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by Ilmari Haapala and Pentti Ojanperä

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GENTHELVITE-BEARING GREISENS IN SOUTHERN FINLAND

BY

ILMARI HAAPALA and PENTTI OJANPERÄ

WITH 8 FIGURES AND 4 TABLES IN THE TEXT

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One small greisen-type genthelvite occurrence has been found in the Eurajoki area and three in the Kymi area. The greisen bodies are associated with topaz-bearing biotite granites which represent late-stage varietes of the Finnish rapakivi granites. The mineral association in the genthelvite-bearing assemblages is: white mica, chlorite, genthelvite, fluorite, ± quartz, ± relict feldspar, ± topaz, ± cassiterite, ± sulfides, ± apatite. Quartz is usually the most abundant mineral, but it is not necessarily present. Sulfide minerals (sphalerite, galena, chalcopyrite) are found in association with genthelvite only in the Eurajoki occurrence. Genthelvite is partly replaced by white mica and chlorite in all of the occurrences, and in the Eurajoki occurrence also by the sulfides.

A chemical analysis of the genthelvite-bearing greisen from Eurajoki showed that the rock contains enriched amounts of iron, zinc, aluminium, beryllium, fluorine and sulfur as well as reduced amounts of sodium and silica compared with the unaltered granite. Analyses are also presented for muscovite and chlorite (ripidolite) from one of the Kymi occurrences. Chemical analyses of genthelvite from the Eurajoki and two of the Kymi occurrences showed that the minerals are almost identical in composition. Comparison is made with other genthelvite occurrences and the formation conditions of genthelvite are discussed, It is suggested that there may be significant ore mineralizations (Sn, Be, W etc.) in association with certain late-stage varietes of the rapakivi granites.

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CONTENTS

INTRODUCTION

Beryllium occurrences are usually divided into two main types: pegmatitic and nonpegmatitic. Commercial deposits have been almost entirely beryl-bearing pegmatites. Since the Second World War, however, continuous interest has also been paid to the study of nonpegmatitic occurrences, some of which are mined for beryllium. The recent discoveries of large nonpegmatitic deposits in the U.S.A. have shown that the world's principal resources of beryllium are in the nonpegmatitic deposits (e.g., Shawe 1968, Sainsbury 1968). The nonpegmatitic deposits (disseminations in acid igneous rocks, skarn deposits, greisen deposits, quartz-rich veins, fluorite-beryllium deposits, late-stage formations in alkaline rocks etc.) are essentially of pneumatolytic-hydrothermal or hydrothermal origin (Beus 1966). The most

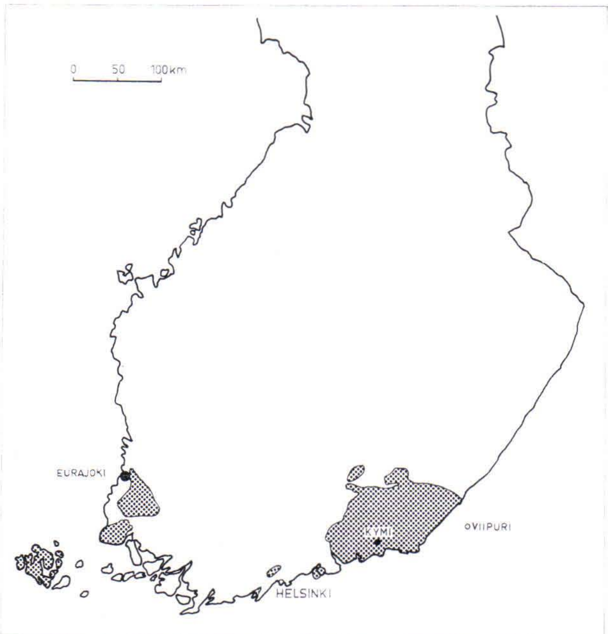


FIG. 1. Location of the Eurajoki and Kymi areas. The rapakivi granite massifs and related intrusives are hatched.

important beryllium minerals are bertrandite, beryl, chrysoberyl, minerals of the helvite group, herderite, phenakite and barylite.

Since 1967, the Geological Survey of Finland has been prospecting for tin, tungsten and beryllium in the areas of the Laitila and Wiborg (Viipuri) rapakivi massifs (age group 1700 m.y.) in the southern Finland. Many greisen bodies associated with the late biotite granites have been found during these reconnaissance studies. The greisen bodies are mainly replacement veins and lodes, rarely pipes, roundish or irregular formations. Some of them contain variable amounts of sulfides, cassiterite, wolframite, genthelvite (a mineral new to Finland), beryl or bertrandite. Besides the cassiterite-bearing greisen bodies, those containing genthelvite $(Zn,Fe,Mn)[BeSiO_4]_3S$ are especially interesting. Their beryllium content may be remarkably high, but the occurrences so far found are small in size.

The present paper is a report of the genthelvite-bearing greisen occurrences found in the Eurajoki and Kymi areas in southern Finland (Fig. 1). A short preliminary description is also given of the granite types and greisen formations of these areas. Of the authors, Pentti Ojanperä was responsible for the chemical analyses and Ilmari Haapala for the other laboratory studies and the field work. The latter also wrote the paper and drew the conclusions.

THE EURAJOKI AREA

The Eurajoki massif

In the Eurajoki area a roundish rapakivi granite massif, 8—9 km in diameter, intrudes older Precambrian migmatites. This Eurajoki massif is practically outside, but just in contact with the great Laitila rapakivi massif, of which it forms a part as a satellitic massif. Horizontal diabase dikes overlie parts of the contacts between the granite massif and migmatite (Fig. 2). The general geology of the Eurajoki area has been described in brief by Laitakari (1928) and Kahma (1951).

