

## Chrome-Bearing Mineral Phases in the Carbonatites of Northern Transbaikalia

G. S. Ripp, N. S. Karmanov, A. G. Doroshkevich, M. V. Badmatsyrenov, and I. A. Izbrodin

*Geological Institute, Siberian Division, Russian Academy of Sciences, ul. Sakh'yanovoi 6a, Ulan-Ude, 670047 Russia*

*e-mail: ripp@gin.bsc.buryatia.ru*

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**Abstract**—This paper presents the results of a study of the Vesely carbonatite occurrence in a new carbonatite-bearing area of northern Transbaikalia. The REE patterns, oxygen and carbon isotope compositions of carbonates and magnetites, and strontium isotope composition of dolomite allow us to classify the rocks as carbonatites. This study focused on minerals from xenoliths that were identified as mantle-derived on the basis of structure and mineral composition. The compositions of Cr-bearing chlorite, phengite, magnetite, rutile, ilmenite, and titanite are reported. Aggregates of closely intergrown magnetite and rutile occurring in the xenoliths resemble exsolution structures. A possible origin of these aggregates is discussed.

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### INTRODUCTION

Elevated Cr contents are typical of mafic–ultramafic rocks and mantle xenoliths. Most other igneous rocks, including carbonatites, are depleted in Cr [1]. The presence of Cr-bearing phases in carbonatites is commonly related to mantle-derived xenoliths occurring in extrusive and volcanic facies. Cr-spinel, Cr-bearing pyroxenes and phlogopite are common minerals in the xenoliths. Magnetite is also a concentrator of Cr. The Cr content of magnetite from ultramafic rocks reaches 10 wt %, whereas it is usually no higher than hundredths or thousandths of percent in magnetite from more silicic rocks. The enrichment of magnetite from carbonatites in Cr has been established only in a few cases [2–4]. Since high Cr concentration in carbonatites bears important genetic information and is sometimes regarded as evidence for their mantle origin, such carbonatites are interesting targets for investigation. The recently discovered Vesely carbonatite occurrence in northern Transbaikalia is among such objects.

### RESEARCH METHODS

Carbonatites from the Vesely occurrence were studied by petrographic and ore-microscopic methods; their major- and trace-element compositions were determined by atomic absorption spectrometry (AAS) and X-ray fluorescence (XRF). Minerals were analyzed using an upgraded MAR-3 electron microprobe at an accelerating voltage of 20 kV, a beam current of 40 nA, a counting time of 20 s, and a beam diameter of 2–3  $\mu\text{m}$ . The microscopic structure of rocks, the morphology of minerals, their relationships and composition were studied in detail on a LEO-1430 electron microscope

with an IncaEnergy-300 energy dispersive spectrometer.

To establish the nature of igneous carbonate rocks, isotopic studies were also carried out. The oxygen and carbon isotopic compositions of carbonates and oxygen isotopic composition of magnetite were determined at the Laboratory of Stable Isotopes, Analytical Center of the Far East Division, Russian Academy of Sciences. The analytical uncertainties for carbonates were better than  $\pm 0.02$  for carbonates and better than  $\pm 0.5\%$  for magnetite. The Sr isotope ratios of Rb-free minerals were determined by V.F. Posokhov on an MI-1201T mass spectrometer at the Geological Institute, Siberian Division, Russian Academy of Sciences.

### GEOLOGY OF THE VESELY OCCURRENCE

The Vesely occurrence is situated in northern Transbaikalia within a new carbonatite-bearing area related to the framing of an inlier of the Early Precambrian crystalline basement composing the North Muya Block. It is suggested that the carbonatites are Late Riphean in age, similar to the Pogranchny carbonatite occurrence in the same zone. The carbonatites of the Vesely occurrence are hosted by Late Precambrian muscovite–quartz–feldspar schists and gneisses with lenses of amphibolite and marble. The schists are intruded by gneissic granites, small bodies of altered basic rocks, and ultramafics transformed into talc–carbonate rocks and listwaenites. No alkaline silicate rocks comagmatic with the carbonatites are known in this region.

