Abstract

Results of the field surveys in the Skallen region during 1969–1970 are summarized with descriptions of stratigraphy and considerations on geotectonic history of the region. Field and aerial photographs, route maps, and field descriptions are also given.

Basement rocks of the Skallen region are metamorphic rocks consisting of paragneisses, brown gneisses, marble, quartzite, and metabasite, and plutonic rocks consisting of charnockitic rocks, garnet gneissose granite, and pink granites. The metamorphic rocks comprise four stratigraphic units, namely, Skallen brown gneiss formation, Skallen lower calcareous formation, Skallen siliceous formation, and Skallen upper calcareous formation, in ascending order. These formations belong to the Skallen group, the total thickness of which, including most of the intercalated plutonic rocks which are transformed *in situ* from the metamorphites, is over 1500 meters. All the formations are conformable to each other, except the lowermost Skallen brown gneiss formation which is tectonically separated from other formations. The fundamental geologic structure of the region is nappe and associated isoclinal folds with gently and easterly plunging axes and axial planes dipping north; hence a part of the stratigraphic column of the present region is doubled. Some other folds or fractures were found, being overprinted by or superposing on the main nappe structure.

The geotectonic history of the Skallen region is as follows from older to younger: moderately plunging recumbent anticline (nappe)—easterly and gently plunging recumbent anticline (nappe)—east-northeasterly or west-southwesterly and gently plunging open folding—east-southeasterly plunging minor folding—easterly gentle folding and northeasterly open synform—conjugate set of west-northwesterly and northeasterly fractures. The change of stress field from older N-S compressional to younger E-W compressional is estimated. A granulite facies metamorphism resulting in the formation of the metamorphites is considered to be synchronous with both or either of the recumbent anticlines, a dynamic metamorphism to take place during the earlier nappe, formation of charnockite to be synchronous with or slightly later than the subhorizontal recumbent anticline and partly to prolong

until the completion of the plunging open folding, intrusion of pink granites, which indicate amphibolite facies conditions and the radiometric age of which is already obtained as about 500 m.y., to be around the stage of the gentle folding. Neither metamorphic nor plutonic effect was found in relation to the fractures.

1. Introduction

The Skallen region is one of the wide ice-free terrains on the east coast of Lützow-Holmbukta, east Antarctica, lying about 70 km south of Syowa Kiti (Station). The region consists of three small ice-free areas, *viz.*, Skallen, Skallevikhalsen, and Hjartøy. The areal extension of the region is about 20 km^2.

This region was first mapped by HANSEN (1946) based on the oblique aerial photographs taken by CHRISTENSEN (in his 1937 expedition). The first landing on the region was made by Japanese scientists (TATSUMI, 1958) including a geologist, and the outline of the geology was given (TATSUMI and KIKUCHI, 1959; TATSUMI *et al.*, 1964; TATSUMI and KIZAKI, 1969). Since then, rock specimens collected by them have been investigated in some laboratories (HAYASHI and NAGASHIMA, 1961; NICOLAYSEN *et al.*, 1961; SAITO *et al.*, 1961; BANNO *et al.*, 1964 a, b; SUWA, 1968; SUWA and TATSUMI, 1969).

In 1969 and 1970, the present author had a chance to survey the region with H. ANDO. The operation and the results of the survey were briefly reported (MURAKOSHI, 1969; YOSHIDA, M., 1970; KUSUNOKI, 1971; YOSHIDA and ANDO, 1971). The recently published geologic map of the Skallen region with an explanatory text (YOSHIDA *et al.*, 1976) gives somewhat detailed geology and descriptions of rock types based mainly on the results of the surveys in 1969–1970. The present article may provide further data and considerations. The original field data of these surveys are also given in this article as appendix. Tectonics and petrography of the region will be reported separately in future.

2. Operation of the Survery

The first survey of the Skallen region by H. ANDO and the present author was made from February 3 to 6, 1969 with the biologic, geomorphologic, and glaciologic investigators of the 9th and 10th Japanese Antarctic Research Expeditions 1967–70 (JARE-9 and -10). The transportation was made by the Sykorsky S-61A helicopter, which easily landed the flat surface of bedrocks on the southwestern side of the Skallen Ôike (lake), this place provide to be a comfortable campsite during the field survey. The second survey was made on October 2, 1969 by H. ANDO and the present author on their way back to Syowa Kiti from the Shirase Hyôga (glacier) by the Komatsu KC20 oversnow vehicle during the geological and glaciological expeditions of the wintering team of the JARE-10. The sea ice was hard enough around the Skallen and between Skallevikhalsen and Hjartøy so that extensive surveys were possible. The third survey was made in Skallevikhalsen from February 4 to 6, 1970 by the present author as a joint work of JARE-10 and -11. The Sykorsky S-61A helicopter was able to land the snow field at the southern periphery of the eastern part of Skallevikhalsen. All these surveys were assisted by the logistic members of the Japanese Antarctic Research Expeditions and the transportation for the summer operations was assisted by the crew of icebreaker FUJI.

The duration of the geological survey in the field is 13 man-days. Aerial photographs were utilized in the laboratory work during and after the wintering; such photographs are very useful for analyzing geologic structure of this region because of distinct differences in color among different geologic bodies (Plates 1–6). Route maps made during the field surveys are presented in appendix. Rock specimens collected during these surveys amounted to 113 pieces and 230 kg. These specimens are in the custody of the present author.

3. Geomorphology and General Geology

Skallen is a somewhat equidimensional area about 5 km in diameter and maximum height 186 m. The area is surrounded by sea, except its southern margin which meets the continental ice sheet. The area is a gentle lowland with undulations of some hundreds of meters in wavelength, the axis of the undulations running east, being generally parallel to the main geologic structure. Two distinct depressions with an easterly trend, one running along the Skallen thrust and the other containing Skallen Ôike, divide the Skallen area into three subareas, northern, central, and southern (Plates 1b, 7–8). Skallevikhalsen is an EEN elongated area about 2 km in width and 7 km in length. The area is a precipitous slope between the continental ice sheet in the south and Lützow-Holmbukta in the north, the highest peak being 277 m. Undulated and stepped landform subparallel to the general trend of the geologic structure is characteristic of this area. A distinct depression with a northeasterly trend containing Dairi Ike (lake) divides this area into western and eastern parts of Skallevikhalsen (cf. Plate 1a, c). A small inlet, Skallevika, about 1 km in width, lies between Skallen and Skallevikhalsen, with an outlet glacier at the southern end of the inlet. Hjartøy is a small, heart-shaped island. This island has the highest peak of 100 m at the northern side, with a steep cliff on its north slope facing the sea and with the gentle south slope.

The bedrocks of the Skallen region are all scoured by formerly glaciation and the morainic deposits or erratics are sporadically found throughout the region. In places lower than 25 m in altitude, elevated beach deposits were found (YOSHIDA, Y., 1970; YOSHIDA *et al.*, 1976). Many small and shallow ponds often with thick moss were found throughout this region. The C-14 concentration of lake water of Skallen Ôike was made being $+253 \sim +278$‰ (OMOTO, 1972). Cirque-like embayments with a steep cliff were found at the northern sides of Skallen and Skallevikhalsen (Plate 9). The bedrocks are hard and fresh throughout the region except in the marble-skarn zones of the calcareous formations. Glacial striae were often observed generally trending NW. Congelifraction and stone nets were often found suggesting the present periglacial climatic conditions. Honeycomb structure of rocks was found on the shore of Skallen (Plate 10). The continental ice sheet on the south-

ern side of this region is almost stagnant. The surface flow of the small outlet glacier flowing down to Skallevika was 4 m per year on the average (AGETA and NARUSE, 1971).

The geologic map and profile of the region are presented in Figs. 1 and 2. The crystalline basement rocks comprise four formations, *viz.*, from bottom upwards, Skallen brown gneiss formation, Skallen lower calcareous formation, Skallen siliceous formation, and Skallen upper calcareous formation; these four formations constitute the Skallen group which is an important part of the Lützow-Holm Bay System designated by TATSUMI and KIZAKI (1969).

The lithology of the formations is characterized by metamorphic rocks which suffered plutonic metamorphism, *viz.*, paragneisses, brown gneisses, concordant metabasites, marbles, quartzite, and others. These rocks correspond to the gneisses and metabasites described by YOSHIDA and ANDO (1971) and include many of the metamorphic rocks already described by TATSUMI *et al.* (1964) and BANNO *et al.* (1964a). Most of these rocks have been considered to belong to the granulite facies (*e. g.*, BANNO *et al.*, 1964 a, b; SUWA, 1968). Plutonic rocks (garnet granite, charnockite, and pink granites) and minor intrusives (discordant metabasite, biotite microgranite, and pegmatites) are also developed. Summarized stratigraphy and lithology of the region are presented in Table 1. Petrographic characteristics of the basement rocks are described in other publications (YOSHIDA *et al.*, 1976; YOSHIDA, in preparation). These basement rocks are generally gently or moderately inclined north or south with an east trend. Complicated and superposed folds, however, are developed throughout the region as will be mentioned in a later chapter.

Table 1. Stratigraphy of the Skallen region.

	Formations (thickness)	Lithology
Skallen group	Skallen upper calcareous formation (400 m+)	Marbles, skarn and allied rocks, feldspathic garnet gneiss, siliceous gneisses, and metabasites with a charnockite mass (200 m+ thick) in the upper horizon.
	Skallen siliceous formation (620 m)	Alternation of paragneisses and metabasites with a charnockite-garnet granite mass (220–80 m thick) in the middle horizon and another charnockite-garnet granite mass (170–0 m thick) in the lowermost horizon.
	Skallen lower calcareous formation (400 m+)	Marbles, skarn and allied rocks with minor feldspathic garnet gneiss in the upper horizon, brown gneisses and siliceous gneisses with few metabasites and skarn and allied rocks in the lower horizon with a charnockite-garnet granite mass (360–50 m thick) in the lower horizon.
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	Skallen brown gneiss formation (175 m+)	Brown gneiss-metabasite alternations, more or less affected by migmatization of pink granites, with a pink gneissose granite mass (30 m thick) in the upper horizon.

