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Regional carbon isotope curve and biotic events in the Silurian of the Western slope of the Subpolar Urals and Chernov Uplift

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We present a new regional event scale based on a generalized analysis of results of determination of event-stratigraphic boundaries of biotic events of various levels and $\delta^{13}\text{C}$ isotope anomalies in studied reference sections of the Subpolar Urals and the Chernov Uplift.

The combined regional curve of carbon isotopic composition allows finding out several isotopic events in the Silurian.

Keywords: carbon isotope record, event stratigraphy, Silurian, Chernov Uplift, Subpolar Urals.

Региональная кривая изотопов углерода и биотические события в силуре западного склона Приполярного Урала и поднятия Чернова

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В статье приводятся результаты изучения следов глобальных биотических и изотопных ($\delta^{13}\text{C}_{\text{карб}}$) событий, сохранившихся в опорных разрезах силура на Приполярном Урале и поднятии Чернова. Актуальность проводимых региональных исследований определяется необходимостью понимания истории развития Тимано-Североуральского морского палеобассейна в силуре с целью ее реконструкции, а также для межрегиональной и глобальной корреляции. Изотопная кривая составлена путем обобщения новых и ранее полученных авторских данных (более 500 анализов) по изотопному составу углерода в карбонатах, биостратиграфически привязанных к событийным интервалам в изученных разрезах и региональным горизонтам. Интегрированная региональная событийная шкала основана на анализе результатов определения событийно-стратиграфических рубежей различного ранга и С-изотопных аномалий. Следы региональных событий рассмотрены в тесном контексте с основными глобальными изотопными, эвстатическими и биотическими событиями.

Проведенные исследования позволили пересмотреть некоторые сложившиеся представления о строении разреза силура, провести корреляцию с разновозрастными отложениями Эстонии, в которых установлены соотношения карбонатных и сланцевых пород, охарактеризованных граптолитовой фауной. Полученные результаты послужили обоснованием установленных авторами перерывов в осадконакоплении в среднем лландовери (на рубеже азрония и теличия), между лландовери и венлоком и в позднем лудлове. Также внесены существенные уточнения, дополнения и изменения в стратиграфическую и корреляционную схемы изученной территории.

Ключевые слова: изотопы углерода, событийная стратиграфия, силур, поднятие Чернова, Приполярный Урал.

Introduction

This article presents the results of study of traces of global biotic and isotopic ($\delta^{13}\text{C}_{\text{carb}}$) events preserved in the reference sections of the Silurian in the Subpolar Urals and the Chernov Uplift (Fig. 1).

The relevance of the ongoing regional studies is conditioned by the need to understand the history of the development of the Timan-Northern Ural marine paleobasin in the Silurian time with the aim of its reconstruction, as well as for interregional and global correlation.

The isotopic ($\delta^{13}\text{C}_{\text{carb}}$) anomalies and biotic events established in the Silurian succession suggest that region-

al and global biospheric events coincide in time. The proposed composite regional curve of carbon isotopic composition of carbonates was compiled by summarizing the data obtained by the authors from the main of the reference sections. Carbon isotopic analyzes (more than 500 analyzes) were performed at the Center for Collective Use «Geonauka» of the Institute of geology FRC Komi SC UB RAS (I. V. Smoleva)

Each event is confined to the section in which it was found and to the regional horizon. The proposed regional carbon isotope curve will be further refined and supplemented as new material is studied.

