Compositional variation in columbite-group minerals from different types of granitic pegmatites of the Eräjärvi district, South Finland

Variace chemického složení minerálů columbitové skupiny v různých typech granitických pegmatitů oblasti Eräjärvi v jižním Finsku (Czech summary)

(8 text-figs, 4 tabs)

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Compositional variation of columbite-group minerals in different LCT-types of granitic pegmatites of the Eräjärvi district, Orivesi, South Finland, was studied by 611 electron-microprobe analyses of 145 crystals that were collected from 30 beryl-columbite pegmatites, 15 beryl-columbite-phosphate pegmatites and one complex pegmatite of the amblygonite subtype. Fe, Mn, Nb and Ta dominate the composition, but the minerals may include some Ti (< 0.1 *apfu*) and Sn, W, and Sc (< 0.05 *apfu* each) as well. Progressive enrichment of Mn and Ta in columbite-group minerals from the most primitive beryl-columbite pegmatites to the highly fractioned complex pegmatites is a significant overall feature in the pegmatite sequence, although the increase in both Mn/(Mn+Fe) and Ta/(Ta+Nb) in the mineral is not proportional in the different types of the dykes. The average values of Mn/(Mn+Fe) and Ta/(Ta+Nb) in the columbite-group minerals increase markedly from beryl-columbite pegmatites (0.39 and 0.24, respectively) to beryl-columbite-phosphate pegmatites (0.47 and 0.48, respectively), and the values are highest in the Viitaniemi amblygonite pegmatite (0.79 and 0.51, respectively).

In the beryl-columbite pegmatites, the variation in Mn/(Mn+Fe) of columbite-group minerals is extensive, but that of Ta/(Ta+Nb) limited. Ferrocolumbite is most common and manganocolumbite is encountered in the more evolved dykes of this category. In the beryl-columbite-phosphate pegmatites, which also contain triphylite-lithiophilite as a characteristic accessory mineral, Ta/(Ta+Nb) increases much more than Mn/(Mn+Fe) during pegmatite evolution. Ferrocolumbite occurs in the marginal, ferrotantalite and minor manganocolumbite in the central parts of the dykes. Concomitant increase in Mn/(Mn+Fe) and Ta/(Ta+Nb) with pegmatite evolution is characteristic of columbite-group minerals from the complex pegmatites enriched in Li minerals such as elbaite, lepidolite, spodumene and amblygonite-montebrasite. Manganocolumbite and manganotantalite are characteristic of this type of dykes, but their marginal zones may also contain minor ferrocolumbite. The compositional trend of columbite-group minerals from the Viitaniemi pegmatite, a typical complex pegmatite of the amblygonite subtype, extends from the ferrocolumbite field through the manganocolumbite field up toward the manganotantalite corner of the columbite quadrilateral.

Key words: ferrocolumbite, ferrotantalite, manganocolumbite, manganotantalite, chemical composition, granitic pegmatite, granite, Proterozoic, Eräjärvi, Orivesi, Finland

Introduction

A spectrum of various LCT-types of rare-element pegmatites enriched in B, Be, Li, Rb, Cs, Nb, Ta, Sn and P occurs in the Eräjärvi district, Orivesi, South Finland (Lahti 1981, 1989). For this study a number of columbite $(Fe,Mn)(Nb)_2O_6$ – tantalite $(Fe,Mn)(Ta)_2O_6$ and other Nb-Ta mineral samples were collected from the pegmatites and analysed using electron-microprobe methods. Compositional variation in columbite-group minerals between the various types of the pegmatites and between the different parts of individual dykes is discussed.

The mineral samples were collected during petrological mapping in nineteen seventies and eighties, and later during detailed pegmatite studies. Preliminary data on composition and zoning of columbite-group minerals in the pegmatites have been reported in earlier publications by the author (Lahti 1981, 1984, 1986, 1987). For this study all the analytical data on Eräjärvi columbite-group minerals were collected and a number of new Nb-Ta mineral samples were studied.

Small-scale mining has been carried out in the district from the beginning of this century, but the quarries are not operated nowadays. Altogether about 30 dykes, most of them relatively small rare-element pegmatites, have been mined mainly for feldspar, quartz, beryl and columbite-group minerals.

Geology and distribution of the pegmatites

The Eräjärvi district is situated in the eastern part of the Early Proterozoic Tampere schist belt, South Finland (Fig. 1). The rocks were metamorphosed in amphibolite-facies conditions, and intruded by various plutonic rocks during the Svecokarelian orogeny 1.80–1.90 Ga ago. Field observations and radiometric dating indicate that the rare-element pegmatites are Svecofennian late- or postmetamorphic rocks (Lahti 1981).

The pegmatites occur as tabular dykes or lenses usually following the east-west-trending foliation of the metamorphic host rocks. Most of the rare-element pegmatites are associated with granite and pegmatitic granite intrusions located in the southern and western parts of the research area. Broad pegmatite dykes and lenses occur in the granite itself, but especially in the surrounding schists close to the contacts of the granitic stocks.

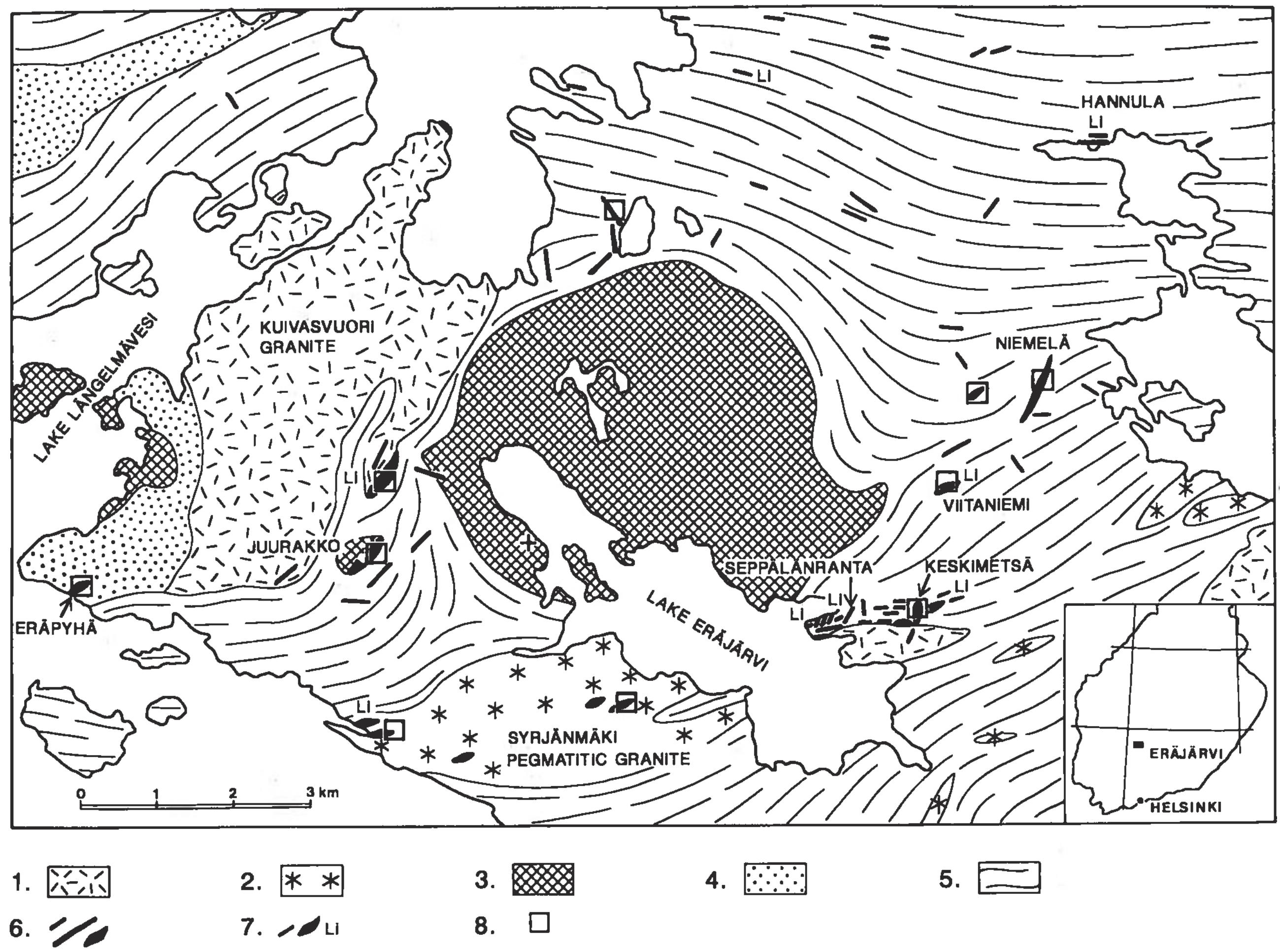

Fig. 1. Geological map of the Eräjärvi district showing distribution of the rare-element pegmatites. Explanations: 1 – granite, 2 – pegmatitic granite, 3 – diorite and gabbro, 4 – tonalite and quartz diorite, 5 – mica schist, minor metavolcanics, 6 – beryl-columbite pegmatites, 7 – beryl-columbite-phosphate pegmatites and complex pegmatites, 8 – quarry. Minor rare-element pegmatites around the Seppälänranta and Keskimetsä dyke swarms could not be marked in the map because of large number of the dykes.

