The granites of the Mykle region in the southern part of the Oslo igneous province, Norway

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The granites exposed around lake Mykle constitute two discrete massifs. The western granite massif, the subject of the present paper, is an intrusive complex, with larvikite as country rocks making up the topographic highs and occurring as stoped blocks within the granite. Two types of granite were identified: a marginal, fine- to medium-grained, reddish granite and a central, younger, coarse-grained, white to grey granite akin to ekerite. The reddish granite displays chilled margins at the contacts with larvikite and locally contains mafic rocks as net-veined complexes. It is metaluminous to weakly peraluminous and yields the highest contents of incompatible elements. Though later than syenite and the reddish granite, the ekerite displays sharp contacts only, with no chilled margins, indicating that no significant temperature gradients were created during its emplacement. Miarolitic cavities, abundant in all rock types, are evidence of fluid exsolution from volatile-rich magmas. The present surface level corresponds to the poorly exposed roof near part of a larger intrusion, emplaced within larvikite and rhomb porphyry lavas by magmatic stoping and perhaps cauldron subsidence.

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Introduction

Igneous rocks cover about 75 % of the area of the Oslo Rift of southern Norway (Oftedahl 1978). Granites make up about 20% of this area and constitute about 33% of the area of plutonic rocks (calculated from Table 1, in Oftedahl 1978). The related extrusive rocks (rhyolite and trachyte) are comparatively rare, only 0.4% of the area, and are especially associated with cauldron structures (Oftedahl 1978). The plutonic rocks, including granites, are concentrated in three main complexes, geographically separated by outcrops of sedimentary rocks and lavas, namely the northern Nordmarka-Hurdalen area, the central Drammen-Finnemarka area, and the southern Larvik-Skrim area (Fig. 1). In the southern area, the Larvik complex is apparently devoid of granites and, to our knowledge, the single sheet of granite intersecting larvikite that can be observed at Eidanger, about 30 km south of Mykle (unpublished observation), represents the southernmost granite occurrence within the entire province.

The Skrim area includes the Mykle granites, exposed in the hills dominating lake Mykle, thus forming the southernmost large granite massif of the province. On older geological maps (e.g., Dietrich et al. 1965), the Mykle granites are shown as a southwestern extension of the peralkaline variety of granite at lake Eikeren which was named ekerite (Brøgger 1906). The detailed geological mapping of the Siljan map-sheet carried out by staff and students from the Geological Institute of the University of Copenhagen has

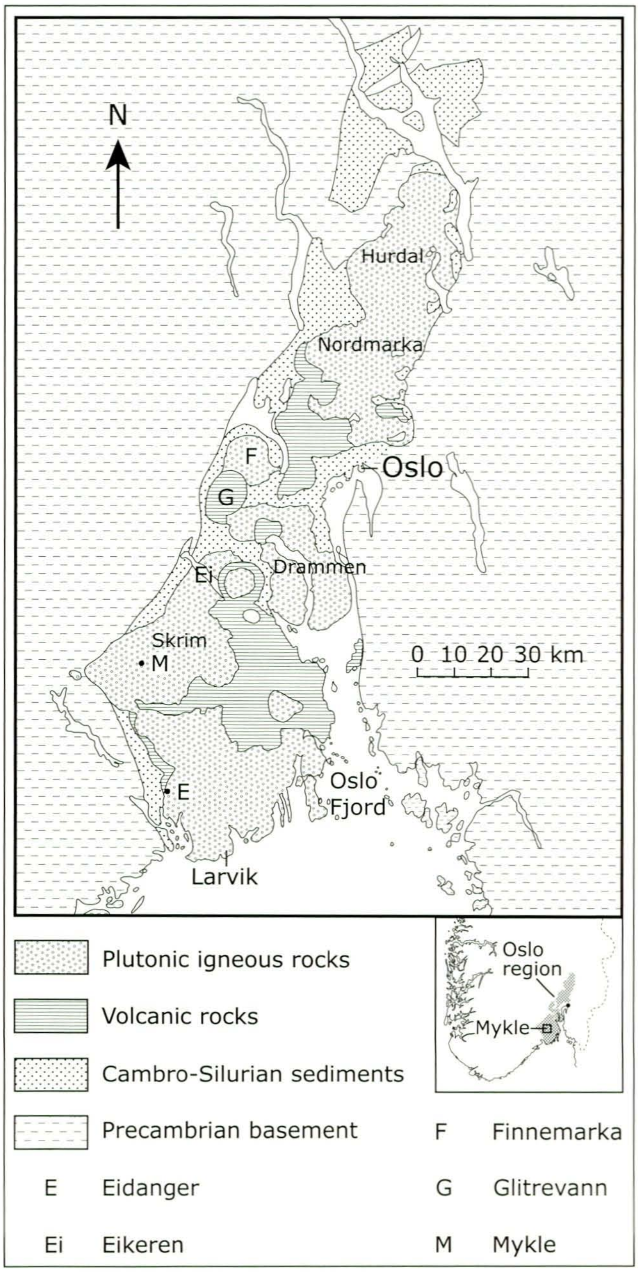

Fig. 1. Generalised geological map of the Oslo Igneous Province.

