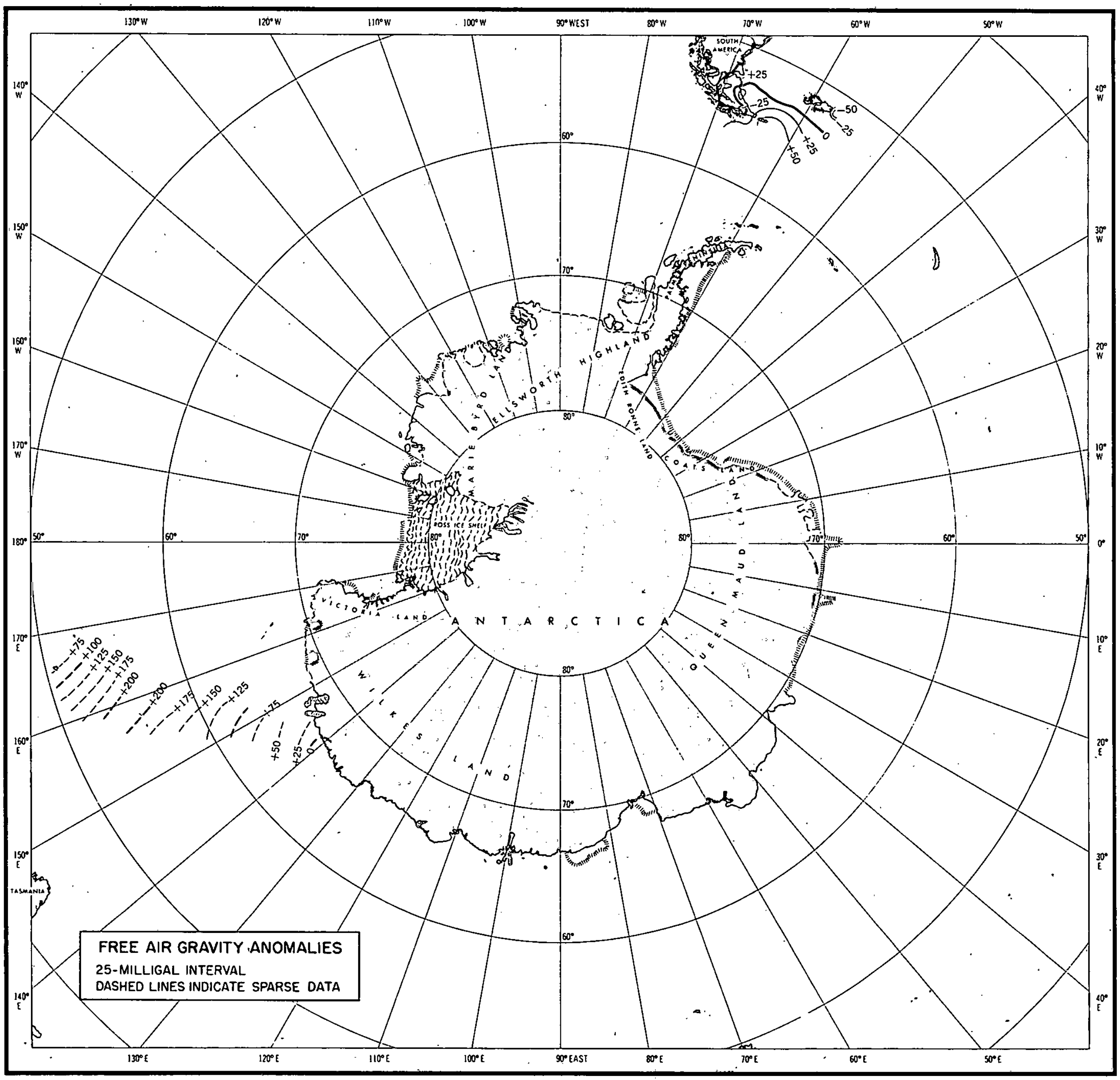

FIGURE 22–39. FREE AIR GRAVITY ANOMALIES

The scarcity of known epicenters on the Antarctic continent may be due to a lack of adequate recording stations rather than to the infrequency of seismic activity. While this scarcity of reported activity may indicate that the expected shocks in the continental area would be of low magnitude, it should be noted that a low-magnitude earthquake occurring at shallow depths (0–60 kilometers) may be more destructive in the vicinity of the epicenter than a stronger but deeper shock. All the shocks in the Area listed in *Source 54* occurred at shallow depths, with the exception of 5 shocks in the vicinity of the South Sandwich Islands.

The following tabulation shows earthquake distribution by class for the 4 quadrants of the Area. This list probably contains the majority of Class A, B, and C shocks which have occurred in the Area during the period covered (1904–1952). It does not reflect all of the innumerable minor unreported shocks (Class D and lower) which undoubtedly have occurred in the Area during this period.

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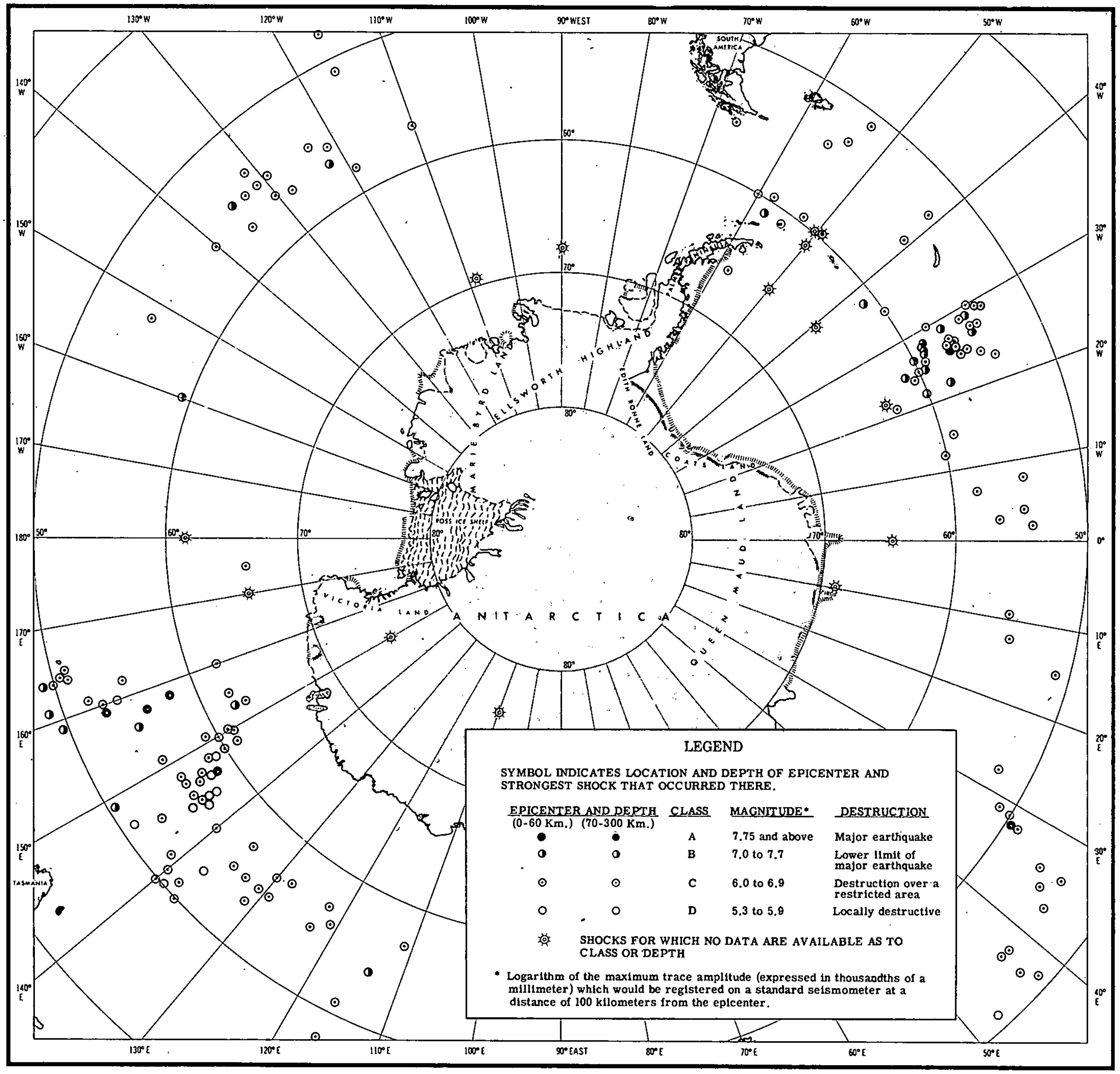

FIGURE 22–40. EARTHQUAKE EPICENTERS

QUADRANT	CLASS A	B	C	D	Unknown	TOTAL
90°E. to 180°	2	6	58	18	4	88
90°W. to 180°	0	2	16	0	2	20
0° to 90°W.	1	23	43	0	7	74
0° to 90°E.	1	0	15	1	1	18
Total	4	31	132	19	14	200

(b) VOLCANISM — Thirteen active volcanoes have been reported within the Area (FIGURE 22–41). Of these, 9 are situated along the Scotia Arc and associated structural features. Of those remaining, 3 are situated in the Balleny Islands and 1 on Ross Island (*14*).

With the exception of Mount Erebus (FIGURE 22–42), which appears to be in a constant state of activity, no definite predictions can be given as to the probable nature or date of future activity of any of the volcanoes in the Antarctic. However, records of volcanic activity in other portions of the world indicate that the eruption of any of the quiescent volcanoes is possible. While a steam eruption would be of little importance, an ash fall may affect military operations because of its abrasive nature and effect on visibility. Further, since the ash from some volcanoes contains relatively high percentages of magnetic minerals, an

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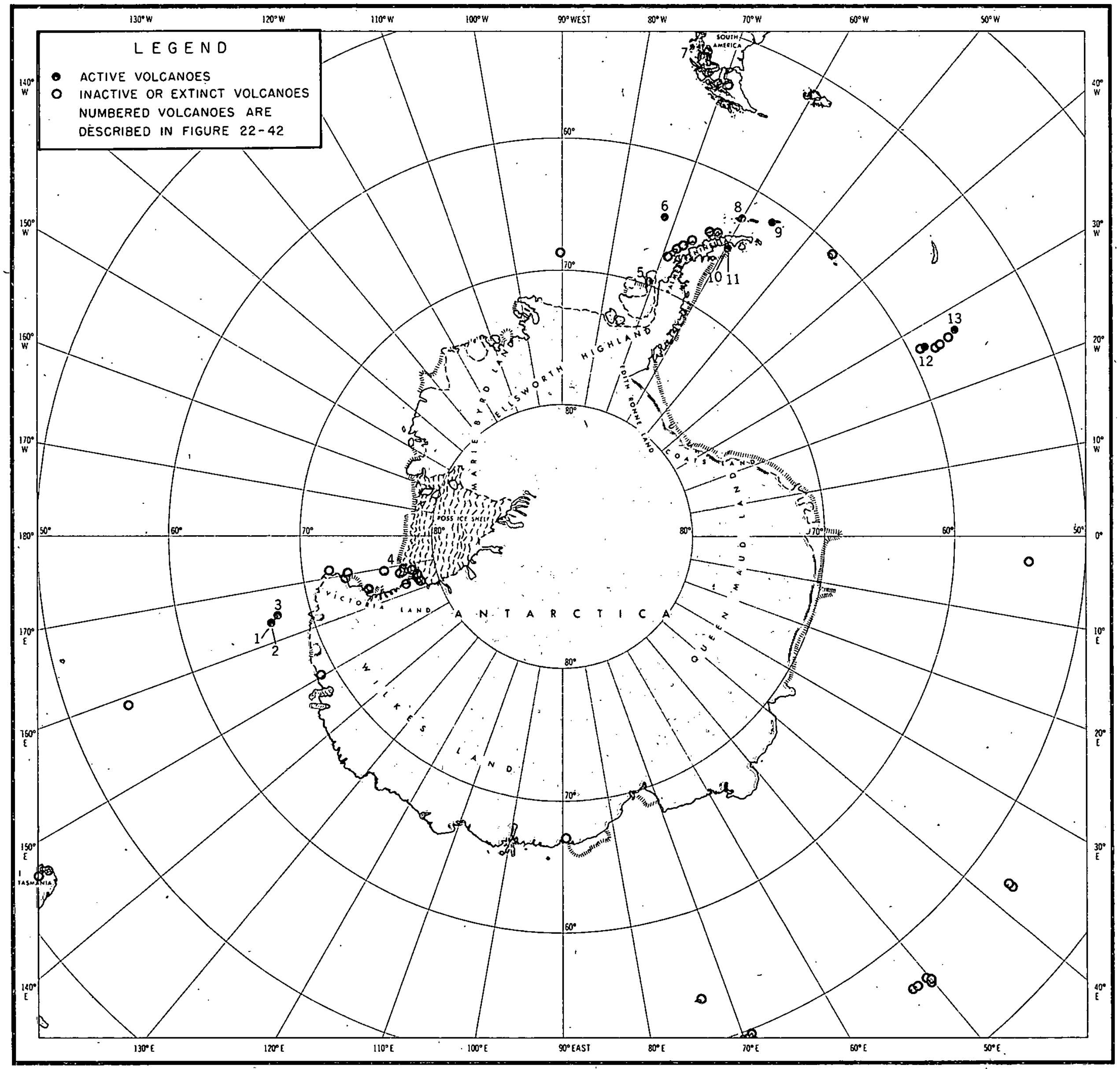

FIGURE 22–41. VOLCANOES

ash fall may change the magnetic characteristics of the bottom sediments; such changes could influence magnetic sweep effectiveness and/or the magnetic characteristics of mines placed on the bottom.

(c) TSUNAMIS — Although no tsunamis (seismic sea waves) have been recorded at Antarctica, phenomena of this type probably occur from time to time; however, no predictions of their magnitude can be given. Tsunamis generated by distant earthquakes and volcanic eruptions are most likely to occur along the Pacific coast; those generated by local earthquakes and/or volcanic eruptions are most likely to occur in the vicinity of the Palmer Peninsula, the Scotia Arc, the Weddell and Ross Seas, and eastern Wilkes Land.

Tsunamis have been recorded in the Antarctic periphery in regions such as the southern tips of Africa and South America and in the vicinity of Australia and Tasmania.

(3) *Magnetism*

(a) LOCAL MAGNETIC ANOMALIES — With the exception of a single aeromagnetic survey and observations at two points, no detailed information is available on the local anomalies of the magnetic field on the Antarctic continent. Possible high vertical or horizontal magnetic anoma-

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FIGURE 22–42. REPORTED VOLCANIC ACTIVITY

LOCATION ON FIGURE 22–41	NAME	LATITUDE	LONGITUDE	REMARKS
1	Freeman Peak*	66°25′S.	162°23′E.	Reported active by Balleny in 1839, has not been verified.
2	Buckle Island	66°48′S.	163°15′E.	Balleny reported smoke from two craters 1839. The *Southern Cross* reported smoke 1899. No activity reported by the *Discovery* 1904, or *Discovery II* 1936 and 1939.
3	Sturge Island	67°24′S.	164°15′E.	Activity reported, but date and observer unknown. No activity noted by the *Discovery* in 1904.
4	Mount Erebus	77°35′S.	167°10′E.	Almost continuous activity. Steam clouds, which rose 3,000 feet above summit, and fire at night noted in 1908 on 18, 21, 25, 30 June; 6, 15, 16, 17, 19, 27 July; 1, 25 August; 18 September. Ash and pumice reported 1912.
5	Sjovold Mountain*	69°12′S.	72°50′W.	Thick black smoke reported by the *Bouvet III* 1931. No steam or smoke noted by the *Thorshaven* 1935.
6	New Island*	65°12′S.	72°12′W.	Reported by Lutterfeld 1877. Existence highly doubtful.
7	Monte Burney	52°18′S.	73°24′W.	Reported active 1910; no data available as to type of activity.
8	Mount Pond	62°56′S.	60°34′W.	No date. Glacier contains layers of ash. Active fumaroles along the beach at Whalers Bay.
9	Bridgeman Island	62°04′S.	56°40′W.	Eruptions reported in 1821 and 1839. Charcot landed 1909 and found evidence of recent activity.
10	Christensen Nunatak.	65°06′S.	59°34′W.	Reported active by Larsen 1893. Nordenskjöld found crater extinct in 1902.
11	Lindenberg Island	64°55′S.	59°42′W.	Larsen 1893 reported thick black smoke. The ice melted for a considerable distance around the island. Ejected stones were observed on the ice. No activity noted by Nordenskjöld in 1902. Sulfur flow reported in 1908.
12	Mount Darnley	59°03′S.	26°30′W.	Lava flow reported 1936.
13	Zavodovski Island	56°20′S.	27°34′W.	Sulfur flow reported 1908.

* Location and name not verified by U.S. Board on Geographic Names.

lies (FIGURE 22–43) have been inferred from the magnetic character of the rocks near and on the surface. Local magnetic anomalies are of some military importance; for example, they are used in the setting of dip needle mines, and as a means for submarine evasion of the Magnetic Airborne Detector.

The known geology of the Palmer Peninsula and the islands about it indicate igneous rock; hence, magnetic anomalies of 1,000 to 3,000 gammas probably occur.

Near Little America, a sharp total-force magnetic anomaly of about 1,000 gammas was found at 79°35′S., 169°50′W. by aeromagnetic survey. Near Ross Island *(14)* at 77°51′01″S., 166°36′42″E., a horizontal anomaly of over 2,500 gammas was recorded during a magnetic survey by the British *Discovery* Expedition.

The Auckland Islands area contains several magnetic anomalies. At 50°44′30″S., 166°08′24″E. there is a negative vertical anomaly of more than 1,000 gammas. At 50°48′30″S., 166°00′48″E. there is a large anomaly in declination of about 10°: the declination in this Auckland area is normally about 18°E. but the compass at this location reads about 7°50′E. Such a change from the normal declination would require a magnetic force perpendicular to the magnetic meridian of about 1,500 gammas.

(b) SHORT-DURATION MAGNETIC FLUCTUATIONS — Large magnetic time variations usually occur within and at the boundaries of the auroral zone. In such areas it is not unusual for magnetic time changes with rates as high as 1 to 2 gammas per second to occur. To show the regions over which such rates can be expected to occur, the zones of high auroral activity are illustrated in FIGURE 22–44. Quantitative data of short duration fluctuations in this Area are rare. The few rapid-run magnetograms available for the Antarctic are of too short a time period to evaluate statistically.

(c) MAGNETIC CHANGES OF LONGER DURATIONS — FIGURE 22–45 shows tabularly magnetic changes of longer duration for the auroral zones delimited in FIGURE 22–44. The numbers in the body of the table show the number of days, weeks, months, etc., which are expected to elapse before the daily, weekly, monthly, etc., range of the component considered will exceed a certain magnitude. For example, for the *H* component (representing horizontal intensity) the number *12* at the intersection of the *day* row and the *1,000* column shows that 12 days are expected to elapse before the daily range of the *H* component will exceed 1,000 gammas.

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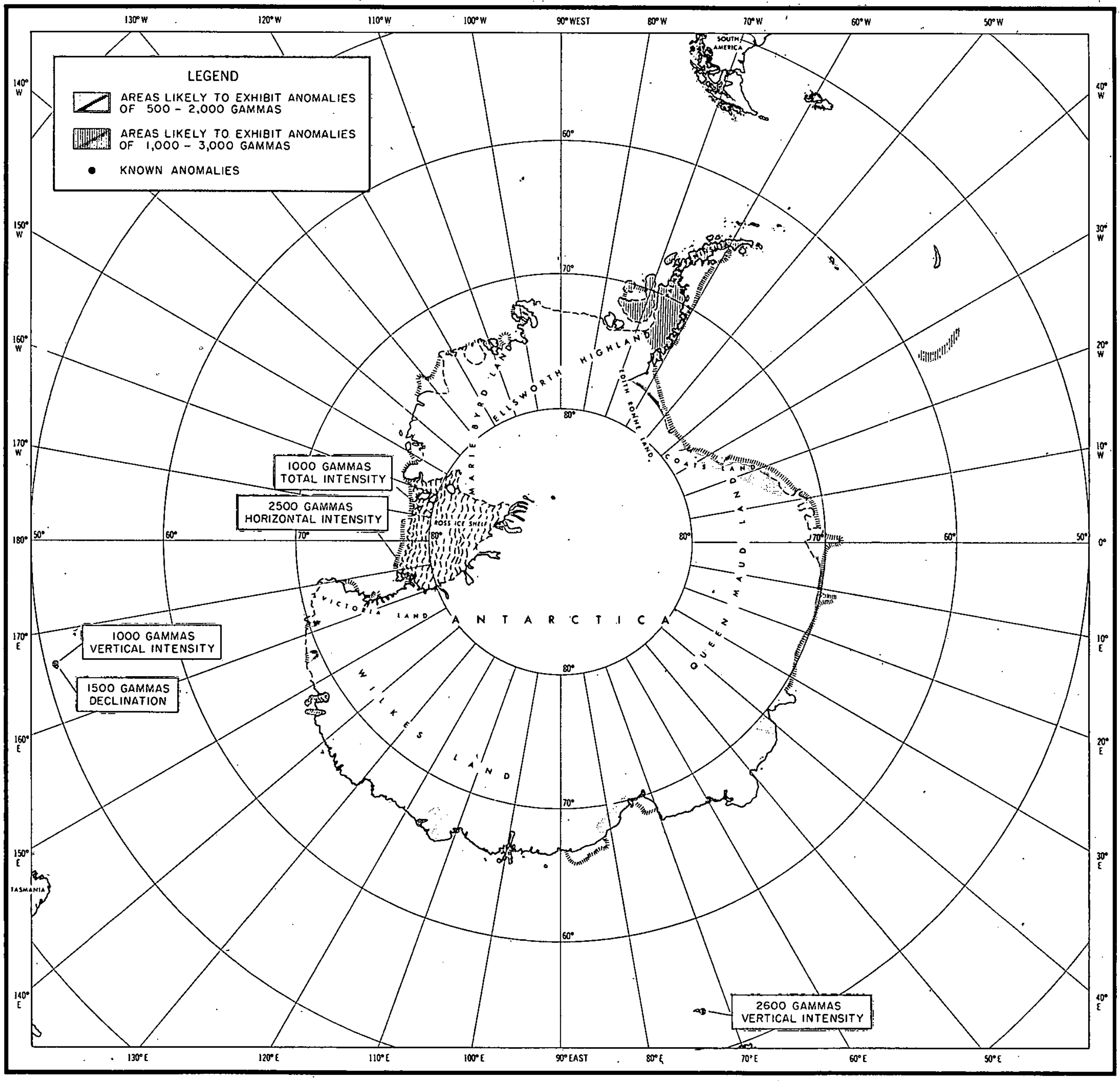

FIGURE 22–43. MAGNETIC ANOMALIES

7. Marine biology

a. ATTACHMENT FOULING

(1) *General* — Fouling is the attachment and growth of sessile marine algae and invertebrate animals upon underwater ordnance and equipment. On ships' hulls this attachment can result in loss of speed and increased fuel consumption. It also may interfere with the normal operation of underwater ordnance such as antisubmarine nets, mines, and sonic devices.

Collections by various Antarctic expeditions point to a generally abundant and varied invertebrate fauna; however, little if any work has been done on growth rates and periods of reproduction in relation to various ecological factors of the Area. The only known specific fouling study was conducted for a one-year period at Heard Island. Algae, some of which may contribute to fouling, are discussed in topic 7, c.

(2) *Geographic variation* — The Area may be divided roughly into two regions, the subantarctic and the Antarctic, where some differences in fouling characteristics are noted.

(a) SUBANTARCTIC REGION — This region includes the portion of South America and the islands between 40° and 60°S., with the exception

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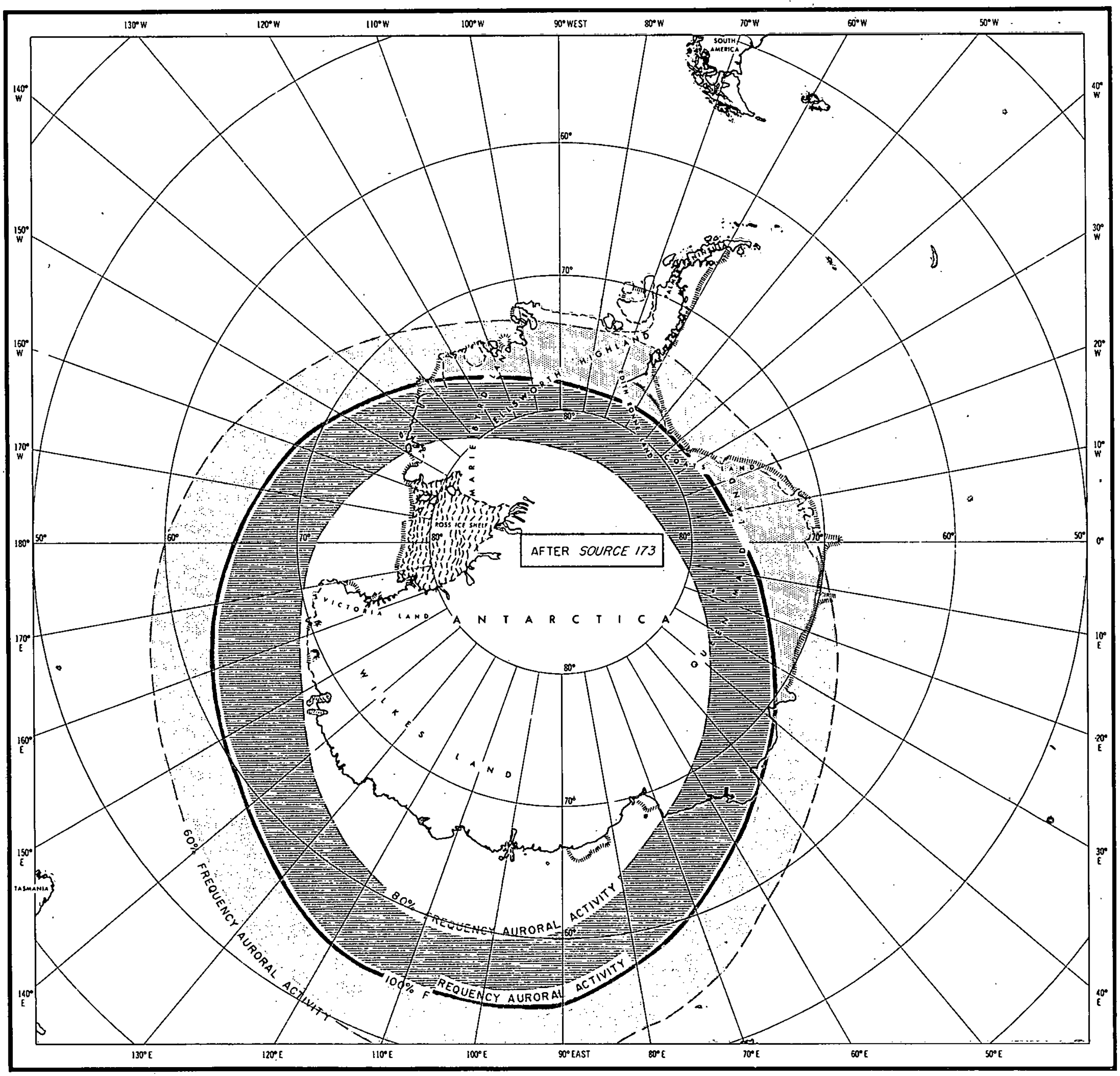

FIGURE 22–44. SOUTHERN AURORAL ZONE

FIGURE 22–45. MAGNETIC RANGES IN THE SOUTHERN AURORAL ZONE*

TIME PERIOD	H				D				Z			
	Magnitude (gammas)				Magnitude (gammas)				Magnitude (gammas)			
	200	500	1000	1500	200	500	1000	1500	200	500	1000	1500
Day	1	...	12	...	1	...	350	...	1	...	20	...
Week	...	...	2	...	...	...	17	...	...	...	4	...
1-month	...	...	1	...	...	...	30	...	...	...	1	...
3-month	...	1	1	30	...	2	15	200	...	1	6	...
6-month	...	...	1	...	...	...	8	...	...	...	2	...
Year	...	...	1	...	...	...	3	...	...	...	1	...

* Values in the graph indicate expected average number of time periods elapsing before ranges in horizontal intensity (H), Magnetic declination (D), and vertical intensity (Z) will exceed the magnitudes indicated.

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of the South Sandwich Islands. The degree of fouling in parts of this region has been estimated in other NIS's as generally slight, although it may range to moderate in many localities. In the study at Heard Island, only algae attached to the test panels. A number of organisms, nevertheless, are expected to be prominent in the fouling complex, and are present generally throughout the region. Mussels, algae, barnacles, tubeworms, hydroids, sponges, bryozoans, and tunicates may attach in that order of abundance. In the cold waters of this region the period of attachment probably is limited to one to three of the warmest months, February, March, and April. Where ice abrasion occurs, fouling cannot develop on exposed surfaces.

(b) ANTARCTIC REGION — Ice abrasion is probably the most important factor affecting fouling in this region. Where ice abrasion is absent or rare, fouling develops on suitable surfaces. Attachment probably occurs during the warmest part of the summer season, but growth of the attached organisms is believed to be slow. The following organisms may be expected to be present in descending order of abundance: bryozoans, sponges, algae, sea anemones, tunicates, hydroids, barnacles, and tubeworms.

b. BORERS — Gribbles (*Limnoria*), the most destructive of crustacean borers, are represented in the Area by a single known species *Limnoria antarctica*. This species is fairly common in such places as South Georgia, but no evidence of boring has been recorded. Borer activity is expected in some of the northern extremes of the Area, but no records are available.

c. ALGAE

(1) *General* — Large brown algae commonly called kelp occur in the Area. At least five species are of such large size or occur in such abundance that they are considered important to military operations (FIGURE 22–46). *Macrocystis,* the largest alga in the Area, commonly grows to depths of 150 feet in small to enormous fringing or offshore beds. The floating portions of these plants form dense entangled masses on the water surface which may be impassable to small propeller-driven craft. *Durvillea* is a massive plant of wave-exposed shores. Its thick leathery blade may be broad or split into several strap-shaped sections. *Lessonia,* a treelike form, may have a trunklike stem (stipe) as thick as a human thigh. It grows chiefly below the lowest tide level, where groves of these plants resemble submarine forests. *Phyllogigas* is an inhabitant of the sublittoral zone to depths of over 100 feet. *Desmarestia,* another sublittoral alga, covers many bottom areas with dense growths. Many other algae contribute to the littoral and sublittoral flora.

The last three forms, when growing abundantly in their habitat, may interfere with wire drags and mechanical minesweep gear. Beds of the algae also may offer some concealment to minefields and may interfere with the placement and operation of listening devices.

(2) *Geographic distribution*

(a) SUBANTARCTIC REGION — The greatest abundance of algae in the Area exists along the subantarctic coasts. Luxuriant growths of four of the large brown algae exist along the southern coasts of South America, and about the Falkland Islands. The subantarctic islands have generally abundant marine floras, although ice action has a limiting effect around some of the islands.

(b) ANTARCTIC REGION — Only one large kelp (*Phyllogigas*) is known from this region. On rock, cobble, or sand and shell bottoms, it grows within its depth range wherever ice abrasion is absent or rare. Under optimum conditions, it occurs in dense stands. This alga has been reported specifically from such widely separated localities as the South Orkney Islands, Palmer Peninsula, McMurdo Sound (*11*), and Commonwealth Bay (*6*). Its distribution probably is circumpolar. *Desmarestia* is usually abundant in all suitable localities, usually extending to greater depths than *Phyllogigas*.

(3) *Plankton* — Several worldwide reports concerning blockage of ship intake lines by high concentrations of plankton are recorded. In the vicinity of Peter I Island (*24*) and in the Ross Sea region, the high concentration of diatoms and copepods caused the evaporators of the U.S.S. *Atka* to become clogged with a thick coating. This condition resulted in faulty operation of the evaporators, requiring frequent cleaning.

(4) *Seagrasses* — True seagrasses, such as *Zostera,* do not grow in the Area.

d. BIOLUMINESCENCE (PHOSPHORESCENCE)

(1) *General* — Antarctic waters are particularly rich in nutritive salts which well up into the cold surface layer enabling an abundance of planktonic organisms to flourish. The principal bioluminescent animals included in this luxuriant plankton are those which produce a discrete sparking type of light, such as euphausiids, copepods, and ostracods. The euphausiids, or krill as they are known to the whalers, are the main source of food for whales and often occur in tremendous shoals numbering billions of individuals.

Two other types of bioluminescent displays may be seen in this Area: the diffuse ball-like glows of jellyfish and tunicates, and the brilliant sheetlike luminescence caused by large shoals of protozoans. The first type often takes the form of separate

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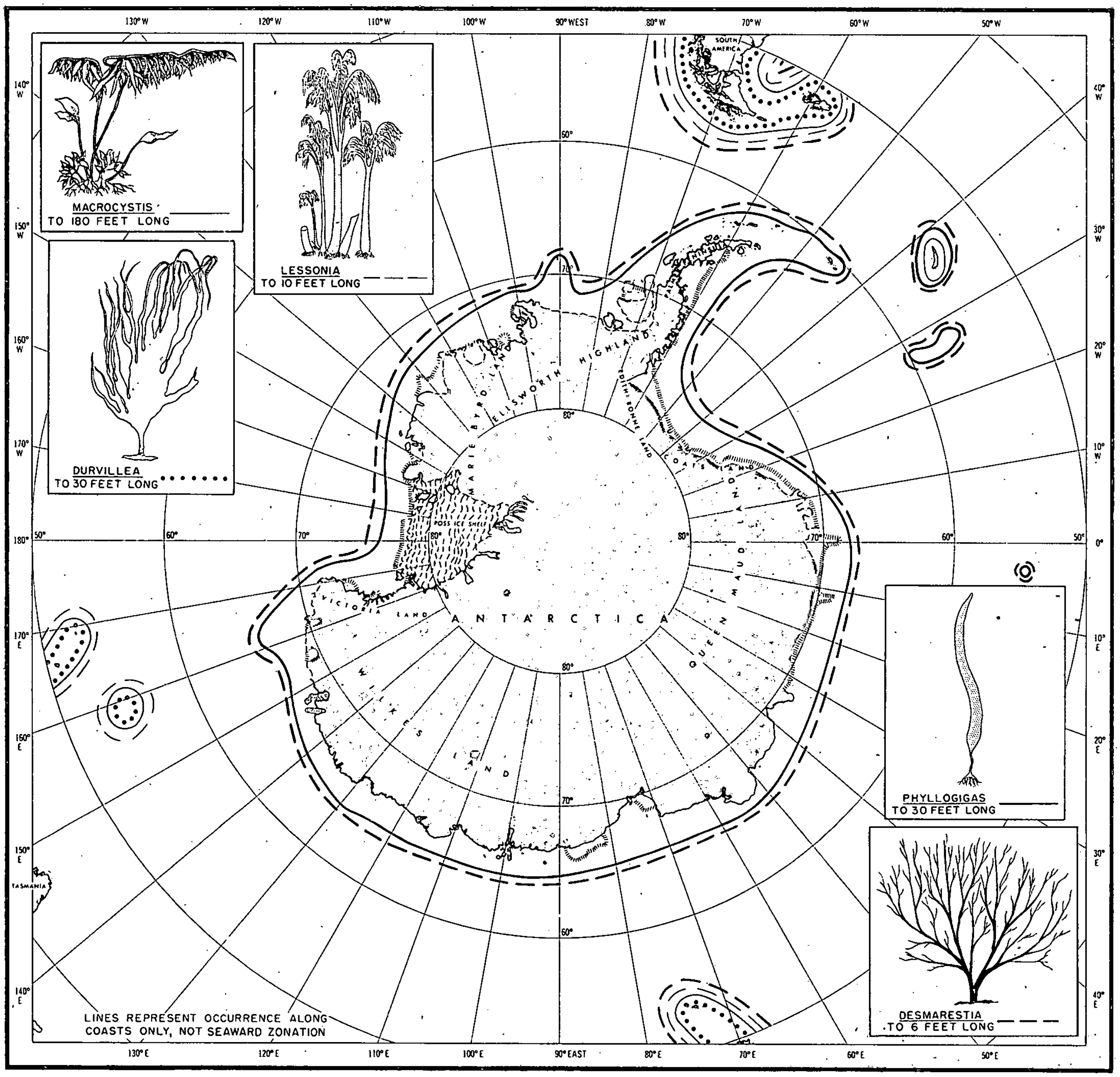

FIGURE 22–46. DISTRIBUTION OF KELP AND OTHER LARGE ALGAE

flashes of light which glow brightly for a few seconds and fade out. However, if jellyfish or tunicates are sufficiently concentrated, a sizable area may be suffused by their luminescence. The sheetlike displays produced by protozoans may extend for several miles along the sea surface.

