Chromitites of Ultramafic Complexes of the Valizhgen Peninsula, Koryak Highland

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Abstract—This paper covers the results of a study of ore and accessory chromite mineralizations in an ultramafic rock complex of the Valizhgen Peninsula. It was found that the chromite mineralization belongs to the podiform type, is located in lens-shaped dunite bodies, and is represented by several structural-textural varieties. The ore and accessory chrome-spinellides have some specific compositional features in the rocks of either series distinguished as follows: chrome-spinellides of the cumulative dunite–orthopyroxenite–chromitite series have elevated Cr, Ti, and Fe^{3+} contents, while spinellides from residual harzburgites are typically low in TiO_2 and Fe_2O_3 and variable in Cr and Mg contents. The specific location of chromitites in mafic–ultramafic massifs of the peninsula and the composition of ore and accessory chrome-spinellides from ultramafics can be accounted for by an interaction of primitive mantle magmas with host harzburgites. The calculations using mineral thermobarometry indicate a relatively low pressure and high temperature and oxygen fugacity during the formation of chromite mineralization. The chemical and Re-Os isotopic compositions were also studied for platinum group element (PGE) minerals from placers of the Valizhgen Peninsula. It is suggested that chromitites of the mafic-ultramafic massifs are sources of these placers.

INTRODUCTION

Most of the Alpine-type ultramafic massifs of Koryakia and eastern Kamchatka, except for small bodies, include chromite ore mineralization of podiform type after Trayer (1969). This mineralization varies in scale from large commercially valuable ore occurrences in the Kuyul'sk, Krasnogorsk, and Tanvatnei massifs to small veins and schlieren, as well as alluvial heaps of blocks and separate boulders, only of mineralogical interest. There is a distinct correlation between the rock composition and scale of chromite mineralization: the largest ore occurrences are confined to the strongly depleted rocks of the dunite-harzburgite series, whereas the slightly depleted lherzolites generally contain accessory chrome-spinellides (Dmitrenko *et al.*, 1990). The strongly depleted spinellide harzburgites, the main ultramafic rock variety of the Valizhgen Peninsula, are of great interest with respect to chromite ore mineralization. The ultramafic rocks of the Valizhgen Peninsula have been known for a long time. However, the related chromite mineralization has not been studied in detail yet. In this paper, we characterize the ore and accessory chromite mineralizations in ultramafic rocks of various types, consider some aspects of the chromitite formation, and estimate the chromite potential of

the massifs of the peninsula. Bearing in mind a close relation of PGE to chromite mineralizations, we could also estimate the prospects of the region for mineral accumulations of the platinum group elements (PGE).

GEOLOGY

Ultramafic rocks are abundant in the Valizhgen Peninsula in the southwestern part of the Koryak Highland and belong to the Talovo–Pekul'nei ophiolite belt comprising ophiolites of various ages and peridotites and gabbroic rocks of various petrochemical types (Palandzhyan, 1992). More than a hundred isolated ultramafic rock bodies scattered over the Valizhgen rise are suggested to be fragments of a large low-angle plate-shaped body composed of several sheets (Velinskii, 1979; Chekhov, 1982). Ultramafic rocks, together with associating gabbroids and Paleozoic (?) silicic-tuffaceous rocks, occur among the slightly deformed Upper Jurassic-Lower Cretaceous terrigenous rocks of the Myalekasyn and Tylakryl suites (Fig. 1). The ultramafic rocks always have tectonic contacts with host arkose sandstones and siltstones. All these rocks are overlain by terrigenous Upper Cretaceous deposits at the flanks of the rise.

The largest ultramafic rock body, the Dlinnaya Mt. (Dlinnogorsk) Massif, to which the main occurrences
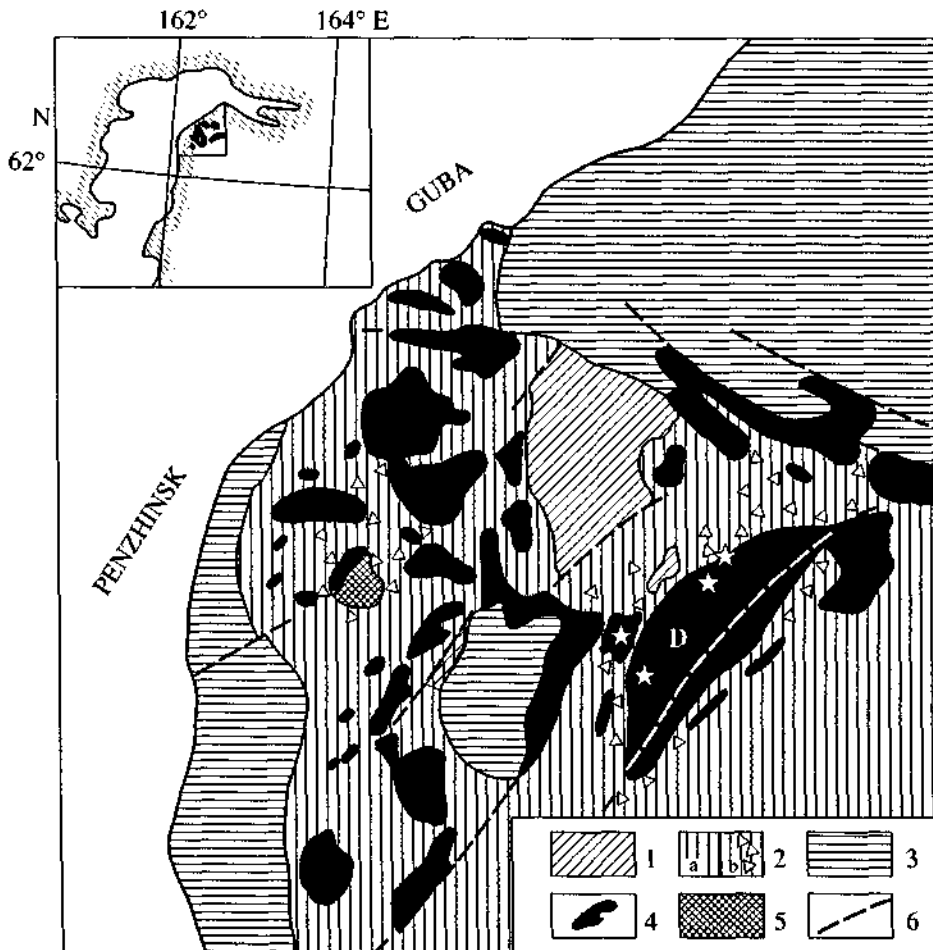
Fig. 1. Location and geological scheme of the Valizhgen rise (modified after Kolyasnikov and Krasnyi, 1981). (1) Paleozoic–Mesozoic (?) silicic-tuffaceous rocks; (2) Lower Cretaceous terrigenous rocks: straticulate (a), coarse clastic (b); (3) Upper Cretaceous terrigenous rocks; (4) ultramafics and their breccias; (5) gabbroids; (6) faults. D represents the Dlinnaya Mt. mafic–ultramafic massif. Chromitite bedrock outcrops are shown with stars.

of the chromite ore mineralization are related, is located in the central part of the Valizhgen rise and is about 13 km in extent and 42 km² in total area. The massif is a plate-shaped body slightly concave at the central part. The tectonic contacts of the massif with host rocks are marked by the development of thick zones of mylonitization and cataclasis both in the terrigenous and ultramafic rocks. The specific structure of the massif is defined by the juxtaposition of massive rocks of the dunite-harzburgite association with cataclastic ultramafic rocks varying in clast sizes from ultramafic breccias to sedimentary serpentinite sandstones and siltstones. The structure and rock composition of the Dlinnaya Mt. Massif were considered in many publications (Mikhailov, 1962; Pinus *et al.*, 1973; Chekhov, 1982; Palandzhan, 1992; etc.), and the origin of the exotic ultramafic sedimentary rocks is the subject of discussion (Kolyasnikov and Krasnyi, 1981; Markovskii, 1988; etc.).