The Eurajoki massif consists of an even-grained marginal granite (Tarkki granite), a more or less porphyritic central granite (Väkkärä granite) and porphyry dikes intersecting the Tarkki granite. The contacts between the granite types are sharp. The Tarkki granite contains quartz, strongly altered plagioclase, orthoclase, biotite and chloritized hornblende as the main constituents. In the younger Väkkärä granite the major minerals are quartz, microcline, albite, biotite and topaz.

The greisen bodies

Greisen bodies occur in various parts of the Eurajoki massif (Fig. 2). Most of the greisens are sterile quartz-mica-chlorite rocks, but many of them also contain ore minerals (Haapala and Ojanperä 1969). Beryllium minerals are beryl, genthelvite and bertrandite. The Tarkki granite itself contains danalite as an accessory mineral (Haapala and Laajoki 1969).

The important greisen bodies and their interesting mineralizations are marked in Fig. 2. Sulfides, especially sphalerite, are common constituents in the greisen lodes and veins in the Tarkki granite and, therefore, are not marked on the map.

There are appreciable quantities of beryl in greisen-bordered veins in a vein swarm in the SW part of the granite massif. Quartz, cassiterite, wolframite and

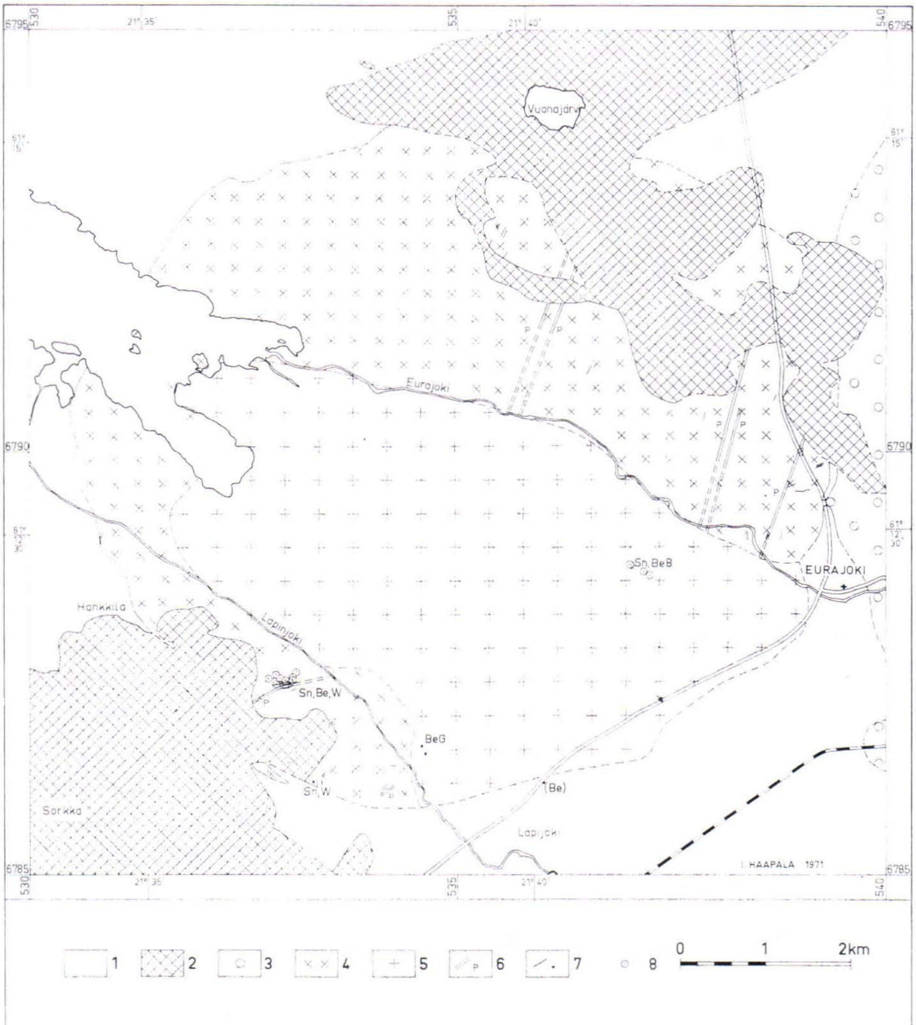


FIG. 2. Geological map of the Eurajoki area. (1) Migmatite; (2) diabase; (3) normal rapakivi granites; (4) the Tarkki granite; (5) the Väkkärä granite; (6) porphyry dike; (7) greisen; (8) drill hole; (Be) beryl; (BeB) bertrandite; (BeG) genthelvite; (Sn) cassiterite; (W) wolframite.