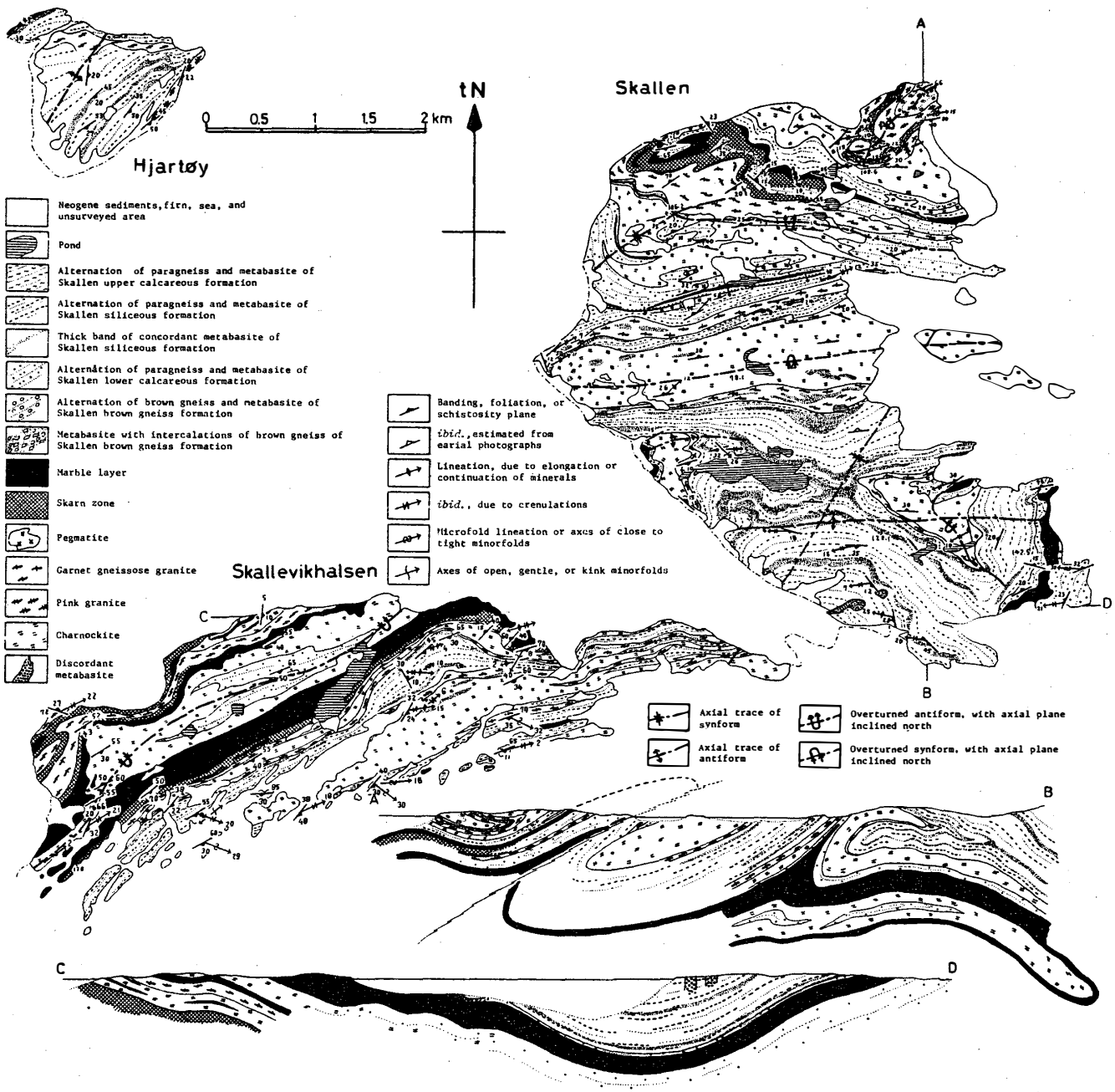

Fig. 1. Geologic map of Skallen.

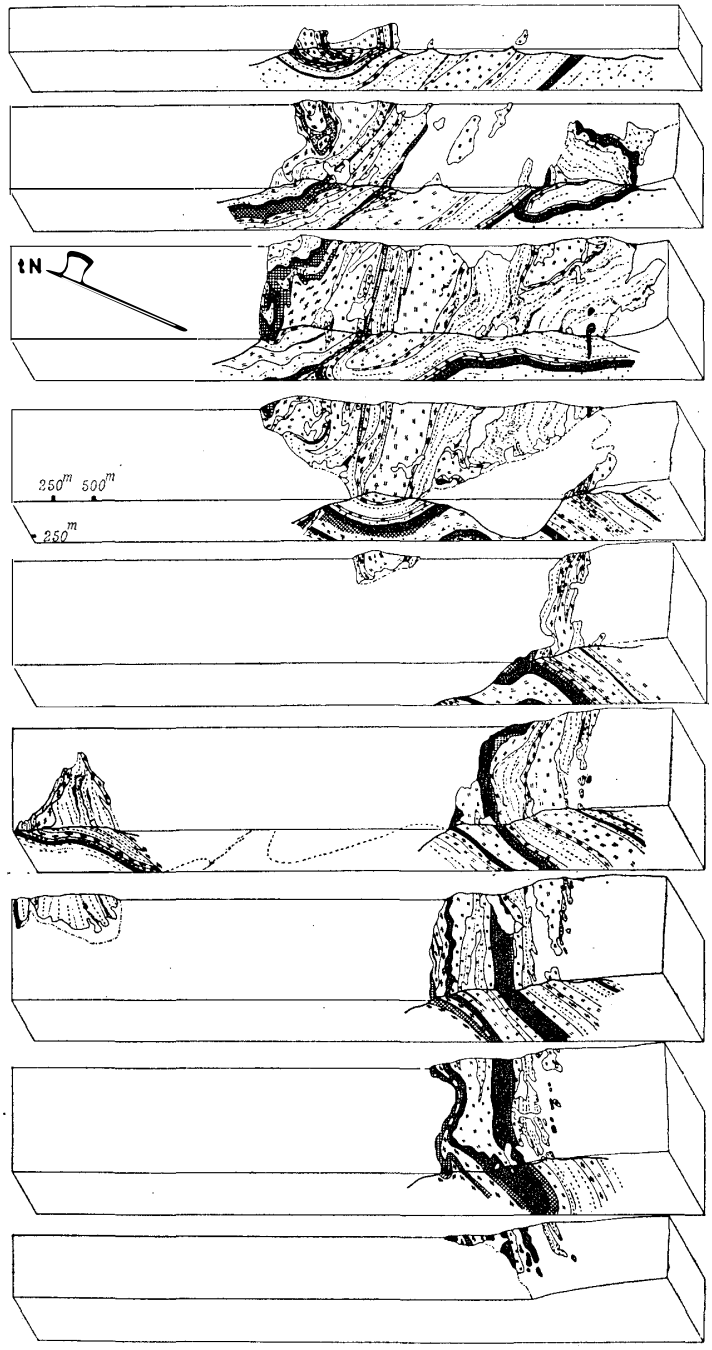

Fig. 2. Block diagram of the Skallen region, scale vertical: horizontal is equal. Symbols of the geologic bodies are same as those of Fig. 1.

4. Stratigraphy

4. 1. Skallen brown gneiss formation

The Skallen brown gneiss formation is typically developed in the northeastern peninsular in the northern part of Skallen. This formation is composed of brown gneiss (originated from siliceous and quartz-feldspathic gneisses) -metabasite alternations and metabasite layers intercalated with a minor amount of brown gneisses. Acid part of the alternation is generally reddish or brownish. This is mainly because of the colored salic minerals and partly of the characteristic weathering. This formation comprises an overturned synform with a northeasterly moderately plunging axis, and intense minorfolds were often found in the field (Plates 11–12). A sheet-like mass of pink gneissose granite 30 m thick is intercalated in the upper horizon.

The upper and lower limit of this formation is unclear. The overturned synform structure of this formation is considered to be an overturned recumbent anticline (nappe?*). The uppermost horizon of the formation, *i. e.*, the outermost margin of the "nappe", is discordantly cut by a charnockite mass probably belonging to the Skallen siliceous formation (Plate 12b). The lower horizon may continue into sea northeastward occupying the core of the "nappe". The thickness of the formation is more than 175 m, including** a mass of the pink gneissose granite.

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* Because the intense folding prior to the charnockite formation is well developed in the Skallen brown gneiss formation, the formation is considered stratigraphically lowest. It is, therefore, still possible that all the intense foldings are ascribed to local phenomena and that the stratigraphic position of the Skallen brown gneiss formation is invalid. If the plunging recumbent anticline is regarded as a degitation of the main nappe (subhorizontal recumbent anticline, cf. p. 14) of the Skallen region, and if no tectonic separation exists at the frontal zone of the digitation, rocks now designated as Skallen brown gneiss formation may belong to the Skallen siliceous formation.

** The plutonic rocks except some of the pink granites are considered to have been derived nearly *in situ* from the metamorphites. Hence the thickness of these plutonic rocks may well be included in the thickness of each formation.

4. 2. Skallen lower calcareous formation

The Skallen lower calcaleous formation is typically developed in the western part of Skallevikhalsen and in the northern part of Skallen. Minor developments of this formation are also recognized in the northwest of Skallen Ôike, the central part of Skallen, and around Magoke Misaki (point), the southern part of Skallen.

This formation is composed of brown gneiss (probably derived from garnet-biotite gneiss, siliceous gneisses, and quartz-feldspathic gneisses) -concordant metabasite alternations, quartzite (most of which is very coarse-grained and often mobilized as a pegmatitic rock) -metabasite alternations, marbles (a part of these rocks shows intrusive occurrence to the surrounding rocks), skarn and allied rocks, and quartz-feldspathic gneisses from bottom upwards. The area where this formation is distributed is characterized by somewhat weathered topography and bad outcrops. Quartzite and siliceous gneiss of this formation are very coarse-grained or pegmatitic and are distinguished from the similar rocks in the Skallen siliceous formation. The Skallen lower calcareous formation comprises a recumbent anticline, its core being observed at the western corner of Skallevikhalsen. A mass of charnockite 50–360 m thick is developed in the lower horizon of this formation associated with two thinner masses (50 m thick for each) of garnet granite. Metamorphic rocks including marbles are often converted to layered type migmatite with the charnockite throughout the formation (Plate 13). Small masses of pink granites and pegmatites were often found throughout the formation.

The lower limit of this formation is unknown because of no outcrop (inner to the core of the recumbent anticline). The formation is conformably overlain by the Skallen siliceous formation. A charnockite-garnet granite mass is intercalated between the two formations in Skallevikhalsen and in the northwest of Skallen Ôike. The thickness of the formation is over 400 m including the intercalated plutonic masses.

4. 3. Skallen siliceous formation

The Skallen siliceous formation is typically developed in the eastern part of Skallevikhalsen and southern and central parts of Skallen. Minor developments of this formation are also recognized in the northern part of Skallen. Paragneiss-metabasite alternations developed in the most part of Hjartøy are considered to belong to this formation.

This formation is composed mainly of paragneiss (*sensu rato*, including quartzite, siliceous gneisses, and quartz-feldspathic gneisses)-metabasite alternations, each layer being from several tens of centimeters to several meters thick. Open to close minor-folds are generally conspicuous, and boudinage structure of metabasite layers and tight minor fold of the alternations were sometimes observed in a metabasite layer (Plate 14a, b). The thickness of a paragneiss layer in the alternation is not constant; three layers 10 m thick or more, lacking or poor in the metabasite, were re-

cognized in the lowermost, middle, and upper horizons of the formation. These portions are very white and are well recognizable in aerial photographs. Two masses of the charnockite, generally associated with thinner masses of the garnet granite, the total thickness of which is 300 m, are distributed in the Skallen siliceous formation, in its middle and upper horizons. Garnet granite was often found in contact with the charnockite masses, the former being derived from the thick paragneiss layer with poor metabasite mentioned above.

