

Cl-rich scapolite from Ødegårdens Verk, Bamble, Norway

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Scapolites from a rutile–phlogopite–scapolite rock associated with the apatite–phlogopite–enstatite veins at the old Ødegårdens Verk, Bamble, South Norway appear to be the most Cl-rich variety hitherto reported. Besides Cl (3.74–3.91 wt%, 0.92–0.94 atoms per formula unit), SO₃ (0.57–0.81 wt%) and Br (328 ppm) are present. Together with the results of Mora and Valley (1989), the Ødegårdens Verk scapolites indicate a revision of the solid solution line between the Cl-free and Cl-rich end members in the Al–Cl diagram. Together the scapolites define a solid solution line between approximately Si_{7.2}Al_{4.8}Cl₀ and Si_{8.3}Al_{3.7}Cl₁. This is explained by coupling the scapolite substitution CaAl–CaCO₃ = NaSi–NaCl to the Al = Si substitution.

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The Bamble Sector of southern Norway, and especially the Kragerø and Bamble communities, is one of the world's best known and most famous scapolite areas (Michel-Lévy 1878; Judd 1889; Schetelig 1915; Brøgger 1934). Both Cl and CO₂-rich, SO₃-poor (Brøgger 1934), and CO₂ and SO₃-rich, Cl-poor, varieties (Aitken 1983) have been reported. Recent investigation of a rutile–phlogopite–scapolite rock associated with the apatite–phlogopite–enstatite veins from the old Ødegårdens Verk, Bamble (Lieftink 1991; Lieftink & Nijland 1992) showed that the scapolites from this rock are the most Cl-rich hitherto reported. Together with the medium Cl-rich scapolites from Idaho (Mora & Valley 1989), the results indicate a revision of the mixing line between the marialite and meionite end members in the Al–Cl diagram (Shaw 1960a, b; Evans et al. 1969; Orville 1975; Coolen 1980).

The apatite deposits at Ødegården were discovered in 1872, and exploited until 1918 (Bugge 1922; Neumann et al. 1960; Morton 1961). The apatite–phlogopite–enstatite veins cut across scapolitized metagabbro and amphibolites, the so-called 'ødegårdites' of Brøgger (1934). Relationships between the rutile–phlogopite–scapolite rock and the apatite–phlogopite–enstatite veins are uncertain; the sample was collected at the entrance to one of the old mine shafts. The rock is not the same as the 'sand-rock' of Brøgger & Reusch (1875), as it lacks enstatite and contains almost no apatite. Scapolite occurs as several centimeter-long euhedral crystals, with the much finer grained phlogopite and rutile grains in between. The scapolite constitutes about 85% of the rock, and has a birefringence of 0.01, indicating a meionite content of ca. 22%. Rutiles are nearly opaque with a purple lustre. Some accessory apatite is present. Late oxides and adularia sporadically occur as alteration products of phlogopite.

The scapolite analyses were performed with a Jeol JXA 8600 Superprobe at the Department of Geochemistry, Utrecht. Operating conditions were 15 keV, 10 nA and 30 seconds counting time. Wollastonite (Si, Ca), diopside (Si, Ca, Mg, Fe), jadeite (Si, Al, Na), quartz (Si, kyanite (Si, Al), periclase (Mg), corundum (Al), halite (Na, Cl), pyrite (Fe, S), potassium-titanium phosphate (KTP; K, Ti, P), Cl-apatite (Ca, P, Cl) and fluorite (Ca, F) were used as standards. Data were corrected with a Tracor Northern PROZA correction program. Trace elements were analyzed from a scapolite separate using INAA techniques at the IRI, Delft University of Technology. Coarse grained scapolite was grounded and purified by handpicking, and subsequently milled in a tungsten carbide mill. Details regarding INAA techniques can be found in De Bruin (1983).

Scapolites were normalized to (Si + Al) = 12. They are extremely Cl-rich (Table 1), containing 3.74–3.91 wt% (0.91–0.94 atoms per formula unit). Trace amounts of K substitute for Ca and Na. The meionite percentage varies between 20 and 25%, whereas the equivalent anorthite percentage ranges from 23 to 30.

INAA analyses (Table 2) show minor Sr and REE substitution for Ca, and some substitution of Br (328 ppm) for Cl. Rare earth analyses of scapolites are extremely scarce (e.g. Grauch 1989). Nevertheless, rare earth contents of the Ødegårdens Verk separate are nearly seven (Yb) to thirty-five (La) times chondritic values (Cl chondrite of Sun & McDonough 1989). The chondrite normalized REE pattern decreases slightly from the light REE to the heavy REE (Fig. 1). No anomalies occur, i.e. the positive Eu anomaly so common for other Ca-silicates like plagioclase (e.g. Pride & Muecke 1981; Nystrom 1984) and epidote (e.g. Nystrom 1984) is not observed in scapolite.

