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Davidite-loveringite in early Proterozoic albite felsite in Finnmark, north Norway

The Biggejavri davidite-loveringite occurrence is situated within the Kautokeino volcano-sedimentary belt of early Proterozoic age in Norway's northernmost county, Finnmark. This belt is dominated by basic volcanic rocks, but also includes two thick formations of sandstone and quartzite (Siedlecka *et al.*, 1985). Both continental rifting (Torske, 1978; Witschard, 1980) and ensialic back-arc basin situations (Pharaoh and Pearce, 1984) have been suggested as depositional environments for the supracrustals. The rocks were deformed by the Sveco-Karelian Orogeny and metamorphosed in the amphibolite facies.

The Biggejavri mineralization (Olerud, 1985) consists of a uranium, scandium and rare-earth-bearing albite felsite found near the top of the tholeiitic basalt sequence of the Suoluvuobmi Formation (Solli, 1983), which is one of the lower units of the Kautokeino volcano-sedimentary belt. The volcanites are succeeded by schists of the same formation. Field evidence shows that the emplacement of albite felsite was probably pre-deformational, and detailed and regional mapping indicate a stratabound character for the rock. A slightly radioactive granular albite felsite also occurs as post tectonic dykes. The origin of the albite felsite is currently under study.

The radioactive albite felsite is medium to fine grained and consists of more than 90% albite. The rock also contains a Cr- and V-rich variety of davidite-loveringite, calcite, quartz, muscovite, chromite and rutile. Accessories are La-Ce carbonates, monazite, orthite, thortveitite, coffinite, uranophane, brannerite, zircon, pyrite, sphalerite, galena, Cr-rich chlorite and an unidentified *REE* mineral. Whole-rock analyses of this unusual rock are given in Table 1. The content of scandium, and perhaps also the rare earth elements, is of possible economic interest, and a pilot project to produce scandium and other metals from a mineral concentrate is in progress.

Davidite and loveringite are members of the crichtonite mineral series with the general formula $AM_{21}O_{38}$. The different minerals of this series are defined by a principal large cation occupying the *A* position in the formula, e.g. Sr(crichtonite), Pb(senaite), U-*REE*(davidite), Na(landauite), Ba(lindsleyite), K(mathiasite) and Ca(loveringite) (Grey *et al.*, 1976; Grey and Lloyd, 1976; Gatehouse *et al.*, 1978; Grey and Gatehouse, 1978; Haggerty *et al.*, 1983). In the general formula for davidite, *A* represents the large cations *REE*, U, Ca, Y, Sr, Th, Pb, and *M* the small cations Ti, Fe, Mg, Cr, Al and Sc. In loveringite the *A* cations are Ca, *REE*, Y, Th, U and Pb, while the *M* cations are Ti, Fe, Cr, Mg, Zr, Al, V and Mn. The relationship between loveringite and davidite is based on the ratio of Ca:(U+*REE*) in the *A* site. This ratio must be greater than 1.0 for classification as loveringite (Gatehouse *et al.*, 1978).

Table 1. XRF analyses of radioactive albite felsite from Biggejavrri in Finnmark, N.Norway.

No.	901-A	901-C	902-C	average
SiO_2	63.52	63.62	65.01	63.19%
Al_2O_3	18.53	18.35	18.89	18.42
Fe_2O_3	1.16	1.08	1.74	1.33
TiO_2	1.75	1.58	1.54	1.62
MgO	0.70	0.60	0.63	0.64
CaO	0.61	0.76	0.81	0.73
Na_2O	10.3	10.3	10.5	10.4
K_2O	0.15	0.30	0.31	0.25
MnO	0.03	0.04	0.03	0.03
P_2O_5	0.03	<0.01	<0.01	
l.o.ign.	1.48	1.58	1.44	1.50
Sum	98.26	98.21	97.84	
U	883ppm	1200ppm	852ppm	978ppm
Th	24	24	17	22
Nb	<5	<5	<5	<5
Zr	103	89	87	93
Y	258	234	253	248
Sr	31	28	33	31
Rb	23	31	23	26
Pb	89	341	189	206
Cu	<5	5	<5	<5
Zn	19	15	38	24
Co	26	25	22	24
Ba	81	75	70	75
Mo	15	19	13	16
V	867	760	1100	909
Ce	741	602	473	605
La	1300	991	790	1027
Sn	<10	<10	<10	<10
W	17	12	14	14
Ga	34	34	32	33
Sc	136	116	115	122

Davidite is known from a wide range of rocks of metamorphic as well as hydrothermal association. At the Bidjovagge gold-copper deposit in the same volcano-sedimentary belt, a complex titanium mineral occurring in albite felsite was described by Mathiesen (1969). The mineral was subsequently determined to be a davidite (Mathiesen, pers. comm., 1986). At Radium Hill Mines in South Australia davidite was the main uranium-bearing mineral occurring in shear zones characterized by

Table 2. Electron probe analyses of a davidite - loveringite crystal shown in fig.1, from the Biggejavri occurrence in Finnmark.

