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# Mineralogy and Petrography of Siilinjärvi Carbonatite and Glimmerite Rocks, Eastern Finland

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Mineralogy and Petrography of Siilinjärvi Carbonatite and Glimmerite Rocks, Eastern Finland			
Abstract			
<p><i>Samples of three different rock type (silico-carbonatite, carbonatite-glimmerite and apatite- glimmerite) were collected from Siilinjärvi ultramafic alkaline-carbonatite complex. The three samples were characterized with respect to chemistry, mineralogy, and petrology.</i></p>			
<p>The silico-carbonatite sample composed mainly of apatite-calcite-dolomite also contains small amounts of barite (max. size 100 x 180 µm). Calcite and dolomite are both Fe- and Sr-bearing. Apatite and barite are both Sr-bearing. Monazite grains are mostly very small grains (diameter = 10 x 10 - 12 x 50 µm) and occurs as inclusions in calcite and apatite or in contact of calcite and dolomite. Strontianite occurs also as very fine grained clouds in calcite (diameter = 9 x 17 - 20 x 50 µm).</p>			
<p>Carbonatite-glimmerite sample is mainly composed of calcite-apatite-phlogopite-dolomite, with some occurrences barite. Calcite and dolomite are both Sr- and Fe-bearing. Apatite and barite are both Sr-bearing. In addition there are mostly very small grains of Ce-phosphate (monazite) and Sr-Ca-carbonate (strontianite). Few grains of Nb-minerals have been seen and analyzed, these include two types: 1) Nb-Ca-Ti-Ta (+ Ce, Nd) mineral and 2) = Nb-Ti-Ca-Ta (+ Ce, Nd, La, Sm, Gd) mineral.</p>			
<p>Apatite- glimmerite sample is composed mainly of phlogopite and apatite rock, which is also, contains small amounts of dolomite (grain size max. 500 x 1200 µm). Maximum grain size of apatite is 1 x 2 mm. Small amounts of pyrrhotite and zircon found in the cracks of apatite and Fe-oxide together with phlogopite. This sample is marking the occurrences of Nb- bearing minerals (max.40 x 100 µm) between phlogopite flakes. There are at least two different types of Nb-minerals: 1) nioboaeschynite: Nb-Ca-Ti-Ta- with small amounts of REE and 2) barytolamprophyllite: Nb-Ta-Ba-Ca-Sr-Ti-Fe with high U content.</p>			
Keywords			
<i>silico-carbonatite, carbonatite-glimmerite, apatite- glimmerite and Siilinjärvi Complex,</i>			
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<i>Siilinjärvi</i>			
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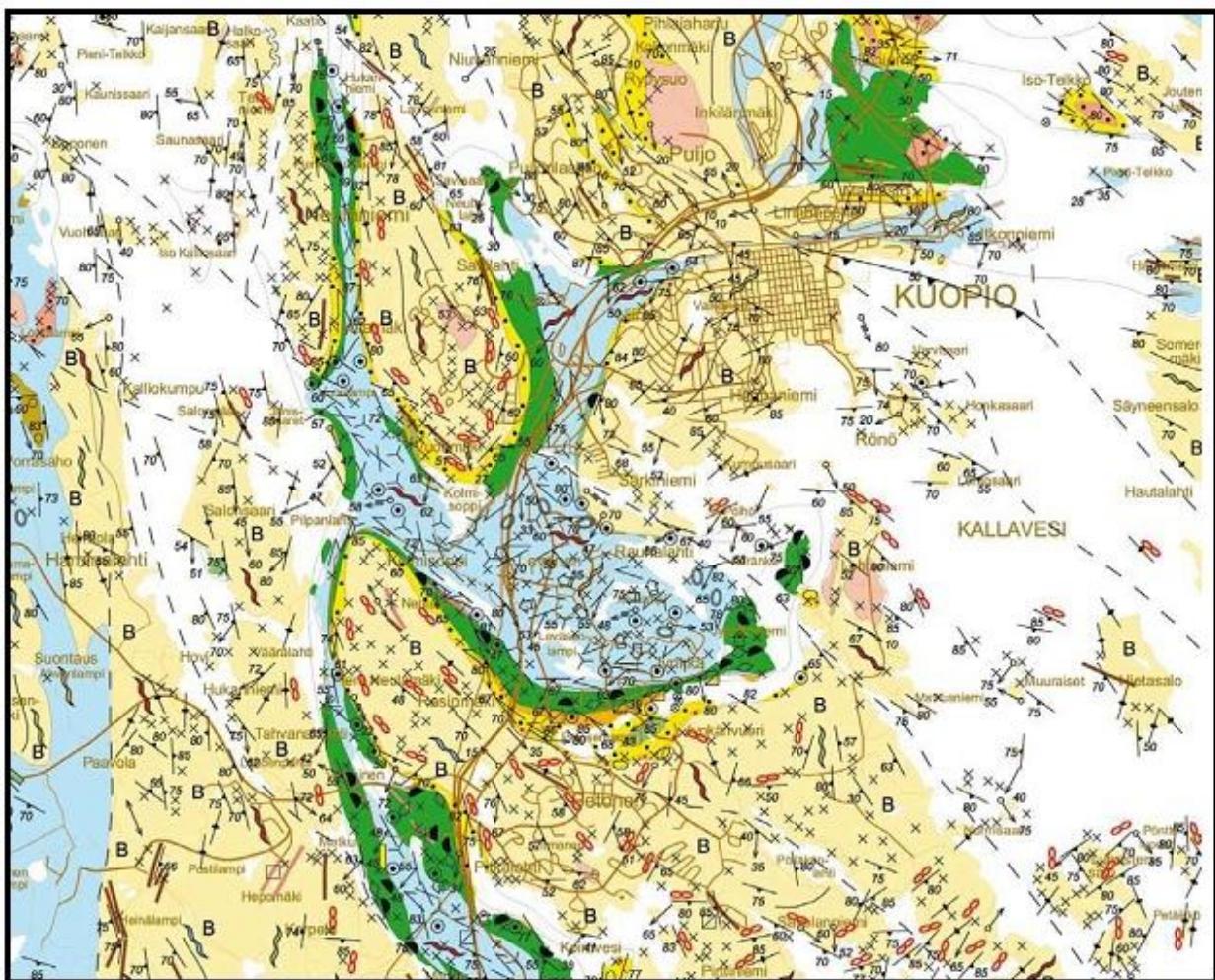
### LITERATURE



1 INTRODUCTION

The Siilinjärvi ultramafic alkaline-carbonatite complex is situated some 20 km to the north of the city of Kuopio in eastern Finland (Fig. 1). The entire complex, about 16 km long and up to 1.5 km wide, covers an area of 14.7 km<sup>2</sup>. The rocks of the complex comprise (from the oldest to the youngest) glimmerite, syenite and carbonatite. The complex is intrusive into surrounding granite gneiss which extends some 100 km to the north from Siilinjärvi (Kauko Puustinen, 1971).

This report deals with rare minerals occurrence and other accessory minerals in studied carbonatite and glimmerite rocks. We present petrographic and mineralogical data for the Siilinjärvi alkaline-carbonatite and associated rocks, to study the nature, abundance, composition, grain-size distribution, textural relationships and associations of REE-minerals with apatite, phlogopite and carbonate minerals.



