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GEOCHEMISTRY

Early Cretaceous Cortlandite–Pyroxenite–Gabbro Association of the Upper Amur Region: Geochronological and Geochemical Data

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The Dambukin block of the Stanovoi terrane encloses abundant small (up to 5 km^2) massifs, dikes, and sills composed of the cortlandite–pyroxenite–gabbro association. Previously, they were arbitrarily considered as Early Archean and Early Proterozoic formations. The dikes and sills are 1–2 km long and a few dozen meters thick. The association is largely represented by mesocratic and melanocratic gabbro, hornblendites, pyroxenites, cortlandites (hornblende peridotites), and less common dunites. In addition, phlogopite and pargasite (hornblende) are characteristic of cortlandites, while brownish green hornblende is typical of gabbroids. Pyroxenites and hornblendites occur frequently together in a single intrusion. Cortlandite and pyroxenite sills and dikes contain Pt-bearing Cu–Ni mineralization. Syngenetic disseminated and epigenetic (vein, brecciated, and massive) varieties are remarkable among Cu–Ni sulfide ores. Syngenetic ore minerals of low-grade and ordinary ores are largely represented by pyrrhotite with pyrite and chalcopyrite admixture and subordinate arsenopyrite and gold. High-grade epigenetic brecciated, vein, and massive ores are confined to marginal parts of intrusions. In some places, the ores are developed in Lower Archean (sometimes, graphite-bearing) gneisses with interbeds of amphibolites and jaspilites. Ore minerals include pyrrhotite, chalcopyrite, and pentlandite, with admixture of pyrite, galena, sphalerite, molybdenite, native gold, sperrylite, and kotulskite. Sulfide ores occur in intergrowth with subordinate quartz or, rarely, muscovite. Cu–Ni mineralization of some deposits in North Korea [1] and the Shanuch deposit in Kamchatka [2] is thought to be associated with cortlandites.

Geochronological–geochemical studies of rocks from the Dzhalta River basin, a right tributary of the Ilikan River, made it possible to demonstrate the Early Cretaceous age of the association under consideration and to characterize geochemical properties of its rocks.

Major elements were determined in the chemical laboratory of the Amur Complex Research Institute (Blagoveshchensk), applying the standard silicate method. Trace elements, including REE, were determined by the ICP-MS method using the Elan DRC II Perkin-Elmer (United States) equipment at the Khabarovsk Analytical Center of the Institute of Geophysics and Tectonics, Far East Division, Russian Academy of Sciences. The relative error of determination does not exceed 5%. The accuracy and reproducibility of measurement methods were estimated using internal and international standards.

Table 1 presents contents of trace elements in representative samples of rocks of the cortlandite–pyroxenite–gabbro association.

The rocks are referred to the normal calc-alkaline series and characterized by moderate and low K contents. Distribution trends of minor elements in the rocks relative to the primitive mantle demonstrate common patterns with insignificant differences (Fig. 1). Cortlandites are characterized by similar distribution plots with negative anomalies of Th, U, La, Hf, Ti, and Sr, and positive Cs, K, P, and Sm anomalies. In contrast to cortlandites, pyroxenites demonstrate Cs and Sr negative anomalies, in addition to Th, La, Hf, and Ti anomalies, and positive K, P, and Sm anomalies. Gabbroids yield negative Hf and Ti anomalies and positive K, P, and Sm anomalies, which makes them similar to pyroxenites.

