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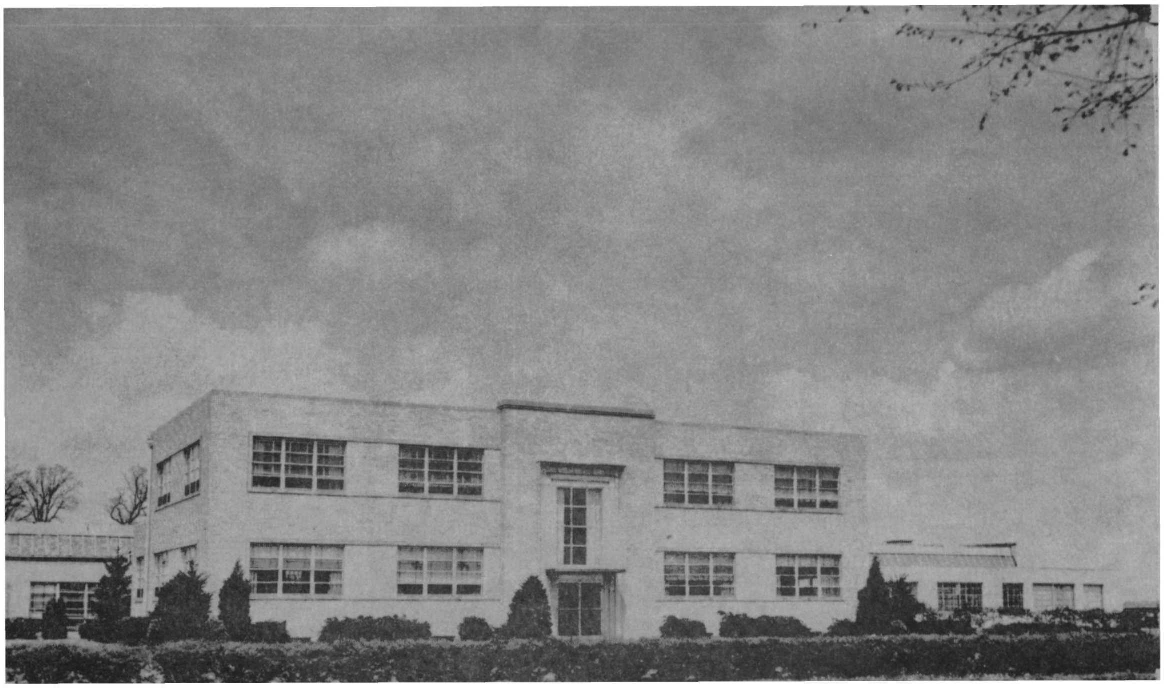

RESEARCH FOUNDATION

USNC-IGY ANTARCTIC GLACIOLOGICAL DATA
FIELD WORK 1958 AND 1959

(Multiple Glaciation in the McMurdo Sound, Antarctica)

Report 825-2-Part IX
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Troy L. Péwé

February 1960

USNC-IGY ANTARCTIC GLACIOLOGICAL DATA

Report Number 2: Field Work 1958-59

Part IX

MULTIPLE GLACIATION IN THE McMURDO SOUND, ANTARCTICA

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TABLE OF CONTENTS

LIST OF FIGURES

MULTIPLE GLACIATION IN THE McMURDO SOUND REGION, ANTARCTICA--A PROGRESS REPORT

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MULTIPLE GLACIATION IN THE McMURDO SOUND REGION, ANTARCTICA--A PROGRESS REPORT*

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Troy L. Péwé

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Abstract

At least four major Quaternary glaciations, each successively less extensive than the former, are recorded in the McMurdo Sound region of Antarctica. Deposits of the earliest recognized glacial advance occur high on ridges and flat areas. The deposits are 2,000 feet above the valley floor, are badly weathered, and have little or no morainal form. Ice of this glaciation filled all the valleys and must have filled McMurdo Sound to an elevation of 2,000 feet.

Deposits of the next two succeeding glaciations are distributed around the Sound as well-preserved but considerably subdued moraines of both outlet and alpine glaciers. During the earlier of these two glaciations, alpine glaciers reached the expanded Koettlitz and Ferrar outlet glaciers. Outlet glaciers filled the southern part of McMurdo Sound to an elevation of about 1,000 feet. During the latter of these two advances many alpine glaciers did not reach the outlet glaciers.

The latest major glaciation is represented by well-preserved ice-cored moraines. Number and position of deltas in drained glacier-ice-blocked lakes suggest possibly three stillstands or minor advances during this glaciation. Radiocarbon dating of algae in drained ponds indicates a minimum age of 6,000 years for this glaciation.

Introduction

The existence and character of possible multiple glaciation in Antarctica have been speculated on for half a century. Earlier workers were aware that the ice cap and other glaciers were more extensive in the past--a time of "glacier flooding" (Scott, 1905, p. 360; David, 1914, p. 622-24; Taylor, 1914, p. 374; see Nichols, 1953, for a detailed list). However, no mention was made of more than one advance, or whether the "glacial flood" recorded at one locality was the same "glacial flood" recorded at a different locality in Antarctica. Examination by the writer of well-preserved glacial deposits in the large ice-free areas around

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*Publication authorized by the Director, U. S. Geological Survey

McMurdo Sound (fig. 1) in 1957-58 revealed at least four major glacial fluctuations of the ice cap, each successively less extensive than the former (Péwé, 1958a, 1958b).

An opportunity to study the glacial chronology in the ice-free areas surrounding McMurdo Sound was provided by the United States National Committee for the International Geophysical Year. The writer, assisted by Norman R. Rivard, made observations in the areas east, south, and west of McMurdo Sound from December 1957 until February 1958. This report sketches a possible outline of glacial events in the region and constitutes a progress report of the work. Using existing reconnaissance topographic maps, it is possible to plot in only a very general way the former extent of glacial ice in the region. Provisional names used in this report and shown on figs. 2 and 4 are: Hubley Glacier, McCall Glacier of the South, David Lee Glacier, Blackwelder Glacier, Patty Lake, and Lake Fryxell.

Physical setting

Physiography and geology

The land on the west side of McMurdo Sound may constitute the largest ice-free area on the Antarctic Continent. It is an area 10-50 miles wide and at least 100 miles long, consisting of alternating eastward-trending ridges and valleys with an average relief of 3,000-6,000 feet and a total relief of 13,000 feet. The continental ice cap has withdrawn from the region but a few outlet glaciers and a multitude of small alpine glaciers still exist.

This region is part of South Victoria Land and is dominated by the Royal Society Range which projects 13,000 feet above sea level (fig. 2). The area within 20-30 miles of the sea is composed of metamorphic rocks with granitic intrusions. The highlands farther west (including the Royal Society Range) are composed of flat-lying sedimentary rocks, recently called the Beacon system, and dolerite sills termed the Ferrar Dolerites (Harrington, 1958a). The lowlands are covered with glacial deposits and many of the valleys contain alkaline lakes, remnants of Pleistocene ice-marginal lakes.

Ice-free land on the south and east sides of McMurdo Sound is much less extensive than on the west side and consists of a few areas 1-50 square miles in area, on volcanic cones such as Mount Erebus and Mount Discovery. Some of the volcanic terrain forms "islands" in Koettlitz Glacier and the Ross Ice Shelf (fig. 1).

Two major types of glaciers exist in the region: (1) the huge outlet glaciers which emanate from the ice cap and drain through passes toward the sea, and (2) the small alpine glaciers which originate in the mountains and are independent of the ice cap. The glaciers are polar glaciers and no water issues from underneath or within them; however, during December and January, some melt water runs from the surface of the lower ends of

