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SOME GEOLOGICAL OBSERVATIONS ON THE ARCHEAN NAPIER COMPLEX AT MT. RIISER-LARSEN, AMUNDSEN BAY, ENDERBY LAND

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Abstract: The summer party of the 29th Japanese Antarctic Research Expedition (JARE-29, 1987–1988) performed a brief geological survey at Mt. Riiser-Larsen in Enderby Land, East Antarctica.

The Mt. Riiser-Larsen area is underlain by various kinds of granulite-facies metamorphic rocks of the Archean Napier Complex with minor mafic dike rocks. Metamorphic rocks are composed mainly of felsic gneiss with subordinate pyroxene granulite, pelitic gneiss and quartzite. Magnetite-rich rock (meta-ironstone) and pyroxenite crop out sporadically. Metamorphic rocks show a well-layered sequence due to the difference of lithologies, indicating that most of the metamorphic rocks were derived from sedimentary rocks.

By and large, layering of the metamorphic rocks trends E-W to NE-SW, and dips south homoclinally. The felsic gneiss is locally lineated, due to the preferred orientation of elongated quartz and feldspar grains. These lineations dip south gently. Two types of mesoscopic folds, an earlier isoclinal fold and a later open fold, are found.

Mafic dikes, which include basalt and dolerite, discordantly intrude the metamorphic rocks throughout the area. All the mafic dikes are weakly metamorphosed but igneous textures are well preserved, and the dikes are not folded. They were emplaced after the main stage of the granulite-facies Napier metamorphism and folding. These mafic dikes can be regarded as members of the Amundsen Dikes.

1. Introduction

The Archean Napier Complex has been marked with very high temperature metamorphism and the oldest crystalline basement in Antarctica. Since the first report of the sapphirine-quartz association by DALLWITZ (1968) from Enderby Land, critical minerals and mineral assemblages such as osumilite, calcic mesoperthite, orthopyroxene-sillimanite-quartz have been recognized on a regional scale (*e.g.*, RAVICH and KAMENEV, 1972; SHERATON *et al.*, 1980; GREW, 1982). Experimental results on these mineral assemblages suggest that metamorphic conditions of the Napier Complex were very high temperature, moderate lithostatic pressure and low water pressure. Moreover, SOBOTOVICH *et al.* (1976) reported a 4000 Ma Pb-Pb age, and recently BLACK *et al.* (1986) offered isotopic evidence for felsic crust as old as

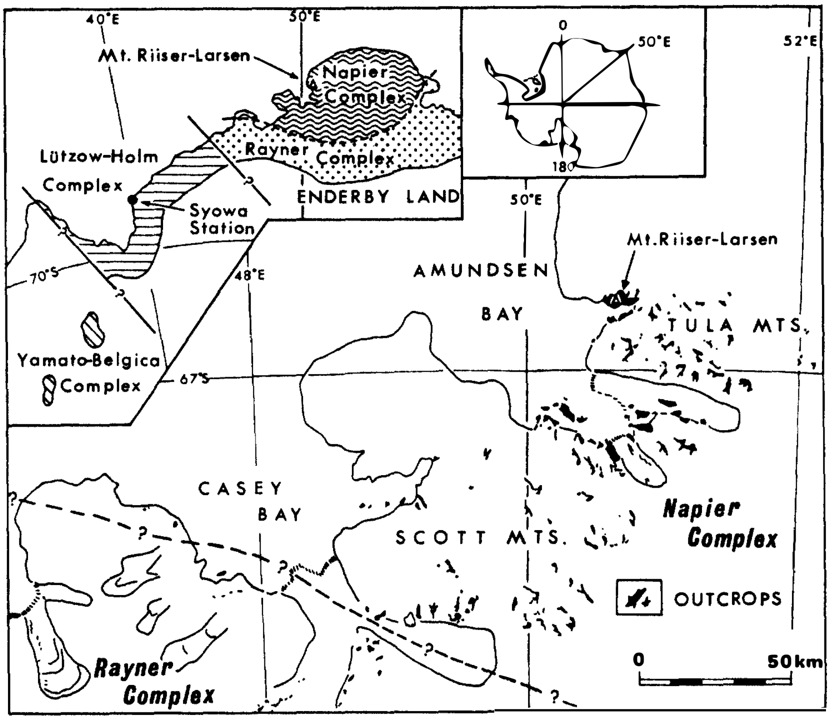

Fig. 1. Location map of Mt. Riiser-Larsen. A broken line with question marks shows the position of the boundary between the Napier Complex and the Rayner Complex (from SHERATON *et al., 1987). Boundaries between the Precambrian metamorphic complexes in index map are from* SHIRAISHI *et al. (1987).*

3930 Ma. In their review of the Napier Complex tectonics. SHERATON *et al.* (1987) showed that in many parts of the Napier Complex, very high temperature granulite-facies metamorphism, under peak metamorphic conditions of 900–1000°C at 7–11 kbar, took place about 3070 Ma ago, while DEPAOLO *et al.* (1982) suggested that the peak metamorphism occurred 2500 Ma ago.

Mt. Riiser-Larsen (66°47′S, 50°42′E) is located on the coast of Amundsen Bay, in Enderby Land (Fig. 1). The Precambrian basement exposed around Mt. Riiser-Larsen consists of granulite-facies metamorphic rocks of the Napier Complex and minor mafic dike rocks. As members of the 29th Japanese Antarctic Research Expedition (JARE-29, 1987–1988), we performed a brief geological survey in the northern part of the Mt. Riiser-Larsen area from February 18 to 22, 1988 (MAKIMOTO *et al.*, 1988). In this paper, we present the results of the field work and petrography of the metamorphic rocks and mafic dikes in order to provide a basis for future detailed investigations.

