Economic potential of potassic feldspar-rich gneisses in Tysfjord/Hamarøy, northern Norway

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Potassic feldspar gneiss in the Tysfjord/Hamarøy area may be a potential resource for future exploitation. The rock consists primarily of microcline (up to 84 %) and quartz (up to 35 %), together with small amounts of plagioclase (1-12 %), commonly albite. Accessory minerals include epidote, micas and magnetite. Six deposits have been indicated by mapping. All are situated within a supracrustal suite of Precambrian age (2500-2100 Ma) dominated by a feldspathic gneiss. The quality of the rock is largely dependent on the texture and grain size, as a fine grain size and complex grain boundaries make separation of the different minerals difficult.

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Introduction

Traditionally, feldspar was extracted from pegmatites by hand sorting. Nowadays, processing techniques such as flotation make it possible to extract feldspar from many rock types. The parent rocks worldwide are dominated by several types of granitoid and alkaline intrusive rocks, including leucocratic granites, albitites, alaskite and aplites. North Cape Minerals AS at Lillesand, southernmost Norway, separate quartz and feldspar from a graphic textured granite by flotation.

Feldspars of commercial interest commonly fall within the range of microcline-perthite-albite-oligoclase. They are frequently used in glass manufacture and in ceramics. In glass applications feldspar is used for container and flat glass, fibreglass, TV-tube glass, and other more specialised uses. The chemical composition of the feldspar product is important for the applications in glass manufacture. Feldspar is principally a source of alumina, which acts as a stabiliser, improves durability, increases viscosity during glass formation, and acts as a matrix former. In general, around 1.5-2 % Al_2O_3 is required for container and flat glass, and up to 15 % for certain glass fibres. The alkalis in feldspar act as a flux by chemically attacking the other glass batch minerals such as quartz (Harben & Kužvart 1997). In ceramics, sodic feldspar is particularly useful in ceramic body and glaze. Potassic feldspar is more expensive, but is preferred in porcelain enamels and in high-voltage electrical porcelain.

At the end of the 1970s, K-rich gneisses in Tysfjord/Hamarøy, northern Norway, were located and investigated by NGU (Åmli 1975, 1978). More comprehensive mapping and further deposit studies were carried out by Karlsen (1990). In the present paper, a summary of the earlier work is presented with special emphasis on deposit geology and composition of the ore.

Geological setting

The investigated deposits are situated at the border between the municipalities of Tysfjord and Hamarøy, northern Norway (Fig. 1). All rocks in the area are of Precambrian age, and are part of the Lofoten-Tysfjord basement. In the Tysfjord and Hamarøy area, the basement is dominated by granitoid rocks with ages around 1800 Ma. The granitoid bodies have intruded into volcanic and sedimentary supracrustal rocks with ages of 2500-2100 Ma or 1910-1880 Ma. Prior to the intrusion of the granites, the supracrustal rocks were affected by the Svecokarelian deformation event at 1900-1800 Ma; in many of the supracrustal lenses, foliation and folds are visible. These structures are not present in the granitoid rocks. Mafic dykes that cross-cut both the supracrustals and the granitoids are the youngest rocks in the area.

The K-rich rock described in this paper has an alkali-rhyolitic composition and belongs to the supracrustal series, comprising 1) K-feldspar gneiss, 2) calc-silicate, K- feldspar-rich gneiss, 3) biotite-bearing K-feldspar-poor gneiss, 4) biotite schist, 5) calc-silicate rock and 6) calcite marble. The K-feldspar deposits are all situated within the dominant K-feldspar gneiss.

Similar rocks, but less deformed and less potassic, outcropping in the Rombak window farther north, have been interpreted as volcanic (Korneliussen & Sawyer 1990, Sawyer & Korneliussen 1990). The potassic gneisses in Tysfjord form a more or less structural continuation of similar rocks present in the Lofoten region where they are more common.

