Albite granite – an exotic rock of the Oslo Rift

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Introduction

My discovery of albite granite in the Oslo Rift was accidentally made during work on my *cand. real.* thesis (hovedfagsoppgave). The study included determination of the elements Th, U and K in the plutonic rocks of the area by gamma-ray spectrometry. A total of 966 rock samples were collected in the summers of 1969 to 1971, and each sample was studied in thin section (Raade 1973, 1978). Two of the samples, from two small granitic plutons north of Sognsvann in the southern part of Nordmarka just north of Oslo, were found to have abnormally low K contents and could be classified as albite granite.

The results of detailed mapping of the igneous rocks north of Oslo were published by Sæther (1962) and were of great help in my field work. Sæther's map shows four granitic plutons in the area between Bogstadvann and Maridalsvann. The largest is the Tryvannshøgda granite to the west, and three smaller plutons to the east are found in Skådalen, west of Lille Åklungen and east of Store Åklungen (Fig. 1). The granite west of Lille Åklungen occurs just east of the small tarn Lorttjern and is named the **Lorttjern albite granite** by me. The signature of this granite on Sæther's map is coarse-grained biotite granite, whereas the three other plutons are indicated as fine-grained biotite granite. The Tryvannshøgda granite is surrounded by fine-grained, partly porphyritic biotite quartz syenite, with gradual transitions between the two rocks, indicating that they constitute a single intrusion. Rock samples collected by me from these plutons are shown in Fig. 2; results of gamma-ray spectrometry are given in Table 1. Samples 919 (Lorttjern) and 923 (Store Åklungen) are albite granites.

Table 1. *Analytical data on some Oslo Rift granitic rocks by gamma-ray spectrometry (Raade 1973).*

Area	Tryvannshøgda					Skådalen		Lort-tjern	Store Åklungen	
Sample	**926**	**927**	**928**	**929**	**935**	**930**	**966**	**919**	**922**	**923**
K_2O wt.%	5.72	4.66	4.60	5.28	5.27	4.81	4.72	**0.14**	3.08	**0.27**
Th ppm	14.4	31.0	22.0	24.9	26.2	40.5	37.4	25.4	24.8	17.7
U ppm	3.4	2.9	5.8	4.4	8.7	14.4	9.7	4.4	3.3	1.9

According to my petrographic studies, the Tryvannshøgda sample 926 is porphyritic biotite granite, and samples 927, 928, 929 and 935 are fine-grained biotite granites (cf. Fig. 2). The Skådalen and Store Åklungen aplitic granites occur along fault zones and are fractured. The elevated Th and U contents of the Skådalen samples should be noted. The Store Åklungen 922 sample, with relatively low K_2O content, appears to be partly albitized. The petrography of the Lorttjern albite granite is outlined below. Sæther (1962) observed intrusive contacts of the Tryvannshøgda and Skådalen granites against Grefsen syenite, and the Sore Åklungen granite intrudes the surrounding "contaminated nordmarkite" (see arrows on Fig. 1).