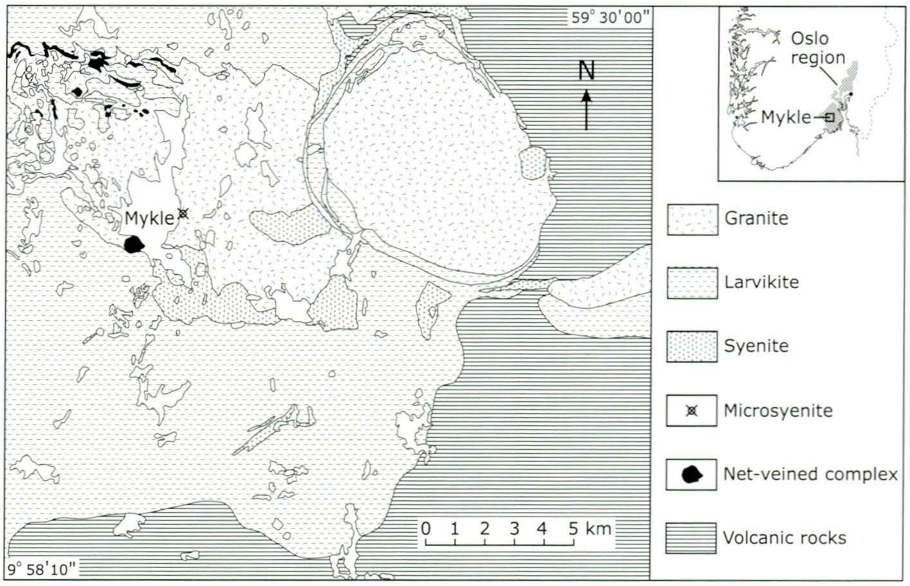

Fig. 2. Simplified geological map of the Mykle area. The contact between the fine- to medium-grained granite and the ekerite is not shown due to poor exposures in large parts of the area. The ekerite occupies the central part, and the fine- to medium-grained granite the marginal parts of the western granite massif.

shown that the exposures of the Mykle and Eikeren granites are separated by a zone of larvikite, syenite and lavas (Fig. 2), though it is not ruled out that the two granite masses may be connected at depth. As a matter of fact, a large part of the Mykle granites is indistinguishable in the field from the Eikeren ekerite.

The aim of this paper is to provide a summary of the geological features and compositions of the rock types and to discuss briefly the magmatic evolution and mode of emplacement of the Mykle granite massif.

Geological setting

Two discrete granite massifs were distinguished in the Mykle area (Fig. 2). The western massif, centred on Lake Mykle, will be described in further detail. The eastern massif constitutes a ring structure (Segalstad 1975) and is separated from the western massif by a 'screen' of syenite and larvikite up to 1 km in width.

The eastern granite massif

The eastern granite massif cross-cuts rhomb porphyry lavas in the east and larvikite in the north and south. An inner core of different granite varieties is rimmed by an outer ring of larvikite and syenite (Fig. 2). The origin of the ring structure is still a matter of debate. Its present annular shape can result from either a ring intrusion of larvikite and syenite post-dating granites, which is contrary to the ubiquitous granites post-dating larvikite elsewhere in the Oslo rift, or a composite granite intrusion which has partly up-domed its roof of larvikite and syenite.

In the second alternative, erosion would have removed most of the flat-lying roof and left the steeper outer walls. This interpretation is supported by the occurrence of disintegrated roof pendants, rafts and fragments of larvikite and syenite in the granite and by granite veins intersecting the rocks of the outer ring. This latter interpretation is, therefore, favoured. The eastern granite massif will not be further discussed in the present paper, which is restricted to the western granite massif.

The western granite massif

Granites around lake Mykle are interpreted as forming a single, 6 km x 5 km-large, composite intrusive body (Fig. 2). A small isolated granite intrusion occurs to the south of the main mass of granite on the southwestern shore of the lake. It consists of a fine- to medium-grained, grey to red granite which contains xenoliths of porphyritic syenite along its southern contact and diorite-gabbro xenoliths in the north (Pedersen & Sørensen 2003).

Country rocks include larvikite, locally with porphyritic syenite (Petersen & Sørensen 1996), in the north, west and south, and a small occurrence of microsyenite in the southeast (Andersen and Sørensen 2003). The tops of the hills in the western part of the granite massif are mostly made up of larvikite that is exposed at nearly the same altitude. They are likely to represent remnants of the roof of the granite massif. The granite contains numerous xenoliths of larvikite in all stages of disintegration. Granite occurring in topographical depressions within larvikite farther south of the massif afford evidence that granites underlie larvikite in this part of the region (see also Segalstad 1975).