Previous processing tests

Potassium feldspar-rich gneisses are known to occur at several places in Norway, and the following deposits have been studied in varying detail for commercial use:

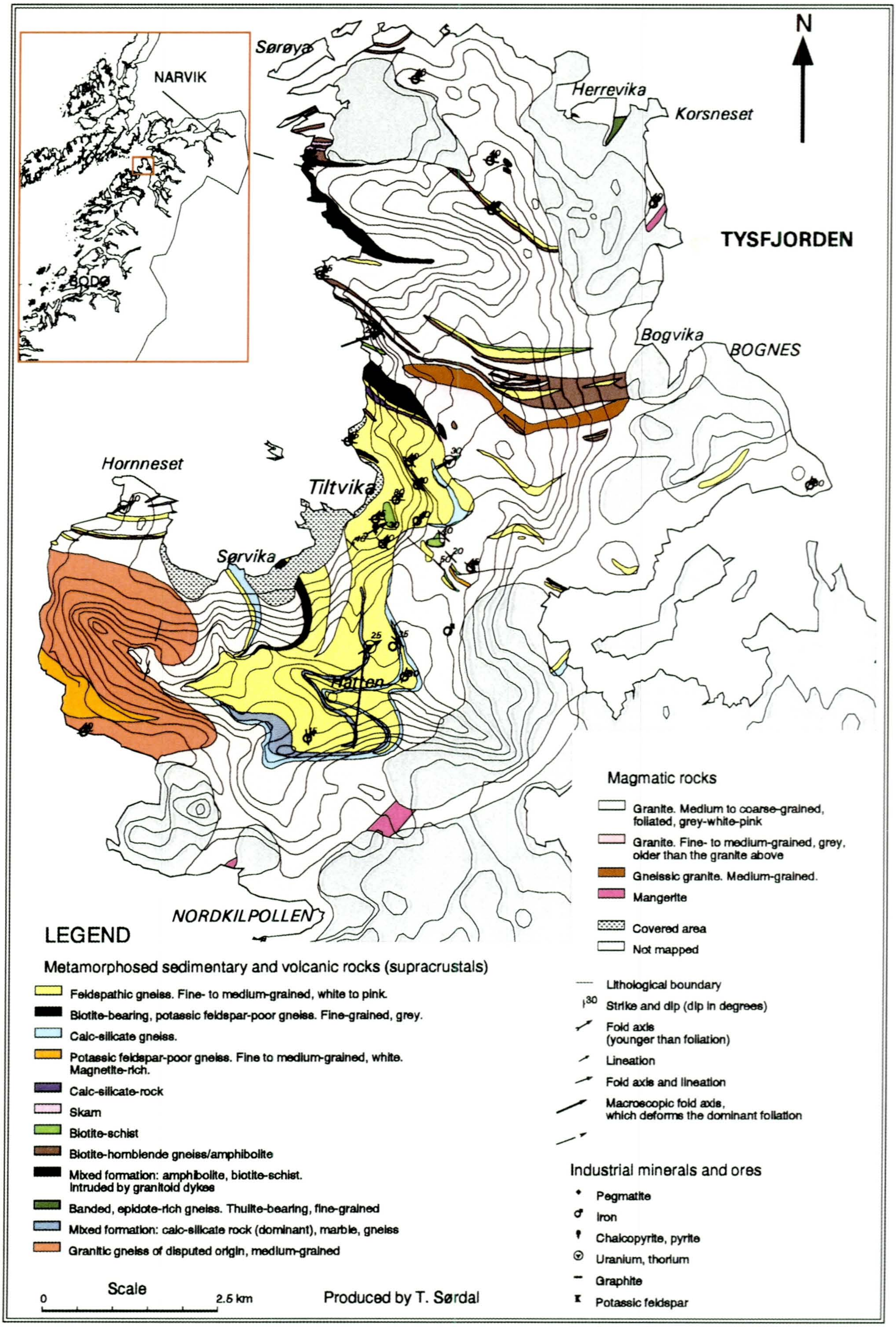

Fig. 1. Geological map of the investigated area.

