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Carbon isotope stratigraphy of the Precambrian–Cambrian Sukharikha River section, northwestern Siberian platform

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Abstract – A high-resolution carbon isotope profile through the uppermost Neoproterozoic–Lower Cambrian part of the Sukharikha section at the northwestern margin of the Siberian platform shows prominent secular oscillations of δ^{13}C with peak-to-peak range of 6–10 ‰. There are six minima, 1n–6n, and seven maxima 1p–7p, in the Sukharikha Formation and a rising trend of δ^{13}C from the minimum 1n of − 8.6 ‰ to maximum 6p of + 6.4 ‰. The trough 1n probably coincides with the isotopic minimum at the Precambrian–Cambrian boundary worldwide. Highly positive δ^{13}C values of peaks 5p and 6p are typical of the upper portion of the Precambrian–Cambrian transitional beds just beneath the Tommotian Stage in Siberia. A second rising trend of δ^{13}C is observed through the Krasnoporog and lower Shumny formations. It consists of four excursions with four major maxima that can be correlated with Tommotian–Botomian peaks II, IV, V, and VII of the reference profile from the southeastern Siberian platform. According to the chemostratigraphic correlation, the first appearances of the index forms of archaeocyaths are earlier in the Sukharikha section than in the Lena–Aldan region.

Keywords: Cambrian, carbon, isotope ratios, stratigraphy.

1. Introduction

Sedimentary rocks of Neoproterozoic–Cambrian age are extensively developed on the Siberian platform, and their outcrops are accessible along river valleys. In contrast to the interior regions, strata at the margins of the platform are often folded, and long continuous successions of inclined beds can here be studied in relatively compact sections. One of these sections at the northwestern margin of the Siberian platform is exposed from 67° 12.516′ N, 87° 21.567′ E (see arrow A in Fig. 1) along ~ 3 km upstream the Sukharikha River, a right tributary of the Enisej River (Rozanov *et al.* 1992; Rowland *et al.* 1998; Fig. 1. The investigated Sukharikha section comprises a 845 m thick succession of the uppermost Neoproterozoic–Lower Cambrian predominantly carbonate deposits of the uppermost Izluchin, Sukharikha, Krasnoporog, and lower Shumny formations (transliteration of Russian names and sedimentological information after Rowland *et al.* 1998) in the eastern part of the Sukharikha anticline (Fig. 1; Rowland *et al.* (1998, fig 2)). The sampled uppermost part of the Izluchin Formation consists of 57 m of siliciclastic shelf deposits represented by reddish and grey argillites, siltstones, and sandstones with dolostone interbeds (Fig. 2). It grades into the Sukharikha Formation, which is here measured to be 543 m thick, consisting of mostly dolostones and subordinate limestones, with recurring flat pebble conglomerates, domal stromatolites, and desiccation-cracked dololaminates (Rowland *et al.* 1998). The thickness of the formation in the Sukharikha River valley varies according to other authors: 619 m after Rowland *et al.* (1998), 570 m after Grigor'ev (1958) and Rozanov *et al.* (1992), and 560 m after Luchinina *et al.* (1997). The contact between the Sukharikha and Krasnoporog formations is regarded a sequence boundary, confirmed by a sharp transition from the proximal carbonate-ramp deposits of the Sukharikha Formation to the open-shelf Krasnoporog Formation. The latter consists of bioturbated lime mudstones with subordinate archaeocyath–calcimicrobial bioherms and biostromes (Rowland *et al.* 1998). The Sukharikha–Krasnoporog boundary is marked by a transition from light grey lime mudstones below to reddish lime mudstones above, but no erosional surface was revealed during field studies. The Krasnoporog Formation is here measured to be ~ 135 m thick ('at least 148 m' after Rowland *et al.* (1998, p. 342), ~ 185 m after Luchinina *et al.* (1997, fig. 6), and

