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GEOLOGY

Primary Data on U/Pb-Isotope Ages and Lu/Hf-Isotope Geochemical Systematization of Detrital Zircons from the Lopatinskii Formation (Vendian–Cambrian Transition Levels) and the Tectonic Nature of Teya–Chapa Depression (Northeastern Yenisei Ridge)

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Abstract—The main results are presented on U/Pb-isotope dating of 100 detrital zircons and, selectively, on the Lu/Hf-isotope system of 43 grains from sandstones of the Lopatinskii formation (the lower stratigraphic level of the Chingasan group). Ages from 896 ± 51 to 2925 ± 38 Ma were obtained with a pronounced maximum of ~1890 Ma in the curve of probability density, along with ε_{Hf} estimates from +8.4 to –15.1, which allow one to throw doubt upon the molasse nature of the Lopatinskii formation.

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The Lopatinskii formation consists of red-colored sandstones with gravelite and siltstone layers. The formation is situated in the Teya and Chapa river basins in the northwestern part of the Yenisei Ridge and constitutes the lower stratigraphic component (450–1100 m [13]) of the Chingasan group overlapping more ancient Riphean metamorphosed forms with structural discordance (Figs. 1a, 1b). This group was commonly related to the top of the Upper Riphean [1, 13] and considered as the molasse [6] filling the Teya–Chapa depression. This latter is among the trough valleys [13] appeared on the western framing of the Siberian Craton (SC) after completion of the collision–accretion events of the latter half of the Neoproterozoic.

Stratotypes of the formations constituting the Chingasan group were described along the Teya River (the Lopatinskii and Karier formations) and the Chapa River (the Chivida formation). Until now, no age evaluations have been available for all the formations mentioned. The most valid notions of the age of the Chingasan group are based upon chemostratigraphy of the sections along the Chapa River [2], as well as on the correlation of tillites occurring in the structure of the section of the Chivida formation at the Chapa River to conglomerates and basaltoids (trachytes) of 703 ± 4 Ma Ar/Ar age [1] located in westward areas of the northern part of Yenisei Ridge (the Vorogovka River basin).

The new data we obtained allow us to throw doubt upon the notions of both the age of the Lopatinskii formation (and hence, the entire Chingasan group) and the molasse nature of the formation.

The authors discovered abundant arumberia-like prints in the stratotypic section of the Lopatinskii formation [5]. Similar finds are characteristic for the tops of the Upper Vendian (Ediacaran) and Lower Cambrian [10]. In view of the character of the magnetic recording, the Lopatinskii formation is a close stratigraphic analogue of a part of the Kotlin layer section, as well as of the bottom of the Lontova layer in the East European Craton [5]; i.e., the accumulation time might be limited to the Late Vendian–Early Cambrian (≤555–540 Ma).

Assuming that "molasses are the products of erosion of growing elevations" [7], one should accept that the Lopatinskii formation was constituted by erosion

