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ANTARCTICA.

The Ohio State University, Ph.D., 1964
Geology

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THE STRATIGRAPHY OF THE OHIO RANGE, 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

William Ellis Long, B.S., M.S.

* * * * *

The Ohio State University
1964

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Frontispiece. The Ohio Range, Antarctica as seen from the summit of Mt. Glossopeteris. The cliffs of the northern escarpment include Schulthess Buttress and Darling Ridge. The flat area above the cliffs is the Buckeye Table.

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With R. Gray, N. Schapiro, and J. M. Schopf, American
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INTRODUCTION

Purpose and Scope

Investigation of the Ohio Range, in Antarctica, was conducted to reveal the nature of the rocks exposed and to interpret the geologic history of this portion of the Antarctic Continent. The Ohio Range was first visited in 1958, at which time an ascent of Mt. Glossopteris was made. The section showed a sequence of nearly 4000 feet of sedimentary rocks of Devonian through possible Triassic age. The results of this initial contact with the geology of the Ohio Range and Mt. Glossopteris indicated that study of the Paleozoic stratigraphy of these mountains could fill important gaps in the stratigraphic knowledge of the continent. Two stratigraphic units not previously known in Antarctica were discovered: the marine and paludal Devonian rocks with numerous fossils, and the Permian or Pennsylvanian tillite. The purpose of the geologic investigation of the Ohio Range, Antarctica, is to provide a geologic map, stratigraphic data, and to suggest interpretations from rocks exposed in the Ohio Range.

The Ohio Range forms the middle part of what is called the Horlick Mountains on older maps. Prior to the official designation of the Ohio Range by the U. S. Board on Geographic Names, these mountains were unofficially called the central range of the Horlick Mountains, the Central Horlick Mountains or the Buckeye Range. Not until 1958 was it known that the poorly defined area on the map called the Horlick Mountains was actually included three separate ranges. The official names of these ranges from east to west, as determined by the U. S. Board on Geographical Names are The Thiel Mountains, the Ohio Range, and the Wisconsin Range. They form a segment of the Transantarctic Mountains, a mountainous belt, which extends from Cape Adare in Victoria Land to the mountainous area of Queen Maud Land a distance of about 2100 miles. Much of the Transantarctic mountain belt is buried under the ice cap and its presence is indicated by crevass systems in the ice.

The Ohio Range is about 5 miles wide and 25 miles long and is surrounded by the Antarctic inland ice. In general, the mountains are composed of horizontally layered rocks which form extensive flat-topped mountains with sharp escarpments. The highest mountain, Mt. Schopf, is about 9700 feet in elevation and is about 4000 feet higher than the inland ice of Marie Byrd Land to the north and west.

History of Ohio Range Investigations

The Horlick Mountains were discovered during the Byrd Antarctic Expedition in 1934 when the range was observed by Kennett L. Rawson from a position of about 83°00' S. and 105°19' W., the end point of a flight from Little America to the southeast on 22 November 1934. During December of the same year Quin A. Blackburn noted mountains when looking up two eastern tributaries of the Robert Scott Glacier.

It is unlikely that Blackburn saw any portion of what today is considered the Horlick Mountains, that is, the Ohio Range or the Wisconsin Range. It is possible that Rawson could have seen the Ohio Range in the distance to the south-southeast from an airplane at the position he gives.

During Operation Highjump 1946-47 a plane flew up the glacier which is located on the western side of the Wisconsin Range.

These ranges were not approached again until 1958 when preparations were being made for the Marie Byrd Land oversnow traverse. In October 1958 a reconnaissance flight was made from Byrd Station to the Wisconsin Range, then to the Ohio Range, the Thiel Mountains and the Whitmore Mountains and return to Byrd Station. The writer was aboard the reconnaissance plane and noted that the Ohio

Range was composed of large thicknesses of stratified rocks. Plans were made for a very quick collecting trip to the Ohio Range during the course of the oversnow traverse.

On 1 November 1958 the Marie Byrd Land oversnow traverse left Byrd Station and traveled in a southwesterly direction toward the Wisconsin Range. Within thirty miles of the Wisconsin Range an extensive crevasse field halted all vehicles but finally the writer and Fred Darling, after walking twenty miles, reached the northeastern end of the Wisconsin Range where a few samples were taken from the base of the granitic cliffs.

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. Due to insufficient time the sedimentary rocks were not examined.

During December 1958 the traverse vehicles progressed to a location about 2 miles from the base of Discovery Ridge in the Ohio Range. Here, at Mile 414, a camp and seismic and glaciological station was made. During the five days which were spent at the Ohio Range an ascent was made of Mt. Glossopteris, brief notes were made on the geology and a small collection of rocks and fossils was made (Long, 1959). Glossopteris found in the shales of Mt. Glossopteris has been discussed by Schopf (1962). Also, brachiopods and a few other fossil invertebrates

found in the lowermost sedimentary unit have been described by Boucot et al. (1963). Samples taken in 1958 belong to the H collection.

The brief investigation made in 1958 was sufficient to indicate that the Ohio Range contained valuable stratigraphic data. Therefore an entirely geological expedition from The Ohio State University was fielded during the 1960-61 summer season. The field party was composed of G. A. Doumani, L. L. Lackey, J. H. Mercer, and the writer.

Camp Ohio, a 16x16 foot Jamesway hut (Fig. 1) was erected on the Buckeye Table at an elevation of about 7000 feet. During the 1960-61 season work was concentrated on the eastern end of the range. A few sections were measured on a plane table map of Terrace Ridge was prepared. Stratigraphic observations made during the 1960-61 season disclosed that the strata could be divided, in ascending order, into four formations: the Horlick Formation, the Buckeye Tillite, the Discovery Ridge Formation, and the Mt. Glossopteris Formation (Long, 1962). Mercer studied the geomorphology in the Ohio Range (Mercer, 1963).

Samples taken in the 1960-61 season belong to the H2 collection. The Glossopteris of the H2 collection has been discussed by Cridland (1963).

Fig. 1. Camp Ohio, Antarctica is located on the Buckeye Table at an elevation of 7000 feet. Mt. Glossop can be seen in the left distance and Mt. Schopf in the right hand distance. The terraces of Terrace Ridge are visible just above the Jamesway hut.

Camp Ohio was reoccupied during the 1961-62 Antarctic summer season when the regular party included G. A. Doumani, M. D. Higgins, J. R. Ricker, C. C. Skinner, and the writer. J. M. Schopf, S. B. Treves and R. Oliver spent about a month in the Range. Sections in all portions of the Ohio Range were measured during this season and the "Dirty Diamond Coal Mine" was dug. Numerous fossils were collected from the Mt. Glossopteris Formation and the Horlick Formation. Samples taken during the 1961-62 season constitute the H3 collection.

No parties other than those from Ohio State University have conducted studies of the Ohio Range. The area remained unvisited until 1958 because of its remote location at latitude $84^{\circ}45'$ S. and longitudes 111° to 117° W.

PHYSIOGRAPHY AND GEOMORPHOLOGY

The Ohio Range is formed of tabular-shaped mountain blocks composed of horizontally layered rocks over a nearly homogeneous, granitic basement rock. The mountains are not highly dissected but appear as flat-topped masses with precipitous sides, particularly on the north. The major escarpment of the Ohio Range faces north and has cliffs of 2000 feet, as shown in Figure 2 and the Frontispiece. Canyons dissect the escarpment and two peninsular-shaped blocks (Darling Ridge and Treves Butte) extend northward from the cliffs of the escarpment. The surface at the top of the escarpment (7000-7500 feet) is called the Buckeye Table. Mt. Schopf rises 2000 feet above the Buckeye Table. These features are shown in Figure 3.

The inland ice of the south polar plateau borders the Ohio Range on the south at an elevation of about 6500-7000 feet. To the north the inland ice of Marie Byrd Land reaches elevations of about 5000 feet. The Ohio Range separates these two physiographic units and acts as a dam for the polar ice which flows northward. The disturbance in the flow of the ice caused by mountains is indicated by ice falls and crevasses which are evident

Fig. 2. The northern escarpment of the Ohio Range as seen from near the top of section 7 displays the entire sedimentary section. Discovery Ridge and Mt. Glossopteris are visible in the background and Schultheas Butte is in the foreground. G = basement granite, Dh = Horlick Formation, Pb = Buckeye Tillite, Pdr = Discovery Ridge Formation, Pmg = Mt. Glossopteris Formation. Measured sections 1, 2, 18, 20 and 22 are indicated.

Fig. 3. Aerial view of the Ohio Range, Antarctica shows the prominent physiographic features of the range. The photograph looks to the northwest so that the northern escarpment is hidden by the Buckeye Table. Camp Ohio is located off the left-hand side of the photograph.

to the east and west of the range. The flow of ice from the polar plateau is toward the north, past the Ohio Range, but on meeting the ice mass of Marie Byrd Land the flow swings to the west, and finally, leaves the continent at the southeast corner of the Ross Ice Shelf, where it becomes a part of this great floating ice mass.

Climate

The climate of the Ohio Range is polar. Except for about 28 days in the spring and fall the sun is either above or below the horizon. The mean annual temperature is $-26.1^{\circ}\text{C}.$, as determined measuring the temperature of the firn 10 meters below the surface of the inland ice to the north of the Ohio Range at an elevation of 5470 feet. (Long, 1961, pp. 1-112). Temperatures at Camp Ohio, elevation 7000 feet, on the Buckeye Table roughly average $-15^{\circ}\text{C}.$ during the summer months as judged from daily temperature measurements. Although air temperature remained below freezing, some melting occurred where snow was near rocks warmed by the sun. Icicles and small cup-like pools of ice up to a few inches in diameter are a result of frozen melt water. The water provides necessary moisture for hydration and oxidation of the minerals making up the rock.

Precipitation occurs only as snow and in limited amounts and can be estimated from data from accumulation poles.

On 18 January 1961 twenty accumulation poles were placed in an L-shaped pattern to the southeast of Camp Ohio as shown on the map of the area (Fig. 4). The poles were placed approximately 300 feet apart and all were at lower elevations than Camp Ohio. The poles were so placed that the top of the pole was 150 cm. above the snow surface.

On 17 January 1962 the accumulation poles were measured in order to determine the accumulation during the intervening year. The data in Table 1 were recorded.

Table 1. Accumulation Poles
and Accumulation

Pole No.	Elevation (feet)	Accumulation (Centimeters)
1	6962	+15.8
2	6953	-20.0
3	6942	+ 4.5
4	6932	+ 3.0
5	6924	+ 8.5
6	6915	+ 1.0
7	6906	+ 7.8
8	6998	- 2.1
9	6990	- 5.0
10	6884	- 3.8
11	6890	-10.4
12	6896	- 6.5
13	6900	- 7.5
14	6904	+ 1.7
15	6908	+ 2.2
16	6911	-10.4
17	6915	+14.7
18	6918	+ 4.6
19	6922	+ 5.0
20	6923	+10.7
Average accumulation - + 0.16 cm. snow		

The above figures indicate that accumulation at the Camp Ohio location is nearly zero. The snow and ice surface becomes harder and bluer as one approaches Mt. Schopf from Camp Ohio, and the ice at the base of the mountain is exposed and blue. Blue ice conditions indicate that the snow accumulation is negative and that the existing firn is wasting away.

To the south-southwest of Camp Ohio (away from Mt. Schopf) the surface becomes softer and newer snow is generally present. Such a surface would result from a net accumulation. The accumulation apparently is related to the obstruction by the mountain allowing ablation to occur in the "wind-shadow" from 0 to 1 mile to the lee of the mountain. Katiabatic warming may also be a factor causing negative accumulation in this area. From 1-4 miles away from the mountain accumulation is about equal to ablation and beyond 4 miles from the mountain accumulation is greater than ablation.

While wind direction and the position of Mt. Schopf are the primary factors involved in this local accumulation variation, small-scale topographic irregularities may also be a factor. The snow surface slopes away from Mt. Schopf and at about six miles distance it is estimated that the surface is from 800 to 1000 feet lower than at the base of the mountain and in the form of a shallow depression.

Accumulation seems greatest in these shallow depressions, which must be present because of underlying topography or peculiarities of flow.

The snow surfaces in areas of greater accumulation are smoother and softer than in areas where there is little or no accumulation. These soft, smooth snow surfaces are ideal landing areas for ski-equipped planes.

Accumulation appeared to be greater in the summer period (November through March) than during the winter months. Boot and vehicle tracks that were made in February 1961 were still present when we returned in November 1961. Yet during each of the two summer seasons, snowfalls occurred which deposited layers sufficiently deep to cover most of the sastrugi. The wind would blow the new snow so that the cache and hut were more nearly buried during the summer than they had been through the entire winter.

From the wind-blown and non-buried appearance of Camp Ohio when it was reopened for the 1961-62 season it can be assumed that heavy winds and light precipitation are typical of the winter period in the Ohio Range.

Winds

Snow was formed into drifts in two directions because the wind blew predominately from the east and from the north. Sastrugi shapes on the snow surface reflect a two-fold prevailing wind direction. These directions differ from what might be expected for drainage winds from the south polar plateau. Snow surface elevations by Bentley and Ostenso (1961, p. 892) show a ridge-like rise to the east of the Ohio Range. Such a feature would cause drainage winds to flow from an easterly direction and account for the winds in the Ohio Range. Winds from the north are

more difficult to explain unless they are a result of local deflection caused by the mountains and perhaps the areas relation to the general weather pattern of the continent.

Wind plays an important role in ablation or accumulation of the snow covered areas. Velocities measured by hand anemometers during heavy blows reached 65 knots. Velocities in excess of 20 knots blew during about 50 per cent of the summer seasons and an estimated mean velocity for the summer months is 20 knots. No measurements have been made during the winter season but probably the winds are more severe. Heavy winds are at least partially responsible for exposing bedrock on ridges of the range. Nearly all of the sand-size and smaller material has been removed from rock outcrop areas. Ripples of gravel-sized material have formed on the more level ridge locations and are evidence of strong winds. Similar features are described by Calkin (1963) from "dry valleys" in Victoria Land.

Weathering

While mechanical activity dominates the weathering processes, chemical activity is indicated by the pits formed in diabase and calcareous siltstone boulders and spheroidal weathering of coarser grained diabase (Fig. 5). Wind erosion tends to polish and modify the surface of

Fig. 5. Exfoliated boulder of diabase on Mercer Ridge indicates that chemical weathering occurs in the Ohio Range.

chemically weathered diabase and the results of this combined action are peculiarly pitted and polished boulders, with reddish brown surfaces, which look like meteorites. Such boulders are found in abundance on the sandstone terraces of Terrace Ridge on Mt. Schopf, as well as on other similar locations in the Ohio Range. Wind-cut channels about $\frac{1}{2}$ inch deep were noted in exposed sandstone ridges (Fig. 6).

No soils were recognized in the snow-free areas of the Ohio Range; since chemical weathering is very slow due to low temperature and scarcity of water. Also the nearly constant and heavy winds remove all grains loosened by weathering process and thus prevents accumulation of finer particles which are necessary for soil.

Pattern ground is present in areas where a rather extensive cover of loose ground cover exists, such as at the base of section 1 (pocket). The patterns developed are nonsorted circles on the nearly level locations and nonsorted stripes on the steeper slopes (terminology of Washburn, 1956).

Escarpment and Surface Evolution

The Ohio Range reaches 9700 feet above sea level. The mass of this mountain unit forms a portion of the major physiographic unit of Antarctica referred to as the

Fig. 6. Wind-eroded channels in feldspathic sandstone of the Mt. Glossopferis formation on the crest of the escarpment at section 4 are evidence of mechanical erosive processes. Pitted patterns of weathering

Transantarctic Mountains. The mountainous belt extends in an arcuate form from the mountains of Victoria Land through the Queen Maud Range, Horlick, Thiel, Pensacola, and the Shackleton Mountains; a distance of about 2100 miles. The Ohio Range makes up about 25 miles of this mountainous structure, projecting above the thick inland ice.

The whole chain of mountains acts as a barrier for the ice which flows northward from the polar ice cap. The polar plateau ice flows around the ends of the Ohio Range, where it descends rather rapidly over step-like features from 7000 to 5000 feet. Crevasses and surface slopes suggest that the bedrock under the ice is not level. These bedrock irregularities, hidden by the present ice, must represent buried mountains which are closely related to the Ohio Range.

The mountains of Victoria Land and the Queen Maud Range have been explained as fault-block mountains by other investigators (David and Priestly, 1914; Gould, 1935).¹ This general concept of the structures of rocks forming the Ohio Range seems correct. Faults are present and offsets of units can be seen. The relationship of the faults to the present landscape, however, is not direct and simple. While uplift and faulting have occurred, the faulting is only partially responsible for the topography of the range. The observed relationships require post-faulting erosion, which has produced obsequent fault line scarps.

¹Gould (1935) shows a photograph (Plate 82) of a portion of the Queen Maud Range in which he has labeled a "fault line scarp" and the "actual position of fault plane". Johnson (1939, p. 174) makes a point that such a feature is an eroded fault scarp, not a fault line scarp. A fault line scarp is one formed at the fault line due to unequal erosion of the rocks on either side of the fault.

Also another photograph (Plate 82) is labeled "Queen Maud Range From the Polar Plateau." This photograph shows much more relief than has been shown by recent aerial photographs. Herbert (1962) of the New Zealand Geological Survey recently ascended Mt. Fridtjof Nansen, the highest mountain in the Queen Maud Range, from the southern side and found no cliffs of large magnitude barring their ascent. The map and the photograph on p. 684 show a fairly gentle snow-covered slope leading to the summit of the range. The scene shown on Plate 82 must be a portion of the northern escarpment of the Transantarctic Mountains and could be the Queen Maud Range or perhaps the Wisconsin Range. A close examination of serial photographs which are now available for the Queen Maud Range possibly would reveal the true location of the photograph.

Fault Blocks

In overall appearance the Ohio Range seems to be a single large block, probably bounded on all sides by faults. The only faulting in evidence is normal faulting which offsets blocks of sedimentary rocks and basement rock. The fault system is discussed more thoroughly in the structural geology section, but in general the faults appear roughly parallel to linear trends of cliffs of the range. Within the main block (which is the Ohio Range) there are faults which displace beds only a few feet to several hundred feet. These occur in zones up to $\frac{1}{4}$ mile wide and bedding within the zones is tilted.

The boundary faults of the range are not exposed and may be present somewhere under the ice. These large faults are assumed to be present because of visible escarpment and because of the cliffs which occur under the ice as indicated by the seismic results of the 1958-59 Marie Byrd Land traverse (Bentley and Ostenso, 1961). A cross-section (Fig. 7) shows the general shape of the bedrock along the N-S line going through Mt. Glossopteris.

The present form of the exposed escarpment is a retreating fault scarp which is produced by differential erosion.

Fig. 7.

The largest offset observed in the Ohio Range exists between Treves Butte (a nunatak) and Discovery Ridge on the main escarpment as shown in Figure 3. The nonconformity, which provides a good reference horizon, is 650 feet above the same surface on Discovery Ridge.

Another faulted zone which is located between Discovery Ridge and Mt. Glossopteris is composed of several small faults which are normal faults with the upthrown side on the north. Thus while the displacement of these smaller faults is less than the displacement of Treves Butte, the relative movement is the same; that is, the northern side upthrown (Fig. 7). In other words, the surface which is presently low is the upthrown side of the fault structure. Post-faulting erosion has modified the basic structure to form an obsequent fault-line scarp.

Obsequent fault-line scarps are discussed by Johnson (1929) and under his classification the Ohio Range could be called an obsequent rift block mountain. Figure 8 shows the steps which are required to achieve topography in which the down-dropped block is higher than the uplifted block.

Erosion of the Escarpment

Today's erosional processes are reducing the amount of level surface of the mountain block. No valleys are

GRABEN FORMATION

EROSION OF
TOPOGRAPHY RENEWAL OF
EROSION DEVELOPMENT OF
RIFT-BLOCK MOUNTAIN

FIG. 4 AFTER DOUGLAS JOHNSON (1929 P. 365)
OBSEQUENT RIFT-BLOCK MOUNTAIN

STAGES LEADING TO
TOPOGRAPHIC INVERSION OF A GRABEN

THIS GENERALLY FITS
THE OBSERVATIONS IN THE OHIO RANGE

Fig. 8.

cut through the top surfaces of the blocks, either on the Mt. Schopf level or on the Buckeye Table. However, the area of uplifted level surface is being or has been reduced from all directions by headward erosion of cirques and glacier-covered cliffs.

At present, no water is available for any sort of stream erosion; indeed no evidence of stream erosion exists in the range today. Hobbs (1910, p. 155) describes the initial stages of the glacial geomorphic cycle and states that young and mature stages can be discerned for glacial topography. The glaciers responsible for the cycle may originate in stream-cut valleys.

Under this sort of classification the escarpment of the Ohio Range could be described as youthful. Only on the west end of the range has the topography reached the mature stage where Eldridge, Vann, and Knox Peaks are small horns.

Erosional processes which have formed the mountains of the Ohio Range must differ from those in areas of more moderate climates. It seems possible that the continent has been covered with glaciers since Late Tertiary time. If this is true, then for more than a million years no significant streams have eroded the mountains. Without stream erosion, glacial erosion must be considered the evident erosion agent or else the topography has been preserved since early- or mid-Tertiary. There are few

other areas in the world where severe polar climates have existed for such a long time. Most of the mountains of Greenland have some streams in them today, and could well have had in the recent past. If similar streams were present in Antarctica they must have passed out of existence much earlier.

Surfaces

Two erosion surfaces dominate the landscape of the Ohio Range; the Mt. Schopf summit surface and the extensive Buckeye Table. Both are mostly ice-covered (Fig. 3).

The summit of Mt. Schopf is about 6 miles long and up to a mile wide. For its entire length, under the snow and ice, the surface is composed of a diabase sill which is at least 600 feet thick and much more resistant to erosion than any other rock unit in the range. It forms a mesa-like structure with the resistant diabase protecting the underlying softer sandstone, shale, and coal. The resistance of the sill to erosion has resulted in the level surface which can be called a structural plain or stripped plain similar to those in South Africa (King, 1942) and the southwestern United States.

Striations on the diabase surface of Mt. Schopf indicate that the summit ice cap was formerly more extensive or the inland ice buried the whole mountain range, as discussed later.

The lower surface, the Buckeye Table, extends the length of the range, a distance of at least 16 miles. Unlike the resistant and uniform lithology of the diabase on Mt. Schopf, the Buckeye Table levels the Buckeye Tillite, Discovery Ridge Formation, and Mt. Glossopteris Formation. Only Mt. Glossopteris and Mt. Schopf stand above the level of the Buckeye Table. In each case these higher mountains represent areas protected by erosion-resistant diabase which in the case of Mt. Glossopteris has disappeared only recently.

Erosion in Antarctica is relatively slow, although intense. Mercer (1963) estimates that some erratic boulders of diabase which have been removed only a short distance from the outcrop are at least 750,000 years old and thus the ice-free slopes in the Ohio Range are at least 750,000 years old. If the slopes are that old, then the rate of down-slope movement and weathering has been very slow for a long period of time. Such slow weathering rates are indicative of polar climates. Then it seems safe to estimate that the Ohio Range was glacier-covered through at least the greater part of the Pleistocene, and possibly longer, and that some of the general features of the topography were produced during the Tertiary. The glaciers during the Pleistocene have greatly modified the landscape however.

While glacial erosion is responsible for deepening and widening valleys, it is very rare that glacial erosion produced cliffs and canyons. Thus as Mercer (1963) suggests the Ohio Range probably is a buried landscape, the primary sculpturing of the blocks having been done by running water during the Tertiary Period. Glaciers have modified the topography by steepening the cliffs, making U-shaped canyons, and carving cirques in the highlands.

The highland during this first stage of uplift consisted of the Mt. Schopf and Mt. Glossopteris levels and the Buckeye Table may have been near base level of erosion. This level could have been a pediment which truncated lower formations.

After the Buckeye Table surface was formed, a second uplift took place which could have been epeirogenic or in the form of block faulting of extensive areas. Erosion by water action commenced, but before streams had dissected the block, glaciers formed. This latter uplift probably was responsible for the high elevation of the range and could have caused or at least aided the formation of the glaciers of the area. Such areas could have been the nucleus of the continental ice accumulation.

The maximum extent of glaciers in Antarctica is not known. Mercer (1963), Pewe (1960), and Cameron and Goldthwait (1960) discuss former levels of inland ice. The youngest moraines studied by Pewe (p. 21) were dated

by radiocarbon methods as being 6000 years old. At least two older glaciations are indicated by moraines and each of the older glaciations is larger than the next younger. Therefore glacially deposited debris indicates that glaciers have been gradually diminishing in size for longer than 6000 years. Also evidence in the McMurdo area suggest that ice has been at least 1000 feet thicker.

Mercer (1963, p. 4) estimated the age of boulders in the youngest moraines on Mercer Ridge (Fig. 9) found no evidence of ice levels above 30 meters higher than present ice level and suggests that weathered diabase boulders indicate that some slopes have been free of snow at least 720,000 years. He also noted that ice must have been less extensive at one time because weathered rocks are presently covered by glacier ice.

Hollin (1962) suggests a theory which explains why continental ice may fluctuate greatly at the margins of the continent and only slightly in the interior. The controlling factor is whether or not the land ice is grounded on the continental shelf areas. Thus sea level greatly affects the thickness of the marginal area but only slightly alters the ice thickness in the interior.

Cameron and Goldthwait (1960) cite reports by observers in the Executive Committee Range and Sentinel Range who saw fresh glacial striations on rocks which are 1000 feet higher than the present glacier surface.

Fig. 9. Moraines deposited by the glaciers on Mt. Schopf are present on Mercer Ridge. Measured section 6 is shown on skyline under ridge. Arrow shows location of striae on top of Mt. Schopf and "x" marks a cairn location.

In summary, while glaciologists do not know for certain whether the Antarctic Ice Sheet is growing or shrinking, geologic evidence indicates that it has been greater 6000 years ago, and still greater prior to that time.

Other explanations for the topography and its relation to glaciation can be suggested. If the area has been frigid throughout the evolution of the range, then all of the erosion of the mountains would have to have been done by ice. This would involve a "glacial geomorphic cycle" similar to that described by Hobbs (1910). Also if glaciers covered the area during the time before uplift, they must have existed prior to the Pleistocene. Whether or not glacierization of Antarctica commenced in the Tertiary is not known at the present time.

The presence of the obsequent fault-line scarp requires either two periods of erosion or a long period of erosion with variable intensity. The faulting-erosion-uplift-erosion sequence mentioned above seems the simplest explanation.

Based on the bedrock elevations, as determined by seismic means, the "uplift" probably means that a block which is larger than the Ohio Range was uplifted. Thus the Ohio Range should represent a down-dropped smaller block within a larger block which was uplifted. The larger block has now been worn away by combined water and ice erosion, leaving the inner, down-dropped block.

A similar situation exists in the Western Range of the Horlick Mountains, only there the down-dropped block is a very small portion of an immense block of granitic rock. This small down-dropped block provides the largest section of sedimentary (younger) rocks in the Western Horlicks.

STRATIGRAPHY

General Statement

Four thousand feet of horizontally bedded Paleozoic strata nonconformably lie on a granitic basement complex. The sedimentary rocks are divided into four sedimentary formations: the Horlick Formation of marine sandstones and paludal shale, the Buckeye Tillite, the Discovery Ridge Formation composed of gray siltstone, dark shales with lenticular beds of unfossiliferous ironstone and limestone, and the Mt. Glossopteris Formation of arkosic sandstone, shale, and coal. A diabase sill caps the sedimentary strata and forms the highest and youngest of the rock units in the Ohio Range. The general stratigraphic section is presented in Figure 10.

The Basement Complex

The basement complex of the Ohio Range is composed of granitic rocks of two general types, a porphyritic biotite granite with pinkish phenocrysts of potassium feldspar and a medium- to coarse-grained granite. A few darker granitoid bodies are incorporated in the more extensive granites. Also several dark dikes cut the basement rock.

36

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LONG, 1963-IPS

Distribution

Basement rocks crop out for the entire length of the northern escarpment where the granitic rock forms precipitous cliffs under the softer sedimentary rock layers. The granitic outcrops are easily seen in Figures 11 and 12. On the eastern end of the range the top of the granitic basement rock is at the level of the inland ice, but on the western end of the escarpment the cliffs of granite rise about 2000 feet above the ice. Three small peaks (nunataks), Eldridge Peak, Vann Peak, and Knox Peak, are composed only of granitic rocks. These small horns have been sculptured from the main block of the range by glacial erosion and their summits are lower than the projected top surface of the basement complex of the main Ohio Range block. On the northeastern end of the range, Treves Butte (Fig. 11) is composed of basement rock with a relatively thin cover of sedimentary strata.

Lithology

The basement granites are massive bodies which tend to weather to a brownish color where exposed for sufficient time to the climate. According to Treves, the basement complex generally consists of a pink, porphyritic quartz monzonite which is intrusive into a gray granodiorite. It is possible that the quartz monzonite is a later phase of the granodiorite because they appear gradational at some locations. Both rock types display fine and coarse

Fig. 11. An ancient erosion surface at the base of Discovery Ridge (section 22) has been exhumed. A nonconformable relationship exists between the granitic basement (G)* and the Devonian Horlick Formation (Dh) and the Buckeye Tillite (Pb). Treves Butte on the right edge of the photograph is displaced upwards 650 feet by faulting. The northern escarpment and same nonconformity can be seen in the background.

Fig. 12. The nonconformity between the granitic basement rock and the overlying Horlick Formation is nicely exposed at the base of measured section 8. The basal sandstone displays current bedding.

textures. Aplite and pegmatite bodies cut the quartz monzonite and granodiorite. The pink quartz monzonite contains inclusions of metamorphosed sedimentary and igneous rocks which are present now as schist, diorite, and other intermediate rock types. Some of the inclusions have reacted with the enclosing magma while others are blocks with distinct boundaries. Late mafic dikes cut all other rock types.

A chemical analysis is given in Table 2.

Table 2. Chemical Analysis of Quartz Monzonite Basement Rock (by U. S. Geological Survey, W.W. Bannock, project leader).

Oxide	%	Oxide	%
SiO ₂	72.9	K ₂ O	5.2
Al ₂ O ₃	13.8	H ₂ O	0.78
Fe ₂ O ₃	0.9	TiO ₂	0.26
Fe ₂ O	1.2	P ₂ O ₅	0.10
MgO	0.57	MnO	0.04
CaO	1.8	CO ₂	0.05
Na ₂ O	2.5		

Age

Treves (in press) reports that radioactive decay age-determinations have been made for basement specimens from Discovery Ridge and Treves Butte. The age as determined by the K-Ar and Rb-Sr methods on feldspar for both are approximately 470 m.y.

The basement rocks of the Ohio Range are very similar to those described by other workers in the Victoria Land area. David and Priestly (1914) recognized that a "pink granite" was intruded into a "gray granite". Gunn and Warren (1962) have given the name, Granite Harbour Intrusive Complex, to the plutonic and hypabyssal intrusives that invade older sedimentary rocks in a portion of Victoria Land.

A potassium-argon age determination of 520 million years was made on a biotite hornblende gneiss from Geniss Point (Goldich, Nier, and Washburn, 1958). This date indicates that intrusion of granites and orogenic activity probably occurred during Late Cambrian or Ordovician time. Hamilton (1960) notes that the granitic rocks of the Horlick Mountains are closely related to those of Victoria Land. Based on lithologies and stratigraphic relationships, it seems likely that the basement complex of the Ohio Range is genetically related to similar basement granites elsewhere in the Transantarctic Mountains.

Nonconformity at the Base of the Sedimentary Section

The nonconformity under the Paleozoic sedimentary units is one of the most obvious features on the cliffs of the northern escarpment of the Ohio Range (Figs. 11 and 12).

This nonconformity represents an erosional surface upon which a sea transgressed during Lower Devonian time. The sandy and poorly sorted nature of the sedimentary rocks immediately over this surface indicate that most of the sandy material weathered from the granites. This old erosion surface is of low relief, generally less than 200 feet. The largest measured relief in the Ohio Range is 68 feet in a distance of several hundred yards.

The nonconformable relationship usually is between the granitic basement and the marine Horlick Formation of Early Devonian age. However, in at least one locality, section no. 1 (map and sections in pocket), the Buckeye Tillite of Permian or Pennsylvanian age lies directly on the basement rock. The nonconformity at this location was caused, at least partially, by glacial erosion during Pennsylvanian or Permian time. The old granitic surface has been polished and grooved (Fig. 13) prior to deposition and the tillite.

Erosional surfaces on basement rocks with overlying Paleozoic sedimentary strata similar to the nonconformity noted above, have been described for most of the ranges which form the Transantarctic Mountains. In Victoria Land this surface is reported by Debenham (1921, p. 105). Gunn and Warren (1962, p. 57) call the old surface in Victoria Land the Kukri Peneplain. Remnants of this surface can be seen in aerial photographs of the Thiel Mountains, the

Fig. 13. Grooves in the granitic basement rock at the base of measured section 1 indicate that glacial erosion removed the overlying Horlick Formation. The glaciers which grooved the basement existed during Permian time.

Ohio Range, the Long Hills, the Wisconsin Range, the Queen Maud Range, and Victoria Land. These localities cover a belt which extends about 1500 miles and nowhere in the belt does the surface have marked relief. Grindley (1963, p. 321) describes this surface in the Queen Alexandra Range. Grindley's Figure 5 shows the Alexandra Formation (Devonian-Carboniferous) resting on steeply dipping phyllites. Warren (1962, p. 57) reports fossil stream channels up to 6 feet deep on the Kukri Peneplain in Victoria Land. In the dry valleys of Victoria Land Zeller et al. (1961) described 80 to 100 feet of local relief on the crystalline basement.

On the basis of the widespread extent of the erosion surface and its low relief, it seems that a major portion of the Antarctic continent was exposed to subaerial weathering for a long time before the Devonian seas invaded the continent in the area of the Ohio Range. Elsewhere on the continent the surface may have been covered at different times by different kinds of sediments, but the nature of these is unknown. The Horlick Formation in the Ohio Range includes the only Lower Devonian marine sedimentary rock now known from the continent. In the Queen Alexandra Range the nonfossiliferous Alexandra Formation, tentatively assigned Devonian to Carboniferous age, covers the erosion surface (Grindley, 1963). In the Mawson to Mullock Glacier area Gunn and Warren (1962)

report Silurian or Devonian strata on the Kukri Peneplain, but the fossil evidence is not fully known. Elsewhere in Victoria Land sandstones and arkoses are present on the old surface (Allen, 1962; Zeller et al., 1961; Harrington and Speden, 1962; Webb, 1963; and Mirsky et al., in press).

Other continental areas, particularly in the southern hemisphere contain an erosional surface of roughly similar age. In South Africa the Table Mountain sandstone rests on a nearly horizontal ancient erosion surface which represents a period of planation prior to Devonian time (DuToit, 1956, p. 240). Similar relationships are found in the Falkland Islands and in parts of South America (Adie, 1962, p. 28). The Cape System of South Africa rests on truncated basement rocks and the Lower Gondwanas of India also have been deposited after a prolonged period of erosion. It should be noted that in South Africa the Table Mountain sandstone is the lowermost sedimentary unit and it has been assigned an Upper Silurian age. The lowermost bed in the Lower Gondwanas is the Boulder Bed of the Talchir Group which is of Upper Carboniferous or Lower Permian age. Thus the ancient erosion surface beneath the strata in the Ohio Range resembles the African relationships more closely than those of India. A following chapter will discuss features of similarity between tillites of the Ohio Range, South Africa, and India.

The Horlick Formation

The Horlick Formation is the lowermost sedimentary rock unit in the Ohio Range and is a sequence of feldspathic and quartzitic sandstones of marine origin interbedded with shales and siltstones of swampy origin. This formation is named after the original name of this mountainous region. The formation was first observed in 1958 (Long, 1959) on the East Spur of Discovery Ridge and the section there is considered the type section. Marine fossils occur in the poorly sorted, dirty sandstones, and fossils of primitive plants are found in the dark shales and siltstones.

Occurrence

The Horlick Formation lies directly on the basement, is one of the most widespread formations in the Ohio Range. On the geologic map (pocket) the outcrop pattern is a long and sinuous line because the formation is very thin. In places glacial erosion prior to deposition of the unit above has eroded through the Horlick Formation. Good exposures are present at nearly all of the sections shown in measured sections (Appendix). Figure 14 shows the Horlick Formation as exposed on Discovery Ridge, West Spur.

Thickness

The Horlick Formation varies in thickness from being absent at section 1 to 176 feet at section 22 (West Spur, Discovery Ridge). The thicknesses which were measured are indicated in Figure 14.

Description

Sandstone, siltstone, and shale dominate the lithology of the Horlick Formation. A prominent feature of these beds is the alternation of sandstone and shale (Figs. 14 and 15). The feldspathic sandstone is medium gray, poorly sorted, and fossiliferous and occurs in strata from a few inches to about 15 feet thick. They would be classified by Crook (1960) as litho-feldspathic arenites, or (Folk, 1961) as subarkose. The grains vary from fine to coarse, and the basal beds can be conglomeratic. The texture of the rocks is granular with angular grains of quartz and feldspar in a clayey and sometimes calcareous matrix. Mica flakes parallel to bedding give a slight directional fabric to the rock.

Thin section analyses of a basal arkosic conglomerate show about 50 per cent quartz grains, subrounded, with both clear and wavy extinction indicating a source from mostly granitic rock, but also from metamorphic rock, and vein quartz. As much as 25 per cent of the rock was plagioclase and 15 per cent orthoclase with single grains

HORLICK FORMATION — MEASURED SECTIONS

Fig. 14

up to 2 cm. in diameter. About 5 per cent of the grains were other rock types. Biotite, muscovite, chlorite, sericite, zircon, tourmaline, and limonite occur in a siliceous matrix.

The deposit is assumed to have formed on a beach because of the brachiopod shells in the sandstone. The source of this beach deposit was possibly three fold. First, the sandstone may be derived from a nearby granitic source of the basement rock on which it rests. Second, well-rounded fragments of sericite schist indicate a source from metamorphic rock at a greater distance. Third, an occasional very well-rounded quartz grain indicates an additional sedimentary source with a longer transport history but of minor importance.

The sandstone of the Horlick Formation occurs in beds above the basal arkosic conglomerate. In Crook's (1960) classification they are feldspathic labile arenites. They show a granular texture of subangular and angular quartz and feldspar with other grains in a matrix which is generally composed of clay, sericite, silt, and sometimes carbonate (sparry calcite). According to Folk (1961), the texture is immature to submature as is indicated by the poor sorting of the grains in a matrix which composes more than 5 per cent of the rock (immature) and, in some cases, less than 5 per cent of the rock (submature). Biotite, muscovite, calcite, and chert are usually present in

amounts greater than 3 per cent of the rock; trace minerals include tourmaline, garnet, zircon, pyrite, rutile, leucoxene, limonite, hornblende, and chlorite. Feldspar is predominantly orthoclase with smaller percentages of plagioclase and microcline. Quartz shows both straight and wavy extinction and has inclusions of bubbles, needles, and submicroscopic particles. From the predominance of grains with straight extinction, the primary source rock is considered to be a nearby granite. Quartz showing wavy extinction and grains of metamorphic rocks indicates a minor source area of metamorphic rocks. Also, a few grains which are very well rounded probably were derived from a sedimentary rock source. Like the basal conglomerates the primary origin of the feldspathic labile arenites is probably the granitic mass over which the Lower Devonian sea transgressed.

The siltstone and shale of the Horlick Formation are medium gray to very dark gray, laminated, thin- to poorly bedded, and grade into sandstone beds. The very dark gray shale is less resistant than the sandstone usually weathers more rapidly. Thus thin shale beds are recessed in sandstone cliffs and larger beds underlie debris as sloping surfaces between sandstone steps or cliffs. Poorly bedded dark mudstones contain Psilophyton, a genus of primitive fossil plants. Flakes of mica are present on most bedding surfaces.

Fossils

Fossils within the Horlick Formation include both plants and animals. Many sandstone beds contained brachiopods, pelecypods, bryozoans, trilobites, cephalopods, and Turretella. The most common brachiopod has been assigned by Boucot et al. (1963) to a new genus, Pleurothyrella, which belongs to the family Terebratuloidae. This genus has been related to similar fossils of South Africa, the Falkland Islands, Bolivia, and New Zealand, and is assigned to the Emsian stage by Boucot et al. (1963). Work on all of the fossils is presently being undertaken by Boucot, Doumani, and others.

Other Devonian rocks have been described in Victoria Land. Woodward (1921) describes "Fish Remains from the Upper Old Red Sandstone of Granite Harbour". Based on a comparison with fish from the Ohio Shale in the United States, he assigned to the rocks an Upper Devonian age. However, the rocks in which the fish were found were not in place, but occurred in morainal boulders which were discovered by Frank Debenham during the British Antarctic Expedition in 1910.

More recently, Gunn and Warren (1962, p. 108) reported fresh water fish remains from outcrops in Victoria Land. The fragments have been assigned a Middle or Upper Devonian age. Plumstead (1962, p. 2) identified two stems as Haplostigma and Protolepidodendron and has assigned them

a Lower to Middle Devonian age. These fossils were found on Beacon Heights West by Harrington and Speden (1962). At this time, no other Devonian fossils have been reported from Antarctica, and the fossils found in the Horlick Formation are the only Lower Devonian fossils known from the continent.

Depositional environment

The Horlick Formation was formed under beach and swampy conditions. The marine fossils in sandstone are evidence that these beds were deposited in a beach environment. On the other hand, the plant fossils in shales and mudstones are indicative of lagoonal or swampy conditions where the psilophytic plants could grow. Poor bedding in some of the mudstones probably represents old soils where the surface was disturbed by animals, plants, and weathering.

The arkosic sandstone is indicative of an arid or cold climate or a rapidly rising uplifted granitic source area. The fact that some feldspar grains are weathered and others are not indicates that the subarkoses probably result from an uplifted granitic area in a humid and possibly cool climate.

The direction of the paleoslope as indicated by 23 cross-bed directions is generally to the southwest; that is, currents flowed from the northeast. However, a 20-foot thick conglomeratic and sandstone bed 6 feet above the

basement contains cross-bedded planes sloping predominantly to the northeast, but this single occurrence may represent only a local meander.

Sandstone beds which are cross-bedded do not contain fossils. These beds may represent deposits of non-marine origin; probably fluvial deposition.

A northeastern direction for source area during the Devonian period is nearly opposite that of the Permian period when a source area lay to the southwest of the Ohio Range. This difference may be real or it may have resulted from local variation or incorrect interpretation of a few current-bedding directions of slope.

The Buckeye Tillite

The Buckeye Tillite takes its name from the Buckeye Table in the Ohio Range. The western end of the Buckeye Table is an erosion surface developed on the tillite. Fully exposed sections, including the type section, are well displayed on Discovery Ridge (map in pocket). The Buckeye Tillite consists predominantly of a bluish-gray boulder clay and also includes a few sandstone and shale beds.

Areal distribution

The Buckeye Tillite forms a major portion of the northern escarpment of the Ohio Range, and crops out along

the entire length of the escarpment as well as on Treves Butte, a nunatak to the north of the escarpment. The tillite caps the sedimentary sequence over all of the western portion of the range so that extensive outcrops are present.

