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GEOLOGY OF THE SCOTT GLACIER AND WISCONSIN RANGE AREAS,
CENTRAL TRANSANTARCTIC MOUNTAINS, ANTARCTICA

DISSERTATION

Presented in Partial Fulfillment of the Requirements for
the Degree Doctor of Philosophy in the Graduate
School of The Ohio State University

by

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The Ohio State University
1967

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ACKNOWLEDGMENTS

This report covers two field seasons in the central Transantarctic Mountains. During this time, the Mt. Weaver field party consisted of: George Doumani, leader and paleontologist; Larry Lackey, field assistant; Courtney Skinner, field assistant. The Wisconsin Range party was composed of: Gunter Faure, leader and geochronologist; John Mercer, glacial geologist; John Murtaugh, igneous petrologist; James Teller, field assistant; Courtney Skinner, field assistant; Harry Gair, visiting stratigrapher. The author served as a stratigrapher with both expeditions.

Various members of the staff of the Department of Geology, The Ohio State University, as well as some specialists from the outside were consulted in the laboratory studies for the preparation of this report. Dr. George E. Moore supervised the petrographic work and critically reviewed the manuscript. Dr. J. M. Schopf examined the coal and plant fossils, and provided information concerning their age and environmental significance. Drs. Richard P. Goldthwait and Colin B. B. Bull spent time with the author discussing the late Paleozoic glacial deposits, and reviewed portions of the manuscript. Dr. Arthur Mirsky was helpful in numerous ways during the course of the research and in editing the report. Dr. Gunter Faure generously supplied
unpublished data on the geochronology and chemistry of the basement rocks, and reviewed the manuscript. Dr. C. H. Schultz examined thin sections of the Permian pyroclastic rocks. Dr. Sambhudas Chaudhuri, Kansas State University, assisted in the X-ray diffraction analyses. Dr. Allison R. Palmer identified the trilobites from the Leverett Formation, and Dr. Norman E. Newell examined pelecypod casts from the Weaver Formation. Drs. R. L. Bates, A. LaRocque, E. Rudolph reviewed the manuscript and offered many helpful suggestions.

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INTRODUCTION

This report covers two seasons field work in the central Transantarctic Mountains and subsequent laboratory investigations at The Ohio State University of specimens collected during the expeditions. The primary responsibility of the author on the expeditions was a study of the stratigraphy and petrology of the Late Paleozoic Beacon rocks; cursory observations were made on the Basement complex and on Cenozoic rocks in the area of the Scott Glacier during the first expedition. Observations on the second expedition, with field headquarters in the Wisconsin Range, were restricted to the Beacon Rocks and metamorphic rocks of the basement.

Field camps were established at Mt. Weaver near the head of the Scott Glacier in the Queen Maud Mountains, and near the Gondwana Escarpment on the Reedy Glacier in the Wisconsin Range of the Horlick Mountains. These areas were selected as field camp sites because they are near easily accessible and well-exposed Beacon rocks. The proximity of the Beacon rocks was necessary because travel in the first parts of the season was restricted to within a few kilometers of the field camps.

Prior to the Scott Glacier expedition, Long (1962) had described the stratigraphic section in the Ohio Range. The Beacon rocks in the Scott Glacier area were investigated in an
attempt to correlate these strata with those of the known sequence in the Ohio Range; only general correlations were possible after the first field expedition. In order to facilitate correlations between the Ohio Range and the Scott Glacier area, an expedition was sent into the Wisconsin Range of the Horlick Mountains, an area situated about half way between the two former localities. As a result of this work it was possible to recognize correlative units throughout the area.
Figure 1. Index map of Antarctica showing principal geographic features and the Antarctic in respect to the other continents of the southern hemisphere.
Figure 3. Index map of the Scott Glacier area.
Figure 4. Index map of the Wisconsin Range area
AREA OF INVESTIGATION

The area of investigation includes parts of the Horlick and Queen Maud Mountains in the central Transantarctic Mountains (Figures 1, 2, 3, 4). The Horlick Mountains include the Ohio Range, Long Hills, and Wisconsin Range. The Wisconsin Range consists of a series of northward and eastward facing escarpments which have been partially dissected by outlet glaciers flowing from the Polar Plateau to the Ross Ice Shelf. The Reedy Glacier is the major glacier in the Wisconsin Range, and separates the Horlick and Queen Maud Mountains.

The Queen Maud Mountains are comprised of the area between the Reedy and Beardmore Glaciers, and consists of a series of smaller mountain ranges, e.g., the Byrd and LaGorce Mountains. The Byrd Mountains are composed of a series of low-lying nunataks and ridges situated between the Reedy and Leverett Glaciers. The LaGorce Mountains are made up of a small range along the eastern side of the Scott Glacier, opposite to the convergence of the Scott and Poulter Glaciers.

The Horlick and Queen Maud Mountains are dissected by several major outlet glaciers, including the Reedy, Scott, and Amundsen. Eastward from the Wisconsin Range outlet glaciers are absent, and the ice of the Polar Plateau grades imperceptibly into the Ross Ice Shelf.
FIELD WORK

During October, 1962, a party of four was flown into the Mt. Weaver area to establish a field camp (Camp Weaver) for geologic investigations in this area (Figure 2). Motor toboggans were used to investigate the exposures in the vicinity of Mt. Weaver during the first two months of the field season. In January, 1963, U. S. Army turbine helicopters were provided for reconnaissance surveys of the mountains within a 75 km radius of the field camp. The field season totaled three months.

In 1964, a field camp (Camp Reedy) was established near the head of the Reedy Glacier in the Wisconsin Range of the Horlick Mountains (Figure 2). During the first part of the season motor toboggans were used; later turbine helicopters were available for the last five weeks of the season. With the aid of these helicopters it was possible to visit the area between the Amundsen Glacier and the Ohio Range, thereby completing a survey of the central Transantarctic Mountains which was initiated in 1960 by members of the Institute of Polar Studies, The Ohio State University.
PREVIOUS INVESTIGATIONS

Prior to 1962, only one expedition had visited the Scott Glacier area. Quin A. Blackburn, a member of the Byrd II Expedition, led a party up the Scott (formerly Thorne) Glacier in 1932 and recorded casual geologic observations. Blackburn and members of his party climbed Mt. Weaver at the head of the glacier and measured a stratigraphic section along the north ridge of the mountain (letter from Quin A. Blackburn to J. M. Schopf, 1963). The stratigraphic section was never published, although Blackburn published a general description of the area in the Geographical Review, noting the presence of coal and fossil plants at Mt. Weaver. Fossils were collected from the moraines near the base of Mt. Weaver and were later examined by Darrah, who concluded on the basis of preliminary investigations that the plants were of Mesozoic age.

The Wisconsin Range was sighted from a plane during Operation Highjump and photographed. In 1958, during an over-snow traverse from Byrd Station, a station was established about 30 miles north of the Wisconsin Range, and William E. Long and Fred Darling walked to what is now known as Mt. Le-Schack and collected a few samples from the granite cliffs. Long (1965) noted that the "only sedimentary rocks which were observed in this portion of the range were above an old erosion surface which was nearly at the top of a 1500-2000 foot cliff." The sedimentary rocks were not examined.
The Long Hills were visited in 1964 by a party under the leadership of W. E. Long, but no reports have been published dealing with this area.

Preliminary reports of the area between the Scott Glacier and Long Hills have been published by the author and others (Minshew and Summerson, 1963; Doumani and Minshew, 1963, 1965; Minshew, 1966).
GEOMORPHOLOGY

The area is divided into three geomorphic provinces: 1) the relatively featureless Polar Plateau, 2) the escarpments which border the plateau but face the Ross Ice Shelf and, 3) the foothills situated between the escarpments and the Ross Ice Shelf, or adjacent to the outlet glaciers which transect the Transantarctic Mountains.

The Transantarctic Mountains serve as a barrier behind which the ice of the Polar Plateau accumulates. Locally, the ice flows through the mountains in long, sinuous glaciers which coalesce at their mouths to form a part of the Ross Ice Shelf.

The Polar Plateau is composed primarily of an ice plain with a few nunataks protruding through the ice near the Transantarctic Mountains. The ice of the plateau passes up onto the upper surfaces of the escarpments. The average elevation of the Polar Plateau in the area of the Transantarctic Mountains is about 2400 meters. Although crevasses are rare in the plateau ice, large crevasse fields are present in the areas near the mountains and escarpments. These heavily crevassed areas probably are caused by local topographic highs on the subglacial bedrock. The summits of the nunataks protruding through the plateau ice are generally only a few hundred meters
high, although a few are up to 700 meters. Some, such as Mt. Howe, may have extensive ice cored moraines along the lee side, and most show some signs of having been covered by ice because of morainal deposits preserved on their crests.

The northward-facing escarpments and mountains which border the Ross Ice Shelf and outlet glaciers provide some of the most spectacular scenery in the area. The escarpments are steep, sometimes nearly vertical, with relief of more than 2000 meters. The summits of the escarpments are relatively flat, and merge into the Polar Plateau. They are of uniform elevation in the area between the Reedy and Leverett Glaciers, but southward from the Leverett Glacier the Mt. Blackburn massif rises about 700 meters above the general level.

The escarpments are composed primarily of igneous and metamorphic rocks of the basement; although flat-lying Late Paleozoic sedimentary rocks form a significant part of some, for example the Nilsen Plateau, they generally form only a thin covering of the summits.

The foothills occupy a belt up to 75 kilometers wide bordering the Ross Ice Shelf and are situated either between the escarpments and the Ross Ice Shelf or adjacent to the outlet glaciers. The foothills attain a maximum elevation of about 2000 meters, and relief of individual hills in excess of 300 meters is common. Cirques, some containing small glaciers, and horns are present in some of the larger hills. Near the Ross Ice Shelf the foothills
are largely covered with snow, but the amount of exposed rock generally increases toward the escarpments.

The bedrock of the foothills is composed almost exclusively of igneous and metamorphic rocks of the basement complex. Stranded and ice-cored Cenozoic moraines are widespread, and locally, small patches of Cenozoic glacio-lacustrine deposits are preserved.
WEATHERING CHARACTERISTICS

On casual observation, the rocks in the Antarctic appear to be slightly weathered, but upon detailed examination, all degrees of weathering are found. Weathering types present in the central Transantarctic Mountains include 1) a pothole-type weathering, 2) spheroidal weathering, 3) granular disintegration, 4) oxidation, and 5) a micro polygonal-type of weathering.

Circular depressions resembling potholes are present on some of the old erosion surfaces of the granitic rocks. The depressions are up to 10 cm in diameter and five cm deep. Some form of disintegration also play a major role in the weathering of the granitic rocks. Accumulations of reddish brown granitic debris up to 10 cm thick are present along the base of small ledges or around large boulders. Minerals in the debris are fresh, and the rock seems to have been disintegrated primarily by physical processes.

Unaltered diabase is light green, weathering to a reddish-brown. Some strongly weathered boulders have pronounced concentric rims, with the exterior of the boulders dark reddish brown. The physical appearance of the boulders suggests that they were altered by chemical processes. In the McMurdo Sound area Kelly and Zumberge (1961) examined deeply weathered
specimens of diorite which appeared to be similar to the weathered diabase in the Scott Glacier area. They studied diorite in all stages of weathering from nearly fresh to completely disintegrated, chemically and mineralogically. Few significant differences were found in either the mineralogy or chemistry between the weather and unweathered portions. Kelley and Zumberge thought that the diorite had been weathered primarily by mechanical processes, although the red color was the result of oxidation of the iron in biotite. They conclude (Kelly and Zumberge, 1961, p. 433) that "...the mechanism primarily responsible for the observed breakdown of the rock is the combined action of frost-wedging and the crystallization of salt in pores and crevices in the weathered rock" and that the study "...ended in providing quantitative proof of the predominance of physical process..." It appears that by comparison, the diabase in the Scott Glacier area may have been weathered primarily by physical processes.

The sedimentary rocks, because of their carbonaceous content, are dark gray to black on fresh exposures, but weather to a light gray or white. The depth of weathering varies from less than one millimeter to several centimeters, and seems to be related to the permeability and grain size of the rock. Poorly consolidated sandstones are much more deeply weathered than shales or siltstones.
Thin sections and chemical analyses of both fresh and weathered rock from the same sample (Table I) were made. Studies of the thin sections indicates that the contact between the weathered and unweathered rock is sharp. The weathering contact forms long narrow embayments corresponding to more permeable zones in the unweathered rocks. Mineralogically, the weathered and unweathered rock are similar. The main difference between the two zones is the near absence of carbonaceous material in the weathered rock. Only a few small flakes of fusain persist in the weathered rock which is transparent under plain light, whereas the unweathered rock is nearly opaque because of the presence of carbonaceous matter.

Sample 1-127, a claystone collected about 300 meters above the base of the Queen Maud Formation from the central face of Mt. Weaver, was analyzed chemically to determine the difference in composition between the weathered and unweathered rock. This sample had an unusually deep weathering rim, about two centimeters thick, which provided enough sample to be analyzed. The analyses for the two samples are given in Table 1.
Table 1
CHEMICAL COMPOSITIONS OF WEATHERED AND UNWEATHERED SAMPLE OF CLAYSTONE

<table>
<thead>
<tr>
<th></th>
<th>Unweathered</th>
<th>Weathered</th>
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<tbody>
<tr>
<td>SiO₂</td>
<td>77.20%</td>
<td>76.92% by weight</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>10.92</td>
<td>11.06</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.67</td>
<td>0.94</td>
</tr>
<tr>
<td>Na₂O</td>
<td>1.02</td>
<td>0.91</td>
</tr>
<tr>
<td>CaO</td>
<td>1.70</td>
<td>1.90</td>
</tr>
<tr>
<td>MgO</td>
<td>0.28</td>
<td>0.23</td>
</tr>
<tr>
<td>Na₂O</td>
<td>2.35</td>
<td>2.61</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.95</td>
<td>0.92</td>
</tr>
<tr>
<td>MnO</td>
<td>0.013</td>
<td>0.020</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.52</td>
<td>0.52</td>
</tr>
<tr>
<td>CO₂</td>
<td>0.84</td>
<td>0.61</td>
</tr>
<tr>
<td>H₂O₅</td>
<td>0.46</td>
<td>0.75</td>
</tr>
<tr>
<td>Moisture</td>
<td>2.79</td>
<td>2.57</td>
</tr>
<tr>
<td>Total</td>
<td>100.42</td>
<td>100.21</td>
</tr>
</tbody>
</table>

The most significant change is the decrease of total carbon content from 0.71% (unweathered) to 0.25% (weathered). This supports the observations from the thin sections that the loss of carbonaceous matter is responsible for the color change in the weathering of the rock. Carbon is most soluble in a basic solution, and it may have been removed by leaching action of meltwater.

Other changes of the weathered rock include: 1) oxidation of the iron, 2) loss of CO₂; 3) increase in the CaO and Na₂O content; 4) increase in the water of crystallization, and 5) decrease in the moisture content.

Meltwater was observed on several occasions on dark-colored rocks such as shale, coal, and basalt when these rocks were
exposed to direct sunlight. When the rocks became shaded, the water would freeze, but prior to freezing some of the water was undoubtedly absorbed by the rock, providing the agent by which the rocks could be weathered. The importance of meltwater in the weathering of these rocks is further suggested by the fact that the more permeable rocks are the most deeply weathered.

An unusual weathering feature, consisting of small polygonal fractures, is exhibited by black shale and coal in the Mt. Weaver area (Figure 5). The polygons developed on the coal are similar to those of patterned ground on unconsolidated deposits; they differ only in size. The polygons rarely exceed one centimeter, and are present only on weathered surfaces of coal or carbonaceous shale. The polygonal pattern of these coal beds could be of one of three possible origins: 1) primary features, perhaps mudcracks, formed during time of deposition; 2) post-depositional structures associated with either diagenetic activity or baking and dehydration of the coal or mud by the intrusion of the diabase sills, and 3) surface weathering.

Sections of weathered coal were polished normal to bedding and etched with hydrofluoric acid to accentuate any primary structures which might be present, but none were observed. A primary origin for the polygons is unlikely, because if they were of primary origin, some evidence of these features should be discernible on the etched surfaces. Furthermore, dessication
Figure 5. A micropolygonal-type weathering pattern developed on shaly coal.
cracks are not common in coal and black shale beds. The polygons could be the result of dehydration associated with diagenesis or metamorphism of the coal caused by overburden pressure, intrusion of diabase sills, or a combination of the two processes. Such a dehydration process could conceivably produce polygons which would later be accentuated during weathering, but such structures should have been visible on the polished surface of coal.

Because the polygons are limited to the exposed surface, weathering is the most probable origin. The mechanism for polygonal weathering may be two-fold: Since the coals in the Antarctic have a high but variable water and volatile content (J. M. Schopf, oral communication), the polygons conceivably could result from a dehydration of the coal and loss of moisture upon exposure to the atmosphere. Once the polygonal pattern was produced, it would be accentuated by freeze and thaw of meltwater. The only other alternative for the origin of the polygonal structures is a strictly weathering process associated with the freezing and thawing of water.
STRUCTURAL GEOLOGY

Historical background:

The first major contribution to the structure of the Transantarctic Mountain was by David and Priestley (1914), who, working in southern Victoria Land, theorized that the mountains formed part of a large horst with parallel faults on both the seaward and plateau sides of the mountain range. No direct evidence of faulting on either side of the mountain range was found.

Little more work was done on the structure of the Transantarctic Mountains until the arrival of the American expeditions under the leadership of Adm. Richard E. Byrd. Laurence Gould, a member of the expedition, led a geologic party to the central Queen Maud Mountains, making observations near the Axel Heiberg Glacier. He noted the relatively flat-lying Beacon rocks overlying the basement complex, and the similarity of the structure of this area to the mountains in southern Victoria Land.

Aerial photographs of the Transantarctic Mountains became available for the first time during the Byrd expeditions. Consequently, it was possible to examine these photographs for the presence of possible fault scarps on the plateau sides of the mountains. Previously, most investigations had been restricted to the Ross Ice Shelf side of the mountains.

Laurence Gould, working primarily from aerial photographs, concluded that a fault scarp was present on the plateau side of
the mountains; this fault was considered to be of similar magnitude to a suspected fault on the Ross Ice Shelf side of the mountains. Thus, Gould extended the horst theory of David and Priestley to include the central Transantarctic Mountains. Unfortunately, one of the photographs Gould based many of his conclusions on was not of a southern facing escarpment as he thought, but of the western face of the Nilsen Plateau, a north-south trending escarpment on the eastern side of the Amundsen Glacier (Long, 1964).

The validity of the horst concept was questioned by Hamilton (1960, 1963) on the basis of observations in southern Victoria Land. Hamilton found no evidence of a fault on either side of the mountains and concluded that the Transantarctic Mountains were of anticlinal origin.

The presence of a major fault on the seaward side of the Transantarctic Mountains was established by Barrett (1964), who found downfaulted Beacon rocks at Cape Surprise near the mouth of the Sheckleton Glacier. He estimated that the Cape Surprise section had been downfaulted at least 5000 meters relative to correlative strata in the escarpments to the south. Thus, for the first time the presence of a major fault on the Ross Ice Shelf side of the central Transantarctic Mountains was established.
Limited geophysical data suggests that no fault escarpment bounds the plateau side of the Transantarctic Mountains (Bull, 1960; Robinson, 1964). Rather, the Transantarctic Mountains seem to pass under the ice of the Polar Plateau at a gentle slope. Therefore, the Transantarctic Mountains appear to represent a gently dipping fault block which has been differentially uplifted along a series of intersecting normal faults.

Scott Glacier and Wisconsin Range

The structure of the Scott Glacier-Long Hills area consists of a series of intersecting high angle block faults, one set of which parallels the length of the Transantarctic Mountains, and the other is perpendicular to it. A fault in the foothills adjacent to the Ross Ice Shelf is suggested by 1) a remarkably straight coast line, 2) rapid increase in elevation from the foothills to the plateau, and 3) numerous inland faults which parallel the coastline.

One of the major inland faults of the area is present along the northern face of Mts. Saltonstall and Innes-Taylor, trending east-west (Figure 3). Along the fault zone the basement rocks have been brecciated and epidotized. The direction and amount of displacement along the fault is not known, but the location of Cenozoic olivine basalts at Paradox Ridge may be controlled by the fault zone, and as such may mark a major crustal dislocation.
A second major fault is thought to be present between Mt. Weaver and Sunny Ridge (Figure 3). The location of the fault zone is covered by an ice fall between Mt. Weaver and Sunny Ridge, but the fault is thought to strike parallel to the face of Sunny Ridge, in a north-south direction. The presence of a fault in this area is suggested by 1) The Beacon rocks' dip being much steeper at Sunny Ridge than at Mt. Weaver, 2) the strata being stratigraphically higher at Sunny Ridge than at Mt. Weaver, and 3) the presence of a volcanic cone (Mt. Early) along the projected fault line. The strata at Sunny Ridge appear to be downthrown in respect to those at Mt. Weaver, but the amount of displacement is not known. As at Paradox Ridge the presence of olivine basalt at Mt. Early may mark a major fault.

A second fault at Sunny Ridge strikes east, approximately perpendicular to the one discussed above, and is downthrown on the north with a displacement of about 100 meters.

The major structural element in the Wisconsin Range is a north-south trending fault along the face of the Gondwana Escarpment. The fault is downthrown to the west, with an estimated displacement of more than 600 meters. The Beacon rocks have been preserved along the downthrown side of the fault. They are steeply dipping to vertical near the fault zone, but flatten out to near horizontal in a few hundred meters west of the fault.
Numerous faults of lesser magnitude transect the major fault at approximately right angles along the Gondwana Escarpment (Figure 6). The displacement along these faults rarely exceeds 30 meters and all of these are downthrown to the south. The Beacon rocks at Mt. Weaver are disrupted by numerous faults, most striking east-west, with an average location of less than 10 meters. Faults of similar magnitude are common throughout the area of Beacon rocks in the area of study.

Surficial deformation plays an important role in the attitude of the Beacon rocks of the Scott Glacier area. The northwestern face of Mt. Weaver consists of a large toreva block, along which the strata have been displaced about 200 meters. The top of the toreva block forms Fault Block Ledge where the plane of slippage is near vertical. The slippage plane becomes more gently inclined downward from Fault Block Ledge to the base of Mt. Weaver, where it is nearly horizontal and parallels the basement-sediment contact. The Beacon strata dip about 45 degrees southwest near the top of Fault Block Ledge, and are nearly vertical toward the base of the mountain.
Figure 6. Structural map of the Gondwana Escarpment area of the Wisconsin Range
STRATIGRAPHY

Introduction

The stratigraphic section in the central Transantarctic Mountains ranges in age from Precambrian to Recent. The section (Figure 7) is divided into three parts for convenience of discussion: the basement rocks, the Beacon rocks, and the post-Beacon rocks. The basement complex consists primarily of granites which intrude a thick sequence of metasedimentary and metavolcanic rocks, and ranges in age from Precambrian to Ordovician. The Beacon rocks, consisting of a thick sequence of clastic sedimentary and pyroclastic rocks with Devonian marine sediments at the base locally, and a tillite elsewhere, unconformably overlie the basement rocks and range in age from Devonian to Permian. The post-Beacon rocks consists of Jurassic sills which intrude the Beacon rocks, and Cenozoic olivine basalt volcanoes and glacial moraines which overlie all the older bedrock.
Figure 7. Generalized stratigraphic section of the central Transantarctic Mountains, Antarctica
BASEMENT STRATIGRAPHY

Introduction

Basement rocks, consisting of an igneous and metamorphic complex, crop out extensively in the foothills of the central Transantarctic Mountains bordering the Ross Ice Shelf, and along the edges of the escarpments near the Polar Plateau. Along the escarpments and flat-topped mountains, the basement rocks are overlain by more than one thousand meters of nearly flat-lying Beacon rocks.

The basement rocks consist chiefly of a series of granitic plutons of different ages which have intruded thick sequences of metasedimentary and metavolcanic rocks. The metamorphic rocks constitute only a small part of the area of exposure, although they have a combined thickness of several thousand meters. They are restricted to the foothills along the mountain front, except for local occurrences within the mountains between Mts. Gardiner and Wyatt, and along the upper part of the Reedy Glacier. Metamorphic rocks also crop out along the western edge of the Nilsen Plateau (McLelland, in press).

The metamorphic rocks are grouped into three formations. The oldest is composed of steeply dipping phyllite, quartzite, and slate of the LaGorce Formation. The LaGorce Formation is thought to be overlain by pyroclastic rocks of the Wyatt Formation.
The youngest strata, the Leverett Formation, consists of slightly metamorphosed gently dipping trilobite-bearing limestones, sandstones, rhyolites, and minor amounts of conglomerate and shale; the Leverett Formation is thought to overlie the LaGorce and Wyatt Formations with angular unconformity.

The LaGorce and Wyatt Formations are intruded by porphyroblastic granitic rocks of Precambrian age (Faure and others, 1966), whereas the Leverett Formation is intruded by only light gray granitic rocks of Cambro-Ordovician age (Minehew, 1965).

Highly deformed amphibolites are present in nunatak A near the head of the Reedy Glacier, but these amphibolites cannot as yet be fitted accurately into the known stratigraphic section. These strata are similar to amphibolites of the Nimrod Group of the Benromore Glacier; the Nimrod Group contains the oldest rocks known in that area. Because of the similarity of the Wisconsin Range amphibolites with those of the Nimrod Group, they are placed in Figure 7 at the base of the section.
GRANITIC ROCKS

Granitic rocks compose the major part of the basement complex and are exposed extensively in the foothills and escarpments in the area between the Scott Glacier and Long Hills. The dominant lithology is a medium to coarse grained, gray biotite quartz monzonite which weathers to a dull reddish-brown. The basement complex is overlain by the flat-lying Beacon rocks, except where they have been eroded to expose the pre-Beacon erosion surface.

Inclusions, some obviously differentiation products and others xenoliths of metasedimentary rocks, are common in the granitic rocks. At Mt. Weaver and Mt. Wilbur and in the Wisconsin Range, the xenoliths are oriented with their long axes vertical or nearly so. Although some of the xenoliths are more than 50 cm in length, the average length is only about 10 cm.

Throughout the area the granitic rocks are cut by numerous pegmatite dikes. The largest dike, well exposed near the summit of Mt. Wilbur, is about one meter thick, dips 50° northwest, and is composed of gray feldspar, quartz, biotite, and muscovite. Tourmaline crystals more than 70 cm in length are common locally in the pegmatite dikes. Malachite and azurite were found in the uppermost part of a weathered exposure.
In addition to the quartz monzonite, aplite and gneissic granite are present on Mt. Wilbur, and a thin dioritic rim surrounds the granitic pluton at the LaGorce Mountains.

Red, coarse-grained, granitic rocks are common at Mt. Mooney, a few kilometers north of Mt. Paine. The relationship of the red and gray granitic rocks is not clear here, but elsewhere the red seems to be a contact facies of the gray.

Mt. Blackburn is composed of gray, porphyroblastic rapakivi granitic rocks. The porphyroblasts of potassium feldspar, up to three centimeters in diameter, are surrounded by albite. This porphyroblastic rock is unknown elsewhere in the Scott Glacier, but Murtaugh (oral comm.) describes similar granitic rocks from the Wisconsin Range and Long Hills.

One K-Ar age determination of brown biotite from a quartz monzonite from Mt. Wilbur gave a date 470 ± 14 m.y. (Table 2). The age of this biotite closely coincides with dates on a quartz monzonite from the Ohio Range obtained by K-Ar and Rb-Sr methods which approximate 470 m.y. (Treves, 1965). Similar dates have been obtained from a variety of rock types from widely separated localities in the Transantarctic Mountains (Craddock and others, 1964; Goldich and others, 1953; Aaron and Ford, 1963).

Recently, Faure and others dated a suite of granitic rocks from the Wisconsin Range using the Rb-Sr whole rock method and
obtained two sets of dates. They note that the "...granitic rocks of the Wisconsin Range batholith give two distinct whole-rock isochron ages of 627±22 and 479±10 million years." A biotite from the older granitic rocks was dated at 505 m.y. This work suggests that some of the 470 m.y. dates obtained throughout the Transantarctic Mountains earlier by the K-Ar method on biotite may indicate the time of metamorphism, not that of intrusion, of the rocks.

A late Precambrian orogeny is suggested by the 627 m.y. date, and the occurrence of a second orogenic event during the Cambro-Ordovician interval is represented by the 470 m.y. dates.

The radiometric data are supported by geologic observations. The Precambrian metasedimentary rocks are intruded by two suites of granitic rocks, whereas the Cambrian strata are intruded by a single granitic suite. Limestones containing lower Cambrian archaeocyathids have been intruded by granitic rocks in some parts of the Transantarctic Mountains (Hill, Trans. Roy. Soc. N. Z.), and the middle Cambrian Leverett formation in the Scott Glacier area is intruded by granite.

The granitic rocks which intrude these Cambrian strata are, in turn, overlain by rocks as old as Early Devonian. Thus, geologic and paleontologic data indicate an orogenic episode between the middle Cambrian and early Devonian, an interval that includes most of the isotope dates of the Transantarctic Mountains. This episode is the Ross Orogeny of Gunn and Warren.
(1962).

Table 2

Analytic Data on Dated Granite Specimen from Mt. Wilbur

<table>
<thead>
<tr>
<th>K Act.</th>
<th>K&lt;sup&gt;40&lt;/sup&gt; ppm</th>
<th>Ar&lt;sup&gt;40&lt;/sup&gt; ppm</th>
<th>Ar&lt;sup&gt;40&lt;/sup&gt;-&lt;sup&gt;40&lt;/sup&gt; K ppm</th>
<th>Age, m.y.</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.85</td>
<td>8.35</td>
<td>0.263</td>
<td>0.0312</td>
<td>470±14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.258</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Constants

\[ \begin{align*}
\text{D} &= 4.72 \times 10^{-10} \text{/yr} \\
\text{C} &= 0.585 \times 10^{-10} \text{/yr} \\
\text{K}^{40}/K &= 1.22 \times 10^{-4} \text{ g/g}
\end{align*} \]

Analyst: Geochron Laboratories, Inc.
LAGORCE FORMATION

Definition and type area:

The LaGorce Formation is named for exposures of chloritic phyllite, slate, and quartzite which crop out in long, low, sinuous ridges around Mt. Paine in the LaGorce Mountains (Figure 2, 3, 8). Mt. Paine is a large, isolated pluton of Cambro-Ordovician rock which intrudes the LaGorce Formation. Exposures of the LaGorce Formation extend outward to the north and south of Mt. Paine. The formation here consists of tightly folded and faulted low grade metamorphic rocks. All the strata have been metamorphosed to the greenschist facies.