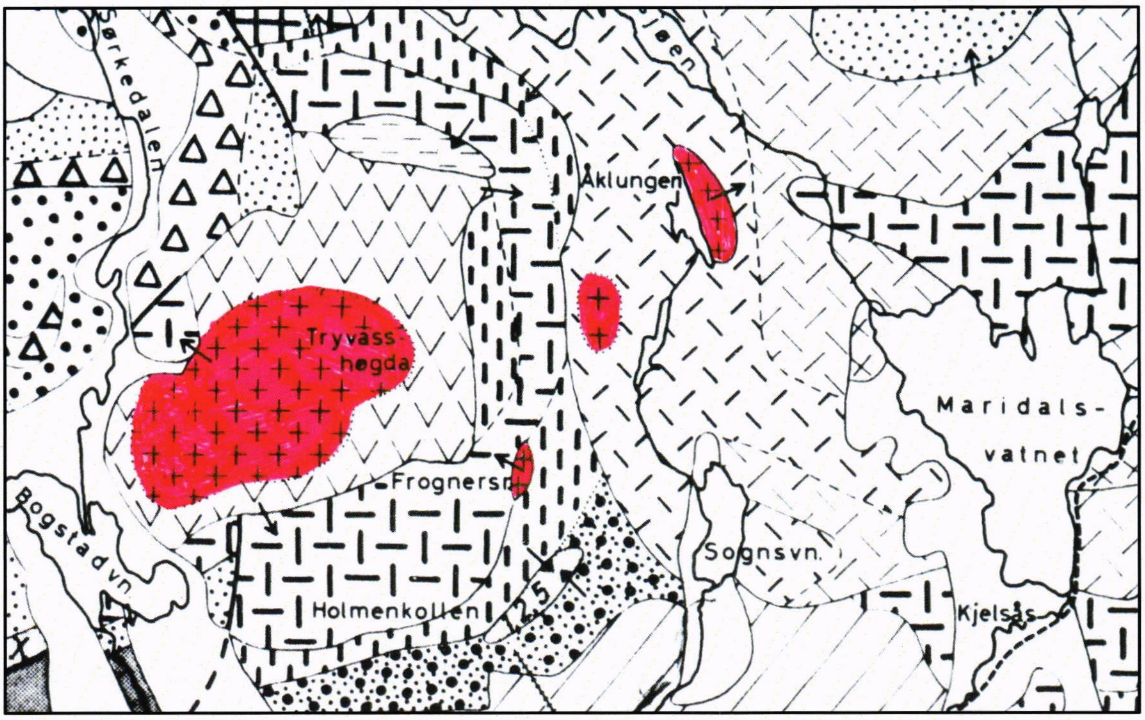

Fig. 1. Section from Sæther's 1962 map. Red colouring of granitic plutons by Raade. The three small plutons to the east are, from south to north: Skådalen, Lorttjern (west of Lille Åklungen) and Store Åklungen. Full legend is not given because of little relevance to the discussion here. For scale, please compare with Fig. 2.

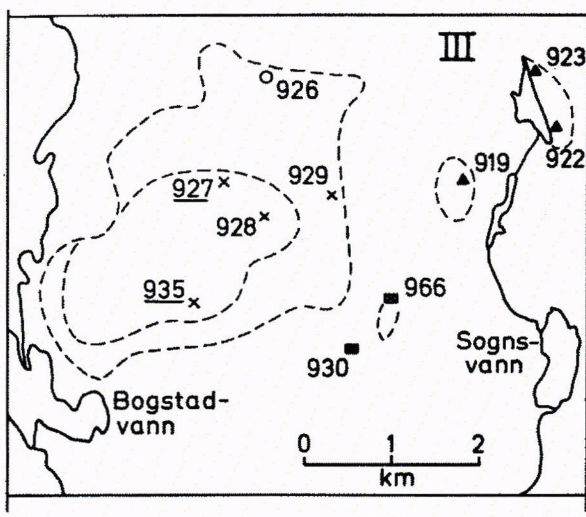

Fig. 2. Simplified map based on Fig. 1, showing sample locations (from Raade 1973). Crosses: fine-grained biotite granite (underlining denotes granophyric texture); open circle: porphyritic biotite granite; filled rectangles: aplitic granite; filled triangles: albite granite (sample 922 is actually partly albitized).

The Tryvannshøgda granite and associated granitic rocks were studied petrographically by Nilsen (1992) and collectively termed the Tryvann Granite Complex (TGC). Nilsen's paper includes whole-rock chemical data of major elements and selected trace elements. His geological map of the area is reproduced here as Fig. 3. Comparison with the map published by Sæther (1962) (Fig. 1) reveals some remarkable differences. There is on Nilsen's map a seemingly sharp border between the Tryvanns-høgda granite and quartz syenite, although the boundary between the two lithologies is in the text reported to be transitional over a distance of approximately 100 m. The separate granitic intrusions of Sæther occurring west of Lille Åklungen (Lorttjern) and east of Store Åklungen are merged on Nilsen's map and are named the Åklungen intrusion. A field of alkali-feldspar granite northwest of Maridalsvann, the Hammeren intrusion, is marked where Sæther has a smaller field of ekerite on his map. Arfvedsonite was observed by Nilsen (1992) as a predominant dark mineral in parts of the Hammeren and Skådalen granites, assumed to indicate a gradation to ekerite.