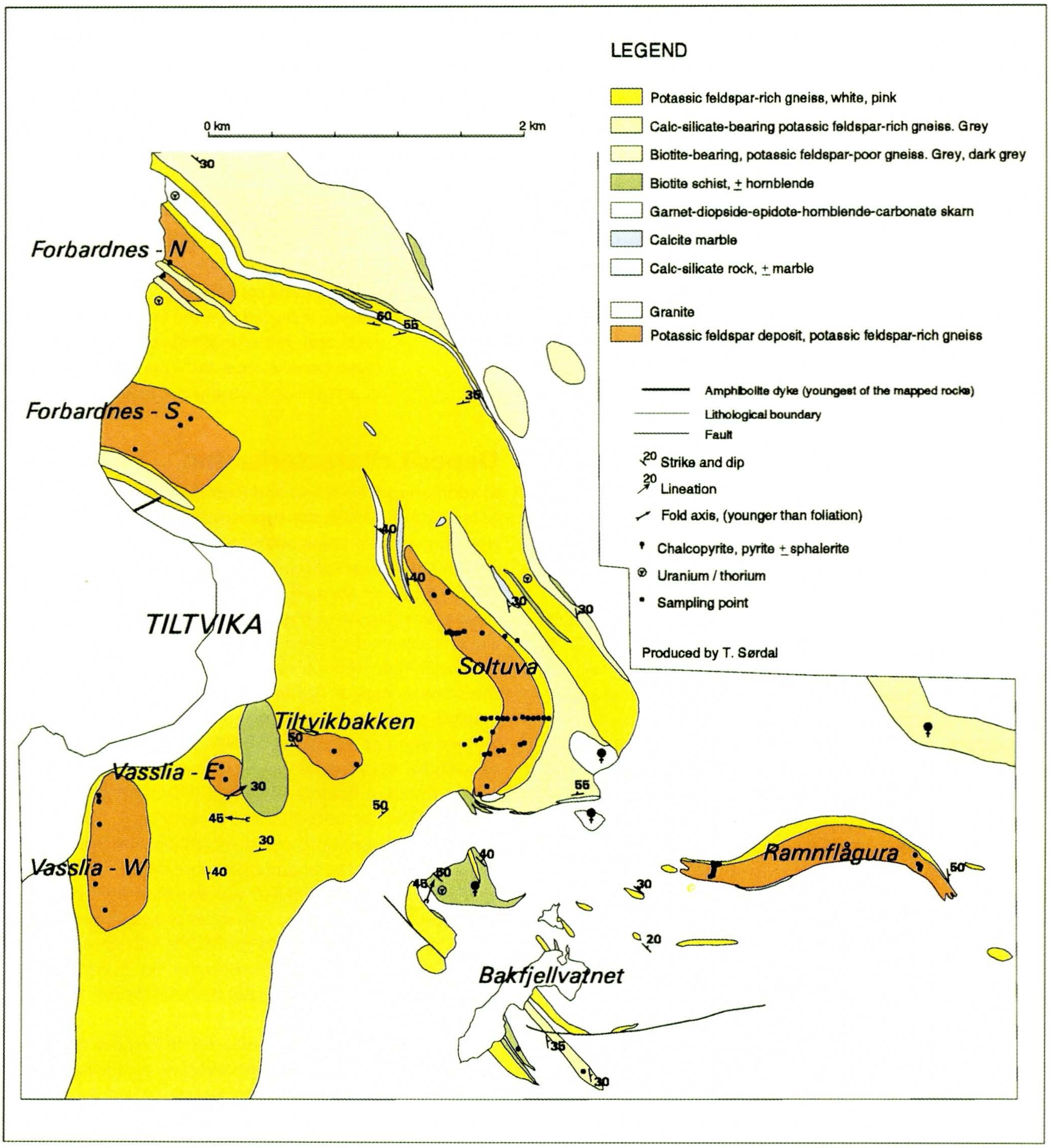

Fig. 2. Detailed geological map showing the deposits of K-feldspar rich gneisses.