This formation is conformably overlain by the Skallen upper calcareous formation at the southeastern margin of Skallevikhalsen. The thickness of the Skallen siliceous formation is 620 m, including the intercalated plutonic masses.

4. 4. Skallen upper calcareous formation

The Skallen upper calcareous formation is typically developed at the southeastern corner of Skallevikhalsen. A marble layer occurring at the northern corner of Hjartøy is considered to belong to this formation.

This formation is composed of two marble layers, several to ten meters thick, associated with minor amounts of skarns, paragneisses (composed mainly of quartz-feldspathic gneisses), and metabasites. Siliceous gneiss of this formation is often pegmatitic. A mass of the charnockite more than 200 m thick is intercalated in the upper horizon of this formation.

The upper limit of this formation is unknown because of the absence of outcrops. The thickness of the formation is more than 400 m, including the intercalated plutonic mass.

5. Plutonic Rocks and Minor Intrusives

5. 1. Plutonic rocks*

Garnet granite forms a sheet-like mass, some meters to several tens of meters thick, often surrounding a charnockite mass. The garnet granite mass is generally parallel to the structure of the country gneisses or charnockite and grades into them, but sometimes discordant with the gneisses; palimpsestic banding and minor fold structures of the paragneisses were sometimes found in the garnet granite, the foliation of the latter is monoclinic (cf. Plate 1). The garnet granite is a leucocratic, white but sometimes pinkish, small- to medium-grained rock mainly composed of K-feldspar, plagioclase, quartz, and garnet, often with a minor amount of biotite. The lithologic features of the garnet granite are somewhat similar to those of the quartz-feldspathic garnet gneiss, and in some part, to those of some types of the pink granites.

Pools of the pink granite are more or less developed in the garnet granite; the more affected facies by the pink granite is more distinct in having the plutonic features (cf. footnote of this page). Thus, a mass of the garnet granite grades not only into a part of the garnet gneiss, which is one of the main types of the paragneisses, but also into a part of the pink granites. The garnet granite is referred to the garnet gneissose granite described by YOSHIDA and ANDO (1971) and by YOSHIDA *et al.* (1976). The garnet granite includes a part of the garnet gneiss described by TATSUMI *et al.* (1964).

Charnockite forms a sheet-like mass from several tens to hundreds of meters thick. The mass is parallel or subparallel to the main structure of each formation in which it is intercalated (cf. Plate 1). The surrounding paragneisses grade into the charnockite and schlieric bodies of metabasites were sometimes observed, being traceable from the gneisses to the plutonic mass (Plates la, 14c). The charnockite is a leucocratic, brownish or yellow-greenish, small- to coarse-grained, inequigranu-

* These rocks are tectonically and lithologically monotonous in comparison with the adjacent gneisses and are tectonically discordant to them (although often macroscopically parallel or subparallel). On account of this feature, the brown gneiss was excluded from the charnockite in spite of the previous report (YOSHIDA *et al.*, 1976).

lar rock being composed of plagioclase, quartz, K-feldspar, rhombic pyroxene, biotite, hornblende, garnet, and opaque mineral. Some of the mafic minerals are sometimes absent. According to the mineral associations, three varieties of the charnockite may be found, *viz.*, hypersthene, garnet, and hornblende charnockite; the last variety is coarser-grained than the other varieties and lacks hypersthene. The charnockite is referred to the gneissose granodiorite described by YOSHIDA and ANDO (1971), brown gneissose granodiorite by YOSHIDA *et al.* (1976), and includes most part of the pyroxene gneiss of TATSUMI *et al.* (1964). A part of this rock is identified as charnockite defined by JOHANNSEN (1939) but many parts as enderbite defined by TILLEY (1936) and some parts as granodiorite and tonalite.

Pink granites occur as small masses of various forms throughout the Skallen region. They are composed of an isolated small masses several tens × hundreds of meters in outcrop at some places in the northern part of Skallen and at the southern margin of Hjartøy. Very small dikes or pools of these rocks are well developed in the paragneisses or plutonic rocks often parallel to the planer structures of these rocks throughout the Skallen region (Plates 11a and 15). Some of the garnet granite and charnockite are partly migmatitically converted to the pink granite. Metabasite occurring in contact with these rocks is generally hornblende metabasite and indicate amphibolite facies conditions.

The pink granites are variable in texture: gneissic, granitic, pegmatitic, or aplitic. They are leucocratic pinkish granitic rocks often with garnet. The schistosity of these rocks is either parallel to the boundary of the intrusive mass or roughly parallel to the planer structure of the country rocks in the migmatitic variety. The radiometric age of biotite and euxenite from pegmatite of these rock types in the northern part of Skallen was determined: 530±16 m. y. for biotite (Rb-Sr, after NICOLAYSEN *et al.*, 1961) and 375–485 m.y. for euxenite (U-Pb, after SAITO *et al.*, 1961). The pink granites are referred to the pink gneissose granite of YOSHIDA and ANDO (1971) and include the granite of TATSUMI *et al.* (1964).

5. 2. Minor intrusives

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 (outcrops of this rock are seen in Plate 3 and Fig. 1). The form of the dike is simple and the boundary is smooth, although a small block about 100 m in diameter was found separate from the main body of the dike. An indistinct thin banding parallel to that of the country rock is developed in the dike. The thin banding is subjected to minor foldings in the similar fassion to the surrounding gneisses. The discordant metabasite is a mesocratic, dark gray with brownish tint, small-grained, equigranular rock composed mainly of plagioclase, rhombic and monoclinic pyroxenes, hornblende, biotite, and opaque mineral. Elongated clots of mafic minerals are scattered showing indistinct foliation structure.

Biotite microgranite occurs as small dikes in the charnockite or in the garnet granite. The boundary of the dike is either smooth or irregular. The charnockite, in contact with this dike, becomes whitish rather than brownish and coarser-grained, and loses hypersthene. The biotite microgranite is a leucocratic, light brownish, small- to medium-grained, and equigranular rock composed mainly of K-feldspar, plagioclase, quartz, and biotite. Scattered crystals of biotite are somewhat preferentially orientated showing indistinct schistosity which is parallel either to the intrusive boundary or to the planer structure of the country rock (Plate 16a).

Pegmatites of various lithology occur as very small and irregular bodies throughout the region. Most part of them is biotite-, hornblende-, or monoclinic pyroxene-bearing white pegmatite, but minor amounts of pink pegmatite, brown pegmatite, and siliceous pegmatite were also found; the pink pegmatite is one of the main rock types of the pink granite, the brown pegmatite may be a variety of the charnockite, and the siliceous pegmatite is derived from quartzite or siliceous gneiss through ultrametamorphism. The white pegmatite is well developed in various sizes and different forms, mostly occurring in the northern part of Skallen and northwestern part of Skallevikhalsen. There may be various kinds of pegmatites in this group of rocks: small-sized masses some tens × hundreds of meters occur in the Skallen lower calcareous formation, quartz-feldspathic pegmatites several meters across occur in the marble-skarn zone, and very small and irregular masses of other pegmatites several tens to some centimeters in size occur here and there in almost all the gneissic and plutonic rocks. Some of these white pegmatite intruded straight in a NW direction at northwestern corner of Skallevikhalsen. In the west of Osiage Hama (beach) a white pegmatite, tightly folded with a gently plunging axis, was found cutting the intensely folded (with a moderately plunging axis) brown gneiss (Plate 16b). In the eastern part of Skallevikhalsen, a pink aplitic granite vein was found, cut by a thin vein of white pegmatite.

6. Geologic Structure

Many types of folds and fractures were found in the Skallen region. Most of these structures can be detected from aerial photographs (cf. Plates 2–6). Figs. 3 and 4 show the general view of these tectonic features.

An overturned synform, its axis very gently plunging EEN in Skallevikhalsen (cf. Plate 13c) is considered to be an overturned recumbent anticline (nappe), and hence is doubling the stratigraphy of the present region. This recumbent anticline is designated as "subhorizontal recumbent anticline" in this article. Recumbent

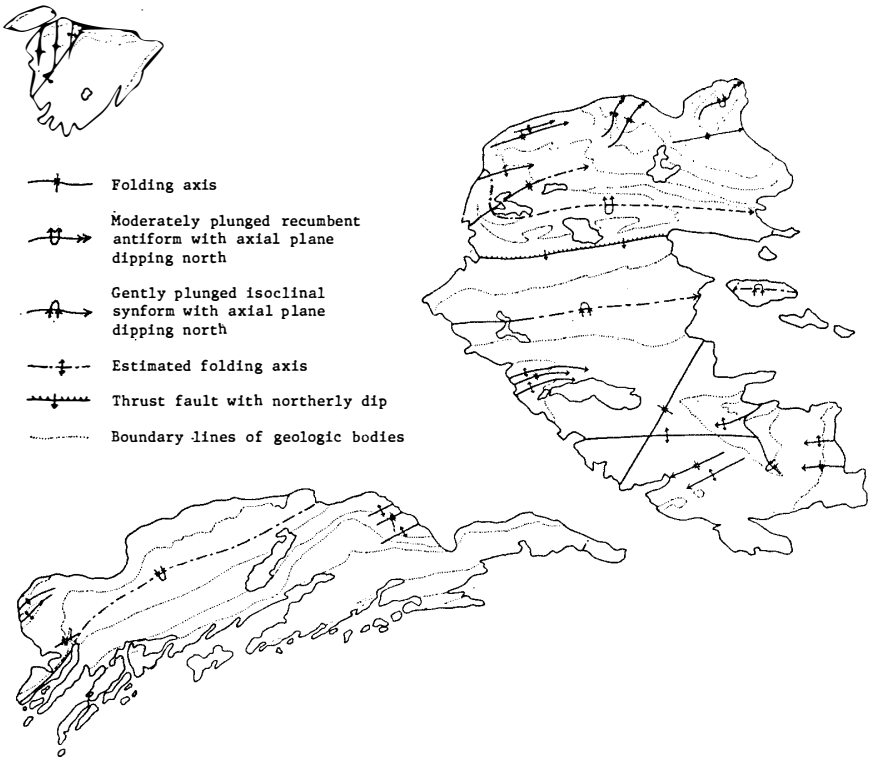

Fig. 3. Distribution of main folds and fault of Skallen region.

Fig. 4. Distribution of fractures traced from aerial photographs. Solid line: fractures, Dotted line: boundary of geologic bodies.

anticlines of a smaller scale were found on the northern slope of Himi Yama (peak) in the southern part of Skallen and in the northwest of Osiage Hama (cf. Plates 1b, 11a, and aerial photographs). Axes of these anticlines moderately plunging SW or NE. These recumbent anticlines of smaller scale are designated as "plunging recumbent anticlines" in this article. Minor folds of recumbent or rootless tight types are sporadically found throughout the Skallen region (cf. Plates 11b, 12, 14, 16b). The axes of these minor folds are parallel either to those of the plunging or subhorizontal recumbent anticlines and hence are related to either of them. The time relationship between the two types of the recumbent folds is not yet clear. The plunging folds, however, may be older, firstly because their axes are more steep and variously plunged and secondly because intence minor folds with axes trending parallel to those of the plunging recumbent anticlines were often found to be superposed by minor folds with gentle easterly plunging axes which are parallel to that of the horizontal recumbent anticline. In the west of Osiage Hama, a pegmatite vein, suffered by tight minor folding with an easterly and very gently plunging axis, was found. The country brown gneiss-metabasite alternations show intense minor folding with axis moderately plunging east-northeastward (Plate 16b). This fact indicates superposition between the two minor folds. It is probable that the earlier mod-

erately plunging minor fold is referred to the plunging recumbent anticline developed just over the Skallen brown gneiss formation which includes the country brown gneiss above mentioned, and the later very gently plunging minor fold to the horizontal recumbent anticline.