Table 1. Scapolite analyses of sample DL137. Oxides in wt%. Normalization to (Si + Al) = 12. Me – meionite percentage (Ca/(Ca + Na + K)); EqAn – equivalent anorthite percentage (100 (Al - 3)/3); Σvol – sum of volatiles.

SiO ₂	56.93	56.69	56.95	56.89
TiO ₂	0.02	0.00	0.02	0.00
Al ₂ O ₃	23.30	21.84	21.96	22.05
FeO	0.00	0.00	0.00	0.00
MnO	0.00	0.04	0.00	0.00
MgO	0.00	0.00	0.00	0.00
CaO	5.58	5.64	5.18	5.96
Na ₂ O	10.26	11.28	11.03	9.84
K ₂ O	0.13	0.23	0.11	0.19
P ₂ O ₅	0.00	0.00	0.00	0.00
SO ₃	0.82	0.72	0.80	0.65
F	0.00	0.00	0.00	0.00
Cl	3.91	3.79	3.74	3.81
Total	100.95	100.23	99.83	99.39
Si	8.09	8.25	8.25	8.24
Ti	0.00	0.00	0.00	0.00
Al	3.91	3.75	3.75	3.77
Fe	0.00	0.00	0.00	0.00
Mn	0.00	0.01	0.00	0.00
Mg	0.00	0.00	0.00	0.00
Ca	0.86	0.88	0.80	0.92
Na	2.83	3.19	3.10	2.77
K	0.03	0.04	0.02	0.04
P	0.00	0.00	0.00	0.00
S	0.09	0.08	0.09	0.07
F	0.00	0.00	0.02	0.00
Cl	0.94	0.94	0.92	0.93
Me	23	21	20	25
EqAn	30	25	25	26
Σvol	1.03	1.02	1.03	1.00

Table 2. INAA analyses of scapolite separate from DL137. Elements in ppm.

Sc	0.301
Sr	100
Zr	141
Cs	4.55
La	8.5
Ce	20.3
Nd	11
Sm	2.83
Eu	0.94
Tb	0.44
Yb	1.17
Lu	0.208
Hf	4.00
Ta	1.38
Th	0.65
Br	328

Table 3. Summary of volatile contents (wt%) of scapolite; nd – not determined. References: 1 – Brøgger (1934); 2 – Aitken (1983); 3 – D. Visser, unpublished data; 4 – T. G. Nijland, unpublished data; 5 – Deer et al. (1963); 6 – Shaw (1960a); 7 – Evans et al. (1969); 8 – Coolen (1980); 9 – Mora & Valley (1989).

Ref.	Area	Cl	CO ₃	SO ₃	F	H ₂ O ⁺
1	Kragerø	1.69–3.55	0.25–1.18	0.00–0.14	nd	0.06–0.44
2	Kragerø	0.15	3.61	1.82	nd	nd
3	Kalstad	3.14–3.28	nd	0.60–0.67	≤0.18	nd
4	Froland	1.78–2.10	nd	0.32–0.42	≤0.14	nd
5	Compilation	0.03–3.30	0.50–4.74	0.00–4.17	≤0.11	0.13–1.20
6	Compilation	≤3.3	≤4.8	≤4.2	≤0.9	≤2.1
7	Compilation	0.02–2.96	1.11–3.20	0.01–2.02	≤0.76	≤0.02
8	Furua	0.03–0.20	1.05–3.34	2.22–6.40	nd	nd
9	Idaho	0.24–2.99	1.24–4.33	0.00–0.59	nd	nd

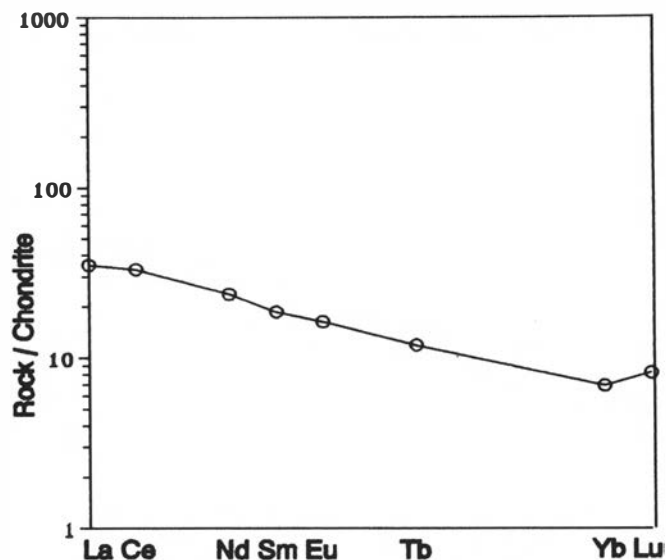


Fig. 1. Chondrite normalized REE pattern for scapolite from DL137. Chondrite values of Sun & McDonough (1989).

