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Petrology of Archean Eclogite Complex Salma from Belomorian Province, Russia

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In the Belomorian province of Baltic shield, Archean eclogite-granulite complexes were firstly reported by Volodichev et al. (2004) and Mints et al. (2010), which may significantly change our understanding of the geodynamics of early Earth (Li, et al., 2013). One of the Archean eclogite complex named as Salma (Shirokaya and Uzkaya) is located nearby the road mark 1192-1198 KM of St. Peterburg – Murmansk federal highway, which consists of lens-type mafic eclogite bodies, (garnet-) amphibolites, piclogite, pegmatite and granitoid veins within the intensely deformed and migmatized TTG (para-)gneiss. In the well-preserved bi-mineralic eclogite (Cpx-Grt), clinopyroxene (mostly Omp with Jd ~ 21-32 mol.%) with relatively high CaEs content (max. 7 mol.%) was found to possess multiple well-orientated quartz (α-SiO2), amphibole (Ed/Parg) and quartz-amphibole composite syngenetic lamellae, whose genesis should be related to the CaEs component (in Cpx) breakdown with fluid participation (for amphibole) during decompression. Reintegration of the lamellae and relic clinopyroxene has been performed after Page et al. (2005) to estimate the proto-clinopyroxene prior to breakdown that slightly elevated CaEs component (max. 8 mol.%) and noticeable reduced CaTs component (less 5 mol.%) have been obtained, thus, reaction CaEs ± Di-Hd, CaTs (in Cpx) + [OH] → Qtz + Ca-Amp can be suggested. In the eclogites with retrogression (Cpx-Pl symplectite started to emerge occasionally), besides mentioned quartz type lamellae, orthopyroxene lamellae as well-orientated thin needles and rods (associated with plagioclase lamellae) in (relict) clinopyroxene (Omp or Jd-Di), or sometimes orthopyroxene grains in the clinopyroxene-plagioclase symplectite, that high-temperature reworking till granulite-facies metamorphism might be involved during the retrogression. Attempt to likewise reintegrate proto-clinopyroxene under the assumption of breakdown mechanism might be pointless as the genesis of the orthopyroxene could be related to either exsolution or metasomatic genesis and it remains an open question. Meanwhile, vermicular plagioclase lamellae, including symplectic ones should answer to the omphacite breakdown via Omp → Di + Pl. The reintegrated precursor clinopyroxene yields quite high CaEs and Jd contents (11-19 mol.% and 20-28 mol.% respectively) that corresponds to some similar works in other HP/HT terrains (e.g. Gayk et al., 1995; Nakano et al., 2007). Garnets in the well-preserved eclogite and retrogressed eclogite show no obvious distinctions morphologically (euhedral/semi-euhedral porphyroblast or fragmental) and chemically (Alm-Grs-Pyp solid solution with varying Pyp content of 30-40 mol.%), besides, no compositional zoning could be found. Amphiboles are exclusively calcic type as edenite and pargasite mostly although some might be Mg-hornblende, actinolite, occurring interstitially, as inclusions (in Cpx and Grt), epitaxial growth (replacing) etc. Plagioclases are albite-series with Ab component dominated (andesine-oligoclase), occurring as Amp-Pl corona around garnets and Cpx-Pl symplectite.

Phase equilibrium modeling has been completed by Theriak-Domino software in NCFMASHO system with assumed H2O in excess, besides, conventional geothermo-, barometers were also applied for appropriate mineral assemblages, and samples for modeling were plagioclase-free eclogite and symplectic eclogites (Shirokaya Salma association). Peak condition of eclogite-facies metamorphism is suggested at P = 19.5-20.5 Kbar, T = 740-780 oC (stage M1), shortly after which, quartz-dominated lamellae in clinopyroxene should start to occur; following decompression (P < 15 Kbar) to granulite-facies occurred with heating up to T = 810-870 oC (stage M2) that orthopyroxene lamellae emerged; continuing retrogression (cooling and decompressing) went into upper-amphibolite-facies with P < 10 Kbar, T = 600-690 oC (stage M3) with more Cpx-Pl symplectite and amphibole occurrence. Thus correlation of mineral lamellae occurrence of quartz, orthopyroxene and plagioclase with certain metamorphic stages can be established. The PT path of Salma eclogites quite resemble the typical modern orogeny-type clockwise