Two main varieties of granite were distinguished: (i) a fine- to medium-grained, commonly reddish granite, (ii) a coarse-grained white to grey granite which is so strikingly similar to ekerite of the Eikeren type locality that it will be referred to as ekerite in this paper. Both varieties are full of miarolitic cavities, especially in the contact zones, and have crusts of manganese oxides filling joints and fractures.

The fine- to medium-grained granite

The marginal zone of the granite massif is occupied by the fine- to medium-grained granite. Chilled margins, a few mm

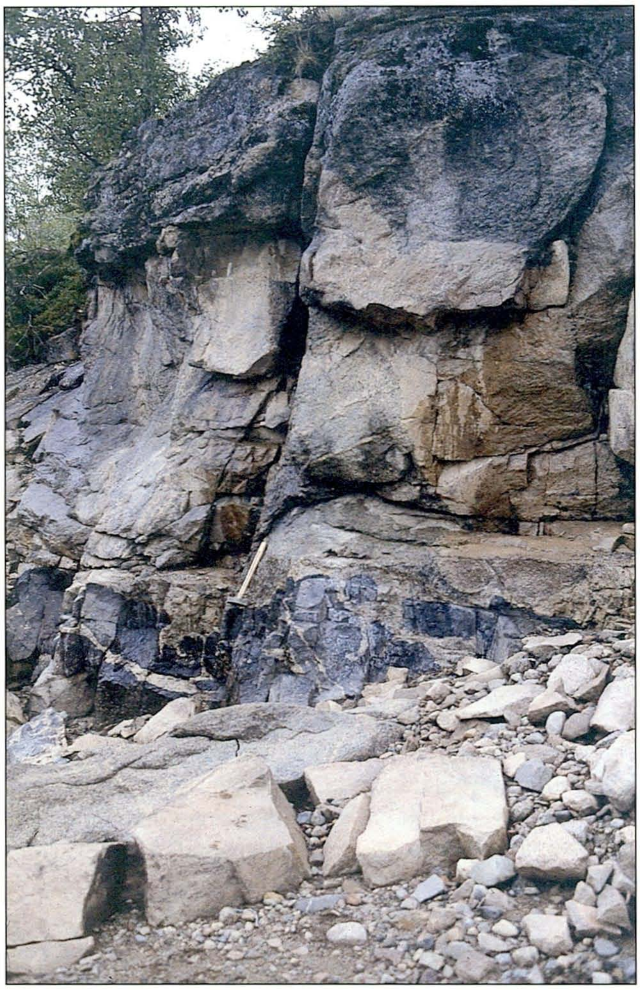

Fig. 3. Contact between larvikite (top part of the photo) and the underlying granite which, in the upper part, is devoid of mafic globules but, in the lower part, contains such globules. Southwest coast of Mykle.

Fig. 4. Dyke of ekerite intersecting the mafic and granitic parts of a net-veined complex. North of Mykle.

wide, are developed at contacts with larvikite. They are rich in quartz and display granophyric intergrowths of quartz and alkali feldspar. Larvikite can, in turn, contain fluorite and be fenitized in the immediate contact zone (unpublished observations).

In the contact zones southwest and northwest of the granite massif, the fine- to medium-grained granite forms net-veined complexes with numerous enclaves of mafic rocks (Fig. 3). This occurrence of mafic rocks is interpreted as resulting from the injection of trachybasaltic to trachyandesitic magmas along the walls of the granite magma chamber in a zone of weakness between the marginal, almost completely consolidated granite and the still liquid granitic magma (Morogan & Sørensen 1995). Pillows of mafic magmas were subsequently disrupted within the granitic magma to form the net-veined complexes. In several places, the net-veined complexes are cross-cut by ekerite (Fig. 4).

Last, in one locality, the fine to medium-grained granite contains xenoliths of nepheline syenite which were intruded by syenite prior to intrusion of the granite (Andersen & Sørensen 1995).

The ekerite

The coarse-grained granite occupies the central part of the granite massif. It shows well developed sheet jointing, which is generally almost horizontal, suggesting that the roof of the granite massif is situated at a short distance above.

The ekerite contains numerous xenoliths of larvikite, measuring from tens of metres to a few centimetres. A closer examination of the xenoliths reveals that larvikite was intruded by the fine- to medium-grained type and, in some cases, by syenite prior to ekerite. This assemblage was intruded and partly digested by ekerite. Larvikite xenoliths show all stages of recrystallisation and disintegration into ekerite.

Precise U-Pb zircon dating gave a Mid Permian age of 279.8 ± 0.7 Ma for the Mykle ekerite, considered as the age of emplacement (Pedersen et al. 1995). The Eikeren ekerite yielded a slightly younger age of 271 ± 2 Ma by the Rb-Sr method (Sundvoll et al. 1990).

Relationships between the two granite types

Sharp contacts between ekerite and the fine- to medium-grained granite were observed in some places along the west coast of Mykle (Fig. 5). No chilled margins are displayed at the contact of ekerite with the fine- to medium-grained granite but, in some localities, crystals of quartz and amphibole have grown within ekerite perpendicular to the contact against screens of the fine- to medium-grained granite (Fig. 6), suggesting that the ekerite was emplaced into a consolidated, but still hot, fine- to medium-grained granite.