The ultramafic rocks are represented by varieties typical of the lower horizons of the ophiolite association after R. Coleman (1979): tectonized residual peridotites and cumulative ultramafic rocks of the dunite-orthopyroxenite series. The massive ultramafic rocks of the largest bodies (for example, the Dlinnaya Mt. Massif) are generally composed of spinellide peridotites (harzburgites and diopside harzburgites) and apoharzburgite serpentinites. Dunites (lenses and bands in peridotites), orthopyroxenites, and websterites are less abundant. The chromite ore mineralization is related mainly to dunites. The mineral compositions of ultramafic rocks of all types studied and chemical compositions of the main rock-forming minerals are shown in Fig. 2. The ultramafics are locally cut by small dikes of gabbroids, whose emplacement caused the formation of hybrid rocks. However, the contact of serpentinized ultramafics with gabbroids in the northern part of the Dlinnaya Mt. Massif (the upper reaches of the Bukhtovaya River) is tectonic and is marked by the development of rodingites, contact calc-silicate metasomatites (Osipenko *et al.*, 2001).
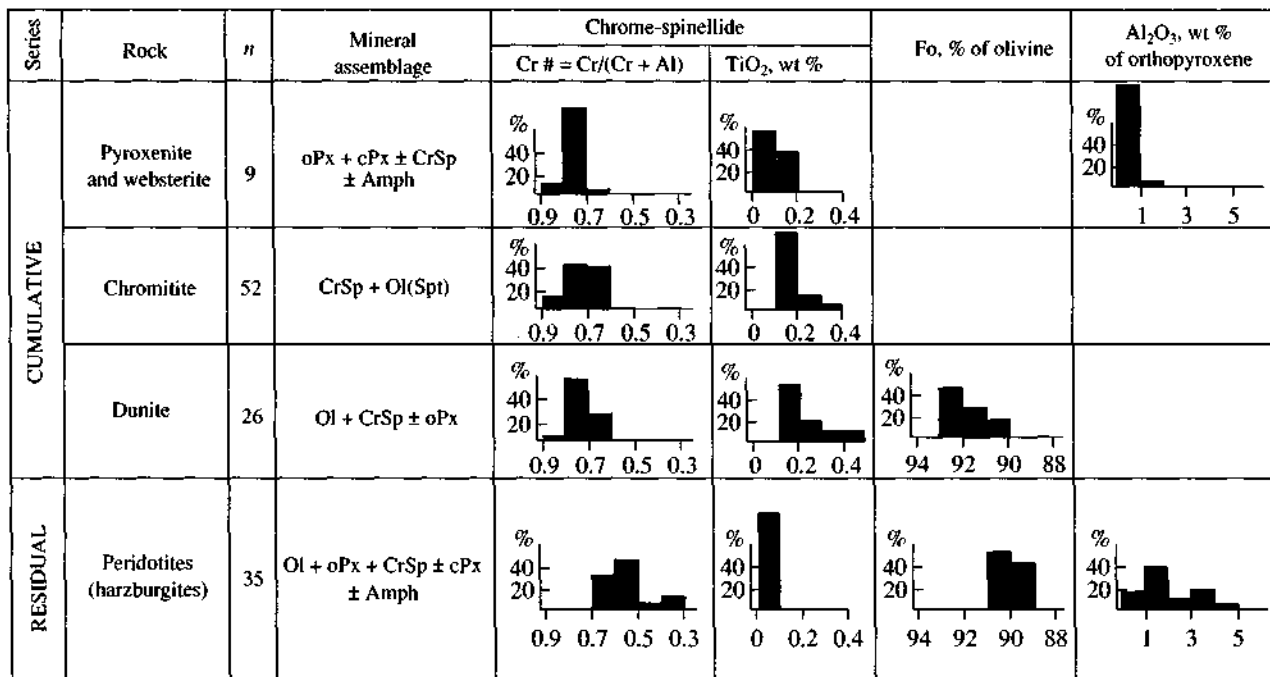
Series	Rock	n	Mineral assemblage	Chrome-spinellide		Fo, % of olivine	Al_2O_3, wt % of orthopyroxene
				Cr # = Cr/(Cr + Al)	TiO_2, wt %		
CUMULATIVE	Pyroxenite and websterite	9	oPx + cPx ± CrSp ± Amph	[histogram]	[histogram]		[histogram]
	Chromitite	52	CrSp + Ol(Spt)	[histogram]	[histogram]		
	Dunite	26	Ol + CrSp ± oPx	[histogram]	[histogram]	[histogram]	
RESIDUAL	Peridotites (harzburgites)	35	Ol + oPx + CrSp ± cPx ± Amph	[histogram]	[histogram]	[histogram]	[histogram]

Fig. 2. Mineralogical features of ultramafic rocks of the Valizhgen Peninsula: (*n*) number of samples, (Amph) amphibole, (cPx) clinopyroxene, (CrSp) chrome-spinellide (Ol) olivine, (oPx) orthopyroxene, (Spt) serpentine.

FORMS OF CHROMITE MINERALIZATION

The main chromite ore occurrences in the Valizhgen Peninsula are situated within the ultramafic massifs of the Gorelaya and Dlinnaya mountains confining more than ten ore occurrences and many sites of ore mineralization. Chromitites are localized in peridotites, which are serpentinized at a various extent. All occurrences of chromite ore mineralization are spatially related to dunites and apodunite serpentinites. The ore bodies in all ore occurrences are rimmed by dunites varying from several tens of centimeters to several meters in thickness. However, large lens-shaped dunite bodies several tens of meters thick normally bear only accessory chromite mineralization, and only some of them include small schlieren-shaped chrome-spinellide accumulations.

The largest chromite ore occurrence in the Valizhgen Peninsula is found in a cliff outcrop in the left side of the middle reaches of the Dozhdlivyi Creek (Dlinnaya Mt. Massif). The lens-shaped chromitite bodies are a few tens of meters long. Most ore bodies are concordant or subconcordant with the schistosity of host peridotites and show textures and structures indicative of ductile flow and recrystallization at high temperatures (Cassard *et al.*, 1981). The bodies are strongly cataclasized and locally show thick platy and blocky parting of ores. The strongest cataclasis is developed in contact zones between ore and host rocks. The chromitites in these zones are deformed and cut by fractures filled with a carbonate and serpentine aggregate.

The central parts of most ore bodies comprise zones of massif chromitites containing 80-95% chrome-spinellide. However, the ore bodies normally consist of disseminated mineralization with various chrome-spinellide contents. Taxitic and nodular varieties of chromite ores also occur. The chromite grains are isometric (Fig. 3a) varying in size from 0.03 to 1.2 mm (mainly, 0.2–0.4 mm). Being closely spaced, the chromite grains usually do not touch each other and are separated by silicates. The ores have massive, mottled, banded, and mottled-reticulate textures. The peripheral parts of the ore bodies have a brecciated texture (Fig. 3b). The brecciated ores consist of clasts (3-10 cm in size) of serpentinites, as well as densely disseminated to massive, medium- to coarse-grained ores, in cementing chromite aggregate. The chromite cement has typical clastic textures, porphyroclastic or rare granoclastic. The host ultramafic crush conglomerates contain ore fragments. The harzburgites contacting with the crush conglomerates include crooked veins, stringers, and bunch aggregates of chromite.

The contacts of chromitite bodies with the above-mentioned dunite rims are usually sharp. However, a transitional zone consisting of alternating layers with various chrome-spinellide contents locally exists between chromitites and dunites. The dunite rims grade outward to spinellide harzburgites (with increasing proportion of modal orthopyroxene). The thickness of the dunite rims does not correlate with the thickness of ore bodies.

The other type of the chromite ore mineralization is presented by alluvial heaps of chromitite blocks found in the middle reaches of the Gorelaya River. The heaps extend for several tens of meters. The blocks reach 25-
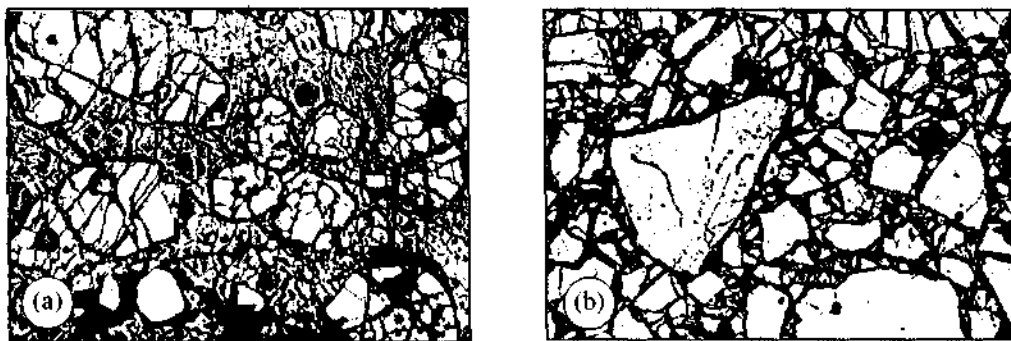
Fig. 3. Microstructural features of chrome-spinellides in various chromitites: (a) massive densely disseminated chromitite (sample 71-88); (b) brecciated chromite ore (sample 124-88). Magnification 40, one nicol.

