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Fe-Ti-V Deposits of Eastern Siberia: Their Similarities and Differences

Bronislav Gongalsky[1], Nadezhda Krivolutskaya[2], Anton Yakushev[1], Vladimir Taskaev[1]

[1]Institute of Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry RAS, Staromonetny per., 35, Moscow, 119017, Russia
[2]Vernadsky Institute of Geochemistry and Analytical Chemistry of RAS, Kosygin st., 19, Moscow, 119991, Russia

brgon@mail.ru

Abstract. Fe-Ti-V deposits related to the basic-ultrabasic intrusions are widespread within eastern Siberia, in its northern and southern parts. Two large massifs are located in the Kodar-Udokan trough Siberian Platform, and in the Taimyr Peninsula. They are the Chineysky intrusion and the Dyumtaleysky massifs consequently. The problem of ore origin includes an estimation of parental melt composition and its evolution. To solve it, we have studied the internal structure, composition of rocks and ores from these massifs. The Chineysky lopolith has a thickness of 2.5 km and consists of four rock groups formed during different stages. Layering is a typical feature of the second group of rocks enriched in titanomagnetite. Economic Cu-Ni sulfide mineralization (Cu/Ni=10-100) concentrates within the lower boundary of the massif and includes the endo-and exocontact ore. Chineysky massif consists of basic rocks with typical crustal characteristics (Ta-Nb negative and Pb positive anomalies). The Dyumtaleysky intrusion represents a tabular body of 600 m in thickness. It consists of two groups of rocks – gabbro (upper zone, 300 m) and peridotites (lower zone, 300 m). It was suggested that they were formed at two stages. The upper zone is characterized by thin layering which is similar to the layering of the Chineysky massif. Sulfides are concentrated within the massif (between upper and lower zones) and in its endocontact zone. The mineralization consists of chalcopyrite, pyrrhotite, pentlandite, millerite, cubanite; Cu/Ni= 1-0.5. In contrast to the rocks of the Chineysky massif, the rocks of the Dyumtaleysky intrusion are characterized by patterns without Ta-Nb anomaly. Gd/Yb ratio demonstrates the origin of these two massifs from different magma sources: shallow for the Chineysky intrusion and deep (with garnet) for the Dyumtaleysky one. Thus, Fe-Ti-V deposits could be formed from different magmas but contain the same type of ores because the leading process of ore formation is a multiple fractional crystallization.

1. Introduction

Magmatic deposits related to basic-ultrabasic intrusions are the main source of Cr, V, Ni, PGE in the world, they supply a significant amount of Fe, Ti, Cu, Se, Te Co well. They are subdivided into two types represented by oxide (Bushveld, Panzhihua, [1-3]) and sulfide (Sudbury, Norilsk, Voicey's Bay, [4-6]) ores usually separated in space minerals. In rare cases, these ores are combined in a single intrusion. The examples of these complex ores are the Chineysky and Dyumtaleysky layered massifs in East Siberia (figure 1). The Chineysky massif is located in the south of the Siberian platform (the Aldan shield) while the Dyumtaleysky massif occurs in the Taimyr peninsula belong to the Yenisei–Aldan metallogenic belt [7]. Despite different size and composition, these intrusions have many common features. They are characterized by good layering and economic mineralization. The origin of the sulfide and titanomagnetite ores of these intrusions (including sources and mechanism of concentration of metals) is under discussion for a long time [8-10]. The main goal of this study is to estimate the magmas compositions to solve some genetic problems.

2. Objects and methods

We have studied the geochemistry of rocks and minerals from the Chineysky and Dyumatleysky intrusions (figure 1) based on the 83 and LP-1 borehole consequently. We have analyzed major elements in rocks by XRF at Institute of Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry RAS, using WD spectrometer (model Axios mAX, PANalytical, Netherlands). Trace elements in rocks were determined by ICP-MS at the Institute of Microelectronics Technology and High Purity Materials RAS (analyst V.K. Karandashev). Mass-spectral determination of elements was performed with an X-7 quadrupole mass spectrometer (Thermo Scientific, USA) at the following parameters: plasma power of 1300 W, argon plasma flow rate – 13 l/min. We have studied rock-forming and ore minerals compositions by electron micrioprobe using GEOL JXA 8200 SuperProbe (1-2-3 Musashino, Akishima, Tokyo, Japan) at IGEM RAS.

