Til Johan Stein , 2/6-87
Ms. innsendt til Mineralogical Magazine. Vi sees hilsen
Svein

DAVIDITE-LOVERINGITE IN EARLY PROTEROZOIC ALBITE FELSITE IN FINNMARK, NORTH NORWAY.

The Biggejavrri 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 includes also 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 & Pearce, 1984) have been suggested as depositional environments for the supracrustals. The rocks were deformed by the Sveco - Karelian Orogeny and metamorphosed in amphibolite facies.

The Biggejavri mineralisation (Olerud, 1985) consists of a uranium, scandium and rare earth bearing albite felsite found near the top of the volcanic sequence of the Suoluvuobmi Formation (Solli, 1983). This formation is dominated by tholeiitic basalts and 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 under current 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 economic interest, and a pilot project to produce scandium and other metals from a mineral concetrate 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. The members of this series are; 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, $AM_{21}O_{38}$, A represents large cations REE, U, Ca, Y, Sr, Th, Pb, and M is 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 the number of Ca:(U+REE) in the A site. This ratio must be greater than 1.0 for classification as loveringite (Gatehouse et al., 1978).

Davidite is known from a wide range of rocks of metamorphic as well as hydrothermal association. At the Bidjovagge gold-copper deposit (Hagen, 1982), in the same volcano sedimentary belt 40km east of the Biggejavri occurrence, a complex titanium mineral was described by Mathiesen (1969). The mineral was subsequently determined to be a davidite (Mathiesen pers. com., 1986). At Bidjovagge the Au-Cu mineralisation occur in veins and dissemination in brecciated and faulted zones in albite felsite, graphite felsite and graphitic schists. Davidite and several uranium and rare earth bearing minerals occur in a restricted area in the albite felsite (Mathiesen, 1969). At Radium Hill Mines of South Australia davidite was the main uranium bearing mineral occurring in shear zones characterized by biotite gangue minerals (Parkin, 1970). From South Norway davidite has been reported from pegmatite dykes (Neumann & 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 is known in the layered intrusion of Bushveld, South Africa (Cameron, 1978). The mineral is found as a weak dissemination 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 using a Tracor four wave length dispersive spectrometers (WDS) using both natural and syntetic standards. An X-ray diffraction study showed the mineral to be metamict, due to radiation damage from the uranium present (1.1-3.3% UO_2).

The analyses of davidite-loveringite from Biggejavri show a highly varyied chemical composition (Table 2). Fig. 1 is an electron picture where 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 25, 26), whilst Ti, V, and Fe are correspondingly reduced. The points 22, 23, 24, 28 are representative for the light phase where the content of light elements is low and the TiO_2 (54-64%), V_2O_3 (4.5-6.5%) and Fe_2O_3 (10.7-12.3%) are high. It has not been possible to obtain totals of more than 93-95%. The same analytical procedure has been used to analyse the non-metamict davidite from the Bidjovagge locality (Mathiesen, pers.com. 1986) where reproducable totals close to 100% were obtained. It is therefore suggested that the light phase of the mineral contain 5-7% metamict water, while the darker phases contain more than 10% water. 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 a alteration rim (fig.1) mostly consisting of rutile, La-Ce carbonates, coffinite, brannerite and various silicates which are difficult to detemine exactly as the chemistry varies widely within 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 4 analyses of the light phase and 3 analalyses of the dark phase in fig 1 and Table 2:

Light phase:
$A=(Ca_{0.19}U_{0.15}Ce_{0.08}Y_{0.05})_{sum=0.47}$
$M=(Ti_{13.48}Fe_{2.57}Cr_{1.95}V_{1.30}Si_{0.48}Al_{0.21}Sc_{0.14}Mg_{0.13})_{sum=20.26}$
Dark phase:
$A=(Ca_{0.89}U_{0.15}Ce_{0.16}Y_{0.09})_{sum=1.29}$
$M=(Ti_{11.26}Fe_{2.19}Cr_{2.11}V_{1.01}Si_{2.53}Al_{0.41}Sc_{0.10}Mg_{0.12})_{sum=19.63}$

The Ca:(U+REE) ratio is 0.83 for the light and 2.89 for the dark phase. According to Gatehouse et al. (1979) this defines the light phase as davidite (Ca:(U+REE)<1) and the dark phase as loveringite. The large variation in chemistry probably relates to late alteration in the damaged crystal structure, and also indicates that davidite and loveringite forms a series between the U+REE and Ca end members.

A heavy mineral concentrate of the davidite-loveringite made by gravitative separation with Gouldhound, Franz magnet 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% TiO_2 0.35% Sc, 2.5% V, 5.9% Cr, 0.076% Sr, 0.34% Y, 0.21% Zr, 0.22% Pb, 2.3% U, 1.0% La, 0.43% Ce, 0.37% Nd, <0.0025% Sm, <0.0025% Eu, <0.01% Tb, 0.17% Yb, 0.032% Lu. 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 transition between davidite and loveringite from Biggejavri will be studied and compared in a subsequent paper with the Bidjovagge locality where non-metamict davidite occurs in an albite felsite which resembles that of Biggejavri.

Acknowlegdements. I wish to thank T. Boassen, Continental Shelf Institute for providing the mikroprobe analyses, C.O.Mathiesen for useful discussions and B.A.Sturt for encouragement and improvement of the text.