Along some contact zones on the west coast of Mykle, alternating sheets of fine- to medium-grained granite and ekerite were observed against overlying larvikite (Fig. 7). This sequence could be caused by fluctuating conditions of crys-

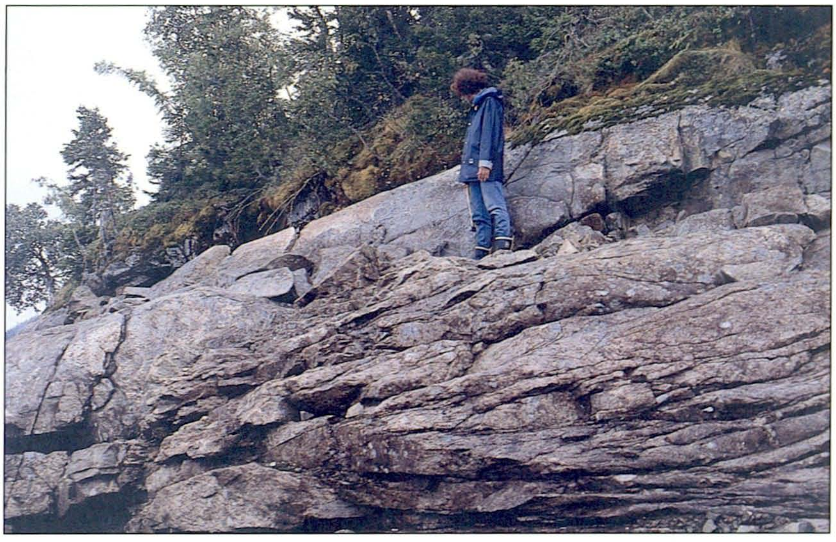

Fig. 5. Contact between ekerite (lower part of the photo below the feet of the person) and the overlying fine-grained granite which, in the background, is overlain by a net-veined complex of trachyandesitic globules in granite. Southwest coast of Mykle.

Fig. 6. Contact between the enclosed screen of fine-grained granite with black dots (left side of the photo) and the enclosing ekeritic granite (lower right side). The contact is marked by crystals of amphibole growing into ekerite. Northwest coast of Mykle. (Photo: Lone Pedersen).

tallisation in the roof of the granite magma chamber, such as variations of PH_2O, but it is more likely the result of injection of ekerite into the sheet joints of the already crystallised fine- to medium-grained granite. This interpretation is supported by the occurrence of (i) ekerite dykes intersecting both larvikite and fine- to medium-grained granite, and (ii) screens of the fine- to medium-grained granite within ekerite (Fig. 6).

Associated dykes and veins

Several generations of granitic dykes and veins intersect the country rocks and show beautiful examples of dilation phenomena. On the southeastern coast of lake Mykle, sheets of ekerite intrude a small occurrence of microsyenite along horizontal sheet joints (Andersen & Sørensen 2003). The sheets display pegmatitic patches and abundant miarolitic cavities, which can be up to 10 cm in diameter.

Fig. 7. Contact between larvikite (dark rock in the upper part of the photo) and the underlying granite which is made up of alternating sheets of fine- and coarse-grained granite. Note the horizontal sheet jointing in larvikite as well as in granite. West coast of Mykle.

Petrography

The two varieties of granite are hypersolvus rocks dominated by mesoperthitic alkali feldspar.

The fine- to medium-grained reddish granite

The grain size of the granite ranges from 1 to 5 mm, locally up to 1 cm. It has a granular texture and consists of turbid grains of mesoperthitic alkali feldspar which may be rimmed by lucid albite, and of quartz, associated with clusters of Fe-Ti oxides, silicic biotite and chlorite. These clusters formed at the expense of primary pyroxene and amphibole, which occur only sporadically. Clinopyroxene, when present, is almost pure aegirine and amphibole varies from ferro-edenite (Petersen & Sørensen 1997) to ferrorichterite to arfvedsonite (M'Rabet-Maamar 1994). Accessory minerals are zircon, Fe-Ti oxides (Ti-magnetite converted into maghemite and ilmenite coated by ilmeno-rutile and rutile), allanite, apatite and fluorite.

The fine- to medium-grained, grey to red granite of the small satellite intrusion on the southwestern shore of lake Mykle consists of mesoperthitic alkali feldspar, quartz, katophorite to ferrorichterite (Pedersen 1994), biotite, ilmenite, magnetite, zircon, apatite, titanite and allanite.

