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Explanatory Text of Geological Map of Skallen, Antarctica

Masaru YOSHIDA, Yoshio YOSHIDA, Hisao ANDO,
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National Institute of Polar Research
9-10, Kaga 1-chome, Itabashi-ku
Tokyo 173, Japan

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Masaru YOSHIDA[1], Yoshio YOSHIDA[2], Hisao ANDO[3], Terumi ISHIKAWA[4] and Tatsuo TATSUMI[5]

1. The Skallen Region

The Skallen region lies on the east coast of Lützow-Holmbukta, East Antarctica. The region was mapped for the first time by HANSEN (1946) based on the oblique aerial photographs taken by CHRISTENSEN (in his 1937 expedition) who is the first observer of the present region. The ground survey of the region was conducted by a Japanese geologist in 1957 and since then some members of the Japanese Antarctic Research Expeditions visited the region with various scientific objects.

The geology and geomorphology of the region was outlined by TATSUMI and KIKUCHI (1959) and the brief petrography was presented by them (TATSUMI *et al.*, 1964). After that, however, the region remained unsurveyed for nearly ten years. From 1967 to 1974, some scientists surveyed the region; geomorphological and/or limnological surveys by T. TORII, R. HIGANO, Y. YOSHIDA, and K. OMOTO in 1967–1969, and J. HIRABAYASHI, K. OMOTO, and K. MORIWAKI in 1973–1974, and geological survey by H. ANDO, M. YOSHIDA, and T. ISHIKAWA in 1969–1972, preliminary reports having been given (YOSHIDA, 1970; YOSHIDA and ANDO, 1971, OMOTO, 1972). The present map and text are mainly based on the surveys conducted by H. ANDO, Y. YOSHIDA, and M. YOSHIDA, but the report also compiles some other data so far presented.

2. Geomorphology and Cenozoic Geology

2.1. Landforms

The Skallen region consists of three districts, *viz.*, Skallen, Skallevikhalsen, and Hjartöy island. The Skallen district displays a gently undulating erosional surface with an area of about 10 km^2 and the maximum elevation of 186 m. The periphery about 23 km in length meets the sea except its 2.7 km long southern

[1] Department of Geosciences, Faculty of Science, Osaka City University, Sumiyoshi-ku, Osaka 558.

[2] Department of Geography, Faculty of Literature, Hiroshima University, Higashi-senda-machi, Hiroshima 730.

[3] Laboratory of Hydrogeology, Hiragishi 5-jo 4-chome, Sapporo-shi, Hokkaido 062.

[4] Department of Earth Sciences, Faculty of Science, Nagoya University, Chikusa-ku, Nagoya 464.

[5] Geological Institute, Faculty of Science, University of Tokyo, Bunkyo-ku, Tokyo 113.

edge where the ice sheet terminates in a stagnant state. The western coastline is rather monotonous in plan, but the eastern is full of indentations facing the floating tongue of the Skallen Glacier.

The trend of undulation with broad ridges and depressions is ENE–WSW to E–W, carved conformably to the general trend of the geological structure indicated by folding and alternation structures of the gneissic bedrock. The surface was apparently subjected to glacial scouring as is shown by well-preserved striations, grooves, and quarried surfaces with stoss-and-lee topography. On the other hand, morainic deposits are distributed only as thin ground moraines or sporadic erratics. This may indicate that the conspicuous stagnation of the margin of the ice sheet had not taken place on the present ice-free area during shrinking of the ice sheet, though weathering of bedrock of the northern part has slightly advanced in comparison with that of the southern part. The boundary between the north and the south is a remarkable depression containing Lake Skallen Ôike. Mechanical weathering such as congelifraction can be seen in some places, but the process may not be intense, as is indicated by the degree of preservation of striated surfaces. This may be partly caused by rather heavy snowfall during winter. On the other hand, stone stripes and stone nets develop on morainic deposits in a few places.

The direction of former ice flow inferred from directions of glacial striae and grooves is commonly NW–SE, intersecting the general trend of major relief. Two directions of striations are often seen, suggesting the change of direction of ice flow during shrinking of the ice sheet.

After retreat of the ice sheet, the periphery of the district had been subjected to marine agency. Then the area was uplifted by 5 to 10 m or more, as is indicated by the elevated beach topography. Elevated beaches are developed along the east coast, and rarely seen on the west. Elevations of beaches decrease in general towards the south.

The Skallevikhalsen district exposes itself from the edge of the ice sheet. This area, 7 km in length, 1.7 km in maximum width, and 300 m in maximum height, is separated from the Skallen district by the narrow Skallevika which ends at the snout of a small receded outlet glacier. A conspicuous feature is the stepped topography with precipitous slopes and rather flat surfaces, its trend being conformable with geologic structure. Two cirque-like depressions are open to sea near the western and the eastern ends. Directions of glacial striae, which are generally parallel to those in the Skallen district, intersect the general trend of the topography. The glacial deposits are only thin ground moraines. The landform made by marine agency is ambiguous, but the sediment containing fragments of molluscan shells is distributed in a small valley down to Lake Dairi below 25 m in height.

A small island at 1.5 km north of the northwestern corner of the district has a polished surface 3 m above sea level partly covered with marine sediment, suggesting the regional uplift of the area after deglaciation.

The name Hjartöy, which means heart island, originated in its triangular

shape with sides of 1.5 km in length. The topography is rather monotonous with a northern precipitous cliff and a gentle back slope where shallow and narrow depressions extend in the direction of NE-SW. Elevated beach topography can not be found in this area.