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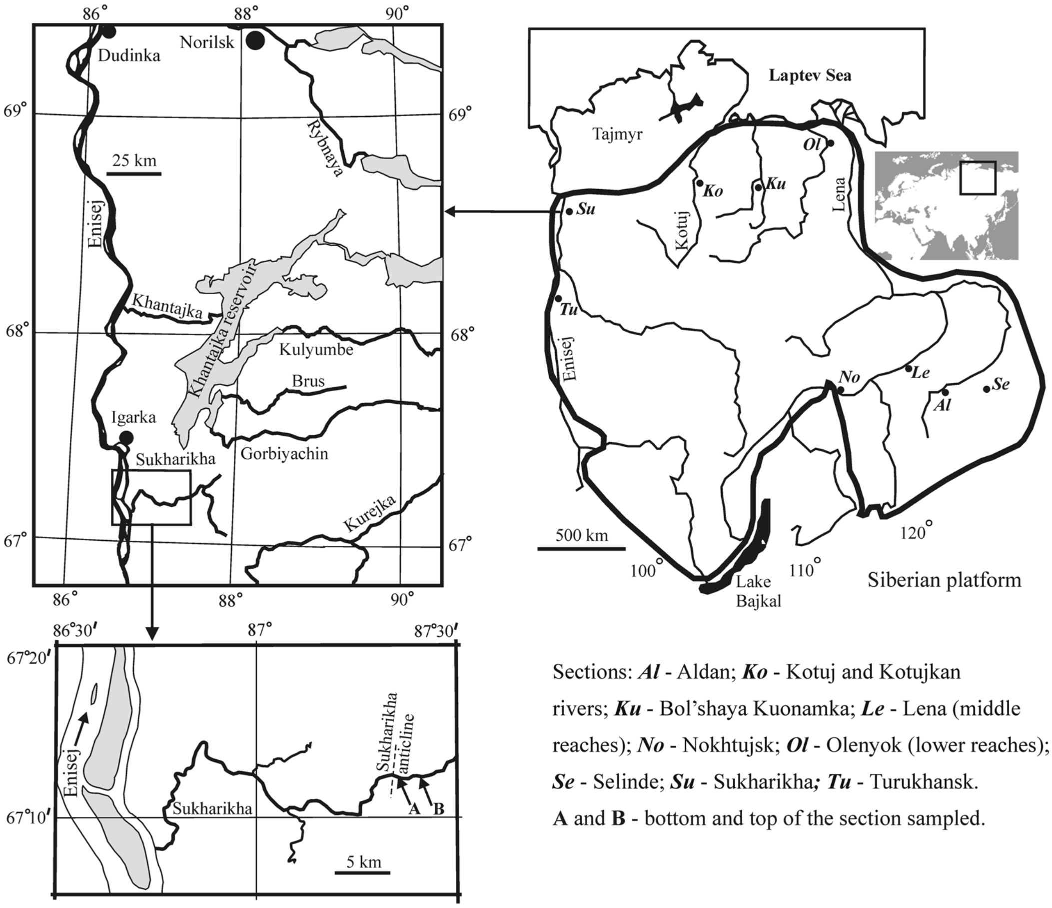


Sections: ***Al*** - Aldan; ***Ko*** - Kotuj and Kotujkan rivers; ***Ku*** - Bol'shaya Kuonamka; ***Le*** - Lena (middle reaches); ***No*** - Nokhtujsk; ***Ol*** - Olenyok (lower reaches); ***Se*** - Selinde; ***Su*** - Sukharikha; ***Tu*** - Turukhansk.
A and **B** - bottom and top of the section sampled.

Figure 1. Location of the Sukharikha section (Su) at the margin of the Siberian platform and other sections discussed.

