Technical Note N-840

"ICE AND SNOW TERRAIN FEATURES McMURDO STATION, ANTARCTICA"

BY

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U. S. NAVAL CIVIL ENGINEERING LABORATORY
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ICE AND SNOW TERRAIN FEATURES -

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ABSTRACT

The ice and snow terrain around McMurdo Station, Antarctica, is used extensively by the U. S. Navy Antarctic Support Forces for runways, temporary camps, travel and cargo-hauling routes, and occasionally as docking areas for cargo ships. The safe and efficient use of this terrain requires the recognition and solution of many problems caused by a variety of factors, such as climate, topography, internal and external changes in the ice and snow areas, movement of the ice shelf, and annual breakout of the sea and shelf ice.

Movement of the McMurdo Lobe of the Ross Ice Shelf causes pressure ridges, crevasses, and periodic calving that requires careful selection of runway sites and road routes to assure safe and long-term operations. Movement of the ice shelf between Pram Point and Williams Field varies from 230 to 281 feet per year. The probable critical thickness beyond which the ice shelf does not calve varies between 90 to 100 feet west of Williams Field to 50 or 60 feet near Pram Point. Hidden subsurface melt pools occur in the glacier ice at Outer Williams Field and, during summer, seriously hamper trafficability of the alternate ice runway at this location.

Dangerous sea ice conditions are caused by late-season differential thinning and deterioration, seal breathing holes, hidden slush zones in deep snow, pressure ridges and flooded, downwarped areas of ice in the embayment south of McMurdo Station. Sea-ice-to-land and sea-ice-to-ice shelf ramps require almost constant repair to maintain the necessary over-ice road network.

INTRODUCTION

The ice and snow terrain around McMurdo Station, Antarctica, is used extensively by the U. S. Navy Antarctic Support Forces for runways, temporary camps, travel and cargo-hauling routes and, occasionally, as docking areas for cargo ships. This terrain includes the Ross Ice Shelf south and east of McMurdo Station and the annual sea ice on McMurdo Sound. Past experience emphasizes the need for more knowledge concerning the characteristics of this constantly changing ice and snow environment. The efficiency and safety of operations in this area are affected by a variety of factors, such as climate, topography, internal and external changes in the ice and snow areas, movement of the ice shelf, and annual breakout of the sea and shelf ice.

This technical note discusses the ice and snow terrain around McMurdo Station. The important natural and cultural features are shown as they existed in December 1965. Some of these features change more than others. For example, the pressure zones on the ice shelf change very little from year to year; however, the position or configuration of the ice shelf edge changes constantly. Occasionally, the sea ice in the embayment south of Cape Armitage may remain for two or more seasons; in other years, it may go out completely.

LOCATION AND PHYSICAL SETTING

McMurdo Sound is located at the western extremity of the Ross Ice Shelf and is part of the Ross Sea that is bounded on the east by Ross Island, the west by the mountains of Victoria Land, and the south by the Ross Ice Shelf. McMurdo Station and Scott Base are located on Ross Island near the tip of Hut Point Peninsula (Figure 1).

The climate of the McMurdo Sound region is characterized by low temperatures, frequent high winds, and drifting snow. Mean annual temperatures for the years 1956 to 1961 vary from -1.3 to 1.8°F, with a mean for the 6 years of -0.1°F. The coldest temperatures occur in July and August, and vary from -40 to -59°F. Maximum temperatures occur in December and January, and can be as high as 42°F (Climatology of McMurdo Sound, 1961).

The freezing index is the number of degree days during a freezing season and is one of the best methods of expressing the duration and intensity of cold. The degree days for any one day equals the difference between the average daily air temperature and 32°F (Linell, 1953, p. 19). The freezing index at McMurdo Station is approximately 13,300 degree days as compared with Point Barrow, Alaska, with a freezing index of 8,500 degree days (Pewe and Paige, 1963, p. 366).

MAPPED AREA

The map in Figure 2 covers approximately 90 square miles of the Ross Ice Shelf, McMurdo Sound, and a small part of Ross Island. The ice shelf south and west of Hut Point Peninsula and east to a line connecting the northern tip of White Island with Cape Mackay is significantly different from the rest of the Ross Ice Shelf and has been called the McMurdo Lobe by MacDonald and Hatherton (1961, p. 861) (Figure 1). South of Hut Point Peninsula, McMurdo Sound forms a kidney-shaped embayment about 4 miles across and 6 miles long that is covered with sea ice for at least 10 months each year. Hut Point Peninsula is a part of Ross Island that has a maximum width of about 3 miles and extends 11 miles southward from the main mass of the island.

To develop the map shown in Figure 2, primary triangulation stations on the ice shelf and the sea ice were used for control points to locate the principal features and to measure the movement of the ice shelf and the sea ice. The stations were established from a base line on Hut Point Peninsula between well-established triangulation stations at Hut Reset, Observation Hill, and Scott Base "J". Distances and angles between the base line and the primary triangulation stations were measured by a U. S. Geological Survey Electrotape crew on 27 October 1965, and on 15 January 1966. Secondary points, such as roads, runways, and other cultural features, were located by transit and from vertical airphotos having a scale of 1 inch to 5,000 feet. All snow and ice features were visited and examined in the field.

McMURDO LOBE OF THE ROSS ICE SHELF

The McMurdo Lobe of the Ross Ice Shelf and the sea ice in the embayment south of Hut Point Peninsula constantly change in response to the seasons and to westward movement of the ice shelf. Many features are temporary and new features may appear at any time. With the exception of dated features, the map in Figure 2 is correct as of December 1965. Features that are marked and dated are correct only as of the indicated date.

Movement

Starting in 1957, preliminary movement studies of the ice shelf near Scott Base indicated a westward component of approximately 272 feet per year (MacDonald and Hatherton, 1961, p. 864). These studies were expanded by Stuart and Bull (1963) who showed a westward movement varying from 300 to 340 feet per year (p. 405). Heine is continuing the measurements and records a rate varying from 295 to 335 feet per year for three stations about 2 miles east of Scott Base.*

During the austral summer of 1965-66, the NCEL survey included five stations (A, B, C, D and NCEL on Figure 2) placed around the edge of the ice shelf. A sixth station (1 on Figure 2) was located on annual sea ice south of Cape Armitage near the center of the embayment. Measurements 75 days apart at these stations (Table 1) indicate that the westward movement along the edge of the ice shelf decreases from 281 feet per year at Station A to no movement at Station D, located 4.7 miles west of Station A. This difference indicates that the westward movement of the ice shelf in this area decreases about 60 feet per year per mile. As these observations cover a period of only 75 days, the annual movement rates are subject to revision following long-term observations.