At Mt. Riiser-Larsen, a Japanese field party also made a short visit during JARE-23 (in February 1982). As a result of this field work, YOSHIDA and MORIWAKI (1983) mapped the geomorphological features of the area, while MOTOYOSHI and MATSUEDA (1984) described the mineralogy of the Archean granulites and deduced conditions of about 900°C, 8–10 kbar for their metamorphism.

2. Geological Outline

The investigated area is enclosed on three sides by steep ridges including the main peak of Mt. Riiser-Larsen (1153 m in altitude), and on the north it is bounded by the frozen marginal lake (Richardson Lake) and ice sheet.

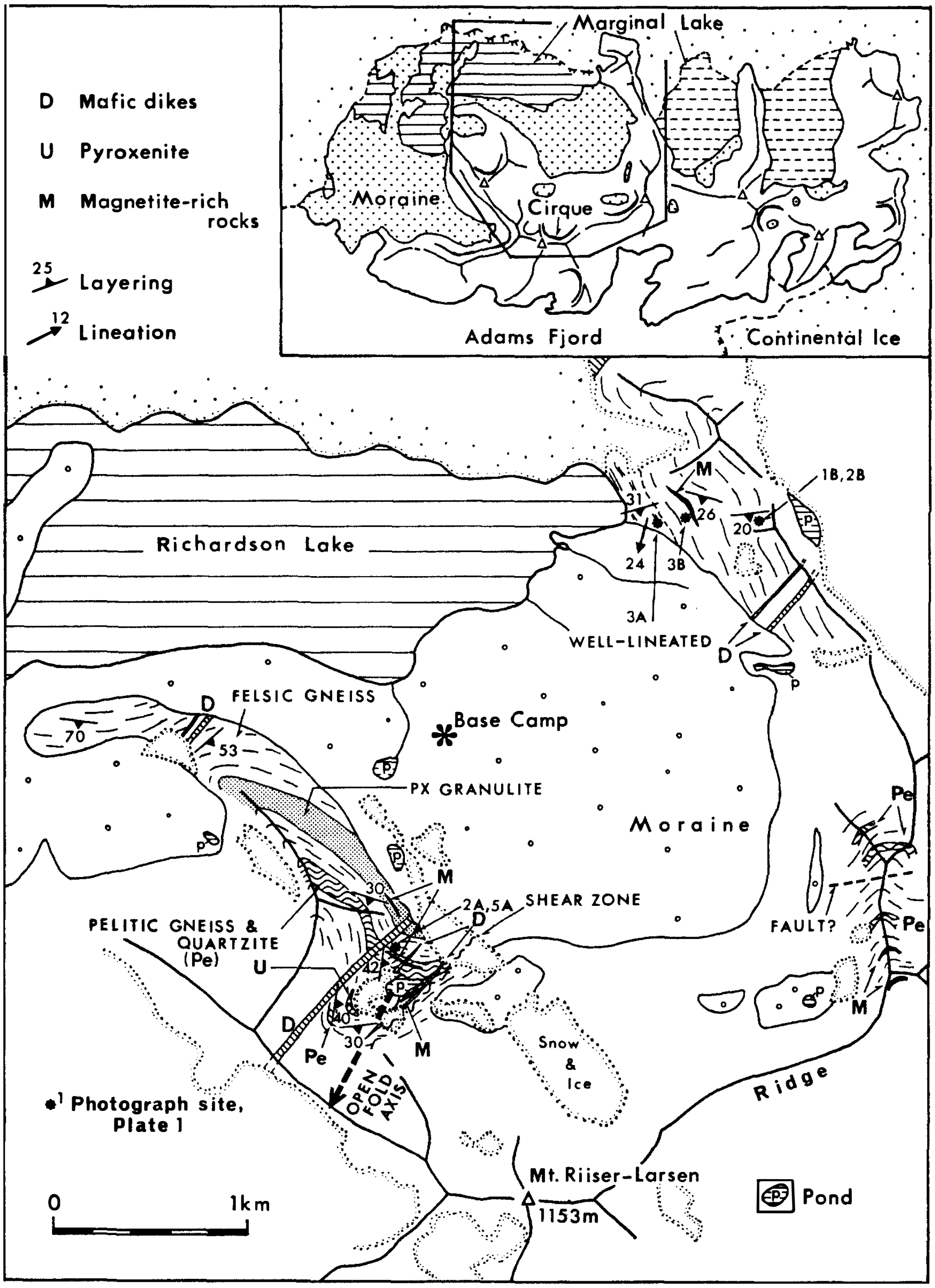

Fig. 2. Major lithologies and geologic structures in the northern part of Mt. Riiser-Larsen. Inserted map showing geomorphological features around Mt. Riiser-Larsen is simplified from YOSHIDA and MORIWAKI (1983). Peak height (1153 m) of Mt. Riiser-Larsen is cited from 1: 25000 topographic map made by K. MORIWAKI of National Institute of Polar Research. Pe=Pelitic gneiss and quartzite.