From a distance the tillite appears dark-colored and slightly bedded. The horizontal nature of different bodies of tillite and the presence of a few water-deposited beds of sandstone and shale suggest stratification of the tillite when seen at a distance. Three beds within the tillite at Discovery Ridge produce cliffs; two of these are composed of sandstone and the other is a more resistant tillite. These beds can be distinguished in Figure 15.

Pebbles and cobbles are randomly scattered in a bluish-gray matrix and after weathering the large clasts can easily be removed from their deposited position in the tillite. Pebbles and matrix fracture nearly uniformly at fresh exposures. The lithology of the large clasts is quite varied, including metamorphic, igneous, and sedimentary rocks. Several water-deposited beds occur within the tillite and the lateral extent of these beds ranges from a few yards to about a mile. Most sandstone bodies are lenticular but one sandstone and shale sequence persists throughout the length of the range. Bedded tillite may be present above sandstone beds.

Fig. 15. Strata of the Harlick Formation (Dh), Buckeye Tillite (Pb), and Discovery Ridge Formation (Pdr) rest on the ancient erosion surface and comprise the West Spur of Discovery Ridge (see map on page 22). About 900 feet of Buckeye Tillite are exposed here and the light-colored, horizontal strata are water-deposited units within the tillite.

Thickness

Six of the ten sections of tillite that were measured contained complete sections and their thickness ranges from 840 feet to 1027 feet. At Discovery Ridge the measured sections are 990 and 945 feet thick. At the extreme western end of the range 910 feet of tillite were measured, which indicates that the tillite is of the same order of thickness throughout the range.

Lithology

The most common rock type among the Buckeye Tillite is a bluish-gray tillite (Figs. 16 and 17). This rock type is not sorted and includes boulders up to 10-15 feet in diameter. These boulders occur most frequently in the lower 200 feet of the tillite and are commonly of the same lithology as the basement rock.

In hand specimen, the tillite is a medium dark, bluish-gray rock with variably sized grains in a silty and argillaceous matrix. The pebbles are of several types.

Pebble count data (given in Table 3) show that sedimentary pebbles (1-3 inch diameter) are the most common lithologic type, and metamorphic pebbles the least common. The percentages of lithology from 1500 pebbles collected at many levels on different exposures are: sedimentary, 72 per cent; igneous, 21 per cent; and metamorphic, 7 per cent.

Fig. 16. Buckeye Tillite in outcrop looks similar to till with large clasts of various rock types randomly scattered in argillaceous and silty matrix.

Fig. 17. Detail of a more sandy facies of the Buckeye Tillite shows texture, fabric, and composition of this glacially deposited rock. The cobbles are dark greenish gray siltstone or graywacke and lighter colored granitic rocks.

The source rock of the sedimentary pebbles is not known but the most abundant lithology is a dark greenish-gray siltstone which could be called a very fine-grained gray-wacke, and may be slightly metamorphosed. These pebbles make up about 50 per cent of all the 1 to 3 inch size pebbles. They are also common in larger sizes and many of them show striations.

The source rock for many of the granitic boulders is quartz monzonite and granodiorite from the basement. Most of the very large boulders are composed of quartz monzonite like that of the basement. Boulders of basement rock are particularly abundant within the lower two hundred feet of the tillite.

Other granitic rocks are present; diorite and blue quartz granite were observed but no ultrabasic rocks were noted. Minor numbers of andesite and rhyolite occur in the tillite from an unknown source. A small percentage of pebbles of gneiss, schist, and phyllite metamorphic rocks are present in the tillite. It is assumed that these rocks come from intruded and metamorphosed parts of the Antarctic shield area. They may be derived from outcrops of early Paleozoic or Precambrian which are distant from the Ohio Range.

Stone morphology

The morphology of the stones in the tillite is presented in Table 3. Most of the stones are subangular, but a considerable number of both angular and subrounded stones is present.

About 12 per cent of the stones are striated. The striae are of the straight parallel type usually associated with glacial striae. They are not the random variety commonly produced as a result of landslide or processes of mass movement.

More than 50 per cent of the stones show some sort of faceting. In preparing this analysis one or two flattened surfaces were considered facets, even though the corner between the two flat surfaces had been somewhat dulled by erosion.

Very few polished stones were counted. This suggests that very little of the smoothing was accomplished by action of moving water.

In thin section, the finer textured tillite grains are poorly sorted and range from angular to rounded with subangular grains predominating. The grain size of the matrix is from 0.02 to 0.6 mm. and the cementing material is argillaceous and calcareous. Calcareous replacements and cement constitute up to 15 per cent of some specimens. The minerals identified and estimated percentages are given for two thin sections.

Table 3. Stone Count
Lithology and Morphology

	I	II (in percentage)	III	IV
Sedimentary Rocks (mostly gray siltstones; some chert and limestone)	73	64	75	76
Igneous Rocks (mostly granitic and rhyolitic)	20	28	24	15
Metamorphic Rocks (mostly gneiss and schist)	7	8	1	9
Very angular	3	0	2	0
Angular	34	21	29	26
Subangular	39	43	39	50
Subrounded	16	28	28	22
Rounded	0	3	2	1
Very rounded	0	0	0	0
Rounded and broken	8	5	0	1
Striated	13	14	7	14
Faceted	54	67	60±	50

Sample H 504

Quartz	40%	Clear, subangular, few inclusions
Orthoclase	15%	Subangular, some altered to clay or sericite
Plagioclase	5%	Subangular, some altered to clay
Matrix	30%	Argillaceous, calcareous
Calcite	10%	Sparry cement
Microcline, garnet, apatite, leucoxene, and rutile		-- trace amounts

Sedimentary rock fragments present

Sample H 505

Quartz	25%	Angular to rounded, some mottled (vein quartz)
Orthoclase	5%	
Plagioclase	7%	
Muscovite	3%	
Calcite	Trace	
Pyrite	Trace	includes quartz grains, poikilitic
Tillite pebble	4x3 mm.	
Matrix	55%	

Sandstone bodies within
the Buckeye Tillite

A thin sandstone stratum and associated shales form stratigraphic marker beds which can be traced for the length of the Ohio Range. The fine-grained sandstone is light grayish-tan and has brownish nodules from about 2 to 5 inches in diameter which make the bed easily recognizable in a section. Thin-sections show angular grains of quartz (30%), plagioclase (10%), and orthoclase (5%) in an argillaceous and siliceous matrix, with about 25 per cent of the rock composed of calcite replacing feldspar, quartz, and matrix. Rarer grains include biotite, muscovite, chert, granules of metamorphic rock, rutile, zircon, leucoxene, and chlorite. A few grains of calcite appear to be represented.

The texture of the sandstone consists of well sorted sand sized grains in a clayey matrix. The grains are angular to subangular grains of quartz and feldspar. These properties indicate that transportation was limited and that deposition was rapid enough to prevent good sorting or removal of the fines.

The shale which lies directly above and below the sandstone just described is very thinly bedded and dark-greenish gray. In some outcrops the bedding surfaces are smooth enough to reflect light and look slimy. Beds range from about one foot to several feet in thickness. The upper shale in some sections grades into a bedded tillite.

The bedded succession of shale--nodular sandstone--shale has been used as a reference datum to draw the section shown in the pocket. It seems probable that the shale was nearly horizontal when deposited, and extended continuously over the length of the range. It also seems reasonable to believe that the shale bed was deposited at nearly the same time at both ends of the range and thus, for practical purposes, represents a time-line. If the shale were continuous and level, then the thickness of tillite below the shale sequence indicates pre-tillite levels. Thus the thickness of tillite below these beds can be noted to give an idea of probable paleotopography.

The sections show high and low areas that probable correspond to the pre-tillite topography. The greater thicknesses probably represent valleys which continued to be low areas while till was being deposited. This is indicated by lenticular bodies of sand which occur above the thicker sections which rest upon the pre-tillite surface. These thick sand bodies are interpreted as outwash stream deposits in old valleys.

Sandstone lenses occur at various levels in the tillite both above and below the datum shale level. Shale beds are also present at various positions as shown by sections in measured sections (pocket). Shale is particularly common in the uppermost 100 feet of the tillite where shale is interbedded with the tillite and forms $1/3$ to $1/2$ of the thickness. On the Discovery Ridge sections (21 and 22) and section 1, the shale is deformed in small, tight, and overturned folds. The beds above and below are undisturbed so the folds must have formed while the sediment was unconsolidated, perhaps from gravity sliding, ice pushing, or load squeezing.

In the upper part of the tillite occasional small calcareously cemented and lenticular sandstone bodies occur which are from about 2 to 10 feet across. These weather a reddish-brown from a medium-gray color. Also bedded tillite (Fig. 18) is present as a transitional lithologic type.

Fig. 18. A bedded tillite facies is sometimes present between water-deposited interbeds and tillite. Siltstones can be seen under the bedded tillite in the bottom of the picture and normal tillite is present above.

Beds of sandstone and shale within the tillite (Figs. 19 and 20) indicate that ice deposition was interrupted and that layers of detritus were sorted and deposited by water. Most of the water-laid deposits are lenticular and elongated, suggesting stream channels. It thus appears that occasionally the ice receded and streams cut channels in the till and deposited outwash sand and gravel in these channels.

The more extensive sandstones and shales must have resulted from larger retreats of ice from the area. The widespread datum shale-sandstone-shale succession probably formed in a lake with the shale deposition occurring in deeper water and the sand forming along a beach. Either the sections are taken parallel to the shore line or they represent a migration of a beach with shale beds covering the beach sands. Rapidly changing water levels seems a better explanation than gradual transgression because of sharp contacts between sandstone and shale.

Direction of ice motion

Striae and grooves are found at many levels through the Buskaye Tillite (Fig. 21). They usually are present on sandstone interbeds or lenses. Several boulder pavements with parallel striae on the boulders are present in the tillite outcrops. Alignment of striae and grooves from all sections and elevations is similar and has been

Fig. 19. Sandstone and conglomeratic bodies are present within the Buckeye Tillite. These sandstone units are of a lenticular nature and were probably deposited by sub-glacial or outwash streams.

Fig. 20. Thinly bedded siliceous and calcareous sandstones are present within the Buckeye Tillite. Typical tillite rock is visible below the bedded deposits.

Fig. 21. A grooved and striated pavement on a sandstone bed is present in measured section 7. Such a pavement indicates a recession of the ice, deposition of sand, and readvance of the glacier.

plotted on map (Fig. 22). Grooves and striae on basement rock (Fig. 13) and Horlick Formation (Figs. 23 and 24) are oriented about N. 75° E. to due E. Striae on a boulder pavement near the top of the tillite section show variation from N. 75° E. to due E (Fig. 25).

Cross-bedding and current-scour marks in the sandstone which are interbedded with the tillite suggest that the paleoslope was up in the west and down to the east. Thus the indications from water-deposited beds agree with the evidence from the tillite.

Indicators of ice movement which were observed include crag and tail, slope of boulders in a boulder pavement, and fragments of a boulder strewn to the downstream side (Fig. 26). These criteria are indicative of a probable ice movement from the west.

Criteria for recognition of tillite

The origin of strata that have little to no bedding and contain scattered pebbles, cobbles, and boulders of various lithologies is not easily ascertained. There are several processes which produce such sediments. It is interesting to note that the origin of such units has been argued ever since the beds were first described. Bain, who first described the Dwyka Tillite in 1856, considered the unit a "claystone porphyry." Others considered

Fig. 22.

Fig. 23. Grooves in the underlying Horlick Formation are poorly preserved but present under the Buckeye Tillite in measured section 2.

Fig. 24. A glacial pavement is present on the Horlick Formation under the Buckeye Tillite near the base of the East Spur of Discovery Ridge (measured section 21). The nonconformity between the Horlick Formation and the basement rock on Treves Butte can be seen in the background.

Fig. 25. A boulder pavement near the top of section 22 on Discovery Ridge contains many boulders which have been embedded in the tillite matrix and then faceted, grooved, and striated by debris-laden ice. Striae are oriented N. 85° E. Evidence suggests that the ice moved from S. 85° W. to N. 85° E.

Fig. 26. A granitic boulder in the boulder pavement near the top of section 22 has been broken and fragments have been strewn to the right of the boulder. This relationship suggests that the ice moved from the left to the right across the boulder, or from S. 85° W. to N. 85° E.

different origins for this perplexing unit of rock and the question became such a problem that the Geological Commission of the Cape of Good Hope considered it yearly for several years before becoming convinced of a glacial origin for the Dwyka Boulder Beds. Today most geologists, even those skeptical of other "tillites", will agree that the Dwyka Boulder Beds were probably glacially deposited.

Because tillite is lithified till, probably a direct and general approach is to expect a tillite to resemble till in outcrops. The till plains of the north-central United States provide many excellent sites for inspection of recognized till deposits. One can notice at once that till has a distinctive appearance. There are other sediments that are similar looking, such as those produced by landslides, mudflows, volcanic tuff, volcanic breccia, and volcanic mudflows. Various submarine deposits have a tillite-like appearance.

Submarine origins for nonsorted and poorly bedded deposits were suggested in 1850 by R. Mallet in a letter to Professor Oldham (Mallet, 1853, p. 126). He suggested that ice, whether floating icebergs, floating river ice, or glaciers, was "an occasional and accidental agent" of transport. The mechanism which Mallet suggested sounds very much like that suggested by Dott (1961), Crowell (1957), or other workers who have studied turbidity currents

and submarine-mass-movements. He stated (p. 126) that "the lateral movements due to gravitation of masses of loose material, whether mud, sand, gravel, or all of these, mixed with boulders ... will, when combined with ... effects of tidal action ... be found a sufficient mechanism for the transport to any distance of drift and boulders". Mallet proposed the above hypothesis to account for what is recognized today as glacial drift deposits and striae in Ireland. His ideas were published only 12 years after the first published theory of glacial transport of debris by Agassiz in 1840.

While Mallet was mistaken concerning the origin of the deposits and striae, he became perhaps the first to suggest the mechanism of mass movements in submarine environments. This concept has only in the last decade become popular with geologists and in some cases may have been over-worked. In the past, glacial deposition has been used with indiscretion as an origin for nonbedded deposits with boulders and cobbles in them. Evidence exists for many origins of such deposits and in order to ascertain the most likely origin the rock itself and its overall geological setting must be carefully considered.

Dott (1961) discusses the Squantum "Tillite" as well as other deposits of similar nature in North America and very clearly demonstrates that several mechanisms, particularly subaqueous or subaerial sliding, can produce

nonsorted, poorly stratified deposits. Extensively grooved and striated pavements provide the most diagnostic evidence of glaciation, according to Dott, but even grooved surfaces can be produced in other ways such as slickenslides due to faulting.

In a discussion of pebbly mudstones in California, Crowell (1957) notes their similarity to tillite. He states that tillites may be distinguished by scattered clasts embedded in a mudstone matrix, many of the clasts are angular, striated or with a "flat-iron" shape, in thin sections an abundance of angular fragments are present, there is an extraordinary range of size grades, striated and grooved pavements are present beneath the tillite. However, for every criterion listed, some other mode of origin also is possible.

Dott (1961, p. 1302) states, "In the final analysis, over-all paleogeological relationships must constitute essential, -- probably the most essential factors, in evaluation of evidence for ancient glaciation!" Thus he suggests that glacial beds which betoken glacial conditions in the geologic history of an area should be complimentary with the histories suggested by all other geologic evidence. Besides having the proper lithologic and stratigraphic properties, a glacial deposit should agree with paleogeographic, paleotectonic evidence. There are few deposits

for which all the suggested evidence exists, therefore it is not surprising that ideas of origin for some deposits are in disagreement.

In summary, a tillite should look like a till. According to Pettijohn (1949, p. 221), important properties of a till are:

- 1) High range of sizes which are usually unsorted.
- 2) Rock fragments (shape, roundness and surface markings).
 - a) Usually subangular or angular with several facets.
 - b) Some rounded pebbles or boulders.
 - c) Fragments blunted at one or both ends, or rather pointed at one end and blunted at the other.
 - d) Fragments beveled on one or more sides, the sides usually not parallel.
 - e) Concave fractures.
 - f) Striated fragments, nailhead scratches.
- 3) Rock fragments (lithology)
 - a) Greatly varied.
 - b) More local than foreign.
- 4) Rock fragments (fabric and packing)
 - a) Sparsely distributed pebbles show preferred orientation parallel to flow.
- 5) Matrix usually clay.
- 6) Lower part of till has finer matrix and more striated pebbles than top.
- 7) Till often rests on grooved or striated rock pavement.

- 8) Unstratified.
- 9) Near top of till, intercalated stratified lenses may be found; such "nests" and layers are usually contorted.

Both Crowell (1957) and Dott (1961) state that each property of a "tillite" can be produced by some other means. Dott (p. 1289) says that very poor sorting, faceting, and rafted erratic fragments in fine, laminated mudstone are not adequate evidence to prove glaciation. However, "an extensive, preserved, grooved and polished pavement overlain by poorly sorted, till-like material ... particularly if non-marine, is compelling glacial evidence".

Besides the properties of the deposit, a tillite should be consistent with the paleogeographic and paleotectonic evidence for a region.

The origin of the Buckeye Tillite

Having considered criteria such as those discussed in the last section, a glacial origin seems most likely for the Buckeye Tillite. A glacial origin is indicated by the following properties of the deposit:

- 1) The texture and fabric of the rock.
- 2) The shape and numerous types of grains and boulders.
- 3) Boulder pavements with parallel striae on the boulders intercalated in tillite.

- 4) Striae and grooves on intercalated, lenticular sandstone strata.
- 5) Striae and grooves on a glacial pavement under the tillite.
- 6) General stratigraphic agreement with recognized tillites in other southern hemisphere continents.
- 7) General paleogeographic and paleotectonic compatibility with what is known of the geologic history of Antarctica.

The above features are discussed elsewhere in this paper and so will not be elaborated upon here. Points 1-5 are described in this chapter on the Buckeye Tillite. Point 6 is considered in detail for South Africa and India in following chapters. Point 7 is handled under the chapter on Historical Geology.

Relation to underlying and overlying rocks

The previously mentioned erosion surface and pavement beneath the tillite truncate both Horlick Formation and basement rocks. Thus, the relationship of the tillite to underlying rocks is disconformable as well as nonconformable. The upper tillite is disconformably overlain by the Discovery Ridge Formation. The tillite at its uppermost level contains shale beds which are very slightly folded (Figs. 27 and 28) and can be a disconformity or a very slight angular unconformity.

Fig. 27. The disconformity between the Buckeye Tillite (Pb) and the overlying Discovery Ridge Formation (Pdr) can be seen on Discovery Ridge between measured sections 21 and 22. A man stands on the contact (in circle).

Fig. 28. A closeup view of the Buckeye Tillite and Discovery Ridge Formation shows hard, silty, platy shale on tillite.

Age and correlation

The age of the tillite is difficult to ascertain. Stratigraphically it must be younger than the Devonian Horlick Formation and older than the Permian Mt. Glossopteris Formation. A few of the shales which are interbedded in the upper tillite have yielded spores. According to Dr. J. M. Schopf, these spores are similar to Permian spores in the United States and no older fossil material has been identified. The upper part of the tillite, then, is probably of Permian age.

The Buckeye Tillite, when first described (Long, 1962) was the only described tillite from the continent. It should be noted, however, that Alan Reece (1958, p. 75) in the discussion of a paper presented by L. C. King (1958) presented a stratigraphic section from Dronning Maud Land and made the following statement: "Although the conglomerates from the red beds at the top bear a marked resemblance to the Dwyka tillite shown by Professor King, it appears unlikely that these beds should be at the base instead of the top of the sequence. Neither in the field nor in thin section have these conglomerates shown any convincing evidence that they are of glacial origin."

The section given by Reece is as follows:

1050-1500	Red quartzite with occasional breccia beds consisting of chocolate and purple mudstone fragments. Occasional conglomerates up to 10 m. thick.
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- 850-1050 Grey, green, and buff quartzites with black mudstone and siltstone occupying 10 to 20 per cent. Occasional conglomerates 1 metre thick.
- 550-850 Mostly grey-green quartzite and chocolate-coloured shale in equal proportions.
- 0-550 Brown, red, yellow, grey, and white quartzites: black siltstones and mudstones. The proportion of quartzite decreases from about 90 per cent at the bottom to 50 per cent at the top.

During the following years additional ancient glacial deposits have been described from other locations in the Transantarctic Mountains. From near the Beardmore Glacier, Grindley (1962) reported a stratigraphic succession which includes glacial deposits with striated cobbles and boulders which he called the Pagoda Tillite. The entire stratigraphic section is similar to that of the Ohio Range. Gunn and Warren (1962) describe a sedimentary succession from Victoria Land but show no tillite of similar position and age as the Buckeye Tillite. However, they recognize a younger unit which they call the Mawson Tillite. Owing to association with volcanic deposits and relations to fossil plants, a Jurassic or Cretaceous age has been suggested. The lithology of the Mawson Tillite which contains a high percentage of volcanic rock and erratics, and interbedded shale, suggests that non-glacial agencies may be responsible for its deposition. The Mawson Tillite cannot be considered equivalent to the Buckeye Tillite.

Tillite-like strata which have been called the Whiteout Conglomerate have been described from the Sentinel Range by Craddock et al. (1963), but the age relationships are unknown at this time.

On a worldwide basis the Buckeye Tillite can be compared with other Gondwana tillites. A following chapter compares details of the Buckeye, the Dwyka, and the Talchir tillites. Other tillites of Carboniferous or Permian age in the southern hemisphere include those of Argentina, Brazil, Falkland Islands, Australia, and Madagascar.

The Discovery Ridge Formation

Definition and type area

The name Discovery Ridge Formation is given to a succession of dark gray and black shales which overlies the Buckeye Tillite and are in turn overlain by the Mt. Glossopteris Formation. The formation is composed of two members: a lower platy-shale member and an upper carbonaceous, fissile shale member. The type section for the lower member is located on the northwestern end of Discovery Ridge (84°44" S. and 114°05" W.) and the type section for the upper member is located at outcrop 1 of the northern escarpment of the Ohio Range.

Areal distribution

The Discovery Ridge Formation is present only in the eastern half of the Ohio Range because to the west it has been removed by erosion. The formation crops out on the North Ridge of Mt. Glossopteris, Discovery Ridge, section 1 and section 2. Outcrops do not form conspicuous features because of the ease with which the rock is weathered and eroded. The only uninterrupted outcrop is that in section 1; however, nearly complete and well exposed outcrops are located on Discovery Ridge and on the north ridge of Mt. Glossopteris.

Lithology

The Lower Member of the Discovery Ridge Formation is composed of dark gray, hard, platy, silty shale which breaks in slabs about $1/4$ to $3/4$ of an inch in thickness (Figs. 29 and 30). Silt grains make up about 40 per cent of the rock and clay-sized material about 60 per cent. The silt-sized grains, as estimated from thin section, are composed of 70 per cent angular to subangular quartz; 20 per cent flakes and shreds of muscovite; 5 per cent secondary calcite; 5 per cent plagioclase feldspar; and trace amounts of biotite and chlorite.

The Upper Member of the Discovery Ridge Formation (Figs. 31 and 32) is a soft, easily weathered carbonaceous shale with interbedded calcareous beds of dark gray calcite or siderite up to 6 inches thick. The carbonaceous shale is

Fig. 29. The Lower Member of the Discovery Ridge Formation is composed of hard, platy siltstone and shale which is well exposed on the nearly flat part of Discovery Ridge.

Fig. 30. Tracks of unknown origin are present in the hard, platy, silty shale of the Lower Member of the Discovery Ridge Formation. These are present about 10-20 feet above the base of the formation near the top of measured section 22.

Fig. 31. The north ridge of Mt. Glossopteris (measured section 19) includes the Lower Member and Upper Member of the Discovery Ridge Formation. Soft shales of the Upper Member have eroded back leaving a flattish shelf.

Fig. 32. The Upper Member of the Discovery Ridge Formation is exposed on Discovery Ridge. The upper boundary of the formation is a faulted contact and dotted lines show the probable position of faults.

fissile and black but weathers to a dark gray. The calcareous beds weather to a reddish brown or tan. Shaly partings do not follow bedding planes. Fine sand and silt grains compose about 30 per cent of the rock, and a carbonaceous and clay material form the remaining 70 per cent. The maximum size of the large grains is 0.4 mm.

The fine sand and silt portion of the rock, as estimated from thin section, is

quartz	10%	angular and subangular (up to 0.2 mm.)
plagioclase	10%	altered to clay and replaced by calcite
carbonate	5%	secondary
chlorite	3%	discontinuous veinlets of chlorite and clay
muscovite	Trace	elongate shreds, parallel to bedding.

Lenticular bodies of impure ferruginous limestone or ironstone are interbedded with the carbonaceous shales. These nonfossiliferous carbonate bodies are elliptical or lenticular in section, up to 12 or 15 feet across and up to about 6 inches thick. The origin of these features is not known but, on a larger scale, they resemble banded ironstones of Paleozoic coal measures. Cone-in-cone structures, chiefly calcitic, are commonly associated with these broadly lenticular bodies.

Thickness

The Discovery Ridge Formation as measured at section 1 is 640 feet thick; the Lower Member is 150 feet thick and

the Upper Member 490 feet thick. On Discovery Ridge and Mt. Glossopteris the thickness has been measured at about 550 feet. However normal faults, seemingly minor but with an unknown displacement, occur near the top of Discovery Ridge and on the North Ridge of Mt. Glossopteris. Direct measurements of exposed sections must, for this reason, be regarded as minimum estimates.

Relation to underlying and overlying rocks

The lower boundary of the Discovery Ridge Formation is a disconformable contact with the Buckeye Tillite (Figs. 27 and 28). The even-bedded platy shales are deposited over a slightly wavy surface of tillite. The upper limit of the formation is marked by a gradational lithologic change from the black carbonaceous shales to the bottom-most brownish-gray, feldspathic sandstone or the Mt. Glossopteris Formation. The contact is transitional and small animal burrows are present from about 10 feet below the contact to about 50 feet above it.

The contact between the Lower Member and the Upper Member is gradational with fissile, carbonaceous shale alternating with platy dark gray shale throughout 50 feet of section.

Age and correlation

The Discovery Ridge Formation has not produced fossil material which is adequate for dating. Macerations of

random samples throughout the formation have yielded no fossil spores or pollen grains according to J. M. Schopf. Numerous and varied fossil tracks and trails are present in the shales of the Lower Member of the formation. One type is shown in Figure 30. Various fragments of material which it was hoped might be fossiliferous were collected but none have been identified.

At the present time there is no direct evidence for the age of the Discovery Ridge Formation, other than its stratigraphic position below the Mt. Glossopteris Formation of Permian age and above the Buckeye Tillite. If the tillite is Permian, the Discovery Ridge Formation must be of Permian age, too.

The Mt. Glossopteris Formation

Definition and type area

The name Mt. Glossopteris Formation has been given to an interbedded and repetitive coal measures succession of arkose, feldspathic sandstone, siltstone, shale, and coal. In the Ohio Range this formation is most complete on Mt. Glossopteris (Fig. 33) where it was first observed. The mountain is named for the leaves of Glossopteris which have been found in the shales of the formation. The most complete section of Mt. Glossopteris Formation is located on the North Ridge of Mt. Glossopteris, however the most

Fig. 33. The north face and northwest ridge of Mt. Glossopieris are composed of more than 2000 feet of excellent outcrops of the Mt. Glossopieris Formation (Pg) and are the type section. The contact with the underlying Discovery Ridge Formation (Pdr) is indicated by arrows and a small fault is located with a dashed line.

studied section is on Terrace Ridge of Mt. Schopf. The type area for this formation is in the eastern half of the Ohio Range on Mt. Glossopteris and Mt. Schopf, and should include both Terrace Ridge and the North Ridge and face of Mt. Glossopteris. The type section is the north face of Mt. Glossopteris which has been only partially measured.

Areal distribution

The Mt. Glossopteris Formation crops out only in the eastern end of the map area where it forms the upper 2300 feet of Mt. Glossopteris and all of the sedimentary rocks exposed on Mt. Schopf (with the possible exception of the extreme northeast end). Smaller outcrops are located along the uppermost portion of the northern escarpment where sandstone cliffs are present from Canyon Peak to Quartz Pebble Hill. Portions of these outcrops are shown in sections 1, 2, 3, 4, and in the section on Discovery Ridge.

The outcrops of Mt. Glossopteris Formation usually are of a step-like nature because the siltstones and shales weather more readily than the sandstones. Some of the sandstone cliffs on Mt. Glossopteris are 50 to 100 feet in height presenting obstacles to easy access. On Terrace Ridge the horizontal sandstone beds form broad, flat terraces as shown on the map of Terrace Ridge (pocket).

A few harder, Glossopteris-bearing shale beds are present on the surface of the terraces and provide excellent collecting sites for fossil leaves.

Relation to underlying
and overlying rocks

The base of the Mt. Glossopteris Formation is gradational with the underlying formation, and has been placed at the first massive sandstone above the black, fissile shales of the Discovery Ridge Formation. Animal burrows are present in the zone of transition and above it. Locally the burrows indicate the basal portion of the formation. The lower contact is visible on the north ridge of Mt. Glossopteris and just under the sandstone which caps the escarpment from Canyon Peak to outcrops just east of Quartz Pebble Hill. On Discovery Ridge, the contact has been disturbed by faulting and cannot be seen except as a fault-contact.

The top of the Mt. Glossopteris Formation is not present in outcrops in the Ohio Range. A diabase sill, which caps Mt. Schopf, has intruded the formation and at present is the highest lithologic unit in the range. All strata above the sill have been removed by erosion and it is assumed that the Mt. Glossopteris Formation was originally thicker. Thus the top of the Mt. Glossopteris Formation now is the intrusive contact with the diabase sill. Baked zones are

present near the sill and the effects of the heat from the intrusion extend for about 100 feet into the sandstone and shale below. Heat probably has caused an increase in the rank of the coal throughout most of the thickness of the formation, even though the noncoaly rocks show little or no effects.

Thickness

The Mt. Glossopteris Formation as measured on Mt. Glossopteris is 2300 feet thick. The measurement was done by hand level, except for the uppermost 370 feet which was measured by a Paulin System altimeter. The section measured on Terrace Ridge is 1450 feet thick and is probably equivalent to and, in part, stratigraphically higher than the upper part of the Mt. Glossopteris section. The thickness of the Mt. Glossopteris Formation in the Ohio Range is less than many other similar sections in Antarctica. Coal measures sections, which apparently are correlative with the Mt. Glossopteris Formation, are very widespread in Antarctica, and may be as much as 5000 feet thick (including sills).

Lithology

Feldspathic sandstone, as exposed on Terrace Ridge, comprises about 597 feet or 40 per cent of the section. It occurs in beds from less than a foot to 85 feet in

thickness and forms steep slopes, cliffs, and broad terraces. The bedding varies from thin to thick and many of the feldspathic strata are cross-bedded. The color of the outcrops is typically light yellowish brown on the weathered surface, but may be brownish-gray on the fresh surface. Many feldspathic sandstone beds contain ironstone concretions and limonitic wood. Shale, coal (Figs. 34 and 35), and carbonaceous laminae also can be present as partings in the beds. Fragments of fossil plants, particularly fossil wood, are abundant in some of the beds (Figs. 36 and 37).

In thin-section, the feldspathic sandstone is composed of subangular to angular grains of quartz, feldspar, mica, and fragments from metamorphic rocks in a matrix of silica, clay, sparry calcite, and iron oxide. The quartz shows predominantly straight extinction, but some grains show wavy extinction and have inclusions of very fine dark spots, needles (rutile), bubbles, and tourmaline. Plagioclase is about as abundant as orthoclase, and both fresh and weathered grains are present. Calcite replaces much of the feldspar and also some of the quartz and the matrix. Mica shreds account for less than 5 per cent of most beds and muscovite is more common than biotite. Fragments of metamorphic rocks usually comprise less than 10 per cent of the grains and are generally of schistose texture. Opaque mineral grains commonly are limonite or leucoxene.

Fig. 34. The "Dirty Diamond Mine" was dug into an 11-foot thick coal seam in order to obtain less weathered coal samples.

Fig. 35.

Fig. 36. Fossil logs are present on Big Log Ledge on Terrace Ridge of Mt. Schopf. Some are 2 feet in diameter and 24 feet long. The logs are preserved in limonite. Pitted diabase boulders are present between the logs in the photograph.

Fig. 37. A fossil tree in upright position was found on Terrace Ridge in sandstone of the Mt. Glossopteris Formation. The cross section in the photograph contains 34 annual growth rings up to 1 cm. thick.

Some of these oxides may have been deposited shortly after the deposition of the sand grains because limonite commonly preserves the plant structure in the fossil wood. The matrix and cementing agents in the rocks are a mixture of silica, clay, sericite, carbonate, and iron oxide, although not all are present in every thin section. Replacement minerals (calcite, sericite, oxides) have complicated the matrix.

The texture of the feldspathic sandstone is usually that of moderately sorted, subangular to angular grains in an argillaceous and calcareous matrix. The grain size varies from bed to bed throughout the section from very fine-grained sand to pebble conglomerate with fine- to medium-grained sand being the most common. Most grains show no oriented fabric but some specimens contain shreds of mica and carbonaceous debris which are aligned with the bedding.

Shale, siltstone, and mudstone make up 699 feet or 48 per cent of the Terrace Ridge section. This category includes all the detrital rocks with grains smaller than fine-sand size. The structure, texture, and color of the beds of this nature are quite variable. Some beds have shaly cleavage, others are more massive with no laminated bedding planes, and a few have a high iron content which makes the weathered rock easily seen in outcrop. Much of the fine-grained material is carbonaceous and grades into

coal beds. Mudstone in the outcrop shows poor bedding and fractures from weathering into block-like units. Mudcracks appear to have formed on some mudstone surfaces. Many of the shaly rocks are of high silica content and are rather tough rocks so that splitting along bedding planes is difficult.

In thin-section the shaly rocks are formed of clay-sized particles with small amounts of silt-size grains randomly scattered in the rock. Carbonaceous particles as well as mineral fragments are present. Shales contain Glossopteris and related leaf fossils as discussed in an earlier section.

Coal. The Terrace Ridge exposure contains a total of 76 feet of coal and impure coal in beds which range from 4 to 12 feet thick. These beds are shown on the map of Terrace Ridge (pocket), and on the stratigraphic sections of Terrace Ridge (pocket). Coal beds are interbedded in sandstone and shale, and tend to be concentrated in the middle part of the section. The coal is low volatile bituminous to semianthracite in rank but contains a high percentage of ash, and thus is of low grade.

Schopf (1962) discusses coal from an initial (and limited) collection made from Mt. Glossopteris in 1958. Based on analyses of this collection, Schopf and Long (1960) suggested that the rank of the coal is a result of pre-sill metamorphism. Data from later expeditions show that the rank of the coal is not directly related to distance from

the diabase sill. That is heat and pressure are the two causes for increased coal rank, plots of rank against distance from the sill show that the obvious source of heat (the sill) has only slight effect on the rank of the coal. It is assumed that pressure from sediment load caused the coal to reach a high rank prior to the intrusion of the sill. Subsequent erosion has removed the overlying strata.

A second explanation for the somewhat erratic rank distribution through the section is that more than one diabase intrusion may be or have been present in the area. The thick sill which caps Mt. Schopf is the only sill which has been observed in the Ohio Range outcrops, however.

A (horizontal) adit, unofficially called the Dirty Diamond Mine (Fig. 34), was dug in the lowest large coal seam of Terrace Ridge in order to secure less-weathered samples of the coal. Figure 35 is a diagrammatic cross-section of the adit and shows where the column sample was taken. The sample, as analysed by the United States Bureau of Mines under the direction of F. E. Walker, gives a dry, mineral-matter-free, fixed carbon value of 80.7 which places the coal in low volatile bituminous category. The ash content is variable from 8.6 per cent to 41 per cent, but is mostly below 20 per cent.

In the "Dirty Diamond" adit the coal is composed of much attrital coal with thin to thick bands of vitrain and thin bands of fusain. Some layers of impure nonbanded coal and a lenticular limonitic layer were present. A lenticular body of iron sulfide about 16x6 inches was also recovered at depth in the adit. Fracture surfaces of the coal were typically covered with yellowish-brown limonitic stain and slickenslide surfaces were present along zones of slippage. Fused cleat is present and is indicative of high rank. A description of the coal on the face of the adit is given in the Appendix.

The coal beds are of undetermined lateral extent due to the cover of snow and rock debris. On Terrace Ridge most coals are continuous across the exposed rock (about 4000 feet). The seam in which the adit was dug is covered by snow at other locations across the ridge. The large coal seam (11 feet) at 960 feet below the sill was traced across the slope as were the two thinner seams above it.

On the ridge to the northeast of Terrace Ridge the stratigraphic succession is similar to that of Terrace Ridge but the various beds appear to persist and others do not. It is assumed that the coal seams are more or less lenticular and may not be continuous over distances greater than a mile or two.

Environment of deposition

The Mt. Glossopteris Formation represents nonmarine deposition. The abundance of cross-bedding in the sandstones, and the plant fossils are evidence of terrestrial deposition.

Paleocurrents in the Ohio Range were derived from cross-bed slope directions. More than 1000 readings were made of cross-beds in the Ohio Range. Most of the readings were made on Terrace Ridge and diagrams showing these data are seen in Figures 38 and 39. These show that the predominant slope is to the east which indicates a general highland in a westerly direction. Current directions change slightly from bed to bed up the section of Mt. Glossopteris Formation which may indicate a changing highland but probably reflects changes in the bed of the stream of deposition. The movement of streams from the west agrees remarkably well with the direction of the striae throughout the Buckeye Tillite, which indicate ice movement from nearly due west. The highland during the time of glaciation evidently persisted into the time of coal swamps.

The feldspathic, sandy deposits of the coal measures contain 10 to 25 per cent feldspar grains, 5 to 50 per cent quartz grains, and 15 to 75 per cent matrix and cement. Evidence suggests that the rocks are from a granitic source area. Feldspar grains showing severe replacement and

CROSSBED DIRECTIONS (DOWNSTREAM) (TRUE)
TERRACE RIDGE, MT. SCHOPF

A-BEDS BELOW FIRST MAJOR
TERRACE (32 READINGS)

B-FIRST MAJOR TERRACE
(85 READINGS)

C-SECOND MAJOR TERRACE
(100 READINGS)

D-MAIN GLOSSOPTERIS LEDGE
(100 READINGS)

E-BIG LOG LEDGE (100 READINGS)

F-LUNCH LEDGE (100 READINGS)

G-VERTEBRARIA LEDGE (100 READINGS)

H-SANDSTONE ABOVE VERTEBRARIA
LEDGE (100 READINGS)

I-UPPERMOST SANDSTONE UNIT
(100 READINGS)

Fig. 38.

NOTE: SEE FIG. A FOR PERCENTS
W. E. LONG 1963, 1 P 5

BIG LOG LEDGE LOG DIRECTIONS (TRUE)

A.

LONG AXES OF LOGS AT
SAME AREA AS B.

BIG LOG LEDGE

B.

NEAR MIDDLE OF SECTION

Fig. 39. Comparison of cross-bed slopes and log directions on Big Log Ledge.

accompanying fresh feldspar grains suggest that the climate was humid so as to cause chemical weathering in some areas and that the relief was high enough to cause rapid erosion of valleys. The scarceness of conglomerates indicates that the depositional environment is more distant from the source than an alluvial fan. The high percentage of fine-grained matrix and the interbedded shales and siltstones are indicative of flood plain deposits.

The Mt. Glossopteris Formation probably includes portions of many flood plains which covered successively a broad drainage basin area. Numerous reports of coal along the Transantarctic Mountains mean that the general area of deposition was not restricted. The main streams probably meandered widely, leaving local sandy channel deposits in the adjacent flood plain. Deposition evidently was fairly rapid on occasion, as indicated by the numerous occurrences of erect stumps of trees. Many of the stumps are petrified by limonite and silica.

Fossils

Fossil plant material is commonly found in the beds of the Mt. Glossopteris Formation and consists of leaves, wood fragments, stems, and seeds.

The first Glossopteris leaves were found on the slopes of Mt. Glossopteris in 1958 (Long, 1959; Schopf, 1962) from ledges of hard shale and siltstone on the west shoulder

about 400 feet above Museum Ledge. The following more detailed field studies disclosed that Glossopteris-bearing beds were to be found wherever strata of Mt. Glossopteris Formation cropped out.

Probably the finest exposures are those on Terrace Ridge (map in pocket) where broad terraces of feldspathic sandstone and silty-shales provide large flat areas, some of which are covered with slabs of shale profusely loaded with Glossopteris. The ledge which contains the most abundant Glossopteris-bearing shales is called "Main Glossopteris Ledge". "Giant Glossopteris Ledge" was so designated because the very large leaves (13 inches long) of Glossopteris ampla were found there.

Glossopteris-bearing beds have been found within a few feet of the sill which caps Mt. Schopf and they have been found in shales within 200 feet of the contact with the Discovery Ridge Formation so they are well dispersed stratigraphically within the Mt. Glossopteris Formation.

Fossil wood is also widely distributed in the formation, and generally is found in the feldspathic sandstones. The wood occurs in many forms, from small chips to nearly complete logs as much as 24 feet long. Throughout most of the formation, small pieces of fossil stems are randomly scattered throughout the section. These pieces can be

highly compressed leaving only a carbonaceous film, of they can have their nearly original shape preserved with limonite or silica.

A few sandstone units contain numerous and large logs. At such locations it is easy to imagine ancient forests growing along the shores of a meandering stream. This impression is aided by observing fossil stems which have been buried by sand in a vertical growing attitude. One such area is "Big Log Ledge" on Terrace Ridge where more than 100 logs were counted within a distance of about 300 feet. Figure 39 shows the direction of the axes of 100 logs from Big Log Ledge. Two logs are 24 feet long and one stump measured 27 inches in diameter.

From field observation the wood is of at least two different kinds, one with growth rings of about 0.2 cm. and the other with ring spacing of about 1.0 cm. The wood is presently being studied by J. M. Schopf who (personal communication) states that different specimens of gymnospermous wood will be referable to several genera.

Vertebraria has been found in siltstones, sandstones, and conglomerates on Terrace Ridge, the ridge east of Terrace Ridge, and on Mercer Ridge. Vertebraria was noted particularly in the upper part of the formation, especially in the upper 500 feet. An excellent example of Vertebraria was collected in a conglomeratic sandstone on Mercer Ridge a few feet lower than the level of Leaia Ledge.

Schopf (1962) described plant fossils collected during the first investigation of Mt. Glossopteris in 1958. Plant microfossils were rather poorly preserved in carbonaceous sediments and include: Coniferous pollen grains, Accinctisporites(?) sp., Striatites(?) sp. Microfossils also included other forms of spores and pollen grains as well as fusain fragments.

Fossil wood which was present in sandy sediments was referred to Antarcticoxylon sp. Fossil leaves and seeds include: leaves, Glossopteris indica; seeds, Samaropsis longii; stem, Arthrophyte(?).

Animal trails were present parallel on the bedding planes of a fine-grained sandstone, but the nature of the animal which made the trail is unknown.