1. Gåslandsvann, Bø in Vesterålen (Åmli 1976)
2) Storjord-Tiltvika, Tysfjord/Hamarøy (Åmli 1975, 1978, Karlsen 1990)
3. Bleikvassli (Larsen et al. 1995).

Potassium-rich rocks at Gåslandsvann were investigated by NGU in 1976-1977 (Åmli 1976). The raw material consists of 60 % orthoclase, 21 % quartz, 6 % plagioclase, 6 % cordierite, 2 % sillimanite and 4 % magnetite + ilmenite. In addition, the following accessories occur: biotite, apatite, garnet, zircon, corundum and white mica. Samples of 50 kg were taken from 3 locations. A simple processing by flotation and strong-field magnetic separation gave promising results regarding K-feldspar concentrates. In addition to a K-feldspar product, it was realised that production of quartz and cordierite/sillimanite concentrates might be achievable. The achieved feldspar concentrate contained 85-90 % feldspar (ca. 85 % K-feldspar and the remainder albite), and 10-15 % quartz and sillimanite. A laboratory report from SINTEF concluded that a feldspar concentrate containing ca. 13.5 % K_2O, 1.8 % Na_2O and 0.10-0.12 % Fe_2O_3 should be attainable by more comprehensive tests.

The industrial potential for potassic feldspar gneiss in Tysfjord/Hamarøy was pointed out by Åmli (1975). Partly because of this, a radiometric (gamma spectroscopy) survey was undertaken from helicopter in parts of Tysfjord and Hamarøy (Håbrekke 1979). The measurements gave promising results and were followed up by ground measurements (Åmli 1978). Two deposits, Soltuva and Ramnflågura, were identified (Fig. 2). Chemical and petrographic descriptions, as well as simple processing tests were made. From the processing tests it was concluded that it is possible to make concentrates of K-feldspar containing low amounts of Fe by conventional methods, including flotation.

400 kg of raw material from both the Soltuva and the Ramnflågura deposits were collected for processing tests (Åmli 1978). The tests were performed in 1978 on average samples by Oppredningslaboratoriet, NTNU, and Norfloat A/S, and were reported by Åmli (1978). A later test made by Norfloat A/S concluded that the process produced too great a proportion of fines.

Oppredningslaboratoriet did a simple test by strong-field magnetic separation in order to remove Fe-bearing minerals, and the achieved products contained 0.12 % and 0.09 % Fe_2O_3, respectively. It was concluded that Fe-poor feldspar concentrates could be achieved by relatively simple processes.

Norfloat A/S (now part of North Cape Minerals AS) at Glamsland made high magnetic separation and flotation tests of the same material in order to find out if it was possible to achieve a pure K-feldspar concentrate. Two samples were tested. The following products were achieved:

Sample a:

< 0.5 mm: 63.3 % feldspar concentrate with 9.7 % K_2O and 0.19 % Fe_2O_3
13.7 % quartz concentrate with 0.34 % Al_2O_3
18.7 % 'Fe-concentrate'

< 0.3 mm: 26.3 % K_2O-concentrate I with 13.2 % K_2O and 0.07 % Fe_2O_3
23.8 % K_2O-concentrate II with 8.7 % K_2O and 0.08 % Fe_2O_3
18.1 % Quartz concentrate with 0.26 % Al_2O_3 and 0.06 % Fe_2O_3
24.6 % 'Fe-concentrate'

Sample b:

< 0.5 mm: 63.6 % feldspar concentrate with 11.8 % K_2O and 0.25 % Fe_2O_3
9.1 % quartz concentrate with 0.17 % Al_2O_3
20.1 % 'Fe-concentrate'

< 0.3 mm: 51.9 % feldspar concentrate with 12.7 % K_2O and 0.11 % Fe_2O_3
11.6 % quartz concentrate

It was concluded that the fine grain size of the rock and impregnations of mafic minerals make beneficiation to high-grade feldspar or quartz/feldspar products difficult.

