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GEOLOGICAL AND PETROLOGICAL CHARACTERS OF THE PLUTONIC ROCKS IN THE LUNCKERYGGEN-BRATTNIPENE REGION, SØR RONDANE MOUNTAINS, EAST ANTARCTICA

Tohru SAKIYAMA[1], Yuhei TAKAHASHI[2] and Yasuhito OSANAI[3]

[1]*Institute of Geology and Mineralogy, Faculty of Science, Hiroshima University, 1-89, Higashi-Sendamachi 1-chome, Naka-ku, Hiroshima 730*
[2]*Geological Survey of Japan, 1-3, Higashi 1-chome, Tsukuba 305*
[3]*Department of Earth Sciences, Fukuoka University of Education, 729, Akama, Munakata 811-41*

Abstract: Plutonic rocks in the Lunckeryggen-Brattnipene region, Sør Rondane Mountains are divided into the older (late Proterozoic) and younger (early Paleozoic) intrusive rocks. The older intrusive rocks are composed of tonalite, quartz diorite, granodiorite and small sheet-like granite, granodiorite and trondhjemite. They have a gneissose structure and show a concordant relation to the surrounding metamorphic rocks. On the basis of their field occurrences, it seems that they have intruded before or during the period of the regional mylonitization. The younger intrusive rocks are composed of syenite, quartz syenite and granite. They occur as stocks or dikes intruding discordantly into the surrounding rocks. The older intrusive rocks give low values of magnetic susceptibility in general, while most of the younger intrusive rocks give high magnetic values in Lunckeryggen and the neighborhood. Magnetic values on the discordant granites of the younger stage decrease northward in the Lunckeryggen-Brattnipene region. Moreover, the magnetic values of the younger intrusive rocks in the western Sør Rondane Mountains show a possibility that the lateral variation extends farther west from the Lunckeryggen-Brattnipene region.

The younger intrusive rocks are composed of alkaline rocks in contrast with the older intrusive rocks dominated by tonalite and granodiorite with low K_2O content in the Sør Rondane Mountains.

Syenitic rocks in the Sør Rondane Mountains are characterized by high K_2O and low Na_2O contents. Such extremely high K_2O/Na_2O ratios correspond to that of the syenitic rocks in the Yamato and Belgica Mountains and it is considered that the high K_2O/Na_2O ratio may be a general characteristic of the early Paleozoic plutonism in the eastern Queen Maud Land. The transition of the plutonism from calc-alkaline to alkaline affinity corresponds to the tendency of the Pan-African magmatism.

1. Introduction

The Sør Rondane Mountains, located at 22° to 28°E longitude and 71.5° to 72.5°S latitude, are underlain by various metamorphic and plutonic rocks. Belgian and Japanese geologists have performed the geological surveys and have outlined the geology of the mountains (VAN AUTENBOER, 1969; VAN AUTENBOER and LOY, 1972; KOJIMA and

SHIRAISHI, 1986; ISHIZUKA and KOJIMA, 1987), but many petrological problems still remain open. Among them, of special interest is the genesis and the tectonic significance of the latest Proterozoic to early Paleozoic magmatism. The present authors have performed the detailed geological survey in the central part of the Sør Rondane Mountains, where the metamorphic and plutonic rocks are exposed very well. This paper presents the detailed geology, petrography and some data of magnetic susceptibility and chemical composition of the plutonic rocks.

2. Outline of Geology

Generalized geological map of the surveyed area and detailed geological map of Lunckeryggen are shown in Figs. 1 and 2, respectively. The metamorphic rocks in the Sør Rondane Mountains are divided into the Telte-Vengen group and the Nils-Larsen group by the E-W trending shear zone named the Main Shear Zone (VAN AUTENBOER, 1969; KOJIMA and SHIRAISHI, 1986). The Telte-Vengen group is composed mainly of pelitic and psammitic gneisses associated with some intercalated basic and calcareous rocks. They have been subjected to the granulite- to upper amphibolite-facies metamorphism (KOJIMA and SHIRAISHI, 1986). The Nils-Larsen group is composed mainly of gneissose tonalite and basic schists which have been subjected to mylonitization under

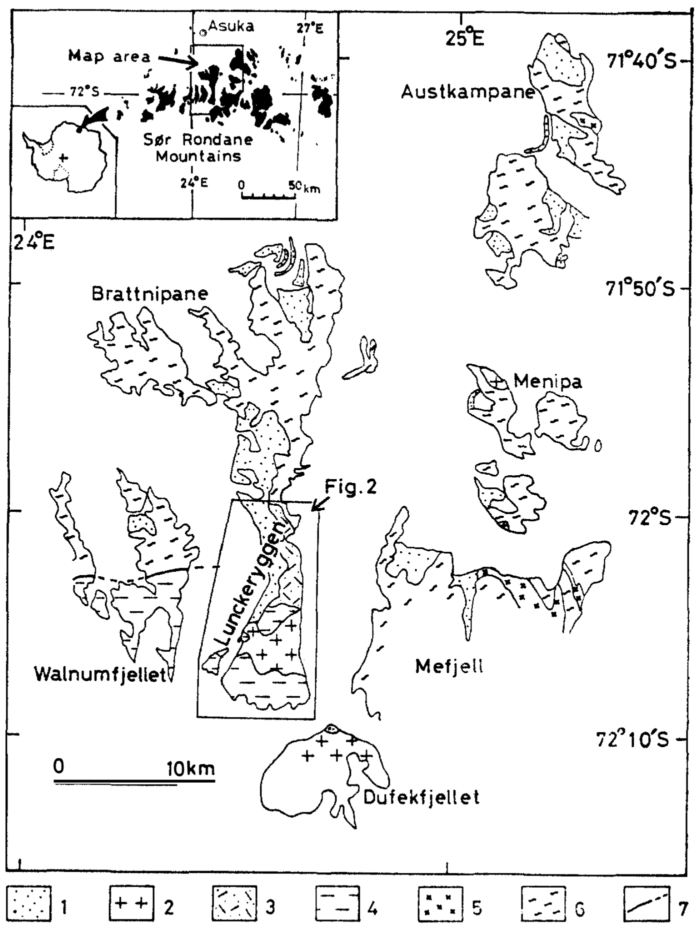

Fig. 1. Schematic geological map of surveyed area. 1: Moraine, 2, 3: Younger intrusive rocks (2: Granitic rocks, 3: Syenitic rocks), 4, 5: Older intrusive rocks (4: Tonalite, 5: Granodiorite to granite), 6: Metamorphic rocks, 7: Main Shear Zone.