2.2. Cenozoic geology

No Tertiary rock is known to occur in Prince Harald and Olav Coasts except gravels dredged by the Umitaka Maru from the Gunnerus bank off the Cape Cook. The gravels were assigned to Tertiary sedimentary rock by NIINO (1958), though evidence is insufficient. Therefore, the Cenozoic System of Skallen is composed of glacial drifts and marine sediments.

Glacial drifts occur in the form of ground moraines resting on shallow depressions and leesides of hillocks and as erratic boulders distributed sparsely on glacially scoured bedrock. Evidence suggesting their ages is not available. They might have been deposited during the late Quaternary and the Recent, judging from the topography.

Marine sediments occur as elevated beaches below perhaps 25 meters above sea level. They consist of silt, sands, and gravels. In some places, the deposits are obviously composed of reworked moraines. They often contain fragments of shells, worm tubes and tests of Foraminifera. The age of the sediment is not yet determined, but it may be younger than 30,000 years, probably younger than 6,000 years, inferred from ^{14}C dating of marine sediments in the nearby ice-free areas (YOSHIDA, 1970) and from the topography.

3. Basement

3.1. General

The crystalline basement rocks consist of paragneisses, metabasites, marbles, skarn and allied rocks, quartzite, garnet gneissose granite, charnockites, and minor intrusives, all these rocks belonging to the Lützow-Holm Bay System designated by TATSUMI and KIZAKI (1969). These basement rocks of the Skallen region constitute four formations, *viz.*, from bottom upward, Skallen lower calcareous formation, Skallen siliceous formation, and Skallen upper calcareous formation, the first two formations being widely distributed throughout the region and the last formation being only found at the southern margin of Skallevikhalsen and northern margin of Hjartöy island. Skallen brown gneiss formation exposed near Osiage Beach, northern part of Skallen is another unit though its stratigraphic position is yet invalid (Table 1). These basement rocks are gently or moderately inclined to the north or the south with the east trend. Complicated and superposed folds, however, are developed throughout the region. Good exposures and difference in color among different geologic bodies are advantageous for tracing a geologic boundary on aerial photographs (Plate 1-a, b).

Radiometric age determinations of the basement rocks are listed in Table 2. Chemical compositions of rocks* and minerals of the region are presented in

* Most of chemical analyses of rocks were made by Dr. S. KANISAWA of Tohoku University through the courtesy of him.

Table 1. Stratigraphy of the Skallen region.

Formation (thickness)	Lithology
Skallen upper calcareous formation (400 m+)	Marbles, skarn and allied rocks, feldspathic garnet gneiss, siliceous gneisses, and metabasites with a brown gneissose granodiorite mass (200 m+ thick) at the upper horizon.
Skallen siliceous formation (620 m)	Alternation of paragneisses and metabasites with a brown gneissose granodiorite-garnet gneissose granite mass (220–80 m thick) in the middle horizon and another brown gneissose granodiorite-garnet gneissose granite mass (170–0 m thick) in the lowermost horizon.
Skallen lower calcareous formation (400 m+)	Marble-skarn zone with minor feldspathic garnet gneiss in the upper horizon, and brown gneisses and siliceous gneisses with few metabasites and skarn and allied rocks in the lower horizon with a brown gneissose granodiorite-garnet gneissose granite mass (360–60m thick) in the lower horizon.
Skallen brown gneiss formation (175 m+)	Brown gneisses-metabasite alternations, more or less affected by migmatization of pink granites with a pink granitic gneiss mass (30 m thick) in the upper horizon

Table 2. Radiometric ages of minerals from the Skallen region.

Rock type	Analysed mineral	Method	Age	Ref.*
Granitic pink pegmatite in the brown gneissose granodiorite	Biotite	Rb-Sr	530±16	1
Pink pegmatite	Euxenite	U-Pb	375–485	2

*1. JARE57102622, NICOLAYSEN *et al.*, 1961.
*2. JARE57102623, SAITO *et al.*, 1961.

Tables 3 and 4.

3.2. Petrography

3.2.1. Paragneisses

Paragneisses constitute major parts of the basement rocks of the Skallen region. They occur as alternations of different gneisses, mostly quartz-feldspathic gneisses and siliceous gneisses, each layer being some tens of centimeters to some tens of meters thick (Plate 2-a). Minor amounts of garnet-biotite gneiss and porphyroblastic biotite-plagioclase rock were also found as intercalations or as veins.

1) Quartz-feldspathic gneisses

Quartz-feldspathic gneisses are one of the main constituents of the basement rocks throughout the four formations. Quartz-feldspathic garnet gneiss and quartz-feldspathic biotite gneiss are the main varieties. A very small amount of quartz-feldspathic sillimanite gneiss was also found.

Quartz-feldspathic (garnet or biotite) gneisses are well developed in all the formations except the Skallen brown gneiss formation. The gneisses are very

leucocratic*, white, coarse- to very coarse-grained**, and inequigranular rocks composed of small- to very coarse-grained quartz, small- to medium-grained K-feldspar, plagioclase, garnet, and fine-grained biotite. Minor amounts of opaque mineral, apatite, zircon, sericite, and chlorite are also associated. The total and relative amounts of these constituent minerals are variable, and some of K-feldspar, garnet, biotite and opaque mineral are sometimes absent. Quartz-feldspathic garnet gneiss denotes the garnet-bearing variety and quartz-feldspathic biotite gneiss means those rocks bearing only biotite as mafic constituent. Thin (several millimeters in thickness) laminae***, which are more abundant in mafic mineral aggregates than the quartz-feldspathic matrix, are developed at intervals of several centimeters; hence the rock shows a thinly banded structure. Coarse- to centimeter-grained quartz plates (ribons of clear quartz) are well developed parallel to the banding.