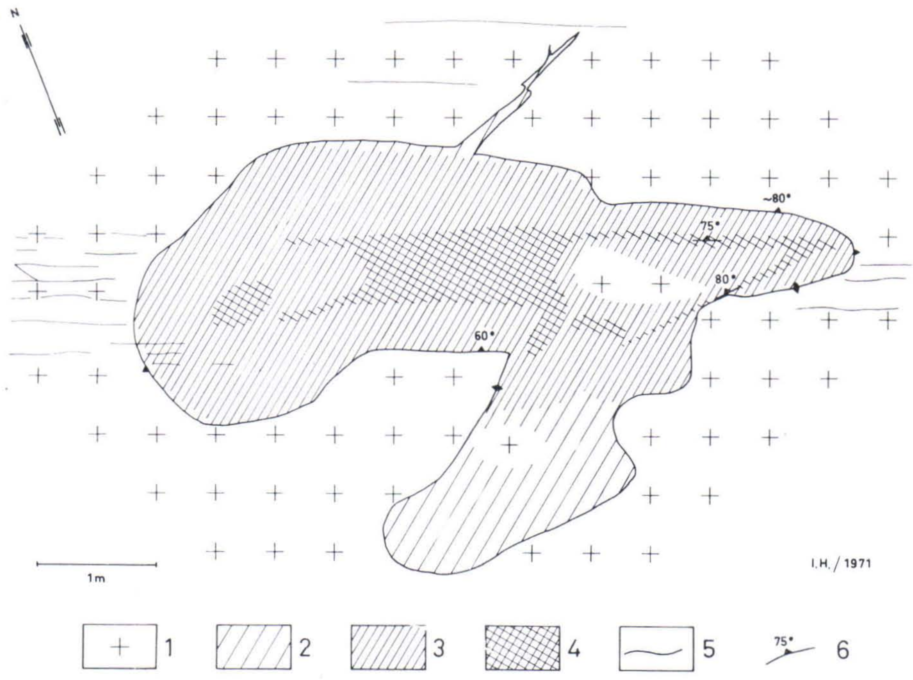


FIG. 3. The genthelvite-bearing greisen body from Eurajoki. (1) Väkkärä granite; (2) mainly quartz-sericite greisen; (3) quartz-sericite-chlorite greisen; (4) quartz-sericite-chlorite-genthelvite greisen; (5) quartz veinlet; (6) contact showing dip.

molybdenite are usually associated with it. Small amounts of beryl are also met with in a thin veinlet cutting migmatite on the SE side of the massif. Bertrandite occurs in variable amounts in some small greisen bodies intersected by drill holes, about two kilometers to the west of the Eurajoki church.

The genthelvite occurrence

Genthelvite occurs in a greisen body in the Väkkärä granite. In the outcrop the greisen appears as an approximately 5 m long and 2 m broad irregular lens (Fig. 3). The form of the greisen body is obviously controlled by intersecting fractures. Its three-dimensional shape is unknown. Possibly the body is a carbona or a pipe.

A zonal structure can be recognized in the greisen body. There is usually a seam of light green rock, consisting mainly of quartz and sericite, at the contact against the Väkkärä granite. The amount of quartz is higher in this rock than in the original granite. A broader and darker zone follows composed mainly of quartz, sericite and chlorite. In the central part and along some fractures in the greisen body there is a dark grey zone with quartz, sericite, chlorite, genthelvite and topaz as the main

FIG. 4. A zoned tetrahedral genthelvite crystal (medium grey), partly replaced by a sericite-chlorite-quartz mass (dark grey) and sulfides (white). q is quartz. Polished section, magn. 65 x. Photo Erkki Halme.

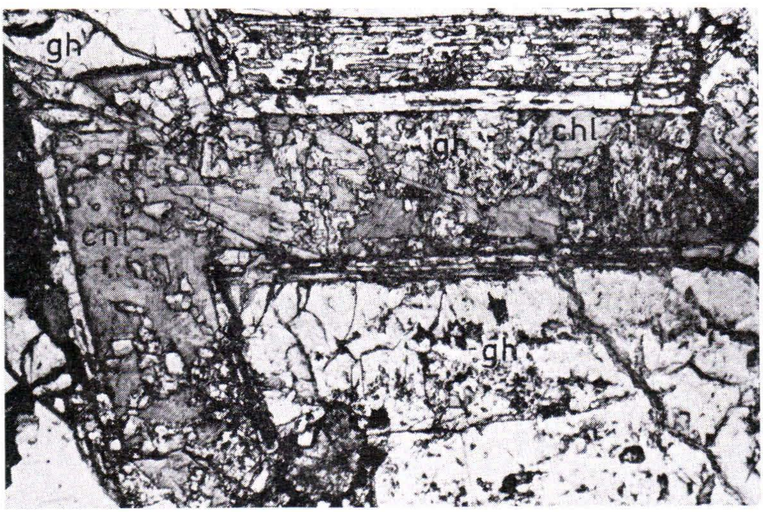


FIG. 5. Zonal replacement of genthelvite by chlorite. Some marginal zones of a genthelvite tetrahedron are essentially replaced by chlorite (chl), while the central part (lower right part of the photograph) is almost unreplaced. In the marginal parts of the crystal there are zones and fragments of unreplaced genthelvite (gh) in chlorite matrix. One nicol, magn. 80 x. Photo Erkki Halme.

minerals. Sericite and chlorite often replace genthelvite along fractures and crystallographic zones (Figs. 4 and 5). Quartz and topaz sometimes occur as euhedral inclusions in genthelvite. The quartz content is clearly lower than in the original granite. Small amounts of fluorite and secondary Fe—Ti oxide occur in all zones. Minute cassiterite crystals are encountered occasionally. In the central parts of the greisen body there are also irregular distributions of sphalerite, galena and chalcopyrite. These accessory sulfides often fill microfractures in the greisen and are clearly younger than quartz and genthelvite. Typically sphalerite and the other sulfides occur in association with genthelvite veining and replacing it along fractures and crystallographic zones in the same way as sericite and chlorite (Fig. 4).

A 15 kg sample taken from the genthelvite-bearing zone was crushed and analysed chemically. The chemical composition is presented in Table 1, compared with that of unaltered Väkkärä granite (locality: x = 6787.54, y = 535.00). According to the

TABLE 1

Chemical analyses of the genthelvite-bearing greisen and the Väkkärä granite from Eurajoki. The wet-chemical analyses by Pentti Ojanperä, the spectrographic analyses (BeO and the elements given in parts per million) by Ringa Danielsson.