The carbonatites occur as dikes disintegrated to a varying extent and localized within a 0.5–0.7-km wide band extending over 4 km in an approximately N–S

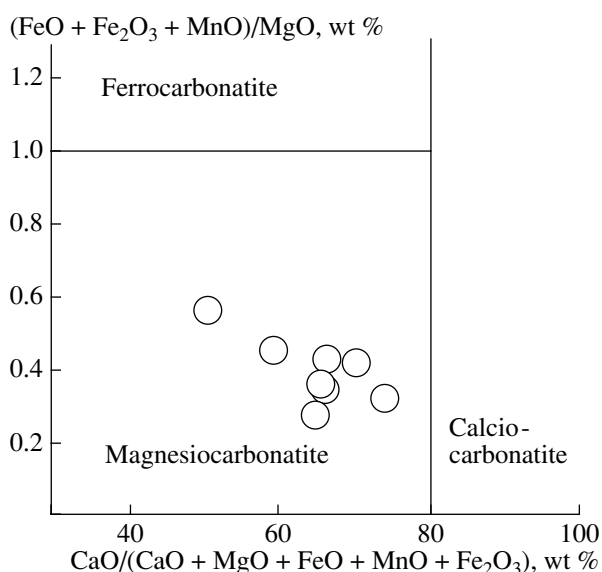


Fig. 1. Chemical compositions of carbonatites from the Vesely occurrence. The compositional fields are given after [6].

direction. A geochemical anomaly of phosphorus, 4 km<sup>2</sup> in area, which was delineated in the course of geological mapping, marks the zone of carbonatite occurrences. Similar to the crystalline schists, the carbonatites contain newly formed phengite with ~0.5 Fe and Mg p.f.u. and 3.30–3.45 Si p.f.u. This phengite composition corresponds to pressures of 7.5–10.0 kbar at a temperature of 500°C, which is typical of the mineral assemblages of greenschist metamorphic facies [5].

The carbonatites are massive fine-grained rocks. They show banding conformable with the contacts formed by the common orientation of apatite and dolomite grains and bands enriched in magnetite and rutile. The contacts with the country rocks are tectonized, and the material of the latter is often incorporated into the carbonatitic matrix. Thin phlogopitized zones are occasionally retained at the contacts. The carbonatites underwent extensive cataclasis, which resulted in the formation of numerous nearly parallel zones of varying thickness composed of strongly crushed minerals.

Carbonatite formation was followed by the development of dolomite and calcite veinlets with disseminated Sr-bearing barite and barytocelestite and dolomite replacement after talc. Superimposed silicification, pyritization, and chloritization are related to tectonic dislocations.

The chemical composition of rocks falls into the field of magnesiocarbonatite (Fig. 1) and differs from the average composition of dolomitic carbonatite [6] by elevated contents of Sr, Ti, F, Cr, Ni, and, especially, P. The REEs are mainly represented by LREEs, and their composition is generally similar to that of other carbonatites.

The carbonatites consist of 70–80% Fe-rich dolomite, 10–20% apatite, and up to 5–15% calcite. Magnetite, rutile, F-phlogopite, and alkali amphiboles are minor minerals (1–3%) occurring as discrete grains and small chains elongated parallel to the banding. The amphiboles are magnesioriebeckite (6.6 wt % Na<sub>2</sub>O) and K-bearing richterite (up to 1.9 wt % K<sub>2</sub>O). The fluorine content of phlogopite and apatite reaches 3.7–4.1 wt %. The average SrO content of apatite is 1.7 wt % SrO; 0.5–0.7 wt % SrO were detected in dolomite, calcite, and monazite. Calcite fills interstices between the dolomitic grains. Lenticular and vermicular exsolution lamellae of dolomite occur in calcite.

Zircon is a common accessory mineral; monazite, titanite, ilmenite, molybdenite, allanite, celestite, and barite are less abundant.

The carbon and oxygen isotopic compositions of dolomite (–2.2‰ δ<sup>13</sup>C PDB and 8.9‰ δ<sup>18</sup>O SMOW) are close to typical carbonatitic values; δ<sup>18</sup>O = 1.5‰ was determined in magnetite associating with dolomite. The <sup>87</sup>Sr/<sup>86</sup>Sr ratio of dolomite (0.7038) falls within the range typical of Late Riphean mantle-derived rocks.