Areal distribution:

The LaGorce Formation in the area of the Scott Glacier is restricted to the LaGorce Mountains. From the LaGorce Mountains, the nearest exposures are in the foothills along the western side of the Reedy Glacier where the formation is exposed in the Chlorite Hills and in the ridges northeast of Mt. Teller. East of the Reedy Glacier, the LaGorce Formation crops out in the foothills in the Wisconsin Range in the area between the Reedy Glacier and Mt. LeSchack. The formation is also exposed in a small outcrop on the Gondwana Escarpment near the head of the Olentangy Glacier. No other exposures are known in the area of study.

Westward from the Scott Glacier, rocks similar to the
Figure 8. Type locality of the LaGorce Formation. The low ridges in the foreground are composed of steeply dipping phyllites, and the escarpment in the background, Mt. Paine, is a granitic pluton which intrudes the LaGorce Formation.

Figure 9. Type locality of the Leverett Formation. The long, low ridges in the central foreground are composed primarily of the Leverett Formation.
LaGorce Formation crop out intermittently along the escarpment of the Nilsen Plateau (McClelland, in press).

**Thickness:**

Neither the top nor the bottom of the LaGorce Formation has been observed, consequently the thickness of the formation can only be estimated. Exposures of vertically dipping strata extend for several kilometers in some areas. On this basis, allowing for some duplication of strata, the formation is estimated to be at least several thousand meters thick.

**Structure:**

Throughout its outcrop area the LaGorce Formation is characterized by vertically dipping strata which strike eastward, parallel to the trend of the Transantarctic Mountains. Gentle or undulatory dips are known from only one exposure, along the western side of the Reedy Glacier, east of Mt. Teller (G. Faure, oral communication). Possible repetition of strata resulting from parallel folding has not been determined because of the absence of any diagnostic marker beds. In some exposures, however, graded bedding indicates that the beds become younger to the north and that they have not been isoclinally folded. Small thrust faults disrupt the strata in the exposures south of Mt. Paine in the LaGorce Mountains, but elsewhere faulting is rare.
Petrology:

The LaGorce Formation at the type locality consists of evenly stratified chloritic phyllite with a few thin bands of quartzite. Limestones are rare, although calcite veins and vugs are common. Volcanic rocks are present, but not common (S. B. Treves, oral communication). The quartzites are light gray, composed principally of interlocking quartz grains.

The phyllites consist of about 80% very fine sand or silt size grains of quartz, microcline, and albite in a matrix of recrystallized quartz, sericite, and chlorite. The detrital grains are generally finer than 0.15 m, and are subangular to angular. All the quartz has undulatory extinction. Sericite is the most common constituent in the matrix, followed in decreasing abundance by recrystallized quartz and chlorite. Secondary veinlets of calcite are common. The long axes of the elongate mineral grains display good orientation parallel to the bedding planes.

Two distinct facies are recognized in the LaGorce Formation in the vicinity of the Reedy Glacier, a calcareous-argillaceous facies at Chlorite Hills near the Byrd Mountains, and a more silty facies a few kilometers north of Chlorite Hills in the foothills northeast of Mt. Teller. At the former locality, the LaGorce Formation consists of alternating calcareous argillites and sandstone. Amphibole crystals and pyrite cubes are present.
in the more argillaceous beds, which average about 1.5 meters thick. The arenaceous beds are somewhat thinner.

The more silty facies crops out near the edge of the ex-carpment forming Mt. Teller. They consist chiefly of thin-bedded metasiltstones, closely resembling the LaGorce Formation at the type locality.

**Primary structures:**

Regular, uniform laminations are one of the most characteristic features of the LaGorce Formation. The individual beds are usually only a few centimeters thick, but are more than a meter in Chlorite Hills. Graded bedding and current bedding are recognized locally, and sole markings are common.

**Intrusive contacts:**

The LaGorce Formation is intruded by granitic rocks at Mt. Paine and several areas in the Wisconsin Range. At all localities, the intrusions are dioritic near the contact, and grade away from the contact into granite or quartz monzonite. Near the contact with the metasedimentary rocks, the diorite is characterized by large grains of anhedral blue quartz, greyish feldspar phenocrysts up to several centimeters in diameter, and an increase in the mafic mineral content. The diorite is thought to have formed through assimilation of metasedimentary rocks by granitic magma.

**Paleontology:**

No fossils have been found in the LaGorce Formation, and the
only indication of organic activity is obscure trail-like markings which are present along the base of a few beds. Insoluble residues obtained by treatment of phyllites with hydrofluoric acid are barren of organic remains.

Environment of deposition:

The immaturity of the sedimentary rocks, the repetitious uniform laminations, the presence of graded bedding, sole markings, and volcanic rocks suggest deposition in eugeosynclinal environment, with at least some of the rocks being deposited by turbidity currents. The absence of ripple marks may suggest deposition below wave base; the presence of ripple drift cross-laminations suggest that some of the strata were deposited from traction currents for some of the strata. The high percentage of matrix in the phyllites, generally more than 20%, suggests deposition in an environment with little winnowing. The great thickness of the formation could be the result of rapid or prolonged deposition.

The minerals present, including primarily quartz, microcline, albite, and matrix suggest that the sediments were derived from a crystalline shield-type area.

Age

Most evidence pertaining to the age of the LaGorce Formation is indirect, determined by the relationships to the granitic rocks of the basement complex. The LaGorce Formation is intruded by two suites of granitic rocks in the Wisconsin Range.
(Faure and others, 1966). Faure and others dated phyllites from the LaGorce Formation and obtained a whole-rock isochron of $460^{\pm}16$ m.y. The age of the phyllites is, within experimental errors, the same as that of the younger granitic rocks of this area. Evidently the intrusion of the younger granitic rocks caused loss of radiogenic strontium from the phyllites.

On the basis of these studies, the age of the LaGorce Formation is greater than $627^{\pm}22$ m.y. that of the older granitic rocks which intrude the formation. Thus, the LaGorce Formation is Late Precambrian in age.
Introduction

The Wyatt Formation is composed of pyroclastic rock of acidic composition, and is thought to overlie the LaGorce Formation. It is intruded by two suites of granitic rocks, and is overlain with angular unconformity by the Middle Cambrian Leverett Formation.

Definition and type area:

The Wyatt Formation, a black rhyodacitic metavolcanic unit of pyroclastic origin is named for exposures at Mt. Wyatt, situated near the northern edge of the convergence of the Scott and Poulter Glaciers in the Queen Maud Mountains (Figure 2). The Wyatt Formation here consists of massive, black rhyodacite containing phenocrysts of quartz and feldspar up to one centimeter in diameter, in a black, dense matrix. Petrographic investigations indicate that the fine-grained black material is composed primarily of plagioclase, quartz, biotite, rock fragments, and unidentified matrix.

The Wyatt Formation at the type locality is intruded by numerous pegmatite dikes, and is overlain by about 100 meters of Late Paleozoic Beacon rocks and Jurassic diabase sills.

Areal distribution:

The Wyatt Formation crops out extensively in the nunataks north of Mt. Wyatt, forming a large part of the basement complex.
between Mts. Wyatt and Gardiner (Figure 2). Eastward from the Scott Glacier, the Wyatt Formation forms the major part of Metavolcanic Mountain near the head of the Reedy Glacier in the Wisconsin Range. It also crops out in small isolated patches along the eastern end of the Gondwana Escarpment, and along the escarpment on the western edge of the Reedy Glacier in the Queen Maud Mountains. The Wyatt Formation is known elsewhere from scattered exposures reported by McLelland (in press) in the Nilsen Plateau, facing the Amundsen Glacier.

Lower contact:

The lower contact of the Wyatt Formation has not been observed, and its relationship to the other metamorphic rocks in the basement complex is inferred. The LaGorce and Wyatt Formations are exposed together only at the eastern end of the Gondwana Escarpment near the head of the Olentangy Glacier. The Wyatt Formation here occurs topographically above the LaGorce Formation, but the contact is covered by debris (John Murtaugh, oral communication). If the beds here have not been overturned or faulted and represent a normal stratigraphic succession, the Wyatt Formation is younger than the LaGorce Formation.

The upper contact of the formation has not been observed, but the Wyatt and LaGorce Formations are thought to be overlain with angular unconformity by the Leverett Formation.

Structure

The structure of the Wyatt Formation is largely unknown be-
cause of the absence of primary structures such as bedding. Foliation in the area between Mt. Wyatt and Mt. Gardiner dips steeply and strikes east, parallel to the mountain range; however, few measurements on foliation were made. It is not known if foliation and bedding are parallel.

**Thickness**

It is not possible to determine the thickness of the Wyatt Formation because of the absence of primary structures within the rock, preventing the determination of the structural attitude of the beds. The wide areal distribution of the formation in the vicinity of the Scott Glacier could be the result of moderate to great thickness, gentle dips, or repetition by folding or faulting. In the area of the Scott Glacier the Wyatt Formation can be traced for several kilometers in a horizontal direction and a few hundred meters in a vertical direction with little perceptible change.

**Petrology**

Four samples of the Wyatt Formation were examined petrographically (Table 3). The samples were collected from the area between Mts. Wyatt and Gardiner, on the western side of the Scott Glacier (Figure 2). Sample 64128 is from Mt. Wyatt, samples 64244 and 64236 are from the Mid-glacier Nunataks about half way between Mts. Wyatt and Gardiner, and sample 64226 is from near the central part of the eastern face of Mt. Gardiner.

The rocks of the Wyatt Formation seem to grade from
unmetamorphosed pyroclastics at Mt. Wyatt to equigranular metavolcanics of the biotite zone of metamorphism at Mt. Gardiner. Detailed descriptions are given below.

Sample 64218, from Mt. Wyatt, is a pyroclastic rock consisting mostly of quartz, plagioclase, rock fragments, and biotite in a fine-grained matrix. The matrix, 43% of the total sample, is greenish, presumably the result of microcrystalline chlorite. Scattered throughout the matrix are small anhedral grains with low index of refraction and low birefringence, probably quartz or feldspar.

Plagioclase, the most abundant mineral in the rock, is subhedral, and most grains show oscillatory twinning with gradational boundaries. The plagioclase is slightly altered, commonly to sericite, with the central, most calcic, portions of the grains the most strongly sericitized. Minor amounts of magnetite and chlorite are present in some of the grains. Plagioclase grains vary in size from more than two mm to less than 0.1 mm. Potassium feldspar is rare, compared to plagioclase, and makes up less than one percent of the sample.

Quartz occurs in two forms: Very small grains scattered randomly throughout the matrix and large isolated grains with symmetric extinction. The small grains in the matrix range from 0.01 to 0.1 mm in diameter, and were identified by the index of refraction. The large quartz grains with symmetric
extinction have maximum diameters of about four mm. Some of the grains are partially rounded, probably the result of resorption. Resorption is further suggested by the presence of embayments in the grains; most of the embayments are filled with cryptocrystalline material or, in places, with subhedral grains of epidote and apatite. Some of the grains are bi-pyramidal in outline, and probably are resorbed beta-quartz pseudomorphs. The quartz grains show signs of moderate cataclastic deformation.

Biotite is common, and occurs as elongate slightly fracture flakes as much as four mm in length, and contains inclusions of magnetite and apatite. Most of the biotite is fresh, but some grains are chloritized, and others are surrounded by chloritic halos.

Rock fragments are abundant, consisting mostly of large rounded grains of volcanic or hypabyssal rock, and phyllite. The igneous fragments have a microaphanitic texture and are composed mostly of minute plagioclase laths. The phyllite is dense, very fine-grained, and contains a few sand-size grains of plagioclase in a sericitic matrix.

Epidote is rare, and occurs as very small subhedral grains in the matrix or closely associated with the biotite.

The samples from the Mid-glacier Nunataks differ from that collected at Mt. Wyatt. Microfoliation is pronounced in the samples from the nunataks, but is absent in the Wyatt sample.
Table 3
Mineralogic composition of samples of the Wyatt Formation from the Scott Glacier Area

<table>
<thead>
<tr>
<th>Sample</th>
<th>quartz</th>
<th>plagioclase</th>
<th>orthoclase</th>
<th>matrix</th>
<th>biotite</th>
<th>chlorite</th>
<th>muscovite</th>
<th>rocks</th>
<th>opaques</th>
<th>epidote</th>
<th>calc</th>
<th>gar</th>
</tr>
</thead>
<tbody>
<tr>
<td>64218</td>
<td>15</td>
<td>21</td>
<td>0.5</td>
<td>43</td>
<td>5</td>
<td>tr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>14.5</td>
<td>1</td>
</tr>
<tr>
<td>64244</td>
<td>14.5</td>
<td>18</td>
<td>4</td>
<td>58</td>
<td>3.5</td>
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<td>tr</td>
<td>tr</td>
<td>tr</td>
<td>tr</td>
<td>tr</td>
<td>tr</td>
</tr>
<tr>
<td>64236</td>
<td>2</td>
<td>20.5</td>
<td>6</td>
<td>58.5</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>64226</td>
<td>52.5</td>
<td>12</td>
<td>12</td>
<td>18.5</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Chlorite is well developed; the samples from the nunataks contain 3.5 and 12 percent chlorite, compared to trace amounts in the one from Mt. Wyatt. Orthoclase is more abundant in the nunataks. The plagioclase content is about the same as at Mt. Wyatt, but the quartz content is variable, comprising 14.5 and two percent. Epidote, apatite, and garnet are common accessory minerals. The matrix content is slightly higher than that in the sample from Mt. Wyatt. Rock fragments were not observed in the nunatak samples.

The plagioclase is highly sericitized in the nunatak samples, and in places can be recognized only by clusters of sericite. Where not severely altered, the plagioclase retains oscillatory zoning. The orthoclase is dusty and slightly altered. Ghosts of plagioclase laths seems to be present within some orthoclase grains.

Chlorite occurs as microcrystalline matrix and as numerous elongate isolated grains. Some of the grains are as much as six mm in length, but most are one mm or less. Most of the chlorite formed as alteration products of biotite, and contains inclusions of epidote, apatite, garnet, and opaques. In addition to chlorite, the matrix contains sericite and minor amounts of what may be micocrystalline quartz and feldspar.

Sample 64226, from Mt. Gardiner, is an equigranular metavolcanic rock. In hand specimen, it is similar to the other
rock types of the Wyatt Formation, but petrographically it is quite distinct. The most striking difference is the absence of matrix material in this sample; the rock is composed of equigranular interlocking minerals with an average diameter of about one mm, with some grains as much as four mm in diameter. The specimen differs from those of other localities in the abundance of quartz, as much as 52.5% in the sample studied. Plagioclase and orthoclase are present in equal amounts. Chlorite, apatite, epidote, and garnet present only in trace amounts, but biotite and muscovite, or a white mica, are abundant. Much of the plagioclase is clouded with sericite flakes, and oscillatory zoning is extremely rare.

Chemical composition

The whole rock chemical analysis of sample 64226 from Mt. Gardiner is given below.

Table 4

Whole Rock Chemical Analysis of a Metamorphosed Rhyodacite from Mt. Gardiner

<p>| | | | | | |</p>
<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>67.46%</td>
<td></td>
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<tr>
<td>Al₂O₃</td>
<td>15.62</td>
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<tr>
<td>Fe₂O₃</td>
<td>1.12</td>
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<tr>
<td>FeO</td>
<td>3.81</td>
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<tr>
<td>CaO</td>
<td>2.23</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>MgO</td>
<td>1.91</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na₂O</td>
<td>2.96</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>K₂O</td>
<td>3.20</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>MnO</td>
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</tr>
<tr>
<td>TiO₂</td>
<td>0.66</td>
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</tr>
<tr>
<td>CO₂</td>
<td>0.34</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Moisture</td>
<td>0.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H₂O</td>
<td>0.26</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>99.89%</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
The chemical analysis suggests that the rock is of rhyodacitic composition.

**Metamorphism**

The rocks at Mt. Wyatt represent virtually unaltered pyroclastics. Some of the biotite in the sample has been chloritized, but minor amounts of chlorite can form in conditions other than metamorphism. The formation can be traced laterally through various stages of metamorphism to the biotite zone at Mt. Gardiner. The rocks at Mt. Gardiner show the highest degree of metamorphism reached by the Wyatt Formation in this area.

The rocks in the Mid-glacier Nunataks are thought to represent the chlorite zone of the greenschist facies of regional metamorphism. The following factors suggest that these rocks belong to the chlorite zone: chloritization of the biotite; presence of epidote, apatite, and garnet; extensive recrystallization, mostly sericite and chlorite, of the matrix; high degree of alteration of the more calcic plagioclase; biotite is absent. This mineral assemblage agrees with that which Winkler (1964) terms the quartz-albite-muscovite-chlorite subfacies of the greenschist, corresponding to the chlorite zone of Scotland. The first appearance of epidote and chlorite in quantity mark the initiation of this facies.

The rock at Mt. Gardiner represents the quartz-albite-epidote-biotite subfacies of the greenschist facies. Winkler (1964) correlates this subfacies with the biotite zone of metamorphism.
This metamorphic grade is suggested for the Mt. Gardiner sample by the equigranular nature of the rock, the abundance of biotite and muscovite, and the absence of chlorite. In the biotite zone of metamorphism, biotite first enters the mineral assemblage as a metamorphic mineral, and remains stable thereafter throughout the entire range of metamorphism.

The grade of metamorphism of the Wyatt Formation is higher in the Wisconsin Range than in the Scott Glacier area. In the former locality the Wyatt Formation can be traced into granitic rocks in a distance of about two km in the escarpment bordering the western side of the Reedy Glacier (G. Faure, oral communication).

The mechanism and time of metamorphism of the Wyatt Formation are difficult to determine. The rocks are thought to have been deposited in a geosynclinal area, and were affected by at least two periods of orogenic activity. Winkler (1964) states that depth of burial alone cannot produce rock of the greenschist facies. Thus, the metamorphism of the Wyatt Formation must be associated with Precambrian and Early Paleozoic orogenic events.

Origin

The Wyatt Formation is thought to have originated primarily as a pyroclastic deposit in a geosynclinal area. A volcanic origin for these rocks is suggested by the zoning in the plagioclase and the abundance of matrix or groundmass material. The
absence of flowage structures and of trachytic or diabasic-type textures may be indicative of a pyroclastic origin.

Age

Samples of the Wyatt Formation from the Wisconsin Range have been dated by the Rb-Sr whole rock method of Faure and others (1966). They obtained an isochron for these rocks that indicates an age of 633±13 m.y., a date identical to that obtained for the Precambrian granitic rock which intrude the Wyatt Formation and some of the metamorphic equivalents of the Wyatt Formation. Faure and others believe the 633 m.y. date may indicate the isotopic homogenization of the Wyatt Formation; the actual age, i.e. time of deposition, may be greater than 633 m.y.
LEVERETT FORMATION

Definition and type area

The Leverett Formation, consisting of a few thousand meters of poorly exposed interbedded limestone, sandstone, shale, and pyroclastics with minor amounts of shale, is named for exposures in a small series of nunataks at about 1500 meters elevation, just north of the Leverett Glacier, in the western part of the Byrd Mountains (Figure 9). A section was measured along one of the ridges which trends normal to the strike of the beds. Northward from these nunataks, additional low-lying nunataks facing the Ross Ice Shelf appear to be composed mostly of similar metasedimentary and metavolcanic rocks.

The Leverett Formation is divided into seven units at the type locality, each unit designated by letter, with A as the lowest (Figure 10). The thicknesses of all units are estimates, based on the use of altimeter and pace.

Areal distribution

The Leverett Formation is known only from the type locality, although rocks of similar lithology and structural attitude are exposed in a small nunatak south of Metavolcanic Mountain near the head of the Roedy Glacier. The relationship of these strata to the Leverett Formation is uncertain.
Figure 10. Stratigraphic section of the Leverett Formation
Thickness

The Leverett Formation probably exceeds 2000 meters in thickness. On the southern face of the nunataks at the type locality, about 1000 meters of section were measured. The stratigraphic succession seems to continue uninterrupted on the northern face of the nunataks through more than a thousand meters of strata composed principally of pyroclastics and interbedded coarse-grained quartzite and conglomerates with stretched pebbles. Neither the top nor the bottom of the formation was observed.

Structure

At the type locality, the strata strike east and dip 30°-50° N; cross-bedding indicates that the beds are not overturned. The strata are only slightly metamorphosed, but locally are severely fractured. Veins of gray to pink calcite cut the rocks, and the entire sequence is intruded by pegmatite dikes. Near the eastern end of the nunataks at the type locality, the sediments are intruded by reddish-weathering, gray granitic rocks characteristic of much of the basement of this area.

Stratigraphy

Unit A is the lowest subdivision of the Leverett Formation. It consists of about 300 meters of coarse-grained red cross-bedded arkosic sandstone, the base of which is not exposed. The cross-bedding is mostly small scale and planar, and dips gently northward.
The sandstones are generally poorly sorted, and the grains are angular to subangular. Quartz and potassium feldspar are the most common detrital minerals. The quartz grains average about 1.5 mm in diameter, are angular to subangular, and have undulose extinction. Most of the grains are elongate, with the long axes approximately parallel to the bedding. Secondary overgrowths are common.

Potassium feldspar is one of the primary constituents of the sandstones, varying from about 10 percent to more than 60 percent, with an average content of about 15 percent. Much of the feldspar in some of the sandstones is of secondary origin, in the form of overgrowths on detrital feldspar. Also, subhedral crystals of orthoclase are present in the pore spaces between individual grains. Microcline is the most common detrital feldspar. The detrital feldspar is generally subangular and fresh. Plagioclase is rare, making up less than five percent of most samples; the plagioclase is sodic, fresh, and unaltered.

Rock fragments are abundant in the sandstones, and consist of the following (in order of decreasing abundance): limestone, phyllite, siltstone, shale, and volcanics. Reworked limestone fragments, subrounded and with a thin oxidized rim, comprise up to one half of some samples; the fragments average about 1.5 mm in diameter. Metamorphic rock fragments are abundant in some samples. They consist mostly of sericitic matrix enclosing a
few detrital grains. The phyllite fragments are elongate and as much as several mm in length.

Chlorite is present in minor amounts, and occurs as detrital flakes and microcrystalline replacement of the matrix. Muscovite is absent in most samples, and biotite is rarely present. The matrix is commonly sericitized.

Unit B, overlying unit A, is a sequence of poorly sorted red massive pebbly mudstone about 100 meters thick. The contact between the units is covered by snow. The mudstone is composed of angular to well rounded sand-size grains of metamorphic and, to a lesser extent, volcanic rock fragments in a red clayey sericitic matrix that makes up about 60% of the samples. The mudstone is bimodal, consisting predominantly of clay and sand size fragments. The long axes of the larger grains are well aligned, producing a microfoliation approximately parallel to bedding. A few coarser beds of this unit are composed of granule-to pebble-size particles of shale and metamorphic rock fragments in a clayey matrix. The mudstone contains minor amounts of copper-bearing minerals, and is cut by numerous pegmatite dikes containing abundant malachite and azurite.

Unit C, a thin-bedded silty shale, rests conformably on the pebbly mudstone. The shale, predominantly green and brown, with lesser amounts of red and black is highly fractured, but locally the bedding is well preserved. The shale is intruded by pegmatite dikes, but shows little indication of thermal
metamorphism. Stringers of gypsum are common throughout the unit. No organic remains were found in the shale, which is estimated to be 125 meters thick.

Unit C grades upward through a few meters into 150 to 175 meters of interbedded limestone and shale that constitute Unit D. The shale beds average about one meter in thickness and their color varies from dark green to black, with light brown the most prominent. The thickness of the limestone beds is generally about 10 to 20 centimeters. Some beds are characterized by well-developed laminations produced by alternating laminae of micritic calcite and microcrystalline calcite. The limestones vary from light to dark gray, weathering to a light pinkish-brown. Structures similar to sole markings occur rarely at the base of the limestone beds throughout the unit. No organic remains were found.

Gradational through approximately a five-meter interval with unit D is a thin-bedded dark gray argillaceous limestone, unit E, estimated to be more than 175 meters thick. Grayish-brown limestone, shale, and volcanic sandstone become abundant in the upper part of the unit. The limestones are generally dark gray, and are composed of micrite near the base of the unit, with coarse-grained limestone more abundant near the top.

Trilobite fragments are abundant in some of the limestone beds near the middle of the unit. The trilobites are highly
broken, and are in coarse-grained limestone containing a few fragments of well-rounded shale or slate.

A one-meter bed of tuffaceous limestone is present about 50 meters above the base of unit E. The rock is composed of about equal amounts of microcrystalline calcite and detrital grains of plagioclase and quartz. The plagioclase grains, mostly subhedral and as much as three mm in length, have been altered to sericite and laumontite. Potassium feldspar is rare. Small opaque cubic crystals are present in minor amounts.

Overlying unit E is a white massive cliff-forming limestone, unit F, about 100 to 150 meters thick. Unit F is conspicuous in outcrop because of its color, and is easily recognizable from great distances. The limestone is characteristically vuggy, with some of the vugs containing small amounts of native copper. The lower part of the unit is a fine-grained micritic limestone, which becomes coarser upward until it consists of sparry calcite with rounded sand-size grains of calcite embedded in it. Chert nodules are abundant in the upper few meters of the limestone, and a few thin beds of chert are present.

Unit G, consisting of pyroclastic rocks of rhyolitic composition and interbedded coarse-grained conglomeratic sandstone, probably a thousand or more meters thick, is gradational with the underlying limestone of unit F. The lower part of unit G consists of tuffaceous limestone and calcareous tuffites.
Sample 64123, a calcareous tuffite, is from the lower few meters of the unit. The sample is composed of 30 percent calcite, 30 percent chloritized matrix, and the remainder of plagioclase, potassium feldspar, quartz, and laumontite, and minor amounts of biotite and chlorite. The chlorite is interspersed throughout the matrix, replacing biotite and plagioclase. Some of the plagioclase has oscillatory twinnings; the plagioclase is commonly partially replaced by laumontite, which is also present as radiating crystals filling voids. This rock type grades upward into the thick pyroclastics, of which sample 64124 is representative.

Sample 64124 was collected about 30 meters above the base of unit G, near the crest of the ridge at the type locality. The sample is composed principally of the following minerals: quartz, about 10 percent; potassium feldspar, about 10 percent; plagioclase, about 30 percent; matrix, about 50 percent. Additional minerals in trace amounts include chlorite, sericite, muscovite, epidote, and opaques.

Muscovite occurs as large elongate isolated grains, some of which are several millimeters in length, and they are present in stringers throughout the sample. Associated with the large muscovite flakes are abundant grains of quartz and feldspar, which are concentrated along the stringers of muscovite. The stringers of muscovite, quartz, and feldspar are thought to represent original differences in the composition of the rock;
because the detrital grains are more concentrated here than in the rest of the sample, they may represent pockets of washed and sorted material.

The matrix of the sample is light gray, has a low birefringence and low index of refraction, and is thought to be composed primarily of micro to cryptocrystalline quartzose and feldspathic minerals.

The sandstones which overlie the volcanics are coarse-grained and poorly sorted. They are highly fractured, and many of the pebbles in interbedded conglomerates are stretched and elongated parallel to bedding. The matrix in the sandstones has been recrystallized, and consists of interlocking anhedral grains of quartz and feldspar. The detrital grains, consisting primarily of quartz, and to a lesser extent, microcline, are up to six millimeters in diameter, averaging about three to four millimeters. The grains are subangular to subrounded, with abundant secondary overgrowths of quartz and orthoclase.

**Chemistry**

Sample 64124, a pyroclastic rock from the lower part of unit 6 of the Leverett Formation, was chemically analyzed. The whole rock chemical analysis is given in Table 5.
Table 5

WHOLE ROCK CHEMICAL ANALYSIS OF A RHYOLITIC TUFF OF THE LEVERETT FORMATION

<table>
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<th>Element</th>
<th>%</th>
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<tr>
<td>Al₂O₃</td>
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<tr>
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<tr>
<td>TiO₂</td>
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<tr>
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</tr>
<tr>
<td>H₂O</td>
<td>2.28</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>99.85%</strong></td>
</tr>
</tbody>
</table>

*Analysis courtesy G. Faure; analysed by Andrew S. McCreath & Sons, Inc.

The sample contained more potassium oxide than sodium oxide. However, petrographic analysis indicates that plagioclase is more abundant than potassium feldspar. Some of the potassium must be present in the groundmass, which makes up a major part of the rock. Based upon the percentage of silica, the sample is a rhyodacite.

Primary structures

The most common sedimentary structure is small-scale planar cross-bedding in the sandstones. The individual cosets are only a few centimeters thick, and the bedding dips uniformly to the north. Large-scale festoon cross-bedding with a northerly dip is present in the conglomeratic sandstones of unit G.

Paleontology and age

The trilobites from unit E of the Leverett Formation were described by Allison R. Palmer (written communication, 19 November,
1965). Although they are distorted and broken, Palmer recognized three distinct species. Concerning this fauna, Palmer states: "The commonest trilobite...has features which indicate that its general affinities seem to be with the genus Mapania. This genus is apparently found at several levels within the Middle Cambrian. One of the trilobites seems closest to the genus Lisamiella, also of Middle Cambrian age. The third trilobite species is a nearly featureless form that could perhaps represent another Middle Cambrian genus, Sunaspis...." In conclusion, Palmer states that the rock contains"...a deformed trilobite fauna of general Asiatic aspect that is suggestive of a Middle Cambrian age...." He further notes that this fauna is different from the others so far found in the Antarctic. Insoluble residues failed to reveal any additional faunal elements.

Faure and other (1966) dated rhyolites from unit G of the Leverett Formation by the whole rock Rb-Sr method, obtaining an age of 472±11 m.y. Thus, the Leverett Formation is at least Middle Cambrian in part, and the date on the rhyolites is suggestive of Upper Cambrian to Lower Ordovician. However, the upper and lower age limits of the formation are unknown.
Environment of deposition

The sediments of the Leverett Formation accumulated in a shallow marine shelf-type environment. The immaturity of the sandstones suggests first cycle sediments, derived primarily from a granitic and metamorphic terrain, containing intermittent volcanic contributions.

A moderate to high energy environment is thought to have existed during the deposition of the sandstones in the lower part of the formation. This is suggested by the lack of sorting, the presence of numerous shale-pebble conglomerates, and the general coarseness of the sandstone. Little sorting or winnowing took place; if it had, the matrix material would have been removed. The mudstones may have been formed by some type of mass movement. Once the materials reached the site of deposition, no sorting occurred. The shales in unit C probably formed in quiet conditions. A reducing environment may be suggested by the predominantly green color of the shales.

Units D and E formed in quiet conditions where periods of fine carbonate deposition alternated with periods of clay deposition. Very low energy conditions are suggested by the fineness of the material comprising the limestone. High energy conditions must have been present at times to form the coarse-grained limestones in unit E, which contain the severely broken up trilobite fragments. The tuffaceous limestones represent volcanic ash falls.
into an area of carbonate deposition. Toward the end of de-
position of unit F, volcanic activity increased and ash falls
became abundant. During the early stages of volcanic activity,
the ash was deposited in a marine environment. Much of the
volcanic rock of unit G accumulated as pyroclastic debris, with
some reworking by water as suggested by the concentrations of
mineral fragments in thin bands shown in sample 64124.