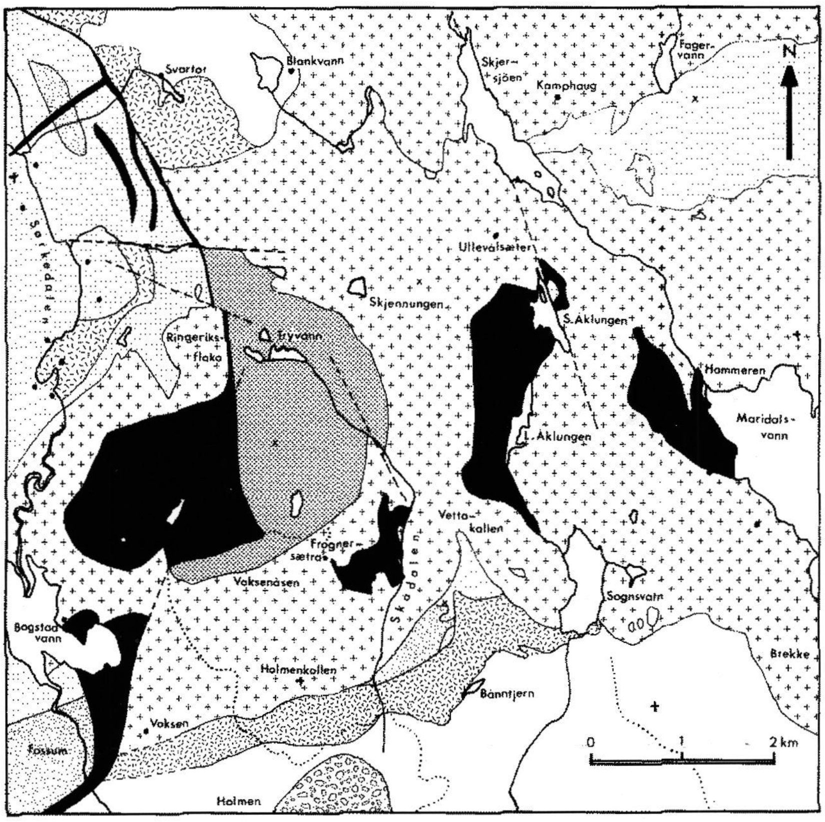

Fig. 3. Geological map of the southern Oslo Nordmark region (Nilsen 1992). Black: alkali-feldspar granite (and ring dykes of the Bærum Cauldron to the west). Dense dots: alkali-feldspar quartz syenite. Crosses: undifferentiated syenites (nordmarkite and Grefsen syenite).

Nilsen (1992) describes late- to post-magmatic hydrothermal alteration of the TGC along fracture zones, with concomitant albitization of the granites. He also has observed small domains of greyish-white albite granite within the Tryvann, Skådalen and Åklungen granites, covering 200–2000 m^2, with transitional boundaries to the adjacent pinkish alkali-feldspar granite. The albite granites do not show any apparent spatial relationship with the fracture-controlled albitization, but they show petrographical and textural relationships similar to the fracture-bound alteration. Unfortunately, no detailed description of the albite granites is made by Nilsen (1992), and his observations should be compared with my account of the Lorttjern albite granite given below.

The Tryvann (Tryvannshøgda) granite has been dated at 241 ± 3 Ma (2σ) with $^{87}Sr/^{86}Sr = 0.7057(3)$ (Sundvoll *et al.* 1990). This constitutes the last stage of magmatic activity in the Oslo Rift, before termination of the rift activity (Larsen *et al.* 2008).

The Lorttjern albite granite

This granite was mapped in detail by me 6–8 July 1977 (Fig. 4). The map shows observed outcrops without any attempt at extrapolation. The northern and southern parts of the granite are separate at surface level.