Thickness

Very little is known about the thickness of the McMurdo Lobe because of the scarcity of direct measurements. MacDonald and Hatherton (1961, p. 863) were the first to discuss thickness changes near Scott Base in considering the equilibrium of the ice shelf as it moved towards Hut Point Peninsula. Stuart and Bull (1963, p. 409) used data collected from pits, bore holes, and surface elevations to show that the ice shelf is strongly wedge-shaped, with drastic thinning towards Scott Base. The height of the ice shelf edge around the McMurdo Sound embayment rises from 8 feet near Pram Point to 20 feet at Station A, and then diminishes to only 3 feet at Station D (Figure 2). Direct measurements from two drill holes during the austral summer of 1965-66 show that the ice shelf thins from 164 feet at Williams Field to 48 feet at the edge of the ice shelf near Pram Point (Figure 3).

Line A - A' in Figure 3 shows the rate of thinning between the two drill holes to be 116 feet in 2.54 miles. Line A - B - B' shows the extrapolated thickness of the ice shelf based on surface elevations. The surface elevation at the Williams Field drill-hole site (Point A)

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*Heine, A. J., 1966, personal communication

Table 1. Observed and Computed Daily and Yearly Movement of the NCEL Stations Along the Edge of the Ice Shelf and on the Sea Ice Near McMurdo Station, Antarctica.

Station	75-Day Observed Movement	Computed Movement (ft per day)	Computed Movement (ft per year)	Direction
Ice Shelf Edge South of Hut Point Peninsula				
NCEL	54.8	0.73	266.4	West
A	58.0	0.77	281.0	West
B	47.2	0.63	230.0	West
C	14.6	0.19	69.4	West
D	None	--	--	--
Sea Ice South of Cape Armitage				
1	46.7	0.62	226.3	West

is 45 feet above sea level; the surface at the 1965-66 shelf edge (Point B) was 20 feet above sea level; and, during the austral summer of 1963-64, the shelf edge (Point B') was 10 feet above sea level. Using the same bottom slope obtained between Points A and A' for line A - B - B', the thickness of the ice shelf at Point B is about 90 feet at B and about 55 feet at B'. This extrapolation indicates a thickness decrease of about 109 feet in 2.1 miles.

The rapid thinning of the McMurdo Lobe as it moves westward has been attributed to bottom melting caused by warm currents (MacDonald and Hatherton, 1961, p. 863) (Stuart and Bull, 1963, p. 412). Gilmour (1963, p. 417) records the seawater temperatures in McMurdo Sound and calculates the melting potential as the water moves eastward under the shelf. The temperature of the upper 16 feet of the seawater begins to rise rapidly in mid-December and peaks at $-1.42^{\circ}C$ (the melting point of sea ice is $-1.8^{\circ}C$) by mid-January. This temperature rise occurred in 1961 even though the surrounding several square miles of water was still covered with sea ice (Tressler and Ommundsen, 1961, p. 33).

The changing location of the ice shelf edge between 1962 and 1966 is shown in Figure 4. Extensive calving of the ice shelf is probably related to a critical thickness that occurs periodically as the shelf moves westward into McMurdo Sound. This critical thickness is apparently 90 to 100 feet for the shelf area west of the DF-66 Williams Field Air Facility (Point B) but decreases to 50 or 60 feet near Pram Point (Point A). There is no record of calving having occurred farther eastward than the February 1966 ice shelf edge where the thickness varied from 90 feet at Point B to about 55 feet at Point A.

Pressure Zones

Pressure zones occur in only two areas on the ice shelf shown on the map in Figure 2. The largest and most prominent pressure zone is adjacent to Hut Point Peninsula north of Scott Base. The pressure ridges in this zone trend generally north-south (Figure 5). This pressure zone is circumnavigated by the snow road between Scott Base and the DF-66 Williams Field Air Facility (Figure 2).

The second zone of pressure ridges on the ice shelf is located across the embayment south of Cape Armitage. These are smaller and less dangerous than those near Scott Base but still cause rough travel conditions for tracked vehicles.

Crevasses

Crevasses are generally rare on the McMurdo Lobe. In the area shown in Figure 2, they were found mostly in the pressure zones where they occurred both parallel with, and normal to, the crests of the pressure ridges. Most of these pressure zone crevasses were fairly small and were seldom more than 15 to 20 feet deep; however, they present some danger both to walking personnel and to vehicles.

Five crevasses not associated with the pressure zones were found in the mapped area. They were 4 to 6 feet wide and 30 to 50 feet deep. They were bridged by 1 or 2 feet of drifted snow that often sagged downward during the summer and offered some clue to their presence (Figure 6). These crevasses are especially dangerous because they are usually as wide at the bottom as at the top.

Snow-Ice Transition Zone

The ice shelf south of the embayment and west of Observation Hill is in a transition zone between positive and negative accumulation areas. To the east of this zone, annual accumulation of snow exceeds ablation; to the west, ablation exceeds accumulation. The transition zone between the two areas is about 4,000 feet wide where the snow becomes progressively thinner westward. The transition zone in Figure 2 has an extremely rough snow surface caused by intense differential ablation during the summer (Figure 7).

Glacier Ice

West of the transition zone, the glacier ice is covered with thin, patchy drifts of snow. An ice runway (Figure 8), designated as Outer Williams Field (Figure 2), was located in this area during the summer of 1965-66. The surface of this glacier ice is fairly smooth except for a hummocky ice topography with a relative relief of 1 or 2 feet. By mid-summer, however, subsurface melt pools form that are usually at least 3 feet deep and may span circular areas if 50 to 70 feet. These pools are attributed to the greenhouse effect of solar radiation on the ice and occur beneath the surface. The ice over the pools thins to as little as 3 inches and, during late December and early January, the area becomes almost impassable even for light tracked vehicles. These subsurface melt pools are a major obstacle in utilizing the new Outer Williams Field glacier ice runway.

SEA ICE ON McMURDO SOUND

The embayment on McMurdo Sound south of Hut Point Peninsula (Figure 2) is covered with sea ice for at least 10 months each year. The maximum breakout commonly occurs in late January or in February and the sea begins to freeze over again by late March (Heine, 1963, p. 399). The annual sea ice is used extensively throughout most of the summer season for travel routes and runways. The sea ice runways and roads (Figure 2) are usually abandoned late in the season when the ice becomes too thin for safe use.

