# MELT AND FLUID INCLUSIONS IN ZIRCON FROM LATE ARCHEAN GREY GNEISSES FROM THE KOLA SUPERDEEP BOREHOLE (BALTIC SHIELD)

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The biotite-plagioclase gneisses with the tonalite-trondhjemite composition ("grey gneisses") dominate among the Archean rocks intersected by the Kola Superdeep Borehole (KSDB) at a depth of –6842 to –12262 m. These gneisses are among the oldest rocks of the continental crust within the northwestern part of Baltic Shield. In order to develop sound pertrological interpretations of the U-Pb age dates of zircons extracted from the gneisses, origin of these zircons must be established. It is thought that the age of ca. 2.83 Ga corresponds to crystallization of zircons from the effusive protolith of these gneisses, whereas the age of ca. 2.74 Ga is attribute to the metamorphic zircons, formed at the late stages of the Late Archean amphybolite metamorphism (Bibikova et al., 1993; Orlov, Laverov, 1998). Direct information regarding the origin of zircon may be obtained from studies of the melt and fluid inclusions. Studies of melt inclusions in zircon from Archean orthogneisses allow for identification of the relic-magmatic (pre-metamorphic) zircon, as well as to determine compositions and the pattern of crystallization of magmas, responsible for formation of gneiss protoliths (Chupin et al., 1994; Chupin et al., 1998).

This paper presents the first results of studies of inclusions in zircons and the rock-forming minerals of the biotite-plagioclase gneisses from the eighth unit of the KSDB (sample No.26 from –10780 m; sample No. 39861 from –10840 m; and sample No. 40302 from –11125 m). Crystals of zircon were encountered in quartz, plagioclase, apatite, as well as at the boundaries between minerals. Zircons are colorless, sometimes brownish, sometimes fractured. The dominant morphology is subidiomorphic prismatic crystals with aspect ratio of 1.5 to 3.5; much less common are the isometric grains possessing large number of minute crystal faces. Prismatic crystals are somewhat rounded; some of them exhibit weak zonation. Rarely, they contain internal individuals, which might represent cores of the earlier zircon. Microprobe analyses have revealed systematic increase in $HfO_2$ from 0.86 wt.% in the central part of zircon grains to 1.62 wt.% in their outer parts. This geochemical feature allows for the assessment of the relative entrapment time of different inclusions in the prismatic zircon crystals.

Prismatic zircon crystals contain different micro-crystals (likely, phenocrysts), which sometimes are inter-grown, melt inclusions, and, extremely rarely, primary fluid inclusions. Based on optical microscopy and microprobe analyses, quartz, plagioclase (from albite to oligoclase with $K_2O$ contents ranging up to 2.1 wt.%), K-Na feldspar (in outer parts of the crystals), biotite, Ti-magnetite and F-apatite (short- and long-prismatic crystals) have been determined among the micro-crystals. The short-prismatic apatite contains 1.6 to 2.4 wt.% of F, whereas long-prismatic apatite contains 3.4 to 3.8 wt.% of F. Both types of apatite contain less than 0.1 wt.% of Cl.

Only prismatic zircon hosts primary melt inclusions, which indicates that this morphologic type of zircon crystallized from melt. Inclusions are small (2 to 6 μm, rarely up to 14 μm along the longest axis). They contain finely crystallized silicate aggregate along with the interstitial fluid phase. Upon heating, crystalline phases melt (up to 950-1000°C) and the interstitial fluid forms a bubble. The complete homogenization of inclusions has not been achieved even at 1200°C, which suggests the loss of volatiles from inclusions. The microprobe analyses of glass from heated inclusions (Table) indicate that prismatic zircon of the relic-magmatic type began to crystallize from calc-alkaline dacitic melt (close to tonalite in composition), which evolved to rhyodacitic melt of the granodioritic composition and then to leucocratic rhyolite melts of the trondhjemite composition (with $K_2O/Na_2O << 1$). Leucocratic rhyodacitic and rhyolitic melts (with $K_2O/Na_2O \geq 1$) crystallized, likely, at the final stages of the protolith's formation. The melts contained very little F and Cl.