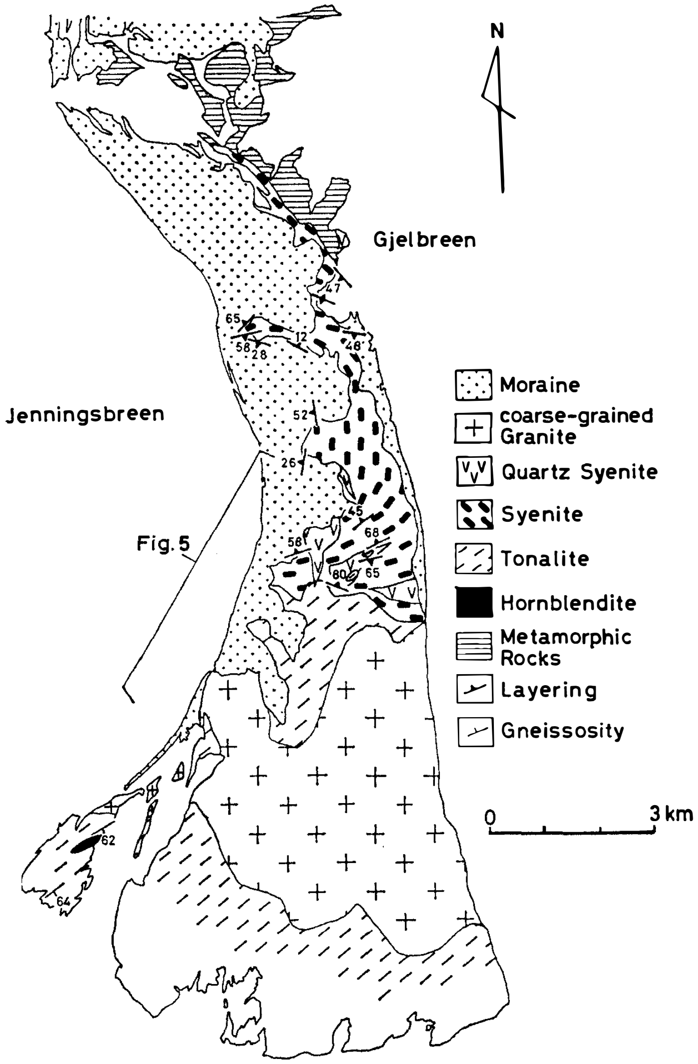

Fig 2. Geological map of the Lunckeryggen area.

condition of the green schist to epidote amphibolite-facies (KOJIMA and SHIRAISHI, 1986).

Based on the field occurrence, plutonic rocks are subdivided into older and younger intrusive rocks. The older intrusive rocks generally show concordant relations to the metamorphic rocks and have foliation parallel to the structure of the surrounding metamorphic rocks. They are sheared or mylonitized and often thermally metamorphosed by the younger intrusive rocks. PASTEELS and MICHOT (1968) has reported a U-Pb age of 950 Ma on the tonalite which is the most widespread among the older intrusive rocks. The younger intrusive rocks are found as discordant stocks and dikes. They intruded after the regional mylonitization represented by the Main Shear Zone. The U-Pb and Rb-Sr ages of 450 to 602 Ma on the younger intrusive rocks have been reported by PICCIOT *et al.* (1963) and PASTEELS and MICHOT (1968, 1970).

3. Description of Plutonic Rocks

Mutual intrusive relations of the plutonic rocks are given in Fig. 3 and their modal compositions are shown in Fig. 4. Older intrusive rocks are composed of tonalite, granodiorite and related quartz diorite, and small sheet-like bodies of granitic rocks. On the other hand, younger intrusive rocks are composed of syenitic complex, Lunckeryggen granite and small granitic dikes.

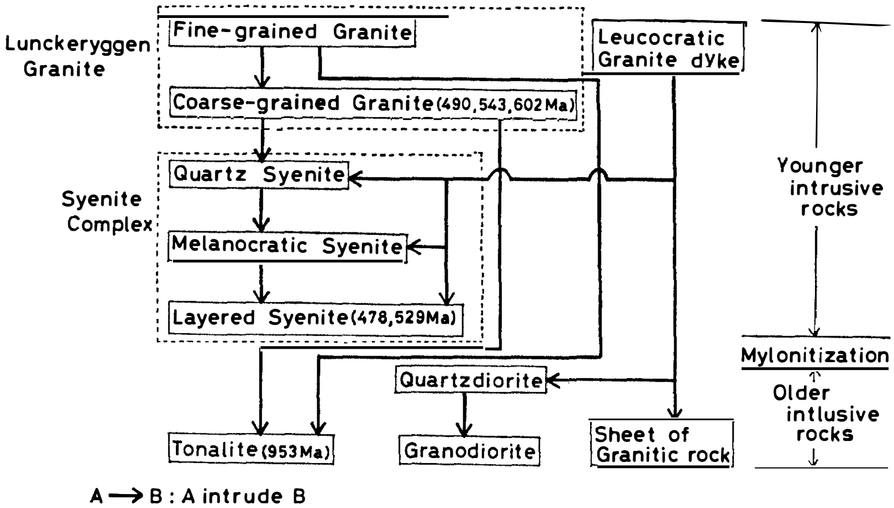

Fig. 3. Mutual relations of the intrusive rocks. Age data from: PICCIOTTO *et al. (1963) and* PASTEELS *and* MICHOT *(1968, 1970).*

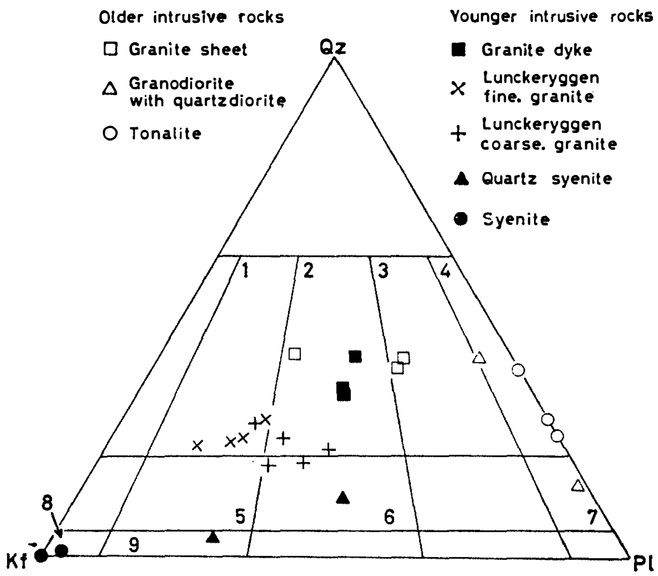

Fig. 4. Modal quartz(Qz) -plagioclase(Pl) -potash-feldspar(Kf) diagram. Lithologies are: 1. granite, 2. adamellite, 3. granodiorite, 4. tonalite, 5. quartz monzosyenite, 6. quartz monozonite, 7. quartz diorite, 8. syenite, 9. monzosyenite.

3.1. Tonalite

Tonalite occurs in the southern part of the study area and can be traced as far as 70 km west of Lunckeryggen (KOJIMA and SHIRAISHI, 1986). It is medium- to coarse-grained biotite-hornblende tonalite and has many lenticular basic inclusions (Plate 1-A).