30 cm in size and are composed of fine- to medium-grained chromite ores with banded or densely disseminated textures.

The accessory chrome-spinellides in the Valizhgen ultramafic rocks are also of great interest. Dunites have the highest content of accessory chrome-spinellide (up to 5-6 vol %). The accessory chrome-spinellide is locally accumulated to form dunites rich in chrome-spinellide. In the other rock varieties, the accessory chrome-spinellides are uniformly distributed. Their highest contents are up to 3–4 vol % in orthopyroxenites and up to 1 vol % in websterites. Chrome-spinellides are very rare in gabbroids. All accessory chrome-spinellides in the Valizhgen ultramafics are strongly cataclasized and cut by thin serpentine stringers. Chrome-spinellides are usually replaced by magnetite at the grain margins and in fractures. The accessory chrome-spinellides in orthopyroxenites and websterites usually show exsolution textures (magnetite grid).

CHEMICAL COMPOSITIONS OF CHROME-SPINELLIDES

Analytical Techniques

The mineral compositions were analyzed with a *Camebax-micro* microprobe with EDS *Kevex* in the Institute of Volcanology, Far East Division, Russian Academy of Sciences, Petropavlosk-Kamchatskii (analysts V.M. Chubarov, S.V. Moskaleva, and T.M. Filosofova). The compositions were measured in points using an accelerating voltage of 20 kV, beam current of 15 nA (20–30 nA for the PGE minerals), counting time of 10 s at every analytical line, and standard correction procedures and programs considering the calculated coefficients for interference lines. Synthetic and natural minerals were used as standards in the analysis of chrome-spinellides and silicates, while pure metals and natural minerals were utilized in the analysis of PGE minerals (analytical lines M_α for Os; K_α for S, Fe, and Cu; and L_α for the other elements).

Spinellides

The representative analyses of chrome-spinellides from various ultramafic rocks of the Valizhgen Peninsula are shown in Tables 1 and 2. The mineral formulas are recalculated to 32 oxygen atoms. The ferrous and ferric irons are calculated from mineral stoichiometry. The spinellides are compositionally variable. According to the classification developed by Pavlov *et al.* (1979), chrome-spinellides of chromitites and dunites are mainly chromites and alumochromites, those from orthopyroxenites are ferrialumochromites, and chrome-spinellides from harzburgites vary from picotite to chrome picotite. The main parameters characterizing the chrome-spinellide compositions are traditionnaly Cr, Mg, TiO_2 content, and iron oxidation degree (Fe3# concentration). The variations of these parameters in ore and accessory chrome-spinellides in ultramafic rocks of the Valizhgen Peninsula are discussed below.

The chrome-spinellides from chromitites have relatively narrow ranges of Mg (0.60–0.73) and Cr (0.69–0.82) content (Table 1; Figs. 4a, 4b). These spinellides are more magnesian than those from dunites and orthopyroxenites. Spinellides from the latter two rocks are similar in Cr concentration values. It is known that Mg content of chrome-spinellides depends on spinellide and olivine proportions in a rock. It is suggested that these relationships are caused by subsolidus diffusion of Fe and Mg between chrome-spinellide and silicates on cooling (Zhou *et al.*, 1996). The Cr and Mg content values of chrome-spinellides are similar in the inner and outer parts of ore bodies and are not spatially variable. The compositions of chrome-spinellides from the massive and banded ores, as well as from cement and clasts of the brecciated chromitites, are also very similar (Table 1). All the ore chrome-spinellides analyzed are lacking the compositional zoning. All spinellides from chromitites have elevated TiO_2 contents (0.10–0.34 wt %) and iron oxidation degree (Fe3# concentration = 0.03-0.07) as compared to the accessory spinellides from harzburgites (Figs. 4b, 4c). The elevated iron oxidation degree of the ore chromitites in the Alpine-type ultramafics was also reported by some other researchers (Laz'ko, 1989; Talkhammer, 1996; etc.). In

Table 1. Compositions (wt %) of chrome-spinellides from chromites of the Valizhgen Peninsula

Components	13-88 c	13-88 r	13-1-88 c	13-1-88 r	19-88 c	19-88 r	44-1-88 c	44-1-88 r	44-2-88 c	44-2-88 r	71-88 c	71-88 r	74-88 c	74-88 r	124-88 c	124-88 r	124-2-88 c	124-2-88 r
TiO_2	0.10	0.12	0.11	0.15	0.13	0.11	0.13	0.16	0.17	0.18	0.11	0.10	0.14	0.11	0.11	0.12	0.18	0.16
Al_2O_3	13.63	13.92	12.29	12.41	8.59	8.64	16.41	16.47	15.09	15.21	14.60	14.70	16.12	16.19	8.60	8.68	12.22	12.89
Cr_2O_3	56.88	56.22	57.49	57.44	60.97	60.85	53.63	53.74	54.97	54.45	55.59	55.55	54.27	54.58	61.03	61.11	56.93	56.61
FeO^*	14.37	14.68	16.04	16.04	17.84	17.82	14.03	13.75	17.19	17.36	16.97	16.88	14.28	14.16	18.31	18.04	16.12	15.56
MnO	0.24	0.15	0.24	0.21	0.24	0.28	0.18	0.19	0.22	0.25	0.23	0.20	0.20	0.20	0.26	0.31	0.32	0.35
MgO	14.41	14.27	13.67	13.90	12.53	12.36	15.04	15.09	12.84	12.90	12.59	12.72	15.16	15.00	12.23	12.23	13.60	14.42
NiO	0.20	0.16	0.04	0.08	0.05	0.06	0.20	0.19	0.07	0.12	0.04	0.05	0.18	0.29	0.09	0.12	0.00	0.00
ZnO	0.00	0.08	0.07	0.08	0.03	0.05	0.02	0.02	0.05	0.04	0.01	0.08	0.10	0.03	0.04	0.02	0.00	0.00
Total	99.83	99.60	99.95	100.31	100.38	100.17	99.64	99.61	100.60	100.51	100.14	100.28	100.45	100.56	100.67	100.63	99.37	99.99
$Fe_2O_3^{**}$	2.93	2.91	3.46	3.69	3.98	3.83	3.11	2.86	2.58	2.98	2.17	2.24	3.36	3.10	4.00	3.80	3.57	4.05
FeO^{**}	11.73	12.06	12.93	12.72	14.25	14.37	11.23	11.18	14.87	14.68	15.01	14.86	11.26	11.37	14.71	14.62	12.90	11.91
Ti	0.019	0.023	0.021	0.029	0.025	0.022	0.024	0.030	0.032	0.034	0.021	0.019	0.026	0.020	0.022	0.023	0.035	0.030
Al	4.055	4.150	3.692	3.709	2.631	2.654	4.814	4.831	4.482	4.516	4.370	4.389	4.700	4.718	2.633	2.657	3.691	3.840
Cr	11.348	11.238	11.581	11.511	12.522	12.533	10.550	10.570	10.948	10.840	11.157	11.123	10.610	10.677	12.527	12.544	11.532	11.310
Fe^{3+}	0.557	0.554	0.663	0.704	0.779	0.751	0.583	0.535	0.489	0.564	0.415	0.428	0.625	0.576	0.782	0.742	0.689	0.771
Fe^{2+}	2.479	2.553	2.758	2.699	3.100	3.135	2.339	2.328	3.136	3.095	3.191	3.151	2.330	2.354	3.197	3.179	2.768	2.521
Mn	0.051	0.032	0.052	0.045	0.053	0.062	0.038	0.040	0.047	0.053	0.050	0.043	0.042	0.042	0.057	0.068	0.070	0.075
Mg	5.427	5.385	5.198	5.258	4.858	4.806	5.585	5.603	4.827	4.848	4.770	4.808	5.595	5.534	4.739	4.739	5.200	5.438
Ni	0.041	0.033	0.008	0.016	0.010	0.013	0.040	0.038	0.014	0.024	0.008	0.010	0.036	0.058	0.019	0.025	0.000	0.000
Zn	0.000	0.015	0.013	0.015	0.006	0.010	0.004	0.004	0.009	0.007	0.002	0.015	0.018	0.005	0.008	0.004	0.000	0.000
Cations	23.977	23.983	23.986	23.986	23.984	23.986	23.977	23.979	23.984	23.981	23.984	23.986	23.982	23.974	23.984	23.981	23.985	23.985
Cr#	0.74	0.73	0.76	0.76	0.83	0.83	0.69	0.69	0.71	0.71	0.72	0.72	0.69	0.69	0.83	0.83	0.76	0.75
Mg#	0.69	0.68	0.65	0.66	0.61	0.61	0.70	0.71	0.61	0.61	0.60	0.60	0.71	0.70	0.60	0.60	0.65	0.68
Fe3#	0.03	0.03	0.04	0.04	0.05	0.05	0.04	0.03	0.03	0.04	0.03	0.03	0.04	0.04	0.05	0.05	0.04	0.05