The ekerite

The grain size can reach up to one centimetre and even more in pegmatitic patches. The texture and mineralogy are identical to ekerite of the Eikeren type locality. Euhedral to subhedral grains of white mesoperthitic alkali feldspar and rounded grains of quartz may be segregated into elongated patches due to flowage during emplacement of the granitic melt. There are small interstitial grains of albite. Aegirine and green to blue arfvedsonite are present as minor components, mainly as interstitial small grains, but aegirine may occur as prismatic grains up to one cm in length. In some samples, aegirine forms rims on arfvedsonite, whereas the opposite relationship is seen in others, and the two minerals also constitute parallel intergrowths. Pyroxene and amphibole grains are commonly converted into aggregates of silicic biotite, stilpnomelane and Fe-Ti oxides (ilmenite, rutile) (M'Rabet-Maamar 1994). Crystals of astrophyllite up to one centimetre in size are seen in some localities on the east coast of Mykle. Zircon is always present as small, clear crystals and as more irregular metamict grains. Pyrochlore and fluorite may also be present. Zoned dykes and veins of ekerite have feldspar-rich rims and a quartz-rich central core.

Miarolitic cavities contain crystals of quartz, albite, fluorite and calcite. Larvikite and gabbro overlying the horizontal sheets of granite and quartz syenite may display strings of miarolitic cavities that are arranged at a steep angle to the contact with the intrusive sheets.

Bulk-rock chemical compositions

Major elements were analysed by X-ray fluorescence on fused glass discs at the Laboratoire de Pétrographie et Volcanologie, Université de Paris-Sud. Most trace elements were analysed by X-ray fluorescence on powdered samples, and Li and Be by atomic absorption spectrophotometry at the Geological Institute, University of Copenhagen. Cs, REE, Hf, Ta, Sc and U were analysed by instrumental neutron activation analysis at Tracechem A/S, Copenhagen.

The analytical results are listed in Table 1a, b. One sample of the southwestern satellite granite (81084), four samples of the fine- to medium-grained granite (86018, 86035, 86044 and 86069), and four samples of ekerite (86022, 86045, 86057 and 86060) were chosen for bulk-rock chemical analyses. As for the fine- to medium-grained granite, sample 86018 was taken at the contact with larvikite, sample 86035 at the contact with the underlying ekerite, sample 86069 at the contact of a net-veined complex, and sample 86044 is a granite enclosing globules of trachyandesite of the net-

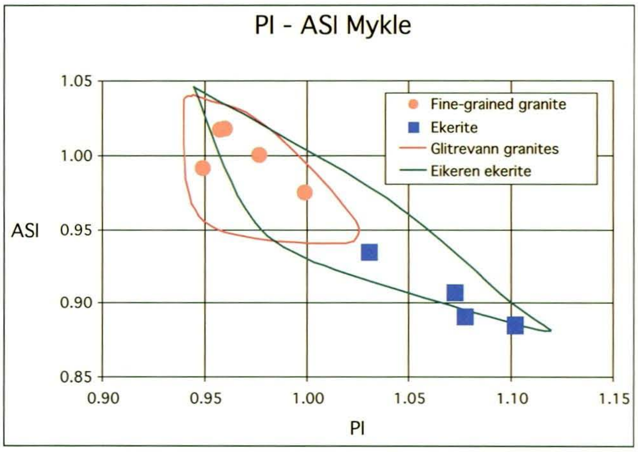

Fig. 8. PI-ASI diagram. The Alumina Saturation Index is defined as the $Al_2O_3/(CaO + Na_2O + K_2O)$ molar ratio. The Peralkalinity Index PI is defined as the $(Na_2O + K_2O)/ Al_2O_3$ molar ratio. The polygonal areas are the composition fields of the Glitrevann Cauldron (adapted from Jensen 1985) and the Eikeren ekerite (adapted from Neumann et al. 1990).

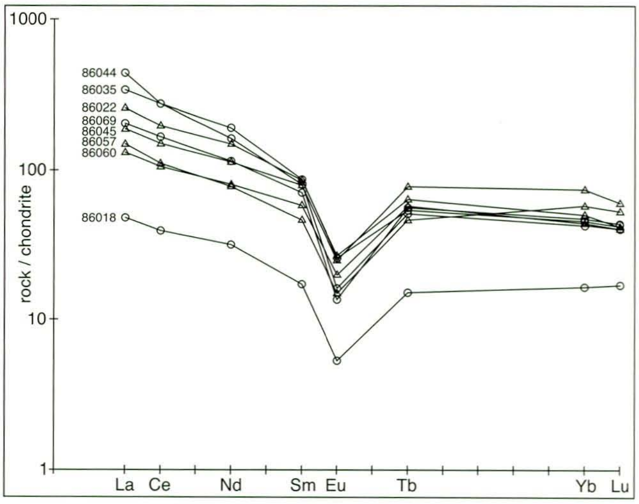

Fig. 9. Chondrite-normalised REE diagram.