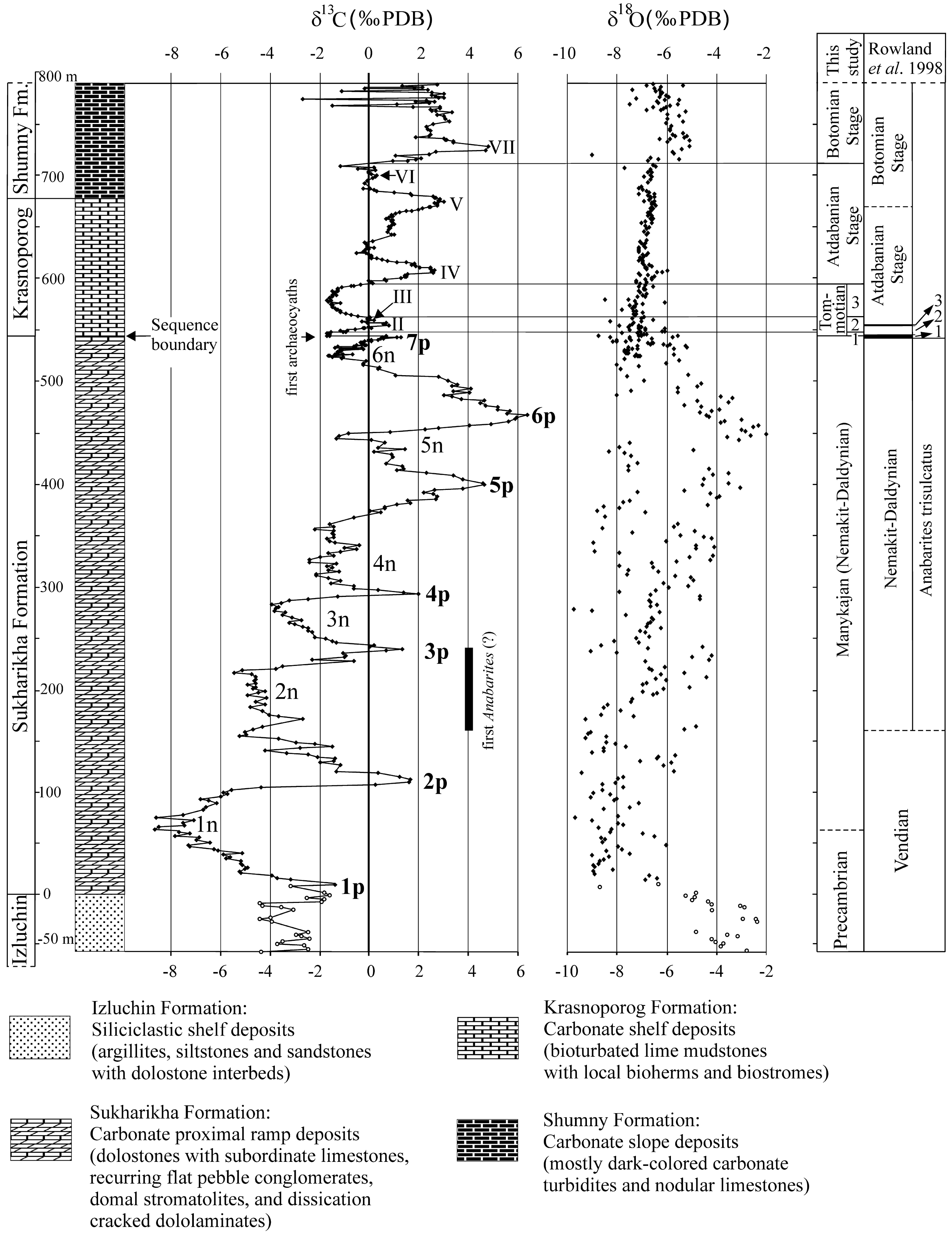
160–200 m after Astashkin *et al.* (1991) and Rozanov *et al.* (1992)) and grades into the deeper-water slope deposits of the Shumny Formation, represented mostly by dark-coloured carbonate turbidites and nodular limestones (Rowland *et al.* 1998). The Shumny Formation is 239 m thick according to Savitsky, Shishkin & Shabanov (1967) and Rozanov *et al.* (1992). Sampling from the lower part of the formation (~ 110 m) is reported herein (Fig. 2).