An isoclinal synform was found at Kado Misaki (point), Skallen, and an isoclinal antiform is considered to run along the middle zone of the Skallen lower calcareous formation in the northern part of Skallen. These folds are designated as "isoclinal folds" in the present article. These folds have easterly and very gently plunging axes with axial planes trending east and moderately dipping north and are considered to run throughout the Skallen. A thrust fault runs on the southern side of the antiform. This thrust fault is designated as "Skallen thrust". It is probable that these isoclinal folds and the thrust occurred in association with the subhorizontal recumbent anticline, judging from the similarity in trend and plunge of the folding axes and from the sense of dip of the axial planes of the isoclinal folds and the thrust fault.

Plunging folds of gentle to open types with steep axial planes and wavelength of several hundreds of meters are developed near the 186.2 m peak in the northern part of Skallen, near Skallen Ôike, near the 128.1 m peak in the southern part of Skallen, and on the northeastern and northwestern coasts of Skallevikhalsen. These folds are designated as "plunging open folds" in the present article. Most of the axes of these folds gently plunge ENE or NE except those WSW ones in the southern part of Skallen. Minor folds of open to close type are well developed throughout the region. The folding axes of these minor folds are similar in trend to the plunging open folds mentioned above. The trend of the plunging open folds and the minor folds does not change significantly at both rimbs of the subhorizontal recumbent anticline or isoclinal folds and their steep axial planes are distinctly disharmonic with those of the recumbent or isoclinal folds. Thus the plunging open folds are considered to postdate both of the recumbent and isoclinal folds.

East-southeasterly and gently plunging open, gentle, or kink minor folds are well developed in Skallevikhalsen, cutting minor folds with axes trending northeast, east-northeast, or east, and also cutting lineations of various kinds with similar orientations. Small-scale folds of this trend are developed on the northern slope of the 141 m peak in the northern part of Skallen, disturbing the east-notheasterly plunging open folds. These folds, designated as "ESE minor folds" in the present article, thus postdate the plunging open folds.

Horizontal easterly gentle folds with nearly vertical axial plane and wavelength over several kilometers were found at the west of Osiage Hama in the northern part of Skallen and near the 128.1 m peak in the southern part of Skallen. These folds are designated as "gentle folds" in this article. These gentle folds disturb the above mentioned plunging open folds, as will be found from aerial photographs.

A northeasterly open synform with wavelength over 4 km, running between Skal-

len Ôike and the 128.1 m peak in the southern part of Skallen is later than the plunging open folds and resulted in the general disturbance of the latter. This synform is designated as "NE synform" in the present article.

Time relationship among ESE minor folds, gentle folds, and NE synform is not yet valid. For the convenience, the present writer prefers to indicate the time order as earlier ESE minor folds and later gentle folds and NE synform, by introducing a fact observed on the northern coast of Skallen Ôike (Y69020401 point, in Fig. A-1 of Appendix) that minor folds with axes similar to those of the three folds mentioned above show superposition in the order as indicated above.

Diagonal set of vertical fractures with NE and WNW directions are 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 are sometimes found in aerial photographs, but they are not so great and were overlooked in the field. Dihedral angle of these fractures is generally 40°–60°, the acute bisectrix being in an EEN direction. It may not be unreasonable to consider these fractures as constituting a conjugate set, judging from their wide and constant paired occurrence. It is probable, therefore, that these fractures were made by an east-northeasterly compressional stress. 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.

In view of the stress field during the tectonic succession above mentioned, the earlier N-S compressional for the subhorizontal recumbent anticline, isoclinal folds, and plunging open folds, and later E-W compressional stress field for the conjugate set of fractures are estimated. There remain some other folds, the stress field of which can not be estimated (Table 2). Furthermore, among the folds grouped as being formed in the N-S compressional stress field, the movements of the recumbent folds and that of the open folds may be quite different. These are the main tectonic problems to be studied in future.

The summarized succession of tectonics is shown in Table 2 supplemented by considerations on geologic history.

7. Geologic History

Some of the dikes or plutonic rocks described in the foregoing pages provide useful information on time relations among different tectonics and between tectonics and metamorphism. They are mentioned again in the following from this viewpoint.

Discordant metabasite represents metamorphic appearance in having the thin banding structure which is folded and presents crenulation lineation similarly to the surrounding country rocks of the Skallen siliceous formation, an equally sized granular texture although the grain size is smaller than any other metamorphites of this region, and the granulite facies mineral assemblage which is similar to the concordant pyroxene metabasite. The style of the fold is referred to the plunging open folds. Thus the discordant metabasite is considered to have intruded prior to both of the plunging open folds and granulite facies metamorphism. It is probable, therefore, that the granulite facies condition existed or prolonged until after the plunging open folds. The present writer considers the possibility that the banding structure of the discordant metabasite is of dynamic metamorphism origin, the metamorphism may be associated with the nappe tectonics. Thus the discordant metabasite is considered to be earlier than the recumbent anticlines.

Charnockite shows a gentle structure in both its form and foliation, which are generally parallel or subparallel to the surrounding gneisses even where the gneisses suffered an isoclinal fold. The analogous relationship is considered with the recumbent anticline of the sub horizontal type, although the discordancy is somewhat distinct than in the former case. In the west of Osiage Hama, intensely mesoscopically folded brown gneisses, which form a macroscopic plunging recumbent anticline, were found being cut by a mass of charnockite (cf. Plate 12b). At the western corner of Skallevikhalsen, a charnockite band occurs cutting the horizontal recumbent anticline. Small-scale open to tight folds, most of which are considered to have developed in synchronous with the plunging open folds and are often well developed in the paragneisses, are not conspicuous in the charnockite throughout the region. Thus the charnockite is considered to be later than the horizontal recumbent anticline and at least a part of the charnockite is probably later than the plunging open folds. The

possibility still remains that some of the charnockite are synchronous with the subhorizontal recumbent anticline, they show macroscopically good conformity with this folding structure. Field occurrence, texture, and mineral associations of charnockite indicate plutonic condition under the granulite facies metamorphism.

A pegmatized quartzite is developed surrounding the boudins of metabasite in the southern area of the western part of Skallevikhalsen. The foliation of the pegmatite, which is parallel to the periphery of the boudins, is folded on a minor scale by an east-southeasterly and gently plunging axis, this minor fold being considered to belong to the ESE minor folds. Thus the pegmatization of quartzite is considered synchronous with the ESE minor folds.

Pink granites are generally developed as discordant veins, often along shear planes, in the other plutonic and metamorphic rocks with branches of pools concordant with the pre-existing planer structures of the country rocks. Abundant rootless pools of the pink granites are sometimes observed resulting in the wide distribution of the stromatic type migmatite. These rocks have foliation parallel to their own boundary or are massive. Thus the pink granites postdate the main tectonics of this region as exemplified by EW trend foldings, and the formation of easterly foliation. Field occurrence, texture, and mineral associations of these rocks indicate migmatitic conditions under moderate temperature and pressure during their formation.

Summarizing these additional data on plutonic or intrusive rocks with the geologic structures previously mentioned, the following succession of eight stages of geologic events is obtaned (Table 2).

Stage 1. Accumulation of original rocks of the metamorphic and most of the plutonic rocks of the Skallen region. Almost all the alternation structures of these rocks were formed during this stage.

Stage 2. Intrusion of the discordant metabasite.

Stage 3. Plunging recumbent anticline (first nappe) associated with intense minor folds. Strong dislocation might have occurred during this tectonics. Some of the thin compositional banding of metamorphites and of discordant metabasite might have been formed during the tectonics of this stage.

Stage 4. Subhorizontal recumbent anticline (second nappe). Isoclinal folds and a thrust fault are considered to have been associated. Granulite facies metamorphism probably occurred around both or either of the two stages of the recumbent foldings. Most of the paragneisses and pyroxene metabasite were formed probably at about the time of this metamorphism.

Formation of the charnockite associated with the alteration of paragneisses into the brown gneisses, is considered to be synchronous with or slightly later than the horizontal recumbent anticline.

Stage 5. East-northeasterly or west-southwesterly and gently plunging gentle to open folding associated with open to close minor folds. Formation of some parts of the charnockite might have continued until the completion of this tectonics. The

Table 2. Geotectonic development of the Skallen region.

Stages	Tectonics	Stress field	Plutonic and igneous rocks	Metamorphism
1	Development of the sedimentary basin.	?	Basic rocks (origin of the concordant metabasite)	?
2		?	Discordant metabasite	
3	Recumbent anticline (nappe) with moderately plunging axes, associated with tight minor folds.	?		Dynamic ?
4	Recumbent anticline (nappe) with easterly and gently plunging axis. Easterly and gently plunging isoclinal folds with northerly dipping axial planes, and easterly running thrust with a moderate dip.	N–S compressional		Granulite facies
5	Open folding with west-southwesterly or east-northeasterly and gently plunging axis, associated with open to close minor folds.		Charnockite formation	
6	Open, gentle, and kink minor foldings with east-southeasterly and gently plunging axes.	?	Pegmatization of quartzite	
7	Gentle folding with easterly horizontal axis and northeasterly synform.	?	Pink granites	Amphibolite facies
8	Conjugate set of fractures with NE and WNW trends.	E–W compressional	Latest white pegmatite	?

stress field of stage 4 and stage 5 is considered N-S compressional.

Stage 6. ESE minor folds, consisting of open, gentle, and kink minor folds with east-southeasterly and gently plunging axes. Pegmatization of some of the quartzite is synchronous with this tectonics.

Stage 7. Horizontal easterly gentle folding with a vertical axial plane and an open synform with a NE trend. Time of the intrusion of the pink granites under the amphibolite facies conditions is unclear but possibly around this stage. Age of this intrusion is considered around 500 m.y., judging from the radiometric age of minerals from pink pegmatite. Time of the intrusion of the latest white pegmatite is unclear but possibly around this stage or the next stage. Some of the pegmatite intruded along northwesterly fractures.

Stage 8. Fracturing of the region by NE and WNW set of nearly vertical planes

probably under the E-W compressional stress field.