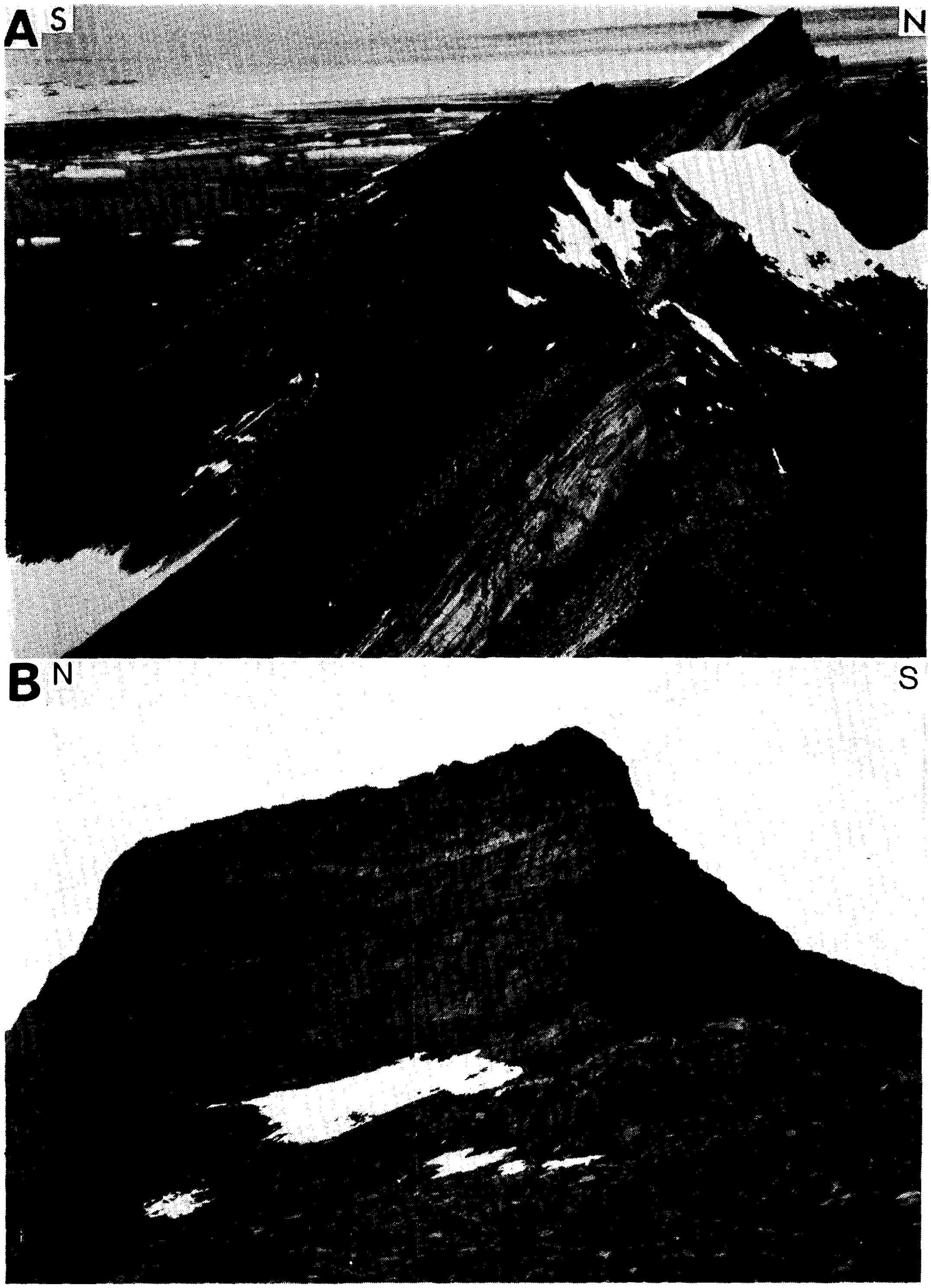

Plate 1. A: Well-layered sequence of metamorphic rocks around the peak of Mt. Riiser-Larsen (arrow), view from helicopter. Strike of layering is subparallel with E-W-trending ridge of Mt. Riiser-Larsen, and the dip is about 45° to the south. B: Nearly flat-lying felsic gneisses at cliff northeast of the Base Camp. Height of cliff is about 160 m.