Metamorphism

The prevalence of laumontite in sample 64123 from the
lower part of unit G indicates that the Leverett Formation has
not been metamorphosed above the zeolite facies; Coombs and others,
(1959) state that laumontite disappears with the beginning of
the greenschist facies.

The sandstones comprising the upper part of unit G seem to
be more highly altered than the rocks in the lower part of the
formation, and may represent a higher degree of metamorphism.
BASEMENT CORRELATIONS

Because most of the work done until now has been of a reconnaissance nature and from widely separated areas, correlations within the Antarctic are, of necessity, of a much broader scale and more generalized than in most other parts of the world. Thus, the following correlations serve only as preliminary attempts which will be refined later. Sedimentary sequences similar to that in the basement of the Scott Glacier-Long Hills area are widespread within the Transantarctic Mountains from the Weddell Sea to Victoria Land (Figure 11).

The stratigraphic section in the Pensacola Mountains has been divided into three sequences, each separated by an angular unconformity (Schmidt and others, 1965). The oldest sequence, the Patuxent Formation, consists of several thousand meters of interbedded siltstone and sandstone, most of which have been metamorphosed to the greenschist facies. In places the rocks possess rhythmic and graded bedding, and basaltic flows with pillow structures are present through the unit. This first sequence, which is considered by Schmidt and others to be late Precambrian, is tentatively correlated with the LaGorce Formation because of similar structure, lithology, and degree of deformation, and because the strata are overlain angular unconformity by Cambrian limestones.
REGIONAL CORRELATION CHART OF BASEMENT ROCKS
OF THE TRANSANTARCTIC MOUNTAINS

<table>
<thead>
<tr>
<th>PRECAMBRIAN</th>
<th>THIEL MOUNTAINS</th>
<th>WISCONSIN RA-SCOTT GLACIER</th>
<th>DUNCAN MOUNTAINS</th>
<th>SHACKLETON GLACIER</th>
<th>SHACKLETON-NIMROD GLACIERS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SCOTT GLACIER</td>
<td>MINSHEW</td>
<td>McGREGOR</td>
<td>WADE AND OTHERS</td>
<td>GRINDLEY AND OTHERS</td>
</tr>
<tr>
<td></td>
<td>SCHMIDT MOUNTAINS</td>
<td>FORD</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>WYENS FORMATION</td>
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<td></td>
<td>GAMBACORTA FORMATION</td>
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<tr>
<td></td>
<td>NELSON LIMESTONE</td>
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<td></td>
<td>LEVERETT FORMATION</td>
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<tr>
<td></td>
<td>HENSON MARBLE</td>
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<td>TAYLOR FORMATION</td>
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<td>QUARTZ MONZONITE PORPHYRY</td>
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<td>GOLDIE FORMATION</td>
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<tr>
<td></td>
<td>AMPHIBOLITES</td>
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<tr>
<td></td>
<td>NIMROD GROUP</td>
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</table>

Figure 11
The second sequence, which is about 1000 meters thick, consists of three conformable formations: in ascending order, the Nelson Limestone, the Gambacorta Formation (a felsic volcanic unit), and the Wiens Formation (a siltstone-shale unit). The Nelson Limestone contains a Middle Cambrian trilobite fauna, and thus is correlative with at least part of the Leverett Formation.

The third sequence, consisting of a few thousand meters of predominantly clastic materials, may range in age from lower to upper Paleozoic, and correlates generally with the Beacon rocks which overlie the basement in the Scott Glacier-Long Hills area.

The Thiel Mountain consists primarily of a quartz monzonite porphyry which has been intruded by biotite granite (Ford and Aaron, 1962). The porphyry contains zones plagioclase in a fine-grained groundmass, and is petrographically to the Wyatt Formation except for the presence of minor amounts of cordierite in the former. A late Precambrian date was obtained by the Lead Alpha method, and the porphyry is tentatively correlated with the Wyatt Formation.

A major part of the basement of the Long Hills is composed of pyroclastic rocks of rhyolitic composition which have been dated by Faure and others (1966), suggesting an identical age with the rhyolites of unit G of the Leverett Formation.

The stratigraphic succession of the Duncan Mountains near the Axel Heiberg mountains was described by McGregor (1965).
The oldest sedimentary unit, the Duncan Formation, consists of more than 3500 meters of dark pelitic hornfels and schists; graded bedding is common. The Fairweather Formation, composed of up to 3000 meters of dark colored rocks, overlies the Duncan Formation. McGregor (1965) originally suggested the Fairweather Formation was a cataclastically deformed sandstone, but he now is of the opinion that it is a metamorphosed volcanic rock (McGregor, written communication). Thin sections of the Fairweather Formation furnished by McGregor are very similar lithologically to samples of the Wyatt Formation from Mt. Gardiner and Mid-glacier nunataks, and seem to be of a similar grade of metamorphism.

The Fairweather Formation is overlain by more than 500 meters of limestones comprising the Henson Marble, the top of which was not seen. In nearby localities, thick volcanic units with conglomerates containing stretched pebbles were found. The Henson Marble and overlying conglomerates and volcanics may be in part correlative with the Leverett Formation.

In the area near the Shackleton Glacier, the sedimentary rocks in the basement complex are divisible into a two-fold succession similar to that elsewhere in the central Transantarctic Mountains, although no fossils have been found. The oldest strata here consist of more than 3500 meters of metagreywackes and slates of the greenschist facies, the Goldie Formation, which seems to be correlative with the LaGorce
Formation, and was correlated by Wade and others (1965) with the Goldie Formation of the Beardmore Glacier area. These metasediments are overlain by a thick unit of quartzites, conglomerates, calcareous sandstones and marbles of the Taylor Formation. The Goldie and Taylor Formations were not observed in contact. One of the more conspicuous units in the Taylor Formation is a cliff-forming, massive, white, crystalline limestone, similar to unit F of the Leverett Formation. The Taylor and Leverett Formations are considered to be in part correlative. No formation equivalent to the Wyatt Formation is known in this area, or in any localities north of the Shackleton Glacier.

As summarized by Grindley and other (1964) the basement stratigraphy of the area between the Shackleton and Nimrod Glaciers consists of a two-fold division similar to that of the area covered by this report. The oldest sedimentary rocks in the Shackleton-Nimrod Glaciers area are steeply dipping phyllites and slates, most of which have been metamorphosed to the green-schist facies. These rocks are characterized by uniformity of lithology and great thickness, and are assigned to the Goldie Formation (in a few areas local formational names have been applied). The Goldie Formation and its equivalents are overlain by thick sequences of limestones, sandstone, and occasionally volcanic rocks, which have been assigned a number of different formations, of which the Shackleton Lime-
stone is best known (Laird, 1963). The Shackleton Limestone was first described in the area of the Beardmore Glacier, by Laird; the most notable feature of the formation is the presence of a well-preserved Archaeocyathid fauna, establishing the age as Early Cambrian (Hill, 1963).
ISOLATED EXPOSURES OF BASEMENT ROCKS

Several nunataks were visited whose rocks could not be related to nearby exposures nor fitted into the known stratigraphic sequence.

The Reedy Glacier splits into two equal parts near its head, being divided by several small nunataks which crop out on the edge of the Polar Plateau (Figures 2, 12). The southernmost nunatak, nunatak A, consists of intensely folded, black, hornblende-plagioclase amphibolite. Nunatak A is separated by a small patch of snow from nunatak B, which is composed of more than 1000 meters of coarse-to medium-grained sandstones, striking northwestward, and dipping 45° southwestward. By projection of the dip of the sandstones, it seems that they rest on the amphibolites in nunatak A, although the nature of the contact is not known.

The sedimentary succession at nunatak B begins with a coarse-grained, conglomeratic sandstone, about 300 meters thick (Figure 12). The conglomerates are composed mostly of discoid or rounded pebbles of chloritic shale. Cross-bedding, mostly planar, is well-developed throughout the sandstone, and dips about 15° northeastward. This basal sandstone is overlain by about 100 meters of alternating fine-grained sandstone and siltstone, characterized by alternating light and dark beds,
Figure 12. Stratigraphic section of Nunatak A
which average about two centimeters in thickness.

Overlying the sandstone-siltstone sequence are a few hundred meters of medium-to fine-grained sandstone and quartzite. A snow patch covers the next few hundred meters of section, and this is followed by about 1000 meters of quartzitic sandstone similar to that described above.

The amphibolites from nunatak A are quite distinct from any other rock types in the basement in this area, and cannot be correlated with any of the known rock sequences. Nor is the stratigraphic position of the sandstones known. Lithologically and structurally, these rocks are similar to the Leverett Formation, the most notable difference being the absence of limestones and volcanics. The metamorphic grade is similar to that of the LeGorce Formation, but thick deposits of coarse-grained clastics are not known from that formation. Similar deposits are present in the Pensacola Mountain, where their stratigraphic position is also unknown (Dwight Schmidt, oral communication).

This sequence is cut by pegmatites which contain specular hematite. Schmidt (oral communication) also noted the presence of hematite in pegmatites cutting similar rocks in the Pensacola Mountains.
Several workers have theorized that the basement metasedimentary rocks in the Transantarctic Mountains were deposited in a geosyncline which extended along the present position of the mountain range from Cape Adare to Coats Land near the Weddell Sea (Hamilton, 1960; Gunn and Warren, 1962).

Previously, it was believed that sedimentation was nearly continuous from the late Precambrian into the early or middle Cambrian, but it now seems that a major unconformity is present separating the metasediments of Precambrian age from the overlying Cambrian strata. Angular unconformities are now known to be present in the Pensacola Mountains and in the area of the Nimrod Glacier (Schmidt and others, 1966; Malcolm Laird, written communication, 3 May, 1965). Laird, discussing the Nimrod Glacier area, states: "A strong unconformity separated isoclinally folded Precambrian metagraywackes from the overlying Cambrian limestone and quartzite.... At some localities, the limestone, which contains Lower Cambrian Archaeocyathine, overlaps directly on the greywacke."

An angular unconformity is thought to be present in the Scott Glacier-Long Hills area separating the Leverett Formation from the LaGorce and Wyatt Formations. The presence of the unconformity is suggested by the following: The LaGorce Formation
is generally vertically dipping, and the Leverett Formation is gently sipping; the LaGorce and Wyatt Formations have been generally metamorphosed to the greenschist facies or higher, whereas the Leverett Formation is metamorphosed only to the upper part of the zeolite facies: the LaGorce and Wyatt Formations are intruded by two granitic suites, whereas the Leverett Formation is intruded by only one. These relationships are not restricted to the Scott Glacier-Long Hills area, but seem to be the same wherever rocks of similar sequences are present in the Transantarctic Mountains. Grindley and others (1964) argue for a conformable sequence in the Beardmore Glacier area; some of their evidence is based on field observations by McGregor, but in a recent letter to the author, McGregor (written communication) states that his field observations need not be interpreted as Grindley and others have done and that he, McGregor, believes that an angular unconformity may be present separating the two rock sequences in this area.

Thus, it seems that the geosyncline in which the greywackephylite sequence accumulated was subjected to orogenic activity along much, if not the entire length, of the Transantarctic Mountains during the late Precambrian. The granitic rocks from the Wisconsin Range dated at 627 m.y. probably represent the orogenic episode during which the Precambrian rocks were folded and metamorphosed.
It is interesting to note further that in all situations which permit observations on grade of metamorphism, the grade increases in a northerly direction. Although the data are meager, they suggest stronger orogenic activity during the Precambrian and Cambrian to the north, in a direction toward the Ross Ice Shelf.

The basement rocks upon which the LaGorce Formation and younger strata were deposited is largely unknown. In the Nimrod Glacier and Duncan Mountains areas strata equivalent to the LaGorce Formation are considered to overlie a thick complex of isoclinally folded gneisses, marbles, quartzites, orthogneisses, and amphibolites which comprise the Nimrod Group (Grindley and others, 1964). The Nimrod Group is thought to represent part of the older Precambrian basement complex upon which the Late Precambrian were deposited. The amphibolites at Nunatak B near the head of the Reedy Glacier are similar lithologically to those of the Nimrod Group, and may be correlative with the Nimrod Group. If this correlation is correct, the amphibolites at Nunatak B may represent part of the basement complex upon which the LaGorce Formation was deposited.
GEOLOGIC HISTORY OF THE BASEMENT COMPLEX

During the late Precambrian, large quantities of clastic sediments were deposited in an eugeosynclinal-type environment coinciding with the position of the present Transantarctic Mountains. Following deposition of these sedimentary rocks, great thicknesses of acid pyroclastics were deposited in the area between the Thiel and Duncan Mountains. After the formation of these pyroclastic rocks, and perhaps partly synchronous with them, the basement strata were severely deformed, metamorphosed, and intruded by granitic plutons. Locally, some of the sedimentary and volcanic were granitized. Subsequently, the area was uplifted and eroded.

Following erosion, the area subsided, and Cambrian marine sediments were deposited. Shallow shelf-type conditions must have existed when thick, fine-grained limestones accumulated. Volcanoes were present along the fringe of the sea, at times providing significant contributions of rhyolitic pyroclastics. During the Late Cambrian to Early Ordovician, volcanic activity increased, and thick sequences of rhyolitic rocks accumulated in parts of the Transantarctic Mountains. The rhyolites may represent the extrusive equivalent of the Early Ordovician granitic rocks. During this event the Ross Orogeny, the Cambrian strata were metamorphosed to the zeolite facies, and the entire area uplifted. The conglomeratic sandstones in
the upper part of the Leverett Formation probably represent detritus derived from a rising land mass associated with this orogeny.

Following the uplift associated with the Ross Orogeny, the area was subjected to erosion and bevelled, and Devonian or younger sedimentary rocks were deposited over the basement complex.
Introduction

Overlying the basement rocks with unconformity the length of the Transantarctic Mountains is a series of nearly flat-lying clastic sedimentary strata, ranging in age from Devonian to Jurassic, and collectively called the Beacon rocks (Figure 13). They are intruded by thick diabase sills of Jurassic age and in some places overlain by theolitic basalts. The Beacon rocks in the central Transantarctic Mountains are divided by a disconformity that probably represents most of the Carboniferous. The strata beneath the disconformity, present only locally, are generally mature sandstones and are considered to be Devonian. The strata above the disconformity range from Permian to Jurassic and are composed of a thick sequence of immature rocks. In the central Transantarctic Mountains the section has a tillite at the base, overlain by shales that grade upward into coal measures containing pyroclastic detritus.

In the designation of the above strata, conflict exists between those who wish to retain the name Beacon because of its traditional use, those who wish to attempt a more rigorous application of the stratigraphic code, and those who propose the abandonment of the term (Mirsky, 1964, and others).

Beacon was first used by Ferrar (1907) for the relatively
<table>
<thead>
<tr>
<th>PENSACOLA MOUNTAINS</th>
<th>OHIO RANGE</th>
<th>WISCONSIN RANGE</th>
<th>SCOTT GLACIER</th>
<th>NILSEN PLATEAU</th>
<th>MT. F. NANSEN</th>
<th>SHACKLETON GLACIER</th>
<th>BEARDO MORE GLACIER</th>
<th>DARWIN GLACIER</th>
<th>S. VICTORIA LAND</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>QUEEN MAUD FORMATION</td>
<td>QUEEN MAUD FORMATION</td>
<td>QUEEN MAUD FORMATION</td>
<td>UNIT C</td>
<td>BUCKLEY COAL MEASURES</td>
<td>BUCKLEY COAL MEASURES</td>
<td>MISTHOUND COAL MEASURES</td>
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<td>WEAVER FORMATION</td>
<td>AMUNDSEN FORMATION</td>
<td>UNIT B</td>
<td>UNIT A</td>
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<td>SCOTT GLACIER FORMATION</td>
<td>SCOTT GLACIER FORMATION</td>
<td>UNNAMED CONGLOMERATE</td>
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<td>DARWIN FORMATION</td>
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<tr>
<td>GALE MUDSTONE</td>
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<tr>
<td>DOVER SANDSTONE</td>
<td>HORLICK FORMATION</td>
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</tr>
</tbody>
</table>

**Figure 13**
Figure 14. Stratigraphic section of Beacon rocks at Mt. Weaver
Figure 15. Stratigraphic section of the Beacon rocks in the Wisconsin Range.

- TILL (PLEISTOCENE?)
- QUEEN MAUD FORMATION
  GLOSSOPTERIS SHALE
  SANDSTONE WITH ANIMAL BURROWS
- WEAVER FORMATION
  INTERBEDDED SILTSTONE AND SHALE
  WITH TRACE FOSSILS
  SHALE WITH ANIMAL TRAILS, AND
  ICE-RAFTED PEBBLES
- BUCKEYE FORMATION
  TILLITE
- GLACIO-LACUSTRINE BEDS
- BASEMENT COMPLEX
  GRANITE AND METAMORPHICS
flatlying quartzitic strata at Beacon Heights west and east in southern Victoria Land; he applied the name Beacon Sandstone Formation to these exposures and to the overlying Glossopteris bearing arkosic units throughout the "Dry Valleys" area. Since then the term has been used in Beacon Sandstone Group, Beacon Formation, Beacon Sandstone, and others. Only Beacon Group is acceptable under the American and International Codes of Stratigraphic Nomenclature, although it may be unusual to include within a single group, strata with such a wide range in age and separated by a disconformity representing most of the Carboniferous.

Recently, the informal terms Beacon rocks and Beacon strata have been applied to the relatively undeformed sedimentary rocks of the central Transantarctic Mountains (Wade and others, 1965; Barrett, 1966), and southern Victoria Land (Mirsky and others, 1965). Used in this manner, the term will continue to serve a worthwhile purpose, even after the rocks are formally subdivided and group and formational names applied to them.

The Beacon rocks in the area of investigation are divided into four stratigraphic units (Figures 14, 15). The stratigraphic sequence generally consists of a tillite at the base which grades upward into a regressive shale-siltstone-sandstone sequence that is disconformably overlain by coal measures containing abundant pyroclastic debris (Figure 14). The entire
sequence is considered to be of Permian age.

The tillite and related glacial deposits which occur at the base of the Beacon rocks are placed in two laterally equivalent formations. The tillites and interbedded water-laid sediments in the Wisconsin Range are placed in the Buckeye Formation; those in the Queen Maud Mountains are placed in the Scott Glacier Formation. The two formations are considered to be lateral equivalents, but because they differ considerably in lithology, color, and thickness, they are classified as separate formations.

The Weaver Formations overlies the glacial deposits with gradational contacts, except for local disconformities in the area of the Scott Glacier. The formation is divided into three members. The lower member is generally composed of black shale containing sideritic concretions and abundant animal trails. The middle member is composed of interbedded shale and siltstone or fine-grained sandstone, and is gradational with the lower member. The upper member is gradational with the middle member and is composed of massive weathering arkosic sandstone and arenaceous limestone with minor amounts of black shale and shaley coal near the top of the formation.

The Weaver Formation is disconformably overlain by quartz pebble conglomerates of the Queen Maud Formation. The basal quartz pebble conglomerates are overlain by more than 400 meters
of coal measures composed of cyclic alternations of sandstone, siltstone, shale, mudstone, tuffites, and coal. Volcanic detritus first appears in the quartz pebble conglomerate and becomes more abundant upward. The Queen Maud Formation is characterized by a prolific Glossopteris flora.

The Beacon rocks are intruded by great thicknesses of Jurassic diabase which have metamorphosed the Beacon rocks to varying degrees. Frequently, the diabase sills comprise more than half of the exposed stratigraphic sections.
BUCKEYE FORMATION

Introduction

The Buckeye Formation comprises the Late Paleozoic glacial deposits in the Horlick Mountains. The formation in the Wisconsin Range is composed of more than 100 meters of interbedded unstratified tillite and stratified glacio-lacustrine deposits. Glacial pavements containing striae, grooves, and plucked surfaces are ubiquitous on the erosion surface beneath the Buckeye Formation.

Definition and type area

The Buckeye Formation was first described from exposures in the Ohio Range of the Horlick Mountains as a "...bluish-gray boulder clay and...a few sandstone and shale beds..." by Long (1962, p. 319) who gave them the name Buckeye Tillite. The formational name, Tillite, however, is misleading, because these deposits include not only ice-deposited morainal sediments, but also water-laid deposits. In fact, in some areas morainal material comprises only a small part of the Buckeye Tillite. Moreover, confusion has resulted from Long's use of the term tillite in referring to a lithologic type. It is proposed that the more general term Formation be used for the stratigraphic unit and tillite reserved for lithified glacial deposits.
At its type locality in the Ohio Range, the Buckeye Formation rests on lower Devonian sandstones or on the quartz monzonites of the basement complex and is disconformably overlain by shales of the Discovery Ridge Formation. The thickness of the Buckeye Formation in the Ohio Ranges varies from about 250 to more than 350 meters.

The Buckeye and Scott Glacier Formations comprise the Late Paleozoic glacial deposits of the central Transantarctic Mountains. The formations are lithologically distinct, but are considered to be correlative; the Buckeye Formation may be older in part than the Scott Glacier, and because of this, the Buckeye Formation will be discussed first.

Areal distribution

The Buckeye Formation crops out in the Ohio Range, Long Hills, and the Wisconsin Range in the Horlick Mountains (Figure 2). The formation is well exposed along the Gondwana Escarpment near the eastern margin of the Olentangy Glacier, on the spurs extending westward from the escarpment, at Mt. Le-Schack in the western part of the Wisconsin Range, and in a down-faulted block between Perkins Canyon and Faure Peak (Figure 17). The Buckeye Formation is not recognized west of the Reedy Glacier. Correlative strata in the Queen Maud Mountains are assigned to the Scott Glacier Formation.
Figure 16. Central face of Mt. Weaver viewed from the Scott Glacier. The central face of the mountain is the type locality of the Scott Glacier, Weaver, and Queen Maud formations.

Figure 17. Tillite Spur viewed from Red Spur. The basement rocks are overlain by the Buckeye Formation which is about 100 meters thick here. Bedding seen in the upper part of the Beacon rocks is in the lower member of the Weaver Formation.
Lower Contact

The Buckeye Formation rests on the basement complex, mostly granite, in the Wisconsin Range and Long Hills. Near the head of the Olentangy Glacier and on Todd Ridge in the Long Hills, the formation overlies metamorphic rocks and volcanics.

The unconformity between the basement complex and the Buckeye Formation is undulatory, with a relief of less than 10 meters in most places although relief in excess of 30 meters is present on Tillite Spur in the Wisconsin Range. The crystalline rocks beneath the unconformity are generally unweathered and in most areas exhibit well-developed glacial pavements. At Mt. LeSchack the Buckeye Formation overlies about 50 centimeters of partially decomposed granitic rock which grades downward into fresh granite.

The surface of the unconformity is well exposed on Polygon Spur adjacent to the Olentangy Glacier. The erosion surface here exhibits a hummocky topography of circular or elongate hills and depressions. The elongate hills trend east-west and are commonly asymmetrical with steep eastern and gentle western slopes. The surface is everywhere striated (Figures 18, 19).

Relief of only about five meters is present on the erosion surface at Tillite Spur, but near the Gondwana Escarpment a steep, nearly vertical granite hill is present, surrounded by stratified sedimentary rocks. The hill appears to have been
Figure 18. Striated glacial pavement on granite beneath the Buckeyes Formation. The pavement can be traced beneath tillite in situ.

Figure 19. Striated glacial pavement on granite beneath the Buckeyes Formation at Tillite Spur. Large rectangular objects on the pavement are porphyroblasts in the granite.
sculptured by removal of granite along joint planes.

In addition to the ubiquitous striated glacial pavements, other features are common. Glacial grooves as much as one meter deep are present locally at Tillite Spur. Crescentic markings are locally well-developed, and Roches moutones are common on Tillite and Polygon Spurs.

**Thickness**

In the Ohio Range the Buckeye Formation attains a maximum thickness of more than 325 meters (Long, 1962). In the Wisconsin Range the Buckeye Formation varies from more than 135 meters at Mt. LeSchack, where the top of the formation is not present, to a minimum of 80 meters along the Gondwana Escarpment. Thus, regionally, the formation thins progressively westward from the Ohio Range into the Wisconsin Range.

**Lithology**

The Buckeye Formation is divisible into two lithologic types: stratified deposits and tillite. Tillite, including both unstratified and roughly stratified types, comprises the major part of the formation; locally, stratified deposits are more abundant. Generally, stratified deposits are more abundant in the Ohio Range and Long Hills than in the Wisconsin Range. Thick stratified deposits are present at several horizons in the Buckeye Formation in the Ohio Range, but in the Wisconsin Range the stratified deposits are restricted to lenticular
deposits at the base of the formation, and two thin lenticular horizons of varved-like deposits are interbedded with the tillite.

Stratified deposits are abundant at the base of the Buckeye Formation along the Gondwana Escarpment in the Wisconsin Range (Figure 20). Here they are composed principally of interbedded silty shales and poorly sorted somewhat calcareous clayey sandstone. Clasts as much as one meter in diameter are scattered abundantly within these beds. The beds are generally well stratified, with bedding varying in thickness from less than one to about five centimeters. Many of them are graded, some with couplets up to 10 centimeters thick.

The clasts disrupt the layers of the deposits, and individual laminae either drape around the clasts or are penetrated by them. Most of the clasts are subangular to subrounded, and are striated, faceted and soled. Most of the clasts are less than four centimeters in diameter, and are granite similar to the underlying basement rocks; quartzite and limestone clasts are abundant, forming about twenty percent of the total.

The stratified deposits thin over topographic highs on the basement surface, and some of the highs are overlain by tillite. Many of the stratified deposits around the topographic highs are severely slumped. Ripple marks, both symmetrical and asymmetrical, are present in the stratified deposits, and traction current bedding and sole markings are rare.
Figure 20. Texture of glacio-lacustrine beds near the base of the Buckeye Formation at Tillite Spur. Some of the beds are varved, and striated clasts are present.

Figure 21. Varvites with granitic clast at Tillite Spur. The varvites are interbedded with tillite.
A thin lenticular cross-bedded poorly sorted conglomerate forms the basal part of the Buckeye Formation at Mt. LeSchack and in the Long Hills. This conglomerate is not known west of Mt. LeSchack. At Mt. LeSchack and the Long Hills, relief of about 15 meters influences the thickness of the conglomerate. Channels at the base of the formation are steep walled, and trend in an easterly direction; the cross-bedding dips consistently to the east. The lithologies of pebbles within the conglomerate are chiefly those of the local basement. The conglomerate is overlain by tillite which is interbedded with thin lenses of evenly stratified sandstone and siltstone. These stratified deposits, containing numerous ripple marks and current lineation, are moderately sorted and have rare clasts.

Other stratified deposits in the Buckeye Formation consist of thin beds of varved-like sediments exposed along the Gondwana Escarpment in the Wisconsin Range (Figure 21). Varved-like deposits are present at approximately the middle of the formation along the length of the escarpment, and probably represent the same interval. These stratified deposits average about 1.5 meters in thickness, and contain clasts up to 20 centimeters in diameter. These beds are conformable, at both the top and the bottom, with tillite.

Point count analyses were run on the sand and finer size fraction of the stratified deposits exposed at the base of the
Buckeye Formation at Tillite Spur. Five hundred points were determined from each of five thin sections (Table 6).

The stratified deposits consist chiefly of unidentified matrix material and quartz. Quartz, comprising between 22 and 43 percent, occurs in three forms: as large well-rounded grains up to two mm in diameter, as small angular grains up to 0.5 mm, and as mosaics of secondary quartz. The large well-rounded grains comprise about one half of the quartz present, and all grains are characterized by undulatory extinction.

Orthoclase is the most abundant potassium feldspar, varying from five to eleven percent, although microcline is present in all samples. Much of the orthoclase is partially weathered to clay minerals, but the microcline is fresh and angular. Plagioclase is generally rare, but in one sample forms 10 percent of the rock. Much of the plagioclase is severely altered to chlorite, calcite, and sericite.

Table 6

MINERALOGIC COMPOSITION OF GLACIO-LACUSTRINE DEPOSITS OF THE BUCKEYE FORMATION FROM TILLITE RIDGE

<table>
<thead>
<tr>
<th>Sample</th>
<th>Ortho</th>
<th>Plag</th>
<th>Qrtz</th>
<th>Calc</th>
<th>Chlor</th>
<th>Rks</th>
<th>Opaq</th>
<th>Gar</th>
<th>Mat</th>
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<td>8</td>
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</tr>
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<td>43</td>
<td>11</td>
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<td>tr</td>
<td>52</td>
</tr>
<tr>
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<td>5</td>
<td>7</td>
<td>43</td>
<td>10</td>
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<td>3</td>
<td>22</td>
<td>10</td>
<td>T</td>
<td>T</td>
<td>T</td>
<td>T</td>
<td>59</td>
</tr>
</tbody>
</table>
Calcite is a major constituent in some samples, and is present in trace amounts in others. In samples 54 and 205, calcite 10 and 22 percent, respectively, occurs as anhedral mosaics encompassing the detrital grains. It is restricted to the sandy laminae, and little matrix material is present. Most of the calcite is cement partially replacing other minerals, especially plagioclase. Some of it is obviously of detrital origin, however, occurring as rounded to subrounded grains, many of which are coated with limonite.

Chlorite occurs in grains over two mm in length, replacing biotite and plagioclase, and less commonly as detrital grains. Microcrystalline chlorite is present in the matrix material.

Rock fragments generally comprise less than one percent of the samples in thin section. The most common rock type is granite, followed by metamorphic fragments. They generally range from one to four mm in diameter, and are subrounded.

Many mineral grains contain limonite coatings, and a few grains of magnetite and leucoxene are present. Grossularite, occurring as well-rounded grains and averaging about 0.5 mm in diameter, is present in small amounts.

The matrix is generally the most abundant constituent of the samples, comprising between 31 and 59 percent. It consists of clay size material either interspersed among the coarser grains or of clayey laminae containing a few coarser grains.
**Tillite**

The Buckeye Formation includes two varieties of tillite: stratified and unstratified. The unstratified tillite is most common, the stratified being restricted to the upper few meters of the formation.

A sharp color change is present between the tillite and the interbedded stratified deposits discussed above. The stratified deposits are light gray, weathering to a reddish-brown, whereas the tillite is dark greenish gray. The color of the tillite is controlled primarily by the amount of chlorite present. The stratified deposits are poor in chlorite, whereas chlorite or chloritic matrix is abundant in the tillite.