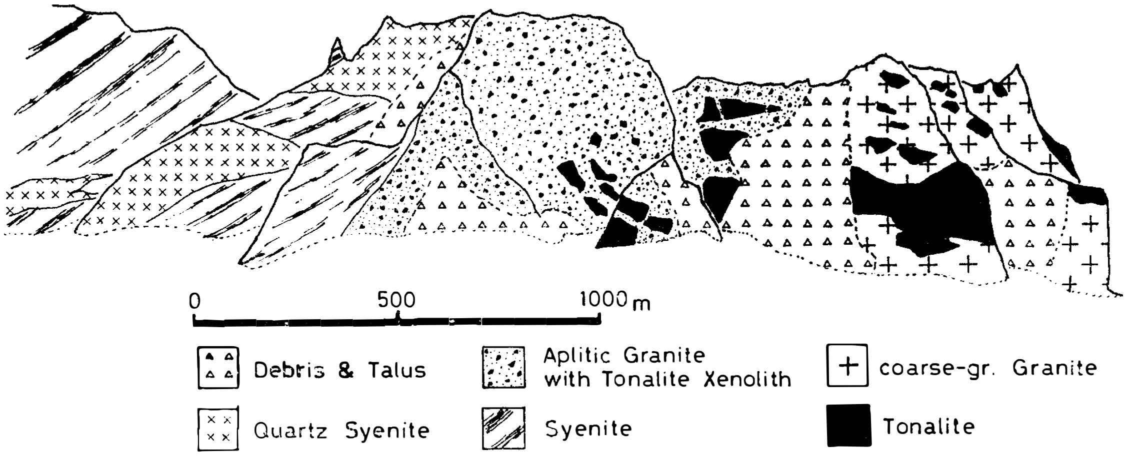

Fig. 5. Sketch of an outcrop showing the intrusive relations among the plutonic rocks in Lunckeryggen. Sketched area is shown in Fig. 2.

In Lunckeryggen, the tonalite is intruded by numerous reticular veins of the coarse-grained granite and aplitic granite and is present as blocks in such granites (Fig. 5, Plate 1-D). Principal constituents are plagioclase, quartz, hornblende and biotite with accessory apatite, zircon and opaque minerals. Hornblende and biotite crystals show a preferred orientation. Opaque minerals are dominated by ilmenite with a minor amount of magnetite, but it is questionable whether all of the magnetites have been crystallized in the magmatic stage. Secondary chlorite, epidote and magnetite are almost invariably present, and plagioclase is often saussuritized.

3.2. Granodiorite with quartz diorite

Small masses of coarse-grained granodiorite to granite, accompanied by medium- to fine-grained quartz diorite, are distributed in Austkampane and Mefjell. The granodiorite to granite are composed mainly of quartz, plagioclase, alkali feldspar, hornblende and biotite. Clinopyroxene fringed with hornblende is rarely present in the granodiorite. Accessory constituents are zircon, apatite, sphene and ilmenite.

Quartz diorite intrudes the granodiorite and the surrounding metamorphic rocks, and it includes the xenoliths of those rocks in Mefjell. Quartz diorite is variable in composition, consisting of various ratios and combinations of such chief constituents as plagioclase, quartz, biotite, hornblende and clinopyroxene. Accessory constituents are zircon, apatite, sphene and ilmenite. Anhedral garnet is rarely found and is partly converted into hornblende and quartz. These granodiorite to granite and quartz diorite are thermally metamorphosed and most of the hornblende and biotite are recrystallized into the xenomorphic granules of those minerals.

3.3. Granite sheet

Moreover, there are innumerable sheet-like bodies of granite, granodiorite and trondhjemite which are too small to be represented on the geological map. They concordantly intrude the metamorphic rocks. Their contacts with the metamorphic rocks are commonly obscure and they often give a migmatitic appearance (Plate 1-B, C).

3.4. *Syenite complex*

There is a syenite–quartz syenite complex in the central part of Lunckeryggen. It is composed of layered syenite, melanocratic syenite dikes and quartz syenite. Layered syenite shows conspicuous rhythmic layering ranging in thickness from a few centimeters to a few meters (Plate 2-A). Euhedral potash feldspar and mafic minerals in the syenite show preferred orientation. Such layering and preferred orientation show a basin structure of the mass (Fig. 2) Mylonitization is generally absent in the mass, except the northern and southern margins of the mass. Marginal part of the mass partly shows remarkable mylonitic structure which is parallel to the contact plane of the mass. Constituent minerals of the layered syenite are potash feldspar, biotite, amphibole and clinopyroxene with accessory sphene, apatite, zircon and magnetite, but their assemblages and modal compositions vary with layer. Light-colored layers are rich in potash feldspar and poor or lacking in clinopyroxene. On the other hand, dark-colored layers are rich in clinopyroxene and poor in potash feldspar and amphibole. Potash feldspar shows brownish schillerization owing to the inclusions of minute hematite. Clinopyroxene is aegirine-augite with zoning from the pale green core to the greenish rim. Bluish Na-rich hornblende replaces the clinopyroxene.

Small dikes of fine-grained melanocratic syenite discordantly intrude the layered syenite. These dike rocks have minerals of the same assemblage as the layered syenite, but they are fine-grained and very rich in mafic minerals. Thus, they come under the category of ultramafic rock.

Medium- to fine-grained quartz syenite is present as dikes, sheets or reticular veins intruding the layered syenite and the melanocratic syenite (Fig. 5 and Plate 2-B). It has an appearance of brecciated rock owing to abundant angular xenoliths of precedent rocks (Plate 2-C). Miarolitic cavities are common throughout the rock. It contains potash feldspar, plagioclase, quartz and amphibole (Na-rich hornblende), with or without biotite and clinopyroxene (aegirine-augite). Accessory constituents are sphene apatite, zircon, allanite and magnetite. Interstitial fluorite is rarely present.

3.5. *Lunckeryggen granite*

The Lunckeryggen granite is composed of a stock of coarse-grained granite and many dikes of fine-grained granite. Coarse-grained granite is generally homogeneous and massive, but it has foliation which may be the primary flow structure along the northern margin. Dark inclusions of about twenty centimeters in diameter are sometimes present. Contact plane of the granite mass and the country rocks dips outerward. The granite intrudes into tonalite and quartz syenite and has angular xenoliths of these rocks (Fig. 5). Principal constituents are quartz, potash feldspar, plagioclase, and biotite, with or without hornblende. Most of biotite occur interstitially. Accessory constituents are sphene, apatite, zircon and magnetite, with or without fluorite.

Fine-grained granite dike intrude coarse-grained granite and there are abundant xenoliths of the coarse-grained granite and tonalite (Plate 2-D). They show similar mineral assemblage to the coarse-grained granite, but hornblende is absent. Interstitial fluorite always occurs.