Deposit characterisation

In addition to the Soltuva and Ramnflågura deposits investigated by Åmli (1978), the supracrustal series in the Tysfjord-Hamarøy area contains additional deposits. Detailed mapping in the region (Karlsen 1990) revealed deposits at the following localities: Forbardnes N, Forbardnes S, Tiltvikbakken, Vasslia W and Vasslia E (Fig. 2 & Karlsen 1990). The three largest deposits are described below:

The *Soltuva* deposit, situated along the border between the communities of Tysfjord and Hamarøy at an altitude of 300-375 m, covers an area of approximately 200 x 700 m. In general, the deposit strikes SE-NW, and dips at around 30° towards NE. In the hanging wall, the ore lies in contact with a similar, but more epidote-rich and less K-rich gneiss. Towards the north the ore becomes less potassic as the plagioclase content increases at the expense of microcline. Towards the western footwall, the boundary is more difficult to define by eye, but a sudden drop in K_2O was encountered by the radiometric survey. Geochemical analyses of 33 samples (Karlsen 1990) indicate K_2O contents of 6-9.5% with an average of 7.6% (Table 1). Variations are shown in Fig. 3. Petrographic analyses by point-counting indicate a microcline content at around 65%.

The *Ramnflågura* deposit, situated in Tysfjord municipality, at an altitude of 150-240 m, covers an area around 800 x

Table 1. Average whole-rock major element XRF analyses of the K-feldspar deposits. For comparison, single samples from Gåslandsvann in Vesterålen and from Bleikvassli (Larsen et al. 1995) are included.

Deposit	No. of samples	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MgO	CaO	Na_2O	K_2O	MnO	P_2O_5	LOI
Soltuva	33	68.52	14.91	2.96	0.26	0.33	1.24	2.70	7.58	0.04	0.08	0.25
Ramnflågura	12	66.08	15.52	3.15	0.34	0.43	0.93	1.75	10.17	0.06	0.10	0.17
Tiltv.b.,Vassl.W/E	9	71.79	13.36	2.18	0.16	0.28	0.57	2.07	7.65	0.03	0.04	0.27
Forbardnes N & S	7	71.46	13.53	2.58	0.22	0.53	0.40	1.75	8.05	0.04	0.04	0.27
Bleikvassli	1	63.66	17.69	2.60	0.38	0.26	1.17	3.79	8.74	0.02	0.16	0.34
Gåslandsvann	1	62.92	17.00	6.42	0.65	0.68	0.41	1.26	9.38	0.10	0.24	0.45

Table 2. Mineralogical content (modal %) of selected samples of the ore. 'x' = observed in trace amounts.

Sample	Deposit	Kfsp	Qtz	Plag	Ep	Biot	Musc	Mgt/Ilm	Apat.	Zirc.	Calc.	Grt	Chl	Amph	Tita.	Others
L12	Soltuva	67	23	6	x	x	2.5	1.5	x							
L35	Soltuva	48	35	3	12	1	x	0.5		x						
L41	Soltuva	63	20	12	1	1	1	1	x	x						
L43	Soltuva	66	17	5	5	3		3.5	x	x		x			x	
L53	Soltuva	62	33	3.5	x	0.5	x	x	x	x						
L55	Soltuva	66	23	1.5	4	0.5	3.5	1	x	x	x					
L61	Soltuva	54	32	6	2	x	4	1	x	x	x	x				
L69	Soltuva	65	16	9	3.5	2.5	1.5	1	x	x						
L73	Soltuva	68	22	5	4	x	x	0.5	x	x	x					
L93	Ramnfl.	81	11	4	1	1.5	x	1	x	x		x	x			
L97	Ramnfl.	84	3.5	3	4	3		2	x	x		x	x			x
L103	Ramnfl.	74	15	5.5	3	0.5	0.5	1.5	x	x			x			
L120	Skardv.	34	23	38	x	0.5	x	4								
L148	Vass.W	79	8	2	7	2.5		1		x		x	x	x	x	x
L156	Forb.S	61	23	7	3	5	x	0.5		x						
L158	Forb.S	49	45	3	1	x	1	1	x							x
OppF	Forb.S	65	22	x	3	2	7	1	x				x			