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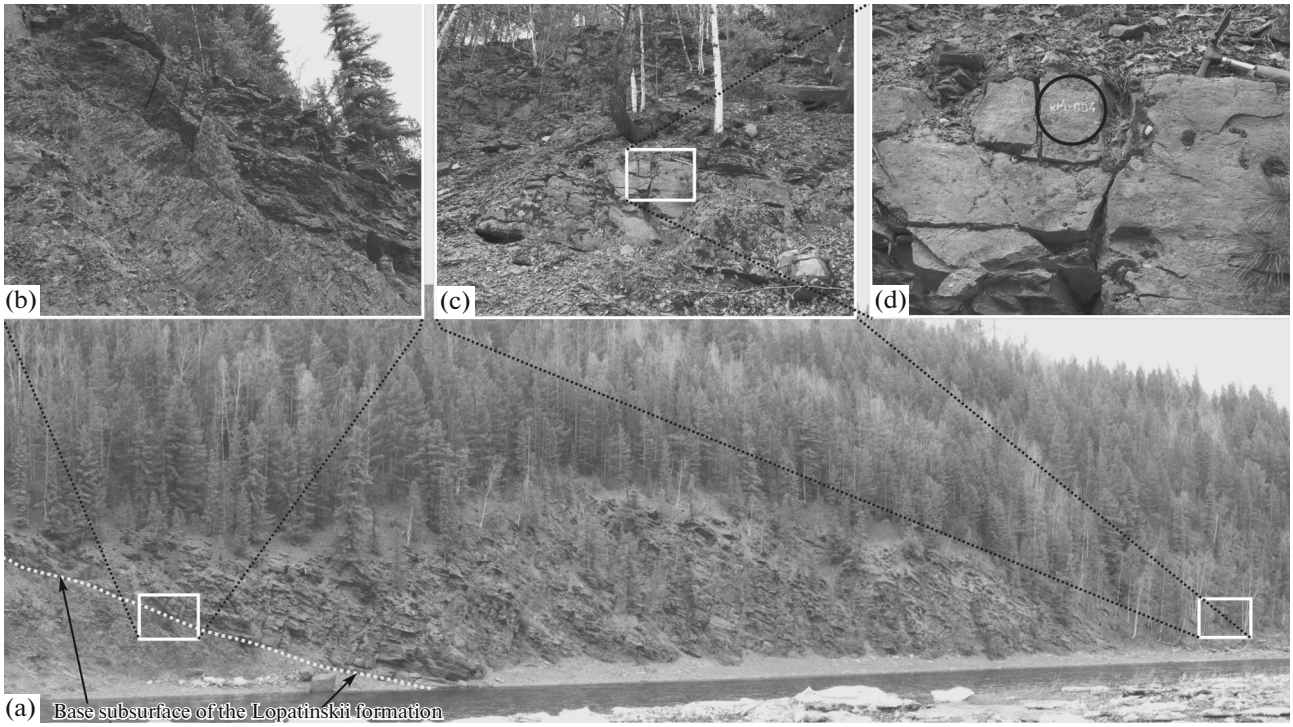

Fig. 1. (a) General view of the stratotypical section of the Lopatinskii formation. The white dotted line marks the formation of the base surface overlapping with discordance with the more ancient Riphean formations. (b) A view of the relationship between the Lopatinskii formation (top) and underlying layers (bottom). (c, d) The collection location of sample K14-004.

products of an orogen existing in the southwestern part of the SC during the accumulation time of this formation. The orogen as such might be a mountainous structure the relics of which constitute at present the western zones of the Yenisei Ridge. These tectonic zones are considered as terrains accreted to the SC western edge 620–600 Ma [15]. The orogen structure contained Neoproterozoic igneous complexes including the Predivin rhyolites (637 ± 5.7 Ma) and diorite-plagiogranites of the Yagunov and Porozhninskii massifs (628 ± 3 and 697 ± 4 Ma, respectively), along with various granitoids with ages of 880–860 and 760–720 Ma [15].

Sample K14-004 of yellowish pink sandstone (~1.5 kg) was collected from the section of the Lopatinskii formation (50 m from the base; 60°20.362′ N, 92°34.981′ E; Figs. 1c, 1d). The detrital zircons (dZr) were separated at the Institute of Precambrian Geology and Geochronology (St. Petersburg, Russia). The subsequent preparation and U/Pb-isotope dating (LA ICP-MS) were performed at Newcastle University (Australia).

