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SHORT COMMUNICATIONS

Ancient Plagiogneisses of the Onot Block of the Sharyzhalgai Metamorphic Massif: Isotopic Geochronology

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The oldest rocks of our planet are an interlink between the pregeological history of the material composing the Earth and its evolution during subsequent geological processes. The comprehensive studying of these rocks sheds light onto the distinctive features of the primary material of our planet and the conditions under which its early crust was formed and evolved.

The age when the Earth's early crust was formed and the conditions of this process can be evaluated by solving such problems as the age of the oldest crustal rocks, their geochemistry, and occurrence.

The dating of the oldest rocks is based on the application of various techniques of isotopic geochronology to whole-rock samples and some of their minerals. The most reliable isotopic dates of the oldest rocks were obtained by the U–Pb isotopic dating of accessory zircon. This method is one of the principal techniques used to determine the ages and sequences of geological processes in the Early Precambrian. Zircon is universally recognized as a mineral suitable for geochronology, because of its resistance to mechanical wearing and chemical alterations, extremely high melting temperature, the presence of an internal isotopic control, its highly radiogenic Pb composition, and the availability of methods developed for the graphical interpretation of discordant isotopic ages [1].

Significant progress in zircon dating was achieved with the development of methods and techniques for the local analysis of material on secondary-ion mass spectrometers (ion microprobes). On the one hand, high-spatial resolution of these analyses allows the researcher to conduct analyses within the best preserved portions of zircon crystals and to obtain concordant isotopic ages and, on the other, makes it possible to use a single multiphase grain of accessory zircon to date the succession of geological events.

The oldest rocks found at Precambrian shields worldwide are so-called gray gneisses, which are high-grade metamorphic granitoids of predominantly tonalite composition. These rocks are often older than 3.6 Ga and mark the stage when the first sialic crust was produced. Such rocks with an age close to 3.6 Ga were found and dated in the former Soviet Union in the Ukrainian Shield and Omolon Massif in northeastern Siberia [2]. The identification and reliable dating of each new area with these ancient rocks provides better insight into the timing of the origin of the Earth's early crust and the scale and mechanisms of these processes.

In 1982 we published the results of isotopic dating of zircons separated from gneiss-granites of the Onot block of the Sharyzhalgai metamorphic massif [3]. The classic U–Pb isotopic dating of zircon yielded an age equal to 3250 ± 100 Ma for the upper intercept of the concordia and discordia. Thus the first evidence was obtained that rocks of such an age occur in the area. Further studying of the plagiogneisses of the Onot block made it possible to conduct more precise measurements and obtain even a slightly older age of 3287 ± 10 Ma [4]. However, the complicated inner structures of the zircons required more sophisticated approaches to their dating. This publication reports the results obtained by further study of the age of plagiogneisses from the Onot block. These studies were conducted using both the classic U–Pb dating of small zircon samples and the spot analyses of zircon on an ion microprobe.

The Early Archean plagiogneisses and gneiss-plagiogranites of the Onot block compose elongated linear blocks and nappes up to 10–12 km^2 in area, which have tectonic contacts with the surrounding stratified metasedimentary and metavolcanic rocks of the Onot greenstone belt. In places, the plagiogneisses are