Note: Samples 13-88 and 13-1-88 are poorly disseminated banded ores (Gorelaya R.), samples 44-1-88 and 44-2-88 are massive chromitites (Dozhdlivyi Creek), sample 71-88 is densely disseminated banded ore (Dozhdlivyi Creek), sample 74-88 is a chromitite schlieren in dunite (Dozhdli'vyi Creek), samples 124-88 and 124-2-88 are brecciated chromite ores (124-88 is chromite from a clast and 124-2-88 is chromite from breccia matrix) (Dozhdli'vyi Creek). Here and in Table 2: * all iron is given as FeO; ** Fe_2O_3, and FeO are calculated by the stoichiometry; c, grain cores; r, rims; and tz, transitional zones; Cr# amount = Cr/(Cr + Al), Mg# amount = Mg/(Mg + Fe^{2+}), Fe3# amount = $Fe^{3+}/(Fe^{3+} + Cr + Al)$.

Table 2. Compositions (wt %) of chrome-spinellides from ultramafic rocks of the Valizhgen Peninsula

| Rock	Dunite												Peridotite					Orthopyroxenite and websterite			
	6-1-88		7-88		10-88			4-1-88		4-3-88			30-88	36-88	5-88		17-2-88	
Components	c	r	c	r	c	tr	r	c	r	c	tr	r	c	c	c	r	c	r
TiO_2	0.13	0.21	0.13	0.22	0.18	0.22	0.18	0.01	0.00	0.04	0.00	0.00	0.01	0.01	0.09	0.05	0.13	0.07
Al_2O_3	13.95	13.82	12.18	11.77	8.90	9.20	8.66	18.38	17.93	26.01	25.69	27.35	15.67	37.74	12.93	13.20	11.64	12.85
Cr_2O_3	54.92	54.90	56.65	57.45	60.89	60.81	61.57	52.16	51.42	44.01	43.22	41.47	54.17	30.25	53.93	54.45	54.12	52.63
FeO^*	19.47	20.09	20.24	21.15	18.04	16.79	19.14	20.86	21.53	17.11	17.24	17.53	18.44	15.36	24.45	23.53	27.08	27.50
MnO	0.29	0.35	0.30	0.42	0.47	0.46	0.46	0.46	0.43	0.23	0.20	0.12	0.43	0.08	0.52	0.43	0.55	0.43
MgO	11.64	11.09	10.48	9.55	11.53	11.46	10.37	9.72	9.58	13.80	13.34	13.21	11.38	16.47	8.93	8.90	6.96	6.24
NiO	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.02	0.00	0.00	0.00
ZnO	0.00	0.00	0.05	0.00	0.00	0.06	0.00	0.20	0.10	0.12	0.05	0.09	0.11	0.10	0.01	0.01	0.12	0.22
Total	100.40	100.46	100.03	100.56	100.01	99.07	100.38	101.79	100.99	101.32	99.74	99.77	100.21	100.10	100.88	100.57	100.60	99.94
$Fe_2O_3^{**}$	3.31	3.06	2.68	2.03	2.72	1.60	1.88	0.75	1.54	2.08	1.98	1.71	1.77	1.99	4.42	3.33	4.45	3.69
FeO^{**}	16.49	17.34	17.83	19.33	15.59	15.35	17.45	20.19	20.14	15.24	15.46	15.99	16.85	13.67	20.47	20.52	23.07	24.17
Ti	0.025	0.041	0.025	0.043	0.036	0.044	0.036	0.002	0.000	0.007	0.000	0.000	0.002	0.002	0.018	0.010	0.026	0.014
Al	4.202	4.179	3.739	3.627	2.751	2.867	2.694	5.363	5.225	7.303	7.338	7.767	4.704	10.061	3.962	4.054	3.649	4.054
Cr	11.093	11.132	11.662	11.870	12.622	12.708	12.842	10.515	10.313	8.286	8.279	7.897	10.905	5.408	11.081	11.214	11.378	11.134
Fe^{3+}	0.637	0.590	0.524	0.399	0.537	0.319	0.374	0.144	0.295	0.373	0.361	0.310	0.339	0.388	0.865	0.654	0.891	0.743
Fe^{2+}	3.527	3.723	3.888	4.229	3.423	3.397	3.854	4.250	4.278	3.038	3.135	3.225	3.592	2.529	4.455	4.477	5.137	5.417
Mn	0.063	0.076	0.066	0.093	0.105	0.103	0.103	0.098	0.093	0.046	0.041	0.025	0.093	0.015	0.115	0.095	0.124	0.098
Mg	4.438	4.245	4.073	3.725	4.512	4.521	4.083	3.648	3.627	4.905	4.824	4.749	4.325	5.558	3.464	3.460	2.762	2.492
Ni	0.000	0.000	0.000	0.000	0.000	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.016	0.004	0.000	0.000	0.000
Zn	0.000	0.000	0.010	0.000	0.000	0.012	0.000	0.037	0.021	0.021	0.009	0.016	0.021	0.017	0.002	0.002	0.024	0.044
Cations	23.985	23.986	23.987	23.986	23.986	23.986	23.986	24.057	23.852	23.979	23.987	23.989	23.981	23.994	23.966	23.966	23.991	23.996
Cr#	0.73	0.75	0.76	0.77	0.82	0.82	0.83	0.66	0.66	0.53	0.53	0.50	0.70	0.35	0.74	0.73	0.76	0.73
Mg#	0.56	0.53	0.51	0.47	0.57	0.57	0.51	0.46	0.46	0.62	0.61	0.60	0.55	0.70	0.44	0.44	0.35	0.32
Fe3#	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.05	0.04	0.06	0.05
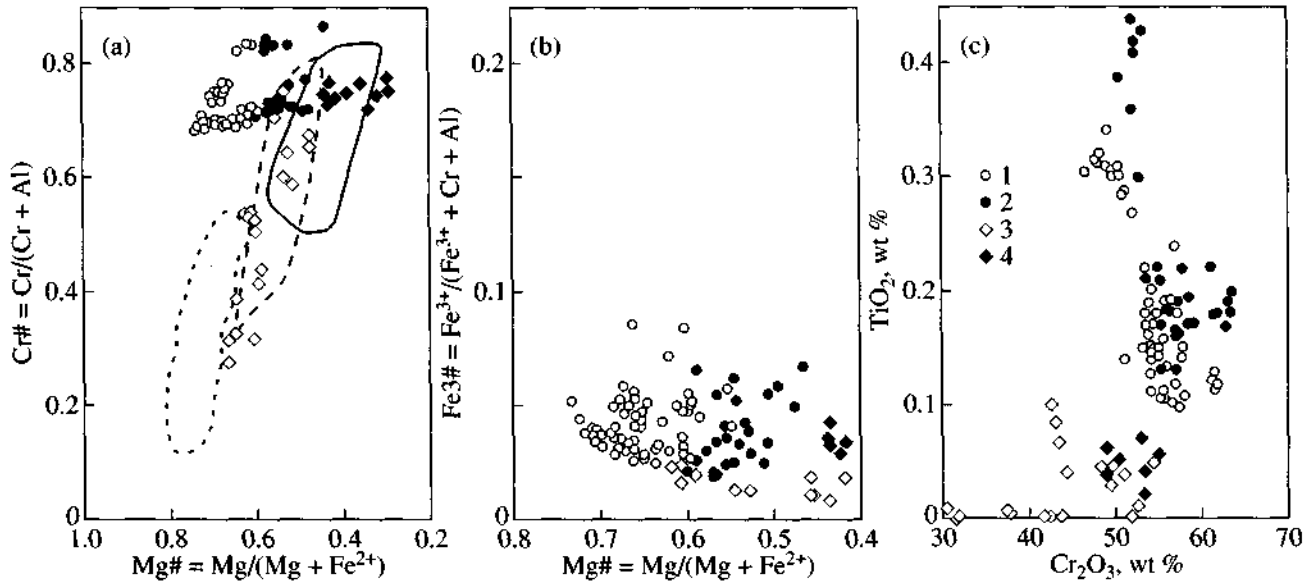
Fig. 4. Compositions of ore and accessory chrome-spinellides from ultramafic rocks of the Valizhgen Peninsula: (1) Chromitites; (2) dunites; (3) peridotites; (4) pyroxenites and websterites. (a) Shown are fields of chrome-spinellide compositions in abyssal peridotites (dotted line), island-arc peridotites (dashed line), and island-arc dunites (solid line). Compositional fields are according to Dick and Bullen (1984) and Ishii et al. (1991).

