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GEOCHEMISTRY

Refined $\delta^{13}C$ Trend of the Dal'nyaya Taiga Series of the Ura Uplift (Vendian, Southern Part of Middle Siberia)

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ABSTRACT—New data were obtained on $\delta^{13}C_{carb}$ and $\delta^{18}O$ variations in the sequence of deposits of the Dal'nyaya Taiga series at the western and eastern flanks of the Ura anticline. The summary $\delta^{13}C$ curve was plotted in view of the correlation of sequence–stratigraphic data of the basin analysis. A series of positive anomalies was found within the succession. Alternatives for global chemostratigraphic correlation of the Dal'nyaya Taiga series of the Ura uplift were considered.

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The Late Precambrian deposits of the Ura Uplift (UUL) including the Dal'nyaya Taiga, Zhuinskaya, and Trekhverstnaya series are considered as the reference section for the Vendian in the southern part of Middle Siberia [1]. The set of stratigraphic characteristics aligns this section with the standard ones for the Ediacaran in China, Namibia, Oman, Australia, and Canada. Diamictites of the Bolshoi Patom series at the basement of the UUL section are correlated to the Marino glaciation [1]. The overlying Barakun series begins with the reference layer of "crowning" dolomites [2]; the series was characterized by finds of the Vendian *Beltanelloides sorichevae* [3]. A wide variety of acanthomorphids was found in the upper part of the Ura stratum of the Dal'nyaya Taiga series. The upper part of the Trekhverstnaya series contains small-shell fauna of the Upper Vendian Nemakit–Daldyn stage [5]. The Vendian attribution of the Zhuinskaya and Trekhverstnaya series is confirmed by the dating of detrital zircons [6]. The sequence of deposits of the Dal'nyaya Taiga and Zhuinskaya series is characterized by a Vendian-inherent increase in the $^{87}Sr/^{86}Sr$ ratio and abnormal $\delta^{13}C$ variations from +9 to –13‰ in the Dal'nyaya Taiga and Zhuinskaya series, respectively [7–9].

The determination of the density of $\delta^{13}C$ values and $^{87}Sr/^{86}Sr$ ratios in the UUL section from the top of the Bol'shoi Patom to the Zhuinskaya series is still insufficient to reveal a trend (22 and two samples, respectively, for over 2 km thickness) [7]. The stable trend of minor $\delta^{13}C$ variations within the range of high values in the section of the Dal'nyaya Taiga series at the UUL (Fig. 1) is inconsistent with wider scattering of $\delta^{13}C$ values registered in the remote sections of the Dal'nyaya Taiga series and the proposed analogs in the Patom basin [7, 8]. Thus, one may suppose that the $\delta^{13}C$ trend should be changed after more detailed survey of the section of the Dal'nyaya Taiga series at the UUL. The comparison of this trend to that in Ediacaran sections should affect the notions of the stratigraphic volume of the section of the Dal'nyaya Taiga series with preserved climatic and biotic events.

To plot the adjusted $\delta^{13}C$ curve for the Dal'nyaya Taiga series of the UUL, the samples were collected from the outcrops of the Barakun, Ura, and Kalanchevskaya series uncovered in the Ura River valley on the western and eastern flanks of the Ura anticline (Fig. 1). The exposure amounted to 24 and 27% of the total thickness of the western and eastern sections, respectively. The shape of the summary $\delta^{13}C$ curve depends on the correlation of these two sections because the deposits of the Dal'nyaya Taiga series are different in their thickness and facies composition at the anticline flanks. The correlation was performed by