These phenomena are the result of some physical, chemical, or mechanical stimulus, such as surface wave action, internal waves, general turbulence, precipitation, salinity and temperature changes, and movements of vessels and marine animals. However, bioluminescent displays of military importance would require large concentrations of luminous organisms.

(2) *Geographic distribution* — The distribution of bioluminescent organisms is indicated in FIGURE 22–47. They are generally abundant south of the Antarctic Convergence, with the exception of the eastern part of the Bellingshausen Sea (*25*), off the Palmer Peninsula, and about the South Shetland and South Orkney Islands. The zone of maximum abundance shown in FIGURE 22–47 roughly follows the Antarctic Divergence where upwelling of nutrient-laden water renders conditions especially favorable for the growth and reproduction of plankton. The southern boundary of this zone is the pack-ice edge. The rich Weddell Sea water is carried northward into the Scotia Sea,

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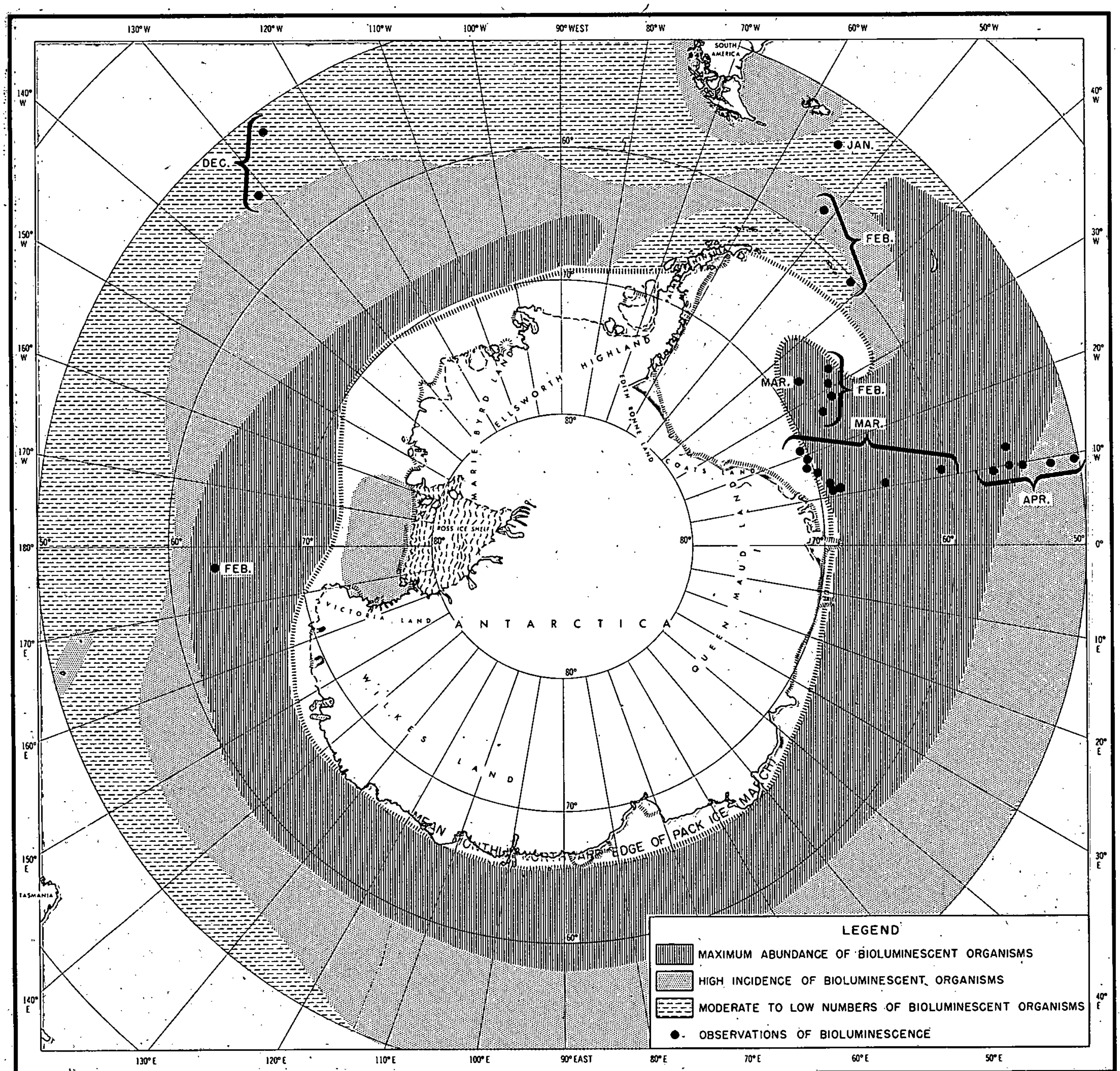

FIGURE 22–47. DISTRIBUTION AND RELATIVE ABUNDANCE OF BIOLUMINESCENT ORGANISMS AND RECORDS OF BIOLUMINESCENT DISPLAYS

thus accounting for the dense plankton populations of the South Georgia and South Sandwich Islands whaling grounds.

Bioluminescent displays are expected to be most common in the waters known to support large populations of plankton as shown in FIGURE 22–47; however, local conditions may promote the rapid increase of plankton anywhere in the Area. The fact that it is a common phenomenon in these southern waters is brought out in FIGURE 22–47 by the relatively large number of positive observations reported by the few expeditions that have recorded such data.

(3) *Seasonal variation* — Summer, particularly late in the season (February-March), is the time of greatest organic activity in Antarctic waters. In mid-November, a marked increase in plankton occurs south of the Antarctic Convergence to the pack ice. Pelagic life continues to flourish until it reaches a maximum in late February or early March, the center of abundance moving south with the receding pack ice. Studies on the principal species of krill show that these luminescent crustaceans tend to concentrate along the edge of the pack.

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Many bioluminescent organisms are present at the surface in reduced numbers through the winter, but most of the plankton descends to depths during the coldest months.

e. DANGEROUS MARINE ANIMALS — Dangerous marine animals in this Area are confined mainly to jellyfishes and killer whales. Jellyfishes, the only dangerous invertebrates in these southern waters, occur as far south as the icepack. Among the Antarctic coelenterates are certain members of the family Cyaneidae which are jellyfishes well known for the virulence of their sting. They usually are found in relatively shoal water.

Killer whales are undoubtedly the most dangerous animals in this Area. These fierce mammals hunt in small packs preying on other warm-blooded animals in the sea. They have been observed attacking seals on ice floes by crashing against the under side of the floe to dump the seal into the water. A photographer with an early Antarctic expedition was attacked in this manner by a small group of killers. They came up under the ice on which he was standing, breaking it into fragments. He barely escaped death by leaping onto firmer ice. Killer whales roam these waters all year, being most numerous along the edge of the icepack and about the southern islands.

f. HUMAN SURVIVAL IN WATER — Owing to low surface water temperatures, survival time of immersed individuals in this Area is relatively short. Where water temperature ranges from 35° to 40° F. survival is less than 90 minutes and in less than 35° F. water, survival time is less than 45 minutes.

These times are those which may be expected by individuals dressed in ordinary shipboard clothing and kept afloat by life jackets. Actual field experiments and laboratory tests have shown that struggling or swimming in cold water will increase survival time much more than merely clinging to wreckage or floating passively on life belts.

g. SONIC MARINE ANIMALS

(1) *Sonic fishes* — None of the true Antarctic fishes, which include the nototheniids and a few other families, is known to possess sonic qualities. Therefore, no fish noise is expected south of the Antarctic Convergence.

Limited interference caused by sonic fishes may be encountered in summer off the tip of South America and about the Falkland Islands. Here are found a few pelagic fishes with sound-producing characteristics, namely, herring, jacks, and some bottom fishes belonging to the cod and scorpionfish families.

(2) *Sonic mammals* — Whales, porpoises, and seals are common within the Area, and all are potential noise sources. Whale migration and movement habits are usually presented in the NIS; however, in this Section areawise monthly distribution of the commercial species is the main presentation. In general, this presentation is based on recorded movements of blue whales (*Balaenoptera musculus*), fin whales (*Balaenoptera physalus*), humpback whales (*Megaptera nodosa*), sei whales (*Balaenoptera borealis*), and sperm whales (*Physeter catodon*). In addition, right whales (*Balaena australis*), bottlenosed whales (*Hyperoodon planifrons*), and little piked whales (*Balaenoptera acutorostrata*) occasionally are considered in the statistics.

The vast majority of the whales are present during November through March. The few whales which remain in the Area during the remainder of the year are found in direct relation to the position of the pack-ice edge. Whales here are circumpolar in distribution, depending largely on the occurrence of krill (*Euphausiids*). In FIGURE 22–74, the average monthly population densities are presented in the artificial areal breakdown of the International Whaling Commission as limited by 50°S. latitude and the average monthly pack-ice position. Occurrence is presented both in numbers of whales expected during any specific month per 10,000 square nautical miles and as the number of square nautical miles per whale. Average densities range from 8 to 90 whales per 10,000 square nautical miles or one whale per 111 to 1,250 square nautical miles.

Area I (70°W. to 160°W.) was closed to whaling for several recent years. Consequently, the only data are from the strip sampling of the U.S.S. *Canisteo* (1946–47). These data show an average concentration of one whale per 34 square nautical miles of open water outside the pack, and trips into pack-ice leads showed one whale per 13 square nautical miles of open water. Only fin and little piked whales were considered in these data; therefore, they cannot be compared directly to the statistics of the catch.

Whale movement during the summer months is concentrated in lateral dispersal within 5° latitude adjacent to the pack ice. No set pattern has been discerned as yet for these dispersal movements.

Approximately 22 species of lesser whales and porpoises have been recorded from the NIS 69 Area. When considered as a group, these animals are distributed circumpolarly. The killer whale (*Orcinus orca*) is the most important of these, ranging along the pack around Antarctica where it feeds on other porpoises, seals, and penguins.

Seals are circumpolar in relation to pack and fast ice in the Antarctic proper; however, they are not found in great concentrations. Weddell seals (*Leptonychotes weddelli*) are essentially animals of fast ice, utilizing breathing holes in the ice. They are also found in small numbers on many islands of the Area. The rare Ross seal (*Ommatophoca*

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rossi), the leopard seal (*Hydrurga leptonyx*), and the crabeater seal (*Lobodon carcinophagus*) are animals of the pack ice. These are also found on many of the islands of the Area.

The elephant seal (*Mirounga leonina*) is found principally within the subantarctic regions of the Area, particularly South Georgia where the population is over 250,000. Elephant seals have also been reported along the northern fringe islands of Antarctica.

h. Deep scattering layer

(1) *General* — The term "deep scattering layer" (DSL) has been given to the phenomenon of a horizontally stratified sound scattering layer in the sea. The distinguishing characteristic of the layer is a diurnal vertical migration, usually of 100 fathoms or greater, descending during the morning and ascending during twilight hours. Generally, it is believed that the scattering is caused by living organisms such as plankton, squid, or fish. The layer trace as recorded on fathometers often has been misinterpreted as representing true bottom depth, and the term "phantom bottom" has been applied.

(2) *Geographic occurrence* — DSL observations in the Area are available from four ships. The tracks and a single station where the layer was observed, together with the prevailing daytime depths of the layer, are illustrated in FIGURE 22–48.

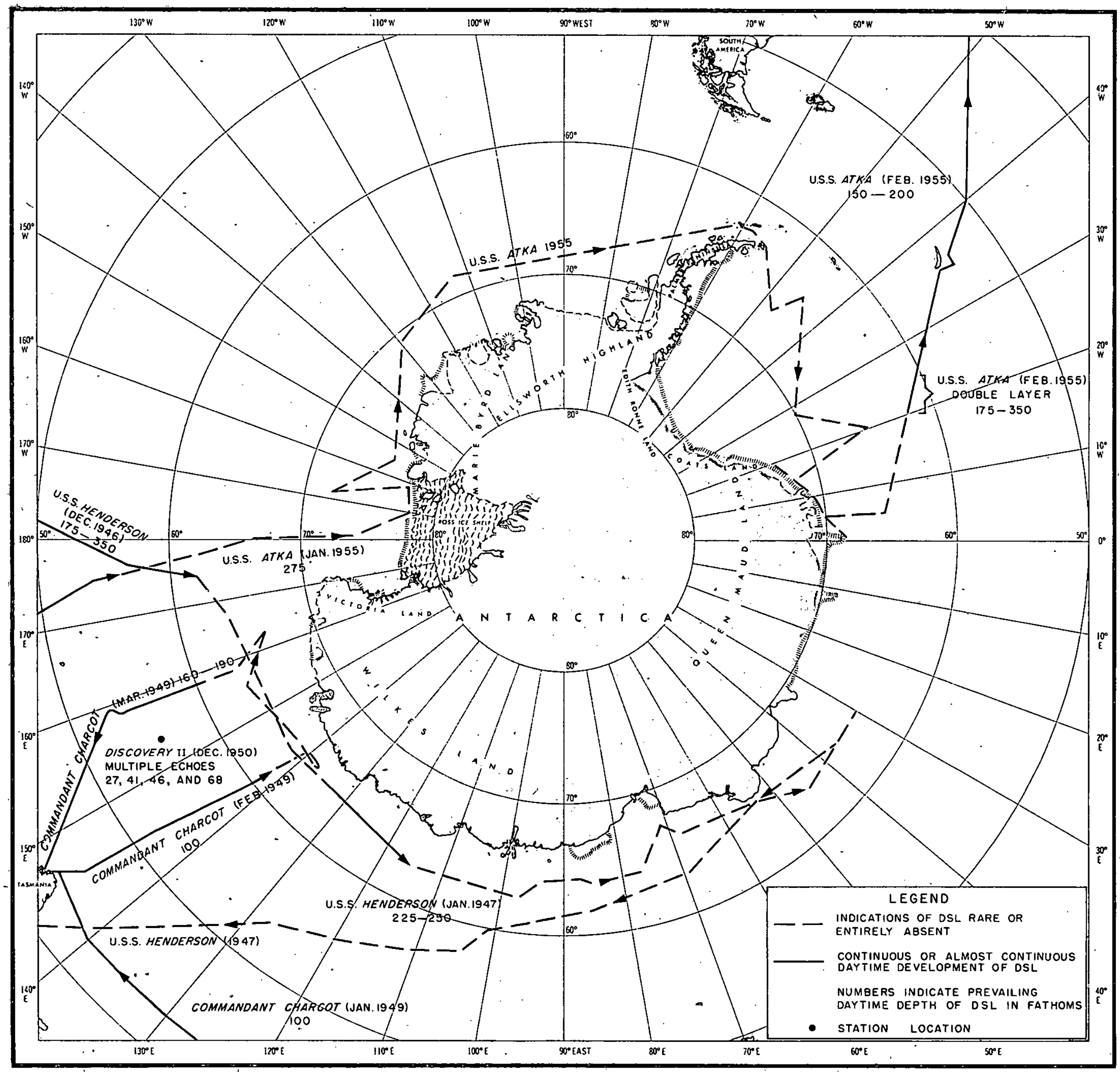

FIGURE 22–48. TRACKS AND STATION WHERE DSL HAS BEEN OBSERVED

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The southernmost observations of DSL were made by the U.S.S. *Henderson* and were the only ones reported by any ship navigating through or immediately adjacent to the icepack. It may be especially significant that the layer was neither recorded nor heard on the echo sounder of the U.S.S. *Atka* during its navigation around western Antarctica. Discrepancies exist regarding the latitudes at which the layer reportedly disappeared in the Antarctic region. Termination of the layer at about 56°S. (about 7° north of the Antarctic Convergence at that time) was recorded aboard the *Atka*. The *Henderson* recorded the temporary termination of the DSL when crossing the Antarctic Convergence (about 62°S.), whereas the *Commandant Charcot* did not lose the layer trace until the limit of drifting pack ice was reached (about 64°S.), almost 10° to the south of the convergence at that time. Reappearance of the layer was recorded at about 61°S. by the *Commandant Charcot* and at about 62°S. by the *Atka* when leaving Antarctic waters.

Some correlation was noted between the depths of the multiple echoes detected by the R.R.S. *Discovery II* and temperature layering as shown by bathythermograph traces. This ship also used lower frequency sound than the other ships (10 kilocycles instead of 18 or 24 kilocycles). The possibility exists, therefore, that the sources of the echoes were of a different nature from those causing the deep scattering layer detected by the other ships.

All known DSL observations in this Area have been made during the months December through March, since no ships reporting or recording the layer have navigated in Antarctic waters during the other months. On the basis of available observational data, it is believed that detection of the deep scattering layer reasonably may be expected in the circumpolar waters to approximately 60°S. during the period December through March, and possibly may occur there during the remainder of the year. In higher latitudes, it may be expected to be rare or entirely absent.

C. Coastal Sector 1: Palmer Peninsula, South Orkney Islands, and South Shetland Islands

60°S. to 75°S.; 44°W. to 79°W. (FIGURE 22–76; USHO Chart 6639; B.A. Chart 1775)

1. General

Coastal Sector 1 includes the Palmer Peninsula, South Orkney Islands, South Shetland Islands, and other islands off the coasts of the peninsula. The northern end of the Palmer Peninsula, which is the most northerly extremity of Antarctica, lies approximately 560 n. miles south of South America. The peninsula is about 950 miles long and is bounded on the west by the Pacific Ocean, on the north by Drake Passage, and on the east by the Weddell Sea. The South Orkney Islands lie approximately 360 n. miles northeast of the peninsula, and the South Shetland Islands lie about 60 n. miles north of the northeast part of the peninsula. Disregarding small coastal irregularities, the coasts of Coastal Sector 1 total about 4,000 miles in length.

Most of the west coast of the Palmer Peninsula is relatively ice free during at least a part of the summer; however, approaches to this coast are channelized by the many off-lying islands, islets, rocks, and shoals. Similar ice conditions prevail in the approaches to the South Orkney Islands and the South Shetland Islands during most of the summer months. Except at the northeast end the east coast of the Palmer Peninsula is unapproachable on account of the dense pack ice of the Weddell Sea. The greater part of the east coast of the Palmer Peninsula, except for stretches at the northeast and south ends, are rimmed by shelf ice.

The islands and mainland in this coastal sector are for the most part quite mountainous, particularly along the northwest and west coasts of the peninsula, and on the South Orkney and South Shetland Islands, where rocky promontories, nunataks, and mountain peaks protrude through a mantle of snow and ice. During the summer months the enveloping ice melts back along portions of these coasts, exposing rocky cliffs and in some places stretches of pebble beach.

The Palmer Peninsula is one of the most readily accessible parts of the Antarctic mainland. The peninsula and the off-lying islands, particularly the South Shetland and South Orkney Islands, were the sites of some of the earliest landings. Bays within the coastal sector have been used as layover stations by whalers and sealers for many years, and several of the bays have been the sites of regularly maintained supply caches. Numerous landings have been made within this coastal sector and several permanent and semipermanent camps for exploratory and scientific purposes have been maintained here in recent years.

2. Coast and landing places

From Cape Adams to Cape Knowles the coast trends approximately 400 miles northward. Heavy pack, broken by a few open water leads, fronts this mountain-dominated stretch of coast. Scattered peaks behind the southern portion of the coast around the Nantucket Inlet reach maximum elevations of about 7,000 feet. Th entrance to the inlet is more or less ice free, whereas the bay itself is choked with ice.

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Wright Inlet, which extends into the piedmont about 30 miles north of Nantucket Inlet, contains numerous patches of open water. At the head of this bay a 5,000-foot-high rock mass, Mount Tricorn, rises above the surrounding terrain and presents a distinctive appearance with its snow-free, nearly vertical rock faces. Between Wright Inlet and New Bedford Inlet, a distance of about 30 miles, the piedmont gradually rises to the interior mountains. New Bedford Inlet, which is about 10 n. miles wide at its entrance, is filled with crevassed ice and fringed with cliffed shores that are formed by the vertical, ice-free faces of the piedmont. These cliffs are broken only by a series of glaciers descending steeply from the high, rugged, interior mountains. The head of the inlet is marked by a snow-covered mountain that is rocky on its eastern or bay side.

Between New Bedford Inlet and Violante Inlet, the next indentation to the north, mountain masses are isolated and scattered. Several glaciers descend from the high interior. Inside the mouth of Violante Inlet is the small, snow-covered Pullen Island, which is cliffy along its northern coast and gently sloping along its southern coast. A very steep glacier marks the head of the large bay, and the walls of the bay rise to low, ice-covered peaks.

The embayed, cape-studded coast continues northward to Hilton Inlet, of which Cape Knowles is the northern entrance point. Low, snow-covered Cape Darlington forms the southern entrance point. The bay is headed by the wide Gruening Glacier, which descends between steep, often bare, rock walls.

From Cape Knowles to Cape Agassiz the coast trends north-northwestward for about 350 miles. The irregularly indented, 180-mile-long stretch of coastline between Cape Knowles and the southern tip of Hearst Island is accessible through several leads in the sea ice, but from Hearst Island to Cape Agassiz the coast is fronted by the Larsen Ice Shelf. The coast between Cape Knowles and Cape Boggs is indented by a succession of inlets and, in general, consists of cliffed headlands and vertical, often snow-free, rock walls. Coastal islands in this area are described as "high, snow-covered mounds." The Cape Knowles – Cape Boggs portion of coast is dominated by Mount Andrew Jackson, which attains a height of 13,750 feet and towers above the high interior plateau. A coastal range of lesser elevations lies between Mount Andrew Jackson and the coastline.

Lehrke Inlet, the northern entrance point of which is Cape Boggs, appears to be the only one of the Richard Black Coast bays bordered by any appreciable coastal lowland areas, and here the lowlands are enclosed by steep icefalls along the edges of the massive coastal ridges.

Cape Boggs, a precipitous headland, marks the seaward edge of the high, rugged Eternity Mountains, which are reported to rise about 6,000 feet above a 6,500-foot-high plateau farther inland. The northern side of the peninsula ending in Cape Boggs forms the southern shore of Smith Inlet, a large bay at the head of which is a steep glacier. High coastal cliffs extend around the bay to Cape Collier, the northern entrance point of Smith Inlet.

The mainland north of Cape Collier is terraced but presents a fairly even skyline. Along this portion of coast there are not as many rock outcrops as elsewhere on the Cape Knowles – Cape Agassiz stretch of coast. Hearst Island, which lies within the southern limits of the Larsen Ice Shelf, is approximately 42 miles long from north to south. The eastern coast of the island is fronted by heavy sea ice with pressure ridges and several icebergs, and the western or landward coast is bounded by the ice shelf. Hearst Island is snow-covered and crevassed; no bare rock is visible. Behind the ice shelf the mainland coast west of Hearst Island and northward to Cape Agassiz is rugged, with cliffed headlands separating broad, steep glaciers. Bare rock is visible on many of the vertical fault walls and cliff faces.

From Cape Agassiz to Cape Longing the coast is approximately 350 miles long along the seaward edge of the Larsen Ice Shelf. Except for the southern shore of the peninsula ending in Cape Longing, the mainland coast is completely fronted by this massive ice shelf, which extends seaward for 10 to 100 n. miles. The Weddell Sea, which fronts the ice shelf, is beset almost constantly by heavy pack ice that constitutes an extreme navigational hazard and makes approach to the edge of the shelf very difficult. The absence of soundings in this portion of the Weddell Sea evidences the inability of vessels to thus far penetrate these icefilled waters.

The edge of the ice shelf itself presents another problem. Changing from year to year in location, height, and configuration and even showing a considerable variation from season to season, its location and description is at best an approximation. The face of the shelf along the southern and central portions of the coast is considerably higher than it is along the northern portion. The central part of the Larsen Ice Shelf is heavily crevassed, and along its seaward edge, which sometimes reaches heights of 100 to 200 feet, it is marked by overhanging cliffs and deep indentations. The shelf increases perceptibly in elevation shoreward. The northern part of the Larsen Ice Shelf slopes downward toward its northern end.

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All of the islands between Cape Agassiz and Cape Longing lie inside the edge of the ice shelf, thus promoting considerable disagreement as to their extent and even to their existence. Several small nunataks are reported, particularly near the mainland coast. Jason Island, which lies off the center of the Cape Agassiz – Cape Longing stretch of coast, is reportedly snow free in its lower parts. The island's eastern extremity, Cape Framnes, is a bold, conspicuous promontory that extends beyond the edge of the shelf at times.

Robertson Island, a dome-shaped, snow-covered island about 35 n. miles south-southwest of Cape Longing, has an extinct volcano at its northern end. Lindenberg Island, a high, dark, and much smaller island about 8 n. miles northward, is reported to be an extinct volcano. The Seal Nunataks, a chain of about 11 snow-free islets of volcanic origin, extend west-northwestward from Robertson Island.

Between Cape Agassiz and Cape Northrop, about 80 miles northwestward, the mainland coast is indented by Mobiloil Inlet and a number of smaller inlets. Mobiloil Inlet, located well within the Larsen Ice Shelf, is dominated by a myriad of glaciers converging at the head of the inlet at Hub Nunatak, and the complex is known as The Traffic Circle.

Between Cape Northrop and Mill Inlet, about 35 coastline miles to the northeast, the coast is dominated by a series of steeply sloping, snow-capped peaks and ridges. The glacier in Mill Inlet is about 8 miles wide at its mouth and extends inland a considerable distance between the rock walls of a valley.

From Mill Inlet northeastward the coast is bordered by a series of peaks and ridges with almost perpendicular cliffs. The northern and eastern slopes are snow free while the separating valleys are filled with ice.

The Richthofen Valley, about 80 miles northeast of Mill Inlet, is a glacier-filled depression that is about 7 miles wide at its mouth and extends inland some 15 miles between steep rock walls. The southern portion of the 75-mile-long Oscar II Coast, extending northeastward from the valley, is indented by several inlets separated by rugged promontories. Behind this stretch of coast the steep edges of the interior plateau are broken in places by steep glaciers. North of the glaciers the coastline is indented by a series of long, deep embayments bordered by steep rock peninsulas.

The Nordenskjöld Coast, which constitutes the northern part of the coast between Cape Agassiz and Cape Longing, is a high, ice-covered plateau with a steeply sloping seaward fringe. A number of glaciers descend onto the ice shelf that fronts the southwestern part of this coast. Deep fiords extend several miles inland along the rest of the coast, which is dominated by Cape Sobral, a partly snow-free promontory that appears to be an island from the air, and by Cape Longing, 12 miles away across Larsen Inlet.

From Cape Longing to Cape Dubouzet the coast trends northeastward for 150 miles. Several large islands front most of the mainland coast, which is covered by an almost continuous ice sheet and fronted by ice cliffs and nearly always frozen coastal channels. Approaches are blocked by the icepack throughout most of the year. From November through February the icepack is broken, but the approaches are imperilled by heavy floating ice.

Anchorage is reported available in 6 fathoms over good holding ground about 100 yards off the northwest coast of Snow Hill Island, which lies east of Cape Longing. Anchorage is also reported off the southeast coast of the same island about 1 n. mile offshore in 16 fathoms over good holding ground. A third anchorage is reported in a bay off the northwest coast of Joinville Island, the largest island off the tip of the Palmer Peninsula.

The James Ross Island group is separated from the mainland by the Prince Gustav Channel, which has never been observed to be ice free. James Ross Island, the largest of the group, is essentially an ice-covered, table-topped island dominated by the large, conical Mount Haddington (6,561 feet). The coast of the island is indented by bights and is fronted by vertical cliffs and icefalls interrupted by glaciers that are 1 to 2 miles in width and terminate in ice cliffs. The Naze, a low sandy cape, marks the northeast tip of the island and extends to within 3 n. miles of the rocky, precipitous Vega Island. Vega Island reaches a maximum height of 2,180 feet. Sidney Herbert Sound, which separates James Ross Island from Vega Island, has never been navigated because of the ice conditions and the numerous rocks and islets.

Snow Hill Island is separated from James Ross Island to the northwest by Admiralty Sound, a deep but almost always ice-blocked channel. On the northwest coast of the northeastern projection of Snow Hill Island there is a low shore on which landings have been made (landing place **(1)**). The Swedes under Nordenskjöld landed in 1901 and were rescued in 1903 by the Argentinians. An American expedition under Ellsworth also made a landing here during 1934–1935. The southeast coast of the projection consists of an ice cliff 4 to 20 feet high. The island's interior icecap rises to a huge level plain which has been utilized as an aircraft landing area.

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Seymour Island, about 1 n. mile northeast of Snow Hill Island, is reported to be entirely snow free. The island is, in general, fringed by low perpendicular cliffs, but many slopes are gradual enough to provide landing places, particularly on the southeast coast. A small island about 3 n. miles to the north has a beach along its north coast.

Andersson Island and Jonassen Island, about 20 n. miles northeast of Vega Island, are separated from the James Ross Island group by Erebus and Terror Gulf. This gulf, noted for variable currents and heavy ice conditions, contains depths of 100 to 200 fathoms. Andersson Island and Jonassen Island are flat topped, and the icecaps of the islands fall in gentle slopes to ice cliffs at the sea. The eastern extremity of Andersson Island evidences volcanic origin in a lofty precipice composed of an irregular mass of volcanic tuff rising perpendicularly from the sea. A narrow channel, Fridtjof Sound, separates these islands from the mainland and has been safely navigated even when Antarctic Sound, the channel farther north between the mainland and the Joinville Island group, was observed to be blocked by heavy pack ice.

Paulet Island, the southernmost and smallest of the Joinville Island group, is located about 16 n. miles due east of Andersson Island and is practically snow free. It is apparently volcanic in origin, has terraced slopes, and rises to a cone-shaped summit reaching an elevation of 1,263 feet. The steep slopes of the island are the site of a large penguin rookery. A low gravel beach bounded by cliffs lies in a deep bight on the eastern side of the island. Along the northwest coast is a campsite where provisions were left in 1903 by the shipwrecked crew of the Norwegian ship *Antarctic*.

Other islands of the Joinville Island group include Joinville Island, D'Urville Island, Dundee Island, and a number of smaller islands and islets, most of which are connected by sea ice. The group is separated from the tip of the Palmer Peninsula by Antarctic Sound, which is usually blocked by ice. On Joinville Island, the largest of the islands, a mountain reaches an elevation of 3,700 feet. The rest of the group is covered by a low, smooth icecap, bare rock appearing only where surfaces are perpendicular. At the northwestern end of Dundee Island there is a rocky beach (landing place (2)) backed by a 40-foot-high ice face. Ellsworth landed here during his 1935–36 expedition. Aircraft have landed on the snow plain in the northern portion of the island.

The coastal peaks that emerge from the ice sheet on the mainland between Cape Longing and Cape Dubouzet are the fringes of the interior frozen tableland. This inland plateau is high, marked by elevations of 2,000 to 3,000 feet. A peak on Cape Longing is reported to reach an elevation of 5,500 feet, and a large glacier breaks the ice cliffs just north of the cape.

The mainland coast trends northeastward from Cape Longing along Prince Gustav Channel to Duse Bay, some 7 n. miles wide and 3½ n. miles deep. This stretch of the mainland is marked by jutting headlands and ice-filled inlets. The eastern shore of Duse Bay is formed by Tambarin Peninsula, which extends southeastward from the tip of the Palmer Peninsula. The northeast face of the Palmer Peninsula is indented by Hope Bay, which is 1¾ n. miles wide and about 2½ n. miles long. A British stone hut and meteorological station have been located within the bay in Hut Cove since 1946. Landings have been effected inside the cove (landing place (5)) and southwest of the western entrance point. The ice cliff between Hope Bay and Cape Dubouzet is the seaward edge of a vast glacier.

The South Orkney Islands, some 345 n. miles northeast of the tip of the Palmer Peninsula and lying between latitudes 60°S. and 61°S., consist of two barren, mountainous islands and a number of smaller islands and islets. The main islands, Coronation and Laurie Islands, have a combined coastline length of only about 100 miles. Approaches to the group are hazardous because the islands are inadequately charted, are covered usually by fog, and are fronted by icebergs, rocks, and shoal areas. Tide rips which may be caused by sunken rocks are common, and the combination of floating ice and currents makes navigation close off the coasts and between the islands extremely dangerous.

Coronation Island, the largest of the South Orkney Islands, is about 30 miles long and 3 to 8 miles wide. It is dominated by a mountain ridge that extends the length of the island and reaches its greatest height in the eastern part where it ascends to 3,000 feet. Completely glaciated, the terrain of the island descends steeply to the sea in rugged cliffs except along the northern and northwestern coasts where the icecap descends to the water's edge in gentle slopes. All coasts are indented, but the anchorages in the indentations are for the most part temporary at best. Only Sandefjord Bay on the west coast has desirable conditions for anchoring. Here the holding ground is good in 5 to 18 fathoms and shelter from the weather is provided by headlands and nearby islands. In the bay and throughout the surrounding waters, great care must be taken to avoid the numerous rocks and bergs, both grounded and afloat. Landings have been made on the western part of Coronation Island (landing place (4)).

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Laurie Island, the other major island of the group, is considerably smaller, being only about 12½ miles long and in places less than 1 mile wide. The island is essentially a complex of ice-covered peninsulas separating several embayments. Scotia Bay, an embayment at the western end of the south coast, has been the site of an Argentine meteorological station since 1904. Anchorage may be taken in 8 to 10 fathoms in the entrance of a cove at the north end of the bay; however, anchorage is not recommended in the bay because the holding ground is poor, the bay is exposed, and the cove is small. In this cove, which is the location of the Argentine station, landings have been effected (landing place (3)). The bay entrance is flanked by some of the numerous rocks and islets that encircle the island. Scotia Bay is ice locked during the winter, as is the entire island group, and is clear of ice for only a short time during the summer.

South of Coronation Island are several islands, islets, and rocks. Several good anchorages are available in this area, which has long served as a station for whalers. Borge Bay, located off the east coast of Signy Island, is one of the more frequented anchorages. On the west shore of the bay there is a good beach where fresh water is available.

Powell Island, east of Coronation Island, and two smaller islands form Ellefsen Harbor, a small but well-sheltered anchorage with depths of 8 to 13 fathoms over good holding ground.

The South Shetland Islands are separated from the northwest coast of the Palmer Peninsula by Bransfield Strait, which is 60 to 70 n. miles wide. The islands are arranged in a chain that extends in an east-northeast – west-southwest direction for a distance of approximately 280 n. miles. The island chain is divided into two groups by a broad strait that is about 65 n. miles wide and contains a few relatively small islands. The most important islands in the northeastern group are Clarence Island and Elephant Island, and in the southwestern group are King George Island, Livingston Island, and Deception Island. The islands are of volcanic origin, mostly mountainous, and range in size from tiny islets to King George Island, which is 48 miles long and 18 miles wide.

Approaches from the north to most of the South Shetland Islands are restricted by a gently sloping insular shelf; by numerous islets, rocks, and submerged obstacles extending far offshore; and by strong currents. Strong currents also flow through the narrows between the islands. Navigable channels allow passage between most of the islands, and approaches to the group from the south are clear except for scattered islets, rocks, and reefs, most of which are found close offshore.

