A new occurrence of gabbro in the Oslo Rift, South Norway

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Xenoliths made up of an assemblage of gabbro, diorite and biotite monzonite in syenite and granite and veined by these rocks have been found within a small area at the south end of lake Mykle in the southern part of the Oslo Rift. The xenoliths most probably represent the remains of a former gabbroic neck similar to those occurring elsewhere in the Oslo Rift. The Mykle occurrence is located about 50 km to the south and in prolongation of a linear belt of gabbroic necks in the northern part of the rift zone. Gabbro, diorite and biotite monzonite may represent remnants of a composite neck, or the biotite monzonite and perhaps also the diorite may be gabbro modified by infiltration of fluids from the enclosing syenites and granites. Xenoliths of larvikite in xenoliths of biotite monzonite indicate that gabbroic rocks in this region were later than larvikite and older than syenite and granite.

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Introduction

Gabbroic rocks make up about 0.3 % of the area occupied by plutonic igneous rocks in the Oslo Rift (Barth 1945, Oftedahl 1960). Fifteen gabbroic necks ranging in size from about 300 m to exceptionally 3 km are aligned along trends N-S and NNE-SSW, parallel to prominent faults in the rift (Larsen et al. 1978, Neumann et al. 1985), and are located near the margins of the rift zone (Fig. 1). Most of them are intruded into the Precambrian basement and its cover of Palaeozoic sedimentary rocks (Neumann et al. 1985, fig.1). Rare xenoliths of gabbroic rocks have been observed in the plutonic rocks of the rift (Larsen et al. 1978), the most prominent example being the syenitic ring dyke of the Glitrevann cauldron. One of these xenoliths is composite, and is composed of basalt (local term B_3) as well as the overlying rhomb porphyry (RP_{13}) (Oftedahl 1960, fig. 102). The basalt is intruded by gabbro. One occurrence at Eiangen in the southwestern part of the rift is located at the contact between larvikite and the Precambrian basement to the west of the rift (Neumann et al. 1985, fig. 1).

The gabbroic necks are composed of gabbro, pyroxenite, monzonite and other rocks and commonly have a concentric internal structure (Neumann et al. 1985). They are considered to represent feeder channels to central volcanoes.

During mapping of the Siljan map-sheet in the southwestern part of the rift, xenoliths consisting of gabbroic and related rocks were observed in syenite and granite on the southwest and southeast coasts of lake Mykle. This occurrence is located about 15 km to the east of the Eiangen gabbro and about 50 km to the south of the nearest occurrence