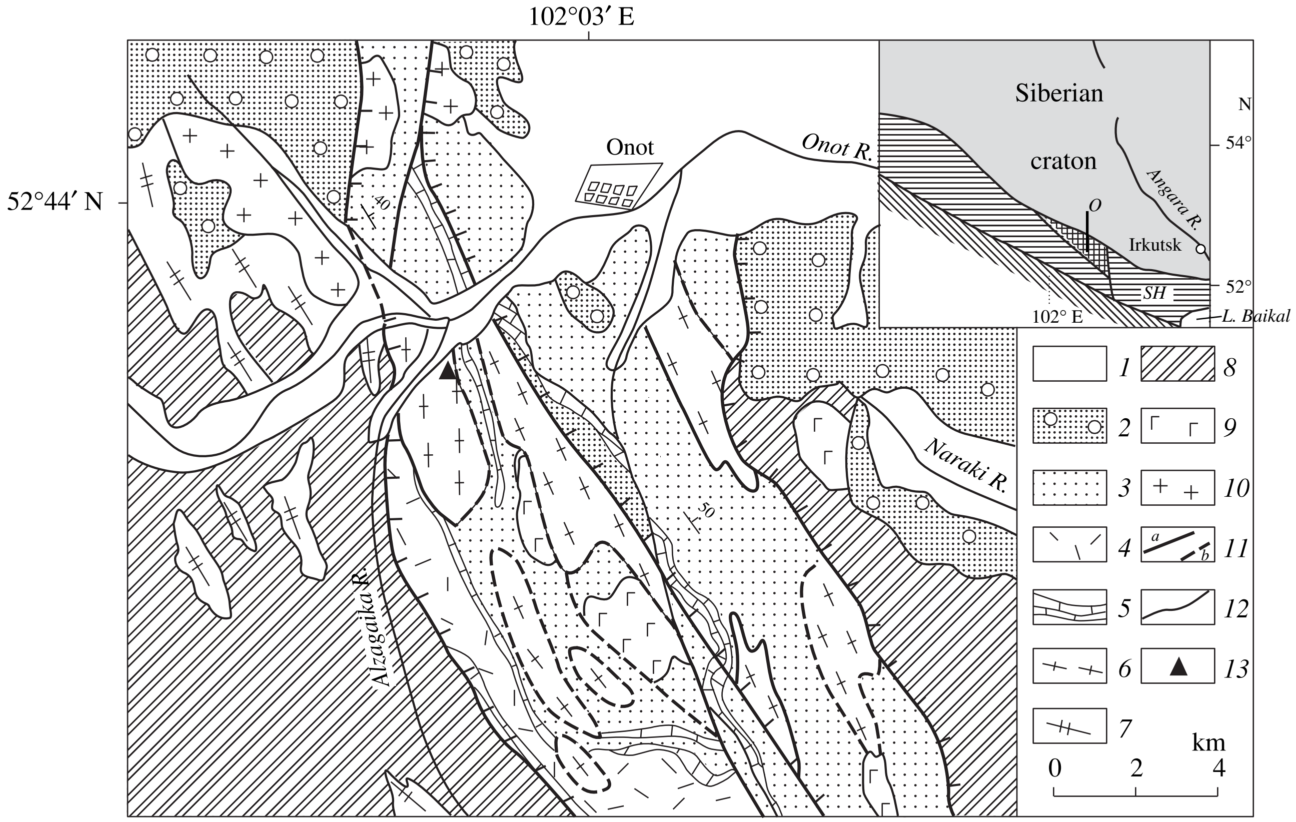

Fig. 1. Schematic geological map of the northwestern part of the Onot block. (*1*) Modern alluvial deposits; (*2*) platform deposits; (*3–5*) rock associations of the Onot greenstone belt: (*3, 4*) supracrustal metasedimentary–volcanic rocks: (*3*) amphibolites, amphibole schists, and metapelites with beds of marbles and BIF, (*4*) biotite and amphibole–biotite orthogneisses with beds of amphibolites and marble lenses on the bottom part of the sequence, (*5*) marble marking beds; (*6*) Early Archean plagiogneisses and plagiogneiss-granites with amphibolite inclusions; (*7*) Late Archean granites of the Kitoi Complex; (*8*) granite-gneiss complex of the Kitoi block; (*9*) Proterozoic gabbroids; (*10*) Early Proterozoic granitoids; (*11*) overthrusts: (*a*) observed, (*b*) inferred; (*12*) boundaries of geologic bodies; (*13*) sampling site (sample 40-3). The inset is a location map of the Onot block in the structure of the base of the southwestern Siberian Platform. *SH*—Sharyzhalgai metamorphic complex, *O*—Onot block.