2. Material and methods

For the purpose of carbon isotope analyses, *c.* 530 samples of whole-rock carbonates were collected in August 2004 along the Sukharikha River. The samples were cut and their polished cleaned sections examined with a light microscope. A Dremel MiniMite micro-drill tool was used to extract rock powder from areas selected for their micritic composition. An amount of 200–400 μg was analysed from one or more spots from each sample situated *c.* 1 cm apart. Carbon and oxygen isotopes from carbonates of the samples were analysed with a Finnigan MAT 253 equipped with a ThermoFinnigan Gasbench II at the Department of Earth and Space Sciences, University of California, Los Angeles. The carbon isotope composition is defined as a deviation in permil of the ratio $^{13}C/^{12}C$ and $^{18}O/^{16}O$ between a sample and a standard expressed in the conventional $\delta^{13}C$ and $\delta^{18}O$ notations relative to V-PDB. Secondary standards used are NBS-19, IAEA-CO-1, IAEA-CO-8, and an internal laboratory standard, CARM-1. All measurements are available in the Pangaea database (http://doi.pangaea.de/10.1594/PANGAEA.526943).

ThermoFinnigan Gasbench II enables a precision of the carbonate analyses better than ± 0.1 ‰ for carbon and oxygen that is comparable to dual inlet techniques typically used for such a purpose. Powdered samples were loaded into septum-capped 12 ml glass vials (Labco exetainer) and placed into a heated block at 70 °C (40 vials per run including 6 vials with the secondary and in-house standards). The vials were then successively flush filled with helium (~ 6 min/vial), loaded with a few droplets of ~ 100 % phosphoric acid by a microlitre pump, and analysed using an autosampler (~ 20 min/vial). Time between the beginning of sample digestion by phosphoric acid and measurements of isotope ratios in the resulting CO_2 gas was ~ 80 minutes.

Elemental analyses, including Mg/Ca and Mn/Sr ratios, were carried out with ICP-OES (Varian Vista Pro Ax) at the Department of Geology and Geochemistry,



Biozones of the Tommotian Stage: 1- *Nochoroicyathus sunnaginicus*; 2- *Dokidocyathus regularis*;
3- *Dokidocyathus lenaicus-Tumuliolynthus primigenius*.

Figure 2. Carbon and oxygen isotope profiles through the Sukharikha section. Carbon isotope peaks and troughs are numbered 1p–7p and 1n–6n respectively.

Stockholm University, to check for a possible diagenetic alteration. Mg/Ca and Mn/Sr are used to estimate dolomitization and meteoric alteration of carbonates respectively (Kaufman & Knoll, 1995). These proxies were analysed from the sampled uppermost part of the Izluchin and lowermost Sukharikha formations, where a mixed dolomitic–terrigenous composition of rocks predominates (see files in Pangaea database http://doi.pangaea.de/10.1594/PANGAEA.526943). Samples from the Izluchin Formation represent dolostones with highest values of Mn/Sr > 10; these were therefore regarded as probably containing altered isotopic composition. In the lowermost 15 m of the Sukharikha Formation dolostones appear to be less altered, with Mn/Sr ratios between 6.8 and 10.7. The overlying 35 m of carbonates of the Sukharikha Formation demonstrate an unaltered signature (data in Pangaea database). Therefore, all samples from the Izluchina Formation and the lower 7–8 m of the Sukharikha Formation are probably altered and shown as void circles in Figure 2.