The larger islands of the South Shetland Islands are indented by many large bays providing adequate shelter for anchorage. Many of these bays have been used or visited by whaling and sealing vessels. A British meteorological station and an Argentine meteorological station are located on the shores of the bay that is enclosed by the horseshoe-shaped Deception Island (FIGURE 22–49A). In addition to the larger embayments, numerous protected coves indent the coasts of almost all of the larger islands.

The coasts of the South Shetland Islands are steep, consisting of ice cliffs and barren rocky bluffs. Many of the smaller islands are little more than bare, steep-sided conical rocks jutting up from the water. A few islands have low, almost flat profiles, but most of the islands have rugged, mountainous interiors. All but the aforementioned steep-sided, conical islets are capped with snow and ice. Sheltered sand and gravel beaches suitable for landings are available on Clarence Island, King George Island, and Deception Island (landing places **(6)**, **(8)**, and **(10)**).

From Cape Dubouzet to Cape Kater the coast of the Palmer Peninsula trends southwestward for about 100 miles and is indented by a few partly sheltered bays and several minor indentations. The coast is covered by ice through which only a few pinnacles project. Bransfield Strait, which separates the Palmer Peninsula from the South Shetland Islands is, in general, clear. The strait is approximately 38 to 64 n. miles wide. Approaches from the strait to the coast are partly obstructed by two small islands, each about 2½ miles in diameter. One of the islands lies about 10 n. miles off Cape Kater and the other lies about 11 n. miles off the center of the coast between Cape Dubouzet and Cape Kater. In addition, numerous islets, rocks, and reefs are found in the vicinity of each island and as far as 12 n. miles off portions of the mainland coast.

The shores of the mainland are mostly fronted by ice cliffs. However, a few bare rock and pebble beaches are found at the tips of promontories and at the foot of ice cliffs. Two of the promontories were used as landing places (landing places **(7)** and **(9)**). The entire coast is backed by an almost featureless plateau that is about 2,000 feet high behind the northeast end and 6,000 feet high behind the southwest end of the coast. Numerous glaciers flowing northward off this plateau join to form an almost level ice platform that extends to the sea.

The Palmer Archipelago, which consists of Trinity Island, Brabant Island, Anvers Island, and smaller associated islands, extends northeast – southwest for 135 n. miles off the northwest coast of the Palmer Peninsula between Cape Kater and Cape Renard. Approaches to the islands of this

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group are clear from the open sea to the north and northwest and through Bransfield Strait to the northeast. Passage between the group and Palmer Peninsula, however, is restricted to a continuous channel that is composed of several straits and has a minimum width of 3 n. miles between Trinity Island and the mainland. The channel is encumbered by islets and rocks, the greatest concentration of which are found at the southwest entrance of the channel off the south coast of Anvers Island. Approaches to the east coast of Anvers Island and the west coast of Brabant Island are through a broad bay that is partly obstructed by a group of islands. This bay narrows to the south to a channel 1½ n. miles wide. Approaches to portions of the northeast coast of Brabant Island and the south coast of Anvers Island are restricted to narrow channels by close-lying islands. The channel off the northeast coast of Brabant Island is short, encumbered by several small islands, and about 2 n. miles wide. The channel along the south coast of Anvers Island is approximately 19 n. miles long, 1 to 3 n. miles wide, and channelized at either end by smaller islands. The remaining islands of the archipelago are small and are located far enough apart from one another and the mainland to have relatively clear approaches. In places, however, the approaches to the islands are encumbered by groups of islets and rocks extending a maximum of 5 n. miles offshore.

A good anchorage reportedly used by whaling vessels is available off the west coast of Wiencke Island, which is located off the south coast of Anvers Island. The harbor is sheltered from wind, swell, and drift ice by a smaller island and several rocks.

Trinity Island, which is approximately 15 miles long and 13 miles wide, lies 3 to 17 n. miles off the Palmer Peninsula coast and is located about 18 n. miles west of Cape Kater. Approaches to large portions of the coast of this island are fouled by rocks and reefs for a distance of 5 n. miles offshore. The southwest portion of the island consists of an ice-covered tableland that merges with the high, partly exposed rock characteristic of most of the island. The summit, 3,670 feet high, is located approximately at the center of the island.

Brabant Island, which is 33 miles long and 20 miles wide, lies 4 to 28 n. miles off the mainland and about 64 n. miles west-southwest of Cape Kater. The island is predominantly mountainous with bare rock showing only on the peaks and steeper slopes. A landing was made on the northern portion of the island (landing place **(11)**). Several small islands and numerous islets and rocks encumber the approaches to parts of the coast of the island, and foul ground extends as far as 5 n. miles off the west coast of the northern extremity of the island. Several of the bays indenting the coast of the island offer possible shelter, but most of the bays contain encumbrances. The east coast of Brabant Island is backed mostly by the ice cliffs of glaciers rising to the snow-covered foothills and peaks of a mountain range that parallels most of the coast. The northern extremity of the island is a high rocky peninsula, much of which is fronted by high rocky cliffs. The west coast is intersected by mountain ridges ending in rocky promontories, between which are cliff-faced glaciers descending through valleys. Of the several mountain peaks that closely back the west coast of the island, the highest reaches an elevation of 8,054 feet.

Anvers Island, which is 43 miles long and 28 miles wide, lies about 8 to 40 n. miles off the mainland and is separated from Brabant Island by a bay, 4 to 18 n. miles wide. Islets, rocks, and shoals extending as far as 6 n. miles offshore are found in great numbers off the north, west, and southwest coasts. Only scattered encumbrances lie off the other coasts of the island. The southeast coast of the island is fronted by steep rocky cliffs from which icefalls and hanging glaciers descend to the shore. The glaciers originate in the valleys of a mountain range. The peaks of the range attain the highest elevations found on the island, almost 10,000 feet. The remaining highly indented coasts of the island are bordered by a belt of piedmont ice that is backed by glaciers descending from the rugged mountainous interior. Landings were made on the southwest part of Anvers Island (landing place **(17)**), but elsewhere the shores of the island afford only a few possible landing sites.

The remaining islands of the Palmer Archipelago are considerably smaller than Brabant Island and Anvers Island, and most of them are found in the body of water between Brabant Island and Trinity Island. The small islands are predominantly mountainous with coasts backed by rock cliffs, cliff-faced glaciers, and gentle, snow-covered slopes. Landings were made on three of these small islands close off Anvers Island (landing places **(13)**, **(14)**, and **(16)**).

From Cape Kater to Cape Renard the mainland coast trends southwestward for about 200 miles. This irregular stretch of coast has many embayments and is sheltered by the Palmer Archipelago. Approaches to the coast are restricted to numerous straits and passages by the islands of the Palmer Archipelago, which extend as far as 40 n. miles offshore. Passage between the mainland coast and the islands is through a strait that is 3 to 11 n. miles wide but is encumbered by islets, rocks, and reefs. The approaches from the strait to the mainland coast are encumbered by many islets and rocks that are found off most of the promontories and at the heads of several of the bays. Sheltered an-

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chorages are available in many of the bays, though the usefullness of these anchorages is severely limited by the danger of the calving of encircling ice cliffs.

Most of the coast between Cape Kater and Cape Renard is fronted by the ice cliffs of glaciers. However, bare rock is found on many of the promontories and on the sides of the numerous narrow glacial fiords indenting the coast. A few landings were made on the southwest half of the coast (landing places **(12)** and **(15)**). The coast is characterized by numerous rocky promontories extending inland as ridges to a high interior plateau that has an approximate elevation of 6,000 feet. Many glaciers descend from the plateau between the ridges.

From Cape Renard to Cape Rey (66°44′S., 66°30′W.) the mainland coastline trends southwestward for about 240 miles and is extremely irregular. Approaches to the northeast part of the coast are restricted by a concentration of small islands, islets, and rocks lying from a few hundred yards to 32 n. miles offshore. Approaches to the southwest part of the coast are channelized by the Biscoe Islands, 16 to about 50 n. miles offshore, and by numerous smaller islands, islets, and rocks in the strait between the Biscoe Islands and the mainland.

The Biscoe Islands lie in a northeast – southwest line that roughly parallels the mainland coast for a distance of approximately 85 n. miles. The islands vary in length from 2 to 25 miles and all are relatively low (maximum elevation 600 feet), featureless, and covered by ice. Rock is exposed only at the bases of some of the ice cliffs that rim most of the islands. The islands are all oriented with their lengths parallel with the axis of the island chain. On some of the islands the icecap summit is located closer to the southwestern end of the island.

Three small islands lying 1 to 4 n. miles off the portion of the mainland coast just southwest of Cape Renard restrict approach to that part of the coast to a narrow channel. The small islands are snow- and ice-covered rock masses, with an elevation of 2,100 feet recorded on the largest island. Fiords indenting two of the islands have been used as anchorages.

The mainland coast for about 100 miles southwest of Cape Renard is indented by several bays 8 to 14 n. miles long. The bays are separated by narrow strips of land, many of which terminate in high, cliff-faced promontories. A few small islands, 1 to 3 miles in diameter, lie close off some of the promontories and restrict entrance into several of the bays. Although most of these islands have bold profiles and reach elevations up to 2,500 feet, landings have been made on two of them (landing places **(18)** and **(19)**). Near the southwest end, the mainland coast is indented by Marin Darbel Bay, a broad embayment situated between Cape Bellue and Cape Rey. Most of the coast is rimmed by ice that joins with the calving ice cliffs of the valley glaciers at the bayheads; however, a landing was made at one point (landing place **(20)**). A particularly broad glacial sheet formed by several valley glaciers lines the shores of Marin Darbel Bay. Valley glaciers dissect the high plateau (elevation 6,000 feet) closely backing the entire coast. Numerous ridges extend seaward from the plateau and end in rocky promontories.

From Cape Rey to Camp Point (67°58′S., 67°19′E.) the coast is about 220 miles long. The greater part of the coast is shielded by Adelaide Island, which lies close off a broad, mountainous cape that dominates the mainland coast. Approaches are through Matha Strait and Marguerite Bay, located to the north and south respectively of Adelaide Island, and through a strait 50 n. miles long and ¾ to 19 n. miles wide that separates Adelaide Island from the mainland. Passage through Matha Strait is, in general, clear through a broad strait separating the Biscoe Islands from Adelaide Island. The strait is encumbered only by a few scattered groups of islets. Approach to the mainland from the south through Marguerite Bay is restricted by a chain of islets, rocks, and reefs that extends more than 20 n. miles south of Adelaide Island. An island approximately 5 miles in diameter and several smaller islands divide the northern part of the strait between Adelaide Island and the mainland into two channels. Four elongated islands, 3 to 7 miles long, channelize passage through the narrower part of the strait to the south. Farther south, Pourquoi Pas Island and several smaller islands channelize approaches to the extremely irregular southern part of the mainland coast. The channels are mostly clear, as much as 25 n. miles long, and ½ to 7 n. miles wide; however, they are difficult to navigate because of the strong currents that flow through the narrows and the strong local offshore winds.

Adelaide Island is approximately 78 miles long and 35 miles wide. Approaches to portions of the north, south, and east coasts of the island are encumbered by groups of islets, rocks, and shoals. A range of mountains separated into five distinct masses trends the length of the island. The steep, snow-covered mountain slopes drop off sharply to the irregular east coast of the island, while the west coast of the island is backed by a broad snow- and ice-covered terrace that spreads seaward from the base of the mountains. The shores of the west coast consist of calving ice cliffs, 100 to 140 feet high, that are notched by numerous minor indentations.

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Pourquoi Pas Island, which is 17 miles long and 15 miles wide, and the other smaller islands restricting approaches to the southern part of the Cape Rey – Camp Point stretch of coast are distinguished by the predominance of steep, bare cliffs lining their shores. Snow- and ice-capped mountains reach maximum elevations of 5,400 feet on Pourquoi Pas Island and more than 3,000 feet on the smaller islands.

A comparatively regular stretch of mainland coast about 45 miles long fronts the broad cape of land that is closely bordered by Adelaide Island. A mountain chain with a maximum elevation of over 5,500 feet extends north-south parallel to the coastline of the cape. From the mountain chain steep, snow-covered slopes and valley glaciers descend to the strait. The north coast of the cape is indented by a large fiord 22 n. miles long and 10 to 12 n. miles wide, the head of which is rimmed by several valley glaciers. The fiord is bounded on the east by steep rock cliffs and on the west by the ice cliffs of a glacial mass that descends from the mountainous interior of the cape. The south coast of the cape is backed by steep rocky slopes that flank the ice cliffs of a valley glacier extending northward across the neck of the cape to the fiord. The remainder of the mainland coast south of the cape to Camp Point is unusually free of ice and is indented by a bay and several fiords. Valley glaciers descend from the high interior plateau and fill the heads of the fiords. The walls of the fiords consist of bare rock. Landing places might be found on the raised beaches and glacial moraines at the foot of the cliffs along portions of this part of the mainland coast.

Between Camp Point and Cape Jeremy (69°24′S., 68°51′W.), a distance of about 170 miles, the coast is almost entirely bordered by ice cliffs. The dominant terrain feature, a continuation of the high interior plateau, decreases in altitude to the south and gives way to a rift valley behind the southern part of the coast. This rift provides an overland link between the east and west coasts of the Palmer Peninsula.

Approaches to this stretch of coast are through Marguerite Bay, a large body of water 130 n. miles long and 60 n. miles wide (FIGURE 22–49B). The entrance to the bay is quite broad, extending more than 60 n. miles between Adelaide Island to the north and Alexander Island to the south. The northern part of the entrance is fouled by a chain of islets, rocks, and reefs that extend more than 20 n. miles south of Adelaide Island. Navigation within the bay is restricted by scattered groups of ice-covered islets and numerous uncharted, submerged pinnacles. Marguerite Bay is generally filled with ice, even throughout most of the summer months. When most of the bay is relatively clear, navigation is still hazardous in the southern part of the bay because of the large quantity of sea ice and bergs carried there by prevailing northerly winds.

Several ice-covered islands ranging in size from tiny islets to islands 4 miles in diameter restrict approaches to the northern portion of the mainland coast. These islands lie 6 to 17 n. miles south of Camp Point and extend as far as 5 n. miles directly offshore. One of the islands, Stonington Island, has been used as a base camp for several expeditions (landing place (22)). Groups of islets, rocks, and reefs front a promontory located 20 n. miles south of Camp Point, lie as far as 8 n. miles off a cape located 48 n. miles south of Camp Point, and extend a few hundred yards to 24 n. miles northwest of Cape Jeremy.

The Camp Point – Cape Jeremy stretch of coast is indented by a fiord and several bays, the largest of which fronts most of the southern part of the coast. A landing was made on the northern part of the coast by the British expedition of 1934–1937 (landing place (21)). Most of the shore is immediately backed by the ice cliffs of piedmont glaciers. The glaciers are relatively narrow along the northern part of the coast, but widen southward to a width of 18 n. miles and fill most of the large bay that indents the southern part of the coast. Backing the coastal ice are the steep slopes of mountain peaks, ridges, bluffs, and blunt promontories between which numerous glaciers descend seaward from the high interior plateau. A fiord 7 n. miles long and 3½ n. miles wide lies 18 n. miles south of Camp Point. The fiord is flanked by the steep cliffs of the plateau to the north and a promontory to the south. At the head of the fiord is a large glacier which flows northwest from a vast interior basin. The glacier also flows southeast from the basin to the Bowman Coast on the east coast of the Palmer Peninsula. Several other glacial valleys merge in this basin and offer sledge routes between the east and west coasts of the peninsula.

Between Cape Jeremy and the western entrance of Carroll Inlet the coast is about 500 miles long and is sheltered by Alexander I Island, a large crescent-shaped land mass approximately 260 miles long and 170 miles wide. This island is separated from the mainland by a rift known as George VI Sound, which is almost entirely filled with shelf ice that renders the sound virtually impenetrable by vessels.

Approaches to most of the south and east coasts of Alexander I Island and to the bordering mainland coast are obstructed by shelf ice that is edged by ice cliffs and has an extremely irregular surface composed of pressure ridges, hummocks, rifts, and depressions. However, the northeastern part

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of George VI Sound for 25 to 35 n. miles south of Cape Jeremy and the southwestern part of the sound through Ronne Entrance are relatively free of ice. Approach to the mainland south of Ronne Entrance is restricted by several islands ranging in size from less than a mile in diameter to more than 70 miles in length. Passages that separate these islands from each other and from the mainland are almost entirely filled with extensions of the shelf ice of the sound. Approach to the west coast of Alexander I Island is encumbered by Charcot Island, which is approximately 55 miles in diameter. Passage by vessel between Charcot Island and Alexander I Island is blocked by shelf ice that almost completely fills the intervening Wilkins Strait. Groups of islets restrict approaches to the north end of Alexander I Island, and numerous rocks, reefs, and other obstacles, most of which are uncharted, make approaches hazardous to much of the remainder of the island.

Most of the mainland coast, the coast of Alexander I Island, and the coasts of the smaller offlying islands are rimmed by ice cliffs with few possible places for landing; however, a landing was made on the northern coast of Charcot Island (landing place (23)). Broad piedmont glaciers broken in places by scattered nunataks back the north and west coasts of Alexander I Island and the mainland coast south of Alexander I Island. Rising from the piedmont ice in the northern part of Alexander I Island are the steep, barren slopes of several mountain ranges, the peaks of which attain maximum elevations of over 10,000 feet. The mountain slopes lie close behind most of the north half of the east coast of the island. The coasts of the southern part of Alexander I Island and most of the mainland coast are backed by isolated mountains and groups of mountains between which broad glaciers gradually descend from the interior highlands. Charcot Island and the smaller off-lying islands are almost completely capped by snow and ice. A few mountain peaks back the north coast of Charcot Island, and scattered terrain features appear through the mantle of snow and ice on the smaller islands.

D. Coastal Sector 2: Western entrance of Carroll Inlet to Cape Colbeck, including Peter I Island

73°S., 79°W.; 77°S., 158°W.
(FIGURE 22–76; USHO Charts 6637 and 6638)

1. General

The mainland stretch of coast between Carroll Inlet and Cape Colbeck is approximately 2,200 miles long and fronted by exceedingly heavy pack ice. Aerial survey has revealed little of the coastal configuration because ice covers the coast and extends seaward. The only landings effected in Coastal Sector 2 were on Peter I Island, about 240 n. miles north of the eastern part of the coastal sector, and on Edward VII Peninsula, located at the western extremity of the coastal sector.

The South Pacific Ocean lies off the entire coast, though the Bellingshausen Sea and Amundsen Sea immediately border the east half of the coastal sector. Areas of open water are reported along the coast of the central and western portions of the coastal sector; however, passage through the pack has never been achieved. The approach of the one landing effected on the mainland coast of this coastal sector was made through the Ross Sea.

Coastal terrain behind the almost continuous ice cliffs is generally described as rugged, consisting of numerous coastal ranges and isolated mountain massifs. The Ellsworth Highland of the central and eastern part of the coastal sector lies between the coastal ranges and the interior plateau. Heights in the Ellsworth Highland reach about 12,500 feet. The coastal ranges are, in general, somewhat lower, but two coastal peaks midway along the coastal sector are reported to reach 15,000 feet.

2. Coast and landing places

Between Carroll Inlet and Cape Flying Fish the coast is approximately 500 miles long and is bordered by the Bellingshausen Sea. During the summer, pack ice probably extends about 180 n. miles from the coast, but ice conditions are difficult to forecast. It is considered likely that no open water exists along this stretch of the mainland coast during the summer as it does along many other portions of the coast.

Between Carroll Inlet and about 85°W. longitude, the coast is called the George Bryan Coast and consists entirely of ice cliffs. Behind this coastal stretch lies the highland belt called the Ellsworth Highland, which extends from the base of the Palmer Peninsula to the interior continental plateau. A mountain range dominated near its northern end by the 12,500-foot Mount Ulmer lies a considerable distance inland in the highland belt.

From 88°W. to about 100°50′W. the coast is called the Eights Coast. The coastline at the western end of this stretch of coast is not charted because of the irreconcilability of the sources. Near 97°W. longitude the coast trends northward along the Noville Peninsula, which ends in Cape Palmer. At the base of the peninsula is a 4,000-foot-high mountain and a mountain range about 3,000 feet high extending northward to the tip of the peninsula. The eastern side of the peninsula is indented by bays that are probably always filled

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with shelf ice. The two Fletcher Islands lie just off this coast.

The Thurston Peninsula, of which Noville Peninsula is an offshoot, extends northwestward and westward for about 80 miles and terminates in Cape Flying Fish.

The only landings in the area have been made on Peter I Island, located about 240 n. miles north of the mainland coast (FIGURE 22–50A). Extending about 14 miles in a north-south direction, the island is covered by snow and ice except where slopes are precipitous. The Norwegians in 1928–1929, and again in 1947–1948, and an American expedition in 1947–1948 have landed on the island (landing place (**24**)).

The greatest elevation on Peter I Island is an extinct volcano which reaches a height of about 4,000 feet. The east coast is precipitous while the west coast is lower but contains a high piedmont in its central portion. Both the northern and southern sides of the island have more gradual slopes and terminate in low ice cliffs. The cliffs, which look very much like cliffs of shelf ice, appear to be afloat in some places, but in other places a narrow shelf of bare rock is visible at the water's edge. Twin glaciers cut the northern coast. Anchorage in 21 fathoms over sand and volcanic stones is available in a bay along the island's western coast, but little shelter is afforded from the winds.

Between Cape Flying Fish and Cape Dart, approximately 410 n. miles west-southwestward, the coast is about 1,000 coastline miles in length and consists mostly of peninsulas separated by bays. The extent and shape of most of the bays are unknown. When observed from the air (1946–1947) all but one small embayment were almost completely filled with shelf ice. This stretch of coast is bordered by the Amundsen Sea.

Because of heavy pack ice in the approaches to this coast, no vessel has thus far been able to reach the continental shores. From the air long stretches of open water have been observed along the shore of the western part of the coast. Several islands lie in the approaches to the mainland; two groups of small islands are located in the southeastern part of Amundsen Sea, and three large islands lie mostly within the edge of the shelf ice in the large bays along the central part of the coast.

From Cape Flying Fish to the head of Pine Island Bay, located about 180 n. miles to the south, the coastline is highly irregular. Except for one small embayment on the south side of Canisteo Peninsula, which is about 110 n. miles south of Cape Flying Fish, the embayments in this part of the coast were mostly covered by shelf ice during 1946–47. The coast is backed by mountains about 1,800 to 3,400 feet high.

From the head of Pine Island Bay the shore trends westward for about 240 miles to the base of Martin Peninsula. Two bays separated by Bear Island and an ice tongue are features of the coastline. Bear Island, which is about 52 miles long from north to south and 32 miles wide, is enveloped on the south and west sides by the shelf ice. Martin Peninsula, about 25 to 33 n. miles west of Bear Island, projects about 90 miles northward. This part of the coast is backed by an extensive coastal mountain range about 7,000 feet high.

Between the northernmost point of Martin Peninsula and Cape Dart, about 190 n. miles westward, the coast is indented by a large and a small bay separated by a peninsula that is about 75 miles wide along its seaward edge. The large bay as charted is about 55 n. miles wide between Martin Peninsula and the broad peninsula to the west, but other dimensions and the shape of the embayment are unknown. An island about 25 miles long and 11 miles wide lies in the middle of the entrance of the bay. The extent and shape of the smaller bay is unknown though it is charted as being about 28 n. miles wide. The mainland coast from the western entrance point of this bay to Cape Dart is formed by the glaciated slopes of Mount Siple, which rises to about 10,200 feet approximately 10 to 20 miles inland. Elsewhere the terrain behind the Martin Peninsula – Cape Dart stretch of coast is largely unknown, but mountains about 5,000 feet high have been reported about 35 miles inland of the eastern part, and an unbroken ice sheet has been reported behind the western part.

Between Cape Dart and Cape Colbeck the coast trends about 750 miles southwestward and is indented by two large bays and three small bays. The large bays are mostly filled by shelf ice, and two of the small bays are almost completely filled by glaciers.

The approaches to the mainland coast between Cape Dart and Cape Colbeck are through a wide belt of heavy pack ice. Few ships have penetrated very far into the pack. A vast area of open water was observed in December 1940 to extend from the northern edge of the Getz Ice Shelf, which lies southwest of Cape Dart. Patches of water have been seen in other embayments along this part of the coast, but none of the bays have been found to be ice free.

Between Cape Dart and a point about 190 n. miles west-southwestward the coast is indented for about 120 n. miles by a large embayment known as Wrigley Gulf, which is almost completely filled by the Getz Ice Shelf. The coast of the gulf is

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composed of steep mountains that are mostly ice covered and separated in places by outlet glaciers from the polar ice sheet. From the western entrance point of Wrigley Gulf the coast known as Hobbs Coast trends west-southwestward for about 140 miles to the eastern side of Emory Land Glacier, which is about 25 miles wide. The coast continues west-southwestward for about 90 miles to the northeastern entrance point of Paul Block Bay. This stretch of coast, known as the Ruppert Coast, consists of an ice slope and many snow-covered ridges. Paul Block Bay, which is about 15 n. miles wide, extends eastward into the continent for an unknown distance. The Hobbs Coast is backed by mountains of the Hal Flood range, the highest summit of which is about 10,000 feet high. The Ruppert Coast is backed by the northern end of the Edsel Ford Ranges, a series of mountain groups about 2,500 to over 4,000 feet high. An island about 35 miles long was reported (1940) to lie about 18 n. miles north of the western part of Ruppert Coast, but its existence is doubtful.

From the western extremity of Ruppert Coast the coast trends southward for about 100 miles, westward for about 75 miles, and northwestward for about 55 miles, forming the shores of Sulzberger Bay. The bay is about 115 n. miles wide and extends southeastward about 60 n. miles. The eastern coast of Sulzberger Bay is composed of mountains dissected by large glaciers that flow into the bay from the polar ice sheet. The ice sheet reaches the southern coast of the bay through shallow valleys in the form of large glaciers. Rock walls do not clearly mark the borders of the valleys. The western coast of Sulzberger Bay, which is formed by the eastern side of Edward VII Peninsula, is covered by the ice sheet descending from mountains into the bay as widely crevassed, glacier icefalls. Most of Sulzberger Bay is covered by heavy shelf ice which makes the coast inaccessible to vessels. The largest island in the bay, Guest Island, is about 48 miles long and has a maximum elevation of about 1,200 feet near its eastern end.

Except for an 18-mile stretch of coast near the western end, the coast between the southwestern entrance point of Sulzberger Bay and Cape Colbeck, about 65 miles westward, is fronted by heavy shelf ice.

The only landing made on the Cape Dart – Cape Colbeck stretch of mainland coast was effected on the northern side of Edward VII Peninsula by members of a Japanese expedition in 1912 (landing place (25)). The approach to the coast was made from the west through the Ross Sea.

E. Coastal Sector 3: Ross Sea Area, Cape Colbeck to Cape Adare

158°W. to 170°E.; 71°S. to 86°S.
(FIGURE 22–76; USHO Chart 6636 and B.A. Chart 3177)

1. General

This coastal sector includes the coast of the Ross Sea, an extensive embayment in the South Pacific side of the Antarctic continent about 600 n. miles wide between Cape Colbeck, the northwesternmost point of Edward VII Peninsula and Cape Adare, about 625 n. miles northwestward. Most of the Ross Sea is covered by the Ross Ice Shelf which is about 450 n. miles long north – south, from the ice cliffs at its seaward edge to the escarpment of the Queen Maud Range, and is about 425 n. miles wide between the western shore of Marie Byrd Land and the easternmost point of Ross Island, the largest island in the western part of the Ross Sea.

The approaches to the shores of the Ross Sea and to the face of the Ross Ice Shelf are through a belt of pack ice which varies in nature and position from year to year, in accordance with the weather of the previous season, and which may also vary during any one season. The best approach known thus far is along, or no more than about 4 degrees eastward or westward of, the 180th meridian. Ships have approached the Ross Sea at greater distances from the 180th meridian but more time is required for passage through the pack ice in these waters and the dangers to ships are greater. Southward of the belt, the Ross Sea, except in the northeastern part around Cape Colbeck, has always been free from pack ice during the summer months of the years in which observations have been made.

Scott Island lies about 315 n. miles northeastward of Cape Adare. A few volcanic islands lie along the western side of the Ross Sea. A few other islands lie in the shelf ice near the east and west sides of the embayment.

2. Coast and landing places

The shoreline of the Ross Sea from Cape Colbeck, the eastern entrance point, around the head of the embayment to Cape Adare is about 1,900 miles, exclusive of indentations. The eastern shore of the embayment is backed by the ice-covered polar plateau, broken in a few places on Edward VII Peninsula by small peaks of the Rockefeller Mountains. The other shores are backed mostly by high, glaciated mountain peaks and ridges.

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From Cape Colbeck to Ross Island, along the seaward edge of Ross Ice Shelf, is about 455 n. miles. The western shore of Edward VII Peninsula, for about 35 miles between Cape Colbeck and the eastern edge of the Ross Ice Shelf, is an inaccessible ice cliff about 125 to 200 feet high. From this point ice cliffs about 180 feet high form the seaward edge of the Ross Ice Shelf and extend westward to Ross Island with only two known indentations. Two other indentations which have previously existed and have been used as landing places or as shelter, no longer exist (1955).

One of the existing indentations, Okuma Bay, about 50 miles south of Cape Colbeck, is about 3 miles wide and indents the shelf ice for about 4 miles near the point where the shelf ice is in contact with the shores of Marie Byrd Land. Although a landing was reported to have been made by a Japanese expedition in 1912 (landing place (**26**)), the bay is reported to ordinarily be clear of ice early in the spring, leaving high cliffs which afford no landing places. When observed in January 1955, the bay was considered unsuitable for a landing site not only because of the high cliffs but also because of the heavy pressure of the bay ice inside. Vast pressure ridges extend southeastward into the shelf ice from the head of Okuma Bay.

Kainan Bay, about 50 miles west of Okuma Bay, is about 2⅞ miles wide (1955) and recedes about 2 miles into the shelf ice (FIGURES 22–50B through 22–51B). The bay is bounded by the shelf ice which forms cliffs about 35 to 80 feet high around the bay and rises to about 150 feet 2 miles inland. The southern part of the Kainan Bay is bounded by an area of pressure ridges which rise about 15 to 25 feet above the sea. The pressure area extends about 1 to 2 miles back from the bay with a long prong extending to the southwest and a crescent-shaped arm curving to the east. The pressure area has a seaward face of low escarpments about 10 to 30 feet high, behind which a series of isolated knobs and ridges, interspersed with crevasses, rise above a fairly level snow plain. This plain is depressed about 25 to 50 feet below the general level of the surrounding shelf ice. A Japanese Expedition landed in Kainan Bay in 1912 and the U.S.S. *Atka* moored to the fast ice, which was about 8 to 10 feet thick, in the bay (landing place (**27**)) 21 January 1955. Access to the shelf ice from Kainan Bay was over snow ramps in the southeastern and southwestern corners of the bay in 1955, and also several landings were made on the shelf ice by helicopter from the U.S.S. *Atka* while the ship was moored to the bay ice.

The Bay of Whales area, headquarters site of several Antarctic expeditions, about 32 miles southwestward of Kainan Bay has been known, in one form or another, for more than 100 years (FIGURES 22–52A and 22–52B). Since discovery by James C. Ross in 1842 the width of the entrance to the embayment has varied from about 10 miles to as little as 200 feet (1946–47) and the length, from about 10 to 15 miles. Movement of a considerable amount of ice from the Bay of Whales area has left ice cliffs about 20 to 100 feet high exposed to the open sea and the bay, as it now exists, cannot be used as shelter (1955). The area is formed at the junction of two separate shelf ice systems, the southern shores of which appear to be aground; the ice system which forms the eastern shores moves westward and the system which forms western shores moves northward. Several landings have been made in the Bay of Whales area, from the sea, and from the air (landing place (**28**)).

Discovery Inlet, which was a deep inlet in the shelf ice about 75 miles west of the Bay of Whales area, has been destroyed by extensive calving of the Ross Ice Shelf (1955); however, the disappearance may not be permanent. The U.S.S. *Bear of Oakland* moored to the ice at the head of the inlet in 1935 (landing place (**29**)). The Ross Ice Shelf continues westward (FIGURE 22–53A) to the coast of Victoria Land at McMurdo Sound.

Three snow-covered islands are known in the eastern portion of the Ross Ice Shelf. Roosevelt Island, about 103 miles long in a north – south direction, 40 miles wide, and approximately 1,200 feet high, lies in the shelf ice an undetermined distance behind the Bay of Whales area. Another island which lies about 34 miles westward of Roosevelt Island is about 23 miles long, in a general east – west direction, and about 17 miles wide. About 52 miles southeastward of Roosevelt Island lies another snow-covered island which is about 57 miles long, in a northeast – southwest direction, and is about 40 miles wide. This island lies in the entrance to a large ice-filled embayment which extends eastward into the continental plateau.

The part of the continental land mass which borders the eastern side of the Ross Ice Shelf, about 500 miles long, has been seen from the air, but very little of it has been explored and it is largely unknown. The shore is entirely covered by the continental ice which appears to move off the continental land mass into the eastern side of the Ross Ice Shelf.

That part of the land mass along the southern, southwestern, and western sides of the Ross Ice Shelf and the Ross Sea is much better known, as most of it has been seen from the Ross Sea or from the shelf ice, and some areas have been explored. In general, this part of the shore, where known, is bordered by high mountain ranges which stand up mostly as high rock or ice cliffs, except where broken by a few embayments, or cut down

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by valley glaciers originating on the seaward side of the structure and by many outlet glaciers from the great ice sheet which covers the vast south polar plateau. The mountains rise to elevations of over 3,000 to about 15,000 feet and stands up in places as much as about 9,000 feet above the ice sheet which covers the polar plateau.

Several of the glaciers which flow into the Ross Ice Shelf and into the Ross Sea have been named and described. The southeasternmost is imperfectly defined on its eastern and northern margins. This glacier, although of comparatively low gradient, appears to bring a large volume of ice from the plateau to the shelf ice. The next four outlet glaciers to the northwest which flow into the southern end of the Ross Ice Shelf form a continuous piedmont for about 132 to 138 miles along the shore. The piedmont, deflected northwestward by outflow from the southeasternmost glacier and the ice sheet northward of it, produces extensive folds and other disturbances in the ice sheet between the other glaciers, which may extend some distance into the shelf ice in front of the piedmont. This stretch of the shore consists of outlet glaciers flanked by steep sided remnants of the foothills of the Queen Maud Range, in turn backed by the high tabular mountains of the same range some of which rise to more than 13,000 feet about 15 miles inland. One of the glaciers, the Axel Heiberg Glacier, was traversed by Amundsen during the south polar expedition of 1911.

For about 155 miles west-northwest to Beardmore Glacier, the shore line is indefinite and in part unknown, but most of it is probably bordered by steep mountains and cliffs. One peak rises to approximately 15,000 feet, about 12 miles inland.

From the Beardmore Glacier, the coast trends northwestward for about 190 miles, then north about 160 miles, then turns northeastward for about 115 miles to the edge of the ice shelf at the head of McMurdo Sound, an indentation about 45 n. miles long and 40 n. miles wide between Ross Island and the mainland. Five glaciers are shown on charts of this part of the coast but only two are named and of nine charted inlets which indent the coast, only five are named.