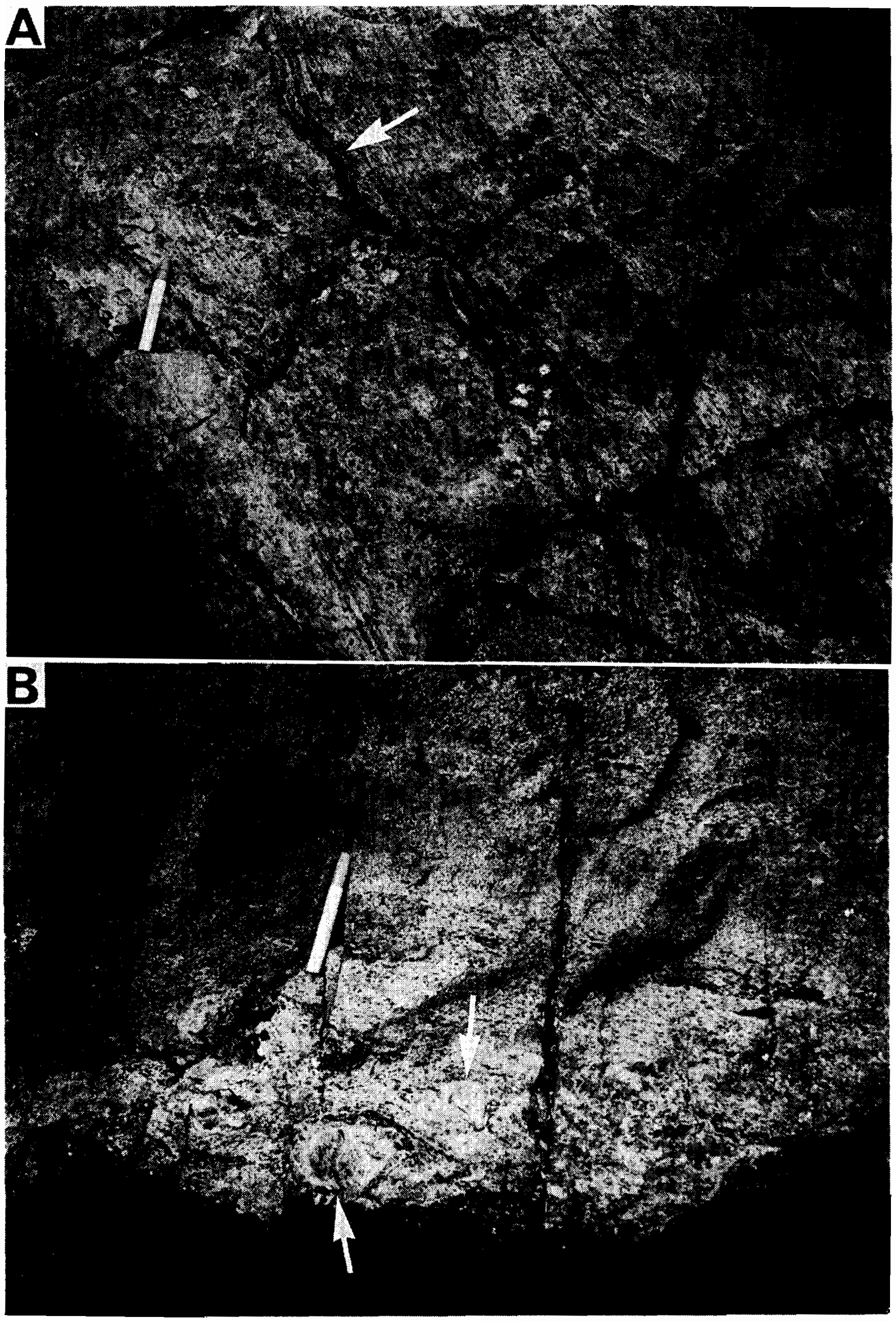

Plate 2. A: Garnet-quartz-feldspar gneiss with thin sapphirine-rich layers (arrow) at a locality south of the Base Camp. B: Orthopyroxene-quartz-feldspar gneiss with plagioclase pods (arrow) at an outcrop northeast of the Base Camp.

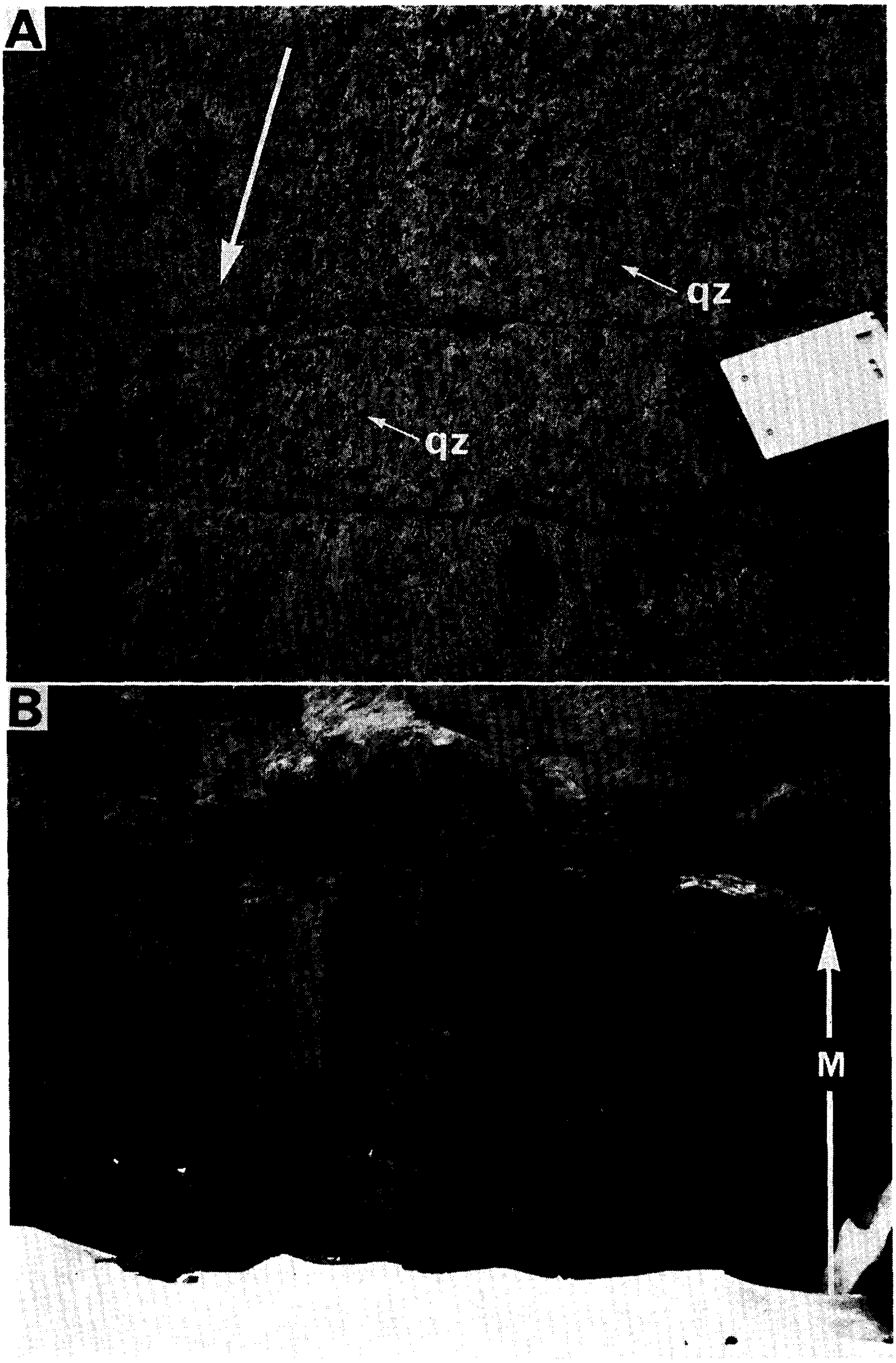

Plate 3. A: Well-lineated orthopyroxene-quartz-feldspar gneiss; large arrow shows trend of the elongated quartz grains (dark; some examples are arrowed); view from south. B: Magnetite-rich rock (M; 1.5 m thick) overlain by orthopyroxene-quartz-feldspar gneiss. Both A and B are northeast of the Base Camp.