Mineralogy and classification

Beryl, columbite-group minerals and cassiterite are characteristic accessories, in addition to schorl, fluorapatite and garnet, in most of the rare-element pegmatites in the research area, but a number of the dykes contain various Li silicates and Li phosphates as well. A list of the typical accessory minerals discovered in the dykes studied in detail is given in Table 1. Detailed descriptions of the pegmatite minerals are given by Volborth (1954), Lahti (1981, 1986, 1987, 1988), Lahti et al. 1983, Lahti – Saikkonen 1985 and Teertstra et al. (1993).

Columbite-group minerals usually form 0.5 to 5 cm-long platy or columnar prismatic crystals or crystal aggregates. Larger crystals weighing 0.x to a few kilograms are rare. The colour of the mineral is black, but the varieties rich in Ta and Mn may be brown, resembling cassiterite, wodginite and ferrotapiolite, which also occur sporadically in the pegmatites.

The Eräjärvi rare-element pegmatites are distinctly zoned. The dykes are composed of a fine-grained border zone abutting the wall rock, a wall zone (or zones) and an intermediate zone, which is composed of a very coarse-grained pegmatite and occupies the central parts of the dykes (see Lahti 1981). Large lenticular or irregular quartz cores surrounded by blocky crystals of microcline-perthite are characteristic of the cores of the dykes. Beryl, Nb-Ta minerals, Li minerals and other rare minerals are concentrated in the intermediate zone; they are enriched in the albite-rich units between the blocky microcline crystals and in the branching intraformational dykes commonly characterised by platy or saccharoidal albite.

In total about 70 rare-element pegmatites are known in the research area. Following the generally accepted classification by Černý (1990, 1991, 1992), the pegmatites are beryl-columbite, beryl-columbite-phosphate and complex pegmatites enriched in Li minerals. About 50 of the rare-element pegmatites are various beryl-columbite pegmatites, subtypes of the beryl type. Beryl-columbite pegmatites are less evolved and contain beryl and columbite as typical accessories with fluorapatite and garnet. Schorl is also common and is usually the main accessory mineral in the dykes.

Triphylite-lithiophilite is characteristic of the beryl-columbite-phosphate pegmatites in addition to the above-mentioned minerals. The author has discovered a total of 20 triphylite-lithiophilite-bearing pegmatites in the district and seven of them contain, in addition, variable amounts of other Li minerals such as lepidolite, elbaitic tourmaline, spodumene and amblygonite-montebrasite. Most of these pegmatites can be regarded as varieties of beryl-columbite-phosphate pegmatites rather than separate members of the complex pegmatite group, because triphylite-lithiophilite is the predominant Li mineral in them.

Table 1. Characteristic accessory minerals in the Viitaniemi amblygonite pegmatite, in the beryl-columbite-phosphate pegmatites (Hannula, Keskimetsä, Seppälänranta) and in the beryl-columbite pegmatites (Eräpyhä, Juurakko, Niemelä).

Mineral	Viitaniemi	Hannula	Keskimetsä	Seppälänranta	Eräpyhä	Juurakko	Niemelä
Ferrocolumbite	•	•	•	•	•	•	•
Manganocolumbite	•	•	•	•	•	•	•
Ferrotantalite		•	•	•	•		
Manganotantalite	•		•				
Ferrotapiolite	•		•	•			
Microlite-pyrochlore	•			•	•	•	•
Wodginite	•						
Ixiolite			•	•		•	•
Niobian-tantalian rutile					•		
Cassiterite	•	•	•	•	•	•	•
Beryl	•	•	•	•	•	•	•
Bertrandite	•			•	•		•
Schorl	•	•	•	•	•	•	•
Elbaite	•		•	•			
Lepidolite	•			•			
Topaz	•			•		•	
Almandine- spessartine	•		•		•	•	•
Zircon	•	•		•	•	•	•
Apatite	•	•	•	•	•	•	•
Triphylite	•	•	•	•			
Lithiophilite	•		•				
Sicklerite-ferrisicklerite	•	•	•	•			
Heterosite-purpurite	•	•	•	•			
Varulite-alluaudite	•	•	•	•			
Hydrous Fe, Mn-phosphates	•	•	•	•			

Triphylite-lithiophilite occurs in the pegmatites as nodules and crystal accumulations measuring from a few centimetres up to a few decimetres. The mineral is often replaced by alluaudite-varulite, ferrisicklerite-sicklerite and heterosite-purpurite. In addition, numerous hydrous Fe-Mn phosphates occur as alteration products of triphylite-lithiophilite. Preliminary chemical analyses indicate that triphylite is characteristic of the poorly-fractionated beryl-columbite-phosphate pegmatites and the Mn-end member lithiophilite is found in the more-fractionated pegmatites with amblygonite and various Li silicates.

In addition to triphylite-lithiophilite, green or red elbaitic tourmaline and lepidolite indicate increased Li concentrations in the pegmatites. Both of them were discovered in seven beryl-columbite-phosphate pegmatites. Spodumene occurs in five dykes, but it is exceptionally enriched in only a single dyke. Three phosphate-rich Li pegmatites contain, in addition to triphylite-lithiophilite and fluorapatite, variable amounts of amblygonite-montebrasite. The mineral forms large crystals in the Seppälänranta dyke east of Lake Eräjärvi, but it is exceptionally enriched in the Viitaniemi pegmatite one kilometre north of the above-mentioned dyke. The Viitaniemi pegmatite has all the typical features of the complex pegmatites, and it is classified as a member of the amblygonite subtype.

Chemical data

The chemical composition of columbite-group minerals was determined in samples from 46 rare-element pegmatite dykes. This study is based on 611 chemical analyses of 145 crystals (Table 2). In addition, the composition of the other Nb-Ta minerals such as ferrotapiolite, manganotapiolite, wodginite, ixiolite, microlite, niobian and tantalian rutile, were determined from a few selected pegmatites studied in detail. The data used for this study come from 30 beryl-columbite pegmatites, 15 beryl-columbite-phosphate-pegmatites including amblygonite-, spodumene- and lepidolite-bearing varieties, and from the Viitaniemi amblygonite pegmatite (Tables 2 and 3).

Table 2. Sampling and analytical statistics.

Pegmatite type	Number of dykes	Number of crystals	Number of analyses
Beryl-columbite pegmatites, narrow dykes (width <5m)	16	18	113
Beryl-columbite pegmatites, broad dykes (width>5m)	14	70	223
Beryl-columbite-phosphate pegmatites, narrow dykes (width <5m)	6	26	85
Beryl-columbite-phosphate pegmatites, broad dykes (width>5m)	9	17	123
Amblygonite pegmatite (Viitaniemi)	1	14	67
Total	49	145	611

Polished thin sections were made from the samples of columbite-group minerals and studied first in reflected light. X-ray powder-diffraction methods were used in mineral identification. The analytical points were marked on the photographs taken from the surface of the sections. The main elements Fe, Mn, Ta and Nb as well as the minor elements Ti, W, Sn, Sc, Mg and Ca were analysed at the Geological Survey of Finland. Backscattered electron images and X-ray composition images were taken first to record zoning and heterogeneity of most specimens before the quantitative analysis.