From a distance, the massive tillite appears to be stratified because of the presence of interbedded stratified bodies, and because the tillite weathers into exfoliation fragments of pseudobedding (Figures 22, 23). These fragments are about two to four cm in diameter and up to one cm thick; consequently, weathered exposures resemble poorly bedded shale or siltstone.

The most common type of tillite is greenish gray, unsorted, devoid of bedding, and characterized by an abundance of striated and faceted clasts, up to five meters in diameter. The tillite is composed predominantly of clay to sand-size particles; particles coarser than four centimeters probably make up less than five percent of the rocks.
Figure 22. General view of unstratified tillite of the Buckeye Formation near the Gondwana Escarpment. Sideritic concretions are abundant.

Figure 23. Striated pebble embedded in tillite of the Buckeye Formation at Tillite Spur. The tillite weathers into small slabs of "pseudobedding" so that some exposures resemble poorly bedded shale.
Clasts near the base of the tillite are composed primarily of granitic rocks with some sedimentary and metamorphic rocks, which become more abundant upward in the formation. Table 7 represents a composite sample of 700 pebbles between four and ten centimeters in diameter collected about 50 meters above the base of the tillite at Tillite Spur.

Table 7
PEBBLE COUNT DATA OF THE BUCKEYE FORMATION FROM TILLITE SPUR

<table>
<thead>
<tr>
<th>Qtzte</th>
<th>Gran</th>
<th>Metavolc</th>
<th>Limestone</th>
<th>Phyllite</th>
<th>Quartz</th>
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<td>23.5</td>
<td>34.5</td>
<td>7.75</td>
<td>22.5</td>
<td>8.0</td>
<td>4</td>
<td>0.5</td>
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Granitic clasts similar to those of underlying basement rocks are most abundant, and limestone and quartzite clasts are common. The quartzites and phyllites are chloritic and resemble rock types in the LaGorce Formation. The fine-grained, gray limestone clasts resemble limestones of the Leverett Formation. The metavolcanic rock clasts are acidic. Quartz occurs as angular clasts and seems to be of vein or pegmatitic origin.

All clasts larger than about 15 centimeters are of granitic composition. The smaller clasts, those less than 10 centimeters in diameter, are generally fresh, whereas some of the larger ones are deeply weathered. Most of the non-granitic clasts are either striated, faceted or soled, and all show some degree of rounding (Figure 23). Cursory observations on about 50 clasts
suggest that the long axes are aligned in an easterly direction, similar to the striations on glacial pavements beneath the formation, and are inclined to the west.

Table 8 represents a pebble count from Knack Point in the Long Hills, based on 150 pebbles. The pebbles were collected in three one-meter grids, about 25 meters above the base of the formation. The basement at this locality is granite, but elsewhere in the Long Hills rhyolites are present.

Table 8
Pebble Count Data of the Buckeye Formation from the Long Hills Qtzite Granite Metavolc. Limestone Phyllite Quartz Chert 38.5 15.0 23.25 8.5 2.75 2.25 9.75

The high content of metavolcanic rocks is the result of the rhyolites present in the basement nearby. Sedimentary and metasedimentary fragments account for nearly one half of the total. The abundance of these clasts may be indicative of extensive sedimentary and metasedimentary rocks in the basement complex nearby, but all these areas are snow covered. The amount of chert is surprisingly high, considering its rarity in the exposed basement of the central Transantarctic Mountains. The only known occurrence of chert is in the Leverett Formation, which contains abundant chert nodules in the limestones near the top. It is interesting that limestone decreases from 22.5 to 8.5 percent from the Gondwana escarpment to the Long Hills. The only known source of limestone is in the Leverett Glacier to the west, perhaps suggesting ice movement from west to east.
Thirty samples of unstratified tillite from Tillite Spur were examined in thin section. Point count analyses of 500 points per sample were made. The compositions of eight representative samples of tillite and one carbonate concretion are listed in Table 9.

Thin section analyses indicate the tillites are totally unsorted, without apparent size modes. The mineral grains and rock fragments are embedded in a clayey matrix with few grains in contact with each other. Fabric of many samples shows the long axes of most of the grains inclined to the horizontal, and some grains, mostly those larger than two millimeters, horizontal.

Samples 43, 50, and 54 are from the Long Hills; the remainder are from Tillite Ridge. Quartz and matrix material are the major constituents of most samples, although rock fragments form a major part of samples 27 and 50. As in the stratified deposits, quartz is the most abundant recognizable mineral in the tillite, comprising from 13 to 42 percent of the samples. The grains, with no apparent modes, vary in size from more than two millimeters to less than 1/16 mm. The coarser grains are rounded to well rounded, whereas smaller grains are angular. Undulatory extinction is characteristic of all the quartz.

Potassium feldspar is a minor constituent of all samples, ranging from one to six percent with a mean of 4.3 percent. The potassium feldspar is mostly orthoclase, only a few grains of
microcline being present in each sample. The orthoclase is angular to subrounded, with an average diameter of about 0.75 millimeters; it is slightly weathered and sometimes altered to a zeolite (?), whereas the microcline is fresh.

Table 9
MINERALOGY OF SELECTED SAMPLES OF TILLITE OF THE BUCKEYE TILLITE

<table>
<thead>
<tr>
<th>Sample</th>
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</tr>
<tr>
<td>303</td>
<td>14</td>
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<td>85</td>
<td>—</td>
<td>—</td>
<td>—</td>
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</tr>
</tbody>
</table>

Plagioclase is rare in the tillite, comprising less than two percent in most samples, with a maximum of six percent in sample 1. Most of the plagioclase is weathered or altered to either chlorite, calcite, or unidentified zeolites.

Calcite is also rare in the tillite, generally being present only in trace amounts, but forming five percent of sample 34. The calcite occurs as replacements of plagioclase, as isolated detrital grains, or as small veinlets.

A few grains of muscovite occur in all samples and chlorite
is an important constituent of samples, but is rare in others. The chlorite listed in Table 9 consists of those grains that could be identified by petrographic methods. However, chlorite is more abundant in the tillite than the point-count analyses indicate, because the matrix material is largely chloritic. The chlorite, other than that of the matrix, varies from large stringers several millimeters in length to silt-size grains. The larger grains have a yellowish birefringence, whereas the smaller grains are bluish-green.

Rock fragments form a major part of some samples, but are rare in others. The most common rock types are granite and quartzite, with lesser amounts of schist and phyllite. Some of the metamorphic fragments are rounded to well-rounded, but the granite fragments are generally subangular to angular.

Opaque minerals are present in trace amounts in all samples. The matrix comprises from 21 to 76 percent of the tillite. Under crossed nicols the matrix appears light greenish, the result of abundant chlorite.

Sample 303 is a concretion from the lower part of the tillite on Tillite Ridge. Many concretions occur in the area, ranging from about two centimeters to more than two meters. Rock clasts or siderite crystals are generally present in the center, although some have massive interiors. The fabric of the tillite is preserved in the concretions, indicating their diagenetic origin. Concentric bands of siderite are generally present
near the center of the concretions.

Sample 303 is composed of 85 percent carbonate. The composition of the carbonate could not be determined by petrographic techniques, but similar concretions from the Ohio Range have been analyzed chemically, and they possess a high iron and manganese content (information courtesy J. M. Schopf; analyses performed by U. S. Geological Survey). These concretions are probably of sideritic composition.

The siderite is microcrystalline and, except for small amounts of quartz and feldspar, has completely replaced the tillite.

Chemistry

The chemical composition of sample 6432, a greenish-gray tillite from Tillite Ridge is given in Table 10.

Table 10
CHEMICAL ANALYSIS OF A TILLITE (SAMPLE 6432) OF THE BUCKEYE FORMATION

<table>
<thead>
<tr>
<th>Compound</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>SiO₂</td>
<td>72.72%</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>12.26%</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.45%</td>
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<tr>
<td>FeO</td>
<td>3.74%</td>
</tr>
<tr>
<td>CaO</td>
<td>1.46%</td>
</tr>
<tr>
<td>MgO</td>
<td>1.88%</td>
</tr>
<tr>
<td>Na₂O</td>
<td>1.34%</td>
</tr>
<tr>
<td>K₂O</td>
<td>2.40%</td>
</tr>
<tr>
<td>MnO</td>
<td>0.08%</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.54%</td>
</tr>
<tr>
<td>CO₂</td>
<td>0.78%</td>
</tr>
<tr>
<td>Moisture</td>
<td>0.04%</td>
</tr>
<tr>
<td>H₂O</td>
<td>1.50%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>99.19%</strong></td>
</tr>
</tbody>
</table>
The chemical analysis (Table 10) is in close agreement with the mineralogic composition. The abundance of magnesium oxide and ferrous oxide is probably related to the chloritic matrix, and supports that identification. The silica content is somewhat higher than that of most fine-grained rocks, but this may be attributed to the moderate quartz content.

Origin

Recently, several authors have questioned the origin of many so-called "tillites" or pebbly mudstones, and have proposed agents of deposition other than moving ice (Crowell, 1957; Dott, 1961). However, concerning the recognition of ancient glacial deposits, Crowell (1965, p. 87-88) states: "Straited pavements and evidences of plucking, with local deposits of till, may allow their acceptance unequivocally." Dott (1961, p. 1269) states: "An extensive, preserved, grooved and polished pavement overlain by poorly sorted till-like material...particularly if non-marine, is compelling glacial evidence." All of these features, as well as numerous others, are preserved in the Buckeye and Scott Glacier Formations in the central Transantarctic Mountains, suggesting a glacial origin for these areas.

The following characteristics (Table 11), all suggestive of a glacial origin, are found in these deposits: 1) striated
Table 11
RECOGNITION CRITERIA OF ANTARCTIC GLACIAL DEPOSITS

<table>
<thead>
<tr>
<th>LOCALITY</th>
<th>GLACIAL UNIT</th>
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<th>X</th>
<th>X</th>
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<th>X</th>
<th>X</th>
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<td>Whiteout Conglomerate</td>
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<tr>
<td>Pensacola Mountains</td>
<td>Gale Mudstone</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td>Ohio Range</td>
<td>Buckeye Formation</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td></td>
</tr>
<tr>
<td>Long Hills</td>
<td>Buckeye Formation</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td>X</td>
<td>X</td>
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</tr>
<tr>
<td>Wisconsin Range</td>
<td>Buckeye Formation</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Watson Escarpment</td>
<td>Scott Glacier Formation</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Mt. Blackburn</td>
<td>Scott Glacier Formation</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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</tr>
<tr>
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<td>X</td>
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</tr>
<tr>
<td>Mt. Weaver</td>
<td>Scott Glacier Formation</td>
<td>X</td>
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<tr>
<td>Queen Alexandra Ra.</td>
<td>Paqoda Formation</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Nimrod Glacier</td>
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<tr>
<td>Darwin Glacier</td>
<td>Darwin Formation</td>
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<table>
<thead>
<tr>
<th>Glacial Unit Characteristics</th>
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</thead>
<tbody>
<tr>
<td>Till-like sediments</td>
</tr>
<tr>
<td>Crescentic markings</td>
</tr>
<tr>
<td>Ice-rafted clasts</td>
</tr>
<tr>
<td>Glacial-lacustrine deposits</td>
</tr>
<tr>
<td>Varved-like deposits</td>
</tr>
<tr>
<td>Grooved pavement</td>
</tr>
<tr>
<td>Varved-like bedding</td>
</tr>
<tr>
<td>Striated clasts</td>
</tr>
<tr>
<td>Absence of bedding</td>
</tr>
<tr>
<td>Unsorted matrix</td>
</tr>
</tbody>
</table>

106
and grooved bedrock pavements, 2) streamlined and plucked blossom-like hills, 3) chatter and crescentic markings on pavements and clasts, 4) faceted, soled, and striated clasts, 5) great range in grain size with little or no sorting, 6) oriented fabric, 7) highly variable lithologic content, 8) small variations in thickness over short distances, 9) stratified outwash-like sediments with stratified clasts, 10) abundant non-marine till-like sediments, 11) varved-like deposits, and 12) pebbles in bedded shale.

Each of these features, considered alone, can be explained by diverse origins, but together, they are irrefutable evidence of a glacial origin. It is difficult to explain extensive polished pavements with striations, grooves, chatter marks, and boss-like hills on a granitic terraine by any other means. Nearly every exposure between the Ohio Range and the Nilsen Plateau exhibits a polished pavement on the basement rocks beneath the Buckeye Formation and the correlative strata.

Environments of Deposition

Several environments of deposition are represented by the Buckeye Formation. Two general environments are: water-laid and glacial; several variations of each are present.

The stratified deposits in the formation formed in either lakes or streams. Those of the base of the formation at the Gondwana Escarpment probably formed in proglacial lakes adjacent to the ice front. The ubiquitous glacial pavements beneath the
stratified deposits indicate that the surface was eroded by glaciers prior to deposition. The stratified sediments pinch out toward the crests of some of the topographic highs which may have been islands in the lakes. Sediments comprising the stratified deposits were probably derived from the nearby ice front. The abundance of coarse clasts in the generally fine-grained lake sediments appears to be the result of ice rafting, suggesting that calving of bergs from the nearby ice front was common. The icebergs produced in this fashion appear occasionally to have touched bottom and produced short, irregularly oriented gouge marks in the upper surfaces of some of the beds (Figure 24). These markings are easily distinguished from the striae produced by the ice sheet advancing across the lake sediments (Figure 25). The former are short and irregularly oriented, seldom more than 10 centimeters long and one centimeter deep. The striae, however, extend across entire outcrops and are oriented parallel to those on the glacial pavements beneath the sediments.

The basal conglomerate at Mt. LeSchack and the Long Hills appears to have been deposited by streams in front of the ice sheet. The widespread distribution of these deposits makes their interpretation as an esker unlikely.

The stratified deposits in the Long Hills, with the exception of the basal conglomerate, differ from those of the Gondwana Escarpment in that they are finer-grained and better sorted.
Figure 24. Glacial markings in glacio-lacustrine sediments of the Buckeye Formation at Tillite Spur. These markings are thought to have been formed by icebergs touching bottom locally.

Figure 25. Glacial pavement in glacio-lacustrine deposits of the Buckeye Formation.
In addition, clasts and graded bedding are rare in these deposits in the Long Hills. The paucity of clasts in these strata is unusual, in view of the fact that they are interbedded with tillite. The absence of varved-like sediments may indicate the absence of annual ice covers of the lakes.

The varved-like sediments near the center of the formation at the Gondwana Escarpment appear to have formed in periglacial lakes during local retreats of the ice sheet. The widespread distribution of these deposits may be suggestive of a general retreat of the ice sheet in this area. The periglacial origin is suggested by graded bedding, presence of striated clasts, and conformable upper and lower contacts with tillite.

The unstratified tillite formed as ground moraine beneath an ice sheet. This origin is suggested by the following criteria: 1) absence of sorting, 2) absence of stratification and 3) abundance of striated and faceted clasts.

The upper few meters of the Buckeye Formation consist of stratified tillite which grades upward into shale containing striated clasts; the upper contact of the Buckeye Formation can be placed within a one-meter interval.

The presence of stratification in the upper part of the tillite suggests that water must have been a contributor to the deposition of these sediments. The absence of clasts larger than a few centimeters in diameter could be suggestive of deposition
distant from an area of active erosion.

These stratified tillites are thought to have formed either in an ice-shelf environment in which the ice was not stranded, but floated in water, or else in a pack-ice area. In such an area, water currents would have some effect on the bottom sediments, partially sorting them and producing stratification. Toward the edge of a pack-ice area, the amount of sediment contributed directly from glacial ice would diminish in importance, tending to produce a bedded deposit of fine muds containing isolated clasts.

The salinity of the water in which the upper few meters of the tillite were deposited is questionable. The absence of graded bedding, or varved-like rocks, may be suggestive of brackish to marine water (R. P. Goldthwait, oral communication). If the water had been fresh, varved-like sediments probably would have formed.

The widespread distribution of stratified tillite in the upper part of the glacial deposits in the Horlick and Queen Maud Mountains indicates that deposition in water was characteristic of the last stages of glaciation in these areas.

Paleontology

Other than obscure animal trails along bedding planes from near the base of the Buckeye Formation, fossils are unknown in the Wisconsin Range and Long Hills. Sinuous animal trails are abundant on the upper surfaces of the shale beds of the glacio-
lacustrine deposits at the base of the formation. The trails average about five millimeters in width and seldom exceed 20 centimeters in length.

Age

Little is known about the age of the Buckeye Formation. It overlies Devonian deposits in the Ohio Range and is overlain by strata as old as Upper Permian. The only identifiable fossils found from the glacial deposits are spores from a shale interbedded with the tillite in the Ohio Range (Long, 1965). These spores are similar to Permian spores found in several Gondwana localities, including the glacial deposits at Bachus Marsh, Australia (J. M. Schopf, oral communication). Thus, the upper part of the Buckeye Formation may be Permian age; the lower limit is post-Early Devonian.

Directions of ice movement

Directions of ice movement are frequently difficult or impossible to determine in the Antarctic tillites. Striations and grooves serve only for orientation. The following criteria have been found to be useful for the determinations of ice movement directions in the Wisconsin Range: Roches moutonees, plucked surfaces, mailhead markings, and oriented fabric. These features suggest an eastward movement of ice (Figure 26).

Measurements were made on 114 sets of striae along the Gondwana Escarpment for orientational purposes (Figure 27). The vector mean of the striae is N 87 E, and the standard deviation
Figure 26. Asymmetric hill on striated glacial pavement beneath the Buckeye Formation at Tillite Spur. The hill is steeper in the background, suggesting ice movement in that direction.
Figure 27. Glacial striae map of the Gondwana Escarpment area, Wisconsin Range
29 degrees. Striae orientations are remarkably parallel along the escarpment except on Polygon Spur. The wide diversity of striae directions in this area is partially controlled by topography on the erosion surface. Most of the widely divergent measurements were taken along the sides of hills on the erosion surface. Striae directions on flat surfaces coincide closely with the striae on Tillite and Red Spur.

Striae orientations were recorded from four glacial pavements at Mt. LeSchack in the eastern part of the Wisconsin Range. The vector mean of these striations is N 06 E, and the standard deviation five degrees.

The long axes of fifty pebbles embedded in the tillite at Tillite Spur were measured. The pebbles are inclined gently to the west, and the vector mean of the long axes of the pebbles is N 89 E, and the standard deviation is 35 degrees. This preliminary work on the orientation of the pebbles also suggests an eastward movement of ice.

Ripple marks in the glacio-luustrine beds at the base of the Buckeye Formation along the Gondwana Escarpment suggest an eastward movement of water. The ripple marks strike approximately perpendicular to the orientation of the striae (Figure 27). Ripple marks in the Long Hills strike N.70 E.

The glacial striae directions and the paleocurrent data from the overlying beds at the Gondwana Escarpment are very similar (Figure 28). The vector mean for the striations is
Figure 28. Paleocurrent data of the Beacon rocks in the Wisconsin Range. The circles indicate the number of readings measured.
N 87 E; the mean for lineation from the lower member of the Weaver Formation is N 64 E, that for sole markings from the middle member of the Weaver Formation is N 77 E; the cross-bedding mean for the upper member of the Weaver Formation is S 84 E; the mean of cross-bedding of the basal conglomerate of the Queen Maud Formation is N 81 E. The similarity of the glacial striae and the paleocurrent data from the overlying beds suggest that the late Paleozoic ice sheet moved down the regional paleoslope in the Wisconsin Range.
SCOTT GLACIER FORMATION

The Late Paleozoic glacial deposits in the eastern Queen Maud Mountains are placed in the Scott Glacier Formation, which is the lateral equivalent of the Buckeye Formation. Compared with the Buckeye Formation, the Scott Glacier Formation is remarkably thin; it varies in thickness from zero to about 40 meters, averaging about 15 meters. The Scott Glacier Formation is predominantly light grayish, while the Buckeye Formation is dark grayish-green. Glacial pavements are relatively rare beneath the Scott Glacier Formation; however, they are common beneath the Buckeye Formation. No thick outwash-like deposits, such as those in the Buckeye Formation in the Ohio Range, are found in the Scott Glacier Formation. It is because of these differences that the glacial deposits of the central Transantarctic Mountains are separated into two formations, the Buckeye and the Scott Glacier.

Definition and type area

The lowest sedimentary unit in the area of the Scott Glacier is a conglomerate, or tillite; because it is so persistent, uniform and recognizable through the area, it is here named the Scott Glacier Formation. The formation is well exposed and easily accessible at Mt. Weaver, near the head of the Scott Glacier, and the detailed work was done there (Figures 2, 3, 29). Therefore, the Mt. Weaver section is designated as
Figure 29. Type locality of the Scott Glacier Formation near the southern part of the central face of Mt. Weaver.

Figure 30. Striated glacial pavement on metavolcanic rocks beneath the Scott Glacier Formation near the head of the Leverett Glacier on the Watson Escarpment.
the type locality for this formation.

Outcrops of sedimentary rocks are rare between the Reedy Glacier at the western edge of the Wisconsin Range, and the Scott Glacier in the Queen Maud Mountains. In this area, the Scott Glacier Formation crops out at only four localities on the Watson Escarpment, and overlies a striated glacial pavement at each locality (Figure 30). All the late Paleozoic glacial deposits from the Reedy Glacier westward to the Nilsen Plateau are included in the Scott Glacier Formation (Doumani and Minshew, 1965).

Areal distribution

The Scott Glacier Formation crops out at the base of the Beacon rocks on most of the mountains bordering the Scott Glacier, and in isolated exposures between the Reedy and Amundsen Glaciers. Westward from the Reedy Glacier, the first exposures are on the Watson Escarpment near the Harold Byrd Mountains. Southward, the Watson Escarpment swings around, connecting with the Mt. Blackburn Massif. Between these two features the Scott Glacier is exposed at two localities, and is well exposed along the eastern and southern faces of Mt. Blackburn. Southward from Mt. Blackburn, the formation is exposed on isolated mountains and nunataks. It is poorly exposed along the Faulkner Escarpment north of Mt. Wyatt. Beacon rocks are present on some of the nunataks between the Faulkner Escarpment and the Scott Glacier, but the Scott Glacier Formation is covered by either
snow or talus at these localities. The formation is well exposed in the Nilsen Plateau in the escarpment facing the Amundsen Glacier. Long, (in press) reports discontinuous exposures for a distance of about 60 kilometers along this escarpment. Westward from the Amundsen Glacier, rocks closely resembling the Scott Glacier Formation are present in the Mt. Nansen area, but these have not yet been assigned formation status (Barrett, 1966).

Lower contact

A clearly defined erosion surface separates the Scott Glacier Formation from the underlying basement rocks. In the Scott Glacier area, the formation rests on granitic plutons, except for the exposures near the Harold Byrd Mountains on the Watson Escarpment and at Mt. Wyatt, where the formation overlies acidic volcanic rocks. In the area of the Amundsen Glacier, the formation overlies most rock types of the basement complex.

The erosional surface upon which the Scott Glacier Formation was deposited is gently undulatory, with local relief probably not in excess of 20 meters. The erosional contact is sharp, and the underlying rocks generally exhibit little or no effect of weathering. On the summit of Mt. Wilbur, the sedimentary rocks have been removed, exposing a large area of gently rolling erosion surface; with an elongate depression trending in an east-west direction. Relief of about 10 meters is present from the crest to the floor of the depression, a distance of
Relief of 7-10 meters is present along the basement-sediment contact near the central face of Mt. Weaver, where a topographic high apparently trends in a northwest-southeast direction. Conglomerate pinches out toward the crest and black shale of the Weaver Formation overlies weathered granitic rock.

Glacial pavements with striations on the exhumed erosion surface were observed at only one locality on an exposed ledge at Mt. Weaver. Because of extensive Pleistocene glaciation, it could not be determined if the striae were of Pleistocene or Paleozoic age.

Glacial pavements are present beneath the Scott Glacier Formation at all exposures north and east of Mt. Paine. The glacial pavements are obviously of pre-Scott Glacier Formation age because the formation can be seen directly overlying the pavements. Long (in press) observed glacial striae at several locations in the Nilsen Plateau, along the chatter marks and nail-head markings. Striations, grooves, chatter marks, nail head markings, and plucked surfaces are present on the glacial pavements in the Mt. Blackburn area (Figure 30).

**Thickness**

The Scott Glacier Formation at the type locality varies in thickness from zero to about 18 meters, and averages about 5 meters. In the Nilsen Plateau adjacent to the Amundsen Glacier, Long (in press) measured a maximum thickness of 45
meters, but the average thickness of the formation there is similar to that of the Scott Glacier area.

The maximum thickness of the formation at Mt. Weaver is 18 meters. Along the western part of the central face of the mountain, adjacent to the Scott Glacier, the thickness varies from 1-3 meters, and is absent at the topographic high near the center of the mountain. Near Mts. Saltonstall and Innes-Taylor, the thickness of the formation is similar to that at Mt. Weaver. The thickest exposures of the Scott Glacier area, about 20 meters, are near Mts. Blackburn and Paine.

The variations in thickness of the formation result from the undulatory nature of the underlying surface and from post-depositional erosion.

Lithology

Tillite, consisting predominantly of granitic clasts interspersed in a matrix ranging in size from clay to sand, is the major lithology of the formation. Locally present are beds of poorly sorted sandstone with only a few rounded clasts, along with a few lenticular beds of massive claystone and siltstone.

The clasts within the tillite are angular to well rounded, and consist of lithologies similar to those of the underlying basement. The clasts range in size from boulders up to three meters to fragments only a few millimeters in diameter. Generally, the smaller clasts are more deeply weathered than the larger ones.
One boulder nearly three meters across was observed near the top of the formation at Mt. Weaver. The boulder is rectangular with sharp angular corners and is apparently unaltered. The appearance of the boulder suggests a joint block of the underlying granite which was transported only a short distance.

As can be seen from Table 12 the local basement lithology directly influences the composition of the clasts. The granitic clasts are mostly gray hornblende granite; a few are red granite and gray aplite. The metasedimentary rocks are quartzites and phyllites similar to the rocks of the LaGorce Formation. Although most of the metasedimentary clasts are rounded, a few are angular. Most of those from the Watson Escarpment and Mt. Blackburn areas are striated, faceted, and soled. The metavolcanic rocks are of acidic composition, similar to the rhyolites of the Leverett Formation and the Wyatt Formation.

Lenses of blocky massive claystone are present throughout the formation in beds generally a few centimeters thick, but one has a thickness of about one meter. Some of the beds are finely laminated, and some contain randomly distributed clasts, most of which are less than eight centimeters in diameter. Thin laminae of siltstone are present in some of the beds, and some couplets are graded.

**Primary sedimentary structures**

The lower part of the Scott Glacial Formation is generally massive and void of sedimentary structures, whereas bedding,
<table>
<thead>
<tr>
<th>Location</th>
<th>Granite</th>
<th>Sedimentary</th>
<th>Metasedimentary</th>
<th>metavolcanic</th>
<th>Basement Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mt. Wilbur</td>
<td>97</td>
<td></td>
<td>2</td>
<td>1</td>
<td>Granite</td>
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<tr>
<td>Mt. Weaver</td>
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<td>8</td>
<td></td>
<td>Granite</td>
</tr>
<tr>
<td>Mt. Weaver</td>
<td>63</td>
<td></td>
<td>37</td>
<td></td>
<td>Granite</td>
</tr>
<tr>
<td>Watson Escp.</td>
<td>4</td>
<td>13</td>
<td>16</td>
<td>67</td>
<td>Metavolcanic</td>
</tr>
<tr>
<td>Nilsen Plat.</td>
<td>3</td>
<td></td>
<td>35</td>
<td>64</td>
<td>Metavolcanic</td>
</tr>
<tr>
<td>Nilsen Plat.</td>
<td>62</td>
<td></td>
<td>7</td>
<td>31</td>
<td>Granite</td>
</tr>
<tr>
<td>Nilsen Plat.</td>
<td>81</td>
<td></td>
<td>12</td>
<td>7</td>
<td>Granite</td>
</tr>
</tbody>
</table>
varying in thickness from less than one mm to a cm or more, is commonly present in the upper part. The bedding is wavy and distorted and in places is bent or penetrated by clasts, the long axes of which are inclined to the bedding. Individual laminae thicken toward the clasts.

Small scale cross-bedding is present locally in the upper part of the formation. Cosets are only a few centimeters thick and individual strata a few mm. The cross-bedding dips S 15 E to S 30 E.

**Petrology**

Four samples of the sand-to clay-size fraction of the Scott Glacier Formation were examined petrographically, two from Mt. Weaver and two from Mt. Wilbur. The rock is unsorted, consisting of a gradation from clay to granule size. A few thin laminae of clay-to silt-size particles are present in some samples, but generally the samples are massive. The samples consist of angular to subangular grains floating in a paste of quartz silt and clay.

The sand is mostly quartz, followed in decreasing amounts by plagioclase, microcline, orthoclase, biotite, and rock fragments. Most of the quartz grains are angular to subangular; a few are subrounded. Most of the grains are elongate, and are arranged in a subparallel pattern roughly parallel to the horizontal; other grains are roughly arcuate, forming small crescent
shapes; some are rectangular; and a few retain vestiges of crystal facets.

Total feldspar content of the samples varies from 12 to 25 percent, and includes sodic plagioclase, microcline, and orthoclase. Plagioclase is the most abundant, varying from five to 17 percent. Much of the plagioclase is highly sericitized, and small resorption embayments, filled with sericite or clay, are present in many grains. Laumontite commonly replaces plagioclase. Fresh and unaltered microcline is the most abundant potassium feldspar.

Biotite is a minor constituent of the samples, averaging about one percent in all samples except 3, in which it makes up six percent of the sample. The biotite occurs in large isolated flakes, many of which have been severely altered to a light-colored chlorite and unidentified opaques.

Rock fragments, calcite, and laumontite, a calcium-sodium zeolite, occur in trace amounts. The rock fragments are granitic, and occur in large rounded grains up to six mm in diameter. Calcite occurs as finely disseminated anhedral grains in the groundmass, as veinlets, or as replacements of plagioclase.
Chemistry

Table 13 presents the chemical analysis of sample Ma-62-1-52, a tillite of the Scott Glacier. The sample was collected on the south ridge of Mt. Weaver.

Table 13

CHEMICAL COMPOSITION OF A TILLITE FROM THE SCOTT GLACIER FORMATION

<table>
<thead>
<tr>
<th>Element</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO</td>
<td>74.56% by weight</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>11.81</td>
</tr>
<tr>
<td>CaO</td>
<td>1.74</td>
</tr>
<tr>
<td>MgO</td>
<td>1.00</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.96</td>
</tr>
<tr>
<td>FeO</td>
<td>0.64</td>
</tr>
<tr>
<td>K₂O</td>
<td>3.02</td>
</tr>
<tr>
<td>Na₂O</td>
<td>4.28</td>
</tr>
<tr>
<td>MnO</td>
<td>0.06</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.31</td>
</tr>
<tr>
<td>H₂O⁻</td>
<td>1.03</td>
</tr>
<tr>
<td>Moisture</td>
<td>0.16</td>
</tr>
<tr>
<td>CO₂</td>
<td>0.453</td>
</tr>
</tbody>
</table>

Total 100.02%

Sodium is present in greater amounts than would be expected from the mineralogic composition of the sample; it probably represents metasomatic enrichment associated with the intrusion of the diabase sills, and will be discussed more fully in the chapter of metamorphism of the Beacon rocks.