3.6. *Granite dike*

Medium- to fine-grained dike rocks composed of biotite granite, two-mica granite, and garnet two-mica granite are found all over the area. Light-colored aplitic granite, aplite and pegmatite intrude the granitic rocks. Potash feldspar in such rocks intruding the syenite sometimes occurs as amazonite attaining to five centimeters.

Fine-grained granites containing muscovite and garnet are mainly exposed in Mefjell. They are composed mainly of quartz, potash feldspar, plagioclase, biotite and muscovite, with or without garnet. Accessory constituents are zircon, apatite and allanite.

4. Bulk Chemical Composition of Plutonic Rocks

Chemical analyses of the intrusive rocks have been made on ICP by the Chemex Labs Ltd. in Canada. Average chemical compositions of the intrusive rocks are shown in Table 1. The analyses have been summarized into some variation diagrams (Figs. 6, 7 and 8).

The older intrusive rocks in the study area belong to the calc-alkaline affinity (Fig. 7). Most of the tonalites have intermediate silica contents (SiO_2=52–64 wt%) except a sample showing an acidic composition. As SiO_2 increases, all major oxides decrease, except Na_2O and K_2O which remain almost constant. Other intrusive rocks of the older stage widely range in composition, but most of them plot between the tonalite and the younger intrusive rocks.

On the other hand, most of the younger intrusive rocks are alkaline (Fig. 8). Syenites have the basic to intermediate silica contents (SiO_2=43–59 wt%). They are extremely rich in K_2O and P_2O_5 and slightly rich in TiO_2, but poor in Na_2O. These are reflected in the modal composition of the minerals in the syenite in which potash

Table 1. Average chemical compositions of intrusive rocks.

	Older intrusive rocks			Younger intrusive rocks					
	A	B	C	D	E	F	G	H	I
n	7	5	5	6	5	6	4	3	7
SiO_2	58.34	58.75	71.23	47.40	58.32	58.29	68.92	72.06	72.84
TiO_2	0.51	0.78	0.21	1.82	0.91	1.09	0.56	0.09	0.14
Al_2O_3	16.70	17.14	14.48	9.12	15.62	15.88	13.87	13.91	14.35
Fe_2O_3	2.27	1.29	0.79	3.93	1.72	2.07	1.49	0.89	0.58
FeO	4.49	4.56	1.32	4.86	1.95	2.25	1.13	0.40	0.53
MnO	0.13	0.11	0.02	0.17	0.05	0.06	0.02	0.01	0.02
MgO	2.92	2.17	0.47	7.05	2.13	1.69	0.78	0.14	0.22
CaO	7.34	5.31	2.09	10.40	3.48	3.48	1.91	1.19	1.26
Na_2O	3.13	4.20	3.88	1.50	2.19	3.56	3.63	3.81	4.39
K_2O	0.70	3.59	3.69	6.26	9.84	6.52	5.92	6.13	4.69
P_2O_5	0.12	0.20	0.06	2.22	0.59	0.54	0.24	0.04	0.05
BaO	0.03	0.20	0.25	1.11	1.91	0.94	0.29	0.16	0.08

n: Number of specimens analyzed. A: Tonalite, B: Granodiorite with quartz diorite, C: Granite sheet, D: Syenite (melanocratic layer), E: Syenite (leucocratic layer), F: Quartz syenite, G: Lunckeryggen coarse-grained granite, H: Lunckeryggen fine-grained granite, I: Granite dike.

feldspar, apatite and sphene are abundant and plagioclase is absent. As SiO_2 increases, K_2O and Al_2O_3 significantly increase and Na_2O remains constant, while other major oxides show a steady decrease successively in SiO_2-richer rocks. These variations of the

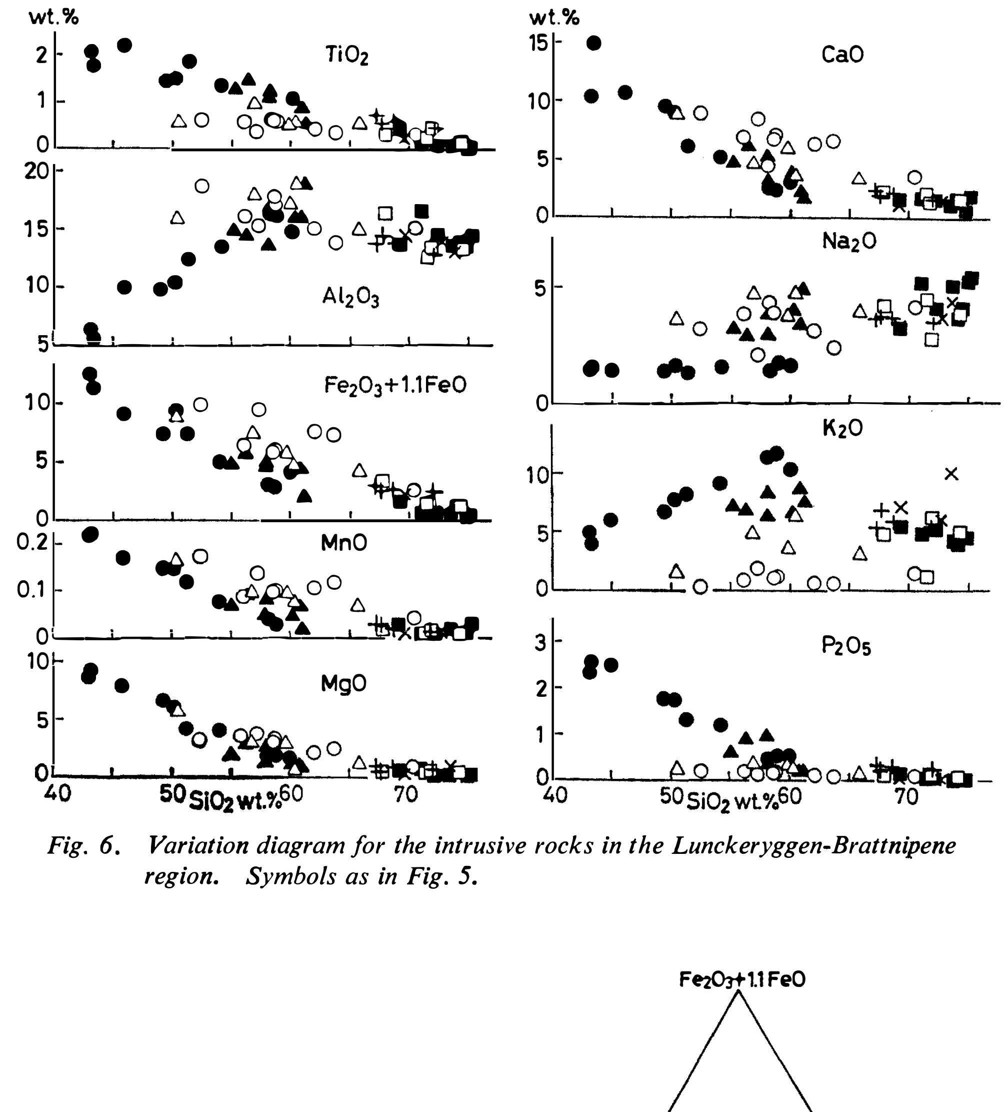

Fig. 6. Variation diagram for the intrusive rocks in the Lunckeryggen-Brattnipene region. Symbols as in Fig. 5.