The geologic history summarized above is in good conformity with that preliminarily mentioned by YOSHIDA and ANDO (1971) from wide area surveys around Lützow-Holmbukta and Yamato Sanmyaku (Queen Fabiolifjella), and that discussed in some detail by YOSHIDA (1975) in the Botnneset region about 50 km to the west. The metamorphic or tectonic histories so far obtained from detailed studies of Langhovde 50 km to the north (ISHIKAWA, 1974, 1976; ISHIKAWA *et al.*, 1976), Ongul Islands 70 km to the north (KIZAKI, 1964), and Yamato Sanmyaku 200 km to the southwest (KIZAKI, 1965; OHTA and KIZAKI, 1966) are somewhat conformable with that of the present region.

Thus the general scheme of the geologic and metamorphic history of the region around Lützow-Holmbukta has come to be clarified. There stil remain some different views among different authors concerning tectonic style and succession, and time relationship between tectonics and metamorphism. These are problems to be discussed and solved in future works.

It is worthy of note, however, that ISHIKAWA *et al.* (1977) and YANAI *et al.* (1977) recently clarified the presence of nappe structure in Skarvsnes, 20 km to the north and YOSHIDA *et al.* (1977) explained such structures being common throughout the region around Lützow-Holmbukta.

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APPENDIX

Route Maps and Field Descriptions of the Skallen Region

Observation- and specimen-number — Observations in field. Sp: specimen was collected, Sk: Sketch was made, Ph: photograph was taken. Gn/Mb means alternation of gneiss and metabasite. Abbreviations are illustrated at the end.

SKALLEN

Y69020513–0516 route (Fig. A-2)

(No. 513–516 of the route map means Y69020513–Y69020516).

Y69020513 Pink Kf augen gn Gr (Sp).

0513z Close minor fold of basic band. Peg vein folding with the basic band by the same axis was found.

0513y Peg (with big white Kf) with weak schistosity, its orientation is bent, becoming parallel to that of the country rocks. Folded with the axis (N85°E20°) common to the country rocks.

0513x Basic rock and pink gr Gn are banded in the similar fashion as thin alternation structure of the si bed.

0514 Augen-shaped body of Px-Ga rock (Sp).

0514z Green intrusive sheet.

0515 Green skarn rock (Sp).

0515z Low angle microfold lineation cuts high angle microfold lineation (Sk).

0516 Gn Gr with a relic block of Qzt/concordant Mb. The relic block represents folding structure (Sk, Ph).

0516z Gn Kf Gr is banded subparallel to the country rocks.

Y69020511–0512 route (Fig. A-3)

(No. 511–512 of the route map means Y69020511–Y69020512)

Y69020511 Relic blocks of intensely folded acid granulitic rock (Cha) occurring in basic granulite (Mb). Pyroxenitic rock occurs in the periphery of the relic blocks (Sp, Sk, Ph).

0511z Earlier minor folding axes (Ph).

0511y Recumbent minor fold (Ph).

0511x Folded Peg pool in folded Gn. Superposed minor foldings were found (Sk, Ph).

0512 Ga Gn—Cha, cutting the intensely folded acid granulitic rocks/basic granulitic rocks (Sp, Ph).

0512z A part of the Cha cuts the intensely folded basic/acid granulites (Ph).

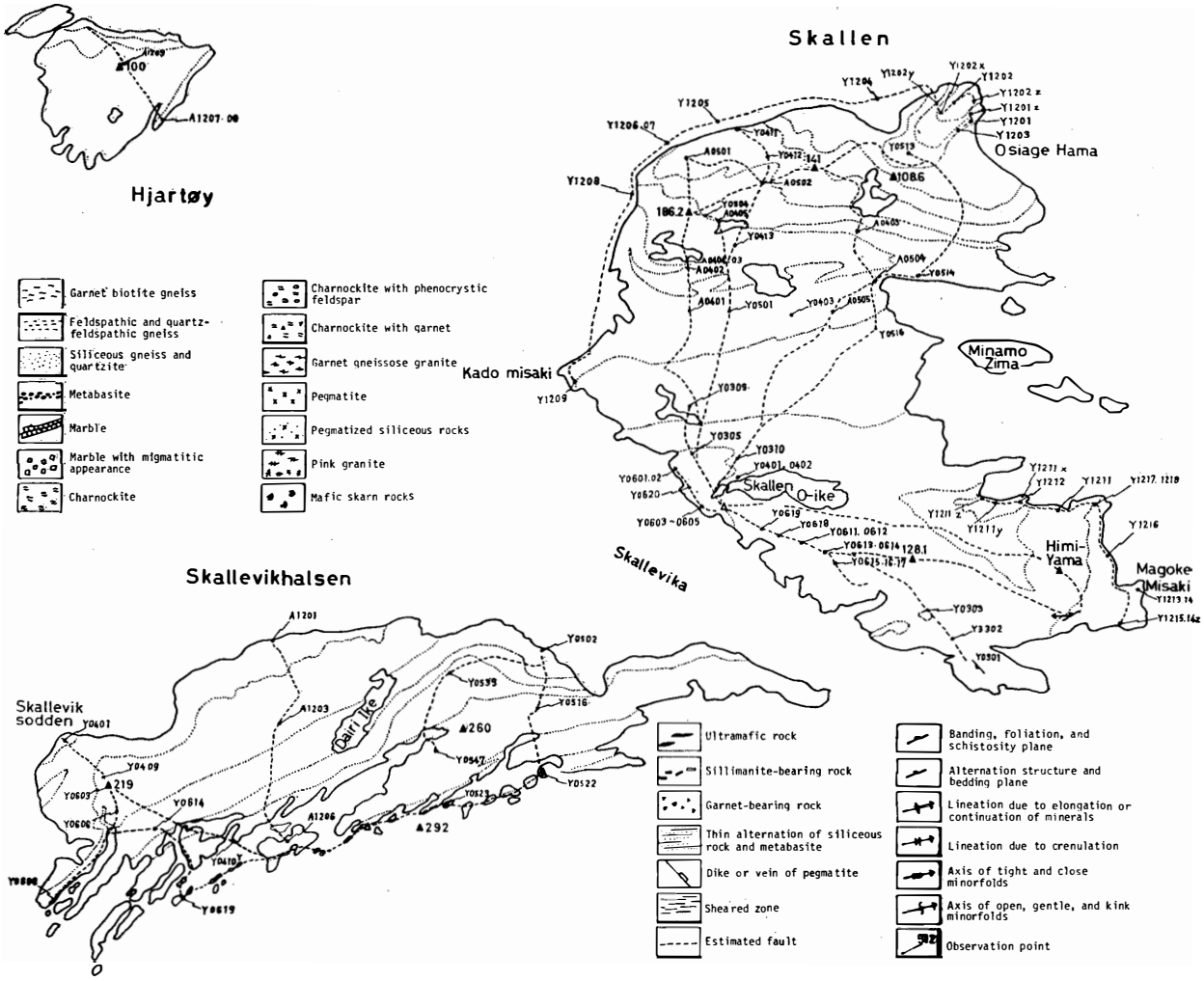

Fig. A-1. Compiled route map of the Skallen region.

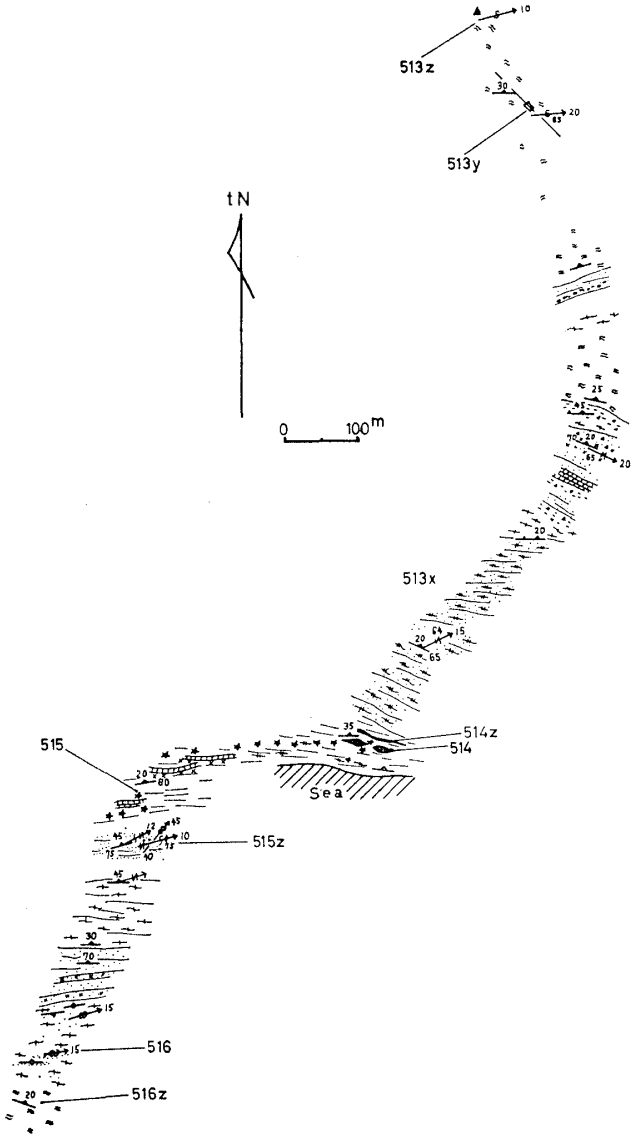

Fig. A-2. Y69020513–0516 route.

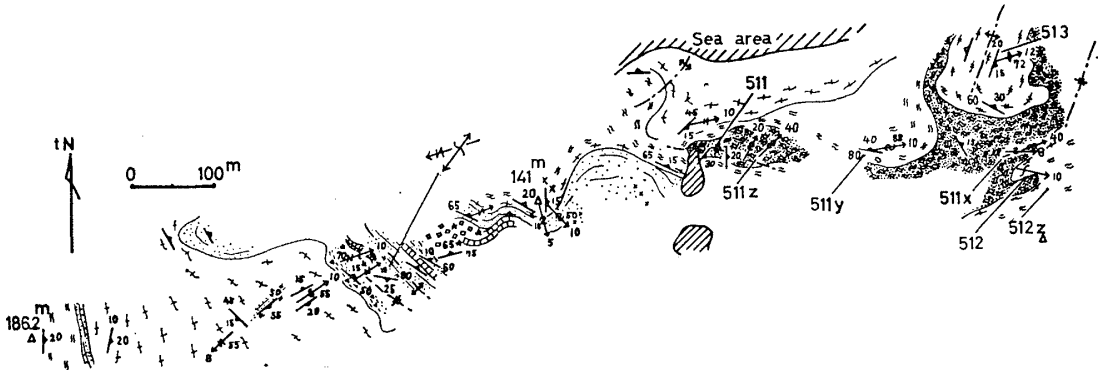

Fig. A-3. Y69020511–0512 route.

Y69020304–0504 route (Fig. A-4)

(No. 304–504 of the route map means Y69020304–Y69020504)

Y69020304 F Ga gr Gn (Sp), with concordant pools–veins of Qz-Kf aggregates.

0305 Xenolithic Qzt (Sp) in the Cha.

0305z Granitized Qzt or si Gn with Bi elongation lineation. Vein–pool of Kf Ap develops.