Figure 1. Position of the studied deposits in eastern Siberia

3. Brief geology

Eastern Siberia comprises the Siberian platform and surrounding folded belts. The Siberian platform consists of AR foundation and V-P_2 sediments covered by P_3-T_1 volcanic rocks (Siberian flood basalts, 251 Ma, [11]). Tuffs, tholeiitic basalts and coeval numerous intrusive bodies form the Siberian trap province [12,13] which includes magmatic rocks of the Taimyr peninsula as well. Numerous PGE-Cu-Ni deposits related to these magmatic rocks are located in the Noril'sk area. Several mineralized intrusions were discovered in Taymyr too. The Dyumtaleysky massif is the most important object in this area because it comprises both Cu-Ni and Fe-Ti-V ores (figure 1). It is located in the boundary of the terrigenous-coal-bearing rocks C_2-P_1 and volcanic rocks. Similar intrusions with titanomagnetite and sulfide ores are located in the southern part of the Siberian platform, in its foundation (Aldan Shield). The Chineysky massif occurs in the Kodar-Udokan trough [14, 15] in Paleoproterozoic sedimentary rocks of the Udokan Super Group.

4. Results and discussions

4.1. The internal structure of the Chineysky and Dyumtaleysky layered intrusions

The Chineysky massive is exposed on the square of 120 km^2 and has a thickness around 2.5 km (Figure 2). It consists of gabbroids (gabbro, gabbronorites, anorthosites, leucogabbro, olivine gabbro, pyroxenites) enriched in titanomagnetite. There are four rock groups were recognized in the massif: (1)