#### CHROME-BEARING MINERALS

Elevated Cr (0.0106 wt %) and Ni (0.0122 wt %) contents, 3–4 times higher than the average values for carbonatites [6], are characteristic of the carbonatites. This is related to the occurrence of small (up to 3–5 mm) resorbed aggregates with Cr-bearing minerals. These aggregates are regarded as xenoclasts on the basis of their textural and structural characteristics. They contain high-Ti minerals enriched in Cr, and in some cases in Ni, and are altered to a varying degree by superimposed processes. They usually appear as segregations of small intergrown or disintegrated grains of magnetite, rutile, ilmenite, and titanite. Primary silicate phases, except for titanite, are not preserved and replaced by phengite and chlorite.

Chrome was detected in magnetite, rutile, titanite, ilmenite, chlorite, and phengite. The chlorite contains from 1.68 to 6.15 wt % Cr<sub>2</sub>O<sub>3</sub> (Table 1, analyses 4–6) and up to 1.33 wt % NiO. The Cr<sub>2</sub>O<sub>3</sub> content of phengite is up to 1.7 wt % (Table 1, analyses 1–3).

Magnetite and rutile are represented by several generations, and their total content in the carbonatites is less than 1–2 vol %. They may be free of chrome and differ in trace element composition. Magnetite is mostly associated with dolomite and occurs as fine disseminations and chains of grains elongated parallel to the banding. Two generations of magnetite are clearly seen in Fig. 2. Magnetite-1 occurs as inclusions within more abundant magnetite-2. The inclusions are rimmed by rutile, which also forms tabular grains (Fig. 2). The magnetite is enriched in Ti and V (0.6–1.65 wt % V<sub>2</sub>O<sub>3</sub>) and devoid of Cr (Table 2, spectra 3, 6). More abundant magnetite-2 contains less Ti and V and is also Cr-free

**Table 1.** Chemical composition of phengite and chlorite, wt %

No.	SiO <sub>2</sub>	TiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Cr <sub>2</sub> O <sub>3</sub>	FeO	MgO	CaO	K <sub>2</sub> O	NiO	Total
1	48.71	0.79	26.44	1.72	3.72	2.56	–	11.96	–	95.92
2	47.10	0.61	26.58	1.45	3.74	2.33	–	12.13	–	93.95
3	47.39	0.38	29.77	1.13	4.02	1.43	–	11.81	–	95.92
4	29.77	–	12.25	6.15	14.59	21.72	0.23	–	1.33	86.04
5	29.08	–	14.90	2.34	14.71	23.16	0.69	–	0.79	85.67
6	32.58	–	15.41	1.68	14.16	26.54	–	–	0.65	91.12

Note: (1)–(3) Phengite, (4)–(6) chlorite. BaO, Na<sub>2</sub>O, and F were not detected. Here and in Tables 2–5, analyses were obtained on an IncaEnergy-300 energy dispersive spectrometer attached to a LEO-1430 electron microscope. FeO is total iron, and dashes denote elements not detected.

(Table 2, spectra 1, 2). There is a later generation (magnetite-3) occurring as thin (2–3 mm) monomineralic veinlets cutting the carbonatites. A few analyses testify to its depletion in Ti and V (0.24 wt % TiO<sub>2</sub> and 0.31 wt % V<sub>2</sub>O<sub>3</sub>).

Two groups of Cr-bearing magnetite were recognized; both occur in xenoliths. Magnetite-4 is represented by single grains in association with ilmenite, titanite, and rutile. It contains 4–18 wt % Cr<sub>2</sub>O<sub>3</sub> (Table 3) and usually shows high and variable TiO<sub>2</sub> concentration. The magnetite grains are often broken and represented by angular fragments and splinters. The morphology of these grains and their relationships with other minerals, including magnetite exsolved from a Fe–Ti mineral, are demonstrated by Figs. 5 (spectra 1 and 3) and 6 (spectrum 7).

Magnetite-5 occurs as symplectic intergrowths with rutile similar to exsolution structures. These aggregates have sharp boundaries with the host matrix and contain titanite and ilmenite inclusions (Figs. 3–5). Magnetite-5 is depleted in Cr relative to magnetite-4 but is characterized by more uniform Cr distribution; Cr<sub>2</sub>O<sub>3</sub> contents of 0.5–2.5 wt % are most common (Table 4). The TiO<sub>2</sub> content of this mineral is much lower, and V was detected in small amounts in some grains.