No.	MgO	Al_2O_3	SiO_2	CaO	Sc_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	Fe_2O_3	Y_2O_3	La_2O_3	Ce_2O_3	Nd_2O_3	WO_3	PbO	UO_2	sum
101	0.08	0.57	1.44	0.52	0.45	55.96	6.78	9.00	0.37	12.35	0.21	1.10	0.55	0.08	0.26	0.14	2.33	92.19
102	0.10	0.46	1.48	0.52	0.51	59.71	7.02	7.03	0.38	11.29	0.20	0.91	0.55	0.07	n.d.	0.28	2.54	93.05
103	0.17	0.99	13.23	4.45	0.30	44.71	4.07	8.13	0.39	7.27	0.74	2.25	1.66	0.21	0.11	0.22	2.97	91.87
104	0.48	0.98	14.07	4.25	0.30	46.17	3.42	7.11	0.46	5.66	0.68	2.16	1.48	0.16	0.22	0.14	3.51	91.25
105	0.28	1.13	16.14	4.60	0.29	40.15	3.80	7.63	0.40	6.70	0.77	2.38	1.63	0.16	0.08	0.05	2.56	88.75
106	0.04	0.59	1.32	0.46	0.45	55.62	6.95	9.44	0.36	12.01	0.28	1.08	0.58	0.06	0.04	0.25	2.25	91.78
107	0.11	0.50	1.71	0.53	0.52	54.63	7.24	8.97	0.43	12.67	0.13	1.06	0.89	0.02	0.09	0.18	1.92	91.60
108	0.19	0.39	1.58	0.40	0.49	55.50	7.20	11.18	0.31	12.73	0.22	1.30	0.98	0.14	n.d.	0.11	0.84	93.56
109	0.22	0.40	1.57	0.38	0.50	54.81	7.12	10.26	0.31	12.75	0.13	1.30	0.79	0.10	n.d.	0.21	0.97	91.82

biotite gangue minerals (Parkin, 1970). From South Norway davidite has been reported from pegmatite dykes (Neumann and Sverdrup, 1960).

Loveringite is known from bronzite cumulates in the layered ultrabasic intrusion of Jimberlana, Western Australia (Gatehouse *et al.*, 1978; Campbell and Kelly, 1978). A mineral with chemistry resembling that of loveringite occurs in the layered intrusion of Bushveld, South Africa (Cameron, 1978). The mineral is found disseminated in the Critical Zone which underlies the Merensky Reef of the Bushveld Complex.

The davidite-loveringite from Biggejavri has an unusually high content of Cr and V compared to published analyses (Gatehouse *et al.*, 1978, 1979). Electron probe analyses of the mineral (Table 2) were made at the Continental Shelf Institute Trondheim on a Jeol Superprobe 733 with four Tracor wavelength-dispersive spectrometers (WDS) using both natural and synthetic standards. An X-ray diffraction study showed the mineral to be metamict, due to radiation damage from the uranium present (0.8–3.5% UO_2).

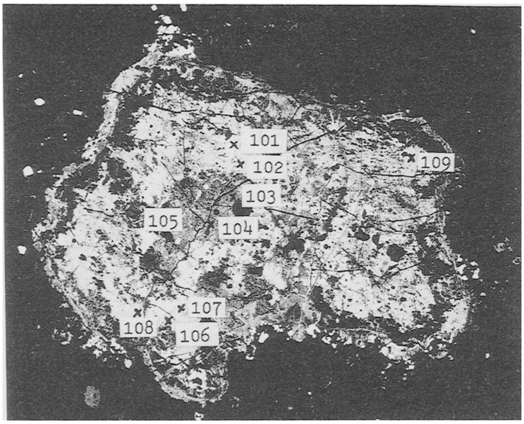

FIG. 1. Electron micrograph of a davidite-loveringite crystal from the Biggejavri occurrence. The chemical composition is highly varied and Table 2 shows the composition of the point analyses marked. The width of the crystal is 0.8 mm.

The analyses of davidite-loveringite from Biggejavri show a highly varied chemical composition (Table 2). Fig. 1 is an electron micrograph on which the point analyses in Table 2 are marked. The darkest parts of the grain have the highest contents of the light elements Si, Ca and Al (points 103, 104 and 105), whilst Ti, V and Fe are correspondingly reduced. The points 101, 102, 106, 107, 108 and 109 are representative of the light phase where the content of light elements is low, and TiO_2 (54–59%), V_2O_3 (6.7–7.2%) Cr_2O_3 (7.0–11.1%) and Fe_2O_3 (11.2–12.7%) are high. The dark phase is clearly enriched in *REE* and U compared with the light phase. No thorium has been detected.