general, the ore-forming chrome-spinellides in the Valizhgen ultramafics, like in chromitites of the other Alpine-type massifs of the region, have low total iron content and belong to magnesian varieties of chromites and alumochromites. On the contrary, the ore chrome-spinellides of concentrically zoned massifs of the Vatyna–Vyvenka belt, occur as lens-shaped bodies and have Fe-rich compositions corresponding to ferrichromites and ferrialumochromites (Granovskii and Gulyaeva, 1981; Batanova and Astrakhantsev, 1992).

The Cr-richest chrome-spinellides are found in the rocks of the dunite–orthopyroxenite series (Cr content values of spinellides are 0.71–0.83 in dunites and 0.71–0.81 in orthopyroxenites). The spinellides in dunites also have elevated TiO_2 contents (0.12-0.44 wt %). There are no systematic differences between spinellide compositions in dunites, orthopyroxenites, and chromitites. This fact supports close genetic relation of these rocks, which could be comprised in a dunite–orthopyroxenite-chromitite series. A combination of elevated TiO_2 contents and with high Cr# of spinellides in the rocks of this series, as well as the high Mg content of coexisting olivine (FO_{90-93}) (Fig. 2), indicate a probable cumulative origin of chrome-spinellides and host rocks. The elevated iron oxidation degree of spinellides from dunites and chromitites (Fig. 4b) is consistent with the above conclusion. The TiO_2 contents in chrome-spinellides from orthopyroxenites of the dunite–orthopyroxenite–chromitite series are slightly lower than in those from dunites and chromitites (Fig. 4c), which is typical of chrome-spinellides from vein cumulative rocks of the mantle portion of ophiolite section (Dmitrenko et al., 1985; Ishii et al., 1992; Bazylev et al., 1999).

Chromium numbers of accessory chrome-spinellides from harzburgites of the Valizhgen Peninsula widely vary and overlap a significant part of the interval typical of the spinellide compositions in oceanic and island-arc peridotites (Fig. 4a). The Cr content of spinellide varies from 0.27 to 0.64 and positively correlates with Fe content, which is typical of residual mantle peridotites (Dick and Bullen, 1984). The spinellide compositions in most of the harzburgites studied correspond to a moderate depletion and indicate the residual nature of these rocks. The location of the mineral compositions on the classification diagrams points to a suprasubduction origin of ultramafics (Dick and Bullen, 1984; Arai, 1994; Ishii et al., 1992) (Fig. 4a). This conclusion is verified by relationships between indicative parameters of spinellides (Cr, Mg, and TiO_2 concentrations) and by the correlation of the Cr content of spinellides with that of coexisting olivine and orthopyroxene (Arai, 1994) (Figs. 5a, 5b). The Cr content of chrome-spinellides is the main parameter characterizing the peridotite depletion and depends on the rock type. It decreases regularly from spinellide harzburgites to diopside-bearing harzburgites (pseudolherzolites). This variation in the chrome-spinellide composition is related to different stages of the rock recrystallization with the development of Cr-bearing clinopyroxene. The recrystallization is also developed in websterites, whose chrome-spinellides have a lower Cr and Mg contents as compared to those in orthopyroxenites.

The distribution of the chrome-spinellide compositions from different rocks of the ultramafic massifs of the Valizhgen Peninsula in the classification diagrams is generally similar to that in many ophiolite complexes
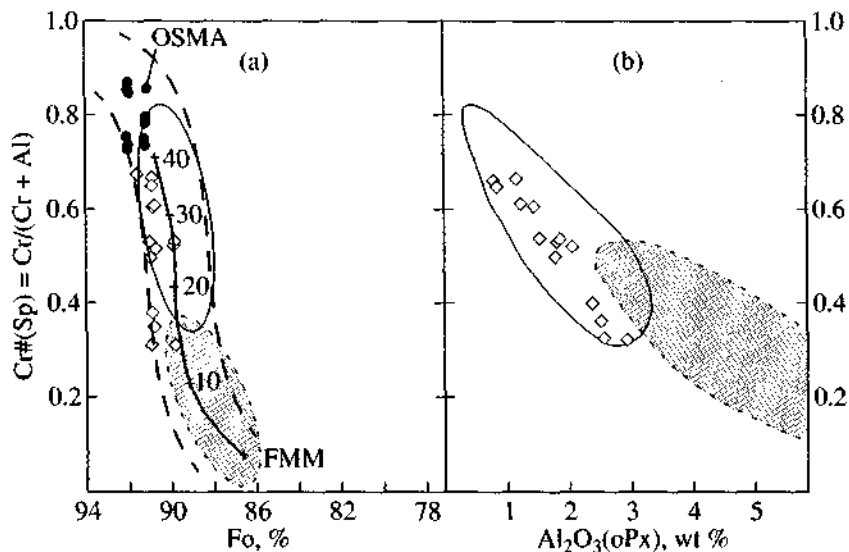
Fig. 5. Dependence of *Cr* content of chrome-spinellides on Mg content of olivine (a) and Al_2O_3 content (wt %) of orthopyroxene (b) for coexisting minerals from ultramafic rocks of the Valizhgen Peninsula: (a) The thick dashed line outlines the compositional field of equilibrium olivine–crome-spinel mantle assemblages (OSMA) (Arai, 1994). Mineral compositions in abyssal (gray) and supra-subduction (white) mantle peridotites (Pearce *el al.*, 2000). Figures near the model curve correspond to the melting degree (%) of the primary undepleted mantle source (FMM) during MORB derivation (Pearce *et al.*, 2000). (b) Compositional fields for coexisting minerals from abyssal (gray) and suprasubduction (white) mantle peridotites (Bonatti and Michael, 1989; Ozawa, 1986). See Fig. 4 for a symbol explanation.

(Dmitrenko *et al.*, 1985, 1990; Zhou *et al.*, 1996; Arai and Yurimoto, 1995; Melcher *et al.*, 1997; etc.), which probably indicates the universal character of processes of chromite formation in the complexes of this type.

DISCUSSION

Mechanism of Formation of Chromitite Ore Bodies

According to recent ideas, the principal mechanism responsible for the formation of chromite mineralization in ultramafic rocks of ophiolites [podiform type of chromitites (Thayer, 1964)] is the interaction of primitive mantle magmas with residual peridotites and mixing of magmas of various compositions (Arai, 1994; Arai and Yurimoto, 1994, 1995; Kelemen *et al.*, 1992; Zhou *et al.*, 1996; etc.). The chromitite formation can be subdivided into the following stages (Fig. 6). At stage I, a primitive mantle melt (A) penetrates the depleted peridotites along permeable zones. At relatively low pressures and high temperatures and P_{H_2O}, which are favorable for selective orthopyroxene dissolution, the latter mineral reacts and is removed from the peridotite with the formation of secondary (or residual, after Zhou *et al*, 1996) dunite and a magma (B) enriched in SiO_2 and Cr_2O_3 (stages II and III). Mixing of the secondary magma (B) with fresh portions of a primitive magma (C) causes the precipitation and accumulation of chrome-spinellide crystals and the formation of chromite ore mineralization in the newly formed dunites (stages IV and V).

This model (Fig. 6) explains specific features of chromitite location in ultramafic rocks of the Valizhgen Peninsula. All of the chromite ore occurrences are confined to the cumulative dunites. The inner parts of veins and lens-shaped bodies of dunites are most enriched in chromite, while the transitional zones from dunites to residual peridotites are less abundant in this mineral. Only accessory chrome-spinellides occur in harzburgites of the residual series. Dunites normally gradually pass into harzburgites with an increasing proportion of modal orthopyroxene. Like the occurrences of chromite ore mineralization in other mafic–ultramafic ophiolite massifs, the chromitite bodies in the Valizhgen Peninsula have shapes of elongated lenses or veins, which mark the fracture zones which served as primitive mantle magma conduits in primary peridotites.