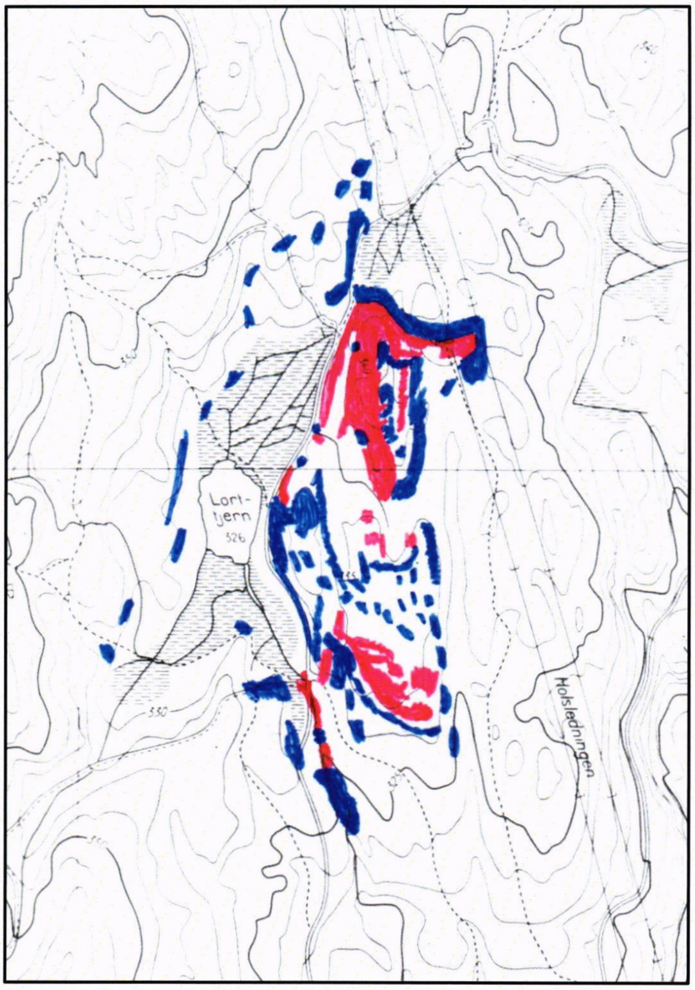

Fig. 4*. Outcrop map of the Lorttjern albite granite and adjacent syenite. Part of map sheet N-5-2 Tryvannshøgda in original scale 1:5.000, issued by Oslo oppmålingsvesen 1974. Shown here at reduced scale 1:7.000. The lake Lille Åklungen is found just outside the map area to the east. Reproduced from a transparency presented at a colloquium at Mineralogisk-Geologisk Museum 28 April 1981. Red: albite granite; blue: syenite.*

The Lorttjern intrusion is made up of light grey, medium-grained, equigranular and rather homogeneous albite granite. It has sharp but irregular contacts to the surrounding syenite (Fig. 5A). Apophyses of albite granite are seen to protrude into the syenite. Where not in contact, the two rocks may be difficult to distinguish in the field, as the syenite varies in appearance. It was classified as nordmarkite contaminated by assimilation processes by Sæther (1962). Quartz-rich veins were found to brecciate the albite granite (Fig. 5B). Miarolitic cavities or pegmatites were not observed. Of great importance is the occurrence of rounded xenoliths of pink granite (Figs. 5C-E), most likely of the Tryvannshøgda type, but sampling was difficult and it has not been studied in detail. Xenoliths of syenite, which should be sharp-edged, were not observed in the albite granite. There can be no doubt about the magmatic, intrusive character of the granite.

The albite granite consists predominantly of quartz and Ab-dominated plagioclase with minor amounts of chlorite. The texture is mainly hypidiomorphic. Quartz and plagioclase may form myrmekitic intergrowths. Accessory phases are titanite, zircon, apatite and opaques. The An content of the plagioclase was determined by powder X-ray diffraction to 3 ± 2. It is apparently unzoned and is in places non-twinned. The results of electron microprobe analyses are shown in Table 2. They indicate a rather pure albite with empirical formula $(Na_{0.95}K_{0.01})(Al_{1.02}Fe_{0.01})Si_{2.98}O_{8.00}$. CaO, BaO, SrO, MnO, MgO and TiO_2 were below detection limits, although minor Ca is certainly present.