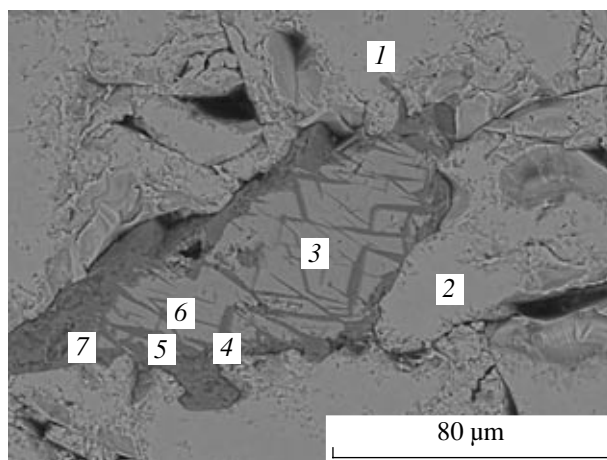
Similar to magnetite, there are several generations of rutile in the carbonatites. Rutile-1 is associated with dolomite and occurs as disseminated grains and chains of grains oriented conformably with the banding of rocks. Rutile-1 is free of Nb, always contains V (Table 5), and shows elevated Fe contents.

Two generations of rutile were recognized in xenoliths. Early rutile-2 forms rims around high-Cr magnetite-4. This rutile generation shows high Nb<sub>2</sub>O<sub>5</sub> contents (0.95–2.30 wt %) (Table 6). Rutile-3 occurs in intergrowths with magnetite (Figs. 3–6) and is also enriched in Cr, but Nb was not detected. Its Cr<sub>2</sub>O<sub>3</sub> content varies from 0.3 to 2.9 wt % and is usually within 0.5–0.7 wt %. The composition of this rutile generation is shown in Table 4.

The Cr content of ilmenite is much lower, and this element was not detected in some samples. The ilmenite is enriched in MgO and CaO (Table 7). From 0.3 to 0.5 wt % Cr<sub>2</sub>O<sub>3</sub> were determined in 9 of 15 analyzed titanite samples from xenoliths.

## DISCUSSION

Currently, the most favored model for carbonatite origin is the differentiation of carbonate–silicate melt. Such carbonatites are associated with alkaline mafic and ultramafic complexes but are usually characterized by low Cr contents. Another model suggests that carbonatites are direct partial melts of mantle materials. This hypothesis is difficult to prove, and it is largely based on calculations and experimental data. The reality of such a mechanism of carbonatite generation is



**Fig. 2.** Two generations of magnetite associating with carbonate in grain 2-6. Magnetite-1 occurs in an inclusion (spectra 3, 6) containing tabular rutile grains (dark gray). The inclusion is rimmed by rutile (spectra 4, 5, 7). The main field is composed by late low-Ti magnetite-2 (spectra 1, 2). Chrome was not detected in any analysis of magnetite and rutile. Analytical results are given in Table 2. This figure and Figs. 3–6 are BSE images.

**Table 2.** Chemical composition of magnetite and rutile in association with carbonatite, wt %

Component	Spectrum number						
	1	2	3	6	4	6	7
	Magnetite				Rutile		
TiO <sub>2</sub>	–	0.34	8.57	9.16	89.74	95.88	84.81
Cr <sub>2</sub> O <sub>3</sub>	–	–	–	–	–	–	–
FeO	93.89	92.65	83.54	82.87	9.31	4.34	14.34
V <sub>2</sub> O <sub>3</sub>	0.86	0.74	1.62	1.65	1.34	1.08	1.12
Total	94.75	93.73	93.74	93.69	101.39	93.69	100.27

Note: (3) and (6) magnetite-1; (1) and (2) magnetite-2. Spectra are shown in Fig. 2 (grain 2-6).