**Figure 1.** Geological map of Siilinjärvi, after (Lukkarinen Heikki, 2008).



## 2 ANALYTICAL TECHNIQUES

Three samples of Siilinjärvi alkaline-carbonatite were selected as best display based on varieties of rocks in studied area. Three polished thin section were prepared for petrographical study and for electron microprobe analyses. Electron microprobe analyses of minerals were performed by the wavelength dispersive technique using a Cameca SX100 instrument at the Geological Survey of Finland (GTK) in Espoo. All analyses were determined using an accelerating voltage of 15 kV. Probe current and beam diameter used were 10-20 nA and 5-10 micrometers depending on the analyzed mineral. Natural minerals and metals were employed as standards. Analytical results were corrected using the PAP on-line correction programmed (Pouchou & Pichoir, 1986).

## 3 PETROLOGY

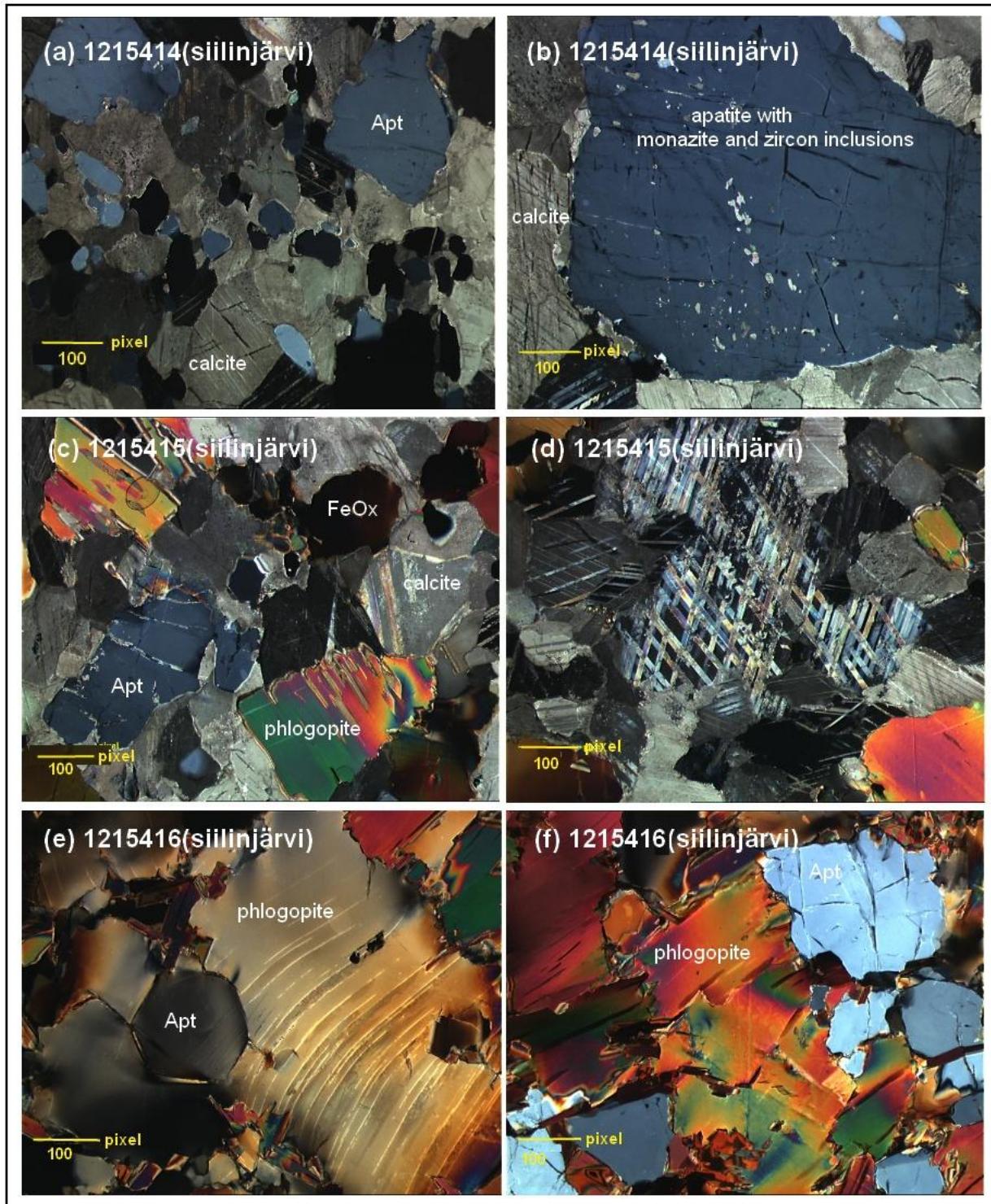
The samples examined in the present work represent three varieties of rocks were selected from The Siilinjärvi complex. These rocks including the silico-carbonatite (sample 1215414), carbonatite-glimmerite (sample 1215415) and apatite-poor glimmerite rock (sample 1215416).

The Siilinjärvi carbonatitic rocks (sample 1215414), which are brecciated, fine to coarse-grained, brown-yellowish colour, and strongly enriched in calcite, dolomite and apatite. Phlogopite, ilmenite and magnetite are also present (Fig. 2a, b). Apatite occurs as coarse grains (1-2mm), prisms and also as irregular grains. In thin section it is colourless in (PPL) and gray to greenish yellow in (XPL). Apatite contains inclusions of zircon and REE-minerals as monazite and pyrochlore (Fig. b)

The main constituents of carbonatite-poor glimmerite (sample 1215415) rocks are calcite, phlogopite and dolomite, with apatite, strontianite, barite, zircon, ilmenite and magnetite as minor constituents. This sample was represented a typical example of mixing between carbonatite and glimmerite with large fractured crystals of apatite (Fig. 2c). Calcite has very high birefringence, with rhombic cleavage visible in many samples and has maximum interference colours of high order white. Twinning is visible in the grain at Figure (2d), in which all the other grains exhibit high-order white interference colours. Phlogopite occurs as platelets (0.1-0.2 mm) and larger anhedral grains, up to 0.2 mm (Fig 2c). They show very strong, distinctive red-brown to pinkish yellow pleochroism, which may be attributed to high Fe<sup>+3</sup> contents (Mitchell, 1985). The reverse pleochroism of the anomalous phlogopite is due to Fe 3+ in tetrahedral sites of the mica structure (Faye and Hogarth, 1969); in this case Al<sup>3+</sup> has been partially or completely replaced by the Fe 3+ ions. Skosyrev et al. (1988) has been mentioned that this kind of phlogopite occurs in most of alkaline carbonatite complexes.

Sample 1215416 was represented apatite-glimmerite rock composed mainly from brown phlogopite and apatite is dominated. The studied glimmerite rocks are fine to medium grained and foliated. The amount of phlogopite in the studied glimmerite sample typically more than 80 per cent by volume and is associated with small amounts of apatite 15 per cent by volume. The accessory minerals include ilmenite, magnetite, calcite, dolomite and pyrochlore. Rutile and zircon occur in trace amounts. Most phlogopite grains are coarse-grained with averages less than 2 mm in size, rarely attains 3mm, occurs as thick plates or flake. The pleochroism is rather yellowish brown with an optic angle less than 15 ~ and weak dispersion (Fig. 2e and f).