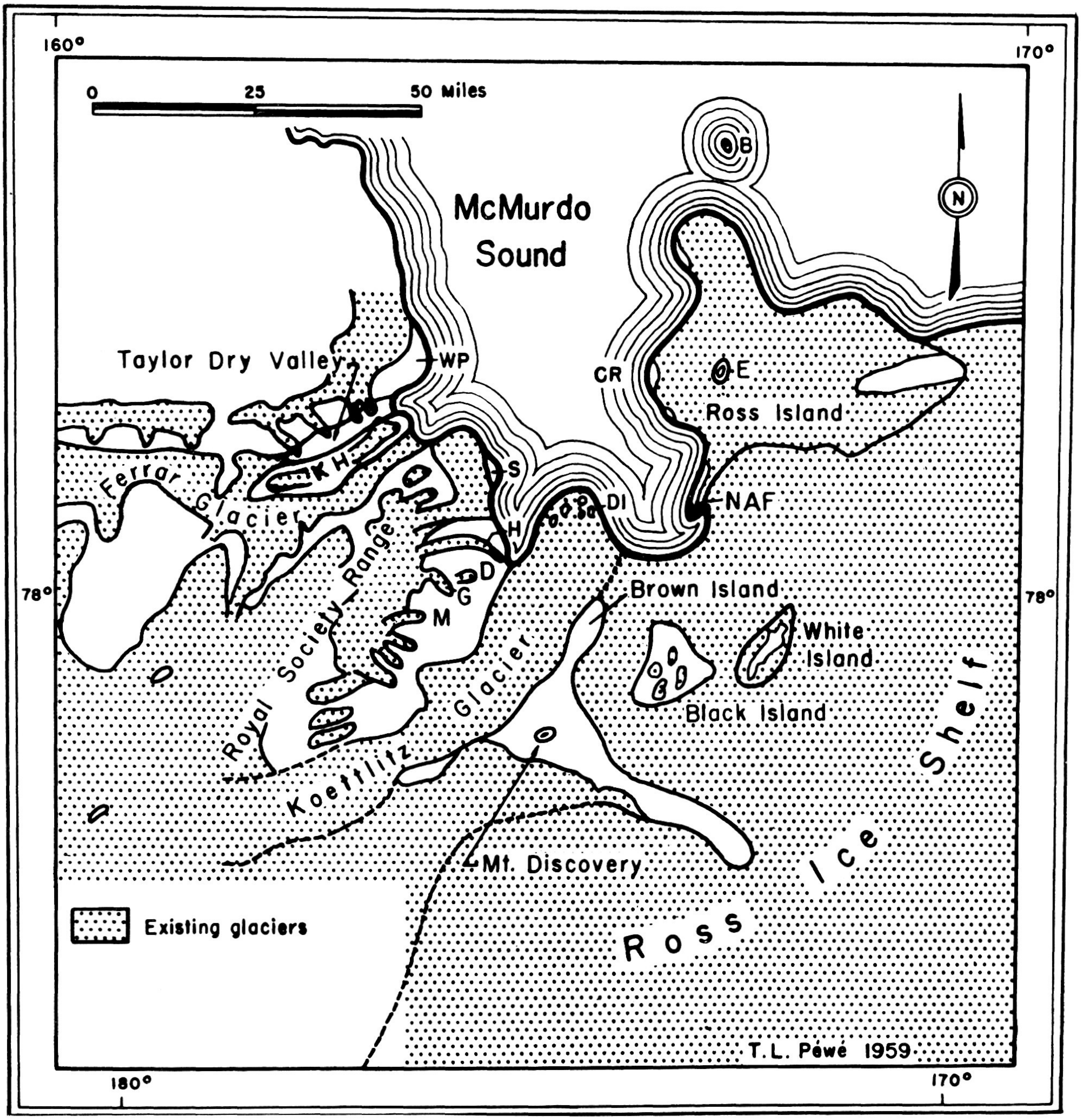

Figure 1 Sketch map of McMurdo Sound, Antarctica showing extent of existing glaciers. Letter symbols on map are: B, Beaufort Island; WP, Wilson Piedmont Glacier; CR, Cape Royds; E, Mount Erebus; KH, Kukri Hills; S, Stranded Moraines; DI, Dailey Islands; NAF, Williams Naval Air Facility; H, Hobbs Glacier; D, Davis Glacier; G, Garwood Glacier; M, Miers Glacier. Base modified after U. S. Navy Hydrographic Office Chart No. 6636 (Ross Sea) 3rd ed., Sept. 23, 1957.

Figure 2 Aerial view from 15,700 feet above sea level looking southwest to the Royal Society Range, McMurdo Sound, Antarctica. Symbols are: K, Koettlitz Glacier; R, Royal Society Range; P, Patty Lake; B, Blackwelder Glacier; M, Miers Glacier; D, David Lee Glacier; McS, McMurdo Sound; Mc, McCall Glacier of the South; H, Hubley Glacier; G, Garwood Glacier. Photograph by U. S. Navy, Dec. 6, 1956. Identification No. 00090 F-31 VX6 USN 4/14.

the glaciers. This water forms shallow streams for a few days a year. Some of these streams extend to the sea but most of them drain into landlocked lakes, as many of the ice-free valleys are blocked from the sea by glaciers or moraines.

A study of many of the glacial fronts indicates that there has been no perceptible advance or retreat in the last 50 years (Péwé, 1958c, IGY Bull. no. 24, 1959, p. 200) and that the glaciers have a sluggish regimen. The glaciers reflect climatic changes, but the total movement of the front is small.

Climate

The climate of the McMurdo Sound region is rigorous, characterized by low temperatures and aridity. Scattered data from Scott's expeditions and from incomplete IGY observations indicate that the mean annual air temperature near sea level on the east side of McMurdo Sound at Williams Naval Air Facility (fig. 2) is approximately -17°C (1°F). The mean annual temperature for 1957, the only complete year available, was -16.7°C (2.0°F) (IGY Bull. no. 15, 1958). All months of the year have a mean temperature below freezing (fig. 3), and only for a very few days in late November through early February does the air temperature rise 2 to 3 degrees above 0°C. The absolute minimum recorded 1957 temperatures was -41.1°C (-42.0°F), and the absolute maximum 1957 temperature was 3.4°C (38.1°F).

The ice-free west side of the Sound is slightly warmer than the east side, at least from December through February. The writer recorded air temperatures 2 or 3 degrees Fahrenheit higher on the west side in 1957-58 than those recorded at Williams Naval Air Facility. Slightly higher temperatures were also recorded on the west side by Donald Ball of Metcalfe and Eddy Construction Company at Marble Point near Wilson Piedmont Glacier (fig. 1) on the west side of the Sound (John R. Davis, Metcalfe and Eddy Construction Company, written communication, November 12, 1958).

Precipitation in the region is light and falls as snow. Total precipitation recorded at Williams Naval Air Facility in 1957 was 6.38 inches of water. From March through December 1956 only 1.47 inches was recorded at the same station (U. S. Navy, written communication, July 1958). The mean annual precipitation at Williams Naval Air Facility in inches of water probably is between 2 and 6.

Personal observations by the writer in 1958 indicate that the west side of the Sound is drier than the east. These observations were corroborated by workers at Marble Point. The writer noted that lichens grow near sea level on the east side of the Sound. On the west side they rarely grow at an elevation lower than 2,000 feet above sea level, except near the shore. According to G. A. Llano, lichenologist with USNC-IGY (oral communication, December 1957), it is too dry in the ice-free areas on the west side to support lichens below an elevation of 2,000 feet except adjacent to the shore.

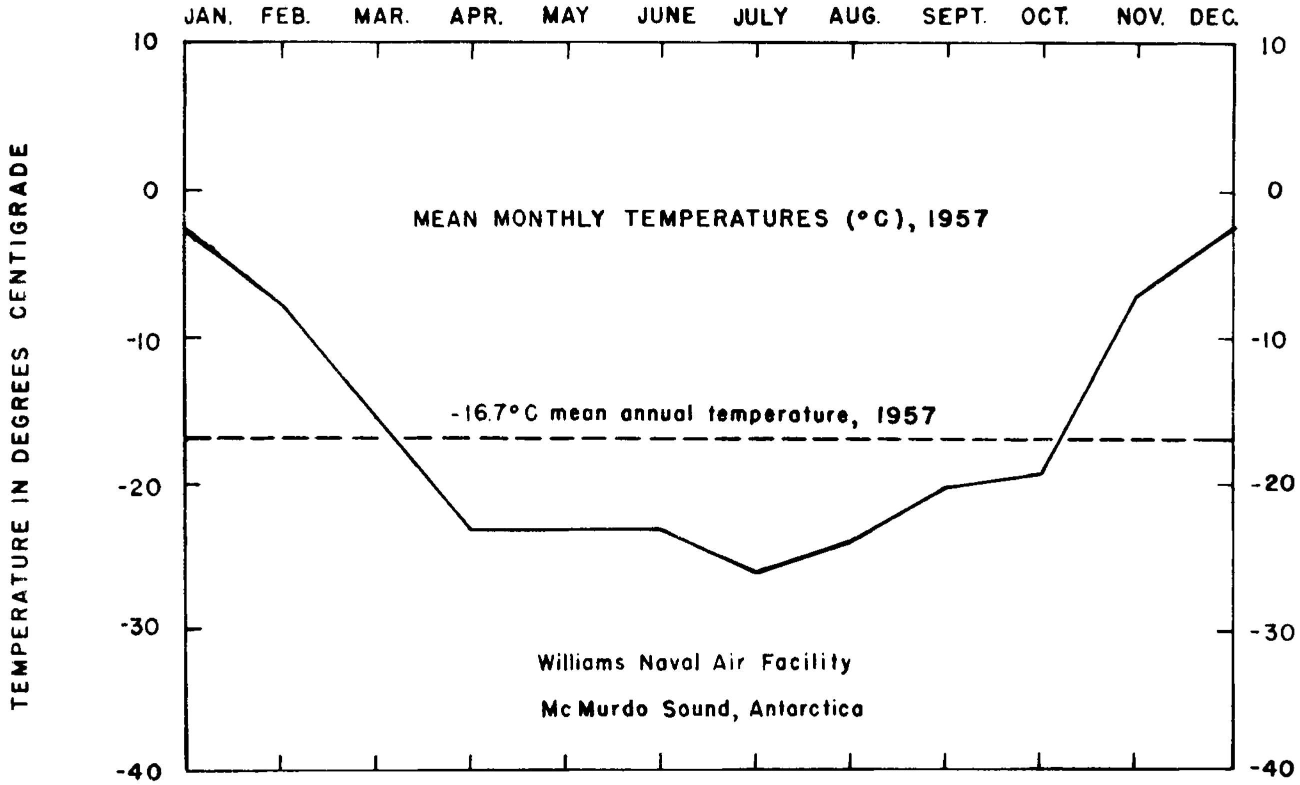

Figure 3 Mean monthly temperature for 1957. Williams Naval Air Facility, McMurdo Sound, Antarctica.