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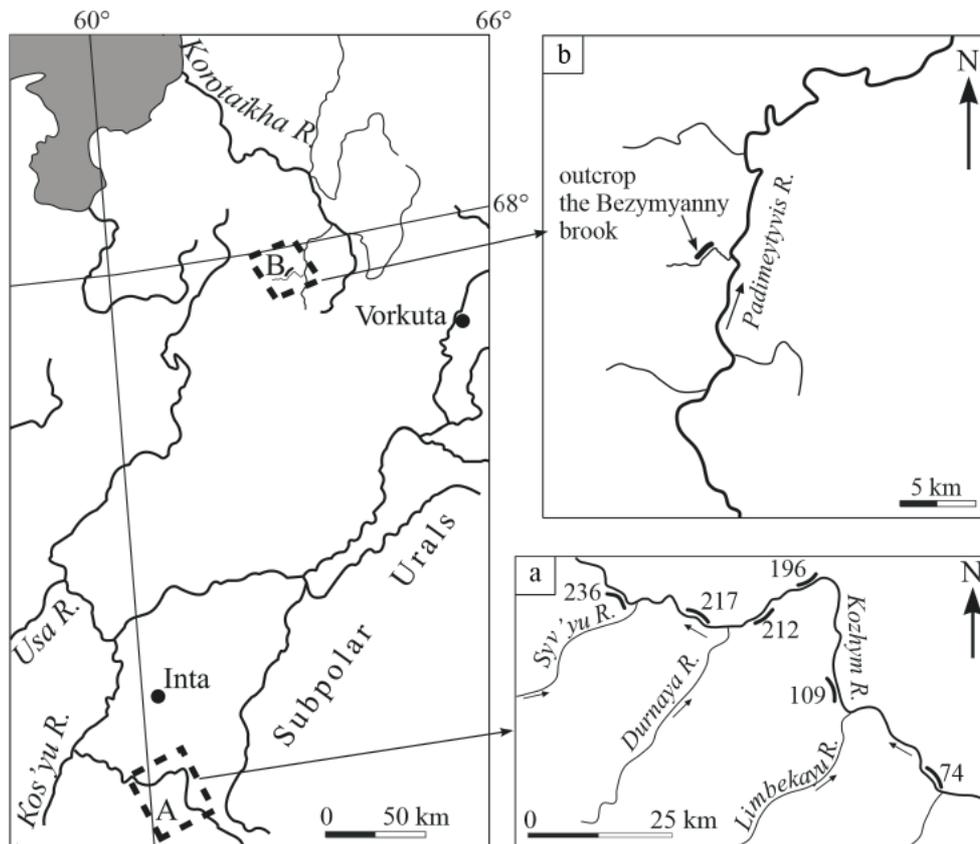


Fig. 1. Scheme of the location of the studied sections: a — western slope of the Subpolar Urals: the Kozhym River (outcrops 74, 109, 212, 196, 217, 236); b — outcrop along the Bezymyanny brook (Chernov Uplift)

Рис. 1. Схема месторасположения изученных разрезов силура: а — западный склон Приполярного Урала: р. Кожым (обнажения 74, 109, 212, 196, 217, 236); б — обнажение на руч. Безымянный (поднятия Чернова)

The presented integrated regional event-stratigraphic scale of the Silurian and established event intervals in the studied sections in the Subpolar Urals and the Chernov Uplift are substantiated by changes in the biota composition, sedimentation conditions and data on $\delta^{13}\text{C}$. The sections with traces of the most serious events are typical for the unified Silurian subdivisions of the Western Ural subregion [32]. The intervals with traces of global events are tied to the horizons of the regional stratigraphic scale (Fig. 2, 3).

The traces of regional events that we have established are considered in close context with main global isotope, eustatic, and biotic events in the Silurian — Late Aeronian/Sandvika Event, Ireviken Event, Mulde Event, Lau Event, and Early Pridolian/Klev Event [2, 14, 17].

The event intervals of the sections, established by us, are characterized by distinct sedimentation features of basin shallowing accompanied by the disappearance of almost all major groups of benthic fauna and the development of stromatolite-forming biota, sedimentation gaps, and $\delta^{13}\text{C}$ anomalies.

The isotope curve for the entire Silurian was compiled by summarizing new and previously obtained data on the carbon isotope composition in carbonates, biostratigraphically attached to the intervals of the reference sections of the Subpolar Urals and the Chernov Uplift [6, 7, 8, 27].

Dating of the considered event intervals in the Silurian deposits is difficult since these deposits often do not contain common fossil remains of fauna (for example, graptolites). In the sections without graptolites, the event interval is determined by conodonts, brachiopods and data on carbon isotopes. The results of our studies of Silurian

deposits showed the synchronism of biotic, eustatic and isotope events traced in the Northern Ural sections.