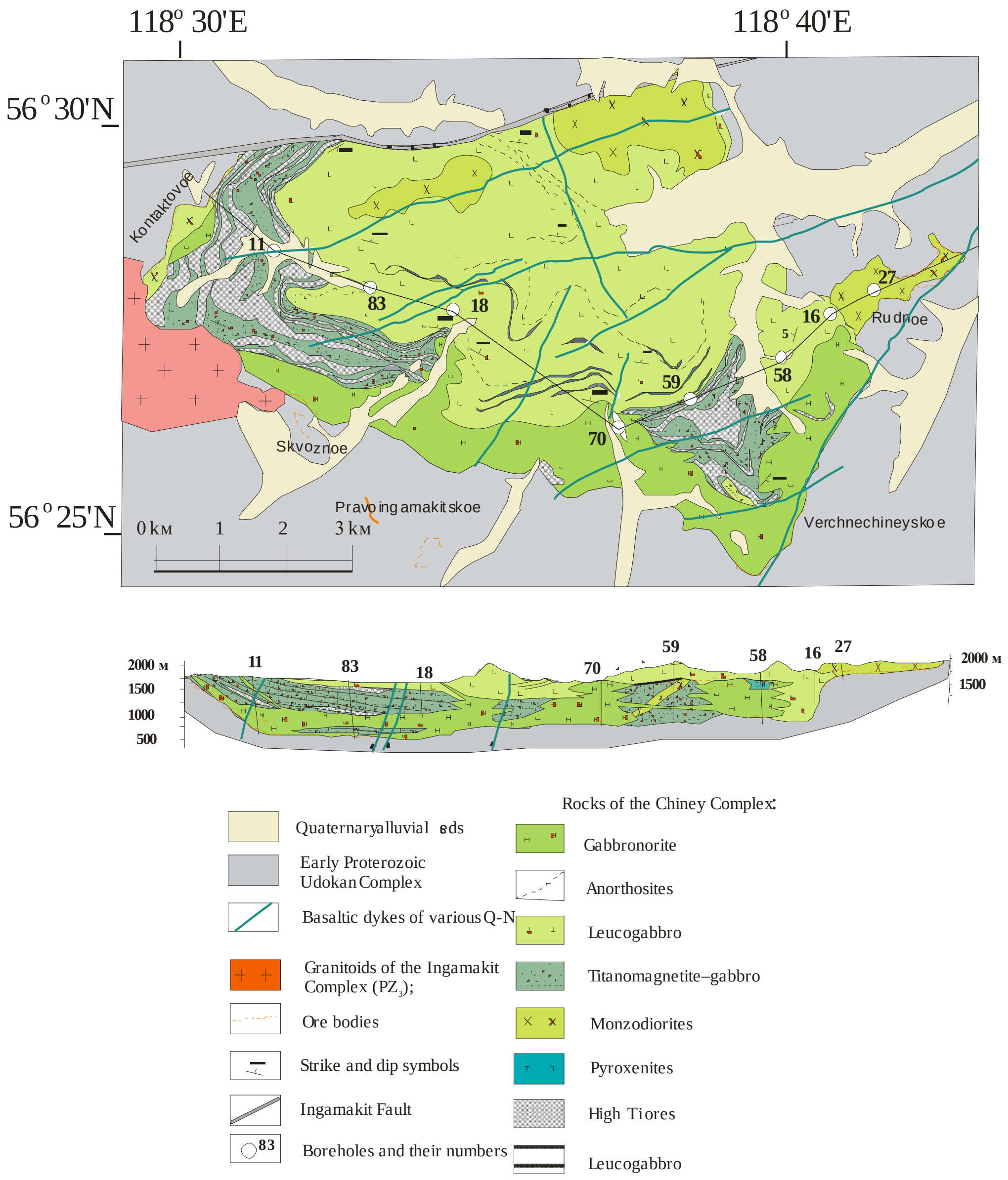

Figure 2. Schematic geological map of the Chineysky massif (after [16])

Coarse-grained anorthosite and monzodiorite, (2) high-Ti gabbroic rocks, (3) low-Ti gabbroic rocks, (4) lamprophyres and fluid–magmatic breccias that are the results of different magma injections.

The rocks of the second and third groups take about 90 vol % of the Chineysky massif and are characterized by distinct layering. There are two types of layering. The first type of layering is well distinguished on the surface due to the alternation of white anorthosite layers with dark gabbro layers of 2-5 m in thickness. The second type of layering is observed in cores of boreholes and reflects the internal structure layers because titanomagnetite accumulates near their bottom.

The middle part of the intrusion is consists of gabbro and gabbronorites while anorthosits dominate in the upper part. The maximal amount of titanomagnetite is concentrated in the middle part of the intrusion where the volume of oxide minerals in rocks changes from 7-10 to 90-100 %. For the first time, M. N. Petrusevich discovered titanomagnetite ore in the Chineysky massif [17]. Sulfides ore are located in the lower part of the massive and outside the intrusive rocks, in sandstones. They are represented by disseminated and massive varieties. Many rare minerals of platinum group elements were found here [18, 19].

The Dyumtaleysky intrusion (figure 3) represents a tabular body of 600 m in thickness. It was followed by boreholes in 50 km. It consists of two groups of rocks – gabbro (upper zone, 300 m) and peridotites (lower zone, 300 m). It was suggested that they were formed at two stages. The upper zone is characterized by layering which is similar to the layering of the Chineysky massif (figure 4). The concentration of titanomagnetite forms disseminated and massive ores of the ribbon shape. There is no massive ore of irregular form. Sulfides are concentrated within the massif (between upper and lower zones) and in its endocontact zone. The mineralization consists of chalcopyrite, pyrrhotite, pentlandite, millerite, cubanite; Cu/Ni= 1-0.5.