Table 3. Microprobe analyses of plagioclase and microcline feldspar. - = not detected.

Sample	L12	L12	L12	L12	L158	L158	L12	L12	L158	L158	OppF	OppF
Deposit	Soltuva	Soltuva	Soltuva	Soltuva	Forb.S	Forb.S	Soltuva	Soltuva	Forb.S	Forb.S	Forb.S	Forb.S
SiO_2	67.30	66.76	64.76	67.39	61.19	67.86	63.02	62.75	63.16	65.28	63.32	63.75
Al_2O_3	19.59	18.64	21.65	19.85	22.25	19.62	17.41	17.73	17.17	17.72	17.39	17.37
TiO_2	-	0.15	-	0.04	0.07	-	0.48	0.12	-	0.08	-	0.81
FeO	0.02	0.03	0.03	0.02	0.14	0.06	-	0.02	0.04	-	0.09	0.10
MnO	-	0.01	-	-	0.02	0.01	0.05	-	0.03	-	0.02	0.02
MgO	0.02	0.02	0.02	0.01	0.04	0.03	-	0.04	-	0.01	0.08	0.03
CaO	0.50	0.34	2.26	0.55	4.33	0.05	-	0.02	0.01	0.03	0.03	0.01
Na_2O	11.02	11.32	9.93	11.04	8.76	11.12	0.50	0.64	1.18	0.76	0.75	0.57
K_2O	0.09	0.11	0.13	0.12	0.19	0.11	15.76	15.77	15.59	15.45	15.83	16.06
BaO	0.10	-	-	-	-	0.11	1.10	0.94	0.10	0.15	0.19	0.19
Total	98.68	97.45	98.80	99.05	97.04	99.02	98.34	98.07	97.32	99.52	97.73	98.96
Type	Plag	Plag	Plag	Plag	Plag	Plag	Microcl.	Microcl.	Microcl.	Microcl.	Microcl.	Microcl.

