Vestnik Otdelenia nauk o Zemle RAN, VOL. 4, NZ9001, doi:10.2205/2012NZ_ASEMPG, 2012

Estimate of Kamchatka cortlandites crystallization conditions by amphibole compositions

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Nickel Sulfide deposits containing PGE had been found in Central Kamchatka Ridge (CKR). These ores are localized in amphibole-bearing ultramific rocks cortlandites. We estimate crystallization pressure of cortlandites while employing our novel Al^{VI} in amphibole geo-barometer. We calibrate pressure dependence of the maximum asymptotic (calculated for Fe^{3+}+Ti = 0 apfu) content of octahedral aluminum in amphibole with using of our and published data obtained in experiments on hydrous andesitic and basaltic melts. Processing of amphibole compositions from CKR cortlandites yields pressure ca 8 kbar close to the peak pressure of cortlandites hosting metamorphic rocks of 6.3–8 kbar. Such high pressure corresponds to the depth 24–27 km at the present day crust thickness at CKR edge of 35–40 km. These observations stay for pronounce Kamchatka crust thickening at the arc collision in Eocene time.

Key words: Amphibole, cortlandite, geo-barometer, tholeitic magma

Citation: Simakin, A. G., O. Yu. Zakrevskaya, T. P. Salova (2012), Estimate of Kamchatka cortlandites crystallization conditions by amphibole compositions, *Vestn. Otd. nauk Zemle, 4*, NZ9001, doi:10.2205/2012NZ_ASEMPG

Large part of Kamchatka was formed at the accretion of Achaivayam-Valaginskaya and Kronotskaya island arcs in Eocene and Pliocene respectively. Collision of island arcks with North-East edge of Asia caused impulses of magmatism of silicic (52 mln yrs ago [*Luchitskaya, et al., 2008*]) and ultrabasic-basic (Eocene [*Konnikov, et al., 2010*]; [*Selyangin, 2009*].) compositions. Mafic-ultramafic formation is represented by the concentric dunite-piroxenite-gabbro intrusions [*Selyangin, 2009*] and small to medium size cortlandite-pyroxenite-gabbro-norite ones [*Selyangin, 2007*].

Ultrabasic-basic cortlanditic intrusions are localized along edge of central metamorphic massif of Kamchatka in the zone extended in meridian direction on 300 km and 30–50 km across. Totally about 50 small to medium size Cu–Ni ore bearing intrusions are encountered in this zone. The largest deposits belong to Dukuk and Shanuch clusters (Fig.1). Cortlandite is defined as a magmatic rock containing 60–70 vol.% of hornblende. Origin of cortlandites is a matter of discussions. However, it is clear that high water content (reflected in amphibole abundance) in the parent high-magnesium picrito-basalt magma somehow is linked with Cu–Ni sulfide ore formation. In the given work we present results of the application of the novel amphibole geo-barometer [*Simakin, et al., 2012*] to cortlandites of Kamchatka.

All previously derived amphibole based geobarometers (with exception of the last model [*Ridolfi, et al., 2010*] inaccurate for pressure determination) are applicable for dacite-rhyolite magmas. In our model we consider content of the octahedral Al in amphibole in the equilibrium with andesitic to basaltic hydrous melts [*Simakin, et al., 2009*]. It is well known that pressure increase causes transition of aluminum from tetrahedral (like Si) to pentahedral and octahedral cation-modifier positions. This structural transformation is reflected in the increase of Al^{VI} content in amphibole calculated with 13eCNK model. To eliminate effect of octahedral Al substitution by high charge cations we calculate asymptotic Al^{VI}_{max} content in amphibole at the sum Fe^{3+}+Ti^{4+} +Cr^{3+}=0. Parameter Al^{VI}_{max} is linearly correlated with pressure in the range 2–12 kbar (T=950–1100°C).