	Weight per cent			Parts per million	
	Greisen	The Väkkärä granite		Greisen	The Väkkärä granite
SiO_2	60.52	74.57	Be	1 400	3 [2]
TiO_2	0.04	0.03	B	15	< 10
Al_2O_3	16.74	14.26	Sc	26	< 10
BeO	0.39	0.00	Ga	90	48
Fe_2O_3	1.54	0.55	Zr	74	< 10
FeO	8.33	0.43	Mo	< 10	< 10
ZnO	2.13	0.00	Sn	77	100
MnO	0.57	0.03	V	< 10	< 10
MgO	0.04	0.03	Cr	< 10	< 10
CaO	0.51	0.60	Cu	< 10	< 10
SrO [1]	0.005	0.00	Ni	< 10	< 10
BaO [1]	0.0	0.0	Co	< 10	< 10
Na_2O	0.08	3.72	Zn		< 100
K_2O	4.06	4.48	Pb	110	19
Li_2O	0.22	0.10	Y	120	53
Rb_2O [1]	0.200	0.092	Yb	14	10
Nb_2O_5 [1]	0.007	0.010	La	< 10	< 10
P_2O_5	0.03	0.01			
CO_2	0.00	0.00			
S	0.33	not anal.			
F	1.78	0.90			
H_2O+	3.10	0.51			
H_2O-	0.04	0.07			
	100.662	100.392			
$-O = F_2$	0.75	0.38			
$-O = S$	0.16	0.0			
	99.752	100.012			

[1]) X-ray fluorescence analysis by Väinö Hoffrén.
[2]) In many other samples the beryllium content is much higher.

analyses, the genthelvite-bearing greisen is characterized by almost complete removal of sodium, considerable removal of silica and substantial additions of iron, aluminium, zinc, beryllium, water, fluorine and sulfur. Potassium, aluminium, iron and water are included essentially in sericite, chlorite and topaz; zinc, beryllium and sulfur mainly in genthelvite.

A partial microprobe analysis made by Dr. Jaakko Siivola showed the chlorite from the genthelvite-bearing zone to be a very iron-rich variety, almost similar in composition to the ripidolite from Kymi (Table 2). According to semiquantitative microprobe determinations, the sericite contains 6.6 % FeO, 10.6 % K_2O and 0.3 % ZnO. For want of a more complete analysis the nature of sericite remains obscure, but it is probably iron-rich muscovite or zinnwaldite. The chemical composition of genthelvite is presented in Table 3.

THE KYMI AREA

The Kymi granite complex

The Kymi granite complex forms a cupola (Fig. 6) on the present erosion level in the Wiborg (Viipuri) rapakivi massif. It intrudes older granite varieties, mainly wiborgite and pyterlite (see Simonen 1965 and Vorma 1971). The complex is roughly oval in outline, about 5 km in length and 3 km in width. The central part of the complex consists of porphyritic granite and the margins of even-grained granite. Both varieties are leucocratic topaz-bearing biotite granites, but the topaz content in the marginal granite is higher and the biotite content lower than in the central granite. Like the Väkkärä granite in Eurajoki, these granites are characterized by their anomalously high fluorine, rubidium, tin and beryllium contents. At the outer contact of the complex, against the »normal» rapakivi granite varieties, there is a rim composed of pegmatite and even-grained granite. This zone is only a few metres or less in width and corresponds to the marginal pegmatite (Stockscheider) commonly met with in the contact zones of the »stanniferous» granites. Besides quartz, feldspars and mica, the pegmatite often contains topaz in abundance and small amounts of fluorite, arsenopyrite, tourmaline, molybdenite, bastnaesite and monazite.

The greisen bodies

Greisen and quartz veins and lodes occur in and around the Kymi granite complex (Fig. 6). Most of these veins and lodes are barren, but some contain one or several of the following minerals: galena, sphalerite, chalcopyrite, wolframite, arsenopyrite, cassiterite, genthelvite and beryl.

Beryl is found in greisen-bordered veinlets in a vein swarm cutting the normal rapakivi (wiborgite) on the SE side of the topaz-bearing granite complex (Fig. 6). The veinlets consist of quartz, fluorite, beryl, arsenopyrite, wolframite, mica and topaz.