Minute (up to 4 μm) primary inclusions of liquid $CO_2$ with density of ca. 0.7 g/cm$^3$ (freezing data) have been found in central parts of the short-prismatic zircon crystals. These fluid inclusions are co-genetic with melt inclusions, which points to the crystallization of early zircon from the $CO_2$-saturated silicate magmas. At early stages of crystallization, the pressure of the separating fluids was as high as 3.5 kbars, which corresponds to a depth of about 13 km.

Isometric, complexly faceted zircon grains do not contain melt inclusions. A primary aqueous gas-liquid (with a crystal of salt) inclusion some 3 μm in size was found in central part of one such zircon crystal (20 μm in size) from a plagioclase grain (sample No.39861). Composition of the inclusion was found to be similar to those of primary metamorphic inclusions (chloride solutions) in quartz and plagioclase from the host gneiss. Similar solutions are trapped as secondary inclusions in some prismatic zircon crystals.

Rounded quartz grains from tonalite-trondhjemite gneisses contain primary monophase fluid inclusions and co-genetic aqueous gas-liquid inclusions (NaCl content up to 30 wt.%). These inclusions, different in compositions, are sometimes found in the same grains. Inclusions are small (up to 4 μm) and well faceted. Monophase inclusions contain liquid $CO_2$ with some admixture of $CH_4$ (up to 10-15 mol.%). The density of inclusions in quartz from trondhjemite gneiss (ca. 0.8 g/cm$^3$; sample No.39861 from –10840 m) is somewhat lower than in tonalite gneiss (ca. 0.9 g/cm$^3$; sample No.40302 from –11125 m). The fluid pressure, assessed from aqueous and $CO_2$-rich inclusions, reached 4.0-4.5 kbars for T = 700 °C (maximum possible temperature of the amphybolite metamorphism during formation of the studied gneisses).

Table. Chemical composition (wt.%) of glasses from heated melt inclusions in zircon from biotitic plagiogneiss (sample No.26) from the Kola Superdeep Borehole.

| # | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | FeO | MgO | CaO | $Na_2O$ | $K_2O$ | Cl | F | Total | ** | *$HfO_2$ | AR | $K_1$ | $K_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 66.51 | 0.31 | 12.76 | 3.89 | 0.74 | 4.06 | 3.12 | 2.58 | 0.07 | 0.09 | 94.13 | C | 1.02 | 2.6 | 0.83 | 0.84 |
| 2 | 70.57 | 0.35 | 10.97 | 3.94 | 0.72 | 4.59 | 3.22 | 3.68 | 0.09 | 0.05 | 98.13 | C-I | 0.95 | 2.6 | 1.14 | 0.62 |
| 3 | 69.17 | 0.23 | 12.99 | 5.07 | 1.21 | 1.06 | 2.91 | 4.17 | 0 | 0.08 | 96.81 | I-O | 1.21 | 2.6 | 1.43 | 1.16 |
| 4 | 72.64 | 0.07 | 14.58 | 0.12 | 0.03 | 1.39 | 4.89 | 2.46 | 0 | n/a | 96.18 | C-I | 1.26 | 2.4 | 0.50 | 1.10 |
| 5 | 74.92 | 0.05 | 12.05 | 0 | 0 | 0.63 | 3.67 | 2.93 | 0 | n/a | 94.25 | I | 1.31 | 2.4 | 0.80 | 1.17 |
| 6 | 72.81 | 0.17 | 13.68 | 0.1 | 0.02 | 1.84 | 5.12 | 2.28 | 0.01 | n/a | 96.03 | I | 1.2 | 3.0 | 0.45 | 0.96 |
| 7 | 73.39 | 0.10 | 14.04 | 0.29 | 0.08 | 1.48 | 4.74 | 1.71 | 0 | n/a | 95.83 | C | 1.04 | 2.6 | 0.36 | 1.14 |
| 8 | 74.59 | 0 | 13.74 | 0.55 | 0 | 1.85 | 3.83 | 1.02 | 0 | n/a | 95.58 | I | 1.26 | 1.8 | 0.27 | 1.27 |
| 9 | 72.03 | 0.02 | 15.53 | 0.14 | 0.01 | 1.23 | 3.43 | 3.37 | 0 | 0 | 95.76 | O | 1.35 | 3.5 | 0.98 | 1.35 |
| 10 | 75.18 | 0 | 12.73 | 0.24 | 0 | 1.56 | 3.32 | 2.78 | 0 | n/a | 95.81 | C-I | 1.37 | 2.8 | 0.84 | 1.13 |
| 11 | 77.07 | 0.03 | 8.98 | 0.01 | 0.02 | 0.73 | 2.85 | 2.72 | 0 | n/a | 92.41 | C-I | 1.15 | 2.5 | 0.95 | 1.00 |
| 12 | 73.31 | 0 | 13.77 | 0.19 | 0 | 1.55 | 2.69 | 3.77 | 0 | n/a | 95.28 | I | 1.45 | 2.7 | 1.40 | 1.22 |
| 13 | 73.33 | 0.27 | 14.95 | 2.17 | 0 | 1.11 | 0.69 | 2.92 | 0 | n/a | 95.44 | O | 1.21 | 2.2 | 4.23 | 2.80 |
| 14 | 76.79 | 0.07 | 14.25 | 0.22 | 0.09 | 0.27 | 1.98 | 4.14 | 0.01 | 0 | 97.82 | O | 1.45 | 2.0 | 2.10 | 1.73 |