Table 1a. Chemical analyses of granites from the Mykle area: major elements (wt.%) and CIPW weight norms

	Fine- and medium-grained granites					Ekerites			
Sample	81084*	86018	86035	86044	86069	86022	86045	86057	86060
SiO_2	72.84	77.14	72.80	74.26	76.47	75.13	76.77	76.08	76.95
TiO_2	0.29	0.09	0.33	0.30	0.19	0.39	0.23	0.27	0.24
Al_2O_3	13.00	11.38	13.18	13.49	12.13	11.61	11.17	11.42	10.94
Fe_2O_3	1.12	1.42	1.95	1.55	2.23	1.87	1.98	2.52	1.65
FeO	1.10	0.41	0.92	0.13	0.14	0.61	0.37	0.09	0.52
MnO	0.09	0.06	0.05	0.03	0.03	0.13	0.12	0.14	0.12
MgO	0.16	n.d.**	n.d.	0.02	n.d.	n.d.	n.d.	n.d.	n.d.
CaO	0.19	0.14	0.16	0.44	0.17	0.25	0.17	0.28	0.18
Na_2O	4.40	3.58	3.96	4.04	3.75	4.01	4.31	4.20	3.99
K_2O	5.31	4.83	5.67	5.69	5.03	4.96	4.82	4.99	4.78
P_2O_5	0.02	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
volatiles	0.42	0.47	0.48	0.47	0.37	0.42	0.38	0.46	0.35
total	8.94	99.52	99.50	100.42	100.51	99.38	100.32	100.45	99.72
A.S.I.***	0.98	1.00	1.02	0.99	1.02	0.93	0.89	0.89	0.91
P.I.****	1.00	0.98	0.96	0.95	0.96	1.03	1.10	1.08	1.07
q	29.17	37.97	27.95	28.21	34.68	33.35	34.29	33.60	36.34
or	30.81	28.79	33.80	33.38	29.77	29.72	28.60	29.54	28.44
ab	36.47	30.47	33.72	34.23	31.76	32.28	30.55	30.97	29.45
an	0	0.67	0.79	1.82	0.84	0	0	0	0
c	0	0	0.23	0	0.20	0	0	0	0
ac	0	0	0	0	0	1.60	5.27	3.92	3.93
en	0.40	0	0	0.05	0	0	0	0	0
fs	0.77	0.11	0.09	0.05	0	0	0.40	0	0.31
wo	0.38	0	0	0.15	0	0.47	0.3	0.57	0.35
mt	1.46	1.07	2.02	0.42	0.08	1.39	0.25	0.45	0.63
hm	0	0.69	0.57	1.27	2.17	0.34	0	0.88	0
il	0.52	0.16	0.62	0.27	0.30	0.62	0.43	0.13	0.46
rt	0	0	0	0.16	0.04	0	0	0.17	0

* from Pedersen (1994)
** n.d. = not detected
*** A.S.I. = alumina saturation index: Al_2O_3 / (CaO + Na_2O + K_2O, molar ratio
**** P.I. = peralkalinity index: (Na_2O + K_2O) / Al_2O_3, molar ratio

Analyst: Mrs. R. Coquet, Laboratoire de Pétrographie-Volcanologie, Université de Paris-Sud, Orsay (France)

Table 1b. Chemical analyses of granites from the Mykle area: trace elements (ppm)

	Fine- and medium-grained granites					Ekerites			
Sample	81084*	86018	86035	86044	86069	86022	86045	86057	86060
Li	n.a.**	n.a.	14	n.a.	n.a.	36	51	41	45
Rb	282	230	270	239	241	251	264	260	220
Cs	n.a.	1.0	2.7	1.7	2.9	1.6	3.9	2.8	4.3
Be	n.a.	n.a.	11	n.a.	n.a.	11	8	36	8
Sr	10	6.3	16	70	17	3.1	2.4	30	22
Ba	43	26	84	218	70	45	16	23	36
Pb	11	77	11	14	21	38	22	17	12
Zr	616	176	618	671	638	704	538	859	669
Hf	n.a.	6.7	21	21.6	25.0	24.1	16.6	28.3	25.7
Nb	214	73	218	151	263	142	228	208	203
Ta	n.a.	5.1	12.	10.3	15.6	13.4	15.6	13.7	14.1
La	102	15	109	142	66	83	60	48	43
Ce	203	38	260	260	158	186	142	105	101
Nd	81	19	98	116	70	90	69	48	49
Sm	n.a.	3.5	16.1	17.6	14.2	17.4	16.0	9.4	11.8
Eu	n.a.	0.4	1.2	1.9	1.0	2.0	1.8	1.1	1.5
Tb	n.a.	0.8	2.6	2.8	2.8	3.2	3.9	2.4	2.9
Yb	n.a.	3.2	8.3	8.8	9.2	9.7	14.3	11.2	8.4
Lu	n.a	0.5	1.3	1.4	1.4	1.3	1.9	1.6	1.3
Y	78	29	87	88	88	98	161	98	101
Sc	6	1.3	4.4	4.3	2.9	3.3	2.7	3.4	2.3
Zn	38	73	41	151	151	115	152	173	118
Th	4.5	11	40	44	45	18	21	15	16
U	n.a.	5.4	12.5	8	13.6	5	8.7	9	9.6
Ga	27	25	32	23	25	25	27	29	34

* From Pedersen (1994)
** Not analysed

Analysts: J.C. Bailey and B. Damgaard, Geological Institute, University of Copenhage R. Gwozdz, Tracechem A/S, Copenhagen. Methods: INAA: Cs, REE, Ta, Hf, Sc, U; atom absorption spectrometry: Li, Be; XRF: other elements.

veined complex. Samples 86022, 86045 and 86057 are ekerite from various localities on the western and eastern sides of the lake, whereas sample 86060 was taken at the contact with microsyenite on the southeastern shore of lake Mykle.