Cridland (1963) studied the collections of fossil leaves which were collected during the 1960-61 season. He identified the following plants:

Leaves, Glossopteris indica
Glossopteris ampla
Glossopteris angustifolia
Glossopteris damudica
Glossopteris browniana
Gangamopteris

Seeds, Samaropsis longii
Samaropsis sp.

Stems, Schizoneura(?)

Others, Unidentified foliar organs.

Cridland concluded that the fossil assemblage is indicative of Permian age, and that the abundant plant growth responsible for the fossil plants in the Ohio Range required a radically different climate than that present today.

The only fossil animals which have been found in the Mt. Glossopteris Formation were collected by Doumani in 1960-61 and 1961-62. Doumani and Tasch (1963) have described two new species of conchostrachans: Leaia, n. sp. and Cyzicus (Lioestheria) n. sp. These fossils were collected from Leaia Ledge on Mercer Ridge (Fig. 40). The conchostrachans lived in a swampy environment and they compare with leaiid zones in South Africa, South America, and Australia. They have been assigned a Middle to Upper Permian age which is the same as the Upper Beaufort beds of South Africa.

Age and correlation

The age of the Mt. Glossopteris Formation is based on fossil plants and a single occurrence of a conchostrachian, Leaia. Schopf (1962) describes Glossopteris leaves, Samaropsis seeds, Antarcticoxylon wood, fossil spores from the 1958 collections. Concerning the age of these fossils, he states, "none of the types of fossils is in conflict with a Permian age."

Fig. 40. Leaia Ledge on Mercer Ridge is the only site in the Ohio Range where fossil invertebrates have been found. A man stands below Leaia Ledge (in circle).

Cridland (1963) described a *Glossopteris* flora from the 1960-61 season's collections. He suggests that the flora is of Permian age.

Perhaps the most accurate age determination from fossils is that by Doumani and Tasch (1963) who describe the Conchostracian Leaia which was found at Leaia Ledge (Fig. 38) on Mercer Ridge. Leaia beds are correlated with the Rio do Rasto beds in Brazil, the Newcastle Coal of Australia, and the Lower Beaufort beds of South Africa. Such correlations indicate an Upper Permian age for deposition of the Mt. *Glossopteris* Formation.

Coal measures similar to the Mt. *Glossopteris* Formation have been reported from widespread localities in Antarctica. Ferrar (1907) was first to describe sandstone with carbonaceous debris which he called the Beacon Formation, but failed to limit or accurately designate the boundaries of the Beacon Formation. The term Beacon has become well established in the literature but has been used in so many ways that it presently includes all nearly horizontal sedimentary rocks from Devonian to Jurassic age. Only some of the Victoria Land "Beacon" sections are of coal measures lithology and contain a *Glossopteris* flora. David and Priestly (1914) and Debenham (1921) described other areas in Victoria Land. Recent stratigraphic studies of

the coal measures of Victoria Land have been conducted by Gunn and Warren (1962), Allen (1962), and Mirsky et al. (in press).

Allen (1962, p. 288) reports that the Mt. Bastion coal measures on Mt. Bastion are composed of nearly 3000 feet of sandstones, siltstones, carbonaceous siltstones, coal seams, and conglomerates. The coal seams are found near the base of the formation. Megascopic fossils in the Mt. Bastion coal measures were scarce but spores were found in a "worm-bored siltstone". These spores were studied by Balme in Australia and assigned to the Artinskian (Leonardian) or Kungurian (Guadalupian) stages of the Permian system. None of the material was described or illustrated. Allen (1962) also describes the base of the Mt. Bastion coal measures at location F2 of the Fortresses.

Gunn and Warren (1962) report finding Glossopteris on Allen Nunatak where it was contained in carbonaceous sandstone and siltstone which were interbedded with quartz arenite. Coal beds were included with the strata. Plumstead (1962, p. 30) identified Gangamopteris Palaeovittaria, Glossopteris, roots and seeds from site M.S. 11 on Allen Nunatak. She assigns them a Permo-Carboniferous age and states that, "the rocks must be homotaxial with the lower coal measures of other Gondwana countries." Gunn and Warren show strata of Permian age

on Mt. Crean and Mt. Feather but they say the sections were not examined.

Plumstead (1962) also reports on fossils of a Glossopteris flora collected by Stephenson from the Theron Mountains.

McKelvey and Webb (1959, p. 723) discuss strata which include carbonaceous sediments. These strata are called Member C and are about 465 feet thick and are located on the west side of Beacon Valley.

Mirsky et al. (in press) state that the measured part of the Mt. Bastion Formation in the Mt. Gran area is composed of about 500 feet of carbonaceous sediments with Glossopteris. These beds are correlated with the Mt. Bastion Coal Measures (Allen, 1962) and with the Glossopteris Sandstone (Gunn and Warren, 1962), and possibly with Member C (McKelvey and Webb, 1959).

Mulligan (1963) describes five coal beds from Mt. Gran in Victoria Land where sandstone, shale, and coal beds have been intruded by diabase sills. The coals collected by Mulligan are within the range of anthracite or semi-anthracite (A.S.T.M. system).

Madigan (1914) describes coal-bearing beds from Horn Bluff which were discovered during the Australasian Antarctic Expedition (1914).

Crohn (1959) describes coal-bearing beds of the Amery Formation which is located near the Amery Ice Shelf. Spores from within the coal are sufficient for assignment of a Permian age.

Coal measures deposits seem very widespread in Antarctica and many of them are of Permian age. At least part of the Mt. Glossopteris Formation is of Upper Permian age and, therefore, is probably correlative with parts of other coal-bearing successions, particularly in Victoria Land. Accurate correlations from area to area are impossible at this time, because the necessary fossil information is not present. Lithologic similarities are useful only as indicators. In the Ohio Range, perhaps all formations except the Horlick Formation are of Permian age. Most Permian sections in Victoria Land do not include tillites or large thicknesses of black shale. Grindley (1962) describes a section from the Queen Alexandra Range which is very similar to that in the Ohio Range. The coal measures overlies dark shale, tillite, and carboniferous or Devonian sandstones. The coal measures of the Queen Alexandra Range are considered Lower Permian which suggests they are older than the Mt. Glossopteris Formation of the Ohio Range.

In summary, the Mt. Glossopteris Formation in the Ohio Range may be of nearly the same age as the Mt.

Bastion Coal Measures (Allen, 1962), the Glossopteris sandstones (Gunn and Warren, 1962), Member C (McKelvey and Webb, 1959), the Mt. Bastion Formation (Mirsky et al., in press), a unit in the Queen Alexandra Range (Grindley, 1962), an unnamed formation in the Theron Mountains (Plumstead, 1962), the Amery Formation (Crohn, 1959), and Horn Bluff (Madigan, 1914). Such widespread locations suggest that conditions around the Antarctic continent were very uniform during at least part of the Permian time. The area of deposition appear to have been a low relief with accumulation of sand, mud, and peat. The source area for the Mt. Glossopteris Formation must have been of fairly high relief and actively being elevated while the area of deposition was undergoing fairly rapid subsidence.

The Diabase Sill - (Ferrar? Dolerite)

The highest and youngest rock exposed in the Ohio Range is the diabasic sill which forms the cap rock of Mt. Schopf. The sill on Mt. Schopf (Fig. 41) is the only one observed in the Ohio Range. Loose boulders of diabase were noted near Quartz Pebble Hill and on the flat area of Discovery Ridge, but none of this diabase has been found in place.

Fig. 41. A diabase sill which forms the top of Mt. Schopf is the highest rock unit in the Ohio Range. The sill contact with the Mt. Glossopteris Formation on Terrace Ridge is shown in the photograph.

Size and distribution

As can be seen in the geologic map the diabase which forms the capping sill of Mt. Schopf is about 5 miles long and up to about 3/4 mile wide. The thickness as measured on Terrace Ridge is 580 feet.

Petrography

According to Treves (personal communication), the sill is a hypersthene-pigeonite-augite diabase with labradorite as the dominant plagioclase. Where the sill is in contact with the sedimentary rocks, it is very fine-grained but the sill is medium-grained in the central and upper parts. Gravitational differentiation is only slightly exhibited.

Correlation

Sills are typical in all areas which have been investigated in the Transantarctic Mountains. In the Victoria Land area, Gunn and Warren (1962, p. 123) say the Ferrar Dolerite of Victoria Land includes all basic igneous rocks of tholeiitic affinities and that these rocks may form sills, dikes, bosses, and laccoliths, as well as extrusive lavas and tuffs. All other workers in Victoria Land have found extensive diabasic bodies intruding the sedimentary strata. In the Queen Alexandra Range, Grindley (1962) found Beacon sedimentary rocks extensively intruded by diabase. Doumani and Minshew (in press) report several sills and dikes in the Mt. Weaver stratigraphic succession

in the Queen Maud Range. Plumstead (1962, p. 17) shows sills which occur in the rocks of the Theron Mountains and the Whichaway Nunataks in the mountains bordering the Filchner Ice Shelf.

The Ohio Range differs from nearly all other areas in which sills have been described because there is only a single sill. This sill rests on top of about 4000 feet of sedimentary strata which are undisturbed by igneous bodies. The absence of many sills makes the sedimentary beds easier to study, and also results in less thermal metamorphism of the fossil material.

Age

The sill in the Ohio Range has not been dated. Due to its lithologic and stratigraphic similarity to sills in Victoria Land, it seems reasonable to assume that a single period of sill intrusion was responsible for the emplacement of shallow intrusive bodies all along the Transantarctic Mountains.

McDougall (1963) dated 10 specimens of Ferrar Dolerite from areas in Victoria Land. He used the K/Ar method and has calculated ages which range from 147 to 163 million years. Thus the sills in Victoria Land appear to be of Jurassic age. If the sill on Mt. Schopf was intruded during the same general episode, then it is also of Jurassic age.

STRUCTURAL GEOLOGY

General

The structure of the range apparently is dominated by block faulting. The Ohio Range itself appears to be a fault block which is down-dropped between two higher standing blocks. The location of boundary faults for the range is unknown because of the extensive ice cover.

Elevation of the Ohio Range area was part of a continental uplift with block fracturing occurring at certain locations. Hamilton (1963) states that he has found no evidence of extensive fault systems in Victoria Land. He has proposed that the elevation of the mountains in Victoria Land resulted from broad anticlinal folding (or doming) of the mountainous area. Block faulting occurred concurrently or after the widespread uplift and the results can be observed as smaller scale blocks within the mountain ranges.

Hamilton's (1960 and 1962) ideas concerning the basic structure of the Transantarctic Mountains generally disagree with those of the earlier workers in Victoria Land. David and Priestly (1914) suggested that the Transantarctic Mountains were basically a great horst structure and called

the mountainous belt the Great Antarctic Horst. These ideas have been well summarized by Fairbridge. Gould (1935, p. 978) says, "the Queen Maud Mountains are a part of one of the grand horst, or fault block, mountain systems of the world." He bases his statement on observations of the linear nature of the northern and southern boundaries of the Queen Maud Range. Gould also discusses the same area about which Hamilton has written, and considers the present front of the mountains a fault scarp which has eroded back some 10 to 20 miles from the actual location of the fault responsible for the elevation of the mountains.

In the Ohio Range, neither of the two hypotheses is proven. Evidence for block faulting exists and the mountains seem to have been formed from differential vertical movement of blocks which contain nearly horizontal strata. However, it would be difficult to say that the individual blocks which are present in the Ohio Range are parts of a "great horst structure" or are the results of the break-up of an epeirogenically elevated large land mass.

Structural features are fairly rare in the Ohio Range because of limited outcrops and the simple structure of the range. It is difficult to find good evidence of the structural history of the area. The present elevation of the strata, many of which were deposited at or near sea

level, gives some indication of the extent of structural activity.

Folding

Large-scale folds are lacking in the rocks of the Ohio Range and the strata are nearly horizontal. However, small folds are present within certain units. One area in which they occur is on Discovery Ridge, within the uppermost 100 feet of Buckeye Tillite. The beds are composed of units of interbedded silty shale and tillite. The folds disrupt as much as 20 to 30 feet of strata but units above and below the folded zone are undisturbed. A slightly over-turned synclinal fold in which the axial plane strikes N. 85° E. (true) is present on the west spur of Discovery Ridge. Similar folds were present on the east spur of Discovery Ridge where the axial plane of the folds displayed an axial-plane strike of N. 50° E. (true), with a dip of 15 degrees to the southeast.

These small folds may either have originated while the sediments were still soft; or perhaps they were folded, by horizontal forces related to block faulting, during later orogenic activity. Such structures have been described (Pettijohn, 1949, p. 221) as probably resulting from ice-push during the fluctuating conditions near the end of a glacial episode. Flint (1957, p. 90) discusses

structural features caused by glaciers which over-ride poorly consolidated beds. He suggests that folds (which are similar to those in the Ohio Range) result from the push of the moving ice over incompetent, clayey beds or from flowage due to the weight of the overlying ice.

A second possibility is that the folds were formed after burial and before lithification. Movement would have been of a squeezing nature caused by the weight of the overlying sediment.

A third possibility is that the folding did not take place until the deformation occurred which was responsible for the elevation and faulting of the Ohio Range. If, during block faulting, a wedge-shaped block was dropped between two other blocks, then forces could result which would cause shearing in a horizontal plane. Such forces could cause folding within weaker strata.

Of these various possible origins, that which calls for deformation prior to lithification seems most applicable because of the stratigraphic limitations within the zone of folding.

Faulting

Faults are the dominant structural features which are displayed in the Ohio Range. Major faults are assumed to bound the range, but are not visible. The escarpments as they exist today probably are eroded back from the original zone of faulting. Based on certain linear trends within the range, the major fault pattern is thought to include two major orientations: northeast-southwest and northwest-southeast. This pattern is shown on the map where the relationship of this pattern to the orientation of the topography can be seen. Faults with northeast-southwest orientation probably exist along the escarpment from Discovery Ridge to Higgins Canyon. Parallel faults occur to the northwest and southeast of Mt. Schopf. These faults probably can be traced to the northeast towards Urbanak Peak and Ivorsen Peak.

Evidence for northeast-southwest oriented faults is provided by the relative levels of the basement erosion surface on Discovery Ridge and Treves Butte. This offset (Fig. 11) has been measured by hand leveling on Discovery Ridge where it is about 650 feet. The sections measured on Mt. Glossopteris and Mt. Schopf suggest that a fault separates the two mountains. The summit of Mt. Glossopteris, 9400 feet, is higher than the base of the sill on Mt. Schopf. Assuming the sill once covered Mt. Glossopteris, the

relationship suggests that Mt. Glossopteris is an uplifted fault block relative to the block which includes Mt. Schopf.

A set of northwest-southeast faults appear to modify the structures of the northeast-southwest faults. Trends of fractures and cliffs suggest a northwest-southeast fault just off the northeast end of the Ohio Range and another crossing the middle of the range from Higgins Canyon to Mercer Ridge on the southwest end of Mt. Schopf. A third fault of this set would account for the linear pattern of the southwest terminus of the Ohio Range.

The boundary fault system must be of large magnitude. Seismic and gravity data (Bentley and Ostenso, 1961), taken during the 1958-59 Byrd Station Traverse, indicated that about 10,000 feet of relief is present between the summit of Mt. Glossopteris and the camp at Mile 414. These locations can be seen on the map (pocket) and are about 4 miles apart. Such elevation differences are fairly common in regions in North America where block faulting has occurred (the Great Basin) and it seems reasonable to assume that faulting has produced such relief in the Ohio Range.

On the other hand, great escarpments in South Africa, such as the Drakensberg Escarpment, are not a result of faulting (King, 1942, p. 299). Such escarpments have been

produced by general uplift, followed by headward erosion of stream valleys. This type of escarpment-forming process produces topography very similar to that in the Ohio Range, but the presence of faults in the latter suggest that faulting played a large part in producing the present topography.

Zones of small faults are present at several localities within the Ohio Range. One zone is located on the upper part of Discovery Ridge and along the escarpment from Quartz Pebble Hill for about half a mile to the southwest. A normal fault on Discovery Ridge has a bed displacement of about 100 feet, which, with an associated fault zone, brings the upper part of the Discovery Ridge Formation in contact with the basal sandstone beds of the Mt. Glossopteris Formation. The fault shown in Figure 32 strikes N. 10° E. and dips about 60 degrees to the southeast. A nearby fault plane strikes N. 75° E. and dips 45 degrees to the southeast, and another strikes N. 70° E. and dips 45 degrees to the southwest.

Along the top of the northern escarpment just to the west of the eastend camp and Quartz Pebble Hill the data in Table 4 were recorded. The attitude of these fault planes nearly parallels the directions of major faulting suggested by the linear trends of the northwest escarpment and Mt. Schopf.

Table 4. Fault Attitudes
Near Quartz Pebble Hill

	Strike	Dip
Fault	N. 50° E.	steep
Attitude of beds	N. 20° E.	55° NW
Within small fault slice	N. 30° E.	30° NW
	N. 30° E.	35° NW
	N. 30° E.	20° NW
Cross-faults	S. 55° E.	vertical
	S. 50° E.	vertical

Mercer Ridge is another area which has been severely disrupted by numerous small faults. A few faults are obvious from a distance on the ridge as seen in Figure 42. The wedge of diabase which is seen in the figure once was continuous with the sill which caps Mt. Schopf and has been faulted to the lower position. A normal fault plane striking N. 50° E. and dipping 70 degrees northwest is present along the fault contact and indicates that the prominent wedge-shaped piece of diabase in Mercer Ridge resulted from normal faulting with the northside having dropped. This fault terminates against the southwest end of Mt. Schopf. The place where the fault disappears is the zone of one of the major cross-cutting faults of the range.

Fig. 42. Major faults on Mercer Ridge are shown as dashed lines. Diabase has been step-faulted. Numerous small faults are present but not visible on the ridge. Leafia Ledge is circled.

The interruption of a fault bearing N. 50° E. by a zone oriented about N. 45° W. suggests that the former faulting took place before the latter. A similar relationship only on a larger scale exists with the junction of the major fault systems in Higgins Canyon where the northeast-bearing fault is offset by the northwest-bearing set.

On Mercer Ridge, there are many small faults with displacements from a few inches to a few hundreds of feet. Bedding attitudes are very erratic and tracing beds for more than several hundred feet is difficult. The ridge gives the impression of having been "shattered." A block of upturned beds on the northwest side of the ridge appears to be a large slump block. Only very detailed mapping will allow a complete analysis of the highly complicated fault system on Mercer Ridge. The geologic map shows only major trends. The complex nature of Mercer Ridge probably results from a junction of the two major fault trends.

Only small faults with a few inches to a few feet of displacement are present on Terrace Ridge. One area on Terrace Ridge displayed highly contorted bedding of very restricted distribution. On the map of Terrace Ridge this zone is called the disturbed area. The origin of the disrupted bedding is unknown.

Faults also were observed on the ridge east of Terrace Ridge. Here normal faults are parallel to the front of Mt. Schopf. One such fault offsets beds sufficiently so

that accurate measurement of the section is not possible. Below the lowest sedimentary rock outcrops on this ridge a small outcrop (about 100 feet across) of diabase is present, suggesting down-faulting on the order of 1400 feet.

Similar evidence for a down-dropped block between Mt. Schopf and Mt. Glossopteris is present in the pass between the south ridge of Mt. Glossopteris and the northeast ridge of Mt. Schopf. Here a small outcrop in the middle of the pass is formed of diabase in contact with sedimentary strata.

Small faults also were present on the south ridge of Mt. Glossopteris. The nature of the faults was not ascertained because of limited outcrops and difficult access. One small "fault block" along the ridge displayed tilted beds with a strike of N. 15° W. and dip of 20 degrees southwest. Such could be a toreva block.

Other faults were observed on the north ridge of Mt. Glossopteris where a fault zone probably cuts the Discovery Ridge Formation along a flat shoulder on the ridge. This fault zone may be a continuation of the zone which truncates the Discovery Ridge Formation on Discovery Ridge. It also could be related to the cross fault system which forms the northeastern boundary of the Ohio Range.

No faults were observed in the rocks of the western end of the range. If the western block is as much fractured as

the eastern block, then snow cover conceals the faulting. Since the granitic basement is higher and most outcrops are composed of tillite, it seems reasonable that the block might be more stable. Even if small offsets were present they would be difficult to discern in homogeneous beds of dark greenish gray tillite.

Joint Patterns

Joint directions were measured on Terrace Ridge in order to see whether or not they were related to fault patterns. Ledges which contained mudstones, siltstones, or sandstones with well-developed joints were used. Joint data are given in Table 5.

Table 5. Joint Directions,
Terrace Ridge.

1)	Sandstone, about 50 feet below sill	N. 20° E.	N. 75° W.
2)	Sandstone, about 130 feet below sill	N. 15° E.	N. 85° W.
3)	Sandstone, about 200 feet below sill	N. 60° E.	N. 30° W.
4)	Mudstone, about 430 feet below sill	N. 45° E.	N. 45° W.
5)	Mudstone, about 610 feet below sill	N. 55° E.	-----
6)	Shale, about 640 feet below sill	N. 45° E.	N. 45° W.
7)	Shale, Big Log Ledge about 710 feet below sill	N. 45° E.	N. 35° W.
8)	Dirty Diamond Mine		N. 25° W.

The above directions show a tendency to group around N. 45° E. and N. 45° W. When plotted on a map of the range, it is perhaps significant that these joint directions are about parallel to the fault pattern which has been suggested for the major boundary faults of the range. Such a parallelism of patterns lends support to the concept of faults as shown on the geologic map.

GEOLOGIC HISTORY

The history of the Ohio Range can be developed from the nature of the sedimentary rocks and from the interpretation of breaks in the stratigraphy and analyses of evidence of intrusion and erosion.

Pre-Sedimentary Rock

The oldest rocks which are exposed in the Ohio Range are the granitic rocks which form the basement complex. These intrusive igneous rocks represent granitic intrusion which probably was related to orogenic activity all along the Transantarctic Mountains. Radiometric age dating methods indicate that orogeny and metamorphism took place about 450 to 500 million years ago or in Early Cambrian time. Orogenic activity and intrusion took place in the Ohio Range at about the same time as similar activity in Victoria Land. It is logical to assume that during Late Cambrian and Early Ordovician time the area of the Transantarctic Mountains was orogenically active.

Thus the history of the Ohio Range started sometime during the Cambrian Period. Based on relationships of granites and metamorphic limestones and graywackes in

Victoria Land (Gunn and Warren, 1962; Grindley, 1962), this intrusion displaced Cambrian deposits and metamorphosed them. A considerable thickness of Early Cambrian or Late Precambrian sedimentary strata must have been present because the quartz monzonite crystallized at considerable depth.

Following intrusion the area was elevated to a position above sea level high enough so that erosion removed the sedimentary cover and dissected and reduced the quartz monzonite itself to a surface of low relief.

The time of erosion of this surface is not exactly known but a long time must have been required to form such an extensive surface of low relief. The extent of the surface is not accurately known but in Victoria Land the nonconformity between basement and horizontal sedimentary rocks is very obvious and mentioned by many authors. Debenham (1921, p. 105) first describes the nonconformity from an area near the Kukri Hills. Gunn and Warren (1962, p. 57) have called this ancient erosion surface the Kukri Peneplain, and have traced it for 900 miles from Mt. Nansen near Terra Nova Bay to Mt. Fridtjof Nansen in the Queen Maud Range. In all areas the surface shows relief up to about 100 feet. The old surface can be seen in aerial photographs in the Wisconsin Range and Thiel Mountains. On the other side of the continent Plumstead

(1962, p. 18) mentions a profound unconformity in the Shackleton Range. Such observations suggest a widespread area of low relief.

Devonian Sedimentary Rock History

In the Ohio Range the great period of erosion was terminated by transgressing seas during the Lower Devonian Period of about 380 million years ago. The deposits left by the Devonian seas comprise the Horlick Formation. The climate just prior to the transgression was conducive to deep physical and chemical weathering. Calm beach conditions prevailed so that old soils were not completely removed and the sand for the beaches was derived from the granitic rocks of the basement.

The brachiopods and other fossils indicate that transportation of the clastic debris was not extensive. The Devonian shore in the Ohio Range supported marine life like brachiopods, pelecypods, bryozoans, trilobites, cephalopods, and gastropods. Extensive transportation of the fossils or reworking from older deposits is not likely because of the preservation of the articulate brachiopod, Pleurothyrella.

Psilophitic plants in the shales of the Horlick Formation grew under swampy and brackish conditions very near sea level. Throughout about 160 feet alternating

sandy beds with marine fossils and dark shales with plant fossils represent alternating conditions of relative sea level. The configuration of the shoreline during Lower Devonian time is not known. Adie (1962, p. 32) suggests that a somewhat limited finger of the sea penetrated into the main continent from the direction of West Antarctica. Such a suggestion is consistent with the one set of data presently available, that from the Ohio Range.

Presumably, deposition in Devonian time continued because in Victoria Land upper Devonian fish scales were discovered by Debenham (Woodward, 1921, p. 51) in dark shales in the Granite Harbour area. Gunn and Warren (1962, p. 108) describe finding poorly preserved fresh water fish scales of Upper Devonian age.

Deposition probably continued but only the Emsian part of the Devonian deposition is recorded in the Ohio Range.

Lower Devonian to Lower Permian

An extensive disconformity is suggested by the distinct erosion surface under the tillite and strata of Mississippian and Pennsylvanian age are missing from the section. The length of time represented by this hiatus is about 80 million years for the Carboniferous and about 30 million years for the Middle and Upper Devonian. For a total of

110 million years the earth's crust in the area of the Ohio Range remained fairly stable, enough so, that the Early Devonian beds were in nearly their original position when the glaciers of the Early Permian spread over the area and smoothed out the larger topographic features.

A time of erosion probably preceeded the onset of glacial conditions in the Early Permian, but even so a large part of the erosion responsible for the present disconformity was caused by glacial action. Striated and grooved surfaces on the Horlick Formation testify to the fact that glacial erosion was active. Such glaciation probably reduced the relief of the pre-tillite topography to a low rolling countryside.

Permian

Conditions during deposition of the Buckeye Tillite are suggested by the name itself. The climate was frigid. The duration of the glacial conditions is not known but if the glacial episode started in Lower Permian it could only have persisted through a small portion of Permian time because all of the overlying beds in the Ohio Range are also of Permian age.

The Permian glacial episode included recessions and advances of the glaciers in a fashion similar to the oscillations of the glaciers in North America during the

Pleistocene Epoch. Interbedded sandstone, conglomerate, and shaly beds represent times when water both sorted and deposited sediment. In the Buckeye Tillite at least two widespread recessions are represented. Lenticular bodies of sandy sediments indicate that at least some sort of glacial fluctuation was allowing streams to deposit sand. Boulder pavements also suggest fluctuations of the ice mass.

The ice in the Ohio Range flowed from a westerly direction which suggests that higher land lay to the west. The pebbles and cobbles of the tillite indicate that the dominant source rock was a graywacke. Such lithologies have been described for the Robertson Bay area (Rastall and Priestley, 1921), from the Edsel Ford Ranges (Warner, 1945), and from Victoria Land where Gunn and Warren (1962, p. 70) refer to it as the Teall Graywacke. Rocks of this type were exposed in highlands to the west of the Ohio Range.

When the tillite of the Ohio Range is compared to tills deposited by Pleistocene glaciers, the largest discrepancy is the thickness of the Buckeye Tillite. Most till sheets in North America are of less than 300 feet. However, tills up to 1400 feet have been reported (Flint, 1936, p. 1860). Such deep accumulations of till are valley fillings. Tills of thickness greater than a thousand feet are also present

in the Seneca and Onondaga valleys of New York (Flint, 1957, p. 111).

Using the North American example it is reasonable to suggest that the tillite seen in the Ohio Range is a valley-fill type deposit. If the valley sloped so that flow was from west to east, then the valley would have to be more than eight miles wide. All the sections of tillite which were measured in the Ohio Range contained thicknesses on the order of 900 feet. While small valleys are ruled out, it is possible that the glaciers could have filled a wide valley. This valley could have been of an erosional origin or a tectonically-formed valley similar to those present today in the Great Basin region of North America.

When discussing thick tillites, the Dwyka Tillite of South Africa must be mentioned. The Dwyka (DuToit, 1956, p. 267) has been described as occurring in a northern and southern facies. The thickness of the northern facies in Central Transvaal ranges from 0-30 feet. In the Cape Province, Dwyka Tillite reaches its maximum thickness of more than 2500 feet. In the Cape Province all other strata are thicker than their northern equivalents. Such a relationship is indicative of a geosyncline and DuToit (1956, p. 274) considers that the great thicknesses of tillite in the Cape Province have resulted from deposition in the Karroo Geosyncline. He has previously (1921, p. 208)

stated that these thick tillites were deposited in bodies of fresh and brackish water and that probably the glacial ice floated like the Ross Ice Shelf does today. The presence of bedded tillite and sandy beds are used as evidence.

It is possible that the Buckeye Tillite could have been deposited in or near a subsiding basin and could be considered a geosynclinal deposit. However, most geosynclines involve marine deposition and are associated with different kinds of rocks than those of the Ohio Range. Most of the deposition of the Buckeye Tillite is of non-marine origin and yet it is a thick deposit for a till.

Three possibilities for the depositional environment of the tillite are valley fill, geosynclinal, or an interior basin. Stratigraphic studies from more widespread localities are needed for a more complete interpretation of this formation. The Ohio Range could have been on a subsiding continental margin and thick deposits would result. It is also possible that a very wide river system filled an eroded and depressed valley area. Also, the area could have been one of interior drainage with uplift around the margins providing detritus to be transported to the basin by ice, water, or wind.

The siltstones and shales of the Discovery Ridge Formation were deposited in rather shallow and restricted waters so that animal tracks of several descriptions are

present. The silt content of the platy shales resulted from sediment supplied from nearby highlands and the carbon content of the silty muds would result from poor oxidizing conditions. The gradational change of the hard, silty shale to the highly carbonaceous, soft, fissile shale resulted from increased isolation of the basin and further restriction of the waters so that reducing conditions were present. Such water is poisonous to most life.

The nature of the body of water in which the Discovery Ridge Formation was deposited is not known. Flattened clay pellets are present and may indicate that it was a fresh water deposit but sure proof for fresh or marine water is not known.

Considering the continental nature of the underlying Buckeye Tillite and the overlying Mt. Glossopteris Formation, it is tempting to suggest that the Discovery Ridge Formation was deposited in a large inland lake.

The Upper Permian Period is represented in the Ohio Range by the Mt. Glossopteris Formation. No depositional break is present between the latter formation and the dark shales of the Discovery Ridge Formation. The sand content increases at the top of the formation until the lithology is no longer a shale but an arkosic sandstone. Such a change could come about from an uplift of a source area, providing an active source of sand grains.

The arkosic sandstones of the Mt. Glossopteris Formation are indicative of rapidly rising granitic highlands. The feldspar grains in the arkoses are both weathered and fresh, suggesting that the source area was of high relief in a humid climate. In such a source area the interstream divide is subject to chemical weathering and produces weathered grains. In sharp valleys where streams are actively eroding the resulting grains are little weathered. A high per cent of matrix suggests that sorting was not efficient and that the arkose is immature (Folk, 1961, p. 115).

The sandstones are commonly cross-bedded, which helps to indicate the continental nature of the beds, and the presence of fossil wood is evidence that the sands were accumulated in a non-marine environment. Some of the sandstone layers have sharp bottoms which have resulted from erosion of the underlying strata. Such beds are considered channel deposits which flowed from higher land to the west of the Ohio Range.

The fossil wood in the arkosic sandstones is good indication that trees flourished during Late Permian time. Many stumps are in vertical growing position, their root areas in siltstones and mudstones indicating that trees grew in place. The growth rings in the trees seemed of two general sizes; a smaller (0.2 cm.) and a larger (1.0 cm.). Data taken from logs on Big Log Ledge has been

discussed earlier. The distinctness and large size of the growth rings are indicative of rapid growth in a seasonal climate (Schopf, 1962, p. 44). Coal beds and the abundant Glossopteris leaves in shale and siltstone beds also indicate that plant growth was profuse during Mt. Glossopteris Formation time.

Sedimentation was fairly rapid. Buried logs, and especially burial of trees in an upright position before the trees can rot require rapid deposition. Replacement of the wood by limonite suggests conditions of oxidation which would cause deterioration of the wood unless quick burial prevented rotting. The thickness of the Mt. Glossopteris Formation is greater than 2300 feet. Such thick deposits also suggest fairly high rate of sedimentation. Compared to the Ohio deposits of Pennsylvanian age, twice as much sediment was deposited in about one-third the time. That is, the rate of sedimentation during the Upper Permian in the Ohio Range was about six times that of the coal measures in Ohio.

The rate of deposition indicates that the area was being depressed and that an active source was present. Thus tectonic conditions during Mt. Glossopteris time seem similar to those of Buckeye Tillite time. In each case, relatively thick deposits are present.

The whole succession of strata in the Mt. Glossopteris Formation can be explained as stream deposits in a very wide valley or coastal plain. Meandering rivers carve channels and deposit sand. Silts, muds, clays, and peat form in the deposits which are adjacent to the channel, that is in the meander belt or entire valley system. If the bedding were one of a coastal plain, then several or many rivers could be involved.

The close of the Permian Period is not recorded in the Ohio Range because all strata younger than Permian have been removed. Evidence that there once was a much greater thickness of sedimentary rocks is provided by observation of the coal. The coal, which has been discussed under a separate heading, which has been analyzed from the Ohio Range is of low-volatile bituminous to anthracite rank. Heat, load pressure, and deformational shear pressure can cause increased rank of coal. The latter is ruled out because of the non-folded structure of the Ohio Range. Early workers thought the high rank of the coal was due to thermal metamorphism from sill intrusion, however, Schopf (1962, p. 50) discusses properties of Antarctic coal which show that the coal had attained fairly high rank (degree of metamorphism) before intrusion of the sills. Schopf's first point is that coal collected in the Theron Mountains (Brown and Taylor, 1961) had the structure

of natural coke. Coal which is about to be coked must be of higher rank than sub-bituminous coal. Therefore, the fact that the heat from the sill was able to coke an adjacent coal bed means that the coal was of at least bituminous rank before sill intrusion. His second point is that if the heat from the sill had caused the change in rank from a brown coal or lignite to a high rank coal, much moisture would be released with a loss of volume within a coal bed which would result in shrinkage cracks. Such evidence is not present in the coal beds.

The above reasoning is evidence that the sills only helped raise the rank of coal. Thus load pressure must have been responsible for increasing the coal to bituminous ranks and heat from the sills elevated it to low-volatile bituminous or anthracite, depending on the nearness of the coal bed to the sill.

The point of the above discussion is that a considerable thickness of sediment must have covered the presently exposed Mt. Glossopteris Formation.

Post-depositional History

Deposition may have continued through Triassic and into Jurassic time, even though only rocks of Permian age are present today. In Victoria Land, Gunn and Warren (1962, p. 111) reported plants which have been assigned (Plumstead,

1962, p. 93) to the Jurassic (Lias) Period. Such strata indicate that deposition in Victoria Land continued into the Jurassic. It is possible that deposition in the Ohio Range was of similar duration but all proof of such is gone.

The highest and youngest rock unit present in the Ohio Range is the diabase sill which caps Mt. Schopf. This sill represents a time of intrusion of basic magma into the horizontally bedded sedimentary rocks. Because sills are widespread over Antarctica and are usually associated with similar rock units, it can be assumed that the sills are of similar age. Ten samples from sills up to 400 miles apart have been dated by McDougall (1963, p. 1537) with a spread of ages from 147 million years to 163 million years. This range neatly fits in the Middle Jurassic. It is probable that the sill on Mt. Schopf was emplaced during the same intrusive interval as the Ferrar Dolerite in Victoria Land.

The record is not present for any geologic history later than Jurassic, except for the final elevation, glaciation, and faulting of the range. Much of the details of the structural features and structural history of the range has been discussed in chapters on Geomorphology and Structural Geology.

The final event in the history of the Ohio Range, however, was the elevation and faulting which has led to the topographic features which presently form mountains of this range and upon which the present glacial processes are working.

Historical Summary

In the overall historical view of the Ohio Range a peculiar cyclicity of events is evident. Climatically the first sedimentary rock (Horlick Formation) of Devonian age testify to fairly equitable conditions with animals and plants living in a beach environment. By Early Permian time glaciers have dominated the scene and cold conditions allow nothing to live. Then in Late Permian the landscape is covered with thick plant growth and animals are nearly absent, but climatic conditions have returned to a temperate nature. The latest interval which is observable, that of today, shows the climate again polar with extremely low temperatures inhibiting nearly all landlife.

Such climatic fluctuations through the last 400 million years are not commonly found in the northern hemisphere. This alternation is typical of portions of most of the southern continents and the similarity has been so obvious that many geologists have suggested that the continents must have been joined at one time in the past. From such

comparisons the concept of Gondwana, the original great continent, was born. In 1885 Suess, in his publication "Anlitz der Erde," proposed the name Gondwanaland for an old landmass comprising Africa, Madagascar, and the Indian Peninsula. During following years other southern hemisphere continents were seen to have belonged to Gondwanaland. In 1919, J. M. Clarke suggested that Antarctica was part of Gondwanaland throughout most of the Paleozoic. Concepts of an ancient continent of large size naturally led to hypotheses concerning the break-up of such a continent and the concept of continental drift resulted. While Snider (1858) was the first to suggest that the continents may have been nearer each other, Wegener was one of the first to comprehensibly discuss the theory in his book, "The Origin of Continents and Oceans."

Many volumes have been and are being written concerning continental drift, but to date no one has produced conclusive evidence for either side of the question. There are many ways in which the hypothesis may be approached. Stratigraphic geology provides some of the best sort of evidence available because the Paleozoic stratigraphy of one part of Gondwanaland must match its separated parts if the continents were once joined. In order to adequately compare stratigraphic successions between continents it is necessary to have fairly detailed stratigraphic data.

Antarctica should be one of the "key" continents in the Gondwanaland concept, but as yet the stratigraphic geology of this frozen continent is only slightly known. From studies of areas such as the Ohio Range a better understanding of Antarctica's geologic past will result. With more stratigraphic studies, particularly at selected locations, questions concerning the nature of Gondwanaland may be answered.

PERMO-CARBONIFEROUS TILLITE IN SOUTH AFRICA

Perhaps the best known glacial beds in the southern hemisphere are those of the Dwyka in the Union of South Africa. The glacial beds or boulder beds of the Dwyka Series belong in the Karroo System. The Karroo System rests on top of the Cape System and contains the Dwyka, Eccra, Beaufort, and Stromberg Series.

The Dwyka Series forms the basal unit of the Karroo System and is composed of three subdivisions: the Lower Shales, the Boulder Beds, and the Upper Shales. The relationship of the Dwyka beds to the Karroo System is shown in Table 6.

Historical Studies of the Dwyka

Many of South Africa's great geologists have written concerning general descriptions and proposed origins of the Dwyka Boulder Beds.

The first description of the Dwyka was in the form of a communication to the Geological Society of London by A. G. Bain in 1856. In describing the "Geology of Southern

Table 6. Karroo System, Union of South Africa

	Series	Cape	Maximum Thickness	Central Transvaal	Mean Thickness
Triassic	Stromberg	Drakensberg Basalts	4500	Bushveld Amygdaloid	1000
		Cave Sandstone	1000	Bushveld Sandstone	300
		Red Beds	1600	Bushveld Mudstone	400
		Moltena Beds	2000	-----	
	Beaufort	Upper Middle	2000 1000	absent	
Permian	Ecca	Lower	9000		
		Upper		Upper	300
		Middle	10000	Middle	200
		Lower Upper Shales	650	Lower -----	200
Carboniferous	Dwyka	Boulder Beds (Tillite)	2500	Glacial Conglomerates	0-30
		Lower Shales	750	-----	
		TOTAL	35,000	TOTAL	2,430

Africa," he describes a unit of rock which he called the "Claystone Porphyry" which he found to be so extensive that he wrote: "I little dreamt then of its enormous extent." He traced the unit for 600 miles around the southern tip of Africa and assumed that the northern limit of the bed must lie "perhaps thousands of miles" to the north.

As indicated by the name, "Claystone Porphyry," Bain considered the Dwyka an igneous rock. He believed the whole rock unit was a volcanic flow which had originated near the junction of the Vaal and the Orange River. Although his concept of the origin of the Dwyka was incorrect, he described the unit with fair accuracy.

Bain noted that there were numerous pebbles of granite, sandstone, quartz, and clay slate in a non-bedded matrix. He also observed that the pebbles were not altered by heat which led him to state that, "one might be led to believe the whole was an aqueous deposit." But because no stratification could be discerned he could not imagine a sedimentary origin for the rock.

In 1870 Sutherland became the first to suggest a glacial origin for the boulder beds. He studied outcrops in Natal where the Dwyka is thinner and rests on glacial pavements. In such a setting the boulder beds are much less igneous in appearance.

Sutherland noted that the matrix was uniform and homogeneous and contained fragments of other rocks. The

unit of boulder clay rests on a deeply grooved and striated surface on older sandstone. Also, the boulder beds graded laterally into "true slate" or bedded deposits. He could find no vent for a possible extrusive source. He did find ripple marks, gradational sandstone and shale, and fragments which had a "rubbed" appearance but there were no signs of chards or glass. Such observations convinced Sutherland that the unit was not of igneous origin.

Many of the boulders had come from miles away and must have been transported in a moist and plastic mass. The rock looked so similar to Scandanavian drift that Sutherland stated that it was probably " a vast moraine of olden time." Further, "ice, in some form or other, has had to do with its formation, at least so far as the deposition of the imbedded fragments in the amorphous matrix are concerned."

The name "Dwyka Conglomerate" was introduced by Dunn in 1875 from outcrops of the formation along the Dwyka River near Prince Albert. He used Dwyka Conglomerate for the southern outcrops and Glacial Conglomerate for the northern occurrences.

In 1896 the geologists of the Geological Commission of the Cape of Good Hope agreed that a glacial origin for the Dwyka Conglomerate or tillite was most reasonable

(Schwarz, 1896, p. 28). During the following years controversy concerning the origin of the Dwyka continued although most geologists who studied the boulder beds in the field were convinced of their glacial origin.

Molengraaff (1899) presented evidence from the Vryheid district which he felt supported the theory of glacial origin. Polished and scratched surfaces showed striae directions of S. 28° E. to S. 33° E., and he felt the ice had come from the southeast. Roches moutonnees were up to 50 feet high under the Dwyka beds. The nature of Dwyka Conglomerates was very similar to that of boulder clay deposited by Pleistocene glaciers. The alteration of stratified and unstratified deposits was indicative of changing condition of till deposition and glacial stream deposition. He reasoned that in such a situation deposits near the center of the ice should be free of stratification and deposits at the perimeter could be of bedded nature. In some places the stratified beds included pebbles and in other places contained no pebbles. Cross-bedding, ripples, and alternate grain sizes were found. He also noted that the sands of the assumed outwash stream were different than ordinary river-deposited sands.