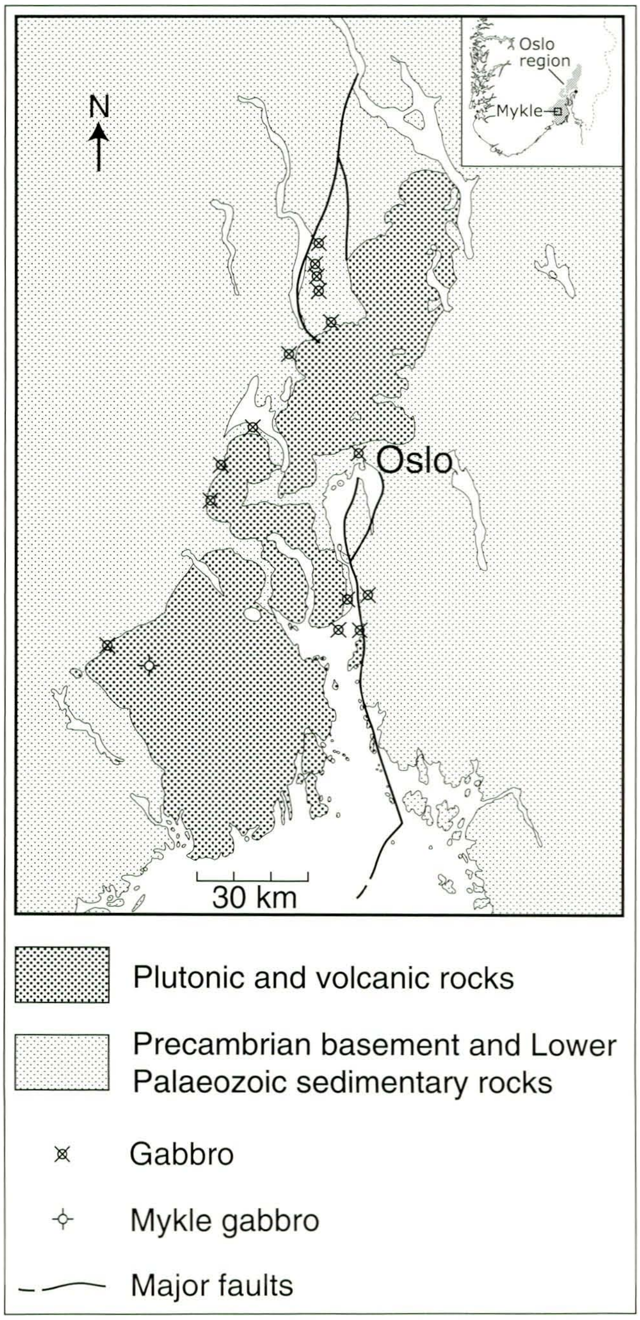

Fig. 1. Sketch map showing the distribution of gabbroic rocks in the Oslo Rift (based on Neumann et al. 1985).

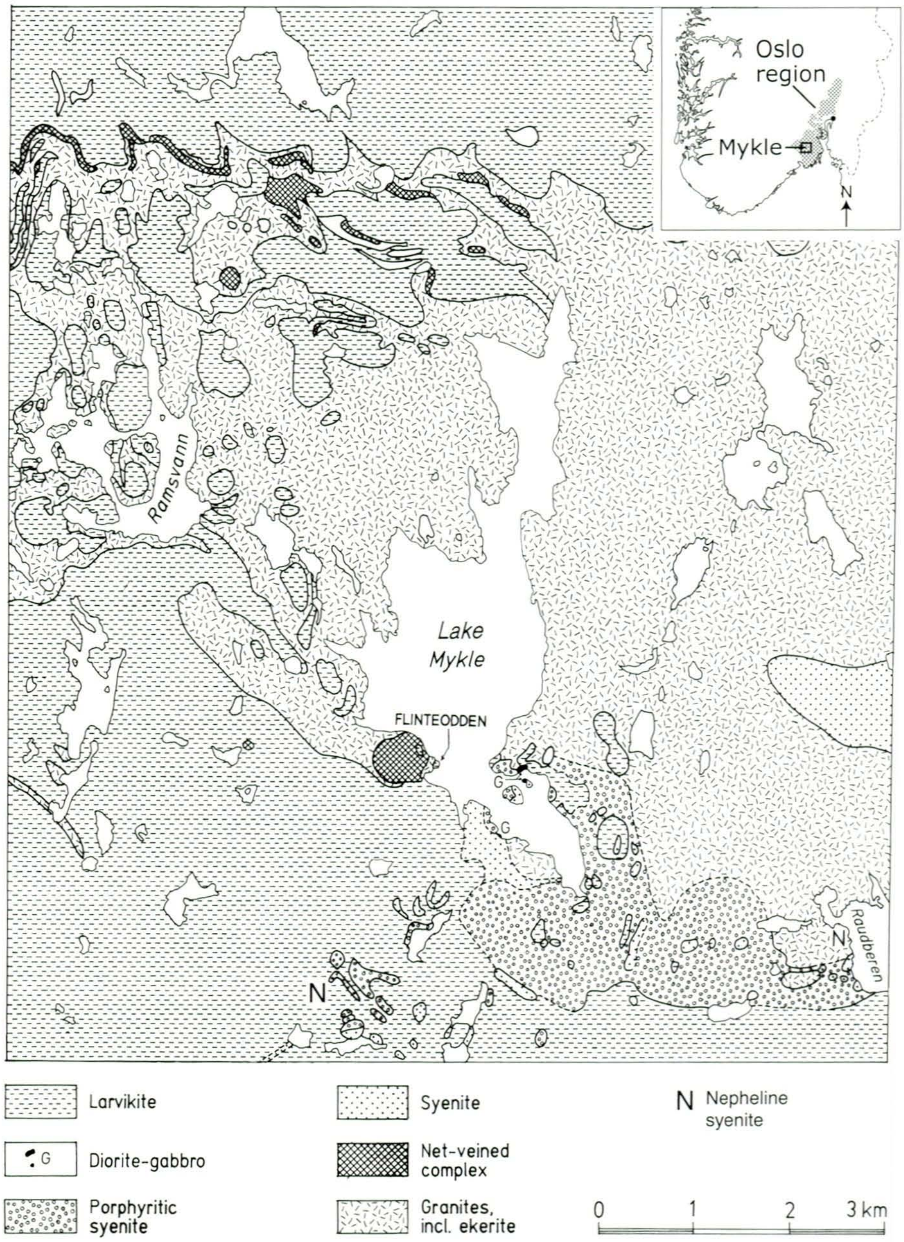

Fig. 2. Simplified geological map of the Mykle area.