Beardmore Glacier, the largest and probably best known has an average width of about 12 miles, is about 100 miles long, and rises from about 200 feet above sea level at the shelf ice surface to more than 7,000 feet where it merges with the plateau ice sheet near the 85th parallel. Mountains over 5,000 to more than 10,000 feet high flank the Beardmore Glacier. On the western side, the rounded peaks of the Queen Alexandra Range are separated by a series of deep valleys cut by glaciers tributary to the Beardmore Glacier. The mountain range bordering the eastern side is rugged but not as high and has only two charted tributary glaciers. The largest tributary is on the eastern side of the upper Beardmore Glacier. It is about 15 miles wide and is flanked on the southern side by the Dominion Range which trends southeastward as a rugged row of peaks over 10,000 feet high. Although the surface of Beardmore Glacier is broken by crevasses and extensive icefalls, it has been traversed by two exploring parties. The glacier was discovered by Sir Ernest Shackleton and traversed by his exploring party in December 1908 in an attempt to reach the south pole, then later, by members of the south polar expedition of Robert F. Scott in 1911. The shelf ice in front of the glacier is corrugated by broad undulations for about 20 miles northward. Koettlitz Glacier lies about 400 n. miles north-northeastward of Beardmore Glacier. This glacier is not as well known as Beardmore Glacier but has been traversed twice by exploring parties, the Robert F. Scott Expedition, 1901–1904 and by members of the British Antarctic Expedition, 1910–1913.

On the east side of Koettlitz Glacier are two mountains connected by a saddle over 2,000 feet high. The highest and easternmost of the mountains, an inactive volcano, is the most conspicuous summit at the head of McMurdo Sound. A long narrow peninsula, about 25 miles long and 5 miles wide, projects southeastward from the slopes of this mountain into the Ross Ice Shelf. Three small islands lie in the ice shelf northward of this peninsula and a number of islets lie farther north in the edge of the shelf ice near the head of McMurdo Sound. The northwest edge of the Koettlitz Glacier flows along the glacierized foothills of a high mountain range which backs the part of the coast from the head of the glacier to the latitude of the head of McMurdo Sound.

Ross Island, bordering the east side of McMurdo Sound, is about 53 miles long east – west and about 50 miles wide north – south. Four volcanos, one of which is active, dominate the terrain of Ross Island. The highest peak, about 13,350 feet, is the active volcano Mt. Erebus, near the western side, and the lowest is Mt. Bird, about 5,640 feet high, near the northern end of the island. A large geyser about 3 miles south of Mt. Bird was active in 1908. The shores are mostly steep but are accessible in a few known places.

Landings by members of two British expeditions, Carsters E. Borchgrevink in 1900 and Robert F. Scott in 1902, were made near the eastern tip of the island (landing place **(30)**). Landings were made and Antarctic expedition headquarters established at Cape Royds (landing place **(33)**); Cape Evans (landing place **(32)**) (FIGURE 22–53B), about 6 miles south of Cape Royds; and at Hut Point on

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Cape Armitage (landing place (**31**)). Many landings were made on Cape Armitage while H.M.S. *Discovery* was frozen in the ice for two winters during 1902–4. Ernest H. Shackleton established a base on Cape Royds in 1908 and occupied another at Cape Evans in 1914–16 which had been established by Robert F. Scott in 1911–12. Cape Armitage has access to the Ross Ice Shelf and hence the mainland, but the mainland is not accessible throughout the year from Cape Royds and Cape Evans because the routes are subject to condition of the bay ice (FIGURE 22–54A). A landing was made on the southwestern side of Beaufort Island, a volcanic island about 1½ miles in diameter approximately 11 n. miles northward of Ross Island. The landing, which was unofficial, was made in 1903 by a sailor from the vessel *Morning* (landing place (**35**)).

From McMurdo Sound, the head of navigation along the western coast of the Ross Sea, to Terra Nova Bay the coast trends generally northward for about 180 miles. Part of the western shore of McMurdo Sound, from the shelf ice which forms its head to a point about 30 n. miles north-northwestward, is broken by glaciers, inlets, and high rocky promontories. The rest of the western shore of the sound for about 15 n. miles to the western entrance point is formed by part of an extensive ice piedmont. Several glaciers flow into the western side of McMurdo Sound. A bay immediately westward of McMurdo Sound indents the coast for about 6 n. miles. Landings have been made at two places along this part of the coast; on Butter Point (landing place (**36**)) near the foot of Ferrar Glacier, and at Cape Bernacchi (landing place (**37**)). Ferrar Glacier was first traversed from McMurdo Sound to the polar plateau by Scott's expedition in 1901–04, and members of Shackleton's expedition landed on Cape Bernacchi in 1908. This part of the coast has been examined several times by British expeditions based at Ross Island and reconnaissance surveys have been made of most of the area. The shore of McMurdo Sound from near Cape Bernacchi northward for about 15 miles to the western entrance is formed by an ice piedmont which is about 6 to 14 miles wide. The seaward edge of the piedmont is an ice cliff about 5 to 80 feet high. The surface is rough and pitted; near the seaward edge it is furrowed by ravines apparently caused by melt water. The piedmont continues northward from the western entrance of the sound for about 34 miles.

From here the coast continues its northward trend about 103 miles to the foot of the Drygalski Ice Tongue, a large ice tongue which projects about 30 n. miles eastward into the Ross Sea immediately south of Terra Nova Bay. Granite Harbor, a large embayment, indents the coast about 28 miles north of the western entrance of McMurdo Sound. A small ice tongue projects into the head of this bay. This bay has been visited by ships and a landing was made on the shore near a bluff on the southern side of the bay about 8 miles inside the southern entrance point (landing place (**38**)). Most of the shore, from the northern entrance point of this embayment to the foot of the Drygalski Ice Tongue, rises in cliffs which are heavily glacierized. Several of the glaciers end in long ice tongues extending as much as about 5 miles eastward from this shore into the Ross Sea. This part of coast is backed by mountains from about 3,000 feet to over 8,000 feet high.

Franklin Island (FIGURE 22–54B), about 14 miles long north – south and about 7 miles wide, lies about 60 n. miles southeast of the tip of the Drygalski Ice Tongue and about 60 n. miles northward of Ross Island. The shores are mostly rock cliffs about 500 feet high except on the western side where ice cliffs about 30 to 100 feet high form the shore. Landings were made on the island in 1841 by Sir James Ross, and in 1900 by Carsters E. Borchgrevink (landing place (**34**)).

The shores of Terra Nova Bay from the southern entrance point to the head of the bay are formed by ice cliffs, about 50 to 100 feet high, at the seaward edge of the Drygalski Ice Tongue. Except for about 17 miles of low shores near the head of the bay, the remaining shores to the northward are formed by ice cliffs 50 to 150 feet high through which, in places, dark rocks project. A small island, which forms the western side of a cove about 2½ miles wide, lies in the ice tongue near the head of Terra Nova Bay. Landings have been made on the northeastern side of the small island (landing place (**39**)) and the British Antarctic Expedition of 1910–13 established a food depot near the landing place. Two other small islands lie close offshore about 25 n. miles west-southwestward of Cape Washington. Pack ice drifting out of the western side of the Ross Sea is deflected by the ice tongue south of Terra Nova Bay and consequently, in most years, during the summer Terra Nova Bay may ordinarily be free of drifting pack ice. This part of the shore is backed by mountains about 3,000 to more than 9,000 feet high.

From Cape Washington, the northern entrance point of Terra Nova Bay, to Cape Adare the coast trends irregularly northward. Wood Bay indents the coast northward of Terra Nova Bay for about 20 n. miles. The southern shore of the bay is mostly ice cliffs, which are the seaward edge of the ice slopes of a conspicuous, extinct volcano over 8,000 feet high. A large pebble beach forms the shore of a small cove at the head of the bay, and the northern shore is formed by rock cliffs and deep valley glaciers. The bay may be naviga-

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ble, depending on the condition of the pack ice and on swell which enters the bay from the southeast. Most of the south side of Wood Bay is backed by the slopes of Mt. Melbourne, and the other sides are backed by mountain peaks and ridges between which glaciers flow from the high interior plateau. A landing was made near the head of Wood Bay in 1900 by members of Borchgrevink's Expedition (landing place (**40**)).

Northward of Wood Bay is a large indentation which extends about 50 n. miles westward into the coast. The shores of the embayment are backed by high mountains up to about 4,000 feet high. Except for a small inlet in the northeastern part, the embayment is completely filled by an ice shelf. The shelf ice probably varies in shape and size from year to year but the dimensions are now about 58 n. miles long north – south by 50 n. miles wide and the seaward edge is about 20 to 150 feet high. A group of small islands lie in the shelf ice near its southern end. Coulman Island, about 18 n. miles long and 9 miles wide, lies to the east of the ice shelf. The island, flat on top, rises near the northern end to a low dome about 2,000 feet high. It is completely snow-covered except at the shore which is formed by cliffs about 500 to 1,500 feet high. A channel separates Coulman Island from the eastern edge of the shelf ice but this channel has not been explored by ships. Pack ice which breaks out of bays and inlets farther south drifts northward along the face of the shelf ice and becomes congested near Coulman Island, which may in some years, keep the area ice-filled until February. An inlet which extends into the northern end of the shelf ice for about 16 n. miles is accessible to ships.

Landings have been made on the ice inside the inlet (landing place (**41**)) in the shelf ice and on some rocks at the base of the cliffs at the north end of Coulman Island (landing place (**42**)).

The shore along the coast from landing place **41** northward to Cape Adare rises in steep rocky bluffs and cliffs broken in places by ice slopes which extend down to the sea from the icecap, and is backed by the high mountains of Victoria Land.

Possession Islands, a group of 9 volcanic islands and islets, lie about 1 n. mile to 3 n. miles offshore. The islands range in size from about 3 miles long to mere pillars of rock with vertical walls as much as 300 feet high. The northwestern island, about 3 miles across and the largest of the group, is low and bare except for a small peak about 300 feet high at the southeastern extremity. The other islands are rocky and most of the shores are formed by cliffs. The channel between the islands and the mainland has been passed by several ships and is believed to be free of dangers, however, heavy pack ice may block this channel.

Landings were made by Ross in 1841, by Kristensen in 1894, by Borchgrevink in 1899 and by Colbeck in 1903, on a long stony beach on the southwestern side of the largest island in the group (landing place (**44**)).

Scott Island, lying about 315 n. miles northeastward of Cape Adare, is a rocky ice-covered islet about 500 yards long in a north – south direction and about 250 yards wide. The sides are mostly cliffs, high on the north end and sloping gradually to the southern end where they are about 6 feet high. A landing was made in 1902 on the southeastern side of Scott Island by members of the British Colbeck Relief Expedition (landing place (**43**)).

F. Coastal Sector 4: Cape Adare to Cape Adams

71°S., 170°E.; 75°S., 62°W.
(FIGURE 22–76; USHO Charts 6636, 6640, 6641, and 16321–9; B.A. Charts 3171 and 3172)

1. General

Coastal Sector 4 is composed of the Antarctic coast lying west of the Ross Sea and east of the Palmer Peninsula. Cape Adare is the eastern limit of the sector and Cape Adams is the western limit. The Indian Ocean and the South Atlantic Ocean border the coast of the sector, which measures about 5,990 miles in length.

The approaches to most coasts of the sector are obstructed by a broad belt of pack ice that in places lies as far as about 1,000 n. miles offshore. The difficulty in transiting the belt of pack ice is usually least in January and February, and least along certain meridians such as the Greenwich meridian, and between about 70° and 90°E. Between the belt of pack ice and the mainland, broad areas of navigable water usually prevail. A strip of land ice, fringed by sea ice, immediately borders most shores, making the depths in the water adjacent to the ice relatively great. In those areas where vessels may approach ice-free parts of the mainland, or close-lying ice-free islands, the chief navigational danger is the possibility of running aground on uncharted rocks and pinnacles, which seem to abound in such areas. Near most of the ice-free areas the depths and bottom contours are usually quite erratic.

The Balleny Islands lying about 150 n. miles offshore near the east end of the sector, and several scattered islands off the Queen Mary Coast in the vicinity of 90° to 105°E., are the main larger islands in the sector. Many widely spaced groups of small islands, however, border the coast. The small islands, where bordered by a relatively narrow width of sea ice, often constitute the most accessible land. In places such as the Vestfold

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Hills along the east coast of Prydz Bay (about 77°E.), ice-free hills separated by inlets usually afford landing places. Similar areas that are usually ice free lie along the east coast of Vincennes Bay (110°E.), close east of Denman Glacier (100°E.), and southeast of Stefansson Bay (59°E.), but the approaches to these areas are at times obstructed by ice. Except for these ice-free areas, and the ice-free headlands and outcrops along the coast, nearly all coastal terrain is covered by continental ice. In many places in the interior, however, ice-free mountain peaks penetrate the continental ice.

In Coastal Sector 4 a small number of landings have been made at rather widely spaced places. In general these landings are grouped in the vicinity of 140°E., and between 50° and 110°E. The chief factor governing the location of landing sites is the navigability of the adjacent seas, as controlled by the character or absence of ice.

2. Coast and landing places

Between Cape Adare and Cape North, about 100 n. miles to the northwest of Cape Adare, the coast is composed of steep rocky cliffs and headlands separated by glaciers with cliffed faces. This stretch of coast is usually inaccessible to vessels because of the belt of drift ice and icebergs that usually borders the shore. A bay and several fjord-like inlets indent the shore.

The largest and easternmost bay, Robertson Bay, opens about 20 n. miles and is indented about 24 n. miles to the southeast. About one-half mile south of Cape Adare a triangular spit about 1 mile in extent provides the only landing place in the bay. This landing place (landing place (45)) was used by Kristensen and Bull in 1894–95, by Borchgrevink in 1899, and by the northern party of the Scott expedition in 1912. The remaining shores of Robertson Bay are composed largely of steep cliffs and headlands separating glaciers and glacier tongues. Anchorage may be taken almost any place on the east shore of the bay where the holding ground is good. There is a paucity of soundings in the bay, but the large number of grounded bergs observed indicates comparatively shallow water near the eastern shore. Because of ice carried into the bay by strong currents and frequent gales, vessels should keep engines in readiness at all times.

Between Robertson Bay and Smith Inlet, about 45 miles to the northwest of Robertson Bay, the coast consists of steep rocky cliffs and headlands and the cliffed margins of glaciers. Smith Inlet, which appears to be a fjord, is about 8 n. miles wide and recedes inland a considerable distance. Yule Bay, about 6 n. miles wide and indented a similar distance, lies about 19 miles northwest of Smith Inlet. Cape North, a vertical snow-covered cliff over 200 feet high, is about 22 miles westward of Yule Bay. The entire stretch of coast is backed by the mountains of the Admiralty Range.

The Balleny Islands lie about 150 n. miles off Antarctica between 162° and 165°E. longitude. The sea between the islands and the mainland is frequently covered by heavy, impenetrable pack ice. The islands, volcanic in origin, consist of three large and two small islands which extend northwest and southeast for about 100 n. miles. The islands are heavily glaciated with ice tongues projecting into the sea, and the shores are mostly steep with rock or ice cliffs.

Sturge Island, the largest and southeasternmost of the Balleny Islands, is about 32 miles long and 10 miles wide. Most of the shore is formed by rocky cliffs and broad ice tongues.

Buckle Island, about 15 miles long in a general north – south direction and 3 miles wide, lies approximately 30 n. miles northwest of Sturge Island. The island is composed of a gently sloping plateau about 3,000 feet high, ending at the shore in steep rock or ice cliffs. Several rocks and islets, the largest of which is Sabrina Islet, lie about 2 n. miles off the southern extremity of Burke Island.

Young Island, the northeastern island of the group, is about 24 miles long and 6 miles wide. The island terrain slopes gently seaward from a plateau about 3,250 feet high. The northern and southern ends of the island are steep rocky bluffs, and the western side is steep and crevassed, but low. Rocks about 50 feet high lie off the northern end of the island, with foul ground extending for a distance of about 2 n. miles seaward. Two small islands lie off the southern end of Young Island. The largest, Borradaile Island, about 2½ miles long and 1 mile wide, is ice-capped, about 1,250 feet high, and the shores are composed mostly of rock cliffs.

An Australian expedition led by Stuart Campbell landed on Borradaile Island in 1948 (landing place (47)). Another landing was made on Borradaile Island in 1839 by Captain Freeman of the cutter *Sabrina,* which accompanied Captain Bellany's schooner *Eliza Scott* to the area. Members of a French expedition in 1949 landed on Sabrina Islet (landing place (46)).

From Cape North to Cape Freshfield, the coast trends in a west-northwesterly direction a distance of about 390 miles. This part of the coast, and some of the polar plateau behind it, has been seen from the air, a few areas have been observed from the sea, but none have been explored. Lillie Glacier Tongue projects northward for about 20 n. miles between Cape Williams, about 60 n. miles west-northwest of Cape North, and Cape Cheet-

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ham, about 22 n. miles farther westward. The coast between Cape Cheetham and Cape Kinsey, about 110 miles northwestward, has not been observed from the sea. The coast between Cape Kinsey and Archer Point, about 20 miles west-northwest, is rugged and the shore is made up mostly of steep rocky points separated by glaciers and backed by high hills. Between Archer Point and Cape Freshfield, about 160 miles west-northwestward of Archer Point, the only part of the coast that has been observed from the sea is a 50-mile stretch of the shores of Joseph Cook Bay.

Between Cape Freshfield and the east edge of Ninnis Glacier about 90 miles to the west (148°E.), the coast is composed of hilly to mountainous terrain, most of which is covered by snow and ice. A bluff about 28 n. miles west of Cape Freshfield rises almost vertically for about 1,000 feet, capped by about 200 feet of snow. The bluff is composed of columns of red rock overlying horizontal strata that crops out near the top of the 300-foot-high slopes of rock debris that conceal the base of the bluff. About 10 miles west of Cape Wild, which lies about midway along this stretch of coast, cliffs of columnar rock lie along the coast and continue southwestward for an additional 10 miles. In several places between the areas of columnar rock cliffs, small embayments deeply indent the coast. At the west end of this stretch of coast Buckley Bay is enclosed on the west by Ninnis Glacier, which extends almost 80 n. miles seaward as a glacier ice tongue. Most of this stretch of coast was surveyed in 1912–13 by a sledge party from the Australasian Antarctic Expedition based in Commonwealth Bay to the west.

Ninnis Glacier and Mertz Glacier enclose a large bay that was entered in 1840 by Wilkes' ship, the *Vincennes*. Measured along the coastal trend the bay is about 55 miles wide, and including the glaciers the coast measures about 120 miles in length (to 144°30′E.). Most of the coast of the bay consists of ice cliffs, behind which rise ice-covered slopes that reach elevations of about 3,000 feet about 20 to 25 miles inland. For about 5 miles along the coast of the west half of the bay, a rock outcrop about 300 feet high underlies the icecap. Both Ninnis Glacier to the east and Mertz Glacier to the west have heavily fissured surfaces, and both terminate in glacier tongues facing the sea with ice cliffs standing 100 to 180 feet high. Mertz Glacier, which extends about 50 n. miles seaward, descends from the high interior plateau through a steep-walled valley.

West of Mertz Glacier to Point Alden, about 75 miles to the west-northwest (142°E.), the coast consists of three embayments separated by capes bordered by reefs and islets. The two capes are bordered by ice cliffs, but at the head of the middle embayment the elevation of the shore decreases almost to sea level and a valley extends inland. The western embayment, Commonwealth Bay, contains a number of islets and reefs, and in most places is bordered by ice cliffs 60 to 150 feet high. During the summer months the strong southerly winds usually keep the bay clear of pack ice. A cape at the head of the bay, which was the site of the main base of the Australasian Antarctic Expedition (1911–14) of Sir Douglas Mawson, rises about 40 feet above sea level (landing place **(48)**). Near the cape, a landing was made in a small cove that was about 300 yards wide and 1,000 yards long, with depths of about 15 feet. The cape was again landed upon in 1931 by Mawson's British-Australian-New Zealand Antarctic Research Expedition, and again in 1950 when the French Antarctic Expedition laid a depot there. About 8 miles west of the cape, another rocky cape rises about 80 feet above the sea and is off-lain by reefs and an islet. About 10 miles northwest of the second cape, Point Alden marks the western entrance point to Commonwealth Bay. The boundary between George V Coast on the east and Adélie Coast on the west lies near Point Alden.

From Point Alden to Cape Robert (138°E.), the slightly irregular coast measures about 125 miles in length. This stretch of coast was viewed by Wilkes in 1840, and landed upon by D'Urville. The latter expedition sighted a cape about 12 miles west of Point Alden, but was unable to land because of pack ice. The expedition successfully landed men among the islands near Astrolabe Glacier, however, which lies above 70 miles west of Point Alden (landing place **(51)**). About 17 miles west of Point Alden, the French Antarctic Expedition in 1950 landed and made their base camp (landing place **(49)**). The expedition also laid a depot on the coast a short distance east of Cape Bienvenue between Point Alden and Astrolabe Glacier (landing place **(50)**).

Between Point Alden and Cape Robert the coast is bordered by groups of small islands that serve as rookeries for Antarctic birds. Access to the mainland in most places is obstructed by ice cliffs that are breached in places by glaciers that extend 2 to 5 n. miles seaward. Back of the ice cliffs the inland ice rises toward the interior and reaches elevations of about 2,500 feet about 15 to 18 miles inland.

From Cape Robert to Cape Folger, the coast extends westward about 785 miles. From the vicinity of Cape Robert, westward about 195 miles to Cape Mose (130°E.), the coast is usually bordered by pack ice extending as much as 60 to 80 n. miles offshore. The ice commonly contains icebergs which may drift into the pack on the prevailing ocean currents. This stretch of coast, most of which lies

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within the limits of the Clarie Coast, has been described as being composed of high, snow-covered hills.

The Banzare Coast, named after the British-Australian-New Zealand Antarctic Research Expedition of 1929–31, extends west from Cape Mose to 122°E. and measures about 170 miles in length. Porpoise Bay, which indents the coast between Cape Mose and Cape Goodenough (126°E.), was named after one of the vessels of the Wilkes expedition of 1840. The bay, whose limits are not defined, is about 85 n. miles wide and recedes southward about 50 n. miles. From the Banzare Coast, west to Cape Folger (110°30′E.), the coast measures about 335 miles in length. This stretch of coast includes the Sabrina Coast (approximately 116° to 122°E.) and, at the western extremity, the Budd Coast (approximately 110° to 116°E.). In the past, access to most of this coast has been denied by a wide area of pack ice containing imprisoned icebergs. In 1840 when Wilkes' ship lay 35 to 40 n. miles offshore, he reported the Budd Coast as composed of a lofty, snow-covered mountain range trending nearly east and west, and showing many ridges and indentations.

From Cape Folger to Cape Elliott, the coast extends generally westward about 246 miles. Vincennes Bay lies immediately west of Cape Folger. The bay is about 66 n. miles wide between the eastern entrance point, Cape Folger, and the western entrance point, Cape Nutt (108°20′E.), and is indented about 30 n. miles. A group of islands lies in the eastern part of the bay near Cape Folger (FIGURE 22–54C) and another group in the western part of the bay near Cape Nutt. In 1948 a party from U.S. Navy Task Force 39 landed by boat on the islands in the east part of the bay (landing place (52)). Their ship reported depths of 45 fathoms 800 yards offshore, and depths of 800 fathoms about 1 n. mile offshore. Several glaciers discharge along the head and east coast of Vincennes Bay.

From Cape Nutt, the western entrance point to Vincennes Bay, the coast trends west-northwest to Cape Elliott (103°E.), a distance of about 170 miles. All of this coast is part of the Knox Coast, which was viewed by Wilkes in February 1840. Wilkes described the coast as high, rounded in form, and terminating in vertical ice cliffs. Bowman Island, covered by ice and about 17 miles long, lies about 30 n. miles northeast of Cape Elliott. Pack ice usually extends 40 to 60 n. miles off this coast and to the westward merges with Denman Glacier and the Shackleton Ice Shelf. In 1948 a party from the U.S. Navy Task Force 39 made a helicopter landing on a small islet lying close offshore about 37 miles west-northwest of Cape Nutt (landing place (53)).

From Cape Elliott, west-southwest about 200 miles to Farr Bay (95°E.), the coast is continuously fronted by ice that at times extends 200 n. miles seaward. All except the eastern part of this stretch of coast is bordered by the Shackleton Ice Shelf which might extend as much as 120 n. miles out to sea. The shelf ice, which encompasses many islands, extends westward from Denman Glacier which lies about 90 miles from Cape Elliott. Denman Glacier is the largest of the many glaciers along this stretch of coast. The glacier usually terminates at sea in ice tongues that at times reach as much as 45 n. miles seaward. Flanking Denman Glacier about 25 to 50 miles inland are mountain peaks at elevations of approximately 4,000 feet. The coast between Cape Elliott and Denman Glacier was landed upon by helicopter in 1948 by men of the U.S. Navy Task Force 39 (landing place (54)). Most of the area landed upon was composed of hills with a maximum of 400 feet of relief, and covered by glacial material (FIGURE 22–55A). Nearly all ponds and inlets in the area were found to contain salt water. The coast west of Denman Glacier was explored in 1912–13 by men of Mawson's Australasian Antarctic Expedition. The base for this group of men was located on the Shackleton Ice Shelf near Farr Bay (landing place (57)). Parties from the U.S. Navy Task Force 39 in 1948 landed by boat on islets near the Shackleton Ice Shelf (landing place (56)), and by helicopter on islets protruding through the shelf ice (landing place (55)). All except the eastern extremity of this entire stretch of coast is part of the Queen Mary Coast (92° to 100°E.).

From the east edge of Farr Bay, west about 215 miles to Cape Penck (about 88°E.), most of the coast is bordered throughout the year by at least a narrow belt of sea ice. At the west end of the coast, however, Cape Penck is encircled by the West Ice Shelf which in that immediate vicinity extends about 40 n. miles offshore. The coast between Farr Bay and Cape Penck is bordered by the Davis Sea which is usually navigable during the Antarctic summer. The approaches to the sea, however, are often encumbered by pack ice, especially off the Shackleton Ice Shelf, but ships usually are able to reach the Davis Sea by approaching from the north along the 90° meridian.

Drygalski Island lies about 45 n. miles off the mid-portion of this coast. The island is about 9 miles in diameter and rises to an elevation of about 1,200 feet, but is completely covered by ice and is encircled by sheer ice cliffs. Depths of 65 to 100 fathoms have been found close off the island. A small number of islands and islets lie close off the mainland.

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A landmark along the coast is Gaussberg, an extinct volcano that rises to an elevation of about 1,148 feet about 48 miles east of Cape Penck. The mountain, pyramidal in shape and in places bare of snow and ice, stands close back of the shore. A landing by Drygalski's German Antarctic Expedition of 1901–3 was made near Gaussberg (landing place (**62**)), though their ship, the *Gauss,* wintered in the ice about 50 n. miles offshore. In 1948 parties from the U.S. Navy Task Force 39 landed at four places along the coast between Farr Bay and Gaussberg (landing places (**58**) through (**61**)). Two of the landings, made to points above the ice cliffs, were accomplished by helicopter; one landing on sea ice near the coast was accomplished by helicopter; and one landing on an island was accomplished by traversing the sea ice in a "Weasel."

Between Cape Penck and Cape Darnley (69°30′E.), about 450 n. miles to the west-southwest, the coast is indented about 190 n. miles by a broad embayment. Several stretches of the embayment coast are free of the usual cover of continental ice and have been landed upon by several expeditions. The waters close off the coast are often free of critical pack ice, though about 100 to 300 n. miles from shore the ice conditions are commonly much worse. A reef of doubtful existence has been charted about 105 n. miles northeast of Cape Darnley. For a distance of about 50 n. miles northeast of the cape, icebergs often become stranded and cause congestion of the ice pack.

The West Ice Shelf, which in most places ranges from about 10 to 20 n. miles in width, borders the coast for about 230 miles southwest from Cape Penck. This stretch of coast constitutes the Leopold and Astrid Coast. The remainder of the southeastern coast of the broad embayment measures about 490 miles in length and is called the Ingrid Christensen Coast. Prydz Bay lies off the Ingrid Christensen Coast, between it and the Amery Ice Shelf. The southwestern coast of the broad embayment, most of which is fronted by the Amery Ice Shelf, is called the Lars Christensen Coast. MacKenzie Bay lies to the northwest between the Amery Ice Shelf and the northern part of the Lars Christensen Coast.

From the southwestern extremity of the West Ice Shelf, west-southwest about 93 miles to the Vestfold Hills, the coast is covered by continental ice that at sea terminates in ice cliffs. The continental ice is heavily crevassed near the ice front, but is essentially featureless toward the interior. From the ice cliffs the rate of ascent toward the interior is at first comparatively rapid (about 5 feet per 100 feet), but shortly levels off to an imperceptible rise toward the interior ice plateau.

Southwestward of the ice cliffs the ice-free Vestfold Hills stretch about 28 miles along the coast, and extend inland a maximum of about 14 miles. The hill area is fronted by scattered islands and perhaps by scattered reefs, and is intruded by inlets and fjords (FIGURE 22–55B). The hills, which rise to maximum elevations of about 425 feet, are steep-sided on most lower slopes. The hills are composed of bedrock intruded by dikes, and in a few places are lightly covered by morainal material. The hills reach their highest elevations near the center of the group, but toward the interior the elevations decrease. Along the inner margin of the hills the edge of the continental ice near sea level rises in ice cliffs, but on the hillsides gradually thins to a low, morainal ridge. Back of the hills the continental ice gradually rises to the high interior plateau the same as the continental ice to the northeast. The Vestfold Hills area was landed upon in 1935 by Captain Mikkelsen of the Norwegian Lars Christensen expedition, and in 1939 by men of Ellsworth's expedition (landing place (**63**)).

Southwestward from the Vestfold Hills to the head of Prydz Bay, a distance of about 140 miles, the coast is bordered by glacier ice tongues separated in places by ice-free hills and in places is offlain by groups of ice-free islands. The glacier tongues range in width from about 9 miles in the Sørsdal Glacier ice tongue adjacent to the Vestfold Hills (FIGURE 22–56A), to about 35 miles in the multiple tongues that make up the Publication Ice Tongues about 78 miles to the southwest. Of the island and hill areas, which range in width from 12 to 29 miles, the Rauer Islands and the Larsemann Hills make up the most conspicuous areas (FIGURE 22–56B). In 1939, men of Ellsworth's expedition landed on some of the ice-free islands of this area (landing place (**64**)).

In general, each ice-free area is very roughly comparable to the Vestfold Hills in composition, height, and appearance. Like the Vestfold Hills, along its landward margin each island and hill area is overlain by the edge of the continental ice which terminates in moraines and ice cliffs. Toward the interior the continental ice gradually rises to the ice plateau of the interior, reaching elevations of about 7,700 feet above 100 miles inland, and higher elevations farther inland. In two known areas, however, the continental ice rises as much as 1,500 feet in the first mile from the sea.

Near the southwest end of this coast one of the Publication Ice Tongues extends about 20 to 40 n. miles into Prydz Bay, almost reaching to the Amery Ice Shelf on the opposite side of the bay. The two opposing ice formations constrict the entrance to a bay which lies to the southwest and is probably covered with ice almost every summer. Scattered islands border the southeastern shores of the bay

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and Baker Three Glacier discharges into the head of the bay.

The Amery Ice Shelf extends about 60 to 70 n. miles north-northwest from its near juncture with the Publication Ice Tongues. At least part of the terrain behind the ice shelf is mountainous. Mackenzie Bay, which lies to the northwest of the Amery Ice Shelf, is almost entirely bordered by ice cliffs. Nevertheless, landings were made at the head and along the western shore of the bay by men of Lars Christensen's ship, the *Torlyn,* in 1931 (landing places (**65**) and (**66**)).

From Cape Darnley, westward about 135 miles to Cape Daly (64°30′E.), most of the coast is bordered by ice cliffs, but landings have been made in two places near the middle of this stretch of coast. In approaching this coastal stretch, vessels should attempt to make a landfall well to the eastward, and then work westward. The approaches to the eastern half of this coastal stretch are reported as clear, except for the tendency of icebergs to become stranded within 50 n. miles northeast of Cape Darnley and cause congestion of pack ice. Several rocks and reefs are charted in the approaches to the west half of the coast, and it is reported that many rocks and submerged pinnacles are uncharted. Foul ground is reported about 45 n. miles northeast of Cape Daly.

Near the middle of this stretch of coast, two huge rock masses lying about 4 miles apart rise steeply from the waters edge. Several uncharted reefs are reported to lie in the near vicinity. The eastern rock mass, Murray Monolith, rises sheer about 1,250 feet above the sea and the western rock mass, Scullin Monolith, rises to an elevation of about 1,550 feet. Several expeditions have made landings near Murray Monolith (landing place (**67**)). A landing has also been made near the scree-strewn slopes of Scullin Monolith, and a cache of supplies been deposited there (landing place (**68**)).

Along the western two-thirds of this stretch of coast scattered mountain peaks that reach elevations of about 1,500 to 3,300 feet penetrate the continental ice at distances of about 3 to 20 miles from the shore. All of this stretch of coast is part of the Mac-Robertson Coast, which continues farther to the west.

Between Cape Daly and Austnes Point (57°20′E.), the northern entrance point of Edward VIII Bay, the coast measures about 220 miles in length. This stretch of coast is bordered by groups of islands and islets which during the summer are usually free of snow and ice, and often are joined by sea ice. Though open water is commonly found a short distance off the coast, at times northerly swell and west-setting currents press pack ice and icebergs in toward the shore. To the north, however, between about 62° and 66°S., pack ice often impedes the approach to the open water nearer the shore. Ships usually find the easiest route of approach to lie between about 70° and 80°E., by-passing the area of pack ice and approaching the coastal segment from the east. The east half of the coast is part of the Mac-Robertson Coast, and the west half comprises the Kemp Coast.

The groups of islands along this coast extend a maximum of about 20 n. miles offshore, and are surrounded by widely ranging depths. Most of the islands range in height between 100 and 400 feet, and some of the larger ones are dotted with fresh water lakes. When clear of ice the small bay lying about 87 miles southeast of Austnes Point, adjacent to Stefansson Bay, may afford shelter for vessels and the shores may afford landing places. In 1936 the British Discovery Investigations expedition landed and investigated the bay (landing place (**70**)).

Most of this stretch of coast is bordered by ice cliffs, interrupted in places by high rock cliffs, most of which are about 600 to 1,200 feet high. In places, however, heavily crevassed icefalls overlie the cliffs and, especially along the Kemp Coast, ice-free hills are separated by tongues of continental ice that at sea end in ice cliffs. The coast between about 25 and 55 miles west of Cape Daly is backed by ranges of north – south trending ridges that rise about 5 to 10 miles inland, and are charted as far south as about 40 miles inland. The ridges, which make up the Framnes Mountains, rise to about 3,000 to 5,000 feet in elevation. Farther to the west, scattered peaks show through the continental ice. In 1931 Mawson's British-Australian-New Zealand Antarctic Research Expedition landed at a point about 95 miles west of Cape Daly (landing place (**69**)).

Between Austnes Point and the head of Ice Bay (49°30′E.), the coast measures about 290 miles in length. Most of this stretch of coast is fronted by ice cliffs but near the northernmost part of the coast, small groups of islands that in the summer are free of ice lie in front of the cliffs. The largest of these islands, Proclamation Island, rises to about 800 feet and was landed upon in 1930 by the British-Australian-New Zealand Antarctic Research Expedition (landing place (**71**)). Pack ice that is anchored by these islands and by grounded icebergs, and is held ashore by winds and swell, obstructs the approaches to much of this coast. The approaches to the western part of this coastal stretch and to Ice Bay are perennially obstructed by ice. In 1929, men from the Norwegian Lars Christensen expedition ship *Norvegia,* under Captain Riiser-Larsen, landed by airplane on the sea ice near Cape Ann, about 90 miles west-southwest of Proclamation Island (landing place (**72**)). The interior of Enderby Land is covered by the continental ice sheet.

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Mountain peaks, most of which reach elevations of about 1,500 to 2,000 feet, pierce the icecap within about 20 miles of the sea. Farther inland the peaks and mountain ranges rise to higher elevations.