**Figure 2.** Photomicrographs of studied samples with crossed polarizer. a) Heavily veined and fractured gouge sample. b) Calcite vein in mudstone filled by coarse twinned calcite cement. c) Calcite vein/patch within siltstone matrix. d) Calcite patches with intersecting deformation twins. e) Fibrous calcite crystals are not twinned and not fractured indicating that healing processes outlasted the period of brittle faulting. f) Calcite vein with only few twinned grains, dominantly by a twin set with straight and thin twin lamellae.



## 4 MINERALOGY

We analyzed the microstructures and microchemical analysis of three samples obtained from Siilinjärvi Complex. Most minerals were analyzed with spectrometers on Cameca SX100 electron microprobe using the routine system for the mineralogical laboratory of GTK-Espoo.

### *Calcite and dolomite*

Calcite is the most common carbonate mineral in Siilinjärvi carbonatitic rocks. Its proportion may locally reach 35 vol. % of the rock in silico-carbonatite, and up to 50 and 85 vol. % in carbonatites. Calcite carbonatite appears to be the most common carbonatite present in the samples examined and may contain accessory magnesium calcite (dolomite), strontianite and apatite (Figure 2a, b).

The calcite from EMPA shows unperceived variation in terms of its Sr content (~1.4 wt. % SrO). The Mg, Mn and Fe contents are very minor, and none of the respective oxides attain concentrations above 0.3 wt. % (Table 1). Sr-enrichment is generally characteristic of primary calcite in carbonatites worldwide; secondary or late-stage calcite invariably shows some depletion in Sr, probably as result of re-equilibration and recrystallization of the calcite in presence of hydrothermal fluids. The liberated strontium from calcite has been recycled to form strontianite.

Major elements (Mg, Ca, Fe, Mn, and Sr) in the dolomite phase were quantified by electron microprobe analysis (EMPA). Dolomite show homogeneous and limited composition and are, in general, low in FeO content (between 2.4-2.9 wt %). The SrO and MnO proportions are consistently low with an average of 0.5 wt% and 0.24 wt% respectively (Table 1).

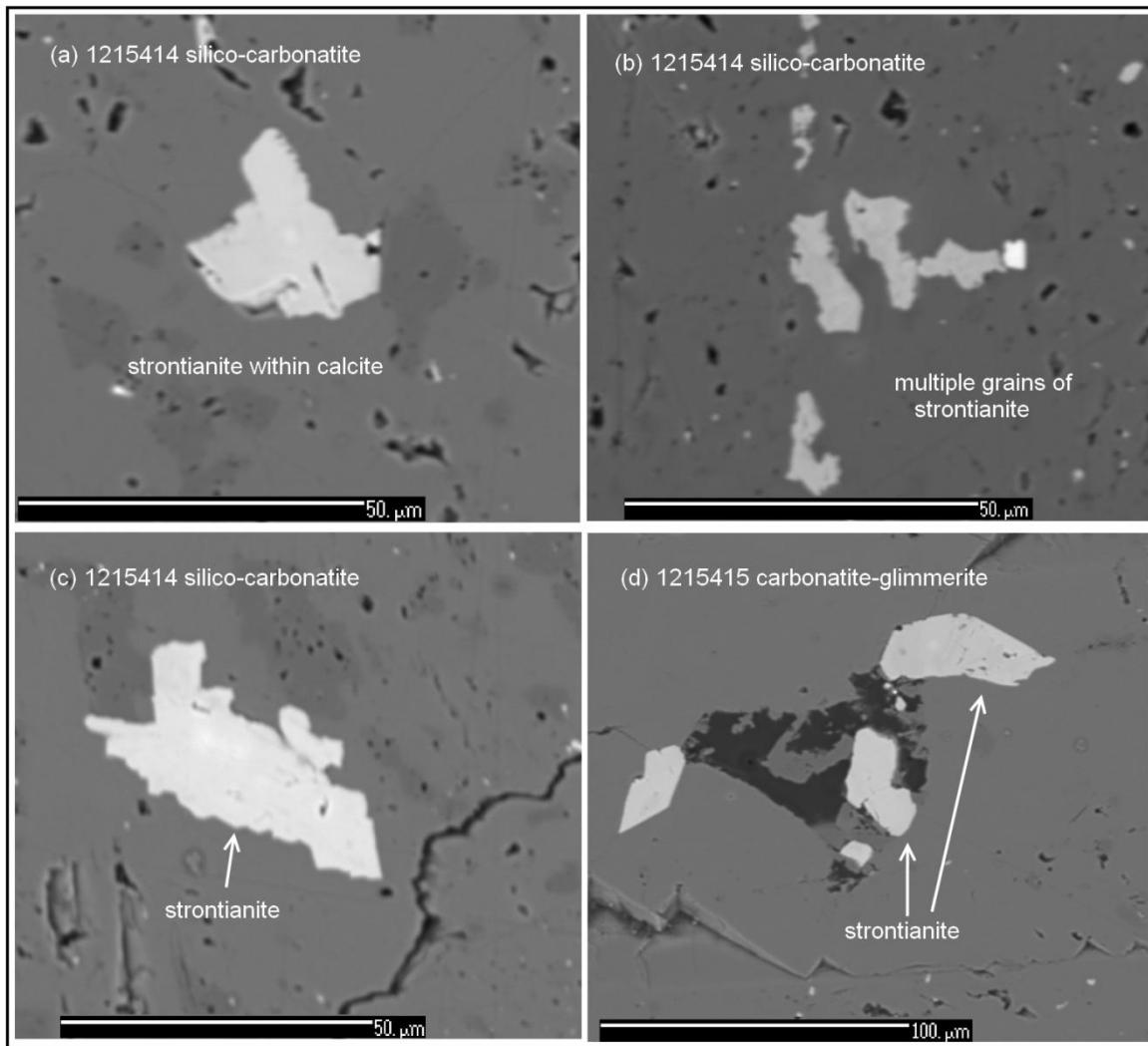
**Table 1.** Representative composition of carbonate minerals from carbonatite - glimmerite rocks at Siilinjärvi Complex (wt %).