Table 1a illustrates the differences of chemical compositions of the fine- to medium-grained granite and ekerite. Apart from the two quartz-rich contact samples, 86018 and 86069, the fine- to medium-grained granite yields lower contents of SiO_2 and normative q and higher contents of or than ekerite. The ekerite samples have a peralkalinity index P.I., calculated as (Na_2O + K_2O)/Al_2O_3 (molar ratio), markedly higher than one, while the metaluminous to weakly peraluminous, fine- to medium-grained granite samples yield values lower than or close to one (Fig. 8). Low CaO abundances explain exceedingly low contents of normative an and cpx. Accordingly, all ekerite samples have normative ac, two fine- to medium-grained granite samples have normative c, and four fine- to medium-grained granite samples have normative cpx.

When compared with ekerite, the fine- to medium-grained granite is lower in Li, Cs, Y and Zn, and a little higher in Al, K, Rb, Ba, the components of alkali feldspar in agreement with higher normative or. Additionally, the low-silica, fine- to medium-grained granite samples are enriched in LREE (Fig. 9), Sc, Th and perhaps U relative to ekerite.

Among the fine- to medium-grained granite samples, 86018 and 86069 differ from the two other samples by higher contents of SiO_2 and lower contents of most other elements. These samples were taken near the contacts and the high contents of quartz may have 'diluted' the contents of the other elements. The two other samples, 86035 and 86044, have lower contents of SiO_2 than ekerite. Sample 81084 is chemically (and mineralogically) so similar to samples 86035 and 86044 that the small satellite intrusion to the south of the main mass of granite is likely to represent a southern extension of the fine- to medium-grained granite of the eastern granite massif.

The ekerite compositions are highly similar, with the only exception of higher Sr contents in samples 86957 and 86060. This may be caused by the occurrence of astrophyllite in the case of sample 86057. Sample 86060 comes from ekerite intruding and assimilating a microsyenite located at the southeastern contact of the granite massif. This rock contains about 750 ppm Sr (Andersen & Sørensen 2003).

Discussion

Two topics will be addressed: (i) the relationships of the Mykle granites with the other ekerite occurrences in the Oslo Igneous Province, (ii) the magmatic evolution and mode of emplacement of the Mykle western granite massif.

The Mykle western granite massif and other ekerite occurrences in the Oslo Igneous Province

In their monograph on ekerite of the Oslo region, Dietrich et al. (1965) describe associations of the granite varieties described in the present paper and various syenitic rocks (see also Dietrich & Heier 1967). The late-stage granites, compared with the early stage quartz-poor rocks, are higher in Si, Be, Li, Rb, Cs, Nb, Zr, Pb and Ta and lower in Ti, Al, Fe, Mg, Ca, Na, K, Ba, Sr, La and Nd. Ekerite is considered to have formed from volatile-rich residual liquids undergoing chemical fractionation as a result of mineral settling and volatile transfer, partly resulting in loss of volatiles. In agreement with this model, the massive rocks are higher in incompatible elements than the miarolitic varieties.

Rasmussen et al. (1988) and Neumann et al. (1990) emphasise the role played by a combination of crystal fractionation and volatile transfer in the formation of the Eikeren ekerite. It was not possible to subdivide the Eikeren granite into separate intrusive units on the basis of field, petrographic or compositional criteria, and cross-cutting relations in the Eikeren ekerite are believed to reflect movements within the crystallising magma body rather than separate intrusions (Neumann et al. 1990).

The Mykle western granite massif is also composite but, by contrast with the Eikeren ekerite, separate rock units could be defined. Chilled margins are displayed at the contacts with the earlier larvikite and enclaves of nepheline syenite, implying that these already consolidated rocks were cool enough to create a sharp gradient of temperature when the granitic magmas were emplaced. On the contrary, though later than syenite, granites were emplaced when syenite were still hot, implying a short time lag between the two intrusive events. Accordingly, no chilled margins occur in the granites at the contact with syenite. The two granite varieties, also, were emplaced in a short period of time; sharp contacts were observed, but with no chilled margins. The sequence: fine- to medium-grained granite → ekerite is shown by xenoliths of larvikite and mafic rocks of the net-veined complexes invaded by and enclosed within the fine- to medium-grained granite, prior to the emplacement of ekerite.