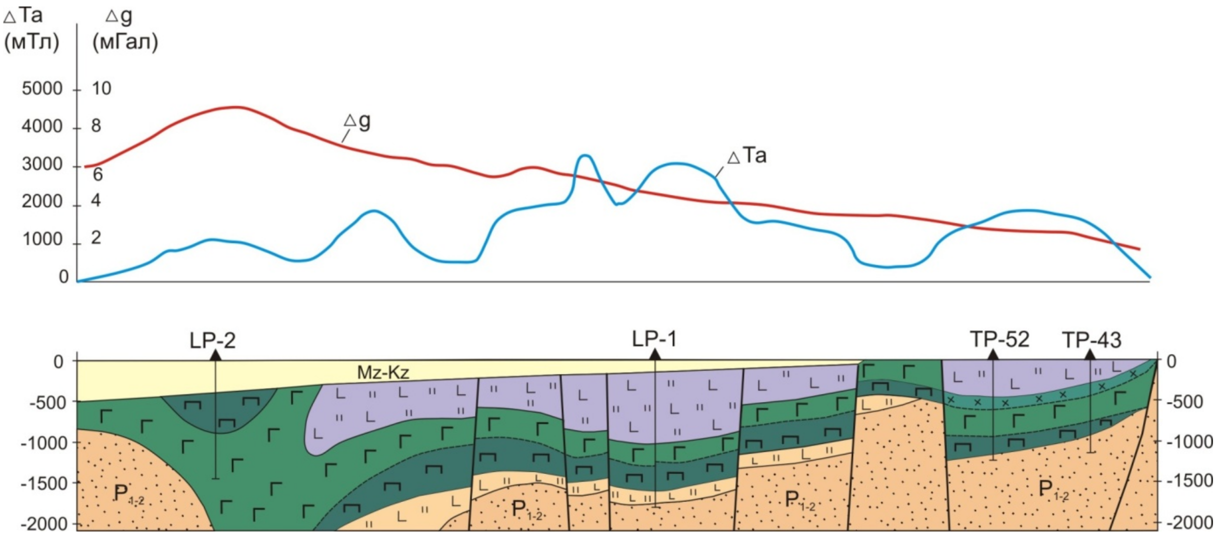

Figure 3. Schematic cross-section of the Dyumatleysky massif (after NorilskGeologia data)

The main ore-forming minerals of these two massifs are clinopyroxene, orthopyroxene, olivine, titanomagnetite; rare minerals are zircon, apatite, titanite. But their relationships are different in these massifs: orthopyroxene is more abandoned in the Chineysky pluton while olivine is rare mineral here. The Dyumtaleysky intrusion consists of typical gabbro and verhlites.