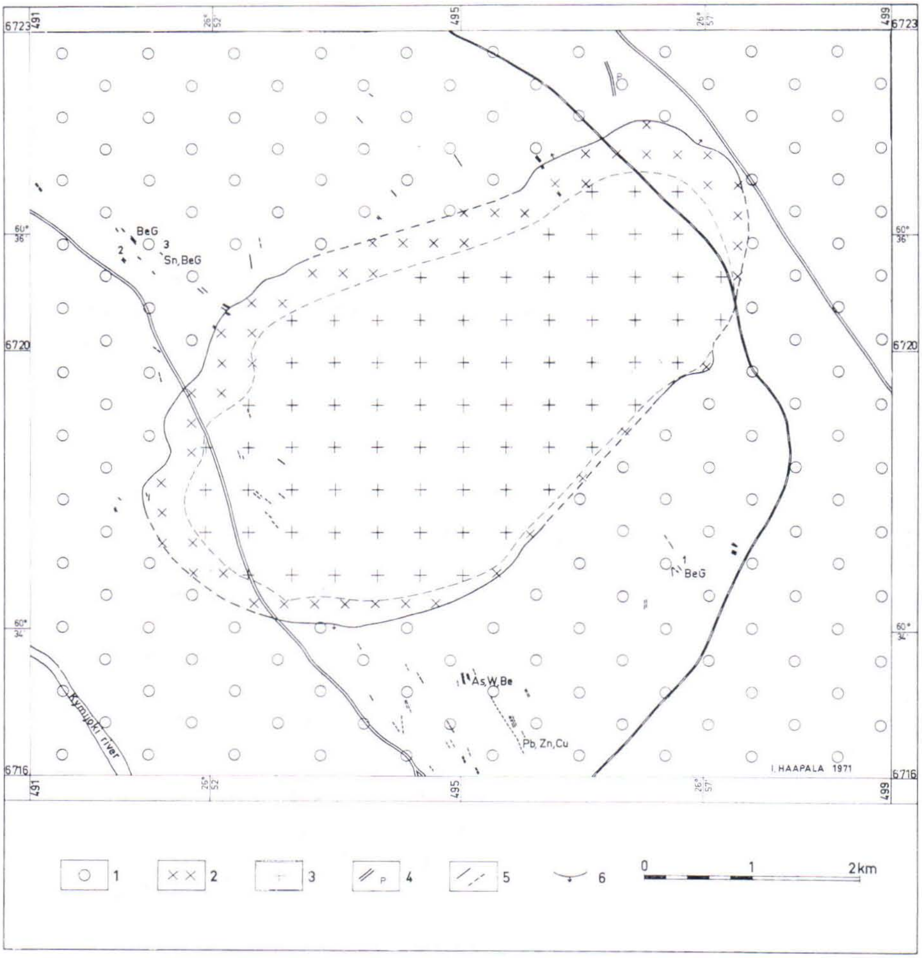


FIG. 6. Geological map of the Kymi area. (1) Normal rapakivi granites; (2) even-grained granite; (3) porphyritic granite; (4) porphyry dike; (5) greisen and quartz (broken line) veins or lodes; (6) contact showing dip; (Be) beryl; (BeG) genthelvite; (As) arsenopyrite; (W) wolframite; (Sn) cassiterite; (Pb) galena; (Zn) sphalerite; (Cu) chalcopyrite.

The genthelvite occurrences

Genthelvite occurs as one of the main minerals in a greisen lode cutting wiborgite (occurrence 1 in Fig. 6). On the basis of its mineralogical composition, the greisen can be divided to 1) muscovite-chlorite, 2) muscovite-chlorite-genthelvite, 3) quartz-muscovite-chlorite (-biotite) and 4) quartz-muscovite-genthelvite-chlorite types. Chlorite replaces muscovite along small fractures. Fluorite occurs in appreciable amounts in the different greisen types. Apatite, monazite, zircon, Fe—Ti oxide,

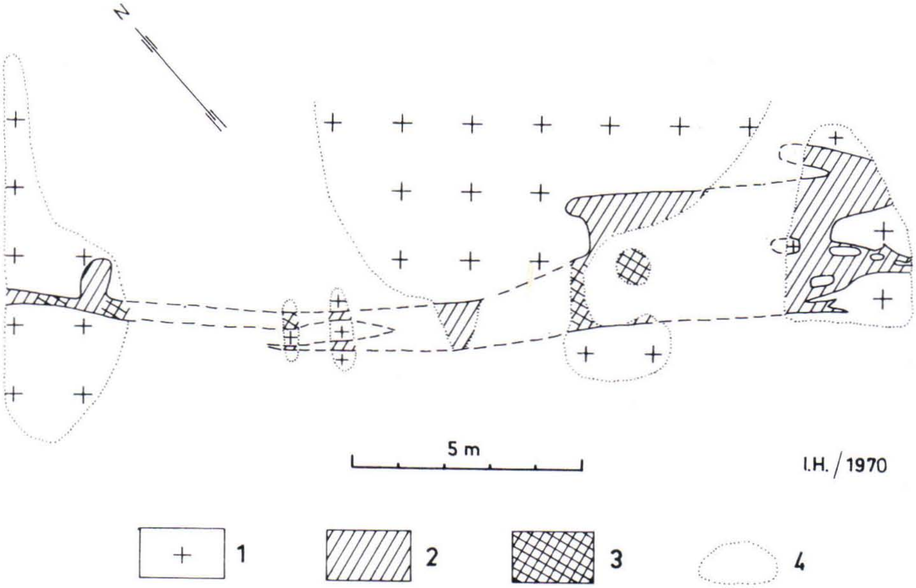


FIG. 7. The genthelvite-bearing greisen body (occurrence 1) from Kymi. (1) Wiborgite; (2) greisen; (3) genthelvite-bearing greisen; (4) outcrop.

chalcosite and malacite are occasionally met with, apatite together with genthelvite. The quartz-muscovite-chlorite (-biotite) rock which also contains remnants of feldspar occurs mainly at the margins of the greisen body. Because the lode is only partly uncovered, the types are not differentiated on the sketch (Fig. 7). The most prominant types are the muscovite-chlorite and muscovite-chlorite-genthelvite greisens. The rapakivi texture (see, e.g., Vorma 1971) of the granite is clearly visible as relict in the greisen body. Genthelvite occurs primarily as irregular disseminations or as small streaks in the greisen. It is also found in quartz veinlets in the central part of the greisen lode. The disseminated genthelvite crystals have often replaced the plagioclase mantles around the former potash feldspar ovoids. It is common for the genthelvite and fluorite crystals to be partly replaced by muscovite and chlorite.

Muscovite, chlorite and genthelvite were separated from the greisen variety containing these minerals as the main constituents with Clerici solution and a Franz isodynamic separator. Any impurities were then removed by hand picking. In the final muscovite fraction practically no impurities were detectable. The chlorite concentrate contained about 2 % muscovite as an impurity. The muscovite and chlorite analyses are presented in Table 2. According to the analysis, the muscovite has notable high iron and tin contents. No cassiterite was detected in the heavy mineral fraction. The chlorite is high in iron and very low in magnesia and corresponds to the iron-rich variety (aphrosiderite) of ripidolite (Deer, Howie and Zussman 1962).

TABLE 2

Chemical analyses and physical properties of muscovite and chlorite from the Kymi occurrence (1) (analyses by Pentti Ojanperä) and partial microprobe analysis of chlorite from the Eurajoki occurrence (analysis by Jaakko Siivola).