The writer believes that the percent of time of cloud cover on the west side of the Sound is also less than the average of 63 percent recorded at Williams Naval Air Facility. The McMurdo Sound region is windy. The average wind velocity for a 23-month period in 1956-57 was 13.7 mph (11.9 knots) at Williams Naval Air Facility. Maximum wind speeds of 65 mph or greater were registered at least one day of each month from May through November 1957. A peak gust of 96 mph was recorded in May and a peak of 97 mph was measured in June (IGY Bull. no. 15, 1958, p. 1001). Surface winds at Williams Naval Air Facility are mostly from the E, ENE, and ESE (U. S. Navy, written communication, July 1958).

Glacial chronology

At least four major Quaternary glaciations are recorded in the ice-free valleys on the west side of McMurdo Sound and around the islands and mountains projecting above the outlet glaciers. The term glaciation is used to denote a glacial advance and retreat represented by deposits and landforms that can be distinguished from other glacial deposits of different ages. The term glaciation does not necessarily imply stadial or substadial rank. The youngest advance left drift that is still cored with glacial ice; the two next older advances are marked by subdued moraines; deposits of the oldest recognized glaciation are scanty and preserved only on high ridges.

McMurdo Glaciation

The earliest and most extensive glacial advance recognized has been named the McMurdo Glaciation (Péwé, 1958b) after McMurdo Sound, around which high-level glacial deposits are found. Patches of drift of this glaciation occur on ridges 2,000 feet above sea level[1] on the west side of Koettlitz Glacier (fig. 2), and in Taylor Dry Valley (fig. 4) about 3,000 feet above sea level 2,500 feet above the floor of the valley near the top of Mount Nussbaum. A probable deposit of such drift was seen from the air on the bedrock bench at 2,500 feet above sea level on the north side of Taylor Dry Valley just south of Lacroix Glacier (fig. 4).

The old drift near Mount Nussbaum is composed of granitic and metamorphic rocks, but on the high ridges west of Koettlitz Glacier the old drift contains some kenyte, a soda-rich lava. At 2,300 feet on Mount Nussbaum large granitic erratics rest on marble bedrock, and 2,000 feet above sea level on the west side of Davis Valley, downvalley from Davis Glacier (fig. 1), black wind-polished cobbles of dolerite lie on marble bedrock. The boulders in the drift have no fresh faces and in all exposures most of the boulders and cobbles in the till have been abraded to the level of the ground surface by the constant wind. Morainal form is absent.

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[1]Elevations used in this report are altimeter readings and do not necessarily fit the reconnaissance topographic maps made 50 years ago.

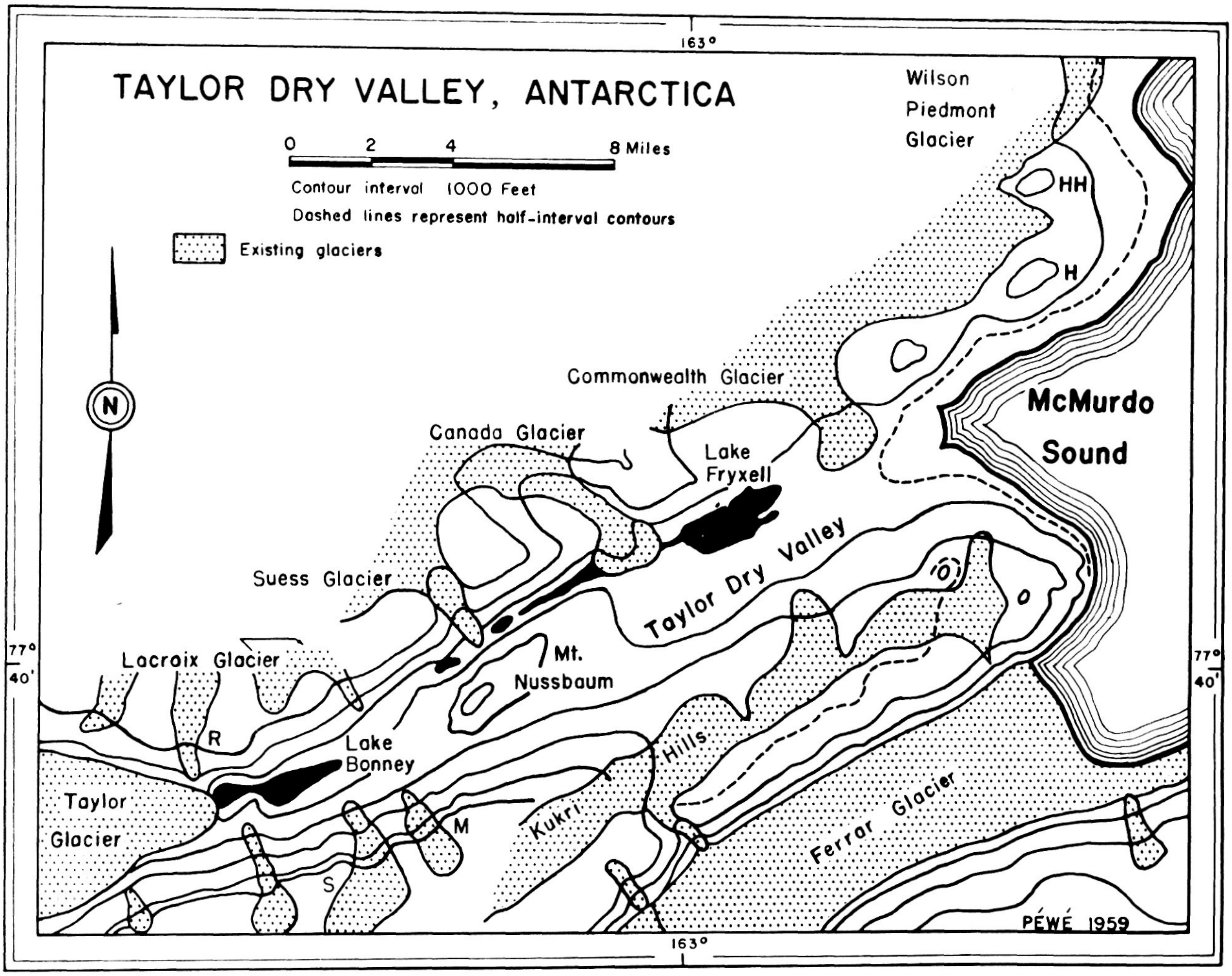

Figure 4 Sketch map of Taylor Dry Valley, Antarctica showing existing glaciers. Letter symbols on map are: HH, Hogback Hill; H, Hjorth Hill; R, Rhone Glacier; S, Sollas Glacier; M, Marr Glacier. Base modified after map of Ferrar-Koettlitz District, British Antarctic Expedition 1910-13 "Terra Nova".

Great antiquity of the McMurdo Glaciation deposits is indicated by the lack of morainal form and the boulders and cobbles planed level with the ground surface by wind abrasion. The vigorous wind sculpture is due not to a more exposed position of the boulders but to a longer time of exposure than the less severely wind-eroded boulders on the younger drifts. Wind is commonplace both on the ridges and in the valleys. More sand is available in the valleys than on the ridge tops to be blown by the wind. A swarm of hornblende diorite and andesite dikes 2-5 feet wide on the upper part of Mount Nussbaum has been etched out in relief 3-8 feet by weathering since the retreat of the McMurdo ice, a process that must have taken a long time.

During McMurdo Glaciation, Taylor Glacier, draining the expanded ice cap, filled Taylor Dry Valley to an elevation probably higher than 3,000 feet (fig. 5), and coalesced with the expanded Koettlitz Glacier in McMurdo Sound, as did the Ferrar Glacier.

Koettlitz Outlet Glacier rose to at least 2,000 feet above sea level on the west side of the Koettlitz Valley (fig. 5). It also coalesced with the Ross Ice Shelf and it is conjectured, by projecting old ice-surface profiles, that the ice completely covered Brown Island, 2,300 feet high, and Black Island, 3,500 feet high. Also, if Mount Discovery, probably in part a Pleistocene volcanic cone, were near its present height, the ice surrounded the mountain up to an elevation of approximately 5,000 feet.

The ice of the McMurdo Glaciation must have extended to 2,000 feet above sea level on the flanks of ancestral Mount Erebus. No information is available as to the northern extent of the glacier ice into the Ross Sea. Beaufort Island (fig. 1), if present, must have been overridden by ice. Hough (1950) and Stetson and Upson (1937) report glacial sediments on the sea bottom 300-400 miles north of the present ice shelf, but these probably were rafted out on bergs.