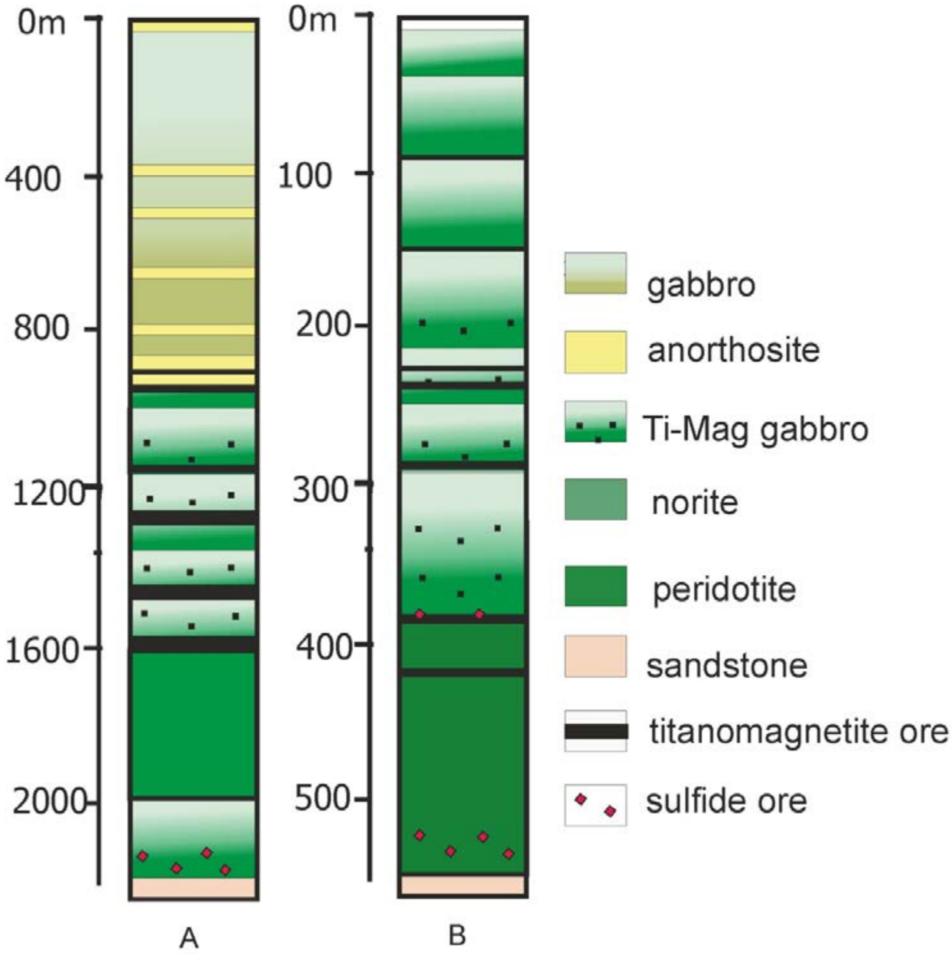

Figure 4. Sections of the Chineysky and Dyumtaleysky intrusions

Comparison of the clinopyroxene compositions of the Chineysky massif with compositions of this mineral from the Dyumataeysky intrusion and Bushveld Complex (table 1) demonstrates its specific features: it is characterized by lower Mg#, Cr_20_3, CaO, NiO and higher TiO_2, MnO contents in comparison with the pyroxenes of the Dyumtaleysky and Bushveld plutons. These data reflect the different rocks compositions of these

4.2. Titanomagnetite ores of the Chineysky and Dyumtaleysky layered intrusions
The package of high-Ti layered rocks in the middle part of the Chineysky massif forms the Etyrko Fe-Ti-V deposit in its western part. Massive titanomagnetite ores of irregular shape and lenses occur in its eastern part forming the Magnitny deposit. In the upper part of the massif, the disseminated titanomagnetite ores are associated with mesocratic gabbro and a great amount of anorthosites and leucocratic varieties. The lower member of this sequence is characterized by the association of massive ores with anorthosites. One of the titanomagnetite layers is exposed at the bank of the Lower Ingamakit River, where the two-member section crops out. The thickness of titanomagnetic layers in the lower and upper rhythms are 1.5 and 3.0 m, respectively. The upper parts of rhythms are composed of massive gabbronorite. The titanomagnetite ore layers are strongly fragmented. Being the most brittle, they undergo intense bedding-plane deformations.

Table 1. Representative analyses of clinopyroxenes from the studied intrusions, wt%

No	Sample, No	Mg#	SiO_2	FeO	MgO	CaO	Al_2O_3	Na_2O	TiO_2	Cr_2O_3	MnO	NiO
1	503-3a	72.80	51.29	9.56	14.36	20.90	2.64	0.34	0.66	0.00	0.31	0.00
2	503-4	72.53	50.94	9.34	13.82	21.42	3.02	0.42	0.70	0.00	0.29	0.00
3	503-5	71.01	51.07	11.58	15.91	17.64	2.54	0.26	0.65	0.00	0.34	0.01
4	508-65	65.96	51.32	12.32	13.39	18.29	2.30	0.18	0.46	0.00	0.26	0.00
5	508-66	67.50	50.62	11.15	12.98	21.51	2.51	0.32	0.71	0.00	0.31	0.00
6	508-67	65.42	49.34	13.11	13.91	13.44	5.24	0.67	1.25	0.00	0.17	0.00
7	876-29	63.76	52.12	18.05	17.80	10.24	1.54	0.15	0.34	0.01	0.45	0.01
8	876-30	70.93	51.69	10.14	13.88	21.36	1.25	0.31	0.40	0.01	0.25	0.01
9	876-31	63.18	52.37	21.94	21.12	2.83	1.37	0.06	0.32	0.02	0.45	0.02
10	876-32	63.78	52.52	21.67	21.41	3.02	1.09	0.04	0.26	0.02	0.47	0.02
11	1269.5	77.28	52.30	7.90	15.07	22.34	2.77	0.49	1.39	0.00	0.21	0.04
12	1269.5	77.42	52.27	7.84	15.08	22.50	2.41	0.50	1.16	0.03	0.23	0.00
13	1193.6	74.59	52.60	9.24	15.22	21.04	3.12	0.58	1.64	0.00	0.26	0.03
14	1193.6	75.39	51.42	8.28	14.23	22.18	3.76	0.55	1.74	0.01	0.22	0.01
15	1383.3	75.87	50.15	8.19	14.44	22.09	3.56	0.55	1.80	0.02	0.20	0.00
16	1383.3	75.46	50.30	8.18	14.11	21.96	3.58	0.50	1.85	0.01	0.17	0.03
17	1383.3	76.85	50.85	7.84	14.59	22.20	3.02	0.56	1.58	0.00	0.18	0.00
18	1610.3	80.29	53.04	6.97	15.93	21.42	1.23	0.56	0.55	0.21	0.24	0.05
19	1610.3	80.43	53.31	6.92	15.96	21.65	1.14	0.57	0.52	0.22	0.20	0.07
20	25-254	80.36	53.16	6.71	15.40	22.76	1.00	0.09	0.26	0.24	0.20	0.05
21	25-255	80.06	53.18	6.75	15.20	22.63	1.36	0.23	0.40	0.27	0.17	0.06
22	25-256	80.45	52.65	6.56	15.14	22.77	1.77	0.20	0.33	0.29	0.17	0.06
23	25-257	80.42	53.12	6.68	15.39	22.68	0.92	0.17	0.26	0.26	0.18	0.06