The rocks are characterized by low REE contents (23.1–87.6 ppm). In most cases, LREEs prevail over HREEs, except for Sample A-708 (Fig. 2). Cortlandites

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Table 1. Chemical composition (wt %) of representative samples from the cortlandite–pyroxenite–gabbroic association and contents of accessory elements (ppm)

Component	514	A-708	A-676	250-2	CK-6/1	510-2	512
	1	2	3	4	5	6	7
SiO_2	47.80	46.30	40.90	44.60	36.00	47.50	52.30
TiO_2	0.45	0.50	0.38	0.75	0.73	0.53	0.77
Al_2O_3	9.47	8.78	3.79	7.38	7.11	13.13	12.12
Fe_2O_3	2.27	2.84	7.55	4.21	15.72	3.27	2.28
FeO	7.83	8.33	6.57	7.15	10.06	5.82	8.26
MnO	0.22	0.17	0.27	0.18	0.36	0.25	0.12
MgO	19.07	23.00	29.15	22.50	8.40	10.94	8.86
CaO	9.13	6.97	3.06	6.61	11.10	15.09	11.15
Na_2O	1.43	0.56	0.22	0.83	0.83	1.91	1.71
K_2O	0.72	0.25	0.15	0.22	0.66	0.34	0.97
P_2O_5	0.05	0.04	0.03	0.07	0.21	0.04	0.11
L.O.I.	1.34	2.09	7.31	4.07	7.09	0.84	0.70
S	–	0.05	1.87	0.29	6.94	–	–
Total	99.77	99.82	99.37	98.57	98.27	99.66	99.35
Be	0.25	0.30	0.30	0.41	0.50	0.26	0.88
Sc	29.3	29.7	32.5	24.7	28.4	51.6	34.5
V	171	169	202	180	223	247	278
Cr	1367	1668	1825	1451	66	465	465
Co	72	78	76	88	231	51	47
Ni	828	867	884	770	266	173	146
Cu	134	30	18	27	546	17	59
Zn	38	66	84	57	59	77	109
Rb	29	8	5	5	14	5	40
Sr	55	77	46	9	58	111	184
Y	13.3	11.0	12.6	13.5	29.5	11.3	21.4
Zr	30	21	23	37	87	24	27
Nb	1.3	–	–	1.3	2.3	2.1	7.1
Mo	0.4	0.4	0.5	0.4	1.3	0.4	1.0
Sn	5.5	1.1	1.7	2.3	5.2	0.5	1.1
Cs	2.3	0.5	0.6	0.1	0.3	0.1	0.8
Ba	18	32	–	–	11	–	–
La	2.66	1.44	1.99	3.56	13.89	4.76	15.47
Ce	6.22	4.00	6.09	10.55	28.29	9.98	32.93
Pr	0.86	0.61	1.00	1.74	3.45	1.31	4.10
Nd	4.07	3.04	5.15	8.41	13.92	5.62	16.22
Sm	1.26	1.09	1.71	2.30	3.27	1.68	3.65
Eu	0.46	0.41	0.45	0.53	0.96	0.72	1.07
Gd	1.75	1.41	2.09	2.53	3.97	1.95	4.11
Tb	0.33	0.26	0.37	0.41	0.69	0.34	0.63
Dy	2.06	1.71	2.21	2.37	4.37	2.01	3.72
Ho	0.42	0.35	0.42	0.44	0.91	0.43	0.80
Er	1.29	1.07	1.22	1.24	2.95	1.17	2.19
Tm	0.21	0.18	0.19	0.19	0.50	0.17	0.33
Yb	1.33	1.09	1.10	1.13	3.14	1.06	2.11
Lu	0.20	0.16	0.16	0.16	0.50	0.15	0.29
Hf	0.84	0.65	0.77	1.04	1.83	0.83	0.88
Pb	2.1	4.0	2.7	1.0	4.0	4.4	4.6
Th	0.2	0.2	0.3	0.4	0.9	0.3	3.8
U	0.1	0.1	0.1	0.2	1.0	0.3	0.8
Ga	5.7	5.3	4.8	5.0	7.6	–	–

Note: (1–4) Phlogopite-bearing cortlandites; (5) phlogopite-bearing pyroxenites; (6, 7) gabbro. (–) No data.