Quartz-feldspathic sillimanite gneiss, less than a meter thick, was found in the lower horizon of the Skallen siliceous formation and in the upper horizon of the Skallen lower calcareous formation. This gneiss is a leucocratic, white, coarse-grained, and inequigranular rock composed of medium- to coarse-grained quartz, K-feldspar, and garnet, and small- to coarse-grained needles of sillimanite. These constituent minerals are variable in both total and relative amounts. Small amounts of small-grained plagioclase and fine-grained biotite are sometimes associated. Garnet is somewhat concentrated in thin laminae, exhibiting banded structure. Sillimanite needles are well orientated, showing a remarkable lineation.

2) Siliceous gneisses

Siliceous gneisses are abundant in the Skallen siliceous formation, sporadical in the Skallen lower calcareous formation and Skallen upper calcareous formation, alternating with metabasites along with the quartz-feldspathic gneisses.

These rocks are almost similar in lithology to the quartz-feldspathic gneisses, except the predominance of quartz in the former. Garnet bearing-variety and garnet-free and biotite-bearing variety are again recognized in the siliceous gneisses as in the quartz-feldspathic gneisses.

3) Garnet-biotite gneiss

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* According to the percentage of colored minerals, the following classification is used in this report. Very leucocratic: 0-5%, leucocratic: 5-30%, mesocratic: 30-60%, melanocratic: 60-95%, very melanocratic: 95-100%.

** Division of the grain size is mainly based on that of TEUSCHER (1933): micro- (-0.1 mm), fine- (0.1-0.3 mm), small- (0.3-1 mm), medium- (1-3 mm), coarse- (3-10 mm), and very coarse- or centimeter- (10 mm-) grained.

*** Planer structures of the plutonic and metamorphic rocks distinguished in the present region are as follows, with their constituting unit in parentheses. Alternation (bed or layer): over meters thick; banding (band or thin layer): decimeters to centimeters thick; thin banding (lamina): millimeters thick, the continuation or extension of which being generally impossible to be traced over meters; foliation (folium): millimeters thick, being leaflike form; schistosity: generally less than millimeters thick, being composed of preferred orientation of inequant crystals.

A small amount of garnet-biotite gneiss was found in all the formations except Skallen brown gneiss formation. It is a thin (within some meters thick) layer intercalated between the siliceous or quartz-feldspathic gneisses and metabasites, sometimes grading into these rocks.

The gneiss is a leucocratic to mesocratic, coarse-grained, and equigranular rock composed of medium- to coarse-grained quartz, plagioclase, and K-feldspar, coarse- to centimeter-grained garnet, and fine-grained biotite. Very small amounts of opaque mineral and allanite were found. Biotite is scattered showing preferred orientation, exhibiting schistosity.

4) Porphyroblastic biotite-plagioclase rock

A small amount of porphyroblastic biotite-plagioclase rock was found in both the Skallen siliceous formation and Skallen lower calcareous formation. It is a thin concordant layer some tens of centimeters thick or a thin discordant body some tens of centimeters wide with an irregular boundary. Concordant metabasite is distributed in contact with the porphyroblastic biotite-plagioclase rock; at least a part of the metabasite is altered into this rock.

The rock is mesocratic, medium- to coarse-grained, and inequigranular, being composed of very coarse- and small-grained plagioclase and coarse-grained biotite. Small amounts of mirmekitic quartz and antiperthitic K-feldspar are associated. Very small amounts of opaque mineral, apatite, and/or zircon(?) are present in some specimens. Aggregates of plagioclase, which are very pale yellowish green, show a porphyroblastic form 20 mm in diameter; biotite is distributed between the porphyroblastic aggregates. Weak schistosity is shown by the elongation of the porphyroblastic aggregates, and by the lattice and dimensional preferred orientations of biotite.

3.2.2. Concordant metabasites

Concordant metabasites constitute a considerable portion of all the formations of the Skallen region, occurring as layers or bands intercalated with the paragneisses or brown gneisses. They are sometimes boudinaged, otherwise tightly folded between the gneisses. Small amounts of schlieric bodies of these rocks are also found in the garnet gneissose granite and brown gneissose granodiorite (Plate 2-b). These rocks are melanocratic rocks compared with the alternating rocks or country rocks, and hence they are easily distinguished in the field. The thickness of a band of these rocks is generally some meters, but exceptionally is some tens of meters. These rocks are mainly composed of pyroxene metabasite. Small amounts of hornblende metabasite and garnet metabasite were also found. Melanocratic rocks associated with marbles are considered to be skarns and hence are described in a later section.

1) Pyroxene metabasite

Pyroxene metabasite is developed abundantly in the Skallen siliceous formation and Skallen brown gneiss formation. It also occurs, though sparsely, in both of the calcareous formations, garnet gneissose granite, and charnockites. The rock is mesocratic, dark brownish to dark grayish, medium-grained (1 mm±), and equigranular,

being composed of plagioclase, rhombic and monoclinic pyroxenes, magnetite, biotite, and hornblende, all being equant except flaky biotite. Quartz occurs in a rare case. The total and relative amounts of mafic minerals are variable and some of them are sometimes absent. Very small amounts of apatite and zircon are associated.

The compositional banding (mafic-rich and mafic-poor bands) several millimeters thick is generally developed. Biotite is scattered and shows lattice and dimensional preferred orientations. Other mafic minerals often form clot, elongated parallel to the banding. Thus the rock presents schistose, foliated, and thinly banded structures, but these are not very conspiceous and apt to be overlooked, so the rock appears massive in the field.