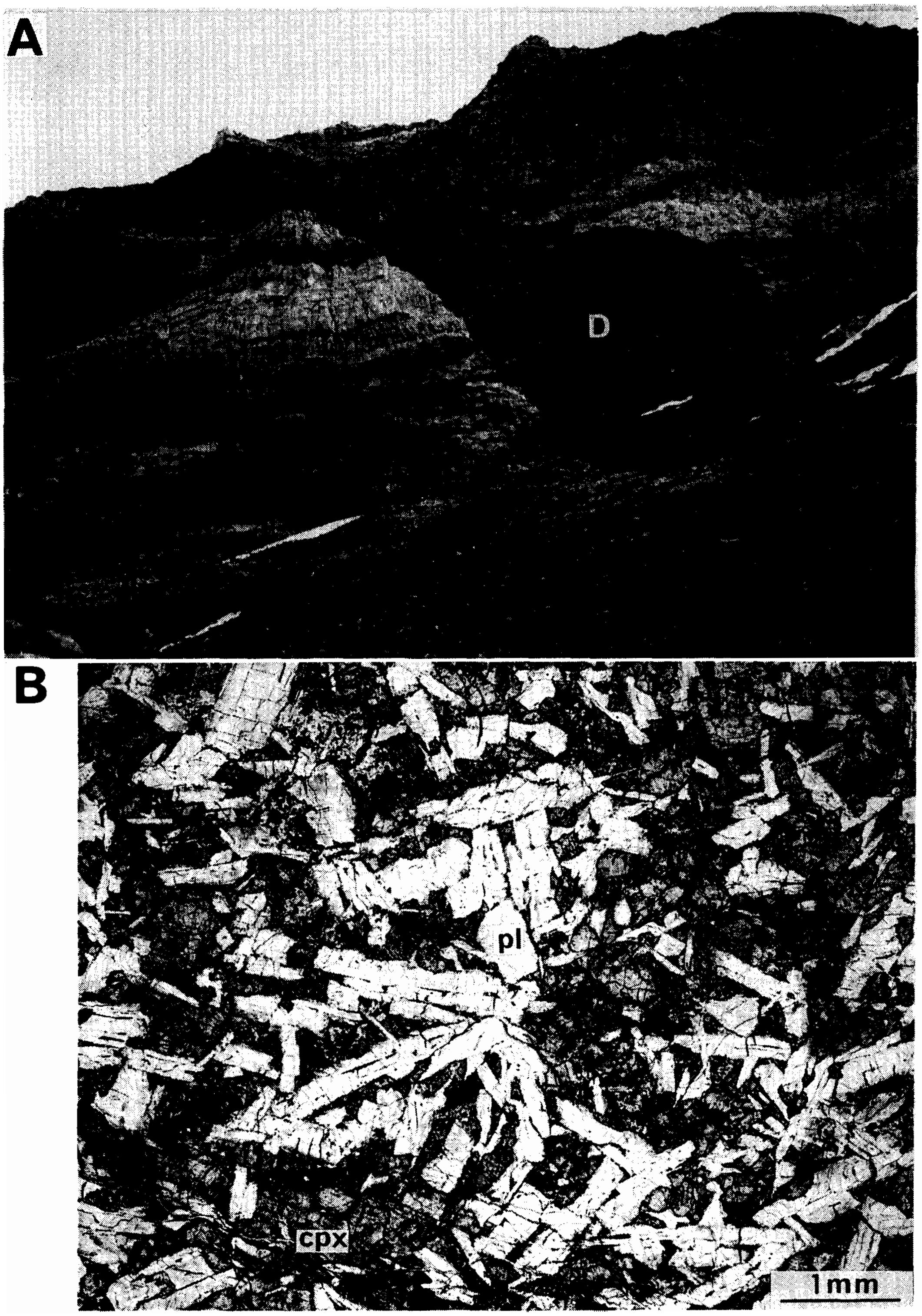

Plate 4. *A: Mafic dike (D) cutting discordantly well-layered metamorphic rocks in steep slope south of the Base Camp (view west). Width of dike is about 25 m. B: Photomicrograph of dolerite (sample: HM88021806). Plane light. Pl: plagioclase, Cpx: clinopyroxene.*