A minor amount of the lime is present as calcite, the remainder contributing to the formation of laumontite. Magnesium is rather high, and is accounted for in the chlorite. Ferric oxide in excess of ferrous is suggestive of a slightly oxidizing environment.

Environment of deposition

The Scott Glacier Formation is considered to be of glacial glacio-lacustrine (or marine), and glacio-fluvial origin. The
proportion of ice-and water-laid sediment varies from one area
to another; however, the lower part is considered to be primarily
ice laid, and the upper part is considered to be of glacio-
lacustrine or glacio-marine origin.

A glacial origin is suggested by the following criteria:
glacial pavements with striations, grooves, crescentic and nail
head markings beneath the formation; absence of sorting in the
unstratified deposits; presence of striated, faceted, and soled
clasts; graded deposits containing clasts. Not all of these
features are present at any one exposure, but all are present
in the Scott Glacier Formation in the area between the Leverett and
Amundsen Glaciers.

The stratified upper part of the formation is considered to
have been deposited in water by ice, as either ice bergs or,
probably, an ice shelf. The nature of the body of water in which
deposition occurred is unknown; it may have been a lake, a series
of lakes, or marine water. As in the Buckeye Formation of the
Wisconsin Range, the Scott Glacier Formation grades upward into
shale by a decrease in the number of clasts and an increase in
the regularity of bedding.

Glacio-fluvial deposits are rare in the Scott Glacier Formation
although Long (in press) attributes a glacio-fluvial origin to
some deposits in the Nilsen Plateau. Some of the conglomerates
with cross-bedding, at Mt. Weaver, may be of fluvial origin, but
such deposits are not abundant.

**Direction of ice movement**

The late Paleozoic ice sheet which deposited the Scott Glacier Formation moved to the southeast. The direction of ice movement was determined by the following criteria: nail head markings, chatter marks, roches moutonees, and overturned folds. Less definite criteria used for the determination of the direction of movement include plucked surfaces, striations and grooves, and cross-bedding in interbedded deposits.

Glacial striae were measured at Mt. Blackburn and the Watson Escarpment on the basement glacial pavement; at both localities the striae trend N 75 E. At the latter locality, a secondary set of poorly preserved striae trend S 70 E. Long (in press) measured striae orientations in the Nelsen Plateau to be S 15 E to S 30 E and S 70 E.

**Age**

Little evidence is present concerning the age of the Scott Glacier Formation. It occurs at approximately the same stratigraphic position as the Buckeye Formation to the east which contains spores suggestive of a Permian age. On this basis, the Scott Glacier Formation is also considered to be Permian in age.
Figure 31. Correlation chart of the late Cenozoic glacial deposits. The glacial beds thin rapidly from the Ohio Range to the foot of the Queen Maud Mountains and pinch out in Victoria Land.
RESUME ANTARCTIC GLACIAL DEPOSITS

Introduction:

The best known ancient glacial deposits in the Antarctic are those found in the central Transantarctic Mountains, from the Ohio Range to the Amundsen Glacier (Figure 31). Wade and others (1965) reported an unusual conglomerate near the base of the sedimentary section at Shackleton Glacier which may be of glacial origin. A deposit of probably glacial origin was also described from the Darwin Mountains (Haskell and others, 1964), but north of that area beds of Paleozoic are interpreted as of glacial origin are unknown.

The stratigraphic section of southern Victoria Land, ranging in age from Early Devonian to Jurassic, is composed predominantly of arenites, although coal measures are abundant in the upper part of the section. A major disconformity is present separating the coal measure of Permien age from the underlying arenites of Devonian age (David Matz, written communication). This disconformity could account for the absence of late Paleozoic glacial deposits in this area.

Glacial deposits of late Paleozoic age are rare outside the Transantarctic Mountains, although a thick conglomerate in the Sentinel Range of the Ellsworth Mountains is now considered to be a marine tillite (Craddock and others, 1965). This deposit
Figure 31. Correlation chart of the Late Paleozoic glacial deposits. The glacial beds thin markedly from the Ellsworth Mountains toward the Queen Maud Mountains and pinch out in Victoria Land.
is overlain by strata containing a *Glossopteris* flora similar to that in the strata overlying the glacial deposits in the Transantarctic Mountains. Thus, this unit may be correlative with the known glacial deposits in the central Transantarctic Mountains.

A glacial deposit of unknown age is present in the Zukkertoppen Nunataks in Dronning Maud Land (Neethling, 1964). No fossils have been found associated with these deposits, and their relationships to the Paleozoic glacial beds in the Transantarctic Mountains are not known. Neethling considered them to be late Precambrian.

**Ohio Range**

On the basis of widespread late Paleozoic glacial deposits in the other continents of the southern hemisphere, it had been theorized that similar deposits should be present in the Antarctic. Tillite was first recognized in 1962 from the Ohio Range of the Horlick Mountains (Long, 1962).

In the Ohio Range, the glacial deposits disconformably overlie the oldest sedimentary rocks of this area, the early Devonian Horlick Formation, which is composed of coarse-grained, gritty sandstone with minor amounts of black fissile shale. The glacial deposits in the Ohio Range are included in the Buckeye Formation (the Buckeye Tillite of Long, 1962), which varies in thickness from about 225 to about 350 meters. Where the Horlick Formation has been eroded away, the Buckeye Formation rests on unweathered
quartz monzonite.

The most common rock type in the Buckeye Formation is a dark greenish-gray, massive, poorly-sorted tillite consisting of clasts up to 10 meters in diameter in an unsorted silty to clayey matrix.

There are abundant interbedded bodies of conglomerate, sandstone, and shale in the tillite. Most of the conglomerates within the formation are characterized by well-developed, festoon cross-bedding. Sandstones occur at various levels throughout the formation. Beds of thin-bedded, dark greenish-gray shale, most common in the upper 30 meters of the formation, range in thickness from less than one meter to several meters, and are locally deformed into small overturned folds. The Buckeye Formation is disconformably overlain by the Discovery Ridge Formation, consisting of interbedded shale and siltstone.

Numerous primary directional features in the Buckeye Formation were measured by Long (1965). Some of the more positive indicators of ice movement directions which are found at several levels within the formation, are 1) crag and tail, 2) slope of boulders in a boulder pavement, and 3) fragments of a boulder strewn to the downstream side. The dominant direction of ice flow, according to Long, was west to east (Figure 32).

Recently, Frakes and others (1966) questioned the direction
Figure 32. Ice-movement directions of the Late Paleozoic ice sheet in the central Transantarctic Mountains. The paleoslope of the overlying non-glacial beds is nearly parallel to the ice-movement directions throughout the area.
of ice movement in the Ohio Range. The following criteria were
cited by them as valid for the determination of ice movement
directions:

1) "Striated ends of clasts on 'striated boulder pavements' are
located on the up-glacier end of the clasts." This criterion
should be used with extreme caution, for it is difficult to
demonstrate that the clasts were striated after lodgement at
the base of the ice sheet. Most striations are produced during
transport, and the entire surface of the clast must be examined
in detail.

2) "Smoothly beveled ends of clasts on 'striated boulder
pavements' are located on the up-glacier end of the clasts." This
method is of questionable validity. Gary McKenzie (oral
communication), studying till being deposited under a present
day glacier, found that the beveled end of clasts may be oriented
in either direction.

3) "Plucked ends of clasts on 'striated boulder pavements' are
located on the down-glacier ends of the clasts." Likewise,
McKenzie found that the plucked ends of clasts may be on either
down-or up-glacier directions.

4) "The more steeply inclined transverse fractures in
friction cracks dip in an up-glacier direction." Flint (1957)
states that this criterion cannot be used to determine the
direction of ice movement.
Long suggested that the tillite formed as morainal material beneath an ice sheet. Many of the sandstone lenses were interpreted as having formed in streams in front of the ice sheet. The shale probably formed in periglacial lakes. The conglomerates and much of the sandstone formed as outwash in front of, and perhaps also below, the main ice sheet. Obviously, the ice front or morainal material was nearby, or the striae on pebbles within the conglomerates would have been destroyed in short distances of transport by water.

The presence of repeated bedded deposits interspersed throughout the formation suggests fluctuations of the ice margin in this area.

**Nilsen Plateau**

During the 1963-64 field season the Amundsen Glacier area, about 100 kilometers northwest of Mt. Weaver, was examined by W. E. Long (in preparation), who found the Scott Glacier Formation to be present continuously along the escarpment bordering the Nilsen Plateau, about 50 kilometers in length. There, the formation ranges in thickness from three to about 40 meters, and consists of tillite, conglomerate, pebbly sandstone, siltstone, shale, and varvites.

Where the formation is thickest, the basal part commonly consists of tillite containing striated and faceted clasts. The clasts are granitic, metavolcanic, and metasedimentary, the
proportion of rock types within the tillite being a direct reflection of the local basement lithology.

A fine-grained clastic unit commonly overlies the basal tillite. This unit consists of yellowish-gray siltstone or mudstone, and locally includes varvites and thin stringers of tillite. The striated deposits are deformed into small folds, presumably the result of glacial ice advancing across unconsolidated sediments.

The upper part of the formation consists of thin-bedded siltstone and arkosic sandstone with randomly scattered cobbles and a few boulders up to 1.5 meters in diameter. Within the formation, the varvite beds, with clasts more than one meter in diameter, grade upward into tillite and downward into sandstone.

The contact of the formation with the basement rocks is sharp, clean, and unweathered. The upper contact of the formation with the overlying black shale of the Roaring Valley Formation is disconformable.

A striated pavement was found beneath the formation at one locality; a few crescentic and nailhead markings, along with mammilated hills, were also present. According to Long, the dominant direction of ice movement, determined by nailhead markings and plucked and mammilated hills, was S 15 E to S 30 E, very similar to the direction of the Scott Glacier area.
There is a secondary direction of movement of about S 50 E to S 70 E. Long interpreted the Scott Glacier Formation as consisting of glacial, glacio-lacustrine, and glacio-fluvial beds; tillite, however, is the least common rock type.

Western Queen Maud Mountains

Between the Amundsen and Beardmore Glacier, little is known about the nature and distribution of the late Paleozoic glacial deposits. Barrett (1965) reports glacial deposits from the base of the Beacon rocks at Mt. Fridtjof Nansen, near the head of the Axel Heiberg Glacier. The unit varies in thickness from zero to about three meters, usually being restricted to topographic lows on the basement erosion surface, and is very similar lithologically to the Scott Glacier Formation. The glacial beds are conformably overlain by a green shale which grades upward into black shale. The paleoslope in this area, determined from structures in the overlying units, is S 15 E to S 30 E.

Barrett also reports similar beds at the base of the Beacon rocks at Mt. Wade, near the Shackleton Glacier. He (Barrett, 1965, p. 349) states: "At Mt. Wade, lenses of conglomerate and grit two feet thick were found in the six feet of basal sandstone. The pebbles, some of which are at least two inches across, are mainly of sedimentary and granitic derivation." A glacial or fluvio-glacial origin is considered
likely for these beds on the basis of sorting characteristics.

Barrett also described glacial deposits from Cape Surprise, near the mouth of the Shackleton Glacier, where the glacial beds attain a maximum thickness of 15 meters. He considers these deposits to be a tillite, but those at Mt. Wade appear to have been somewhat sorted, and may be outwash. The paleoslope of the overlying beds at the Shackleton Glacier is to the south-southeast.

Recently, Wade and others (1965) described the geology of the area around the head of the Shackleton Glacier. They divided the Beacon rocks into five formations, the lowest of which is the Butters Formation. It is about 60 meters thick, and comprises a lower member composed of gray to yellow conglomerate, boulders up to one meter in diameter, and sandstone; and an upper member, about 18 meters thick of fine-grained, massive, conglomeratic siltstone. Little evidence is present concerning the age of the Butters Formation, but the type locality is only 29 kilometers from the glacial beds described by Barrett, so the two sections are probably correlative.

**Queen Alexandra Range**

Glacial deposits from the Queen Alexandra Range near the Beardmore Glacier, about 180 kilometers west of the Shackleton Glacier, were described by Grindley (1963). These glacial beds were named the Pagoda (Tillite) Formation, after the type
locality at Pagoda Peak in the foothills of the Queen Alexandra Range.

The Pagoda Formation, about 150 meters thick, consists mainly of massive arkosic sandstone with abundant small angular clasts of basement rocks. Beds of tillite up to seven meters thick, with clasts more than a meter in diameter, are present throughout the formation (John Lindsay, oral communication). During the past field season Lindsay found glacial pavements at several horizons throughout the formation.

The glacial beds rest directly on Devonian arenites in this area.

The clasts in the formation consist of 70% granite, granodiorite or diorite, 15% hornfels and graywacke, 10% quartz, 5% sandstone, and a few pebbles of limestone and conglomerate (Grindley, 1963). The matrix within the tillite is silty and unsorted, with little clay-size material (P. J. Barrett, oral communication).

A few thin beds of black shale containing clasts several centimeters in diameter occur in the upper part of the formation in association with small-scale slump structures and shale pebble conglomerates. The major part of the Pagoda Formation appears to consist of glacio-fluvial and related deposits, possibly of periglacial origin.

The contact of the Pagoda Formation with the overlying shale
is gradational. The shale is similar to that which overlies the Buckeye and Scott Glacier Formations farther to the east, and contains numerous clasts within the lowest few meters.

Although Grindley provided no data as to the paleoslope or the direction of ice movement, Lindsay (oral communication), reports that the ice sheet appears to have moved to the south-east.

**Darwin Glacier area**

Probable late-Paleozoic glacial beds, included in the Darwin Formation, were described recently from the Darwin Mountains (Haskell and others, 1964). The Darwin Formation, at its type locality in the Darwin Mountains, is less than 35 meters thick, and is divided into three members. The lower member, about 15 meters thick, is composed of mottled red and green sandstone containing clasts up to one meter in diameter. The middle member, about seven meters thick, consists of couplets of graded sandstone and siltstone. Small intraformational folds within the middle member strike north, and are considered to be drag folds caused by overriding ice (Haskell and others, 1964). The upper member is about eight meters thick, and is lithologically similar to the lower. The clasts within the formation are mostly well-rounded, and deeply weathered, and without striae or facets.

Although the Darwin Formation rests on Devonian arenites,
about 70% of the clasts are granite, similar to the basement rocks of the area. Much of the sand-size material is well-rounded, and is probably reworked Devonian arenite.

The massive sandstone containing clasts is interpreted by Haskell and others to be a moraine deposit. The middle member is considered to be "varved or outwash deposits".

The Darwin Formation is disconformably overlain by coal measures containing a Glossopteris flora. Elsewhere in the Transantarctic Mountains, with the exception of the area around the Nimrod Glacier, the Paleozoic glacial deposits and the coal measures are separated by a thick shale-siltstone-sandstone sequence.

Glacial deposits of Paleozoic age, overlain by coal measures, were recently found in the area of the Nimrod Glacier, about half way between the Beardmore and Darwin Glaciers, but little information is available concerning the nature of these beds (Laird, 1965).

Pensacola Mountains

Recently, a thick pebbly mudstone, the Gale Mudstone, more than 600 meters thick, was described from extensive outcrops in the Neptune Range of the Pensacola Mountains (Schmidt and others, 1965). Schmidt and others (1965, p. 116) state: "The Gale Mudstone consists of a black homogeneous, well-indurated mudstone containing scattered pebbles, cobbles and boulders of
granite, granitic gneiss, and the underlying sedimentary rocks. The clasts, which are scattered, constitute less than 1 percent of the whole rock. They are angular to subrounded; the larger ones average about 3 inches in diameter, and the largest are about 2 feet in diameter. Bedding or other sedimentary structures have not been found within the formation. More recently, Frakes and others (1966) report clasts up to three meters in diameter, and also report a few thin layers of stratified deposits. They found striated glacial pavements beneath the Gale Mudstone and at three horizons within the formation, and postulated that the ice sheet flowed in a westerly direction, away from the Filchner Ice Shelf area.

**Ellsworth Mountains**

The Ellsworth Mountains lie about 750 kilometers east of Byrd Station between the polar plateau of West Antarctica and the Filchner Ice Shelf (Figure 1). The late Paleozoic glacial deposits here are represented by about 1000 meters of marine tillite, the Whiteout Conglomerate, which is composed of massive "tillite" with a few thin interbeds of dark shale and light gray sandstone. The most distinct characteristics of the formation are its great thickness, massiveness, and lack of sorting (Craddock and others, 1965). Bedding is rare within the formation, but from a distance faint traces are discernible. Large rock fragments make up more than five percent of the unit. Some of the clasts are as much as six meters in diameter, and a few are
striated. The clasts are of diverse lithology and some of the rock types are not known in the Ellsworth Mountains. The matrix is argillite, with little or no sorting.

Concerning the origin of the Whiteout Conglomerate, Craddock and others (1965, p. 635) conclude, "The Whiteout Conglomerate is actually a thick conglomeratic graywacke that probably was formed in quiet water from materials rafted by glacial ice, possibly under conditions similar to those of the Antarctic shelf today."

Victoria Land

No Paleozoic glacial deposits have been recognized in southern Victoria Land, although beds similar to those above and below the glacial deposits elsewhere are present. Recently, Mirsky (1964) and Harrington (1965), working independently, concluded that the stratigraphic sequence in this area is divided by a major disconformity similar to that below the glacial deposits in the mountains farther south. The formations below this erosion surface contain Devonian fish remains (David Matx, written communication), whereas the strata above the erosion surface are probably Permian (Schopf, 1963). The time of the late Paleozoic glaciation elsewhere may be represented by this disconformity.

Regional Analysis of Ice Movement Directions

Most of the reliable data on the direction of ice movement are from the central Transantarctic Mountains, in the area between
the Pensacola Mountains and the Nilsen Plateau. During the 1966-67 field season John Lindsay obtained excellent data concerning the direction of ice movement in the Beardmore Glacier area.

In the Pensacola Mountains the ice sheet appears to have moved from west to east, and in the Horlick Mountains from west to east, with perhaps some movement in the opposite direction. Westward from the Horlick Mountains, the direction of movement changes from a westerly to a northerly source, so that in the area of the Scott and Amundsen Glaciers the ice sheet moved to the southeast (Figure 32). However, in both the Watson Escarpment and Nilsen Plateau poorly developed striae indicate a secondary direction of ice movement from the west, coinciding closely with the direction of movement in the Horlick Mountains. In the Queen Alexandra Range, adjacent to the Beardmore Glacier, Lindsay has found evidence suggesting that the ice moved to the southeast. Thus, all available data suggest that in the area between the Reedy Glacier and the Queen Alexandra Range the ice moved in a rather uniform southeasterly direction.

Extensive paleocurrent data have been collected from the more than 1000 meters of Permian strata which overlie the glacial deposits. These data indicate that during the Permian the regional paleoslope was to the east in the Horlick Mountains, gradually swinging around to a more southerly component in the Queen Maud Mountains and Queen Alexandra Range (P. J. Barrett,
oral communication). The concordance of the paleocurrent directions from these overlying beds with the directions of ice movements throughout the area is striking. Apparently, the late Paleozoic ice sheet moved down what was then, or later became, the regional paleoslope.

By analogy with nearby areas, it may be inferred that the ice sheet in the western Queen Maud Mountains moved to the southeast, the direction of the regional paleoslope of the overlying beds.

The thickest glacial deposits in the Antarctic appear to have accumulated in an area toward which the ice sheet was moving (Figures 31, 32). The thickest glacial beds known in the Antarctic are those in the Ellsworth Mountains, which were evidently the site of a rapidly subsiding basin, perhaps marine, in which ice rafted fragments of rocks into an area of accumulation of fine-grained sediments.

Southward from the Ellsworth Mountains the nearest known glacial deposits are in the Pensacola Mountains, where the beds attain a thickness of about 600 meters. Southward from here, the glacial beds thin progressively toward the Scott Glacier area, or central Queen Maud Mountains, where the glacial deposits are thin or missing.

By comparison of Figures 31 and 32, it can be seen that the glacial deposits of the Queen Maud and Horlick Mountains thicken in a direction in which the ice sheet is considered to have moved, i.e., to the east. Additionally, several outwash sheets appear
to be present in the Tillite at the Ohio Range, while in the Wisconsin Range only two varvite beds are interbedded with the tillite. In the Queen Maud Mountains the glacial beds are considered to be primarily morainal deposits, although sorted deposits are locally more dominant.

The glacial deposits in the Ohio Range are considered to have formed nearer to the periphery of the ice sheet than those of the Queen Maud Mountains. The Queen Maud Mountains were nearer a center of glaciation and were probably being eroded during much of the time when sediments were accumulating nearer the edge of the ice sheet. The thinning of the glacial deposits in the Queen Maud Mountains is analogous to the thinning of the Pleistocene deposits from the central United States onto the Canadian Shield area.

Mountain vs. Continental Glaciation

A late Paleozoic glaciation of the Antarctic by a continental ice sheet is suggested by the following criteria: 1) wide areal distribution, 2) low relief on the erosion surface beneath the tillite; relief of more than 15 meters is rare, 3) moderate variation in thickness; it is unusual to find thickness variations of tillite more than 30 meters within a distance of several kilometers; 4) varied clasts in the tillite; although most of the clasts at any one locality are of local derivation, a small number are usually of foreign character;
mountain glaciation would probably not produce such a varied assemblage; 5) uniformity of striae directions; striations produced from mountain glaciers would be much more diversified, especially over wide areas.

These criteria, considered collectively, suggest a Late Paleozoic continental ice sheet.
Introduction

The Weaver Formation overlies the Buckeye and Scott Glacier formations throughout the area of study, and is composed of interbedded sandstone, conglomerate, arenaceous limestone, shale, siltstone, and coal. The formation is well exposed and easily accessible at the central face of Mt. Weaver, where the most detailed work was done. Thus, Mt. Weaver is designated as the type locality of the formation.

The Weaver Formation at the type locality is divided into three members, with a combined thickness of about 200 meters (Figure 33). The lower member, about 15 meters thick, is composed of interbedded black shale and arkosic sandstone. The middle member, about 90 meters thick, is gradational with the lower member, and consists of interbedded siltstone, shale, and fine-grained micaceous sandstone with a few thin interbeds of limestone. The upper member comprises more than 95 meters of arkosic sandstone, arenaceous limestone, and lesser amounts of black shale and siltstone with two thin beds of coal near the top. The Weaver Formation is disconformably overlain by the quartz pebble conglomerates of the Queen Maud Formation.

At the type locality, the Weaver Formation is intruded by three diabase sills which have metamorphosed adjacent strata.
Figure 33. General view of the Weaver Formation at the Gondwana Escarpment. The observer is standing on the lower member. The middle member occupies the talus covered slopes beneath the massive cliffs, and the upper member comprises the massive weathering cliffs near the top of the escarpment.
to the hornblende hornfels facies, and the formation as a whole
to the Zeolite facies.

LOWER MEMBER

Areal distribution

The lower member of the Weaver Formation is exposed along
the central face and south ridge of Mt. Weaver. Northward from
Mt. Weaver, similar beds are present at Mts. Saltsonstall, Innes-
Taylor, Paine, Blackburn, and Wyatt, several areas along the
Watson Escarpment, the mid-glacier nunataks, Rawson Mountains,
and Gondwana Escarpment in the Wisconsin Range. Similar strata
are present also in the Nilsen Plateau, although Long (in press)
assigned them to a separate formation.

Lower contact

The Weaver Formation, at the type locality, rests dis-
conformably on the Scott Glacier Formation, and at one locality
directly on basement rocks. Either sandstone, siltstone, or
black shale of the Weaver Formation rests on the underlying rocks.
Locally, a conglomerate composed mostly of granitic boulders
is present at the contact.

A disconformity is also present beneath these strata in the
Nilsen Plateau (Long, in press), but at all localities except
the two discussed above, the Weaver Formation is gradational
with the underlying glacial deposits (Figure 34). Generally,
black to greenish-gray shale or poorly sorted sandstone grades
Figure 3U. Poorly-bedded pebbly shale of the transition zone from the Buckeye to the Weaver Formation at Tillite Spur in the Wisconsin Range. The pebble adjacent to the hammer is striated.
downward into tillite, except at the northern part of Mt. Blackburn where the glacial beds grade upward into red siltstone of the Weaver Formation.

**Thickness**

The lower member of the Weaver Formation at the type locality is about 15 meters thick. Throughout the area of the Scott Glacier it is of similar thickness, but at the Gondwana Escarpment in the Wisconsin Range, the lower member is about 75 meters thick.

**Lithology:**

The most common rock type of the lower member of the Weaver Formation is black shale, although other lithologies predominate locally. Generally, the succession at Mt. Weaver begins with a basal conglomerate consisting of pebbles and boulders of granite in a poorly sorted matrix which grades upward into a medium to coarse grained sandstone; the sandstone and conglomerate have a maximum thickness of about seven meters, and grade laterally and vertically into black to green silty shale with abundant sideritic concretions. Locally, the sandstones are absent and the entire member is composed of black shale with abundance of animal trails concentrated along the bedding planes. Interebedded with the black shale are thin lentils of limestone, usually not more than two centimeters thick. Pyrite is abundant in the shale, occurring along bedding planes as very fine-grained concentrations or as euhedral crystals up to one
centimeter in diameter. Associated with the pyrite are thin beds of disseminated sulfur-like material which weathers easily and is generally deeply decomposed into a loosely consolidated greenish-yellow aggregate.

Northward from Mt. Weaver, the lower member of the Weaver Formation at Mts. Innes-Taylor and Wyatt is similar to that at the type locality, but at Mt. Paine the lower member comprises about 15 meters of very fine-grained, moderately sorted sandstone.

The lower member of the Weaver Formation in the Mt. Blackburn is highly variable lithologically. On the southern face of the mountain it is similar to that at Mt. Weaver, except for the presence of striated clasts in the lower few meters of shale. Along the northern face of Mt. Blackburn and at exposures on the nearby Watson Escarpment these strata grade into very fine-grained red sandstone and siltstone containing numerous dessication cracks (Figure 35) and animal trails. Eastward from the Watson Escarpment, the red sandstone and siltstone again grade into black shale and interbedded sandstone at exposures near the head of the Leverett Glacier.

Exposures of the Weaver Formation are absent between the Leverett Glacier and the Gondwana Escarpment in the Wisconsin Range, where the formation is exposed at several localities along the escarpment and adjacent cliffs. Detailed work was done at Tillite Ridge, where the section is representative of the
Figure 35. Dessication cracks in a red siltstone of the lower member of the Weaver Formation near the northern part of Mt. Blackburn (photo by G. Doumani).

Figure 36. Trails of an unknown animal in black shale of the lower member of the Weaver Formation.
area. The lower member here differs from the exposures in the Queen Maud Mountains primarily in the greater thickness of the unit, about 75 meters. It consists of black shale with striated clasts in the lower part, grading upward into interbedded shale and sandstone. The sandstone is dark gray, moderately sorted, with parallel laminations and parting lineations; some of the beds are up to eight meters thick. The sandstone shale sequence is overlain by black shale similar to that in the lower part of the member except for the absence of striated clasts.

Two prominent zones of sideritic concretions are present in the lower member at Tillite Ridge, and concretions are scattered throughout the member. The lower concretionary zone is about 40 meters above the base of the formation, and the upper zone is present near the top of the member. Well-preserved plant remains are abundant in the concretions of both zones, although none were found in the concretions in other parts of the member.

Chemistry

Sample 62-1-53, a laumontite cemented arkosic sandstone from the lower member of the Weaver Formation was analyzed chemically (Table 14). The sample was collected about one meter above the base of the Weaver Formation along the central face of Mt. Weaver.
Table 14

CHEMICAL ANALYSIS OF A LAUMONTITE CEMENTED ARKOSIC SANDSTONE
FROM THE LOWER MEMBER OF THE WEAVER FORMATION

<table>
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<tr>
<th>Element</th>
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<td>0.94</td>
</tr>
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<td>Fe₂O₃</td>
<td>1.22</td>
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<tr>
<td>FeO</td>
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</tr>
<tr>
<td>K₂O</td>
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</tr>
<tr>
<td>Na₂O</td>
<td>2.49</td>
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<tr>
<td>MnO</td>
<td>0.08</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.22</td>
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<td>H₂O</td>
<td>2.80</td>
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<tr>
<td>H₂O₂-</td>
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<tr>
<td>CO₂</td>
<td>0.005</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>99.91</strong></td>
</tr>
</tbody>
</table>

The laumontite occurs primarily as a cement and to a lesser extent as a replacement of plagioclase. Most of the biotite has been chloritized, and the sample is badly fractured. The proximity of a diabase sill suggests that the laumontite cement may be related to metasomatism by the diabase.

Primary Sedimentary Structures

Primary sedimentary structures are restricted to the sandstones and siltstones. Festoon cross-bedding is present locally in the conglomeratic sandstone at Mt. Weaver, dipping about 15° eastward. Ripple drift cross-laminations, dipping southeast, are common in the fine-grained sandstones at Mt. Paine and the southern face of Mt. Blackburn. Parting
Lineation is present in some of the sandstones at Tillite Ridge. There is small-scale convolute bedding in the fine-grained sandstone at Mt. Paine and some of the conglomeratic lenses at Mt. Weaver. Polygonal dessication cracks are well developed in the red sandstone and siltstone at Mt. Blackburn and adjoining exposures on the Watson Escarpment. Individual polygons average about 4-5 centimeters in diameter and are generally five or six sided (Figure 35). The cracks of the polygons are about 0.5 centimeter in width and up to one centimeter deep; they are commonly filled with red silty clay.

Paleontology

Small, sinuous, animal trails in the black shale are the only evidence of animal activity in the lower member of the Weaver Formation (Figure 36). Plant remains from the concretions in the Wisconsin Range have not been identified, but are similar to the Glossopteris flora which is abundant in the overlying strata (J. M. Schopf, oral communication).
MIDDLE MEMBER

Introduction

The middle member of the Weaver Formation, composed of interbedded sandstone, siltstone, and shale with minor amounts of limestone, is well exposed along the central face of Mt. Weaver, the type locality (Figure 37). Here, the middle member is characterized by rhythmic-like alternations of sandstone and shale, and numerous ripple drift cross-laminations, sole markings, and trace fossils concentrated along the bedding planes. Color of the sandstone and shale alternates between green, red, grey, and light brown; the sandstones are most commonly grey. The middle member at Mt. Weaver in intruded by two diabase sills.