About one half of the analyses – the oldest determinations – were done with a Jeol Superprobe 733 electron microprobe using an accelerating potential of about 15 kV, specimen current 100 nA and beam diameter 1–15 μm. The standards were: manganocolumbite (for Mn, Fe, Nb, Ta and W), ilmenite (Ti), cassiterite (Sn), antimony (Sb) and wollastonite (Ca). The second half of the chemical analyses performed more recently were done with a Cameca SX 50 electron microprobe using metal standards. Normally three points of each crystal were analysed and 3–7 additional points from the inhomogeneous crystals.

Results of the chemical analyses are presented as values of atomic ratios of the main elements in the columbite quadrilateral. The composition of columbite-group minerals from the narrow (width 0.5–5.0 m) and broad (width > 5 m) beryl-columbite pegmatites, beryl-columbite-phosphate pegmatites and from the Viitaniemi amblygonite pegmatite are shown separately in Figs 2, 4 and 6.

Detailed studies were carried out in three selected beryl-columbite pegmatites, (Eräpyhä, Niemelä and Juurakko), in three beryl-columbite-phosphate pegmatites (Seppälänranta, Keskimetsä and Hannula) and in the Viitaniemi complex pegmatite. The composition of 10–20 crystals from different parts of each dyke was analysed. The compositions and the fractionation trends of columbite-group minerals for these seven pegmatites are presented in Figs 3, 5, 6 and 8. Representative analytical data of the columbite-group minerals from the pegmatites studied in detail are given in Table 3.

Most of the crystals of the columbite-group minerals display only minute compositional zoning characterized by substitution of Nb by Ta and Fe by Mn. The new chemical data confirm the earlier observations by the author (Lahti 1987). Larger compositional variations, oscillatory zoning or more complex zoning textures occur locally in crystals from narrow beryl-columbite and beryl-columbite-phosphate pegmatites. The chemical data of the zoned crystals seem to plot within the general composition trend of the mineral in the parent pegmatite dykes.

Columbite-group minerals in the beryl-columbite pegmatites

The beryl-columbite pegmatites are mineralogically and geochemically the most primitive rare-element pegmatites in the district. Columbite-group minerals from the beryl-columbite pegmatites are characterised by Fe>Mn and Nb>Ta. The compositions are concentrated in the ferrocolumbite and manganocolumbite quadrants of the columbite quadrilateral (Fig. 2).

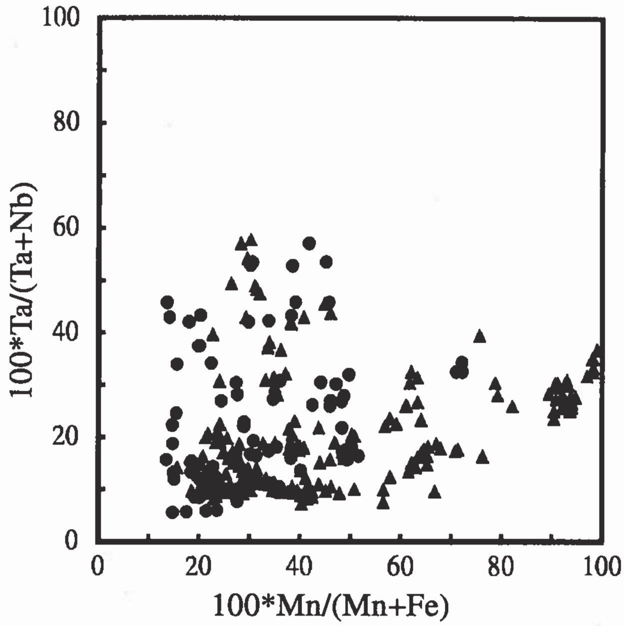

Fig. 2. Compositional variation of columbite-group minerals (at. ratios) in beryl-columbite pegmatites. Spots – samples from thinner dykes, triangles – samples from broader dykes.

The average of Ta/(Ta+Nb) is very low, only 0.23, and it is almost the same in the narrow and broad dykes (Table 4). Almost all of the compositions analysed from the narrow dykes plot in the ferrocolumbite field, but the data from the broad dykes are distributed in both ferrocolumbite and manganocolumbite fields. The average Mn/(Mn+Fe) is only 0.31 in the narrow dykes, but much higher, 0.47, in the broad dykes (Table 4).

Columbite-group minerals in selected individual dykes

Compositional variation of columbite-group minerals in three selected beryl-columbite pegmatite dykes (Niemelä, Juurakko and Eräpyhä) was studied in detail. The Juurakko and Eräpyhä pegmatites are located close to the contact of the Kuivasvuori granite intrusion in the western part of the research area. Both occurrences seem to be lens-like bodies, although their exact dimensions and shape are unknown. The Niemelä pegmatite dyke is several hundred metres long, located in mica schists far away from granites in the eastern part of the district (Fig. 1).

Although the pegmatites are mineralogically quite similar, the internal structures in the Juurakko and Niemelä dykes are much more complex than in the Eräpyhä pegmatite. All the dykes are relatively broad (maximum width >10 m) and well-zoned. Large, lenticular or round quartz cores surrounded by blocky crystals of microcline-perthite are characteristic of the central parts of the dykes.

In the Juurakko and Niemelä dykes, irregular units of albite-rich pegmatite occur between the microcline crystals close to the quartz cores. Different kinds of intraformational dykes composed of variable amounts of microcline, albite, quartz and muscovite are characteristic of

Table 3. Representative analytical data (wt. %; the cations on the basis of 6 oxygen/formula unit) from the columbite-group minerals of the Eräjärvi district. Samples 1–12 from beryl-columbite pegmatites (1, 6, 7, 8 from Eräpyhä; 2, 5, 9, 11, 12 from Juurakko; 3, 4, 10 from Niemelä), samples 13–24 from beryl-columbite-phosphate pegmatites (13, 14, 16, 23 from Hannula; 17, 18, 22 from Keskimetsä; 15, 19, 20, 21, 24 from Seppälänranta), samples 25–36 from the Viitaniemi amblygonite pegmatite. Electron microprobe analyses done at the Geological Survey of Finland.

	1	2	3	4	5	6	7	8	9	10	11	12
WO_3	1.09	0.91	0.66	0.58	0.94	0.70	1.06	0.99	0.99	0.64	0.92	0.42
Ta_2O_5	8.79	10.17	10.96	11.93	11.74	12.20	16.95	21.87	21.87	26.32	36.30	41.06
Nb_2O_5	67.24	67.35	67.65	66.61	65.47	65.80	61.73	57.06	57.06	51.33	40.81	37.59
TiO_2	0.72	0.65	0.45	0.42	0.86	0.80	0.46	1.25	1.25	0.25	1.49	2.19
SnO_2	0.05	0.10	0.07	0.04	0.04	0.20	0.03	0.17	0.17	0.11	0.39	0.45
Sc_2O_3	0.19	0.23	0.16	0.11	0.43	–	0.21	0.17	0.17	0.53	0.28	0.53
FeO	12.36	11.52	12.38	11.10	13.05	15.90	7.43	13.89	13.89	7.99	0.36	13.52
MnO	8.25	8.03	8.24	9.03	7.18	5.00	12.51	5.34	5.34	10.82	17.60	3.91
Total	98.71	98.96	100.63	99.82	99.79	100.60	100.38	100.86	100.86	98.02	98.23	99.83
W	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.02	0.01
Ta	0.14	0.16	0.17	0.19	0.19	0.19	0.28	0.36	0.36	0.46	0.66	0.75
Nb	1.80	1.80	1.79	1.78	1.75	1.75	1.68	1.57	1.57	1.49	1.23	1.13
Ti	0.03	0.03	0.02	0.02	0.04	0.04	0.02	0.06	0.06	0.01	0.07	0.11
Sn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
Sc	0.01	0.01	0.01	0.01	0.02	0.00	0.01	0.01	0.01	0.03	0.02	0.03
Fe^{2+}	0.61	0.57	0.60	0.55	0.64	0.78	0.37	0.71	0.71	0.43	0.02	0.75
Mn	0.41	0.40	0.41	0.45	0.36	0.25	0.64	0.28	0.28	0.59	1.00	0.22
100*Mn/(Mn+Fe)	40.34	41.38	40.27	45.17	35.78	24.16	63.04	28.03	28.03	57.83	98.02	22.65
100*Ta/(Ta+Nb)	7.29	8.33	8.88	9.73	9.74	10.03	14.18	18.74	18.74	23.57	34.86	39.65