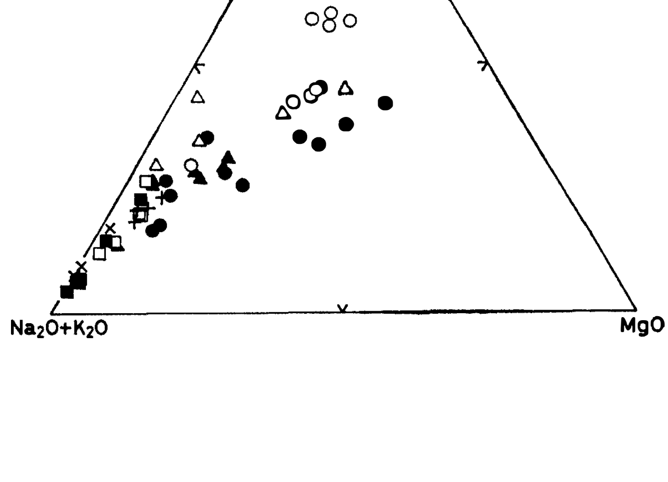

Fig. 7. (Fe_2O_3 + 1.1 FeO)-MgO-(Na_2O+K_2O) diagram. Symbols as in Fig. 5.

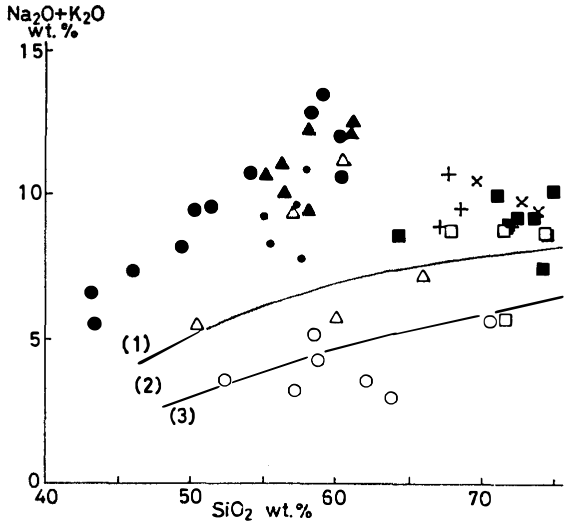

Fig. 8. SiO_2-(Na_2O+K_2O) diagram. Symbols same as in Fig. 5. Dots show the syenitic rocks from the Yamato and Belgica Mountains (KOJIMA et al. 1982; SHIRAISHI et al., 1983a). (1) Alkaline rock, (2) High-alkali tholeiite, (3) Low-alkali tholeiite.

major oxides are in accordance with the change of the modal composition in the layered syenite. That is, potash feldspar increases and clino-pyroxene decreases from a dark-colored layer to a light-colored layer. Melanocratic syenites have similar composition to the dark-colored layer in the layered syenite. Quartz syenites have intermediate silica contents (SiO_2=55–62 wt%) and show many similar characteristics to the layered syenite, but have higher Na_2O contents than the layered syenite. Coarse-grained granites and fine-grained granites in the Lunckeryggen granite have overlapping silica contents, but the former has slightly higher SiO_2 contents than the latter (SiO_2 contents are 67 to 73 wt% in the coarse-grained granites and 69 to 74 wt% in the fine-grained granites). Nearly all of them are plotted whithin the field of alkaline rock on the (Na_2O+K_2O)-SiO_2 diagram (Fig. 8) because of comparatively high Na_2O and K_2O contents. Other granite dikes in the younger intrusive rocks have various chemical compositions, but most of them have generally similar compositions to the Lunckeryggen granite.

5. Magnetic Susceptibility

Magnetic susceptibility has a positive correlation with the content of magnetite and its measurement is a most convenient way to know the magnetite content. The magnetic susceptibility was measured by KT-5 (Geofyzika Bruno, Czechoslovakia) and K-2 (Scintrex, Canada) and was expressed in SI unit. It was measured on the outcrops and on some hand specimens collected by KOJIMA and SHIRAISHI (1986). SATO and ISHIHARA (1983) classified the plutonic rocks into L-facies ($<25\times10^{-4}$SI), I-facies ($25\sim100\times10^{-4}$SI) and H-facies ($>100\times10^{-4}$SI) based on the data of their magnetic susceptibilities in the Kofu area, Japan. Furthermore, they pointed out that the ilmenite-series and the magnetite-series proposed by ISHIHARA (1977) correspond to the L-facies and the H-facies, respectively. The I-facies is a transition between the two series. Figure 9 shows magnetic susceptibilities of plutonic rocks in the central to western Sør Rondane Mountains.

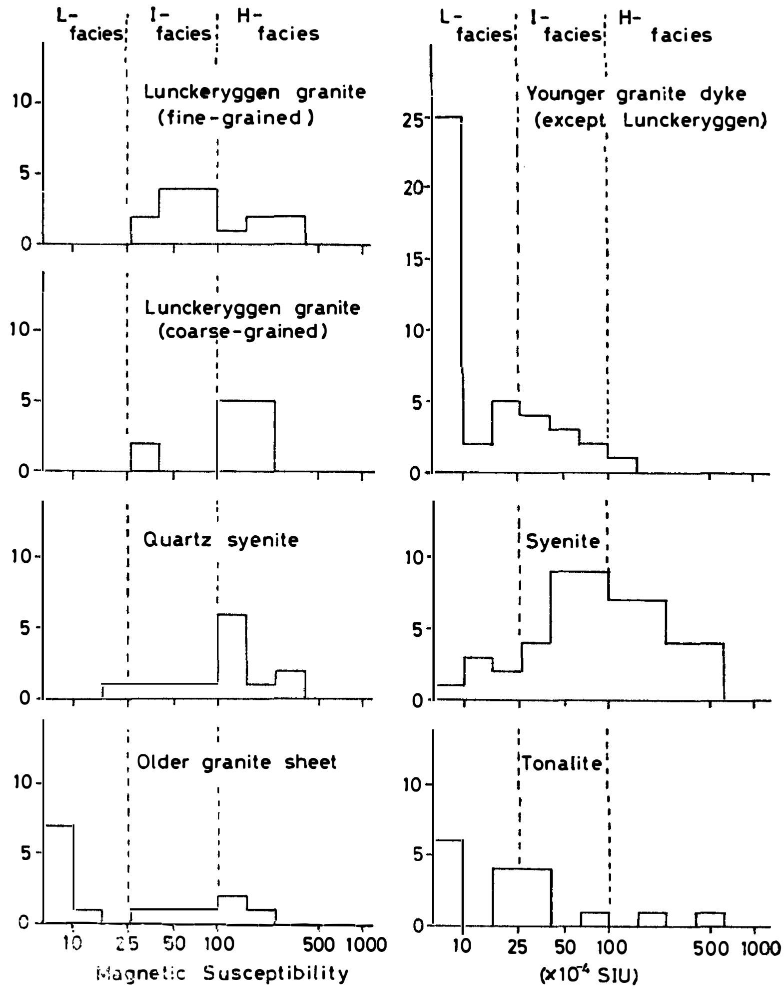

Fig. 9. Histograms of the magnetic susceptibility for the plutonic rocks in the central to western Sør Rondane Mountains.