Note. No Analyses, Massif: 1-10 – Chineysky, 11-19 – Dyumtaleysky, 20-23 – Bushveld.

Table 2. Representative analyses of oxide minerals from studied intrusions, wt%

No	FeO	Cr_2O_3	TiO_2	NiO	ZnO	MnO	V_2O_3	CaO	MgO	Al_2O_3	SiO_2
1	90.14	0.05	2.49	0.06	0.02	0.09	1.38	0.02	0.01	0.88	0.04
2	90.45	0.04	3.99	0.03	0.06	0.11	1.47	0.01	0.05	1.28	0.01
3	84.65	0.01	9.13	0.04	0.10	0.24	1.42	0.02	0.02	0.76	0.06
4	88.85	0.10	4.40	0.03	0.03	0.13	1.53	0.01	0.03	0.49	0.05
5	48.73	0.02	50.67	0.00	0.00	1.47	0.21	0.00	0.08	0.02	0.04
6	50.41	0.02	47.96	0.00	0.04	1.25	0.24	0.03	0.04	0.01	0.01
7	40.52	0.16	51.36	0.06	0.01	0.81	0.15	0.02	3.09	0.02	0.03
8	41.72	0.23	53.10	0.04	0.00	0.77	0.18	0.01	2.98	0.02	0.00
9	79.12	3.52	3.74	0.24	0.11	0.19	0.62	0.01	0.79	3.21	0.01
10	73.94	5.84	6.98	0.27	0.22	0.30	0.64	0.02	0.83	3.60	0.00
11	76.08	5.62	5.27	0.25	0.16	0.26	0.74	0.02	0.85	3.34	0.01

Note. Analyses, Massifs: 1-7- Chineysky, 8-11 – Dyumtaleysky.

Disseminated titanomagnetite ores in the Dyumtaleysky intrusion are situated in gabbro and olivine gabbro. Massive ores are located in the bottom of the gabbro series. Titanomagnetite occurs in the lower part of the section, in peridotites, as well but it has no

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economic value here. Main ore minerals are titanomagnetite and ilmenite in both deposits (figure 5 a-f). These minerals are characterized by different contents of impurities. The titanomagnetite from the Chineysky massif is enriched in TiO_2, V_2O_3 and Al_2O_3 and depleted in MgO, NiO and Cr_2O_3 in comparison with the titanomagnetite of the Dyumtaleysky massif (table 2).