Regional Event Stratigraphic scale, isotopic and biotic events in the Silurian

This paper summarizes results of our study of traces of regional events, which are considered in close context with main global events of extinction in the Silurian (Fig. 3). The characteristics of the studied sections, in which event intervals and an updated stratigraphic scheme of the Timan-Northern Ural region of the Silurian were identified, are given in publications [6, 7, 8, 27]. Changes in the Silurian global carbon cycle were closely related to major crises in marine ecosystems, as well as to paleoclimatic changes [12, 23, 30].

The Late Aeronian/Sandvika Event was first described in Norway as a major biotic extinction event of graptolites of the zonal species *Lituigraptus convolutus* and *Stimulograptus sedgwickii*. In sections where graptolites are absent, this interval is characterized by extinction of conodonts *Pranognathus tenuis* (Aldridge) and brachiopods of the genus *Pentamerus*. The chemostratigraphic data allowed comparing the Sandvik bioevent with the Late Aeronian isotope Event [8].

Traces of the Late Aeronian/Sandvika Event were established in the biostratigraphically well-studied section of the Lolashor Regional Stage (Aeronian) on the western slope of the Subpolar Urals. The assumption about the possible presence of traces of the Sandvika Event at the base of the Lolashor Regional Stage in outcrop 217 in the



GSS [33]			Stratigraphic scheme of the Urals [32]	Proposed scheme (North Ural region)						
SYSTEM	SUBSYSTEM	SERIES	Stage	Regional stage	Regional stage	Brachiopod zone [7]	Ostracod zone [1]	Beds with conodonts [28]		
SILURIAN	LATE	PRIDOLI	Karpov	Karpov	<i>A. insignae</i> <i>Gr. parvula</i>	<i>Kiaeria katerinae</i> - <i>K. alata</i>				
			Belush'ya	Belush'ya	<i>A. scheiji</i> - <i>H. pseudogibbosa</i>	<i>Calcaribeyrichia grebeni</i> - <i>Eokloedenia bacata</i>				
		LUDLOW	Ludfordian	Sizim	Sizim	<i>D. didyma</i>	<i>Dolgitia triangulata</i> <i>Eokloedenia subbacata</i> <i>Leiocyamus clausus</i>	<i>Polygnathoides siluricus</i>		
			Gorstian	Padimeityvis	Padimeityvis	<i>Gr. uberis</i>	<i>Leiocyamus paulus</i> <i>Beyrichia posterior</i> <i>Signetopsis bicardinata</i> <i>Simplicibeyrichia parva</i>			
		LOWER	WENLOCK	Homerian	Ust'Durnayu	Voivyv	<i>S. nordensis</i>	<i>Herrmannina insignis</i> <i>Eukloedenella grandifabae</i>		
				Sheinwoodian					<i>Ozarkodina kozhimica</i> <i>Apsidognathus tuberculatus</i> <i>D. staurognathoides</i>	
	LLANDOVERY		Telychian	Marshrutnyj	Marshrutnyj	<i>F. flabellata</i>	<i>Microcheilinala convexa</i> <i>M. variolaris</i> <i>Gibirella aff. praetiosa</i>			
			Aeronian	Lolashor	Filipp"el'	Filipp"el'	Интерзона	<i>Hogmochilina ex.gr. elognata</i>	<i>Galerodus magalius</i>	
			Rhuddanian	Yareny		<i>Pentamerus oblongus</i>		<i>Pranognathus tenuis</i> <i>Pranognathus siluricus</i> <i>Aspelundia cf. expansa</i>		
						<i>V. barrandei</i> - <i>Z. duboisi</i>		<i>Distomodus kentuckyensis</i>		

Fig. 2. Stratigraphic and correlation scheme of the West Ural subregion with clarifications and changes

Рис. 2. Стратиграфическая и корреляционная схема Западно-Уральского субрегиона с уточнениями и изменениями