The pebbles and boulders of the boulder beds were predominantly of a lithology similar to that of the local rock under the tillite. However a few boulders of

lithologies from distant outcrops were included. In the Vryheid district the sub-Dwyka beds are at differing levels, ranging from 1500 to 3500 feet. Much of this is probably due to faulting and some from glacial and pre-glacial erosion. The thickness of the tillite is variable and the thickness is greater over pre-tillite depression than it is over ridges. The average thickness is about 300 feet.

In summary Molengraaff stated that none of the main characteristics of a moraine are missing from the Dwyka.

Mellor (1905) discusses various features of the Dwyka. The earlier paper is devoted, in large part, to descriptions of glacial pavements and also presents the first report of the Glacial Conglomerate in the northern part of the Karroo Basin near Pretoria. He preferred to call the unit "Glacial Conglomerate" rather than "Dwyka Conglomerate" because of the difference of lithology between the northern and southern outcrops. He thus was one of the first to note the facies variation in the Dwyka.

The Glacial Conglomerates northeast of Pretoria were composed of glacial boulders embedded in a matrix of angular rock fragments. The rock did not have the igneous appearance that the southern facies displayed and it seemed to be of a different nature and origin. Its lithology was uniform over many miles and it displayed the character of ground moraine. The boulders were of miscellaneous size

and shape. Some of them were polished and many of them were faceted. A few, particularly fine-grained rocks, were striated. Sandstone interbeds with the Glacial Conglomerate were irregular in thickness, massive, of a white, yellow or cream color, not persistent, and frequently showed fine lamination.

The glacial beds were usually relatively soft and easily eroded and seldom visible at the surface. Occasionally an outcrop could be found on a valley slope and contacts were hard to locate due to soil cover. The Glacial Conglomerate was irregular in distribution and probably had been deposited on a surface with good relief. Many of the escarpments and valleys today in the area are of similar magnitude to the pre-glacial conglomerate land features. Patches of the glacial beds were found at many elevations.

The most common lithology of the boulders was a quartzite like the Waterberg Quartzite, the local pre-glacial formation. Many well-rounded, medium-sized pebbles of white quartzite were present in a brown, sandy matrix. The second-most abundant pebble and boulder lithology was granitic, particularly syenite and granite porphyry. Wherever the glacial beds were over conglomerates or shale of the Pretoria Series, shale boulders were present.

Striae on glacial pavements as well as identifiable boulders from known strata indicated that ice moved from north-northwest to south-southeast.

Evidence of widespread glaciation is provided by (1) the nature of the glacial deposits; (2) constant striae direction (up to 25 miles apart); and (3) the wide distribution of the beds.

Mellor notes that the Glacial Conglomerate is distributed over a large part of South Africa, including major portions of the Cape Colony, Natal, Orange River, and southeastern Transvaal.

The glacial beds grade downward into greenish shales which in turn grade into Witteberg Quartzite. To the north, the Dwyka Series overlapped lower divisions of the Cape System and in the northerly areas rests on pre-Cape System rocks. In the Cape Colony and Natal, the Dwyka was gradational upwards into Eccra shales and mudstones.

Mellor discusses the thick (about 1000 feet) facies of the southern Cape Colony, the moderate (about 700 feet) thickness of the Dwyka in the northern Cape Colony, and the thin (less than 50 feet) nature of the glacial beds in the northern areas. The difference in thickness, hardness, and character of the beds suggests that the Dwyka in the southern Cape Colony was deposited from glaciers entering a deep body of water. The northern deposits were a result of glacial deposition on land.

Wagner (1915) described glacial beds of the Dwyka Series in South-West Africa. Earlier descriptions of the Dwyka in South-West Africa stated that the beds were

deposited as ground moraine but because of a gradational contact with beds containing Euredesma and Conularia Wagner proposed that the glaciers invaded a shallow sea. He presented a few sections, like that in Table 7, which show relationships of the lithologies.

Table 7. Tillite Section, Keetmanshoop District, South-West Africa

Bedded conglomerate and shaly sandstone	4 feet
Tillite	2 feet 6 inches
Grit	6 inches
Bedded conglomerate	2 feet
Calcareous sandstone	1 inch
Diagonally-bedded grit	12-18 inches
Basal tillite	7 inches

The boulder mudstone is a dark, bluish-green weathering rock with an argillaceous-sandy matrix in which are scattered rounded and faceted pebbles and boulders. The boulders are like those in tillite. The boulder mudstones are gradational with Conularia- and Euredesma-bearing beds.

The sequence of events that Wagner proposes is as follows:

- (1) Advance of ice in a west-southwest direction, forming basal tillite.
- (2) Retreat of ice with fluvial glacial streams or sub-ice streams depositing sediment.

- (3) Advance of ice with upper tillite forming.
- (4) Retreat of ice, conglomerates forming.
- (5) Subsidence with deposition of boulder mudstone and Euredesma shales.

Other theories have been proposed for the origin of the Dwyka Tillite. Bain, "The Father of South African Geology" (who has already been mentioned), thought that the mass was a flow from a large volcano. Others thought it was a "coarse shingle" formed along a receding breccia. Early in the history of South African geology, most geologists favored a volcanic theory, perhaps submarine volcanoes.

Probably the most comprehensive and modern stratigraphic consideration of the Dwyka Series are presented by DuToit (1922, 1926, 1956). The following table shows the relative thicknesses of the Dwyka in northern and southern South Africa.

Table 8. Dwyka Tillite, Section in Cape Province and Central Transvaal (after DuToit, 1956, p. 268).

Cape			Central Transvaal	
Dwyka	Upper Shales	650	-----	
	Boulder Beds	2500	Glacial Conglomerate	0-30
	Lower Shales	750	-----	
TOTAL		3,900	TOTAL	0-30

Subdivisions of the Dwyka include the Lower Shales, Boulder Beds, and the Upper Shales. The Upper Shales contain a very distinctive white-weathering bed of dark gray cherty shale called the White Band.

Distribution of the Dwyka

In South Africa the Dwyka Series generally crops out around the borders of the Karroo Basin which covers most of the central part of the Union. For a short distance along the southeast the formation crops out under the sea. In the north, in Transvaal, the tillite is thin and erratic and tends to be overlapped by beds of the Eccca Series, so outcrops are small and scattered. To the northwest of the Cape Region extensive outcrops are present in Gerdonia and South-West Africa. The Dwyka in the Cape Region is thick and has been highly folded into the mountains of the Cape Ranges.

Lithology of the Boulder Beds

The rock is blue or greenish, compact, and fine-grained with small fragments of sand and various minerals included in a very fine-grained, argillaceous matrix. Pebbles and boulders of many lithologies are present in the matrix. Some rock types of which boulders are formed are:

conglomerates, quartzites, sandstones, shales, slates, crystalline limestones, jaspers, banded ironstones, granites, gneisses, diabases, amygdaloidal lavas, quartz porphyries, and serpentines. The lithology of the inclusions is variable with different localities.

Small fragments are angular but large ones may be rounded. Boulders are randomly scattered throughout the matrix and are up to 10 feet in diameter. Many of the boulders have striated surfaces and flattened faces.

A striated pavement occurs under the boulder beds but is only well displayed at a few localities. The most well-known of the areas of striated pavement is near Kimberly where tillite rests on amygdaloidal lavas. DuToit (1922) maps showing flow directions are based in large part on directions of striae on pavements.

In the southern areas the tillite is a hard, bluish rock which fractures across pebbles and matrix together. The tillite in northern outcrops is less lithified so that pebbles can be picked out of the matrix. The orogenic forces which have formed the Cape Folded Ranges probably caused a slight metamorphism of the tillite with its resulting uniform hardness. Also, the folding has caused a slight cleavage in the tillite which results in peculiar lenticular slabs when the rock weathers.

A curious feature in both the northern and southern areas is a regular and close jointing of inclusions so that the cobbles and pebbles appear to have been sliced into flat pieces.

Varieties of Dwyka

The predominant rock of the Boulder Beds is the bluish to greenish, unbedded tillite which has already been discussed. Some rocks are definitely stratified and are of shaly structure. This is called "bedded Dwyka" by DuToit (1956, p. 273), and is found at definite levels which are interpreted as breaks in normal deposition of till.

Such beds are particularly common in South-West Africa and in the Vaal-Harts Valley. The "bedded Dwyka" grades upward into "boulder-mudstone" or "boulder-shale" which are olive-colored, argillaceous rocks with erratically distributed inclusions of pebbles. These rocks often grade into pure shale. Hard, brown-weathering bands and lenses of limestone may be present. Another type of lithology present is "gravel Dwyka" which may grade into sandstone beds with confused structures with irregular lenses of pebbles. These beds are thought to have been formed by outwash streams.

Phases of the Dwyka

Evidence suggests that the Dwyka was deposited as ground moraine over most of South Africa. However conditions differed from south to north.

In the southern Karroo thicknesses of tillite are greater than 2000 feet. DuToit (1956, p. 274) explains such thicknesses by assuming that the deposits were formed near an ice-front which discharged its load into fairly deep water. Intercalated sandstones and shales represent times of non-glacial deposition when the glaciers probably had retreated. Near Laingsburg, five distinct tillite zones have been recognized.

In the northern Karroo and adjacent areas of Gordonia, Natal, and Zululand, the moraine, which is now tillite, formed on land which was of low relief and about sea level. Tillite formed on the higher areas. Shale covers the tillite in lower areas but much of the shale is boulder-shale. The boulders are thought to be transported by icebergs and dropped into the muds. In South-West Africa, similar boulder-shales formed in a shallow marine sea.

In the Transvaal, which was well above sea level at the time of deposition of the till, deposits were probably exposed to weathering for a prolonged time after recession of the glaciers and were not covered up until Ecca time.

Thus the tillite is thin and irregular. The color of the thin tillite of the Transvaal is a pale bluish-gray or gray, which is lighter than the tillite in the Cape area.

Thickness of the Dwyka

In the northern areas of the Karroo Basin the tillite is patchy. In some areas it may be completely missing but in an immediately adjacent section may be greater than 100 feet thick where it has filled a pre-tillite hollow.

The thickness of the tillite increases toward the south to where it forms part of what is called the Karroo Geosyncline. Two thousand feet of tillite have been measured at several locations and greater than 2500 feet were measured near Laingsburg.

Striated Pavements

It is possible that north of latitude 33°S. the undulating floor on which the tillite rests is striated and polished. Exposures of the pavement are not common because they are easily ruined by erosion.

Roches moutonnees are seen in areas where the sub-tillite floor is uneven. The longer axes of these features tend to parallel the striae directions. Crag and tail and stoss and lee sides of these hummocks can be

ascertained. Striated surfaces are present on extrusive rocks on the Vaal River near Pniel, Douglas and Riverton. The original description of a pavement by Sutherland in 1868 was made in this area from a site near Durban.

Striae are more or less parallel but in cases where more than one ice sheet has eroded the area, two sets of striae are present. Chatter marks are occasionally present and "plucking" can be detected on the lee side of high areas.

Boulder pavements have been observed in a few places. These are in the middle portion of a tillite sequence, and are thought to be formed by advancing ice eroding till which was deposited earlier.

The Direction of Ice Flow

Indication of the direction of ice flow has been provided by striated pavements and evidence of plucking. Erratics have also been of value in determining the path of ancient ice streams. DuToit (1922) recognized four bodies of moving ice coming from four centers of accumulation.

- (1) The Transvaal ice radiated from the central and northern Transvaal. Over much of the area of accumulation no glacial deposits are present.

- (2) Griqualand West formed a minor accumulation center.
- (3) Namaland ice sheet probably originated in the Windhoek Highlands and moved southward.
- (4) The Natal sheet accumulated to the east of the present eastern coastline. This body was apparently deflected by south-moving Transvaal ice.

Since all of the directions in South Africa are from the north, it is assumed that a very large body of inland ice was present and that it radiated northward, as well as toward the south. Such an ice body would extend into Angola and the eastern Congo.

Upper and Lower Boundaries

The Dwyka Series in the Cape Colony is composed of the Lower Shales, the Boulder Beds, and the Upper Shales as shown in Table 8. However, in northern South Africa only the Boulder Beds are present and rest on a pavement which has been cut into Precambrian rocks and is overlain by Ecca coal measures. In the middle portion of the country drill holes have revealed that the tillite is variable in thickness (Haughton et al., 1953, p. 38), and rests on a surface of considerable topography. Thicknesses in the southern

part of the Orange Free State range from 2 to 621 feet.

The tillite appears to be deposited in hollows and not on highs. In this area the tillite is overlain by the Upper Dwyka shales and the Eccra Series.

COMPARISON OF THE BUCKEYE TILLITE AND THE DWYKA TILLITE

Stratigraphic Position

In a very general way the strata of the Ohio Range are comparable to those of the Cape System and the Karroo System of the Union of South Africa. A generalized correlation chart is provided in the following table.

Table 9. Correlation (generalized)
Table, Antarctica and South Africa

ANTARCTICA		SOUTH AFRICA	
	Mt. Glossopteris Formation	Lower Beaufort	
	Glossopteris Leaia, Sam- aropsis		
		Upper Ecca	
Permian	Discovery Ridge Formation	Ecce-Middle Ecce	
	- - - - -	Lower Ecce	
?Pennsyl- vanian	Buckeye Tillite	Dwyka	Upper Shales Boulder Beds Lower Shales
	- - - - -	Witteberg	
Lower Devonian	Horlick Formation	Bokkeveld	
	Malerino Kaffric fauna (Pleurothy- rella)	Malvino- Kaffric fauna (Pleurothyrella)	

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Distribution

The Buckeye Tillite can only be traced with certainty in the Ohio Range and therefore is difficult to compare with the very extensive Dwyka. A more meaningful comparison would be that of all the tillite of similar stratigraphic position in Antarctica. To date only a few areas are known to contain tillite. The limited data from areas so far investigated in Antarctica indicate that glacial deposits are absent in many regions, even though sections are exposed to basement rock. Thus Antarctic tillites do not seem to be as widely distributed as the Dwyka tillites.

So far all the tillites which have been reported from Antarctica are found in nearly horizontal attitudes. Block faulting has disrupted the continuity of bedding but no severe folded structures have been encountered. One possible exception to the above statement may be in the folded Sentinel Range where Craddock et al. (1963) observed a conglomeratic unit (Whiteout Conglomerate) which may be a tillite.

Lithology

The lithology of the Buckeye Tillite is very similar to that of the Dwyka Tillite. Based on a sample from Discovery Ridge and a sample from an outcrop located

2 miles east of Matjesfontein, the Dwyka has a dark bluish gray matrix which is mostly argillaceous but contains visible silt and sand grains. Light-colored pebbles are scattered randomly through the matrix. The light-colored grains are predominantly granitic rock fragments. Larger pebbles of basaltic rock are present. Cobbles of granite, basalt, and jasper were present in the outcrop, and pebbles of quartzite and sandstone are also present. The matrix includes small flecks of biotite.

The Buckeye Tillite is composed of a slightly lighter shade of medium dark bluish gray matrix than the Dwyka. The matrix is finer grained so that fewer grains of silt and sand-size are visible in the hand specimen. The pebbles in the Buckeye Tillite are dominated by dark gray siltstone which has been mentioned earlier. Other pebble and cobble rock types are granitic, volcanic, sandstone, and conglomerate. Jasper pebbles are very scarce but are present in the Buckeye Tillite.

The pebbles and cobbles from both tillites are commonly faceted and subangular. More cobbles from the Buckeye Tillite are striated which is probably related to the ease with which limy siltstone cobbles are striated.

The matrix is more cemented to the pebbles and cobbles in the Dwyka Tillite sample and some cobbles break across rather than around the grain. In the Buckeye Tillite,

particularly on a slightly weathered surface, pebbles and cobbles can be plucked from the surface with one's bare fingers which is more similar to the Dwyka of the northern facies.

Both tillites show no bedding and form massive outcrops and are more resistant to weathering than adjacent formations. Parallel patterns of fractures which make a cobble or boulder look as if it has been run through a bread-slicing machine are present in both tillites.

Varieties of Tillite

The Buckeye Tillite is dominantly of the lithology discussed under the last section. However, there are other lithologies within the tillite unit. Bedded tillite was noted above 400 feet above the basement on several sections where the Buckeye Tillite was measured. Such beds may be comparable to the "bedded Dwyka." However in the Ohio Range the bedded tillites (about 5 feet thick) grade upward into tillite and downward into shaly siltstones of water-deposited origin. This differs from the "bedded Dwyka" which may grade upward into sandstone. In both cases, the bedded tillites seem to be a transitional sediment which is deposited in water during an advance or retreat of glacier ice.

A few shale beds up to about 2 feet thick are present in the Buckeye Tillite as well as the Dwyka Tillite. Also sandstone and conglomeratic beds in the Buckeye Tillite are probably similar to the "gravel Dwyka" mentioned by DuToit (1956). Brown-weathering carbonate lenses occur in the upper portion of the Buckeye Tillite and may be comparable to the hard, brown-weathering lenses and bands of which are found in the Dwyka. All of the lithologies other than the tillite itself have been deposited in the presence of water. The waters in which or by which the sediments were deposited must have been closely associated with the glaciers. The sandy and gravely deposits may represent outwash deposits, which filled channels below glacial terminae. Small lenses with tillite on all sides possibly represent sub-ice features such as eskers. Even the presence of eskers is indicative of glacial fluctuation, because eskers can only form when the temperature at the base of the glacier is above freezing (Carey and Ahmed, 1961). Thus the presence of an esker deposit or a stream deposit indicates probable warming of the glacier.

Beds such as shales and bedded tillites suggest larger bodies of standing or quiet water and muds gradually accumulating on the bottom. If ice floats, either as a shelf or as icebergs over the body of water, pebbles and boulders can be dropped into the muds, resulting in shales

with occasional large grains which could be called bedded tillite. If this tillite formed near the location where the ice shelf was grounded, it would indicate that "wet-base" glaciers (those warmer than 32°F.) were feeding the ice shelf (Carey and Ahmed, 1961). If the bedded tillites were beyond the ice shelf and were a result of iceberg rafting, then a dry-base glacier transport is suggested. The "dry-base" glacier is colder than freezing and when it contacts the water of the sea or lake, it receives an accumulation from water freezing on its base. The newly frozen water acts as a cap and insulation so that debris carried by the ice is not dropped, but is carried away by the ice and dropped at a more distant location. Icebergs which are formed from cold-bottom ice will carry much more pebble and boulder debris to be added to deeper marine deposits.

Wet-base glaciers continue to melt and may melt even more rapidly upon entering a body of water. Thus they are apt to deposit much more till-like material to the beds forming on the basin floor. Both fine- and coarse-grained material is provided by the glacier in proportions of grain-sizes which must be similar to that of a tillite. If this debris were dumped into a standing body of water, the resulting product should be a shale with numerous and randomly scattered pebbles, cobbles, and boulders.

Such beds in the Buckeye Tillite are interpreted as being produced under such a situation. The sub-ice shelf environment followed a shale and sand-depositing environment. Such a sequence suggests an advancing glaciation.

In summary, the Buckeye and Dwyka Tillites contain similar varieties of sediments, including tillite, bedded tillite, sandstones, conglomerates, shales, mudstones, and brown-weathering calcareous lenses.

Phases of the Tillite

The Dwyka Tillite is thought to have been deposited under conditions of ground moraine, an inland sea, and in marine waters. These phases were rather widely separated in South Africa with the ground moraine deposition covering the northern area. Very thick deposits suggest that inland sea deposition occurred in the southern area where the glacier was supposed to have dumped debris into a subsiding Karroo Geosyncline. In South-West Africa, glaciers deposited material in basins normally filled with sea water.

A consideration of phases in Antarctica requires knowledge of a larger area than that of the Ohio Range because the Buckeye Tillite represents only one restricted section. Probably it was deposited under terrestrial conditions very near sea level in a subsiding basin.

Subsidence is required for the large thickness, as well as the preservation of the thickness. That the area was subsiding fairly actively and that it need not be sea-covered is also suggested by the overlying arkoses and shales of the Mt. Glossopteris Formation. The plant fossils in these beds grew in a land environment and yet they are buried. Such tectonic conditions must have been taking place from the time of Buckeye Tillite deposition through the time of Mt. Glossopteris Formation deposition.

The Buckeye Tillite phase of deposition does not compare well with any of the three major phases of Dwyka Tillite. It perhaps is comparable to a transitional phase from the northern Dwyka to the southern Dwyka.

Thickness

The thickness of the Dwyka Tillite ranges from nothing, where it is absent in parts of the north, to more than 2500 feet in the south. The Buckeye Tillite is about 900 feet thick throughout all of the Ohio Range and therefore can only be compared to some middle portion of the Dwyka. Such a thickness is comparable to the Dwyka at areas north of the Karroo Geosyncline area but south of the Transvaal.

Striated Pavements

Striated pavements occur under the Dwyka in the northern portions of the outcrop areas where the glaciers are thought to have been on land and not floated by water. In the Ohio Range, striated and grooved pavements are found under the tillite at several locations. Striated pavements in the Ohio Range suggest that it is comparable to areas north of the very thick tillites of southern South Africa, and compliment thickness comparisons.

Roches moutonnees were not observed in the Ohio Range so they cannot be compared to such features which have been described from under the Dwyka Tillite. It is possible that bedrock "highs" such as that in section 1 could be roches moutonnees but insufficient knowledge can be gained of its shape to identify it as a roches moutonnees.

Striae throughout the Buckeye Range are roughly parallel which compares only partially well with striae in South African pavements. Dwyka pavements some times have several directions of striae which are interpreted as representing different ice bodies, but they could also have been formed at different times by the same ice body.

Boulder pavements are present in both the Dwyka and Buckeye Tillites and indicate that glaciers have eroded their own deposits. Whether a glacial retreat is required

before a readvance of the ice with consequent striating of the previously emplaced boulders is not certain, but at least minor glacial oscillations seem necessary. The cobbles and boulders in the pavement must be cemented or frozen into the matrix in order to be held sufficiently fast to be flattened and striated. Of these, cementing seems the most likely. Cementing would require a fairly long time but if the tillite were deposited under high pressure it might become cemented rather rapidly so that thinner ice would be unable to dislodge boulders and cobbles. In any case, boulder pavements occur in both tillites.

The Direction of Ice Flow

The centers of ice accumulation and direction of the four major streams of Dwyka ice have been mentioned. In the Ohio Range the Buckeye Tillite striae and related phenomena suggest that ice came from nearly due west.

Summary

In summary, the Buckeye Tillite is of very similar stratigraphic position to the Boulder Beds of the Dwyka Series and probably of about the same age. The thick quartzites of the Witteberg which underlie the Dwyka are

not present in the Ohio Range, but the Witteberg is not present in the northern areas of the Karroo Basin.

Distribution of tillite in South Africa seems more widespread and continuous than in Antarctica. Of the areas investigated in Antarctica, only two are known to have well displayed tillite sections. However most of Antarctica's exposed rocks have not yet been studied in detail, so a meaningful comparison of distribution is impossible.

The lithologies of the tillites of the two areas are very similar. Both are composed of a dark bluish-gray matrix in which pebbles and boulders up to several feet across are scattered. The Dwyka is slightly darker gray and contains a slightly coarser grained (more silt) matrix. The cobbles and pebbles of the Dwyka are more granitic in origin while the most common pebble in the Buckeye Tillite is a dark gray siltstone. Erratics in both tillites are angular and faceted with some striated grains and the erratics are of many different lithologies.

The varieties of beds within the two tillite units are very similar. Both contain bedded tillite, conglomerate, sandstone, shale, and dark brown-weathering calcareous lenses.

The phases of the Dwyka include the terrestrial land deposition of the north, glacial marine deposition of the northwest, and geosynclinal deposition on the south of

South Africa. The Buckeye Tillite environment of deposition is probably similar to a transitional phase of the Dwyka between the southern and northern facies.

The thickness of the Dwyka Tillite ranges from 0-2500 feet which encompasses the 900-foot thickness of the Buckeye Tillite.

Striated pavements are present in both tillites, but roches moutonnees have been observed only in South Africa. The striae in the Ohio Range show only one direction of motion. Some Dwyka striae have two or more sets of directions.

It is tempting to assume that the Buckeye Tillite compares quite favorably to portions of the Dwyka Tillite which are slightly north of the Cape Colony. Such areas can only be studied by drilling. Haughton et al. (1953) provide data from drilling which rather closely fits what is known of tillites in Antarctica at the present time.

The pre-tillite topography of this middle facies of the Dwyka is fairly similar to the pre-tillite topography in Antarctica. Several areas in Antarctica have been investigated closely enough to determine whether tillite exists and it has been identified only in the Ohio Range and the Queen Alexandra Range (Grindley, 1963). Perhaps peculiar conglomerates from the Robert Scott Glacier area (Doumani and Minshew, in press) and that mentioned by

Reese (1958) are very thin glacial deposits. In other areas it is clear that no tillite is present. Such a variable pattern of tillite deposition is very similar to the middle parts of the Union of South Africa.

The above and most of the other comparative properties of the two tillites which have been discussed in this section lead one to the conclusion that comparable sections exist in South Africa.

PERMO-CARBONIFEROUS GLACIATION IN INDIA

History

The first evidence of glaciation during Carboniferous or Permian time was recognized in 1856 by W. T. Blanford, H. F. Blanford, and W. Theobald during an investigation of the "Talcheer Coal Field" in the Cuttack district. The Talchir Basin, according to Blanford (p. 44) extends about 70 miles in an east-west direction and is about 15 to 20 miles wide, almost the entire northern boundary and part of the southern boundary are formed by faults with up to 200 feet displacement. The original section published by Blanford (pp. 45-46) is shown in Table 10.

These general rock divisions are still used by Indian geologists. Table 11 shows the section of Upper and Lower Gondwana beds as given by Krishnan (1960, p. 276).

Blanford (p. 47) states that the lowest bed which is found resting on a gneiss is usually the "boulder bed," which is in some places a coarse conglomerate. In some areas the boulder bed is absent and the tessellated sandstone rests directly on the gneiss.

Table 10. Blanford's Original Measured
Section in the Talchir Basin.

Proposed Names	Character of beds	Estimated thickness in feet	
1. Mahadewa Group or Upper Grit Series	Unfossiliferous, quartzose grits, conglomerates and coarse sandstones, the conglomerates predominantly toward the base of the series.	1500 to 200	
2. Damoodah Group or Carboniferous Shale Series	fossiliferous a) Interstratification of blue and black shale, often very micaceous, iron stone, and coarse feldspathic sandstone b) Carbonaceous shales of Gopalprasad and Talcheer. c) Shales and coarse sandstones interstratified, the latter predominating chiefly at the base.	1500 or more more than 150 not less than 100	Total nearly 1800
3. Talcheer Group or Lower Sandstone Series	but slightly fossiliferous ----- a) blue nodular shale b) fine sandstone ("Tesselated Sandstone") c) Boulder Bed	500-600	

Table 11. Upper and Lower Gondwana Sections, India

Standard Scale			Gondwana Divisions	
Upper Gondwanas	Cretaceous	Lower	Jabalpur	Umia Jabalpur
		Upper		
	Jurassic	Middle	Rajmahal	Kota
		Lower		Rajmahal
	Triassic	Rhaetic	Mahadeva	Maleri
		Keuper Muschelkalk		Pachmarbi
<hr/>				
Lower Gondwanas		Bunter	Panchet	
	Permian	Upper		Raniganj
		Middle		Barren Measures
		Lower	Damuda	
	Carboniferous	Upper	Talchir	Barakar-Karharbari
				Rikba
Talchir Boulder-bed				

The "boulder-bed" consists of boulders of granite and gneiss up to 4 or 5 feet in diameter. The granite boulders are usually smaller than those of gneiss. The matrix in which the boulders are imbedded varies from coarse sandstone to fine shale. "The most usual matrix of this boulder bed is a fine bluish sandy and rippled shale." At some localities the matrix is a dark-green silt with no sand-size fraction, but full of boulders. Sometimes the matrix assumes a shaley structure.

Other lithologies within the boulder-bed unit include lenticular beds of very coarse sandstone up to 20 or 30 feet thick which are interpreted as channel-sand deposits. Over these sandstone lenses the boulder beds are of more usual lithology and about 100 feet thick.

The origin of the boulder-beds as suggested by Blanford is that of "ground-ice." He also considers multiple stream deposition in a lake basin and deposition of boulders by a floating medium. But after considering other possibilities concludes that "...it resembles exactly the effects of the action of ground-ice, which, enabling boulders to be carried down by a sluggish current, would undoubtedly produce such an inter-mixture of large rounded masses of rock and fine silt, as is seen in the present case."

In spite of the above statement, Blanford continues "...we have here no evidence whatever of the action of glaciers,..." This statement is based on his observation that most of the boulders in the boulder-beds were rounded and not angular. Also he did not see striae on any of the boulders but suggested that some possibly could be found. He was also disturbed by the fact that present temperatures in India would not permit glacial conditions.

The unit over the boulder-bed in the Talchir Basin was called the Tasselated (checkered) Sandstone by Blanford and he states that the contact between the two units is gradational in some places.

The "Blue nodular shale beds," which are located higher in the section, have pebbles and boulders of granite and gneiss in them. Again ground ice is suggested as "the only theory which can satisfactorily explain all the observed phenomena."

Blanford in 1872 discusses the geology of Nagpur. He (p. 10) describes the Talchir boulder beds as not typical but he found a few outcrops of "the typical fine silty shales..., breaking up into minute flakes and only differing from the Talchirs of Bengal and Orissa in their dull red colour." Reddish calcareous and sandy layers were intercalated which was the case for many other outcrops in India. Pebbles and boulders were abundant and were commonly coated

with a calcareous crust. Some boulders and pebbles were rounded and many were angular and their lithology included metamorphic rocks, quartzite, and limestone from the Vindhyan(distant outcrops only) and slate of unknown origin.

The distribution of the Talchir beds was surprisingly widespread for such a thin unit. Blanford (p. 28) mentions that beds of the same description are found in Nagpur, Bengal, Orissa, and in the Narbada Valley. In every case the gray "mudstones," the fine pale brown or greenish sandstones with their peculiar tassellated weathering, and the presence of huge transported blocks, generally rounded, are characteristic of the group.

The origin of the boulder beds is discussed again by Blanford (p. 28) and he considers a marine conglomerate origin but notes that such conglomerates are better sorted and do not look like the Talchir Boulder Beds. He then considers stream and lake deposits but the widespread, blanket-like nature of the Talchir is inconsistent with alluvial or lacustrine deposits. The absence of sorting would be contrary to deposition by moving water either on land or at sea.

One of Blanford's most interesting considerations of origin would today be termed turbidity currents.

In spite of other possible origins for the boulder beds and the fact that India's present climate was non-glacial, Blanford proposed an ice-borne origin for the boulder bed deposits of the Talchir.

Oldham (1872) described striated boulders and striated pavements. The pavements were formed on Vindhyan limestone and the striae were long parallel lines. These pavements and striated boulders were considered to confirm the origin of the boulder beds as suggested by Blanford (1856).

Fedden (1875) describes his discovery of the striated pavement about which Oldham (1872) wrote. These features are located "near the village of Irai on the right bank of the Pem River, not quite a mile above its confluence with the Wardha, and ten miles to the west south-west of Chanda." The Talchir beds in this area occupy low-lying areas of the pre-Talchir topography, which must have been of low relief. For this reason Fedden feels that glaciers probably did not cover the area because they would have had to come from highlands. "Ground-ice" is suggested as the cause of the striae.

Striae and grooves were cut into the Lower Vindhyan limestone and are parallel. The pre-Talchir surface at the striae location sloped at an angle of about 15 degrees to the west and it appeared that the glaciers moved upslope toward the northeast and north-northeast.

The boulder bed lithology contained boulders of limestone, quartzite, granite (which may be up to $2\frac{1}{2}$ feet in diameter). While some boulders were rounded, many displayed polished surfaces and striated surfaces. The matrix was a "fine gravelly bed of heterogeneous material, conglomeratic near the base."

The source area for many of the boulders was thought to be to the southwest. Fedden concludes, "The evidences for the glacial origin of these deposits is as conclusive as that for the ice-age formations of Europe."

Near Madras, Foote (1870, p.15) described strata which included boulders up to "800-1000 cubic feet in bulk." These boulders were of the same lithology as basement rocks which were located about 8 miles to the northwest. Thus a direction of ice motion to the southeast is indicated. Foote suggests that the boulders are relicts of the basement rock below. He dismisses a glacial origin because of India's warm climate at the present time.

By 1886 the boulder beds had been recognized throughout much of India and had been correlated with glacial beds in Australia and with the boulder beds of South Africa (Blanford, 1874). Blanford (1886) reviews the publications concerning glacial beds in India and states the problem of explaining why there were glacial conditions at 16 degrees north when at the same time warm, humid conditions promoted

growth of plants further north in Europe. Such problems have yet to be answered.

Fox (1931) discusses boulder beds of the Talchir deposits and notes that in peninsular India there are four basins in which the glacial formations have accumulated, the Satpura region, the Wardha-Godavari area, the Mahanadi area, and the South Rewa and Son Valleys.

The direction of ice movement is difficult to determine in most areas. Evidence of flow direction usually is provided by marker boulders and in Wardha Valley the ice evidently flowed northward (up-valley) and then turned to the west and west-northwest into Rajistan.

The thickness of the boulder bed lithology seldom exceeds 100 feet and it usually is less than 50 feet, although the Talchir Group ranges from about 800 to 1000 feet. The boulder beds are not usually stratified and normally are found at the base of the series. No fossil plants are found in the type areas of the Talchir Series. Plant fossils have been found in the Talchir shales at seven localities and the Eurydesma and Conularia were found in the shales directly over boulder beds in the Salt Range.

In summary, the boulder beds form the lowest member of the Talchir Group which was named after the Talchir Coal Field in Orissa, where it was first studied by Blanford in 1856. The boulder bed forms a widespread unit which ranges

from 50-200 feet thick in peninsular India where the beds appear to have been deposited in four basins. Equivalents of the Talchir Boulder Beds are present in the Salt Range, Kashmir, Gashwal, and in Simla.

The boulder beds are composed of unsorted mixtures of boulders, pebbles, and smaller rock fragments in a clayey, silty or sandy, bluish- or greenish-gray matrix. Many of the outcrops in peninsular India show stratification which suggests that they may have been deposited in bodies of water in which glacier ice floated. Some boulders are faceted, striated or polished and many can be traced to distant sources. Striated and grooved pavements have been found beneath the boulder beds and the direction of ice movements was generally to the northeast.

Fossils are not found in the lower boulder beds but in the upper sandstones. Gangamopteris, Glossopteris, and Vertebraria as well as spores, insect wings, and worm tracks have been found. In the Salt Range, Conularia and Eurydesma are in beds which directly overlie the boulder beds.

The origin of the boulder beds was discussed for many years following its initial description, but most students of Indian geology agree that a glacial origin for the boulder beds of the Talchir Group is correct.

COMPARISON OF THE BUCKEYE TILLITE WITH THE TALCHIR BOULDER BEDS

Stratigraphic Position

The position of the Talchir Group is at the base of the Lower Gondwana System and it usually rests on a pavement or old erosional surface cut into Cambrian rocks. The stratigraphic break below the Talchir beds includes Ordovician through Mississippian time. The boulder beds have been assigned to the Upper Carboniferous.

The Buckeye Tillite rests on Lower Devonian strata which in turn rests on a surface which may have been formed during Silurian time. The age of the Buckeye Tillite may possibly be Upper Carboniferous or Pennsylvanian but probably it is of Lower Permian age. Thus it can be seen that the two tillite deposits are in about the same position in the stratigraphic column, but the Talchir Boulder Beds probably are slightly older than the Buckeye Tillite. Also the lower boundary differs. In both cases shales lie directly over the tillites and these shales grade into sandstones which contain undecomposed feldspar. The Upper Talchir shales contain elements of the Glossopteris flora

while no fossil plants have been found in the shales of the Discovery Ridge Formation in the Ohio Range. A comparison of the stratigraphy of the Ohio Range with Gondwana divisions and the section from the Damodar Valley is given in Table 12.

Table 12. Correlation Table,
Antarctica and India

Standard Time Scale		Antarctic Fms. Ohio Range	Gondwana Divisions (Damodar Valley)	
Triassic	Bunter		Panchet	Panchet
	Upper	Mt. Glossopteris fm. 2000 ft.	Raniganj (2000- 3000 ft.)	
	Middle	Discovery Ridge fm.	Barren Measures (1400- 2000 ft.)	Damuda
	Lower		Barakar- Karharbari (2000 ft.)	
Carboni- ferous	Upper		Rikba Talchir ir (500-900)900	Talchir
			Boulder Bed (50-200)	
	Middle Lower			
Devonian	Upper			
	Middle	Horlick fm.		
	Lower			

Age of the Tillite

The ages of the Indian formations listed above are based on the plant fossils which have been found in all but the boulder beds. A recent discovery (Ghosh, 1954) found marine beds intercalated with boulder beds. These marine beds are very similar to the Umaria marine beds which overlie Talchir boulder bed near Umaria. The Umaria beds contain marine fossils which have both Carboniferous and Permian characteristics. Such data suggests that the Talchir beds could possibly be of a younger age than the above chart indicates. This would make the Talchir Boulder Beds more similar in age to the Buckeye Tillite.

The age of the Talchir beds has been stated by most authors as Upper Carboniferous (Krishnan, 1960; Fox, 1931; Ahmed, 1960; King, 1958). Also most authors base this opinion on the fact that the Glossopteris flora has been found in Talchir shales above the Boulder Beds. Also Conularia and Euredesma have been found in marine beds which are slightly higher than the boulder beds in the Salt Range (Jacob, 1952, p. 159).

The absence of Glossopteris or related macroscopic plant fossils in the boulder beds has led Fox (1931) to suggest that the Glossopteris flora did not exist during the time of Talchir glaciation. Studies by Virkki (1946) have shown that spores and pollen grains are present in

shales which are $1\frac{1}{2}$ feet above the boulder bed in the Salt Range. Sahni (1946) reports finding spores and woody tissues from shales interbedded in the boulder beds of the Salt Range.

Neither Virkii nor Sahni states the age of the microfossil material. These fossils could be of Permian age but nearly all authors assign them to the Upper Carboniferous.

The Buckeye Tillite is of Pennsylvanian or Permian age. Based on spores which were taken from interbedded shales, Schopf (personal communication) suggests that Buckeye Tillite is probably of Permian age.

King (1958) and Ahmed (1960) state that the glacial beds are not of the same age in the various Gondwanaland continents. King suggests that the climatic controls which governed the advance of glaciers moved across the Gondwana continent, affecting first South America, then southern Africa, Peninsular India, Antarctica, and finally eastern Australia. Based on the possible ages of the glacial beds which have been discussed above such a relationship seems reasonable for India and Antarctica. However, neither the Buckeye Tillite nor the Talchir Boulder Beds have provided sufficiently clear evidence of age to make accurate statements regarding the beginning or end of glacial conditions.

Distribution

The Talchir Boulder Beds are quite widespread, covering much of peninsular India and also into the foothill areas of the Himalaya. The distribution suggests that there were several basins where deposition was greater.

The distribution of tillite in Antarctica does not seem too great based on studies which have been conducted to date. There is a suggestion that there are areas where the tillite was deposited and intervening areas where no tillite was deposited. This pattern of deposition seems similar to that of India. The position of the tillites in space in Antarctica is as yet not sufficiently understood for meaningful comparison with a region such as India.

Lithology

The Talchir Boulder Beds many times are composed of a stratified matrix in which boulders of many lithologies are imbedded. The matrix is predominantly fine-grained and silty. Also many descriptions indicate that the matrix is of a sandy nature and sometimes a dull red color, but most common color for the boulder matrix is a greenish-gray. The boulders are as large as 800 to 1000 cubic feet in Madras. Usually the boulders are subangular to subrounded,

and are composed of quartzite, granite, gneiss, and other metamorphic rocks. The most common boulder lithology is that of the local pre-Talchir rocks, which commonly are from the Vindhyan beds. While rocks of local derivation may be rounded, those from distant outcrops are angular and often faceted and striated. The striae are subparallel on the boulders and have been one of the criteria used as evidence of glacial deposition.

The lithology of the Buckeye Tillite differs from the Talchir Boulder Beds in structure, color, and matrix grain-size. Only a few thin beds of stratified rocks are present in the Ohio Range. Some of these include pebbles and boulders and some do not. All of the Buckeye Tillite in the Ohio Range is a dark bluish to greenish gray which is probably similar to the color of much of the Talchir but obviously different from the reddish boulder beds. The grain-size of the matrix in the Buckeye Tillite is mostly clay- and silt-sized while much of the Talchir Boulder Beds is sandy.

The Buckeye Tillite lithologically resembles the boulder beds of the Talchir Group in the overall fabric of pebbles and boulders in a fine-grained matrix. Also the greenish-gray color of much of the Talchir is similar to the color of the Buckeye Tillite.

Lithologically the Buckeye Tillite is less similar to the Talchir Boulder Beds than it is to the Dwyka Tillite.

Varieties of the Tillite

The lithologic variations within the Talchir Boulder Beds are not well described. Thus it is difficult to state whether similar lithologic variations exist between the two deposits. As mentioned earlier, both bedded and non-bedded boulder beds are present in Indian sections. The Indian sections apparently have a much larger percentage of bedded tillite than is present in the Ohio Range.

Lenticular sandstone bodies are present in both tillites and probably represent subglacial or outwash stream deposits.

Phases or Facies of the Tillite

Facies of boulder beds in the Talchir Group include the glacial-fluvial and glacial deposits of peninsular India with marine-glacial deposition suggested for the northern Indian outcrops in the foothills of the Himalaya. None of the Talchir sections are more than 200 feet thick which suggests that the facies which occurred in subsiding basins are not present.

The Buckeye Tillite probably was formed in a subsiding basin where occasionally the beds were covered by water. The Indian basins evidently were not as active during the

time of glaciation as were those of the Ohio Range. Again it is necessary to bear in mind that the Ohio Range section represents deposition at only one location.

Thickness

The thickness of the Talchir Boulder Beds has been discussed under other headings and is shown on the chart in this chapter. No where in India have boulder beds been described which are as thick as the Buckeye Tillite. The maximum thickness given by Krishnan (1960), Fox (1931), and Ahmed (1960) is 200 feet. However the total thickness of the Talchir Group reaches 900 feet in Raniganj (Ahmed, 1961, p. 23).

It is doubtful that the Discovery Ridge Formation is equivalent to beds of the sandstones and shales of the upper Talchir Group because Gangamopteris and Glossopteris have been found in the beds above the boulder beds. No such fossils have been found in the Discovery Ridge Formation.

The Buckeye Tillite in the Ohio Range is 900 feet thick and thus about nine times thicker than most sections of the Talchir Boulder Beds.

Striated Pavements

Striated pavements under the Talchir Group have been found at several localities in India and are present in the Ohio Range. In this regard the two deposits compare favorably.

The direction of ice movement in India apparently was in a northerly direction in peninsular India and a northerly direction in northern India (Ahmed, 1960; Oldham, 1872). Ice movement in the Ohio Range was probably from the west. The comparison of directions of glacier flow is of little or no value in comparing sections. In a very broad sense, such information can give clues as to pre-glacial topography. Such information is sufficiently detailed on two continents where they were supposed to have been joined in the Paleozoic to form Gondwanaland, should be one line of evidence for or against the drift hypothesis. At this time the details for such comparisons are inadequate in both continents.