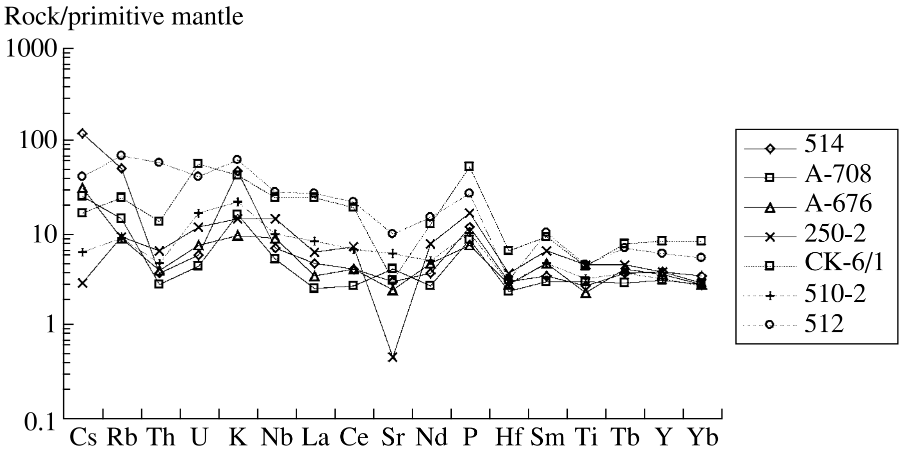

Fig. 1. PM-normalized [9] spidergrams of rocks from the cortlandite–pyroxenite–gabbro association of the Upper Amur region. Numbers in Figs. 1 and 2 correspond to sample numbers in Table 1.

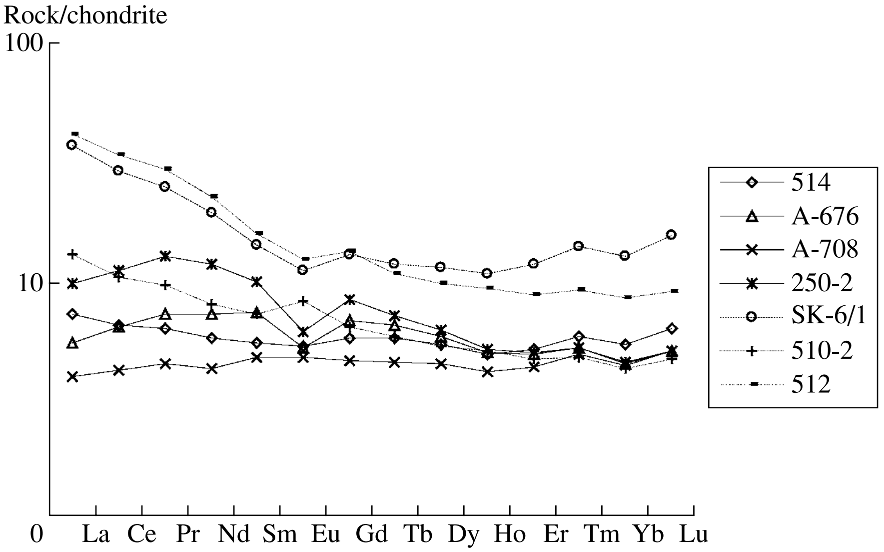

Fig. 2. Plots of chondrite-normalized [9] REE contents in rocks from the cortlandite–pyroxenite–gabbro association of the Upper Amur region.

of samples 514 and A-708 have the minimal concentrations of both LREEs and HREEs. Therefore, their plots reflect a relatively uniform REE distribution ($(La/Yb)_N$ = 0.9–1.4) lacking the Eu anomaly (Eu/Eu* = 0.95–1.02). Plots of pargasite-rich cortlandites from samples A-676 and 250-2 exhibit convex LREE area and negative Eu anomalies: $(La/Yb)_N$ = 0.9–1.4; Eu/Eu* = 0.67–0.74. Low negative or positive Eu anomalies are registered for pyroxenites and gabbroids: Eu/Eu* = 0.82–1.2, $(La/Yb)_N$ = 3.0–5.0.