2) Hornblende metabasite

Hornblende metabasite was found as a schlieric band in the biotite-hornblende brown gneissose granodiorite. Thin layers of this rock were also found associated with the metabasite-paragneiss alternations.

This metabasite is medium- to coarse-grained, mesocratic, dark gray to blackish, and equigranular for the schlieric band but inequigranular for those alternating with the paragneisses. The metabasite is composed of plagioclase and hornblende, generally associated with biotite and sometimes with quartz. Very small amounts of apatite and opaque mineral are associated. Hornblende and biotite show preferred orientation exhibiting schistosity, and, often, lineation. Compositional banding is absent. Some specimens of the metabasite have porphyroblastic texture due to aggregated plagioclase and grade into the porphyroblastic biotite-plagioclase rock.

3) Garnet metabasite

Garnet metabasite occurs as alternating bands with paragneisses and brown gneisses or as schlieric bands in the brown gneissose granodiorite. The metabasite is a small- to coarse-grained, inequigranular, massive, and melanocratic rock composed of monoclinic pyroxene, plagioclase, garnet, rhombic pyroxene, and hornblende. Small amounts of biotite, opaque mineral, and apatite are associated. Rhombic pyroxene is sometimes absent. In some varieties with rhombic pyroxene, garnet appears only in very thin mafic-poor laminae, and in other varieties with rhombic pyroxene, garnet appears in gray spots composed of symprectic rhombic pyroxene-plagioclase aggregates. The amount of garnet in the gray spot gradually decreases and finally disappears; the rock finally changes to pyroxene metabasite with gray spot. The last variety grades into the ordinary type of the pyroxene metabasite.

3.2.3. Quartzite

Quartzite occurs as alternating layers with metabasites in all the formations except the Skallen brown gneiss formation. Thickness of a unit layer ranges from some meters to over ten meters. The petrographic characteristics of this rock are similar to those of some of the siliceous gneisses, and the distinction between the two types in the field is rather arbitrary. A part of the siliceous gneiss layer,

in which mafic and feldspar minerals are extraordinarily rare, is quite similar in appearance to the quartzite in a hand specimen. The terminology of a layer, as siliceous gneiss or quartzite in the field, depends on the relative amounts of quartzite and siliceous gneiss in the layer.

The quartzite is a very leucocratic, white, coarse-grained, equigranular, and massive rock, composed chiefly of quartz with very small amounts of other minerals such as feldspars and biotite. Sillimanite was found in one specimen. Thin (1 mm or less) lamina rich in biotite or sillimanite was sometimes found; the lamina is parallel to the alternation structure, the crenulation and mineral lineations being generally associated with this thin banding. Quartz is generally equigranular and equant, but extremely coarse-grained aggregates of quartz are found in some specimens, forming patches 10×50 mm in size. Quartzite, occurring in the Skallen lower calcareous formation in the northern part of Skallen, is very coarse-grained (several tens of millimeters) and looks like quartz pegmatite. Some of this very coarse-grained type intrude into the surrounding quartzite-metabasite alternations.

3.2.4. Marbles

Marbles constitute a considerable part of the two calcareous formations. Two layers over some meters thick occur in the Skallen upper calcareous formation while three or four layers from some meters to several tens of meters thick occur in the Skallen lower calcareous formation. The layers are generally associated with the skarn and allied rocks. Intrusive appearance of marbles into other plutonic and metamorphic rocks was observed in many places. Migmatitic appearance with xenolithic blocks of surrounding rocks, the blocks being margined by a reaction rim, is not unusual. The marbles are classified into pure marble and marbles with scattered colored minerals, both being variable in mineral assemblages.

1) Pure marble

Pure marble constitutes a main part of the marble layers. The rock is very leucocratic, very white, coarse- to very coarse-grained, and equigranular, being composed mostly of equant calcite. Very small amounts of small-grained phlogopite, spinel, and/or graphite occur as rare cases.

2) Marbles with scattered colored minerals

Marbles with scattered colored minerals occur as marginal parts of a marble layer, as small lenticular bodies intercalating with other rocks, or as irregular intrusive bodies often with altered xenolithic blocks of other rocks.

These rocks are very leucocratic, white with scattered colored minerals, coarse-grained, and equigranular, being composed of calcite, forsterite, phlogopite, dolomite, graphite, spinel, monoclinic pyroxene, and amphibole. Serpentine is generally associated with forsterite. All these minerals except calcite are small in amount and variable in both total and relative amounts. All the minerals do not coexist in a hand specimen: some of the colored minerals are scattered, but indistinct compositional bandings, some centimeters to tens of centimeters thick, being rich and poor in these minerals, were sometimes found.

3.2.5. Skarn and allied rocks

Various kinds of ultramafic to mafic rocks with extraordinary compositions are distributed in both of the calcareous formations alternating or being randomly mixed with the marbles. They are pyroxene rocks and phlogopite rocks.

1) Pyroxene rocks

Two kinds of pyroxene rocks were discovered, *viz.*, massive pyroxene rock and banded pyroxene rock.

Massive pyroxene rock occurs in a form of thin (some centimeters to some tens of centimeters thick) vein or dike in the other rocks in the marble-skarn zone. Similar dike-like masses, sporadically occurring outside of the marble-skarn zone, may belong to this rock. This rock is green, or green and black, coarse- or very coarse-grained, and equigranular, being composed of equant diopside with minor amount of biotite and amphibole. Very small amounts of scapolite and anorthite(?) were sometimes found.