	13	14	15	16	17	18	19	20	21	22	23	24
WO_3	0.95	0.12	1.12	0.18	0.20	0.10	0.11	0.06	0.26	0.30	0.30	–
Ta_2O_5	10.81	15.73	18.51	23.26	30.10	32.00	31.40	45.01	51.79	51.30	58.10	63.10
Nb_2O_5	66.11	62.80	57.91	56.52	51.90	51.00	48.35	35.97	30.07	28.70	22.40	20.90
TiO_2	0.37	0.55	1.65	0.62	0.80	0.70	0.64	0.18	0.42	0.30	0.40	0.40
SnO_2	0.01	0.15	0.15	0.01	0.60	0.40	0.11	0.16	0.26	0.10	0.10	0.10
Sc_2O_3	0.29	0.29	0.35	0.29	–	–	0.29	0.23	0.37	–	–	–
FeO	11.78	8.90	14.86	8.74	9.20	8.90	8.49	12.21	11.02	10.90	8.50	11.60
MnO	8.46	10.62	4.88	10.28	7.90	8.20	10.02	5.86	6.12	8.20	10.60	4.80
Total	98.78	99.17	99.59	99.90	100.70	101.30	99.41	99.72	100.33	99.80	100.40	100.90
W	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00
Ta	0.18	0.26	0.31	0.39	0.52	0.55	0.55	0.84	0.99	0.99	1.16	1.27
Nb	1.78	1.71	1.59	1.58	1.48	1.45	1.41	1.12	0.96	0.93	0.74	0.70
Ti	0.02	0.02	0.08	0.03	0.04	0.03	0.03	0.01	0.02	0.02	0.02	0.02
Sn	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.00	0.01	0.00	0.00	0.00
Sc	0.02	0.02	0.02	0.02	0.00	0.00	0.02	0.01	0.02	0.00	0.00	0.00
Fe^{2+}	0.59	0.45	0.75	0.45	0.48	0.47	0.46	0.70	0.65	0.65	0.52	0.72
Mn	0.43	0.54	0.25	0.54	0.42	0.44	0.55	0.34	0.37	0.50	0.66	0.30
100*Mn/(Mn+Fe)	42.11	54.72	24.96	54.36	46.52	48.27	54.45	32.71	36.00	43.24	55.81	29.53
100*Ta/(Ta+Nb)	8.95	13.09	16.13	19.84	25.86	27.40	28.09	42.95	50.88	51.81	60.94	64.49

	25	26	27	28	29	30	31	32	33	34	35	36
WO_3	0.66	0.50	0.51	0.00	0.29	0.03	0.35	0.03	0.29	0.10	–	–
Ta_2O_5	19.76	21.30	21.99	31.56	41.72	47.83	47.88	59.30	61.29	64.98	69.80	69.80
Nb_2O_5	59.23	56.90	56.55	49.00	38.15	33.94	31.50	23.18	19.30	16.85	16.40	14.70
TiO_2	0.46	0.50	0.39	0.23	0.25	0.26	0.52	0.28	0.72	0.08	0.20	0.20
SnO_2	0.10	0.20	0.09	0.06	0.06	0.14	0.32	0.17	0.23	0.21	0.40	0.50
Sc_2O_3	0.16	–	0.17	0.21	0.24	0.32	0.27	0.32	0.40	0.32	–	–
FeO	9.58	10.00	3.95	5.66	3.00	2.99	2.11	1.47	1.62	0.79	0.80	1.00
MnO	10.64	9.10	16.51	13.36	15.72	15.43	16.24	15.61	14.68	16.11	13.10	13.00
Total	100.60	98.60	100.19	100.17	99.43	100.95	99.21	100.43	98.82	99.44	100.70	99.50
W	0.01	0.01	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.00
Ta	0.33	0.36	0.37	0.55	0.77	0.89	0.92	1.18	1.26	1.35	1.45	1.48
Nb	1.62	1.61	1.57	1.42	1.17	1.05	1.00	0.77	0.66	0.58	0.57	0.52
Ti	0.02	0.02	0.02	0.01	0.01	0.01	0.03	0.02	0.04	0.00	0.01	0.01
Sn	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.02
Sc	0.01	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.02	0.00	0.00
Fe^{2+}	0.49	0.52	0.20	0.30	0.17	0.17	0.12	0.09	0.10	0.05	0.05	0.07
Mn	0.55	0.48	0.86	0.72	0.91	0.90	0.97	0.97	0.94	1.05	0.85	0.86
100*Mn/(Mn+Fe)	52.94	47.96	80.89	70.51	84.14	83.94	88.63	91.49	90.17	95.38	94.31	92.94
100*Ta/(Ta+Nb)	16.71	18.38	18.96	27.92	39.68	45.88	47.76	60.61	65.64	69.88	71.91	74.07

Table 4. Variation in average Mn/(Mn+Fe) and Ta/(Ta+Nb) (at.), and the limits of average Mn/(Mn+Fe) and Ta/(Ta+Nb) in the columbite-tantalite.

Pegmatite type	Range of Mn/(Mn+Fe)	Average of Mn/(Mn+Fe)	Range of Ta/(Ta+Nb)	Average of Ta/(Ta+Nb)
Beryl-columbite pegmatites, narrow dykes (width <5m)	0.13–0.72	0.31	0.07–0.66	0.24
Beryl-columbite pegmatites, broad dykes (width >5m)	0.16–0.99	0.47	0.07–0.60	0.21
Beryl-columbite Pegmatites (all)		0.39		0.23
Beryl-columbite-phosphate pegmatites, narrow dykes (width <5m)	0.22–0.92	0.47	0.09–0.96	0.48
Beryl-columbite-phosphate pegmatites, broad dykes (width >5m)	0.13–0.94	0.37	0.13–0.82	0.50
Beryl-columbite-phosphate pegmatites (all)		0.42		0.49
Amblygonite pegmatite (Viitaniemi)	0.17–0.96	0.79	0.12–0.96	0.51

the central parts of the dykes, but they may also cut the wall and border zones of the dykes. The blocky feldspar crystals in the intermediate zone of the pegmatites are often cut by narrow dykes and cross-cutting veinlets composed mainly of saccharoidal and platy albite.

Small crystals of ferrocolumbite and beryl were observed in the wall zones and sporadically in the border zones of the dykes. Beryl, manganocolumbite, cassiterite, fluorapatite and zircon are common in the intermediate zone, but they are concentrated in the albite units and albite-rich dykes crystallized after the consolidation of the bulk of the pegmatite dyke. Columbite-group minerals are the predominant Nb-Ta minerals in the pegmatites, but a few crystals of ixiolite also were encountered in the Niemelä pegmatite. The sample studied in detail is partly surrounded and replaced by microlite-pyrochlore.

The intraformational dykes observed in the Niemelä and Juurakko pegmatites crystallized at various stages of the consolidation of the main dyke. In the Juurakko pegmatite topaz (or mica pseudomorphs after topaz), beryl, cassiterite and manganocolumbite are characteristic of the albite-rich dykes that cut the intermediate zone, but the minerals also occur in the albite-dominated parts of the intermediate zone. Inclusions of niobian and tantalian rutile, uranian pyrochlore-microlite, monazite and hafnian zircon were observed in the Juurakko manganocolumbite. Locally, crystallization continued in the pegmatites down to very low temperatures as indicated by diverse mica pseudomorphs, hydrothermal löllingite+sphalerite+pyrite fracture fillings, and crystalbearing cavities that are common especially in the Juurakko pegmatite (Lahti 1988, 1989).

In the Eräpyhä pegmatite the intraformational dykes, irregular bodies and branching veins of platy albite are virtually absent. Only a few narrow veinlets composed of saccharoidal albite with accessory cassiterite, zircon, uranothorite and almandine-spessartine were observed. The marginal parts of the dyke, the border and wall zones are exceptionally enriched in iron-rich minerals such as biotite, schorl and minor garnet.

Thin platy crystals of ferrocolumbite were discovered in the wall zone of the pegmatite, but larger crystals or crystal accumulations are characteristic of the intermediate zone with beryl, fluorapatite, cassiterite and uranian pyrochlore. Microscopic studies indicate that pyrochlore-microlite may replace marginal parts of the columbite crystals, and small inclusions of columbite-group minerals with high Ta also occur as inclusions in pyrochlore samples.