Movement

Observations 75 days apart at Station 1 (Figure 2) showed a westward movement of 46.7 feet in the sea ice near the middle of the McMurdo Sound embayment south of Hut Point Peninsula. As shown in Table 1, this rate indicated an annual movement of 226 feet per year for the ice in this location, compared with an indicated movement of 281 feet per year at the edge of the ice shelf about 1-1/2 miles due east of Station 1. This observation demonstrates that the sea ice moves in response to pressure from the ice shelf.

Thickness and Deterioration

During the winter months, March to October, the ice sheet grows at a fairly steady rate of about 1 foot per month. In October and November, the growth rate decreases and, by mid-December, the ice reaches its maximum thickness of 8 to 11 feet. Surface melting is negligible in the McMurdo Sound area but in mid-December, the ice begins to deteriorate and thin because of bottom melting. This change is related to increasing ambient and seawater temperatures and strong solar radiation during the summer. Between mid- and early February, the ice usually begins to break up into individual floes of varying sizes. No two breakout periods occur at the same time and the breakout limits vary widely from year to year (Heine, 1963, p. 396).

Ice over the shoal water near Cape Armitage is known to become dangerous to travel because of unusually rapid thinning in mid-summer (Figure 2) (Paige and Lee, 1966, p. 10). This rapid thinning occurs at a time when the remainder of the ice in the embayment is still thick enough for safe travel. The unusual thinning is caused by shoal water and currents of 3 to 4 knots (Tressler and Ommundsen, 1962, p. 80). The anomolous thin ice in the Cape Armitage area nearly cost the lives of two men in January 1964.

Pressure Ridges and Downwarped Ice

Movement of the ice shelf forms pressure ridges (Figure 9) and downwarped areas in the sea ice. Both are common in the area from Pram Point to Cape Armitage although they can occur anywhere along the edge of the ice shelf. The magnitude and extent of the pressure ridges differ from year to year, depending on the position and configuration of the ice shelf edge. Pressure ridges generally form every year in the Pram Point-Cape Armitage area and become a definite obstacle to travel by mid-summer. Tension cracks frequently form in the swale between pressure ridges or in the areas of downwarped ice and cause flooding of the surface near the crack.

Slush Zones

The flooding of snow-covered sea ice creates slush zones in areas where the snow cover is 1 or more feet in thickness. These zones may be several hundred square yards in extent and may not be visible because of an undisturbed crust of wind-packed snow. Vehicles occasionally break through this crust and become immobilized in the slush. Otherwise, these zones are seldom dangerous to travel. Slush zones are common in the Cape Armitage-Pram Point area and along the edge of the ice shelf where snowdrifts become quite deep.

Cracks

Cracks are a common feature in sea ice and occur in one or a combination of the following forms:

1. Tidal cracks which occur at sea-ice-to-land and sea-ice-to-ice shelf contacts.
2. Dry surficial cracks that are usually narrow and penetrate only a short distance into the ice.
3. Wet working cracks that completely penetrate the ice sheet, with the ice on one side of the crack moving relative to the ice on the other side.
4. Wet cracks that do not penetrate the ice sheet but that are partly filled with brine that has drained from the adjacent ice.

Tidal cracks occur completely around the periphery of the sea ice in the McMurdo area. They are crossed by numerous travel routes (Figure 2) but become troublesome only late in the summer when they tend to widen. Cracks up to 14 inches wide have been observed in the sea ice on McMurdo Sound and were probably formed by a combination of thermal stresses, tidal and wave action, and horizontal stresses caused by movement of the ice shelf. During the summer of 1964-65, a wet, brine-filled crack 14 inches wide occurred on the crosswind sea ice runway but penetrated only 44 inches in sea ice 105 inches thick (Paige and Lee, 1965, p. 4). Because it was not a working crack, it had little effect on the load-carrying capacity of the ice sheet. The wet working cracks observed on the ice sheet reduce its load-carrying capacity about 50% in the vicinity of the crack.

Seal Breathing Holes

Seal breathing holes are rare early in the summer around McMurdo Sound and occur only in pressure-ridge areas, near tidal cracks, or in other areas of broken or disrupted ice. As the ice sheet progressively thins, seal holes appear in greater numbers but are still somewhat restricted to the area off Cape Armitage, Hut Point, and the pressure-ridge and tidal-crack areas south and east of Pram Point. Seal holes have no effect on the bearing capacity of the ice sheet but can become enlarged enough to be dangerous to travel in small vehicles. Occasionally, the ice around a seal hole also becomes dangerously thin.

Ramps

Sea ice in the McMurdo area is used extensively for travel and cargo hauling during most of the summer. Transition ramps are used at sea-ice-to-land and sea-ice-to-ice-shelf crossings, and create special maintenance problems for the over-ice roads.

At sea-ice-to-land crossings, the most common obstacles are tidal cracks and occasional downwarped ice and flooded areas. The tidal cracks vary in width from several inches to 1 or 2 feet. Traffic can be maintained over these cracks by frequently refilling them with earth, snow, and ice. Roads across downwarped ice are much more difficult to maintain because extensive flooding usually occurs in these areas by mid-summer.

Sea-ice-to-ice-shelf ramps are usually easy to build because abundant wedge-shaped snowdrifts occur just beyond the edge of the ice shelf. The sea ice adjacent to the moving ice shelf may buckle downward and become flooded (Figure 10). The lower layers of snow composing the ramp then become soaked with seawater, with a resulting loss of bearing capacity. Eventually, the ramp will collapse and have to be relocated or rebuilt.

Icebergs

Tabular icebergs occasionally calve from the McMurdo Ice Shelf and become stranded when the water in McMurdo Sound freezes over. In October 1965, many stranded bergs were present around the edge of the ice shelf. By mid-December, seal breathing holes appeared around the edges of some of these bergs and enlarged as the summer progressed. The ice around the seal holes was often covered with 1 or 2 feet of snow and became dangerously thin by late December. Stranded icebergs in the McMurdo area may be hazardous and should be approached with caution, especially late in the summer.

FINDINGS

1. Based on a 75-day period of summer observation, movement of the McMurdo Lobe of the Ross Ice Shelf is not everywhere uniform but diminishes from east to west. Observations over an extended period are needed to determine summer versus winter movement rates.

2. The thickness of the ice shelf decreases as it moves westward, but the rate and amount of seasonal thinning is unknown. Periodic measurements are needed to more precisely determine this rate.

3. The probable critical thickness beyond which the ice shelf no longer calves is apparently 90 to 100 feet west of the DF-66 Williams Field Air Facility, and 50 to 60 feet near Pram Point. Precise knowledge of this critical thickness is needed because of its importance to the location of safe travel routes, runways and other facilities in this area.