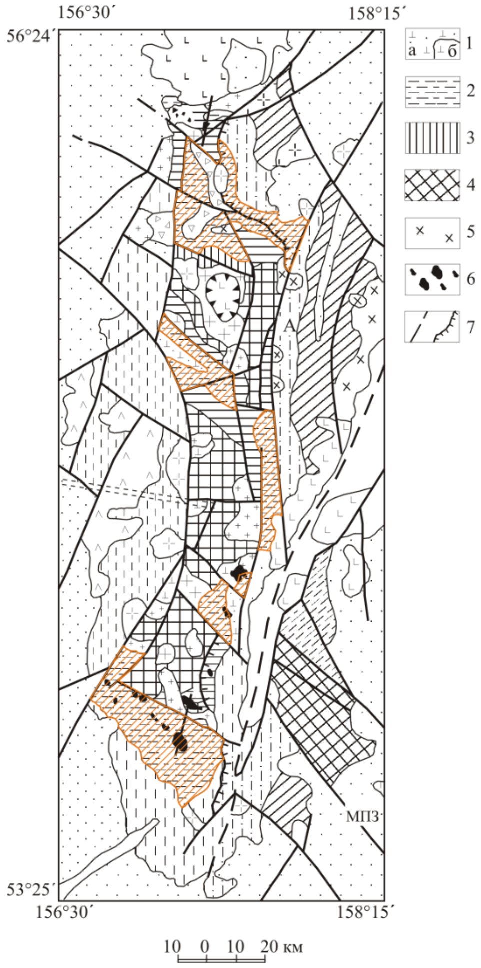


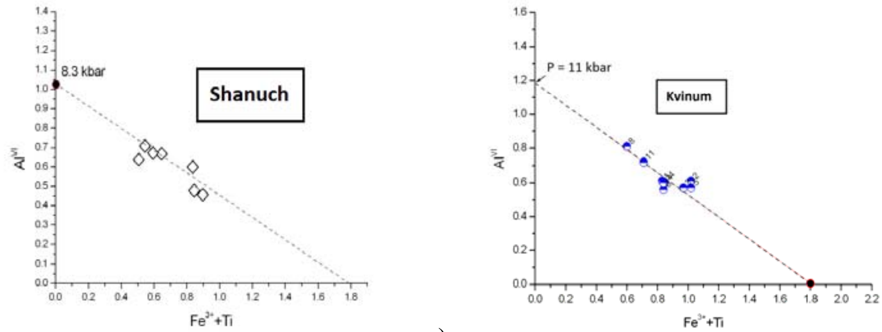
Fig.1. Geologic map of Central Kamchatka massif and localization of Ni-bearing intrusions [*Selyangin, 2009 with modifications*].
1: a) alistroskaya and chimkinskaya suites, b) comagmatic subvolcanic intrusions; 2) heivanskaya suite (labeled by orange hatching); 3) andrianovskaya suite; 4) Ganal massif; 5a) levoandrianovsky intrusive complex b) Dukuk cortlandite–orthopyroxenite–gabbro–norite intrusive complex; 7 – faults: a – steep, b – thrusts 8 erase

Published and our amphibole compositions were used to estimate cortlandite crystallization pressure (see Table 1).

Table 1. Representative compositions of Ca-amphiboles from Shanuch ore field, Kamchatka from [*Selyangin, 2003*].

oxides	**1**	**3**	**8**	**9**	**10**	**11**	**12**	**13**	**17**
SiO_2	52.37	44.30	45.79	45.51	53.20	53.63	43.42	44.07	45.64
TiO_2	-	1.17	1.85	1.55	0.15	-	2.80	2.16	2.45
Al_2O_3	30.04	13.16	11.39	11.84	3.46	29.22	12.74	12.63	12.31
FeO	0.10	15.34	11.86	13.60	11.47	0.23	11.19	15.18	9.91
MnO	0.06	0.07	0.09	0.10	0.01	-	-	0.13	0.09
MgO	-	10.54	13.71	11.95	15.56	0.03	13.22	10.30	13.32
CaO	12.14	11.87	10.70	10.74	12.32	11.71	11.21	11.21	10.61
Na_2O	4.56	1.23	1.92	1.38	0.35	5.42	1.65	1.72	1.65
K_2O	0.07	0.64	0.57	0.55	0.09	0.16	0.67	0.83	0.58
Cr_2O_3	-	-	-	-	-	-	-	-	0.04
Sum	*99.34*	*100.35*	*99.95*	*99.27*	*98.68*	*100.40*	*98.96*	*100.26*	*98.87*
oxides	**21**	**24**	**27**	**34**	**35**	**37**	**40**	**42**	
SiO_2	42.44	41.34	45.43	44.86	55.07	45.25	45.33	45.33	
TiO_2	2.56	1.98	1.39	1.31	-	2.42	3.85	3.85	