Banded pyroxene rock was found in the southern margin of the zone of the Skallen lower calcareous formation distributed in the northern part of Skallen. The rock occurs as augen-shaped bodies some meters × ten meters in the skarn zone. This rock is blackish and dark grayish, thinly (several cm thick) banded, coarse-grained, and equigranular, composed of monoclinic pyroxene and amphibole with a monor amount of biotite.

2) Phlogopite rocks

Phlogopite rocks generally occur as small sized (some tens of centimeters to some meters in diameter) irregular xenolithic blocks in the marble-skarn zone. These rocks are characterized by predominance of golden brown phlogopite, light gray scapolite, and amphibole. Monoclinic pyroxene is often associated. This rock is coarse- or very coarse-grained and inequigranular, showing neither schistosity nor foliation. Compositional banding parallel to the margin of the xenolithic block is developed.

3.2.6. Garnet gneissose granite

Garnet gneissose granite occurs as a concordant sheet-formed mass from ten to several tens of meters thick, running macroscopically parallel to the other members of the Lützow-Holm Bay System. In detail, however, paragneiss-metabasite alternations are altered into the garnet gneissose granite ; palimpsestic minorfolding structure was observed. A large-sized mass of the garnet gneissose granite generally occurs in contact with the brown gneissose granodiorite, surrounding the latter. Brown gneissose granodiorite is generally parallel but sometimes discordant to the mass of the garnet gneissose granite. Layers of the garnet gneissose granite were sometimes found being cut by the brown gneissose granodiorite. The petrographic features of the garnet gneissose granite are similar to those of the quartz-feldspathic garnet gneiss. In most cases, the quartz-feldspathic garnet gneiss is undistinguishable from the garnet gneissose granite in a hand specimen; the latter forms a thick layer lacking alternating metabasites, and often presents palimpsestic structures. Pools or veins of pink granites are pre-

ferentially found in the garnet gneissose granite.

The garnet gneissose granite is a very leucocratic, white but sometimes pinkish, medium- to very coarse-grained, and inequigranular rock composed of medium-grained K-feldspar and plagioclase, medium- to very coarse-grained quartz, small-, medium-, or coarse-grained garnet, and fine-grained biotite. The total and relative amounts of mafic minerals are variable; either of the mafic minerals is sometimes absent. Very small amounts of apatite, zircon, and sericite are also present. Thin (several cm thick) pools of pink granitic rock are developed in some of the garnet gneissose granite, giving a pinkish tint to the rock. Thin (some millimeters to some centimeters) folia or laminae rich in biotite are often developed, showing foliation or thin banding. In some outcrops, quartz and K-feldspar form augens.

3.2.7. Charnockites

Charnockites are one of the main rock types in the present region; they occupy one-half to one-eighth of the total thickness of the basement rocks. Brown gneissose granodiorites and brown gneisses are the two main groups of the charnockites, although the brown gneisses are shown as members of each formations in the geological map.

1) Brown gneissose granodiorite

Brown gneissose granodiorite forms a sheet-like mass, generally from some tens to several hundreds of meters thick. Five masses of this rock were found, in the middle part of the Skallen lower calcareous formation, in the lowermost horizon of the Skallen siliceous formation, in the middle part of the Skallen siliceous formation, in the Skallen upper calcareous formation, and between the Skallen brown gneiss formation and the Skallen siliceous formation. Paragneiss-metabasite alternations, and sometimes, garnet gneissose granite, generally grade into, or are cut by, the brown gneissose granodiorite. Foliation of this rock is generally gentle and shows little sign of disturbance by minorfoldings, which was commonly observed in the paragneiss-metabasite alternations. At the eastern piedmont of the 108.6 m peak in the northern part of Skallen, intensely folded (rootless-type) brown gneiss-metabasite alternations are clearly cut by the brown gneissose granodiorite with a very low angle (gentle) boundary plane.

The brown gneissose granodiorite is a very leucocratic, brownish or yellow-greenish, small- to coarse-grained (most of the constituents are medium-grained), and inequigranular rock composed of medium- to coarse-grained K-feldspar, plagioclase, and quartz, small-grained biotite, small- to medium-grained rhombic and monoclinic pyroxenes and garnet, and medium-grained hornblende. Very small amounts of apatite, zircon, chlorite, sericite, and opaque mineral are also present. K-feldspar generally predominates over plagioclase. The relative amount of mafic minerals is variable and some of them are sometimes absent; hence two main varieties of the brown gneissose granodiorite are hypersthene- and/or garnet-bearing variety and biotite-hornblende variety. The latter is somewhat coarser-grained than the former. A small amount of coarse-grained phenocrystic

K-feldspar is sometimes present. Thin folia (1×several mm) or laminae (1×some to tens of mm) rich in biotite are generally developed, with about an interval of 10 millimeters; hence the rock is foliated or thinly banded, although not very distinct due to the dark color of the salic minerals.

2) Brown gneisses

The brown gneisses constitute main part of the Skallen brown gneiss formation. The gneisses also occur in the Skallen lower calcareous formation throughout the Skallen region. The rocks are generally alternated with pyroxene metabasite, and are sometimes thinly banded with pink granitic gneiss. Intense minorfold was often observed (Plate 2-c).

The brown gneisses are generally very leucocratic, light brownish, small- to medium-grained, and somewhat equigranular rocks composeds of small- to coarse-grained K-feldspar, plagioclase, and quartz, and small-grained biotite and garnet. Small- to medium-grained hornblende and rhombic pyroxene are sometimes present. Very small amounts of zircon, apatite, chlorite, and sericite are associated. Quartz and feldspars are generally equant, but in some specimen, some quartzes are elongated and some feldspars are phenocrystic. Very thin folia or laminae composed of aggregates of mafic minerals are generally developed showing foliation or thin banding structures.