4. The annual sea ice in the McMurdo Sound embayment south of Hut Point Peninsula responds to pressure from the ice shelf by downwarping, buckling and movement in a westward direction.

5. Ice and snow areas that are smooth and apparently free of obstacles may contain hidden slush zones, crevasses covered with weak snow bridges, or dangerously thin ice, especially between mid-December and late February.

6. Hidden subsurface melt pools occur in the glacier ice at Outer Williams Field and, during summer, seriously hamper trafficability of the new alternate ice runway in this location. A study of this area is needed to determine the nature of these melt pools and ways of preventing their formation.

7. Pressure ridges are usually easy to avoid, but, if they must be traversed, crevasses of varying sizes may be expected in the crests.

CONCLUSIONS

1. The snow and ice terrain in the McMurdo Sound region constantly changes in response to seasonal factors and to stresses caused by the

moving ice shelf. These changes affect the safety and efficiency of utilizing the area for travel routes, runways, and various other installations.

2. Study of this area should continue to determine:

   a. The magnitude and extent of the most important changes.

   b. Whether or not certain changes are cyclic in nature.

   c. The rate of thinning of the ice shelf.

   d. The nature and extent of the vast, apparently stagnant glacier ice area in the vicinity of Outer Williams Field.

3. All changes and new observations should be delineated and documented for future use.

FUTURE PLANS

The movement study will continue during Deep Freeze 67, with additional electrotape and theodolite measurements, where possible, to maintain the existing accuracy. Continuation of these measurements over a 12-month period should provide more accurate annual movement rates on the ice shelf and the sea ice, and should indicate whether there is a seasonal velocity difference in these movements.

Important new features appearing on either the ice shelf or the annual sea ice during Deep Freeze 67 will be located and included on an up-to-date map of the area. Thickness of the annual sea ice and the 1966-67 front along the ice shelf will be included on the revised map.

Direct thickness measurements on the McMurdo Lobe of the Ross Ice Shelf should provide additional data concerning its rate of thinning. Such knowledge, coupled with the rate of movement, will provide additional information for the selection of future operational sites in this location.

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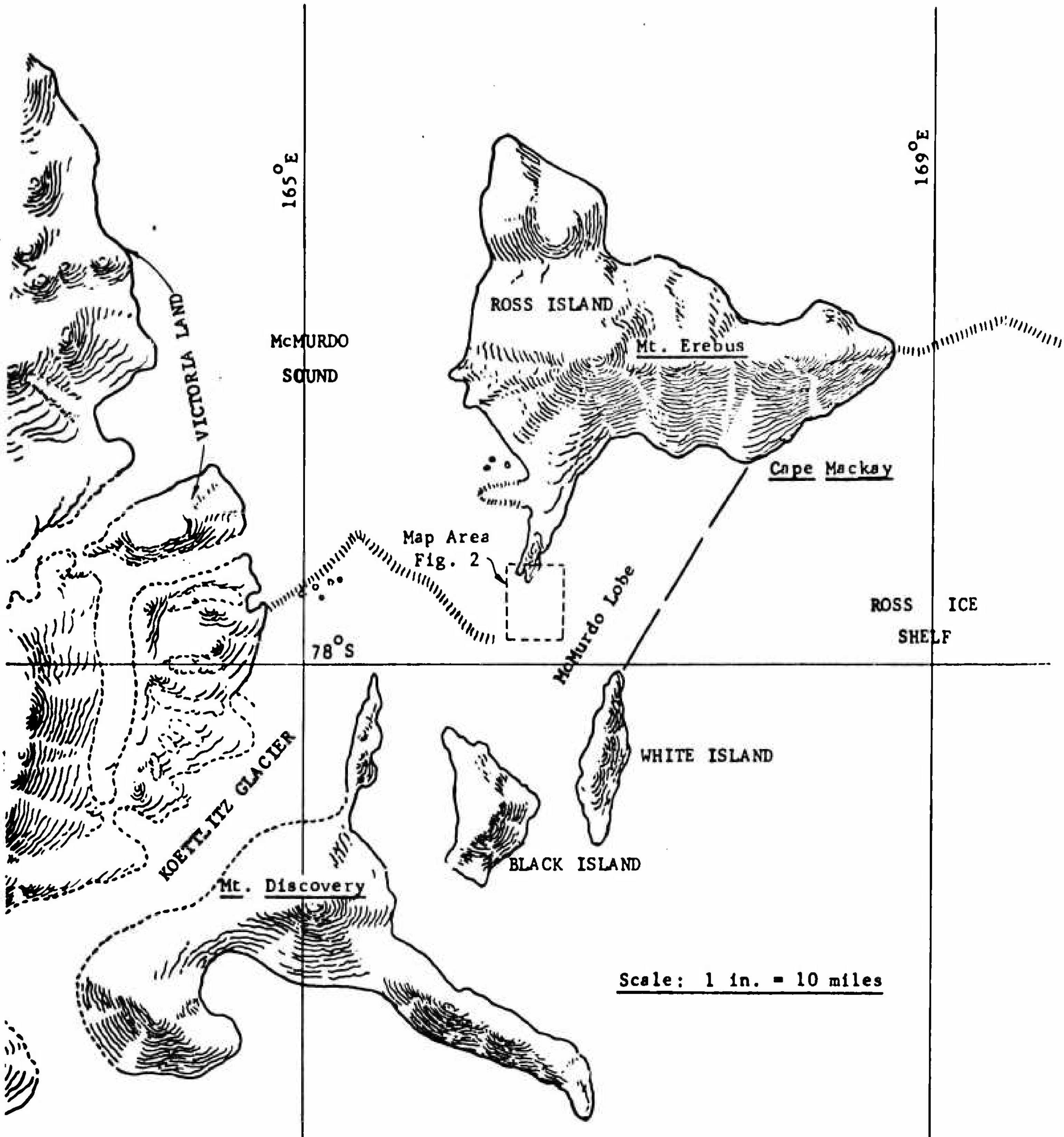

Figure 1. Index map of the McMurdo Sound Region, Antarctica.