Increase in Mn from the contact to the inner parts of the dykes is characteristic of columbite-group minerals. The compositional fields of columbite in the three pegmatites differ from each other, but all the analytical points are located in the ferro- and manganocolumbite quadrants (Figs 3 and 8). The range of Mn/(Mn+Fe) is extensive in the samples of the columbite-group minerals from the Niemelä and Juurakko pegmatites, but limited in the poorly fractionated Eräpyhä dyke. In contrast, variation in Ta/(Ta+Nb) is limited in all three pegmatites.

The compositional trend of columbite in the Eräpyhä pegmatite is short, subhorizontal and restricted to the ferrocolumbite field (Fig. 3A). In the Niemelä pegmatite and especially in the Juurakko dyke the trendline is long, stretching from the ferrocolumbite field throughout the whole manganocolumbite field (Fig. 3B and C). The compositional trend of columbite-group minerals from these two dykes shows two branches toward the tantalite field, indicating that the Nb/Ta fractionation was locally more intense (Fig. 3B and C).

Columbite-group minerals in the beryl-columbite-phosphate pegmatites

The beryl-columbite-phosphate pegmatites are more evolved than the beryl-columbite pegmatites. Compositions of the columbite-group minerals are scattered around the centre of the quadrilateral (Fig. 4). Average Ta/(Ta+Nb) is 0.49 and that of Mn/(Mn+Fe) is 0.42 (Table 4). Slightly over a half of the compositions of columbite-group minerals are in the ferrotantalite-manganotantalite field.

Ferrocolumbite and manganocolumbite are characteristic of the poorly evolved dykes, manganotantalite and especially ferrotantalite in the more evolved dykes. Almost all columbite-group minerals with Ta>Nb and Mn>Fe come from the amblygonite-, lepidolite- and spodumene-bearing varieties of the beryl-columbite-phosphate pegmatites. Ferrotantalite rich in Fe is typical of the Li mineral-bearing pegmatites that occur close to the contacts of the granites.

It is surprising that the compositional variation in columbite-group minerals between narrow and broad dykes is not so distinct as in the beryl-columbite pegmatites (see Table 4). The average Mn/(Mn+Fe) for the narrow dykes (0.47) is even a little higher than that in the broad dykes (0.37), but the average Ta/(Ta+Nb) does not show large variation.

Columbite-group minerals in selected individual dykes

Compositional variation of columbite-group minerals in three beryl-columbite-phosphate pegmatites (Hannula, Keskimetsä and Seppälänranta) was studied in detail. The Hannula pegmatite belongs to a small dyke swarm, which is situated in mica-schists far from granite outcrops in the northern part of the research area. The pegmatite occurs as a three-metre-thick sheet-like dyke that follows the foliation of the mica-schist wall rock. The Seppälänranta and the Keskimetsä dykes are in the mica-schist close to the contact of the eastern end of the Syrjänmäki pegmatitic granite intrusion. Both pegmatites form irregular, locally swelling dykes (3–10 m wide) that are oriented normal to the contact of the granite intrusion and cut foliation of the schists at steep angles.

The pegmatites are well zoned. The grain size of the minerals increases from the border zone toward the central parts of the dykes. Large, lenticular or roundish quartz cores are surrounded by coarse, blocky crystals of feldspar, characteristic of the intermediate zone of the dykes. Sporadic beryl, fluorapatite and ferrocolumbite occur in the marginal parts, in the border and wall zone with feldspars, quartz, muscovite and schorl. Beryl, columbite-group minerals, triphylite-lithiophilite and other accessory minerals such as fluorapatite and zircon are in the albite-dominated units of the intermediate zone or in the intraformational dykes and veinlets characterised by platy or saccharoidal albite.

The Hannula and Keskimetsä dykes are mineralogically and structurally similar, whereas the Seppälänranta pegmatite is richer in rare-element minerals such as Li phosphates and Li silicates, and its internal structures are also more complicated. The zoned structure of the Seppälänranta dyke is often destroyed by strong albitization. Large units composed of platy albite, quartz, muscovite, triphylite, montebrasite, lepidolite, coloured elbaitic tourmaline, ferrotantalite, cassiterite and montebrasite occur in the central parts of the dyke.

Albite-rich dykes and veinlets rich in Li minerals locally replace the marginal zones and reach the contact of the pegmatite. Because triphylite dominates in the dyke, the Seppälänranta pegmatite is classified as a member of the beryl-columbite-phosphate subtype, although large crystals of amblygonite with lepidolite and elbaitic tourmaline are also locally common.

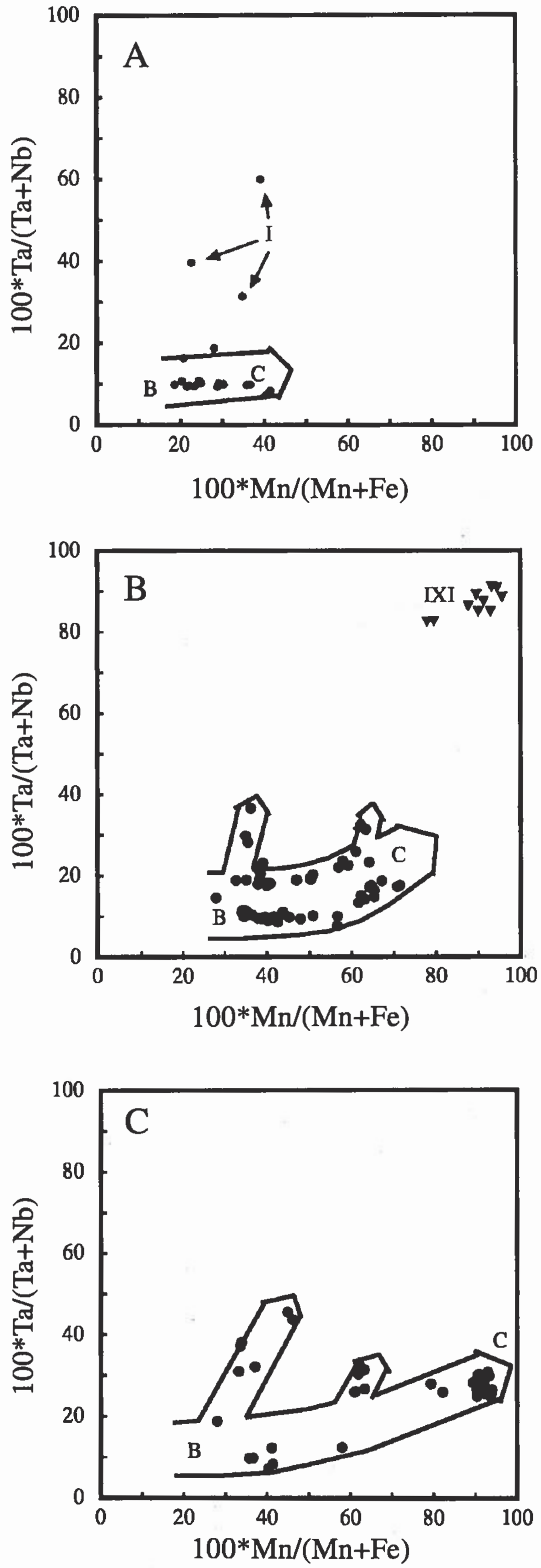

Fig. 3. Compositional trends for the columbite-group minerals from beryl-columbite-pegmatites. Samples from A) Eräpyhä, B) Niemelä, C) Juurakko pegmatites. Marks in figures: B – samples from marginal parts of the dykes, C – samples from central parts of the dykes, I – columbite inclusions in microlite, IXI – ixiolite (triangles).

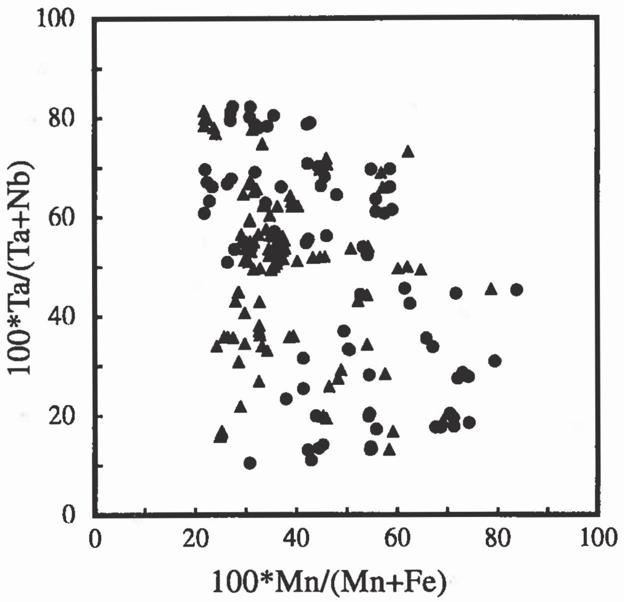

Fig. 4. Compositional variation of columbite-group minerals in beryl-columbite-phosphate pegmatites. Spots – samples from thinner dykes, triangles – samples from broader dykes.