Subpolar Urals was first made by S. V. Melnikov because of finds of conodonts *Pranognathus tenuis* (Aldridge) [28]. The results of our study of the deposits of the Lolashor Regional Stage in outcrops 109, 196, and 217 (Fig. 1) showed that traces of the global Late Aeronian Sandvika Event contained deposits of not the lower, but the upper part of the Lolashor stage [8]. In the sections, the event was characterized by extinction of brachiopods of genus *Pentamerus* and conodonts *Pr. tenuis* that emerged from the base of the Lolashor Regional Stage. Sedimentation signs of shallowing of the sea basin observed in the upper part of the section of the Lolashor Regional Stage, as well as a positive $\delta^{13}C_{carb}$ anomaly up to +1.2 ‰ (Fig. 3), correlated with the Sandvika biotic Event and the Late Aeronian positive carbon isotope event. Small values of $\delta^{13}C_{carb}$ are probably due to a sedimentation gap [8].

A gap at the boundary of Aeronian and Telychian is also present in sections of other regions of the planet. A significant negative excursion of $\delta^{13}C_{carb}$ with a value of -7.7 ‰ in the Ural section marks the boundary of Aeronian and Telychian [9, 16, 20] (Fig. 3).

Ireviken Event (Early Wenlock). It is known that the Early Wenlock positive excursion $\delta^{13}C_{carb}$, corresponding to the Ireviken Event and the interval directly above it, is global [19].

The study of the reference section of the Lower Silurian in the Subpolar Urals in outcrop 212, 217 (Fig. 1) showed no signs of Early Wenlock positive excursion of $\delta^{13}C_{carb}$ and a significant, yet biostratigraphically unconfirmed gap, which falls on the Llandovery-Wenlock boundary interval [3, 4, 24] (Fig. 2). The obtained results are in good agreement with the biostratigraphic conclusions about the structure of the Severnaya Zemlya section, where the Lower Wenlock deposits are also absent [26].

Mulde Event (Wenlock) is one of the three largest events in the Silurian [15, 18, 19, 23]. This event is characterized by the extinction of the graptolite and conodont fauna, as well as by the double positive excursion of $\delta^{13}C_{carb}$, which can be traced in many sections of the world [13, 19, 31].

Traces of the Mulde Event are preserved in outcrop along the Bezymyannyj brook in the Chernov Uplift in the basin of the Padimeityvis River (see Fig. 1). The event