	Weight per cent				Ionic ratios on the basis of			
					24(O, OH, F)		36(O, OH)	
	1	2	3		1		2	
SiO_2	45.77	23.03	23.6	Si	6.276	8.00	5.316	8.00
TiO_2	0.56	0.52	0.5	$Al^{[4]}$	1.724		2.684	
Al_2O_3	31.77	20.61	17.8	$Al^{[6]}$	3.411		2.923	
Fe_2O_3	2.43	2.86		Ti	0.058		0.090	
FeO	2.30	35.09	40.7	Fe^{3+}	0.251		0.497	
ZnO	0.30	1.73	1.0	Fe^{2+}	0.264	4.14	6.774	
MnO	0.50	5.17	3.6	Zn	0.030		0.295	
MgO	0.24	0.93	0.6	Mn	0.058		1.019	
CaO	0.23	0.07	0.1	Mg	0.049		0.320	12.04
SrO [1]	0.00	0.00		Li	0.017		0.013	
BaO [1]	0.17	0.00		Ca	0.034		0.017	
Na_2O	0.21	0.03		Ba	0.009		0.000	
K_2O	11.60	0.26	0.02	Na	0.056	2.13	0.013	
Li_2O	0.03	0.05		K	2.029		0.077	
Rb_2O [1]	0.21	0.00		Rb	0.019		0.000	
Cs_2O	0.009	0.00		F	0.260		0.000	
ZrO_2 [1]	0.00	0.00		OH	3.238	24.00	15.090	36.00
Sn [1]	0.06	0.00		O	20.502		20.910	
P_2O_5	0.01	0.09		The physical properties				
CO_2	0.00	0.00						
Cl	0.00	0.00		β	1.603 ± 0.002		1.667 ± 0.002	
F	0.60	0.00		γ	1.605 ± 0.002			
H_2O+	3.54	9.80		$2V\alpha$	24 ± 2°		20 ± 5°	
H_2O-	0.06	0.04		Sp.gr.	2.89 ± 0.02		3.22 ± 0.02	
	100.599	100.28						
$-O = F_2$	0.25							
	100.349							

[1]) X-ray fluorescence analysis by Väinö Hoffrén.

1. Muscovite from the genthelvite occurrence (1) from Kymi.
2. Chlorite from the genthelvite occurrence (1) from Kymi.
3. Chlorite from the genthelvite occurrence from Eurajoki.

The ZnO content (1.73 %) is anomalously high, but the tin content is low. Sphalerite has not been detected in the greisen lode. It appears that practically all the zinc and tin of the greisen are in silicates (chlorite, muscovite, genthelvite).

Small amounts of genthelvite are met with on the northwestern side of the granite complex in a swarm of greisen veins about 5—10 cm in width (occurrence 2). The associated minerals are quartz, fluorite, sericite and chlorite. Sericite and chlorite replace genthelvite and fluorite. An analysis of genthelvite from one of the veins is presented in Table 3.

There is a third occurrence of genthelvite in the Kymi area (occurrence 3) on the northwestern side of the granite complex in an approximately 0.5 m wide greisen lode.

In this case minor amounts of genthelvite are associated with quartz, relict feldspar, sericite and chlorite. Cassiterite and fluorite occur in small amounts.

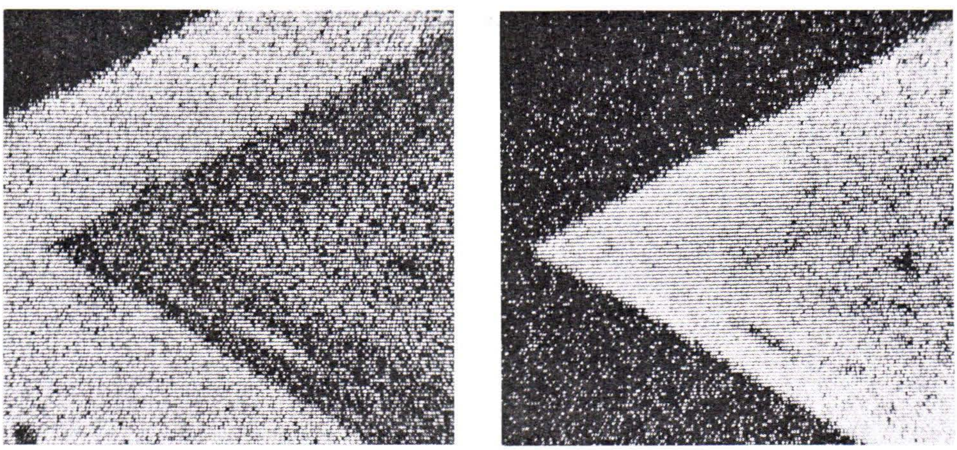
Before genthelvite had been found in the described occurrences by the first author (I.H.), the mineral had been identified in the Geological laboratory of the Outokumpu Co. (Yrjö Vuorelainen, oral communication in 1968) from the sulfide-bearing lode marked with Pb, Zn, Cu in Fig. 6. The authors of this paper have not found genthelvite in this lode, so it obviously occurs erratically or in very small amounts.

THE MINERALOGY OF GENTHELVITE

In all of the described occurrences genthelvite occurs as yellow-brown tetrahedral crystals, about ½ cm or less in diameter. Small faces of negative tetrahedron have been detected in a few crystals. Because such faces are visible also in thin section, they can not be due to octahedral cleavage. In all of the occurrences genthelvite is partly replaced by white mica and chlorite (Figs 4 and 5), and in the Eurajoki occurrence also by sulfides.

Especially in the Eurajoki occurrence, the genthelvite crystals are often strongly zoned. The zonality is usually oscillatory and visible under the microscope as differences in colour and refractive index. According to microprobe analyses made by Dr. Jaakko Siivola, the marginal zones are enriched in zinc and the central parts in iron (Fig. 8).