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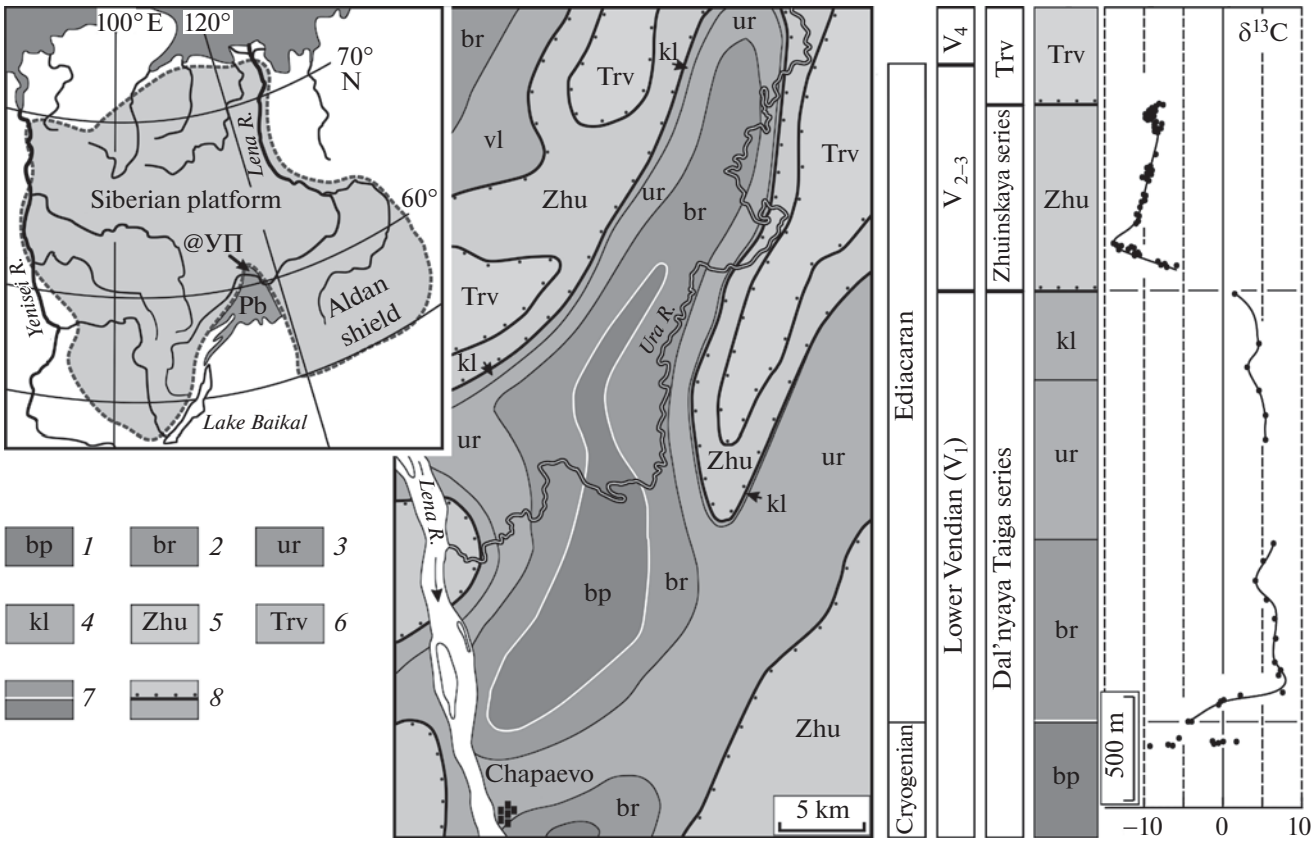

Fig. 1. Geographical location of the Patom basin, schematic geological map of the UUL central area, summary stratigraphic succession of deposits, and the variations of carbon isotope composition in the section of the Dal'nyaya Taiga and Zhuinskaya series by [7]. *1*, Diamictites of the Bolshoi Patom series; *2*, Barakun series, carbonates, sandstones, argillites; *3*, Ura series, siltstones and argillites; *4*, Kalanchevskaya series, carbonates and marls; *5*, Zhuinskaya series, carbonates and marls; *6*, Trekhverstnaya series, sandstones, carbonates; *7*, crowning dolomite layer; *8*, stratigraphic breaks; *Pb* is the Patom basin.

the authors in the course of basin and facies analyses. As a result, two sequences were distinguished within the Barakun and Ura–Kalanchevskaya areas. The sequences were separated with a conformable boundary and constituted in general the continuous transgression–regression cycle limited at the top by the fore-Zhuinskaya stratigraphic unconformity (Fig. 2). The bulk of sediments (64–74%) associated with the middle part of the whole Dal'nyaya Taiga cycle was accumulated under intense bowing under the conditions of deep-water homocline carbonate–clayey ramp. The ramp subsidence to the southeast (in current coordinates) had indicated more deep-seated conditions of the formation and greater thickness of the progradation wedge within the eastern flank of the Ura anticline. The sediments in the lower and upper parts of the cycle (15–13 and 21–13%, respectively) were formed in the sublittoral areas of the early–Barakun terrigenic–carbonate shelf and of the Kalanchevskaya carbonate platform, respectively. The tectonic conditions and facies features of the Dal'nyaya Taiga basin point to a permanent high rate of sedimentation until the end of the Kalanchevskaya time when the section showed signs of the paleokarst and of areal erosion marking the fore-Zhuinskaya break.