The MgO content in cortlandites and pyroxenites is as high as 19–29 and 8.4 wt %, respectively. In terms of the MgO content, as well as the low Cr content and high contents of TiO_2, REE (including La and Sm), the cortlandites and pyroxenites differ from typical mantle peridotites and pyroxenites and resemble crustal rocks [3]. Cortlandites and pyroxenites are characterized by maximal concentrations of Ni and Cu (770–884 and 546 ppm, respectively).

The U–Pb zircon dating was carried out using the SHRIPM-II ionic microprobe at the Center of Isotopic Studies of the Karpinskii All-Russia Research Institute of Geology (St. Petersburg), in line with the procedure in [4]. The intensity of the primary beam of molecular negatively charged oxygen ions was 5 nA and the beam (crater) diameter was 25 μm. The SQUID program [5] was used for data processing. The U–Pb ratios were normalized to the value of 0.0668 attributed to the TEMORA standard zircon, which corresponds to its age of 416.75 Ma [6]. The analytical uncertainty of some measurements (ratios and ages) was at the 1σ level and that of calculated concordant ages and intercepts with

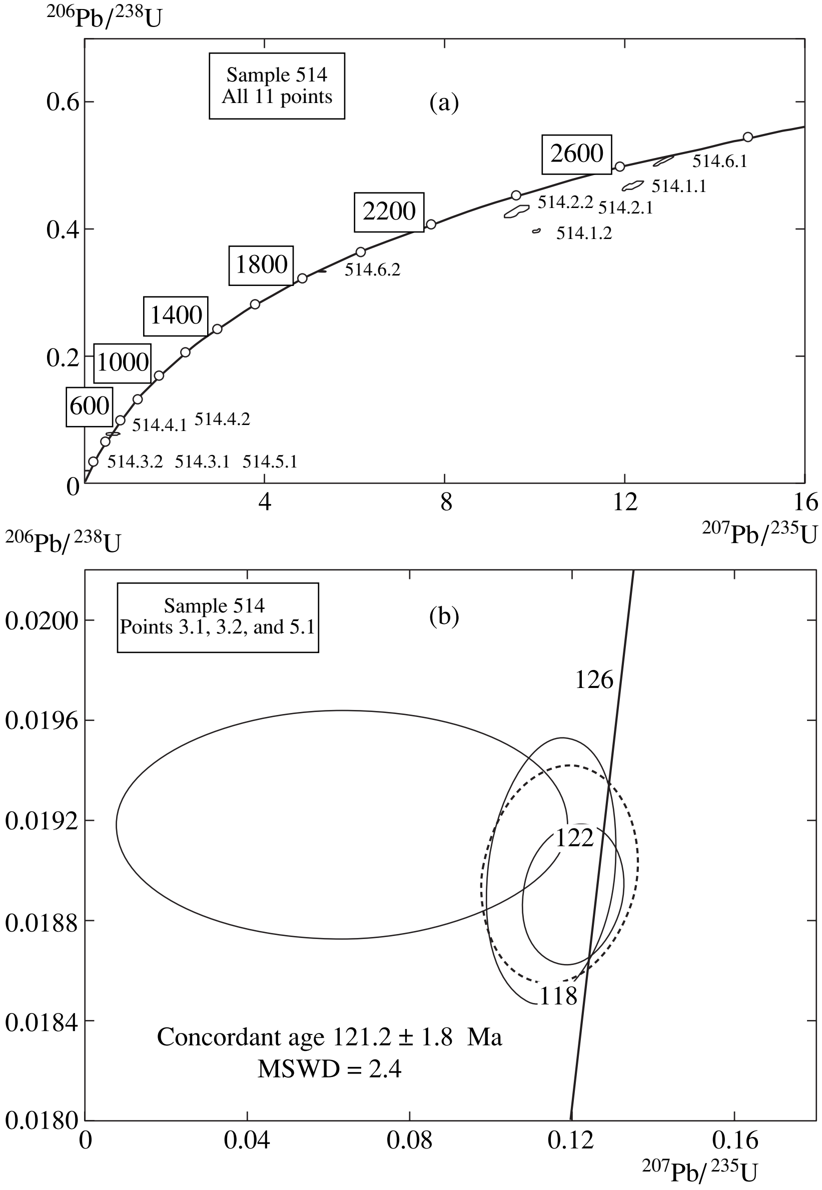

Fig. 3. Diagram with concordia for zircons from cortlandites: (a) for all zircon grains (Table 2), (b) for grains 514.3.2, 514.5.1, and 514.3.1.

concordia were at 2σ. The ISOPLOT/EX [8] program was used for constructing plots with concordia [7].

Zircons from cortlandites (Sample 514) are represented by yellowish, transparent and semitransparent, subeuhedral and euhedral, short- to long-prismatic crystals. The cathodoluminescence image of zircons demonstrates concentric and sectorial zonal growth, which indicates their magmatic origin. The U–Pb age of zircons from cortlandites determined with the SHRIMP-II microprobe is 121.2 ± 1.8 Ma (Table 2, Fig. 3). Thus, the rocks formed during the Early Cretaceous (rather than the Early Archean or Early Proterozoic, as was assumed previously) stage of the Stanovoi terrane development.

