

Two new rare-earth-rich mineral associations in the Ilímaussaq alkaline complex, South Greenland

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Two new types of REE-rich mineral associations have been discovered at Kvanefjeld in the northern part of the Ilímaussaq alkaline complex. Type 1 consists of ussingite veins intersecting lujavrite and containing 5–7% nacareniobsite-(Ce) and 2–4% steenstrupine-(Ce); the adjacent altered lujavrite contains up to 10–12% nacareniobsite-(Ce). Type 2 consists of cavernous sodalite-rich veinlets and vugs in lujavrite containing 5–8% vitusite-(Ce). The chemical compositions and unit cell parameters of REE minerals are given.

Nacareniobsite-(Ce) and vitusite-(Ce) were considered to be extremely rare minerals in the Ilímaussaq complex. Nacareniobsite-(Ce) is now known to be of more widespread occurrence in some hyper-agpaitic rocks of the Ilímaussaq complex, and vitusite-(Ce) is known to be the precursor of the widespread occurrence of the yellow pseudomorphs termed erikite.

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The agpaitic rocks of the Ilímaussaq alkaline complex and their pegmatites are rich in the rare-earth elements (REE), their average REE content being up to thirty times higher than the average contents in the Earth's crust (Gerasimovsky 1969). The main REE concentrating minerals in the complex are eudialyte and rinkite (in sodalite foyaite, naujaite and kakortokite and their pegmatites, eudialyte also in lujavrites), and steenstrupine-(Ce) (in naujaite and lujavrites and their pegmatites). Steenstrupine-(Ce) is a major mineral in the REE-U deposit at Kvanefjeld in the northern part of the complex (Sørensen 1992; see Sørensen 2001, fig. 1, this volume, for place names mentioned in the text).

Two new types of REE-rich mineral associations have been discovered in material from the adit on the southern slope of Kvanefjeld. Hyper-agpaitic pegmatitic veins and their surrounding rocks contain abundant nacareniobsite-(Ce), $\text{Na}_3\text{Ca}_3(\text{Ce},\text{Nd})(\text{Nb},\text{Ti})(\text{Si}_2\text{O}_7)_2\text{OF}_3$ (type 1) and vitusite-(Ce), $\text{Na}_3(\text{Ce},\text{La})(\text{PO}_4)_2$ (type 2).

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Type 1 consists of ussingite veins up to 15 cm wide and the adjacent arfvedsonite lujavrite and medium- to coarse-grained lujavrite. The veins are composed of about 90 vol.% pink to lilac massive ussingite, 5–7 vol.%

nacareniobsite-(Ce), 2–4 vol.% steenstrupine-(Ce) and 1–2 vol.% aegirine and sodalite. Light-grey altered lujavrite adjacent to the veins contains up to 10–12 vol.% nacareniobsite-(Ce), whereas steenstrupine is practically absent. Nacareniobsite-(Ce) within and around the veins occurs as lemon-yellow bunches and spherulites up to 7 mm in diameter consisting of curved and split board-like crystals. Nacareniobsite-(Ce), which was first described as an extremely rare mineral from small cavities in lujavrite from the Kvanefjeld adit (Petersen *et al.* 1989), is a minor rock-forming component of these ussingite veins and the adjacent lujavrite and is the main concentrator of REE and Nb here. It is also now known to be of more widespread occurrence in contact modified rocks from the volcanic roof of the complex (H. Sørensen, personal communication 2000).

The chemical composition (Table 1) of this nacareniobsite-(Ce) gives the formula:

$\text{Na}_{2.98}\text{Ca}_{2.62}(\text{Ce}_{0.55}\text{Nd}_{0.29}\text{La}_{0.17}\text{Pr}_{0.07}\text{Sm}_{0.04}\text{Y}_{0.04}\Sigma_{1.16})(\text{Nb}_{0.79}\text{Ti}_{0.22}\Sigma_{1.01})(\text{Si}_{4.22}\text{Al}_{0.01}\text{O}_{14})\text{O}(\text{F}_{2.86}\text{O}_{0.29})\Sigma_{3.15}$. The unit cell parameters are: $a = 18.865 \pm 5$, $b = 5.683 \pm 2$, $c = 7.464 \pm 5$ Å, $\beta = 101.25 \pm 2^\circ$, all uncertainties on the last digit.