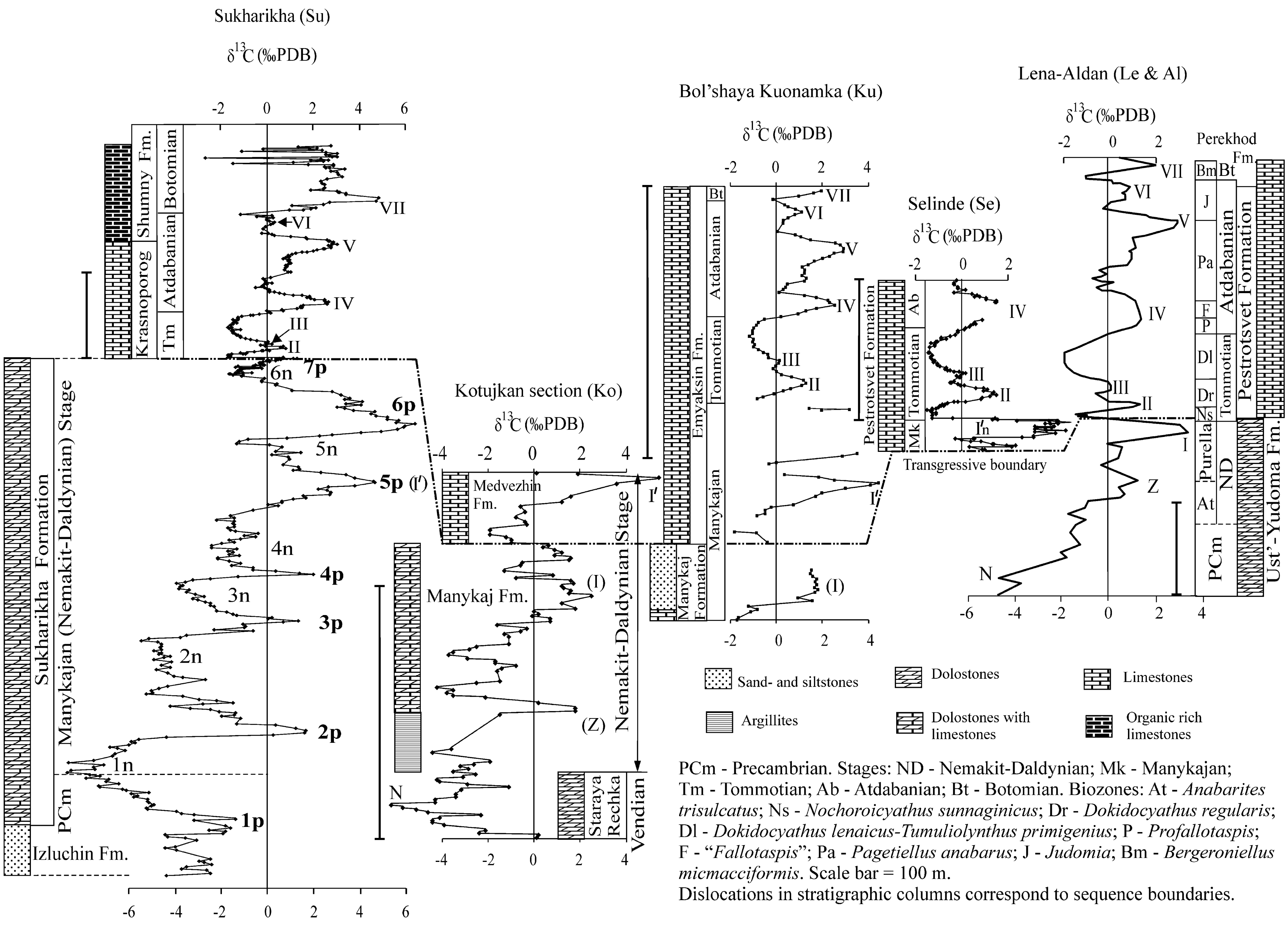
In sedimentary carbonates δ^{18}O values below − 10 ‰ can result from a considerable diagenetic resetting of δ^{18}O by meteoric waters and hydrothermal fluids (Kaufman & Knoll, 1995). Although δ^{13}C is much less prone to diagenesis than δ^{18}O, very light oxygen isotope ratios suggest a possible alteration of the carbon isotopic record as well. Therefore, two samples from the Sukharikha (A249) and Krasnoporog (A348) formations with δ^{18}O less than − 10 ‰ (analyses in Pangaea database) are considered unacceptably altered and are not included in the Sukharikha isotopic profile. Scattered values of δ^{13}C and their erratic changes can also indicate a diagenetic overprint (Buggisch, Keller & Lehnert, 2003). According to this criterion, erratic oscillations of δ^{13}C in the Shumny Formation at the top of profile, above feature VII (Fig. 2), are considered to be resulted probably from diagenetic oxidation of the organic matter contained in dark-coloured rocks of the Shumny Formation.