Between Ice Bay and Riiser-Larsen Peninsula (34°E.), the coast measures about 290 miles in length. Most of this stretch of coast is bordered by ice cliffs that have been perennially unapproachable because of the pack ice, which may be held ashore by northerly swell. Most of the coast has been viewed only from an airplane. In the bay immediately east of the Riiser-Larsen Peninsula, many islands border the east coast, which is made up of many rocky headlands. Between the head of this bay and Ice Bay to the east, the inland ice rises in steep slopes which contain countless nunataks and peaks. This stretch of coast is the Prince Olav Coast. To the south of the bay, mountains that are usually ice-free in the summer protrude through the inland ice. The west coast of the bay is the Prince Harald Coast.

The coast extending about 780 miles westward from the northwestern extremity of the Riiser-Larsen Peninsula to about 5°E., makes up the Princess Ragnhild Coast and the Princess Astrid Coast. The Riiser-Larsen Peninsula is covered by ice and is devoid of nunataks and outcrops. The entire stretch of coast is bordered by ice cliffs and in places, notably along the western part of the Princess Astrid Coast, the ice cliffs contain many indentations. Rugged mountains 6,000 to 10,000 feet high lie about 75 miles inland along most of the Princess Ragnhild Coast. Mountain peaks from 10,000 to 13,000 feet high lie about 100 miles inland along the Princess Astrid Coast. In 1933 a sledge party from a Norwegian expedition under Captain Riiser-Larsen landed somewhere on the Princess Ragnhild Coast (landing place **(73)** (position indefinite)). In 1939 a party from the German Antarctic Expedition under Captain Ritscher landed near the western limit of the Princess Astrid Coast (landing place **(74)**).

The Princess Martha Coast, about 540 miles in length, lies west of the Princess Astrid Coast between about 5°E. and 20°W. Most of the Princess Martha Coast is bordered by ice cliffs, though three short stretches lying west of the Greenwich meridian are free of ice cliffs. During the early part of the summer a belt of pack ice lying in the vicinity of the 60°S. parallel obstructs the approach to the Princess Martha Coast, though south of the belt of ice the seas are usually navigable. The belt of pack ice usually disappears in late December and early January. The route of approach that best minimizes the barricade of pack ice lies along the Greenwich meridian.

The Princess Martha Coast lying east of the Greenwich meridian is entirely fronted by ice cliffs, behind which snow-covered nunataks pierce the continental ice. Astride the Greenwich meridian, an ice tongue about 25 to 45 n. miles wide extends about 70 n. miles seaward, with depths of about 1,000 fathoms at the seaward extremity. Along the west side of the ice tongue a broad rift opening about 2½ n. miles has been named Byrd Bay (FIGURE 22–57A). Toward the interior the bay narrows, and about 5 n. miles from the entrance is covered by bay ice. In 1955 the U.S. Navy icebreaker *Atka* tied up to the bay ice (landing place **(75)**) (FIGURE 22–57B).

West of the broad ice tongue the coast is bordered by ice cliffs, except for three comparatively short stretches along the ends of projecting peninsulas. Near the first peninsula the German Antarctic Expedition of 1938–39 landed in two places (landing places **(76)** and **(77)**). About midway between the first and second breaks in the ice cliff, Atka Bay indents the ice cliff about 7 n. miles (FIGURE 22–58A). In places around the bay the ice cliffs are only about 15 feet high, so probably can be landed upon. Men from the U.S. Navy icebreaker *Atka* were transported to the top of the ice cliff by helicopter (landing place **(78)**). Along the second break in the ice cliff the Norwegian-British-Swedish Antarctic Expedition of 1949–50 landed and set up their base, *Maudheim* (landing place **(79)**). A short distance west of the third break in the ice cliff, which extends both east and west from Cape Norvegia, men from the *Atka* also made a landing (landing place **(80)**).

The terrain backing the Princess Martha Coast is characterized by snow-covered slopes, many of them so precipitous as to be snow-free, and rising to altitudes reportedly greater than 13,000 feet.

That part of Coats Land lying between the Princess Martha Coast and Duke Ernst Bay (35°W.), which measures about 385 miles in length, faces the Weddell Sea in an almost continuous ice cliff. During the early summer months pack ice lying about 700 to 1,000 n. miles offshore obstructs the approaches to the coast, though navigable seas immediately border the coast.

The eastern 100 miles or more of this stretch of coast is bordered by shelf ice. To the west the succeeding 45 miles of coast is unsurveyed. Most of the remainder is bordered by shelf ice, interrupted in several places by broad glaciers terminating in very high cliffs. Soundings of 80 fathoms or more have been taken a short distance off the ice front. These comparatively shallow soundings, plus evidence of tide marks on the ice, indicate that the glacier ice is not afloat.

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From Duke Ernst Bay to Cape Adams, the coast, which is fronted completely by the Filchner Ice Shelf, trends northwestward about 425 miles to Cape Adams (75°04′S., 62°20′W.). The treacherous ice of the Weddell Sea prevents approach to the coast, except during the summer season when some penetration from the east is possible. At the head of Duke Ernst Bay, two glaciers, Schweitzer Glacier and Lerchenfeld Glacier, descend from the high inland terrain. With a German expedition Filchner landed in this area in 1912, but later abandoned the site (landing place **(81)**). The southern entrance point of the bay is marked by Bertrab Nunatak, a bare rock about 1,000 feet high.

Except for a rough outline of the face of the Filchner Ice Shelf, the coast between Duke Ernst Bay and Cape Adams is uncharted. The edge of the shelf ice is very irregular as far as Gould Bay, an indentation in the shelf about 100 miles westward of Duke Ernst Bay. Gould Bay, about 15 miles across, is indented about 20 miles southward. West of Gould Bay the shelf ice front is comparatively regular. The interior, called Edith Ronne Land, is completely uncharted.

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CHARTS

185. ARGENTINA, MINISTERIO DE MARINA, DIRECCION GENERAL DE NAVEGACION E HIDROGRAFIA. *Navigation Charts:* 31, 64, 65, 100, 101, 103, 104, 114, 116.

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187. GERMANY, OBERKOMMANDO DER KRIEGSMARINE. *Navigation Charts:* 384, 397, 402, 547, 1057, 1062, 2702, 2704.

188. GREAT BRITAIN, HYDROGRAPHIC DEPARTMENT. *Navigation Charts:* 1774, 2202A, 2202B, 2203, 2683, 3170, 3171, 3172, 3173, 3174, 3175, 3176, 3177, 3196, 3202, 3205, 3213, 3570, 3571, 3579, 3585, 3589, 3593, 3596, 3866.

189. U.S. HYDROGRAPHIC OFFICE. *Contoured Position Plotting Sheets* (BC series): 0110S–0115S, 0209S–0217S, 0309S–0317S, 0408S–0417S, 0507S–0517S, 0608S–0617S, 0709S–0717S, 0810S–0817S, 0910S–0917S, 1010S–1018S, 1110S–1118S, 1209S–1218S, 1308S–1318S, 1407S–1418S, 1508S–1515S, 1609S–1615S, 1709S–1715S, 1810S–1815S, 1910S–1915S, 2009S–2015S, 2109S–2115S, 2208S–2215S, 2307S–2315S, 2408S–2415S, 2509S–2514S, 2610S–2614S, 2710S–2714S, 2810S–2814S, 2910S–2914S, 3009S–3014S, 3108S–3114S, 3207S–3214S, 3308S–3314S, 3409S–3414S, 3509S–3514S, 3610S–3614S.

190. ———. *Navigation Charts:* 0453, 0454, 0825, 958, 2003, 2451, 2452, 2453, 3570, 3866, 3875, 5411, 5412, 5446, 5801, 6636, 6637, 6638, 6639, 6640, 6641, 6650, 6652, 6653, 6654, 6661, 16321–24, 16429.

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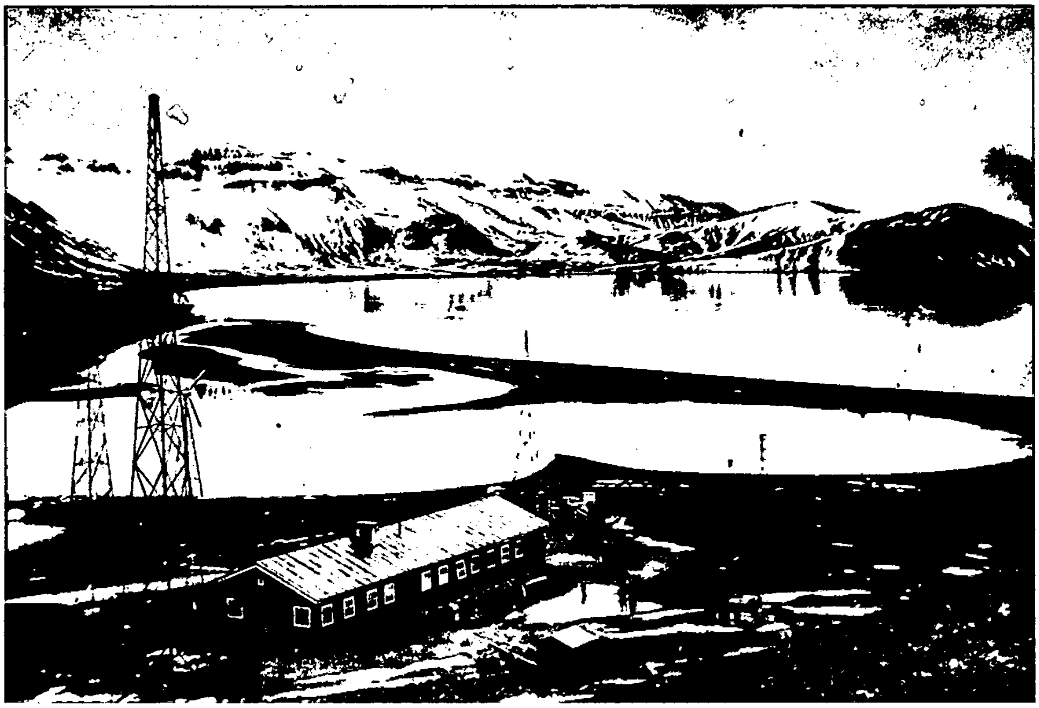
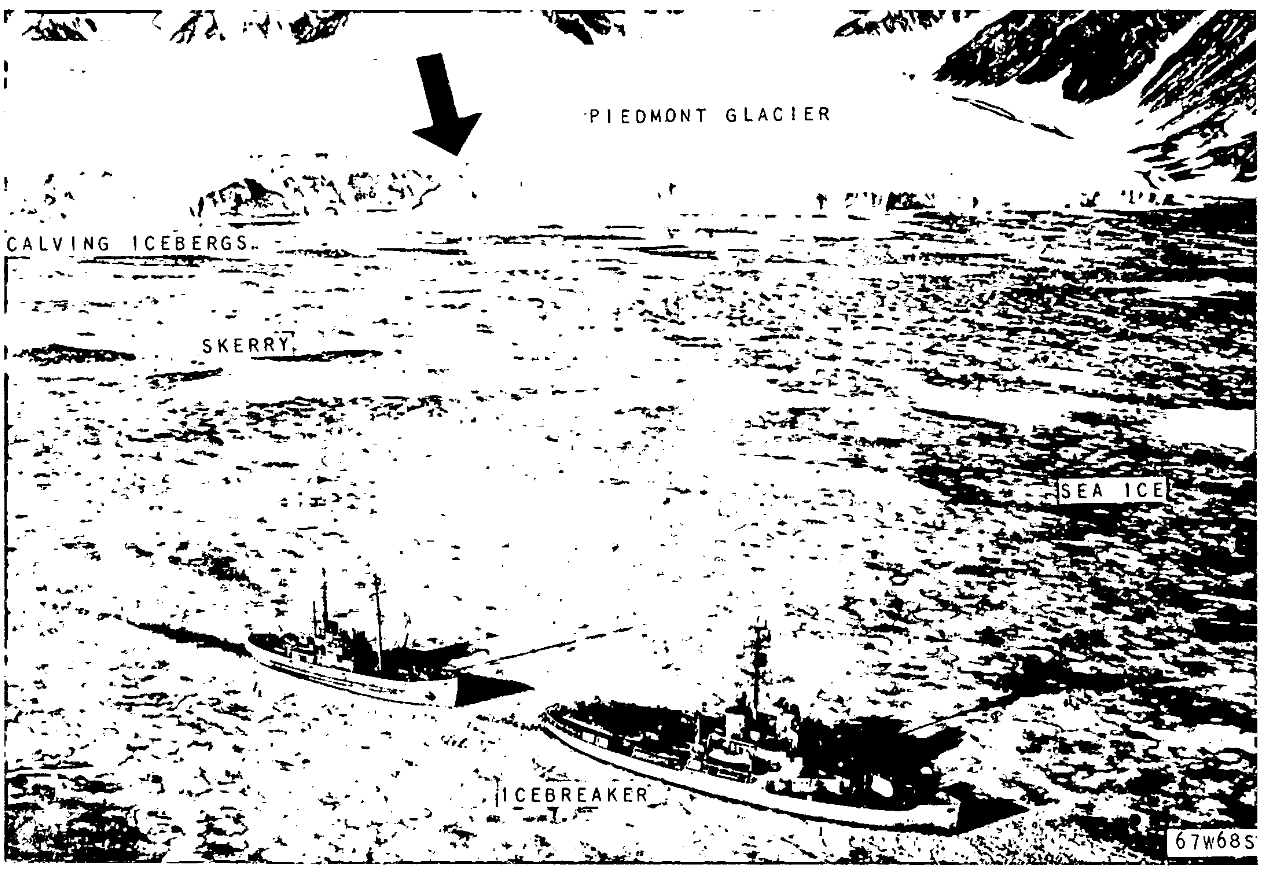


A. Coastal Sector 1. Deception Island. Argentine base at head of small bay in southeast part of island. Approximate position 62°59′S., 60°34′W. Probably 1954.



B. Coastal Sector 1. Marguerite Bay. Note sea ice in foreground, cliffed front of glacier in background, and steep, rocky terrain in right background. Photo portrays type of coast common to many areas of Antarctica. Arrow denotes direction of ice movement. Approximate position 68°S., 62°W. 1948.

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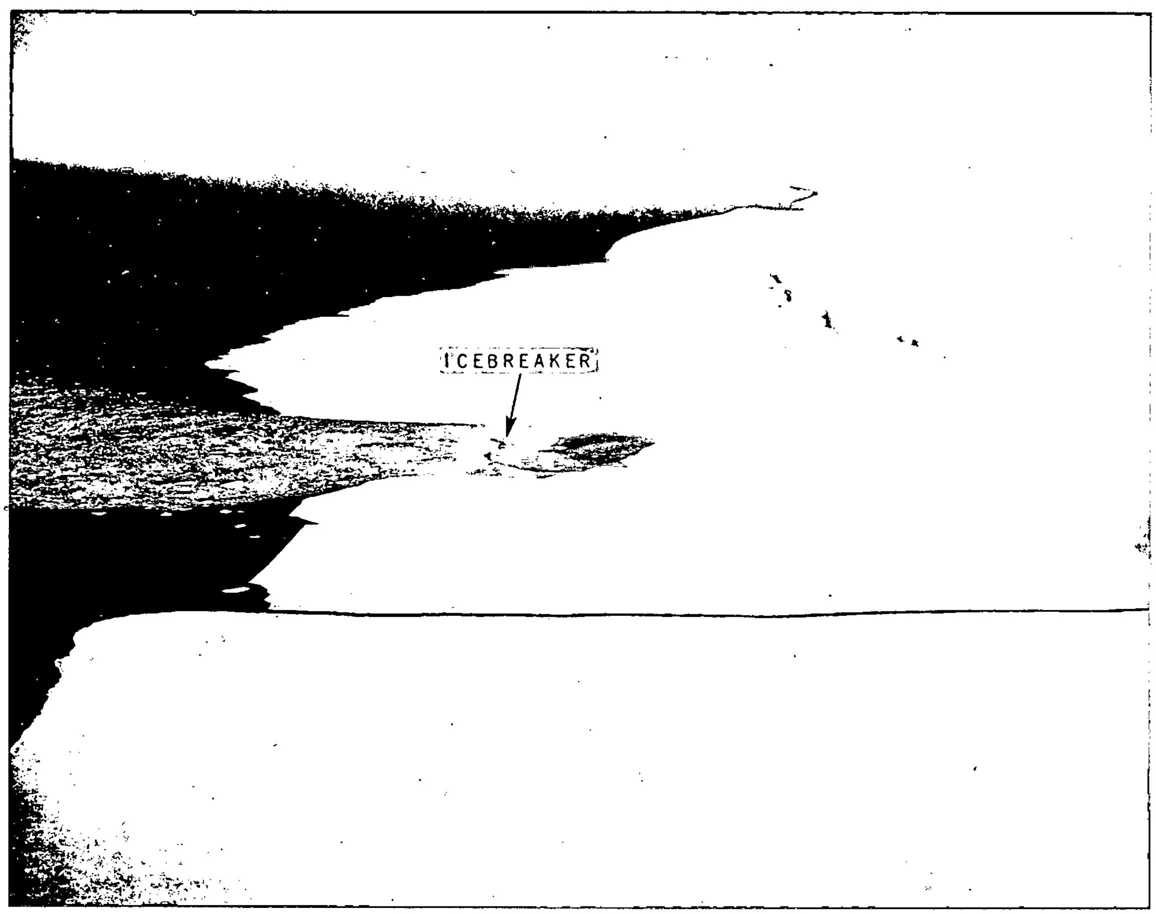
A. Coastal Sector 2. Northern extremity of Peter I Island. Approximate position 68°43′S., 90°32′W. February 1955.



B. Coastal Sector 3. Kainan Bay in east edge of Ross Ice Shelf. Landing place (27). View eastward from west of bay showing U.S.S. *Glacier* of "Operation DEEPFREEZE" breaking out ice for berthing of cargo ships. Shelf ice in foreground and background, bay ice in middleground. Approximate position 78°S., 162°W. 1956.

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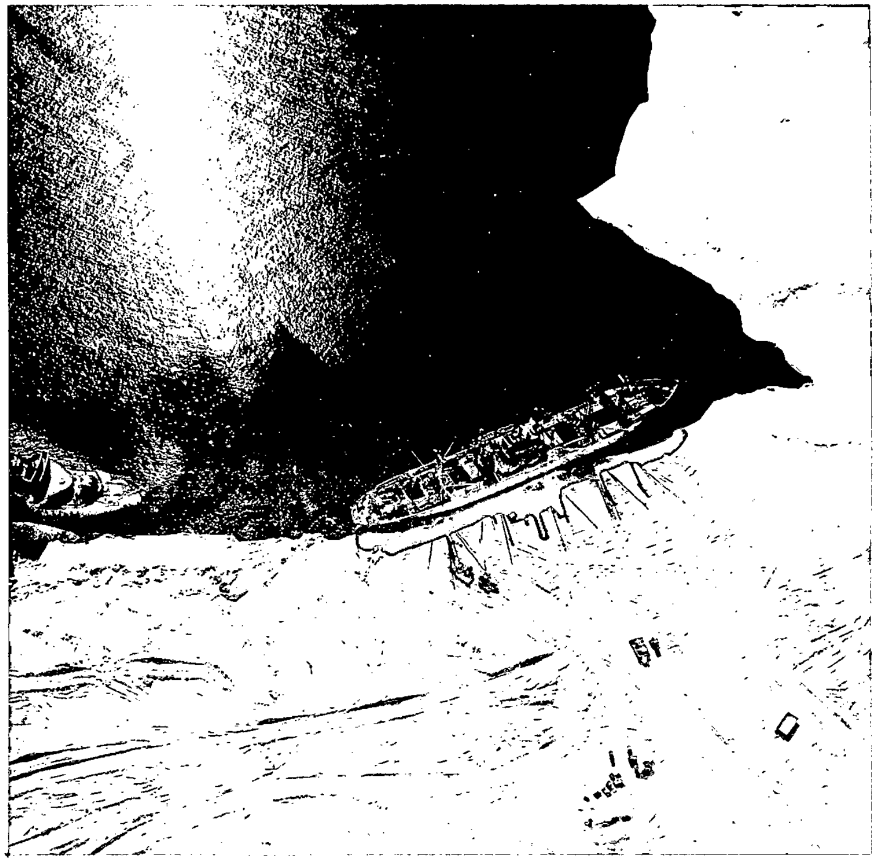
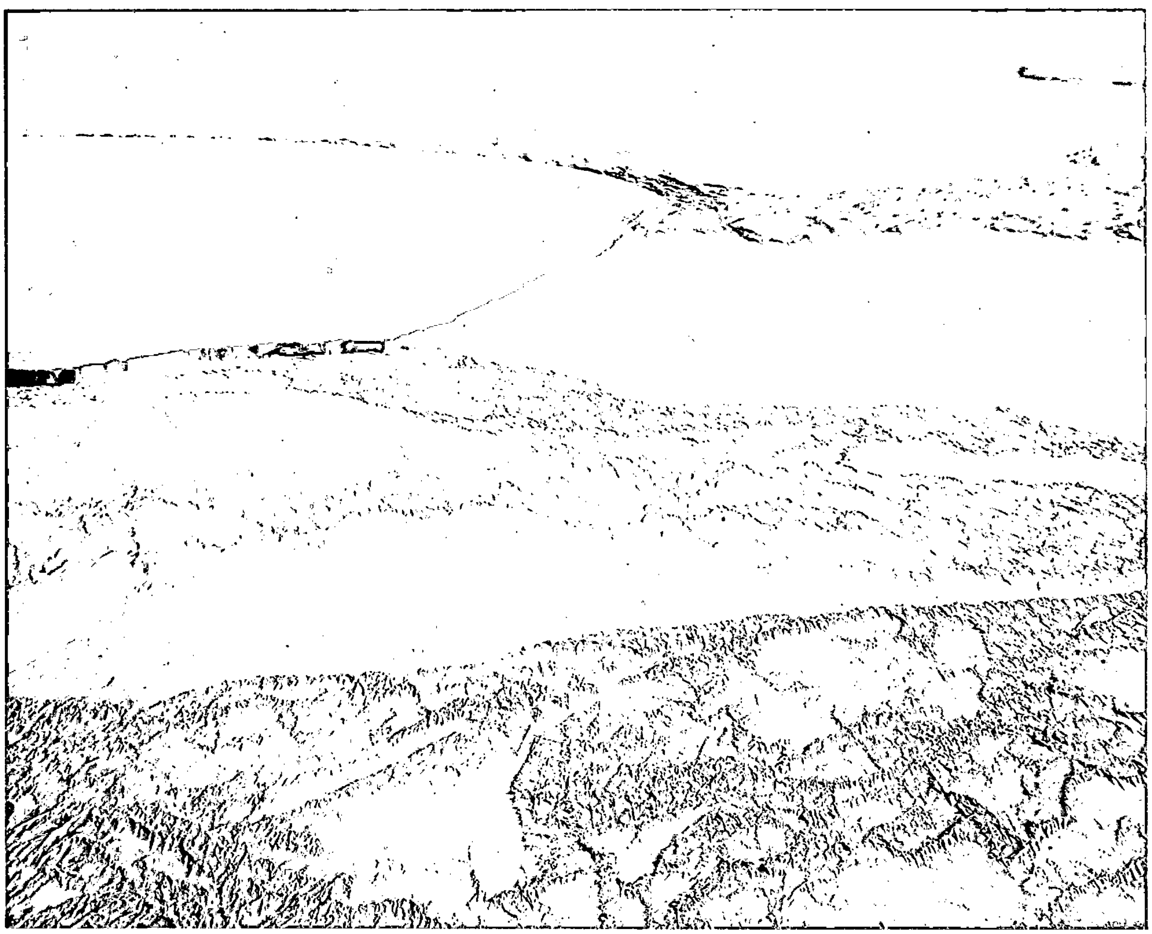


A. COASTAL SECTOR 3. KAINAN BAY IN EAST EDGE OF ROSS ICE SHELF. Landing place (27). Supply ship and icebreaker of "Operation DEEPFREEZE" moored to bay ice at head of bay. Approximate position 78°S., 162°W. 1956.



B. COASTAL SECTOR 3. KAINAN BAY IN EAST EDGE OF ROSS ICE SHELF. Landing place (27). Photograph taken during "Operation DEEPFREEZE." View looking south over bay ice in foreground, shelf ice in left middle-ground, and pressure area in right background. Approximate position 78°S., 162°W. 1956.

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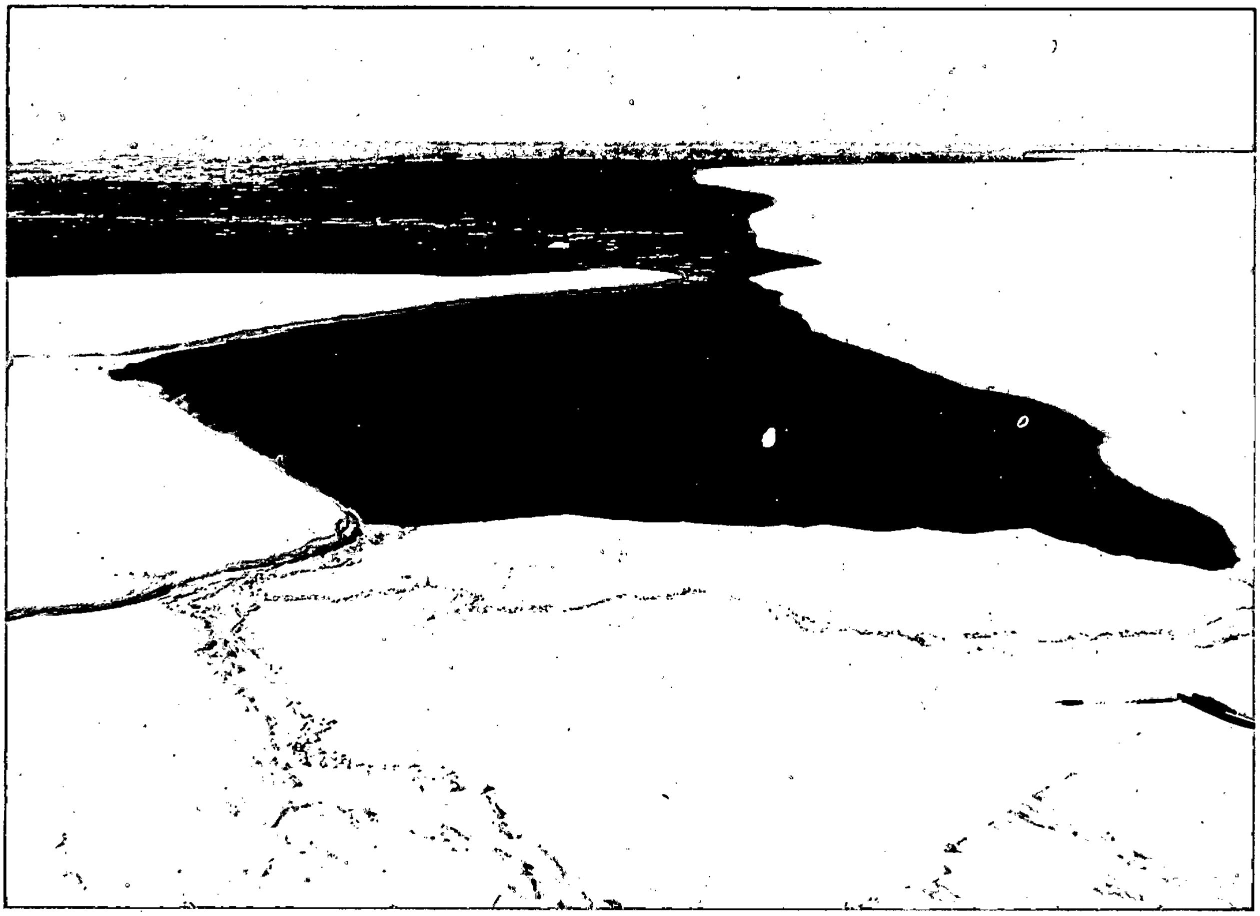
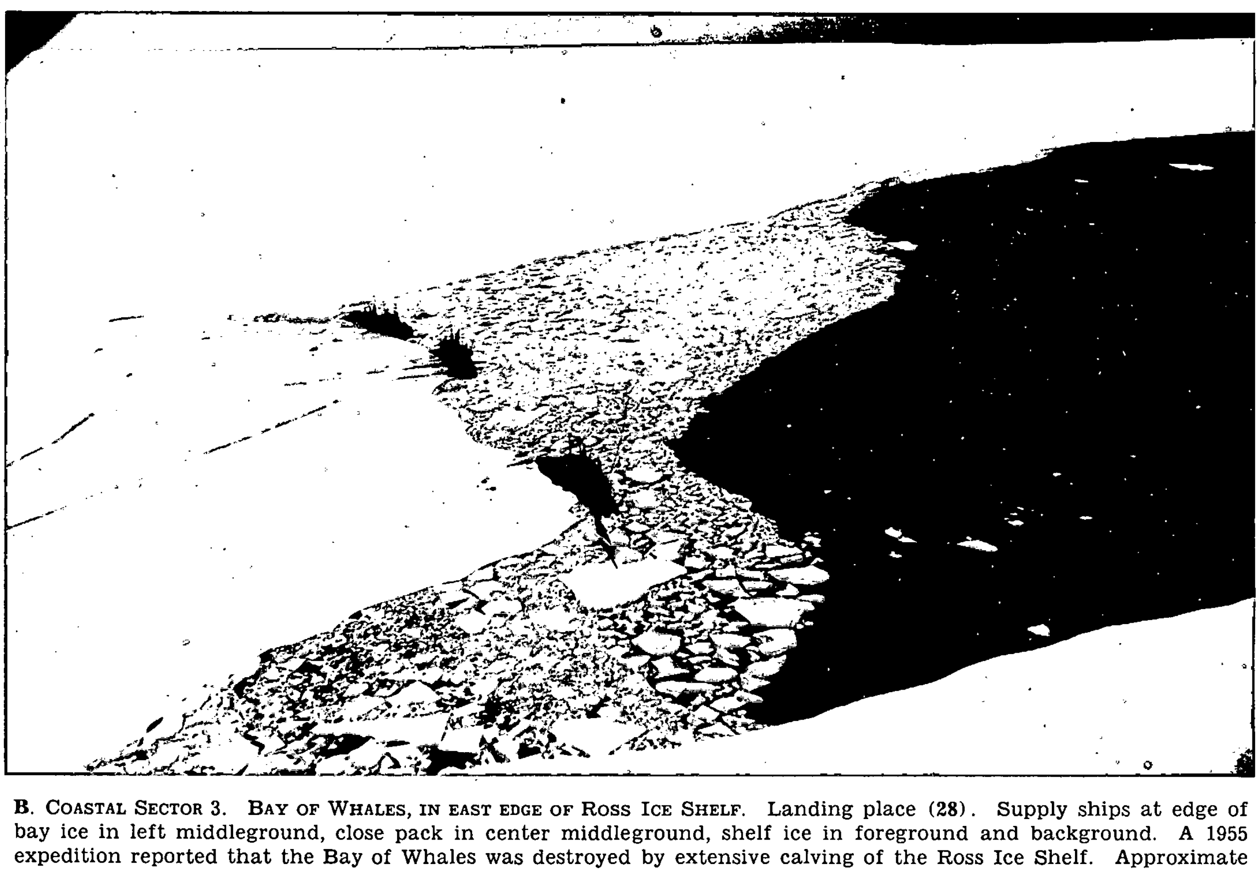


A. Coastal Sector 3. Bay of Whales, in east edge of Ross Ice Shelf. Landing place (28). View northeastward with pressure-ridged bay ice in foreground. A 1955 expedition reported that the Bay of Whales was destroyed by extensive calving of the Ross Ice Shelf. Approximate position 78°S., 164°W. 1947.



B. Coastal Sector 3. Bay of Whales, in east edge of Ross Ice Shelf. Landing place (28). Supply ships at edge of bay ice in left middleground, close pack in center middleground, shelf ice in foreground and background. A 1955 expedition reported that the Bay of Whales was destroyed by extensive calving of the Ross Ice Shelf. Approximate position 78°S., 164°W. 1947.

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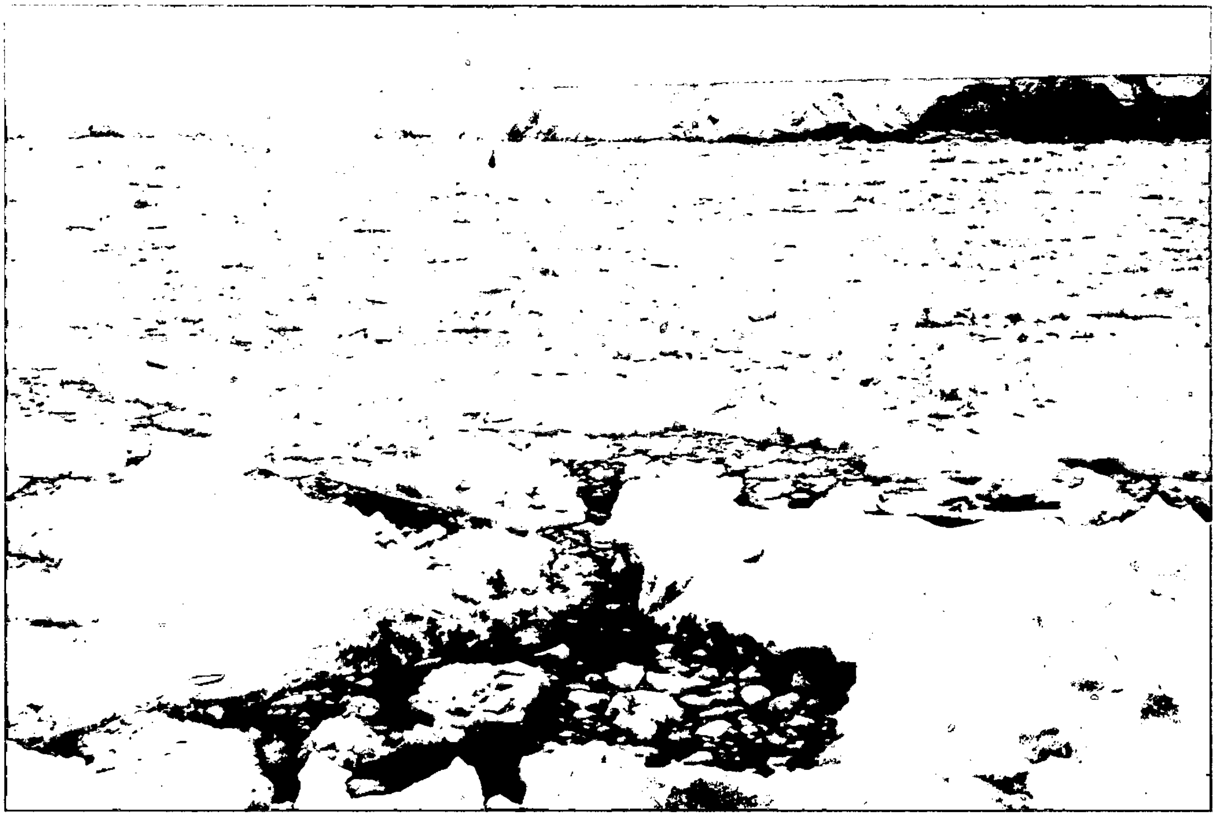
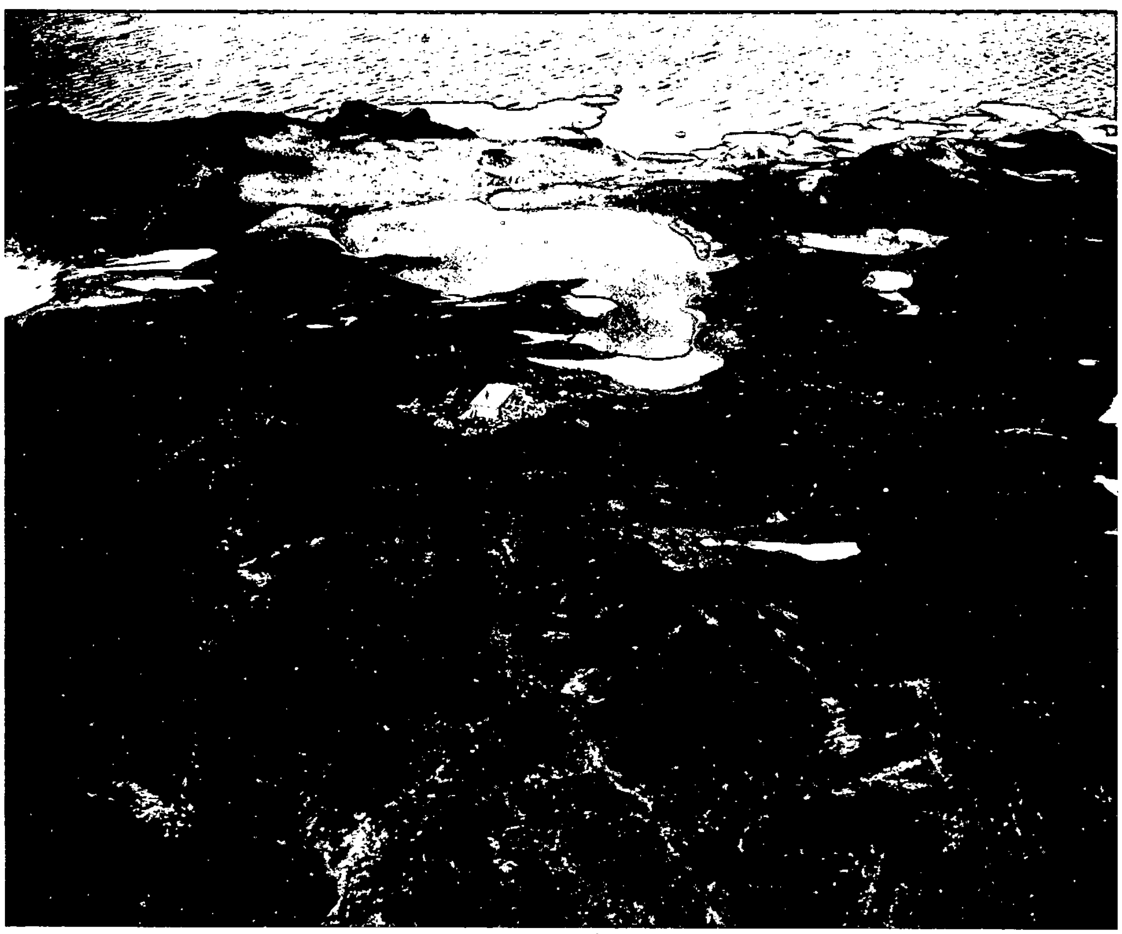


A. Coastal Sector 3. West of Bay of Whales. Pack ice, made up of fragments of sea ice, in foreground, and the edge of the Ross Ice Shelf in background. Approximate position 78°S., 178°W. 1955.