A patch of drift of McMurdo age lies on a flat area 1,800 feet above sea level on the ridge of metamorphic rocks forming the south side of the valley occupied by Miers Glacier. The drift, which is downvalley 5 miles from the present front of Miers Glacier (fig. 2), is composed mainly of red porphyritic granitic rocks; the boulders are planed by wind erosion. The composition of the till and the amount of wind sculpture of boulders is greatly different from the black, less wind-cut drift of the Taylor Glaciation which flanks the lower slope of the ridge in Miers Valley, and is composed mainly of dolerite, basalt, and kenyte. Such differences between tills suggest differences in age and ice source. If the ice source remained the same, yet the lithology changed (considerable black volcanic rocks added), it would suggest that the ice withdrew and lava flows occurred which were overridden in the succeeding glacial advance. This last suggestion is supported by the numerous dark lava cones and flows that formed in the area during Pleistocene and Recent time.

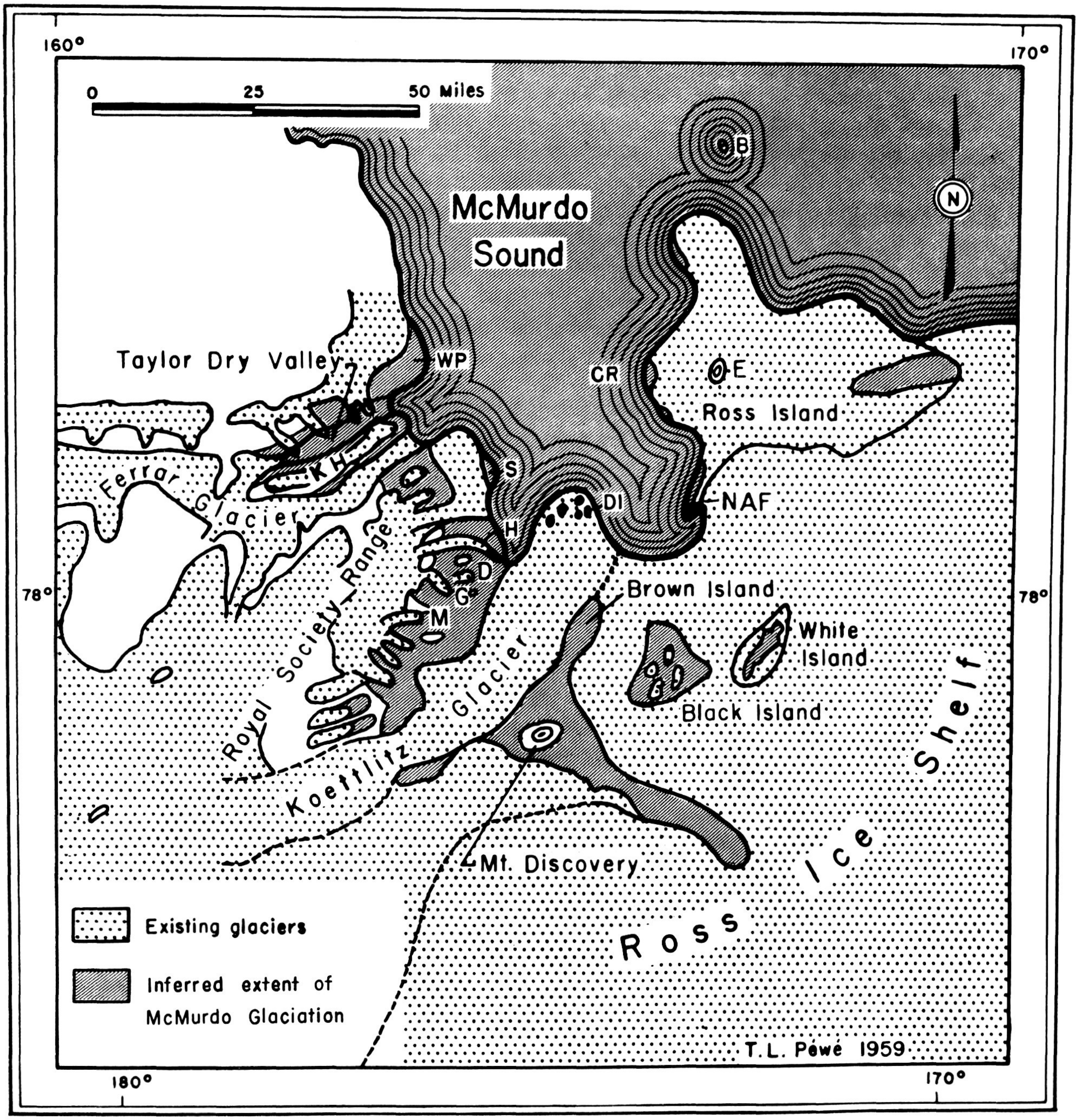

Figure 5 Sketch map of McMurdo Sound, Antarctica showing extent of existing glacial ice and inferred extent of McMurdo Glaciation. Letter symbols on map are: B, Beaufort Island; WP, Wilson Piedmont Glacier; CR, Cape Royds; E, Mount Erebus; KH, Kukri Hills; S, Stranded Moraines; DI, Dailey Islands; NAF, Williams Naval Air Facility; H, Hobbs Glacier; D, Davis Glacier; G, Garwood Glacier; M, Miers Glacier. Base modified after U. S. Navy Hydrographic Office Chart No. 6636 (Ross Sea) 3rd ed., Sept. 23, 1957.

Taylor Glaciation

The next recognized glacial advance in the McMurdo Sound region is here named the Taylor Glaciation from the widespread deposits on the floor and lower slopes of Taylor Dry Valley (fig. 6). This glaciation was less extensive than the McMurdo. Deposits formed by the small alpine glaciers on the west side of McMurdo Sound during this and succeeding glaciations can be differentiated from those of the outlet glaciers, mainly the Koettlitz, by lithology. Drift of the alpine glaciers is light colored and composed mainly of granite, marble, and gneiss with some dolerite cobbles. The Koettlitz Glacier drift is rich in dark volcanic rocks, especially kenyte.[2]

Deposits of this glaciation are more extensively preserved than those of the McMurdo Glaciation and have been recognized throughout the region.

A subdued morainal blanket of granitic and metamorphic rocks with a few cobbles and boulders of sandstone and dolerite of the Beacon system mantles Taylor Dry Valley and extends upslope to approximately 1,000 feet above sea level. The characteristic black lateral moraines of the Koettlitz Glacier extend up to 1,000 feet above sea level in the eastward-trending valleys on the west side of the Koettlitz Glacier. The boulders on the surface of the drift of Taylor age are wind-abraded and ventifacts and desert pavement are well developed. Deposits of small alpine glaciers occur 1/2-2 miles in front of the present alpine ice in these valleys. Granite erratics are found 2,400 feet above sea level on Black Island, a volcanic island composed mostly of basalt, and David and Priestley (1914, p. 262) reported granite erratics 1,000 feet above sea level, on the west side of Ross Island near Cape Royds. These erratics may be of either McMurdo or Taylor Glaciations.

During the Taylor Glaciation the Taylor Glacier filled Taylor Dry Valley with ice to an elevation of approximately 1,000 feet above sea level (fig. 7). Ice did not cover Mount Nussbaum as it did in the McMurdo advance.

Ferrar Glacier pushed out into the Sound as the ice cap expanded. Strong ice push from the Koettlitz Glacier to the south evidently caused the Ferrar Glacier to wrap around the base of the Kukri Hills, merge with Taylor Glacier, and push up to 1,000-1,200 feet above sea level around Hjorth Hill and Hogback Hill. This ice coalesced with the Wilson Piedmont Glacier (fig. 6).

Koettlitz Glacier expanded and bulged laterally 4-5 miles up the empty eastward-trending valleys on its west side (fig. 8). On its east side, the glacier combined with the Ross Ice Shelf and covered Brown

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[2]Source of this kenyte was not found by the writer. The rock may come from near the head of Koettlitz Glacier. It does not come from the only presently known source in the area, Mount Erebus.