In all, 169 values for the $\delta^{13}C_{carb}$ and $\delta^{18}O$ isotope compositions were obtained, including 113 for the summary section of the western flank of 2030 m thickness and 56 for the eastern flank of 2700 m thickness. The samples for isotope analyses were taken on a fresh cut from the micrite part of the carbonate rock containing neither coarse-crystalline veins nor pigmentation. To study the heterogeneity of the C-isotope composition in the rocks, the sparry cements were sampled. The analyses were carried out by the procedure in [7]. The reproducibility of $\delta^{13}C$ and $\delta^{18}O$ determination in the standards was within ±0.1 and ±0.2‰, respectively. The values presented are related to the V-PDB standard.

In addition, four limestone samples from the Barakun series uncovered on the Malyi Patom River were examined, which matched the geochemical criteria of retention (Mn/Sr < 0.2 and Fe/Sr < 4). The ratio increased here upwards through the section from

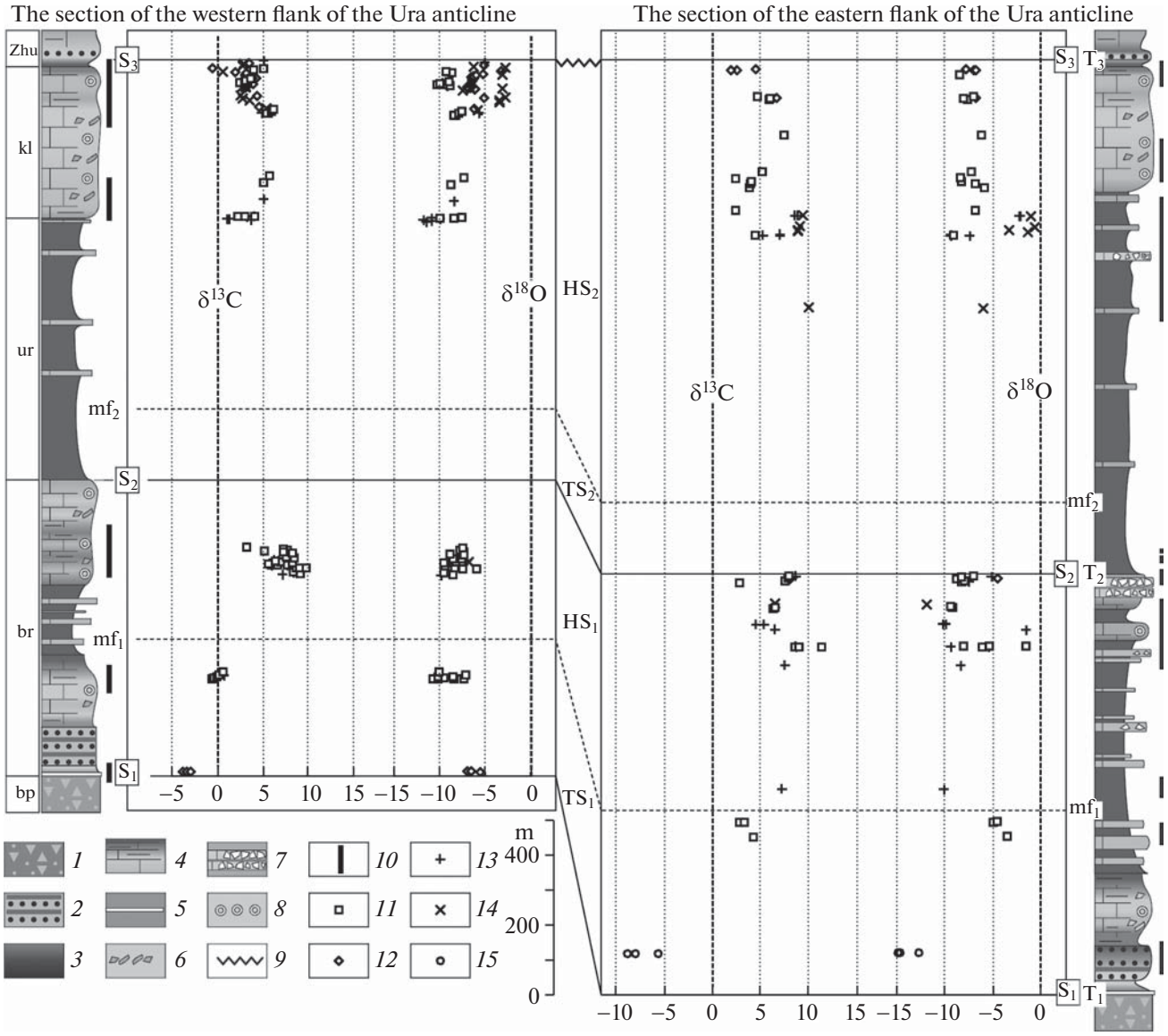

Fig. 2. Variations of $\delta^{13}C$ and $\delta^{18}O$ values in the deposits of the Dal'nyaya Taiga series at the western and eastern flanks of the Ura anticline and their correlation based on the analysis of the basin. *1–8*, Deposit compositions: *1*, diamictites; *2*, sandstones, siltstones, and argillites; *3*, aleuro-argillites; *4*, carbonates, clayey carbonates, and marls; *5*, crowning dolomite layer; *6*, intraclastites; *7*, landslide breccia; *8*, oolites; *9*, stratigraphic break; *10*, stratigraphic location of the studied sections; *11–15*, $\delta^{13}C$ values in