The dZrs separated from sandstones of the Lopatinskii formation are characterized by dimensions from 40 to >150 μm and a pronounced roundness. The analysis of the dZr cathode luminescence images showed that about 70% of zircons were characterized by a zonal inner structure. In general, 100 grains of the separated volume were dated, with ages from 896 ± 51 to 2925 ± 38 Ma. Here, all the analyses showed a discordance within <±10% (Fig. 2a). The maximum in the curve of probability density conforms to 1890 Ma and fits into the time range of the SC cratonization when the blocks of Archean crust were joined within 1.7–2.0 Ga [4] by collision orogens (the Angara, Kotuikan, Khapchan, and Akitkan systems as well as the zones of Paleoproterozoic mobilization within the Aldan–Stanovoi shield) conforming to the age of the formation of the Columbia (Nuna) Paleoproterozoic supercontinent ([11] with refs.). The distribution of dZr ages in the sample from the Lopatinskii formation is quite similar on the whole to that for the Karier and Chivida formations we studied formerly [3]. The occurrence of exclusively more ancient grains than ~0.9 Ga among the dZrs from sandstones of the Chingasan group points to the absence of erosion products of the Late Proterozoic (Late Riphean and Early Vendian) crystalline complexes, which presently occur in the western part of Yenisei ridge.

In addition to the U/Pb isotope dating of 100 dZrs from sandstones of the Lopatinskii formation, the Lu/Hf isotope system was studied selectively for 43 grains at the Analytical Center of James Cook University (Townsville, Australia). To calculate ε_{Hf} values, the chondrite ratios $^{176}Hf/^{177}Hf = 0.282785$ and $^{176}Lu/^{177}Hf = 0.0336$ were used [8]. The half-life of ^{176}Lu equal to 1.867×10^{-11}/year [14] was applied in the calculations. Positive ε_{Hf} values in dZrs (the posi-