Another example of a composite granite stock in the Oslo rift has been described from the Glitrevann cauldron (Jensen 1985). Three distinct granite types are distinguished, a medium-grained granite, a porphyritic granite and an aplitic granite. The porphyritic granite may represent a contact facies of the medium-grained type, but the aplitic granite is youngest and intrudes the two others. The chemical compositions (Fig. 8) of the two first-named types are very close to that of the fine- to medium-grained Mykle granite, e.g., relatively low SiO_2, relatively high Al_2O_3 and normative c. The chemical composition of the aplitic type, though similar, is less peralkaline than the Mykle ekerite, e.g., high SiO_2, low Al_2O_3, but low normative ac. Accordingly, no sodic pyroxene or amphibole are mentioned in the aplitic type which contains biotite. The magmatic trend of the Glitrevann granites matches that of the Mykle fine- to medium-grained granite and differs markedly from the more peraluminous biotite granites of the Drammen and Finnemarka batholiths (Trønnes & Brandon 1992).

Implications for magmatic evolution and modes of emplacement

Granite complexes are frequently composite, whatever their sites of emplacement. In the Oslo Igneous Province, they were emplaced at shallow depths within the upper crust of a Late Carboniferous to Permian continental rift.

The granites of the Oslo Rift can be classified at a first step into two major varieties: biotite granite and ekerite, covering areas of similar size. This classification should also include the related syenites. There is presently a consensus that syenites and ekerite are genetically related (e.g., Rasmussen et al. 1988), but this is less clear for biotite granite. Following Sæther (1962), Gaut (1981) introduced a two-fold classification of biotite granite based on field relationships, with BG I corresponding to granites forming large massifs and showing no transitions to other rock groups, and BG II generally forming smaller bodies in association with syenite and ekerite. Trønnes & Brandon (1990) showed that BG I is mildly peraluminous, while BG II, based on the example of the Glitrevann Cauldron (Jensen 1985), is metaluminous, weakly peraluminous and even weakly peralkaline. The shift from peraluminous to peralkaline compositions for small chemical variations is mostly related to the exceedingly low abundances of CaO, resulting in trends passing through or near the (1.00/1.00) coordinates in an PI-ASI plot (Fig. 8).

The Mykle western granite massif is composed of a sequence of three intrusions: (i) syenite, (ii) fine- to medium-grained granite, akin to the above-mentioned BG II, and (iii) ekerite. The time lag between the intrusive events was short enough to prevent any significant gradient of temperature between the already solidified wall rocks and the intruding magma. It is suggested that the intrusive magmas were tapped successively from the quickly evolving top of a magma chamber and, then, emplaced at shallower depths within the thick cap of larvikite and related rhomb porphyry lavas. The abundant miarolitic cavities occurring within the intrusive rocks and their wall rocks near the contacts are evidence of a subvolcanic level of emplacement, inducing fluid exsolution from volatile-rich magmas (Raade 1972) and continuing transport of fluids at subsolidus temperatures (Neumann et al. 1990).

The maximum shape of the Mykle western granite massif is not displayed at the present surface level, as shown by the flat contacts between the intrusive rocks and their overlying country rocks. On the basis of topographic lows, aeromagnetic anomalies and the observation of a 4-8 m-wide ring dyke of syenite near Fjellvann, 10 km southwest of lake Mykle, Segalstad (1975) suggested that the Mykle granites correspond to the exposed roof of a larger ring structure, up to 20 km in diameter, into which larvikite and related rocks subsided and were locally disrupted by stoping. This suggests that the emplacement of the granites took place by cauldron subsidence in combination with magmatic stoping, processes frequently described in plutonic complexes emplaced in anorogenic geodynamic settings (e.g., Bonin 1986).

From an examination of the aeromagnetic map (Segalstad 1975, fig. 2), it is suggested that the Mykle ekerite is likely to be disconnected at depth from the Eikeren ekerite and the eastern granite massif could constitute a satellite of the western granite massif.

Summary and conclusions

The granites exposed around lake Mykle constitute a western and an eastern massif. Only the western massif is treated in the present paper. It forms an intrusive complex with the following characteristics:

* Country rocks are larvikite occurring in the topographic highs and as stoped blocks within the granites.
* Two types of granite were identified: an early, marginal, fine- to medium-grained, reddish granite; and a younger, central, coarse-grained, white to grey ekerite.
* The fine- to medium-grained reddish granite displays chilled margins at the contacts with larvikite and locally contains mafic rocks as net-veined complexes. The granite, akin to type BG II of the biotite granite classification of Gaut (1981), is metaluminous to weakly peraluminous and yields the highest contents of incompatible elements.
* Though later than syenite and the fine- to medium-grained granite, the ekerite displays sharp contacts only, with no chilled margins, indicating that no significant temperature gradients were created during its emplacement.
* Miarolitic cavities, abundant in all rock types, are evidence of fluid exsolution from volatile-rich magmas and continuing transfer of fluids at subsolidus temperatures.
* The present surface level corresponds to the poorly exposed roof of a larger intrusion, emplaced within larvikite and rhomb porphyry lavas by magmatic stoping and perhaps by cauldron subsidence.

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