It has not been possible to obtain totals of more than 93.5%. The same analytical procedure has been used to analyse the non-metamict davidite from the Bidjovagge locality (Mathiesen, pers. comm., 1986), where reproducible totals close to 100% were obtained. Heating a mineral concentrate in a simultaneous thermal analyser, STA 409, shows a total weight loss of 5.82% on heating to 1000 °C. This is probably metamict water and can explain the low total values of the analyses. It is therefore suggested that the light phase of the mineral contain some 4–6% metamict water, while the darker phases probably contain 6–11%. A similar water content was found in a metamict crichtonite from Oslo by Segalstad (1984) who proved a weight loss of 12.14% on heating the mineral. The outer part of the davidite grain always has an alteration rim (Fig. 1) mainly consisting of rutile, La–Ce carbonates, coffinite, brannerite and various silicates which are difficult to determine exactly, as their chemical compositions varies widely over a few microns. Common inclusions in the davidite grains are rutile, pyrite, albite, chromite, galena, zircon and thortveitite.

Calculation of formulae (based on 38 oxygens) have been made on the average of six analyses (nos. 101, 102, 106, 107, 108 and 109, Table 2) of the light phase and three analyses (nos. 103, 104 and 105, Table 2) of the dark phase in Fig. 1:

Light phase:
$A = (\mathrm{Ca}_{0.15}\mathrm{La}_{0.13}\mathrm{U}_{0.12}\mathrm{Ce}_{0.10}\mathrm{Y}_{0.03}\mathrm{Pb}_{0.02}$
$\mathrm{Nd}_{0.01})_{\Sigma 0.55}$
$M = (\mathrm{Ti}_{12.77}\mathrm{Fe}_{2.81}\mathrm{Cr}_{2.23}\mathrm{V}_{1.71}\mathrm{Si}_{0.46}\mathrm{Al}_{0.16}$
$\mathrm{Sc}_{0.13}\mathrm{Mn}_{0.09}\mathrm{Mg}_{0.05}\mathrm{W}_{0.005})_{\Sigma 20.43}$

Dark phase:
$\mathrm{A} = (\mathrm{Ca}_{1.41}\mathrm{La}_{0.25}\mathrm{U}_{0.20}\mathrm{Ce}_{0.17}\mathrm{Y}_{0.12}\mathrm{Pb}_{0.01}$
$\mathrm{Nd}_{0.02})_{\Sigma 2.18}$
$\mathrm{M} = (\mathrm{Ti}_{9.78}\mathrm{Fe}_{1.47}\mathrm{Cr}_{1.79}\mathrm{V}_{0.90}\mathrm{Si}_{4.31}\mathrm{Al}_{0.36}\mathrm{Sc}_{0.08}$
$\mathrm{Mn}_{0.11}\mathrm{Mg}_{0.14}\mathrm{W}_{0.01})_{\Sigma 18.94}$.

Foord *et al.* (1984) point to the uncertainty surrounding the reported $\mathrm{FeO/Fe_2O_3}$ ratios in davidite and loveringite. The calculated formulae here are based on total Fe expressed as $\mathrm{Fe_2O_3}$. Valencies used for the other elements are given in Table 2. The $\mathrm{Ca}:(\mathrm{U}+REE)$ ratio is 0.40 for the light and 1.87 for the dark phase. According to Gatehouse *et al.* (1979) this defines the light phase as davidite ($\mathrm{Ca}:(\mathrm{U}+REE) < 1$) and the dark phase as loveringite. The large variation in chemistry probably relates to late alteration in the damaged crystal stucture, and also indicates that davidite and loveringite form a series between the $(\mathrm{U}+REE)$ and Ca end members.

A heavy mineral concentrate of the davidite-loveringite made by gravitational separation, magnetic separator and heavy liquids provided a mineral concentrate with specific weight 3.91 g/cm^3. This mineral concentrate was analysed by neutron activation and found to contain 48% $\mathrm{TiO_2}$, 5.9% Cr, 2.5% V, 2.3% U, 1.0% La, 0.43% Ce, 0.37% Nd, 0.35% Sc, 0.34% Y, 0.22% Pb, 0.21% Zr, 0.17% Yb, 0.076% Sr, 0.032% Lu, < 0.01% Tb, < 0.0025% Sm and < 0.0025% Eu. Such enrichment of both light and heavy *REE*, and depletion in the intermediate *REE* was earlier reported for davidite by several authors (e.g. Neumann and Sverdrup, 1960; Dixon and Wylie, 1951), and attributed by Gatehouse *et al.* (1979) to the fact that the *REE* occupy two distinct crystallographic sites in the davidite.

The Cr- and V-rich variety of the davidite-loveringite series from Biggejavri will be studied and compared in a subsequent paper on the Bidjovagge locality where non-metamict davidite occurs in an albite felsite which resembles that of Biggejavri.

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