B. Coastal Sector 3. Ross Island at Cape Evans. Landing place (32). Open water of McMurdo Sound in background. Hut Camp established by Captain R. E. Scott in 1911 in middleground. Approximate position 78°S., 167°E. 1956.

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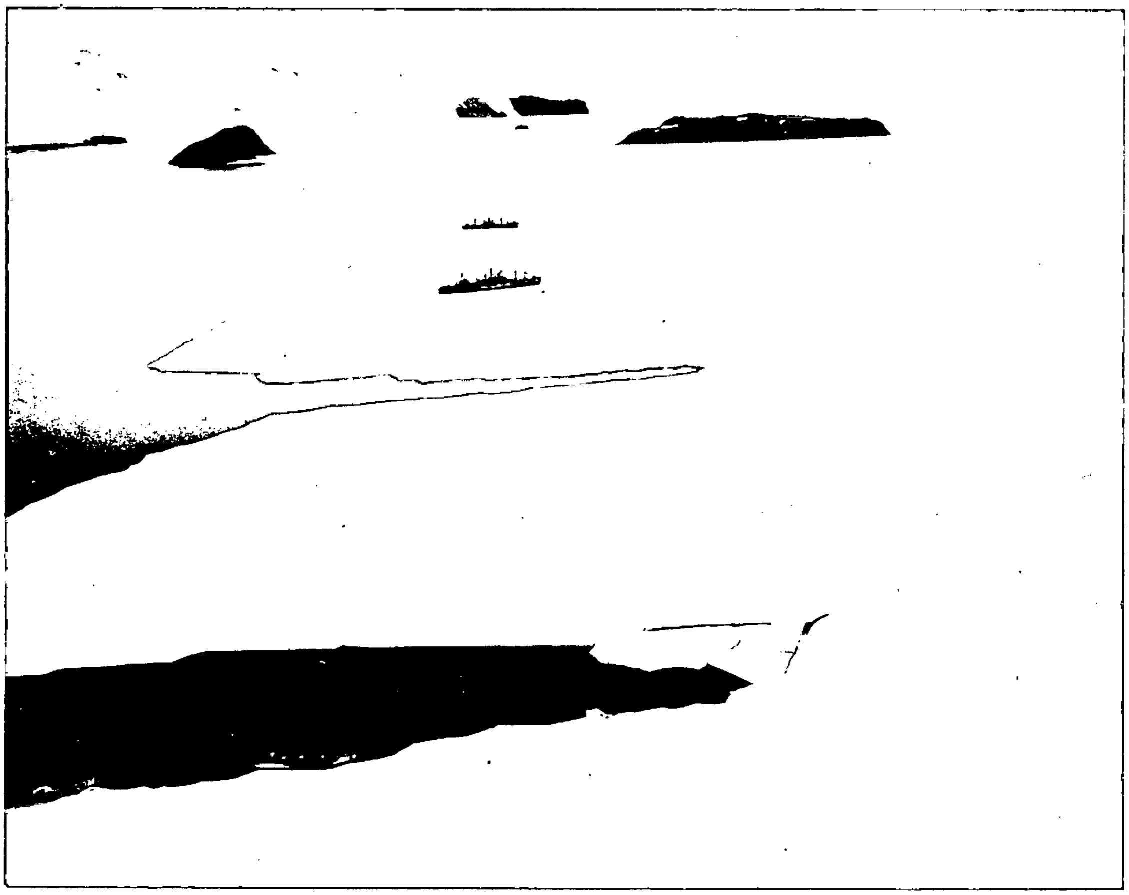
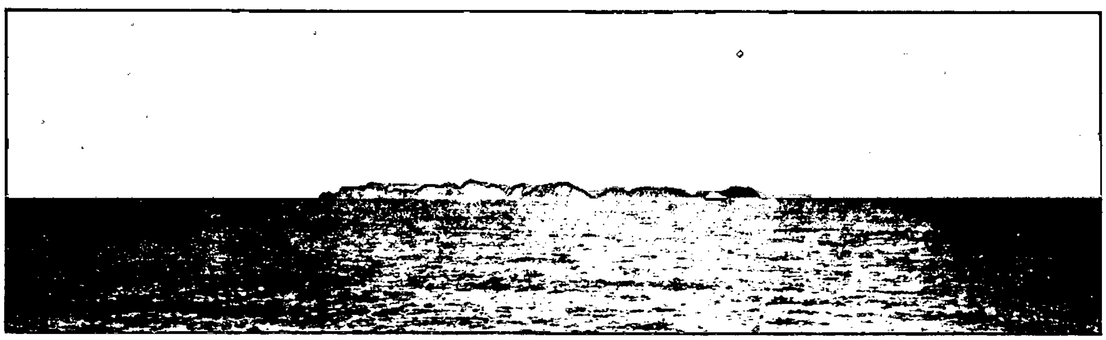
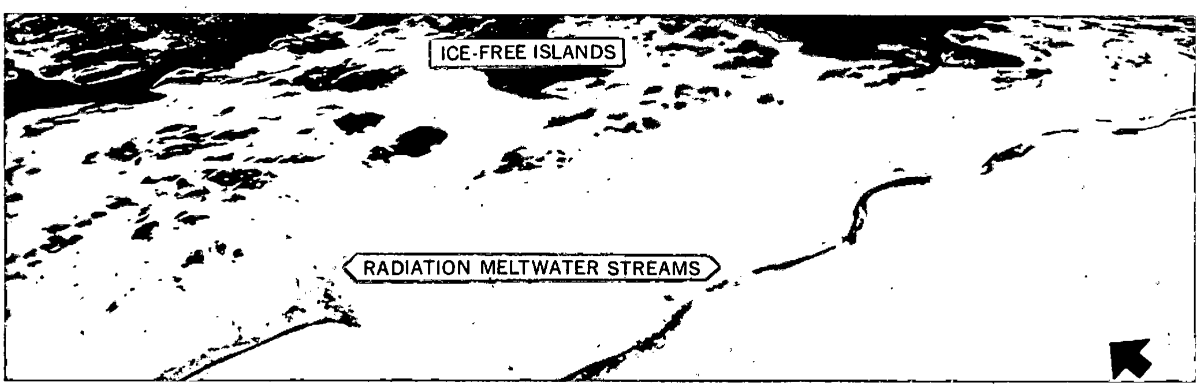


A. COASTAL SECTOR 3. MCMURDO SOUND. View southeastward showing supply ships of "Operation DEEP-FREEZE" moored to ice at head of McMurdo Sound. Inaccessible Island in left background and Tent Island in right background. Approximate position 78°S., 166°E. 1956.



B. COASTAL SECTOR 3. FRANKLIN ISLAND. View westward from U.S.S. *Glacier* of "Operation DEEP-FREEZE" lying approximately 12 n. miles east of the island. Approximate position 76°S., 168°E. 1956.



C. COASTAL SECTOR 4. COASTAL AREA NEAR CAPE FOLGER. Oblique view of ice-free islands in background and continental ice in right foreground, separated by moraine composed of rock fragments. Arrow denotes direction of ice movement. Approximate position 66°S., 111°E. 1947–48.

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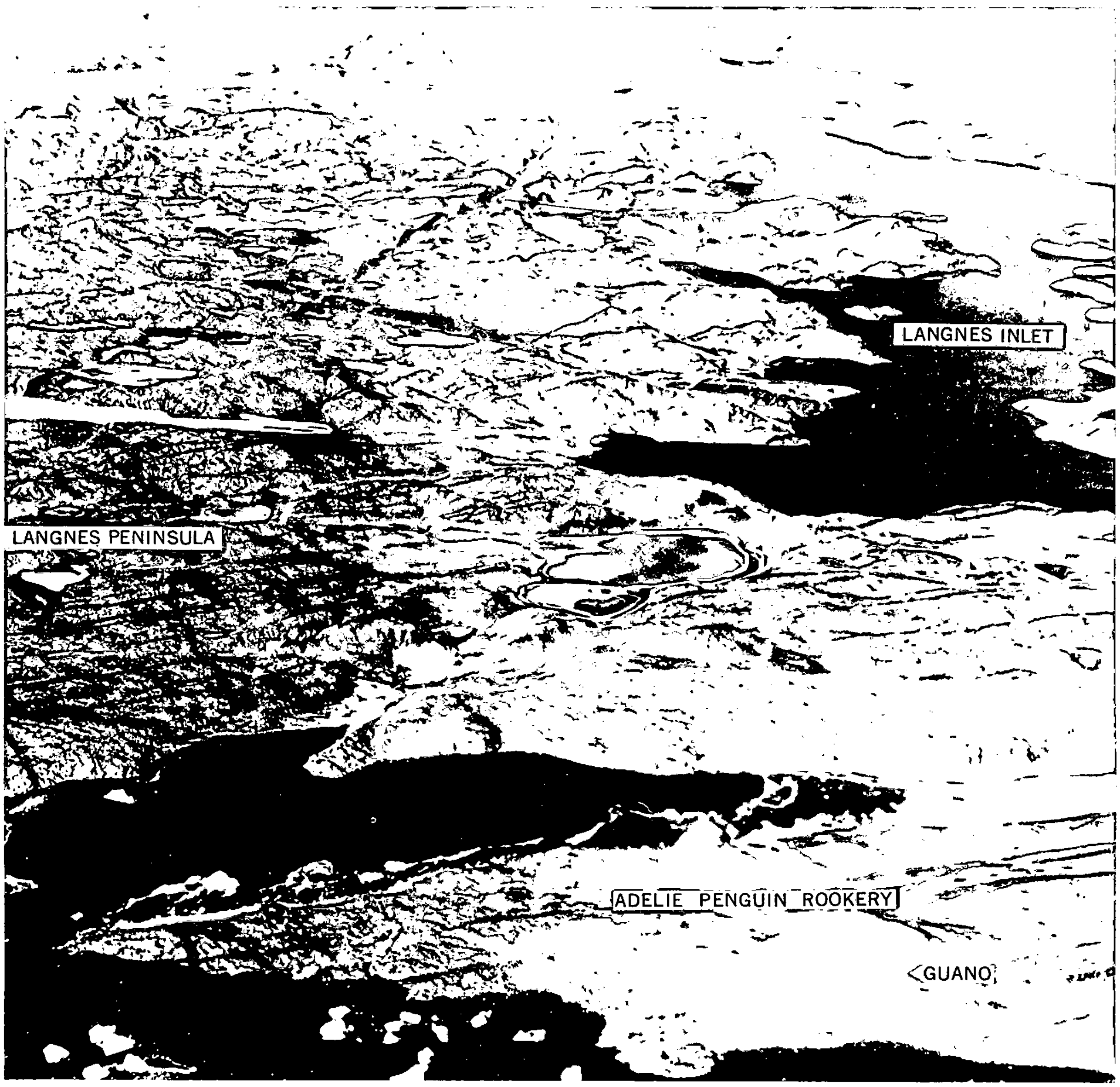
A. COASTAL SECTOR 4. ICE-FREE COASTAL AREA AT LANDING PLACE (54). In contrast to Vestfold Hills in FIGURE 22-55B, note blanket of rock fragments covering surface of hills. Approximate position 66°S., 101°E. 1947-48.



B. COASTAL SECTOR 4. VESTFOLD HILLS. Landing place (63). View looking southeast showing bare rock surface of hills (contrast with boulder-covered terrain of FIGURE 22-55A). Hill area intruded by inlets from sea. Note steep slopes near sea level. Approximate position 69°S., 78°E. 1946-47.

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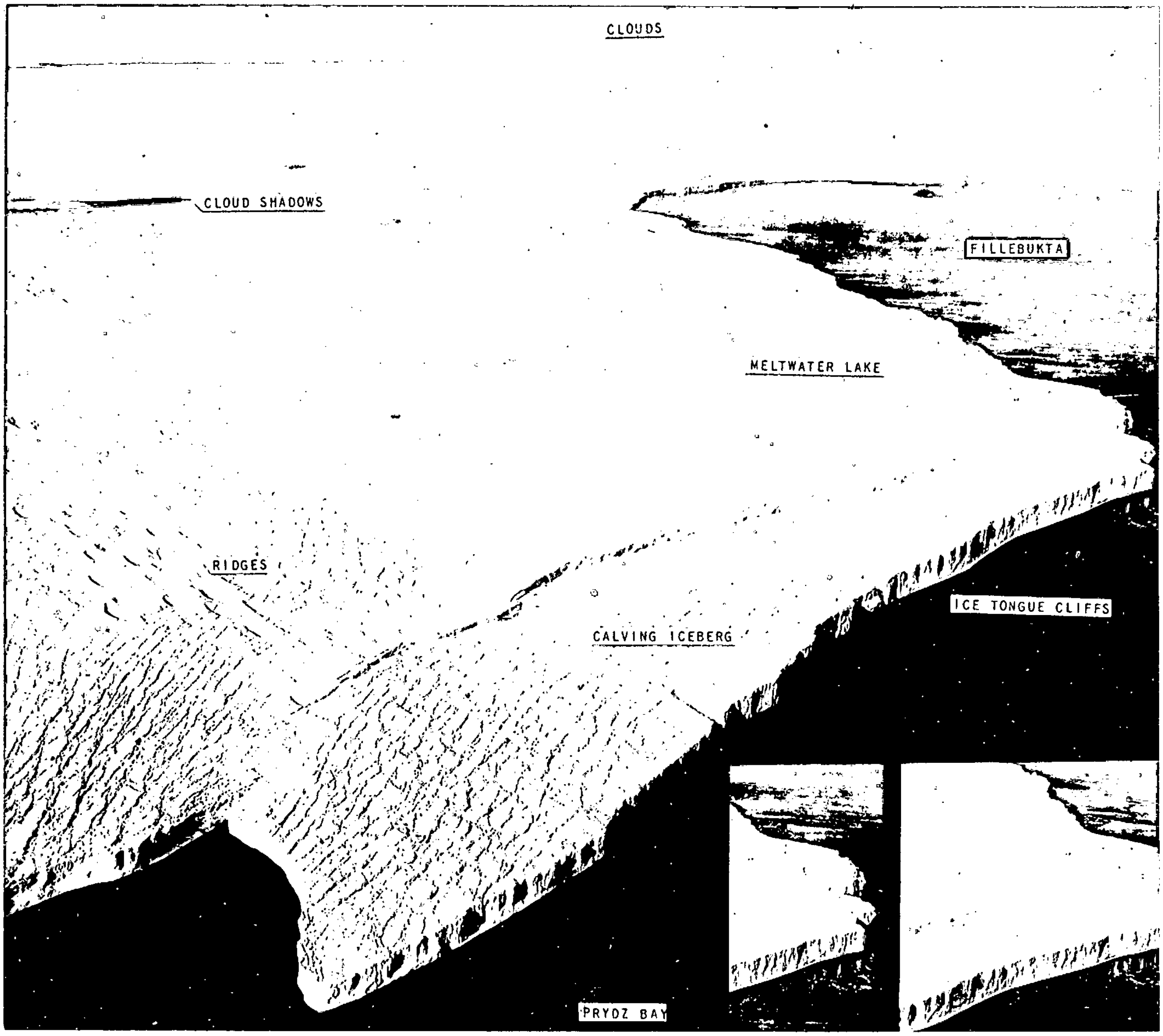
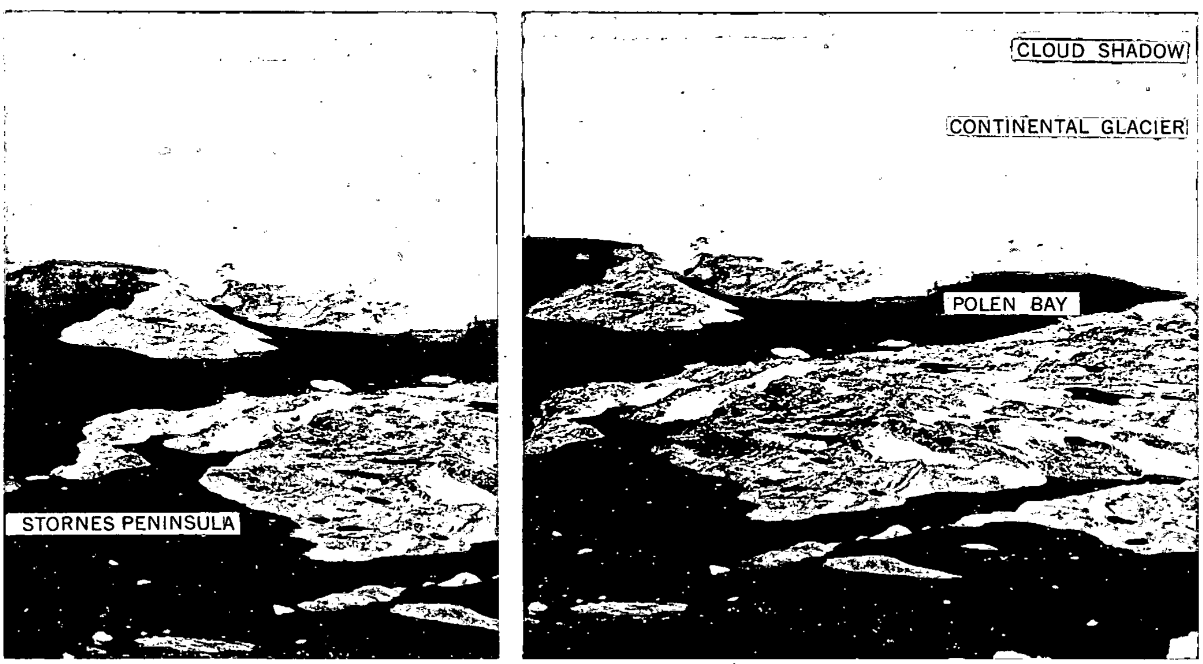


A. Coastal Sector 4. Sørsdal Glacier tongue showing typical cliffed edges and deeply crevassed surface. Inset is stereo pair of portion of glacier tongue in right middleground. Approximate position 69°S., 77°E. 1946–47.



B. Coastal Sector 4. Stereoscopic view looking southeast over Larsemann Hills. Note scattered islets among ice fragments in foreground. Also note vertical ice faces where continental ice terminates in water, but smooth edge of ice terminating against hills. Approximate position 69°S., 76°E. 1946–47.

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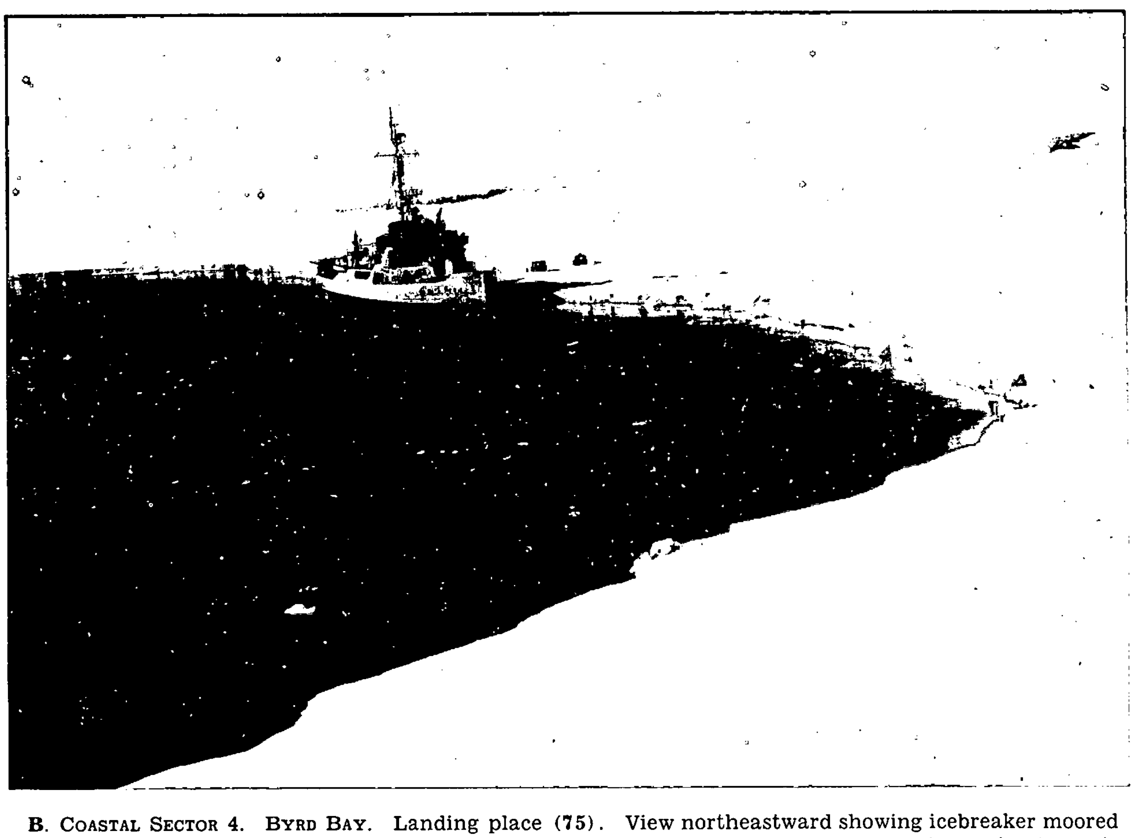
A. COASTAL SECTOR 4. BYRD BAY. Landing place (75). View looking east. Ice cliff in foreground 20 to 60 feet high. Icebreaker moored to bay ice at head of bay. Approximate position 70°S., 01°W. 1955.



B. COASTAL SECTOR 4. BYRD BAY. Landing place (75). View northeastward showing icebreaker moored to bay ice. Note snow ramp leading to higher, ice-tongue surface in background. Approximate position 70°S., 01°W. 1955.

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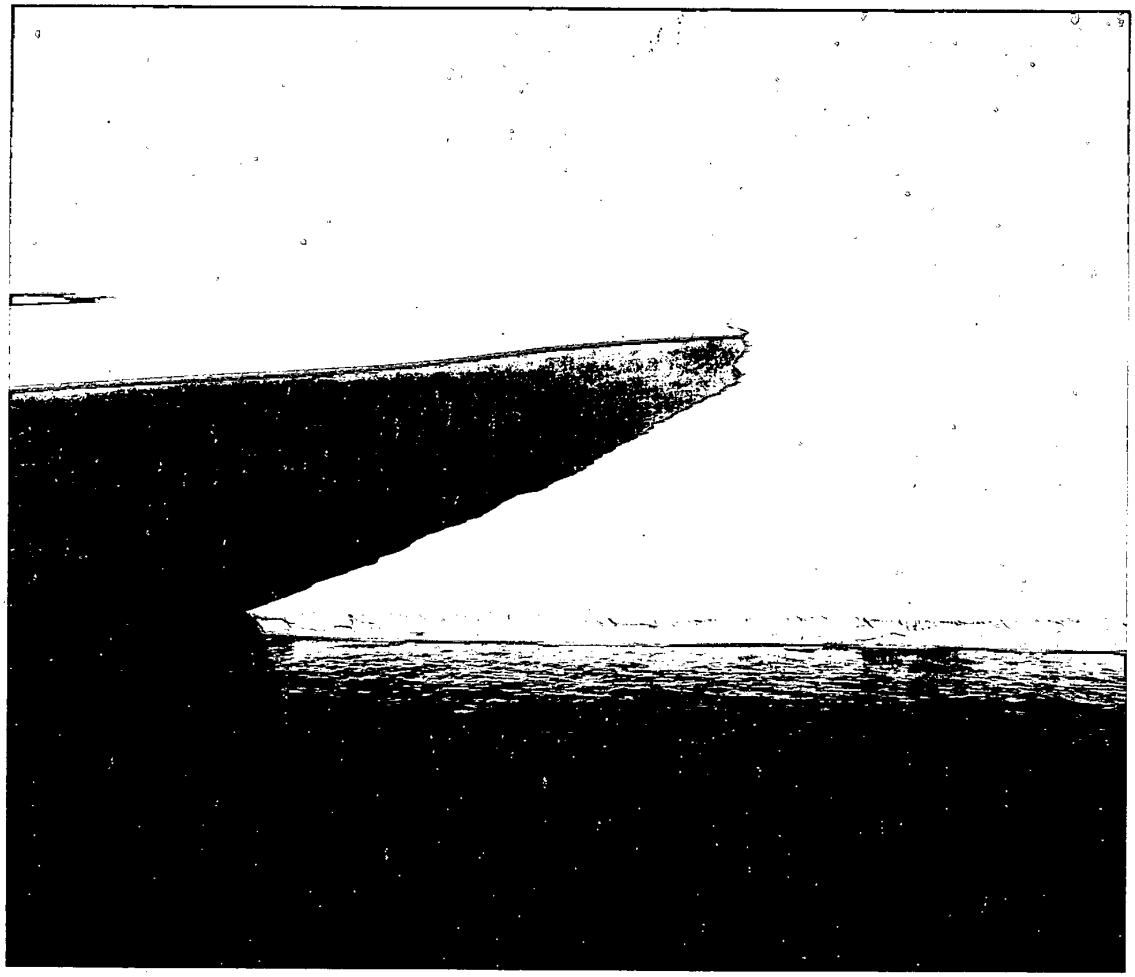
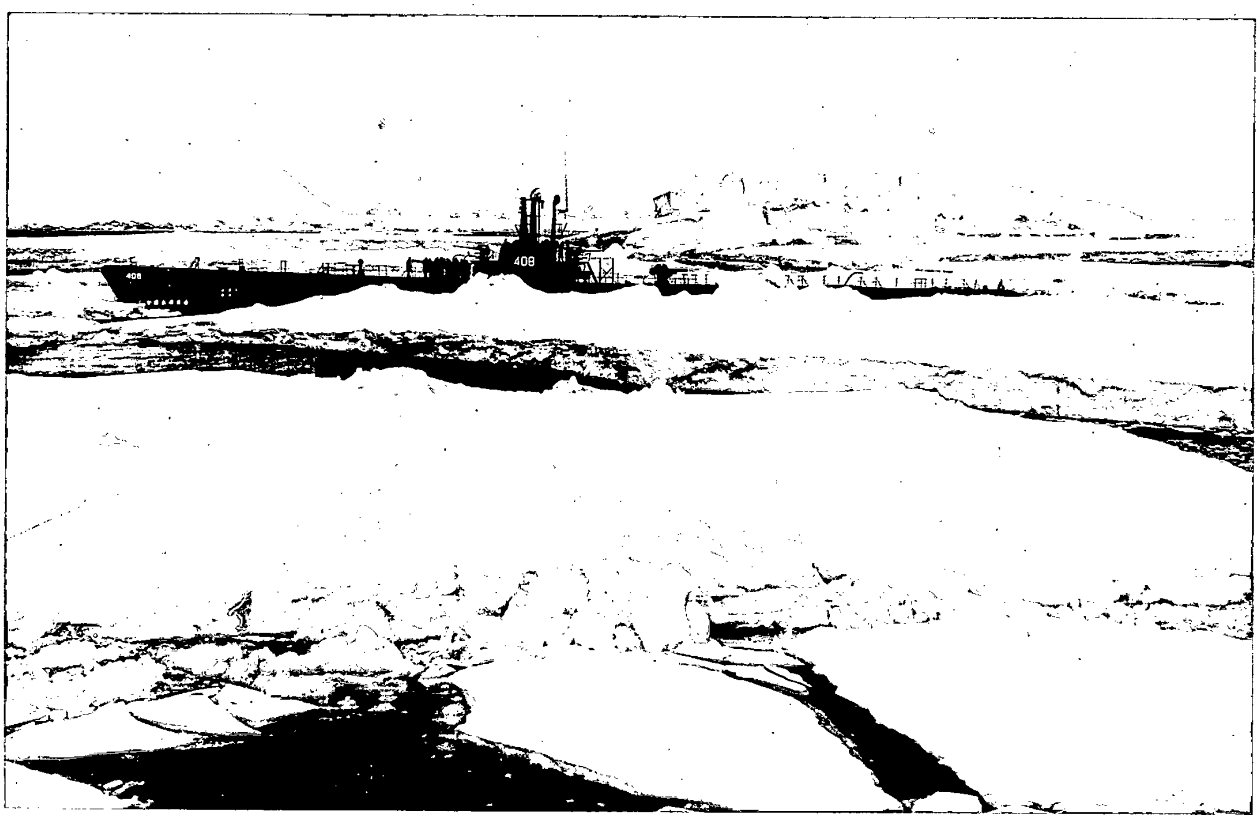


A. Coastal Sector 4. Atka Bay. Landing place (76). Note extensive shelf ice surrounding bay. Approximate position 71°S., 08°W. 1955.