Sample Mineral	1215414				1215415				1215416	
	Calcite	Dolomite	Calcite	Dolomite	Dolomite	Dolomite	Dolomite	Dolomite	Dolomite	Dolomite
SiO <sub>2</sub>	0.00	0.07	0.00	0.17	0.28	0.00	0.02	0.00	0.00	0.00
Al <sub>2</sub> O <sub>3</sub>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Cr <sub>2</sub> O <sub>3</sub>	0.01	0.00	0.01	0.05	0.01	0.00	0.03	0.00	0.00	0.02
FeO	0.49	0.48	2.72	2.93	0.49	0.49	2.61	2.46	2.14	2.21
MnO	0.28	0.15	0.19	0.25	0.20	0.22	0.23	0.21	0.31	0.22
MgO	<b>1.56</b>	<b>0.93</b>	<b>18.27</b>	<b>18.00</b>	<b>1.45</b>	<b>1.60</b>	<b>18.03</b>	<b>18.0</b>	<b>19.00</b>	<b>18.65</b>
CaO	<b>53.26</b>	<b>54.12</b>	<b>28.49</b>	<b>28.23</b>	<b>53.97</b>	<b>53.83</b>	<b>28.17</b>	<b>28.3</b>	<b>28.00</b>	<b>28.09</b>
Na <sub>2</sub> O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K <sub>2</sub> O	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.02	0.00	0.02
SrO	<b>1.41</b>	<b>1.21</b>	<b>0.62</b>	<b>0.42</b>	<b>1.45</b>	<b>1.40</b>	<b>0.62</b>	<b>0.57</b>	<b>0.41</b>	<b>0.45</b>
BaO	0.00	0.00	0.00	0.00	0.04	0.02	0.00	0.00	0.00	0.00
NiO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.02	0.00
ZnO	0.00	0.12	0.13	0.03	0.10	0.14	0.13	0.19	0.15	0.11
SO <sub>2</sub>	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.02
F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cl	0.01	0.02	0.01	0.00	0.02	0.00	0.01	0.00	0.01	0.00
CO <sub>2</sub>	<b>42.98</b>	<b>42.90</b>	<b>49.56</b>	<b>49.91</b>	<b>41.99</b>	<b>42.28</b>	<b>50.14</b>	<b>50.3</b>	<b>49.92</b>	<b>50.22</b>
Total	100	100	100	100	100	100	100	100	100	100



### Strontianite

Strontianite is also a carbonate mineral rich in Sr, occurring as nodules or platy crystals enclosed in calcite and often connected with veins within the calcite (Fig. 3). The chemical composition of strontianite from studied samples is characterized by noticeable variation in terms of its Ca content (1-7 wt% of CaO) and low content of other elements includes Ba, La, Ce and Nd ( $\text{REE}_2\text{O}_3 = 0.25 - 1.5 \text{ wt. \%}$ ) see (Table).



**Figure 3.** Strontianite occurs as very fine grained clouds within calcite (diameter = 9 x 17 - 20 x 50  $\mu\text{m}$ ).

**Table 2.** Representative composition of strontianite from carbonatite - glimmerite rocks at Siilinjärvi Complex (wt %).

Sample	1215414				1215415			
SiO <sub>2</sub>	0.1	0.0	0.0	0.1	0.1	0.0	0.1	0.0
MgO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CaO	<b>7.0</b>	<b>1.9</b>	<b>6.2</b>	<b>2.0</b>	<b>1.1</b>	<b>1.6</b>	<b>1.2</b>	<b>5.3</b>
Na <sub>2</sub> O	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1
K <sub>2</sub> O	0.0	0.0	0.0	0.1	0.2	0.2	0.1	0.0
SrO	<b>50.7</b>	<b>54.9</b>	<b>51.1</b>	<b>54.9</b>	<b>56.7</b>	<b>53.8</b>	<b>55.6</b>	<b>52.5</b>
BaO	0.0	0.0	0.1	0.1	0.0	0.0	0.3	0.1
Y <sub>2</sub> O <sub>3</sub>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ce <sub>2</sub> O <sub>3</sub>	0.2	0.4	0.2	0.8	1.0	0.9	0.7	0.4
Nd <sub>2</sub> O <sub>3</sub>	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.2
La <sub>2</sub> O <sub>3</sub>	0.0	0.0	0.0	0.2	0.3	0.3	0.2	0.1
SmO	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1
Gd <sub>2</sub> O <sub>3</sub>	0.0	0.2	0.0	0.1	0.1	0.1	0.1	0.1
Dy <sub>2</sub> O <sub>3</sub>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
CO <sub>2</sub>	<b>41.8</b>	<b>42.3</b>	<b>42.2</b>	<b>41.0</b>	<b>40.1</b>	<b>42.3</b>	<b>41.6</b>	<b>41.3</b>
Total	100	100	100	100	100	99	100	100

### Barite

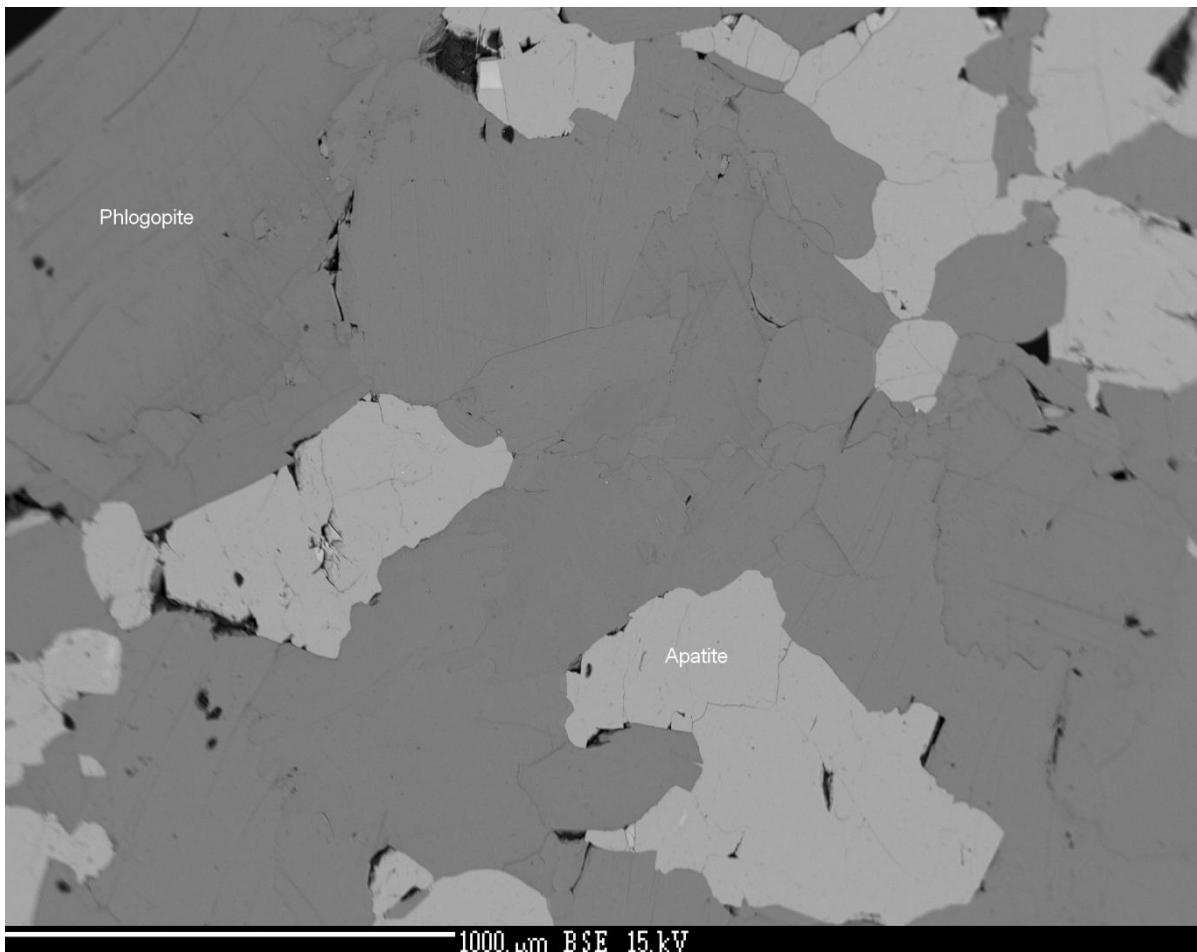
Barite is a ubiquitous late-stage mineral in carbonatites (e.g., Kapustin 1980). In Siilinjärvi carbonatitic rocks, this mineral occurs as scarce minute (<50  $\mu\text{m}$ ) inclusions in calcite, or as intergrowths with strontianite. The barite is show only a small replacement of Ba by Sr (1-4 wt. % of SrO) and Na (0.2- 0.3 wt. % of Na<sub>2</sub>O) and low proportions of Ca (0.1–0.17 wt.% CaO) see (Table 3). Late-stage and secondary barite is typically characterized by low Sr and Ca contents (Wall & Mariano 1996, Zaitsev *et al.* 1998).