Tonalites have generally low magnetic values (L- to I-facies), but a few samples show high magnetic values (H-facies). Such rocks of high magnetic values are remarkablly mylonitized near the Main Shear Zone or occur as xenoliths in the Lunckeryggen granite. Most of the concordant granites of the older stage have low magnetic susceptibility values. However, some concordant granites, which occur as the sheet-like bodies intruding the two-pyroxene gneiss in the north of Brattnipene, give high magnetic values.

On the contrary, most of the younger intrusive rocks are characterized by high magnetic rocks which belong to the magnetite-series. Syenites have intermediate to high magnetic values (I- to H-facies), but a few samples are low in magnetic values (L-facies). All of the quartz syenites and Lunckeryggen granite give high magnetic values (I- to H-facies). On the other hand, most of the granite dikes intruding the metamorphic rocks in Brattnipene give low magnetic values. Therefore, the lateral variation shows that magnetic susceptibility of the granitic rocks of the younger intrusive rocks decreases northward in the Lunckeryggen-Brattnipene region (Fig. 10).

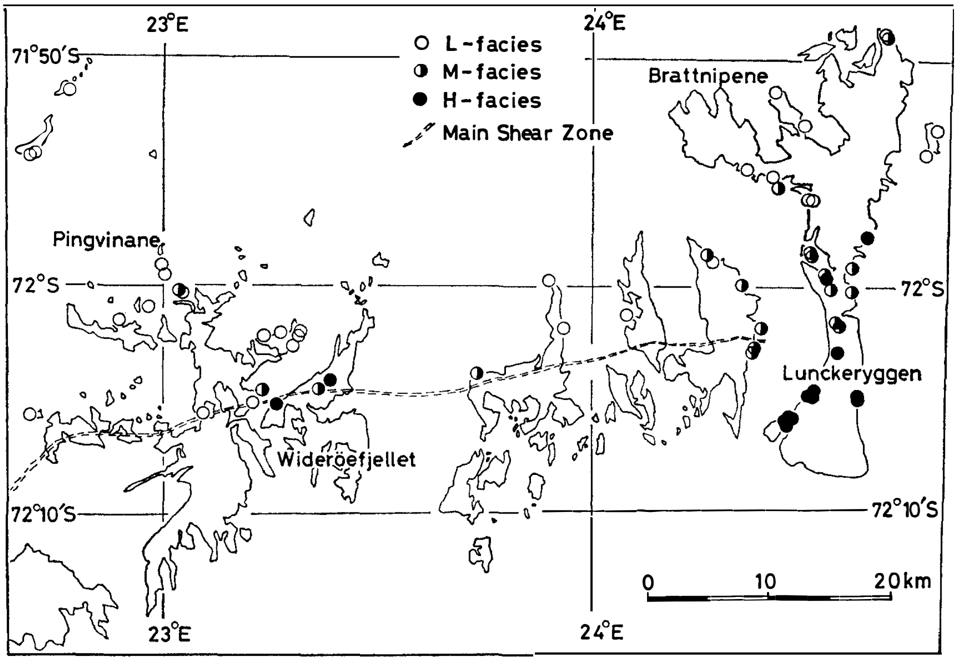

Fig. 10. Regional variation of magnetic susceptibility of the younger granitic rocks in the central to western Sør Rondane Mountains.

6. Summary and Discussion

6.1. Temporal variation of the plutonism

Summary of the temporal variations on the late Proterozoic to early Paleozoic plutonism in the Lunckeryggen-Brattnipene region is given here. The older intrusive rocks have an obviously gneissose structure and show concordant relations to the surrounding metamorphic rocks. Their foliations and the boundary between the intrusive rocks and the wall rocks are often cut by the mylonite. Moreover, the tonalites are recrystallized under the green schist facies condition related to the mylonitization (KOJIMA and SHIRAISHI, 1986). These facts support that the older intrusive rocks are synkinematic rocks. On the other hand, the younger intrusive rocks are postkinematic rocks. They are sometimes rich in the miarolitic cavities and the surrounding rocks are brecciated. Such occurrence is characteristic of shallow-level intrusion. Therefore, it is considered that a change of the geological environment took place between the older and the younger intrusive rocks. It may show a tectonic event with respect to uplift of the region from the metamorphic field of the granulite facies to the shallow position accompanied with mylonitization. With the change of the tectonic environment, changes of the magnetic susceptibilities and chemical compositions are recognized.

As already stated, the older intrusive rocks generally give low magnetic values, whereas the younger intrusive rocks give high magnetic values. Such difference in the magnetic susceptibility between the older and the younger intrusive rocks is also shown in the (Fe_2O_3/FeO)-SiO_2 diagram (Fig. 11). Most of the older intrusive rocks have low Fe_2O_3/FeO ratio, while those of the younger intrusive rocks are generally high and increase with the acidity of the rocks. The magnetic susceptibility and the Fe_2O_3/FeO

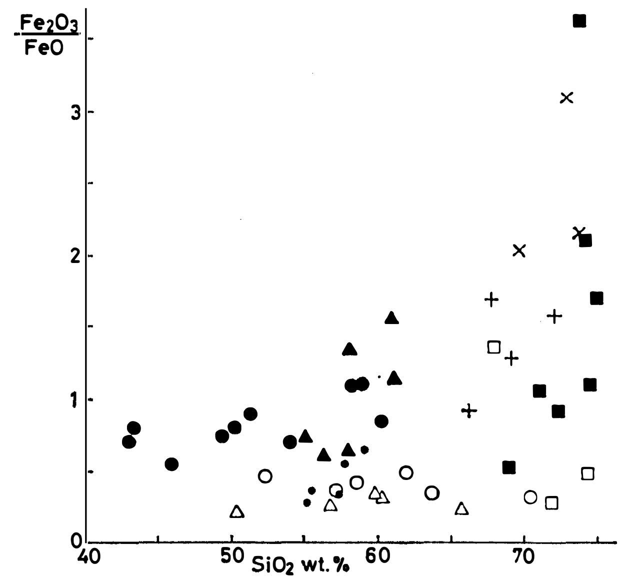

Fig. 11. SiO_2-Fe_2O_3/FeO diagram. Symbols as in Figs. 5 and 8.

ratio indicate that most of the younger intrusive rocks may have been formed under condition of higher oxygen fugacity than the older ones.