B. Ross Sea. U.S.S. *Sennett* in pack ice. 1947.

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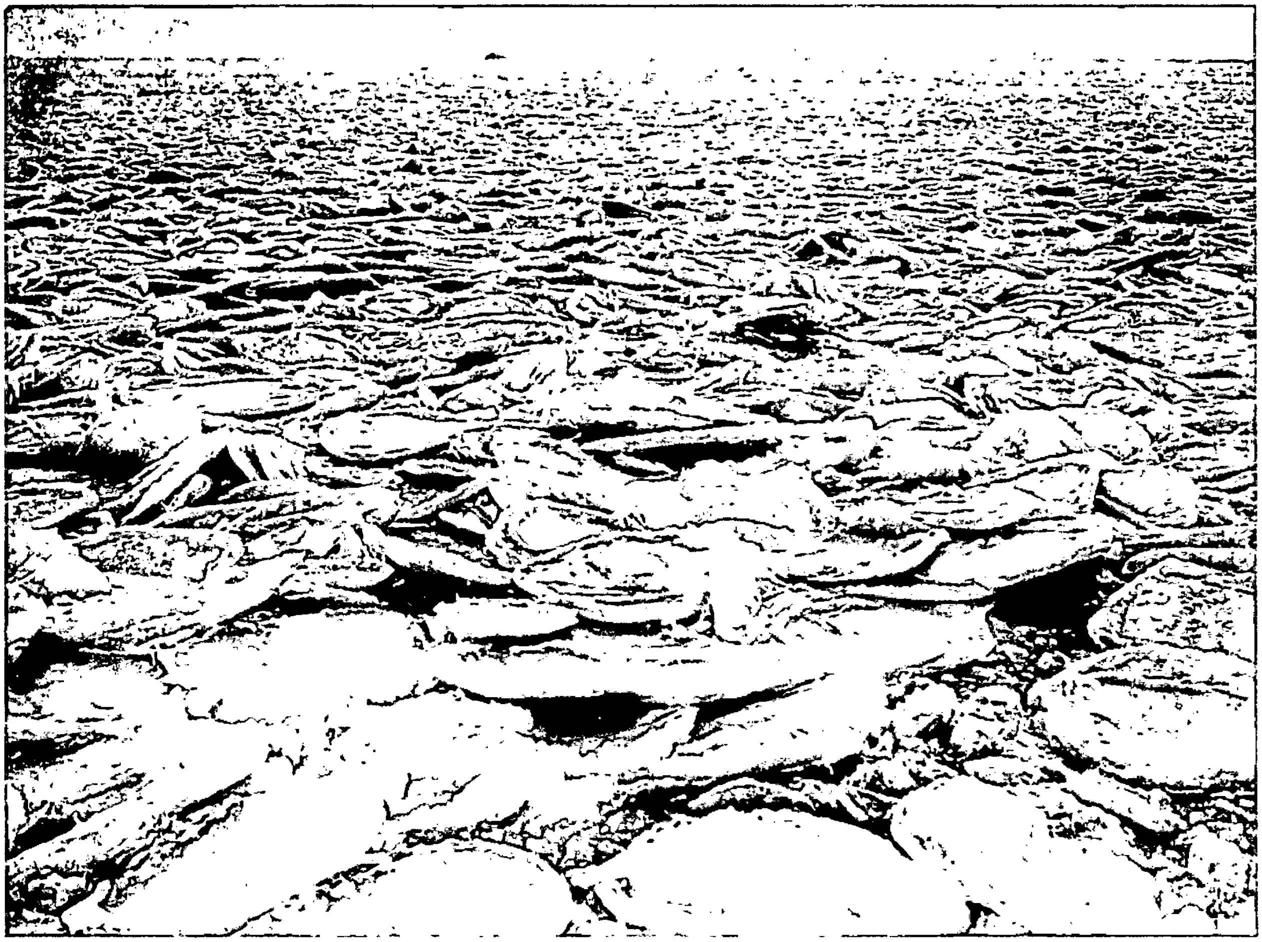
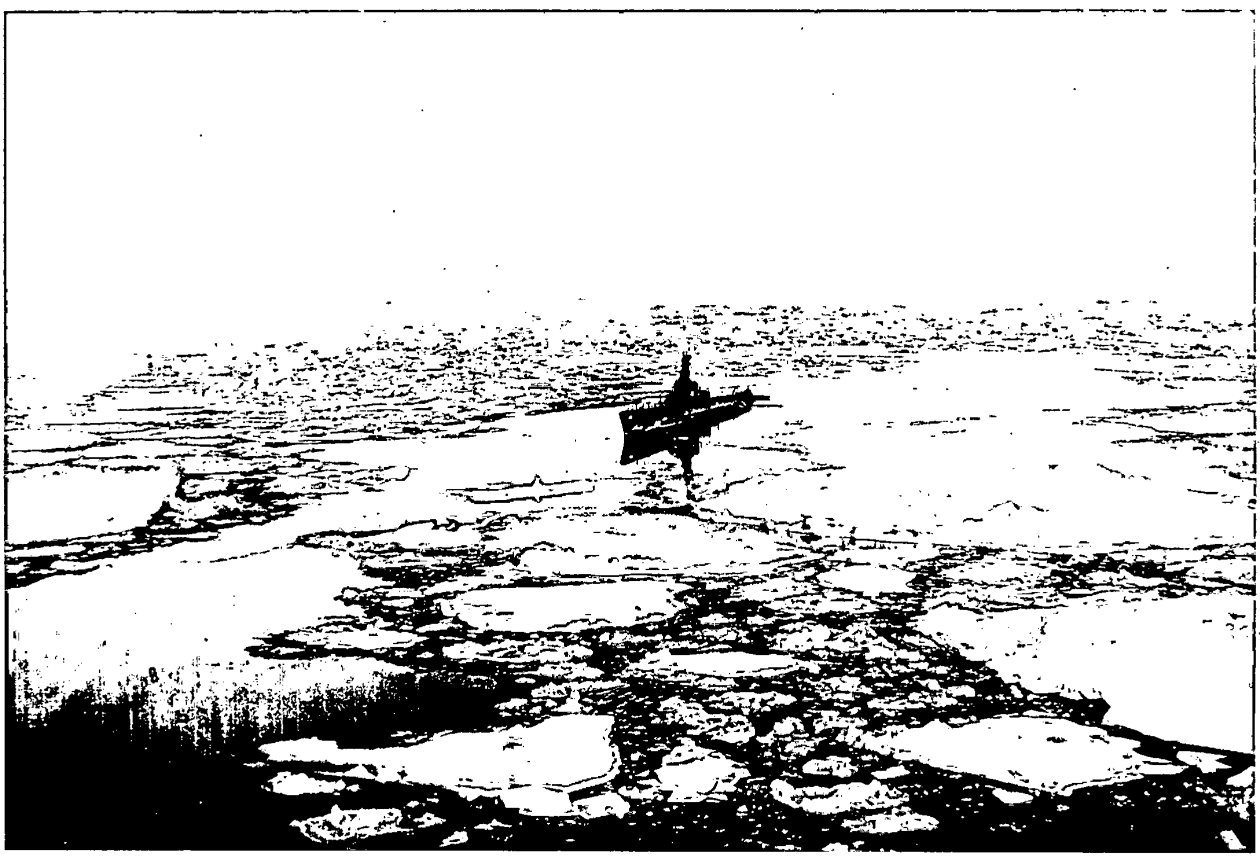


A. Ross Sea area. View, probably in Ross Sea, showing pancake ice several feet thick in layers. 1911.



B. Ross Sea. Scattered sea ice fragments and brash such as shown here are normally easily navigable. 1947.

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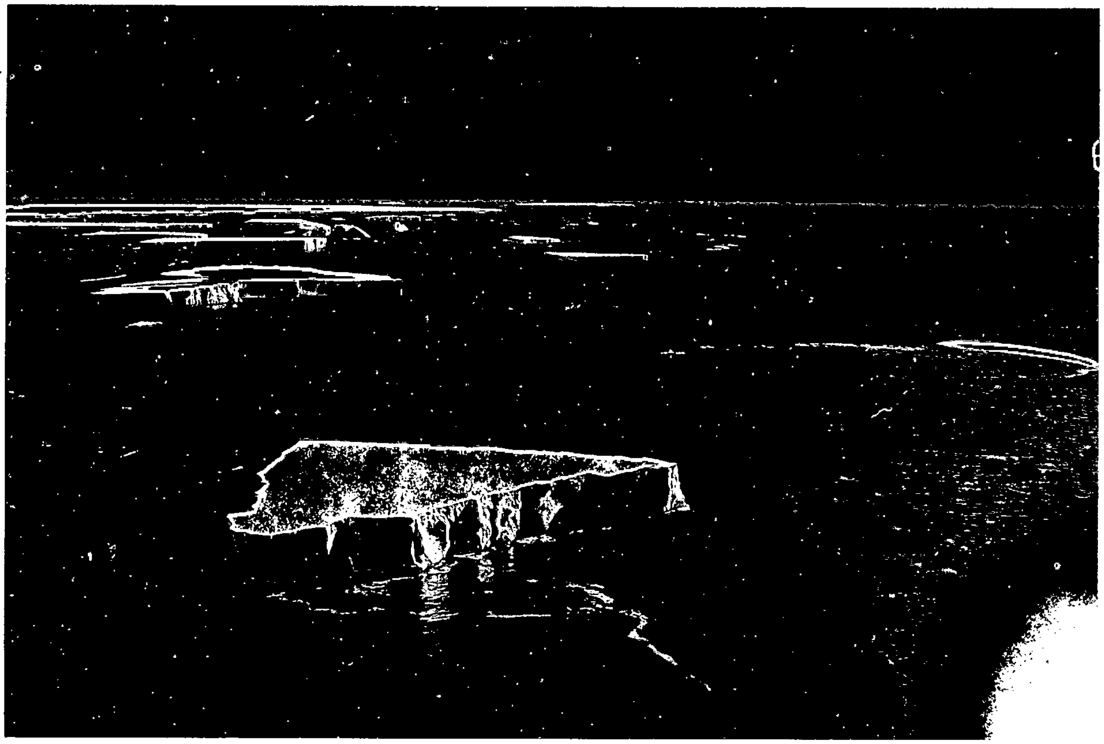
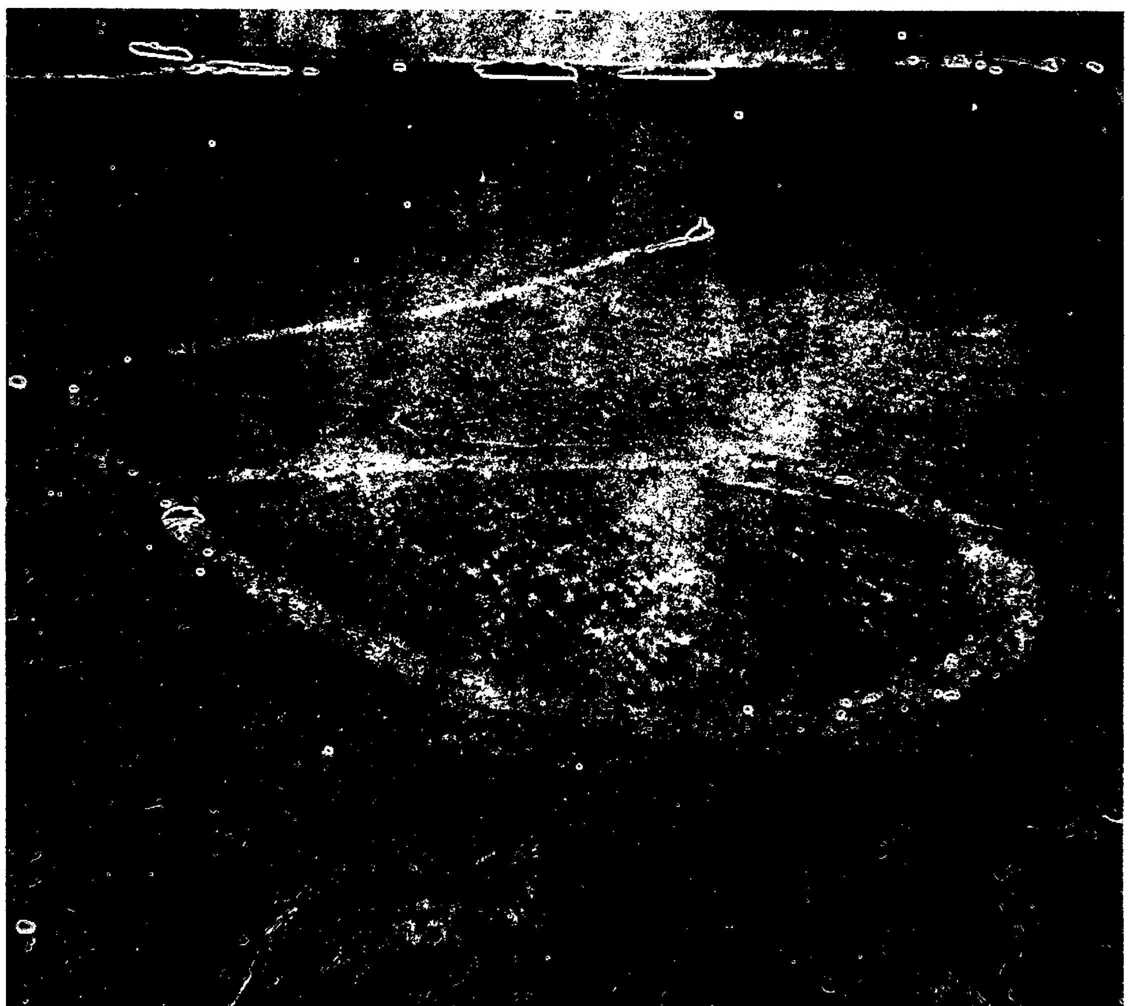


A. ATKA BAY AREA. Tabular bergs. 1955.



B. MCMURDO SOUND. View approximately south, showing icebreaker making passage through continuous cover of relatively thin sea ice. December 1955.

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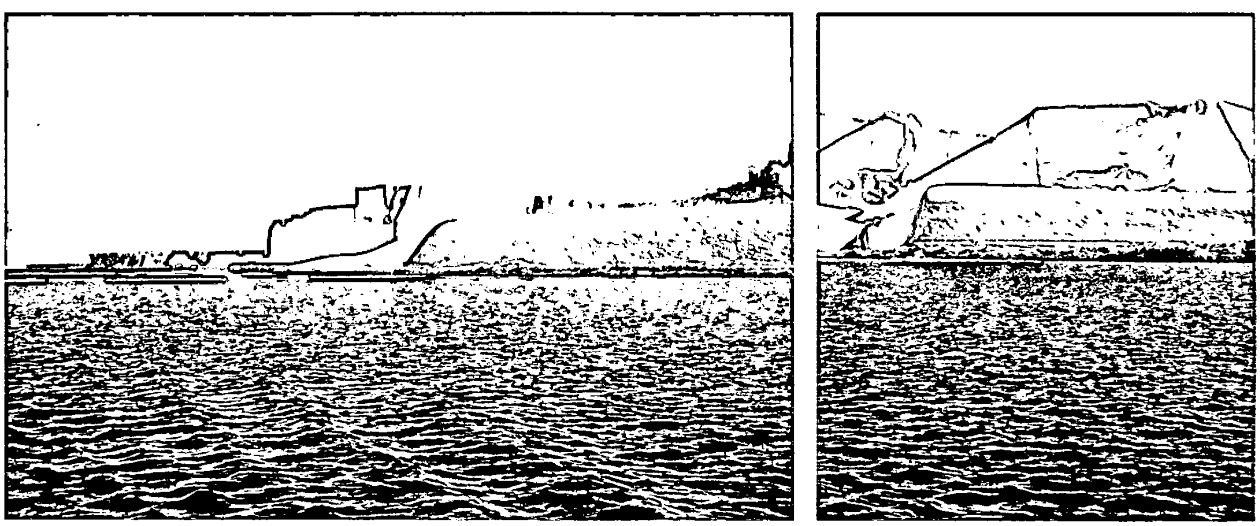
A. Western Ross Sea. Looking west toward Beaufort Island. Note seasonal disintegration of pack and very large tabular berg or shelf ice. January 1956.



B. McMurdo Sound area. Section of iceberg which blocks passage between Beaufort Island and Ross Island. January 1956.

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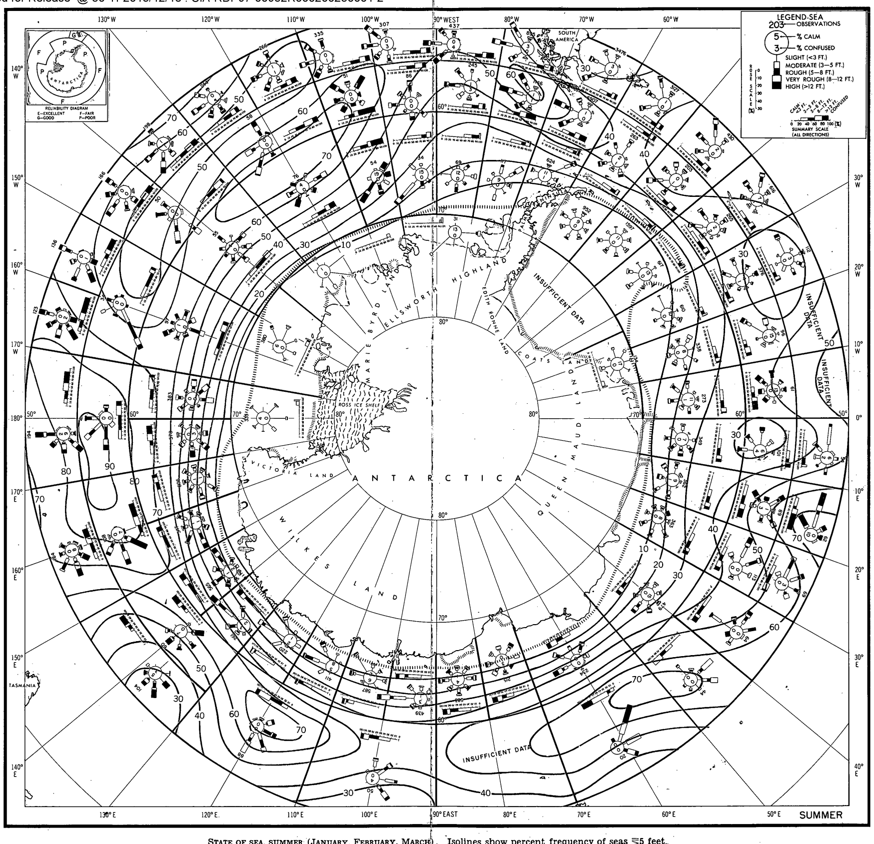

STATE OF SEA, SUMMER (JANUARY, FEBRUARY, MARCH). Isolines show percent frequency of seas ≧5 feet.

50X1

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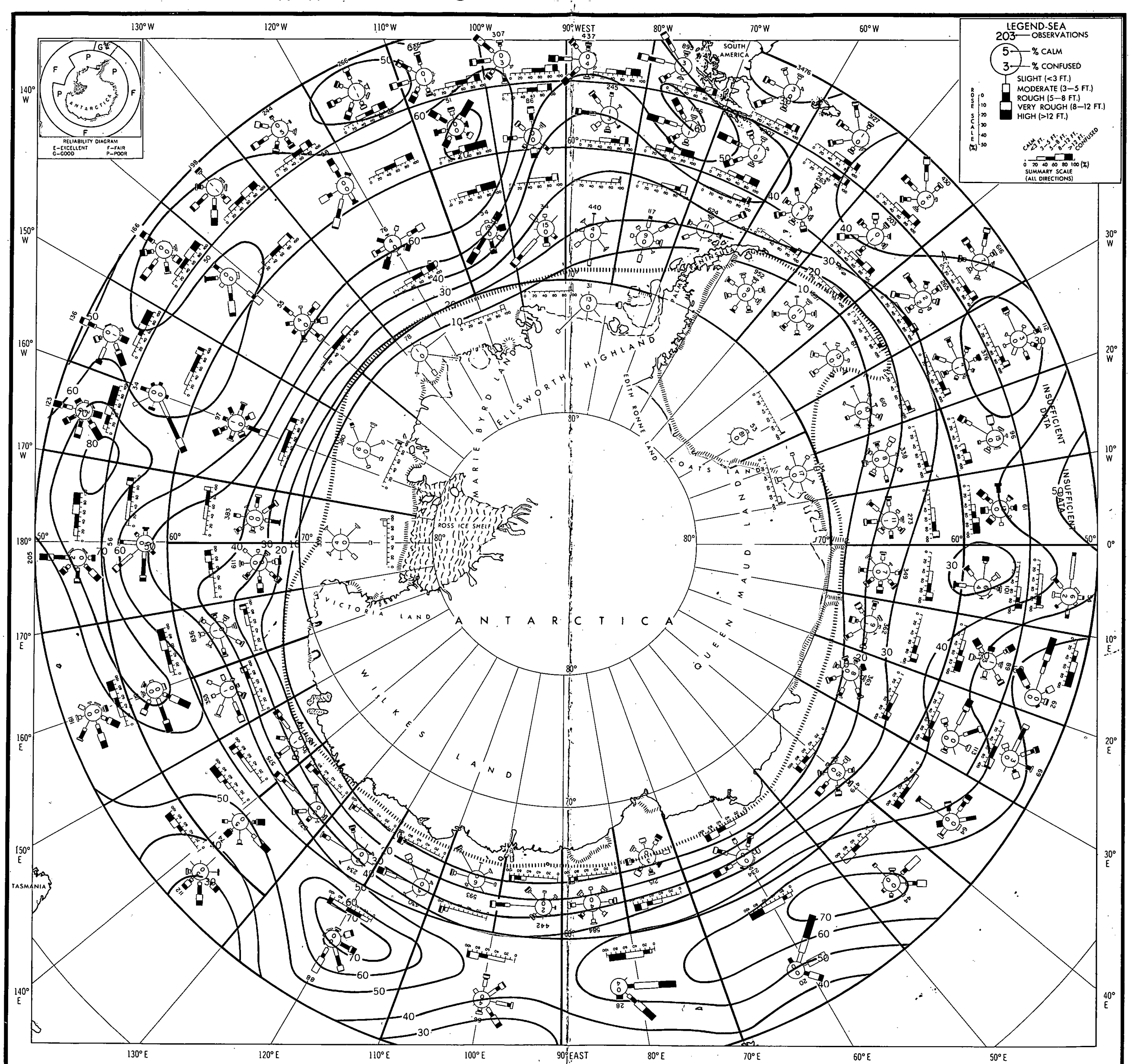

STATE OF SEA, SUMMER (JANUARY, FEBRUARY, MARCH). Isolines show percent frequency of seas ≧5 feet.

"This November 1957 revision supersedes Figure 22–62 dated January 1956 for NIS 69, Section 22."

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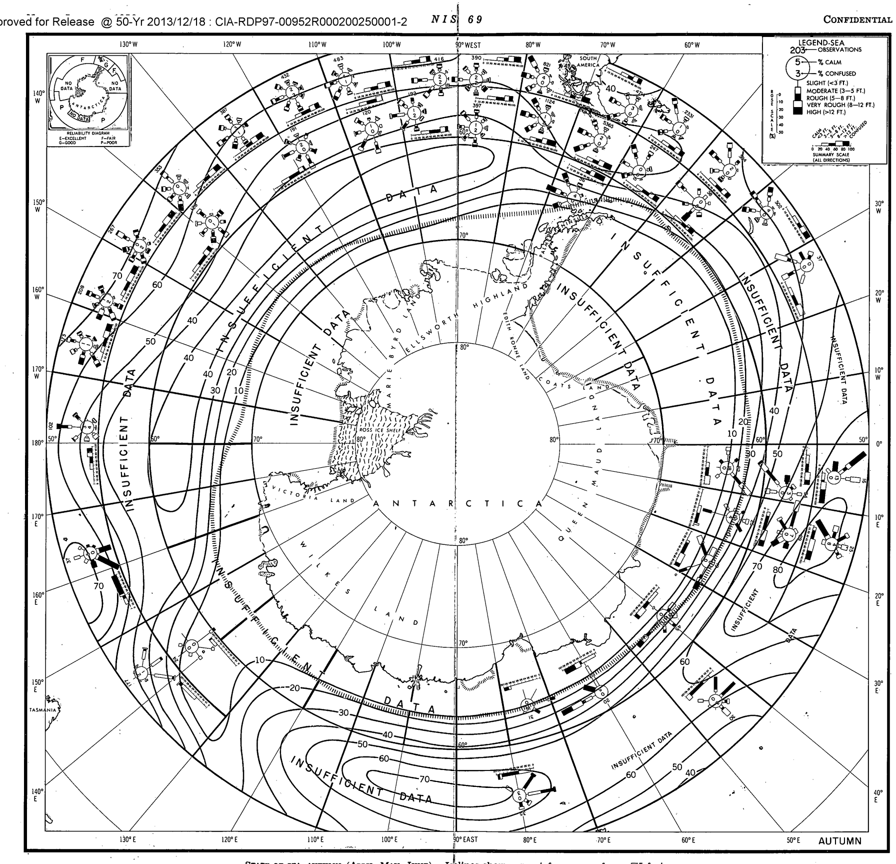
CONFIDENTIAL



STATE OF SEA, AUTUMN (APRIL, MAY, JUNE). Isolines show percent frequency of seas ≧5 feet.

50X1

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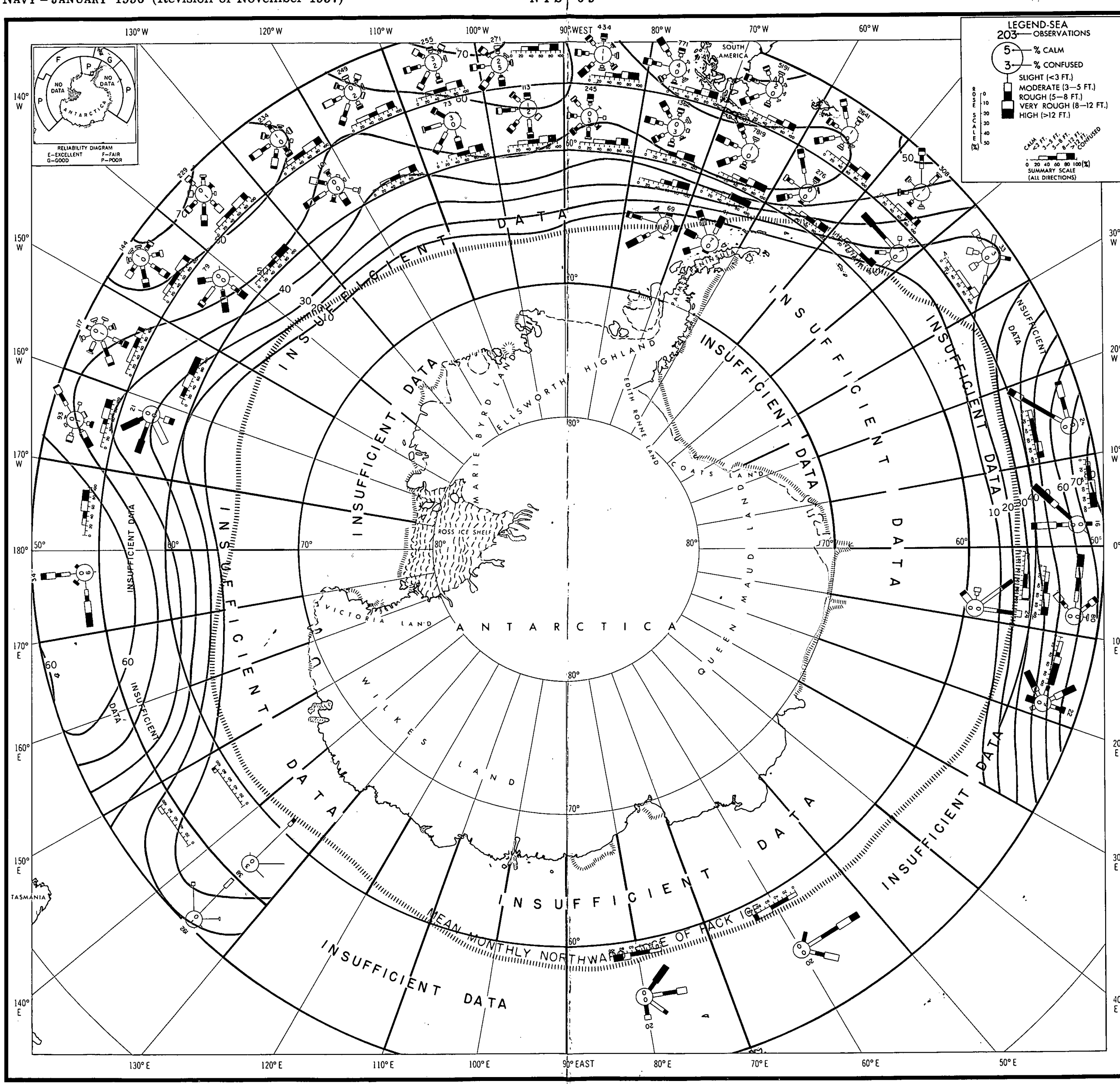

STATE OF SEA, WINTER (JULY, AUGUST, SEPTEMBER). Isolines show percent frequency of seas ≥5 feet.

"This November 1957 revision supersedes Figure 22–64 dated January 1956 for NIS 69, Section 22."

50X1

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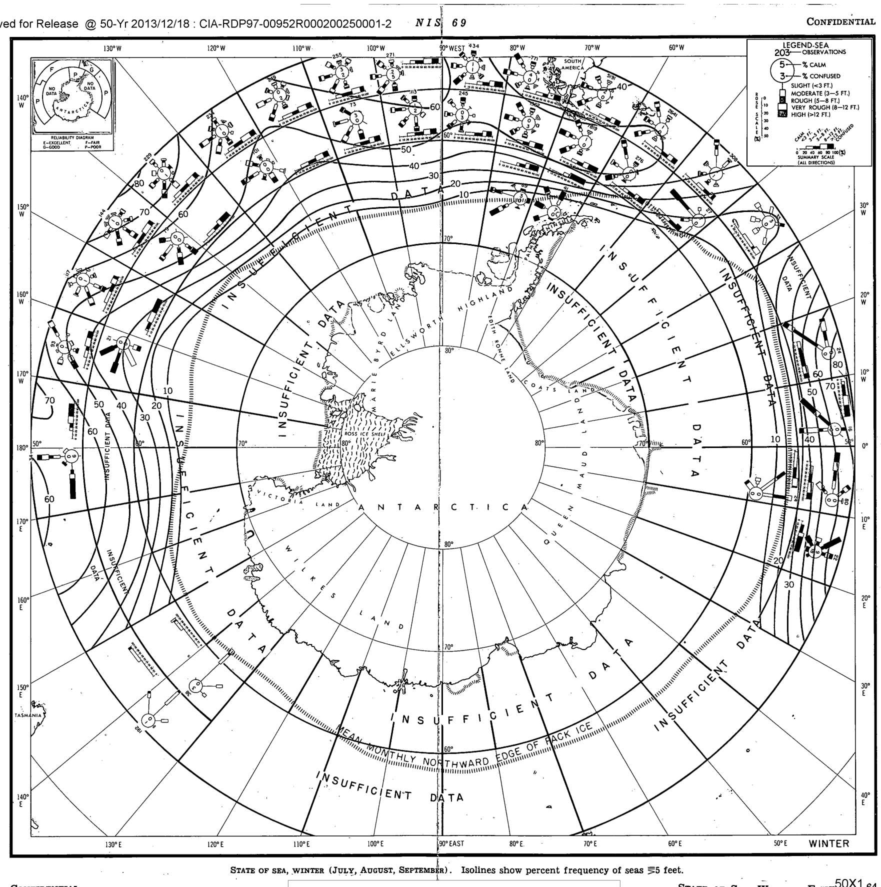

STATE OF SEA, WINTER (JULY, AUGUST, SEPTEMBER). Isolines show percent frequency of seas ≧5 feet.

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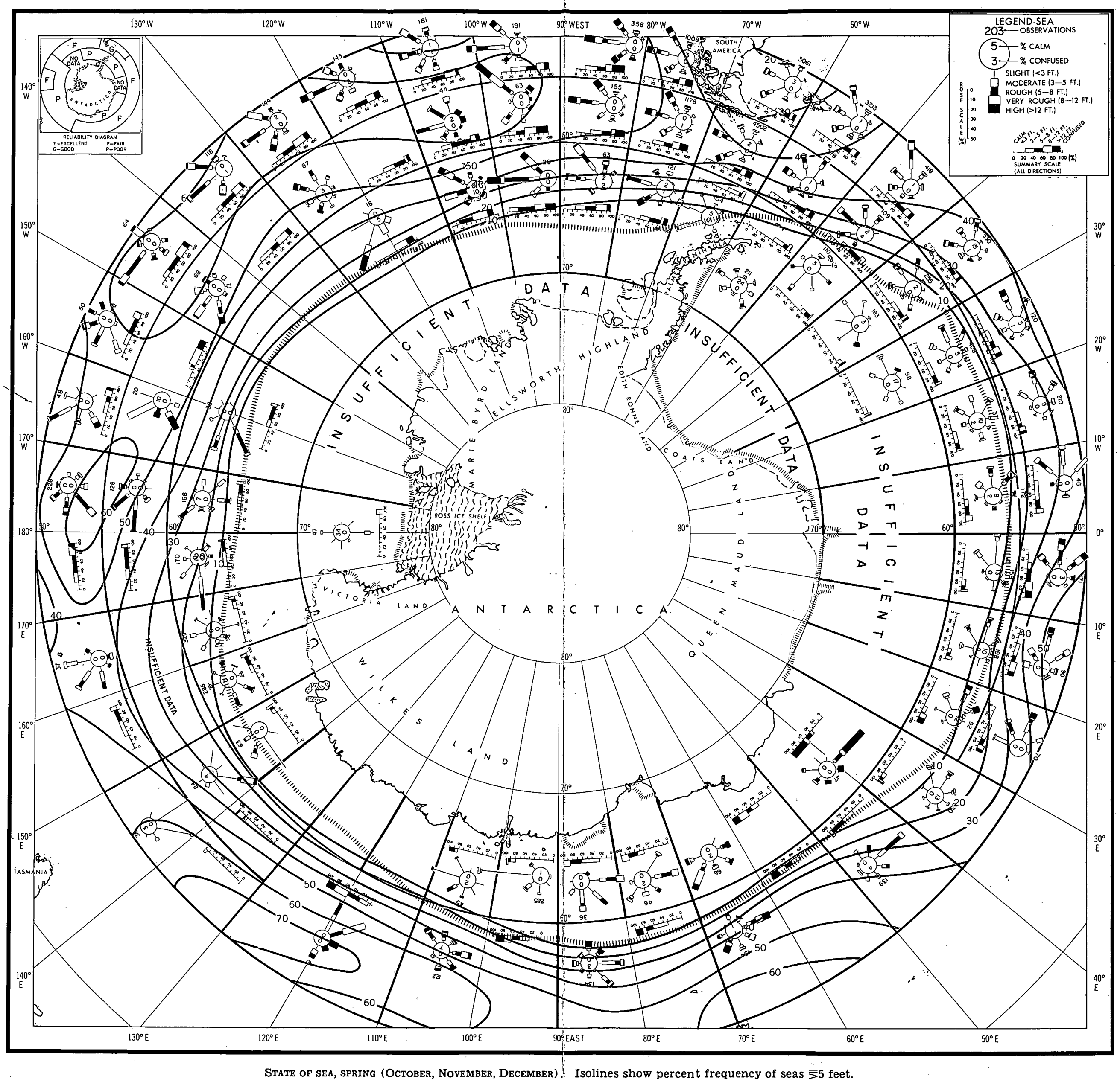

STATE OF SEA, SPRING (OCTOBER, NOVEMBER, DECEMBER). Isolines show percent frequency of seas $\geqq$5 feet.

"This November 1957 revision supersedes Figure 22–65 dated January 1956 for NIS 69, Section 22."

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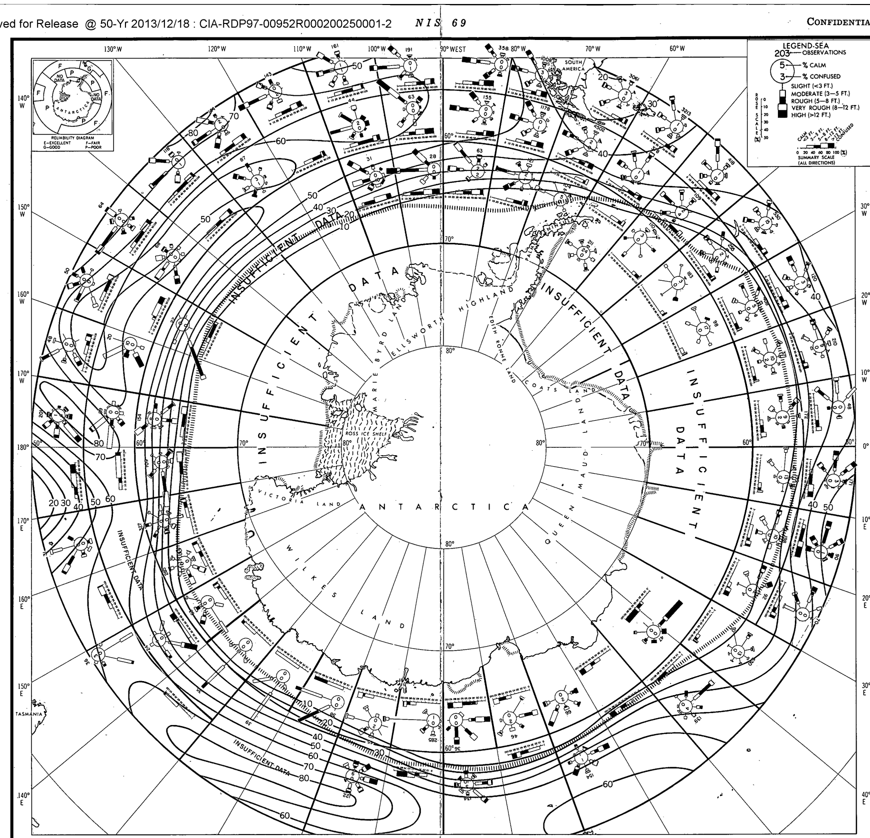

STATE OF SEA, SPRING (OCTOBER, NOVEMBER, DECEMBER). Isolines show percent frequency of seas ≧5 feet.

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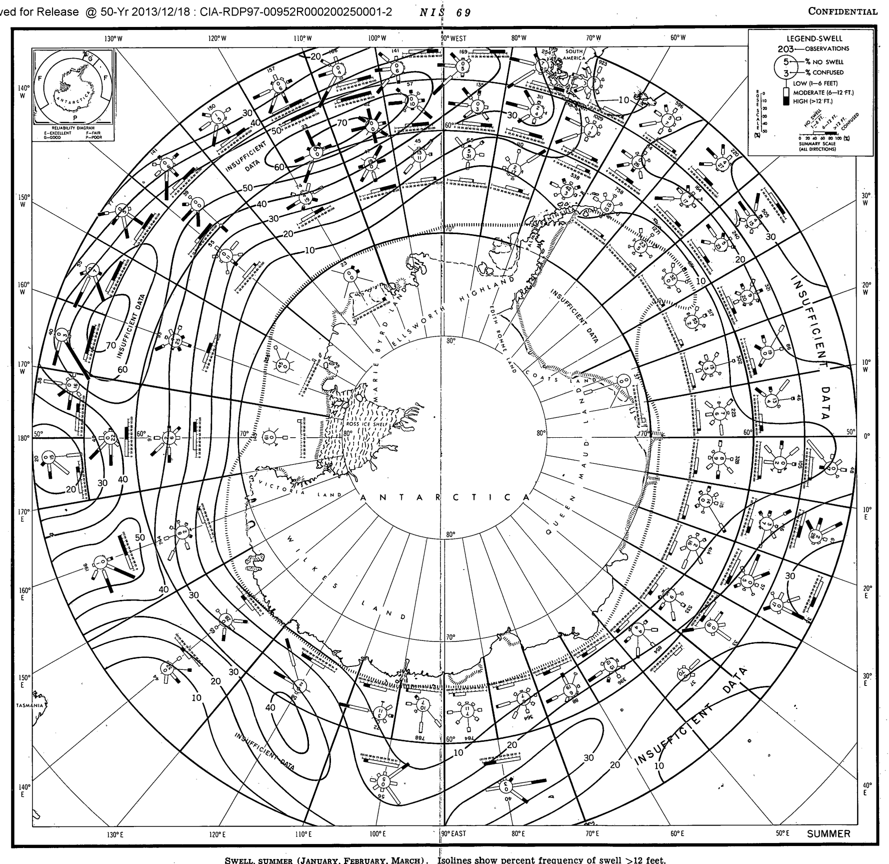

SWELL, SUMMER (JANUARY, FEBRUARY, MARCH). Isolines show percent frequency of swell >12 feet.