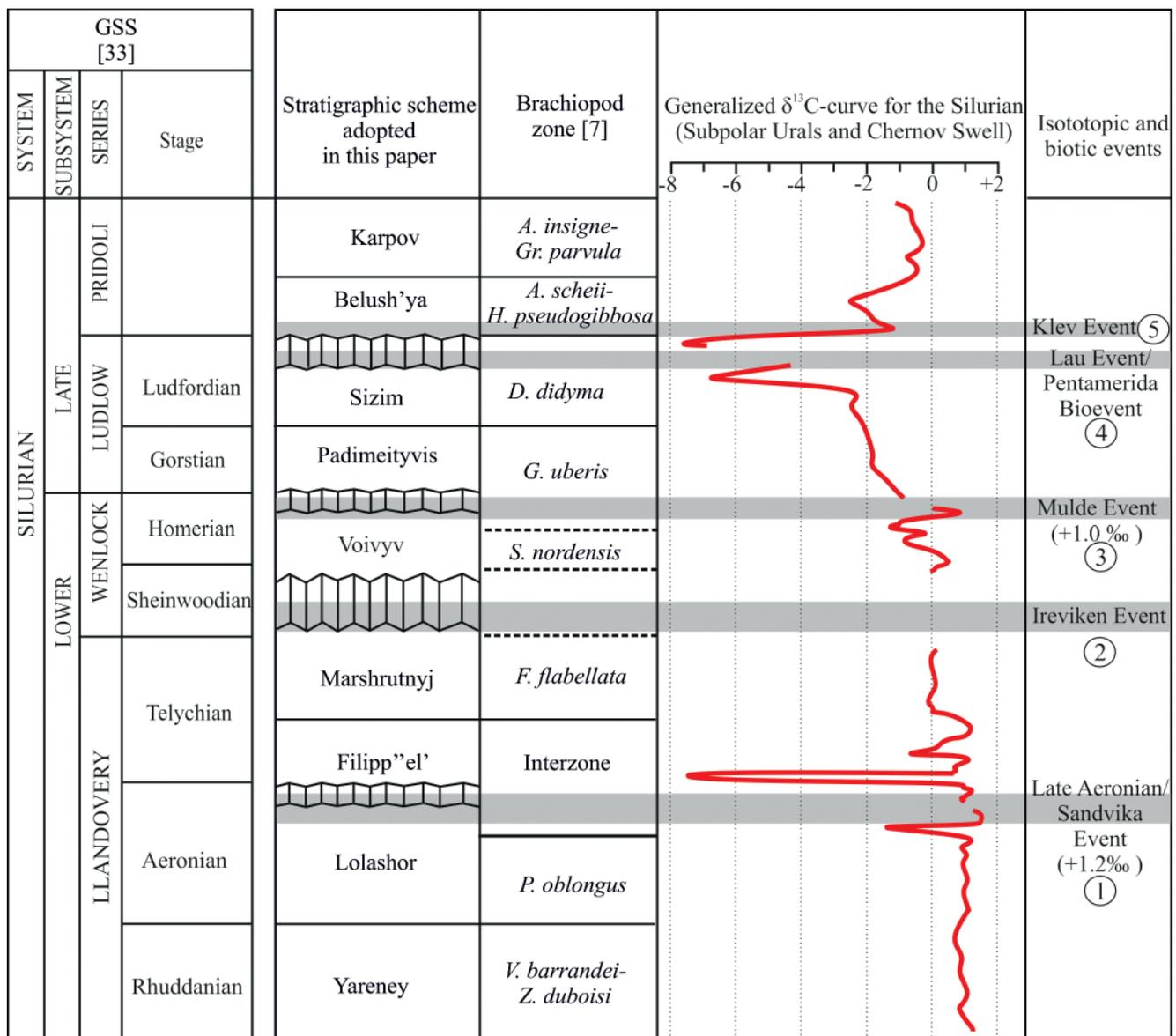


Fig. 3. Silurian Regional Event scale and generalized isotope curve for the Silurian (western slope of the Subpolar Urals and Chernov Uplift). 1–outcrops 109, 196, 217; 2–outcrops 212, 217; 3–outcrop along the Bezmyannyj brook; 4–outcrops 236, 74; 5–outcrop 236;

Рис. 3. Силурийские региональные события и обобщенная изотопная кривая для силура (западный склон Приполярного Урала и поднятие Чернова): 1 – обнажения 109, 196, 217; 2 – обнажения 212, 217; 3 – обнажение по ручью Безымянный; 4 – обнажения 236, 74; 5 – обнажение 236

interval is characterized by bioclastic, microstratified, clayey limestones with interbeds of unsorted detrital limestones, biomorphic limestones with ostracods, stromatolitic limestones with interbeds of flat pebble conglomerates (tempestites?) and signs of wave ripples [4, 27]. The Wenlock age of the event interval is determined by the brachiopods *Spirinella nordensis* (Ljash) and the ostracods *Herrmannina insignis* Abush [4]. This interval is characterized by the extinction of the Wenlock brachiopods, ostracods and conodonts. Out of 18 species of conodonts, 14 species were extinct (*P. Männik's* definitions). The carbonates of the event interval are characterized by a positive excursion of $\delta^{13}\text{C}_{\text{carb}}$ from -6.3 to $+1$ ‰ (Fig. 3). This isotopic shift is correlated with the beginning of time interval of Mulde Event in this section [27]. The absence of a double positive excursion is probably due to a sedimentation gap in this interval of the section (Fig. 2).

Lau Event (Late Ludlow) is characterized by a global drop in world sea level, the death of Ludlow reef ecosystem, and the global extinction of brachiopods *Pentamerida* (Bioevent Pentamerida) [34], and conodonts *Polygnathoides siluricus* Branson et Mehl at the end of the Ludlow [2, 10, 11]. This event is associated with one of the largest positive excursions of $\delta^{13}\text{C}_{\text{carb}}$ in the Phanerozoic [19, 22].