to the north and in prolongation of the line of gabbro necks located along the west border of the rift (Fig. 1). A detailed description has been presented in an unpublished dissertation (Pedersen 1994). The present paper gives a brief account of the geology, petrology and geochemistry of this occurrence.

General geology

The area around lake Mykle is dominated by granitic rocks (Fig. 2) that have intruded a large massif of larvikite. Petrographically, larvikite comprises augite syenitic to augite monzonitic rocks. Roof pendants of larvikite overlie the granite in the western part of the granite massif. Around the southern end of lake Mykle a succession of intrusive phases has been distinguished in the contact zone between granite and larvikite. From the oldest to the youngest they are:

1. Larvikite.
2. Gabbro/diorite (Pedersen 1994) and nepheline syenite (Andersen & Sørensen 1994) found as xenoliths in syenite and granite. Xenoliths of larvikite and intersecting dykes show that these rocks are younger than the larvikite. The age relationship between gabbro and nepheline syenite is unknown.
3. Porphyritic syenite intruding the gabbro and cut by syenites and granites (Petersen & Sørensen 1997). Its age relationship to the nepheline syenite is not known.
4. Several phases of quartz alkali-feldspar syenite (nordmarkite).
5. Several phases of granite, the youngest being the

Fig. 3. Gabbro xenolith in porphyritic syenite, southeast coast of Mykle.

coarse-grained peralkaline granite termed ekerite (Bonin & Sørensen 2003). In some contacts between larvikite and granite, net-veined complexes occur (Morogan & Sørensen 1994).

Composite xenoliths of gabbro and accompanying diorite and biotite monzonite occur along the southeast coast of Mykle and also 1 km to the south on the south coast of the lake (Fig. 2). The xenoliths are enclosed in porphyritic syenite (Fig. 3), nordmarkitic syenite and granite and range in size from a few cm to more than 10 m. The xenoliths are in all stages of disintegration into the enclosing rocks and are intricately veined by several generations of syenite (Fig. 4) and granite. Xenoliths of biotite monzonite in the southern part of the area contain xenoliths of larvikite. About 1 km to the south of the xenolith area, larvikite is intersected by a dyke of leucodolerite, petrographically similar to the gabbro of the xenoliths. This may support the view that the gabbro and accompanying rocks are younger than the larvikite.

Fig. 4. Sketch map of relationships between gabbro/diorite, porphyritic syenite and syenite, west coast of Mykle.

Petrography

The rocks of the mafic xenoliths vary petrographically from true gabbro to diorite, monzodiorite and monzonite. The rocks commonly contain plates of biotite up to 1 cm in size. This is especially the case adjacent to intersecting veins of syenite and granite. The matrix of the rocks is fine- to medium-grained, and the grain size is 1-5 mm. The gabbro and diorite are equigranular and show distinct doleritic texture (Fig. 5); the biotite monzonite is heterogranular (Fig.6). The colour index is rather low, about 30 in the gabbro, c. 40 in the diorite and 20-30 in the monzodiorite/monzonite (Table 1).

The plagioclase of the gabbro has cores of labradorite and rims of oligoclase and in some cases alkali feldspar. There are interstitial grains of orthopyroxene ($Wo_{2-3}En_{61-67}Fs_{30-37}$) overgrown by Ca-rich clinopyroxene which also occurs as two types of interstitial grains, one brown ($Wo_{43-45}En_{40-43}Fs_{13.5-14}$) and the other green ($Wo_{43-44}En_{37-49}Fs_{16-18}$) in thin-section (mineral data from Pedersen 1994). The brown augitic variety was earlier than the green diopsidic variety. The brown variety has 0.4-1.2 % TiO_2 and 1.5-2.7 % Al_2O_3, the green variety 0.2 % TiO_2 and 0.6-1 % Al_2O_3. Magnetite (up to 30 % ulvöspinel) and ilmenite ($Ilm_{90-99}He_{1-10}$) form independent grains. Accessory minerals are allanite, pyrite and chalcopyrite. The Fe-Ti oxides are often rimmed by biotite, the clinopyroxene by actinolitic amphibole.