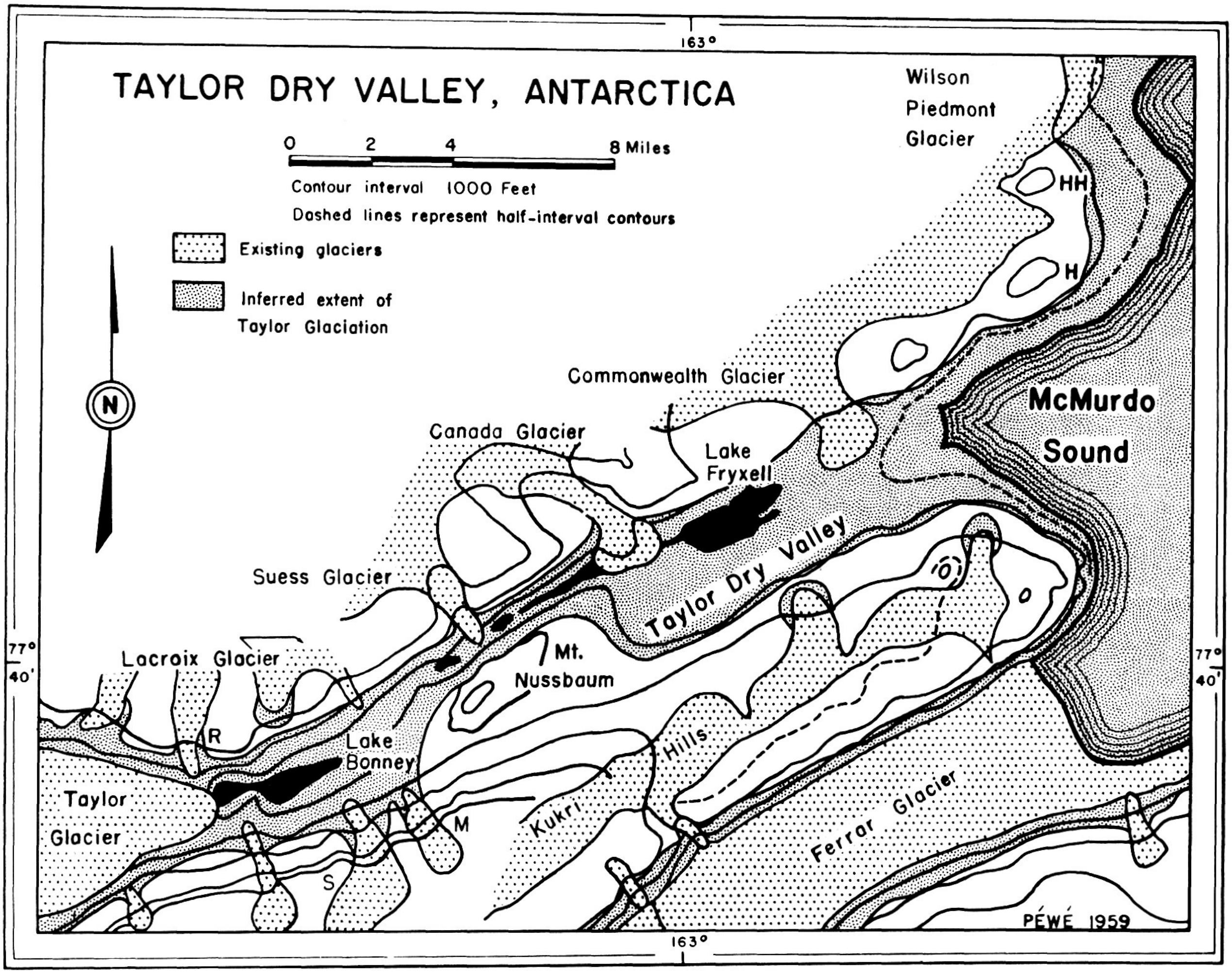

Figure 6 Sketch map of Taylor Dry Valley, Antarctica showing extent of existing glacial ice and inferred extent of Taylor Glaciation. Letter symbols on map are: HH, Hogback Hill; H, Hjorth Hill; R, Rhone Glacier; S, Sollas Glacier; M, Marr Glacier. Base modified after map of Ferrar-Koettlitz District, British Antarctic Expedition 1910-13 "Terra Nova".

Figure 7 Aerial view from 15,000 feet above sea level looking east down the lower half of Taylor Dry Valley, McMurdo Sound, Antarctica. Symbols are: CB, Cape Bernacchi; HH, Hogback Hill; H, Hjorth Hill; McS, McMurdo Sound; Co, Commonwealth Glacier; F, Lake Fryxell; C, Canada Glacier; Ch, Lake Chad; E, Mt. Erebus; K, Kukri Hills. Photograph by U. S. Navy, Dec. 5, 1956. Identification No. 00161 F-31 VX-6 USN 3/11.

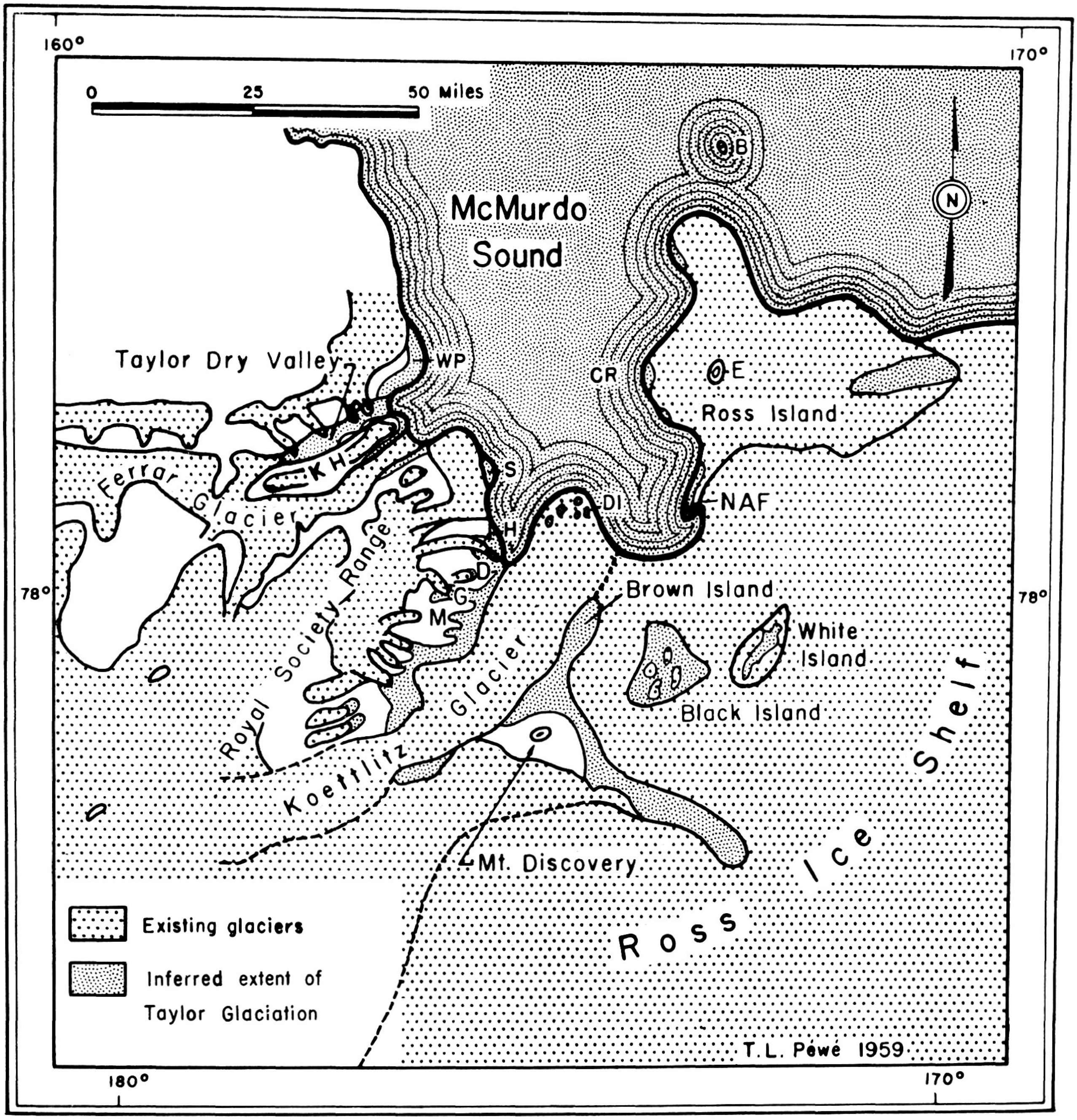

Figure 8 Sketch map of McMurdo Sound, Antarctica showing extent of existing glacial ice and inferred extent of Taylor Glaciation. Letter symbols on map are: B, Beaufort Island; WP, Wilson Piedmont Glacier; CR, Cape Royds; E, Mount Erebus, KH, Kukri Hills; S, Stranded Moraines; DI, Dailey Islands; NAF, Williams Naval Air Facility; H, Hobbs Glacier; D, Davis Glacier, G, Garwood Glacier; M, Miers Glacier. Base modified after U. S. Navy Hydrographic Office Chart No. 6636 (Ross Sea) 3rd ed., Sept. 23, 1957.

Island. It covered Black Island up to at least 2,400 feet above sea level, and ice extended up to at least 2,350 feet on Mount Discovery. The glacier sloped downward to the north and probably reached to an elevation of at least 1,000 feet on the west side of Ross Island. The granitic erratics on the west side of Ross Island could have been deposited by Ferrar Glacier but it seems more likely that the Koettlitz Glacier was the contributor. The erratics are typical granite, marble and other rocks of East Antarctica (Stewart, 1959). The granitic erratics that occur up to at least 650 feet above sea level on Beaufort Island[3] were probably brought in by glacial ice from the south or west and may have been deposited during this or an earlier glaciation.