0306 Very c–m Qzt (Sp), with agmatitic band of Mb.

0307 Concordant Mb (Sp). Bio Dio vein develops, with very c Bi scattered sporadically.

0308 Ga-Qz-Sill rock (Sp). Ga is very c.

0309a m/c Cha (Sp), Sp is m facies bearing Hyp and Ga.

0309b C gn Gr with veins (Sp) of very c peg Gr and micro Gr. Xenolithic bands of Mb are developed.

0309z Peg Qzt/si Bi Gn.

0309y F si Bi Gn.

0309x Intermediate facies between Cha and Ga gn Gr, this facies carries Ga.

0309w Felsic Gn/Mb.

0310 Agmatitic Mb is abundantly developed in f gr Gn. Ga spots–gray spots are developed in the central part of the Mb. The spot is composed of symplektic Hyp and Pl. The Ga spot is formed from the gray spot.

0310z Ga-bearing ap Gn with pink Kf.

0310y Ga-bearing Cha.

0501a Violetish ore rock (Sp).

0501b Q–F Peg (Sp). Feld: light yellowish green.

0501c Bi-bearing calcic Amph? (Sp).

0501d Qz-Kf-Bi Peg (Sp).

0502 Typical basic Gn (Sp) that is developed around this route (Sp is si Cha with Ga).

0502z Intrusive Ma with scattered mafics, with an appearance analogous with microdiorite.

0503 Pink Kf Peg (Sp).

0503z Si rock banded, very c and appears like Qz Peg.

0504 Cha gr Gn, with pools of pink Kf.

0504a Cha with pink Gr pool (Sp), the specimen is a part rather poor in the pink gr pool.

0504b Cha (Sp), mixed facies of pink Gr and Cha.

Routes shown in the compiled route map (Fig. A-1)

Y69101201 Ga-bearing basic granulite (Mb) (Sp) alternating with the leucocratic Gn. Banding: N80°E40°S, mineral lineation and axis of open to

close minor fold: N80°E15°.

1201z Si Gn is almost absent. The si Gn is found only where the Ga gn Gr occurs.

1202 Dark green mineral-Bi rock (Sp) intruding along the foliation (Sk).

1202z Ga-bearing melanocratic Pl-black Px Mb/leucocratic si Gn.

1202y Basic/acid Gn, being imperfectly granitized.

1202x The si facies is often peg and is alternating with the Mb.

1203 Green mylonite and gn Peg cutting the alternations of Ga-bearing Mb/leucocratic Gn (Sp, Sk, Ph).

1204 All the rock units show monoclinic structure (Sk, Ph).

1205 The si Gn occurring in both sides of the gully of Ma-skarn appears to belong to a same horizon (Sk, Ph).

1206 Green conglomerate-look rock with rounded fragments of Ma (cataclasite) (Sk, Ph).

1207 Basic rock with pink Kf banding (Sp). Crenulation lineation same as the si Gn is developed (in Sk of 1206).

1208 Steep monoclinic structure with northeasterly dip (Sk, Ph).

1209 Mb (Sp) alternating with the Ga gn Gr. The Mb is often Pl porphyroblastic in network, pool, cutting the folia. Gn Gr of the last stage cuts clearly both the Gn alternation and porphyroblastic Gn (Sk, Ph).

1209z Ga gn Gr–gr Gn with schlieric Mb. Planer structure: N50°E50°S, crenulation lineation and axis of close minor fold: N60°E70°.

1209y Cha with very f Ga and with porphyroblasts of Kf. Planer structure: N20°W12°E, crenulation lineation: N60°E8°.

1209x Mb intercalation.

1211 Si peg Gn/Mb (Sp).

1211z Felsic Gn with big Ga/Mb.

1211y Ma. Overlying si peg Gn/amph Mb.

1211x Si Gn/Mb, with planer structure: N55°E30°W and crenulation lineation: S75°E7°.

1212 Ga-Bi Gn, in Ma zone. A thin Ma band shows small antiform. To the east, the structure changes monoclinic with a westerly dip (Sk).

1213 Mb/si Peg (Sp), the latter being somewhat granitized. Rocks adjacent to 1213 are similar to the rocks lying beneath the cataclasite of point 1206 in the northern part of Skallen.

1214 Pink Q-F rock (Sp) alternates with the 1213, and both are cut by pink Peg.

1214z Thickness of the Ma bed is over 50 m.

1215 Mb/brown Gn (Sp, acid part of the brown Gn), this brown Gn appears to resemble pink Gr.

1216 Bi-Hyp-bearing ap schistose rock (Sp) in the Ma zone. Flakes of

graphite are scattered.

1217 Basic sheet (Sp) of 1 m wide, located between the lower Ma bed and the upper Mb/felsic Gn with Ga spot (Sk).

1218 Big Kf porphyroblastic rock in the Ma zone of SK1217.

Y69020401 Superposed minor folds and crenulaton lineation are observed (Sk, Ph).

0403 Zone of gr Gn 50 m wide with Qzt with Mb band to the north. The banding is closely folded with axis N70°E8° (SK).

Y69020411 Cha is cut by pink Kf-Qz-Bi Peg, either discordantly in vein or concordantly in pool or vague granitization form. F–c gn Gr is formed in the Cha. A vein of dark green Pyroxenite cuts clearly these rocks.

0411a Original Cha (Sp).

0411b Gn Gr (Sp) formed by the intrusion of the Peg into the Cha. The gn Gr is not brownish. Pink Kf Peg vein parallel to the foliation.

0411c Migmatite (Sp) formed by the intrusion of the Peg into the Cha.

0412a Ho-Px rock (Sp) in Ma/Skarn.

0412b Basic granulite/acid charnockite (Sp).

0413a Hyp-Diop? rock (Sp), originated from Ma.

0413b Green intrusive rock (Sp) associated with Kf peg Gr.

A69020401 Peg (Sp) cutting the limy ore bed.

0401z Cha/Qzt.

0401y Ga gn Gr, quartzitic.

0402 Green very c rock (Sp).

0403 C–f alternated basic granulitic Gn (Ga-Bi Gn).

0404 F gr Gn (Sp) (Q-F Ga-Sill Gn), pink Kf Peg is well developed near it.

A69020501 Ma band (Sp), 15 m wide, lying just under the Skallen si formation.

0502 Ga gn Gr (Sp) with pink Kf banding.

0503 Pink Kf banded (Sp).

0504a Ga-Bi white Gn (Sp) of sheared gn rock.

0504b Ga-Bi brown Gn, pink Kf veined (Sp), of the sheared gn rock.

0504z Si rock.

0505 Basic rock alternating with Qzt (Sp).

Y69020301 Qzt/Mb (Sp-b), the Mb is nebulitic. F Gr vein cut clearly the alternation, and c Gr (Sp-a) veined into the Gn. The c Gr is probably a variety of the f Gr.

0302 Alternation of Qzt and Bi rich band.

0303 Discordant Mb (Sp), generally with clear discordant contact, sometimes with thin compositional banding, which is folded in the similar fashion to the Gn.

Y69020601a Ga-bearing Q-F Sill Gn (Sp), lying just under the Ma bed.
0602b Ma (Sp), with alternation structure N40°E20°N, with open minor fold (its axis: N70°E22°).
0602c Ma-skarn with intrusive occurrence (Sp, Ph).
0602d Very c Ma (Sp) with intrusive form (Sk, Ph).
0602e Ma (Sp) with many mafic minerals.
0603a Ga gn Gr (Sp) composed of typical Ga gn Gr part and relic Cha part (Sk, Ph).
0603b Ga-bearing Cha, relic facies in 0603a facies (Sp).
0604 Cha (Sp) with Kf Gr pools.
0605a Ga-bearing Bi Cha (Sp), being injected by pink Kf-Qz-Ho? Peg.
0611 Alternation of layers of reddish and white Qzt (Sp), the reddish layer shows Qz elongation lineation (Ph).
0612 Amph rock (Sp), alternating with the Qzt of 0611.
0613 Concordant Mb alternating with the si Gn (Sp). Gray spot (composed of symplektic aggregate of Hyp-Pl)–Ga spot occur in the Mb.
0614 Ga porphyritic gr band (Sp) developed in the alternation of quartzitic-dioritic band and the concordant Mb of 0613 (Ph).
0615 Gray spotted basic rock (Sp), probably the earlier stage than the 0613 rock (Sk, Ph).
0616 Pl-Bi porphyroblastic vein (Sp). This may cause to form the Ga spotted rock when this develops network in the amph Mb.
0617 Pl-Bi peg rock in the Amph (Ph). This type of Peg develops sometimes at the contact between the dioritic rock and the basic Gn, but sometimes does regardless of their distribution.
0617a Central part of the Peg 0617, very c, with very few or no Ga. Ga is only found in the c Peg when present.
0617b Marginal facies (Sp) of the Peg 0617, somewhat smaller-grained, and Ga-bearing.
0618a Q-F sill-Ga Gn (Sp), distributed between the Ga gn Gr mass and the si Gn bed.
0618b Ga-bearing compact rock (Sp) just under the 0618a rock.
0618c Q-F Sill-Ga Gn (Sp).
0619a Ga gn Gr, its feldspathic facies (Sp) with pink Kf-Qz gr pools, distributed in the upper horizon of the Ga gn Gr mass.
0619b Pink gn Gr (Sp).
0619z The pink Kf-Qz gr pool in the Ga gn Gr (0619a) is continuous with the granitic vein which cuts the Ga gn Gr (Sk, Ph).
0619y Si Gn/Basic Gn, folded. Granitization occurred only on the si Gn. Foliation of the si Gn is discordant to the bedding plane but appears subparallel to the axial plane of the fold.

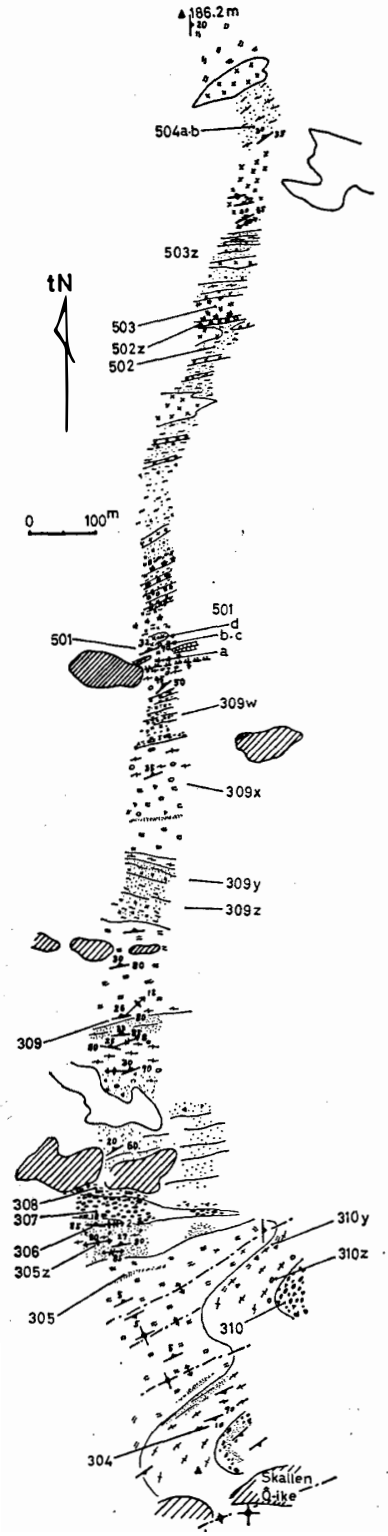

Fig. A-4. Y69020304–0504 route.