The plagioclase of the diorite can have cores of

Table 1. Modal analyses of gabbro, diorite and biotite monzonite, the Mykle area, South Norway.

	Gabbro 76287	Diorite 81791	Biotite monzonite 77173	Leucodolerite 23238
plagioclase	63	57	30	74
alkali feldspar	7	2	38	8
clinopyroxene	15	13	3	8
orthopyroxene	4	-	-	-
amphibole	-	4	12	2
Biotite	6	17	10	4
Opaques	4	5	5	4
Apatite	1	1	1	<1
Titanite	-	1	<1	<1

Fig. 5. Photo of whole thin-section of gabbro. Sample no. 72286, crossed polars. The length of the thin-section is 3 cm.

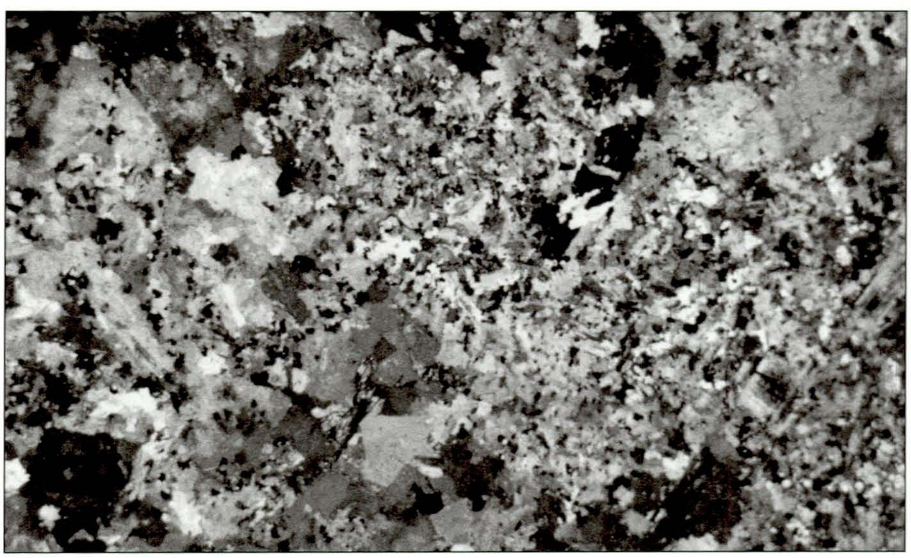

Fig. 6. Photo of whole thin-section of biotite monzonite showing heterogeneous texture. Sample no. 81755, crossed polars. The length of the thin-section is 3 cm.

labradorite, generally more sodic than the plagioclase of the gabbro, and have rims of oligoclase and alkali feldspar. There are brown ($Wo_{45-48}En_{38.5-41}Fs_{11-17}$) and green ($Wo_{46-48}En_{37-40}Fs_{13.5-15}$) grains of clinopyroxene. The brown variety has 1 % TiO_2 and 1.8-3.7 % Al_2O_3, the green variety 0.4-1 % TiO_2 and 0.4-1 % Al_2O_3. Pargasitic to edenitic hornblende forms rims on clinopyroxene and also occurs as independent crystals. There are independent grains of magnetite (0-2 % ulvöspinel) and ilmenite ($Ilm_{90}He_{10}$). The diorite is generally more strongly altered than the gabbro. The plagioclase is altered to epidote and albitic plagioclase, the mafic minerals to actinolite and chlorite, ilmenite to titanite and alkali feldspar to sericite.

The monzodiorite/monzonite is more heterogeneous than the gabbro and diorite (Fig. 6) and contains abundant biotite. Parts of the rocks have a doleritic texture, other parts a more granular texture. The cores of the plagioclase can consist of labradorite, but the crystals are dominated by a more sodic plagioclase. Alkali feldspar forms rims on plagioclase and also occurs as interstitial grains. Diopsidic pyroxene ($Wo_{43-46}En_{32-41}Fs_{15.5-21.5}$) occurs as interstitial grains which may be rimmed by amphibole and biotite. Independent amphibole grains vary in composition from magnesiohornblende to actinolitic hornblende. Magnetite (0-2 % ulvöspinel), ilmenite ($Ilm_{88-96}He_{4-12}$), zircon, apatite, allanite, pyrite and chalcopyrite are accessories. Titanite is secondary after ilmenite.