Glacial lakes

Many glacial lakes were formed when the "dry valleys" on the west side of McMurdo Sound were blocked by ice or moraines from the huge outlet glaciers during and immediately after the Taylor Glaciation. A large lake 1,000 feet deep formed in Taylor Dry Valley when the glacial ice in the valley began to recede. The water was held in by the glacial ice or ice-cored moraine which filled the Sound and blocked the valley (fig. 6). This lake is here named Glacial Lake Washburn after A. Lincoln Washburn, noted polar glacial geologist and geomorphologist. Weakly developed but easily observable shorelines occur up to 1,000 feet above sea level on the walls of Taylor Dry Valley and extend upvalley to Taylor Glacier (fig. 7).

Many dissected deltas and a thick deposit of laminated lake silt and clay are widespread in the valley bottom and attest the former presence of the lake. Many of the stratified lake deposits are severly contorted by formation of sand-wedges in a polygonal pattern (Péwé, 1959). The lake deposits were subsequently dissected and overridden by later glacier advances.

Fryxell Glaciation

The next recognized glacial advance is here named the Fryxell Glaciation after well-preserved moraines adjacent to Lake Fryxell in lower Taylor Dry Valley (fig. 4). Lake Fryxell is the previously unnamed lake between Canada and Commonwealth Glaciers (fig. 7). This glaciation was less extensive than the Taylor Glaciation. The advances of the Taylor and Fryxell glaciations in the Koettlitz Glacier area are very closely related and the deposits are not easily differentiated everywhere. In Taylor Dry Valley the deposits of the two glaciations are relatively easily differentiated.

The evidence for the glaciation consists of drift with fair to well-preserved morainal form. Most alpine glaciers in this region carry little debris and upon retreat leave a thin drift, only 1 or 2 feet thick. A

[3] Charles G. Johnson, U. S. Geological Survey, written communication, May 22, 1959.

terminal moraine may or may not be present. Rather well-preserved moraines may exist only 100 yards to 2 miles in front of existing alpine glaciers.

Some moraine loops or lateral moraines are present, such as that which exists 3/4-mile in front of Canada Glacier in Taylor Dry Valley (fig. 7). The Rhone, Sollas, and some other glaciers in Taylor Dry Valley have prominent lateral moraines but no terminal moraines because the glaciers ended in a lake (fig. 9). The moraines are dissected and in some places have well-formed ventifacts on the surface.

Rocks in the moraines of the alpine glacier are mainly dolerite and granitic and metamorphic rocks. The moraines of Commonwealth Glacier that formed during the time of the Fryxell Glaciation (fig. 10) contain broad areas rich in kenyte[4] and blocks of Beacon sandstone. The kenyte may, alternately, be from a lobe of the extended Koettlitz Glacier which abutted the expanded Commonwealth Glacier during this time. The moraines of Fryxell Glaciation age in the Koettlitz Glacier area, where recognized, are rich in basalt and kenyte.

During the Fryxell Glaciation glaciers on the walls of Taylor Dry Valley expanded into the valley bottom (fig. 10). The glaciers in upper Taylor Dry Valley coalesced and covered the perennially frozen lake sediments of Glacial Lake Washburn; sediments which had been dissected by streams after the lake was drained but prior to Fryxell Glaciation. Canada Glacier pushed out as a terminal bulb onto the broad valley bottom. Commonwealth Glacier also spread out in the valley and pushed a mile into McMurdo Sound (fig. 10). Wilson Piedmont Glacier probably pushed out into the Sound a short distance.

The Koettlitz Outlet Glacier was less extensive during this glaciation than in the immediately preceding Taylor Glaciation. The glacier bulged 2-3 miles up the ice-free valleys on the west. It is thought that the Koettlitz Glacier did not push as far north as in the time of the Taylor Glaciation because the ice tongue of the extended Ferrar Glacier in the time of Fryxell Glaciation was not pushed northward against Hjorth Hill as it was in the time of the Taylor Glaciation (fig. 8). Therefore, the glacial ice in McMurdo Sound may have reached several hundred feet up the flanks of the west side of Ross Island but did not push far into the Ross Sea. An alternate interpretation is that if the kenyte adjacent to Commonwealth Glacier is from a lobe of the Koettlitz Glacier, ice may have pushed farther into the Ross Sea and also may have pushed against Hjorth Hill. It is not known if glacial ice from the south reached Beaufort Island.

The Fryxell Glaciation is very old, as indicated by the well-developed desert pavement on the drift and the widespread well-developed ventifacts. Also, gullies and canyons have been cut through the drift by small streams that exist only a few days a year. A series of raised marine beaches, the

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[4]Identified as a tuffaceous kenyte by Robert B. Forbes, Department of Geology, University of Alaska.

Figure 9 Aerial view from 15,000 feet above sea level looking west up the upper half of Taylor Dry Valley, McMurdo Sound, Antarctica. Symbols are: F, Ferrar Glacier; S, Sollas Glacier; M, Marr Glacier; T, Taylor Glacier; B, Lake Bonney; R, Rhone Glacier; L, Lacroix Glacier. Photograph by U. S. Navy, Dec. 5, 1956. Identification No. 163 F-33 VX-6 USN 3/11.

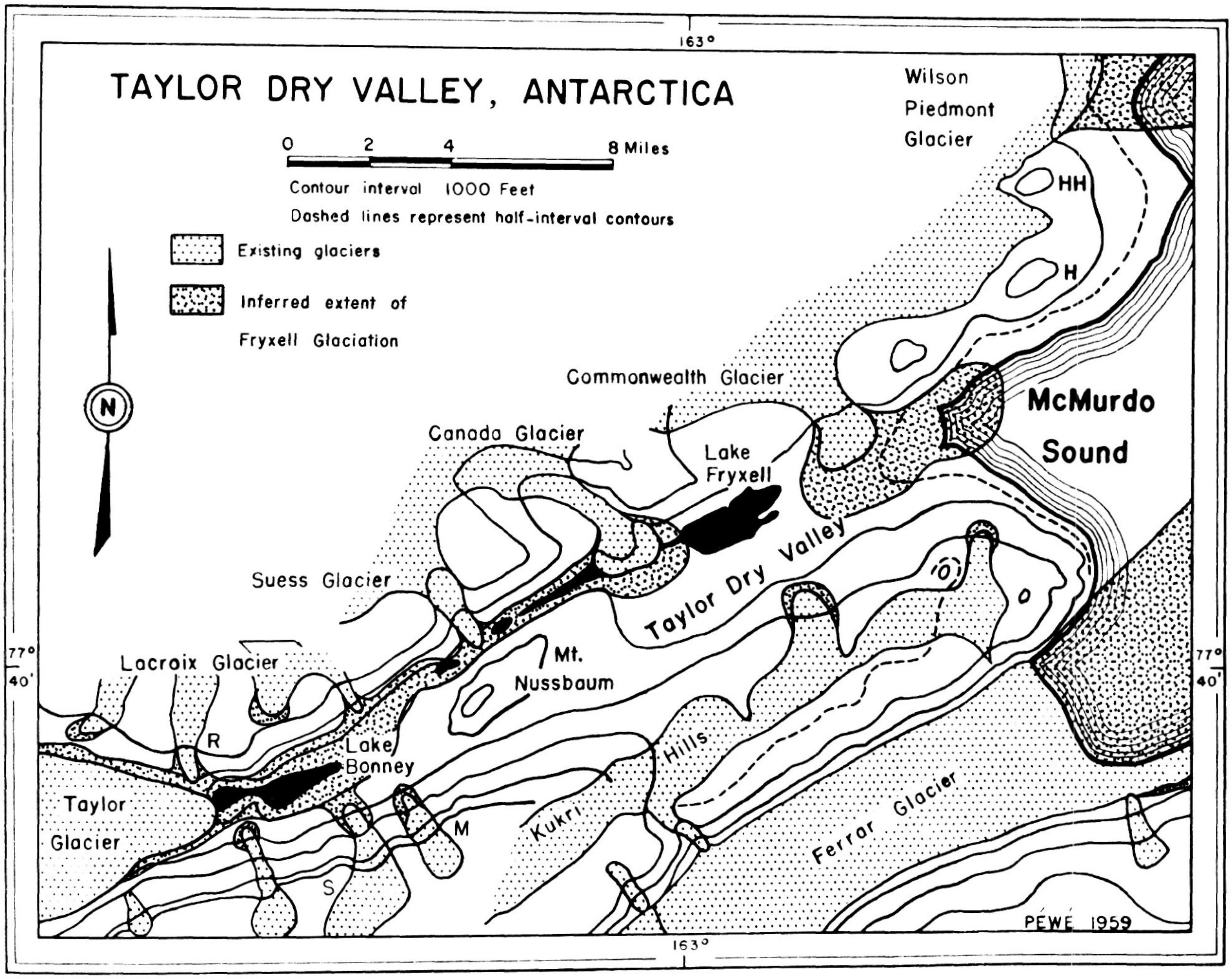

Figure 10 Sketch map of Taylor Dry Valley, Antarctica showing extent of existing glacial ice and inferred extent of Fryxell Glaciation. Letter symbols on map are: HH, Hogback Hill; H, Hjorth Hill; R, Rhone Glacier; S, Sollas Glacier; M, Marr Glacier. Base modified after map of Ferrar-Koettlitz District, British Antarctic Expedition 1910-13 "Terra Nova".

highest about 80 feet above sea level, occur in front of Wilson Piedmont Glacier (fig. 1). They formed since the Wilson Piedmont Glacier withdrew from the area (fig. 7) at the close of the Fryxell Glaciation. This phenomenon may also be used as a crude measure of the age of the Fryxell Glaciation because it must have taken considerable time for uplift and formation of the beaches in a Sound which is frozen most of the year.