**Table 3.** Chemical composition of magnetite-4 from xenoliths in carbonatite, wt %

No.	TiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Cr <sub>2</sub> O <sub>3</sub>	FeO	V <sub>2</sub> O <sub>3</sub>	Total
1	3.67	–	3.67	88.95	–	92.28
2	0.52	0.43	18.27	71.65	–	93.58
3	9.20	–	6.10	75.83	0.50	92.16
4	1.66	–	3.93	88.74	0.28	95.06
5	2.46	–	4.27	89.10	–	95.83
6	1.89	–	3.02	92.19	–	97.10

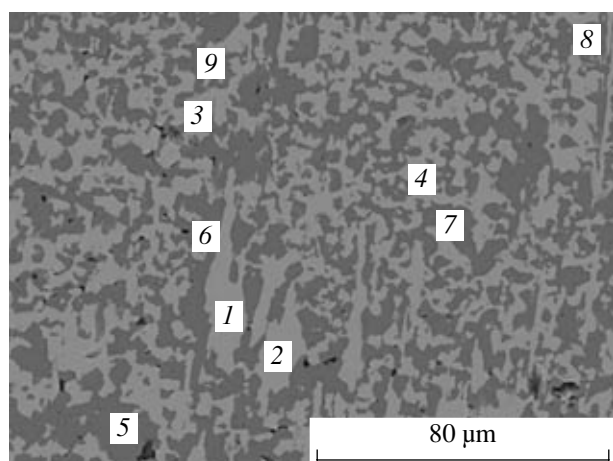
supported only in very rare cases by the occurrence of mantle xenoliths [7]. Despite the equivocal interpretation of the cause of appearance of these xenoliths in carbonatites, they bear important petrochemical and geochemical information.

High-Cr magnetite and rutile are typical of ultramafic rocks rather than of carbonatites. Ilmenite coexisting with them also shows elevated Cr<sub>2</sub>O<sub>3</sub> contents [8].

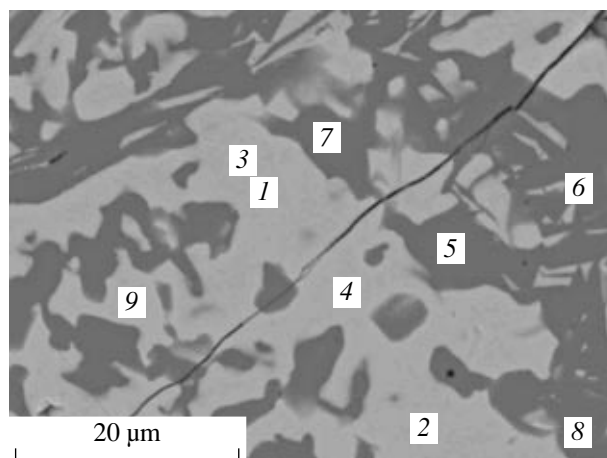
The average Cr concentrations in calcitic and dolomitic carbonatites are 13 and 55 ppm, respectively [6]. Some effusive and extrusive carbonatites are much richer in Cr [9], which is explained by the presence of mantle-derived xenoliths. Wooley and Church [10] pointed out at the 32nd IGC that mantle xenoliths were found in 15 of 39 known occurrences of extrusive carbonatites. The absence of such xenoliths in intrusive carbonatites is explained by the slower ascent of their melts to the upper crust [10]. Garnet, phlogopite,

Cr-spinel, orthopyroxene, and clinopyroxene were identified in mantle-derived xenoliths. Elevated Cr content is an important feature of minerals from such xenoliths. For example, most minerals from xenoliths in the melilite-bearing carbonatitic tuffs of southern Italy, including orthopyroxene, clinopyroxene, phlogopite, and spinel, are enriched in Cr [11]. High-Cr pyroxene was found in xenoliths from Tenerife, Canary Islands [12]. Extrusive carbonatites from the United Arab Emirates contain magnetite with 0.3 wt % Cr in association with Cr-spinel [13].