Traces of the Lau event were found in the upper Ludlow section in outcrops 236 and 74 in the Subpolar Urals [5, 6] (Fig. 1). The event interval in this section begins above the layers with *Polygnathoides siluricus* and is characterized by a distinct sedimentation signs of shallowing – appearance of oolitic limestones, increase in layers with stromatolites, with flat pebble conglomerates, with drying cracks and surfaces of the breaks. The limestones contain brachiopods *Didymothyris didyma* (Dalman), vertebrates *Phlebolepis elegans* Pander, small ostracods, gastropods, pelecypods and crinoid fragments.



The strengthening of regressive tendencies, wide development of stromatolite structures, cessation of Silurian reef formation, and extinction of the Uralian brachiopods of the order Pentamerida (outcrop 74) testify to a major ecosystem rearrangement in the Late Ludlow. The regional Late Ludlow event correlates with the global Lau Event. The biostratigraphically dated $\delta^{13}\text{C}_{\text{carb}}$ curve in this section demonstrates carbon isotopic anomalies with negative $\delta^{13}\text{C}_{\text{carb}}$ values of -7.4‰ (Fig. 3). The absence of a significant positive global Ludford excursion of $\delta^{13}\text{C}$ in this Ural section is associated with a sedimentation gap at the end of the Ludlow [6]. It is possible that the amplitude of this gap correlates with the Ozarkodina snajdri and Ozarkodina crispa zones in the Upper Ludlow conodont sequence [3, 4]. Gaps in sedimentation at the end of the Ludlow are known in sections on Gotland Island, in Sweden, Estonia and Great Britain [30, 31, 34].

Our obtained evidence of the sedimentation gap, as well as the isotopic and biostratigraphic characteristics of the event interval [6], do not agree with the previously published results of studies by other researchers of the same reference section of the Upper Silurian in the Subpolar Urals [29].

Early Pridolian/Klev Event was established in the sections of Gotland Island, Lithuania, Czech Republic and other sections. The event coincided with the beginning of the Early Pridolian transgression. The event was preceded by the disappearance of conodonts *Ozarkodina crispa* Walliser [25, 35].

Traces of the Early Pridolian Event were found in outcrop 236 at the base of the Belushya stage in the Subpolar Urals (Fig. 1). The event interval coincides with the beginning of the transgression and is associated with a major ecosystem rearrangement [6, 7]. The event interval in this section is characterized by calcareous dolomites with large lithoclasts, limestones with interlayers of black carbonaceous mudstones and greenish-gray, as well as limestones with brachiopods, which form distinct marking layers that can be traced in numerous sections and wells in the Timan-Pechora oil and gas province [6, 7]. This interval is characterized by a sharp shift of the isotopic curve from negative values of $\delta^{13}\text{C}_{\text{carb}}$ of -3.6‰ to positive values of -0.6‰ (Fig. 3).

Conclusion

The presented regional event scale of the Silurian is based on the results of study of the distribution of carbon isotopic composition in carbonates of the biostratigraphically well-studied reference sections of the Silurian on the western slope of the Subpolar Urals and the Chernov Uplift. The event intervals are characterized by the gradual extinction of fauna (brachiopods, conodonts, ostracods) and development of stromatolite formations. Regional manifestations of Late Aeronian/Sandvika Event, Ireviken Event, Mulde Event and Lau Event are associated with large-scale eustatic regressions. The Early Pridolian/Klev Event coincided with the transgression at the beginning of the Pridolian.

Thus, the results of our studies indicate the global nature of biotic and isotopic events, traces of which are preserved in the studied sections. The use of event-stratigraphic correlation levels allows compensating for the shortcomings of the biostratigraphic method associated

with the ecological control of the distribution of organisms.

It should be noted that the correlation of regional and global events is preliminary. As additional data becomes available, the isotope curve will be refined in the course of further research in this direction.

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