The monzonite/monzodiorite contains fine-grained grey xenoliths up to 10 cm across. They consist of plagioclase, clinopyroxene, apatite and Fe-Ti oxides and have large flakes of biotite.

The dyke of leucodolerite to the south of the occurrences of gabbro xenoliths consists of plagioclase forming a pronounced trachytic texture, clinopyroxene ($Wo_{46.5}En_{37.5}Fs_{16}$) with 0.5-0.7 % TiO_2 and 1.4-1.8 % Al_2O_3, amphibole varying from pargasite to hastingsite, alkali feldspar, magnetite and ilmenite. The colour index is around 15.

Whole-rock chemistry

The outcrops of the gabbro are so weathered that it was impossible to collect samples fresh and large enough for chemical analyses. Chemical analyses of diorite and monzodiorite/monzonite are presented in Table 2. Major elements were analysed by XRF on fused glass discs at the Geological Survey of Denmark and Greenland, trace elements by XRF analysis on powder mounts at the Geological Institute, University of Copenhagen, and uranium by the delayed neutron method by Tracechem A/S, Copenhagen.

The diorite may be interpreted as a metasomatically modified gabbro and the monzodiorite/monzonite as a further stage in the modification of the gabbro or perhaps as differentiates of a gabbroic magma. Thus, the contents of CaO, MgO, Ni, Cr, V and normative *an*, *ol* and *ne* decrease and contents of K_2O, normative *or*, *ap*, and of most trace elements increase from diorite to monzonite.

The chemical composition of the diorite is more evolved than most analyses from other basic complexes in the Oslo Rift but it is rather similar to analyses reported from basic necks at Sønstebyflakene and Dignes (Neumann et al. 1985, table 3) and to analyses of sørkedalite from Kjelsås (Bose 1969).

The chemical composition of the monzodiorite/monzonite is more evolved than the rocks analysed by Neumann et al. (1985, table 3) but it is similar to that of larvikite 1 from the Sande cauldron (Andersen 1984) and of leucocratic kjelsåsite from Kjelsås (Bose 1969). The monzodiorite/monzonite has a less evolved chemical composition than the larvikites of the rift zone; cf. the compilation of analyses by Neumann (1980).

Table 2. Chemical analyses of diorite and biotite monzonite from the Mykle area, South Norway and CIPW weight norms (major elements in weight percent, trace elements in ppm).

	Diorite	Biotite monzonite	
Sample	81791	81755	77173
SiO_2	48.41	51.99	52.96
TiO_2	2.84	2.42	2.06
Al_2O_3	16.19	15.97	16.84
Fe_2O_3	3.99	3.29	3.22
FeO	6.96	6.33	5.40
MnO	0.18	0.17	0.16
MgO	4.96	3.62	3.00
CaO	6.36	5.85	6.19
Na_2O	4.54	4.48	4.66
K_2O	2.31	2.81	3.01
P_2O_5	0.65	0.72	0.75
Volatiles	1.48	1.51	1.21
Total	98.88	99.16	99.46
Or	14.03	17.10	18.11
Ab	36.12	41.25	40.14
An	17.44	15.58	15.73
Ne	3.44	0	0
Di	8.49	7.60	8.51
Hy	0	6.76	4.37
Ol	10.75	3.21	2.30
mt	4.29	3.53	5.05
Il	4.06	3.46	4.02
ap	1.40	1.52	1.77
Rb	95	114	122
Ba	925	910	909
Sr	1110	990	1170
Pb	2	5	13
La	61	100	87
Ce	119	202	185
Nd	56	93	84
Y	43	68	57
Zr	288	724	551
Nb	63	91	76
Th	8	17	22
U	4.0	5.0	5.3
Zn	112	118	103
Cu	63	91	76
Ni	57	31	26
Sc	15	16	16
V	224	163	154
Cr	20	10	10
Ga	21	22	26