Summary

In the stratigraphic section, the Buckeye Tillite overlies Devonian beds while the Talchir Boulder Beds usually rest on Cambrian or older rocks. Dark shales are present above the Buckeye Tillite but the boulder beds are usually covered by the "Speckled Sandstone." The age of

the glacial deposits in the Ohio Range is probably Lower Permian and those in India are possibly Upper Carboniferous so an age discrepancy exists which might be expected from areas even less separated than India and Antarctica. Such a difference would also be compatible with a Gondwanaland concept.

Comparisons in distribution of the two glacial deposits would require more knowledge of Antarctic tillite distribution than is presently available. The lithology of the Buckeye Tillite is in general similar to that of the Talchir Boulder Beds except that the Buckeye Tillite has a finer grained matrix, is less stratified, and is gray rather than reddish, as a few of the Talchir deposits are. Variations of lithology of the deposits include tillite, bedded tillite, and lenticular sandstone beds.

Regional facies or varieties are not known for the tillites of Antarctica. However, the facies represented in the Ohio Range is thicker than any of the described sections in India. Such a thickness probably represents a subsiding basin of deposition which was not present in India. The thickness of the Buckeye Tillite is about 900 feet while the Talchir Boulder Beds are from 50 to 250 feet thick.

The Indian glacial beds rest on striated pavements at several locations and a striated and grooved pavement is present under the Buckeye Tillite.

The comparison of these deposits from two widely separated localities shows many similarities. From such comparisons it seems logical to assume that both were deposited by similar agencies during Upper Carboniferous or Lower Permian time. The assumption that glaciers were responsible for producing the deposits seems justified. This comparison, however, does not give any evidence which will support or negate the concept of "Continental Drift."

APPENDIX 1
STRATIGRAPHIC SECTIONS

STRATIGRAPHIC SECTIONS

Section No. 1
Measured 31 January 61, hand level

Basement Rock, quartz monzonite and granodiorite cut by
aplite bodies striated and grooved pave-
ment present on surface relief of 68 feet
measured
no Horlick Formation visible over about
1/8 mile of outcrop
grooves in pavement N12E, N15E; joints
N75E, N5W

Height above basement (feet)	Thickness (feet)	
0		grooved pavement, N85E
19	19	tillite, bluish gray
		sandstone lens, 1 ft. thick, (H 3-312)
		poorly sorted, calcareous cement,
		medium gray, weathers yellow-gray
	103	tillite, several pieces of Horlick
		Formation (H 3-313)
		boulders up to 6 ft. diameter
122	6	sandstone, lenticular, fine-grained,
		massive, greenish-gray, weathers
		reddish-brown, few thin conglomerate
		layers up to 6 in. thick (H 3-314,
		H 3-315), calcareous cement
128	11	tillite, as below
139	15	sandstone and tillite interbedded,
		bedding is contorted and lenticular
		and up to 2 ft. thick, siliceous
		cement, greenish-gray, quartzitic
		(H 3-316)
154		ledge and pavement, reddish brown,
		tillite has sandy matrix (H 3-317),
		greenish-gray, calcareous and
		siliceous bands
		no grooves present, boulder of
		Horlick Formation with fossils
		(H 3-318)
	20	tillite

Height above basement (feet)	Thickness (feet)	
174		conglomerate lens (H 3-319), tillitic texture, dark bluish gray, poor grooves on upper surface, N10E
	62	tillite (H 3-320 at 185 ft.), medium dark bluish gray, weathers light gray, pebble count no. 2 (?)
236		
	50	tillite, boulders up to 18 in.
286		striated pavement (H 3-321), grooves N80E, greenish-gray with red stain
	60	tillite, boulders up to 6 ft. in diameter
346		opalescent quartz boulder (H 3-322)
	13	sandstone (H 3-323), fine, medium- and coarse-grained, light brownish-gray, weathers light reddish brown, calcareous cement, well-sorted
359		striated surface, grooves N85E, S85E, N84E
	11	tillite
370		
	3	shale (H 3-324), dark greenish gray, platy, beds up to $\frac{1}{2}$ in. thick
373		6 in. of tillite under sandstone
	4	sandstone (H 3-325), medium gray, weathers reddish-brown, well-sorted, fine-grained, brownish nodules up to 3 in. in diameter, fewer nodules than in other areas
377		
	2	sandstone, very fine-grained, silty, shaly, calcareous, dark and light gray, platy (H 3-327)
379		
	17	tillite, bedded in lower few feet (H 3-326), pebbles up to 1 in.
396		
	1	sandstone (H 3-328), weathers reddish brown, calcareous cement, ripple marks like convergent current ripple marks
		pebble count no. 3 at 407 ft. above basement (matrix, H 3-329A)
397		
	188	tillite, calcareous concretions in upper part (H 3-329B)
585		pebble count no. 4
	71	tillite
656		sandstone, 2 in. thick, pebbles up to 1 in. in diameter in it, grooves due E
	109	tillite, boulders up to 3 ft. diameter, concretions

Height
above
basement
(feet) Thickness
(feet)

210

765		sandstone lens, 3 x 8 ft. (H 3-330), fine-to medium-grained, gray, cal- careous, well-cemented
	23	tillite
788		pebble count no. 5 (matrix, H 3-331)
	17	tillite, grades into shale
805		
	1	shale, sandy, weathers brown
806		
	72	shale, greenish gray, hard (H 3-332), silty, interbedded with tillite, upper 30 ft. contains highly distorted sandstone beds
878		
	15	tillite
893		TOP OF HORLICK FORMATION
	68	shale, platy, light and lower member dark gray Discovery Ridge Formation
961		
	97	shale, platy, fairly carbonaceous
1058		
	476	siltstone (H 3-333), calcareous, carbonaceous with sideritic and cone in cone carbonate beds, lower member, Discovery Ridge Formation
1534		TOP OF DISCOVERY RIDGE FORMATION (H 3-334 from base of Mt. Glossopteris Formation)

Section No. 2
Measured 31 January 61, hand level

Height above basement (feet)	Thickness (feet)	
0		basement, quartzmonzonite, porphyritic, weathers pinkish brown, well-rounded, joint surfaces.
	5	sandstone, cross-bedded, coarse-grained, and conglomerate, pebbles mostly quartz, bedding nearly horizontal
5		
	51	Horlick Formation, mostly covered with rubble, fossil bed, at 17 ft. above basement, with trilobites, brachiopods, and tentaculites
56		
	7	sandstone, fine-grained, cross-bedded, weathers yellowish-tan, heavy minerals on cross-bedding surfaces, shaly partings
63		
	3	covered interval, shaly, brownish-gray, soft
66		
	24	sandstone, fine-grained, weathers yellowish-tan
90		
	2	conglomerate, pebbles to 3/8 in. in diameter
92		TOP OF HORLICK FORMATION
	18	mostly covered with rubble, may be shale and sandstone interbedded with tillite
110		
	67	tillite, granite boulders and greenish-gray siltstone boulders, one boulder of basement ro 7 x 10 x 6 ft.
177		
	7	sandstone, cross-bedded, fine-grained, pinkish, lenticular, slumped
184		
	99	tillite, fewer granite boulders, mostly greenish-gray siltstone
283		
	3	siltstone and sandstone, pebbly, lenticular, ledge-former
286		
	54	tillite, few large granitic boulders

Height above basement (feet)	Thickness (feet)	
340	58	sandstone, lenticular, tillite interbedded, striae due E, N85E, 2 ft. of platy shale 8 ft. below top of unit
398	63	rubble-covered
461	348	snow-covered
809	46	siltstone, light brown and dark green, also platy shale interbedded tillite, shaly
855	10	siltstone, platy, dark green
865	2	sandstone and siltstone, reddish gray
867	80	tillite, very platy with few pebbles, distorted sandstone lenses up to 150 ft. long and 6 ft. thick
947	69	TOP OF BUCKEYE TILLITE shale, black, siltstone, greenish- and brownish-gray
1016	125	siltstone, dark greenish gray, few dark purple siltstone beds
1141	436	shale, platy, black, carbonaceous, in last 36 ft. silt content increasing and black changing to brown
1577	15	limestone, cone-in-cone, lens
1579	70	TOP OF DISCOVERY RIDGE FORMATION siltstone and sandstone, fine-grained, weathers grayish-brown to tan
1649		top of exposure

Section No. 3
Measured 30 December 60, altimeters

213

Crest of northern escarpment, about 4 miles southwest of
Mt. Glossopteris, on east side of Higgins
Canyon

Height above basement (feet)	Thickness (feet)	
0		started measurement near bottom of sandstone which is about the base of the Mt. Glossopteris Formation
	10	siltstone and sandstone (H 2-85) with vertical animal burrows, fine-grained, slightly calcareous, dark gray, weathers yellowish gray
10		
	20	shale, carbonaceous with animal burrows (H 2-86), micaceous with thinly bedded siltstone (H 2-87)
30		
	10	siltstone and sandstone (H 2-88), feldspathic, bedding $\frac{1}{4}$ to $\frac{1}{2}$ in. thick, limonite, feldspar and mica grains, animal burrows
40		
	50	siltstone, carbonaceous, and shale, carbonaceous, with few sandstone beds to 1 ft. thick (H 2-89)
90		
	15	siltstone and sandstone interbedded
105		
	30	sandstone (H 2-90), bedding massive to 1 ft. thick, crossbedded, feldspathic, fine-grained, micaceous, medium gray, limonite on crossbedding planes, weathers yellowish brown
135		
	6	shale, carbonaceous (H 2-91), fissile, micaceous, silty
141		
	15	sandstone, feldspathic (H 2-92), massive, weathers light yellowish brown, plant fossils at base
156		
	30	mudstone, fissile, black (H 2-93), micaceous, friable

Height
above
basement
(feet)

214

Thickness
(feet)

186	90	sandstone (H 2-94, H 2-96, H 2-97, H 2-98), very fine-grained, micaceous massive, cliff-former, dark gray, weathers light gray, plant remains near base, $\frac{1}{2}$ in. thick carbonaceous partings, 6-in. carbonaceous shale near bottom, crossbedded, 3 in. thick bed of pebble conglomerate near top
176	10	sandstone (H 2-100), massive, medium- to fine-grained, feldspathic, micaceous, light gray, weathers lighter gray, calcareous and argillaceous cement
186	40	sandstone, like that below
226		top of large sandstone bed, fossils (H 2-106), 3 in. coal bed (H 2-107)
	30	shale, black, laminated (H 2-101,, H 2-102), silty, micaceous
256	20	siltstone and sandstone, very dark gray, plant fossils present (H 2-103)
276	1	coal, 1 in. thick at top of hill (H 2-104)
277		top of section

Section No. 4 (Canyon Peak)
Measured 15 November 61, hand level

215

Height above basement (feet)	Thickness (feet)	
0		started measurement below bottom of a thick sandstone bed which is near the base of the Mt. Glossopteris Formation
	36	shale, thin, flaky, sandy, dark gray, carbonaceous and micaceous, animal burrows present (H 3-4)
36		
	17	sandstone, massive, some crossbedding, weathers light gray and tan, shale 1 ft. thick near top (H 3-5)
53		
	12	siltstone, platy (H 3-6)
65		
	30	shale, dark gray, silty (H 3-7)
95		
	52	sandstone and shale interbedded (H 3-8, H 3-9, H 3-10), sandstone beds thinly bedded to massive
147		
	107	sandstone, massive, light grayish tan, cliff-former (H 3-11, H 3-12)
254		top of low end of ridge
	27	sandstone (like that below it), H 3-13, pebble conglomerate (H 3-14) lens few inches thick
281		
	5	shale, dark gray, silty and coaly (H 3-15)
286		
	50	sandstone, light gray, wood remains (H 3-17), quartz pebble conglomerate lens with pebbles up to 4 cm. diameter (H 3-16)
336		
	30	shale, black, surface disturbed by frost heaving (H 3-18)
366		
	22	sandstone (H 3-19, H 3-20), flaky surface
388		
	6	sandstone (H 3-21), baked appearance, reddish brown, crossbedded
394		
	10	sandstone, thin-bedded

Height above basement (feet)	Thickness (feet)	
404	3	shale, coaly (H 3-22)
407	25	sandstone, flaky surface, thin-bedded (H 3-23)
432	6	shale (H 3-25), dark gray, and coal (H 3-24)
438	30	sandstone, quartz pebbles up to 2 in. diameter scattered in it
468	3	shale, black
471	25	sandstone, flaky, with quartz pebbles
496	3	shale, very dark gray, coaly, flaky (H 3-26)
499	6	sandstone, massive (H 3-27)
505	20	shale, dark gray (H 3-28), and shale, coaly (H 3-29)
525	64	sandstone, thinly bedded, crossbedded (H 3-30), shale partings, some sandstone, dark brownish with wood impressions (H 3-31), some shale contains <u>Glossopteris</u> (H 3-32), carbonaceous material in some sandstone (H 3-33)
589	3	coal (H 3-34)
592	4	sandstone, massive
596	16	shale, very dark gray, coal up to 2 ft. thick (H 3-35) at upper boundary of unit
612	27	sandstone, medium gray, crossbedded, massive, 2 in. lens of dark calcareous rock (H 3-36, H 3-37)
639	13	shale, dark gray
652	14	sandstone
666	2	shale, coaly (H 3-38)

Height above basement (feet)	Thickness (feet)	
668	8	sandstone, massive, grayish brown
676	3	shale, dark gray, weathers light gray
679	15	sandstone and shale interbedded
694	48	sandstone, massive, crossbedded, quartz pebbles and wood fragments present (H 3-39, H 3-40)
742	2	shale, coaly (H 3-41)
744	6	sandstone, dark gray, weathers light gray, flaky surface
750	1	sandstone, dark, thinly bedded (H 3-42), tracks and plant impressions
751	35	sandstone, quartz pebbles present, massive, weathers yellowish gray (H 3-43)
786		top of exposed rock on "Canyon Peak"

Section No. 5
Measured 16 November 61, hand level

218

On Schulthess Buttrass, about 8 miles west-southwest of
Mt. Glossopieris

Height above basement (feet)	Thickness (feet)	
0		basement, porphyritic quartz monzo- nite, BASE OF HORLICK FORMATION
	10	sandstone, medium- to coarse-grained, light greenish color, well-cemented (H 3-44)
10	5	shale, black, carbonaceous, silty, micaceous (H 3-45)
15	25	sandstone, not examined
40	10	shale, carbonaceous, silty, micaceous, fissile (H 3-46)
50	20	sandstone, coarse-grained, light gray, poorly sorted, thick-bedded to mass- ive, cement slightly calcareous (H 3-47)
70	92	TOP OF HORLICK FORMATION tillite, bluish gray, weathers light greenish gray, matrix has pebbles up to 1 in. across (H 3-48)
162	60	sandstone, light greenish gray, micaceous, layers of chert (H 3-49) and lenses of tillite present
222	120	grooves, N80E, on pavement (H 3-50) tillite, matrix greenish gray with pebbles up to 1/8 in. (H 3-51)
342		top of sandstone lens 4-10 ft. thick, greenish gray, quartzitic, medium- to fine-grained (H 3-52)
	54	tillite
396		grooves, N85E
	14	sandstone, fine- to medium-grained, gray (H 3-53)
410	135	tillite, matrix dark greenish gray (H 3-54, H 3-107 JR), ledge-former (H 3-55, from a boulder)
545	153	tillite

Height above basement (feet)	Thickness (feet)	
698		base of tillite cliff
	30	tillite
728		top of cliff (H 3-56), dark greenish gray matrix
	89	tillite
817		
	48	mudstone, gray, compact, silty, poor cleavage
865		
	11	tillite
876		
	16	shale, gray, silty (H 3-58), gray to greenish gray near top (H 3-59) (H 3-60), pollen
892		
	1	sandstone, dark gray, thickly bedded, coaly fragments on bedding surfaces, calcareous and argillaceous cement (H 3-60A)
893		
	98	tillite, dark gray (H 3-61), fewer erratics, fine matrix
991		
	54	siltstone or mudstone, medium bluish gray, weathers light yellowish gray, tracks on bedding surfaces (H 3-62)
1045		TOP OF BUCKEYE TILLITE (approximately)
	29	shale, dark gray, platy
1074		
	17	shale, carbonaceous, fissile, black, includes bed of dark, tough silt- stone (H 3-63)
1091		
	91	shale, dark, mostly snow-covered
1182		

Section No. 6 (Upper Mercer Ridge)
Measured 13 January 62, hand level

220

Non-faulted portion of Mercer Ridge, just under the diabase
sill on the southwest extremity of Mt. Schopf,
about 5.5 miles from Mt. Glossopieris

Height above basement (feet)	Thickness (feet)	
0	85	shale, carbonaceous, very dark gray, weathers light gray, coaly surfaces on bedding, mostly debris-covered
85	66	sandstone (H 3-446, H 3-447, H 3-448), feldspathic, micaceous, medium- to coarse-grained, weathers light brown- ish gray, bottom under snow, top forms small terrace, calcareous and argillaceous cement and matrix
151	54	shale, carbonaceous, weathers light gray, coaly material and small plant fragment, silty near top
205	83	sandstone (H 3-449, H 3-450, H 3-451, H 3-452, H 3-453, H 3-454), weathers light brownish gray, ledge-former, light greenish gray, medium- to coarse-grained, feldspathic, low angle crossbeds near top, laminae of light and dark gray, calcareous and argillaceous cement
288	28	shale, carbonaceous, dark gray, weathers light gray
316	92	sandstone (H 3-455, H 3-456, H 3-457, H 3-458, H 3-459), feldspathic, medium- to coarse-grained, light brownish tan, crossbedded, ironstone beds, light and dark grains define laminae
408	14	siltstone, shaly structure, medium gray, (H 3-460) silty, medium gray with flecks of dark gray

Height
above
basement
(feet)

221

Thickness
(feet)

422	11	shale, carbonaceous, coaly, (H 3-461), weathers light gray, fusain and plant fragments present
433	68	sandstone (H 3-462, H 3-463, H 3-464, H 3-465, H 3-466), fine- to medium-grained, greenish gray to medium gray, weathers medium light yellowish gray and to reddish-brown stain, lumpy appearance with even and horizontal bedding
501	5	siltstone (hornfels), (H 3-467), light gray, blocky fracture, light and medium gray laminae
506	1	shale, coaly, baked (H 3-468)
507	28	hornfels, medium gray, (H 3-469), fossiliferous, <u>Vertebraria</u> carbonized plant remains
535		DIABASE SILL

Section No. 7
Measured 9 December 61, hand level

222

Western ridge of Schulthess Buttriss, about 8 miles west-southwest of Mt. Glossopteris, on the east side of Ricker Canyon

Height above basement (feet)	Thickness (feet)	
0		basement composed of quartz monzonite (H 3-233)
	27	sandstone and conglomerate, arkosic at base, weathered zone at top of basement about 3 ft. thick, sandstone very light yellowish-gray and reddish-brown stains around grains (H 3-234) (H 3-235 loose)
27		
	14	sandstone, medium- to coarse-grained, grading into shale, dark gray which weathers brownish gray (H 3-236)
41		TOP OF HORLICK FORMATION
	40	tillite, sandy matrix, weathers light yellowish-gray, boulders up to 2 ft. across (H 3-237, boulder of Horlick Formation)
81		
		sandstone, lenticular 3 x 15 ft. (H 3-238) with pebbles up to 2 in. diameter
	45	tillite (H 3-239), dark greenish-gray, argillaceous to sandy matrix
126		
	31	sandstone, calcareous cement and siliceous cement, conglomerate lens present, tillite lenses (H 3-240) grooves, N85E
157		
	40	sandstone, with tillite interbeds; sandstone light grayish tan, medium- to fine-grained, silty, siliceous matrix and calcareous cement grooves, N85E
197		
	23	tillite, lens in sandstone bed (H 3-243), silty and argillaceous matrix
220		
	28	sandstone, massive, yellowish-gray, cocoa brown, wavy bedding planes, bed continuous east and west, but pinches out to south (H 3-244)

Height above basement (feet)	Thickness (feet)	
248		grooves, excellent, N87E, pavement sample (H 3-245)
	142	tillite (H 3-246 at 90 ft.), sandy matrix, weathers light gray, boulders to 4 ft. diameter
390	2	conglomerate and sandstone, poorly sorted, pebbles up to 2 in. diameter, weathers reddish gray (H 3-247), calcareous cement
392	14	tillite, sandy matrix, weathers light gray, boulders up to 2 ft. diameter
406	7	tillite, structure more shaly than last
413	3	shale, dark greenish gray, platy (H 3-248, H 3-249)
416	18	sandstone, medium light gray, weathers medium brown, fine-grained, feldspathic, calcareous and argillaceous cement, light brown calcareous nodules (H 3-251), cliff-former (H 3-250)
434	1	tillite, very dark gray, bedded (H 3-252)
435	57	tillite, medium dark-gray matrix, weathers yellowish-gray, pebbles up to 1 in. diameter of siltstone, quartz and ironstone (H 3-253)
492	54	tillite, medium dark bluish-gray matrix, indistinct bedding planes up to 1/16 in. thick (H 3-254), top of cliff, striae due E (H3-255)
546	28	tillite
574	69	pebble count no. 1 tillite, medium dark gray, concretions (H 3-256), calcareous, weathers dark reddish brown
643	0.5	ledge tillite, bedded, greenish gray (H 3-257), ripple marks show current from N20E

Height above basement (feet)	Thickness (feet)	
643	123	grooves, S67E tillite, dark greenish gray, with calcareous concretions of sandy lime- stone, medium dark gray, weathers medium light greenish gray (H 3-258, H 3-259)
766	4	sandstone, siltstone, and bedded tillite
770	40	grooves, poor, S80E mostly rubble covered
810		TOP OF EXPOSED SECTION

Section No. 8
Measured 26 November 61, hand level

225

Portion of northern escarpment on Lackey Ridge, about 15
miles west-southwest of Mt. Glossopieris

Height above basement (feet)	Thickness (feet)	
0		basement of porphyritic quartz monzonite
	6	sandstone, large cross-beds, sharp contact, medium- to coarse-grained, light gray, argillaceous and calcareous cement (H 3-140)
6	2	sandstone and shale, finely interbedded, dark gray, micaceous, weathers greenish to yellowish gray, carbonaceous (H 3-141)
8	0.5	sandstone, coarse-grained, poorly sorted, fossiliferous
	0.2	shale and siltstone, finely bedded
9	4	sandstone, light yellowish gray, poorly sorted, micaceous, bedding from 1-8 in. thick, fossiliferous (H 3-142)
13	0.5	shale, black, silty, reddish brown stains on surface (H 3-143)
	2	sandstone, light yellowish gray, fine- to medium-grained, weathers medium brownish gray, micaceous, limonitic stains, calcareous cement (H 3-144)
15	5	shale, very dark gray, silty, micaceous (H 3-145), contains sandstone lenses with fossils
20	2	sandstone, light greenish-gray, fossiliferous, medium-grained, weathers reddish brown, argillaceous and calcareous cement
22	12	shale, black, silty, micaceous, fossiliferous (<u>Tentaculite</u> and trilobites)

Height above basement (feet)	Thickness (feet)	
34	2	shale, black, silty, micaceous, fossiliferous (<u>Tentaculite</u> and trilobites)
36	6	sandstone and shale
42		fossil bed, 6 in. thick (H 3-148), sandstone, poorly sorted, dirty gray, calcareous cement
43	1	shale, dark gray, silty
	2	sandstone, poorly sorted, light gray, fossiliferous
45	3	shale, black, with sandstone inter- beds
48	3	sandstone, light gray, medium-grained, fairly well-sorted, calcareous and argillaceous cement (H 3-149)
51	12	shale, very thinly bedded with silt- stone beds, fossiliferous (H 3-150, H 3-151)
63	1	sandstone, medium-grained, medium gray, micaceous, reddish brown, weathered surface (H 3-152)
64		TOP OF HORLICK FORMATION
92	28	tillite
	6	tillite, bedded, medium gray matrix, sandy (H 3-153)
98	23	tillite
121	2	conglomerate lens
123	40	tillite
163	17	sandstone lens and sandy tillite (H 3-154), bed continuous for about 1/4 mile in each direction
180	102	grooves, poor, S80E tillite

Height above basement (feet)	Thickness (feet)	
282	20	sandstone, lens, channel-like bottom contact, four lenses across slope (H 3-155), light brownish gray, fine-grained, well-sorted, calcareous cement
302	5	tillite
307	12	shale, dark greenish gray (H 3-156), platy
319	25	tillite
344	3	shale, dark gray (H 3-157), tough, platy
347	2	sandstone, fine- to medium-grained, greenish gray, quartzose, calcareously cemented, fossils? (H 3-158)
349	214	tillite, dark gray, fine-grained matrix (H 3-159)
563	1	sandstone, lenticular, greenish-gray, weathers reddish gray, fine-grained, calcareous cement (H 3-160)
564	80	tillite, greenish-black, fine-grained matrix, base of tillite ledge (H 3-161)
644	63	tillite
707	4	sandstone, lens, light greenish-gray, fine-grained, calcareous cement (H 3-162)
711	40	tillite
751		top of escarpment
	97	tillite
848		high point on Lackey Ridge to west of line of ascent up escarpment

Section No. 9
Measured 24 November 61, hand level

228

Southern side of Lackey Ridge, nearly opposite Section No.
10, about 15 miles west-southwest of Mt.
Glossopeteris

Height above basement (feet)	Thickness (feet)	
0		basement, quartz monzonite
	65	Horlick Formation, undifferentiated, (H 3-112) from 45 ft. above basement, slope debris-covered
65		TOP OF HORLICK FORMATION
	36	tillite (H 3-113), dark greenish-gray
101		
	17	shale, dark greenish gray, platy, tough, waxy luster, pollen (H 3-114)
118		
	44	tillite, dark greenish gray, coarse- to medium-grained matrix (H 3-115)
162		
	4	sandstone, creamy light brown, cross- bedded, fine- to medium-grained, quartzose, calcareous cement, (H 3-116), in lenses 10-30 ft. long
166		
	82	tillite, greenish gray matrix (H 3-117)
248		
	6	sandstone, lenticular, cross-bedded, light gray, fine-grained, greenstone and quartz pebbles, (H3-118)
252		
	92	tillite
344		
	4	shale, dark greenish gray, platy, (H 3-119)
348		
	18	sandstone, light brownish gray with 2 to 3 in. spherical concretions, (H 3-120), fine-grained sand, well- sorted, medium to light gray, weathers yellowish gray (H 3-121)
366		
	15	tillite
381		
	4	sandstone lens and tillite
385		top of hill

Height above basement (feet)	Thickness (feet)	
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Change of direction and transfer of line to the top of sandstone bed at 366 ft. in initial section line.

366		top of fine-grained sandstone with spherical brown concretions
	100	tillite
466	5	sandstone, lenticular, medium gray, siliceous and calcareous cement, weathers reddish- and yellowish-brown (H 3-122)

471	314	tillite
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785		top of Lackey Ridge
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Turn travers direction to west toward high point on Lackey Ridge

985	200	tillite high point on south side of Lackey Ridge
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Section No. 11 (Darling Ridge)
Measured 25-26 November 61, hand level

230

On prominent peninsular portion of northern escarpment,
about 14.5 miles west of Mt. Glossopieris

Height above basement (feet)	Thickness (feet)	
0		basement, quartz monzonite
	0.1	shale, very dark gray
	1	sandstone, dark gray, weathers yellowish, coarse-grained, poorly sorted, feldspathic and micaceous, (H 3-123)
1		
	6	sandstone, medium-grained, dark greenish gray, weathers brownish gray, poorly sorted, argillaceous cement micaceous, (H 3-124)
7		
	0.5	shale, dark gray
	4	sandstone, dark gray, medium- to coarse-grained, fossiliferous, (H 3-125)
12		
	2	sandstone, light gray, coarse-grained, cross-bedded (H 3-126)
14		
	3	shale, black, micaceous, platy (H 3-127)
17		
	2	sandstone, light gray, massive
19		
	3	sandstone, dirty yellow with shaly partings
22		
	3	sandstone, light gray, medium coarse-grained, poorly sorted, fossiliferous
25		
	8	shale, dark gray, silty, micaceous (H 3-128)
33		
	4	sandstone, dirty, thin-bedded, shaly partings, fossiliferous
37		
	8	sandstone, dirty, cross-bedded, medium-grained, weathers yellowish and reddish (H 3-129)
45		
	2	sandstone, light gray, with many fossils, massive

Height above basement (feet)	Thickness (feet)	
47	23	sandstone, fine-grained, greenish gray, weathers reddish, lenticular beds with fossils present, (H 3-130)
70	18	sandstone, light greenish gray, weathers reddish, platy, micaceous, silty, (H 3-131)
88	19	sandstone - undescribed
107	76	TOP OF HORLICK FORMATION tillite, sandstone lenses present, (H 3-132, H 3-133)
183	26	tillite
209	4	conglomerate and siliceous and calcareous sandstone (H 3-134)
213	60	tillite, with sandstone lenses
273	12	shale, dark gray, slimy looking bedding surfaces (H 3-135), pollen
285	54	tillite
339	1	shale, dark gray
340	3	sandstone, fine- to medium-grained, cement partially calcareous, medium gray, contains calcareous brownish nodules up to few inches diameter (H 3-136)
343	1	siltstone
344	4	tillite, shaly
348	1	siltstone, greenish with brownish patches
349	274	tillite
623		high point on Darling Ridge

Section No. 12 (Leaia Ledge Section)
Measured 13 January 62, hand level

232

Mercer Ridge on the southwestern tip of Mt. Schopf, about
six miles south of Mt. Glossopteris

Height above basement (feet)	Thickness (feet)	
0		snow-rock boundary
	3	sandstone, light tan, basal ledge, covered with scree and diabase boulders
3		
	7	sandstone, mostly covered with talus and snow, 3 in. of shale on top of unit
10		
	6	sandstone, dark gray, silty, contains 4-in. bed of black shale
16		
	29	talus, shaly and diabase debris, bedrock probably shale
45		
	3	siltstone, brown, shaly structure, irregularly platy, plant impressions present, prominent banding
48		
	72	covered with brown soil-like debris, no outcrop
120		
	6	sandstone, light brown, poorly bedded, iron oxide stains, (H 3-18JR)
126		
	12	covered, probably siltstone, perhaps some fault gouge
138		
	39	siltstone, light brown to gray, vari- able bedding, frost heaving in shale, attitude of bedding N65E, 18SE, iron- stone and shale interbeds (H 3-19JR)
177		
	42	shale, bedding less than 3 in. thick, siltstone interbeds, bedding attitude N50E, 25SE
219		
	2	shale, black, papery
221		
	2	siltstone, light gray to tan, platy, shaly partings
223		
	2	shale, talus covered

Height above basement (feet)	Thickness (feet)	
225	1	siltstone, brown, muddy looking, (H 3-20JR)
226	2	shale, black
228	1	mudstone, light gray to white, carbonaceous debris (H 3-21JR)
229	12	shale, light gray, carbonaceous debris
241	30	sandstone, prominent cliff, cross- bedded, pinkish distinct beds, fine- grained, mafic minerals on cross- beds, logs at 15 ft., coal partings (H 3-22JR)
271	12	LEAIA LEDGE sandstone, shaly structure, mudstone interbeds, bedding attitude N50E, 25SE, logs present
283	48	talus over papery shale
331	68	shale, tannish-gray, platy, silty, ironstone bands up to 1 in. thick interbedded with 3 to 6 in. bands of siltstone, bedding attitude N20W, 25NE, coaly in uppermost 5 ft.
399	70	siltstone, platy, tannish-brown, N10W, 50NE, thin-bedded, weathers dark brown, lithologic units up to 6 ft. thick
469	27	siltstone, tan to brown, cross-beds present, N40W, 20NE
496	6	siltstone, platy, shaly structure
502	5	siltstone, tan, sandy
507	5	siltstone, brown, platy, shaly, 6 in. lens of chocolate brown
512	1	siltstone, platy, brown
513	7	mudstone, light gray, attitude N65E, 15SE, siltstone bands of chocolate brown

Height above basement (feet)	Thickness (feet)	
520	15	covered
535	18	siltstone, light brown, platy
553	7	shale, platy with siltstone
560	7	mudstone and siltstone, platy, coaly fragments, interbedded in 2 in. bands
567	24	covered, probably brown siltstone
591	110	siltstone, light gray to light brown, thin-bedded, logs present, dark brown layers, mudstone bands of variable thickness
701	2	shale, black, weathers brown
703	12	siltstone, brown, platy, occasionally shaly, one foot mudstone
715	22	covered
737	30	siltstone, light brown, faint bedding, logs, mudstone, light gray in one foot thick beds, coaly shale at 26 ft., attitude N40E, 25SE
767	48	covered
815	78	siltstone, light brown, sandy, grades into sandstone with mudstone impurities, bedding N50E, 25SE, cross-beds rare, fossil wood and coarse sandstone, dark purple lenses, N60E, 12SE
893	70	covered, shale and siltstone top of ridge
963		

Section No. 13 (Terrace Ridge)

235

Measured 6 January 62, hand leveled and plane table mapped

On the northwestern end of Mt. Schopf, about 5 miles south
of Mt. Glossopteris

Height above basement (feet)	Thickness (feet)	
0		started measurement at lowest rock outcrop
	40	sandstone, feldspathic, medium- to coarse-grained, weathers yellowish brown from grayish brown, small blackish flecks on fresh surfaces, cross-bedded, (H 3-340), carbonaceous siltstone parting (H 3-341, H 3-342)
40		
	45	sandstone, feldspathic, cross-bedded, medium-grained, weathers yellowish brown to yellowish gray, conglomeratic at base (H 3-343, H 3-344)
85		
	11	snow
96		
	12	sandstone, medium-grained, few conglomeratic lenses, cross-bedded, weathers yellowish brown
108		First Major Terrace
	63	snow
171		
	11	sandstone, fine- to medium-grained, dark gray, weathers medium gray, beds 1-3 in. thick (H 3-345)
182		
	2	siltstone and silty limestone, greenish gray with hematite stains, mostly covered (H 3-346)
184		
	9	snow, likely over siltstone
193		
	13	sandstone, carbonaceous partings, thin to thick beds, fine- to medium-grained, argillaceous, micaceous (H 3-347)
206		minor ledge
	10	snow covered
216		
	2	sandstone, gray to dark gray, weathers yellowish gray, thin to thick beds, carbonaceous partings, fine-grained, argillaceous and calcareous cement (H 3-348, H 3-349)

Height above basement (feet)	Thickness (feet)	
218	6	shale and siltstone, light gray, grades into black shale
224	23	sandstone, felspathic, medium- to coarse-grained, cross-bedded, pebble conglomerate lenses, fossil wood fragments and logs, weathers yellowish gray to yellowish brown
247	31	Second Major Terrace (H 3-350) sandstone, beds about 2 ft. thick, carbonaceous, silty shale partings 2-4 ft. thick (H 3-351, H 3-352)
278	9	sandstone, gray, fine-grained, weathers light yellowish gray, argillaceous and calcareous cement (H 3-353)
287	4	shale, carbonaceous
291	13	sandstone, cross-bedded, forms large terrace
304	30	Third Major Terrace, frost heaves about 10 ft. in diameter and 4-5 ft. high shale, dark gray with siltstone beds up to 6 in. thick
334	4	sandstone and siltstone, gray with brownish hue from limonitic cement, medium-grained, silty, calcareous (H 3-354)
338	1	ironstone, calcareous (samples taken for paleomagnetic analysis)
339	14	shale, carbonaceous
353	1	sandstone, dark gray, weathers light gray, fine- to medium-grained, silty, highly calcareous, micaceous, carbonaceous partings (H 3-355), <u>Glossopteris</u> (H 3-356 loose specimen)
354	9	shale, carbonaceous with few ironstone beds up to 3 in. thick
363	12	coal - DIRTY DIAMOND ADIT

Height above basement (feet)	Thickness (feet)	
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237

375	8	shale, carbonaceous, less carbon and more silt toward top of unit, <u>Glossopteris</u>
383	4	sandstone, gray, mottled with brown specks of limonite, fine- to medium-grained, silty, calcareous, streaks of coaly material (H 3-357)
387	25	Fourth Major Terrace shale-siltstone, platy, dark gray, weathers light yellowish brown, profuse <u>Glossopteris</u> , ironstone concretions
412	34	Main Glossopteris Ledge shale, carbonaceous, darker near top
446	2	sandstone, gray, weathers light gray, fine- to medium-grained, faintly banded, micaceous (H 3-358)
448	2	shale, black
450	1	limestone, dark brownish gray, argillaceous, slightly sandy, weathers light rusty brown (H 3-359)
451	28	shale, carbonaceous, weathers light gray
479	10	coal and coaly shale
489	26	shale, carbonaceous and coaly
515	10	coal and coaly shale
525	61	shale, dark gray and coaly, siltstone interbeds up to 6 in. thick, shale beds 2-4 in. thick, silty (H 3-360)
586	2	sandstone, weathers reddish-brown from medium gray, fine- to medium-grained, calcareous and clayey cement (H 3-361)
588	36	shale and siltstone interbeds, siltstones up to 2 ft. thick make small ledges

Height above basement (feet)	Thickness (feet)	
624	2	sandstone, massive, light gray, fine- to medium-grained, feldspathic, carbonaceous streaks (H 3-362)
626	6	coal and coal shale (H 3-363)
632	12	sandstone, very fine-grained, medium gray, weathers light gray, slightly calcareous, thin carbonaceous laminae (H 3-364)
644	17	coal and coaly shale
661	57	Base of Big Log Ledge sandstone, feldspathic, fine- to medium-grained
718	28	Low area on Big Log Ledge sandstone, feldspathic
746	8	Big Log Ledge, numerous fossil logs siltstone, thin-bedded, dark gray, weathers light gray
754	4	coal and coaly shale (H 3-366)
758	7	sandstone, fine-grained, medium gray, weathers light yellowish brown, calcareous, limonitic streaks (H 3-367)
765	12	siltstone and shale, dark gray, platy
777	5	coal and coaly shale
782	7	siltstone, shaly structure, medium gray
789	10	sandstone, feldspathic, fine- to medium-grained, gray, weathers light brown, slightly micaceous, fossil logs, (H 3-368)
799	18	siltstone and sandstone, shaly structure
817	10	siltstone and sandstone
827	9	shale, dark gray, platy, weathers light gray (H 3-369)
836	13	coal and coaly shale

Height above basement (feet)	Thickness (feet)	
849	46	siltstone and shale, black, weathers gray, carbonaceous (H 3-370, H 3-371)
895	5	shale, coaly, and mudstone
900	6	shale and mudstone, dark gray, weathers light gray, iron stains (H 3-372)
906	7	sandstone, very fine-grained, dark gray, weathers light gray, upright trees (H 3-373)
913	7	shale, coaly, and mudstone, light gray, ironstone bed 6 in. thick
920	1	siltstone, weathers very light gray
921	58	shale, coaly
979	5	sandstone, fine-grained, medium gray, weathers light gray, calcareous
984	10	shale, coaly
994	57	mudstone, blocky fracture, dark gray, weathers very light gray (H 3-375, calcareous lens, H 3-376)
1051	17	siltstone, thin- to thick-bedded, weathers light gray, top 3 ft. are carbonaceous ironstone shale
1068	28	sandstone, medium- to coarse-grained, dirty, grains up to 1 cm. diameter, cross-bedded, weathers light brownish-gray (H 3-377, H 3-378)
1096	8	Lunch Ledge shale, carbonaceous, (H 3-379), much coalified plant debris
1104	9	shale and siltstone, dark gray, weathers light gray, platy and blocky
1113	27	shale, carbonaceous (coaly)
1140	74	sandstone, feldspathic, gray, medium- to coarse-grained, silty, micaceous, many dark minerals (H 3-380, H 3-381, H 3-382) (H 3-383, <u>Vertebraria</u> fossil)

Height above basement (feet)	Thickness (feet)	
1214		Vertebraria Ledge
	38	shale, carbonaceous
1252		
	85	sandstone, feldspathic, light gray and medium gray, fine- to medium-grained, low-angle cross-beds, lenses of medium dark gray (zeolites) sandstone, salt and pepper-colored beds, lumps like lumpy mush, lenses of very dark brown gray sandstone (used for paleomagnetic samples) (H 3-384, H 3-385, H 3-386, H 3-387)
1337		
	20	shale, coaly, carbonaceous, weathers dark and medium gray, siltstone and mudstone beds interbedded, <u>Vertebraria</u>
1357		
	67	sandstone, feldspathic, medium-grained, medium to dark gray, weathers light brownish gray, cross-bedded, lenses of zeolitic sandstone and dark reddish-brown beds up to 18 in. thick (H 3-389, H 3-390, H 3-391, H 3-392, H 3-392A, H 3-393)
1424		highest sandstone ledge, built small cairn
	5	shale, carbonaceous, slightly coaly, yellowish-red stain
1429		
	9	siltstone, or hornfels, medium gray, blocky
1438		
	10	arkose, even-bedded, fine- to medium-grained, weathers light reddish-gray, spotted (hornfelsic)
1448		
	17	hornfels, medium gray, baked siliceous shale or mudstone
1465		DIABASE CONTACT

Section No. 14 (Ridge East of Terrace Ridge)
Measured 23 November 63, hand level

241

Located near the southwest end of Mt. Schopf, northeast of Terrace Ridge and about 4 miles south of Mt. Glossopteris

Height above basement (feet)	Thickness (feet)	
0		measurement started at lowermost sedimentary rock outcrop, single exposed bed of sandstone cross-bedded, fossil wood impressions, fine- to medium-grained, medium gray, calcareous cement
33	33	snow-cover
35	2	shale, with coaly layers, light gray, fossil stem impressions, <u>Glossopteris</u> sandstone bed, thick, massive, block fracture 1 ft. thick
46	11	snow-cover (H 3-74 float)
75	29	shale, weathers light gray and brown, silty, numerous plant impressions, mostly stems (H 3-75)
87	12	sandstone, grayish brown, weathers yellowish brown, lens of dark gray crystalline material (H 3-77)
116	29	shale, siliceous, iron-stained, <u>Glossopteris</u> impressions, other plant impressions too (H 3-76, H 3-38)
124	8	shale and sandstone
125	1	coal (H 3-79), sparsely and thinly banded, impure
126	1	ironstone bed (H 3-80), very dark gray, weathers to boxwork pattern
168	42	shale, slope mostly covered with debris, <u>Glossopteris</u> in shale
169	1	coal (H 3-81), impure, sparsely and thinly banded
	30	snow-cover

Height.
above
basement
(feet)

242

Thickness
(feet)

199	80	shale and shaly sandstone, dark gray, weathers light gray with many thin carbonaceous streaks, <u>Glossopteris</u> impressions, calcareous (H 3-82)
279		cairn on sandstone ledge
	3	shale, silty, weathers light gray
282		
	3	coal and coaly shale (H 3-83), thinly banded with sparse bands, thin fusain bands present
285		
	17	shale, medium gray, weathers light gray, brown lenticular beds included, fossil logs, <u>Glossopteris</u>
302		
	11	coaly shale and coal, prominent bed
313		
	5	shale, dark gray, silty
318		
	27	sandstone, cross-bedded, ledge-former, medium gray, fine- to medium-grained, calcareous (H 3-84), fault
345		fault to southeast of sandstone
335		coaly shale, silty
	26	shale, dark gray, weathers light gray
361		
	11	coal and coaly shale (H 3-85), impure, sparse bands thinly banded, impure attrital coal
372		
	5	shale, dark gray, weathers light brown
377		
	17	sandstone, fine-grained, medium gray, thin-bedded, iron-stained, weathers light gray, flaky surface, well-sorted (H 3-86)
394		
	20	sandstone, platy, like bed below
414		
	17	shale, dark gray, weathers light gray, profuse <u>Glossopteris</u> , cross-bedded, fossil logs up to one foot diameter..
431		
	6	coal and coaly shale, thin bands, sparsely banded, vertical fractures with precipitate staining fracture surfaces