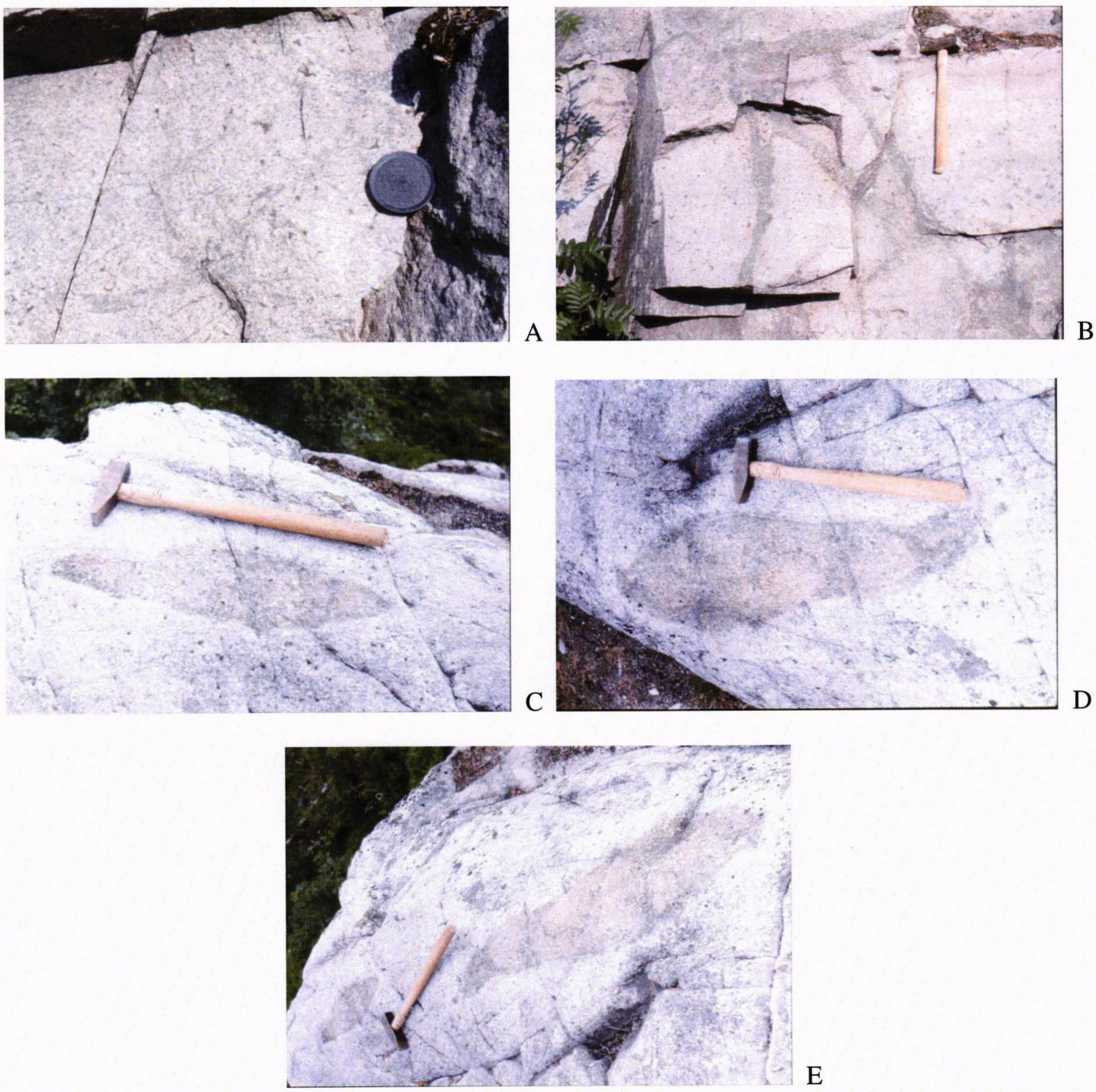

Fig. 5. Field appearances of the Lorttjern albite granite. A: Contact to syenite on the right. Diameter of lens cap is 6 cm. B: Veins of quartz-rich material. C–E: Elongate and rounded inclusions of pink granite, swimming like fishes in albite granite. Notice that A and B are from fresh exposures in road cuts whereas C–E are weathered surfaces.

Table 2. *Albite compositions from electron microprobe analyses (wt.%).*

	1	2	3	Average	Ab theor.
SiO_2	68.85	68.83	68.74	68.81	68.74
Al_2O_3	20.12	19.97	19.90	20.00	19.44
Fe_2O_3	0.43	0.38	0.46	0.42	
Na_2O	11.34	11.34	11.27	11.32	11.82
K_2O	0.16	0.13	0.14	0.14	
Total	100.90	100.65	100.51	100.69	100.00

Six rock samples were selected for chemical analysis, and the results are displayed in Table 3A. Four samples are albite granite, one from Store Åklungen and three from Lorttjern. Those with numbers 968 and 969 were collected 4 September 1972 and are not part of the Raade (1973) thesis. Analytical data were obtained by X-ray fluorescence and are corrected for loss on ignition. Divalent iron was determined by titration. CIPW norms are shown in Table 3B. A norm is the theoretical mineral composition of a rock, calculated according to certain rules from the chemical analysis. It is mainly used for assigning a rock to a norm system of rock classification. The norm does not normally coincide with the real (modal) mineral composition. For instance, normative corundum (C in table 3B) is an artificial result. In the case of albite granite, with a simple composition of three main components, SiO_2, Al_2O_3 and Na_2O, the normative data involving quartz and albite may be assumed to be representative of the modal composition.

Table 3A. *Chemical analytical data for rocks from the Tryvann Granite Complex (TGC) (wt.%).*

Sample	**929**	**966**	**923**	**919**	**968**	**969**
SiO_2	70.74	75.40	72.33	75.55	71.89	74.21
TiO_2	0.40	0.21	0.51	0.30	0.31	0.32
Al_2O_3	14.38	13.65	15.95	13.53	15.28	13.21
Fe_2O_3	1.13	1.87	2.32	1.50	1.46	1.24
FeO	0.94	0.21	0.24	0.54	0.65	0.86
MnO	0.14	0.21	0.31	0.25	0.21	0.19
MgO	0.42	0.06	0.15	0.23	0.54	0.41
CaO	0.58	0.09	0.35	0.47	0.71	0.55
Na_2O	4.78	4.68	8.30	7.49	9.08	7.81
K_2O	5.25	4.72	0.32	0.19	0.19	0.17
P_2O_5	0.06	0.02	0.06	0.02	0.07	0.02
Total	98.82	101.12	100.84	100.07	100.39	98.99
LOI	0.43	0.57	0.57	0.39	0.31	0.26