Na-rich steenstrupine-(Ce) is a minor concentrator of REE (Table 1) in this mineral association.

Type 2 is made up of cavernous veinlets up to 5–7 cm wide and vugs in lujavrite. The veins and vugs consist mainly of sodalite with subordinate amounts of nephe-

Table 1. Chemical composition of rare-earth minerals from hyper-agpaitic veinlets, Kvanefjeld adit

	1	2	3
SiO ₂ (wt%)	29.00	24.6	0.33
TiO ₂	2.01	0.0	-
ZrO ₂	0.04	0.0	-
ThO ₂	0.03	2.8	0.08
UO ₂	-	0.8	-
Al ₂ O ₃	0.03	0.2	-
Fe ₂ O ₃	-	1.2	-
La ₂ O ₃	3.19	9.0	16.09
Ce ₂ O ₃	10.34	13.9	18.28
Pr ₂ O ₃	1.35	0.0	1.30
Nd ₂ O ₃	5.57	3.2	3.44
Sm ₂ O ₃	0.83	0.0	0.05
Y ₂ O ₃	0.48	1.1	0.04
MnO	-	3.1	-
CaO	16.88	3.1	1.92
SrO	-	-	0.18
Na ₂ O	10.57	14.6	23.12
P ₂ O ₅	-	14.6	36.93
Nb ₂ O ₅	12.03	-	-
F	6.22	-	-
- O for F ₂	2.62	-	-
	95.95	92.2	101.76

1: nacareniobsite-(Ce) from type 1 association.

2: steenstrupine-(Ce) from type 1 association.

3: vitusite-(Ce), from type 2 association.

Microprobe data, average values of several points; analysts: I.M. Kulikova (1,3), A.N. Nekrasov (2).

Conditions of analysis: analyses 1 and 3 were made with a CAMEBAX micro-beam analyser, 20 kV, 20 nA (10 kV for F and Na, beam diameter 10 µm); analysis 2 was made with a Jeol JXA 850 microprobe, 15 kV, 20 nA. Standards for both machines: REEPO₄ for La, Ce, Pr, Nd and Sm, YPO₄ for Y, ThO₂ for Th, UO₂ for U, albite for Na and Al, SrSO₄ for Sr, MnTiO₃ for Mn and Ti. For CAMEBAX only: diopside for Ca and Si, hornblende for Fe, wadeite for Zr, LiNbO₃ for Nb and MgF₂ for F. For Jeol JXA only: andradite for Ca, Fe and Si, zirconium for Zr and niobium for Nb.

-: not analysed.

line, aegirine, potassic feldspar, arfvedsonite, and vitusite-(Ce). The content of vitusite-(Ce) in the veinlets and the bordering sodalite-rich lujavrite is 5–8 vol.%. The mineral forms isometric and tabular grains up to 5 mm across; well-shaped crystals are found in cavities. Their morphology is precisely the same as the erikite crystals described by Bøggild (1903) from Nunarsuatsiaq in the central part of the Ilímaussaq complex. Erikite is a pseudomorph after vitusite made up of common REE phosphates (rhabdophane, monazite) and Na zeolites formed under low-alkaline hydrothermal conditions (Pekov *et al.* 1997).

Vitusite-(Ce) from the Kvanefjeld adit is strongly dichroic: it is greenish brown in daylight and honey coloured when examined in electric light; weak lilac UV fluorescence is observed. The chemical composition (Table 1) corresponds to the formula:

$$(\text{Na}_{2.88}\text{Ca}_{0.13}\Sigma_{3.01})(\text{Ce}_{0.43}\text{La}_{0.38}\text{Nd}_{0.05}\text{Pr}_{0.05}\text{Sr}_{0.01}\Sigma_{0.93})(\text{P}_{2.00}\text{Si}_{0.02}\Sigma_{2.02}\text{O}_8$$

The parameters of the orthorhombic cell are: $a = 5.342 \pm 3$, $b = 18.661 \pm 5$, $c = 14.061 \pm 4$ Å.

Concluding remarks

The two types of REE-rich mineral associations described in the present paper demonstrate that the mode of concentration of REE in hyper-agpaitic rocks strongly differs from those in all other natural materials, including the agpaitic rocks proper. In hyper-agpaitic rocks rare minerals such as nacareniobsite-(Ce) and vitusite-(Ce) can become the main concentrators of REE and even occur as rock-forming minerals, as described here.

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