3.2.8. Pink granites

Small masses of the pink gneissose granite and pink pegmatite occur sporadically in the Skallen region. Very small dikes or pools of gneissic, granitic, aplitic, or pegmatitic varieties of the pink granites are well developed throughout the region. In many cases, the rocks occur as crosscutting veins or as pools parallel to the foliation of the country rock. Rootless pools are also very common. Alternating bands from some centimeters to tens of centimeters thick were also often found. The crosscutting veins are often aplitic or pegmatitic and the former has schistosity parallel to the wall of the veins. The permeating or rootless pools are gneissic, granitic, or pegmatitic, and the alternating bands are generally gneissic or granitic. Metabasites, which contact with or occur near the pink granites, are generally hornblende or garnet metabasites.

The pink granites are very leucocratic, pinkish, small-, medium-, coarse-, or very coarse-grained rock composed of K-feldspar, quartz, plagioclase, and biotite, with or without garnet. Very small amounts of apatite, zircon, sphene, opaque mineral, sericite, and chlorite are associated. Biotite is fine-grained and scattered in the aplitic variety, and aggregated in folia or laminae in the gneissic variety. Quartz is generally small- or medium-grained and equigranular, aggregating with feldspars; but in some gneissic variety, some quartzes are coarse- or very coarse-grained and elongated. Some of the pegmatitic varieties occurring in the northern part of Skallen carry euxenite, the U-Pb dating of the euxenite and Rb-Sr dating of biotite from the pegmatite being already reported (NICOLAYSEN *et al.*, 1961; SAITO *et al.*, 1961).

3.2.9. Minor intrusives

Very small amounts of intrusive rocks occur sporadically in the present region. They are discordant metabasite, brown microgranite, and pegmatites. Monoclinic pyroxene rocks occurring in dike-forms are considered to be the skarn and allied rocks and described in the foregoing section.

1) Discordant metabasite

Discordant metabasite occurs in the southern part of Skallen. It is a small dike 50×300 meters in size cutting the paragneiss-metabasite alternations of the Skallen siliceous formation. The form of the dike is very simple and the boundary is smooth. Indistinct thin banding parallel to that of the country rock is developed in the dike. The thin banding is folded in minor-scale, the style of the fold and the trend of the axis being similar to those of the country rock.

The discordant metabasite is a mesocratic, dark gray with brownish tint, small-grained, and equigranular rock composed of plagioclase, rhombic and monoclinic pyroxenes, hornblende, biotite, and opaque mineral. A small amount of elongated clot of biotite is scattered showing schistosity.

2) Brown microgranite

Two small dikes of the brown microgranite were found, one in the brown gneissose granodiorite at the southern marginal part of the northern part of Skallen, and the other in the garnet gneissose granite in west of Skallevikhalsen. The boundary of the dikes is not a smooth plane but is well recognized due to the distinct difference in grain size or in color. The brown gneissose granodiorite intruded by this dike is coarser-grained type without hypersthene and garnet, although these minerals occur in this country rock several tens of centimeters apart from the boundary.

The brown microgranite is a very leucocratic, light brownish, small- to medium-grained, and equigranular rock composed of small- to medium-grained K-feldspar, plagioclase, and quartz, and fine- to small-grained biotite. Very small amounts of apatite, chlorite, sericite, and carbonate mineral are also present. The scattered biotite is somewhat preferentially orientated showing an indistinct schistosity which is parallel to the schistosity of the country rock but is inclined from the boundary of the dike.

3) Pegmatites

Very small and irregular bodies of various pegmatites were found throughout the region. They are white pegmatite, brown pegmatite, and pink pegmatite; the last rock is one of the main rock types of the pink granites, and was already mentioned in that section.

The white pegmatite is well developed in various sizes and different forms, and may comprise several kinds of pegmatites; biotite pegmatites occur as small masses, hundreds of meters in size, intruding the Skallen lower calcareous formation, siliceous pegmatite is found grading into the quartzite of the Skallen lower calcareous formation as already mentioned, quartz-feldspathic pegmatite occurs in marble-skarn zone, and some other pegmatites occur as irregular and very small masses. Some of the biotite pegmatites clearly cut the other rocks. In the

eastern part of Skallevikhalsen, a pink aplitic granite vein was found being cut by a white pegmatite with biotite.

Two small irregular masses of the brown pegmatite were found; one in the southern part of Skallen, intruding the quartzite-metabasite alternation, associated with the (brown ?) microgranite, and the other in the brown gneissose granodiorite in the western part of Skallevikhalsen. The petrographic features of this rock are similar to those of the white pegmatite except the light yellow-greenish color of feldspars.

Table 3. Chemical composition of rocks from the Skallen region.