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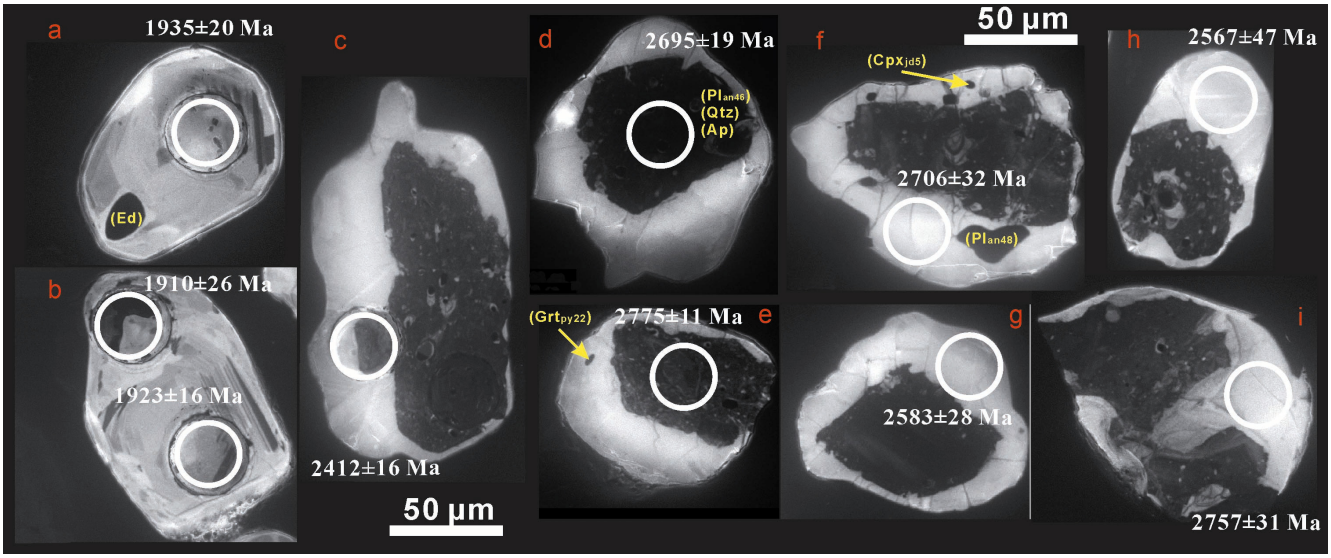

Fig.1 CL images of zircons from well-preserved eclogite (a, b) of sector texture and retrogressed eclogitic rock (c-i) of zonal texture. Indicated ages are concordant ^{206}U-^{238}Pb ages.

curve and consequently a geothermal gradient of 11-12 oC/km can be suggested, which could hardly be considered as a "warm" regime.

U-Pb dating (LA-ICP-MS) has been performed on zircons from eclogite and eclogitic rocks of Uzkaya Salma association. Morphologically they can be grouped into two major types according to their CL image features as (I) equant or short prismatic crystals (~ 100 μm) of homogeneous bright tone with sector textures from well-preserved eclogite (sample UzS-3) [fig.1a, b] and (II) short prismatic or ovoid crystals (~ 50-100 μm) with zonal texture of dark core (filled with abundant inclusions) and bright rim (of scare inclusions) from eclogitic rocks (sample UzS-2, UzS-5) [fig.1c-i]. For zircons from eclogitic rocks, two episodes were determined in the core – 2.76 Ga and 2.51 Ga, and approximately five episodes could be suggested in the rim –2.77 Ga, 2.63 Ga, 2.55-2.58 Ga, 2.42 Ga and 1.86-1.92 Ga (all are upper intercepts of U-Pb discordia with concordia, and concordant U-Pb ages as well). In the scope of geochemical behavior of REEs in zircon, the core parts show high Th (100-400 ppm), U (100-280 ppm), total REEs (820-1189 ppm) and Th/U ratios (0.8-1.6) that more resemble magmatic genesis (inherited zircons), besides, the Ti-in-zircon thermometer yields T = 770-790 oC; and the rim parts, on the contrary, show low Th (20-40 ppm), U (25-40 ppm), total REEs (170-240 ppm) contents and medium-low Th/U ratios (avg. ~ 0.8-0.9) that answers to high-grade metamorphic genesis, and the Ti-in-zircon thermometer yields T = 680-720 oC; and for the 1.86-1.92 Ga episode, they could be much lower as Th ~ 0.3 ppm, U ~ 1.0 ppm, Th/U ~ 0.2, ∑REE ~ 10 ppm that very likely implies high-pressure metamorphic zircons with Ti-in-zircon thermometric estimation T = 620 oC. Among numerous mineral inclusions, Ca-amphibole, diopside, Na-rich plagioclase (Ab) and Ca-rich plagioclase (andesine, bytownite), rutile and carbonate (calcite) were found in the core part of zircons, thus, magmatic genesis with later metamorphic reworking under fluid participation can be suggested, and age of 2.76 Ga should be the age of magmatic formation, and 2.51 Ga – (high-temperature?) metamorphic reworking. In the rim part of zircons, Ca-amphibole, diopside, Ca-rich plagioclase (andesine), Pyp-poor garnet, titanite and rutile were found that seemingly high-temperature metamorphism is predominant at least, although eclogite-facies high-pressure metamorphism might take place additionally as well. Zircons from well-preserved eclogite are much consistent both in geochemistry and U-Pb ages that predominantly ones yield 1.91 Ga age with extreme low Th (~1 ppm), U (~20 ppm), total REEs (~10 ppm) and Th/U raios (~0.05) with negative Eu and positive Ce anomalies. Scare inclusion minerals as Ca-amphibole and Pyp-rich garnet can be found, and the later more certainly confirms the eclogite-facies metamorphism. Therefore, the protolith of Salma eclogites from Belomorian province should form at ≥ ca. 2.77 Ga, and shortly afterwards was subjected to eclogite-granulite-facies metamorphism started at ca. 2.76 Ga and subsequently repeated several times till ca. 2.42 Ga. Eclogite-facies metamorphism under relatively lower temperature occurs at ca. 1.91 Ga that answers to the regional Svecofennian event.

Key words: Belomorian province, Archean eclogite, PT path, U-Pb dating