3. The δ^{13}C record of the Precambrian–Cambrian transition in Siberia

Since the initial publications showing negative δ^{13}C values around the Precambrian–Cambrian boundary from the South China platform (Hsü *et al.* 1985), Morocco (Tucker, 1986), and Siberia (Magaritz, Holser & Kirschvink, 1986), values lower than − 4 ‰ have been recognized at the Precambrian–Cambrian boundary worldwide (Kirschvink *et al.* 1991; Brasier *et al.* 1994; Narbonne, Kaufman & Knoll, 1994; Kaufman & Knoll, 1995; Grotzinger *et al.* 1995; Knoll *et al.* 1995a,b; Kaufman *et al.* 1996; Kimura *et al.* 1997; Bartley *et al.* 1998; Knoll, 2000; Amthor *et al.* 2003; Maloof *et al.* 2005). From the Siberian platform, the first carbon and oxygen isotope analyses were carried out by Magaritz, Holser & Kirschvink (1986) through the Ust'-Yudoma and lower Pestrotsvet formations in the section 'Dvortsy', the stratotype of the Tommotian Stage at the Aldan River. The uppermost 10 m of the Ust'-Yudoma Formation has been sampled in detail at the Ulakhan-Sulugur section, a former Precambrian–Cambrian boundary stratotype candidate (Magaritz, 1989; Brasier, Khomentovsky & Corfield, 1993). Unfortunately, the density of profiling through most of the Ust'-Yudoma Formation of Siberia is not sufficient to allow a detailed comparison with the Sukharikha section dealt with here. The positive excursions I and II spanning the lower Tommotian boundary were first identified in the 'Dvortsy' and Ulakhan-Sulugur sections (Magaritz *et al.* 1991). This record of δ^{13}C oscillations was extended upwards in the Lena–Aldan region and complemented with peaks III–X (Kirschvink *et al.* 1991; Magaritz *et al.* 1991; Brasier *et al.* 1994; Fig. 3). Peaks II–IV are also found in the Selinde section (Kouchinsky *et al.* 2005), II–VII are identified in the Malaya and Bol'shaya Kuonamka (Kouchinsky *et al.* 2001) and the Sukharikha sections (herein).

Already from the first published Siberian results it became apparent that from negative values as low as − 4.5 ‰ there is a rising trend towards the Tommotian Stage, considered at that time the basal division of the Cambrian System (Cowie & Rozanov, 1983; Rozanov, 1984; Magaritz, Holser & Kirschvink, 1986). Peak Z is the first positive peak in this rising trend (Brasier *et al.* 1994), and it is attributed to the *Anabarites trisulcatus* Biozone. This increase in δ^{13}C was interpreted to reflect an oceanographic event of biomass bloom at the eve of the 'Cambrian explosion' (Magaritz, Holser & Kirschvink, 1986). The lowermost Tommotian beds were regarded to reflect the beginning of the 'Cambrian explosion' and marked by a fast drop in δ^{13}C from + 3.4 ‰ to − 1.5 ‰ across the lower Tommotian boundary. Subsequent findings have modified this scenario. The Precambrian–Cambrian boundary stratotype candidate in Siberia was rejected in favour of the one in Newfoundland, and the boundary was correlated to a level of the first appearance of the trace fossil *Phycodes pedum* well below the Tommotian Stage of Siberia (Landing, 1994). The initial Cambrian evolutionary radiation is no longer considered to be concentrated in time to the Precambrian–Cambrian boundary, and a complex oscillating pattern of δ^{13}C with prominent positive isotopic peaks has been found to precede the Tommotian Stage in Siberia and occur in lower Cambrian beds worldwide (Knoll *et al.* 1995a,b; Kaufman *et al.* 1996; Brasier *et al.* 1996; Kouchinsky *et al.* 2001, 2005; Maloof *et al.* 2005).