Discussion

The scattered xenoliths of gabbro and related rocks at the southern end of lake Mykle probably represent the remains of a former gabbroic neck similar to the occurrences described from elsewhere in the province (Neumann et al. 1985). The occurrence may be interpreted as a continuation of one of the linear belts of gabbroic necks towards the south (Fig. 1). In contrast to the occurrences farther north, which intrude the Precambrian basement and its cover of Palaeozoic sedimentary rocks, the Mykle occurrence forms xenoliths in syenitic and granitic plutonic rocks. Xenoliths of gabbroic rocks in plutonic rocks have been described from other places in the Oslo Rift, the most significant example occurring in the syenitic ring dyke of the Glitrevann cauldron (Oftedahl 1953) which is located in the above-mentioned linear belt and ending in the Mykle occurrence. According to Neumann et al. (1985, fig. 1), gabbroic rocks intruding Palaeozoic sediments at Sønstebyflakene are in contact with intrusive rocks. The relationship between gabbro and the other intrusions is not described. The map of the Glitrevann cauldron (Oftedahl 1953, 1960) indicates an occurrence of gabbro in the northern part of the cauldron in contact with Palaeozoic sedimentary rocks and rhomb porphyry lavas. This occurrence was described by Barth (1945, fig. 13). Neither of the descriptions includes information on the relationships between these rocks.

Barth (1945, p. 67) suggested that an occurrence of troctolite at Kjelsås in the northern part of the Oslo Rift may have been formed by remelting and assimilation of a 'buried' gabbroic neck by a larvikitic magma. According to Bose (1969) this rock, sørkedalite, is associated with kjelsåsite towards which it has developed gradual contacts. Kjelsåsite may be described as a plagioclase-rich variety of larvikite. The genesis of the sørkedalite is not clear.

It is not known whether xenoliths of gabbroic rocks are of widespread occurrence in the plutonic rocks of the Oslo Rift. A large part of the area is covered by forests and outcrops are scarce and are mainly restricted to shores of lakes, fjords and rivers and road cuts. The Mykle occurrence shows that xenoliths of gabbroic rocks should be looked for also in other parts of the rift zone.

The spatial association of gabbro, diorite and biotite monzonite indicates that these rocks are closely genetically associated. In consequence of this, the occurrence of larvikite xenoliths in biotite monzonite at Mykle indicates that larvikite, in this place, is older than the gabbro and its associated rocks. This, to our knowledge, provides the first observation of the age relationship between gabbro and larvikite in the Oslo province. It brackets the emplacement of the gabbro between that of the larvikite and that of the syenitic rocks. It should, however, be pointed out that mapping of the Siljan map-sheet has demonstrated several stages of emplacement of larvikite and occurrences of fine-grained larvikite containing cm-large basic xenoliths (unpublished observations). In addition, the large Larvik larvikite massif was formed by a succession of intrusions (Petersen 1977). However, larvikite exposures in the Mykle area are so few and poor that it has been impossible to distinguish separate intrusive phases and to decide if the larvikite, from which the xenoliths in biotite monzonite have been derived, could be an early or late member of a succession of intrusions.

Age determinations of Oslo Rift rocks presented by Sundvoll et al. (1990) give gabbro ages of about 265 Ma whereas the plutonic rocks of the western part of the rift give ages of 281 to 267 Ma and the syenite of the Glitrevann cauldron 266 Ma. However, the nordmarkitic syenite of the Siljan district, which is definitely younger than the lake Mykle gabbro, is reported to be 270 Ma old. The age relations therefore have to be further explored and constrained.

The association of gabbro, diorite and monzonite at Mykle may represent different parts of a zoned neck similar to the necks described by Neumann et al. (1985) and others. It may, however, also represent stages in the transformation of the original gabbro into dioritic and monzonitic rocks as a result of reactions with fluids released from the enclosing syenitic and granitic melts. Both views are in accordance with information obtained on the chemistry and mineralogy of these rocks as described in detail by Pedersen (1994) and briefly outlined in the present paper (Tables 1, 2). However, the occurrence of patches with doleritic texture in the heterogeneous monzonitic rocks (Fig. 6) and the occurrence of two coexisting clinopyroxenes indicate that these rocks probably are recrystallised, which may support the view that the monozonitic rocks rich in biotite are secondary after gabbro/diorite.

Conclusions

Larvikite in the Mykle area was intruded by gabbroic rocks. These were intruded and engulfed by later syenitic and granitic bodies. Xenoliths of gabbro should be looked for in the plutonic rocks of the Oslo Rift, and especially the observation that the gabbro at Mykle appears to be younger than larvikite should encourage the search for gabbroic intrusions in the large larvikite massifs of the rift zone.

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