Genthelvite was separated from three occurrences (the Eurajoki occurrence and occurrences 1 and 2 in the Kymi area) for chemical analyses and mineralogical studies



Fe K_α Zn K_α

FIG. 8. Electron probe scanning pictures showing the distribution of iron (FeKα) and zinc (ZnKα) in a zoned genthelvite crystal from Eurajoki. Magn. 180 x. The iron-rich mineral surrounding genthelvite is chlorite.

TABLE 3

Chemical analyses and physical properties of genthelvite from the Kymi occurrences (1) and (2) and from the Eurajoki occurrence. Analyses by Pentti Ojanperä.

	Kymi (1)	Kymi (2)	Eurajoki
SiO_2	30.00	30.3	30.3
Al_2O_3	0.09	0.02	0.08
BeO	12.83	12.8	12.8
FeO	2.47	3.5	4.4
ZnO	44.79	45.5	44.4
MnO	6.55	5.0	5.0
MgO	0.01	0.04	0.04
CaO	0.04	0.03	0.11
S	5.34	5.4	5.4
	102.12	102.59	102.53
— O = S	2.67	2.7	2.7
	99.45	99.89	99.83

Number of ions on the basis of 26 (O, S)

	Kymi (1)		Kymi (2)		Eurajoki	
Zn	6.528	8.04	6.61	8.04	6.44	8.02
Mn	1.095		0.83		0.83	
Fe	0.408		0.58		0.72	
Ca	0.008		0.01		0.02	
Mg	0.003		0.01		0.01	
Be	6.084	12.03	6.05	12.01	6.04	12.01
Si	5.921		5.96		5.95	
Al	0.021		0.00		0.02	
O	24.025		24.01		24.01	
S	1.975		1.99		1.99	

The physical properties

	Kymi (1)	Kymi (2)	Eurajoki
n	1.743 ± 0.003	1.743 ± 0.003	1.743 ± 0.003
Sp.gr.	3.59 ± 0.02	3.60 ± 0.02	3.58 ± 0.02
a_0 (Å)	8.14 ± 0.01	8.13 ± 0.01	8.14 ± 0.01

by the conventional heavy liquid, magnetic and hand-picking methods. No foreign grains were detectable in the final fractions under a binocular microscope, although they probably contained small amounts of fine-grained mica and chlorite as impurities. According to the analyses, these genthelvites are surprisingly similar in composition (Table 3). The amounts of the genthelvite end member in these mineral samples are 81.2, 82.3 and 80.2 mole per cent. Also the physical properties are nearly similar.

In surface samples genthelvite is often weathered to yellow earthy material which was identified as goethite by X-ray technique.

THE MINERAL ASSOCIATIONS WITH GENTHELVITE

Genthelvite is obviously the rarest of the helvite-group minerals. Until the study of Glass and Adams (1953) it had only been found from one locality in Colorado. However, in the late fifties and sixties a number of new genthelvite occurrences

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TABLE 4
The occurrences and mineral associations of genthelvite

Locality	Occurrence	Associated minerals	References
El Paso County, Colorado, USA	a) unknown	quartz, astrophyllite	Glass *et al.* 1944
	b) cavity in pegmatite in the Pikes Peak granite	quartz, microcline, zircon	Glass and Adams 1953
	c) cavity in pegmatite in the Pikes Peak granite	quartz, microcline, biotite, zircon	Scott 1957
Jos, northern Nigeria	a) albite vein in granite	albite, Li-mica, thorite	Knorring and Dyson 1959
	b) microcline pegmatite in granite	amazonite	
Cairngorm Mountains, Scotland	pegmatite-lined cavities in adamellite	quartz, feldspar, kaolin	Morgan 1967
Lovozero, Kola Peninsula, USSR	feldspar pegmatites in alkaline intrusion	feldspar, Mn-ilmenite, zircon, sodalite, apatite	Eskova 1957
Keyv, Kola Peninsula, USSR	pegmatite in gneiss, associated with alkaline granite	quartz, amazonite, albite, biotite, muscovite beryl, garnet, covellite, gadolinite	Vasilev 1961
Rovgora, Kola Peninsula, USSR	pegmatite, associated with alkaline granite	blocky amazonite, quartz, biotite, ilmenite fluorite, pyrochlore	Lunts and Saldau 1963
The Oslo Region, Norway	a) unknown nepheline-syenite pegmatite	not given	Oftedal and Saebø 1963
	b) nepheline-syenite pegmatite	analcime, zircon, bastnaesite, natrolite, mica, pyrophanite, eudidymite	
	c) nepheline-syenite pegmatite	analcime, albite, sphalerite, galena, egirine, catapleite, astrophyllite, pyrophanite, monazite, fluorite, muscovite	
Ilimaussaq, southern Greenland	albite vein in alkaline intrusion	albite, egirine, neptunite, catapleite	Bollinger and Petersen 1967
Treburland, Cornwall	calc-silicate rock near granite	garnet, calcite, chlorite, galena, molybdenite	Kingsbury 1961
Pitkäranta, Karelia, USSR	calc-silicate rock near rapakivi granite	fluorite, biotite, chlorite, vesuvianite	Bulah and Frank-Kamenetskiy 1961
Unnamed locality, USSR	silicified syenites in granite	quartz, albite, pyrite, galena, molybdenite	Gurvich *et al.* 1963
Unnamed locality, USSR	vein-type metasomatites (quartz + microcline, quartz + albite + microcline, mica + feldspar, quartz + siderophyllite) in granite complex	the named mineral associations plus muscovite, phenacite, willemite, columbite-tantalite, cassiterite, zircon, thorite, bastnaesite, magnetite, galena, molybdenite, sphalerite, pyrite	Galetskiy 1966
Unnamed locality, USSR	greisen bodies in granite complex	quartz, siderophyllite, relict microcline, willemite, phenacite, gahnite, zircon, magnetite	Gurvich *et al.* 1962 Gurvich 1963, Yurk *et al.* 1971
Eurajoki, southwestern Finland	greisen body in topaz-bearing rapakivi granite	quartz, sericite, chlorite, topaz, fluorite, sphalerite, cassiterite, galena	The present study
Kymi, southern Finland	greisen lodes associated with topaz-bearing rapakivi granite (three occurrences)	muscovite, chlorite, fluorite, ± quartz, ± relict feldspar, ± apatite, ± cassiterite	The present study

were described from different parts of the world. The occurrences and mineral associations are summarized in Table 4.