929*: Biotite alkali-feldspar granite, Frønsvollen, Tryvannshøgda.* ***966****: Fractured aplitic alkali-feldspar granite, Skådalen.* ***923****: Fractured albite granite, Store Åklungen.* ***919****,* ***968****,* ***969****: Albite granite, Lorttjern. LOI means loss on ignition.*

Table 3B. *CIPW norms (wt.%) for rocks from the TGC, based on analytical data in Table 3A.*

Sample	929	966	923	919	968	969
Q	21.01	29.79	21.98	29.74	16.56	26.68
C		0.73	1.46	0.20		
Or	31.02	27.89	1.89	1.12	1.12	1.00
Ab	40.45	39.60	70.23	63.38	76.83	66.08
An	2.28	0.32	1.34	2.20	0.37	0.49
Di	0.13				1.61	1.28
Hd	0.04				0.56	0.42
En	0.99	0.15	0.37	0.57	0.60	0.43
Fs	0.37	0.21	0.09	0.48	0.24	0.16
Il	0.76	0.40	0.97	0.57	0.59	0.61
Mt	1.64	0.38	0.15	0.84	0.94	1.80
Hm		1.61	2.21	0.92	0.81	
Ap	0.14	0.05	0.14	0.05	0.17	0.05
Sum	98.83	101.13	100.83	100.07	100.40	99.00
Q	22.2	30.5	23.0	30.8	17.4	28.3
Or	32.7	28.6	2.0	1.2	1.2	1.1
Ab	42.7	40.6	73.6	65.7	81.0	70.1
An	2.4	0.3	1.4	2.3	0.4	0.5
Sum	100.0	100.0	100.0	100.0	100.0	100.0
Q			23.8	31.9	17.7	28.8
Ab			76.2	68.1	82.3	71.2
Sum			100.0	100.0	100.0	100.0

For rock types and localities, see footnote to Table 3A. Mineral abbreviations: Q (quartz), C (corundum), Or (orthoclase), Ab (albite), An (anorthite), Di (diopside), Hd (hedenbergite), En (enstatite), Fs (ferrosilite), Il (ilmenite), Mt (magnetite), Hm (hematite), Ap (apatite).

Although not very successful, the result of an attempted Rb-Sr age determination of the albite granite is reported in Table 4. The resulting isochron, based on four samples, gives an age of 213 ± 55 Ma (2σ) with initial $^{87}Sr/^{86}Sr = 0.7054(2)$. This initial ratio is similar to that of the Tryvannshøgda granite as noted above, and indicates a close genetic relationship between the two rock types. A younger age for the albite granite can be expected, but the very high error makes the obtained date useless. Lack of K-feldspar in the albite granite results in very low contents of Rb and Sr and makes dating difficult. In comparison, the Tryvannshøgda granite has Rb ranging from 120.5 to 209.2 ppm and Sr from 13.8 to 123.9 ppm (Sundvoll & Larsen 1990). Moreover, the three Lorttjern samples, owing to their close Rb and Sr values, cluster in the isochron diagram (not shown here), and the isochron slope is dependent on the single 923 sample from Store Åklungen with higher Rb and Sr contents.

***Table 4**. Rb and Sr isotope data for the Lorttjern albite granite.*

Sample	Rb ppm	Sr ppm	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
919	1.38	25.83	0.053	0.1546(16)	0.7060(1)
923	7.80	55.79	0.140	0.4045(40)	0.7066(1)
968	1.25	42.11	0.030	0.0859(9)	0.7055(1)
969	0.87	23.88	0.036	0.1054(11)	0.7058(1)

Sample 923 from Store Åklungen, the others are from Lorttjern.

Albite granites in general

These are relatively uncommon rocks, although described from a number of different settings. They are occasionally referred to in provincial publications as part of regional bedrock descriptions (e.g. Gilluly 1933). Previously they were almost exclusively regarded as metasomatic rocks, which may be true for many of them. In petrology textbooks, albite granites are most often not considered, in contrast to plagiogranites which carry more An-rich plagioclase. Albite granite has been defined as containing albite with An content 0-10, which coincides with the mineralogical definition of albite. However, in the Streckeisen (IUGS) classification of plutonic rocks (Streckeisen 1974), albite with An 0-5 is combined with alkali feldspar, and this should be the limiting value for albite granite. The rock thus belongs to the alkali-feldspar granite field, whereas plagiogranite belongs to the tonalite field. Albite granites are volumetrically insignificant compared to their associated rock types.