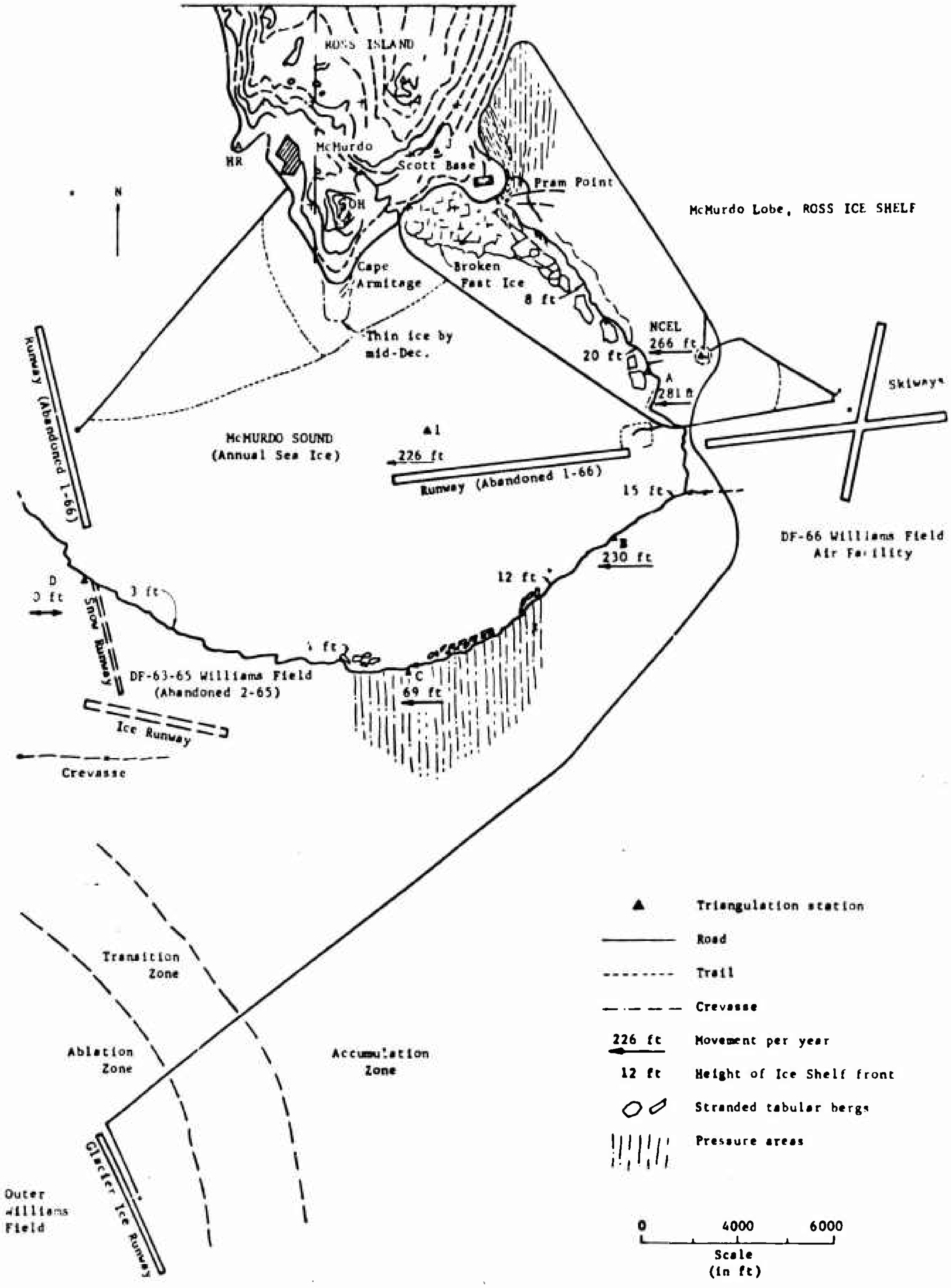

Figure 2. Map of the ice and snow terrain features in the McMurdo Sound Region south of Hut Point Peninsula, Antarctica.