Height above basement (feet)	Thickness (feet)	
437		
	24	shale, silty
461		
	12	sandstone and shale interbedded,, beds about 2 in. thick, weathers brownish gray and light gray, large <u>Glossopteris</u> and upright stumps
473		
	14	shale and sandstone (H 3-88), tough, massive, silty, dark carbonaceous beds
487		
	6	shale, carbonaceous, and sandstone lenses (1 in. thick), lenses of limestone, silty, medium gray, weathers brownish gray (H 3-89)
493		
	2	shale, creamy, dark gray, weathers very light creamy gray
495		
	17	sandstone (H 3-90), fine- to medium-grained, slightly calcareous, weathers light gray, cross-bedded, massive, ledge-former
512		
	5	sandstone, weathers light gray and brownish, thinly bedded with shaly partings
517		
	58	shale, coaly, fissile, weathers light gray (H 3-91)
575		
	50	siltstone or mudstone, blocky (H 3-92), fine-grained sandstone lenses, beds 12-18 in. thick
625		
	2	shale, medium to dark gray, tough, thinly bedded, cherty (H 3-93)
627		(H 3-94) large stem impression
	7	shale, varved (H 3-95, H 3-96), tough, gray with thin beds of brown material, gray bands about 1/16 in. thick, brown band about 1/32 in. thick, slightly silty
634		
	27	sandstone, feldspathic, thin-bedded to massive, cross-bedded, medium- to coarse-grained, gray to light greenish-gray (H 3-97)

Height above basement (feet)	Thickness (feet)	
661	2	mudstone, massive, silty, dark gray, weathers light gray, coalified plant debris (H 3-98)
663	14	shale, weathers light gray and brownish gray
677		bed of dark brown sandstone, 2 in. thick (H 3-99)
	17	sandstone, thin-bedded, fine-grained, slightly calcareous, few carbon streaks (H 3-100)
694	28	shale, dark gray, fissile, abundant <u>Glossopteris</u>
722	80	sandstone, fine- to medium-grained, silty, clayey, dark grayish-black, calcareous and carbonaceous, micaceous, cross-bedded (H 3-101, H 3-102)
802		Ledge (H 3-103)
	33	shale, dark gray with sandstone beds up to one foot thick, many plant impressions, thin, dark brown shale (H 3-104)
835	87	sandstone, light greenish-gray, medium-grained, feldspathic, slightly calcareous, massive bedding, sandy nodules (H 3-105), lenticular brown sandstone beds
922	5	sandstone, fine-grained, light brown
927	23	sandstone (H 3-106), fine-grained, silty, clayey, carbonaceous, thinly bedded, and shale, black, coaly, plant impressions
950	17	sandstone, thinly bedded, grayish tan, zeolites in lenses up to 1 foot thick
967	4	mudstone and shale, carbonaceous
971	6	sandstone, fine- to medium-grained, feldspathic, cross-beds, spotted, weathers brown (H 3-107)

Height above basement (feet)	Thickness (feet)	
977	30	sandstone, even-bedded, thin beds, light greenish-gray, fine- to medium-grained, feldspathic, alternating light and dark beds (H 3-108)
1007	5	siltstone, weathers creamy tan, <u>Glossopteris</u> impressions
1012	4	shale, carbonaceous (H 3-109), thinly bedded, silty, noncalcareous, carbonaceous
1016	23	sandstone, light brown
1039	3	shale, silty, dark gray, plant stems, upright <u>Vertebraria</u> (H 3-110)
1042	10	mudstone, baked, hornfels, upright stems
1052		DIABASE SILL

Section No. 15
Measured 2 December 61, hand level

246

Mt. Schopf, northeast ridge, about 3 miles southeast of
Mt. Glossopieris

Height above basement (feet)	Thickness (feet)	
0		started measurement at lowest rock outcrop below prominent terrace and cliff
	5	sandstone (H 3-180), feldspathic, medium gray, coaly streaks, weathers light yellowish gray, medium-grained with randomly scattered pebbles of siltstone, quartz, and shale present, calcareous and argillaceous cement
5		
	23	snow- and talus-covered
28		
	17	shale (H 3-181), very dark gray, micaceous, weathers dirty gray, carbonaceous layers
45		
	4	sandstone, light brownish gray, massive
49		
	1	coal (H 3-182), moderately banded thick bands, bright attrital coal, thin fusain bands, cleat about 90°
50		
	41	sandstone (H 3-183), feldspathic, fine-grained, medium light gray, weathers light yellowish gray, quartz pebble lenses
91		
	20	shale, very dark gray, weathers medium gray
111		
	1	sandstone, reddish brown
112		
	8	shale, carbonaceous, weathers medium gray
120		
	11	sandstone, feldspathic, massive
131		
	45	snow-covered

Height
above
basement
(feet)

247

Thickness
(feet)

176	30	sandstone (H 3-184), feldspathic, medium gray, limonite stained grains, carbonaceous particles, weathers light brownish gray, calcareous and argillaceous cement, ledge-former
206	13	snow covered
219	126	scree- and rubble-covered, probably shale or siltstone
345	68	sandstone (H 3-185), feldspathic, fine-grained, medium light gray with brown streaks, weathers light yellowish gray, calcareous and argillaceous cement, ledge-former, limonitic wood
413	7	shale, dark gray
420	2	coal (H 3-186), sparsely banded, thin bands, moderately dull attrital coal, thin fusain on surfaces
422	34	shale, carbonaceous, <u>Glossopteris</u>
456	24	sandstone (H 3-187), feldspathic, fine-grained, scattered dark grains, forms small ledge and cliff, upright fossil trees
480	40	shale, sandy, light brown with brown streaks, carbonaceous toward top, interbeds of creamy light-gray weathering mudstone
520	8	shale, coaly (H 3-188), impure attrital coal and very thin bands of vitrain and fusain
528	20	sandstone and siltstone, thin-bedded, with <u>Glossopteris</u>
548	5	coal and coaly shale (H 3-189), sparse, thick bands with dull attrital coal, very thin fusain

Height above basement (feet)	Thickness (feet)	
553	10	siltstone, carbonaceous, thinly bedded, weathers light gray to yellowish gray, plant impressions
563		base of cliff
	57	sandstone (H 3-190), feldspathic, medium-grained, medium light gray, micaceous, massive, cliff-former
620		large ledge, top of cliff
626	6	siltstone
	10	coal and coal shale (H 3-191), thin bands, sparsely bedded, dull attrital coal, very thin fusain, bed offset 20 ft. by fault which parallels ridge, direction N50E (mag.)
636	57	shale, dark gray, weathers medium gray
693	45	sandstone (H 3-192), feldspathic, fine-grained, medium gray, light gray laminae, cross-bedded, argillaceous cement
738	85	shale, silty, dark gray, weathers medium gray, carbonaceous near top
823	97	sandstone, light gray, thinly bedded, shaly structure, cross-bedded at top, cliff-former on crest of ridge
920	128	shale, dark gray, carbonaceous, weathers medium gray, upper 50 ft. silty, medium gray shale, some beds appear varved
1048	45	sandstone (H 3-193), feldspathic, medium gray, light gray nodules about $\frac{1}{4}$ in. diameter, weathers light yellowish gray, medium-grained, calcareous cement
1093	2	sandstone (H 3-194), feldspathic, medium-grained, micaceous, silty, calcareous cement, weathers dark brown in outcrop

Height above basement (feet)	Thickness (feet)	
1095	18	sandstone (H 3-195), feldspathic, very light greenish gray, fine- to medium-grained, calcareous cement, evenly and horizontally bedded
1113	26	sandstone, mostly covered
1139	16	shale, dark black, due to baking from sill (hornfels)
1155		DIABASE CONTACT

Section No. 16
Measured 1 December 61 and 8 January 62, hand level

250

Southeast ridge of Mt. Glossopteris

Height above basement (feet)	Thickness (feet)	
0		started measurement at top of sandstone cliff which is about 80 ft. above the snow-rock line within a tilted fault block with rock: striking N50E and dipping NW, bedding thicknesses have been approximated
1	1	shale, black, silty
3	2	sandstone, light gray, carbonaceous chips with <u>Glossopteris</u> impressions
5	2	shale, black and coaly, (H 3-165)
	0.5	sandstone (H 3-166), fine-grained, dark reddish brown, slightly calcareous
	25	shale, coaly partings, and siltstone interbeds up to 2 ft. thick in middle of unit
30	1	sandstone, medium-grained, light gray, weathers yellowish brown
31	2	shale, coaly (H 3-167), thinly bedded, thin vitrain bands
33	1	sandstone (H 3-168), feldspathic, dark gray, weathers light gray, fine-grained, carbonaceous, slightly calcareous cement
34	6	siltstone, light gray, grades into dark gray
40	5	coal, mostly hidden by rubble
45	20	coal and shale (H 3-169), thinly banded in moderately abundant bands; fossil wood (H 3-170), reddish-brown iron oxide stains (H 3-171)
65	12	sandstone and siltstone, weathers yellowish brown, fossil wood with white oval-shaped structures

Height above basement (feet)	Thickness (feet)	
77	8	sandstone (H 3-172), very fine-grained, dark gray, weathers light yellowish-brown with reddish-brown streaks
85	3	siltstone (H 3-173), light gray, much <u>Glossopteris</u> and seeds, carbonaceous
88		fault - bearing N50W (map.)
<hr/>		
Height above fault (feet)	Thickness (feet)	
	28	shale, black, and coal (H 3-174), impure, sparsely banded thin bands, fusain on bedding surfaces
28	51	siltstone and shale, interbedded, dark gray, weathers light gray to yellowish brown, reddish brown streaks (lenticular), profuse <u>Glossopteris</u> and seeds (H 3-175)
79	58	siltstone (H 3-176), medium-grained, medium gray, weathers light yellowish brown, concretionary structures with gray mudstone outer ring and granular ironstone interior (stem cross section)
129	15	coal and coaly shale (H 3-177), moderately banded thin bands, thin fusain, bright attrital coal, cleat not apparent
144	13	shale, dark gray, and siltstone, light gray, weathers light reddish-gray
157	15	sandstone, feldspathic, light yellowish brown, fine-grained
172	2	mudstone, light gray, <u>Glossopteris</u>
174	12	sandstone, fine-grained, light brown
186	48	siltstone (H 3-178), black, weathers light brownish gray, platy

Height above fault (feet)	Thickness (feet)	
234	40	sandstone or siltstone (H 3-179), feldspathic, rust-colored streaks, thinly bedded, <u>Glossopteris</u>
274	205	Base of Cliffs sandstone with siltstone interbeds, cliffs, generally too steep for access, samples taken from random areas along margin of the cliffs (H 3-399, H 3-400), siltstone, medium gray, weathers light gray, shaly structure, and sandstone medium light gray, fine-grained, weathers light gray, well-sorted grains, massive and cross-bedded, outcrop shows reddish-brown streaks of limonite stain, inter-bedded shales with <u>Glossopteris</u> (H 3-401), ironstone lenses and concretions
479	19	top of cliffs siltstone, much like cliffs
498	8	coal and coaly shale (H 3-402), impure, sparsely banded, thin bands, mostly dull attrital, very thin fusain
506	17	sandstone (H 3-403), feldspathic, massive, medium-grained, medium gray, weathers light gray, well-sorted, carbonaceous grains, calcareous and argillaceous cement
523	8	mudstone (H 3-404), medium gray, weathers light yellowish-gray to powder white, laminae visible but are not planes of weakness (varves), blocky structure
531	3	coal (H 3-405), impure, sparse to moderately banded, thin bands, very thin fusain, mostly attrital coal
534	17	snow-covered
551	40	base of final cliff sandstone (H 3-406), feldspathic, medium light gray, massive, well-sorted, weathers light gray with brown streaks, becomes thinly bedded in top 10 ft., calcareous and argillaceous cement

Height above fault (feet)	Thickness (feet)	
591	16	shale, wavy bedding planes, coaly material on bedding surfaces, concretion (H 3-407)
607	17	shale, coaly (H 3-408), dull black, laminae of coal and carbonaceous shale
624	23	siltstone, weathers light gray, some coaly material, blocky structure
647	11	shale, coaly partings, weathers very light gray
658	24	siltstone and sandstone, weathers light gray, fossil logs and upright stumps, (H 3-409), top beds creamy very light gray with mudcrack-like fractures, bearing N12W and N80E (mag.)
682	57	fault bedding attitudes: strike EW, dip 20°S (mag.)
739	47	sandstone (H 3-410), medium light gray, feldspathic, well-sorted, weathers light gray, argillaceous and calcareous cement
786	7	mudstone (H 3-411), tough, medium dark gray, weathers light powdery gray, <u>Glossopteris</u> weathers yellowish brown on weathered surfaces, shaly with coaly partings near top
793	17	snow-covered
810	9	sandstone, feldspathic, weathers yellowish brown, plant fragments
819	4	shale, dark gray with coaly partings
823	21	sandstone (H 3-412), medium-grained, medium light gray, feldspathic, weathers light brownish-gray, well-sorted, few cross-beds
844	17	snow-covered

Height above fault (feet)	Thickness (feet)	
861	14	sandstone, fine-grained, light gray with ironstone interbeds
875	30	sandstone (H 3-414), feldspathic, medium-grained, light yellowish gray, dark gray spots about twice the size of sand grains, calcareous ironstone beds, yellowish brown, silty, blocky fracture (H 3-413)
905	57	sandstone (H 3-415), feldspathic, medium- to thin-bedded, gray, and lighter gray in $\frac{1}{4}$ to $\frac{1}{2}$ in. beds, medium-grained, slightly calcareous
962	17	sandstone, feldspathic (H 3-416), gray, with alternating fine-grained and medium-grained layers, irregularly bedded and contorted, also sandstone (H 3-417), feldspathic, fine- to medium-grained, silty, micaceous, calcareous, mud pellet conglomerate and stem impressions
979	11	coal and coaly shale (H 3-418), coal impure, sparsely banded
990	7	shale, weathers light bluish-gray, coaly partings
997	51	sandstone (H 3-419), feldspathic, fine-grained, gray, thin streaks of coaly matter, calcareous
1048	28	mudstone (H 3-421), dark gray, weathers light gray, tough, blocky, plant fragments
1076	16	shale (H 3-421), dark gray, weathers light gray, laminated with coaly layers, dark reddish brown, calcareous ironstone lenses
1092	17	shale and mudstone (H 3-422), light olive green to greenish black, siliceous, banded, <u>Glossopteris</u> , concretions

Height above fault (feet)	Thickness (feet)	
1109	11	siltstone, platy, light gray
1120	51	sandstone (H 3-423), poorly sorted, dirty, feldspathic, micaceous, slightly calcareous
1171	15	shale and siltstone, blocky fracture, black, thin white streaks, tough, plant impressions <u>Vertebraria</u>
1186	10	sandstone (H 3-425), feldspathic, fine-grained, medium gray, carbonaceous streaks
1196	7	snow-covered
1203		top of exposed rock
	119	snow
1322		TOP OF MT. GLOSSOPTERIS

Section No. 17
Measured 8 December 61, hand level

256

Northwest or west face and shoulder of Mt. Glossopteris

Height above basement (feet)	Thickness (feet)	
0		measurement started at lowest rock outcrop on slope to west-southwest of summit Mt. Glossopteris
	23	sandstone (H 3-197), feldspathic, fine- to medium-grained, light gray, calcareous
23		
	8	snow-covered
31		
	15	sandstone (H 3-198), feldspathic, dark gray, calcareous, thin- to medium-bedded, platy, iron-stained lenses, weathers light gray
46		
	8	siltstone, thin-bedded, medium gray, weathers light gray, fossil wood, (H 3-202)
54		
	1	sandstone (H 3-199), feldspathic, dark reddish brown, fine-grained, calcareous
55		
	14	siltstone and shale, black, coaly surfaces
69		
	1	sandstone (H 3-200), dark gray, fine-grained, slightly micaceous, calcareous, brownish streaks, medium-bedded
70		
	1	shale, carbonaceous
71		
	0.5	coal (H 3-201), moderately banded, thin bands
	4	shale, dark gray, weathers light gray, with $\frac{1}{2}$ to 1 in. sandstone laminae
75		
	0.5	siltstone (H 3-203), dark gray, weathers light gray, silty, micaceous, stem impressions and <u>Glossopteris</u>
76		MUSEUM LEDGE
	23	snow

Height above basement (feet)	Thickness (feet)	
99	17	shale, dark gray, coaly partings, 2 in. bed of iron-stained sandstone
116	0.5	sandstone (H 3-204), gray-black, very fine-grained, highly calcareous, iron- stained, carbonized plant stems
	6	shale, dark gray, weathers light gray, with platy siltstone beds from 1 to 2 in. thick
122	4	sandstone (H 3-205), fine- to medium- grained, feldspathic, slightly mica- ceous, medium gray with carbonaceous streaks, thin-bedded toward top, wood impressions
126	10	snow-covered
136	2	sandstone, weathers dark grayish brown, cross-bedded
138	5	shale, dark gray, weathers light gray, coaly streaks
143	11	coal and coaly shale (H 3-206), non- banded coal, reddish-brown lenses of tough, blocky siltstone (H 3-207), <u>Vertebraria</u>
154	23	sandstone (H 3-208), feldspathic, medium gray, weathers yellowish gray, medium-grained, massive, ledge-former
177	7	siltstone, shaly structure, dark gray
184	11	shale, coaly (H 3-209), dark gray, blocky
195	63	siltstone, medium gray, weathers light gray, brownish laminae up to 1 in. thick, mudstone beds, up to 1 ft. thick, becomes more sandy near top
258	36	sandstone (H 3-210), feldspathic, massive, level-bedded, cross-bedded, medium gray, weathers light yellowish gray, fine-grained, argillaceous cement

Height above basement (feet)	Thickness (feet)	
294	4	coaly shale (H 3-211), moderately banded, thin bands, bright attrital coal, thin fusain
298	23	sandstone, feldspathic, (H 3-213), gray with light reddish tint, fine-grained, silty and clayey, interbedded with shale (H 3-212), greenish-gray and reddish-gray alternating layers, bedding up to $\frac{1}{4}$ in. thick
321	7	sandstone, fine-grained, feldspathic, weathers light gray, cliff-former, thick-bedded to massive, ironstone lenses
328	48	siltstone, brown laminae, interbedded "varved" beds (H 3-214), alternating reddish gray and light brown varves space about $\frac{1}{4}$ in., silty, tough, noncalcareous, plant impressions, wood fragments
376	5	sandstone (H 3-215), feldspathic, gray, weathers light tan, fine-grained, slightly calcareous and argillaceous cement
381	1	mudstone, weathers light gray
382	2	coal (H 3-216), impure, sparsely banded
384	17	shale, carbonaceous, with siltstone beds 8 in. thick which weathers gray, <u>Glossopteris</u>
401	23	siltstone, shaly with blocky-fractured beds, weathers light gray and light brown, carbonaceous partings
424	2	coal and coaly shale (H 3-217), sparsely banded, thin to medium bands
426	11	siltstone, brown and light gray bands, upright stumps (H 3-219)

Height above basement (feet)	Thickness (feet)	
437	23	siltstone, brown bands, much plant material, varved ? beds, loose sample (H 3-218)
460	2	shale, carbonaceous
462	3	coal (H 3-220), sparsely banded, thin to medium bands
465	40	siltstone, variably bedded, thin-bedded and sandy, blocky mudstone, beds of brown sandstone, ledges from 3 to 6 ft. high
505	1	shale, carbonaceous and coaly
506	12	coal and coaly shale (H 3-221), moderately banded, thin to medium bands
518	28	siltstone, varies from light gray to dark gray
546	2	shale, carbonaceous
548	51	shale and siltstone interbedded (H 3-222, H 3-223, H 3-224), gray, silty, slightly calcareous, weathers very light brown, <u>Glossopteris</u> , upright trees
599	17	sandstone, gray, medium-grained, feldspathic, calcareous cement
616	28	Top of Shoulder sandstone, feldspathic (H 3-225), medium-grained, weathers very light gray, mudcracks on surfaces, many wood fossils, upright trees (18 in. diameter)
644	5	siltstone, flat-bedded, platy, weathers light gray
649	1	mudstone (H 3-226), dark gray, weathers light gray, slightly micaceous, carbonized plant fragments
650	4	coal (H 3-227)

Height above basement (feet)	Thickness (feet)	
654	7	shale, coaly
661	6	shale, carbonaceous
667	43	shale and siltstone with coaly layers every 4 or 6 ft., coaly layers about 6 in. thick, concretions, and iron- stone bands
710	11	sandstone (H 3-228), fine-grained, medium gray, weathers light gray, 1-ft. thick bed of mudstone
721		TOP OF EXPOSED ROCK

Section No. 18
Measured 8 December 61, hand level

261

Long skyline ridge to the north and northwest of the peak
of Mt. Glossopteris

Height above basement (feet)	Thickness (feet)	
0		started hand level measurement at base of continuous outcrop; base of measurement connects with the chain of hand leveled sequences which overlaps 5 ft. with the sections shown under Section Nos. 21 and 22
	5	sandstone or siltstone, weathers light brown to gray, <u>Glossopteris</u> and stem impressions (H 3-2JR)
5	0.3	coal with plant impressions (H 3-3JR)
	15	snow-covered, probably shale or siltstone
20	23	siltstone or sandstone, weathers light brownish-gray to dull red, some beds laminated, ironstone concretions, <u>Glossopteris</u>
43	20	sandstone, fine-grained, cross-bedded, (H 3-4JR), fossil log
63	13	siltstone or sandstone, alternating layers, plant debris and fossil wood
76	8	impure coal (H 3-5JR), plant fragments visible
84	26	siltstone and fine-grained sandstone, weathers reddish to light brownish, ironstone bands in lenses up to 2 in. thick, beds laminated, coalified stems
110	41	sandstone, as below with more ironstone, laminated in 2-in. units, maroon-colored fossil logs
151	8	coal (H 3-6JR), talus-covered
159	2	siltstone or sandstone, very light brown, massive, plant stem impressions.

Height above basement (feet)	Thickness (feet)	
161	1	coalified debria
162	6	coal
168	11	siltstone, massive, weathers light brown to gray, platy areas, plant debris and coalified debris, fossil logs, which weather reddish brown (limonitic)
179	6	coal (H 3-8JR)
185	4	siltstone with coaly layers
189	40	base of cliff siltstone or sandstone, weathers gray to light brown, very fine-grained, cross-bedded, no coaly layers or laminae, weathers into cliffs with beds of differential resistance to weather, ironstone lenses up to 6 in. thick
229	6	siltstone with coalified plant particles, fossil tree stump (H 3-9JR)
235	22	siltstone or sandstone, ironstone concretions
257	7	coal (H 3-10JR)
264	26	siltstone or sandstone, with coaly laminae, brownish siltstone interbedded, plant fossils (H 3-11JR)
290	3	shale, coaly, and coal
293	21	siltstone, debris-covered, coal in debris
314	18	siltstone or sandstone and shale, with coalified laminae, coaly beds more abundant near top
332	3	coal

Height above basement (feet)	Thickness (feet)	
335	18	siltstone or sandstone, massive up to base of cliff, fossil logs
353	81	sandstone (H 3-12JR), fine-grained, cliff-former, cross-bedded, ironstone lenses, fossil logs (limonitic)
434	26	coal and siltstone, plant impressions
460	43	siltstone, interbedded with shaly coal in beds about 2 in. to 1 ft.
503	8	siltstone or sandstone, massive, platy, light brown
511	14	coal (H 3-13JR)
525	59	sandstone, fine-grained, siltstone, cliff-former
586		top of hand-leveled portion of section
	370	snow to summit, measured with altimeter, rocks present but difficult to reach

Section No. 19
Measured 8 December 61, hand level

264

Height above basement (feet)	Thickness (feet)	
0		measurement started at low point of continuous rock outcrop along ridge
	6	debris-covered
6		
	20	sandstone (H 3-14JR), with pebble beds, weathers pale reddish brown, deltaic cross-beds
26		
	2	shale, silty (H 3-15JR), platy
28		
	3	sandstone, cross-bedded
31		
	3	debris-covered slope, soil-like material (H 3-16JR) on surface
34		
	1	sandstone (H 3-17JR), fine-grained, weathers reddish brown
35		
	2	debris-covered, soil-like material
37		
	1	sandstone and siltstone
38		
	3	soil-like material
41		
	10	siltstone and sandstone, grades into coarse pebbly sandstone with rounded pebbles, gray quartz, weathers pinkish red-brown, cross-bedded
51		TOP OF HORLICK FORMATION
	51	tillite, few sandstone beds in first 15 ft.
102		
	1	sandstone (H 3-428), lens, weathers brownish- to greenish-gray, lens about 15 ft. long
103		
	40	tillite, greenish gray (H 3-429), large sandstone lenses at this level to east of section (50 x 10 ft.)
143		
	51	tillite

Height above basement (feet)	Thickness (feet)	
194	14	sandstone, lenticular (H 3-430), and tillite interbeds; sandstone, light grayish brown, medium-grained, quartzose, calcareous cement, porous
208	132	tillite (H 3-432), greenish-gray
340	6	sandstone (H 3-433), lenticular, fine- to medium-grained, quartzose, very calcareous
346	40	tillite, with sandstone lenses which weather reddish-brown (H 3-434)
386	34	tillite (H 3-435), dark greenish-gray
420	9	sandstone and conglomerate (H 3-436A, H 3-436B), light greenish gray, weathers reddish brown, cross-bedded, calcareous matrix
429	6	tillite, dark greenish gray matrix
435	2	shale (H 3-438), dark greenish-gray, with concretionary bodies 6 to 18 in. in diameter, looks like purple pancakes, wind-polished, composed nearly entirely of carbonate
437	2	sandstone (H 3-439), fine-grained, light bluish gray, weathers light brown, well-sorted, calcareous cement large, flat terrace
439	2	shale, light gray, platy tracks on bedding surfaces (H 3-441)
441	5	shale, siltstone and tillite, scour marks around pebbles (H 3-440), indicates direction of NSW (mag.)
446	114	tillite (H 3-442), medium dark bluish-gray
560	36	tillite
596	2	shale (H 3-443), sandy, tillitic texture, bluish gray, alternate layers of siliceous cement and calcareous cement,

Height above basement (feet)	Thickness (feet)	
		weathers light brownish- to greenish-gray, lenses of coaly material
598	308	tillite, with 10-ft. long lenses of pebbly calcareous siltstone
906	17	sandstone (H 3-444), weathers light yellowish-gray, bedding disturbed by slumping, conglomeratic lenses
923	11	sandstone, fine-grained, shaly structure, light greenish gray, spherical brown concretionary bodies, 2-3 in. in diameter
934	15	tillite
949	2	sandstone layer with folds
951	45	tillite
996	3	sandstone bed, highly contorted
999	28	tillite
1027	262	TOP OF BUCKEYE TILLITE shale, but snow-covered
1289	226	top of steep ridge snow- and moraine-covered, last 50 ft. up fissile, carbonaceous black shale of Upper Member of the Discovery Ridge Formation
1515	1	sandstone (H 3-445), dark gray, weathers yellowish gray, micaceous
1516	90	siltstone, dark gray, micaceous, animal burrows
1606	40	TOP OF DISCOVERY RIDGE FORMATION sandstone, massive, even-bedded, weathers light brownish gray, laminae of dark and light grains
1646	40	siltstone, black, animal burrows
1686		base of first major cliff--about 100 ft. of vertical wall

Section Nos. 20 and 21 (Discovery Ridge, East Spur) 267
Measured 25 December 61

Section starts at basement rock contact of the east spur of Discovery Ridge and continues up a faulted slope between Discovery Ridge and Quartz Pebble Hill

Height above basement (feet)	Thickness (feet)	
0		quartz monzonite basement rock with dikes of mafic minerals and weathered zone just under sedimentary rocks
	1	sandstone and conglomerate, very much like granitic basement rock, pebbles up to 1 in. diameter, weather light yellowish brown
1	0.5	shale, black
	0.3	sandstone, coarse-grained, poorly sorted, medium gray, yellow stains on weathered surface
2	0.5	shale, black
	1.5	sandstone, gray, micaceous, poorly sorted, dirty, yellow stains, fossils
4		
	2	shale, black
6		
	1	sandstone, light gray, weathers yellowish gray, yellowish-brown nodules
7		
	6	sandstone and shale, black
13		
	5	sandstone, medium-grained, light gray, carbonaceous particles on bedding surfaces, massive
18		
	4	sandstone, coarse-grained, light brownish gray, calcareously cemented layers
22		
	8	sandstone, medium-grained, light gray, cross-bedded, carbonaceous particles on bedding surfaces, weathers light gray
30		
	6	debris-covered, probably shale
36		
	1	sandstone, dirty, poorly sorted, medium- to coarse-grained

Height above basement (feet)	Thickness (feet)	
37		
	3	shale, black
40		
	1.5	sandstone, massive, light gray, solution holes and yellow nodular lenses about 3 in. long
	0.5	shale, black
42		
	5	sandstone, very thinly bedded, light brownish gray, cross-bedded
47		
	2	shale, black
49		
	1	sandstone, light gray, cross-bedded, medium- to coarse-grained
50		
	1	shale, black
51		
	1	sandstone, medium-grained, cross-bedded, massive
52		
	3	shale, black
55		
	2	sandstone
57		
	6	shale, dark gray
63		
	1	sandstone, dirty, fossil soil zone, rhizome impressions
64		
	1	shale, black
65		
	11	sandstone, light brownish gray, medium- to coarse-grained
76		
	2	shale, black
78		
	8	sandstone, medium- to coarse-grained, light brown and yellowish gray, conglomeratic pebbles up to $\frac{1}{2}$ in. near top
86		
	5	shale, dark and silty
91		
	6	sandstone, medium- to very coarse-grained, light yellowish gray
97		
	12	sandstone, dirty gray, weathers reddish gray, fossils, carbonaceous layers

Height above basement (feet)	Thickness (feet)	
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269

109	6	shale and siltstone, dark brownish gray and carbonaceous
115	17	sandstone, dirty yellowish gray, fossiliferous, iron-stained beds and lenses
132	3	shale, black
135	1	sandstone, medium- to fine-grained, dirty gray, weathers yellowish brown, yellow stains on weathered surfaces, micaceous, shale pebbles up to 2 in. long in sandstone
136	6	shale, black
142	3	sandstone, fine- to medium-grained, brownish gray, weathers yellowish gray, fossiliferous, razor clams
145	2	sandstone, medium gray
147	3	shale, dark gray, silty
150	8	sandstone, yellowish gray, ditty, fossiliferous
158	34	TOP OF HORLICK FORMATION tillite, medium dark bluish-gray matrix
192	46	tillite, large boulders in lower portion, one conglomerate boulder 30 x 8 x 20 ft., many granitic boulders up to 6 ft. in diameter, matrix as below
238	9	sandstone lens (H 3-285), coarse-grained, light gray, weathers reddish-brown, fair sorting, calcareous and argillaceous cement, feldspathic and micaceous
247	120	pavement, with crag and tail indicating a west to east direction of ice movement tillite, light greenish gray matrix, matrix more sandy

Height above basement (feet)	Thickness (feet)	
367	3	sandstone and conglomerate, bands of siliceous and calcareous cement, medium greenish gray, beds slightly contorted, lenticular
370	38	tillite, light greenish matrix, silty and sandy
408	5	sandstone (H 3-286), very light gray, coarse-grained with fine-grained lenses, cross-bedded (N35E, 30°, mag.)
413	43	tillite, medium dark bluish-gray, mudstone matrix
456	1	shale, black, carbonaceous
457	2	siltstone, platy
459	4	sandstone (H 3-287), fine-grained, weathers light yellowish gray, brown calcareous nodules
463	2	siltstone, light gray, platy, few sand grains
465	17	tillite, medium dark bluish-gray matrix
482	23	base of tillite cliff tillite
505	139	top of tillite cliff tillite, medium bluish-gray matrix
644	15	base, cliff tillite and conglomerate cliff, cliff has 3 beds, the middle of which is conglomeratic (H 3-288, H 3-289), calcareous boulders which weather reddish brown in conglomerate (1 x 2 x 0.5 ft.), tillite, bluish-gray
659	245	tillite
904	23	sandstone (H 3-290), fine-grained, light brownish gray, weathers reddish brown, argillaceous and calcareous cement, feldspathic and micaceous, cliff, bottom of sandstone bed uneven, indicative of channel-type deposit, top level with tillite on it (H 3-291)

Height above basement (feet)	Thickness (feet)	
927		top, tillite cliff
	6	tillite, lenses of calcareous sandstone which weathers reddish-brown
933		
	46	shale and shaly tillite, few thin beds of sandstone and siltstone
979		distorted bedding, overturned fold, axis direction N25W, axial plane dips 15°NE
	59	tillite
1038		TOP OF BUCKEYE TILLITE
	145	shale and siltstone, platy beds up to 1/2 in. thick with lenticular beds of dark purplish-black ironstone, and disc-shaped compression forms with radiating slickenslide surfaces from 2 in. to about 3 ft. diameter, many types tracks but no fossil animals or plants found
1183		TOP, LOWER MEMBER, DISCOVERY RIDGE FORMATION
	400	shale, black, fissile, with lenticular beds of dark gray cone-in-cone limestone up to 8 in. thick and lenticular beds of sideritic stone up to 8 in. thick, shale very soft and easily eroded
1583		fault--contact with thick sandstone bed of the Mt. Glossopteris Formation
	239	fault block, tipped, sandstone and shale, Mt. Glossopteris Formation
1822		fault, bearing N30E
	91	up fault trace, Mt. Glossopteris Formation, top of fault block
1913		top of shoulder below Quartz Pebble Hill
	154	sandstone, siltstone, shale and coaly streaks with ironstone concretions and limonitic fossil wood, plant remains, Mt. Glossopteris Formation
2067		
	18	sandstone, feldspathic, with coaly partings about 1/8 in. thick and about 3 in. apart
2058		
	24	shale, dark gray
2109		
	4	coal (Schopf sample)
2113		
	23	shale and siltstone, dark gray

Height above basement (feet)	Thickness (feet)	
2136		
	2	coal
2138		
	27	sandstone with 3-ft. thick conglomerate bed at base
2165		
	7	shale, silty, dark gray, with 8 in. sandstone bed
2172		
	40	sandstone, arkosic, conglomerate lenses, cross-bedded
2212		Top of Quartz Pebble Hill
	291	snow-covered
2503		sandstone outcrop isolated
	572	snow-covered
3075		base of Section No. 18
	586	Section No. 18
3661		
	370	(altimeter to top of mountain)
4031		TOP, MT. GLOSSOPTERIS

Section No. 22
Measured 27 December 61, hand level

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Discovery Ridge, west spur, about 3- $\frac{1}{2}$ miles northwest of
Mt. Glossopteris

Height above basement (feet)	Thickness (feet)	
0	3	sandstone, poorly sorted, dirty greenish-yellow stains, micaceous
3	3	sandstone, medium- to coarse-grained, light gray, light brown traces, cross- bedded
	0.5	shale, black
6	3	sandstone, massive, poorly sorted, weathers yellowish brown, fossiliferous, rust brown and yellow pods
9	1	shale, very dark gray (H 3-298), fossiliferous, very micaceous
10	3	sandstone, weathers yellowish gray, fossiliferous
13	1	shale, black, silty, micaceous
14	1	sandstone, medium-grained, weathers brownish gray, thin-bedded, poorly sorted
15	23	sandstone, light purplish gray, medium- grained, but variable, thinly to thickly bedded, cross-bedded, light gray
38	3	shale, dark gray (H 3-299), micaceous
41	1	sandstone, poorly sorted, dirty, slightly fossiliferous
42	2	sandstone (H 3-300), very dark gray, weathers light brownish gray, fine- to medium-grained, calcareous and argil- laceous cement, abundant brachiopods and other fossils

Height above basement (feet)	Thickness (feet)	
44	0.5	sandstone (H 3-301), coarse-grained, poorly sorted, fossiliferous
	12	debris-covered, possibly dark gray siltstone
56	1	sandstone, dirty gray, micaceous, rusty orange spots
57	5	debris-covered
62	1	sandstone, dirty gray, poorly sorted, yellow stains, fossiliferous
63	4	shale, very dark gray, and siltstone, thinly bedded
67	7	sandstone, cross-bedded, medium- grained, light gray
74	4	shale and siltstone, dark gray
78	2	sandstone, carbonaceous layers, cross- bedded, coarse-grained, light gray, weathers light gray
80	5	shale, very dark gray (H 3-302), micaceous, silty, fossiliferous, plant stems
85	12	sandstone, coarse-grained, cross-bedded, light gray and light yellowish gray, conglomerate lenses
97	9	debris-covered, possibly dark gray silty shale
106	1	sandstone, dirty, coarse-grained, weathers reddish-brown
107	2	shale, very dark gray (most debris- covered)
109	4	sandstone, dirty, micaceous, greenish gray
113	12	sandstone, fossiliferous, poorly sorted, conglomerate beds, light greenish gray, some beds weather brown

Height above basement (feet)	Thickness (feet)	
125	12	sandstone and siltstone, dirty, poorly sorted, yellowish- to greenish-gray, thinly bedded, mostly covered, fossiliferous, micaceous
137	2	sandstone, light gray, poorly sorted, coarse-grained
139	4	sandstone, very poorly sorted, much clay matrix and conglomerate grains, shale inter-beds, very dark gray, weathers brownish gray
143	11	sandstone, light gray, weathers red in places, mostly weathers light gray, dirty, poorly sorted, cross-bedded
154	12	debris-covered, probably shale and siltstone
166	10	sandstone, medium- to coarse-grained, weathers greenish gray, dirty, slightly fossiliferous
176	62	TOP OF HORLICK FORMATION tillite (H 3-303), dark greenish gray, sandy, silty with argillaceous matrix
238	2	conglomerate (H 3-304), fairly well sorted, fine- to medium-grained, quartzose matrix, slightly calcareous, many rounded pebbles of many lithologies
240	19	tillite, dark bluish-gray matrix
259	10	conglomerate, tillitic (H 3-305), lenticular, slump structure, greenish-gray, weathers reddish brown, fine-grained sand matrix, calcareous cement
269	138	tillite, medium dark bluish-gray matrix
407	4	sandstone (H 3-306), medium-grained, feldspathic, light brownish-gray, calcareous cement, few pebble-sized grains, micaceous
411	21	tillite

Height above basement (feet)	Thickness (feet)	
432	2	shale and siltstone, dark greenish gray (H 3-307)
434	3	sandstone (H 3-308), fine-grained, calcareous cement, brown concretions
437	2	siltstone, thinly bedded, light greenish gray
439	4	tillite (H 3-309), bedded, medium greenish-gray, platy structure
443	49	tillite
492		conglomerate lens
624	132	tillite
		foot of tillite cliff
	34	cliff, tillite
658		top of tillite cliff
	231	tillite
889		bottom of sandstone cliff
	25	sandstone, fine-grained, medium light gray, uneven bottom contact (channel)
914		top of sandstone cliff, BOULDER PAVEMENT
	38	tillite, medium bluish-gray matrix
952		bottom of first sheared sandstone
	69	tillite and siltstone interbedded
1021		TOP OF BUCKEYE TILLITE

APPENDIX 2
SAMPLE COLLECTIONS

H Collection (December 1958)

Sample No.	Section	Height (feet) above basement (not accurate)	Description
H-1	21	Basement	quartz monzonite
H-2	21	10	sandstone, arkosic
H-3	21	20	sandstone, coarse-grained
H-4	21	50	sandstone, fine-grained
H-5	21	about 500	tillite
H-6	21	1170	mudstone, animal tubes, hard
H-7	21	1200	mudstone, dark gray, hard
H-8	21	1360	shale, soft, carbonaceous
H-9	20	1600	sandstone
H-10	20	1750	shale, silty, gray
H-11	20	1800?	shale, silty
H-12	20	1850	sandstone, arkosic
H-13	20	1950	sandstone, arkosic
H-14	20	2200	sandstone, fossil plants
H-15	20	2200*	sandstone, fossil wood
H-16	20	2200	coal, thin banded
H-17	20	2210	conglomerate
H-18	20	2210	shale
H-19	18	3260	wood
H-20	18	3200	coal, thin banded
H-21	18	3300*	wood, silicified
H-22	18	3300*	mudstone, light gray
H-23	18	3500*	sandstone

H2 Collection (1960-61 Season)

Sample No.	Feet below sill	Description
TERRACE RIDGE - Diabase Contact		
H2-1	2	diabase
H2-2	4	shale, silty, black
H2-3	7	shale, silty, light gray
H2-4	10	shale, coaly
H2-5	16	sandstone, arkosic
H2-6	42	shale, black
H2-7	52	shale, coaly
H2-8	62	sandstone, arkosic
H2-9	132	coal, impure
H2-10	156	sandstone, light gray
H2-11	163	sandstone, arkosic
H2-12	235	shale, gray
H2-13	262	shale, coaly
H2-14	352	shale, carbonaceous
H2-15	362	mudstone, thinly streaked
H2-16	394	shale, silty, gray
H2-17	402	
	Lunch Ledge	sandstone
H2-18	402	
	Lunch Ledge	wood, limonitic
H2-19	440	siltstone, light yellow
H2-20	465	concretion, carbonate
H2-21	500	shale, coaly
H2-22	530	shale, coaly
H2-23	577 (top)	
	Cirquetop Ridge	sandstone, very fine-grained
H2-24	652 (bottom)	
	Cirquetop Ridge	coal
H2-25	658	coal, sparsely thin-banded
H2-26	660	coal
H2-27	762	wood limonitic
	Big Log Ledge	
H2-28	842	wood
H2-29	870	wood
	cairn (near giant Gloss. Ledge)	
H2-30	1020	wood
H2-31	1070	<u>Glossopteris</u> shale
	(lower than 30)	
	Glossopteris Ledge ±	
H2-32	732	oval concretions
H2-33	762	wood
	Big Log Ledge	
H2-34	762	sandstone, arkosic, cross-bedded
	Big Log Ledge	

Sample Feet below
No. sill

Description

280

TERRACE RIDGE - Diabase Contact (continued)