Glacial lakes

A glacial lake existed between Canada and Commonwealth Glaciers in Taylor Dry Valley (fig. 7) in Fryxell Glaciation time. This lake is here named Glacial Lake Rivard after Norman R. Rivard, field assistant to the writer during this study. The lake abutted against Canada Glacier on the east and no terminal moraine was formed at this spot. Weakly developed shorelines lie at approximately 150 feet above sea level and exist in downward steps to the present Lake Fryxell, which is a remnant of Glacial Lake Rivard, now 55 feet above sea level.

As the ice melted from the upper part of Taylor Dry Valley, a lake formed, blocked by Suess or Canada Glacier. This lake is here termed Glacial Lake Llano after George A. Llano, lichenologist who has studied the vegetation in Taylor Dry Valley. Shorelines of this lake can be traced upvalley to Taylor Glacier. Several glaciers, such as Rhone and Lacroix (fig. 9), terminated in this lake and have no frontal moraines. Lake Bonney is a remnant of Glacial Lake Llano (fig. 9).

Koettlitz Glaciation

The latest major glaciation in the region is here named the Koettlitz Glaciation after the exceedingly well-preserved moraines on both sides of the Koettlitz Glacier. This glacial advance was the least extensive of the major advances and only the outlet glaciers have left widespread deposits.

The deposits are well preserved and distinct; they are easily differentiated from the older glacial drift because the moraines of the Koettlitz Glaciation are still filled with stagnant glacial ice. The ice-cored moraines exhibit well-developed constantly shifting knob and kettle topography. The drift, even though ice-cored, is covered with a network of sand-wedge polygons (Péwé, 1959). The drift of the Koettlitz Outlet Glacier is composed in large part of dark volcanic rocks, and kenyte is common.

The moraines of the alpine glaciers of this age consist mainly of short, ice-cored lateral moraines about 100 feet high, where the glaciers emerged from the valley and spread out on the valley bottoms. No ventifacts have formed on the shifting topography of the ice-cored moraines. The moraine of Koettlitz age flanking Garwood Glacier (fig. 1) is compound; two advances are evident. The outer and inner moraines, both of which lie within 200 yards of the present glacier front, are ice-cored.

During Koettlitz Glaciation, the alpine glaciers that poured into the desert valleys were only a few hundred yards more extensive than they are now (fig. 4). The outlet glaciers and shelf ice were much more extensive. The Koettlitz Glacier pushed 1-2 miles up the dry valleys on the west side of the Koettlitz Glacier Valley. The Koettlitz Glacier was also much thicker and flanked Mount Discovery at an elevation of 1,700 feet above sea level (fig. 11). The ice almost covered Brown Island as it pushed up to 1,200 feet above sea level, and covered the western part of Black Island up to a height of at least 1,000 feet. The little volcanic Dailey Islands (highest 800 feet above sea level) exhibit fresh marble and gneiss erratics (Taylor, 1922, p. 17), the result of being covered by the Koettlitz Glacier during the last major glaciation. The Stranded Moraines (fig. 11) on the west side of the Sound were recognized earlier as being a part of a lateral moraine of the Koettlitz Glacier (Taylor, 1922, p. 141). The writer attributes the Stranded Moraines to the latest major glacial advance. By projecting profiles of the upper ice surface, it is assumed that the ice may have pushed up to at least 500 feet above sea level on the west side of Ross Island. Some of the granitic erratics on Cape Royds may have been deposited at this time.

The Ferrar Glacier pushed out into the Sound as an ice tongue[5] (fig. 11), but probably was not pushed north far enough by the Koettlitz Glacier to bank against the Hjorth Hill area, as it was in the time of Taylor or Fryxell Glaciations. Therefore, the glacier ice in the Sound probably did not push far north into the Ross Sea, and it is thought that Beaufort Island (fig. 11) was not covered by ice from the south during the latest glaciation. This is in contrast to the view held by Harrington (1958b).

The age of the Koettlitz Glaciation is not known, but considerable time must have elapsed to build large deltas in the ice-dammed lakes that existed during this glaciation, because streams in the area are small and extremely ephemeral, flowing only a few weeks a year. Ice-cored moraines in temperate latitudes are no more than a few hundreds of years old; however, the writer believes the stagnant glacier ice can exist for thousands of years in the extremely cold, arid climate of the Antarctic.

Kettle lakes in the ice-cored moraine contain algae. Shifting and draining of such lakes leaves dead algae on the surface, which becomes buried with the shifting of the topography as the underlying glacial ice melts. Radiocarbon dating of samples of dried algae buried 1-10 feet below the surface in the ablation moraine have been dated as follows: (L-462A) from lower end of Garwood Valley is 2,480 ± 120 years and (L-462) from in front of Hobbs Glacier is 5,900 ± 140 years.[6] This indicates a minimum age of 6,000 years for the Koettlitz Glaciation.

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[5]Eight miles of this ice tongue still remain (Taylor, 1922, p. 85).

[6]E. H. Olson and W. S. Broecker, Lamont Geological Observatory, written communication, 1958.

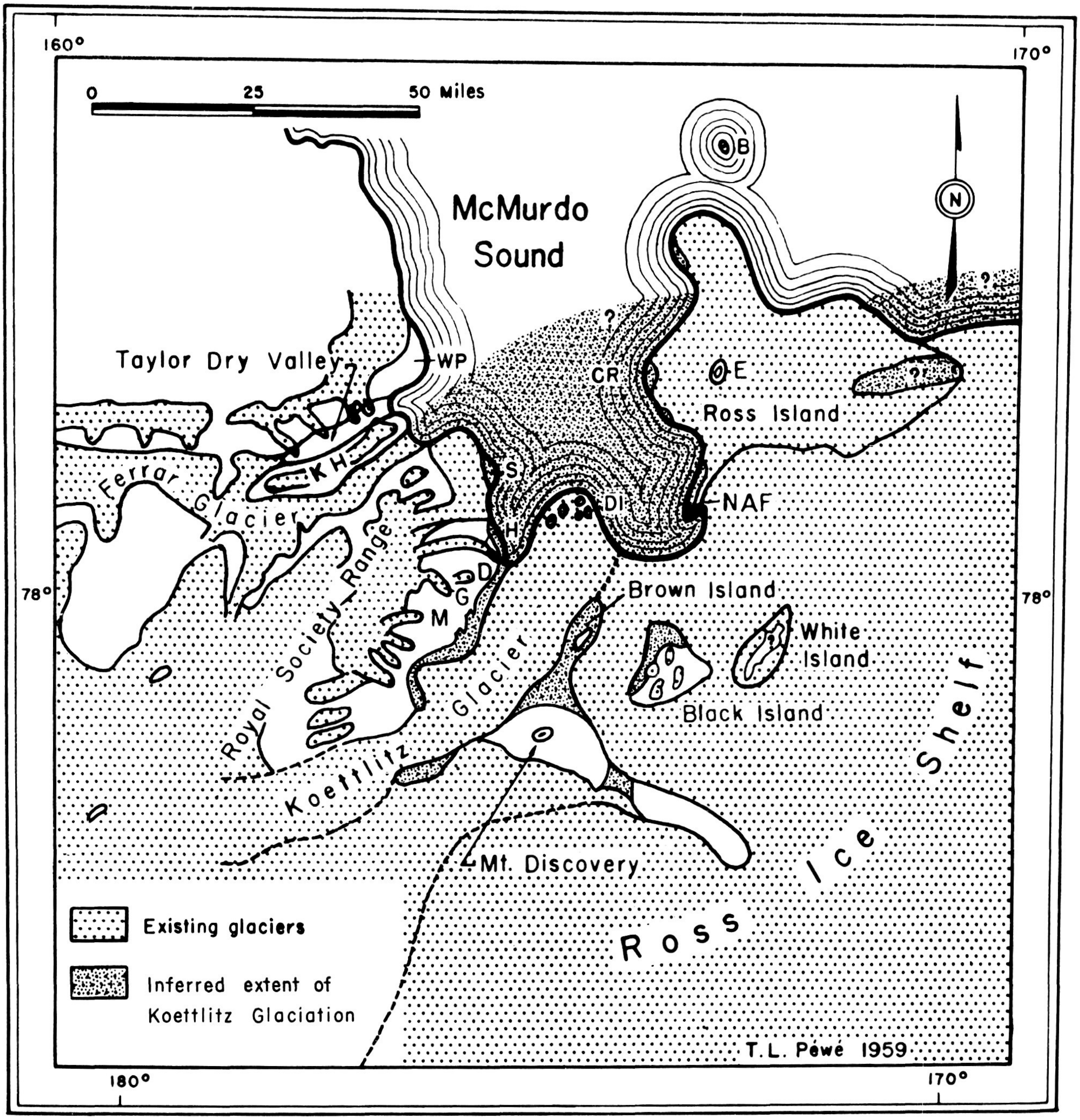

Figure 11 Sketch map of McMurdo Sound, Antarctica showing extent of existing glacial ice and inferred extent of Koettlitz Glaciation. Letter symbols are: B, Beaufort Island; WP, Wilson Piedmont Glacier; CR, Cape Royds; E, Mount Erebus; KH, Kukri Hills; S, Stranded Moraines; DI, Dailey Islands; NAF, Williams Naval Air Facility; H, Hobbs Glacier; D, Davis Glacier; G, Garwood Glacier; M, Miers Glacier. Base modified after U. S. Navy Hydrographic Office Chart No. 6636 (Ross Sea) 3rd ed., Sept. 23, 1957.