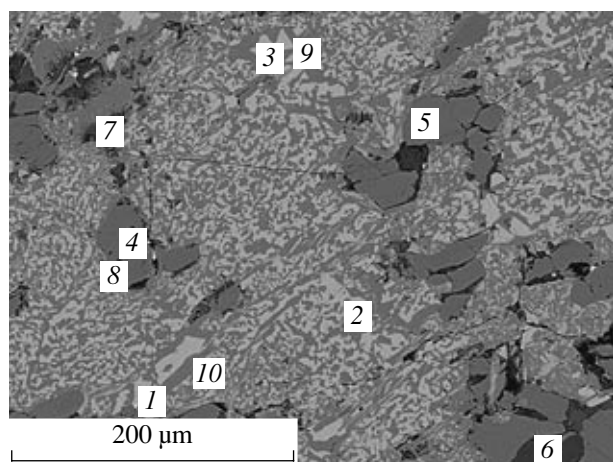
According to numerous studies, the Cr content of magnetite from carbonatites is usually no higher than thousandths of percent and reaches tenths of percent only in rare cases [14]. Such rocks were distinguished into a special group of linear fissure type carbonatites, and it was suggested that they were derived directly from the mantle [2, 14].



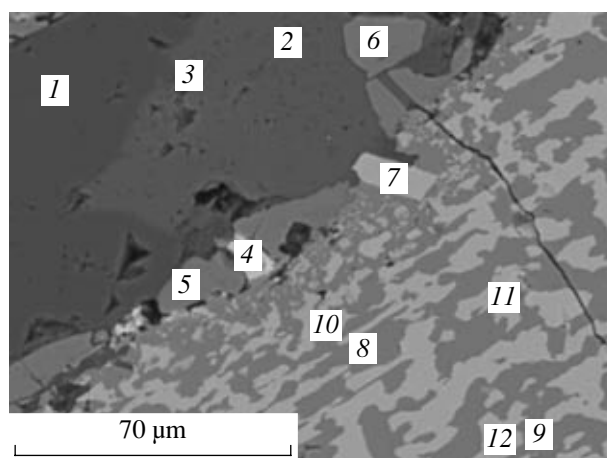
**Fig. 3.** Grain 5-1. Typical appearance of aggregates consisting of Cr-bearing rutile (gray, spectra 5–8) and magnetite (light, spectra 1–4). Spectrum 9 is ilmenite. Small black grains are Cr-bearing chlorite. Analytical results are given in Table 4.



**Fig. 4.** Grain 5-5. Intergrowths of Cr-bearing rutile (spectra 5, 8, 10) and magnetite (spectra 1–4, 9). The roundness of grain boundaries between the two minerals is clearly seen. Analytical results are given in Table 4.



**Fig. 5.** Grain 5-5-2. Assemblage of titanite (gray grains, spectra 4 and 5) and aggregates of intergrown grains of magnetite and rutile with inclusions of crystal clasts of magnetite-4 (angular fragments, spectra 1, 3) rimmed by rutile-2 (spectra 9 and 10). Black grains (spectrum 7) are chlorite with 1.68 wt %  $\text{Cr}_2\text{O}_3$  and 0.65 wt % NiO. Dark gray grain (spectrum 6) is dolomite. Analytical results are given in Table 4.



**Fig. 6.** Grain 5-4. Titanite grains (gray, spectra 5 and 6) in the boundary zone between carbonatite and xenolith containing aggregates of Cr-bearing rutile (spectra 8 and 9) and magnetite-5 (spectra 10–12). Dark gray grains (spectra 1 and 2) are dolomite. Grain 7 is a xenoclast of magnetite-4. Discrete light grains (spectra 3 and 4) are barytocelestite. Analytical results for rutile and magnetite are given in Table 4.

The concentration of Cr in magnetite from the Vesely occurrence is many times higher than in carbonatitic magnetite from other localities, including magnetite from mantle xenoliths. At the same time, Cr-spinel was never found in the Vesely occurrence, although it is rather abundant in mantle xenoliths.

Similar to magnetite, Cr-bearing rutile is also common in kimberlites and mantle xenoliths. The concentration of  $\text{Cr}_2\text{O}_3$  in the rutile varies from hundredths of a percent to a few percents, occasionally reaching 7–8 wt %. The  $\text{Cr}_2\text{O}_3$  content of rutile is usually no higher than 2–3 wt % [15]. Cr-bearing rutile is also considered to be a typomorphic mineral of eclogites [16, 17], which, similar to kimberlites, form under high-pressure conditions.

The ilmenite from the Vesely occurrence is close in Cr content to ilmenite from mantle xenoliths and kimberlites [15]. In contrast to ilmenite from ultramafic rocks, its MgO content is no higher than 2 wt % (ilmenite from mantle xenoliths and kimberlites usually contains more than 5 wt % MgO and often more than 9–10 wt %).