Svein Olerud
Norges geologiske undersøkelse
Box 3006,
N-7002 Trondheim
Norway

Dixon, P., and Wylie (1951) Nature 167, 526.

Cameron, E.N. (1978) Am. Mineral. 63, 37-39.

Campbell, I.H., and Kelly, P.R. (1978) Mineral. Mag. 42, 187-193.

Gatehouse, B.M., Grey, I.E., Campbell, I.H., and Kelly, P. (1978) Am. Mineral. 63, 28-36.

Gatehouse, B.M., Grey, I E., and Kelly, P.R. (1979) Am. Mineral 64, 1010-1017.

Grey, I.E., and Lloyd, D.J. (1976) Acta Crystallographica B32, 1509-1513.

Grey, I.E., Lloyd, D.J., and White, J.S.jr. (1976) Am. Mineral. 61, 1203-1212.

Grey, I.E., and Gatehouse, B.M. (1978) Can. Mineral. 16, 63-68.

Hagen, R. (1982) Geol. Rundschau 71, 94-103.

Haggerty, S.E., Smyth, J.R., Erlank, A.J., Rickard, R.S., and Danchin, R.V. (1983) Am. Mineral. 68, 495-505.

Mathiesen, C.O. (1969) Nor. geol. unders. 266, 86-104.

Neumann, H., and Sverdrup, T.L. (1960) Nor. Geol. Tidsskr. 40, 277-288.

Olerud, S. (1985) Nor. geol. unders. Unpublished survey report 85.159, 19pp.

Parkin, L.W. (1970) Proc. 8th Commonwealth mining and metallurgical congress 1965. Geology of Australian ore deposits, 1, 312-313.

Pharaoh, T.C., and Pearce, J.A. (1984) Precamb. Res. 25, 283-308.

Segalstad, T.V. (1984) Am. Mineral. 69, 388-390.

Siedlecka, A., Iversen, E., Krill, A.G., Lieungh, B., Often, M., Sandstad, J.S., and Solli, A. (1985) Nor. geol. unders. 403, 7-36.

Solli, A. (1983) Nor. geol. unders. 380, 97-105.

Torske, T. (1978) Abstr. XIII Nord. Geol. Vinterm. Jan 1978 Copenhage, 72-73.

Witschard, F. (1980) Geol. Før. Stockh. Førh. 102, 188-190.

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

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

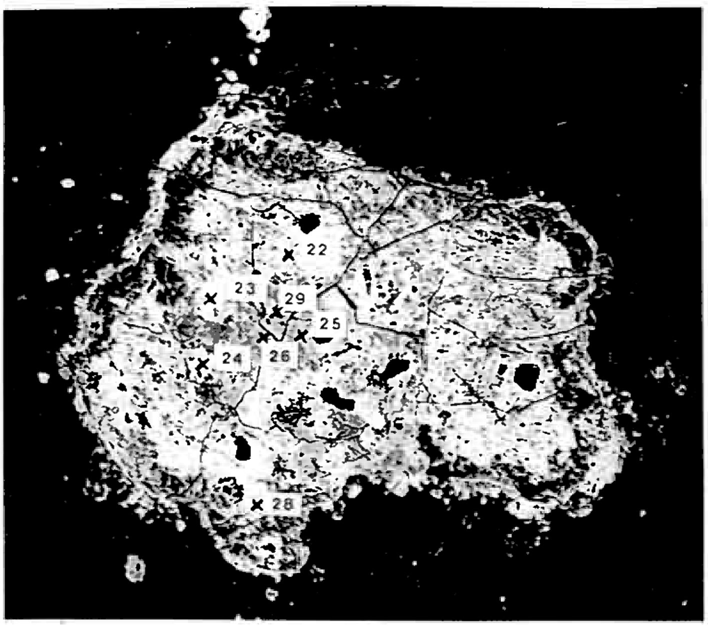

Fig.1. Electron micrograph of davidite-loveringite crystal from the Biggejavri occurrence. The chemical composition is highly varyied and Table 2 shows the composition of the point analyses marked om the picture. The width of the picture is 0.9 mm.

No.	MgO	Al_2O_3	SiO_2	CaO	Y_2O_3	Sc_2O_3	TiO_2	V_2O_3	Fe_2O_3	Cr_2O_3	UO_2	Ce_2O_3	sum
22	0.08	0.67	1.75	0.65	0.36	0.53	60.37	5.94	12.14	8.25	2.13	0.79	93.57
23	0.38	0.64	1.98	0.69	0.56	0.48	62.47	5.28	11.33	7.27	2.85	0.79	94.63
24	0.30	0.52	1.20	0.62	0.16	0.55	64.64	4.52	10.77	7.05	3.29	0.60	94.22
25	0.52	1.62	11.07	2.89	0.68	0.35	46.16	3.91	9.42	8.21	2.27	1.52	88.60
26	0.26	1.18	11.70	3.85	0.87	0.37	47.21	3.54	7.31	7.64	3.27	1.65	88.80
28	0.40	0.61	1.65	0.30	0.29	0.60	57.06	6.47	12.31	11.07	1.08	0.80	92.84
29	0.01	0.60	1.92	1.40	0.16	0.41	52.72	4.90	11.64	10.18	1.14	1.00	86.08

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