**Table 3.** Representative composition of barite from carbonatite - glimmerite rocks at Siilinjärvi Complex (wt %).

Sample	1215415			1215416	
SiO <sub>2</sub>	0.00	0.00	0.05	0.18	0.21
TiO <sub>2</sub>	0.06	0.13	0.15	0.14	0.00
Al <sub>2</sub> O <sub>3</sub>	0.71	0.75	0.74	0.73	0.74
CaO	0.00	0.03	0.02	0.11	0.11
Na <sub>2</sub> O	0.34	0.32	0.35	0.31	0.31
K <sub>2</sub> O	0.00	0.00	0.00	0.00	0.01
SrO	<b>1.7</b>	<b>1.0</b>	<b>1.6</b>	<b>3.9</b>	<b>4.0</b>
BaO	<b>63.43</b>	<b>63.98</b>	<b>62.69</b>	<b>59.75</b>	<b>60.28</b>
NiO	0.05	0.00	0.00	0.01	0.00
ZnO	0.00	0.03	0.00	0.20	0.16
Nb <sub>2</sub> O <sub>3</sub>	0.00	0.03	0.10	0.00	0.03
SO <sub>3</sub>	<b>33.66</b>	<b>33.76</b>	<b>33.87</b>	<b>33.08</b>	<b>33.96</b>
P <sub>2</sub> O <sub>5</sub>	0.00	0.00	0.00	0.00	0.06
F	0.02	0.02	0.02	0.02	0.01
Total	99.99	100.15	99.69	98.53	100.05
					99.3

### Apatite

Apatite in Siilinjärvi occurs mostly in carbonatite and glimmerite as rounded to irregular or form perfect hexagonal prismatic crystals. Large and highly fractured apatite crystals (1-2 mm) have been found within calcite or associated with phlogopite (Fig. 4). The apatite-(CaF) containing the maximum F content allowable in the structure (2.3-3.5 wt. % F); compositions are typical of carbonatites, with strontium average content of 0.8 wt% SrO. The content of SiO<sub>2</sub>, TiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub> and MgO in apatite is very low (<0.1 wt% SiO<sub>2</sub>) or below the detection limit (Table 4).



**Figure 4.** Coarse apatite grains disseminated within phlogopite backgrounds

**Table 4.** Representative composition of apatite from carbonatite - glimmerite rocks at Siilinjärvi Complex (wt %).

Sample	1215414			1215415			1215416		
SiO <sub>2</sub>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TiO <sub>2</sub>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Al <sub>2</sub> O <sub>3</sub>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MgO	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0
CaO	<b>54.5</b>	<b>54.5</b>	<b>54.5</b>	<b>54.4</b>	<b>54.3</b>	<b>54.8</b>	<b>53.1</b>	<b>53.7</b>	<b>54.0</b>
Na <sub>2</sub> O	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.1	0.1
K <sub>2</sub> O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SrO	<b>0.8</b>	<b>0.7</b>	<b>0.9</b>	<b>0.8</b>	<b>0.8</b>	<b>0.8</b>	<b>0.8</b>	<b>0.8</b>	<b>0.8</b>
BaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NiO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZnO	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1
Nb <sub>2</sub> O <sub>3</sub>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SO <sub>3</sub>	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
P <sub>2</sub> O <sub>5</sub>	<b>42.8</b>	<b>42.9</b>	<b>42.7</b>	<b>41.9</b>	<b>42.4</b>	<b>42.6</b>	<b>41.9</b>	<b>42.5</b>	<b>42.7</b>
F	<b>2.3</b>	<b>2.6</b>	<b>3.3</b>	<b>3.1</b>	<b>3.0</b>	<b>2.2</b>	<b>3.4</b>	<b>3.2</b>	<b>3.5</b>
F = O	<b>-1.0</b>	<b>-1.1</b>	<b>-1.4</b>	<b>-1.3</b>	<b>-1.3</b>	<b>-0.9</b>	<b>-1.4</b>	<b>-1.4</b>	<b>-1.5</b>
Cl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cl = O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	99.6	99.8	100.0	99.2	99.2	99.5	98.0	99.1	99.8