Ferrotantalite is a characteristic mineral in the central parts and ferrocolumbite in the marginal parts of the Keskimetsä and Seppälänranta dykes. Both Fe-dominant and Mn-dominant members of columbite and tantalite occur in the Hannula pegmatite. In addition to columbite-group minerals, a few crystals of ixiolite and tapiolite were encountered in the Keskimetsä and Seppälänranta dykes. Microlite-pyrochlore occurs as small inclusions in some columbite-tantantalite samples from the Seppälänranta dyke. Cassiterite is also locally rich in Ta (several wt. % Ta_2O_5).

The chemical analyses confirm that Ta/(Ta+Nb) in the columbite-group minerals from all three pegmatites shows strong increase from the contact to the more fractionated central parts of the dykes (Fig. 5A–C). The compositional variation of Ta/(Ta+Nb) in the columbite-group minerals from the Hannula, Keskimetsä and Seppälänranta pegmatites is extensive, from the columbite field far into the tantalite field. In contrast, variation in Mn/(Mn+Fe) is limited in all dykes and the compositional trends differ markedly from those recorded for the beryl-columbite pegmatites (cf. Figs 3 and 5).

In the Seppälänranta and Hannula dykes, the compositional trends of columbite-group minerals are narrow and subvertical, and they are inclined toward the manganotantalite corner (Fig. 5). Simultaneous with the increase in Ta/(Ta+Nb), the compositional trend of the Keskimetsä columbite-group minerals shows an exceptional decrease in Mn/(Mn+Fe) and the trend is negative. The number of crystals studied is, however, limited, and additional analyses are required to test this observation.

In the Keskimetsä and Seppälänranta pegmatites, Mn/(Mn+Fe) and Ta/(Ta+Nb) in the tantalite samples richest in Ta, in the ixiolite and wodginite samples are nearly the same, and their points plot close to each oth-

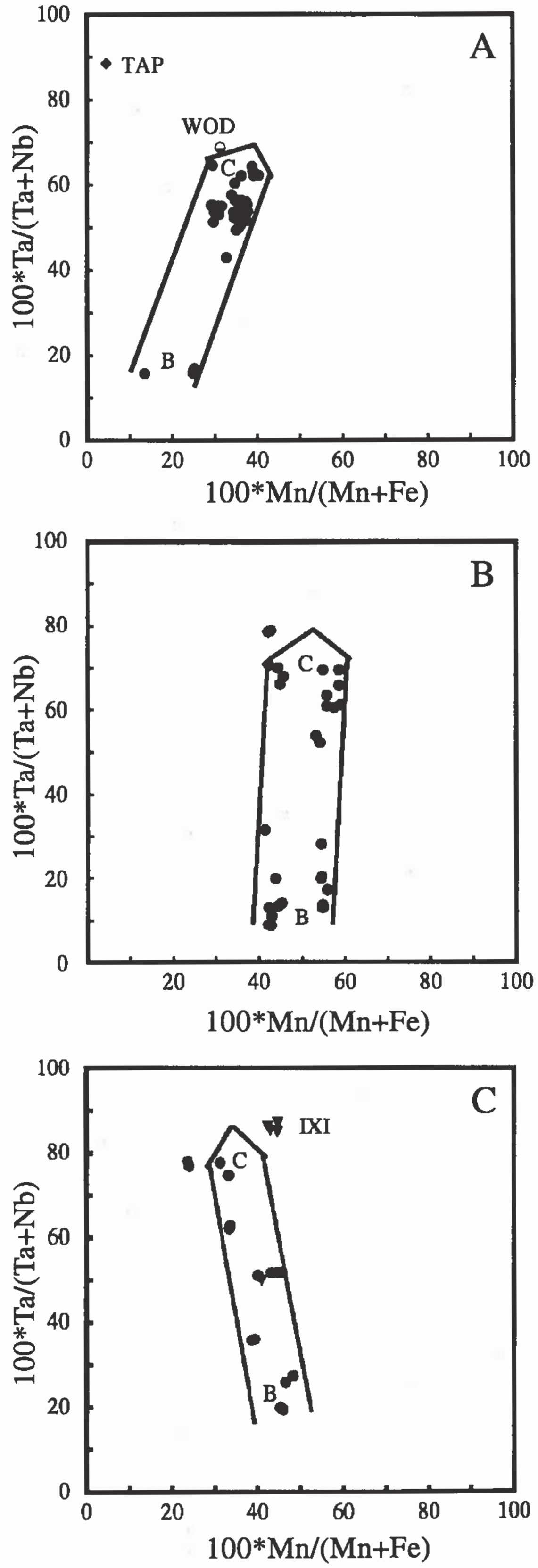

Fig. 5. Compositional trends of columbite-group minerals from the beryl-columbite-phosphate pegmatites. Samples are taken fom A) Seppälänranta, B) Hannula and C) Keskimetsä pegmatites. Marks in figures: B – samples from border and wall zones, C – samples from central parts of the dykes, IXI – ixiolite (triangle), TAP – tapiolite (diamond), WOD wodginite (half-filled dots).

er in the diagram (Fig. 5). Microlite-pyrochlore inclusions in the Seppälänranta columbite-group minerals have minor Fe, but Mn is almost absent so the composition of the mineral is far from the compositional trend of columbite-group minerals.

Columbite-group minerals in the Viitaniemi amblygonite pegmatite

The compositional variation of columbite-group minerals is most extensive in the most fractionated beryl-columbite-phosphate pegmatites enriched in Li silicates and Li phosphates, and in the complex pegmatites. The composition of columbite-group minerals from the Viitaniemi pegmatite that is a typical complex pegmatite of the amblygonite subtype, was studied in detail. The minerals of the pegmatite have been described earlier by Volborth (1954), Lahti (1981), Pajunen – Lahti (1984) and Teertstra et al. (1993).

The Viitaniemi pegmatite dyke is situated in the eastern part of the research area. The pegmatite occurs as a subhorizontal dyke in mica schist far from the granite intrusions. Two outcrops of the pegmatite are exposed, separated by about 150 m. Diamond drilling indicates that the dyke thins and thickens locally between these outcrops (quarries), the maximum thickness being 10 m.

The zoned structure of the dyke is locally destroyed by large albite-rich units, intraformational dykes and veinlets that may reach from the central to marginal parts of the pegmatite. Large, roundish quartz cores are surrounded by microcline-perthite crystals that may be several metres long, characteristic of the intermediate zone.

Tiny platy crystals of ferrocolumbite were discovered in the marginal parts of the dyke, in border and wall zone with beryl, tourmaline and fluorapatite, but the mineral mainly occurs in intermediate zone, in the albite-rich units, dykes and veinlets with various Li silicates, Li phosphates, beryl and Be phosphates. Green elbaitic tourmaline, lepidolite, topaz, triplite, pollucite, zircon and blue Mn-rich apatite are also common minerals in the central parts of the dyke. Locally large accumulations of amblygonite-montebrasite are characteristic and the associated minerals include topaz, lepidolite, beryl, manganotantalite, lithiophilite, eosphorite, hurlbutite, väyrynenite and other beryllium phosphates. So far, nearly 100 different mineral species have been identified in the pegmatite (Lahti 1981).

The most common Nb-Ta minerals in the pegmatite are columbite-group minerals. A few crystals or crystal aggregates of wodginite and uranian microlite were also encountered, associated with amblygonite and other Li minerals. Ferrotapiolite has been identified only once. The cassiterite samples are locally very rich in Ta (up to 10 wt. % Ta_2O_5).