weakly migmatized and transformed into banded migmatites with rare sheet-shaped amphibolite bodies. The predominant rocks are massive to weakly gneissose medium- to coarse-grained biotite gneiss-plagiogranites with amphibolite inclusions. Based on the textural–structural features of these rocks, it is believed that their more massive textures testify to a magmatic intrusive genesis. The structural setting of the amphibolites suggests that they are roughly coeval with or slightly older than the plagiogneisses and plagiogranitoids. Analogous inclusions of metabasites are very typical of gray gneiss complexes at ancient shields and are considered to be relics of the oldest primary mafic crustal material, which was older than the rocks of the tonalite–trondhjemite series [5].

The plagiogneisses are fine- to medium-grained rocks with a granoblastic texture, whose major-element composition corresponds to aluminous tonalites and trondhjemites. The trace-element composition of these rocks is close to the average trace-element composition of Archean rocks of the tonalite–trondhjemite–granodiorite series (TTG). The plagiogneisses show strongly fractionated REE patterns with high $(La/Yb)_N$ ratios (equal to 20–55) and have practically no Eu anomalies (Eu/Eu* = 0.8–1.2) and elevated concentrations of Sr (220–370 ppm), which cause high Sr/Y ratios (21–66). All of these features are typical of Archean TTG [6].

The plagiogneisses and gneiss-plagiogranites have εNd (from 0.4 to –1.7) ranging from values close to those of CHUR (chondritic uniform reservoir) to negative ones. The model ages of these rocks T(DM) are ~3.6 Ga, which suggests that the rocks were derived predominantly from a source with a crustal prehistory [7]. The Nd isotopic composition of the plagiogneisses and the trace-element characteristics of the amphibolites suggest that their protoliths were formed with the participation of older crustal material. According to the calculations of Turkina [7], the εNd values (from +0.4 to –1.7) determined in the plagiogneisses can be obtained at 30–70% crustal material in the source from which these rocks were derived.

We determined the age of the plagiogneisses (sample P-40-3) by the U–Pb isotopic method, including

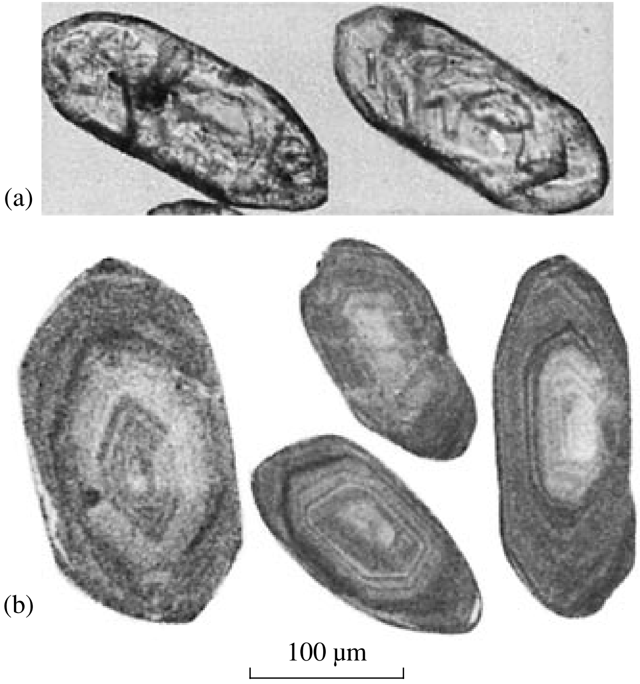

Fig. 2. (a) Transmitted-light photographs of zircons from plagiogneiss (sample P-40-3) and (b) cathodoluminescence images of the zircons.

both its classic variant (at the isotopic laboratory of the Vernadskii Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences) and spot analyses on the NORDSIM ion microprobe (at the Swedish Museum of Natural History, Stockholm). The sample was taken in the vicinity of the mouth of the Alzagaika River, a right-hand tributary of the Onot River (52°42.5′ E, 101°59.5′ N; Fig. 1).