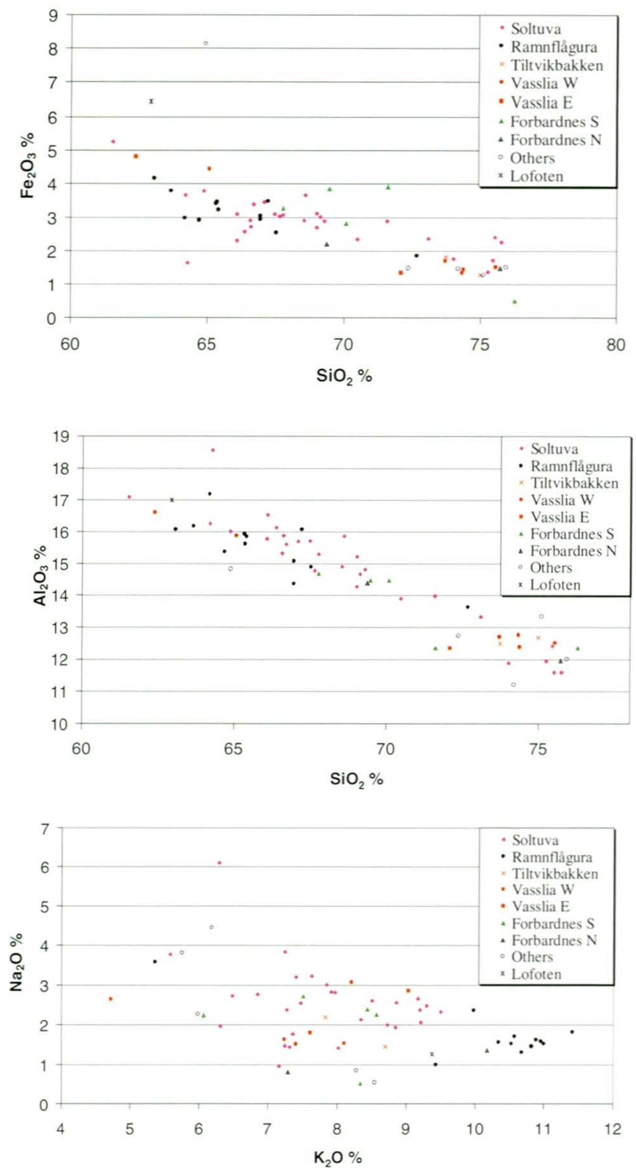

Fig. 3. Variation diagrams of the K-feldspar-rich gneisses, based on XRF analyses.

250 m. The ore is in the form of a plate, striking E-W and dipping at around 50° towards NE, with a thickness of 100 m and length of 800 m. In the south and west, the ore lies in contact with the Tysfjord granite with, in some places, a calc-silicate rock or marble in between. In the north, the potassic gneiss becomes poorer in K_2O close to the contact to the Tysfjord granite. This means that only around 2/3 of the gneissic lens is rich in K_2O. Geochemical analyses of 13 samples (Karlsen 1990) indicate that the ore has a very high and constant K_2O content with an average of 10-11 % (Table 1, Fig. 3). Petrographic analyses indicate microcline contents of up to 84%.

The *Forbardnes S* deposit is situated in Hamarøy municipality, easily accessible from the coast just north of Tiltvika. The size of the deposit is not known as the borders have not been mapped, but it may well be the largest of the deposits. The lens dips at around 40° towards NE. In the south, the ore borders a more biotite-rich, less potassic gneiss and, in some places, also the Tysfjord granite. Geochemical analyses indicate that the ore has a K_2O content between 6 and 10.2 % with an average of ca. 8 % (Table 1, Fig. 3). Petrographic analyses indicate microcline contents up to 65 %.

In general, the deposits contain primarily microcline (48-84 %) and quartz (3-35 %), and some small amounts of plagioclase (1-12 %). Trace minerals include, in decreasing order, epidote, biotite, muscovite, magnetite, ilmenite, apatite, zircon, garnet, chlorite, titanite and calcite (Tables 2 & 3). The microcline has a rather constant composition with 15-16 % K_2O and less than 1% Na_2O (Table 3). Plagioclase is dominated by albite, although oligoclase may occur predominantly as intergrowth lamellae within albite. Epidote has a very variable chemistry; some grains are rich in Fe, others rich in Mn. Magnetite contains from 0 to 13 % TiO_2. Radioactive minerals containing Th and Si in the core, and Nb, Y and U in the rim occur as metamict phases in a sample from one of the deposits. The high content of microcline in the deposits is indicated in the chemical analyses with K_2O in the range 6-11 %. The Fe_2O_3 content is normally in the range 1-4 % (Table 1, Fig. 3).

Textural relationships

A primary concern when dealing with feldspar or feldspar/quartz for glass and ceramics is the content of Fe in the product, which should be as low as possible. Since Fe is located in

Table 4. Grain-size variations of microcline.