The reconnaissance investigations by Pokrovsky & Missarzhevsky (1993) of δ^{13}C from the Staraya Rechka, Manykaj, Medvezhin, and Kyndyn formations on western flanks of the Anabar uplift, complemented with additional sections by Pokrovsky (1996), trace the negative excursion on the northern and southeastern



PCm - Precambrian. Stages: ND - Nemakit-Daldynian; Mk - Manykajan; Tm - Tommotian; Ab - Atdabanian; Bt - Botomian. Biozones: At - *Anabarites trisulcatus*; Ns - *Nochoroicyathus sunnaginicus*; Dr - *Dokidocyathus regularis*; Dl - *Dokidocyathus lenaicus-Tumuliolynthus primigenius*; P - *Profallotaspis*; F - "*Fallotaspis*"; Pa - *Pagetiellus anabarus*; J - *Judomia*; Bm - *Bergeroniellus micmacciformis*. Scale bar = 100 m.

Dislocations in stratigraphic columns correspond to sequence boundaries.

Figure 3. Chemostratigraphic correlation of the Sukharikha section with those of Kotujkan (after Kaufman *et al.* 1996), Bol'shaya Kuonamka (after Kouchinsky *et al.* 2001), Selinde (after Kouchinsky *et al.* 2005), and the reference profile from the Lena–Aldan region (after Brasier *et al.* 1994).

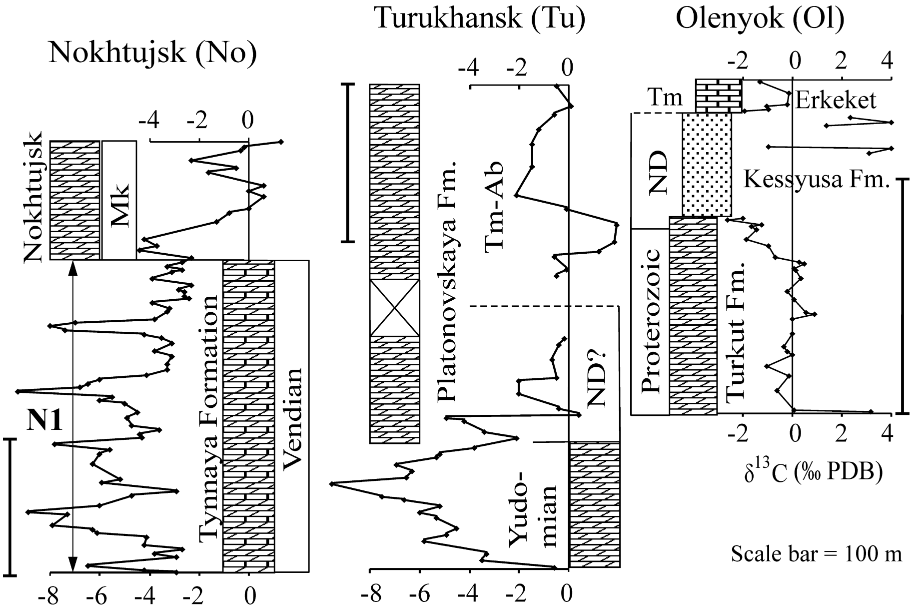


Figure 4. Carbon isotope profiles from the Nokhtujsk section (after Pelechaty, 1998), Turukhansk section (after Bartley *et al.* 1998), and lower Olenyok reaches (after Knoll *et al.* 1995a). For legend see Figure 3.