	1	2	3	4	5	6	7	8	9	10	11
SiO_2	71.97	73.03	63.74	47.96	69.79	55.71	79.63	74.77	45.32	68.97	73.23
TiO_2	0.43	0.34	0.87	0.87	0.85	1.39	0.28	0.26	3.59	0.38	0.26
Al_2O_3	14.03	13.86	22.29	13.52	12.54	16.47	10.77	13.25	15.28	15.78	14.61
Fe_2O_3	1.29	0.81	2.46	7.67	2.10	2.00	1.82	1.01	4.68	0.21	0.72
FeO	1.60	1.61	3.60	6.87	3.25	5.80	0.56	0.80	10.21	2.68	1.14
MnO	0.08	0.09	0.15	0.40	0.16	0.28	0.15	0.07	0.41	0.12	0.09
MgO	0.53	0.44	1.65	11.99	0.93	0.95	0.35	0.32	6.27	1.00	0.50
CaO	1.73	1.38	0.55	8.26	2.62	5.44	1.38	0.81	8.58	1.76	0.76
Na_2O	2.75	2.53	0.92	1.52	2.51	3.62	3.14	2.43	2.97	3.33	2.94
K_2O	5.28	5.08	3.77	0.65	3.76	6.33	1.99	6.22	1.11	4.33	5.11
H_2O+	0.40	0.38	0.32	0.40	0.61	1.05	0.14	0.31	1.22	0.76	0.59
H_2O-	0.02	0.10	0.02	0.01	0.07	0.29	0.05	0.05	0.08	0.24	0.21
P_2O_5	0.26	0.21	0.06	0.15	0.38	0.62	0.22	0.20	0.84	0.13	0.11
Total	100.34	99.86	100.00	100.27	99.57	99.95	100.48	100.50	100.56	99.69	100.27

No. 1. Brown gneiss (Garnet biotite brown gneiss), Y70020520, Analyst, S. KANISAWA.
2. Paragneiss (Quartz-feldspathic biotite-garnet gneiss), Y70020505, Analyst, S. KANISAWA.
3. Paragneiss (Quartz-feldspathic sillimanite gneiss), Y69020618C, Analyst, S. KANISAWA.
4. Concordant metabasite (Pyroxene metabasite), Y69020307, Analyst, S. KANISAWA.
5. Brown gneissose granodiorite (Hypersthene bearing), Y69020309A, Analyst, S. KANISAWA.
6. Brown gneissose granodiorite (Garnet and hypersthene bearing), Y70020603, Analyst, S. KANISAWA.
7. Garnet gneissose granite (Paragneiss-like facies), Y70020508, Analyst, S. KANISAWA.
8. Garnet gneissose granite (Ordinary facies), Y70020617, Analyst, S. KANISAWA.
9. Discordant metabasite, Y69020303, Analyst, S. KANISAWA.
10. Garnet gneissose granite, JARE57102715, BANNO, *et al.*, 1964.
11. Pink granite, JARE57102624, BANNO *et al.*, 1964.

3.3. Geologic structure

Many types of folds and fractures were found in the Skallen region. An overturned synform with ENE axis in Skallevikhalsen is considered to be an overturned recumbent anticline (nappe ?), and hence is doubling the stratigraphy

Table 4. Chemical composition of minerals in rocks from the Skallen region.

	1	2	3	4		5		6	
SiO_2	32.59	36.76	43.30	Fe_2O_3	0.04	Al_2O_3	69.28	MnO	0.05
TiO_2	3.13	4.72	0.32	FeO	0.36	Fe_2O_3	tr	Fe_2O_3	1.07
Al_2O_3	15.39	13.46	13.22	MnO	tr	Cr_2O_3	0.08_2	MgO	0.22
Fe_2O_3	5.81	4.52	1.06	CaO	55.05	FeO	3.35	CaO	0.64
FeO	19.58	19.51	1.26	MgO	0.43	MnO	0.10	Ce_2O_3	0.38
MnO	0.02	0.03	0.04	Na_2O	0.05	MgO	23.78	Y_2O_3	25.26
MgO	12.06	9.31	20.23	K_2O	0.01	ZnO	3.09	PbO	0.92
CaO	tr	0.00	12.79	P_2O_5	41.58	CoO	0.05_1	ThO_2	3.20
Na_2O	0.32	0.26	2.88	H_2O+	0.74	NiO	0.009_3	UO_2	11.49
K_2O	6.54	8.25	0.82	H_2O-	0.01	SiO_2	0.11	UO_3	0.64
H_2O+	3.39	2.79	2.79	Cl	1.95			$(Nb,Ta)_2O_5$	30.76
H_2O-	0.61	0.41	0.10	F	0.854			TiO_2	24.74
P_2O_5			0.05		101.07_4			SiO_2	0.33
			F 0.90	O≡2F	0.36			SnO_2	0.11
			99.76	O≡2Cl	0.44			H_2O+	0.23
			O≡2F 0.38						
Total	99.44	100.02	99.38		100.27_4		99.85		100.04

No. 1. Biotite in pink granite, JARE57102624, BANNO *et al.*, 1964.
2. Biotite in garnet gneissose granite, JARE57102715, BANNO *et al.*, 1964.
3. Hornblende in skarn, JARE57102707, SUWA, 1968.
4. Apatite in marble, JARE57102709B, part of the data are given by SUWA, 1968. The full data are presented by SUWA through the courtesy of him. Analysts: K. WATANABE (all components except Cl and F) and F. HONDA (F and Cl).
5. Spinel in marble, JARE57102734, SUWA and TATSUMI, 1969.
6. Euxenite in pink granite, JARE57102623, HAYASHI and NAGASHIMA, 1961.

of the present region. A recumbent anticline of smaller scale was found on the northern slope of Himiyama Peak in the southern part of Skallen. An overturned synform developed in the northwest of Osiage Beach is also considered to be a recumbent anticline. An axis gently and easterly plunged isoclinal synform with its axial plane trending east and dipping north was found at Kado Point, Skallen. An isoclinal antiform with its axial plane dipping gently north is considered to run along the Skallen lower calcareous formation in its middle zone in the northern part of Skallen. These isoclinal folds run throughout the Skallen district. Open to gentle folds with steep axial planes and wavelength being several hundreds of meters are developed near the 186.2 m peak in the northern part of Skallen, near Lake Skallen Ôike, near the 128.1 m peak in the southern part of Skallen, northeastern and northwestern shores of Skallevikhalsen, and at Hjartöy island. Most of the axes of these folds gently plunge east, except those westerly ones in the southern part of Skallen. Gentle folds with almost horizontal axis, vertical axial plane, and with wavelength over

several kilometers were found in the west of Osiage Beach in the northern part of Skallen, near the 128.1 m peak in the southern part of Skallen, and at the Hjartöy island.