### Phlogopite

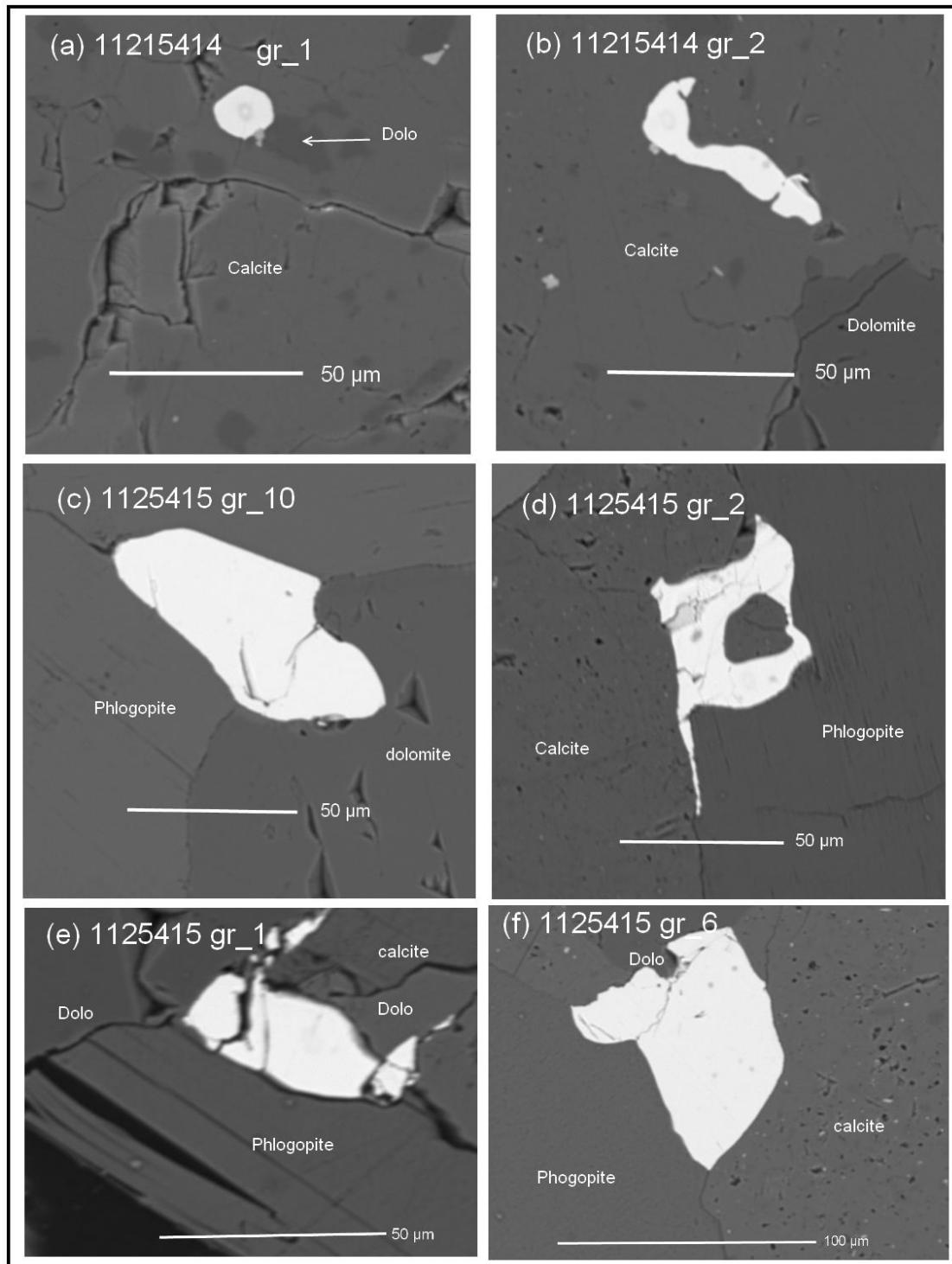
The groundmass of glimmerite rock samples are composed mainly of phenocrysts apatite, phlogopite, and accessory minerals includes amphibole, biotite, chlorite, dolomite, magnetite and zircon. Phlogopite, occurs as tabular crystals and as lamellar or foliated aggregates or disseminated flakes (Fig. 4 same fig of apatite). Representative electron microprobe analyses of the phlogopite are listed in Table (5). Phlogopite is characterized Phlogopite from studied samples is relatively rich in iron (~9 wt. % Fe<sub>2</sub>O<sub>3</sub>). Content of Mg is stable within the range of 24.1–24.5 wt % MgO in all studied samples. Phlogopite grains exhibit a very low content of F and Ba. The content of other elements in phlogopite includes TiO<sub>2</sub> =0.12-0.27 wt. %, MnO = 0-0.04 and CaO=0.01-0.05.

**Table 5.** Representative composition of phlogopite from carbonatite - glimmerite rocks at Siilinjärvi Complex (wt %).

Sample	1215415			1215416		
SiO <sub>2</sub>	<b>42.25</b>	<b>42.17</b>	<b>41.83</b>	<b>41.85</b>	<b>41.48</b>	<b>41.96</b>
TiO <sub>2</sub>	0.12	0.10	0.13	0.16	0.27	0.18
Al <sub>2</sub> O <sub>3</sub>	<b>9.42</b>	<b>9.52</b>	<b>9.43</b>	<b>9.23</b>	<b>9.06</b>	<b>9.22</b>
Cr <sub>2</sub> O <sub>3</sub>	0.00	0.01	0.00	0.01	0.05	0.00
V <sub>2</sub> O <sub>3</sub>	0.00	0.00	0.03	0.00	0.00	0.01
FeO	<b>8.62</b>	<b>8.63</b>	<b>8.55</b>	<b>9.06</b>	<b>9.06</b>	<b>8.91</b>
MnO	0.03	0.04	0.00	0.03	0.00	0.00
MgO	<b>24.09</b>	<b>24.36</b>	<b>24.07</b>	<b>24.52</b>	<b>23.77</b>	<b>24.22</b>
CaO	0.03	0.01	0.02	0.05	0.01	0.04
Na <sub>2</sub> O	0.00	0.00	0.00	0.00	0.00	0.00
K <sub>2</sub> O	<b>10.03</b>	<b>10.20</b>	<b>9.87</b>	<b>9.91</b>	<b>10.13</b>	<b>10.00</b>
SrO	0.00	0.00	0.00	0.00	0.00	0.00
BaO	0.00	0.00	0.00	0.00	0.00	0.00
NiO	0.00	0.00	0.00	0.00	0.00	0.00
ZnO	0.22	0.13	0.20	0.08	0.19	0.05
Nb <sub>2</sub> O <sub>3</sub>	0.00	0.00	0.00	0.00	0.00	0.00
SO <sub>3</sub>	0.00	0.00	0.00	0.00	0.04	0.04
P <sub>2</sub> O <sub>5</sub>	0.06	0.02	0.00	0.00	0.00	0.00
F	0.00	0.00	0.00	0.00	0.00	0.00
Total	94.88	95.20	94.14	94.92	94.07	94.65

### Monazite

Monazite occurs as irregular grains and nodules (diameter = 10 x 10 - 12 x 50 µm) inclusions in calcite and apatite or in contact of calcite and dolomite. It's found also as filling the fractures in phlogopite and apatite (Fig. 5). Based on the EMPA data (Table 6), the studied monazite is strongly enriched in light REE (>67 wt %) as Ce (~38.8%), La (~20.4%), Nd (~7.5%) and Sm (~0.35%).



**Figure 5.** Monazite (diameter = 10 x 10 - 12 x 50 µm) occurs as inclusions in calcite and apatite or in contact of calcite, phlogopite and dolomite.

**Table 6.** Representative composition of monazite (Ce) from carbonatite - glimmerite rocks at Siilinjärvi Complex (wt %).