the rocks: *11*, limestones; *12*, dolomites; *13*, limy marls; *14*, dolomitic marls; *15*, sandstones. The sequence stratigraphy: *S*, sequence boundaries; *mf*, lines of the maximum sea level; *T*, transgression boundaries; *TS*, transgression path; and *HS*, high sea level path. The series: *bp*, Bolshoi Patom; *br*, Barakun; *ur*, Ura; and *kl*, Kalanchevskaya. *Zhu*, Zhuinskaya series.

0.70756 to 0.70793 at the bottom of the series and from 0.70839 to 0.70847 at the top. These values are in agreement with those obtained earlier [8].

The difference in $\delta^{13}C$ and $\delta^{18}O$ values between allochems together with early and late diagenetic cements in the samples is within 1‰. Here, the late diagenetic cement is always depleted in ^{13}C and ^{18}O compared to allochems. The variations of $\delta^{13}C$ values in the sediments of the Dal'nyaya Taiga series are shown subsynchronously in the rocks of different lithology—limestones, dolomites, and limy and dolomitic marls (Fig. 2)—which were subjected variously to postsedimentary transformations depending on the conditions of their formation and permeability. These facts show that the measured $\delta^{13}C$ variations represent the changes in the carbon isotope composition within the sedimentation environment. The retention of the C-isotope system at individual levels is confirmed by the inverse correlation between $\delta^{13}C$ and $\delta^{18}O$ values.

The $\delta^{13}C$ values at the bottom of the Barakun series decreased from −3‰ in cap dolomites to −8‰ in the lower part of the formation (Fig. 3). A gradual $\delta^{13}C$