The proposed model also explains the difference between TiO_2 contents in chrome-spinellides from chromitites and dunites, on one hand, and host peridotites, on the other. Being relatively less mobile in the process of subsolidus redistribution of elements between chrome-spinellide and coexisting olivine, titanium contents highlight the geochemical differences between residual peridotites and the rocks of the dunite–orthopyroxenite–chromitite series.

The rocks of the cumulative series compose a significant part of the total exposed area of the ultramafic complex in the peninsula. The massifs are generally composed of moderately to strongly depleted peridotites, which are most favorable for the formation of podiform chromite mineralization. All these facts allow us
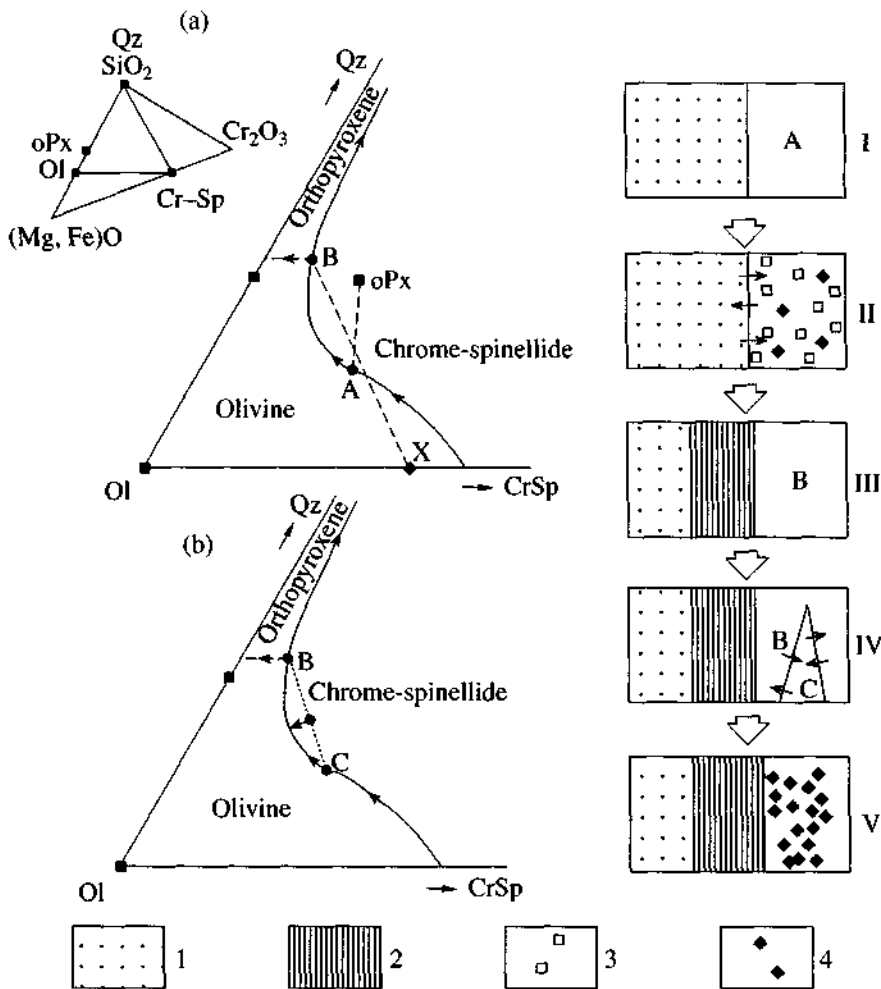
Fig. 6. A genetic model for podiform chromite mineralization as a result of peridotite/magma interaction and magma mixing (Arai and Yurimoto, 1984; Zhou *et al.*, 1996): (a) The dashed line shows the reacting (orthopyroxene and magma A) and resulting (secondary dunite X and magma B) components; (b) the dotted line is a mixing line for magmas B and C: (Ol) olivine; (oPx) orthopyroxene; (Qz) quartz; (CrSp) chrome-spinellide; (1) Harzburgite, (2) secondary dunite, (3) orthopyroxene, (4) chrome-spinellide.

to predict the existence of large chromite ore occurrences. At the same time, the presence of placer occurrences of PGE minerals in alluvial deposits of streams washing the massifs of the peninsula in the northwest and west probably indicates a wider distribution of the rocks of the cumulative series including chromitites at the earlier stages of the massif erosion.

Thermodynamic Conditions of Formation of Accessory and Ore Chrome-Spinellides

The main thermodynamic parameters were calculated for the formation of coexisting minerals in ultramafic rocks of various types in the Valizhgen Peninsula. The temperature and pressure were calculated using coexisting olivine and clinopyroxene (Loucks, 1996; Nimis and Ulmer, 1998). The highest crystallization temperature of 1104°C correspond to a pressure of 10.5 kbar. The temperatures within the interval of 910-1100°C were obtained for the diopside-bearing

harzburgites of the Dlinnaya Mt. Massif and probably correspond to the high-temperature subsolidus metamorphism for this ultramafic rock variety. The calculations for this rock show a concurrent gradual decrease of temperature and pressure. The pressure became invariable (3.5 kbar) at temperatures below 950°C. This pressure probably corresponds to the final emplacement of the massif. A further decrease of temperatures to 670-720°C, which approximate the lowest temperatures of the olivine–chrome-spinellide equilibrium, could be related to a lower temperature metamorphism of peridotites accompanied by the crystallization of amphibole and secondary low-Cr clinopyroxene.

The temperature range of 660-800°C (up to 840°C in rare cases) was calculated by the coexisting olivine and spinellide in harzburgites and dunites using the geothermooxometer proposed by Ballhaus *et al.* (1991). The calculated temperatures are evenly distributed within the interval, and no particular temperatures were revealed that could mark separate stages of sub-

Table 3. Compositions (wt %) of PGE minerals from placers of the Valizhgen Peninsula

Ordinal nos.	Ru	Rh	Pd	Os	Ir	Pt	Fe	Ni	Cu	S	As	Total
1	0.0	0.0	0.0	95.4	0.0	5.3	0.2	0.0	0.0	0.0	0.0	100.7
2	17.2	0.0	0.0	59.3	18.6	4.8	0.0	0.0	0.0	0.0	0.0	99.9
3	5.9	0.0	0.0	51.4	42.6	0.0	0.0	0.0	0.0	0.0	0.0	99.9
4	33.6	0.0	0.0	45.7	18.8	0.2	0.0	0.0	0.0	0.0	0.0	98.3
5	35.0	0.0	0.0	46.5	17.8	0.0	0.0	0.0	0.0	0.0	0.0	99.3
6	3.7	0.0	0.0	46.7	48.4	0.0	0.3	0.0	0.0	0.0	0.0	98.8
7	1.5	0.0	0.0	32.1	55.7	9.9	0.0	0.0	0.0	0.0	0.0	99.2
8	0.0	0.0	0.0	24.7	71.2	3.6	0.1	0.0	0.0	0.0	0.0	99.5
9	3.6	0.0	0.0	32.0	48.0	15.5	0.2	0.0	0.0	0.0	0.0	99.1
10	0.0	0.0	0.0	0.0	5.7	86.0	8.9	0.0	0.0	0.0	0.0	100.6
11	0.0	0.0	0.0	0.0	0.4	90.1	8.1	0.0	0.7	0.0	0.0	99.3
12	0.0	0.0	0.0	0.0	0.0	91.5	8.8	0.0	0.0	0.0	0.0	100.3
13	0.0	0.0	0.0	0.0	0.1	92.4	8.3	0.0	0.1	0.0	0.0	100.9
14	31.9	0.0	0.0	23.0	10.6	0.0	0.0	0.0	0.0	33.3	0.0	98.8
15	48.1	0.0	0.0	9.2	10.3	0.5	0.0	0.0	0.0	32.4	0.2	100.7
16	56.1	0.0	0.3	2.8	1.7	0.0	0.0	0.0	0.0	37.6	0.0	98.5
17	3.3	6.7	0.0	55.3	0.6	4.2	0.2	0.0	0.0	23.8	5.7	99.8
18	1.8	30.6	0.4	0.0	12.7	7.3	0.0	0.0	0.0	14.0	33.0	99.8
19	0.7	13.0	0.0	0.0	32.0	11.8	0.3	0.0	0.0	10.7	30.2	98.7
20	0.0	0.0	0.0	0.0	0.0	84.0	0.0	0.0	0.0	14.7	0.0	98.7
21	0.0	0.0	0.0	0.0	58.5	0.0	3.3	13.3	4.6	18.8	0.0	98.5