The presence of relict zircons in cortlandites dated at 0.5 and 1.9–2.6 Ga suggests contribution of the Archean, Early Proterozoic, and, probably, Hercynian continental crust to the composition of protoliths.

According to geotectonic models, the cortlandite–pyroxenite–gabbro association formed synchronously with igneous rocks of the Stanovoi volcanoplutonic belt after the Mongol–Okhotsk Ocean closure in response to the collision between the Siberian Craton and the Amur terrane.

Previously, single cortlandite dikes were established within the Stanovoi terrane and Amur superterrane [1]. The discovery of Pt-bearing Cu–Ni mineralization confined to the cortlandite–pyroxenite–gabbro association

Table 2. U–Pb isotopic ratios determined by the SHRIMP-II method for rocks of the cortlandite–pyroxenite–gabbro association in the Stanovoi terrane

Point	Content (ppm)			Isotopic ratio				Age, Ma
	U	Th	$^{206}Pb^*$	$^{207}Pb^*/^{235}U$	±%	$^{206}Pb^*/^{238}U$	±%	$^{206}Pb/^{238}U$
514.3.2	460	216	7.52	0.1204	6.8	0.0189	0.98	120.7 ± 1.2
514.5.1	365	175	5.99	0.115	9.2	0.019	1.8	121.3 ± 2.2
514.3.1	363	168	6.8	0.064	58	0.01918	1.6	122.5 ± 1.9
514.4.1	1241	126	93.5	0.621	16	0.0782	2.2	485 ± 10
514.4.2	664	281	45.1	0.615	1.7	0.079004	0.1	490.18 ± 0.49
514.6.2	299	84	85.3	5.327	0.63	0.33223	0.066	1849.2 ± 1.1
514.1.2	929	881	319	10.058	0.58	0.3966	0.37	2153.2 ± 6.8
514.2.2	1239	244	450	9.538	0.62	0.4196	0.49	2258.9 ± 9.4
514.2.1	577	61	216	9.63	1.9	0.4268	1.6	2291 ± 30
514.1.1	126	104	50.8	12.2	1.3	0.4683	1.1	2476 ± 22
514.6.1	503	153	219	12.88	1.2	0.5068	1.1	2643 ± 24

Note: (*) Radiogenic Pb. Isotopic ratios are corrected for ^{204}Pb. Uncertainties of isotopic ratios and ages are given at 1σ level.

in the Dambukin block of the Stanovoi terrane allow us to revise prospects of the Upper Amur region with respect to commercial objects with similar mineralization.

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