The accessory zircon from this plagiogneiss consists of subprismatic crystals with thin inner zoning, which is clearly seen in transmitted light and cathodoluminescence images (Figs. 2a, 2b). Some of the grains possess inner cores.

The zircons selected for analysis by the classic method were subdivided into size fractions, with the analyses conducted on the most transparent grains without visible inclusions. The isotopic study was conducted following the method of Krogh [8] proposed for small samples of this mineral. The U and Pb concentrations were determined by isotopic dilution, with the use of a mixed ^{208}Pb + ^{235}U spike. The blank was 0.1 ng for Pb. The isotopic composition was measured on a TRITON solid-source multicollector mass spectrometer. The isotopic ages were calculated by the program of Ludwig [9]. The errors of the U–Pb ratios were 0.3%. The correction for common Pb was introduced for an age of 3300 Ma, in compliance with the model of Stacey and Kramers [10].

The analytical results are listed in Table 1. One of the zircon fractions was subjected to acid treatment to eliminate the most disturbed phases [11]. The results are plotted in a concordia diagram (Fig. 3a). As can be seen from the arrangement of the data points in the plot, the isotopic ages are fairly discordant and do not yield a good linear regression (MSWD = 67), which predetermines the significant error of the age calculated from the upper intercept of the discordia and concordia. The age is equal to 3351 ± 84 Ma. This scatter of the data can likely be explained by both the presence of older cores in the zircons and the multistage disturbance of their U–Pb isotopic system. To obtain more reliable isotopic ages for the composite zircon grains, we dated them by conducting spot analyses on an ion microprobe.

For dating zircons on an ion microprobe, an epoxy mount was prepared that contained both zircon grains to be dated and standard reference zircon. The mount was polished until the cores of the zircon grains were exposed, after which their inner structures were examined by cathodoluminescence. Immediately before the analyses, the mount was sputter coated with gold. The primary beam of O^{2-} ions bombarded an ellipsoidal area 25 × 40 μm. The secondary ions were analyzed at a resolution of 5600, which enabled us to reliably discriminate between all of the atomic masses in interest. The analytical procedure is described in more detail in [12, 13]. The analyses were conducted accurate to 0.1–0.3% for the Pb composition, the accuracy of the U–Pb isotopic ratios was 1–3%. The results are summarized in Table 2 and on a concordia plot in Fig. 3b.

Table 1. U–Pb isotopic data on zircons from plagiogneisses (sample P-40-3)

No.	Size fraction, μm	Sample, mg	Concentration, ppm		Isotopic composition of Pb			Isotopic ratios and age, Ma		
			U	Pb	^{206}Pb/^{204}Pb	^{206}Pb/^{207}Pb	^{206}Pb/^{208}Pb	^{206}Pb/^{238}U	^{207}Pb/^{235}U	^{207}Pb/^{206}Pb
1	+100	1.14	260.14	157.81	8615	3.8952	13.105	0.5284	18.629	3220.2 ± 1.1
2	−100 … +75	1.18	311.97	150.43	5980	3.989	12.329	0.4202	14.428	3178 ± 1.1
3	−75 … +60	0.8	344.3	168.26	5650	4.1014	12.456	0.4284	14.298	3133.6 ± 1.0
4	−60	0.9	382.5	185.57	4790	4.1213	12.013	0.4244	14.076	3123.5 ± 1.0
5	SD	3.6	–	–	12300	3.6119	12.111	0.625	23.591	3341.8 ± 1.0