Columbite-group minerals from the Viitaniemi pegmatite display very extensive Fe/Mn and Nb/Ta fractionation (Table 3 and 4, Fig. 6). The ranges of Ta/(Ta+Nb) and Mn/(Mn+Fe) in columbite-group minerals are large (0.17–0.96 and 0.12–0.96, respectively) and the averages of Ta/(Ta+Nb) and Mn/(Mn+Fe) very high (0.51 and 0.79, respectively; see Table 3 and 4). Ferrocolumbite is rare and occurs mainly as minute crystals in the marginal zones, but in the central parts of the dyke the mineral is rich in Ta and Mn so that most of the specimens taken from the intermediate zone, albite-rich units and intraformational dykes plot in the manganotantalite field. The curved compositional trend of columbite-group minerals is stretched from the ferrocolumbite field through the manganocolumbite field up to the manganotantalite corner (Figs 6 and 8). The plots of wodginite are close to the end of the fractionation trend of columbite-group minerals in the composition diagram.

Variations in minor elements

In addition to the main components, Fe, Mn, Ta and Nb, the concentrations of Ti, W, Sn, Sc, Ca and Mg were analysed from most of the samples, and the concentrations of the elements between the different pegmatite dykes were compared. The analytical results indicate that the columbite-group minerals studied usually contain Ti < 0.1 *apfu* (atoms per formula unit), W, Sn and Sc < 0.05 *apfu* and traces of Ca and Mg.

The analytical data indicate the columbite-group minerals from the more fractionated beryl-columbite-phosphate pegmatites and from the Viitaniemi amblygonite pegmatite always contain slightly higher concentrations of Sn than the columbite samples than the less evolved beryl-columbite pegmatites. By contrast, the highest concentrations of W and Ti were analysed from the samples of the beryl-columbite pegmatites and narrow beryl-columbite-phosphate pegmatites, but the average composition does not show systematic variation between the different pegmatite categories.

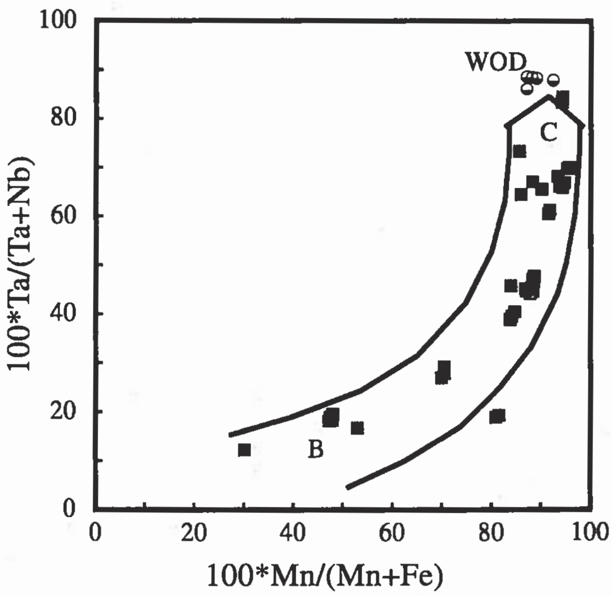

Fig. 6. Composition of columbite-group minerals in the Viitaniemi pegmatite. B – samples from marginal parts of the dyke, C – samples from central parts of the dyke, WOD – wodginite (half-filled circles).

Discussion

The compositional variation in columbite-group minerals and the observations concerning the evolution of the Nb-Ta minerals in the pegmatites of the research area agree well with the descriptions from other pegmatite provinces containing similar LCT pegmatites, although each pegmatite population has a particular geochemical signature of its own (cf. Černý et al. 1985; Černý et al. 1985; Černý – Ercit 1986, Černý – Ercit 1989; Černý 1989, 1990, 1992). Concomitant increase in Mn/(Mn+Fe) and Ta/(Ta+Nb) of columbite-group minerals is characteristic of the pegmatite sequence of the district (Table 4; see also Fig. 7). The averages of Mn/(Mn+Fe) and Ta/(Ta+Nb) in columbite-group minerals are low in beryl-columbite pegmatites (0.39 and 0.23, respectively), but higher in beryl-columbite-phosphate pegmatites (0.42 and 0.49, respectively) and especially in the Viitaniemi amblygonite pegmatite (0.79 and 0.51, respectively).

The increase in Mn/(Mn+Fe) and Ta/(Ta+Nb) in columbite-group minerals is not, however, proportional and the compositional trends of the minerals between various pegmatite types are different (cf. Černý 1985). The factors that control the composition of columbite-group minerals vary from one pegmatite to another as shown by the regional geological studies (Černý 1990, Černý et al. 1985, Černý et al. 1986, Spilde – Shearer 1992, Ercit 1994, Novák et al. 1994, Novák – Povondra 1995, Mulja et al. 1996, Novák – Diviš 1996, Lumpkin 1998, Novák – Černý 1998, Raimbault 1998, Uher et al. 1998, Tindle – Breaks 1998).

Černý (1989, 1992, Černý et al. 1986; see also Novák – Černý 1998) has suggested that the presence of F in the melt and the resultant formation of Ta- and Mn-fluoride complexes would increase fractionation of Mn and Ta from Fe and Nb in the pegmatite melt. Later, Mulja et al. (1996) proposed (quoting experimental results of Linnen – Keppler 1996) that the general increase in Mn/(Mn+Fe) and Ta/(Ta+Nb) of columbite-group minerals in the progressively crystallizing pegmatite magmas may be due to the relative solubility of the two end-members ferrocolumbite and manganotantalite. Ferrocolumbite is less soluble and crystallized first, thereby enriching the residual liquid in Mn and Ta and causing later crystallization of manganotantalite (see Linnen 1998).

The increase in both Mn/(Mn+Fe) and Ta/(Ta+Nb) of columbite-group minerals is generally largest in the most evolved complex pegmatites. The fractionation trend of columbite-group minerals from the Viitaniemi amblygonite pegmatite area is also a long curved line that stretches from the ferrocolumbite field through manganocolumbite field far upwards into the manganotantalite field (Figs 6 and 8). Mn/(Mn+Fe) and Ta/(Ta+Nb) are increased also in other Nb-Ta minerals structurally related to columbite-group minerals, such as ixiolite and wodginite, and their compositions are close to the end of the fractionation trends of columbite-group minerals (Figs 5 and 6). Similar fractionation trends are reported for the most-evolved complex pegmatites in the literature (Černý 1990, Černý – Ercit 1985, Černý et al. 1985, Spilde – Shearer 1992, Mulja et al. 1996).

In the beryl-columbite pegmatites of the research area, the range of Mn/(Mn+Fe) in columbite-group minerals is large, but that of Ta/(Ta+Nb) slight. The minerals show Nb>Ta and Fe>Mn, and a major part of the compositions plot in the ferrocolumbite field (Figs 3 and 8). The fractionation trends are subhorizontal, slightly rising lines from the ferrocolumbite to the manganocolumbite fields. In the poorly-developed dykes, the range of Mn/(Mn+Fe) is limited and the fractionation trends shorter than those of the more evolved dykes (Figs 3 and 5). The compositional trends may show branches toward the tantalite field, indicating that locally in the dykes the Nb/Ta fractionation was more intensive (Fig. 3).

Fe-rich minerals, which are more characteristic of the beryl pegmatites than of their complex counterparts, strongly control the Mn/(Mn+Fe) of columbite-group minerals. The mineral is always exceptionally enriched in Fe, if the dykes or the zones of the dykes contain abundant biotite, garnet, schorl or triphylite with Fe>>Mn. Ferrotantalite and ferrocolumbite samples exceptionally enriched in Fe were discovered in the beryl pegmatites that occur within the Syrjänmäki pegmatitic granite and close to its contacts. The composition of tantalite samples from some of these pegmatites is quite close to the compositional field of the tetragonal polymorph ferrotapiolite-manganotapiolite (see Figs 4 and 7).

It is noteworthy that a substantial proportion of the columbite group mineral compositions from the beryl-columbite-phosphate pegmatites shown in Fig. 4 violates the empirical two-phase field as defined by Černý et al. (1992; see also Černý – Ercit 1989 and Wise – Černý 1996): most of the compositions which fall into the ferrotantalite-ferrotapiolite quadrangle of the columbite quadrilateral must be metastable survivors, which should be replaced under equilibrium conditions by ferrotantalite-ferrotapiolite pairs. It is significant in this respect that the so far unique occurrence of manganotapiolite, considered by Černý – Ercit (1985, 1989) metastable, also comes from a member of the examined pegmatite population, the Tiainen dyke (Lahti et al. 1983). The extent and abundance of the metastable compositions recorded here for the Eräjärvi district are so far quite exceptional on global scale.