Genthelvite occurs most commonly in late-stage assemblages in alkaline or granitic pegmatites, usually together with albite and/or microcline, although it has occasionally been found in calc-silicate rocks (skarns) or in metasomatized alkaline or granitic intrusives.

Previous to this study, genthelvite from greisenised rock has only been described from one (?) area in the U.S.S.R. (Galetskiy 1966, Gurvich *et al.* 1962, Gurvich 1963, Yurk *et al.* 1971). The papers of Gurvich *et al.* (1962) and Galetskiy (1966) make it clear that the occurrences in question are located in a large shear zone in a granite complex, which also includes arfvedsonite and aegirine syenites. The mineral assemblages differ appreciably from those described in this paper. Thus, biotite (siderophyllite), willemite, phenacite and gahnite are not found in association with genthelvite in the Finnish occurrences, but are typical of the Russian occurrences. If the Finnish genthelvite assemblages originally contained biotite, it has now been replaced by chlorite and white mica. In the greisen-type occurrences described by Galetskiy (1966), genthelvite had partly been replaced by mica minerals in the same way as in the Finnish occurrences.

The rarity of genthelvite compared with many other beryllium minerals indicates that the mineral can be formed only under relatively restricted conditions. The great chemical similarities among the Finnish genthelvites further suggest that in these cases the natural conditions were almost identical.

In Finland genthelvite is closely associated with fluorite and occasionally with topaz. This suggests, but does not prove, that fluorine played an important role in the transportation of beryllium. The extraction of fluorine from the mineralizing fluids through the crystallization of fluorite and topaz, and the leaching of alkalies from the surrounding rocks into the solution during greisenization, obviously contributed to the deposition of genthelvite (see Beus 1966, p. 348—360).

Several authors (e.g., Holser 1953, Kingsbury 1961, Beus 1966, Čech and Povondra 1969) have suggested that helvite-group minerals rather than beryl and other Be-Al silicates are formed in environments poor in aluminium. This theory does not appear to hold true in the case of the Finnish genthelvite occurrences. In the genthelvite-bearing assemblage from Eurajoki and in the muscovite-chlorite-genthelvite greisen from Kymi at least, the alumina content is higher than in the original granites. However, this contradiction may be only apparent. The alumina is included in muscovite and chlorite, in the Eurajoki occurrence partly also in topaz. Part of the white mica and chlorite clearly replaces genthelvite. Thus part of the aluminium was obviously introduced into the genthelvite-bearing assemblages after the formation of genthelvite.

The helvite-group minerals are chemically intermediate between pure silicates and sulfides. Besides the necessary concentrations of zinc and beryllium, a proper (not too low, not too high) activity of sulfur is obviously very important for the formation of the species genthelvite (*cf.* Pavlova *et al.* 1966, Beus 1966, p. 359). In the Russian greisen-type occurrences the association of willemite with genthelvite indicates a low activity of sulfur (Pavlova *et al.* 1966). In the Finnish occurrences sulfides play a subordinate part or are not present. Only in the Eurajoki occurrence do appreciable amounts of sulfides occur in the genthelvite-bearing assemblage, and even then they were formed later than genthelvite.

Because beryl and genthelvite have not been found in the same mineral assemblage, their mutual age relations are not clear. It is worth noting, however, that such high-temperature minerals as wolframite, arsenopyrite and molybdenite are not found in the genthelvite-bearing assemblages, but they occur in beryl-bearing quartz veins.

Finally, it must be emphasized that extensive experimental studies are needed for the better understanding of the mutual relations of the beryllium minerals. At present the stability relations of the tens of beryllium minerals are largely uncertain.

CONCLUSIONS

Several greisen bodies containing genthelvite, beryl or bertrandite were found in the Eurajoki and Kymi areas during the reconnaissance exploration work starting in 1967 in the areas of the Laitila and Wiborg rapakivi massifs. Before these studies no beryllium minerals had been recorded in articles on the rapakivi granite massifs of Finland. In Russian Karelia, a beryl-bearing pegmatite (greisen-bordered beryl-biotite-plagioclase-fluorite vein) has been described from Uuksu (Kranck 1929) and helvite- and genthelvite-bearing skarns from Lupikko in Pitkäranta (Trüstedt 1907, Saksela 1951, Bulah and Frank-Kamenetskiy 1961). These occurrences are located outside but near the Salmi rapakivi granite massif, and obviously have a genetic connection with it.

In the Eurajoki and Kymi areas the beryllium and other ore mineralizations are closely associated with topaz-bearing biotite granites. These granites are further characterized by anomalously high fluorine, rubidium, tin and beryllium contents and an anomalously low zirconium content compared with common rapakivi granites and most granites in general.

The mineralizations found in the Eurajoki and Kymi areas and elsewhere in association with the Finnish rapakivi granites show that these granite areas should not be too much belittled by prospectors. There may be important ore mineralizations (Sn, Be, W, etc.) associated with certain types of rapakivi granites. Besides cassiterite and other metallic minerals, special attention should also be paid to the beryllium minerals. Disseminated in greisen bodies, veins, skarns or in altered granite, these minerals may easily be overlooked.

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