Moreover, the alkalinity of the rocks increases from the older to the younger intrusive rocks. The older intrusive rocks generally belong to the calc-alkaline affinity and are characterized by the low K_2O contents. However, the younger intrusive rocks are composed of the syenites and granites belonging to the alkaline affinity.

6.2. *Lateral variation of the magnetic susceptibility*

Lateral variation of the magnetic susceptibility on the younger stage granites is shown in Fig. 10. The magnetic value decreases northward in the Lunckeryggen-Brattnipene region. ISHIHARA (1979) pointed out that the magnetic susceptibility increases toward the marginal seaside in major granitic terranes of the Inner Zone of Southwest Japan and considered that such lateral variation is a fundamental pattern in the magmatic arcs of the island arc environment. Whether such variation is recognized throughout the Sør Rondane Mountains is an important problem to understand the tectonism of the region. Magnetic susceptibilities of some discordant granites in the western Sør Rondane Mountains are also presented in Fig. 10. They show that magnetite-free value granites are predominant in the western Sør Rondane Mountains. However, some high magnetic rocks are exposed in the southern part of the region. That is, there is a possibility that the lateral variation observed in the Lunckeryggen-Brattnipene region extends to the west. Owing to an insufficiency of regional data, a definite conclusion must be reserved at the present time.

6.3. *Correlation with the surrounding area*

As already mentioned, the older intrusive rocks dominated by tonalites and granodiorites are characterized by low K_2O contents and K_2O/Na_2O ratios. On the other hand, the younger intrusive rocks composed of syenites and alkali-rich granites are characterized by extremely high K_2O contents and K_2O/Na_2O ratios. The U-Pb and Rb-Sr ages (PICCIOTTO *et al.*, 1963; PASTEELS and MICHOT, 1968, 1970) of the intrusive rocks in the Sør Rondane Mountains indicate that the older and the younger intrusive rocks intruded during the periods of late Proterozoic and early Paleozoic, respectively. Early Paleozoic plutonism is known over a large portion of the eastern Queen Maud Land, East Antarctica (YANAI and UEDA, 1974; KOJIMA *et al.*, 1982; GREW, 1982). Early Paleozoic syenitic rocks are well exposed in the Yamato and Belgica Mountains east of the studied area (KOJIMA *et al.*, 1982; SHIRAISHI *et al.*, 1983a, b). They have high K_2O/Na_2O ratios the same as the syenite and quartz syenite in Lunckeryggen (Fig. 12). Such extremely high K_2O/Na_2O ratio may be a general characteristics of the early Paleozoic magmatism in the eastern Queen Maud Land. While, the syenitic rocks in the Yamato and Belgica Mountains have remarkably low Fe_2O_3/FeO ratios (SHIRAISHI *et al.*, 1983a) in contrast with Lunckeryggen showing high Fe_2O_3/FeO ratios (Fig. 11). This fact shows that the syenitic rocks in the Sør Rondane Mountains were formed under condition of higher oxygen fugacity than that in the Yamato and Belgica Mountains.

On the basis of the recent reconstruction of the Gondwanaland, it is inferred that the Queen Maud Land was joined with Southeastern Africa. Late Proterozoic to early Paleozoic magmatism (Pan-African magmatism) characterized by calc-alkaline rocks took place throughout Africa. The Pan-African plutonic association is composed of gabbro-tonalite-granodiorite-granite in which tonalites and granodiorites are dominant, while the late to post Pan-African is characterized by the appearance of alkaline rocks (GASS, 1982). Such change in the magmatism from calc-alkaline to alkaline affinities is thought to have taken place between 500 and 700 Ma in age (GASS 1982; JACKSON *et al.*, 1984). Such transition of the magmatism is similar to that of plutonism from the older to the younger intrusive rocks in the Sør Rondane Mountains. This information may support a possibility that the plutonism in the Sør Rondane Mountains is correlative with the Pan-African to post Pan-African magmatism. This point should be further studied in detail.

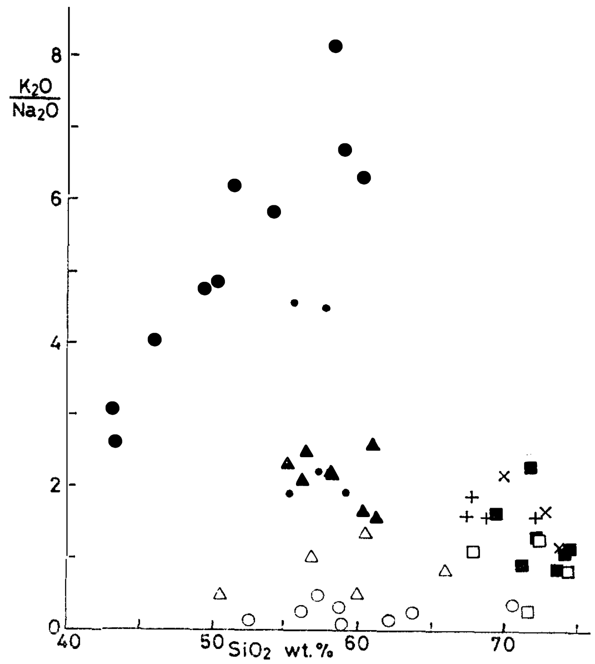

Fig. 12. SiO_2-K_2O/Na_2O diagram. Symbols as in Figs. 5 and 8.