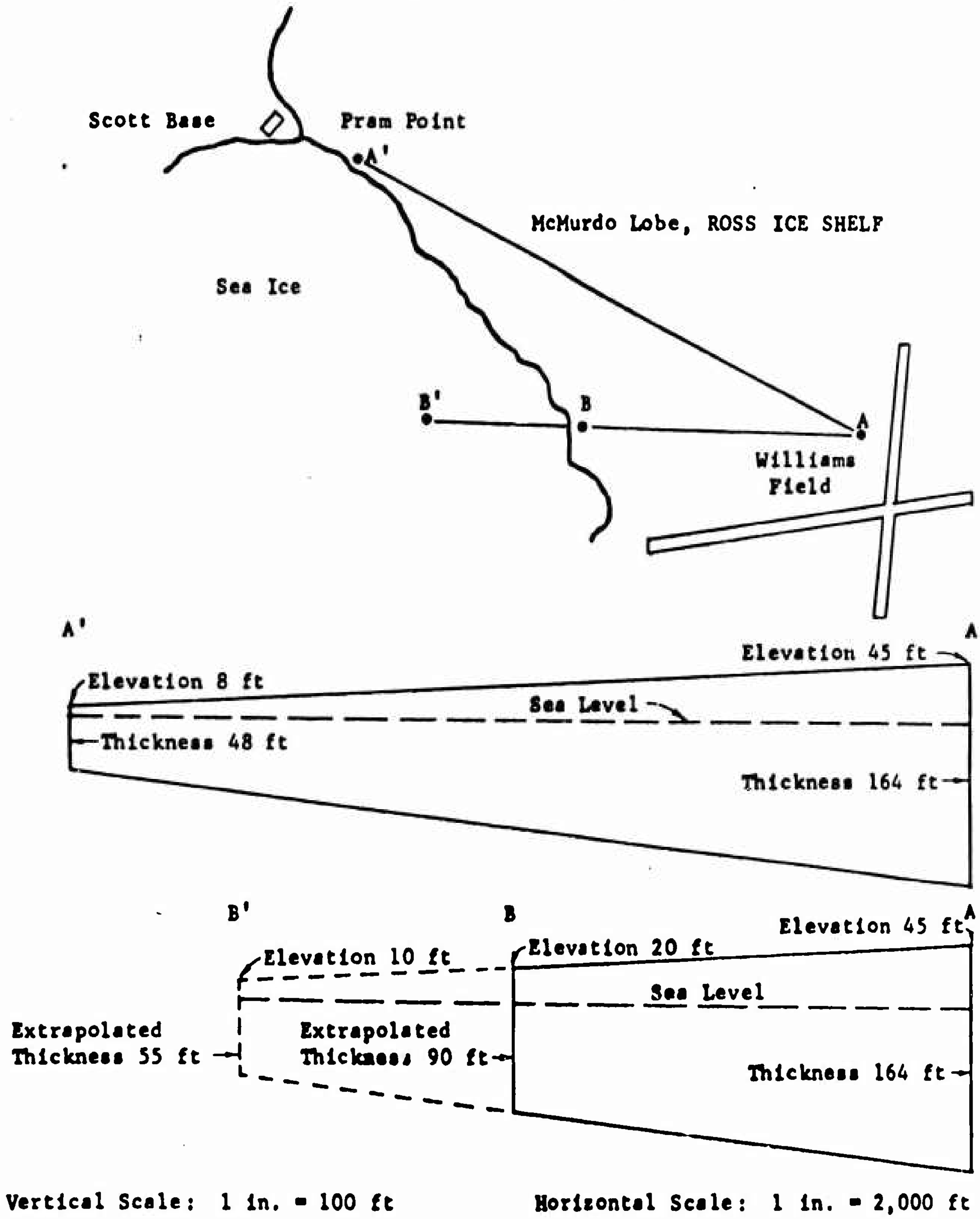

Figure 3. Diagrammatic cross section of the McMurdo Lobe of the Ross Ice Shelf along lines A - A' and A - B - B'.

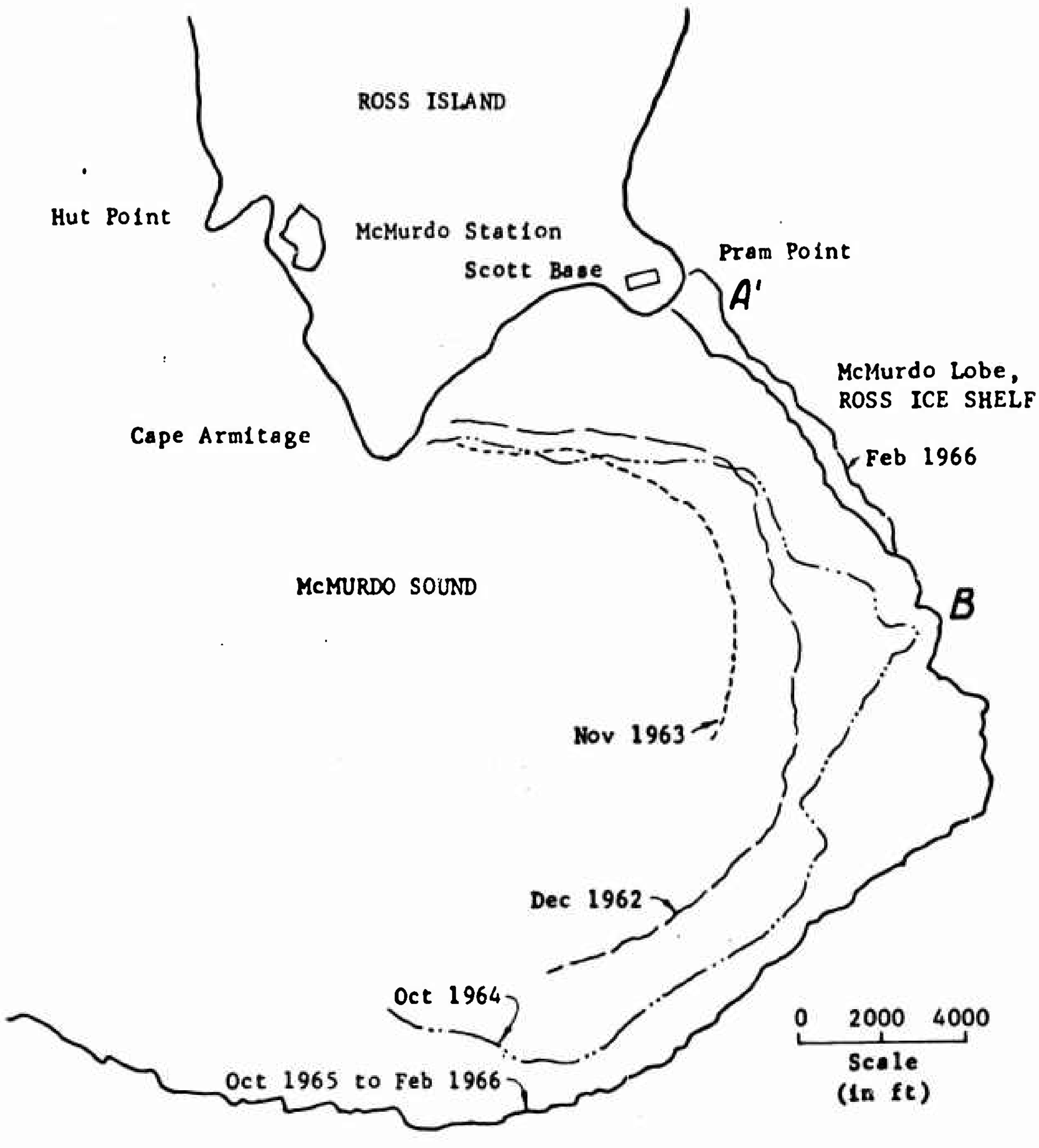

Figure 4. Map of McMurdo Sound showing the positions of the Ice Shelf front from 1962 to 1966.

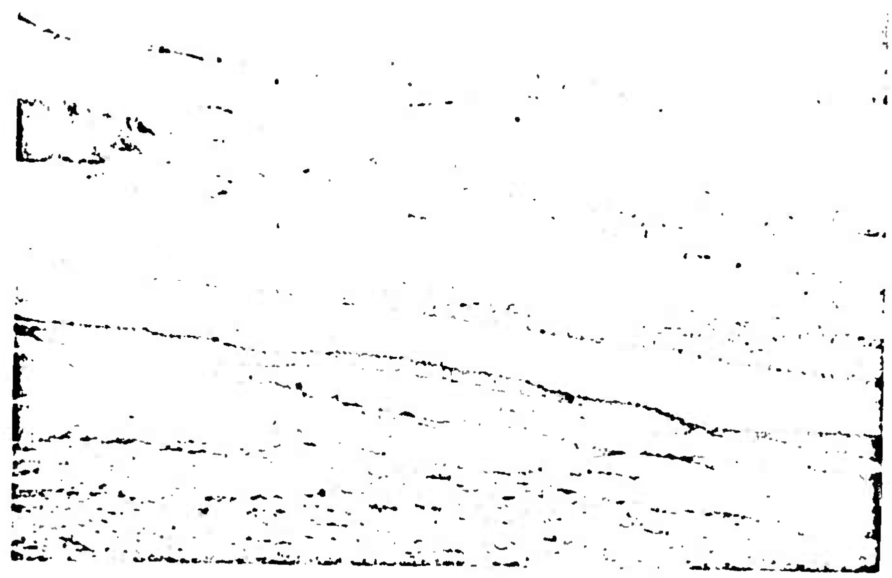

Figure 5. Pressure ridges in the Ice Shelf north of Scott Base adjacent to Hut Point Peninsula.