The fractionation trends of columbite-group minerals in the more evolved beryl-columbite-phosphate pegmatites differ from those of the beryl-columbite pegmatites. The increase in Ta/(Ta+Nb) of columbite-group minerals is always much greater than that of Mn/(Mn+Fe), and the fractionation trends rise steeply upward from the columbite fields far into the tantalite fields (Figs 5 and 8). Mn/(Mn+Fe) may be nearly stable during crystallization of an individual pegmatite, but the value varies between the different dykes.

Similar steep fractionation trends seem to be characteristic especially in the beryl pegmatites (see e. g. Černý 1989, 1992, and Abella et al. 1995). According to Mulja

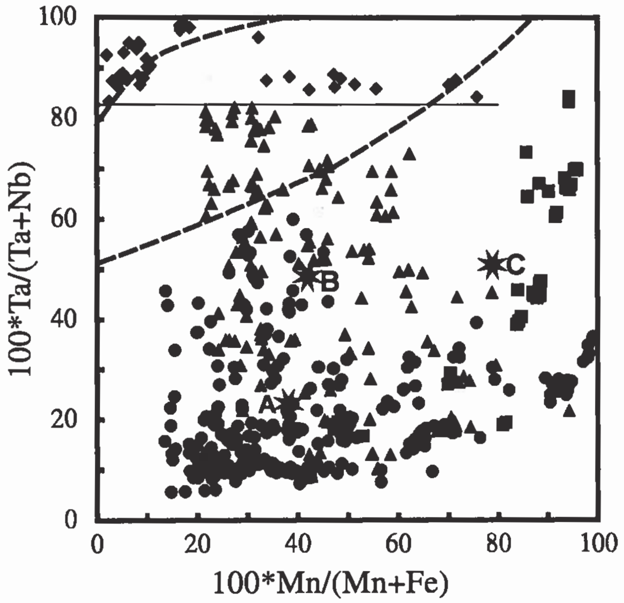

Fig. 7. Chemical compositions of columbite-group minerals (dots, triangles and squares) and its tetragonal analog tapiolite (diamonds) from the pegmatites of the Eräjärvi district plotted on the columbite quadrilateral. Dots – columbite-group minerals from the beryl-columbite pegmatites; triangles – columbite-group minerals from the beryl-columbite-phosphate pegmatites; squares – columbite-group minerals from the Viitaniemi amblygonite pegmatite. The average composition of columbite-group minerals from the beryl-columbite pegmatites is indicated by star-A, from beryl-columbite-phosphate pegmatites by star-B and from the Viitaniemi amblygonite pegmatite by star-C. The solid line separates the observed compositions of ferrotapiolite-manganotapiolite and ferrotantalite-manganotantalite. The dashed curves mark the empirical two-phase field boundaries separating co-existing ferrotapiolite and ferro- to manganotantalite (from Černý et al. 1992).

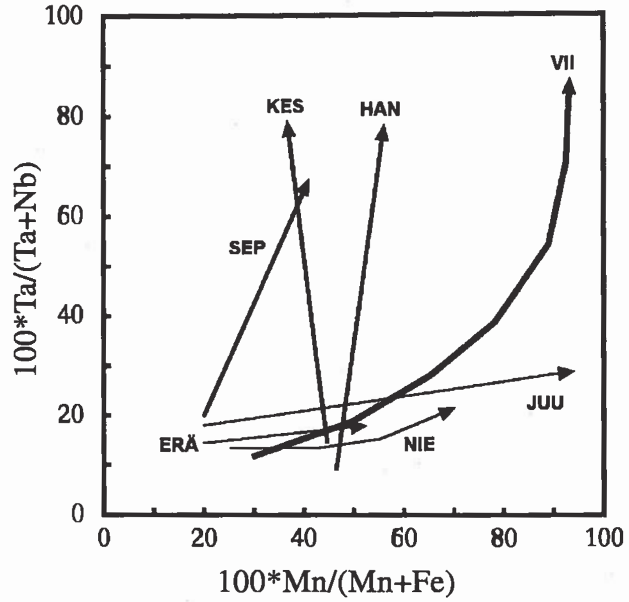

Fig. 8. Simplified fractionation trends for columbite-group minerals in different types of the pegmatites in the Eräjärvi district. Samples from a) beryl-columbite pegmatites: ERÄ – Eräpyhä, NIE – Niemelä, JUU – Juurakko, b) from beryl-columbite-phosphate pegmatites: KES – Keskimetsä, HAN – Hannula, SEP – Seppälänranta, c) VII – from Viitaniemi amblygonite pegmatite. The trend lines are based on Figs 4, 5 and 6.

et al. (1996), the increase in Ta/(Ta+Nb) of columbite-group minerals at a constant Mn/(Mn+Fe) in the beryl and spodumene pegmatites of the Lacorne pegmatite suite, Quebec, Canada, may be caused by simultaneous crystallization of columbite-group minerals and garnet, which is considered to buffer Fe and Mn activities during all stages of evolution of pegmatite magma.

In the beryl-columbite-phosphate pegmatites of the Eräjärvi district, crystallization of the Fe-Mn phosphate triphylite-lithiophilite may have buffered the Fe and Mn activities of the pegmatite melt, and consequently controlled Mn/(Mn+Fe) of columbite-group minerals during crystallization of the dykes. Triphylite-lithiophilite, which is commonly the only Fe-Mn mineral associated with columbite-group minerals in the central parts of the dykes, is more abundant than columbite-group minerals and crystallized simultaneously with it.

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Variace chemického složení minerálů columbitové skupiny v různých typech granitických pegmatitů oblasti Eräjärvi v jižním Finsku

Variace v chemickém složení minerálů columbitové skupiny v LCT granitických pegmatitech oblasti Eräjärvi (Orivesi v jižním Finsku) byly studovány s pomocí 611 analýz 140 krystalů elektronovou mikrosondou. Vzorky byly odebrány ze 30 beryl-columbitových, 15 beryl-columbit-fosfátových pegmatitů a jednoho komplexního pegmatitu amblygonitového subtypu. Složení studovaných minerálů je definováno obsahy Fe, Mn, Nb a Ta, ale podružné obsahy Ti (0,1 *apfu*) a Sn, W a Sc (0,05 *apfu* jednotlivě) jsou časté. Vývoj celé pegmatitové populace je významně charakterizován progresivním obohacením minerálů columbitové skupiny Mn a Ta, od nejprimitivnějších beryl-columbitových pegmatitů až po vysoce frakcionované komplexní těleso (amblygonitový pegmatit), i když vzrůst hodnot Mn/(Mn+Fe) a Ta/(Ta+Nb) není v různých pegmatitových kategoriích souběžný. Průměrné hodnoty Mn/(Mn+Fe) a Ta/(Ta+Nb) columbitových minerálů výrazně rostou od beryl-columbitových pegmatitů (0,39 a 0,24) k tělesům beryl-columbit-fosfátové kategorie (0,47 a 0,48), a kulminují v amblygonitovém pegmatitu Viitaniemi (0,79 a 0,51).

V beryl-columbitových pegmatitech je variace Mn/(Mn+Fe) v minerálech columbitové skupiny výrazná, ale kolísání hodnot Ta/(Ta+Nb) jen omezené. Ferrocolumbit je nejčastější, ale manganocolumbit se také vyskytuje ve více frakcionovaných žilách tohoto subtypu. V pegmatitech beryl-columbit-fosfátového subtypu, které obsahují trifylin-lithiofylit jako charakteristickou akcesorii, hodnoty Ta/(Ta+Nb) vzrůstají během vývoje pegmatitu mnohem rychleji než Mn/(Mn+Fe). Ferrocolumbit se vyskytuje v okrajových částech žil, zatímco ferrotantalit a manganotantalit zaujímají střední části pegmatitových těles. Souběžný vzrůst hodnot Mn/(Mn+Fe) a Ta/(Ta+Nb) charakterizuje vývoj komplexních pegmatitů obohacených Li minerály – elbaitem, lepidolitem, spodumenem a amblygonitem. Manganocolumbit a manganotantalit jsou typické v těchto žilách, i když endokontaktní zóny mohou obsahovat podřadný ferrocolumbit. Trend chemického vývoje v pegmatitu Viitaniemi, typického komplexního tělesa amblygonitového subtypu, probíhá z ferrocolumbitového kvadrantu přes manganocolumbit až k manganotantalitovému extrému columbitového kvadrilateralu.