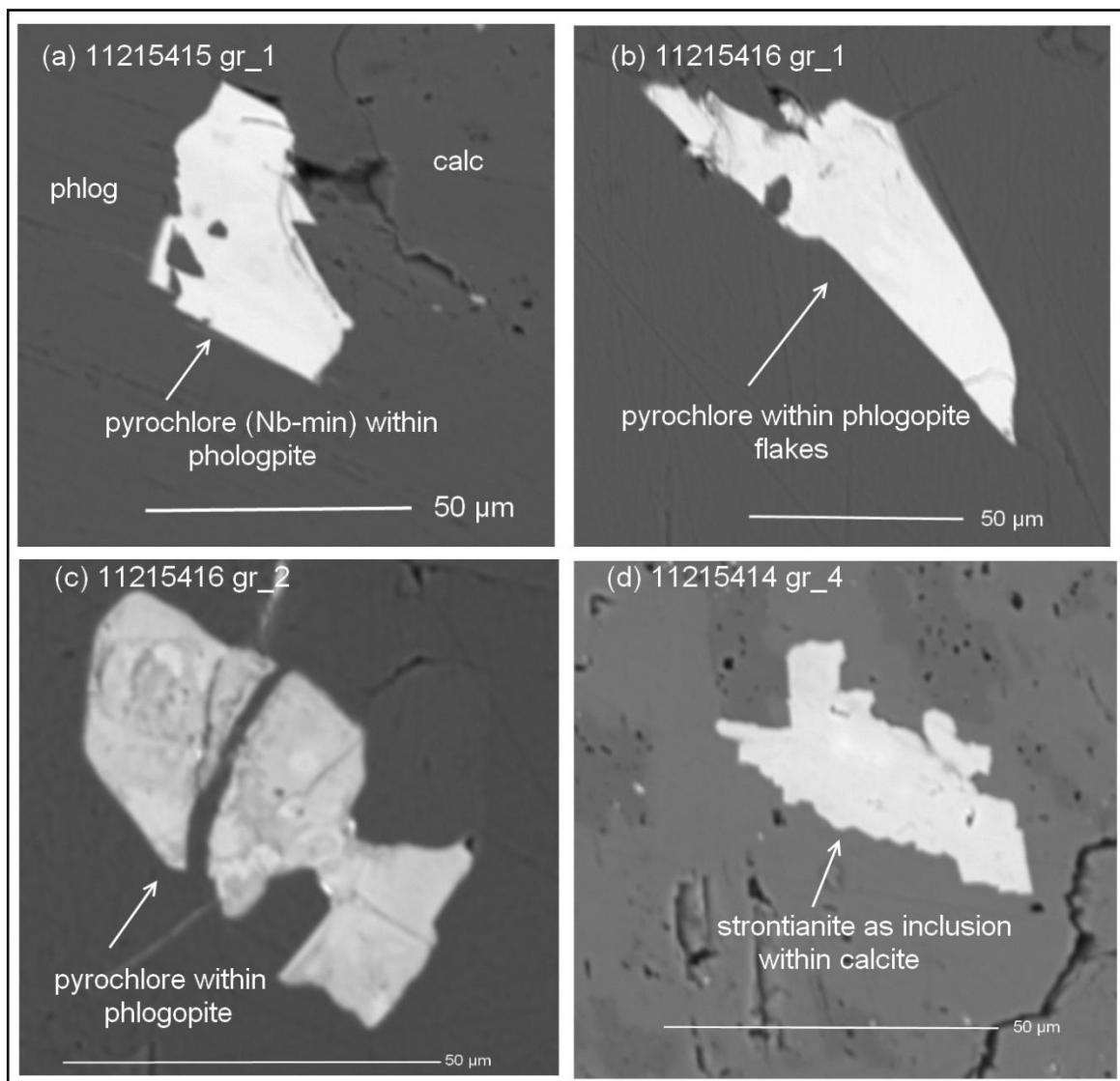
Sample	1215415					1215415			
SiO <sub>2</sub>	0.07	0.18	0.05	0.08	0.41	0.05	0.22	0.24	0.15
TiO <sub>2</sub>	0.01	0.02	0.09	0.00	0.00	0.03	0.01	0.00	0.00
Al <sub>2</sub> O <sub>3</sub>	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.06
FeO	0.02	0.05	0.04	0.07	0.03	0.22	0.13	0.17	0.00
MnO	0.03	0.01	0.09	0.07	0.02	0.01	0.06	0.01	0.06
MgO	0.02	0.02	0.00	0.00	0.00	0.00	0.02	0.00	0.00
CaO	<b>1.35</b>	<b>1.31</b>	<b>1.35</b>	<b>1.26</b>	<b>1.13</b>	<b>0.03</b>	<b>0.04</b>	<b>0.03</b>	<b>0.05</b>
K <sub>2</sub> O	0.00	0.00	0.00	0.00	0.01	0.04	0.02	0.04	0.00
SrO	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.02
BaO	0.05	0.00	0.00	0.00	0.00	0.05	0.05	0.08	0.00
Cs <sub>2</sub> O	<b>0.47</b>	<b>0.51</b>	<b>0.59</b>	<b>0.64</b>	<b>0.48</b>	<b>0.48</b>	<b>0.55</b>	<b>0.51</b>	<b>0.53</b>
P <sub>2</sub> O <sub>5</sub>	<b>29.71</b>	<b>29.45</b>	<b>29.6</b>	<b>29.51</b>	<b>28.70</b>	<b>29.37</b>	<b>29.16</b>	<b>29.53</b>	<b>29.52</b>
UO <sub>2</sub>	0.00	0.01	0.00	0.00	0.05	0.00	0.09	0.26	0.12
ThO <sub>2</sub>	0.00	0.04	0.02	0.00	2.15	0.04	0.00	0.00	0.11
WO <sub>3</sub>	0.15	0.00	0.02	0.28	0.00	0.22	0.00	0.54	0.08
Y <sub>2</sub> O <sub>3</sub>	0.10	0.00	0.00	0.00	0.06	0.06	0.09	0.07	0.00
Ce <sub>2</sub> O <sub>3</sub>	<b>38.82</b>	<b>38.42</b>	<b>38.3</b>	<b>38.92</b>	<b>35.90</b>	<b>40.20</b>	<b>39.92</b>	<b>39.66</b>	<b>39.34</b>
Nd <sub>2</sub> O <sub>3</sub>	<b>6.64</b>	<b>6.56</b>	<b>6.31</b>	<b>7.30</b>	<b>6.04</b>	<b>8.87</b>	<b>9.12</b>	<b>8.89</b>	<b>8.22</b>
La <sub>2</sub> O <sub>3</sub>	<b>21.81</b>	<b>21.37</b>	<b>22.4</b>	<b>21.39</b>	<b>22.84</b>	<b>18.08</b>	<b>18.01</b>	<b>17.85</b>	<b>19.76</b>
SmO	0.16	0.19	0.30	0.21	0.05	0.48	0.66	0.53	0.49
Gd <sub>2</sub> O <sub>3</sub>	0.00	0.00	0.00	0.00	0.13	0.10	0.20	0.21	0.11
Dy <sub>2</sub> O <sub>3</sub>	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.05
F	0.64	0.68	0.64	0.70	0.48	0.65	0.64	0.69	0.72
Cl	0.02	0.05	0.01	0.00	0.01	0.02	0.04	0.01	0.01
Total	99.86	98.79	99.6	100.25	98.57	98.87	98.76	99.15	99.13

### Niobium-bearing minerals

Members of the pyrochlore mineral group are the most important Nb mineral, and their concentrates are produced mainly in carbonatites. The chemical composition of the group is widely variable, with a general formula X<sub>2</sub>Y<sub>2</sub>O<sub>6</sub> (O, OH, F), where X=Ca, Na, Ba, Sr, Pb, U, Th, Mn, REE, Fe, Sn, Bi, Sb; Y= Nb. Pyrochlore mineral is fine-grained (less than 1 mm in size) and euhedral -subhedral, forming neat octahedrons. The crystals are generally unzoned but commonly altered. The alteration patterns are complex, producing several generations of replacements. Niobium-bearing minerals have been found in two studied samples (11215415 and 11215416) from Siilinjärvi carbonatitic glimmerite rocks as several minerals includes pyrochlore, barytolamprophyllite Ba<sub>2</sub>Na<sub>3</sub>(Fe,Ti)3(Si<sub>2</sub>O<sub>7</sub>)<sub>2</sub>(O,OH,F)<sub>4</sub> and nioboaeschynite-(Ce), Ce(NbTi)O(6). Pyrochlore minerals are euhedral, forming sharp octahedrons and usually fine grain size has 50-200 µm in diameter (Fig. 6a, b). These minerals occur scattered among the carbonatite and glimmerite rocks, but in all the cases associated with phlogopite and dolomite (Fig. 6c).