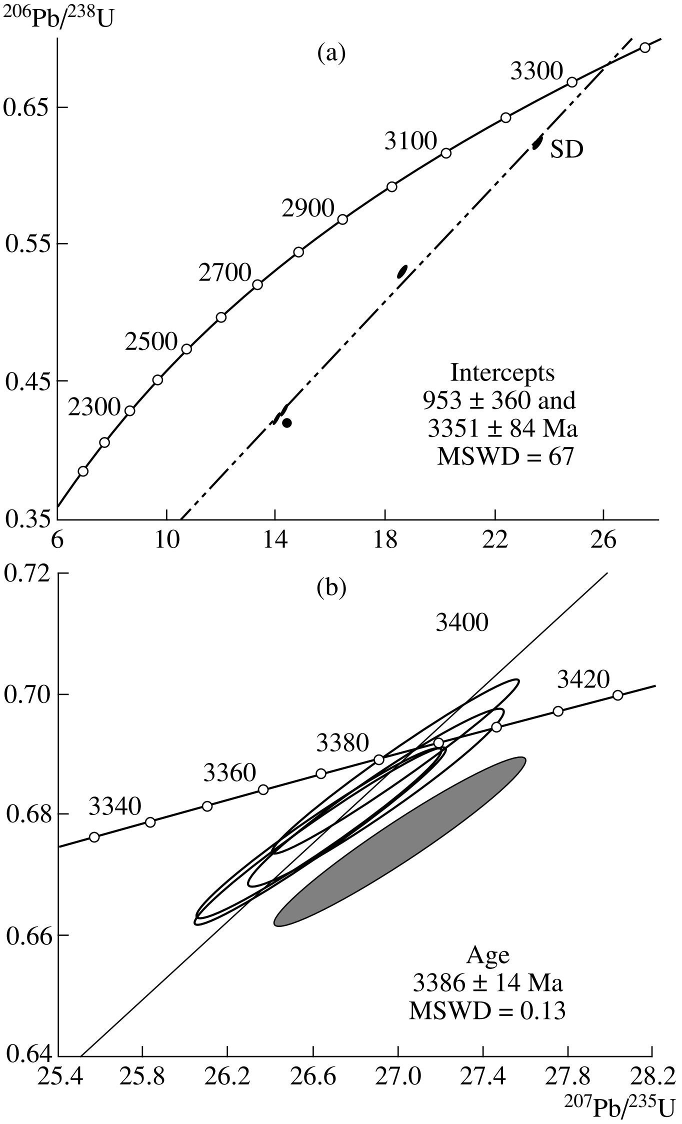

Fig. 3. Concordia diagram for zircons from plagiogneiss (sample P-40-3). (a) U–Pb isotopic dating by the conventional method; (b) results obtained on a ion microprobe.

The data reported in the table indicate that the U concentrations at the analytical spots are much lower than in the integral concentrations in all zircon fractions used for the classic analysis. The isotopic ages of most zircons are practically concordant, with the upper-intercept ages of 3386 ± 14 Ma, MSWD = 0.13. The analyzed core of one zircon grain yielded a $^{207}Pb/^{206}Pb$ age equal to 3415 ± 6 Ma. The occurrence of this core supports the idea of the existence of an older sialic crust that was involved in the genesis of the plagiogneisses, as also follows from the Nd isotopic composition of the rocks. Thus, our research allowed us to reliably date the magmatic zircons of the plagiogneisses at 3386 ± 14 Ma.

The results obtained on the Sm–Nd isotopic system of both this sample and some other orthogneiss samples are summarized in Table 3. The model age T(DM) of the plagiogneiss (sample P-40-3) is 3527 Ma.

Our newly obtained data on the Nd isotopic composition are close to those published earlier in [7]. These data confirm that the genesis of the plagiogneisses was related to the involvement of an older crustal material in melting. A significant fraction of the crustal component that determined the isotopic composition of the plagiogneisses is at variance with the possibility of the origin of these rocks in a subduction environment, in which the recycling of continental material is related to the subduction of sediments. It is more reasonable to suggest the presence of Early Archean sialic crustal material with an age of ≥3.6 Ga, which served as one of the sources of the acid melts.