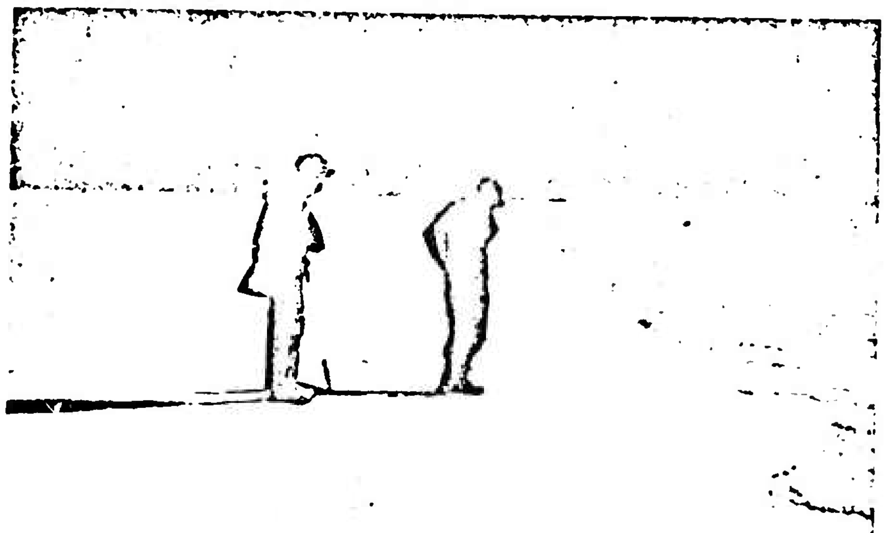

Figure 6. Crevasse in McMurdo Lobe of the Ross Ice Shelf near the DF-63-65 Williams Field Air Facility.

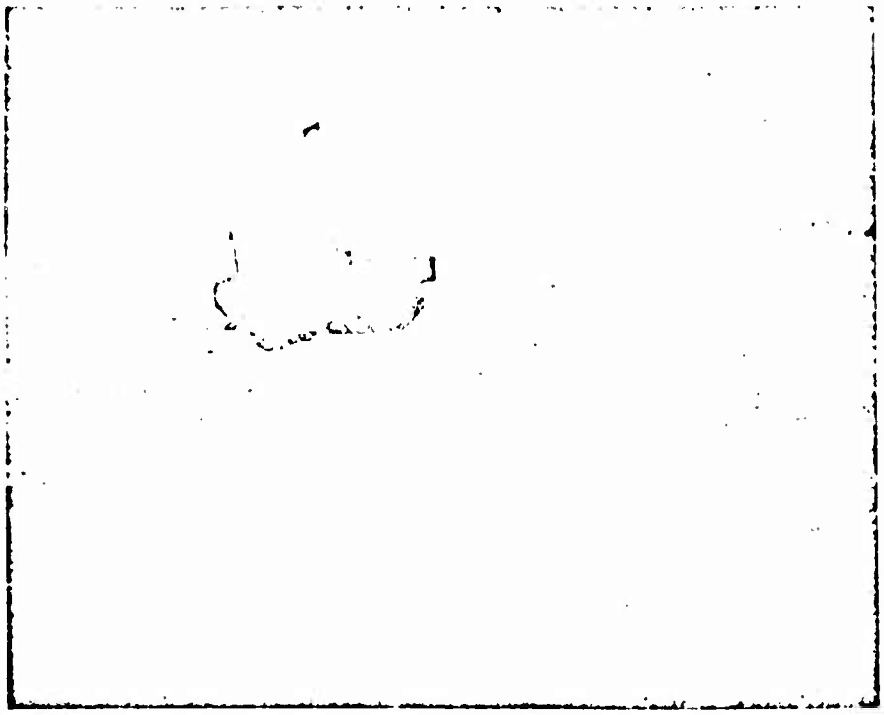

Figure 7. Weasel crossing the transition area.

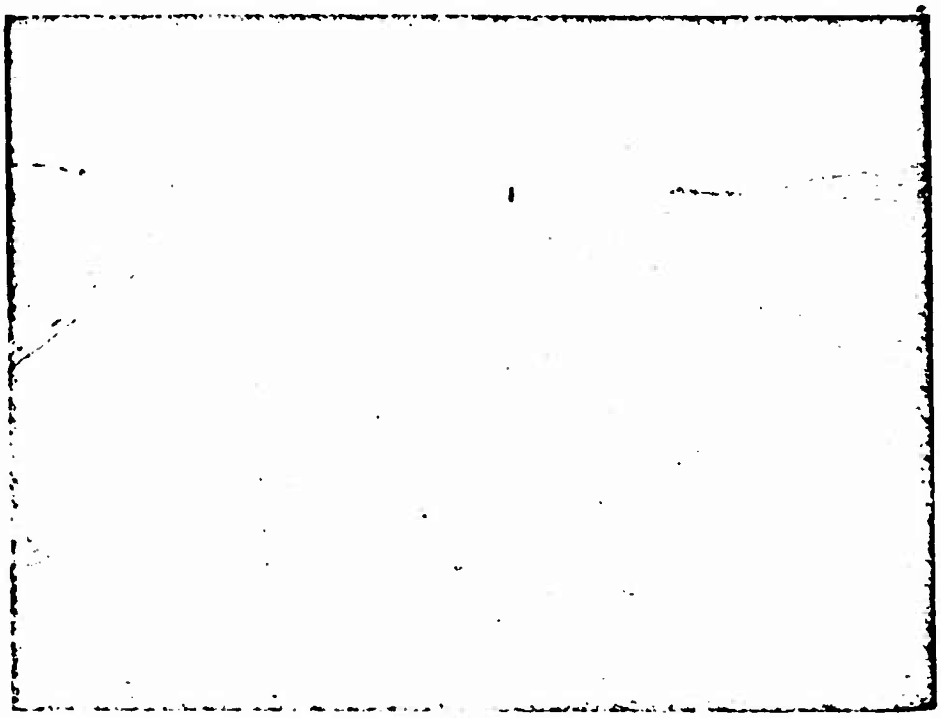

Figure 8. Pressure ridges and flooded zones in the annual sea ice.