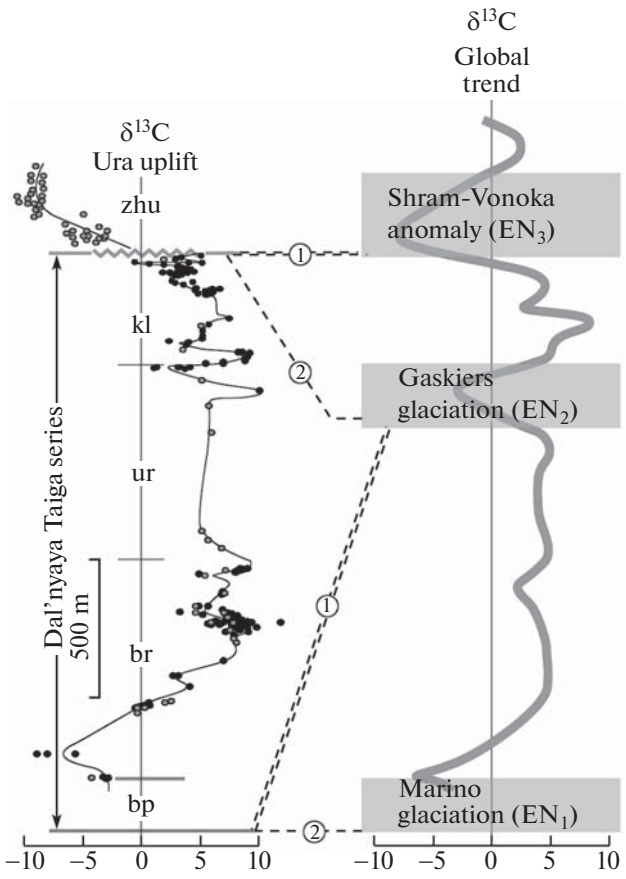

Fig. 3. Summary curve of $\delta^{13}C$ variations for the Dal'nyaya Taiga series of the UUL with the versions of a correlation to the global $\delta^{13}C$ trend by [11]. The negative anomalies are designated by [13] (EN_1, EN_2, and EN_3); the correlation to the Gaskiers and Marino glaciations, by [11]. Black dots are $\delta^{13}C$ values; gray dots are the values by [7] corrected by thickness. Different versions of the correlation of the Dal'nyaya Taiga series are shown with dotted lines marked as *1* and *2*, respectively. See Fig. 2 for the abbreviations of series names.

growth up to +11‰ turned into a reliable decrease to +4‰. The $\delta^{13}C$ values are increased anew to +9‰ at the top of the Barakun series. The deposits of the Ura series are poorly uncovered in the sections considered; however, the $\delta^{13}C$ values amount to about 5‰ at the bottom and the top of the series by the data of [7]. The $\delta^{13}C$ values we obtained for the interlayer of dolomitic marl from the upper part of the Ura series amount to +10‰, decreasing to +1 to +3‰ in the roof of the formation. The Kalanchevskaya series shows gradual $\delta^{13}C$ growth from +4 to +7.5‰. The values in the upper part of the series decreased smoothly to +3‰; stepwise $\delta^{13}C$ variations from –0.5 to +5‰ are seen at the top of the Dal'nyaya Taiga series.

Thus, the section of the Dal'nyaya Taiga series of the UUL is characterized by $\delta^{13}C$ variations from low to abnormally high positive values, which allow one to distinguish one negative excursion and the set of positive anomalies separated with moderately positive values.

According to recent studies of the Doushantuo formation [10], one more negative excursion (EN_2) separating the areas of variable positive values is distinguished in the generalizing $\delta^{13}C$ curve from the Marino glaciation (about 630 Ma) to the negative Shuram–Vonoka $\delta^{13}C$ anomaly (EN_3) [11]. This excursion accompanied with synchronous positive $\delta^{18}O$ excursion and with the signs of a fall in sea level was correlated to the subglobal Gaskiers glaciation (about 580 Ma ago). The probability of a break caused by the eustatic fall in the sea level explains the (EN_2) absence in many other Ediacaran sections. The correlation of the negative anomaly of the Zhuinskaya series to the Shuram–Vonoka anomaly is confirmed by the specificity of the O and Sr isotope compositions [9, 11]. At the same time, no negative (EN_2) excursion was found in the section of the Dal'nyaya Taiga series of the UUL, or in the stratigraphic analogs within the Patom basin [7, 8]. Hence, according to the chemostratigraphic correlation (Fig. 3), either a stratigraphically significant break takes place at the basement of the Zhuinskaya series or the diamictites of the Bolshoi Patom series conform to the Gaskiers glaciation level. The latter is not contrary to the accepted correlation of the Dal'nyaya Taiga and the Baikal series [1] with limestones of 560 ± 30 Ma age [12]. Thus, the contradiction is eliminated on an inconsistency in the age of regional discordance at the basement of the Dal'nyaya Taiga and Baikal series to the time of collision of the Baikal–Muya terrane and the Siberian platform, which is estimated as 600 Ma [13].

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