- Plagiogranites, in rare cases grading into albite granite, occur in continental areas with leucocratic intrusive rocks like trondhjemite, tonalite and quartz diorite. They are developed by fractionation of basaltic magma or through a process of partial melting of amphibolite or eclogite (e.g. Rapp *et al.* 1991).
- Plagiogranite and albite granite also occur in mid-oceanic rift areas and in association with ophiolite complexes. Various theories have been put forward for the genesis of such rocks: low-pressure differentiation of sub-alkaline basaltic magma (Coleman & Peterman 1975), fractional crystallization of gabbroic rocks, based on modelling (Borsi *et al.* 1998), partial melting of gabbros from experimental study (Koepke *et al.* 2004) and even silicate–liquid immiscibility (Dixon & Rutherford 1979). The latter mode of formation, based on a small-scale experimental study, can be rejected because the Fe-rich conjugate magma has not been identified in nature. Leucocratic rocks from ophiolite sequences normally contain strongly zoned plagioclase with calcic cores and sodic rims and may exhibit myrmekitic texture (e.g. Coleman & Peterman 1975).
- Albite granite may occur as quartz-rich members of albitites. An example is known from Kragerø where rutile-bearing "kragerøite" occurs (Green 1956). According to Green, the available evidence indicates a metasomatic origin for most of the albitite bodies, formed from pre-existing gabbro or amphibolite. A discussion of albitites is outside the scope of the present paper. Suffice it to state that albitites have in the past frequently been regarded as magmatic differentiates of basaltic/gabbroic magmas. However, the extensive albitization in the Modum Complex was explained by Munz *et al.* (1994) as a result of retrograde fluid infiltration.
- Of more relevance to the petrogenesis of the Lorttjern albite granite is the association of magmatic albite granites with A-type granites, recorded from just a few locations (Barboni &

Bussy 2013, Lan *et al.* 2015). Typical features of A-type granites are alkaline affinities, anorogenic and rift settings, and they are likely to have evolved from mantle-derived magmas (Bonin 2007).

Petrogenesis of the Lorttjern albite granite

This albite granite has intrusive contacts to the surrounding syenite and carries inclusions of what appears to be pink alkali-feldspar granite. It is consequently of magmatic origin. Lack of miarolitic cavities and pegmatites, and just a minor content of chlorite, indicate a relatively dry magma. Its homogeneity and ordinary granitic texture support a magmatic origin, except for the occasional occurrence of myrmekitic texture. Myrmekite (vermicular intergrowth of quartz in albite) is generally interpreted to form under metasomatic conditions (albitization) by replacement of K-feldspar. However, it may also develop during late stages of crystallization where a volatile phase is locally present (*Encyclopædia Britannica* online: britannica.com) and is common in some plagiogranites as noted above. The occurrence of rounded xenoliths, apparently without reactions rims (Figs. 5C–E), is conspicuous and intriguing and seems to indicate that they are plastically deformed. The albite granite might have intruded the alkali-feldspar granite at a time when it was still hot and not completely solidified, or the inclusions could have resided in the albite-granite magma for some time prior to its solidification. Field occurrence and similarity in initial $^{87}Sr/^{86}Sr$ ratio indicate a genetic relationship between the two types of granite.

Nilsen (1992) has described late- to postmagmatic hydrothermal albitization in fracture zones of the alkali-feldspar granite of the TGC and even in the adjacent Grefsen syenite. Within the granite, the alteration process is generally characterized by a change from the granophyric and equigranular texture of the alkali-feldspar granite to fine-grained, saccharoidal albite granite. Nilsen also has observed outcrops up to 2000 m^2 of greyish-white albite granite within the alkali-feldspar granite, allegedly with transitional boundaries. No specific description is given of these albite granites, except that they "show the same petrographical and textural relationships as the fracture-bound albitic alteration". This is a serious shortcoming of Nilsen's investigations. According to Nilsen (1992), the domains of albite granite "do not show any apparent spatial relationship with the fracture-controlled albitic alteration". Nevertheless, a genetic relationship can safely be surmised. Judging from the magmatic nature of the Lorttjern albite granite, and assuming there is more of its kind within the TGC, the albitization process affecting fracture zones could be related to a late phase of hydrothermal emanations from the albite granite.