Note: (1–9) Os–Ir–Ru alloys: (1–3) osmium, (4, 5) ruthenium, (6) rutheniridosmine, (7–9) iridium; (10–13) Pt–Fe alloys; (14–21) PGE sulfides and sulfoarsenides: (14–16) laurite RuS_2, (17) erlichmanite OsS_2, (18) hollingworthite RhAsS, (19) irarsite (Ir, Rh)AsS, (20) cooperite PtS, (21) monosulfide solid solution $(Ir, Ni)_{1-x}S$.

solidus recrystallization of rocks during their deformations. The calculated temperatures could be the temperatures of final equilibrium between olivine and spinellide for all rock varieties (final recrystallization at the magmatic conditions). In spite of the fact that the estimated temperatures are characteristic of the lower horizons of the Earth's crust, almost all compositions of equilibrium olivine and chrome-spinellide (both in the rocks of residual series and in cumulates) are plotted within the field of mantle compositions OSMA (Fig. 5a) (Arai, 1994).

The pressure of 10 kbar was accepted for all rock varieties of the ultramafic complex of the Valizhgen Peninsula in calculations of redox conditions of subsolidus equilibrium of coexisting olivine and chrome-spinellide (Ballhaus et al., 1991). During the highest temperature metamorphism, f_{O_2} was close to fayalite-magnetite–quartz (FMQ) buffer conditions in both spinellide harzburgites and dunites; however, it was 0.4–0.6 logarithmic units higher in the latter [FMQ + (0.6 to 1.7)] than in the former [FMQ + (0.2 to 1.1)]. These data are consistent with higher degree of iron oxidation of ore and accessory chrome-spinellides in the rocks of the dunite–orthopyroxenite–chromitite series as compared to the accessory chrome-spinellide in harzburgites. The f_{O_2} values for all ultramafic rock varieties of the Valizhgen Peninsula generally correspond to the suprasubduction rock environment (Parkinson and Arculus, 1999).

Platinum Mineralization Related to Chromitites of the Valizhgen Peninsula

The spatial and genetic relation of PGE and chromite mineralizations in the mafic–ultramafic ophiolite complexes is generally recognized (Dmitrenko et al., 1985, 1990; Talkhammer, 1996; Rudashevskii et al., 1999; Melcher, 2000; Melcher et al., 1997; Zhou et al., 1996; etc.). In this context, the study of PGE minerals from placers in alluvial deposits of streams washing the massifs of the peninsula in the northwest and west (Gorelaya and Ilistaya rivers and their tributaries) is important. The PGE minerals are represented in placers by euhedral or slightly rounded crystals and their fragments, as well as microaggregates of PGE minerals. Most grains are 0.2–0.5 mm in size, however, some larger grains of Os–Ir–Ru alloys (up to 7 mm) are also found.
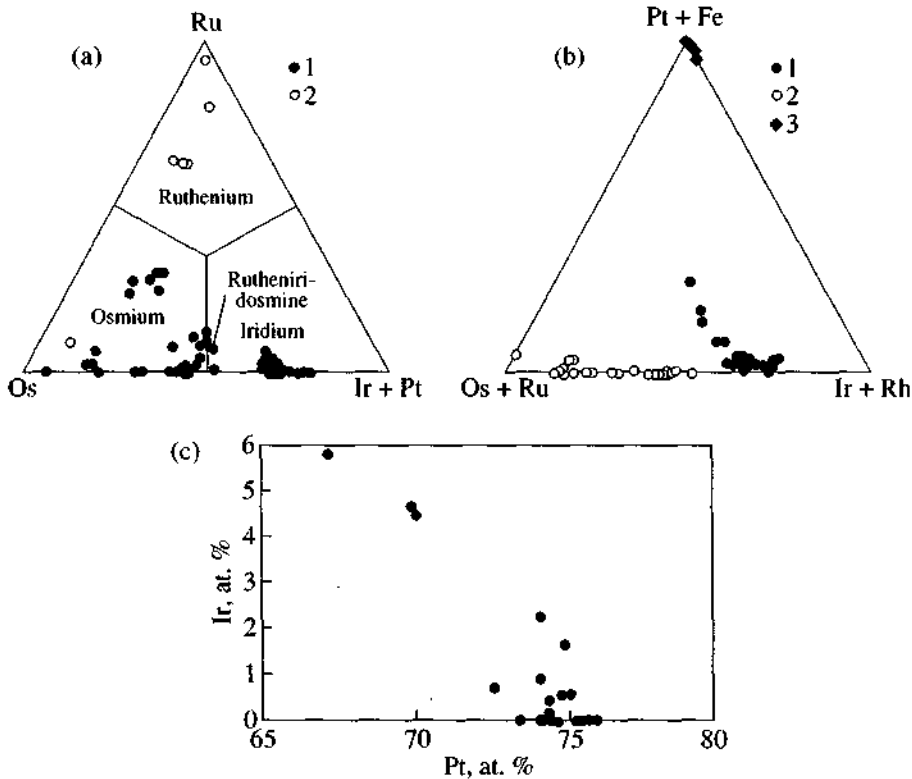
Fig. 7. Compositions of PGE minerals from placers of the Valizhgen Peninsula: (a) Os–Ir–Ru alloys (1) and sulfides of the laurite–erlichmanite series (2) in an Os-Ru-(Ir + Pt) diagram, at. %; (b) iridium (1), osmium (2), and isoferroplatinum (3) in an (Os + Ru)-(Pt + Fe)–(Ir + Rh) diagram, at. %; (c) proportions of Pt and Ir in isoferroplatinum from placers of the Valizhgen Peninsula.

The analyzed samples are all mineral species of the Os-Ir-Ru system, i.e., solid solutions of Ir, Os, and Ru, as well as rutheniridosmines of intermediate composition (Table 3, analyses 1-9; Fig. 7a). This fact emphasizes a close genetic relation of placer PGE minerals of the peninsula to chromitites, because the enrichment of high-melting PGE (Os, Ir, and Ru) relative to the low-melting PGE (Pt, Pd, and Rh) is a typical feature of podiform chromitites of most ophiolite complexes. Platinum concentration in Os is low (up to 5.3 wt %), while that in Ir is up to 24.2 wt % or 22.5 at. % (Fig. 7b), which indicates the highest exsolution temperature of 845°C during the formation of these phases (*Blagorodnye metally,* 1984). The hexagonal alloys (osmium, ruthenium, and iridosmine) show two compositional trends. The dominant ruthenium trend up to 50 at. % Ru (Fig. 7a) is typical of the rutheniridosmine assemblage related to ultramafic rocks of the ophiolitic type (Tolstykh and Krivenko, 1997). The second iridium trend is directed from osmium to iridium up to 50 at. % Ir in osmium and is composed of alloys almost free of Ru. Such Os compositions with small or no Ru admixtures (Table 3, analysis 1) are more typical of the sources of the Alaskan type. The PGE minerals are represented by the following two equilibrium assemblages: (1) intergrowths of osmium and iridium crystals and (2) inclusions of osmium in isoferroplatinum. The first assemblage is typical of PGE minerals of ophiolite ultramafics, while the second one is more characteristic of placers related to concentrically zoned clinopyroxenite–dunite massifs of the Alaskan type.

The Pt–Fe alloys can be affiliated with isoferroplatinum (Pt_3Fe) with Pt content of about 75 at. % with small deviations to compositions richer in Pt or Fe (Table 3, analyses 10–13). The Ir contents in isoferroplatinum are up to 7.2 wt % or 6 at. % (Fig. 7c).