Our data conform the occurrence of another exposure of Paleoarchean rocks in the territory of Russia and

Table 2. U–Th–Pb isotopic data on zircons from plagiogneisses from the Onot block (ion microprobe analyses)

Sample, analytical spot	Concentration, ppm			Th/U	Common ^{206}Pb	Isotopic ratios ± 1σ		Age, Ma	Discordance, %
	U	Th	Pb			^{206}Pb/^{238}U	^{207}Pb/^{235}U	^{207}Pb/^{206}Pb	
Sample 40-3									
n1499-40-1	87	42	84	0.506	0.01	0.6761 ± 100	26.613 ± 360	3393.3 ± 5.0	–2.4
n1499-40-2	82	30	75	0.364	0.07	0.6652 ± 95	25.726 ± 350	3365.8 ± 4.7	–3.0
n1499-40-3	141	55	105	0.383	0.45	0.5378 ± 90	19.102 ± 300	3232.2 ± 5.6	–17.4
n1499-40-4	89	35	85	0.408	0.03	0.6880 ± 100	26.982 ± 360	3387.4 ± 4.4	–0.5
n1499-40-5	41	16	38	0.612	4.57	0.6615 ± 95	23.405 ± 350	3226.0 ± 15.9	1.9
n1499-40-6	64	20	60	0.317	0.04	0.6771 ± 100	26.624 ± 350	3391.5 ± 5.3	–2.2
n1499-40-7	46	17	43	0.372	0.05	0.6758 ± 100	26.974 ± 370	3414.8 ± 6.2	–3.2
n1499-40-9	85	29	80	0.356	0.1	0.6828 ± 100	26.889 ± 370	3393.8 ± 6.0	–1.5

Table 3. Sm and Nd isotopic composition in rocks from the Onot block

Sample	Rock	Nd, ppm	Sm, ppm	^{147}Sm/^{144}Nd	^{143}Nd/^{144}Nd	T(DM), Ma	εNd
P-40-3	Plagiogneiss	11.72	1.85	0.09542 ± 6	0.510396 ± 9	3527	0.7*
2-03	Orthogneiss	68.83	13.11	0.11514 ± 11	0.511019 ± 16	3274	–5.4**
6-03	Orthogneiss	36.24	7.95	0.13264 ± 16	0.511227 ± 25	3589	–7.1**
6-03sh	Granodiorite	88.65	15.27	0.10410 ± 15	0.511121 ± 24	2807	–7.5***
3-03sh	Quartz diorite	89.95	16.45	0.11059 ± 12	0.511159 ± 19	2927	–8.3***

Note: In calculating εNd for ages of *3.4, **2.5, ***1.86 Ga, the following isotopic ratios were used: ^{147}Sm/^{144}Nd = 0.1967 and ^{143}Nd/^{144}Nd = 0.512638 for CHUR and ^{147}Sm/^{144}Nd = 0.2136 and ^{143}Nd/^{144}Nd = 0.51315 for DM. The isotopic compositions were determined at Vernadsky Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences, for sample P-40-3 and at the Geological Institute of the Kola Research Center, Russian Academy of Sciences, for other samples.

indicate that much of the sialic crust that produced the ancient continental cores was already formed in the Early Archean. Insight into the volumes of the Early Archean crustal material is provided by the Nd isotopic composition of the orthogneisses and granitoids of the Onot block. The amphibole–biotite orthogneisses (metadacites) that compose the bottom of the stratigraphic section of the Onot greenstone belt have a model age T(DM) of 3.27–3.59 Ga. These data and the geochemical evidence of the crustal provenance of the parental melts of the acid volcanics [14] indicate that the Early basement of the greenstone belt is made up of Archean tonalite–trondhjemite crustal material. A slightly younger model age of T(DM-2σ) = 2.97–3.0 Ga was determined for the Early Proterozoic A-type granitoids (1.86 Ga), whose emplacement marked the termination of the origin of the regional crust. This was related to the involvement of juvenile mantle material in the magma-generating region [15]. Hence, the development of the ancient tonalite–trondhjemite crust (≥3.4 Ga) was not restricted to the fragments exposed at the modern erosion level, but could also be extended over the whole area of the Onot block.

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