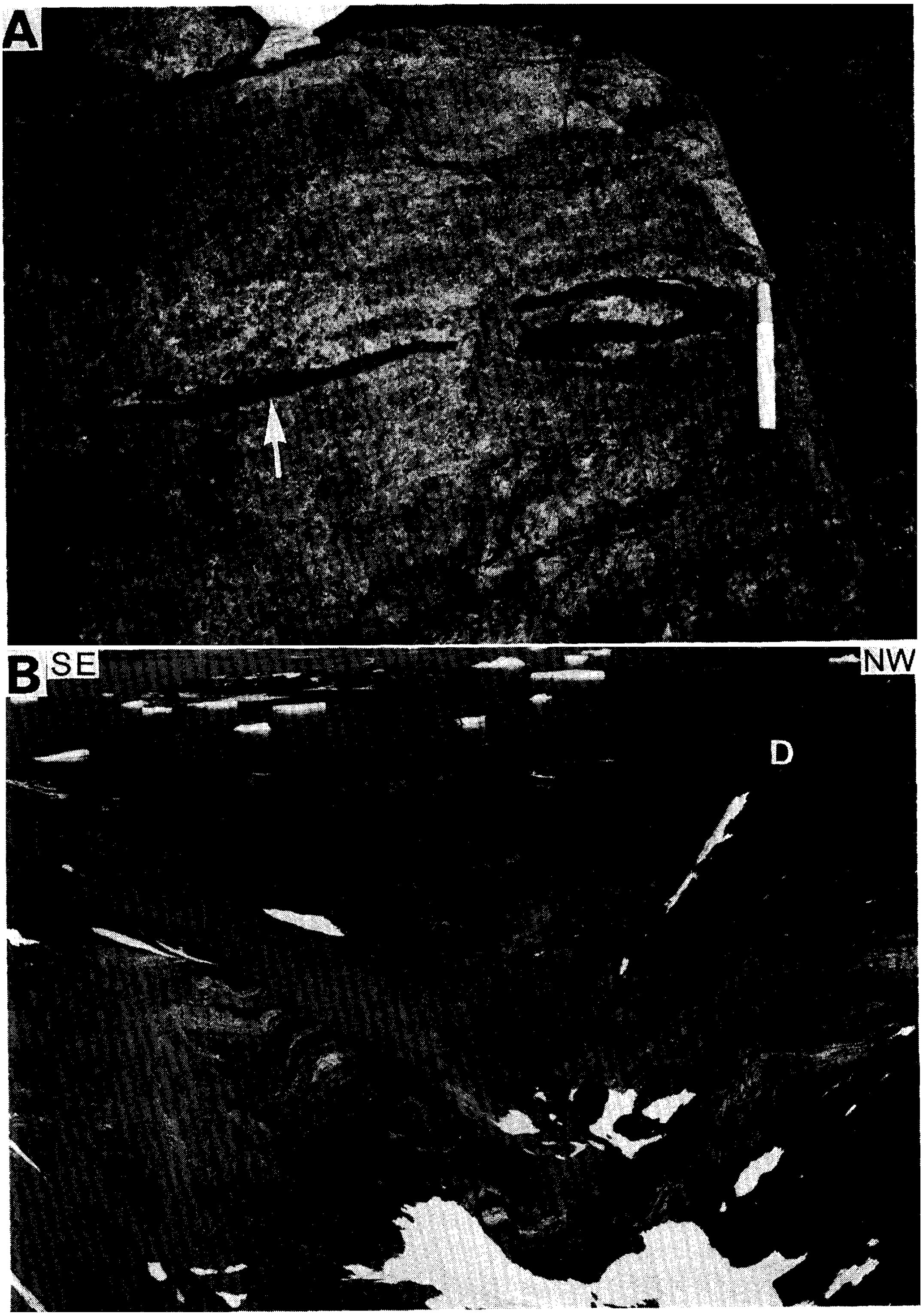

Plate 5. A: Isoclinally folded sapphirine-rich layer (dark) in impure quartzite at a locality south of the Base Camp. B: Mesoscopic open fold in felsic gneiss at an outcrop about 2 km south of the Base Camp. View from the air. Height of cliff is about 300 m. Mafic dike of Plate 4A is also at upper right of view.

Distribution of major lithologies in the surveyed area is illustrated in Fig. 2. Felsic gneiss is dominant among the metamorphic rocks. Pyroxene granulite, pelitic gneiss and quartzite are subordinate; these were found in the southwestern and eastern areas. Magnetite-rich rock and pyroxenite crop out sporadically. No calc-silicate and migmatitic rocks were observed. Metamorphic rocks around Mt. Riiser-Larsen show a well-layered sequence due to the difference of lithologies (Plates 1A and 1B). On the steep northern slopes of Mt. Riiser-Larsen, we can observe the sub-horizontal layered structure. But this gently dipping structure is apparent: layering of the metamorphic rocks generally trends E-W to NE-SW, and dips south (20°–70°) homoclinally. This geologic structure shows that the metamorphic rocks of the southwestern area correspond to the rocks in the eastern area and to the upper part of the rock sequence in the northeastern area.

Mafic dikes, which include basalt and dolerite, discordantly intrude the metamorphic rocks.

3. Metamorphic Rocks

The granulite-facies metamorphic rocks in the Mt. Riiser-Larsen area can be divided into the following six rock types, based on the mode of occurrence and mineral assemblages;

1) felsic gneiss
2) pyroxene granulite
3) pelitic gneiss
4) quartzite
5) magnetite-rich rock
6) pyroxenite

The metamorphic rocks consist primarily of anhydrous minerals, except for the highly magnesian rocks, such as those with osumilite, and for the ultramafic rocks, in both of which phlogopite appears to be part of the high temperature assemblage (*e.g.*, GREW, 1982). In most cases, the hydrous minerals such as biotite* and hornblende are secondary. In the pelitic gneiss and quartzite, a wide variety of critical mineral assemblages characteristic of the Napier complex are found.

3.1. Felsic gneiss

Felsic gneiss is white to gray (pale-brown in weathered surface), fine- to medium-grained, and well-layered. It is locally lineated due to the elongation of felsic minerals (mainly quartz). The felsic gneiss is interlayered with pyroxene granulite, pelitic gneiss and quartzite (Plate 2A). The following mineral assemblages are observed in the rock:

1) orthopyroxene-quartz-mesoperthite
2) orthopyroxene-quartz-plagioclase ± K-feldspar
3) garnet-quartz-mesoperthite
4) garnet-quartz-K-feldspar ± plagioclase

* Biotite (phlogopite) in assemblage 8) on p. 137 is probably primary.