The sum of Cl + SO₃ (1.00–1.03 atoms per formula unit) fills the entire volatile position of scapolite, which excludes the presence of any significant CO₂ or H₂O. Normalization to 16 cations (Mora & Valley 1989) does not significantly change the cation ratios; S-contents remain constant, and Cl even becomes 0.01 or 0.02 atoms per formula unit higher. The scapolites (Tables 1 and 3) appear to be the most Cl-rich ones hitherto reported. However, they are considerably more Al-rich than the marialite end member. The meionite percentage varies between 20 and 25. The equivalent anorthite shows a slightly larger range, from 23 to 30%. This implies that the solid solution line (Fig. 2) between the Cl-free end member meionite and the Cl-rich end member marialite needs to be considerably steeper than the lines based by Shaw (1960a, b) and Evans et al. (1969) in Orville's (1975) Al–Cl diagram for scapolite; these lines were based on common stoichiometry. Recent analyses by Mora & Valley (1989) of regional metamorphic scapolites from Idaho also deviate from these lines. The Ødegårdens Verk scapolites seem to be the near Cl-rich end members in a solid solution line around which the Idaho scapolites also plot (Fig. 2). Together, these scapo-

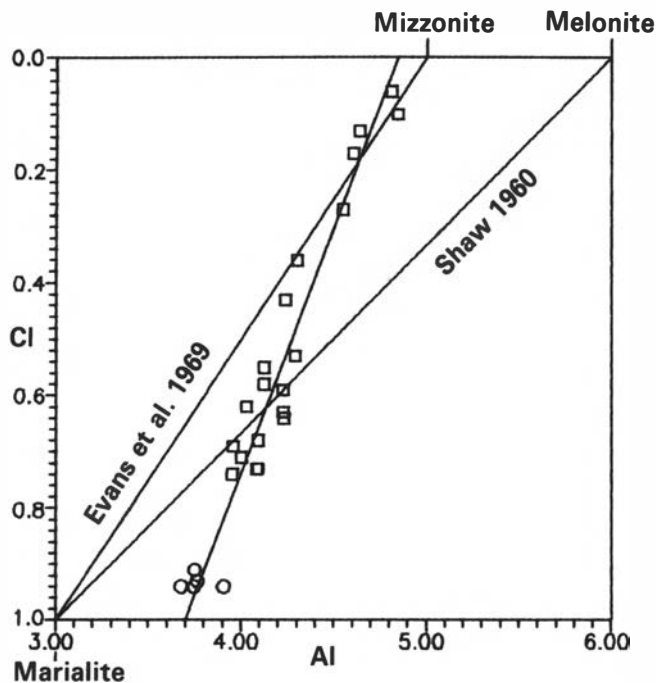


Fig. 2. Orville's (1975) Al-Cl diagram for scapolites. Circles - Ødegårdens Verk scapolites; squares - scapolites from Idaho (Mora & Valley 1989). For comparison the solid solution lines of Shaw (1960) and Evans et al. (1969), based on common stoichiometry. Al and Cl are in atoms per formula unit. All analyses were normalized to $(\text{Si} + \text{Al}) = 12$. For further discussion, please see text.

lites define a solid solution line between approximately $\text{Si}_{7.2}\text{Al}_{4.8}\text{Cl}_0$ and $\text{Si}_{8.3}\text{Al}_{3.7}\text{Cl}_1$; this line has a correlation coefficient of 0.96. The line indicates a total net substitution of $1.1 \text{ Al} + 1 (\text{CO}_3, \text{SO}_4) = 1.1 \text{ Si} + 1 \text{ Cl}$. This would imply that the solid solution between those two end members cannot be simply described by the anorthite + calcite (anhydrite) = albite + halite substitution $\text{CaAl} \cdot \text{CaCO}_3 = \text{NaSi} \cdot \text{NaCl}$. To explain the solid solution, an additional 10% of $\text{Al} = \text{Si}$ substitution is required besides the plagioclase + salt substitution.

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