The crucial question is: How do magmas of albite-granite composition form? Principally, there are two main possibilities. They could be produced as late-formed melts by magmatic differentiation or anatectically by partial melting of a rock with suitable chemical and mineralogical composition. Partial melting of basic rocks and fractional crystallization of basaltic magmas have been proposed for the formation of plagiogranites (see above). These are not viable models for the formation of the Lorttjern albite granite owing to the lack of basic rocks in the area. Crystal fractionation from alkali-feldspar granite to albite granite is also precluded (Lan *et al.* 2015 and references therein). Major-element composition of the Lorttjern albite granite is limited to only three rock samples (Table 3A), but indicates considerable spread in quartz : albite proportions with albite varying from 68 to 82 wt.%, based on norm figures in Table 3B. Clustering of data around the eutectic in the quartz–albite system would be expected if the albite granite were formed as a differentiation product and even if formed by anatexis, dependent on the homogeneity of the source rocks. This eutectic is situated at 58 to 66 wt.%

albite, depending on H_2O pressure (Fig. 181 in Ehlers 1972, not reproduced here owing to copyright restrictions; see also Holtz *et al.* 1992). Nilsen (1992) has shown that the major lithologies of the TGC (excepting albite granite) plot in the low-pressure thermal valley of the Q–Ab–Or system, close to the thermal minimum on the cotectic line for 1 kbar and 4% H_2O, suggesting a residual melt origin.

Papers describing associations of albite granite with A-type granite are considered next. Albite granite of the Proterozoic Dori pluton in Rajasthan, India, has been interpreted to be produced by two-stage, extreme albitization of A-type granites (Kaur *et al.* 2012). A metasomatic model, using chromatographic theory of fluid infiltration, supports the idea of two metasomatic fronts, initially transforming oligoclase to nearly pure albite and subsequently replacing microcline by albite. It seems surprising that the albite granite has sharp contacts to microcline-albite granite, formed during the first metasomatic stage, but this is asserted to be consistent with the theory of infiltration metasomatism. General problems with albitization on a larger scale are that the source of Na-rich solutions is often poorly constrained, and the fate of the released K is unexplained. Where are the K-enriched rocks? Albitization is out of the question for the intrusive Lorttjern albite granite. The other albite granite outcrops within the TGC have not been investigated by me and are inadequately described by Nilsen (1992). The question of their possible metasomatic origin is unresolved.

Barboni & Bussy (2013) described cogenetic and nearly contemporaneous A-type granite and albite granite from a 347 Ma old intrusion in Brittany, France. Fine-grained albite granite was emplaced ca. 0.8 Ma after the A-type granite and forms meter-thick sills that mingle with adjacent mafic layers. Field evidence as well as mineral chemistry and elemental geochemistry support a magmatic origin of the albite granite. The albite-granite magma is considered to be a Na-rich residual melt that was extracted from a partially crystallized A-type granite mush at a late stage of crystallization. This theory is claimed to fit all the available data and explains the very low volumes of this unusual magma composition. An alternative theory, not favoured by the authors, is that the albite granite could result from melting of plagioclase-rich layers formed during A-type granite differentiation.

Paleoproterozoic alkali-feldspar A-type granite (2193 Ma) and albite granite (2171 Ma) are described from the Eastern Block of the North China Craton (Lan *et al.* 2015). Genetic modelling suggests that the alkali-feldspar granite originated from melting of granodiorite, whereas the albite granite most likely derived from reworking of plagioclase-rich layers after extraction of A-type melts. This is similar to the alternative model proposed by Barboni & Bussy (2013), as mentioned above. The large age gap between the emplacement of the two granites suggests complete solidification of the alkali-feldspar granite before the albite granite intruded, and extraction of Na-rich residual melt from partially crystallized A-type granite magma is therefore excluded (Lan *et al.* 2015).

The papers of Barboni & Bussy (2013) and Lan *et al.* (2015) demonstrate that magmatic albite granites do exist and that they can be cogenetic with A-type alkali-feldspar granites. However, their results and conclusions cannot directly be applied to the genesis of the Lorttjern albite granite. Their petrogenetic models are disparate and may to some extent appear speculative. The occurrence of elongate inclusions of pink granite in the Lorttjern albite granite is a major key to understanding their genetic relationships, and detailed investigation of these inclusions is required to fully reveal the origin of the Lorttjern albite-granite magma.

Coda

More data, especially of geochemical and isotopic nature, are required to elucidate the petrogenesis of the intrusive Lorttjern albite granite. The author realizes that he shall not be able to finish this project for international publication. It is still important to publish the available data to avoid losing them, although the proceedings of *Norsk Mineralsymposium* may not be the best vehicle.

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