5) garnet-orthopyroxene-quartz-mesoperthite

Among these assemblages, the last is less common. Usually plagioclase is antiperthite and K-feldspar is perthite. Opaque minerals, zircon, apatite and rutile are minor constituents. Orthopyroxene is locally replaced along the cleavages and the edges by secondary brown biotite. Pale-green hornblende and rarely muscovite are other secondary minerals.

The orthopyroxene-quartz-feldspar gneiss shows fine alternations of orthopyroxene-rich layers (less than 2 mm thick) and quartzo-feldspathic layers (5 mm to 2 cm thick). The garnet-quartz-feldspar gneiss also commonly exhibits alternations of garnet-rich layers and quartzo-feldspathic layers of centimeter- to meter-scale in thickness. In the garnet-rich layers, lenticular garnet-rich aggregates of 1 mm to 5 mm thick and 5 mm to 5 cm long are characteristically present. Garnet, 5 mm in maximum diameter, is orange to pink.

Plagioclase pods (up to 8 cm in diameter) in the orthopyroxene-quartz-feldspar gneiss occur in the northeastern area (Plate 2B). These may be regarded as boudinaged plagioclase-rich layers. The pods consist of coarse-grained plagioclase with minor orthopyroxene and opaque minerals.

3.2. Pyroxene granulite

Pyroxene granulite is gray to dark-gray, massive, and commonly fine-grained (0.1 to 2 mm). But coarse-grained (1 to 5 mm) pyroxene granulite is locally found, and alternates with fine-grained granulite. Pyroxene granulite crops out as a mappable layer about 30 m thick in the southwestern area, and is interlayered with the felsic gneiss. Except for this layer, the pyroxene granulite is recognized as thinner layers 2 cm to several meters thick in the felsic gneiss throughout the area.

The pyroxene granulite consists mainly of orthopyroxene, clinopyroxene and plagioclase (generally andesine or labradorite) with locally subordinate quartz, and is granoblastic. Opaque minerals and apatite are minor constituents, and secondary brownish biotite locally formed around opaque minerals.

3.3. Pelitic gneiss

Pelitic gneiss is light-grey, medium-grained, and well-layered and lineated. This is interlayered with the felsic gneiss and quartzite in the southwestern and eastern areas. Typical mineral assemblages are;

1) sapphirine-quartz-mesoperthite
2) sapphirine-sillimanite-orthopyroxene-quartz-mesoperthite
3) sapphirine-sillimanite-garnet-quartz-mesoperthite
4) sapphirine-cordierite-orthopyroxene-quartz
5) osumilite-sillimanite-quartz-mesoperthite
6) osumilite-sillimanite-orthopyroxene-quartz
7) osumilite-sapphirine-garnet-quartz
8) sillimanite-garnet-spinel-corundum-phlogopite

Biotite, rutile, green spinel and opaque minerals are minor constituents. Garnet porphyroblasts up to 10 cm in diameter are found in assemblage 8). In the sapphirine-bearing assemblages, cordierite $\pm$ K-feldspar $\pm$ orthopyroxene reaction rim between sapphirine and quartz is commonly observed. In all the sections studied, osumilite is partially replaced by a fine-grained symplectitic intergrowth of cordierite, K-feldspar, quartz and orthopyroxene (GREW, 1982).

3.4. Quartzite

Quartzite is white to grey, or blue, and medium-grained. Blue quartz is characteristic in hand specimens. The quartzite is found in the southwestern area and is intercalated with felsic gneiss and pelitic gneiss. It is well-layered and the layers generally range in thickness from 1 cm to several meters. The following mineral assemblages are observed in the quartzite;

1) sapphirine-quartz
2) sapphirine-orthopyroxene-quartz
3) sapphirine-garnet-quartz
4) sapphirine-orthopyroxene-garnet-quartz
5) orthopyroxene-garnet-quartz
6) spinel-quartz

The commonly observed cordierite $\pm$ K-feldspar $\pm$ orthopyroxene reaction rim between sapphirine and quartz is similar to those in pelitic gneiss. Rutile, zircon and biotite are accessories.

3.5. Magnetite-rich rock

At six localities, magnetite-rich rock is recognized as dark-colored layers a few meters thick within the felsic gneiss, pyroxene granulite and quartzite (Plate 3B). The layer of this rock in the northeastern area can be traced for as much as 50 m along strike. Although the magnetite-rich rock is generally massive, medium- to coarse-grained, it often shows an intensive sheared structure. In this rock, lenticular aggregates of fine-grained pyroxene and quartz with undulation extinction and network of cataclastic magnetite are recognized in thin section. The two kinds of mineral assemblages are observed in the rock;

1) quartz-magnetite-orthopyroxene $\pm$ clinopyroxene
2) quartz-magnetite-garnet-orthopyroxene $\pm$ clinopyroxene

Garnet constitutes maximum 20 modal % of the rock. As opaque mineral, minor ilmenite is also present.

3.6. Pyroxenite

The pyroxenite is found only in the southwestern area as a lens (about 15 m$\times$5 m) within the quartzite which is interlayered with felsic gneiss. This rock is medium-grained, massive, and consists chiefly of orthopyroxene with subordinate olivine, brown spinel and phlogopite.

4. Dike Rocks

In the surveyed area, mafic dikes, trending NE-SW, discordantly intrude the metamorphic rocks with clean-cut contacts (Plate 4A). They are not folded, but are locally intensively sheared. The mafic dikes in the northeastern area can be regarded as the northern extension of those in the southwestern area.

Most of the mafic dikes are 1 m to a few meters thick, and are dark-colored massive basalt or dolerite with rarely porphyritic plagioclase. In some thick dikes, ranging in thickness from 20 to 30 m, their marginal part is doleritic, but the central part is coarser-grained and equigranular.