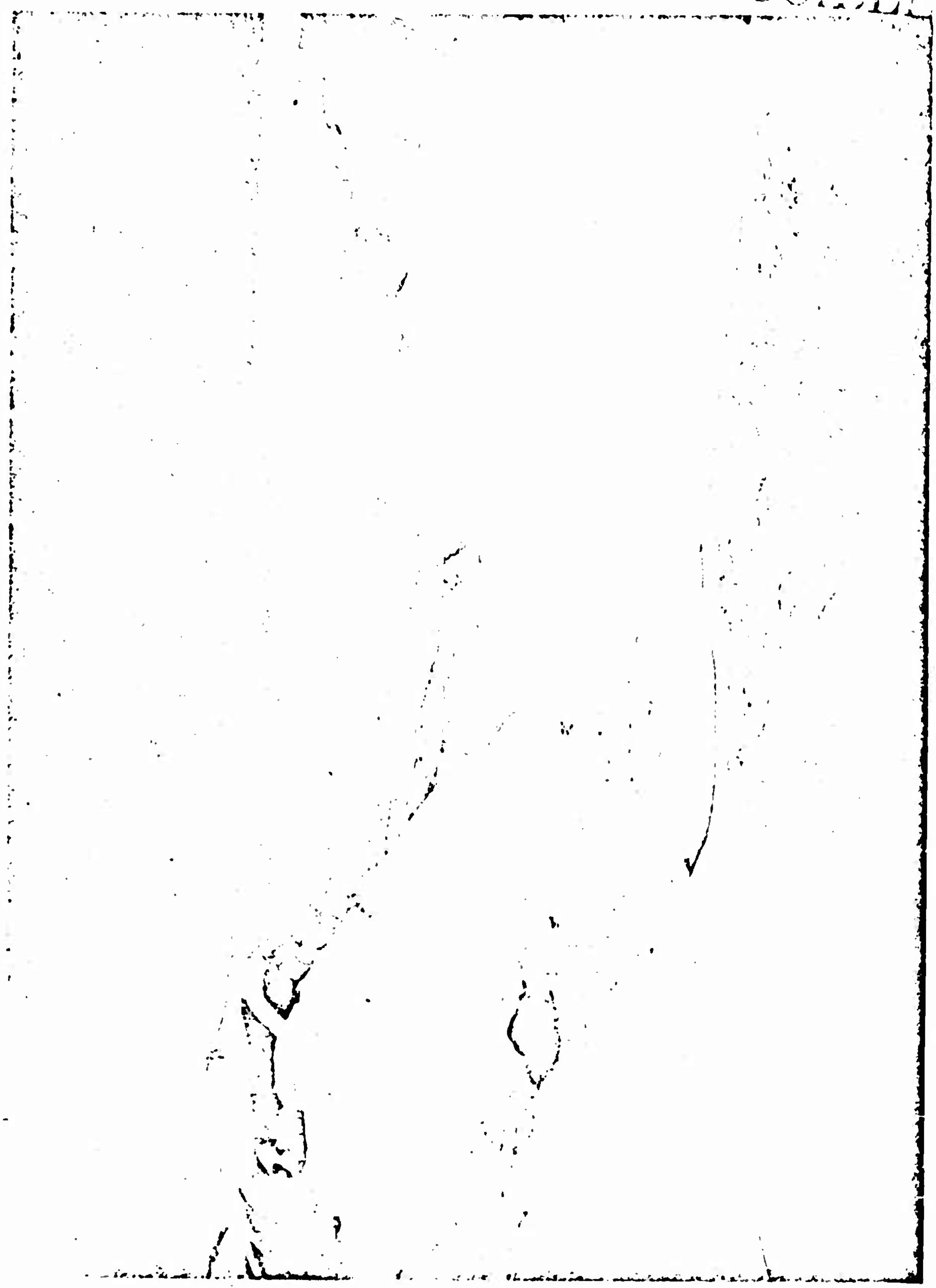

Figure 9. Pressure ridges and flooded zones in the annual sea ice.

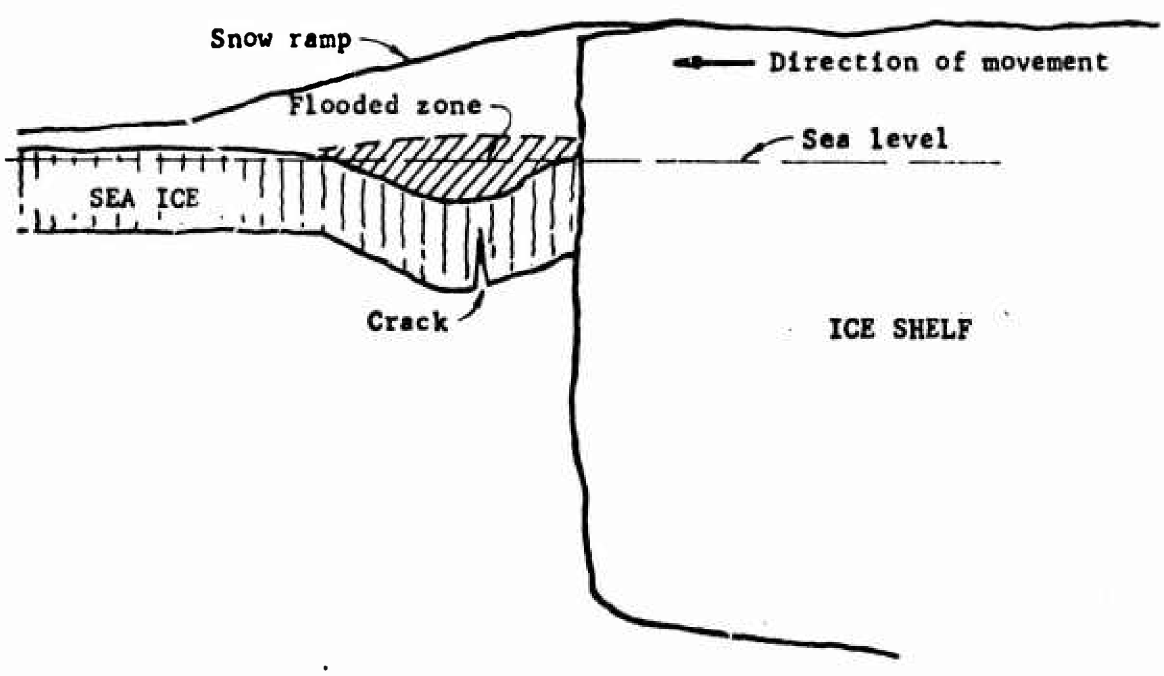

Figure 10. Downwarped sea ice adjacent to the Ice Shelf showing flooded zone that often causes collapse of the snow ramp.