H2-35	790	sandstone, dark, fine-grained
	6-10 ft. lower than top of Big Log Ledge	
H2-36	798	shale, silty, limonitic
	Big Log Ledge	
H2-37	848	siltstone
H2-38	850	sandstone, thin, even-bedded
H2-39	852	shale, coaly
H2-40	880	shale, coaly
H2-41	890	coal, 18 in. thick
H2-42	886	<u>Glossopteris</u> siltstone
H2-43	893	shale
H2-44	894	shale, carbonaceous
	Top of bed, Doumani's leaf	
H2-45	902	sandstone, massive
H2-46	910	siltstone, fossiliferous, light gray
H2-47	957	siltstone
H2-48	962	coal
H2-49	968	coal
	near bottom of bed	
H2-50	972	shale, carbonaceous
H2-51	1015	shale, coaly
H2-52	1023	coal
H2-53	1058	shale, dark, cross-bedded
	bottom of bed	
H2-54	1064	sandstone, massive
	terrace former	
H2-55	1066	shale, carbonaceous
H2-56	1068	siltstone, carbonaceous, with fossils
H2-57	1070	sandstone, light tan weathered surface
H2-58	1072	<u>Glossopteris</u> shale, cross-beds, flat beds
H2-59	1094	sandstone, massive, cross-bedded
H2-60	1122	coal, 1-3 ft.
H2-61	1165	sandstone, ledge-former
H2-62	1178	shale, carbonaceous
H2-63	1190	sandstone
H2-64	1190	sandstone, from core of sandstone "heave"
H2-65	1222	sandstone, ledge-former
H2-66	1252	sandstone
H2-67	1254	pebble conglomerate
H2-68	1254	quartz and quartz pebbles from conglomerate
H2-69	1258	wood
H2-70	1275	shale, carbonaceous

Sample No.	Feet below sill	Description
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TERRACE RIDGE - Diabase Contact (continued)

H2-71	1285	sandstone, dark
H2-72	1292	sandstone
H2-73	1347	sandstone
H2-74	1355	sandstone, massive
first major terrace		

Sample No.	Feet below sill	Description
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NEAR SECTION 12

H2-75	$\frac{1}{2}$ way	plant fossils
H2-76	$\frac{2}{3}$	leaves in shale
H2-77	near top of ridge	<u>Vertebraria</u> float
H2-78	top of ridge SW end, rolling topography	sandstone
H2-79	same area as 78	shale, carbonaceous
H2-80	rise on ridge	diabase
H2-81	near diabase contact	sandstone
H2-82	on ridge	diabase
H2-83	on ridge	sandstone, spotted, thin-bedded, dark and light beds
H2-84	on ridge	siltstone, coaly

Sample No.	Feet below top of hill	Description
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SECTION 3, EAST RIDGE

H2-85	300	sandstone with "worm tracks"
H2-86	320	shale, carbonaceous
H2-87	270	shale, dark
H2-88	290	sandstone
H2-89	270	shale, carbonaceous
H2-90	265	sandstone, massive, cross-beds, laminae limonitic
H2-91	235	shale, carbonaceous
H2-92	230	sandstone, massive, fossiliferous
H2-93	220	mudstone, friable, black
H2-94	190	shale, black
H2-95	190	shale, carbonaceous, fossiliferous
H2-96	190?	sandstone
base of sandstone		
H2-97	150	shale, carbonaceous
H2-98	80	sandstone, cross-bedded
H2-99	75	pebble conglomerate

Sample No.	Feet below top of hill	Description
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SECTION 3, EAST RIDGE (continued)

H2-100	70	sandstone, massive
H2-101	30	shale, black
H2-102	top of outcrop	shale, black
H2-103	5	sandstone, dark, with plants
H2-104	top of outcrop	coal, 1 in. thick
H2-105	top of outcrop, not in place	sandstone, coarse-grained
H2-106	10	siltstone, fossils
H2-107	12	coal, 3 in. thick

Sample No.	Feet below diabase	Description
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RIDGE EAST OF TERRACE RIDGE

H2-108	diabase contact	mudstone with <u>Vertebraria</u>
H2-109	1	siltstone
H2-110	12	shale, coaly
H2-111	50±	shale, coaly, impure coal
H2-112	75	sandstone with zeolite crystals
H2-113	250	shale with plant fossils
H2-114	mid-slope contact with diabase	sandstone
H2-115	200 ft. higher than 114	shale, coaly

Sample No.	Feet below contact	Description
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MERCER RIDGE, SECTION 6

H2-116	diabase contact	mudstone, baked
H2-117	7	mudstone, baked
H2-118	17	siltstone, coaly
H2-119	30	sandstone
H2-120	120	shale, coaly
H2-121	190	sandstone, arkosic
H2-122	210	sandstone, arkosic
H2-123	220	siltstone, platy
H2-124	250	shale, coaly
H2-125	370	shale, medium gray, silty
H2-126	245	basalt?
H2-127	270	sandstone, cross-beds, arkosic
H2-128	280	shale, gray
H2-129	285	sandstone, arkosic
H2-130	290	sandstone, arkosic
H2-131	300	shale, coaly
H2-132	395	shale, gray
H2-133	400	sandstone, arkosic

Sample No.	Feet below contact	Description
MERCER RIDGE, SECTION 6 (continued)		
H2-134	430	sandstone, arkosic
H2-135	490	mudstone, gray
H2-136	520	shale, coaly
H2-137	550	siltstone
H2-138	545	<u>Glossopteris</u> shale
H2-139	570	shale, coaly, with <u>Glossopteris</u>

Sample No.	Feet above basement	Description
DISCOVERY RIDGE (E. SPUR), SECTION 21		
H2-140		basement rock, dark, crystalline
H2-141	0.2	shale, black
H2-142	0.5	sandstone
H2-143	5.5	sandstone, fossiliferous
H2-144	7	shale, black
H2-145	20	sandstone, thin beds, cross-beds, fine to very coarse
H2-146	20	conglomerate
H2-147	40	sandstone, cross-beds
H2-148	45	sandstone, coarse-grained bed
H2-149	90	shale, black, silty
H2-150	97	shale, micaceous, black
H2-151	110	sandstone, fossiliferous
H2-152	160	sandstone, coarse
H2-153	170	tillite?, poorly sorted, blue-gray bed
H2-154	420	siliceous-carbonate bed

Sample No.	Feet above basement	Description
SECTION 2		
H2-155	Basement	granite, porphyritic
H2-156	contact	sandstone
H2-157	50	cobble of sandstone, fossiliferous

Sample No.	Feet above basement	Description
SECTION 1		
H2-158	0	granitic pavement
H2-159	357	grooves in tillite
H2-160	415	grooves in sandy tillite
H2-161	545	tillite, lens, hard
H2-162	995	tillite, carbonaceous
H2-163	1455	siltstone with plant fossils
H2-164	1555	siltstone, micaceous
top of escarpment		

Sample No.	Feet above basement	Description
SECTION 22		
H2-165	914	striated pebbles and cobbles
	Boulder pavement	
H2-166	914	tillite and striated stones
	Boulder pavement	
H2-167	0	basement rock
H2-168	1	quartz arenite on basement
H2-169	150	sandstone, feldspathic
	160	
	in tillite	stone count collection #1
	310	
	in tillite	stone count collection #2
H2-170	410	sandstone, massive
H2-171	450	shale, black, silty
H2-172	470	sandstone, calcareous, nodules
H2-173	460	porphyritic boulder from tillite
H2-174	475	tillite, bedded
H2-175	510	tillite, matrix
	530	stone count collection #3
	760	stone count collection #4
H2-176	890	sandstone, massive
H2-177	914	tillite with wood impression
	Boulder pavement	and cobble
H2-178	915	assorted rock types from pavement
		boulder
H2-179	970	sandstone
H2-180	970	sandstone
H2-181	1030	tracks (parallel) in siltstone
H2-182	----	miscellaneous rocks from flat area on ridge

Sample No.	Feet below sill	Description
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TERRACE RIDGE, SECTION 13

H2-183	980	<u>Glossopteris</u> shale, slab
H2-184	962	coal, shaly
H2-185	862	mudstone, carbonaceous
H2-186	861	<u>Glossopteris</u> shale
H2-187	860	silicified (opalized) wood
H2-188	1070	<u>Glossopteris</u> shale
H2-189	1070	<u>Glossopteris</u> shale
H2-190	1068	<u>Glossopteris</u> shale
H2-191	1070	<u>Glossopteris</u> shale
H2-192	1070	<u>Glossopteris</u> shale
H2-193	No specimen	
H2-194	1105	<u>Glossopteris</u> shale
H2-195	1070	wood

Main Glossopteris Ledge

Sample No.	Feet below sill	Description
<u>TERRACE RIDGE, SECTION 13 (continued)</u>		
H2-196	886	siltstone, weathered, limonitic
H2-197	865	<u>Glossopteris</u> shale
H2-198-218	959-970	coal seam samples
H2-219	1062	fossil wood
H2-220	993	<u>Glossopteris</u> shale
H2-221	1065	pebble conglomerate
H2-222	1021	coal, impure
H2-223	530	shale, silty
H2-224	512	limestone concretion
H2-225	465	mudstone, chert
H2-226	420	<u>Glossopteris</u> shale
H2-227	268	wood
H2-228	268	wood, compressed
H2-229	144	wood in dark gray carbonaceous shale
H2-230	115	<u>Glossopteris</u> in carbonaceous shale
H2-231	15	wood in arkose
H2-232	537	concretion in carbonaceous shale
H2-233	12	shale, carbonaceous, baked, <u>Glossopteris</u>
H2-234	534	ripple marks in siltstone
H2-235-237	863	<u>Glossopteris</u> mudstone
H2-238-240	863	fossil wood
		Giant <u>Glossopteris</u> Ledge
H2-241-242	1070	<u>Glossopteris</u> mudstone
		Main <u>Glossopteris</u> Ledge
H2-243	1060	sandstone, calcareous
H2-244	400	concretion in sandstone?

H 3 COLLECTION

SAMPLE LIST

Sample No.	Lithology	Measured (feet) stratigraphic interval above base of exposure	Generalized height (feet) above base of measurement	Generalized height (feet) above basement
H 3-1	fossil wood, Big Log Ledge			
<u>CANYON PEAK, SECTION 14</u>				
H 3-3	siltstone mudcracks	0-5		
H 3-4	siltstone, at base	0-36	5	1575
H 3-5	sandstone, near top of ss unit	36-53	50	1620
H 3-6	siltstone, platy	53-65	60	1630
H 3-7	shale, dark, platy	65-95	85	1655
H 3-8	sandstone, and sh interbeds	95-147	115	1685
H 3-9	siltstone, and sh interbeds	95-147	115	1685
H 3-10	sandstone, and sh interbeds	95-147	140	1710
H 3-11	sandstone, base	147-254	150	1720
H 3-12	sandstone, top	147-254	250	1820
H 3-13	sandstone, on ridge	254-281	270	1840
H 3-14	pebbles from sandstone (13)	254-281	275	1845
H 3-15	coal	281-286	285	1855
H 3-16	sandstone	286-236	300	1875
H 3-17	wood from (16)	286-236	300	1875
H 3-18	siltstone, black, crossbeds	336-366	340	1910
H 3-19	sandstone, flaky surface	366-388	370	1940
H 3-20	sandstone, flaky surface	366-388	380	1950
H 3-21	siltstone, baked, red brown, crossbeds	388-394	390	1960
H 3-22	coal	404-407	405	1975

Sample No.	Lithology	Measured (feet) stratigraphic interval above base of exposure	Generalized height (feet) above base of measurement	Generalized height (feet) above basement
CANYON PEAK (continued) (SECTION 14)				
H 3-23	siltstone, flaky surface	407-432	430	2000
H 3-24	coal	432-438	435	2005
H 3-25	shale, above (24)	432-438	437	2007
H 3-26	coal	496-499	497	2067
H 3-27	sandstone, massive	499-505	505	2075
H 3-28	shale, dark, crossbeds	505-525	575	2085
H 3-29	coal	505-525	515	2085
H 3-30	sandstone	525-589	558	2120
H 3-31	sandstone with wood impressions	525-589	570	2140
H 3-32	sandstone	525-589	570	2140
H 3-33	sandstone, calcareous	525-589	580	2150
H 3-34	coal, 3 ft. bed	589-592	590	2160
H 3-35	shale, 1-2 ft. bed	596-612	610	2180
H 3-36	diabase ?	612-639	---	2185
H 3-37	sandstone	639-652	645	2215
H 3-38	coal and coaly shale	666-668	675	2245
H 3-39	sandstone, massive, wood frag.	694-742	720	2290
H 3-40	sandstone, massive, wood frag.	694-742	720	2290
H 3-41	shale, coaly	742-744	743	2313
H 3-42	sandstone with tracks and impressions	750-751	750	2320
H 3-43	conglomerate (TOP OF SECTION)	751-786	780	2350

SECTION NO. 5

H 3-44	sandstone, basal, Horlick fm.	0-70	5	
H 3-45	shale, black	0-70	10	
H 3-46	shale, black	0-70	40	
H 3-47	sandstone, 8 ft. thick	0-70	60	
H 3-48	tillite, Buckeye tillite	70-162	150	

Sample No.	Lithology	Measured (feet) stratigraphic interval above base of exposure	Generalized height (feet) above base of measurement	Generalized height (feet) above basement
SECTION NO. 5 (continued)				
H 3-49	sandstone with tillite lenses	162-222	175	
H 3-50	quartzite, pavement, striated		222	
H 3-51	tillite	222-342	300	
H 3-52	sandstone, from top of unit, lenticular	342-396	390	
H 3-53	sandstone, 1 ft. thick, mass- ive	396-410	410	
H 3-54	tillite	410-545	540	
H 3-55	erratic, pegmatite	410-545	540	
H 3-56	tillite	698-817	730	
H 3-57	shale	817-865	860	
H 3-58	shale	876-892	880	
H 3-59	shale, black	876-892	885	
H 3-60	shale, black	876-892	890	
H 3-60A	siltstone			
H 3-61	tillite	893-991	950	
H 3-62	mudstone, wthr. yellow gray	991-1045	1040	
H 3-63	siltstone, hard, dark	-----	1091	
H 3-64	concretion ?			

Sample No.	Lithology	Measured (feet) stratigraphic interval above base of measurement	Generalized height (feet) above base of measurement	Feet below sill
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RIDGE EAST OF TERRACE RIDGE, SECTION 14

H 3-65	(not in notes)			
H 3-66	sandstone, thin-thick beds, lt. gry. with brn. strks.	59-82	75	985
H 3-67	ironstone	82-104	100	960
H 3-68	shale	109-111	110	950
H 3-69	shale	125-126	125	935
H 3-70	coal			

SECTION NO. 10, WEST END OF RANGE

H 3-71	sandstone	-----	ca.250	
H 3-72	shale, dark	-----	ca.400	

MT. SCHOPF, RIDGE EAST OF TERRACE RIDGE, SECTION 14

H 3-73	sandstone, with wood	0-33	30	1050
H 3-74	stem frag. (in sh float)	35-46	---	
H 3-75	shale, fossil wood	46-75	73	979
H 3-76	shale, <u>Glossopteris</u>	87-116	110	942
H 3-77	sandstone, wthr. lt. gry.	75-87	80	970
H 3-78	wood impression in (77), siltstone	87-116	116	936
H 3-79	coal	124-125	125	928
H 3-80	ironstone, sh	125-126	126	926
H 3-81	coal, sh	168-169	169	883
H 3-82	siltstone (with logs), <u>Glossopteris</u>	279-282	280	770
H 3-83	coal, coaly sh	282-285	285	767
H 3-84	sandstone	318-345	340	720

Sample No.	Lithology	Measured (feet) stratigraphic interval above base of measurement	Generalized height (feet) above base of measurement	Feet below sill
<u>MT. SCHOPF, RIDGE EAST OF TERRACE RIDGE (continued) (SECTION 14)</u>				
H 3-85	coal and coaly sh	361-372	370	690
H 3-86	sandstone, flaky surface, iron stains	378-395	390	670
H 3-87	coal, coaly sh	432-438	435	625
H 3-88	shale (with <u>Glossopteris</u>)	474-488	480	580
H 3-89	limestone, carb. with ss lenses	488-494	490	570
H 3-90	sandstone, massive, ledge	496-513	510	550
H 3-91	coal, impure	518-576	570	490
H 3-92	sandstone, plant debris	576-626	615	445
H 3-93	shale, banded	626-628	627	433
H 3-94	shale, large plant impressions, carb.	626-628	628	432
H 3-95	shale, varved ?	628-635	630	430
H 3-96	shale, <u>Glossopteris</u> , <u>Gangamopteris</u> ?	628-635	635	425
H 3-97	sandstone, lt. tan to brn.	635-662	645	415
H 3-98	mudstone, massive, blocky	662-664	665	395
H 3-99	siltstone, 2 in. thick	678-695	680	380
H 3-100	sandstone, thin bedded, lt. gry.	678-695	690	370
H 3-101	sandstone, wthr. gry. tan	723-803	730	330
H 3-102	sandstone, wthr. gry. tan	723-803	750	310
H 3-103	sandstone, ledge, level with Lunch Ledge	803-836	830	230
H 3-104	shale, baked	803-836	835	225
H 3-105	sandstone, lt. grnish-gry.	836-923	910	150

Sample No.	Lithology	Measured (feet) stratigraphic interval above base of measurement	Generalized height (feet) above base of measurement	Feet below sill
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MT. SCHOPF, RIDGE EAST OF TERRACE RIDGE (continued) (SECTION 14)

H 3-106	shale, carb., plant material & ss dk. gry. to blk.	928-951	950	110
H 3-107	sandstone, brn. spots	972-978	975	85
H 3-108	sandstone, even and thin beds	978-1008	1000	60
H 3-109	shale, carb.	1013-1017	1015	45
H 3-110	sandstone, silty, upright <u>Vertebraria</u>	1040-1043	1040	20

SECTION NO. 9, WEST END BUCKEYE RANGE

H 3-111	sandstone, with tracks	talus		
H 3-112	sandstone ?, Horlick Fmn.	0-65	45	
H 3-113	tillite	65-101	80	
H 3-114	shale, dk. gry., cherty	101-118	115	
H 3-115	tillite	118-162	150	
H 3-116	sandstone, creamish, lt. brn., lenses	162-166	165	
H 3-117	tillite	166-248	230	
H 3-118	sandstone lens, quartzitic	248-252	250	
H 3-119	shale, grnish gry.	344-348	345	
H 3-120	sandstone, lt. brn. gry. with spots (2-3 in.)	348-366	360	
H 3-121	concretions (brn. spots of 120)	348-366	365	
H 3-122	siltstone, lens, reddish and greenish tint, TRAVERSE OVER HILL	486-491	490	

Sample No.	Lithology	Measured (feet) stratigraphic interval above base of measurement	Generalized height (feet) above base of measurement
<u>DARLING RIDGE, SECTION 11</u>			
H 3-123	sandstone, wthrs. yellow	0-1	1
H 3-124	sandstone, lt. gry., wthrs. brn., coarse gr.	1-7	5
H 3-125	sandstone, dk. gry., wthrs. yellow, fossils, tillitic	7-12	10
H 3-126	sandstone, lt. gry., coarse gr.	12-14	13
H 3-127	shale, bk.	14-17	15
H 3-128	sandstone, lt. grnish-gry., med. gr., calcareous	25-33	30
H 3-129	sandstone, dirty, crossbeds, wthrs. yellow and red, calcareous	37-45	40
H 3-130	sandstone, fine gr., grnish., wthrs. reddish, fossils	47-70	60
H 3-131	shale, thin bedded, dk. gry.	70-88	75
H 3-132	sandstone, from tillite, ss lenses	107-183	120
H 3-133	tillite	107-183	130
H 3-134	conglomerate and sandstone, calcareous, siliceous	209-213	210
H 3-135	shale, dk. gry., slimy surface	273-285	280
H 3-136	sandstone, lt. gry., wthrs. lt. brn., calc. nodules, massive	340-343	340
H 3-137	tillite, uppermost rock on the Peninsula		623
H 3-138	ground moraine or fault breccia, in saddle of Peninsula	-----	---
H 3-139	quartz monzonite or granodiorite basement near saddle	-----	---

Sample No.	Lithology	Measured (feet) stratigraphic interval above base of measurement	Generalized height (feet) above base of measurement
SECTION NO. 8, WEST END OF RANGE			
H 3-140	sandstone, med.-crss. gr., crossbeds	0-6	5
H 3-141	sandstone, shale, finely interbedded	6-8	7
H 3-142	sandstone, lt. gry., fossils, beds 1-8 in. thick	9-13	10
H 3-143	shale, bk.	13-15	13
H 3-144	sandstone, lt. yel. gry., wthrs. yel.	13-15	15
H 3-145	shale, bk. with ss lens, fossils	15-20	17
H 3-146	sandstone, lt. grn. gry., few fossils	20-22	20
H 3-147	sandstone and bl. shale, dirty, fossils at top	22-34	30
H 3-148	sandstone, dirty, fossil bed	42-43	43
H 3-149	sandstone, lt. gry., med.-crss. gr.	48-51	50
H 3-150	sandstone, fossiliferous	51-63	60
H 3-151	shale	51-63	55
H 3-152	sandstone, red.-brn. surface	63-64	63
H 3-153	tillite, bedded, sandy	92-98	95
H 3-154	sandstone, lens in tillite, grooved	163-180	165
H 3-155	sandstone, lens in tillite, channel	282-302	290
H 3-156	shale, dk. grn., gry.	307-319	315
H 3-157	shale, dk.	344-347	345
H 3-158	sandstone, calcareous, fossils	347-349	348
H 3-159	tillite	349-563	560
H 3-160	sandstone, lens in tillite, grnish, wthrs. reddish	563-564	563
H 3-161	tillite	644-707	650
H 3-162	sandstone, lens in tillite	707-711	710
H 3-163	tillite, top of section	751-848	840

Sample No.	Lithology	Measured (feet) stratigraphic interval above base of measurement	Generalized height (feet) above base of measurement	Feet below top of Mt. <u>Glossopteris</u>
<u>MT. GLOSSOPTERIS, SOUTH RIDGE, SECTION 16</u>				
H 3-164	shale, bk. <u>Glossopteris</u> leaves, seeds, 3 ft. below fault		1321 ft. below summit	
H 3-165	coal, impure	3-5	5	1405
H 3-166	sandstone, lenticular, wthrs. rusty grn.gry., calcareous	5-30	6	1404
H 3-167	coal, impure	31-33	32	1378
H 3-168	sandstone, yel.red, dk. gry.	33-34	33	1377
H 3-169	coal	45-65	50	1360
H 3-170	wood	45-65	60	1350
H 3-171	shale, <u>Glossopteris</u>	45-65	60	1350
H 3-172	sandstone, wthrs. lt. yel.brn. with red brn. streaks	77-85	80	1330
H 3-173	shale, bk., much <u>Glossopteris</u>	85-88	85	1325
H 3-174	coal	88-116	110	1300
H 3-175	shale, <u>Glossopteris</u> and seeds	116-167	167	1243
H 3-176	sandstone, med. gr., crossbeds, concretions	192-217	200	1210
H 3-177	coal and coaly sh	217-232	225	1185
H 3-178	siltstone, dk. gry.	273-319	300	1110
H 3-179	siltstone, lt. gry., rust streaks, <u>Glossopteris</u>	319-369	350	1060

Sample No.	Lithology	Measured (feet) stratigraphic interval above base of measurement	Approximate height (feet) above base of measurement	Feet below sill
<u>MT. SCHOPF, NORTHEAST RIDGE, SECTION 19</u>				
H 3-180	sandstone, lt. gry., massive, flaky	0-5	5	1150
H 3-181	shale, bk., sandy	28-45	40	1115
H 3-182	coal	49-50	50	1105
H 3-183	sandstone, cliff and ledge, crossbeds, qtz. pebble ledges	50-91	75	1080
H 3-184	sandstone, sandy, bk.	176-206	200	955
H 3-185	sandstone, lt. yel. gry., brn. streaks, wood	345-413	400	755
H 3-186	shale, coaly	420-422	420	735
H 3-187	sandstone, cliff and ledge	456-480	470	685
H 3-188	shale, coaly	520-528	525	630
H 3-189	shale, coaly	548-553	550	605
H 3-190	sandstone, lt. gry., massive, ledge	563-620	600	555
H 3-191	shale, coaly	626-636	630	525
H 3-192	sandstone, yel. gry., crossbeds	693-738	720	435
H 3-193	sandstone, med. gry.	1048-1093	1080	75
H 3-194	sandstone, dk. brn.	1093-1095	1095	60
H 3-195	sandstone, lt. gry. and brn.- tan (TOP OF SECTION)	1095-1113	1100	55

Sample No.	Lithology	Measured (feet) stratigraphic interval above base of measurement	Approximate height (feet) above base of measurement	Feet below summit
<u>MT, GLOSSOPTERIS, NORTHWEST FACE (SHOULDER), SECTION 17</u>				
H 3-196	(not in notes) Coal, impure			
H 3-197	sandstone, wthrs. lt. gry., massive	0-23	10	1190
H 3-198	sandstone, med. gry., iron stained lenses	31-46	40	1160
H 3-199	sandstone, dk. red brn.	54-55	55	1145
H 3-200	sandstone, thin bedded, iron concretions	69-70	70	1130
H 3-201	coal, banded	71---	71	1129
H 3-202	wood	46-54	50	1150
H 3-203	shale, dk. gry., <u>Glossopteris</u> , <u>Vertebraria</u> (Museum Ledge)	75-76	75	1125
H 3-204	sandstone, sandy	116----	116	1084
H 3-205	sandstone, with wood, brnish. gry., med. gr.	122-126	125	1075
H 3-206	shale, coaly	143-154	150	1050
H 3-207	siltstone, irony, lens in (206) sh	143-154	150	1050
H 3-208	(not in notes), sandstone, feldspathic	-----	---	----
H 3-209	coal, impure	184-195	190	1010
H 3-210	sandstone, massive, wthrs. lt. yel. gry.	258-294	280	920
H 3-211	coal, banded	294-298	295	905
H 3-212	shale, silty, red & grn. gry.	298-321	310	890
H 3-213	sandstone, silty, fine gr.	298-321	320	880
H 3-214	shale, brn. laminae (varves ?)	328-376	---	825

Sample No.	Lithology	Measured (feet) stratigraphic interval above base of measurement	Approximate height (feet) above base of measurement	Feet below summit
<u>MT. GLOSSOPTERIS, NORTHWEST FACE (SHOULDER) (continued) (SECTION 17)</u>				
H 3-215	sandstone, maddive, med. gr.	376-381	380	820
H 3-216	coal, impure	382-384	383	817
H 3-217	coal, weakly banded	424-426	425	775
H 3-218	shale, varves? from float near (216)	424-426	---	775
H 3-219	wood in siltstone, lt. gry. brn. bands	426-437	430	770
H 3-220	coal, poorly banded	462-465	460	740
H 3-221	coal, banded	506-518	515	685
H 3-222	shale, <u>Glossopteris</u> , siltstone, coaly streaks, mudstone beds	544-599	580	620
H 3-223	sandstone, very fine gr.	544-599	580	620
H 3-224	sandstone, calcareous, feldspathic	544-599	590	610
H 3-225	sandstone, much wood, concretion	616-644	630	570
H 3-226	siltstone, lt. gry.	649-650	650	550
H 3-227	coal	650-654	---	546
H 3-228	sandstone, lt. gry. withring, TOP OF NORTHWEST SHOULDER SECTION	704-715	710	490
<u>MT. GLOSSOPTERIS, NORTH RIDGE, SECTION 18</u>				
H 3-229	coal, shaly	0-22	15	
H 3-230	sandstone	0-22	20	
H 3-231	sandstone	0-22	20	
H 3-232	wood, Museum Ledge	Museum Ledge		1125

Sample No.	Lithology	Measured (feet) stratigraphic interval above base of measurement	Approximate height (feet) above base of measurement
SECTION NO. 7			
H 3-233	granodiorite basement		0
H 3-234	sandstone, conglomerate, basal ss	0-27	20
H 3-235	sandstone, greenish gray, fine-grained, loose at tillite Horlick fm. contact	?	
H 3-236	sandstone, med.-crse. gr., sh dk. gry.	27-41	30
H 3-237	boulder of tillite (Horlick fm.), ss	41-81	50
H 3-238	sandstone, lens of tillite	81-126	100
H 3-239	tillite	81-126	110
H 3-240	sandstone, tillitic, limy, qtzose, lenticular	126-157	140
H 3-241	tillite, with tillite interbeds	157-197	180
H 3-242	grooved sandstone, tillitic	-----	177
H 3-243	tillite, lens in ss	197-220	200
H 3-244	sandstone, yel. brn. and gry., wavy bedding	220-248	230
H 3-245	pavement, sandstone, crse. gr.	-----	248
H 3-246	tillite	248-390	338
H 3-247	tillite, calcareous cement	390-392	390
H 3-248	shale, tillitic, dk. grnish gry., platy	413-416	415
H 3-249	shale, dk.	413-416	416
H 3-250	sandstone, med. lt. gry., fine gr., concretions	416-434	420
H 3-251	concretions in 250	416-434	430
H 3-252	tillite, bedded	434-435	435
H 3-253	tillite	435-492	480
H 3-254	tillite	492-546	525
H 3-255	tillite	546-574	560
H 3-256	concretion, calcareous, in tillite	574-643	608
H 3-257	tillite, bedded, grnish gry, ripple marks	643-643	

Sample No.	Lithology	Measured (feet) stratigraphic interval above base of measurement	Approximate height (feet) above base of measurement
SECTION NO. 7 (continued)			
H 3-258	limestone, sandy, med. dk. gry.	643-766	683
H 3-259	limestone, pink, large clast in tillite	643-766	762
TERRACE RIDGE, SECTION 13			
H 3-260	(not in notes), sandstone, calcareous		
H 3-261	sandstone, very fine-gr., dk. gry., 10 ft. above and to East of plane table station for Doumani's Stump survey.		
H 3-262	shale, very dk. gry., <u>Gangamopteris?</u> impressions	Dirty Diamond Mine	
H 3-263	coal, fused cleat, vitrain	Dirty Diamond Mine	
H 3-264	seeds in shale	47 ft. below Giant Gloss. Ledge	
H 3-265	wood	ca. 10 ft. below Giant Gloss. Ledge	
H 3-266	wood, 35 yr. ring count, upright stem	Giant Gloss. Ledge	
H 3-267	wood, from 24 ft. log	Big Log Ledge	
H 3-268	knot, in wood	Big Log Ledge	
H 3-269	coal, non-banded	Dirty Diamond Mine	
H 3-270	coal	Dirty Diamond Mine	
H 3-271	plants in shale	6 ft. above mine	
H 3-272	<u>Glossopteris</u> in shale and mudstone	terrace above mine	

Sample No.	Lithology	Measured (feet) stratigraphic interval above base of measurement	Approximate height (feet) above base of measurement
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MERCER RIDGE

H 3-273	stem in shale	1/2 way up slope	
H 3-274	stem in shale	20 ft. higher than (273)	
H 3-275	hornfels, contact siltstone	fault block area	
H 3-276	conglomerate with <u>Vertebraria</u>	70 ft. below Leasia Ledge	
H 3-277	pebbles from (276)	70 ft. below Leasia Ledge	
H 3-278	wood from conglomerate (276)	70 ft. below Leasia Ledge	
H 3-279	plant fossils in siltstone	72 ft. below Leasia Ledge	

DISCOVERY RIDGE, SECTION 20

H 3-280	siltstone, hard, reddish brn., <u>Glossopteris</u>		
H 3-281	<u>Glossopteris</u> shale	below Quartz Pebble Hill	
H 3-282	calcareous concretion, lenticular, black	30 ft. below top Discovery Ridge formation	
H 3-283	siltstone, with tracks	3 ft. above top Buckeye tillite	
H 3-284	sandstone, calcareous		

DISCOVERY RIDGE, EAST SPUR, SECTION 21

H 3-285	sandstone, lens in tillite	-----	238
H 3-286	sandstone, lenticular in tillite (a and b)	408-413	410
H 3-287	sandstone, with calc. nodules, lt. brn. gry.	459-463	460
H 3-288	limestone, and tillite, cliff	505-644	510
H 3-289	tillite, cliff	505-644	600
H 3-290	sandstone, cliff near top of tillite unit	904-927	905

Sample No.	Lithology	Measured (feet) stratigraphic interval above base of measurement	Approximate height (feet) above base of measurement
DISCOVERY RIDGE, EAST SPUR (continued) (SECTION 21)			
H 3-291	tillite, cliff	904-927	920
H 3-292	siltstone, in Discovery Ridge fm.	boulder?	
H 3-293	striated boulder	-----	---
H 3-294	plant fragments on sandstone	Mt. Gloss. fm. faulted area	
H 3-295	plant fragments on sandstone	Mt. Gloss. fm. faulted area	
H 3-296	coal	Mt. Gloss. fm. faulted area	
H 3-297	siltstone, calcareous, plants	50 ft. below top Quartz Pebble Hill	
DISCOVERY RIDGE, WEST SPUR, SECTION 22			
H 3-298	shale, black, fossils	9-10	10
H 3-299	shale, black	38-41	40
H 3-300	sandstone, fossils	42-44	43
H 3-301	sample missing	44-56	45
H 3-302	shale, black, and siltstone, fossils	80-85	85
H 3-303	tillite, grn. gry.	176-238	200
H 3-304	conglomerate, lenticular	238-240	240
H 3-305	conglomerate, tillitic, lenticular and slumped	259-269	260
H 3-306	sandstone, lt. brn., med.-fine gr., some crse. gr.	407-411	410
H 3-307	shale and siltstone, dk. grn. gry.	432-434	433
H 3-308	sandstone, fine gr., calc. cement, brn. concretions	434-437	435
H 3-309	siltstone, siliceous cement	439-443	440
H 3-310	tracks in siltstone, Discovery Ridge fm.	2 ft. above base	

Sample No.	Lithology	Measured (feet) stratigraphic interval above base of measurement	Approximate height (feet) above base of measurement
SECTION NO. 1. SCHULTHESS ESCARPMENT			
H 3-311	tillite and basement	0	0
H 3-312	sandstone, lens, 1 ft. thick in tillite, calcareous	19	19
H 3-313	sandstone, boulders from Horlick fm. in tillite	19-122	100
H 3-314	limestone, sandy, lens in tillite	122-128	125
H 3-315	sandstone with (313)	122-128	125
H 3-316	sandstone and tillite interbedded	139-154	150
H 3-317	tillite	-----	154
H 3-318	sandstone, fossils, boulder in tillite	-----	154
H 3-319	conglomerate, lens	154-174	170
H 3-320	tillite, matrix for pebble count "2"	-----	185
H 3-321	pavement, striated	-----	286
H 3-322	granitic erratic, opalescent qtz. grains	-----	346
H 3-323	sandstone, fine-med. gr., wthr. lt. red brn.	346-359	350
H 3-324	shale, dk.	373-377	375
H 3-325	siltstone, calc. cement, wthr. red brn., nodular	373-377	375
H 3-326	tillite under (325)	-----	373
H 3-327	sandstone, calcareous	377-379	378
H 3-328	sandstone, reddish brn. wthring, ripple marks	396-397	396
H 3-329A	tillite, matrix for pebble count "3"	-----	407
H 3-329B	concretion, calcareous	585-656	?
H 3-330	sandstone lens	765-788	780
H 3-331	tillite, matrix for pebble count "5"	-----	788
H 3-332	shale, bl. gry., in top tillite	806-893	890

Sample No.	Lithology	Measured (feet) stratigraphic interval above base of measurement	Approximate height (feet) above base of measurement
SECTION NO. 1, SCHULTHESS ESCARPMENT (continued)			
H 3-333	siltstone, carb.	1058-1534	1100
H 3-334	shale-siltstone, base of Mt. Glossopteris fm.	-----	1510
H 3-335	Glossopteris slab	Main Gloss. Ledge	
H 3-336	Glossopteris slab, Terrace Ridge	Main Gloss. Ledge	
H 3-337	Glossopteris slab, Terrace Ridge	Main Gloss. Ledge	
H 3-338	Glossopteris slab, Terrace Ridge	Main Gloss. Ledge	
H 3-339	Glossopteris slab, Terrace Ridge	Main Gloss. Ledge	

Sample No.	Lithology	Measured (feet) stratigraphic interval above base of measurement	Approximate height (feet) above base of measurement	Feet below sill
TERRACE RIDGE, SECTION 13				
H 3-340	sandstone, med.-crse. gr., wthr. yel. brn.	0-40	10	1435
H 3-341	shale, carb.	0-40	40	1425
H 3-342	sandstone, irony	0-40	30	1435
H 3-343	sandstone, cross-beds, med. gr., wthr. yel.	40-85	45	1420
H 3-344	sandstone	40-85	85	1380
H 3-345	sandstone, fine-med. gr., wthr. med. gry., dk. gry.	171-182	180	1285
H 3-346	siltstone, calcareous	182-184	183	1282
H 3-347	sandstone, carb. partings, thin- thick bedded, micaceous	193-206	200	1265
H 3-348	sandstone, wthr. yel. gry., carb. partings	216-218	217	1248
H 3-349	shale, carb.	-----	237	1228
H 3-350	sandstone, back of 2nd Major Terrace	-----	247	1218
H 3-351	shale, bl., silty	247-278	260	1205
H 3-352	sandstone, calcareous, gry.	247-278	265	1200
H 3-353	sandstone, wthr. lt. yel. gry., massive	278-287	280	1185
H 3-354	sandstone and siltstone (just over 3rd Major Terrace)	334-338	335	1130
H 3-355	sandstone, wthr. lt. brn., med. gry.	353-354	354	1111
H 3-356	plant in sandstone float	353-354	354	1111
H 3-357	sandstone, wthr. yell., med. gry.	383-387	385	1080

Sample No.	Lithology	Measured (feet) stratigraphic interval above base of measurement	Approximate height (feet) above base of measurement	Feet below sill
<u>TERRACE RIDGE (continued) (SECTION 13)</u>				
H 3-358	sandstone, wthr. h. gry. to bn. gry.	446-448	447	1018
H 3-359	limestone, silty	450-451	450	1015
H 3-360	shale, dk., banded	525-586	550	915
H 3-361	sandstone, wthr. red brn. to red gry.	586-588		878
H 3-362	sandstone, wthr. lt. yel. gry.	624-626		840
H 3-363	coal, impure	626-632		845
H 3-364	sandstone, calcareous, very fine gr.	632-641	640	825
H 3-365	sandstone, med. gr., calcareous	Big Log Ledge lowspot) 754-758	718 755	747 710
H 3-366	coal, impure			
H 3-367	sandstone, fine gr., wthr. lt. yel. brn.	758-765	760	705
H 3-368	sandstone, ledge, wthr. lt. yel. brn.	782-789	785	680
H 3-369	shale, dk. gry., platy	827-836	830	635
H 3-370	siltstone	849-895	870	595
H 3-371	shale	849-895	890	575
H 3-372	mudstone, dk. gry.	900-906	905	560
H 3-373	sandstone (upright tree) (cirque top terrace)	906-913	910	555
H 3-374	sandstone, wthr. lt. gry., yel. brn. stains, fine gr., med. gry.	979-984	980	485
H 3-375	calc. lens in (376)	994-1051	1020	445
H 3-376	mudstone, blocky, wthr. very lt. gry.	994-1051	1020	445

Sample No.	Lithology	Measured (feet) stratigraphic interval above base of measurement	Approximate height (feet) above base of measurement	Feet below sill
<u>TERRACE RIDGE (continued) (SECTION 13)</u>				
H 3-377	sandstone, med.-crse. gr., dirty	1068-1096	1070	395
H 3-378	sandstone, Lunch Ledge	1068-1096	1095	370
H 3-379	shale, carb.	1096-1104	1100	365
H 3-380	sandstone, dirty gry, iron beds	1104-1214	1140	325
H 3-381	sandstone, dirty gry., iron beds	1140-1214	1170	295
H 3-382	sandstone, dirty gry., iron beds	1140-1214	1210	255
H 3-383	<u>Vertebraria</u> slab, sandstone	1214-1252	1240	225
H 3-384	sandstone	1252-1337	1255	210
H 3-384B	sandstone lens	1252-1337	1260	205
H 3-385	sandstone	1252-1337	1280	185
H 3-386	sandstone	1252-1337	1300	165
H 3-387	sandstone	1252-1337	1335	130
H 3-388	<u>Vertebraria</u> in sandstone	1337-1357	1345	120
H 3-389	sandstone, calcareous	1357-1424	1360	105
H 3-390	sandstone, silty	1357-1424	1370	85
H 3-391	sandstone, silty	1357-1424	1380	75
H 3-392	sandstone, arkosic	1357-1424	1390	75
H 3-392	sandstone	1357-1424	1410	55
H 3-393	sandstone	1357-1424	1424	41
H 3-394	sandstone, Top of Section (1465)	1438-1448	1440	25
H 3-395	siltstone, with <u>Vertebraria</u> , 2 ft. under <u>Vertebraria</u> sand- stone	-----	----	--
H 3-396	stump fragments, in place, upright	10 ft. above Lunch Ledge		
H 3-397	calcareous concretion			
H 3-398	weathered ironstone bed	15 ft. below Big Log Ledge coal		

Sample No.	Lithology	Measured (feet) stratigraphic interval above base of measurement	Approximate height (feet) above base of measurement	Feet below summit
MT. GLOSSOPTERIS, SOUTH RIDGE, SECTION 16				
H 3-399	siltstone, med.-dk. gry.	0-205	160	890
H 3-400	sandstone and siltstone, med.-dk. gry.	0-205	180	870
H 3-401	shale, <u>Glossopteris</u>	0-205	205	845
H 3-402	coal, impure	224-232	230	820
H 3-403	sandstone, med. gry., wthr. lt. gry.	232-249	235	815
H 3-404	mudstone, wthr. very lt. gry.	249-257	250	800
H 3-405	coal, impure	257-260	260	790
H 3-406	sandstone, cross-beds, gry. wthr. brn. streaks	277-317	315	735
H 3-407	concretion	317-333	325	725
H 3-408	shale, coaly	333-350	345	705
H 3-409	tree in siltstone and sandstone, upright	384-408	390	660
H 3-410	sandstone, brn. gry. and lt. gry.	465-512	470	580
H 3-411	mudstone	512-519	515	535
H 3-412	sandstone, gry.	549-570	560	490
H 3-413	ironstone		600	450
H 3-414	sandstone, gry., arkosic	601-631	610	440
H 3-415	sandstone, thin to med. beds	631-688	650	400
H 3-416	sandstone, very lt. gry. wthring.	688-705	690	360
H 3-417	sandstone, grnish brn. wthring.	688-705	700	350
H 3-418	coal, impure	705-716	710	340
H 3-419	sandstone, med. gr., wthr. lt. yel	723-774	730	320

Sample No.	Lithology	Measured (feet) stratigraphic interval above base of measurement	Approximate height (feet) above base of measurement	Feet below summit
MT. GLOSSOPTERIS, SOUTH RIDGE (continued) (SECTION 16)				
H 3-420	mudstone, lt. creamy gry. wthrng.	774-802	790	260
H 3-421	shale, dk. gry., ironstone lenses	802-818	810	240
H 3-422	shale and limestone, dk. gry.	818-835	830	220
H 3-423	sandstone, poorly sorted, dirty yel. gry.	846-897	870	180
H 3-424	siltstone, <u>Vertebraria</u>	897-912	900	150
H 3-425	sandstone, wthr. lt. gry., massive, med. gr. (TOP OF SECTION)	912-922	915	135
H 3-426	plants from NW shoulder Mt. Glossopteris	-----	---	
H 3-427	mudstone, peck marked, NW shoulder Mt. Glossopteris	-----	---	