The mafic dikes consist mainly of clinopyroxene and plagioclase (andesine to labradorite) in places with minor quartz. Subophitic to gabbroic textures are characteristic in thin section (Plate 4B). Plagioclase is commonly zoned. Minor constituents are apatite and opaque minerals. In many cases, clinopyroxene is partially replaced by a greenish hornblende. In one mafic dike, phenocrysts of clinopyroxene and plagioclase laths have been distinctly preserved, but the groundmass has recrystallized to fine-grained clinopyroxene-green hornblende-biotite-plagioclase-quartz aggregates.

5. Geologic Structure

Stereographic projection of the structural features is shown in Fig. 3. Compositional layering of the metamorphic rocks strikes generally E-W to NE-SW, and dips south. Dips in the southwestern area range from 25° to 70°, while those in the northeastern area, from 20° to 30°. The wide variation of dip angles in the southwestern area is due to a mesoscopic open fold (see below).

Except for the pelitic gneiss, the metamorphic rocks in the study area are not lineated or only slightly so. However, the lowermost unit of the felsic gneiss in the northeastern area, that is, an orthopyroxene-quartz-feldspar gneiss which is at least 30 m thick, is well lineated (Fig. 2; Plate 3A). The lineation is due to the preferred orientation of elongated quartz and plagioclase grains (1 to 2 mm across and up to 8 mm long) which correspond to a uniaxial extension. It strikes NNE-SSW and plunges south gently.

In the metamorphic rocks of the southwestern area, two types of mesoscopic folds are found. One is an isoclinal fold, defined by sapphirine-rich layers in the quartzite (Plate 5A). Its axial plane is parallel to the compositional layering which

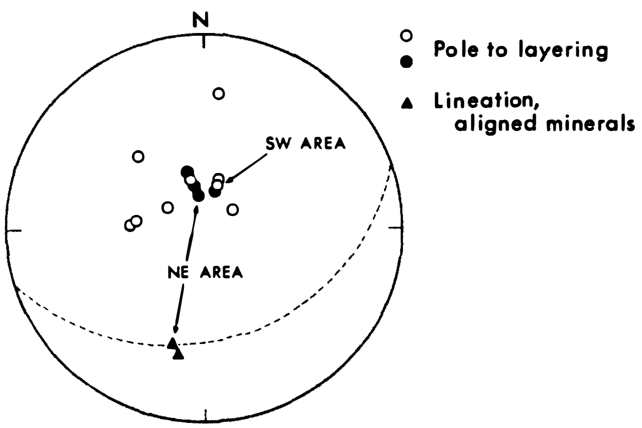

Fig. 3. Stereographic plots of the structural features in the northern part of Mt. Riiser-Larsen.

suggests a sedimentary bedding. The other is an open fold with axial cleavage developed in layers of felsic gneiss (Plate 5B). Its axial plane dips steeply to the west or northwest.

A shear zone, trending NE-SW, is locally developed in the garnet-quartz-feldspar gneiss, magnetite-rich rock and mafic dike rock in the southwestern area (Fig. 2). In garnet-quartz-feldspar gniess, sheared garnet grains and recrystallized greenish biotite between garnet clasts are observed in thin section.

6. Concluding Remarks

Judging from the strike and dip of the layered structures, the total thickness of the metamorphic rocks constituting Mt. Riiser-Larsen is more than 1000 m. The occurrence of the well-layered pelitic, quartz-rich and ferruginous rocks indicates that most of the metamorphic rocks in this area are probably derived from the sedimentary rocks, as was suggested by MOTOYOSHI and MATSUEDA (1984). The felsic rocks may be derivatives from psammitic or acid volcanic rocks. However, there remain many outstanding problems for determining protoliths, so that geochemical considerations, especially on trace elements, will be needed.

In the Napier Complex, five suites of mafic and ultramafic dikes are recognized on the basis of petrography, chemistry and geochronology (SHERATON and BLACK, 1981). All the mafic dike rocks from the Mt. Riiser-Larsen area contain well-preserved igneous textures and cut the geologic structures, including the later folds, in the metamorphic rocks. These facts indicate that the mafic dikes were emplaced after the main stage of the granulite-facies metamorphism and folding. Furthermore, local intensive shearing in the mafic dikes suggests that the dike intrusion was prior to an episode of shearing. Based on the petrographic features, the mafic dikes of this area can be correlated with the Amundsen Dikes of a 1190$\pm$200 Ma Rb-Sr whole rock age (SHERATON and BLACK, 1981). The Amundsen Dikes are subdivided into three groups mainly on the basis of chemistry (SHERATON and BLACK, 1981). More detailed characterization of the mafic dikes is planned.

On the deformation in the Napier Complex, three main folding stages F1 to F3 are summarized by SHERATON *et al.* (1987). In their results, earlier F1 and F2 are the stages of isoclinal folds, and F3 of the last stage is that of an open fold and controls the present regional structures of the metamorphic rocks in the Napier Complex. According to our field observations, two types of folds decribed above, the isoclinal fold and the open fold in this area, may correspond to F1 and F3, respectively. Moreover, the open fold axis is sub-parallel to the π axis related to F3 folds, trending NE-SW, in the west Tula Mountains sub-area (B) of the Napier Complex (SHERATON *et al.*, 1987, Fig. 52). A summary of deformational events at Mt. Riiser-Larsen is as follows:

1) Isoclinal folding associated with peak metamorphism (and formation of lineation in felsic gneiss of the northeastern area?)—F2 fold of SHERATON's *et al.* (1987) were not observed—
2) Open folding with axial cleavage—Emplacement of Amundsen Dikes—
3) Shearing and retrograde metamorphism

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