Analyses were carried out on "Camebax-Micro" microprobe at the UIGGM SB RAS. n/a – not analyzed. * - content of $HfO_2$ in zircon near the inclusion; AR – aspect ratio of a crystal; ** - position inclusions in grains: C – central part, I – intermediate part, O – outer part. Analyses (1-3), and (4, 5) are from the same crystal with the first analysis being from near the center and the second being from near the edge. The contents of $Na_2O$ in the table are increased by 30% to compensate for the loss $Na_2O$ during analysis. $K_1=K_2O/Na_2O$; $K_2$=A/CNK=mol $Al_2O_3/(CaO+Na_2O+K_2O)$.

Our studies allow for discrimination of the two genetic types of zircons from tonalite-trondhjemite gneisses of the KSDB. Prismatic crystals are relic-magmatic; they have crystallized, most likely, from the primary melts of the gneiss's protoliths. Complexly faceted, isometric zircon grains have formed during the metamorphic stage of transformation of these protoliths. Rock-forming minerals of these gneisses crystallized in presence of the metamorphogenic fluids having the $CO_2$-$H_2O$-Cl (+ some $CH_4$) composition. Taking into account the fact that aqueous inclusions and inclusions filled with liquid $CO_2$ appear to by co-genetic, we suggest involvement of a heterogeneous fluid, composed of the two immiscible phases.

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**References**

BIBIKOVA, E. N., VETRIN, V. R., KIRNOZOVA, T. I., MAKAROV, V. A. and SMIRNOV, Y. P. (1993): Geochronology and correlation of rocks from the lower part of the Kola Superdeep Borehole section. Dokl. RAN, **332,** 360-363. (In Russian).

ORLOV, V. P. and LAVEROV, N. P. (eds) (1998): Kola Superdeep. Research results and experience. Moskow, MF Tekhnoneft'gaz, 260. (In Russian).

CHUPIN, V. P., CHUPIN, S. V., POSPELOVA, L. N., KOTOV, A. B. and STEPANYUK, L. M. (1994): Melt inclusions in zircons from Archean gneisses as indicator of origin of protoliths and composition of ancient magmas. Dokl. RAN, **338**, 806-810.

CHUPIN, S. V., CHUPIN, V. P., BARTON, J. M. JR. and BARTON, E. S. (1998): Archean melt inclusions in zircon from quartzite and granitic orthogneiss from South Africa: magma composition and probable sources of protoliths. Eur. J. Mineral., **10**, 1241-1251.