The chemical composition of the pyrochlore from Siilinjärvi carbonatitic glimmerite rocks is enriched in Nb (77% Nb<sub>2</sub>O<sub>5</sub>) and Ca (15% CaO) and low content of Ti (2% TiO<sub>2</sub>), Ta (1.1% Ta<sub>2</sub>O<sub>5</sub>), F (0.1% F) and RE<sub>2</sub>O<sub>3</sub> (<3%) see Table (7). Pyrochlore was produced several minerals during the late stage of replacement and weathering processes such as nioboaeschynite-(Ce) and barytolamprophyllite. Pyrochlore crystals becomes restitic during the replacement processes lead to the depletion of Nb (47% Nb<sub>2</sub>O<sub>5</sub>), Ca (5.5% CaO) and enrichment of Ti (13% TiO<sub>2</sub>) and RE<sub>2</sub>O<sub>3</sub> (25%) to form nioboaeschynite-(Ce) (Table 7). On the other hand, some late generations of pyrochlore during the weathering processes are enriched in Ba (8% BaO), Sr (5% SrO), U (3% UO<sub>2</sub>), F (1% F) and Ta (17% Ta<sub>2</sub>O<sub>5</sub>) to form barytolamprophyllite (Table 7).



**Figure 6.** Nb-mineral grains (max.40 x 100  $\mu\text{m}$ ) occurred between phlogopite flakes.

**Table 7.** Representative composition of Niobium-bearing minerals from carbonatite - glimmerite rocks at Siilinjärvi Complex (wt %).

Sample	1215415						1215416			
	Mineral	Pyrochlore		Nioboaeschynite-(Ce)			barytolamprophyllite			
SiO <sub>2</sub>		0.00	0.00	0.00	0.00	0.00	n.d.	n.d.	n.d.	n.d.
TiO <sub>2</sub>	<b>1.63</b>	<b>1.99</b>	<b>13.22</b>	<b>12.80</b>	<b>12.69</b>	<b>12.76</b>	<b>3.86</b>	<b>3.78</b>	<b>3.88</b>	<b>4.18</b>
Al <sub>2</sub> O <sub>3</sub>	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.03	0.01
FeO	0.13	0.12	0.94	1.37	0.98	1.09	<b>3.72</b>	<b>8.08</b>	<b>3.65</b>	<b>3.87</b>
MnO	0.00	0.06	0.10	0.05	0.07	0.07	0.00	0.00	0.06	0.03
MgO	0.00	0.03	0.11	0.00	0.01	0.00	0.22	0.17	0.09	0.19
CaO	<b>15.09</b>	<b>15.02</b>	<b>5.91</b>	<b>5.13</b>	<b>5.68</b>	<b>5.55</b>	<b>5.82</b>	<b>5.78</b>	<b>5.68</b>	<b>6.33</b>
Na <sub>2</sub> O	0.12	0.08	0.00	0.00	0.00	0.00	0.61	0.46	0.68	0.49
K <sub>2</sub> O	0.00	0.00	0.02	0.01	0.00	0.01	0.61	0.53	0.66	0.51
SrO	0.01	0.06	0.07	0.10	0.04	0.03	<b>5.17</b>	<b>4.17</b>	<b>4.92</b>	<b>4.58</b>
BaO	0.00	0.00	0.00	0.00	0.03	0.00	<b>7.53</b>	<b>9.19</b>	<b>6.83</b>	<b>7.05</b>
Cs <sub>2</sub> O	0.04	0.03	0.18	0.19	0.19	0.18	0.09	0.00	0.00	0.03
P <sub>2</sub> O <sub>5</sub>	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.17	0.08	0.11
UO <sub>2</sub>	0.00	0.00	0.00	0.00	0.00	0.00	<b>3.17</b>	<b>2.22</b>	<b>3.00</b>	<b>2.71</b>
ThO <sub>2</sub>	0.00	0.01	0.00	0.00	0.00	0.00	0.18	0.11	0.14	0.21
Nb <sub>2</sub> O <sub>5</sub>	<b>77.14</b>	<b>76.33</b>	<b>47.19</b>	<b>46.45</b>	<b>47.74</b>	<b>48.24</b>	<b>31.85</b>	<b>26.85</b>	<b>30.02</b>	<b>29.23</b>
Ta <sub>2</sub> O <sub>5</sub>	<b>1.09</b>	<b>1.17</b>	<b>1.68</b>	<b>2.17</b>	<b>1.84</b>	<b>2.13</b>	<b>18.42</b>	<b>15.57</b>	<b>18.34</b>	<b>18.91</b>
Y <sub>2</sub> O <sub>3</sub>	0.11	0.19	0.10	0.19	0.11	0.13	0.00	0.00	0.00	0.00
Ce <sub>2</sub> O <sub>3</sub>	<b>1.44</b>	<b>1.45</b>	<b>11.90</b>	<b>12.00</b>	<b>11.91</b>	<b>11.76</b>	0.47	0.50	0.70	0.60
Nd <sub>2</sub> O <sub>3</sub>	<b>1.66</b>	<b>1.76</b>	<b>9.66</b>	<b>10.17</b>	<b>9.32</b>	<b>9.73</b>	0.00	0.00	0.00	0.00
La <sub>2</sub> O <sub>3</sub>	0.09	0.10	<b>1.27</b>	<b>1.39</b>	<b>1.53</b>	<b>1.39</b>	0.08	0.01	0.06	0.01
SmO	0.15	0.40	<b>1.51</b>	<b>1.48</b>	<b>1.54</b>	<b>1.43</b>	0.00	0.00	0.00	0.09
Gd <sub>2</sub> O <sub>3</sub>	0.30	0.53	<b>0.66</b>	<b>0.89</b>	<b>0.67</b>	<b>0.66</b>	0.00	0.02	0.00	0.14
Dy <sub>2</sub> O <sub>3</sub>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F	0.19	0.09	0.31	0.10	0.18	0.23	0.84	0.80	1.03	0.83
Total	99.41	99.35	94.97	94.59	95.15	95.56	82.46	83.54	79.55	79.93

## 5 REFERENCES

- Flvs, G. H. and D. D. Hochr H.** 1969. On the origin of "reverse" pleochroism of a phlogopite. Can. Mineral. 10, 25-34.
- Kauko Puustinen, 1971.** Geology of the Siilinjärvi carbonatite complex, Eastern Finland, Bulletin de la Commission Géologique de Finlanne N: 249, 43p.
- Lukkarinen, Heikki 2008.** Siilinjärven ja Kuopion kartta-alueiden kallioperä. Summary: Pre-Quaternary rocks of the Siilinjärvi and Kuopio map-sheet areas. Kallioperäkartan selitys 1: 100 000, 3331, 3242. 228 p., 2 appended maps (Elektroninen julkaisu) ISBN 978-952-217-034-7
- Pouchou, J.L. & Pichoir, F. 1986.** Basic expression of "PAP" computation for quantitative EPMA. In: Brown, J.D. & Packwood, R.H. (eds.) 11 th international Congress on X - ray Optics and Microanalysis (ICXOM), 249 - 253.
- Skosyeva, M.V., Bagdasarov, YU. A., Vlasova, E.V. and Zhukhlistov, A.P. 1988.** Typical features of micas from an East European Platform carbonatite deposit (Kursk Magnetic Anomaly region). Geochem. Int. 25(5), 24-34.