Glacial lakes

Lobes of the Koettlitz Glacier that pushed up the dry valleys on the west side (fig. 2) of this outlet glacier blocked drainage, and ice-dammed lakes formed. The lake that formed in the lower end of Davis Valley during this glaciation is here named Glacial Lake Muller, after Siemon W. Muller, pioneer worker in frozen ground of polar latitudes. A similar lake about 2 miles long formed in Garwood Valley (fig. 2) and is here named Glacial Lake Howard, after Arthur D. Howard, geomorphologist in Antarctica with the U. S. Navy Operation High Jump in 1946.

Deltas formed in both of these lakes, and these flat-topped steep-fronted forms are well preserved. Taylor stated (1922, p. 54) that in 1911 the deltas were ". . . bounded by notably cleancut edges, looking as if they had been formed only a few weeks previously." This description applies equally well today.

There are three distinct descending levels of delta surfaces in both lakes, indicative of long stands of lake level, perhaps correlative with glacier stillstands.

A lake formed in the lower end of Miers Valley (fig. 2), when blocked by ice from Koettlitz Glacier. This lake is here named Glacial Lake Trowbridge, after Arthur C. Trowbridge, former head of the Geology Department at the State University of Iowa. This lake is also now drained. In the bottom of extinct Lake Trowbridge there remains a 2-inch thick deposit of gypsum and thin 1/4-inch thick layer of $CaCo_3$ (identified by Richard C. Erd, U. S. Geological Survey), deposited, perhaps, as the lake evaporated.

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SUMMARY AND CORRELATION

At this stage of the investigation the following chronology is suggested for glaciation in the McMurdo Sound region:

Koettlitz Glaciation	Suggestion of a	III	6,000 years minimum age
	two or three	II	
	fold subdivision	I	
Fryxell Glaciation			
Taylor Glaciation			
Long time interval			
McMurdo Glaciation			

The above was a working chronology used in the field and a slight modification was presented at the IGY International Symposium in New Zealand in February 1958 (Péwé, 1958a). In May 1958 Gage and Suggate (1958) published the status of glacial chronology of New Zealand with a possible correlation to North America. In the absence of radiocarbon dating and direct paleontologic correlation it is difficult if not impossible to show correlation between the McMurdo Sound chronology and a chronology of either the northern hemisphere or elsewhere in the southern hemisphere. Nevertheless, the following speculation is presented.

McMurdo Sound, Antarctica (Pewe)	New Zealand (Gage and Suggate 1958)		North America
6,000 years +		Kumara-3	
		Kumara-2 (22,300 years)	Wisconsin
Koettlitz Glaciation	Otiran		
		Kumara-1	
Fryxell Glaciation		Hohonu	
Taylor Glaciation	Waimaungan		Illinoian
Long interval	Interglacial		Yarmouth
McMurdo Glaciation	Ross		

The sequence suggested for the McMurdo Sound area may represent most of the Pleistocene epoch, or it may be equivalent to only the Wisconsin stage of the North American chronology. It is felt that this latter interpretation is unlikely however, because even if the rate of wind erosion and moraine modification in general were twice as rapid as the rest of the world, the oldest glacial drift is at least pre-Sangamon in age.

Additional work now in progress will probably result in changes of the above interpretation; however, the material is presented as a working hypothesis.

In considering the subject of contemporaneity of glacial advances between Antarctica and elsewhere in the world it is well to remember that many years ago Scott (1905, p. 366) suggested that if the climate of Antarctica were to become warmer, the ice cap would not shrink as glaciers would in the rest of the world but, instead, would expand. This idea is based on the premise that the warmer air could hold more moisture. Therefore, evaporation would increase, precipitation would be more abundant, and the main part of the ice sheet would become thicker. He also thought that the main body of the ice cap would be less active during periods of colder climate. Others have suggested that the ice cap would thicken during a glacial age; it has also been suggested that climate and glacial regimen in Antarctica may be unrelated (Flint, 1957, p. 45).

To date, the relation of the regimen of the Antarctic ice cap to climatic variations is still unknown; however, considerable light will be shed on the problem when the data collected in Antarctica during the International Geophysical Year are analyzed. In a recent paper by Wexler (1959) it is suggested that an interpretation of the thermal profile of the upper 300 meters of the ice cap indicates that the climate has warmed by 4.5°C in the past 10,000 years. In the McMurdo Sound region the present writer shows that the glaciers have been retreating for at least the last 6,000 years and no doubt longer. Although it is too early to draw definite conclusions, it is here suggested that climatic warming and glacier retreat have been contemporaneous in Antarctica during the last few thousands of years.

References Cited

David, T. W. E., and Priestley, R. E., 1914, Glaciology, physiography, stratigraphy, and tectonic geology of South Victoria Land, British Antarctic Expedition, 1907-09, Geology, v. 1. Heinemann, London, p. 1-319.

Flint, R. F., 1957, Glacial geology in the Pleistocene Epoch, John Wiley & Sons, Inc., New York, N. Y., p. 45.

Gage, Maxwell, and Suggate, R. P., 1958, Glacial chronology of the New Zealand Pleistocene: Geol. Soc. America Bull., v. 69, p. 585-598.

Harrington, H. J., 1958a, Nomenclature of rock units in the Ross Sea region, Antarctica: Nature, v. 182, p. 290.

______________, 1958b, Beaufort Island, remnant of a Quaternary volcano in the Ross Sea, Antarctica: N. Z. Jour. Geol. and Geophys., v. 1, no. 4, p. 595-603.

Hough, J. L., 1950, Pleistocene lithology of Antarctic ocean-bottom sediments: Jour. Geology, v. 58, p. 254-260.

IGY Bull. no. 15, 1958, p. 3-7; Weather at US-IGY Antarctic stations during 1957: in Am. Geophys. Union Trans., v. 39, p. 997-1001.

IGY Bull. no. 24, 1959, p. 10-13, Antarctic plant life: in Am. Geophys. Union Trans., v. 40, p. 200-203.

Nichols, R. L., 1953, Geomorphology of Marguerite Bay, Palmer Peninsula, Antarctica: Ronne Antarctic Research Expedition, Tech. Rept. no. 12; Office of Naval Research, Department of the Navy, Washington, D. C., 151 p.

Péwé, T. L., 1958a, Pleistocene glacial chronology of the McMurdo Sound region, Antarctica: in Symposium on Antarctic Research, Dept. of Sci. and Indus. Res., Wellington, N. Z., p. 1-3.

__________, 1958b, Quaternary glacial geology of the McMurdo Sound region, Antarctica--a progress report: IGY Glaciological Rept. ser. no. 1, p. VI-1-4.

__________, 1958c, Glacier fluctuation between 1911 and 1958 in the McMurdo Sound region, Antarctica: Geol. Soc. America Bull., v. 69, p. 1755.

__________, 1959, Sand-wedge polygons (tesselations) in the McMurdo Sound region, Antarctica--a progress report: Am. Jour. Sci., v. 257, p. 545-552.

Scott, R. F., 1905, Results of the National Antarctic Expedition, I, Geographical: Geog. Jour., v. 25, p. 353-373.

Stetson, H. C., and Upson, J. E., 1937, Bottom deposits of the Ross Sea: Jour. Sed. Petrology, v. 7, no. 2, p. 55-66.

Steward, Duncan, 195_, Petrography of some erratics from Cape Royds, Ross Island, Antarctica: Jour. Geophys. Res., v. 64 (in press).

Taylor, Griffith, 1914, Physiography and glacial geology of East Antarctica: Geog. Jour., v. 44, p. 365-382.

______________, 1922, The physiography of the McMurdo Sound and Granite Harbour Region: British Antarctic "Terra Nova" expedition, 1910-13, Harrison and sons, ltd., London, 246 p.

Wexler, Harry, 1959, Geothermal heat and glacial growth: Jour. Glaciology, v. 3, p. 420-425.