Areal distribution

The middle member of the Weaver Formation has the same areal distribution as the lower member.

Lower contact

The middle member of the Weaver Formation is gradational through about one meter with the lower member. The approximate contact is easily located from a distance by the break in the weathering slope; the lower member weathers to flat, terrace-like platforms, and the middle member weathers to relatively steep slopes with numerous conspicuous small ledges (Figure 37).
Figure 37. Middle member of the Weaver Formation at Mt. Innes-Taylor, a few kilometers north of the type locality at Mt. Weaver. The uniform laminations are one of the most conspicuous characteristics of the middle member.
Thickness

The middle member at Mt. Weaver varies in thickness from about 90 to 95 meters. The section was measured in greater detail along the central face of the mountain where the unit is 90 meters thick, and is intruded by diabase sills totaling 20 meters. The variation in thickness of the middle member in this area is the result of the erosion surface at the top of the member.

Northward from Mt. Weaver the middle member thickens, and at Mt. Innes-Taylor it is from 120 to 125 meters thick. Only incomplete sections are present between there and the southern face of Mt. Blackburn, where it is more than 100 meters thick. The middle member is not differentiable on the northern face of the mountain, where it interfingers with several hundred meters of cross-bedded, conglomeratic sandstone. Eastward from Mt. Blackburn the middle member is exposed on the Watson Escarpment near the head of the Leverett Glacier, where it is 115 meters thick. No other exposures are present between there and the Bondwana Escarpment, where the middle member averages about 220 meters.

Lithology

Rhythmic alternations of sandstone, siltstone, and shale with a few thin beds of arenaceous limestone constitute the middle member of the Weaver Formation at Mt. Weaver (Figure 38).
Figure 38. Type section of the middle member of the Weaver Formation.
Here the lowermost unit consists of a black shale altered to hornfels with a few interbeds of sandstone with vertical jointing. The hornfels grade upward into a fissile, carbonaceous shale containing abundant carbonate concretions and numerous beds of arenaceous limestone averaging about 2 centimeters thick. This shale sequence, 10.5 meters thick, is overlain by thin-bedded, tan to reddish-brown siltstone with thin interbeds of limestone. Ripple drift cross-laminations are present throughout the siltstone.

The amount of shale decreases upward in the middle member, becoming rare in the upper 50 meters or so. Fine- to medium-grained sandstone interbedded with siltstone is the major lithology of the upper part of the member. The sandstone are generally thin bedded; individual laminae are only a few millimeters thick, and weather into massive ledges and cliffs. Carbonaceous and micaceous (or now chloritic) laminae are common in some of the sandstone. The sandstones and siltstones are conspicuous in outcrop because of alternating colors. The sandstones are generally reddish-brown and the siltstones and shales, green.

Four representative samples of the middle member at Mt. Weaver were examined petrographically (Table 15). Sample 61 is from a thin persistent arenaceous limestone bed about 10 cm thick, 15.4 meters above the base of the formation on the central face of Mt. Weaver. Sample 61 is composed almost
entirely of microcrystalline calcite and anhedral grossularite, with about 1 percent quartz. The grossularite occurs in interlocking mosaics of calcite and the quartz as small remnant grains, many of which are highly corroded and partly replaced by calcite. Point count and quantitative X-ray analyses indicate that grossularite forms 34 percent of the specimen. The presence of the grossularite and calcite suggests that the rock has been metamorphosed to the hornblende hornfels facies of contact metamorphism. Evidently it was originally arenaceous limestone.

Samples 64, 73 and 79 are fine-grained sandstones from the upper half of the middle member at Mt. Weaver (Table 15). Quartz and matrix material are the predominant constituents. The quartz content varies from 34 to 59 percent, and the matrix from 11 to 34. The quartz is mostly angular to subrounded and has undulatory extinction.

Potassium feldspar and plagioclase are present in approximately equal amounts in most samples. The potassium feldspar, which consists of about equal amounts of microcline and orthoclase, varies from four to eight percent. As in most samples from the Beacon rocks in this area, the microcline is fresh and the orthoclase somewhat weathered or altered. The sodic plagioclase is generally fresh and angular,
Table 15

MINERALOGIC COMPOSITION OF SELECTED SAMPLES FROM THE MIDDLE MEMBER OF THE WEAVER FORMATION FROM MT. WEAVER (in percentages)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Qtz</th>
<th>K Feld</th>
<th>Plag</th>
<th>Musc</th>
<th>Bio</th>
<th>Cal</th>
<th>Chl</th>
<th>Gar</th>
<th>Opag</th>
<th>Seri</th>
<th>Matr</th>
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<tr>
<td>61</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td>65</td>
<td>34</td>
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<td></td>
</tr>
<tr>
<td>64</td>
<td>59</td>
<td>4</td>
<td>1</td>
<td></td>
<td>20</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>11</td>
<td></td>
</tr>
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<td>73</td>
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<td>79</td>
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<td>9</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td>34</td>
<td></td>
</tr>
</tbody>
</table>
but some grains are altered to calcite, chlorite and, rarely, sericite and an unidentified zeolite.

The calcite content is highly variable, forming the cement in sample 73, but in other samples occurring only as veinlets in the rock, or as replacement of plagioclase. Biotite is abundant in most samples, but rare in some. The biotite is concentrated along bedding planes, and is frequently severely distorted and altered in varying degrees to a light-colored, low birefringent chlorite. The chlorite content is variable, and is roughly inversely proportional to the amount of biotite present. The chlorite is primarily an alteration product of biotite. Muscovite is rare, being present in only one sample.

Grossularite, excluding sample 61, is present in trace amounts; its origin is uncertain; some is unquestionably metamorphic whereas other may be detrital. The grossularite in sample 61 is of metamorphic origin and occurs in anhedral grains up to one millimeter in diameter. But grossularite has also been found in samples more than 50 meters from the nearest diabase sills. Theoretically, the diabase sill would not have heated the rock sufficiently through such a wide thickness to produce the grossularite in samples other than 61.

Sericite, which is rare, occurs as a replacement of plagioclase. Matrix material is abundant, occurring either interspersed among the coarser grains or in distinct laminae. The
The matrix is light green, slightly birefringent, and seems to be chloritic.

Petrographically, the strata of the middle member are similar throughout the area, the primary difference being the increase in grain size and biotite content toward the Mt. Blackburn area.

Regional stratigraphy

The middle member thickens and coarsens northward from Mt. Weaver toward Mts. Innes-Taylor and Blackburn (Figure 38). At Mt. Innes-Taylor the member consists primarily of medium-grained brown and green sandstone. Northward from Mt. Innes-Taylor, strata similar to the middle member are present in the mid-glacier nunataks about half way between Mts. Wyatt and Blackburn. The strata here are composed of about 80 meters of limonitic sandstone, the upper 30 meters of which contain numerous lenses of quartz pebble conglomerate.

The middle member at Mt. Blackburn is about 95 meters thick and consists of interbedded sandstone and siltstone; beds average about 10 meters thick.

Northward along the northern face of Mt. Blackburn, the middle member interfingers with coarse-grained conglomeratic sandstones several hundred meters thick, including undifferentiated middle and upper members of the Weaver Formation and the lower part of the overlying Queen Maud Formation. The conglomeratic
sandstones are more than 400 meters thick, and contain stringers of quartz pebbles throughout the sandstone, frequently in channel-like masses. Festoon cross-bedding is present throughout the sandstones, dipping at low angles to both north and south. One thick bed of quartz pebble conglomerate is present about 350 meters above the base of the Weaver Formation and is thought to represent the base of the Queen Maud Formation.

Eastward from Mt. Blackburn the conglomeratic sandstone grades into interbedded fine-grained sandstone, siltstones, and shales of the middle member of the Weaver Formation near the head of the Leverett Glacier.

The middle member at the Gondwana Escarpment consists of about 220 meters of interbedded shale and fine-grained, poorly-sorted, sandstone with ripple drift cross laminations (Figure 39). Numerous sole and prod markings are present on the lower surface of the sandstone beds. As in the middle member at Mt. Weaver, animal trails and ubbrows are common, and unidentified plant stems are common in some of the shale beds.

**Primary Structures**

Sole markings are the most common sedimentary structures in the middle member (Figure 40). The structures are restricted to the sandstone interbeds. Flute casts and prod casts are generally well developed along the base of the sandstone, and traction current cross-laminations are generally present in the sandstone interbeds which seldom exceed four cm in thickness.
Figure 39. Interbedded sandstone and shale of the middle member of the Weaver Formation at the Gondwana Escarpment. The massive cliffs in the background are composed of the upper member of the Weaver Formation.

Figure 40. Sole markings on sandstone from the middle member of the Weaver Formation. Such structures are characteristic of the middle member throughout the area of study.
Graded bedding is present locally in the middle member. The sandstones have sharp erosional bases, but grade upward into shale.

Animal burrows are widespread in the middle member, being so common in some beds to produce a mottled massive appearance. The burrows are both vertical and inclined.

**UPPER MEMBER**

The upper member of the Weaver Formation at the central face of Mt. Weaver consists of interbedded sandstone, siltstone, shale, an arenaceous limestone, and two thin beds of low grade coal (Figure 41). The most distinguishing feature of the upper member is the abundance of animal burrows in the sandstones, producing a mottled appearance in some beds. One 14 meter diabase sill is present near the top of the upper member.

**Areal distribution**

Areally, the upper member of the Weaver Formation is more restricted than the other members. Complete sections are present only at Mts. Weaver, Innes-Taylor, and Blackburn, and at the area of the Gondwana Escarpment in the Wisconsin Range. Incomplete sections are present at the Watson Escarpment, Rawson Mountains, and mid-glacier nunataks.

**Lower contact:**

At Mt. Weaver the upper member of the Weaver Formation rests disconformably on the middle member. The amount of relief
Figure 41. Type section of the upper member of the Weaver Formation. The upper member, like the middle member, grades into coarse conglomeratic sandstones at Mt. Blackburn.
on the erosion surface was not determined at Mt. Weaver, but about three meters of relief is present at Mt. Innes-Taylor.

The lower contact is sharp in the exposures on the Watson Escarpment, but it appears to be conformable. The upper member is gradational with the middle member at the Gondwana Escarpment through a thickness of a few meters.

**Thickness**

The upper member of the Weaver Formation at the type locality is 97 meters thick, and like the middle member, thickens northward toward Mt. Blackburn, where the undifferentiated upper and middle members are represented by about 350 meters of undifferentiated conglomeratic sandstone, in contrast to a combined thickness of about 200 meters at Mt. Weaver. The upper member at the Gondwana Escarpment is 125 meters thick.

**Lithology**

Medium to coarse-grained, moderately sorted sandstone, calcareous sandstone, arenaceous limestone, and carbonaceous shale are the principal lithologies of the upper member of the Weaver Formation at the type locality. The lower and upper parts of the member consist primarily of interbedded sandstone and shale, and the middle part of calcareous sandstone and limestone.

The lower 36 meters of the member consist of alternating sandstone and shale. The sandstones are generally thin-bedded,
medium grained, and moderately sorted, with numerous animal borings, some up to one centimeter in diameter and six centimeters long. The sandstones weather into massive rounded cliffs. The shales are thin bedded and carbonaceous, with small unidentified plant fragments. Thin beds of limestone and carbonate concretions are common throughout the unit; the thinnest limestone bed is about 0.5 meter thick, and is three meters above the base of the members.

The middle part of the member consists of medium-to coarse-grained calcareous sandstone and limestone containing abundant reworked shale pebbles. The limestones are generally thin-bedded and weather into massive vertical cliffs. Animal burrows are rare in these rocks.

The upper part of the member consists of interbedded sandstone, shale and coal. The sandstones are similar to those of the lower member except for the greater abundance of ripple-drift cross-laminations, and the presence of contorted strata and convolute bedding. Low-angle planar cross-bedding and oscillation ripple marks are common in some of the beds.

Shale becomes more abundant toward the top of the formation, and frequently is interbedded with two or more thin beds of low grade shaley high rank coal. The presence of carbonaceous shale and associated coal is characteristic of the upper part of the Weaver formation throughout the area of study. Long (in press) reports two thin coal beds near the top of correlative
strata in the Nilsen Plateau, and the upper part of the formation at the Gondwana Escarpment consists of interbedded shale and shaley coal with a prolific *Glossopteris* flora.

Thin sections were made from six samples from the middle member of the Weaver Formation from Mt. Weaver, and one from Mt. Innes-Taylor (Table 16); sample 399 is from Mt. Innes-Taylor.

Quartz, the most abundant constituent in the sandstones, occurs as medium-size subangular to subrounded grains. The potassium feldspar is primarily microcline, and forms up to 15 percent of sample 399 from Mt. Innes-Taylor. The plagioclase is predominantly albite, and is less common than the potassium feldspar. Much of the plagioclase is highly sericitized, some grains being recognizable only by clusters of sericite.

Muscovite is absent in the lower part of the member, but is present in all samples in the middle and upper parts of the unit. Biotite, conversely, is abundant in the lower part of the members and becomes less abundant in the upper part. Chlorite is of remarkably uniform distribution throughout the upper member of the Weaver Formation, occurring primarily as an alteration product of biotite and plagioclase.

Calcite is rare in some of the sandstone, occurring only as a replacement and as void fillings, but it is the primary constituent of the arenaceous limestones (Samples 155, 159 and 160). The calcite in the limestone occurs as large recrystallized mosaics in which quartz and other detrital grains are suspended.
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<td>23</td>
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</table>

Table 16
MINERALOGIC COMPOSITION OF SELECTED SAMPLES OF THE UPPER MEMBER OF THE WEAVER FORMATION
Quartz is the primary detrital mineral in the limestones, and the high percentage of sericite suggests that plagioclase may have originally been abundant.

Garnet, is of uniform distribution, usually one percent of the rocks. The garnet is grossularite, and occurs as subrounded grains up to 1 mm in diameter. The garnet content of sample 399 from Mt. Innes-Taylor is noticeably higher than that of samples from Mt. Weaver. Sample 399 was collected from near two thick diabase sheets, and the garnet is probably of metamorphic origin.

Metamorphic and granitic rock fragments are present in most samples but not in abundance. Opaques, primarily leucoxene, magnetite, and hematite, are present in significant amounts in the lower part of the member but absent in the upper part. Sericite is present in significant quantities throughout most of the samples of the upper member. Matrix material of sericitic composition forms a significant part of most of the sandstones.

Chemistry

Table 17 gives the whole rock chemical analyses of two samples of the upper member of the Weaver Formation. Sample 155 is an arenaceous limestone from the central face of Mt. Weaver and sample 6441 is a micaceous carbonaceous sandstone from the Gondwana Escarpment.
### Table 17

**WHOLE ROCK CHEMICAL ANALYSES OF SELECTED SAMPLES OF THE UPPER MEMBER OF THE WEAVER FORMATION**

<table>
<thead>
<tr>
<th></th>
<th>Sample 155 Arenaceous Les. Mt. Weaver</th>
<th>Sample 6441 Garbenaceous ss, Gondwana Escp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{SiO}_2$</td>
<td>46.30%</td>
<td>69.90% by weight</td>
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<td>$\text{Al}_2\text{O}_3$</td>
<td>9.07</td>
<td>14.51</td>
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<tr>
<td>$\text{Fe}_2\text{O}_3$</td>
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<td>0.67</td>
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<td>$\text{FeO}$</td>
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<td>$\text{CaO}$</td>
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<td>1.18</td>
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<tr>
<td>$\text{MgO}$</td>
<td>0.71</td>
<td>1.48</td>
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<td>2.28</td>
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<td>$\text{TiO}_2$</td>
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</tr>
<tr>
<td>$\text{H}_2\text{O}$-</td>
<td>1.32</td>
<td>1.60</td>
</tr>
<tr>
<td>$\text{H}_2\text{O}$</td>
<td>0.14</td>
<td>0.28</td>
</tr>
<tr>
<td>$\text{CO}_2$</td>
<td>14.78</td>
<td>1.65</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>100.10</td>
<td>99.90</td>
</tr>
</tbody>
</table>

The chemical analysis of sample 155 agrees with the mineralogic composition. The abundance of calcium oxide indicates that calcite is the principal carbonate, the magnesia and ferrous oxide being held primarily in the chlorite and biotite. Soda and potash are present in about equal amounts, but thin section analyses indicate that potassium feldspar is far more abundant than plagioclase. Evidently, the plagioclase must be locked up in some other mineral. The silica content is rather high, the result of the abundance of quartz in the sample.
Sample 6441 is a black carbonaceous, burrowed, micaceous sandstone of the upper member of the Weaver Formation from the upper part of the Gondwana Escarpment in the Wisconsin Range. Ferrous and magnesium oxides are present in significant quantities, as a result of the abundance of biotite in the sample. The calcium oxide is accounted for by small amounts of calcite. The similar quantities of sodium and potassium oxide suggest about equal amounts of potassium feldspar and plagioclase, although some potassium and perhaps sodium is present in clay minerals. The silica content is rather low, and the alumina content high, as would be expected in a poorly-sorted, dirty, micaceous sandstone. The ferrous-ferric oxide ratio may be indicative of a reducing environment.

**Primary sedimentary structures**

Primary sedimentary structures are abundant in the upper member of the Weaver Formation. They differ markedly from structures of the middle member which are generally unidirectional traction current structures, whereas those of the upper member are of more diverse origin, and include ripple marks, cross-bedding, and slumpage structures. Structures produced by oscillatory movements of water are common in the upper member, but rare in the middle member.

Regular, uniform parallel laminations a few millimeters thick are the most common primary sedimentary structures in the upper member of the Weaver Formation.
Cross-bedding is common in the sandstones and limestones. It is generally low angle planar, dipping less than 15°, and occurs in cosets only a few centimeters thick. The cosets generally dip to the north and west, in a direction toward the coarse clastics thickening at Mt. Blackburn (Figure 42).

Oscillation ripple marks are common in some bed. Some of the ripple marks are flat-topped but most are symmetrical, they strike approximately perpendicular to the dip of the associated cross-bedding.

Interference ripple marks are present in some of the sandstones near the top of the formation.

Slumpage structures and overturned folds are present in the lower part of the member, but are rare in the upper part. The slumpage blocks appear to have moved to the south-southeast.

Ripple drift cross-laminations are abundant in some of the finer-grained sandstones, and consistently dip to the east-southeast.

Shale pebble conglomerates are present at the base of many of the sandstone beds. Generally the shale fragments are only a few centimeters in diameter, but locally blocks up to 50 centimeters are present. The conglomerates, represent reworked local deposits, and probably were transported only short distances.

Paleontology

Recognizable organic remains are scarce in the upper member
Figure h2. Low-angle cross-bedding of the upper member of the Weaver Formation. This type cross-bedding is characteristic of the upper member.

Figure h3. Animal burrows in a massive weathering arenaceous limestone of the upper member of the Weaver Formation. Burrows are so abundant in some beds as to produce a mottled appearance.
of the Weaver Formation. A well-developed *Glossopteris* flora is present in the uppermost black shale of the Weaver Formation at the Gondwana Escarpment, and the only known animal fossils from the Weaver Formation were collected here. Unidentified pelecypod casts were located in a debris slope in the Wisconsin Range by Dr. G. Faure. All evidence suggests that these specimens came from the upper member of the Weaver Formation, but they were not found in situ. Norman Newell (written communication) states that these remains cannot be identified.

The numerous animal burrows which characterize the sandstones of the upper member are generally nearly vertical, but a few are inclined, and some are horizontal. They are of uniform diameter the length of the burrow and are most abundant in the dirty carbonaceous sandstones and beds of alternating sandstone and shale. Thin section analyses indicate that organic material is rare in the burrows, but abundant in the surrounding rock. The animals responsible for the burrows are not known (Figure 43).

**REGIONAL DISTRIBUTION OF WEAVER FORMATION**

Sections containing lithologic associations similar to those of the Weaver Formation characteristically overlie basal conglomeratic units of probable glacial origin from the Ohio Range to the Beardmore Glacier. The distribution and lithologies of these strata are shown in Figure 44. At each of these localities
Figure 14. Correlation chart of the Weaver Formation and correlative units in the central Transantarctic Mountains. Note the persistence of individual members throughout the area, and thinning of the formation in the area around the Scott Glacier.
the strata are divisible into three units, starting with fine-grained strata near the base and grading upward into an arkosic, carbonate, or conglomeratic sequence.

In the Ohio Range strata correlative with the Weaver Formation are included in the Discovery Ridge formation (Long, 1965), and in the lower hundred meters or so of the massive-weathering arkosic sandstones of the Mt. Glossopteris Formation. Long placed the lower boundary of the Mt. Glossopteris Formation at the base of the first massive sandstone above the shales of the Discovery Ridge Formation. This sandstone is characterized by numerous animal burrows and is gradational with the underlying shale through a few meters. About 150 meters above the base of the Mt. Glossopteris Formation is a quartz pebble conglomerate.

The Discovery Ridge Formation is composed of two members. The lower member is a black platy shale characterized by numerous animal trails and an abundance of carbonate concretions. The upper member differs in the presence of sandstone or carbonate interbeds with well-developed sole and prod markings at the base of these beds. Animal trails are present, but are not common.

The Discovery Ridge Formation is considered to be equivalent to the lower and middle members of the Weaver Formation. The upper member of the Weaver Formation is probably represented
by the lower hundred meters or so of the overlying Mt. Glossopteris Formation. The quartz pebble conglomerate which occurs in the lower part of the Mt. Glossopteris Formation is thought to represent the basal conglomerate of the Queen Maud Formation elsewhere.

Strata equivalent to the Weaver Formation in the Transantarctic Mountains are recognizable by the following criteria:
1) stratigraphic position, generally occurring above glacial deposits and overlain by Glossopteris-bearing coal measures;
2) basic regressive clastic sequence grading upward from shale to sandstone and carbonates; 3) abundance of sole markings and trace fossils, especially in the middle and upper members.

Westward from the Mt. Weaver area rocks equivalent to the Weaver Formation crop out in a semi-continuous belt from the Thorvald Nilsen Mountains to the Beardmore Glacier. Long (in press) did detailed studies along the Nilsen Plateau, and divided strata equivalent to the Weaver Formation into two units, the Roaring Valley and Amundsen Formations. The Roaring Valley Formation is a thin shale which overlies the Scott Glacier Formation and is correlated with the lower member of the Weaver Formation. Overlying the Roaring Valley Formation is the Amundsen Formation, composed of fine-to coarse-grained sandstone, with minor amounts of siltstone, carbonate, shale, and two thin coal beds near the top of the formation. The Amundsen
Formation is of variable character, and it is difficult to trace individual lithologies for long distances along the escarpment. The contact with the overlying Queen Maud Formation was placed by Long at the first occurrence of Glossopteris leaves, an unfortunate choice, considering that the base of Queen Maud Formation was defined as consisting of a quartz pebble conglomerate, with no mention of the paleontology. In the Wisconsin Range a Glossopteris-bearing shale is present in the upper part of the Weaver Formation.

Evidently, the first appearance of the Glossopteris leaves and the quartz pebble conglomerate are nearly coincidental (Long, oral communication), although the report does not stress this fact.

Little is known of the Beacon rocks from the Amundsen Glacier to the Mt. Fridtjof Nansen area. Barrett (1965), in a reconnaissance study from near the Axel Heiberg to the Shackleton Glaciers, recognized units throughout the area similar to those of the Weaver Formation. At Mt. Fridtjof Nansen the basal conglomerate is overlain by about 35 meters of light greenish gray shale containing large granite clasts, presumably dropped from floating ice. Overlying this unit is about 90 meters of "... light greenish grey, fine sandstone, and dark shale, the latter comprising about one-third of the total thickness" (Barrett, 1965, p. 350). Interspersed throughout this unit, Unit B of
Barrett, are thin beds of limestone. (Barrett correlated Unit B with more than 100 meters of dark shale at Mt. Wade). There are a few thin shale pebble conglomerates in the lower part of the unit. Some of the sandstone has micro-cross laminations and trough-type cross stratification. A disconformity is present at the base of Unit B at Mt. Fridtjof Nansen, but the contact is conformable at Mt. Wade. At both localities, these strata are disconformably overlain by quartz pebble conglomerates of the coal measures.

Barrett's unit A is considered equivalent to the lower and middle members of the Weaver Formation, and Unit B to the upper member. The quartz pebble conglomerates at Mt. Nansen and Mt. Wade occur at a similar stratigraphic horizon to the quartz pebble conglomerate at Mt. Weaver. At each area these conglomerates mark the base of the coal measures.

The area around the head of the Shackleton Glacier was investigated during 1962-63 and 1964-65 by Wade and others (1965). The base of the Beacon rocks here consists of the Butters Formation, found at the position of the known glacial deposits elsewhere, although Wade and others (1965) do not assign a glacial origin to this formation. The Butters Formation is overlain by the Mackellar Formation, composed of two members: The lower member, 137 meters thick is composed of reddish-weathering interbedded siltstone and shale, with fine-grained, cross-bedded sandstone common in the upper part. The upper member, 167 meters
thick, is composed of "buff colored, fine-to-coarse grained sandstone with interbeds of shaley sandstone and black shale" (Wade and others, 1965, p. 14). Cross-bedding is locally prominent. The Mackellar Formation is very similar to the middle and upper members of the Weaver Formation, but strata equivalent to the lower member appear to be absent.

The Mackellar Formation was originally described by Grindley (1963) from the Queen Alexandra Range near the Beardmore Glacier. It is gradational with the underlying Pagoda Formation (Tillite) and contains pebbles, probably of ice-rafted origin, in the lower 30 meters of the shale. The shale has a total thickness of about 70 meters, and is typically dark and carbonaceous. It is overlain by about 50 meters of siltstone and sandstone possessing a rhythmic bedding. The strata are greenish, presumably due to chlorite, as in the middle member of the Weaver Formation at Mt. Weaver. The upper 50 meters of the Mackellar Formation is composed of arkose, with minor amounts of shale near the top. The upper contact of the Mackellar Formation was vaguely defined by Grindley.

The lower 100 meters of the formation are similar to the lower member of the Weaver Formation, and the middle 50 meters of alternating siltstone and sandstone similar to the middle member. The upper 50 meters of arkose appear to be at approximately the same stratigraphic position as the upper member of the Weaver Formation.
Northward from the Queen Alexandra, strata equivalent of the Weaver Formation appear to be absent. Permian coal measures overlie glacial deposits or Devonian arenites in the areas of the Nimrod Glacier (Laird, 1965) and Darwin Glacier (Haskell and others, 1964), and southern Victoria Land (David Matz, written communication). Weaver equivalents in these areas may be represented by a different facies or else are missing.

Stratigraphic successions similar to the Beacon rocks of the central Transantarctic Mountains are present in the Pensecola and Ellsworth Mountains, but detailed reports on the strata above the Late Paleozoic glacial deposits are lacking. Little is known of these areas except that deposits of glacial origin are overlain by a Glossopteris-bearing succession (Schmidt and others, 1965; Craddock and others, 1965).

ENVIRONMENT OF DEPOSITION

The Weaver Formation formed in a complex nearshore, barrier island, and deltaic environment. The salinity of the water in which the sediments accumulated is unknown; most workers suggest a lacustrine environment (Long, 1965; Grindley, 1963; Barrett, 1965), and others tentatively assign the beds to a brackish to marine origin (Minshew, 1966). The following factors must be considered in the determination of the salinity of medium of deposition: the wide areal extent of the beds; gradational contact, without varves, with the underlying glacial deposits;
absence of either diagnostic marine or lacustrine fauna; absence of diagnostic marine minerals, e.g. glauconite. The areal extent of these beds, from the Ohio Range to the Nimrod Glacier, is greater than that of most lacustrine deposits. It is questionable if tillite can grade upward into lacustrine shale without varves having formed. The absence of a diagnostic fauna cannot be taken as indicative of either marine or lacustrine origin as sediments from both environments frequently contain only sparse faunal remains. Although pelecypods have been found from the upper member of the Weaver Formation in the Wisconsin Range, Norman Newell (written communication) states that little environmental information can be obtained from them. The absence of diagnostic minerals such as glauconite from the Weaver Formation may be suggestive of a non-marine origin, but is not proof of it. Thus, on the basis of the present data, it is not possible to assign a definite marine or lacustrine origin to these strata.

Throughout the area of study, the Weaver Formation is composed of a shale at the base, grading upward into thick sandstones and limestones, suggesting that the formation records a regressive episode. Visher (1965) developed several depositional models, two of which are the regressive marine and the regressive lacustrine. The two models differ in only minor details, and essentially can be considered as one. The lacustrine models differs from the marine model primarily in that the transitional
and wave zone deposits are much more restricted and less well developed. Visher (1965, p. 44) notes that in regressive marine model "...deeper water deposits are successively overlain by sediments deposited in shallower and shallower water." He recognizes the following three environments: "(1) the fondotheome where sedimentation is controlled by the settling velocities of particles in water; (2) the clinothem (transitional zone) where sedimentation is cyclic and is controlled by the interaction of density currents, differential settling and possibly by direct wave-produced turbulence; and (3) the undathem (wave zone) where the sediment is under the influence of direct wave action." He further notes that these deposits are generally overlain by lagoonal and fluvial sediments.

Visher (p. 45) summarizes the sediments from each of these environments as follows: "The basal unit is poorly sorted; the size distribution is in the fine silt to clay range, and is usually developed as interlaminated silts and shales...

"The overlying unit is composed of alternating thin beds of fine and coarse detritus. The coarser beds are in the fine sand to silt range and are interbedded with shales and silty shales. One important characteristic of this environment is the presence of graded bedding. Other criteria of this unit are current markings that occur on the surface of the shale beds."
"The topmost unit is primarily composed of well-sorted sandstone, if silts and clays are present they are irregularly distributed through the coarse sand unit. In ancient rocks the uppermost crossbedded unit also characteristically contains carbonate cement, as opposed to the clay matrix found in the rocks lower in the sequence." The lagoonal deposits which overlie these sands are generally composed of carbonaceous silty clays and peat or coal.

The uppermost sand described by Visher accumulated in barrier island and beach environments. Potter (1967) summarized the literature of sediments of these environments in somewhat more detail than Visher. He (Potter, 1967, p. 354) noted that structures in these deposits include: "Asymmetrical ripple marks. Abundant gently inclined bedding. Lamination and lineation conspicuous on beach. Cross-bedding moderately abundant...Variability of cross-bedding orientation is moderate to large; Bimodal distribution may occur on beach. Burrows and channeling common."

The three members of the Weaver Formation are thought to correspond to the three-fold divisions of sediments which accumulate in the model set up by Visher. The upper member is considered to have been formed in a barrier island and beach environment as suggested by the following: low angled, inclined to horizontal bedding; abundant ripple marks (many asymmetrical); bimodal and variable cross-bedding orientation; transitional basal contact in many places, upward increase in grain size;
abundant burrows and mottles, and chemical cement. The middle and lower members are considered to be basinward and deeper water facies of the upper member.