50X1
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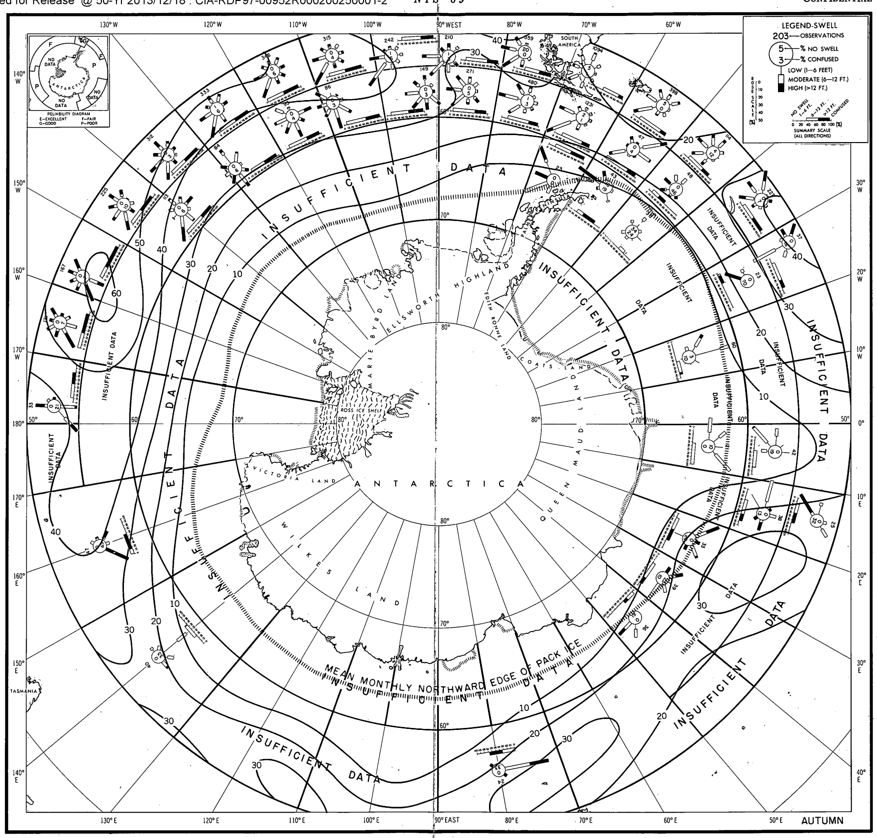

SWELL, AUTUMN (APRIL, MAY, JUNE). Isolines show percent frequency of swell >12 feet.

50X1
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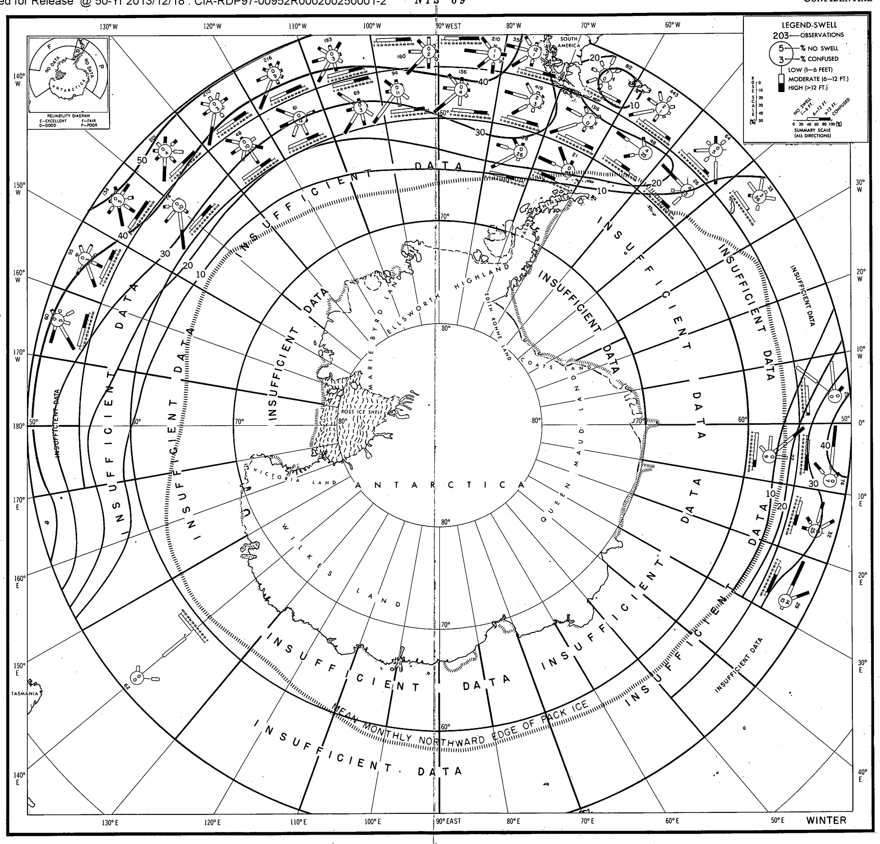

SWELL, WINTER (JULY, AUGUST, SEPTEMBER). Isolines show percent frequency of swell >12 feet.

50X1

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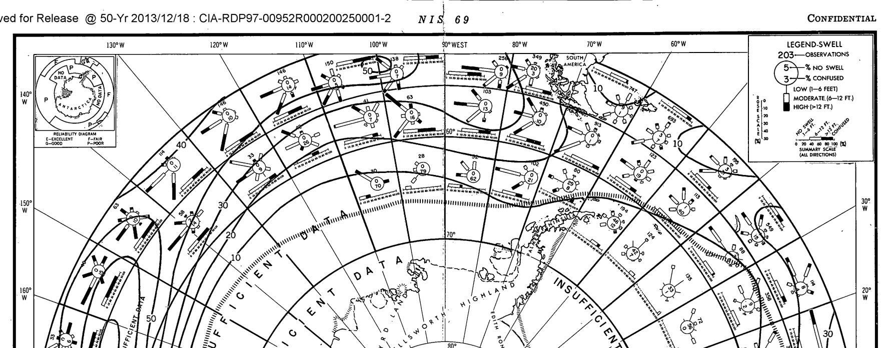

SWELL, SPRING (OCTOBER, NOVEMBER, DECEMBER). Isolines show percent frequency of swell >12 feet.

50X1

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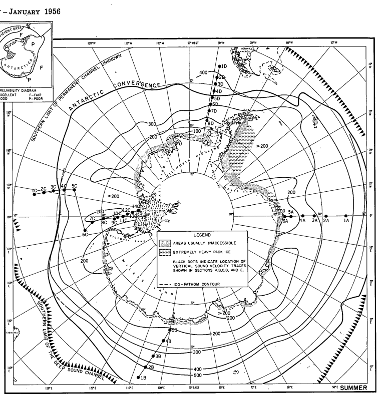
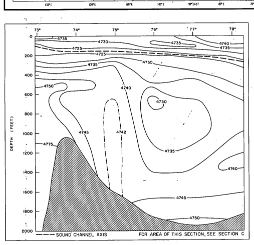
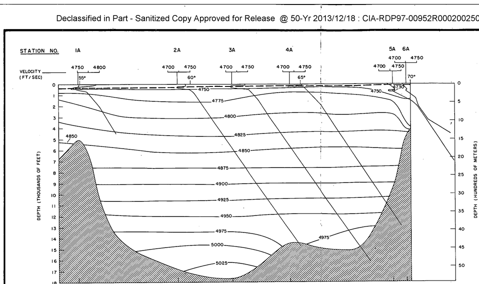


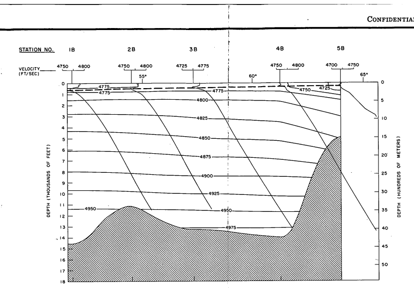
Average depth of the sound channel (feet), summer; locations of vertical sections of sound velocity



Section E. Ross Sea (Detail)



Section A. Atlantic Ocean



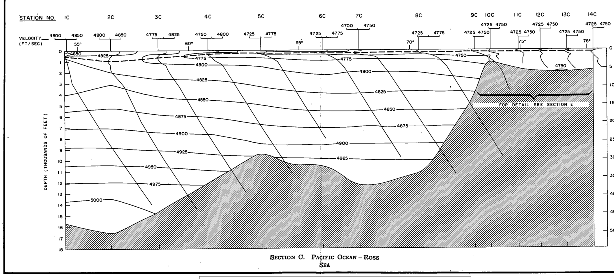
Section B. Indian Ocean

LEGEND

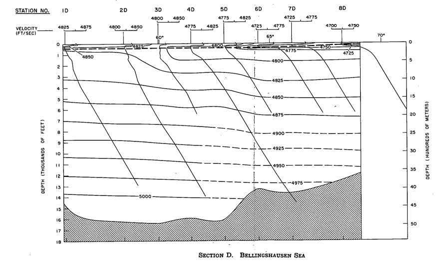
TRACES SHOW CONTINUOUS VELOCITY IN FEET PER SECOND VERSUS DEPTH AT SELECTED STATIONS.

SEE CHART AT LEFT FOR LOCATION OF SECTIONS.

SOUND CHANNEL AXIS



Section C. Pacific Ocean – Ross Sea



Section D. Bellingshausen Sea

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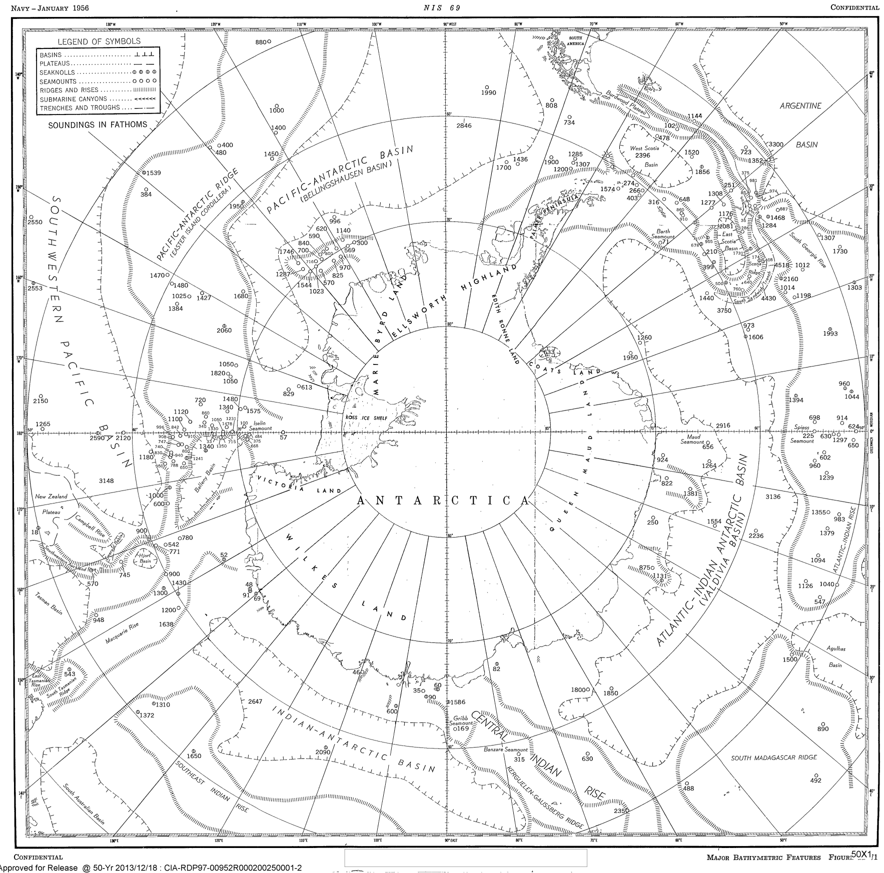

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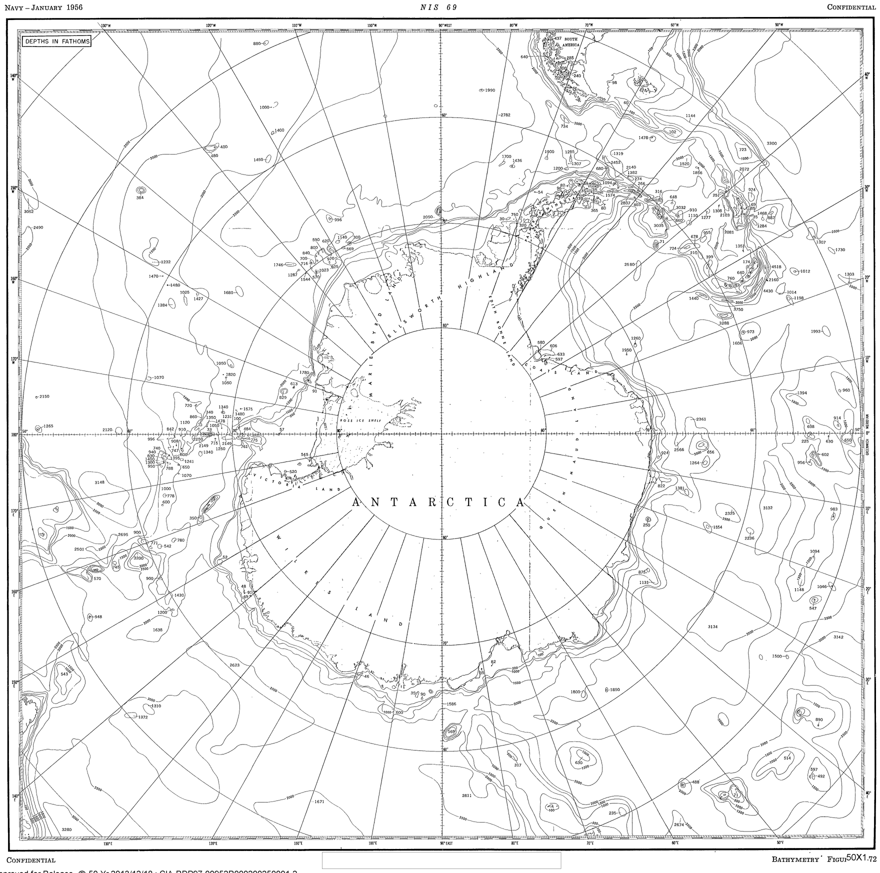

BATHYMETRY FIGU 50X1 72

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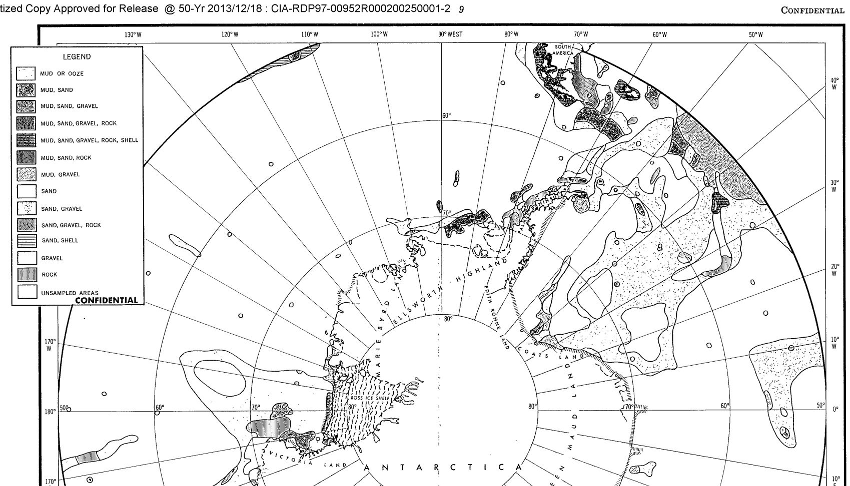
LEGEND
MUD OR OOZE
MUD, SAND
MUD, SAND, GRAVEL
MUD, SAND, GRAVEL, ROCK
MUD, SAND, GRAVEL, ROCK, SHELL
MUD, SAND, ROCK
MUD, GRAVEL
SAND
SAND, GRAVEL
SAND, GRAVEL, ROCK
SAND, SHELL
GRAVEL
ROCK
UNSAMPLED AREAS
CONFIDENTIAL
130° W
120° W
110° W
100° W
90° WEST
80° W
70° W
60° W
50° W
SOUTH AMERICA
ROSS ICE SHELF
VICTORIA LAND
ANTARCTICA
WILKES LAND
QUEEN MAUD LAND
COATS LAND
TASMANIA
130° E
120° E
110° E
100° E
90° EAST
80° E
70° E
60° E
50° E

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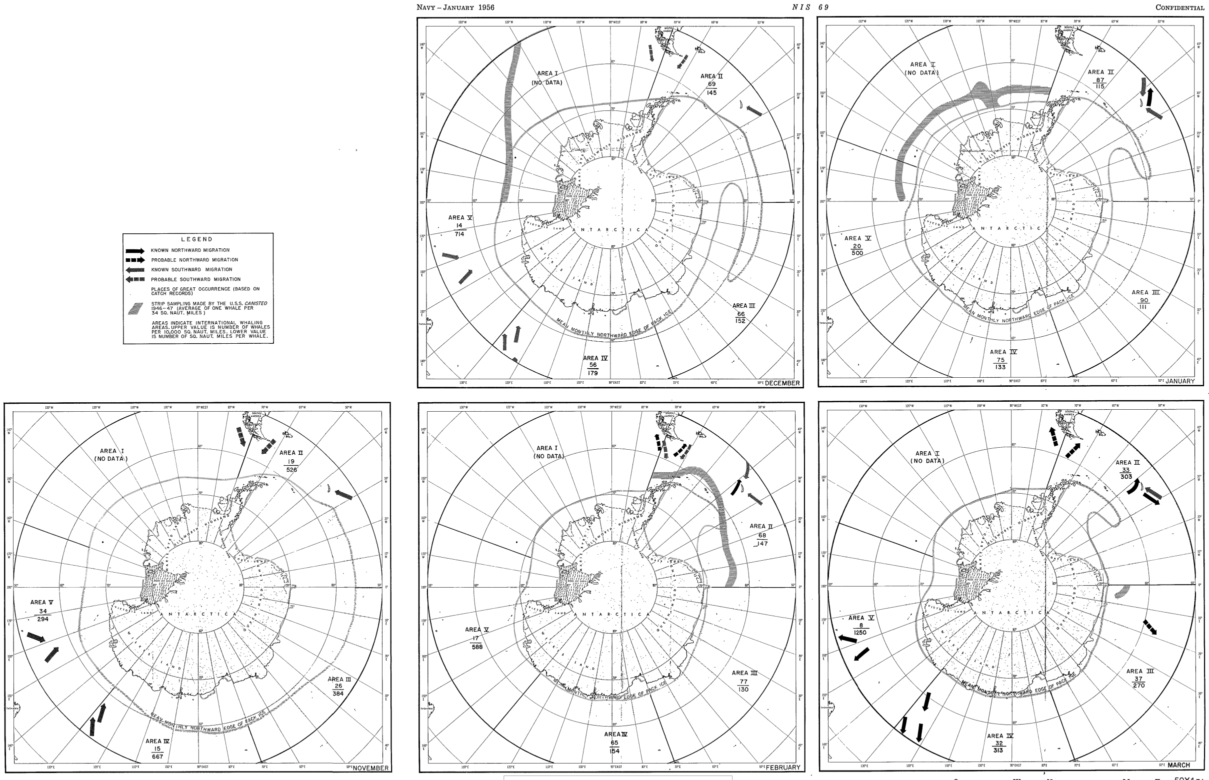

OCCURRENCE OF WHALES, NOVEMBER THROUGH MARCH FIGURE 74

50X1

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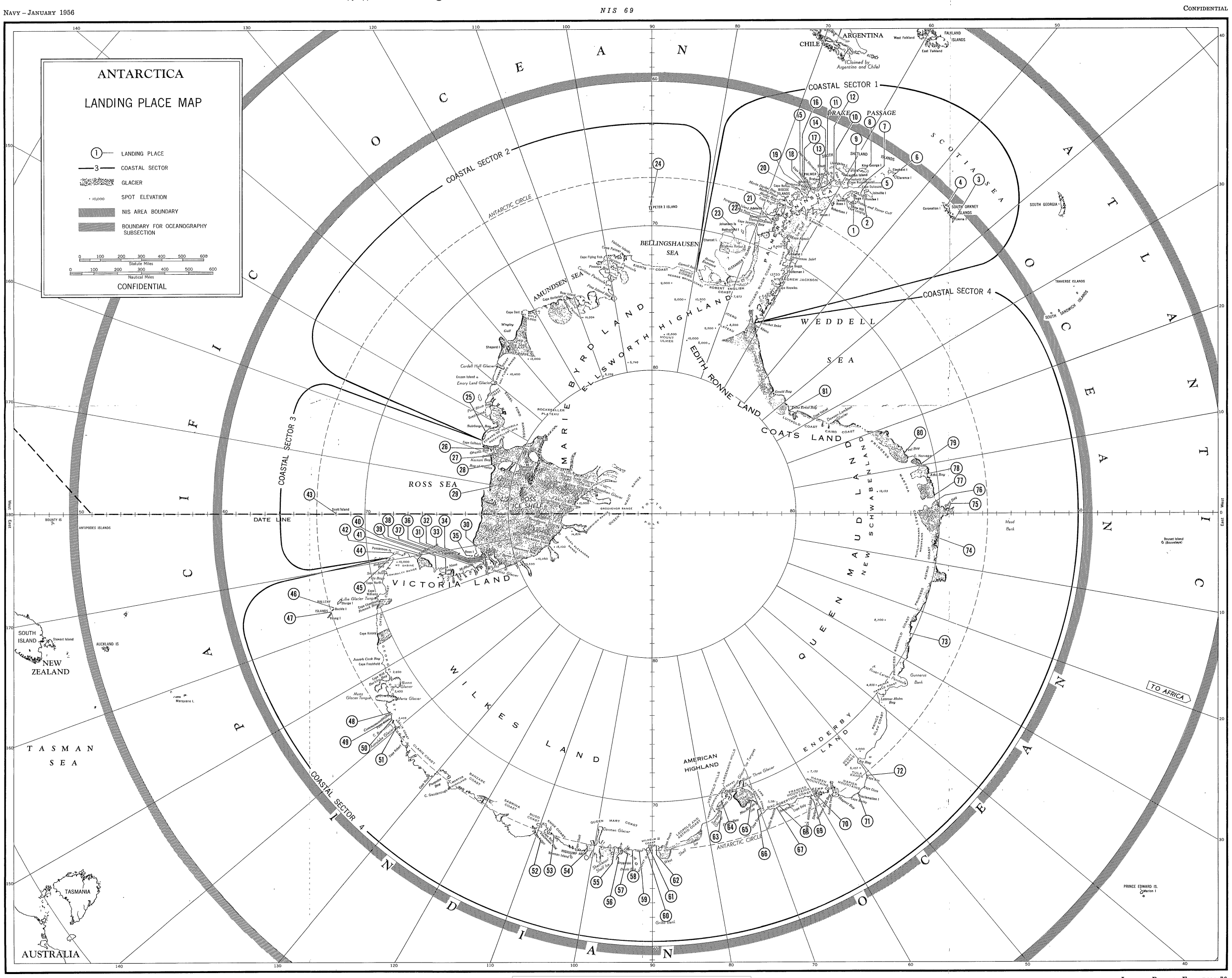
LANDING PLACES
AND
EXPEDITIONS USING EACH LANDING PLACE

Landing Place (1) Expeditions 8, 9, and 35
Landing Place (2) Expeditions 38 and 42
Landing Place (3) Expeditions 13, 34, 46, 50, 51, and 57
Landing Place (4) Expeditions 46 and 49
Landing Place (5) Expeditions 46 and 51
Landing Place (6) Expedition 31
Landing Place (7) Expeditions 50 and 58
Landing Place (8) Expeditions 51 and 52
Landing Place (9) Expedition 8
Landing Place (10) Expeditions 27, 35, 45, 46, 51, and 52
Landing Place (11) Expedition 5
Landing Place (12) Expeditions 5 and 50
Landing Place (13) Expeditions 50, 51, and 52
Landing Place (14) Expedition 22
Landing Place (15) Expeditions 5 and 52
Landing Place (16) Expeditions 5, 34, 37, 45, 51, and 57
Landing Place (17) Expeditions 1 and 50
Landing Place (18) Expedition 12
Landing Place (19) Expedition 15
Landing Place (20) Expeditions 37, 47, and 51
Landing Place (21) Expedition 37
Landing Place (22) Expeditions 43, 44, 47, 50, 51, and 55
Landing Place (23) Expedition 57
Landing Place (24) Expeditions 24, 53, and 54
Landing Place (25) Expedition 18
Landing Place (26) Expedition 18
Landing Place (27) Expeditions 18 and 61
Landing Place (28) Expeditions 6, 16, 18, 23, 25, 32, 33, 43, 48, 54, and 61
Landing Place (29) Expeditions 23 and 32
Landing Place (30) Expeditions 6 and 10
Landing Place (31) Expedition 10
Landing Place (32) Expeditions 17 and 21
Landing Place (33) Expedition 14
Landing Place (34) Expeditions 3 and 6
Landing Place (35) Expedition 11
Landing Place (36) Expedition 17
Landing Place (37) Expedition 14
Landing Place (38) Expedition 10
Landing Place (39) Expedition 17
Landing Place (40) Expedition 6
Landing Place (41) Expedition 6
Landing Place (42) Expedition 6
Landing Place (43) Expedition 11
Landing Place (44) Expeditions 3, 4, 6, and 11
Landing Place (45) Expeditions 4, 6, and 17
Landing Place (46) Expedition 59
Landing Place (47) Expedition 56
Landing Place (48) Expeditions 20, 28, and 59
Landing Place (49) Expedition 59
Landing Place (50) Expedition 59
Landing Place (51) Expedition 2
Landing Place (52) Expedition 54
Landing Place (53) Expedition 54
Landing Place (54) Expedition 54
Landing Place (55) Expedition 54
Landing Place (56) Expedition 54
Landing Place (57) Expedition 20
Landing Place (58) Expedition 54
Landing Place (59) Expedition 54
Landing Place (60) Expedition 54
Landing Place (61) Expedition 54
Landing Place (62) Expedition 7
Landing Place (63) Expeditions 36 and 42
Landing Place (64) Expedition 42
Landing Place (65) Expedition 29
Landing Place (66) Expedition 29
Landing Place (67) Expeditions 38, 39, and 40
Landing Place (68) Expedition 28
Landing Place (69) Expedition 28
Landing Place (70) Expedition 39
Landing Place (71) Expedition 28
Landing Place (72) Expedition 26
Landing Place (73) Expedition 30
Landing Place (74) Expedition 41
Landing Place (75) Expedition 61
Landing Place (76) Expedition 41
Landing Place (77) Expedition 41
Landing Place (78) Expedition 61
Landing Place (79) Expedition 60
Landing Place (80) Expedition 61
Landing Place (81) Expedition 19

EXPEDITIONS

1. Biscoe Expedition, British, 1830–32
2. D'Urville Expedition, French, 1837–40
3. Ross Expedition, British, 1839–40
4. Kristensen and Bull Expedition, Norwegian, 1894–95
5. De Gerlache Expedition, Belgian, 1897–99
6. Borchgrevink Expedition, British, 1898–1900
7. Drygalski Expedition, German, 1901–03
8. Nordenskjold Expedition, Swedish, 1901–04
9. Irizar Relief Expedition, Argentine, 1903
10. Scott Expedition, British, 1901–04
11. Colbeck Relief Expedition, British, 1902–03
12. Charcot Expedition, French, 1903–05
13. First Annual Resupply Expedition, Argentine, 1904
14. Shackleton Expedition, British, 1907–09
15. Charcot Expedition, French, 1908–10
16. Amundsen Expedition, Norwegian, 1910–12
17. Scott Expedition, British, 1910–13
18. Choku Shirase Expedition, Japanese, 1911–12
19. Filchner Expedition, German, 1911–12
20. Mawson Expedition, Australian-British, 1911–14
21. Shackleton Expedition, British, 1914–16
22. Cope Expedition, British, 1921–22
23. C. A. Larsen Expedition, Norwegian, 1923–24
24. Lars Christensen under Nils Larsen, Norwegian, 1928–29
25. Byrd Expedition, American, 1928–30
26. Lars Christensen under Riiser-Larsen, Norwegian, 1929–30
27. Wilkins Expedition, British-American, 1929–30
28. Mawson Expedition, British-Australian-New Zealand, 1929–31
29. Lars Christensen, Norwegian, 1931
30. Lars Christensen, Norwegian, 1932–33
31. Discovery Investigations under John, British, 1931–33
32. Byrd Expedition, American, 1933–35
33. Ellsworth Expedition, American, 1933–34
34. Discovery Investigations under Mackintosh, British, 1933–35
35. Ellsworth Expedition, American, 1934–35
36. Lars Christensen under Mikkelsen, Norwegian, 1934–35
37. Rymill Expedition, British, 1934–37
38. Ellsworth Expedition, American ,1935–36
39. Discovery Investigations under Rayner, British, 1935–36
40. Lars Christensen, Norwegian, 1936–37
41. Ritscher Expedition, German, 1938–39
42. Ellsworth Expedition, American, 1938–39
43. Byrd Expedition, American, 1939–41
44. Harriague Expedition, Argentine, 1943
45. Marr Expedition, British, 1943–45
46. Taylor Expedition, British, 1945–46
47. Bingham Expedition, British, 1946–47
48. Operation Highjump, American, 1946–47
49. Toro Expedition, Chilean, 1947
50. Garcia Expedition, Argentine, 1947
51. Butler Expedition, British, 1947–48
52. Hermelo Expedition, Argentine, 1947–48
53. Nils Larsen Expedition, Norwegian, 1947–48
54. Operation Windmill, American, 1947–48
55. Ronne Expedition, American, 1947–48
56. Campbell Expedition, Australian, 1947–50
57. Fuchs Expedition, British, 1948–49
58. Fontaine Expedition, Chilean, 1948–49
59. Liotard Expedition, French, 1948–50
60. Joint Expedition, Norwegian-British-Swedish, 1949–50
61. U. S. S. Atka, American, 1954–55



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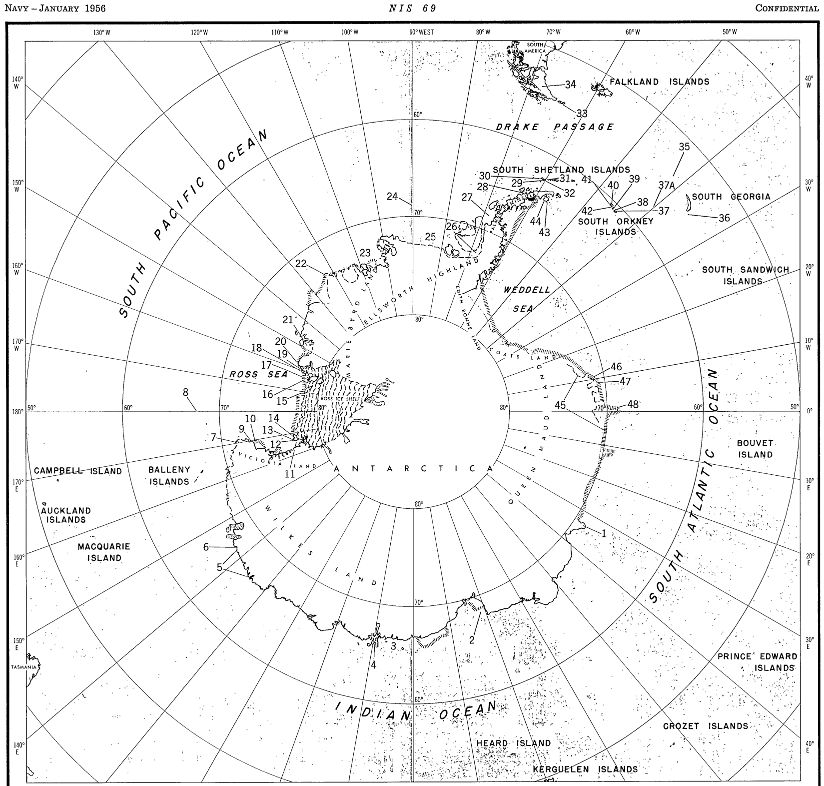
KEY TO PLACES INDICATED ON FIGURE 22–75

NUMERICAL LIST	ALPHABETICAL LIST
1. Riiser-Larsen Peninsula	Adare, Cape (*7*)
2. MacKenzie Bay	Adélie Coast (*5*)
3. Davis Sea	Admiral Richard E. Byrd Bay (*48*)
4. Shackleton Ice Shelf	Amundsen Sea (*23*)
5. Adélie Coast	Atka Bay (*47*)
6. Commonwealth Bay	Bay of Whales (*16*)
7. Cape Adare	Beaufort Island (*13*)
8. Scott Island	Bellingshausen Sea (*25*)
9. Cape Jones	Bird, Cape (*12*)
10 Coulman Island	Clerke Rocks (*36*)
11. McMurdo Sound	Clothier Harbor (*30*)
12. Cape Bird	Colbeck, Cape (*20*)
13. Beaufort Island	Commonwealth Bay (*6*)
14. Ross Island	Coronation Island (*42*)
15. Discovery Inlet	Coulman Island (*10*)
16. Bay of Whales	Dart, Cape (*22*)
17. Little America	Davis Sea (*3*)
18. Kainan Bay	Discovery Inlet (*15*)
19. Okuma Bay	George VI Sound (*26*)
20. Cape Colbeck	Isla de los Estados (*33*)
21. Sulzberger Bay	Jones, Cape (*9*)
22. Cape Dart	Kainan Bay (*18*)
23. Amundsen Sea	Larsen Islands (*41*)
24. Peter I Island	Lewthwaite Strait (*39*)
25. Bellingshausen Sea	Little America (*17*)
26. George VI Sound	Lockyer Island (*44*)
27. Marguerite Bay	Mackenzie Bay (*2*)
28. Paradise Harbor	Marguerite Bay (*27*)
29. Port Foster	McMurdo Sound (*11*)
30. Clothier Harbor	Norsel Bay (*46*)
31. Robert Island	Okuma Bay (*19*)
32. Yankee Harbor	Paradise Harbor (*28*)
33. Isla de los Estados	Peter I Island (*24*)
34. Tierra del Fuego	Port Foster (*29*)
35. Shag Rocks	Princess Martha Coast (*45*)
36. Clerke Rocks	Riiser-Larsen Peninsula (*1*)
37. Scotia Bay	Robert Island (*31*)
37A. Scotia Sea	Ross Island (*14*)
38. Washington Strait	Scotia Bay (*37*)
39. Lewthwaite Strait	Scotia Sea (*37A*)
40. Spine Islet	Scott Island (*8*)
41. Larsen Islands	Shackleton Ice Shelf (*4*)
42. Coronation Island	Shag Rocks (*35*)
43. Snow Hill Island	Snow Hill Island (*43*)
44. Lockyer Island	Spine Islet (*40*)
45. Princess Martha Coast	Sulzberger Bay (*21*)
46. Norsel Bay*	Tierra del Fuego (*34*)
47. Atka Bay*	Washington Strait (*38*)
48. Admiral Richard E. Byrd Bay*	Yankee Harbor (*32*)

* Location and name not verified by the U.S. Board on Geographic Names.



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