Sample	Deposit	Grain size interval	Most common grain size
12	Soltuva	0.05 - 0.8 mm	0.4 mm
41	Soltuva	0.05 - 1.5 mm	0.4 mm
43	Soltuva	0.05 - 2.8 mm	0.8 mm
53	Soltuva	0.08 - 2.0 mm	0.6 mm
55	Soltuva	0.05 - 1.4 mm	0.6 mm
61	Soltuva	0.02 - 1.5 mm	0.4 mm
73	Soltuva	0.1 - 1.5 mm	0.6 mm
93	Ramnflågura W	0.15 - 2.8 mm	1.0 mm
97	Ramnflågura W	0.05 - 1.5 mm	0.6 mm
98	Ramnflågura W	0.05 - 2.3 mm	0.6 mm
103	Ramnflågura E	0.05 - 1.6 mm	0.6 mm
105	Ramnflågura E	0.2 - 2.5 mm	0.6 mm
120	Skardvika	0.05 - 1.5 mm	0.4 mm
148	Vasslia W	0.2 - 4.5 mm	1.3 mm
156	Forbardnes	0.15 - 1.6 mm	0.5 mm
158	Forbardnes	0.05 - 2.5 mm	0.5 mm
OppF	Forbardnes	0.05 - 1.0 mm	0.3 mm

the lattices of minerals such as magnetite, ilmenite, biotite and epidote, it is important that these are removed during processing. For pure feldspar products, it is also important to succeed in separating microcline from quartz and plagioclase, or feldspar in general from quartz. An important factor in such processes is the grain size (Table 4) and the type of grain boundaries in the raw material (see Karlsen 1990).

Microcline occurs as xeno-hypidioblastic grains, 0.05 to 4.5 mm in size, with their longest axes usually oriented parallel to the foliation. The grains contain only very few inclusions, but very small grains of magnetite are common. Inclusions of epidote occur in lesser amounts. Microperthite lamellae are rare and, when observed, are only weakly developed. The grain boundaries are relatively well defined, and vary between being straight to weakly undulating. Quartz usually occurs as single, scattered grains, but is sometimes localised in aggregates defining bands. Quartz grains are commonly smaller than feldspars: 0.05-1.2 mm. Plagioclase has a similar appearance to K-feldspar, but the grain size is typically smaller. White mica and biotite occur as parallel-oriented idioblastic grains (< 0.05-2.2 mm). Epidote occurs as xenoblastic to hypidioblastic grains, <0.05-1 mm, either in monomineralic aggregates or as scattered single grains. Larger grains are commonly compositionally zoned with a core of allanite and a normal epidote rim. The allanite, which contains radioactive elements causes radial joints in the surrounding epidote or pleochroic haloes when sited in biotite. Magnetite and ilmenite occur as xenoblastic - hypidioblastic grains (up to 2.5 mm, but generally < 0.15 mm). These grains are generally associated with epidote and biotite. Otherwise, very fine-grained oxides occur in small amounts evenly distributed throughout the entire sample.

Textural relationships, and especially grain size, are critical to the economic potential of the rock. To obtain optimal results when separating the minerals the rock should be as coarse-grained as possible. The grain size is somewhat variable between samples (Table 4), and for possible future investigation it will be important to characterise the deposits also in terms of grain size.

Conclusions

Several significant deposits of K-feldspar-rich gneisses occur in the Tysfjord and Hamarøy municipalities. Three major deposits are defined: Ramnflågura, Soltuva and Forbardnes S. The Ramnflågura deposit contains 10-11 % K_2O and is the richest in microcline. The Soltuva and Forbardnes S deposits contain K_2O in the range 6-9.5 % with a microcline content around 65%. The small grain size makes separation of the minerals difficult. Processing tests have given rather promising results, but with the production of a large quantity of fines. It is concluded that a more detailed characterisation of the deposits in terms of mineralogy and grain-size variations is necessary in order to obtain more representative samples for testing. It is possible that the variations between the deposits are large enough to influence the results of mineral processing tests. Finally, a chemical and mineralogical comparison between the Tysfjord/Hamarøy deposits and those present in Bleikvassli and Vesterålen should be carried out. The deposits are, nevertheless, an important resource for potential exploitation in the future.

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