The upper member of the Weaver Formation differs from most barrier island sands in that it occurs as a blanket deposit, it is thicker than most barrier island sands, it is more poorly sorted, and the grains are more angular. Visher (1965) notes that some barrier island sands occur as blanket deposits covering several hundred square miles, thus the barrier island origin of the upper member cannot be ruled out on the basis of the extent of the formation. Likewise, Thomas and Mann (1966) described barrier island sands from the Frio Formation in Louisiana more than 200 meters thick. If some of the calcite cement in the sandstones of the upper member of the Weaver Formation was originally present as detrital grains, the sandstones would have been moderately to well sorted.

Deltaic deposits are thought to be represented by the conglomeratic sandstones at the Mt. Blackburn area. These deposits are surrounded to the east, south, and west by fine-grained deposits of the Weaver Formation. Evidently, the Mt. Blackburn area was the site of a topographic high where polygonal jointed red siltstone formed at the stratigraphic position of black shales elsewhere. The Weaver Formation in the area around the Scott Glacier is overall coarser grained than elsewhere, and the
coarseness of the strata is probably the result of the proximity of the supply of detritus from the delta at Mt. Blackburn. A similar facies of conglomeratic sandstones surrounded by finer-grained sediments has been partially defined in correlative strata of the Shackleton Glacier area (F. Alton Wade, oral communication).

Figure 45 compares the Weaver Formation at Tillite Spur and Mt. Weaver with the regressive marine and deltaic models of Visher. The similarities between the sections are striking, and strongly suggest that the Weaver Formation accumulated in these environments (Figure 46).

PALEOSLOPE OF THE WEAVER FORMATION

Primary sedimentary structures in all three members of the Weaver Formation suggest a southeast-easterly paleoslope or direction of current movement throughout the area from the Shackleton Glacier to the Ohio Range (Figure 47). Regional analysis of the paleoslope of the Weaver Formation is plotted in Figure 47 for the area between the Shackleton Glacier and the Ohio Range. From the area of the Shackleton Glacier to the Amundsen Glacier the paleoslope was remarkably uniform, varying from about S 15° E to S 30° E. From the Amundsen Glacier to the Ohio Range the regional paleoslope swings around to almost due East in the Ohio Range and in the Wisconsin Range.
Figure 45. Comparison of representative sections of the Weaver Formation with theoretical models set up by Visher (1965). The similarity between the sections and the models strongly suggests a nearshore to deltaic environment of deposition for this formation.
Figure 46. Hypothetical depositional environments of the Weaver Formation. Deltaic deposits are present at Mt. Blackburn, and similar facies have been partially delimited in the area of the Shackleton Glacier.
Figure 47. Regional paleoslope of the Weaver Formation and correlative strata
Primary sedimentary structures are rare in the lower member of the Weaver Formation, although current lineation is present in the sandstone at the Gondwana Escarpment; and in the area of the Scott Glacier, ripple drift cross-laminations at Mt. Paine and cross-bedding at Mt. Weaver suggest a southeasterly moving current. The structures at both localities dip S 75° E to E. The current lineation at the Gondwana Escarpment strikes to the east.

Sole marks and prod marks in the middle member of the Weaver Formation are particularly useful for paleocurrent determinations. In the Gondwana Escarpment area these markings show a current movement predominantly to the east, with a secondary movement at about 45° S of the easterly movement. Throughout the area of the Scott Glacier, primary structures suggest S 75° E to E currents. Slumpage blocks at Mt. Weaver appear to have moved to the southeast.

Paleocurrent data from the upper member of the Weaver Formation are in close agreement with those from the other members. Ripple drift cross-laminations at Mt. Weaver dip S 75° E to E, and ripple marks strike N 75° - 60° W. Low angle cross bedding at Mt. Weaver dips in a northerly direction, apparently up the regional paleoslope.

Ripple marks from the upper member in the Gondwana Escarpment strike north, and the cross-bedding dips to the west and east.
AGE OF THE WEAVER FORMATION

The Weaver Formation is Permian age. Equivalent strata in the Ohio Range overlie the Buckeye Formation which contains a Permian spore assemblage. These strata are overlain, in turn, by coal measures of Upper Permian age.
QUEEN MAUD FORMATION

Introduction

The Queen Maud Formation is composed of the coal measures of the Wisconsin Range and the eastern Queen Maud Mountains. The formation disconformably overlies the Weaver Formation, and is characterized by a Glossopteris flora. The Queen Maud Formation is considered to be approximately equivalent to similar coal measures exposed in the Ohio Range to the east, and the western Queen Maud Mountains around the Shackleton and Beardmore Glacier areas.

Definition and type area

The Queen Maud Formation, composed of cyclic alternations of volcanic sandstones, siltstones, mudstone, and shale in the upper part, and quartz pebble conglomerates and arenaceous limestones in the lower part, is defined from exposures on the central face of Mt. Weaver. The most complete section of the formation is exposed here, and the exposures are easily accessible (Figure 48).

The lower boundary of the formation at Mt. Weaver is placed at the base of the first quartz pebble conglomerate, which disconformably overlies the Weaver Formation.

The Queen Maud Formation is easily distinguished from the underlying strata at Mt. Weaver. High rank, low grade coal is
common in the Queen Maud Formation, whereas only two shaley coals are present in the Weaver Formation. Cyclic patterns of deposition are well developed in the Queen Maud Formation, but absent beneath it. A Glossopteris flora characterizes the Queen Maud Formation, in contrast to the paucity of plant fossils in the Weaver Formation. Animal burrows are common in the Weaver Formation, but absent in the Queen Maud Formation. Pyroclastic and volcanic debris are present throughout the Queen Maud Formation, but absent beneath it.

Areal distribution

The Queen Maud Formation is most completely developed at Mt. Weaver, and crops out in all exposures south of Mt. Weaver, excluding Mt. Early, the extinct volcano. The strata south of Mt. Weaver are thought to be stratigraphically higher than those at the type section. Northward from Mt. Weaver and the Queen Maud Formation is exposed at Mt. Blackburn and in the Nilsen Plateau.

In the Wisconsin Range, the Queen Maud Formation is restricted to the upper few meters of the Gondwana Escarpment, where the formation is composed of about 25 meters of quartz pebble conglomerate.

Lower contact

The Queen Maud Formation rests disconformably on the upper member of the Weaver Formation at Mt. Weaver, with local relief of about 1.5 meters. Lenticular deposits of massive conglomerate
composed of pebbles and cobbles of quartz in a dense, sandy matrix are present in topographic lows on the erosion surface. The well-rounded to ovoid clasts are up to 50 cm in diameter, although most are only a few centimeters (Figure 49). This conglomerate is overlain by about 15 meters of coarse-grained, cross-bedded sandstone with numerous lenticular stringers of quartz pebble conglomerate. The quartz pebbles, well-rounded and averaging about two cm in diameter, occur in pockets up to about 50 cm thick, and several meters in length. Locally, the quartz pebbles are not restricted to pockets, but occur randomly throughout the sandstone.

The lower contact of the Queen Maud Formation is not easily recognizable at the Mt. Blackburn area; the basal quartz pebble conglomerate is difficult to differentiate from the conglomeratic sandstones of the Weaver Equivalent strata. One unusually thick quartz pebble conglomerate is present about 350 meters above the base of the Beacon; this may represent the base of the Queen Maud Formation.

Relief in excess of 25 meters is present at the base of the Queen Maud Formation at the Gondwana Escarpment in the Wisconsin Range. The quartz pebble conglomerate here disconformably overlies various lithologies of the Weaver Formation, although in most areas it rests on carbonaceous black shale.
Figure 49. Basal quartz pebble conglomerate of the Queen Maud Formation. The quartz pebbles are generally restricted to pockets in a coarse-grained sandstone.
Thickness

The upper contact of the Queen Maud Formation is not present at Mt. Weaver, the type locality. The formation is at least 400 meters thick, and may be much thicker. Thick sections are exposed south of Mt. Weaver; these strata are considered to be stratigraphically higher than those at the type X section. By inclusion of them, the total thickness of the formation may be in excess of 600 meters, of similar magnitude to the coal measures in the Ohio Range (Long, 1965), but much greater than the Queen Maud Formation in the Nilsen Plateau (Long, in press), only a few kilometers north of Mt. Weaver.

Stratigraphy

The Queen Maud Formation comprises the coal measures of the Scott Glacier area. The formation at Mt. Weaver is composed of two parts: The lower, about 75 meters thick, includes conglomeratic sandstone, arenaceous limestone, calcareous sandstone, and minor amounts of shale and low grade coal. The upper part of the formation consists of cyclical alternations of volcanic sandstone, siltstone, shale, coal, sideritic ironstone, and a few beds of lithified tuff. Pyroclastic fragments first appear in the basal conglomerate of the formation, and become more abundant upward, culminating in bentonite and tuffs in the upper part of the section at Mt. Weaver and at Sunny Ridge.
The basal quartz pebble conglomerate is overlain by about 60 meters of interbedded calcareous sandstone, arenaceous limestone, and minor amounts of shale and coal. The limestones and sandstones are difficult to differentiate in the field; both rest disconformably on either shale or coal and are dark gray, weathering to a light gray. Shale pebble conglomerates and festoon cross-bedding are present in the basal part of most limestones; they become finer grained upward and grade into shale or siltstone with ripple drift cross-laminations. This alternation of lithologies produces a poorly developed cyclical pattern (Figure 48). Individual cyclical units vary in thickness from less than one meter to more than 10, averaging about 5 meters.

The shales in the lower part of the formation are thin-bedded and black, and contain sparse fossil leaves. The coals are shaley and low grade; they are lenticular and are frequently interbedded with black shale.

The boundary between the upper and lower parts of the formation is not easily discernible in the field, but is readily recognizable by petrographic means. Because of some difficulty in separating the two parts of the formation in the field, they are not classified as members of the Queen Maud Formation.

Black, irregularly bedded shale is the most common lithology of the upper part of the formation, and most of the sandstones are composed predominantly of volcanic or pyroclastic debris.
Calcareous sandstones are rare, and limestones are absent in the upper part. Plant remains are abundant in the upper part of the formation, but relatively rare in the lower part.

The volcanic sandstones, poorly sorted and fine-grained, weather into small rounded cliffs; they are of variable thickness, ranging from about 15 meters to less than one, with an average thickness of about 7-8 meters. They are composed almost entirely of angular albite, rounded volcanic rock fragments, and zeolitized matrix material. Quartz is important in the volcanic sandstones in the lower part of the formation, but is rare upward in the section.

The sandstones rest disconformably on the underlying strata, sometimes with relief up to two meters. Fragments of the underlying beds, usually shale or coal, are frequently concentrated as basal conglomerates in the lower few cm of the sandstones. The fragments are angular and vary in size from less than one cm to more than one meter. Well-rounded pebbles of quartz or quartzite are sometimes present with the shale fragments in the basal conglomerates. The sandstones become finer grained upward from the basal conglomerate, and grade into siltstone with ripple drift cross-laminations. The siltstones are thin, usually less than three meters, and grade upward into silty shale.

Black carbonaceous shales are abundant in the upper part of the Queen Maud Formation, increasing in abundance toward the
top of the section at Mt. Weaver; the upper 150 meters or so of the section is composed of more than 50% shale. The shales vary in thickness from only a few centimeters to more than 20 meters, the thicker being most common in the upper part of the section at Mt. Weaver. The shales are blocky and irregularly bedded, individual beds averaging about two cm thick. All gradations between shale and mudstone are present, although true mudstones are rare. Carbonitized leaves and stems are commonly preserved along the bedding planes, and a few upright trunks are present.

Lenticular deposits of low-grade coal are interbedded with most of the shale beds. The coal generally rests on an irregular surface of unweathered shale; the irregularity of the surface is thought to be the result of compaction rather than of weathering. The coals are of variable thickness, ranging from only a few cm up to about 10 meters. The deposits are lenticular and interfinger with black carbonaceous shale. One bed of coal eight meters thick pinches out into shale in a few hundred meters along the face of Mt. Weaver. The ash content of the coals is high and variable. The coals are composed primarily of durain and fusain. Vitrain is relatively rare, and occurs as small elongate stringers.

Underclays are rare in the coal measures at Mt. Weaver. Only one underclay is thought to be present in the type section. Sample 127 is a massive, blocky claystone collected from a
toreva block on the northern face of the mountain. The claystone is light gray with numerous manganese stains, and contains rootlets extending downward from the overlying coal. The claystone is about 50 cm thick, and is underlain by black shale.

The absence of underclays is one of the most characteristic features of the Antarctic coal measures, leading some workers to speculate that most of the Antarctic coals are of detrital origin (Schopf and Long, 1966).

The rank of the coals from Mt. Weaver is quite variable, although most of them fall in the high bituminous-subanthracite range (Schopf and Long, 1966). One coal from Mt. Howe is high rank anthracite, and those from Sunny Ridge are anthracite.

The coal beds are closely associated with lenticular deposits of sideritic ironstone. The ironstones are interbedded with carbonaceous shale, and occur either as large, elongate concretions several meters in diameter or as thin stratified deposits. The ironstones most commonly occur immediately above or below the coal beds, and occasionally are interbedded with siltstone. They are composed primarily of siderite and hematite, with lesser amounts of quartz, mica, and carbonaceous material.

Lithified tuffs are rare in the Queen Maud Formation, and are restricted to the upper 200 meters of the section at Mt. Weaver and Sunny Ridge. The tuffs resemble the volcanic san-

stones in the field but they differ in the poorer sorting, absence of cross-bedding, and generally lighter color, varying from dark gray to light greenish gray. The tuffs vary in thickness from less than one meter to about five meters, and are commonly interbedded with black shale. Trees in upright position and small chunks of silicified wood are abundant in the tuffs at Sunny Ridge.

Only one bentonite was found in the Queen Maud Formation, about 10 meters below the summit of Sunny Ridge. The bentonite, in contrast to the adjacent shale, is deeply weathered, and is about two cm thick. It is light gray, and X-ray diffraction analyses indicate it is composed primarily of laumontite and calcite.

The strata south of Mt. Weaver are placed in the Queen Maud Formation because of the presence of a well-developed Glossopteris flora, of high rank coal, and of pyroclastic debris in the sandstones. The section at D'Angelo Bluff consists of about 150 meters of coarse-grained, volcanic sandstones containing numerous lenses of quartz pebbles and an abundance of wood fragments. The sandstones resemble those of the lower part of the Queen Maud Formation at Mt. Weaver in the abundance of quartz pebbles, but differ in the abundance of pyroclastic fragments, up to 50 percent of plagioclase and rock fragments. Because of the abundance of pyroclastic materials, the sand-
stones are thought to be stratigraphically higher than the basal sandstones of the formation at Mt. Weaver. The section at Mt. Howe is quite different from that at D'Angelo Bluff, consisting primarily of shale and mudstone with only minor amounts of volcanic sandstone. One three-meter coal bed is present on the western ridge of the mountain where the sedimentary rocks have been baked to hornfels by a 300 meter diabase sill. The abundance of pyroclastic debris in the sandstones from Mt. Howe and D'Angelo Bluff suggests that these beds are in the upper part of the Queen Maud Formation, and because of their dissimilarity to the beds at Mt. Weaver - the thick volcanic sandstones with numerous quartz pebbles -, they may be stratigraphically higher than those at Mt. Weaver.

**Petrology**

Table 18 summarizes the petrographic data from the Queen Maud Formation for the Scott Glacier area. Thirty-eight samples were sectioned and five hundred points were identified in each section. The results have been tabulated as percentages. Samples 170-276 are from the type section at Mt. Weaver; samples 029, 205, and 209 are tuffites from Sunny Ridge; samples 314-316 are volcanic sandstones from D'Angelo Bluff. Samples 086-139 are from the toreva block on the northern face of Mt. Weaver, and from strata correlative with the upper part of the Queen Maud Formation at the type section on the central face of Mt. Weaver.
Samples 170-197 are from the lower part of the formation; the remained of the samples are from the upper part.

The calcareous sandstones and arenaceous limestones of the lower part of the formation consist primarily of quartz and calcite. The quartz grains average about one mm in diameter, and are rounded to subrounded, with undulatory extinction. Minute inclusions are present in many of the grains, and some contain secondary rims of quartz, calcite, and/or albite.

Crystalline calcite is of primary importance in most of the units of the lower part of the formation, varying between 9 and 68 percent, and averaging 46 percent. The calcite in most samples occurs as large interlocking mosaics in which the remainder of the grains are suspended. Much of the calcite in these samples is thought to have formed as large detrital grains, similar to the quartz, which were later recrystallized to form the calcite mosaics. Pettijohn (1966) states that not more than 35 percent of any rock can be composed of secondary calcite. Thus some, if not most, of the calcite in these samples is detrital, or primary.

Biotite is present as large elongate flakes concentrated along bedding planes. Much of it has been slightly distorted, and much is chloritized in varying degrees.

Potassium feldspar, consisting of about equal amounts of microcline and orthoclase, is abundant in only the basal con-
### Table 18

**Mineralogic Composition of Selected Samples of the Queen Maud Formation from the Scott Glacier Area**

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glomerate (sample 170), and is absent in the volcanic sandstones of the upper part of the formation (samples 198-276). Plagioclase is of minor significance in the samples from the lower part of the Queen Maud Formation. Most of the plagioclase is albite, and some is altered to either sericite or zeolites.

Chlorite is insignificant in most samples, and is present primarily as a replacement of biotite. Likewise, muscovite is rare. Sericite is primarily a replacement of plagioclase, and to a lesser extent an alteration product of the matrix. Grossularite is present in all samples below 248, sometimes in amounts exceeding one percent, but is absent in samples above 248.

The volcanic sandstones of the upper part of the formation differ from the clastics in the lower part primarily by the abundance of pyroclastic debris, scarcity of quartz, absence of microcline, and abundant zeolites. Garnet and sericite are absent, and matrix is abundant.

The pyroclastic debris first appears in abundance in sample 198, which contains 13 percent plagioclase. Plagioclase remains abundant in the higher samples, generally more than 15 and up to 42 percent. The plagioclase is angular, subhedral, and occurs in laths up to 0.5 mm. Universal stage and oil immersion techniques indicate that the plagioclase is Ab$_{95-100}$. Some laths are zoned, and most of them are partially altered to zeolites, calcite. Secondary albite occurs as overgrowths
on potassium feldspar, and as small veinlets cutting the sections. Some of the larger plagioclase laths may be of secondary origin, for a few contain small grains of quartz in the center.

The quartz in the volcanic sandstones is generally similar to that in the sandstones from the lower part of the formation except in samples above 250. The quartz in these samples is fresh and angular, frequently rectangular in outline, and has straight extinction. Some of it is thought to be beta quartz pseudomorphs.

Potassium feldspar is generally rare. It occurs as large fresh and unaltered flakes with excellent cleavage at nearly right angles.

Volcanic rock fragments are one of the most characteristic features of the volcanic sandstones, first appearing in trace amounts in the basal conglomerate and increasing upward. The volcanic rock fragments first appear in abundance in sample 252, the same sample in which the quartz content drops off sharply. The rock fragments occur in grains up to one mm in diameter, and are present in all degrees of rounding. Several types of fragments are present. The most common type consists of minute plagioclase laths aligned in a subparallel pattern and separated by devitrified glass. The next most common type of rock is composed of one or a few large plagioclase laths surrounded, or partially surrounded by, devitrified glass.
A third type consists of large fragments of pumice with angular glass shards, and no recognizable minerals.

Zeolites are abundant in the sandstones and occur as a cement or as a replacement of plagioclase matrix, or glass shards and rock fragments. X-ray analyses indicate the most common zeolite is laumontite, and poor peaks are present at the stilbite and natrolite 100 HKL. Before X-ray diffractometer patterns were used it was not possible to differentiate the various zeolites by petrographic means, but by combining petrographic work with X-ray diffraction patterns, it is possible to differentiate the zeolites with some assurance. Heulandite typically has parallel extinction, and laumontite has extinction angles from about 17 to 35 degrees. Stilbite and natrolite, if present, are too small to determine any petrographic properties.

Matrix material is abundant in all the volcanic sandstone. It was separated from the coarser minerals and analyzed by X-ray diffraction. The matrix was found to consist of the above-mentioned zeolites, sodic plagioclase, minor amounts of potassium feldspar and chlorite, and sericite. There was no quartz.

The zeolites in the matrix suggest it originated as volcanic glass or ash which was later devitrified and recrystallized. Hay (1966) states that clay minerals will not alter to zeolites.
Opaque minerals are generally not abundant in the volcanic sandstones. Most of them are elongated grains composed of limonitic material; the shape suggests that originally some of the opaques may have been amphiboles.

**Geochemistry**

Ten samples of the Queen Maud Formation were analyzed chemically. Pettijohn (1966) has summarized the data on the chemistry of sandstones. The samples from the Queen Maud Formation closely resemble the composition of greywackes in their high sodium and alumina and low potassium and silica content (Table 19). The calcium content is rather high in some samples; however, the presence of significant quantities of carbon dioxide suggests that some of the calcium is present as calcite. The remainder of the calcium is evidently in zeolites; the central portions of plagioclase grains are commonly zeolitized. The potassium content is rather high, considering the scarcity of potassium feldspar in these samples, and the fact that clay minerals in which the potassium might be present are rare or absent in many of the samples. The abundance of potassium suggests that micro-crystalline potassium feldspar may be present in the recrystallized matrix; such material would not be recognizable on X-ray diffraction patterns.

Pettijohn (1966), on the basis of several hundred analyses, concluded that it is possible to differentiate greywackes from
arkoses on the sodium/potassium ratio, on a plot such as Figure 50. Upon this plot, the average composition of greywackes are plotted, along with the average composition of subgreywackes, and rhyolites and dacites (Iddings, 1913). According to Pettijohn, greywackes fall above the 1:1 line, and arkoses below it. All samples of the Queen Maud Formation fall above the line, in the greywacke and subgreywacke fields. This raises a problem in classifying the Queen Maud samples. Chemically and petrographically, the samples fit the definition of greywackes. Unfortunately, however, the term greywacke has taken on genetic significance to many workers, some proposing to classify sandstone on the basis of their primary structures and mode of origin (Crook, 1960). Greywackes suggest to many an impure, poorly sorted sandstone of turbidite-type deposition in geosynclinal areas. The Queen Maud Formation was deposited on an alluvial plain amidst prolonged volcanic activity; because of the bias affixed to the term, it would hardly be acceptable to most workers to classify the Queen Maud samples as greywackes.

Most of the samples of the Queen Maud Formation were subjected to varying degrees of sorting and reworking prior to final deposition, and were subsequently metamorphosed by the Jurassic diabase sills. In order to determine how closely the samples from the Queen Maud Formation represent unaltered and
Figure 5. Sodium oxide-potassium oxide ratios of samples of the Queen Maud Formation.
### Table 19

**CHEMICAL ANALYSES OF SANDSTONES AND TUFFITES OF THE QUEEN MAUD FORMATION**

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<th>Element</th>
<th>Sample 1</th>
<th>Sample 2</th>
<th>Sample 3</th>
<th>Sample 4</th>
<th>Sample 5</th>
<th>Sample 6</th>
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<td>64.06%</td>
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</table>

Total: 99.85 99.80 100.02 100.21 100.86 100.15 100.18 100.08 99.29 100.62
closed systems, the sodium content was plotted in respect to silica (Figure 51). If the samples represent an unalter and closed volcanic system, they should either plot along a rather straight line or form a pattern. Many of the samples do plot along a straight line. Samples 6437, 127 and 501 can be disregarded in this consideration: 6437 is from the quartz pebble conglomerate, 127 is an underclay that was partially altered shortly after burial, and 501 is a silicified tuff. The sodium content of samples 260 and 209 is considerably higher than that of the other samples, yet they have about the same silica content as the others. These samples are thought to have been enriched in sodium, as was sample 52 from the Scott Glacier Formation. The sodium content of sample 52 is considerably higher than that of the other non-volcanic rocks, approaching the amount of sodium in the pyroclastic rocks.

The most likely source of sodium enrichment of these samples are the diabase sills and adjoining strata. In order to determine the relationship of the sodium to the diabase sills, the chemical analyses of the Beacon rocks were plotted in respect to distance from known sills at Mt. Weaver (Figure 52). Samples 206 and 209 are from Sunny Ridge and were included in the figure by placing the stratigraphic sequence at Sunny Ridge directly above the top of the Mt. Weaver section. Samples 52 and 209 were collected only a few meters from thick diabase
Figure 51. Sodium oxide-silicon dioxide ratios of samples of the Queen Maud Formation.
sills, but sample 260 was collected meters from the nearest known sill. The proximity of the diabase sills to the first two samples suggests that sodium metasomatism is related to the diabase sills; the relationship of sample 260 is less clear. The diabase sills at Mt. Weaver are intruded in a highly irregular fashion, and the presence of an unseen sill near the bed from which sample 260 was collected cannot be absolutely ruled out. However, if no diabase is present in this part of the section, the origin of the sodium enrichment is unknown.

Even though the sills seem to have been responsible for sodium metasomatism of the Beacon rocks, the sills themselves are rather deficient in dosium. Several chemical analyses of the Antarctic diabases from various areas are available, and all contain sodium oxide in less than three percent (Treves, McDougall, Gunn, Hamilton). The diabase sills of the Scott Glacier are probably of a similar composition. Walker and Pooldervaart (1949) noted similar sodium enrichment of Karoo rocks near Jurassic diabase sills in South Africa, and commented that the sediments were enriched in elements by which the diabase was deficient.

Primary sedimentary structures

A restricted assemblage of sedimentary structures is present in the Queen Maud Formation, the more common of which are festoon cross-bedding and ripple drift cross-laminations.
Ripple marks and convolute bedding are present locally.

Festoon cross-bedding is present in most of the sandstones throughout the formation, although commonly restricted to the base of individual sandstones (Figure 53). The cross-bedding dips to the southeast at angles varying between 13° and 30°, with approximately 20° most common. Ripple drift cross-laminations are common sedimentary structures that are restricted to the carbonaceous siltstones. The cross-laminations are asymmetrical, with the steeper side in most cases to the southeast. The term ripple drift was first used by Sorby (1859) for cross-laminations produced by one ripple climbing up the stoss slope of the ripple immediately downstream. Recently Walker (1963) described similar structures in situations in which cross-bedded sandstone grades upward into ripple drift siltstone which in turn grades upward into claystone. This is the cross-laminations present in the Queen Maud Formation (Figure 54).

Ripple marks were found in only one location in the Queen Maud Formation, at the top of a sandstone 290 feet below the base of diabase sill capping Mt. Weaver. The ripples are oscillatory, with flat, broad crests up to four centimeters across and up to 15 centimeters in length. Convolute and distorted bedding are present in some of the volcanic sandstones and lithified tuffs, but these features are not common.
Figure 53. Basal sandstone of a cyclothem in the Queen Maud Formation. A few quartz pebbles are scattered along the base of the sandstone and large angular blocks of black shale are abundant.

Figure 54. Ripple-drift cross-laminations in fine-grained sandstone in the Queen Maud Formation.
Cyclic patterns of deposition

One of the most characteristic features of the Queen Maud Formation at Mt. Weaver is the presence of numerous well-defined cyclical units. Individual cyclothsms vary in thickness from less than 10 to more than 15 meters; they are best developed in the middle part of the formation at Mt. Weaver. The cyclothsms generally consist of eight parts, although individual cyclical units frequently contain more or less. Figure 55 depicts a generalized cyclical unit at Mt. Weaver.

A distinct erosion surface is present at the base of each cyclical unit. Relief of more than one meter is uncommon, and the strata beneath the erosion surface are commonly oxidized to a depth of a few centimeters. The basal erosional surface is commonly overlain by a massive, conglomeratic sandstone; the pebbles in the sandstone are generally reworked shale fragments, but quartz pebbles are abundant in some sandstones. The conglomeratic sandstone is generally only a few centimeters thick, but locally may be more than one meter.

The conglomeratic sandstone grades upward into massive, poorly sorted sandstone, usually less than one meter thick, which grades upward into sandstone with well-developed festoon cross-bedding. The cross bedded sandstone, in turn, grades upward into very fine-grained sandstone or siltstone characterized
Figure 55. Representative cyclothems of the Queen Maud Formation
by an abundance of ripple drift cross-laminations (Figure 54). The ripple drift zone is generally only about one meter thick, but in some localities is more than five meters.

The siltstone grades upward into black silty shale with an abundance of plant remains. Fossilized trees are common in the shale, both in growing position and concentrated along the bedding.

Lenticular beds of coal are interbedded with the shale. Most of the cyclical units contain one coal bed, but some have three or more. Lenticular deposits of sideritic ironstone are generally present in the shale immediately above the coal. An erosional surface marks the beginning of a new cyclothem.

Origin

The cyclothems in the Queen Maud Formation are identical to those described from fluvial sediments from many parts of the world. Visher (1966) and Allen (1965) recently described cyclothems from fluvial deposits, and Pettijohn (1966) and others summarized the work on fluvial cyclothems as follows: "The important elements in the alluvial complex are (1) the channel sands and gravels, (2) the cross-bedded point-bar sands, (3) the rippled flood-plain silts, and (4) the backwater silts and clays. Although these are geographically distinct at any given instant, owing to stream meandering and shifting, they are superimposed in the order named and constitute the normal paralic or fluvial cycles. Marked subsidence leads to super-
imposition of these cycles; interrupted subsidence leads to truncated cycles."

It is possible to correlate the components of the Queen Maud cyclothems with those of the model described by Pettijohn and others. The basal conglomeratic sandstones are thought to have formed as lag concentrates in channels, and the cross-bedded sand probably represents point bar deposits. The ripple drift cross-laminated siltstone formed in low tranquil conditions on the inside of meander belts, and the black carbonaceous shale represents flood plain deposits formed by clay settling out from flood waters. The coal probably formed in small lakes and bayous which were present on the flood plain. A similar environment may have existed for the accumulation of the sideritic ironstone. Geochemical investigations have shown that precipitation of siderite and hematite is controlled to a large extent by the Eh and pH of the medium of deposition. In order for these two minerals to precipitate together, a basic reducing environment is necessary. These conditions are present in stagnant bayous on a flood plain.

Thus, the cyclothems in the Queen Maud Formation represent decreasing energy conditions from the erosional channel at the base to the shale and sideritic ironstone at the top. Conditions responsible for the deposition of each component of the cyclothems existed simultaneously on the floodplain. Because of the cyclo-
them are controlled by the meandering of local streams, it would not be expected that individual cyclothems are recognizable over wide distance. It is not possible to correlate individual cyclothems from the central face of Mt. Weaver to the strata on Fault Block Ledge, only a few hundred meters to the north.