The structures and textures of inclusions from the Vesely carbonatites and the high Cr contents of their minerals indicate that they are most likely mantle-derived xenoliths. This, in turn, calls for additional studies to clarify the origin of rocks from this occurrence.

It is necessary to discuss one more problem that arose during the study of the Vesely carbonatites and is related to the presence of magnetite–rutile symplectites in the xenoliths (Figs. 3–5). The pattern of such symplectites repeating in many grains, the roundness of

boundaries between magnetite and rutile, the absence of corrosion contacts, which were not revealed even at high magnification, and the general appearance of intergrowths are similar to graphic exsolution textures. These intergrowths most likely resulted from the exsolution of an Fe–Ti mineral. This suggestion is supported by the correlation of magnetite and rutile sizes within particular grains. In some cases, the boundaries of such aggregates are outlined by discontinuous selvages of titanite grains (Fig. 6). These aggregates do not resemble replacement structures, although it is possible that they are products of oriented joint crystallization.

Rutile–hematite exsolution textures were repeatedly described in the literature, but similar magnetite–rutile textures were never reported. There are no fields with coexisting FeO and  $\text{TiO}_2$  in phase equilibrium diagrams for the FeO– $\text{TiO}_2$ – $\text{Fe}_2\text{O}_3$  system. The magnetite + rutile assemblage is not present at high temperature in the phase diagrams with hematite, ilmenite, rutile, magnetite, ulvospinel, ferropseudobrookite, and pseudobrookite [18]. This assemblage was never obtained in experimental studies of the  $\text{Fe}_2\text{O}_3$ –MgO– $\text{TiO}_2$  and FeO–MgO– $\text{TiO}_2$  systems with the compositions of ferropseudobrookite, ilmenite, and ulvospinel [19]. The magnetite + rutile assemblage is only known at temperatures below 400°C and pressures of 1–2 kbar [18]. A temperature of 720°C was calculated from the compositions of coexisting magnetite and ilmenite in our samples. Thus, the appearance of coexisting magnetite and rutile cannot yet be explained.

It is also not clear which mineral was a precursor of the magnetite + rutile assemblage. Pseudobrookite is not likely to be such a protomineral, because it exsolves

**Table 4.** Chemical composition of magnetite and rutile from symplectitic intergrowths, wt %

Grain number and figure	Mineral	Analysis no.	TiO <sub>2</sub>	Cr <sub>2</sub> O <sub>3</sub>	FeO	V <sub>2</sub> O <sub>3</sub>	Total
Grain 5-1 (Fig. 3)	Magnetite	1	1.95	3.74	90.11	0.33	96.13
		2	2.03	2.55	90.59	0.32	95.49
		3	4.85	0.32	90.72	0.32	96.21
		4	3.72	0.22	92.58	0.27	96.79
	Rutile	5	98.97	0.51	1.03	–	100.51
		6	98.78	0.52	1.38	–	100.68
		7	98.59	0.27	1.02	0.92	100.8
		8	89.36	0.65	8.69	1.22	99.92
Grain 5-5 (Fig. 4)	Ilmenite	9	49.42	0.69	49.61	–	99.72
	Magnetite	1	3.34	0.42	94.50	–	98.26
		2	3.00	1.63	93.20	–	97.83
		3	5.13	0.62	93.11	–	98.86
		4	5.55	0.57	91.89	–	98.01
	Rutile	9	3.39	0.33	93.44	–	97.16
		5	97.76	0.70	1.57	–	100.03
		6	96.4	0.79	3.45	–	100.64
		7	99.33	–	1.38	–	100.71
		8	96.13	0.61	3.95	–	100.69
10		96.23	0.87	3.08	–	100.18	
Grain 5-5-2 (Fig. 5)	Magnetite	1	2.46	4.27	89.10	–	95.83
		2	2.88	0.86	92.75	–	96.49
		3	1.89	3.02	92.19	–	97.10
	Rutile	9	97.91	0.82	1.53	–	100.26
		10	97.00	1.14	0.97	–	99.11
		11	99.29	–	1.65	–	100.94
		12	97.40	–	2.82	–	100.22
Grain 5-4 (Fig. 6)	Magnetite	7	1.66	3.93	88.74	0.28	94.61
		10	3.63	0.67	92.00	0.29	96.59
		11	2.69	2.34	90.48	0.47	95.98
		12	3.01	1.66	90.89	0.27	95.83
	Rutile	8	98.59	0.34	1.20	0.85	100.98
		9	98.09	–	1.27	0.71	100.07

Note: Numbers of analyses correspond to numbers in corresponding figures. The TiO<sub>2</sub> and FeO contents in some small grains are distorted by the contamination with the enclosing matrix.