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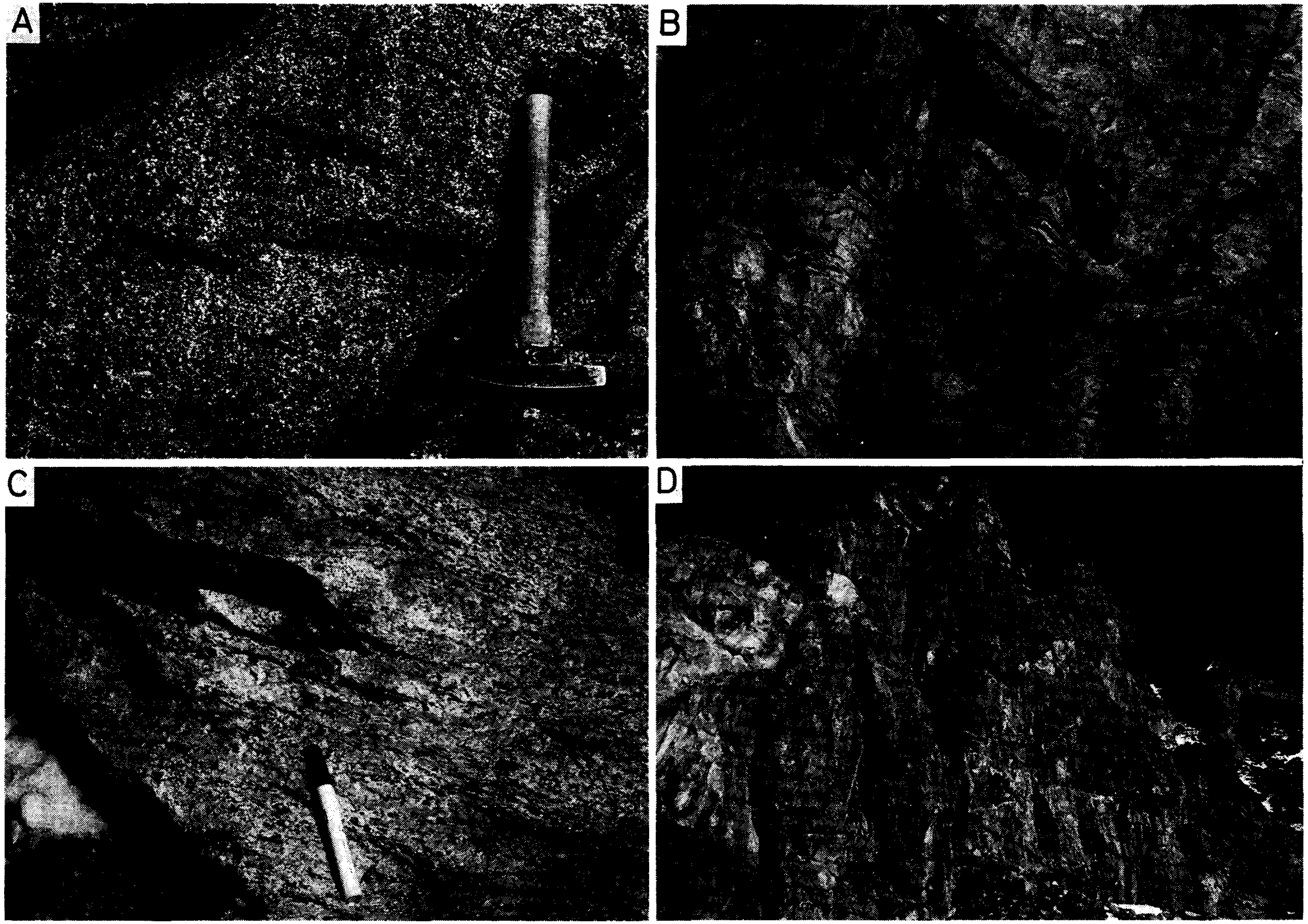

Plate 1. A: Tonalite with lenticular inclusion (Lunckeryggen). B: Older sheet-like granite showing a migmatitic appearance (Walnumfjellet). C: Gneissose structure of the older granite (Brattnipene). D: Reticular granitic veins intruding the tonalite. Height of the cliff is about 800 m (Lunckeryggen).

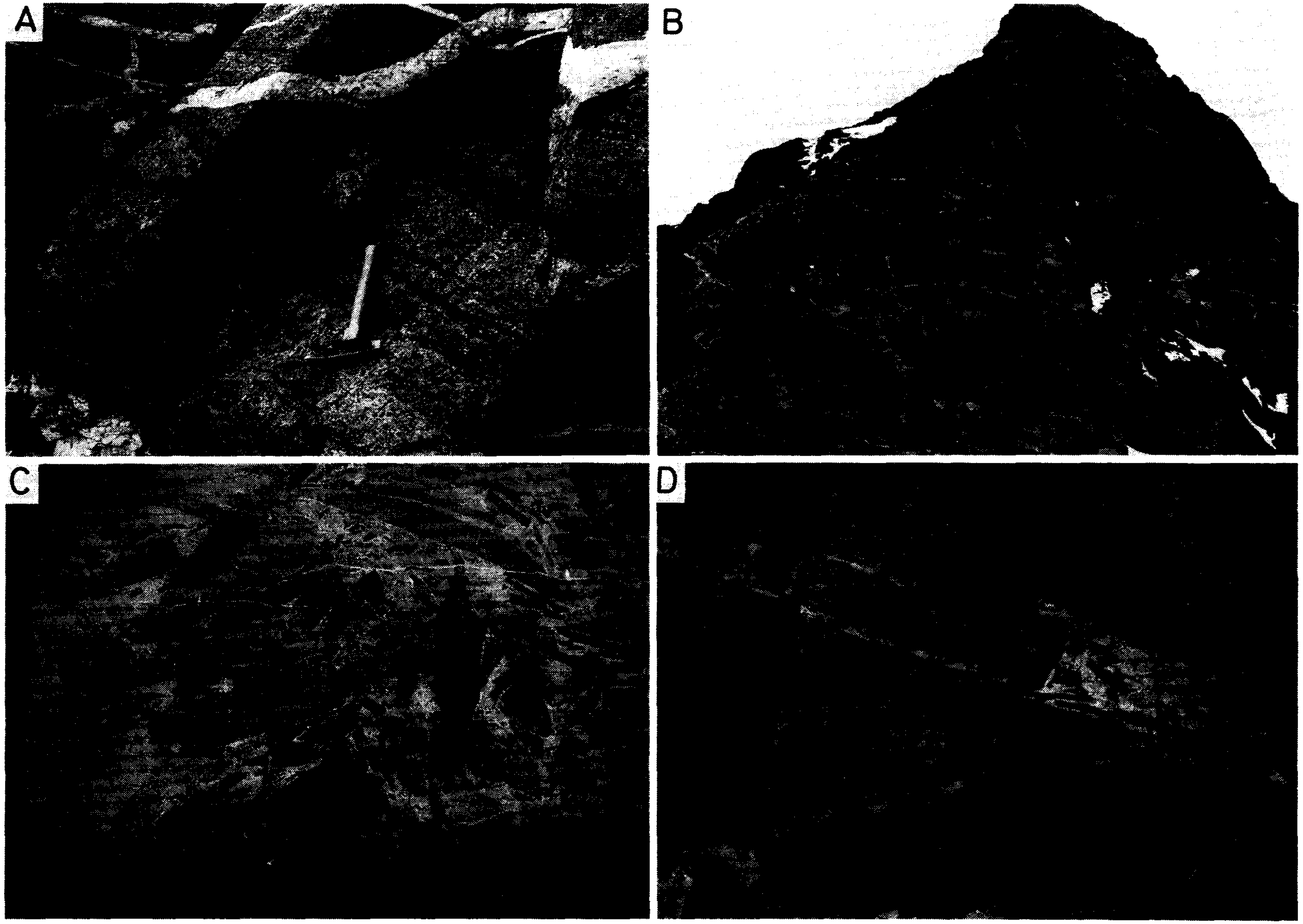

Plate 2. A: Rhythmic layering of the syenite. It is intruded by the aplitic granite (Lunckeryggen). B: Reticular veins of the quartz syenite intruding the syenite. Height of the cliff is 200 m (Lunckeryggen). C: Brecciated xenolith of syenite in the quartz syenite (Lunckeryggen). D: Dike of fine-grained granite intruding coarse-grained granite (Lunckeryggen).