Paleontology:

A *Glossopteris* flora characterizes the Queen Maud Formation; it is represented by both leaves and wood. Animal fossils have not been found in the Queen Maud Formation in either the Queen Maud Mountains or Wisconsin Range, although Doumani and Tasch (1963) report conchostracans from coal measures in the Ohio Range.

The floral assemblage is best preserved in the carbonaceous shales, the leaves occurring along the bedding planes and the wood either as logs in upright position or as fragments concentrated along the bedding planes.

A list of the fossil plants from the Queen Maud Formation in the Scott Glacier area, compiled by J. M. Schopf (written communication), is given below.

*Glossopteris indica* Schimper 1869

G. *angustifolia* Bgt. 1830

G. *decipiens* Feist 1879

G. *amplia* Dana 1849

G. *communis* Feist 1876

G. *conspicua* Feist 1890

G. *stricta* Bumb 1861
G. spathulato-cordata Feist 1890
G. N. sp.

Vertebraria indica Royle 1839
Gangamopteris obvata (Car. 1869) D. W. 1908
G. angustifolia (McCoy) McCoy 1861
G. sp.
Samaropsis longii Schopf 1963
Noeqgerathiopsis sp. leaf fragments
N. Gen ("Pecopteris") Tenuifolia McCoy 1847

The best-preserved fossil leaves are found in the shales near the middle part of the Queen Maud Formation, although fossils are present throughout the Queen Maud and the Weaver Formations.

The most fossiliferous beds in the area are black shales near the central face of Mt. Howe. The shales there have been altered to hornfels by nearby diabase sills, but the plants are well preserved. They are concentrated in mats along the bedding planes.

Vertebraria was found most abundantly in black shales near the summit of Mt. Weaver and in the massive claystone near the top of Mt. Howe.

Fossil wood is scattered throughout the Queen Maud Formation. One fossil trunk more than 70 centimeters in diameter was found in upright position on Fault Block Ledge, with rootlets extending downward into the underlying strata.
The fossil wood is characterized by well-developed growth rings. From a collection of wood from Mt. Glossopteris in the Ohio Range, Schopf (1962, p. 45) noted, "Growth rings are about as prominent in them as in secondary wood in temperate, continental type climates of the present day."

Fossil floras similar to that from the Queen Maud Formation have been described in numerous localities from Antarctica. Schopf (1962) and Criddle (1963) described a similar flora from the Ohio Range. Plumstead (1962) reported Glossopteris from the Theron Mountains and Whichaway Nunataks near the Weddell Sea. Craddock and others (1965) reported the presence of Glossopteris for the first time in West Antarctic from the Ellsworth Mountains, and Schmidt and others reported the presence of the flora in the Pensacola Mountains. The Glossopteris flora is also known to be present in the area between the Queen Maud Mountains and Victoria Land (Wade and others, 1965; Grindley, 1963; Matz, 1966).

**Regional correlations**

Coal measures are widespread in the Transantarctic Mountains, and are known from the Pensacola Mountain to southern Victoria Land. Representative sections from the Transantarctic Mountains are shown in Figure 56. The correlation lines shown on the figure are not time lines, but merely represent the base of the coal measures as described by the various workers. As can be seen
from Figure 56, Long in the Ohio Range and Grindley in the Beardmore Glacier placed the base of the coal measures lower stratigraphically than did workers elsewhere in the Transantarctic Mountains. Both Long and Grindley chose the first massive sandstone as the base, whereas the others, with the exception of those studying the Pensacola Mountains where the base of the coal measures is not exposed and Victoria Land where the coal measures form the base of the Permian rocks, chose the first appearance of quartz pebble conglomerates as the base of the coal measures. Barrett (in press) is re-defining the Buckley Formation in the Beardmore Glacier so that the base of the formation is at the same stratigraphic position as the coal measures elsewhere. Long (1965) described a quartz pebble conglomerate about 150 meters up in his Mt. Glossopteris Formation. Future work may reveal that this conglomerate is at the same position as the quartz pebble conglomerate forming the base of the Queen Maud Formation.

The first appearance of volcanic debris in the coal measures in the central Transantarctic Mountains is considered to represent the best time horizon present in these strata. Even though the volcanic materials have been transported and thus may partially transgress time, the fact that they first appear in the quartz pebble conglomerate at the Wisconsin Range, Scott Glacier area, Nilsen Plateau, and Mt. Nansen suggests that they first occurred at about the same time throughout this
area. Pyroclastic deposits first appear in the Ohio Range in the massive burrowed sandstones which are equivalent to the upper member of the Weaver Formation, but which Long (1962) placed in the lower part of the Mt. Glossopteris Formation. It is tentatively suggested that the lower part of the Mt. Glossopteris Formation is the same age as the quartz pebble conglomerates in the Wisconsin Range and the Queen Maud Mountains.

Paleoslope

Twenty-six orientations of cross-bedding cosets were measured in the sandstones of the Queen Maud Formation at Mt. Weaver, from six sandstones. The cross-bedding data, although scanty, indicate an easterly movement of streams, approximately parallel to the present length of the Transantarctic Mountains. This direction of movement is in close agreement with the direction of paleocurrents from correlative strata elsewhere in the Transantarctic Mountains (Figure 57). From the Beardmore Glacier to the Ohio Range the streams depositing the coal measures strata flowed approximately parallel to the length of the mountains; the paleoslope is approximately the same as that for the Weaver Formation (Figure 47), and for the direction of ice movement from the glacial beds (Figure 32). Thus, throughout the Permian the paleoslope seems to have remained constant, and these conclusions can be drawn: The late paleoslope ice sheet moved down the
Figure 57. Regional paleoslope of the Queen Maud Formation and correlative strata
Regional paleoslope; the Weaver Formation was deposited along an eastward regressing shoreline and nearshore environment; the Queen Maud Formation formed on an alluvial plain adjacent to the body of water in which the Weaver Formation accumulated.

Matz (written communication) has taken several hundred cross-bedding orientations from the Permian coal measures in southern Victoria Land, and has found that the regional paleoslope was to the west, nearly opposite to that of the coal measures strata from the Beardmore Glacier to the Ohio Range. Thus, the possibility exists that a topographic high may have been present somewhere between the Beardmore Glacier and southern Victoria Land. Much more detailed work is needed in this area before the regional paleogeography can be defined more fully.

Age

On the basis of the Glossopteris flora in the Queen Maud Formation, J. Schopf (oral communication) assigns a Permian age to these strata. Correlative strata in the Ohio Range have been dated by conchostracans by Doumani and Tasch (1963), who consider them to be upper Permian (Beaufort). Work on the Rb-Sr dating of the pyroclastics from the upper part of the Queen Maud Formation by Dr. Sanbhudas Chaudhuri, Kansas State University, and the author is as yet incomplete.
PROVENANCE OF THE BEACON ROCKS

Granitic and high grade metamorphic rocks were the primary source materials for the Buckeye, Scott Glacier and Weaver Formations. The abundance of quartz with undulose extinction, of microcline, and of orthoclase, and the presence of garnet, tourmaline, and zircon are suggestive of a crystalline source area.

Pyroclastic detritus first appears in the basal conglomerate of the Queen Maud Formation at Mt. Weaver, Gondwana Escarpment, Nilsen Plateau, and about 400 meters above the base of the Beacon rocks at Mt. Blackburn. Barrett (1966) found laumontite first appearing at the base of the coal measures in the quartz pebble conglomerate at Mt. Fridtjof Nansen. Because laumontite forms primarily as an alteration produce of volcanic debris, its first appearance is assumed to represent the earliest occurrence of pyroclastics in that area. If this is true, the pyroclastics appear at the same stratigraphic position in the area between Mt. Fridtjof Nansen and the Gondwana Escarpment, and represent the best time horizon in the area.

The earliest example of albite in abundance marks the initiation of volcanic activity on a significantly larger scale than before. These pyroclastics obliterated the contributions from other sources, and microcline, garnet, tourmaline, and
zircon are no longer present in the rocks. A second important event is indicated by the appearance of volcanic rock fragments in abundance coinciding with a sharp decrease in the quartz content. This is taken to indicate that the old source area had been covered by volcanic deposits, and that the rock fragments may represent flow material from farther up the paleo-slope. Some of the rock fragments may have been transported by streams to the site of deposition. A flow origin of some of the rock fragments is suggested by the abundance of nearly parallel aligned plagioclase microlites enclosed in a devitrified glass; the stream transport is suggested by the roundness of the fragments. After this time, the contribution of non-volcanic materials is negligible, being restricted to large quartz pebbles which are present in some of the conglomerates in the coal measures and in the sandstone at D'Angelo Bluff.
METAMORPHISM OF THE BEACON ROCKS

The Beacon rocks in the area of the Scott Glacier have been metamorphosed to varying degrees by the diabase sills. The effect of the diabase on the sediments is locally conspicuous where the sills intruded shales, which were changed to black vertically jointed hornfels. The thickness of the hornfels is proportional to that of the sill; hornfels several meters thick are present adjacent to the 300-meter plus sill at Mt. Howe. The effect of the sills upon sandstones and limestones is less apparent, and can be detected only by petrographic investigations. Sample 61 from the middle of member of the Weaver Formation has been metamorphosed to calcite and grossularite, and belongs to the hornblende hornfels facies of contact metamorphism (Winkler, 1966).

Although hornfels are present near the sills, the Beacon rocks that are more than a few meters from the sills exhibit no megascopic evidence of metamorphism. Moreover, the mineral assemblage of the Scott Glacier and Weaver Formations, consisting primarily of quartz, potassium feldspar, and plagioclase, is stable over such wide pressure and temperature ranges that the minerals would not be altered appreciably by intrusion of the diabase sills. However, the mineral assemblage of the Queen Maud Formation, being composed of metastable
volcanic ash, glass shards, and rock fragments, is sensitive to slight changes of pressure and temperature, and records the metamorphic history of the area. The following criteria suggest that the Queen Maud Formation has been metamorphosed: (1) albitization of the plagioclase, (2) chloritization of biotite, (3) zeolitization (primarily laumontite and heulandite), chloritization, and sericitization of plagioclase, matrix, and rock fragments.

The mineral composition of these rocks is very similar to that described by Coombs (1954) for the Mesozoic geosynclinal greywackes and volcanic sandstones from Otago Province in South Island, New Zealand. The greywackes are exposed in a thick steeply dipping sequence that strikes parallel to the length of South Island, except in Otago Province where they strike east and terminate against the Pacific Ocean. The stratigraphic section in this area is considered by Coombs to be more than 30,000 feet (10,000 meters) thick. The upper part of the section consists of unmetamorphosed sediments that can be traced downward through various stages of alteration into strata of the greenschist facies. Between the unmetamorphosed sediments and strata of the greenschist facies, Coombs recognized partially altered strata (Combs and others) to which were later assigned a new facies of metamorphism, the zeolite facies. The characteristic features of the zeolite facies are: (1)
Albitization of plagioclase, (2) presence of laumontite and extensive zeolitization, (3) disappearance of heulandite and the appearance of prehnite and pumpellyite toward the upper limit of the zeolite facies. When heulandite disappears in the upper limit of the facies, laumontite is the sole zeolite present. With the disappearance of laumontite, Coombs and others consider the rocks to be in the greenschist facies. Thus, laumontite is a characteristic mineral of the zeolite facies. The presence of laumontite, prehnite, and albitization of plagioclase in the Beacon rocks indicate that they have been metamorphosed to the zeolite facies.

Although the diabase sills are probably the agents responsible for the metamorphism of the Beacon rocks, the role of overburden pressure must be considered. In order to evaluate the importance of overburden pressure in the metamorphism of these strata, the following facts should be considered:

(1) Diabase sills commonly compose as much as one half of the exposed sections of the Scott Glacier area, and are more abundant in the Nilsen Plateau and Mt. Nansen.

(2) Only laumontite is present in the lower part of the section at Mt. Weaver, where sills are more abundant than in the upper part of the section; heulandite and laumontite occur together in the Queen Maud Formation, about 400 meters above the base of the section. It is unlikely that pressure gradient alone could produce this change.
(3) Prehnite is present at Mt. F. Nansen where sills are more abundant than in the Scott Glacier area (Barrett, 1966), but the overburden is about the same.

(4) Pumpellyite, a high pressure mineral of the zeolite facies, has not been recognized in the Beacon rocks.

(5) Heulandite and laumontite are present together at Sunny Ridge where the proportion of diabase to sediment is about the same as that of the lower part of the section at Mt. Weaver, where only laumontite is present. The deposits at Sunny Ridge are probably about 700-800 meters higher than the base of the section at Mt. Weaver.

(6) Deposits correlative with the upper part of the section at Mt. Weaver are overlain by about 2000 meters of strata in the Beardmore Glacier area. A similar thickness may have been present in the Scott Glacier area, but there is no direct proof of this.

In conclusion, minerals characteristic of the higher grade of the zeolite facies have been found only toward the base of the Beacon rocks. The total stratigraphic section seems hardly enough to greatly influence the metamorphism of the rocks. The absence of pumpellyite suggests that pressure was not important during metamorphism. The rocks toward the base of the section are thought to have been raised to a higher overall temperature by the greater abundance of diabase sills.
Temperature of metamorphism

Estimates indicate that diabase sills are intruded at a temperature of about 1200°C (Jaegger, 1957), and that the temperature at the diabase-sediment contact is 727°C, plus the temperature of the country rock. Jaegger further calculated temperature distributions of the country rock in respect to distance from a known thickness of diabase. Figure 58 illustrates a theoretical temperature distribution of the Beacon rocks in respect to thickness of diabase sheets. The temperature of the country rock, Tc, was placed at 35°C, that which Winkler (1965) assumes for Tc at two kilometers depth.

These charts illustrate the theoretical temperature distributions and the metamorphic facies which should be formed therein. Winkler (1966) states that at Tc of 35°C, the hornblende hornfels facies forms at between about 535°C and 590°C. Sample 61 was probably heated to about these temperatures. Laumontite is considered by Coombs and others (1959) to appear at about 300°C and disappear at about 400°C, although they found laumontite to be unstable in the presence of silica above about 320°C. Barrett (1966) estimates that the section at Mt. Nensen was heated to less than 450°C.

More detailed work is now under way to more closely relate the mineralogy of the Beacon rocks to theoretical heat distribution patterns of the diabase sills.
Figure 58. Theoretical distribution of temperature in Beacon rocks in respect to a known thickness of diabase (modified after Winkler, 1955)
Diabase Intrusives

Diabase sills and dikes intrude the Beacon rocks in the area of the Scott Glacier, where in most places they compose more than half of the exposed sections, but they are absent in the Wisconsin Range. Because of their greater resistance to erosion, the diabase intrusives are cliff formers, and are easily recognized from a distance; the tops of most of the higher mountains in this area are capped by diabase sills.

Five diabase sills are present in the Beacon rocks at Mt. Weaver (Figure 14). For convenience, the sills in this section are designated by the letters A through E, with sill A lowest. The sills vary in thickness from 3 to more than 50 meters, and are more abundant near the base of the section, the lowest sill being intruded along the basement-sediment contact. Figure 59 illustrates some of the relations of the sills to the bedrock.

Similar diabase sills are present at all exposures of Beacon rocks of this area, but because of the lithologic homogeneity of the sills, variations in thickness, and irregularity of the modes of intrusion, it is not possible to correlate individual diabase sheets between various localities.

The diabase sills have altered the adjacent Beacon rocks to hornfels, and the coals to graphite. In the field, metamorphism by the diabase is most apparent where the shales have been altered.
Figure 59. Relationships of selected diabase sills to the bedrock of the Scott Glacier area (after Dowmani and Minshew, 1965)
to siliceous hornfels with columnar jointing. The hornfels zone is generally only a few meters thick, but at Mt. Howe, where the diabase sill is more than 300 meters thick, the strata have been altered to hornfels through a thickness of 20 meters or more. The effect of the diabase sills on the sandstones is less apparent, and can be detected only by petrographic examination.

The age of the diabase intrusives in this area is not known, although similar rocks in other parts of the Transantarctic Mountains have been dated by the K-Ar method. McDougall (1963) dated samples of diabase from the Beardmore Glacier area, and Wade and others (1965) dated a sample from the Shackleton Glacier area. All samples suggest a mid-Jurassic age for the diabase intrusives; the sills in the area of the Scott Glacier are probably of a similar age.
CENOZOIC VOLCANIC ROCKS

The youngest rocks in the area, excluding the morainal and associated deposits of Pleistocene to late Tertiary age, are volcanics consisting of olivine basalt, breccias, tuffs, and related rock types. These rocks are known from Mt. Early (Figures 3, 60), about five kilometers south of Mt. Weaver, and Paradox Ridge between Mt. Weaver and Mt. Saltonstall.

Mt. Early is an extinct partially eroded volcano that consists of olivine basalt, tuff, and volcanic breccias. The eastern third of the mountain has been removed by erosion, revealing the central core consisting of a dense olivine basalt with well-developed columnar jointing.

The core of the volcano is overlain on the northeastern part of the mountain by a few hundred meters of steeply dipping breccia, lahar flows, and tuffs. A basal breccia overlies vesicular olivine basalt which grades into the denser basalt of the core. This breccia consists of basaltic fragments, varying in size from less than one mm to blocks several meters in diameter, in a fine-grained light-colored matrix. The rock fragments in the breccia consist of basalt, porphyritic basalt, and scoria. The basalt fragments are very vesicular and occur in a variety of shapes: angular blocks, rounded blocks, and elongate "stringers" several meters in length and seldom more.
Figure 60. Mount Early, a Cenozoic volcano composed primarily of olivine basalt. The neck of the volcano is partially exposed in the cirque-like feature above the observer (photo by C. H. Summerson).

Figure 61. Ice-cored moraines along the northern face of Mt. Howe. The degree of weathering decreases, and the size of particles in the moraine increases, from left to right.
than one meter thick. Some of the rounded blocks are very fine grained and possess concentric cooling cracks.

The breccia grades upward into a fine-grained yellowish-brown tuff, which dips as much as 60 degrees near the summit of the mountain, but flattens out rapidly toward the base. Near the top of the mountain thin beds of fine-grained vesicular basalt and scoria with pahoehoe structures are interbedded with the tuff.

The interbedded basalt is noticeably lighter in color than that which makes up the bulk of the core.

Explosion ejecta, including bombs several centimeters in length, are abundant in the debris at the foot of the mountain.

The volcanic rocks at Paradox Ridge occur as horizontal flows with no visible vent. The rocks are well-exposed in a nearly vertical, northeasterly facing cliff near the confluence of the Scott and Poulter Glaciers. The section is composed of at least nine flows with a combined thickness in excess of 120 meters.

The lowest volcanic unit exposed at Paradox Ridge is a steeply dipping agglomerate which rests directly on granitic basement, fragments of which are incorporated in the agglomerate. The agglomerate is overlain by an olivine basalt at least 30 meters thick and capped by about three meters of scoria. The remainder of the section is composed of about 65 meters of horizontally layered olivine basalt flows, each about 10 meters
thick. The base of each flow consists of dark grayish black dense olivine basalt; the tops of the flows are scoracious, with abundant ellipsoidal vesicles. Magascopic concentrations of olivine are present near the base of some flows but absent near the top.

Treves (1966) described the petrography of the rocks from Mt. Early and Paradox Ridge. He notes that the "...basalts are diabasic in texture and range from medium to fine grained." Olivine, plagioclase, and hypersthene are present as phenocrysts. Labradorite and pyroxenes are the principal constituents of the ground mass. Palagomite is present as a replacement of glass shards of linings of vesicles.

A chemical analysis and a mode of a basalt from Mt. Early is given below (Treves, 1966)

Table 20
CHEMICAL ANALYSIS AND MODE OF A BASALT FROM MT. EARLY

| SiO₂  | 49.40 |
| Al₂O₃ | 18.34 |
| Fe₂O₃ | 0.72  |
| FeO   | 7.87  |
| MgO   | 5.50  |
| CaO   | 9.28  |
| Na₂O  | 3.59  |
| K₂O   | 1.72  |
| MnO   | 0.15  |
| TiO₂  | 2.26  |
| H₂O   | 0.50  |
| H₂O   | 0.02  |
| P₂O₅  | 0.54  |

Mode
Plagioclase 35.4
Augite 17.4
Pigeonite 6.5
Olivine 1.2
Glass 37.2
Opaques Tr
Apatite  Tr
Volcanic rocks of Cenozoic age are widespread elsewhere in the Transantarctic Mountains. Gair (1965) described several volcanic cones in northern Victoria Land. They consist primarily of olivine basalt, and their distribution is related to structural trends of the area. Similar volcanics in southern Victoria Land are related to the structural features of the Transantarctic Mountains (C. B. Bull, oral communication).

The Cenozoic volcanics and the uplift of the Transantarctic Mountains are thought to be genetically related because of the structural associations of the volcanoes. However, little is known of either the age of the volcanics or the time of uplift of the Transantarctic Mountains. More precise dating of both is necessary before the two can be more closely associated.
CENOZOIC GLACIAL DEPOSITS

Cenozoic glacial deposits, consisting of stranded and ice-cored moraines, are extensive in the area of the Scott Glacier, overlying all the older bedrock of the area. Most of the mountains are covered by thin, discontinuous morainal deposits, and along the base of many are ice-cored moraines along the base. Morainal deposits are most extensively developed in the foothills near the Ross Ice Shelf, but because of logistic difficulties observations were restricted to the mountains and escarpments near the head of the Scott Glacier.

Ice-cored moraines

Ice-cored moraines are present along the northern (lee) faces of most of the mountains. Most of them are at about the same level as the present glacier, but some are stranded up to 60 meters higher. They are extensively developed at Mts. Weaver, Innes-Taylor, Howe, and the LaGorce Mountains.

Ice-cored moraines along the base of the central and northern faces of Mt. Weaver consist primarily of boulders of diabase, sandstone, and olivine basalt. All material composing the moraines is very coarse; little is finer than pebbles. The boulders are fresh, with weathering rims only a few millimeters thick.

Large moraine fields are present along the northern face of Mt. Innes-Taylor, adjacent to Poulter Glacier. Ice-cored moraines
are up to 60 meters above the level of Poulter Glacier, and consist predominantly of diabase boulders. Large perched boulders, many up to six meters in length, are along the face of the mountain up to 150 meters above Poulter Glacier. Most of them are composed of a greenish tillite of unknown source, and are oriented parallel to the length of Poulter Glacier.

Widespread ice-cored moraines are present north of Mt. Paine in the Lagoce Mountains, where morainal deposits are several meters thick and extend for several kilometers north from Mt. Paine toward the Scott Glacier.

The most extensive ice-cored moraines in the area are along the north face of Mt. Howe on the Polar Plateau (Figure 61). Mt. Howe is an elongate east-west trending crescent-shaped mountain, concave to the north. The ice of the Polar Plateau - at an elevation of about 2600 meters - flows northward around Mt. Howe, which rises about 500 meters above the level of the plateau. The ice-cored moraines extend for about 10 kilometers parallel to the northern face of the mountain, and the moraine field has a maximum width of about four kilometers. The ice upon which the moraines rest consists of a series of parallel ridges, with a maximum relief of five meters, and parallel to the length of the mountain. The relief of the ridges becomes less to the north away from the mountain, and ridges are absent in the northern part of the
moraine field.

The moraines consist almost entirely of diabased boulders (the local bedrock itself is composed almost entirely of diabase with a few bands of hornfels) with small quantities of hornfels and a few boulders of olivine basalt, the source of which is unknown. The diabase boulders in the moraines near the mountain are fresh and unaltered, but are progressively more deeply weathered northward across the moraine, and at the outer extremity of the field consist of highly decomposed diabasic debris. Correspondingly, the boulders near the face of the mountain are up to several meters in diameter, but the size decreases progressively northward toward the northern edge of the moraine field, where there is little material coarser than sand. In addition, patterned ground is extensively developed on the outer edges of the moraine, but absent toward the mountain.

Origin of ice-cored moraines:

Two theories have been advanced to explain the origin of moraines of the type at Mt. Howe:

Von Klebelsberg (1943) described similar moraines from Neues Schwabaland as a "morainebreiboden", for areas of low relief almost completely covered by a number of parallel morainic ridges. Von Klebelsberg considered the parallel ridges to represent successive stages in the retreat of the ice sheet, and thought they were formed by water-soaked morainal material being pressed up along the edge of the ice sheet. However,
a necessary condition for this theory is the presence of large amounts of water, which is doubtful at Mt. Howe, considering the latitude (87° 15' S) and elevation of the area (2600 meters).

Schytt (1961), after reviewing Von Klebelsberg's work and making additional field observations, proposed an alternate theory for the formation of such moraines. He believes they formed as shear features, produced by differential movement of the ice. Stagnant ice near the mountains moves more slowly than that not near bedrock, and this differential movement results in shear planes which progress outward from the rock as shrinkage of the ice mass occurs.

Stranded moraines

The oldest Cenozoic glacial deposits in the area are stranded moraines, which rest directly on bedrock, and are generally a few hundred meters above the level of the present glaciers. Two sets of stranded moraines are differentiated on the degree of lithification and elevation above the present glaciers in the area of the Scott Glacier. The more lithified, higher stranded moraine is considered to be the older. It consists of about 15 meters of tillite which caps a section of Beacon rocks on the Watson Escarpment north of Mt. Blackburn (Figures 2, 3). The tillite is composed of striated, faceted, and soled clasts of diabase, phyllite, granite, and sandstone in a light gray, well-
indurated sandy matrix. It forms the highest part of the escarpment in this area, at an elevation in excess of 3000 meters, about 1000 meters above the Scott Glacier and a few hundred meters above the level of the plateau ice.

The younger stranded morainal deposits consist of about two meters of unconsolidated till present along the crest of Fault Block Ledge at Mt. Weaver at an elevation of about 2800 meters, about 500 meters above the Scott Glacier and 300 meters above the level of the plateau ice. The moraine consists primarily of diabase and sandstone boulders in a heterogeneous, unconsolidated matrix; a few boulders of olivine basalt are present, probably derived from nearby Mt. Early. The diabase boulders are deeply weathered, some with weathering rims several cm thick. The upper surface of the moraine is covered with patterned ground.

Age

Little can be determined about the age of the Cenozoic glacial deposits in the Scott Glacier area because of the absence of fossils and of datable organic remains. However, it is possible to establish a general chronology of the glacial deposits on the basis of weathering of diabase in the moraines, degree of lithification of matrix, and height above present ice level. On this basis, the ice-cored moraines, excluding those at Mt. Howe, are the youngest, the moraines at Fault Block Ledge are intermediate, and the lithified till at the Watson
Escarpment are the oldest deposits in the area.

Mercer (in press) suggests that lithified till which caps the Gondwana Escarpment in the Wisconsin Range, and which is similar to the lithified till (of tillite) capping the Watson Escarpment near Mt. Blackburn, must have formed prior to final uplift of the Transantarctic Mountains, possibly during the Pliocene. Previous to Mercer's work, the highest stranded deposits of till were thought to have formed after the final uplift of the mountains when ice of the Polar Plateau was thicker than at present.

The age of the moraines at Mt. Howe is difficult to fit into the above interpretation. Under climatic conditions such as prevail at Mt. Howe, a long period of time must be required for a diabase boulder several meters in diameter to decompose into sand and silt size particles. The deeply weathered fine-grained deposits on the northern extremity of the Mt. Howe moraine field must be considerably older than the moraines consisting of fresh diabase boulders along the face of the mountain. A time span of several tens of thousands, and perhaps a few hundred thousand, years is probably necessary for diabase boulders several meters in diameter to disintegrate. Therefore, it is conceivable that much of the Pleistocene may be represented by the Mt. Howe moraines.
GEOLoGIC HISTORY OF THE POST-BASEMENT ROCKS

Following the Cambro-Ordovician Ross Orogeny, the central Transantarctic Mountains were uplifted and eroded. By Early Devonian, erosion had reduced the area to a near peneplain, and marine sediments were deposited. The extent of the Devonian sedimentation is unknown; these deposits today are restricted in the central Transantarctic Mountains to the Ohio Range and the Beardmore Glacier area. The Devonian strata and the underlying basement rocks were eroded during the Silurian-Carboniferous interval, and during the late Carboniferous to early Permian the area became covered by a continental ice sheet. Stratiform deposits of till and interbedded water laid deposits which were formed in the Ohio Range grade into thin lenticular deposits of till in the area of the Scott Glacier; the Scott Glacier area is thought to have been nearer the center of glaciation than was the Ohio Range. Toward the end of the glaciation, ice shelf conditions are thought to have existed over large parts of the central Transantarctic Mountains, and shale with ice-rafted pebbles formed beneath and adjacent to the ice shelf. Following the disappearance of the shelf ice, the Weaver Formation was deposited in a nearshore, barrier island, and deltaic environment. Through time the strand line along which the upper member of the formation accumulated advanced.

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across the basin down the regional paleoslope. Following the advance of the shoreline across the basin, blanket conglomeratic sandstones were deposited across an alluvial plain. The deposition of the conglomeratic sandstones across the basin coincided with the first appearance of pyroclastic detritus. Evidently the shoreline had not reached the Ohio Range by the time of the initiation of volcanic activity, because sandstone correlative with the upper member of the Weaver Formation at Mt. Weaver contain pyroclastic detritus in the Ohio Range.

Volcanic activity increased, and shortly after the beginning of deposition of the Queen Maud Formation at Mt. Weaver (during the upper Permian), the contribution of volcanic debris became so great as to smother contributions of sediments from all other sources.

Little is known of the Triassic history of this area. Elsewhere in the Transantarctic Mountains, the Permian coal measures are disconformably overlain by Triassic volcanic and sedimentary rocks (P. J. Barrett, oral communication). During the Jurassic, the Beacon rocks of the Scott Glacier area were intruded by thick diabase sills which metamorphosed the rocks to the zeolite and higher facies and resulted in the metasomatism of some of the rocks.

During the Cenozoic, the Transantarctic Mountains were uplifted, and volcanoes consisting of olivine basalt formed along
some of the larger fault zones. The area was glaciated during the late Cenozoic, and attained its present typography.
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LEGEND

CENOZOIC

PERMIAN

UNDIFFERENTIATED

CAMBRIAN

PRECAMBRIAN

ICE

CENOZOIC BASALTS

BEACON ROCKS

GRANITIC ROCKS

LEVERETT FORMATION

WYATT FORMATION

LAGORCE FORMATION

METASEDIMENTS

UNKNOWN AGE

METAVOLCANICS

UNKNOWN AGE

AMPHIBOLITES

UNKNOWN AGE

UNDIFFERENTIATED BASEMENT

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FIGURE

GEOLOGIC MAP OF THE CEN
MOUNTAINS, ANTARCTICA.
TYPE SECTION, QUEEN MAUD FM.
CENTRAL FACE, MT. WEAVER

Figure 48
Figure 52. Distribution of selected compounds of Beacon rocks in respect to diabase sills of the Scott Glacier area.