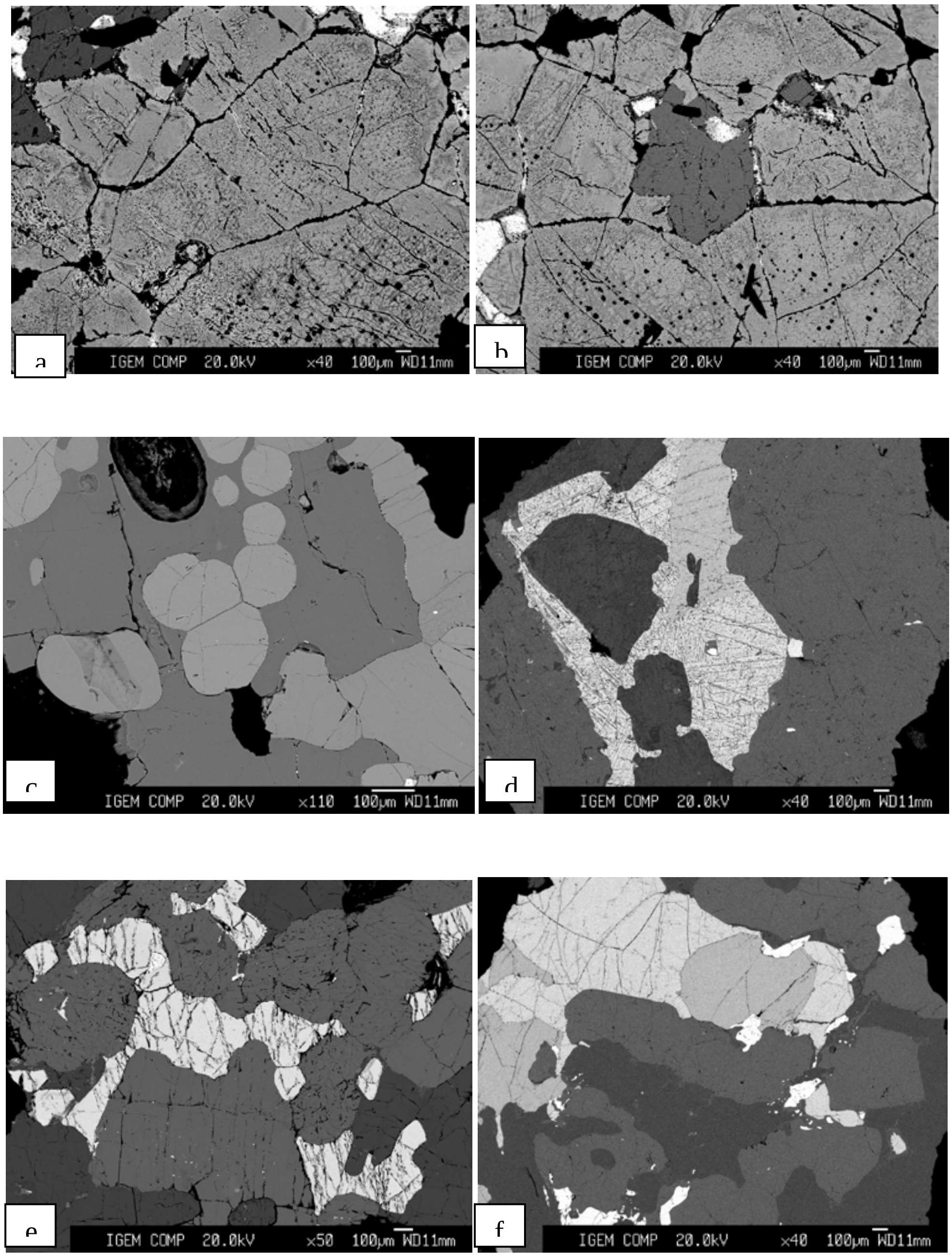

Figure 5. The texture of rocks and titanomagnetite disseminated ores of the Chineysky (a-b) and Dyumtaleysky (c-f) intrusions

4.3. Discussion

The chemical composition of rock-forming minerals (pyroxene, titanomagnetite) reflects the different composition of primary magmas of the Chineysky and Dyumtaleysky intrusions taking into account the major components, i.e. SiO_2 and MgO. The rocks of the Chineysky massif crystallized from tholeitic magma with 6-7 wt% MgO and crustal signatures (negative Ta-Nb anomaly and positive Pb anomaly). In contrast to the rocks of the Chineysky massif, the rocks of the Dyumtaleysky intrusion were formed from high-Mg magma characterized by patterns without Ta-Nb anomaly. Gd/Yb ratio demonstrates the origin of these two massifs from different magma sources: shallow for the Chineysky intrusion and deep (with garnet) for the Dyumtaleysky one. Thus, Fe-Ti-V deposits could be formed from different magmas but contain the same type of ores because the leading process of ore formation is multiple fractional crystallization.

5. Conclusions

Fe-Ti-V ores of the deposits located in Eastern Siberia, despite the similar internal structure and ore compositions, were formed from different parental magmas: mantle for the Dyumtaleysky massif and crustal for the Chineysky massif crustal. The leading process of its origin is a fractional crystallization.

Acknowledgments

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