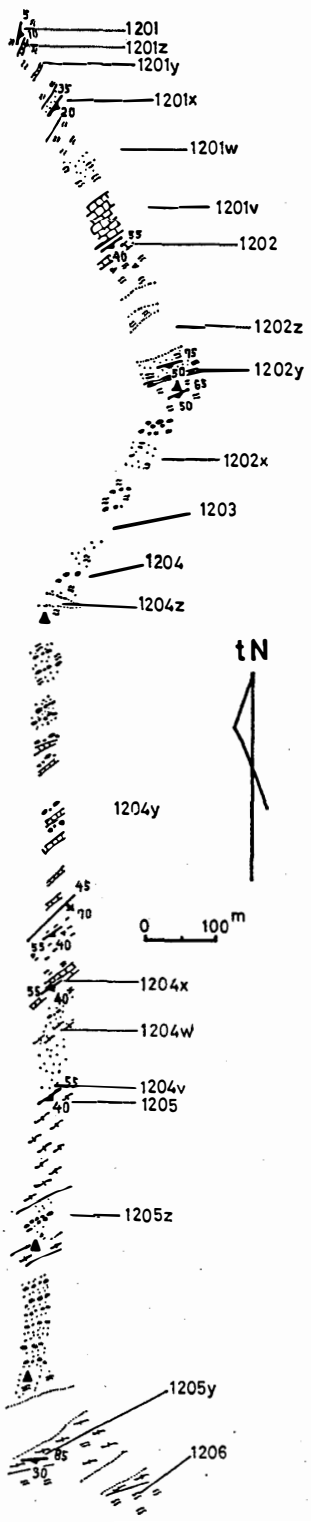

Fig. A-5. A69101201–1206 route.

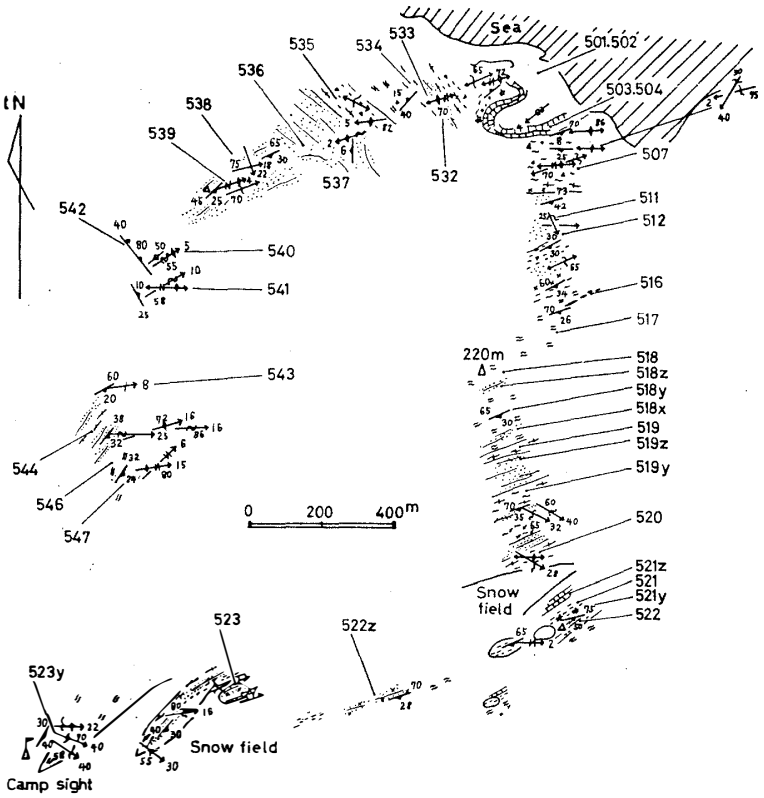

Fig. A-6. Y70020501–0547 route.

0619x Peg Gr vein in Qzt/Mb (Sk, Ph).

0620 Feldspathic Peg (Sp) developed in the Ma bed as augen-shaped small bodies.

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Y70020501–0547 route (Fig. A-6)

(No. 501–547 of the route map means Y70020501–Y70020547)

Y70020501 Ma (Sp) with brown Bi, green Spi, black Px?.

0502 Ga Mb (Sp), xenolithic in the Ma of 0501. Geologic column was made from 0502 to 0515.

0501z Ma and associated rocks are well folded, the gneiss alternation, however, remains flat (not folded) (Sk).

0502z Ga-Px Mb, alternating with felsic Gn with Ga clot, being well affected by weathering.

0503 Dark violet gray ore rock (Sp), 0.5–1.0 meter thick.

0504 Deep green Px rock (Sp) without pink Kf, 5 meters thick.

0505 Ga-bearing si Gn (Sp) without pink Kf, 5 meters thick.

0506 Very c Qzt with thin intercalations of Ga-Px Mb. Horizontal mineral lineation cuts the horizontal minor fold axis.

0506z Cleavage develops, in ENE direction and vertical. Can this be the cause of the easterly lineation?
0507 Ga-bearing felsic gr Gn (Sp), coarser-grained facies than the lower ones.
0508 Felsic ap rock with Ga (Sp).
0509 Px Mb (Sp) without gray spot.
0510 Ga-bearing felsic Gn/Px Mb with Ga clot (Sp). The Sp is not so felsic as others previously occurred. The Px Mb is gray spotted-Ga spotted type.
0511 Salic vein is along the ESE gentle fold lineation.
0512 Typical basic band (Sp) alternating with the Q-F Gn.
0512z Dio rock with big Ga spot.
0513 Px Mb (Sp) band in the Q-F Ga Gn.
0514 Ga-bearing ap Gn (Sp) with Ga-bearing Bi-Pl band. 0509–0514 are generally consisted of Px Gn/si Gn.
0515 Ho Cha (Sp) without Ga.
0515z Pool of Ho-Hyp-Pl rock in the Cha.
0516 Ho-Pl pool (Sp) in the Cha. Ho is somewhat c.
0517 Cha (Sp), Bi-Feld-Qz-Hyp rock.
0517z Bi gr Gn, with rare Ga and some Hyp and with thin bands of Amph, veined by pale pink Kf Peg, being normal and parallel to the foliation.
0518 Amph (Sp) band in Cha.
0518z Si Gn alternations, 5 meters thick, occur among Cha.
0518y Bi Cha without Ga, Hyp, and Ho. Several pools of micro gn Gr develop.
0518x Abundant basic band in Cha, being similar to the si alternations.
0519 Pink Kf gn Gr/Ho Mb (Sp), composed of Ho-Pl Amph.
0519z Si Gn/Mb, composed of Hyp-Ho-Pl.
0519y Si Bi gn Gr with bands of Ho-Pl Mb.
0520 Bi gr Gn with pools of pink Kf Gr (Sp).
0521 Q-F brown Gn (Sp.)
0521z Ma with scattered mica clots.
0521y Green rock with very white felsics.
0522 Basic part (Sp), Hyp rich.
0522z Si Gn alternation. Si part is mobilized.
0523 Skarn rock (Sp).
0523z Si Gn alternations, 20 meters thick and then changes to the ap Ga Gr to the north.
0523y Axis of boudinage.

Y70020531 Faint discordancy is found between the bedding and foliation of Ma.

0532 Si alternations, 15 meters thick.
0533 Ga-bearing si Bi Gn.
0534 Ga-bearing felsic Gn band.
0535 Ga felsic Gn, overlying on si Bi gr Gn. The felsic Gn is pooled by pink Kf Gr.
0536 Alternations of si Gn (Ph).
0537 Gentle folding axis is subparallel to the mineral lineation.
0538 Mafic mineral lineation, N75°E18°, in Qzt.
0539 Elongation of Bi flakes and other mineral show lineation.
0540 C mica elongation lineation is parallel to the microfold lineation.
0541 C mica elongation lineation cuts all the microfold lineations.
0542 Kf porphyroblastic myllonitic Gn.
0543 Streation made of Qz elongation or fault slicken.
0544 Ga bearing leucocratic Gn with abundant pink Kf Peg. This alternates with Px Mb.
0545 Mica elongation and probably Qz elongation, the latter is not so distinct (Ph).
0546 Cha, Kf-Pl-Ho-Qz.
0547 Superposed lineations in Cha. Easterly gentle mineral and crenulation lineation cuts the northeasterly gentle crenulation lineation.

A69101201–1206 route (Fig. A-5)

(1201–1206 of the route map means A69101201–A69101206)

A69101201 Si Cha (Sp) with lath crystals of Ho.
1201z Ma with scattered Px. Paleozomic body of granular Mb is found.
1201y Ma with scattered Px.
1201x Weathered zone.
1201w C Cha, very si part developed. Rich in Qz and Feld, pink Kf bearing, and poor in Amph lath.
1201v Ma with mafic mineral, the neighborhood of the mafic mineral is weathered into brownish.
1202 Pure Ma (Sp), comprising a distinct white band which will be found in aerial photographs.
1202z Morain deposit.
1202y Band of porphyroblastic gr Gn.
1202x Si c Cha.
1203 Si Cha (Sp).
1204 Mb (Sp). Sheet-form, or boudinaged.
1204z Sandy morainic deposit.
1204y Weathered zone of Ma with scattered mafics, Mb bands are often found.

1204x Pure Ma.
1204w Si Gn, somewhat granitic.
1204v Very hard Qzt, a distinct white band.
1205 Gr Gn with Ga (Sp).
1205z Very hard Qzt, alternating with Mb.
1205y F gr Gn with Ga.
1206 Typical c Cha (Sp).

Y70020401–0410 route (Fig. A-7)

(No. 401–410 of the route map means Y70020401–Y70020410)

Y70020401 Typical ap Gn (Sp) with micro gn Gr (Sp 0402) and with abundant intercalations of pools of gn Gr (Sk).
0402 Thin dike of micro Gr (Sp) in the gn Gr of 0401.
0402z An open fold cuts the crenulation lineation.
0402y Qz-Kf-Bi Peg (Sp) vein (N62°W78°N) and micro Gr vein (N45°W 50°N).
0403 Green Diop? rock (Sp) with concentrated–veined aggregates of Ho and Bi, agmatitic in the white Kf Peg. The green rock is banded with the ap Gn.
0404 Sc-Phlogopite rock (Sp) in the Ma.
0405 Foliation of the ap Gn is discordant to the bedding plane (lithologic facies boundary) but appears to be concordant to the axial plane of minor folds with the N50°E30° axis.
0405z Pink Kf bearing f ap Bi Gn/c gr Gn.
0405y Si ap gn Gr.
0407 Basic band in the gn Gr (Sp).
0408 Typical ap Bi Gn–gn Gr (Sp), 25 meters±thick.
0409 Ma (Sp), few concentration balls of mica and with violet Spi and other mafics.
0409z Ga leucocratic Gn–Cha with patches of assimilated Ma.
0409y Ga-bearing Cha (Sp) with Ga-bearing m–c Bi-Pl-Ho Mb band. The Cha is rarely veined by the assimilated or intrusive Ma.
0410z F dio Gn–leucocratic Ga Gn with bands of Px-Pl rock.
0410y Qzt/spotted Px Mb.
0410x Px Mb/felsic Gn.