MT. GLOSSOPTERIS, NORTHEAST RIDGE, SECTION 19

H 3-428	sandstone lens in tillite	51-52	51	
H 3-429	tillite	52-91	60	
H 3-430	sandstone lens	142-156	145	
H 3-431	tillite	142-156	150	
H 3-432	tillite	156-287	280	
H 3-433	sandstone, lenticular	287-293	290	
H 3-434	sandstone, lens	-----	333	
H 3-435	tillite	333-367	350	
H 3-436A	sandstone	367-376	370	
H 3-436B	conglomerate	367-376	370	

Sample No.	Lithology	Measured (feet) stratigraphic interval above base of measurement	Approximate height (feet) above base of measurement	Feet below sill
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MT. GLOSSOPTERIS, NORTHEAST RIDGE (continued) (SECTION 19)

H 3-437	concretions (polished in wind)	382-384	383	
H 3-438	shale, grnish gry. with concretions	382-384	383	
H 3-439	sandstone, fine gr., wthr. lt. brn.	384-386	385	
H 3-440	siltstone with current molds	388-393	390	
H 3-441	tracks in mudstone	388-393	385	
H 3-442	tillite	-----	507	
H 3-443	shale, sandy, lt. brn. gry.	542-544	543	
H 3-444	sandstone, dk. gry., cross-beds	1852-869	860	
H 3-445	sandstone, dk. gry.	1233-1449	1449	

MORaine RIDGE, UPPER PORTION, SECTION 6

H 3-446	shale, dk. gry.	85-151	90	445
H 3-447	sandstone, calcareous	85-151	120	415
H 3-448	sandstone, calcareous, feldspathic	85-151	---	385
H 3-449	sandstone, wthr. lt. brn. gry.	205-288	205	335
H 3-450	sandstone, wthr. lt. brn. gry.	205-288	220	315
H 3-451	sandstone, wthr. lt. brn. gry.	205-288	245	290
H 3-452	sandstone, wthr. lt. brn. gry.	205-288	255	280
H 3-453	sandstone, wthr. lt. brn. gry.	205-288	270	265
H 3-454	sandstone, wthr. lt. brn. gry.	205-288	288	247
H 3-455	sandstone, med.-crse. gr., lt. brn. tan, cross-beds	316-408	320	215
H 3-456	sandstone, ironstone beds, level to Vertebraria Ledge	316-408	340	190

Sample No.	Lithology	Measured (feet) stratigraphic interval above base of measurement	Approximate height (feet) above base of measurement	Feet below sill
<u>MORaine RIDGE, UPPER PORTION (continued) (SECTION 6)</u>				
H 3-457	sandstone, arkosic, ironstone beds, level to Vertebraria Ledge	316-408	360	175
H 3-458	sandstone, arkosic, ironstone beds, level to Vertebraria Ledge	316-408	380	155
H 3-459	sandstone, arkosic, ironstone beds, level to Vertebraria Ledge	316-408	405	130
H 3-460	shale, silty	408-422	415	120
H 3-461	shale, carb. and coaly, wthr. lt. gry.	422-433	430	105
H 3-462	sandstone, feldspathic	433-501	435	100
H 3-463	sandstone, feldspathic	433-501	450	85
H 3-464	sandstone, feldspathic, calcare- ous	433-501	465	70
H 3-465	sandstone, feldspathic	433-501	480	55
H 3-466	sandstone, feldspathic, calcareous	433-501	500	35
H 3-467	siltstone	501-506	505	30
H 3-468	coal, dull	506-507	507	28
H 3-469	hornfels, gry., siliceous, contact	535	535	0

Sample No.	Lithology	Measured (feet) stratigraphic interval above base of measurement	Approximate height (feet) above base of measurement
DISCOVERY RIDGE, EAST SPUR, SECTION 21			
H 3-470	tillite, matrix pebble count A		contact
H 3-471	tillite, matrix pebble count B		200
H 3-472	tillite, matrix pebble count C		400
H 3-473	tillite, matrix pebble count D		600
H 3-474	tillite, oriented	30 ft. above spotted sandstone	
H 3-475	tillite, oriented, boulder pavement	927 ft. above basement	
H 3-476	diabase, erratic, top (flat) Discovery Ridge		
H 3-477	ironstone, top of lower member, Discovery Ridge fm.		
H 3-478	calcareous rock, Discovery Ridge fm., top upper member		
H 3-479	siltstone, oriented, Discovery Ridge, N end		
H 3-480	siltstone, oriented		
H 3-481	siltstone, oriented		
H 3-482	siltstone, oriented, Discovery Ridge, S end		
H 3-483	erratic from tillite, calcareous		
H 3-484	drag folds, float in tillite		
H 3-485	plant fragments, Discovery Ridge fm., float		
H 3-486	calcareous boulder, Quartz Pebble Hill		
H 3-487	conglomerate, Quartz Pebble Hill	555 ft. level	

Sample No.	Lithology	Measured (feet) stratigraphic interval above base of measurement
<u>DISCOVERY RIDGE, EAST SPUR</u>		
H 3-446 Dev	shale, bl.	.5
H 3-447 Dev		2
H 3-448 Dev		14
H 3-449 Dev		26
H 3-450 Dev		32
H 3-451 Dev		42
H 3-452 Dev	Collection for Devonian plants made by Higgins, 9 January 62	44
H 3-453 Dev		47
H 3-454 Dev		55
H 3-455 Dev		68
H 3-456 Dev		79
H 3-457 Dev		99
H 3-458 Dev		100
H 3-459 Dev		123
H 3-460 Dev		129
H 3-461 Dev		131

Sample No.	Lithology	Measured (feet) stratigraphic interval above base of measurement	Feet below summit
<u>MT. GLOSSOPTERIS, NORTHWEST RIDGE, SECTION 21</u>			
H 3-1JR	sandstone, med. gr.		855
H 3-2JR	siltstone, plant impressions	0-5	850
H 3-3JR	coal	5-5	850
H 3-4JR	sandstone	43-63	800
H 3-5JR	coal, impure	76-84	775
H 3-6JR	coal	151-159	700
H 3-7JR	siltstone, fossil plants	168-179	685
H 3-8JR	coal	179-185	675
H 3-9JR	coal	229-235	625
H 3-10JR	coal	257-264	595
H 3-11JR	siltstone, plant fossils	264-290	575
H 3-12JR	sandstone, fine gr.	353-434	465
H 3-13JR	shale, coaly	511-525	335
<u>MT. GLOSSOPTERIS NORTH RIDGE (JOHN RICKER COLLECTION)</u>			
H 3-14JR	sandstone, pebbly	20-26	
H 3-15JR	shale, silty	26-28	
H 3-16JR	soil-like material	31-34	
H 3-17JR	siltstone, fine gr., reddish	34-35	

Sample No.	Lithology	Measured (feet) stratigraphic interval above base of measurement	Feet below summit
<u>MERCER RIDGE</u>			
H 3-18JR	sandstone, pale brn.	127-133	
H 3-19JR	siltstone, shaly	184-226	
H 3-20JR	siltstone, brn., muddy	232-233	
H 3-21JR	mudstone, lt. gry.	236-248	
H 3-22JR	coal	248-275	
H 3-23JR	siltstone, gry.-lt. brn.	727	
<u>MERCER RIDGE (STRUCTURAL TRIP)</u>			
H 3-24JB	zeolite, sandstone	Mercer Ridge, near top fault	

APPENDIX 3
COAL ANALYSES

STANDARD COAL ANALYSES, SECTION 4, CANYON PEAK
(Condition A-E: A, as received; B, moisture-free; C, moisture-
and ash-free; D, moisture- and mineral-free; E, mineral-free (moist))

Coal Sample Identification		Proximate per cent				Ultimate per cent					Rank Classification		
	Condition	Moisture	Volatile Matter	Fixed Carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Calorific Value	Specific Gravity	
CGL 119 F (H 3-22)	A	4.1	11.7	74.8	9.4	---	---	---	---	0.7	12590	Semianthracite	
1975' above basement	B	---	12.2	78.0	9.8	---	---	---	---	0.7	13130		
	C	---	13.5	86.5	---	---	---	---	---	---	---		
	D	---	12.5	87.5	---	---	---	---	---	---	---		
CGL 120 F (H 3-24)	A	4.1	10.8	70.3	14.8	---	---	---	---	0.6	11630	Semianthracite	
2005' above basement	B	---	11.2	73.4	15.4	---	---	---	---	0.6	12130		
	C	---	13.3	86.7	---	---	---	---	---	0.8	14330		
	D	---	11.8	88.2	---	---	---	---	---	---	---		
CGL 122 F (H 3-29)	A	3.5	10.4	70.8	15.3	---	---	---	---	0.6	11760	Semianthracite	
2085' above basement	B	---	10.7	73.5	15.8	---	---	---	---	0.6	12180		
	C	---	12.7	87.3	---	---	---	---	---	0.7	14470		
	D	---	11.2	88.8	---	---	---	---	---	---	---		
CGL 123 F (H 3-34)	A	3.9	10.1	72.7	13.3	---	---	---	---	0.7	12020	Semianthracite	
2160' above basement	B	---	10.5	75.7	13.8	---	---	---	---	0.7	12510		
	C	---	12.2	87.8	---	---	---	---	---	0.8	14520		
	D	---	10.8	89.2	---	---	---	---	---	---	---		
CGL 125 F (H 3-38)	A	3.6	10.2	73.3	12.9	---	---	---	---	0.7	12170	Semianthracite	
2245' above basement	B	---	10.6	76.1	13.3	---	---	---	---	0.7	12630		
	C	---	12.2	87.8	---	---	---	---	---	0.8	14570		
	D	---	10.8	89.2	---	---	---	---	---	---	---		

STANDARD COAL ANALYSES, SECTION 13, TERRACE RIDGE
(Condition A-E: A, as received; B, moisture-free; C, moisture-
and ash-free; D, moisture- and mineral-free; E, mineral-free (moist))

Coal Sample Identification		Proximate per cent				Ultimate per cent						Rank Classification	
	Condition	Moisture	Volatile Matter	Fixed Carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Calorific Value	Specific Gravity	
CGL 99 (H 2-4) 2' bed, 10' below sill	A	1.0	2.7	22.3	74.0	---	---	---	---	0.1	-----		Shale, coaly
	B	---	2.7	22.5	74.8	---	---	---	---	0.1	-----		
	C	---	---	---	---	---	---	---	---	---	-----		
	D	---	---	---	100+	---	---	---	---	---	-----		
CGL 78 (H 2-9) 3' bed, 132' below sill	A	1.7	3.3	31.8	63.2	0.6	32.8	0.7	2.5	0.2	-----		Shale, coaly
	B	---	3.3	32.4	64.3	0.4	32.3	0.7	1.1	0.2	-----		
	C	---	---	---	---	---	---	---	---	---	-----		
	D	---	---	---	100+	---	---	---	---	---	-----		
CGL 82 (H 2-24) Top, 12' seam, 648' below sill	A	7.0	12.8	51.0	29.2	2.0	54.2	1.3	13.0	0.3	8170		Low Volatile Bituminous
	B	---	13.7	54.9	31.4	1.3	58.2	1.4	7.4	0.3	8780		
	C	---	20.0	80.0	----	1.9	84.9	1.4	10.8	0.4	12800		
	D	---	16.9	83.1	----	---	----	---	---	---	-----		
	E	---	---	---	----	---	----	---	---	---	11950		
CGL 83 (H 2-25) Bottom, 12' seam, 648' below sill	A	8.0	14.3	67.5	10.2	2.6	70.5	1.4	14.9	0.4	10860		Low Volatile Bituminous
	B	---	15.5	73.4	11.1	1.9	76.6	1.5	8.5	0.4	11810		
	C	---	17.5	82.5	----	2.1	86.2	1.7	9.5	0.5	13290		
	D	---	16.5	83.5	----	---	----	---	---	---	-----		
	E	---	---	---	----	---	----	---	---	---	12230		

SECTION 13, TERRACE RIDGE (continued)

Coal Sample Identification	Proximate per cent					Ultimate per cent					Calorific Value	Specific Gravity	Rank Classification
	Condition	Moisture	Volatile Matter	Fixed Carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur			
CGL 87	A	5.7	12.7	43.7	37.9	2.0	46.5	1.3	11.8	0.5	7150	Low Volatile Bituminous	
(H 2-41)	B	---	13.5	46.3	40.2	1.4	49.3	1.4	7.2	0.5	7580		
2' seam	C	---	22.6	77.4	----	2.3	82.4	2.3	12.1	0.9	12690		
889' below sill	D	---	17.8	82.2	----	---	----	---	---	---	----		
	E	---	----	----	----	---	----	---	---	---	12130		
CGL 88	A	4.9	11.3	50.0	33.8	2.2	51.6	1.4	10.6	0.4	8070	Semianthracite	
(H 2-48)	B	---	11.9	52.5	35.6	1.7	54.2	1.4	6.6	0.5	8490		
Top 11' seam,	C	---	18.4	81.6	----	2.7	84.1	2.2	10.3	0.7	13180		
959' below sill	D	---	14.5	85.5	----	---	----	---	---	---	----		
	E	---	----	----	----	---	----	---	---	---	12500		
CGL 100	A	5.5	13.2	58.5	22.8	2.3	60.4	1.6	12.4	0.5	9500	Low Volatile Bituminous	
(H 2-184)	B	---	14.0	61.9	24.1	1.8	64.0	1.7	7.9	0.5	10060		
Near top, 11'	C	---	18.4	81.6	----	2.3	84.3	2.2	10.6	0.6	13250		
seam, 960'	D	---	16.1	83.9	----	---	----	---	---	---	----		
below sill	E	---	----	----	----	---	----	---	---	---	12600		
CGL 89	A	5.8	13.6	59.9	20.7	2.5	61.8	1.5	13.0	0.5	9690	Low Volatile Bituminous	
(H 2-49)	B	---	14.4	63.6	22.0	2.0	65.6	1.6	8.3	0.5	10290		
Near base	C	---	18.5	81.5	----	2.5	84.1	2.0	10.7	0.7	13180		
11' seam, 959'	D	---	16.4	83.6	----	---	----	---	---	---	----		
below sill	E	---	----	----	----	---	----	---	---	---	12500		

SECTION 13, TERRACE RIDGE (continued)

Coal Sample Identification		Proximate per cent					Ultimate per cent					Rank Classification	
	Condition	Moisture	Volatile Matter	Fixed Carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Calorific Value	Specific Gravity	
CGL 90	A	5.4	12.0	45.0	37.6	---	---	---	---	---	---		Low Volatile Bituminous
(H 2-51)	B	---	12.7	47.6	39.7	---	---	---	---	---	---		
3' bed, 1015'	C	---	21.0	79.0	----	---	---	---	---	---	---		
below sill	D	---	16.5	84.5	----	---	---	---	---	---	---		
CGL 91	A	5.3	13.0	42.3	39.4	2.1	46.1	1.2	10.9	0.3	7140		Low Volatile Bituminous
(H 2-52)	B	---	13.7	44.7	41.6	1.6	48.7	1.3	6.5	0.3	7540		
2' seam	C	---	23.4	76.6	----	2.7	83.4	2.2	11.1	0.6	12920		
1023' below	D	---	18.7	81.3	----	---	---	---	---	---	---		
sill	E	---	---	---	----	---	---	---	---	---	12450		
CGL 92	A	6.1	14.5	61.1	18.3	2.5	63.9	1.4	13.4	0.5	10000		Low Volatile Bituminous
(H 2-60)	B	---	15.4	65.1	19.5	2.0	68.1	1.5	8.4	0.5	10660		
12' seam,	C	---	19.1	80.9	----	2.4	84.6	1.9	10.5	0.6	13240		
1117' below	D	---	17.4	82.6	----	---	---	---	---	---	---		
sill	E	---	---	---	----	---	---	---	---	---	12400		
CGL 105	A	7.6	11.9	68.2	12.3	2.6	70.5	1.8	12.4	0.4	10990		Semianthracite (moisture-free CO ₂ = 0.54)
(H 2-4P)	B	---	12.8	73.8	13.4	1.9	76.3	2.0	6.0	0.4	11890		
662' below	C	---	14.8	85.2	----	2.2	88.1	2.3	6.9	0.5	13730		
sill	D	---	13.6	86.4	----	---	---	---	---	---	---		
(Doumani Stump)													

SECTION 13, TERRACE RIDGE (continued)

Coal Sample Identification		Proximate per cent					Ultimate per cent					Rank Classification	
	Condition	Moisture	Volatile Matter	Fixed Carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Calorific Value	Specific Gravity	
CGL 164 F	A	7.3	15.3	71.7	5.7	---	---	---	---	0.5	11580		
(H 3-366)	B	---	16.5	77.4	6.1	---	---	---	---	0.6	12490		Low Volatile
710' below	C	---	17.6	82.4	---	---	---	---	---	0.6	13310		Bituminous
sill	D	---	17.0	83.0	---	---	---	---	---	---	---		
CGL 76	A	4.1	10.5	37.2	48.2	1.7	40.0	1.1	8.3	0.7	6230		
(H 2-Several)	B	---	11.0	38.7	50.3	1.3	41.7	1.1	4.9	0.7	6490		Low Volatile
Bottom of 11'	C	---	22.1	77.9	---	2.6	83.9	2.3	9.3	1.4	13060		Bituminous
bed 958' below	D	---	14.6	85.4	---	---	---	---	---	---	---		
diabase sill	E	---	---	---	---	---	---	---	---	---	13000		
CGL 75	A	4.8	12.0	51.7	31.5	2.2	54.1	1.4	10.4	0.4	8440		
(H 2-Several)	B	---	12.6	54.3	33.1	1.7	56.9	1.5	6.4	0.4	8870		Low Volatile
Middle part of	C	---	18.9	81.1	---	2.6	85.0	2.2	9.6	0.6	13250		Bituminous
11' coal bed,	D	---	15.3	84.7	---	---	---	---	---	---	---		
958' below	E	---	---	---	---	---	---	---	---	---	12400		
sill													
CGL 74	A	4.0	10.0	38.9	47.1	1.8	41.2	1.2	8.4	0.3	6400		
(H 2-Several)	B	---	10.4	40.5	49.1	1.4	42.9	1.2	5.1	0.3	6700		Low Volatile
Top part of	C	---	20.5	79.5	---	2.7	84.2	2.4	10.1	0.6	13090		Bituminous
11' coal bed,	D	---	13.6	86.4	---	---	---	---	---	---	---		
958' below	E	---	---	---	---	---	---	---	---	---	13000		
sill													

STANDARD COAL ANALYSES, DIRTY DIAMOND ADIT
(Condition A-E: A, as received; B, moisture-free; C, moisture-
and ash-free; D, moisture- and mineral-free; E, moisture-free (moist))

Coal Sample Identification		Proximate per cent				Ultimate per cent					Rank Classification		
	Condition	Moisture	Volatile Matter	Fixed Carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Calorific Value	Specific Gravity	
Composite	A	6.7	15.1	54.5	23.7	2.6	58.0	1.1	14.2	0.4	9050	1.79	
Sample	B	---	16.2	58.5	25.3	1.9	62.1	1.2	9.0	0.5	9690	----	Low Volatile
28" rejected	C	---	21.7	78.3	----	2.6	83.1	1.6	12.1	0.6	12980	----	Bituminous
CGL 118	D	---	19.3	80.7	----	---	----	---	---	---	----	----	
	E	---	----	----	----	---	----	---	---	---	12170	----	
CGL 117	A	6.5	15.0	62.6	15.9	2.7	65.3	1.1	14.5	0.5	10260	1.71	
1" -- 8" below	B	---	16.0	67.1	16.9	2.1	69.9	1.2	9.4	0.5	10970	----	Low Volatile
top of bed	C	---	19.3	80.7	----	2.5	84.1	1.5	11.3	0.6	13210	----	Bituminous
	D	---	17.8	82.2	----	---	----	---	---	---	----	----	
	E	---	----	----	----	---	----	---	---	---	12406	----	
CGL 116	A	6.7	15.9	56.6	20.8	2.6	60.6	1.1	14.4	0.5	9490	1.77	
9" -- 16.5"	B	---	17.1	60.6	22.3	2.0	64.9	1.2	9.1	0.5	10170	----	Low Volatile
below top of	C	---	22.0	78.0	----	---	----	---	---	---	13090	----	Bituminous
bed	D	---	19.9	80.1	----	---	----	---	---	---	----	----	
	E	---	----	----	----	---	----	---	---	---	12500	----	
CGL 115	A	7.9	17.6	65.9	8.6	2.9	69.5	1.3	17.2	0.5	10810	1.66	
20.8" -- 32.3"	B	---	19.1	71.6	9.3	2.2	75.4	1.4	11.1	0.6	11740	----	Low Volatile
below top of	C	---	21.0	79.0	---	2.4	83.1	1.6	12.3	0.6	12940	----	Bituminous
bed	D	----	20.2	79.8	----	---	----	---	----	---	----	----	
	E	---	----	----	----	---	----	---	----	---	11958	----	

DIRTY DIAMOND ADIT (continued)

Coal Sample Identification	Proximate per cent					Ultimate per cent					Rank Classification		
	Condition	Moisture	Volatile Matter	Fixed Carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Calorific Value	Specific Gravity	
CGL 114	A	7.5	17.3	63.1	12.1	3.0	65.9	1.4	17.0	0.6	10350	1.70	
32.8"--43.5"	B	---	18.8	68.1	13.1	2.3	71.3	1.5	11.2	0.6	11190	----	Low Volatile
below top of bed	C	---	21.6	78.4	----	2.6	82.1	1.7	12.9	0.7	12880	----	Bituminous
	D	---	20.3	79.7	----	---	----	---	----	---	----	----	
	E	---	----	----	----	---	----	---	----	---	11890	----	
CGL 113	A	5.4	12.4	41.1	41.1	2.1	43.3	0.9	12.3	0.3	6750	1.97	
44.2"--54.4"	B	---	13.1	43.4	43.5	1.6	45.8	0.9	7.9	0.3	7140	----	Low Volatile
below top of bed	C	---	23.2	76.8	----	2.8	81.0	1.7	13.9	0.6	12640	----	Bituminous
	D	---	18.0	82.0	----	---	----	---	---	---	----	----	
	E	---	----	----	----	---	----	---	---	---	12157	----	
CGL 112	A	6.7	14.7	50.4	28.1	2.4	53.8	1.1	14.2	0.4	8370	1.83	
60"--72.5"	B	---	15.8	54.1	30.1	1.8	57.7	1.1	8.9	0.4	8970	----	Low Volatile
below top of bed	C	---	22.6	77.4	----	2.6	82.6	1.6	12.6	0.6	12840	----	Bituminous
	D	---	19.6	80.4	----	---	----	---	---	---	----	----	
	E	---	----	----	----	---	----	---	---	---	12015	----	
CGL 111	A	6.2	14.2	47.6	32.0	2.4	50.1	1.1	14.0	0.4	7870	1.86	
74.3"--91.5"	B	---	15.1	50.8	34.1	1.8	53.4	1.2	9.1	0.4	8390	----	Low Volatile
below top of bed	C	---	22.9	77.1	----	2.8	81.0	1.8	13.7	0.7	12720	----	Bituminous
	D	---	19.5	80.5	----	---	----	---	---	---	----	----	
	E	---	----	----	----	---	----	---	---	---	12040	----	

DIRTY DIAMOND ADIT (continued)

Coal Sample Identification		Proximate per cent					Ultimate per cent					Rank Classification		
	Condition	Moisture	Volatile Matter	Fixed Carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Calorific Value	Specific Gravity		
CGL 110	A	6.0	13.4	43.2	37.4	2.4	45.1	1.0	13.7	0.4	7130	1.92		
94.5"--102.8"	B	---	14.3	45.9	39.8	1.9	48.0	1.1	8.8	0.4	7590	----	Low Volatile	
below top of bed	C	---	23.8	76.2	----	3.1	79.7	1.7	14.8	0.7	12600	----	Bituminous	
	D	---	19.2	80.8	----	---	----	---	---	---	----	----		
	E	---	----	----	----	---	----	---	---	---	11970	----		
CGL 109	A	6.6	15.1	54.7	23.6	2.6	57.8	1.6	13.9	0.5	9000	1.78		
103.5"--120"	B	---	16.2	58.5	25.3	2.0	61.9	1.7	8.6	0.5	9600	----	Low Volatile	
below top of bed	C	---	21.7	78.3	----	2.7	82.9	2.3	11.4	0.7	12910	----	Bituminous	
	D	---	19.2	80.8	----	---	----	---	---	---	----	----		
	E	---	----	----	----	---	----	---	---	---	12095	----		
CGL 108	A	7.4	17.4	61.6	13.6	2.8	65.4	1.7	16.0	0.5	10230	1.70		
124"--142"	B	---	18.8	66.6	14.6	2.2	70.6	1.8	10.2	0.6	11040	----	Low Volatile	
below top of bed	C	---	22.0	78.0	----	2.6	82.8	2.1	11.8	0.7	12930	----	Bituminous	
	D	---	20.8	79.2	----	---	----	---	----	---	----	----		
	E	---	----	----	----	---	----	---	----	---	12005	----		

STANDARD COAL ANALYSES, SECTION 14, MT. SCHOPF
(Condition A-E: A, as received; B, moisture-free; C, moisture-
and ash-free; D, moisture- and mineral-free; E, moisture-free (moist))

Coal Sample Identification		Proximate per cent					Ultimate per cent					Rank Classification		
	Condition	Moisture	Volatile Matter	Fixed Carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Calorific Value	Specific Gravity		
CGL 128 F	A	6.9	15.0	72.1	6.0	---	----	---	---	0.6	11700		Low Volatile Bituminous	
(H 3-81)	B	---	16.1	77.5	6.4	---	----	---	---	0.7	12560			
Ridge E. of	C	---	17.2	82.8	---	---	----	---	---	0.7	13420			
Terrace Rid.	D	---	16.5	83.5	---	---	----	---	---	---	-----			
891' below sill	E	---	-----	-----	---	---	----	---	---	---	-----			
CGL 129 F	A	6.9	15.8	73.1	4.2	---	----	---	---	0.6	11760		Low Volatile Bituminous	
(H 3-83)	B	---	16.9	78.6	4.5	---	----	---	---	0.6	12630			
Ridge E. of	C	---	17.7	82.3	---	---	----	---	---	0.7	13230			
Terrace Rid.	D	---	17.3	82.7	---	---	----	---	---	---	-----			
775' below sill	E	---	-----	-----	---	---	----	---	---	---	-----			
CGL 130 F	A	6.4	14.1	78.3	1.2	---	----	---	---	0.5	12430		Low Volatile Bituminous	
(H 3-85)	B	---	15.0	83.8	1.2	---	----	---	---	0.5	13280			
Ridge E. of	C	---	15.2	84.8	---	---	----	---	---	0.5	13440			
Terrace Rid.	D	---	15.0	85.0	---	---	----	---	---	---	-----			
690' below sill	E	---	-----	-----	---	---	----	---	---	---	-----			
CGL 131 F	A	7.2	14.9	61.9	16.0	---	----	---	---	0.4	10130		Low Volatile Bituminous	
(H 3-87)	B	---	16.0	66.7	17.3	---	----	---	---	0.4	10910			
Ridge E. of	C	---	19.4	80.6	-----	---	----	---	---	0.5	13180			
Ter. Rid. 625'	D	---	17.9	82.1	-----	---	----	---	---	---	-----			
below sill	E	---	-----	-----	-----	---	----	---	---	---	-----			

STANDARD COAL ANALYSES, SECTION 15
(Condition A-E: A, as received; B, moisture-free; C, moisture-
and ash-free; D, moisture- and mineral-free; E, moisture-free (moist))

Coal Sample Identification		Proximate per cent					Ultimate per cent					Rank Classification	
	Condition	Moisture	Volatile Matter	Fixed Carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Calorific Value	Specific Gravity	
CGL 132F (H 3-182)	A	4.1	11.2	76.2	8.5	3.2	77.5	1.5	8.6	0.7	12660		Semianthracite
NE Ridge, Mt. Schopf	B	---	11.6	79.6	8.8	2.9	80.8	1.6	5.2	0.7	13200		
1105' below sill	C	---	12.8	87.2	----	3.1	88.6	1.8	5.7	0.8	14480		
	D	---	11.9	88.1	----	---	----	---	---	---	----		
	E	---	----	----	----	---	----	---	---	---	----		
CGL 133 F (H 3-186)	A	6.5	28.6	59.0	5.9	---	----	---	---	0.7	11720		High Volatile Bituminous
NE Ridge, Mt. Schopf	B	---	30.6	63.1	6.3	---	----	---	---	0.7	12530		
735' below sill	C	---	32.7	67.3	----	---	----	---	---	0.8	13510		
	D	---	32.1	67.9	----	---	----	---	---	---	----		
	E	---	----	----	----	---	----	---	---	---	12540		
CGL 134 F (H 3-188)	A	7.7	17.5	71.0	3.8	2.9	74.4	1.4	17.0	0.5	11520		Low Volatile Bituminous
NE Ridge, Mt. Schopf	B	---	19.0	76.9	4.1	2.2	80.6	1.5	11.0	0.6	12490		
630' below sill	C	---	19.8	80.2	----	2.3	84.1	1.6	11.4	0.6	13020		
	D	---	19.3	80.7	----	---	----	---	----	---	----		
	E	---	----	----	----	---	----	---	----	---	----		

SECTION 15 (continued)

Coal Sample Identification		Proximate per cent				Ultimate per cent					Rank Classification		
	Condition	Moisture	Volatile Matter	Fixed Carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Calorific Value	Specific Gravity	
CGL 135 F	A	7.2	16.0	72.1	4.7	---	----	---	---	0.5	11590		Low Volatile Bituminous
(H 3-189)	B	---	17.3	77.6	5.1	---	----	---	---	0.5	12490		
NE Ridge,	C	---	18.2	81.8	----	---	----	---	---	0.6	13160		
Mt. Schopf	D	---	17.6	82.4	----	---	----	---	---	---	-----		
605' below sill	E	---	----	----	----	---	----	---	---	---	-----		
CGL 136 F	A	6.8	14.9	58.6	19.7	---	----	---	---	0.3	9270		Low Volatile Bituminous
(H 3-191)	B	---	16.0	62.9	21.1	---	----	---	---	0.4	9940		
NE Ridge,	C	---	20.3	79.7	----	---	----	---	---	0.5	12610		
Mt. Schopf	D	---	18.4	81.6	----	---	----	---	---	---	-----		
525' below sill	E	---	----	----	----	---	----	---	---	---	-----		
CGL 137 F	A	0.8	2.4	64.9	31.9	----	----	---	---	---	-----		(? Anthracite +) Meta-anthracite
(H 3-196)	B	---	2.4	65.5	32.1	----	----	---	---	---	-----		
NE Ridge,	C	---	3.5	96.5	----	----	----	---	---	---	-----		
20' (approx.)	D	---	0.8	100.8	----	----	----	---	---	---	-----		
below sill	E	---	----	----	----	----	----	---	---	---	-----		

STANDARD COAL ANALYSES, SECTION 16, MT. GLOSSOPTERIS
(Condition A-E: A, as received; B, moisture-free; C, moisture-
and ash-free; D, moisture- and mineral-free; E, moisture-free (moist))

Coal Sample Identification		Proximate per cent					Ultimate per cent						Rank Classification
	Condition	Moisture	Volatile Matter	Fixed Carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Calorific Value	Specific Gravity	
CGL 156 F (H 3-169) 1360' below summit	A	6.0	14.7	67.7	11.6	---	---	---	---	0.6	11110		Low Volatile Bituminous
	B	---	15.6	72.1	12.3	---	---	---	---	0.6	11810		
	C	---	17.8	82.2	----	---	---	---	---	0.7	13470		
	D	---	16.7	83.3	----	---	---	---	---	---	-----		
	E	---	----	-----	----	---	---	---	---	---	-----		
CGL 157 F (H 3-174) 1300' below summit	A	5.5	18.2	66.4	9.9	---	---	---	---	0.6	11440		Low Volatile Bituminous
	B	---	19.2	70.4	10.4	---	---	---	---	0.6	12100		
	C	---	21.5	78.5	----	---	---	---	---	0.7	13500		
	D	---	20.6	79.4	----	---	---	---	---	---	-----		
	E	---	----	-----	----	---	---	---	---	---	-----		
CGL 158 F (H 3-177) 1185' below summit	A	5.6	15.0	69.9	9.5	---	---	---	---	0.6	11430		Low Volatile Bituminous
	B	---	15.9	74.1	10.0	---	---	---	---	0.6	12100		
	C	---	17.6	82.4	----	---	---	---	---	0.7	13450		
	D	---	16.7	83.3	----	---	---	---	---	---	-----		
	E	---	----	-----	----	---	---	---	---	---	-----		

SECTION 16, MT. GLOSSOPTERIS (continued)

Coal Sample Identification	Proximate per cent					Ultimate per cent					Rank Classification		
	Condition	Moisture	Volatile Matter	Fixed Carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Calorific Value	Specific Gravity	
CGL 159 F (H 3-402) 820' below summit	A	5.6	14.3	72.7	7.4	2.9	74.6	1.5	13.0	0.6	11810		Low Volatile Bituminous
	B	---	15.1	77.1	7.8	2.4	79.0	1.6	8.5	0.7	12510		
	C	---	16.4	83.6	----	2.6	85.6	1.7	9.4	0.7	13570		
	D	---	15.6	84.4	----	---	----	---	---	---	-----		
	E	---	----	----	----	---	----	---	---	---	-----		
CGL 160 F (H 3-405) 790' below summit	A	5.4	12.7	73.7	8.2	---	----	---	---	0.6	11980		Semianthracite
	B	---	13.4	78.0	8.6	---	----	---	---	0.6	12660		
	C	---	14.7	85.3	----	---	----	---	---	0.7	13850		
	D	---	13.8	86.2	----	---	----	---	---	---	-----		
	E	---	----	----	----	---	----	---	---	---	-----		
CGL 162 F (H 3-418) 340' below summit	A	7.9	14.7	67.2	10.2	2.4	70.2	1.0	15.9	0.3	10620		Low Volatile Bituminous
	B	---	15.9	73.1	11.0	1.6	76.1	1.1	9.9	0.3	11520		
	C	---	17.9	82.1	----	1.8	85.6	1.2	11.0	0.4	12950		
	D	---	17.0	83.0	----	---	----	---	---	---	-----		
	E	---	----	----	----	---	----	---	---	---	-----		

STANDARD COAL ANALYSES, SECTION 17, MT. GLOSSOPTERIS
(Condition A-E: A, as received; B, moisture-free; C, moisture-
and ash-free; D, moisture- and mineral-free; E, moisture-free (moist))

Coal Sample Identification	Condition	Proximate per cent					Ultimate per cent					Rank Classification	
		Moisture	Volatile Matter	Fixed Carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Calorific Value	Specific Gravity	
CGL 107	A	2.7	7.0	49.5	40.8	2.1	49.7	0.9	6.0	0.5	8140	1.82	Anthracite
(H 3-JMS-1226)	B	---	7.2	50.9	41.9	1.9	51.1	1.0	3.6	0.5	8370	----	Hardgrove
934' below	C	---	12.4	87.6	-----	3.3	88.0	1.7	16.2	0.8	14420	----	Grindability index,
summit	D	---	6.7	93.3	-----	---	-----	---	---	---	-----	----	46.0; Initial Def.
	E	---	-----	-----	-----	---	-----	---	---	---	-----	----	Temp., 2910° Ft.
CGL 106	A	2.6	7.1	44.8	45.5	2.0	45.9	0.9	5.3	0.4	7460		Anthracite
(H 3-JMS)	B	---	7.3	46.0	46.7	1.8	48.1	0.9	3.1	0.4	7660		Hardgrove
934' below	C	---	13.7	86.3	-----	3.3	88.3	1.7	5.9	0.8	14380		Grindability index,
summit	D	---	6.9	93.1	-----	---	-----	---	---	---	-----		46.0
	E	---	-----	-----	-----	---	-----	---	---	---	-----		
CGL 138 F	A	3.2	9.6	71.8	15.4	---	-----	---	---	0.7	11850		
(H 3-201)	B	---	9.9	74.2	15.9	---	-----	---	---	0.8	12240		Semianthracite
934' below	C	---	11.8	88.2	-----	---	-----	---	---	0.9	14550		
summit	D	---	10.1	89.9	-----	---	-----	---	---	---	-----		
	E	---	-----	-----	-----	---	-----	---	---	---	-----		
CGL 139 F	A	3.2	8.2	68.7	19.9	---	-----	---	---	0.5	11250		
(H 3-209)	B	---	8.4	71.1	20.5	---	-----	---	---	0.5	11620		Semianthracite
815' below	C	---	10.6	89.4	-----	---	-----	---	---	0.6	14620		
summit	D	---	8.5	91.5	-----	---	-----	---	---	---	-----		
	E	---	-----	-----	-----	---	-----	---	---	---	-----		

SECTION 17, MT. GLOSSOPTERIS (continued)

Coal Sample Identification	Proximate per cent					Ultimate per cent					Rank Classification		
	Condition	Moisture	Volatile Matter	Fixed Carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Calorific Value	Specific Gravity	
CGL 140 F	A	4.8	12.1	74.7	8.4	---	----	---	---	0.7	12160		Semianthracite
(H 3-211)	B	---	12.7	78.5	8.8	---	----	---	---	0.7	12770		
710' below	C	---	13.9	86.1	----	---	----	---	---	0.8	14000		
summit	D	---	13.0	87.0	----	---	----	---	---	---	-----		
CGL 141 F	A	5.2	12.7	74.6	7.5	---	----	---	---	0.7	12110		Semianthracite
(H 3-216)	B	---	13.4	78.7	7.9	---	----	---	---	0.8	12780		
622' below	C	---	14.6	85.4	----	---	----	---	---	0.8	13880		
summit	D	---	13.7	86.3	----	---	----	---	---	---	-----		
CGL 142 F	A	5.0	12.1	76.7	6.2	---	----	---	---	0.7	12430		Semianthracite
(H 3-217)	B	---	12.8	80.7	6.5	---	----	---	---	0.7	13090		
580' below	C	---	13.7	86.3	----	---	----	---	---	0.8	14000		
summit	D	---	12.9	87.1	----	---	----	---	---	---	-----		
CGL 143 F	A	5.5	13.5	72.8	8.2	---	----	---	---	0.6	11730		Low Volatile Bituminous
(H 3-220)	B	---	14.2	77.1	8.7	---	----	---	---	0.6	12400		
545' below	C	---	15.6	84.4	----	---	----	---	---	0.7	13580		
summit	D	---	14.8	85.2	----	---	----	---	---	---	-----		
CGL 144 F	A	5.9	13.3	72.8	8.0	---	----	---	---	0.6	11720		Low Volatile Bituminous
(H 3-221)	B	---	14.2	77.3	8.5	---	----	---	---	0.6	12450		
490' below	C	---	15.5	84.5	----	---	----	---	---	0.7	13600		
summit	D	---	14.6	85.4	----	---	----	---	---	---	-----		
CGL 145 F	A	4.6	11.3	79.3	4.8	---	----	---	---	0.5	12710		Semianthracite
(H 3-227)	B	---	11.8	83.2	5.0	---	----	---	---	0.5	13320		
358' below	C	---	12.4	87.6	----	---	----	---	---	0.5	14020		
summit	D	---	11.9	88.1	----	---	----	---	---	---	-----		

STANDARD COAL ANALYSES, SECTION 18, MT. GLOSSOPTERIS
(Condition A-E: A, as received; B, moisture-free; C, moisture-
and ash-free; D, moisture- and mineral-free; E, moisture-free (moist))

Coal Sample Identification	Proximate per cent					Ultimate per cent					Rank Classification	
	Condition	Moisture	Volatile Matter	Fixed Carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Calorific Value	Specific Gravity
CGL 147 F (H 3-5-JR) 775' below summit	A	4.4	10.7	75.2	9.7	---	----	---	---	0.7	12300	Semianthracite
	B	---	11.1	78.8	10.1	---	----	---	---	0.7	12860	
	C	---	12.4	87.6	----	---	----	---	---	0.8	14300	
	D	---	11.4	88.6	----	---	----	---	---	---	-----	
	E	---	-----	-----	-----	---	----	---	---	---	-----	
CGL 148 F (H 3-6-JR) 700' below summit	A	3.8	9.5	76.7	10.0	---	----	---	---	0.7	12510	Semianthracite
	B	---	9.8	79.8	10.4	---	----	---	---	0.7	13010	
	C	---	11.0	89.0	----	---	----	---	---	0.8	14520	
	D	---	9.9	90.1	----	---	----	---	---	---	-----	
CGL 150 F (H 3-9-JR) 625' below summit	A	3.9	8.6	78.9	8.6	3.0	78.7	1.5	7.6	0.6	12770	Semianthracite
	B	---	8.9	82.1	9.0	2.7	81.9	1.6	4.2	0.6	13280	
	C	---	9.8	90.2	----	2.9	90.0	1.7	4.7	0.7	14590	
	D	---	8.9	91.1	----	---	----	---	---	---	-----	
CGL 151 F (H 3-10-JR) 595' below summit	A	3.7	9.2	79.5	7.6	---	----	---	---	0.6	12970	Semianthracite
	B	---	9.5	82.6	7.9	---	----	---	---	0.6	13470	
	C	---	10.3	89.7	----	---	----	---	---	0.7	14620	
	D	---	9.5	90.5	----	---	----	---	---	---	-----	
	E	---	-----	-----	-----	---	----	---	---	---	-----	

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TERRACE RIDGE, OHIO RA

IO RANGE, HORLICK MOUNTAIN

MOUNTAINS, ANTARCTICA

GEOLOGIC MAP - OHIO RANGE

HORLICK MOUNTAINS, ANTARCTICA

(AFTER U.S.G.S. PRELIMINARY SHEETS)

APPROXIMATE SCALE: 1 to 50,000

ELEVATION (METERS)

ELEVATION (METERS)

ARROWS POINTING DOWNSLOPE

SECTION

8000-
7900-
7800-
7700-
7600-
7500-
7400-
7300-
7200-
7100-
7000-
6900-
6800-
6700-
6600-
6500-
6400-

MT. GLOSSOPTERIS FO

S N O W

UNITS NOT MEASURED

FAULT

FAULT

DISCOVERY RIDGE FORMATION

UPPER MEMBER

LOWER MEMBER

DISCOVERY RIDGE WEST SPUR

22

1

2

3

CANYON PEAK
4

5

MAIN GLOSSOPTERIS LEDGE
DIRTY DIAMOND ADIT
3RD MAJOR TERRACE
2ND MAJOR TERRACE
1ST MAJOR TERRACE

LEGEND

- SANDSTONE & ARKOSE
- CROSSBEDDED SANDSTONE
- SHALE & SILTSTONE
- TILLITE
- SILTY SHALE
- FISSILE SHALE
- COAL
- COALY PARTINGS
- DIABASE
- GRANITIC BASEMENT
- ANIMAL BURROWS

8

9

MEASURED STRATIGRAPHIC SECTIONS OHIO RANGE, ANTARCTICA

EAST

WEST

MT. GLOSSOPTERIS

MT. SCHOPF