Al_2O_3	13.83	15.17	12.84	13.16	1.22	13.39	11.26	11.26
FeO	14.73	18.34	11.14	8.93	17.58	8.50	8.78	8.26
MnO	0.06	0.12	0.03	0.02	0.69	-	-	-
MgO	10.08	7.59	1.35	14.47	20.11	14.18	14.2	15.76
CaO	11.43	11.34	11.29	11.28	1.83	11.36	11.28	10.97
Na_2O	1.55	1.36	1.60	1.76	0.07	1.37	1.83	2.19
K_2O	0.67	0.79	0.43	0.54	0.04	0.57	0.41	0.51
Cr_2O_3	-	-	0.09	0.17	-	0.36	0.7	0.26
Sum	*99.36*	*100.01*	*99.64*	*98.56*	*98.68*	*99.53*	*99.72*	*99.73*



a) b)

Fig.2. Estimates of pressure by amphibole compositions for Kamchatka cortlandites: a) Shanuch, selected data from [*Selyangin, 2003*] b) Kvinum, our data.

Our pressure estimate for Shanuch cortlandite (see Fig. 2) coincides with peak pressure of surrounding metamorphic rocks [*Selyangin, 2009*]. Deep metamorphic complex with cortalndite intrusions is now exposed due to erosion. At the present day crust thickness at the CKR of 38–40 km [*Levin, et al., 2002b*] this pressure estimate implies maximum crust thickness of 65–70 km gained at collision. Correspondent depth of oceanic slab underlying CKR on some stage of collision was close to the eclogite transition depth (80 km). Densification of oceanic slab at such depth may initiate new subduction zone.

Cu–Ni deposits are genetically linked with high-magnesium basic magmas. High-magnesium tholeites of N-MORB type are proposed as parental magma for Kamchatka cortlandites [*Selyangin, 2009*]. Such magmas arise at the high degree of adiabatic decompression melting of dry mantle in mid-ocean ridges. Similar physical mechanism of decompressional melting is expected in the all ascending mantle flows: in back-arc basins, tectonic windows in subduction zones [*Levin, et al., 2002a*] etc. At the accretion at active continental margins strong ascending mantle flows can be induced by subduction zone transformation including old slab delamination [*Luchitskaya, et al., 2008*] and start of new slab edge submerge.

In the frame of this interpretation origin of cortandites may be explained by the assimilation of metamorphic rocks with water bearing minerals (essentially micas) by dry picro-basalts at the *PT* parameters of amphibolite formation. Reflected by the lowest values of Fe^{3+}+Ti^{4+} sum (0.4–0.5 apfu) low oxygen fugacity well correlates with c their weak magnetization opposite to the common island arc volcanic rocks with magnetite [*Sidorov, 2006*]. Low fO_2 in cortlandites is explained by high graphite content in the assimilated shists of Heivanskaya series [*Selyangin, 2009*]. Presence of graphite tends to buffer oxygen fugacity on the level of C–CO_2 buffer (around QFM-3). At the transition to the low temperature postmagmatic stage of cortlandite evolution oxygen fugacity rises that is also recorded in the values of Fe^{3+}+Ti^{4+} sum increasing to 1.1 apfu.

This study was supported by RFBR grants #10-05-00046-a and #10-05-00697-a.

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