Minorfolds of various forms and orientations are well developed throughout the Skallen region. Their orientations are either parallel or discordant to the above-mentioned folds, among which those parallel to the open to gentle type are dominant although the form of the minorfolds are of close to open types. Other minorfolds, generally comprising tight to close types, have fold axes generally different from any axes of the macroscopic folds mentioned above. Microfold lineation of the similar features were sometimes observed. Banding, foliation, and/or schistosity structures of the plutonic and metamorphic rocks suffered tectonic disturbances. Banding structure is affected by the minorfoldings of various types. Foliation and schistosity often cut the banding as well as some of the minorfolds. Crenulation and mineral lineations, with gentle east or west plunges being nearly parallel to the axis of the minorfolds of the close to open type, are well developed in association with these planer structures. Microfold lineations of the similar trend were also sometimes observed. All the mesoscopic and macroscopic structures of the Skallen region mentioned above are the earlier stage tectonics. These structures of the earlier stage may comprise some different periods of events. But a chronological discussion of the tectonics is not the purpose of this text.

A NE open synform with wavelength over 4 km, in the north of the 128.1 m peak in the southern part of Skallen is the later stage tectonics. Small NW folds disturbing the earlier folds are developed on the northern slope of the 141 m peak in the northern part of Skallen. Open, gentle, and kink minorfolds with NE or NW trend were often found cutting the earlier folds or lineations.

Diagonal set of vertical fractures of NE and NW directions with E-W dihedral angle of 40°-60° is well developed throughout the region. The fractures run straight and are shown by lineages in aerial photographs as continuations of depressions or cliffs. Small dislocations by these fractures were sometimes observed, but they are not so great and were often overlooked in the field. Neither intrusion of rocks nor any other igneous or metamorphic effect was observed along these fractures. The trend of the fractures is generally constant throughout the region, regardless of any folding structures; hence these fractures are the latest tectonics of the Skallen region.

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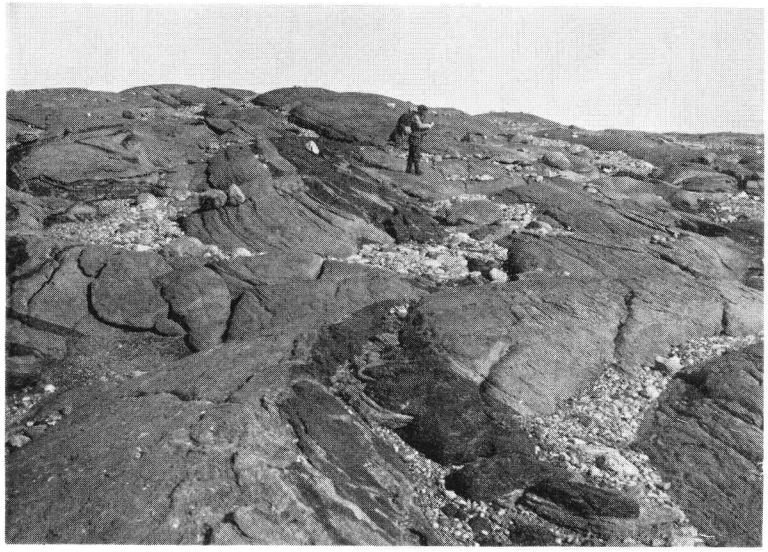
a. Aerial photograph, southern part of Skallen and eastern part of Skallevikhalsen. JARE Antarctic air photo, 6AV 1-2, No. 682.

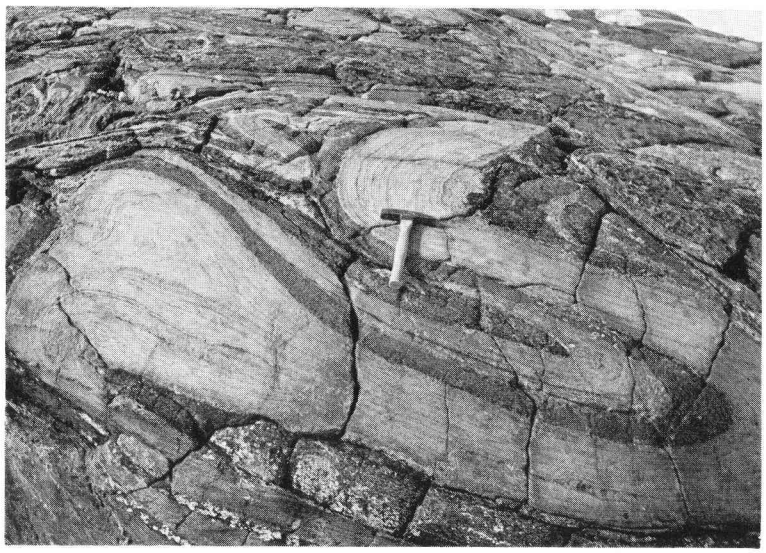
b. Northeastern cliff of Skallevikhalsen, viewed from the southern part of Skallen.

Plate 2

a. Paragneiss and metabasite alternation, south of Lake Skallen Ôike.



b. Brown gneissose granodiorite with schlieric metabasite.



c. Intense folding developea in the brown gneiss layer, north of 108.6 meter peak, northern part of Skallen.

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