**Table 5.** Chemical compositions of rutile-1 associated with carbonates, wt %

Component	1	2	3	4	5	6
TiO <sub>2</sub>	89.74	95.88	84.81	97.28	96.47	98.57
FeO	9.31	4.43	14.34	1.79	1.87	1.58
V <sub>2</sub> O <sub>3</sub>	1.34	1.08	1.12	0.99	1.76	1.03
Nb <sub>2</sub> O <sub>5</sub>	–	–	–	–	–	–
Total	99.05	101.39	100.27	100.06	100.12	101.18

into hematite and rutile both in nature and in experiments. This mineral contains only ferric iron, and therefore its exsolution must result in the formation of hematite rather than magnetite. Furthermore, the calculated average composition of the protomineral is strongly different from that of pseudobrookite. The average composition of the mixture obtained in the scanning mode on the electron microscope is rather homogeneous and approximately intermediate between ilmenite and ferropseudobrookite (60 wt % TiO<sub>2</sub> and 40 wt % FeO). Ferropseudobrookite is metastable at high temperatures [19–21] and decomposes into an

**Table 6.** Chemical compositions of rutile-2 from xenoliths in carbonatites, wt %

Component	1	2	3	4	5	6	7
TiO <sub>2</sub>	97.84	95.93	93.84	96.02	98.61	98.13	98.36
Cr <sub>2</sub> O <sub>3</sub>	1.58	2.11	2.90	2.74	1.33	1.01	1.40
FeO	0.37	–	0.38	–	–	–	0.36
V <sub>2</sub> O <sub>3</sub>	–	–	0.93	–	–	0.88	–
Nb <sub>2</sub> O <sub>5</sub>	1.46	0.95	2.30	1.75	n.a.	n.a.	n.a.
Total	101.25	98.99	100.35	100.51	99.94	100.02	100.12

Note: n.a. denotes not analyzed.

**Table 7.** Chemical compositions of ilmenite from xenoliths in carbonatites, wt %

Sample	TiO <sub>2</sub>	Cr <sub>2</sub> O <sub>3</sub>	FeO	MgO	CaO	Total
1	44.47	1.14	49.75	1.85	0.72	97.93
2	50.64	–	45.3	1.99	0.99	99.23
3	49.42	0.69	49.61	–	–	99.72
4	51.91	0.29	46.71	1.81	0.86	101.59
5	51.06	0.40	46.83	1.82	0.82	100.94
6	51.04	–	48.42	0.62	1.06	101.54
7	54.05	1.33	44.19	–	–	99.58

Note: MnO was not detected.

ilmenite–rutile mixture. At the same time, it is known that ilmenite is a rather stable mineral. Ilmenite from the Vesely occurrence does not show visible evidence of alteration. Nevertheless, ilmenite decomposition with formation of rutile and hematite or magnetite and ulvospinel were described in some publications.

Several mechanisms can be supposed for the formation of the rutile + magnetite assemblage in our case. The initial phase could be rich in ferrous iron, which was responsible for the formation of rutile and magnetite during its exsolution. Another variant assumes reducing conditions providing partial transformation of ferric iron into ferrous iron. Both variants merit attention and need to be evaluated.

## CONCLUSIONS

The enrichment of carbonatites from the Vesely occurrence in Cr was established. The elevated Cr content is caused by the presence of presumably mantle-derived xenoliths. It is not yet clear where these xenoliths were captured. At the same time, the absence of comagmatic alkaline silicate rocks and some mineralogical and geochemical features of the rocks provide some grounds to suggest that the carbonatites of this occurrences are direct products of mantle melting

rather than differentiates of a silicate–carbonate melt formed in a transitional magma chamber.

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