Y70020603–0622 route (Fig. A-8)

(No. 603–622 of the route map means Y70020603–Y70020622)

Y70020603 Cha with few Ga (Sp).
0604 Felsic Ap (Sp). Sp is augen gn part.
0605 Cha-like Bi augen Gn, banding with Px Mb (Sp).
0606 Cal-mica-Px rock (Sp), occurring in the Cha.

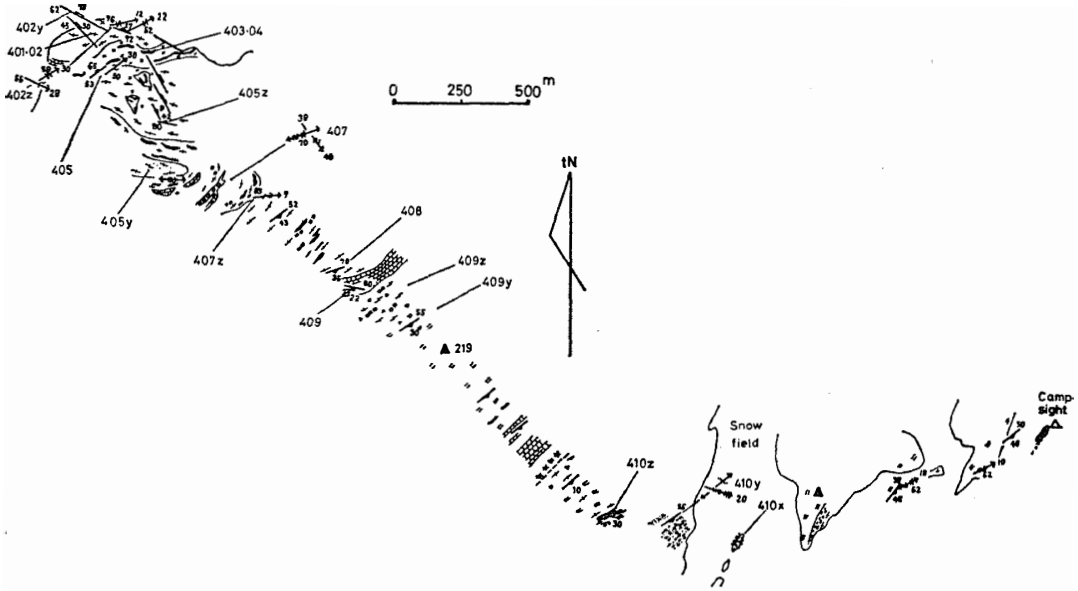

Fig. A-7. Y70020401–0410 route.

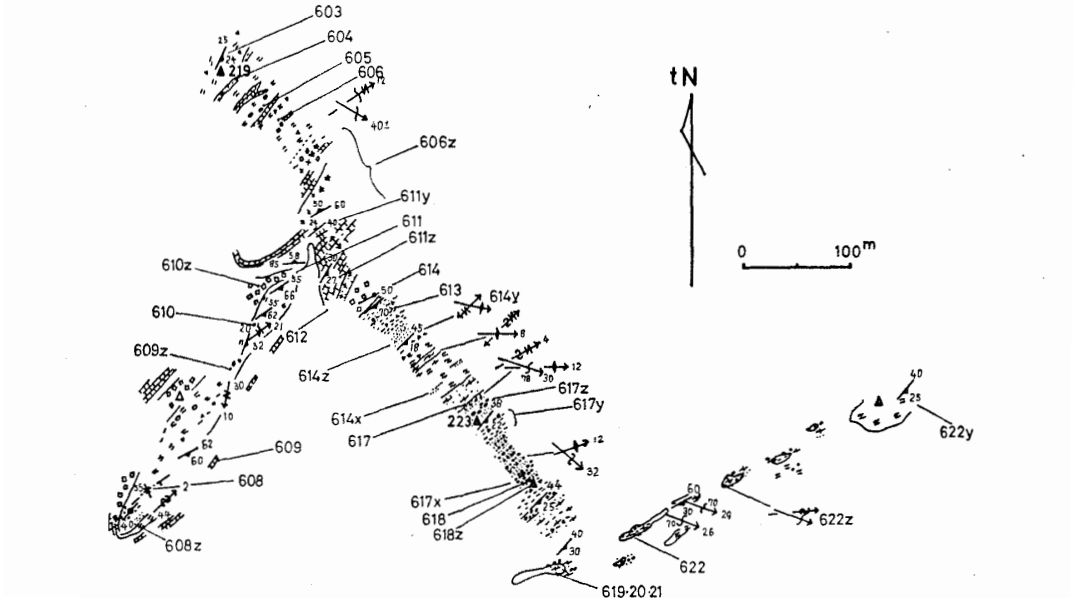

Fig. A-8. Y70020603–0622 route.

0606z Peg/ored rock/Ma.

0608 Bi micro Gr (Sp), clearly cutting minor fold with a gentle easterly plunge (Sk, Ph).

0608z Felsic Gn with Ga, Px Mb, and Ma are folded by an isoclinal large-scale synform (core part of the recumbent anticline). The Cha appears to cut this synform (Sk).

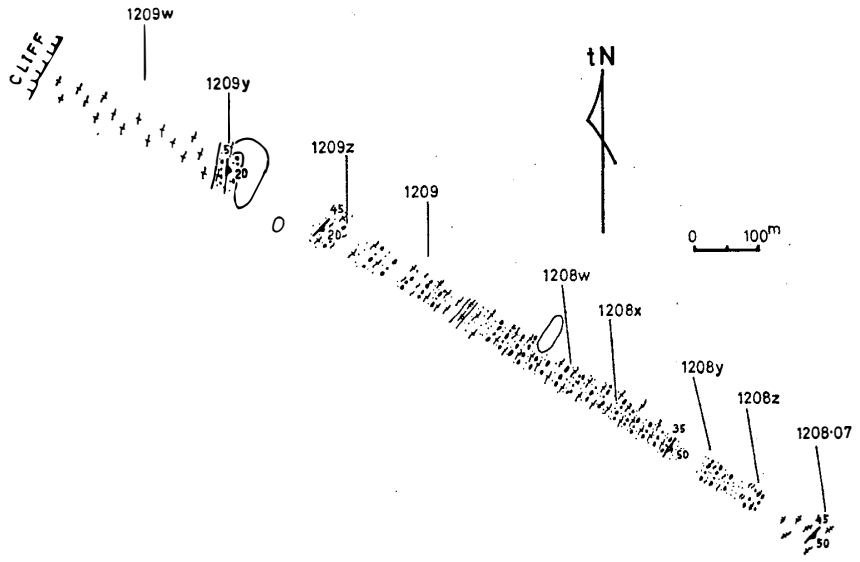

Fig. A-9. A69101207–1209 route.

0609 Green rock (Sp) in Ma.
0609z Augen gn Peg as 0604 and Ga-bearing Bi Cha as 0603.
0610 Southeasterly open antiform cutting the east-northeasterly gentle crenulation lineation (Sk).
0610z Intrusive Ma appears at a glance as Gr. Zenolithic blocks of Peg are found (Ph).
0611 Si gr rock with mafic clot (Sp). Later stage disturbance on the gentle easterly lineation is found. The disturbance accompanies the Ma intrusion (Sk).
0611z C Ho Gr is included in the Ma.
0611y The continuation trend of the Ma bed, N40°E24°W.
0612 White Kf Peg (Sp) intrusion into the gr Bi Gn.
0613 Si Bi Gn (Sp) with Ga clot and felsic Gn with Ga clot.
0614 Ma (Sp) with granitic appearance.
0614z Very white Qzt.
0614y The gentle easterly lineation probably cuts the northeasterly crenulation lineation.
0614x Si alternation disappears into the Cha (Ph).
0616 Px Mb (Sp).
0617 Ga-Bi pink Q-F Gn (Sp). Superposed lineations are found near this point.
0617z Basic band, somewhat thick.
0617y Basic band, somewhat thick.
0618 Ho-Qz Peg–dio rock (Sp), eating both Px Mb and Qzt, making the Mb

as boudins. The Peg has flow foliation folded with east-south-easterly and moderately plunging axis (Sk).

0618z Highest peak in the si alternations. Morainic boulders are scattered on it.

0619 Px Mb (Sp), alternating with si Gn (Sk).

0620 Si Bi gn Gr (Sp)–Gn–Qzt with Mb (Mb of 0619) intercalations and with pools of pink Kf Ap (Sk).

0621 White Kf-Bi-Qz Peg (Sp), cutting the 0619 and 0620 rocks. The Sp is intermediate facies between the pink Kf Ap and the Peg (Sk).

0622 Pink Ga Gr–felsic Gn with thin and few Mb intercalations.

0622z Southeasterly open minor fold cuts the gentle easterly closed minor fold (Ph).

0622y Cha without Ga.

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A69101207–1209 route (Fig. A-9)

(1207–1209 of the route map means A69101207–A69101209)

A69101207 Pink Gr (Sp), pink–orange Kf rich, and with elongated c grains of Qz.

1208 F Bi-Kf-Qz Gn (Sp).

1208z Cha with pink Feld band.

1208y Si Gn/Mb with Ga.

1208x Si f gr Gn, mafic mineral is somewhat abundant than the rocks distributed to the south.

1208w F si gr Gn/Mb.

1209 Ga-bearing f very leucocratic–leucocratic Bi Gn, homogeneous. Almost all of the rocks are si f gr Gn with Mb patches.

1209z Si f gr Gn with Ga with intercalations of Mb.

1209y F gr Gn with a small amount of basic part.

1209x F gr Gn with Ga, somewhat richer in pink Kf band.

Abbreviations for the Appendix Table

Amph: amphibolite, Ap: aplite, Bi: biotite, c: coarse-grained, Cha: charnockite, Cal: calcite, Dio: diorite, Diop: diopside, f: fine-grained, Feld: feldspar, Ga: garnet, Gn: gneiss, Gr: granite, Ho: hornblende, Hyp: hypersthene, Kf: potash feldspar, m: medium-grained, Ma: marble, Mb: metabasite, Peg: pegmatite, Ph: photograph was taken, Pl: plagioclase, Px: pyroxene, Q-F: quartz-feldspathic, Qz: quartz, Qzt: quartzite, s: small-grained, Sc: scapolite, si: siliceous, Sill: sillimanite, Sk: sketch was made, Sp: specimen was collected, Spi: spinnel. These abbreviations are used either as nouns (with capital) or adjectives (small letter).