The PGE sulfides and sulfoarsenides are represented by several mineral species (Table 3, analyses 14–21). Most of them are inclusions in isoferroplatinum except for irarsite (Ir, Rh)AsS, forming rims on isoferroplatinum, and for laurite RuS_2 that also occurs as separate crystals. RuS_2 contains up to 25.8 wt % Os and 10.9 wt % Ir (Table 3, analyses 14–16). Unlike laurite, erlichmanite OsS_2 concentrates Rh and Pt, while the Ir contents in this mineral do not exceed 0.6 wt % (Table 3, analysis 17). A part of S in erlichmanite is replaced by As (up to 5.7 wt %). The Rh- and As-bearing erlichmanite was found earlier in the Levtyrinvayam placer related to the Gal'moenan clinopyroxenite–dunite massif in Koryakia (Tolstykh *et al.,* 2001). Irarsite, hollingworthite, and cooperite (Table 3, analyses 18–20) are characteristic of sources of various types. Normally, they were formed later than isoferroplatinum and their crystalli-

Table 4. Chemical and isotopic compositions and model Re–Os ages of PGE minerals from placers of the Valizhgen Peninsula

Ordi-nal no.	Creek	PGE content, wt %						$^{187}Os/\ ^{188}Os^*$	$T_{Re\text{-}Os}$, Ma**
		Ru	Rh	Pd	Os	Ir	Pt		
Os–Ir–Ru alloys									
1	Gorelyi	23.6	–	–	60.3	16.0	–	0.1143	1900
2	Smyatyi	1.4	–	–	54.2	–	43.4	0.1209	940
3	Ardysh	–	–	–	27.6	65.2	4.8	0.1216	840
4	Smyatyi	–	–	–	32.4	63.9	3.7	0.1230	635
5	Smyatyi	–	–	–	69.0	30.4	–	0.1234	580
6	Ardysh	–	–	–	75.2	24.6	–	0.1246	400
7	Ardysh	–	–	–	29.0	65.4	5.5	0.1250	340
8	Smyatyi	2.5	–	–	30.2	62.9	3.4	0.1247	390
9	Smyatyi	8.1	–	–	48.0	43.5	–	0.1266	110
Isoferroplatinum (Pt$_3$Fe)									
10	Ardysh	–	–	–	Incl.	–	93.7	0.1186	1280
11	Grif	–	–	–	7.3	–	80.6	0.1254	290
Laurite (RuS$_2$)									
12	Ardysh	48.1	–	–	9.2	10.3	0.5	0.1252	300
13	Ardysh	56.1	–	–	2.1	1.7	–	0.1290	–

* Normalized by the $^{190}Os/^{188}Os$ ratio of 1.98379 (Tuttas, 1992).
** Calculated by Eq. (1) from Kostoyanov (1998).

zation depended on S and As activities at the postmagmatic stage. Iridium dominates over nickel in the composition of the monosulfide solid solution $(Ir, Ni)_{1-x}S$. The other PGE are not detected in it, while Fe and Cu admixtures exceed 3.3 and 4.6 wt %, respectively (Table 3, analysis 21). The Ir–Ni monosulfides distinct in Ni dominating over Ir were described in the ophiolitic ultramafic rocks of Kempirsai in Kazakhstan (Melcher, 2000).

Thus, the PGE mineral assemblage in placers of the Valizhgen Peninsula can be related to several different magmatic sources, the main one being chromitites of the ultramafic rock complex. The other source could be presented by zoned clinopyroxene–dunite massifs that are capable of producing valuable Pt placers.

Re–Os Isotope Compositions of Individual PGE Mineral Grains

The $^{187}Os/^{188}Os$ ratios were measured in individual PGE mineral grains from alluvial deposits in the western part of the Valizhgen Peninsula to identify the sources of ore material and determine the Re-Os model ages (Table 4). The isotopic analyses were performed in 13 samples with negative thermal ion mass spectrometry (NTIMS) using a modified MI-1320 mass spectrometer (Russia) (Kostoyanov et al., 2000). The instrumental error of isotopic ratios measurements in a series of parallel determinations was less than 0.3% relative. The ratios were normalized for isobaric and mass-frac-

tionation effects. The correction for mass fractionation corresponded to the exponential dependence of isotopic effects on masses of ions registered. Normally, 250 mass spectra were recorded in each test.

The $^{187}Os/^{188}Os$ ratios in all analyzed samples of PGE minerals from alluvial deposits of streams washing the ultramafic massifs of the peninsula vary within a narrow range of 0.1143–0.1290 and are lower than the modern CHUR values of 0.12736 ± 0.00016 (Yin *et al.*, 1996) except for one laurite grain (Table 4, analysis 13). These ratios indicate a mantle (chondrite) source of elements in the PGE mineralization. The model Re-Os ages for the PGE minerals studied were calculated by a procedure described by Kostoyanov (1998) and vary within a wide interval of 1900–110 Ma, which is typical of minerals from placers related to the Alpine-type massifs of ophiolitic ultramafics (Rudashevskii *et al.*, 1999). Such placers usually contain coexisting PGE minerals of various ages (Rudashevskii *et al.*, 1999). The model Re-Os ages of many of these minerals are much older than the time of the emplacement of ultramafic massifs, to which the PGE mineralization is related. The Re-Os ages of PGE minerals closely approximate the ages of the mineral crystallization (Kostoyanov, 1998). Thus, we suggested that the formation of most PGE minerals occurred in the mantle rocks prior to their emplacement in the upper crustal levels. This feature of the PGE mineralization is more consistent with a protrusion of Alpine-type ultramafics

to the crustal level and with the hypothesis of metasomatic transformation of primary PGE minerals under the influence of mantle fluids with a readjustment of the isotopic system. Therefore, the variations of the Os isotope compositions of PGE minerals in the Valizhgen Peninsula indicate that the formation and evolution of the accessory PGE mineralization in the ultramafic rocks as a primary source of placer minerals generally occurred in the mantle for a long time and during several stages.

The $^{187}Os/^{188}Os$ ratios higher than in the modern mantle chondrite reservoir, which were found in some samples, require the contribution of a component significantly enriched in radiogenic Os relative to the primary mantle rocks. For example, this component could be represented by crustal material. Similar anomalous isotopic characteristics were also found in some other massifs of this type (see, for example, Rudashevskii *et al.*, 1999).

Note that many of the model Re-Os ages of PGE minerals from alluvial deposits of the Valizhgen Peninsula coincide with the age of PGE minerals from placers in some other PGE-bearing regions of the Far East (Kostoyanov, 1998; Malich and Kostoyanov, 1999; Rudashevskii *et al.*, 1999; etc.). Such a coincidence could be caused by global cyclic processes of the PGE mineral generation in the mantle.

CONCLUSION

(1) The mafic–ultramafic massifs of the Valizhgen Peninsula include podiform chromite ore mineralization, which is typical of ophiolite massifs. Chromitites are localized in the partially serpentinized peridotites and confined to the central parts of lens-shaped dunite bodies in harzburgites. The ore bodies in all ore occurrences are rimmed by dunites varying from several tens of centimeters to several meters in thickness. These dunites grade outward to spinellide harzburgites, which only bear the accessory chromite mineralization. The chromite ores are represented by several textural and structural varieties.

(2) The chrome-spinellide compositions considerably vary in different rocks of the ultramafic complex. Regardless of the textural-structural type of ore, the chrome-spinellides from chromitites show insignificant variations of Mg and Cr concentration values. At generally similar Cr values, these spinellides are more magnesian than those from dunites and orthopyroxenites, which compose one genetic cumulative series with chromitites. Additionally to a high Cr content, spinellides from this series of rocks have an elevated TiO_2 content and iron oxidation degree.

Chromium numbers of accessory chrome-spinellides from harzburgites vary widely, overlapping a significant part of the interval typical of spinellide compositions in oceanic and island-arc peridotites and indicate a moderate depletion degree of peridotites. The

titanium contents and iron oxidation degree of these spinellides are extremely low. The compositions of chrome-spinellides and other minerals of peridotites point to a residual origin of the ultramafic rocks in a suprasubduction setting.

(3) The specific location of chromitites in mafic-ultramafic massifs of the peninsula and composition of ore and accessory chrome-spinellides from ultramafics can be accounted for by the interaction of primitive mantle magmas with host harzburgites. The calculations using mineral thermobarometry indicate a relatively low pressure and high temperature and oxygen fugacity during the formation of chromite mineralization.

(4) The mineralogical and geochemical study of PGE minerals from placers of the peninsula shows that chromitites are the main (but probably not single) source of these minerals. The Re-Os isotopic compositions of the PGE minerals are consistent with the formation of PGE mineralization in the mantle rocks prior to their emplacement in the upper crustal levels and subsequent metasomatic transformation of primary PGE minerals under the influence of mantle fluids with the readjustment of the isotopic system, which resulted in a wide interval of model Re-Os ages.

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