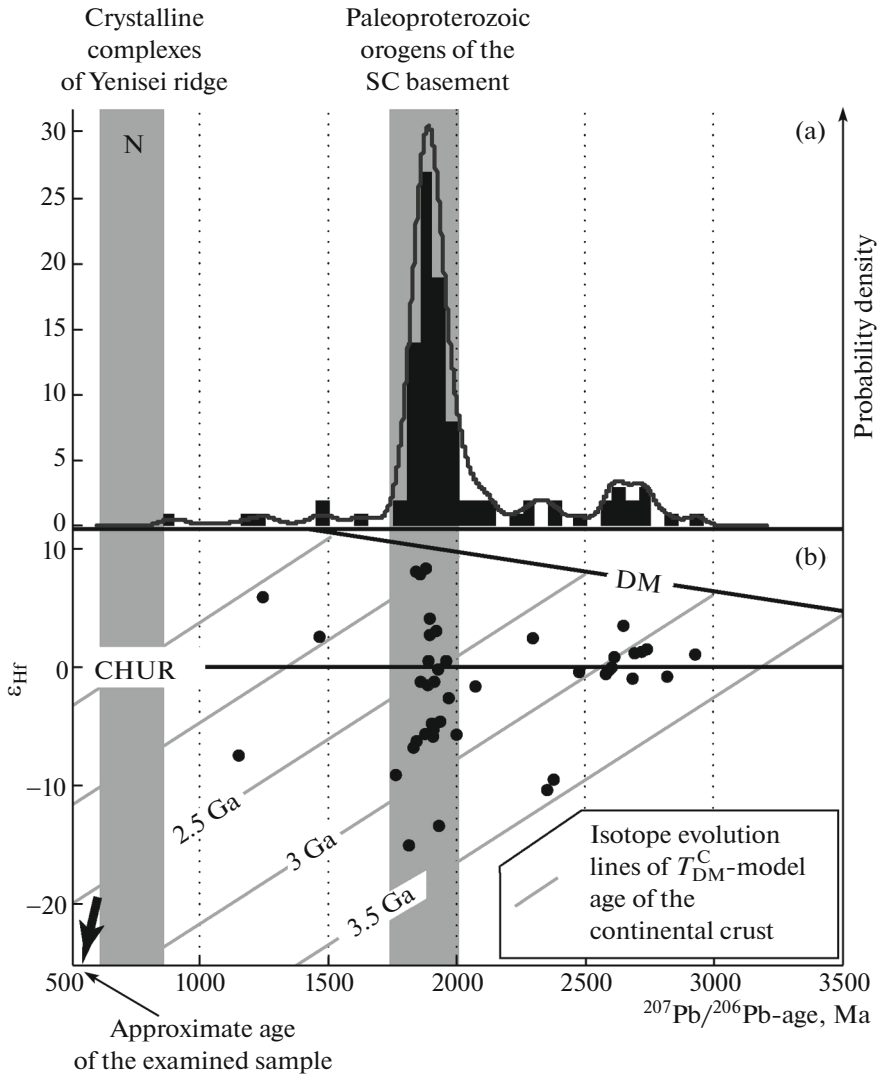

Fig. 2. Histogram and the curve of probability density (a) along with the diagram showing the U/Pb-age dependence of ε_{Hf} values (b) for detrital zircons from sandstones of the Lopatinskii formation (northeastern part of Yenisei ridge).

tions of figurative points in Fig. 2b between the CHUR ($\varepsilon_{Hf} = 0$) and DM lines) show that the juvenile igneous rocks were parental for these dZrs. The negative ε_{Hf} values testify to the occurrence of ancient crustal matter in the substrate the melting of which resulted in the formation of magmas of the dZr parental rocks.

The ratios $^{176}Hf/^{177}Hf_{initial}$ were calculated assuming U/Pb ages for each of the zircons in which the Lu/Hf isotope system was studied. Assuming that $^{176}Lu/^{177}Hf = 0.015$ (conforming to the inclination of the lines of isotope evolution for the average continental crust), the model ages of the parental melt (T_{DM}^{C}) were determined.

The presence of dZrs of 1.7–2.0 Ga and negative ε_{Hf} values as low as –15.1 ($T_{DM}^{C} > 2.5$ Ga) points to the involvement of ancient isotope-mature crust matter into the structure of the substrate of dZr parental igneous rocks. On the whole, the dZrs of 1.8–1.9 Ga from sandstones of the Lopatinskii formation are characterized by a wide range of ε_{Hf} values (Fig. 2b): from substantially positive to strongly negative (conforming to the substance of the depleted mantle and to the ancient crustal matter, respectively). The distributions of ε_{Hf} values as such are characteristic for granitoids of the I- and S-types and suggest that formation of provenance igneous rocks resulted from the mixing of juvenile melts and melting products of mature crustal matter under the rise and differentiation of basalt magma [9]. The detrital zircons of 1.7–1.8 Ga are characterized by ε_{Hf} values from –5 to –15 and by Archean model ages of the substrate (T_{DM}^{C}). These facts point to the formation of dZr parental rocks under the transformation of the Archean crust. Thus, the entire

Paleoproterozoic population of dZrs from sandstones of the Lopatinskii formation was mainly composed of the destruction products of Paleoproterozoic orogens and, moreover, most probably, of the above-listed collision orogens the relics of which join the ancient crustal blocks within the SC basement.

The accumulation of the Lopatinskii formation proceeded ~1.3 Ga after the SC Proterozoic cratonization. During this time, Columbia disintegrated, Rodinia integrated and disintegrated, the SC underwent a number of glaciations, and accretion–collision events and processes took place at the SC edges. However, the study we performed has shown that the destruction products of Paleoproterozoic orogens prevailed in the Lopatinskii formation, whereas younger igneous events were represented only by isolated Mesoproterozoic grains. Here, no grains of Late Proterozoic ages were identified. These facts suggest that the Chingasan group is composed of the destruction products of the ancient SC basement but do not confirm the hypothesis of the molasse nature of the sediments filling the Teya–Chapa depression. The material containing ancient zircons might have been supplied to the Late Vendian–Early Cambrian Teya–Chapa basin both immediately from the SC basement and, for example, through recycling of the deposits of the Sukhoi Pit group underlying the Lopatinskii formation. This group is considered among the components of the structure of the passive SC age [12].

Thus, all the above-mentioned data throw doubt upon the hypothesis of the molasse nature of sediments filling the Teya–Chapa depression.

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