Siberian platform. The former section at the mouth of the Kotujkan River has also been investigated in detail by Knoll *et al.* (1995b) and Kaufman *et al.* (1996). These authors found a lower negative δ^{13}C excursion, N, reaching values as low as − 6.2 ‰ in the upper Staraya Rechka Formation and the upper unnamed negative excursion with two troughs of − 4.2 ‰ and − 3.7 ‰ in the middle part of the Manykaj Formation (Fig. 3). Hence, the lower boundary of the Nemakit-Daldynian Stage in this section is situated between these two negative excursions. A rising trend towards positive values, peaking in the Medvezhin and Kyndyn formations, has been also reported (Pokrovsky & Missarzhevsky, 1993; Knoll *et al.* 1995b; Kaufman *et al.* 1996). Two excursions in this rising trend were tentatively correlated with peaks Z and I of the Ust'-Yudoma Formation (Knoll *et al.* 1995b; Kaufman *et al.* 1996; shown as (Z) and (I) in Fig. 3). The most prominent positive peak, I', of + 5.4 ‰, occurs in the overlying Medvezhin Formation (Fig. 3). This is not consistent with the C-isotopic signature of the Tommotian Stage in the Lena–Aldan region, where such an excursion appears to be missing. A sizeable hiatus between peaks I and II of the reference profile has been suggested to explain this difference (Knoll *et al.* 1995b; Kaufman *et al.* 1996).

An isotope profile through the Neoproterozoic–Lower Cambrian has also been reported from the Khorbosuonka River section at the Olenyok uplift by Knoll *et al.* (1995a). It shows a negative excursion with minimum − 2.6 ‰ in the uppermost Turkut Formation and positive values up to + 4 ‰ in the upper Kessyusa Formation (Fig. 4). A similar shift to negative values is reported from the upper Turkut Formation at the Olenyok River (Pelechaty, Kaufman & Grotzinger, 1996; Pelechaty *et al.* 1996). However, the profile above the negative excursion is not continuous, and it does not include the rising trend of δ^{13}C towards the Tommotian Stage. The authors correlated the negative shift with the Precambrian–Cambrian boundary, although the reported values in the Turkut Formation are higher than the negative carbon isotope excursion spanning the Precambrian–Cambrian boundary around the world with a δ^{13}C spike lower than − 4 ‰ (Brasier *et al.* 1994; Knoll *et al.* 1995b; Kaufman *et al.* 1996; Maloof *et al.* 2005).

Two negative excursions with values less than − 7.5 ‰ in the lower part and − 4.9 ‰ in the middle part of the Platonovskaya Formation are reported by Bartley *et al.* (1998) (Fig. 4). It is suggested that the lower excursion and preceding moderately negative values in the lowermost Platonovskaya Formation are situated below the Nemakit-Daldynian Stage, while the second excursion is placed above. This conclusion is supported by a similar signature from the Kotujkan River section (Pokrovsky & Missarzhevsky, 1993; Knoll *et al.* 1995b; Kaufman *et al.* 1996) and the Aldan River (Brasier *et al.* 1994). At the Aldan River, one negative excursion, N, is situated below and another (unnamed excursion between peaks Z and I in Fig. 3) above the lower Nemakit-Daldynian boundary (Magaritz *et al.* 1991). Thus, according to Bartley *et al.* (1998), these two negative excursions may possibly constrain its position.

Pelechaty (1998) investigated the Tynnaya Formation of the Nokhtujsk section on the southern Siberian platform, where isotopic interval N1 of negative shift with high-frequency negative oscillation as low as − 9 ‰ was revealed (Fig. 4). It has been suggested that the Tynnaya Formation shows a prolonged interval N1 of oscillating negative values. Although δ^{18}O values from that section range between − 0.3 ‰

and − 20.5 ‰, consistent with possible diagenesis in some of the samples with very low numbers, the δ^{13}C values were interpreted by Pelechaty (1998) as the complete record of secular variation in δ^{13}C of the Precambrian–Cambrian boundary carbon isotope anomaly otherwise known as N (Knoll *et al.* 1995b). Pelechaty (1998) placed this series of 4–5 oscillations below the boundary, suggesting that the shift to negative values precedes the boundary.

4. Carbon isotope results and stratigraphic correlation of the Sukharikha section

The negative δ^{13}C values characterizing the Precambrian–Cambrian boundary worldwide are encountered in the Sukharikha section. The carbon isotope profile through the Sukharikha Formation begins with a drop of δ^{13}C values from *c.* − 1.5 ‰ to as low as − 8.6 ‰ and a subsequent rise to + 1.6 ‰ (Fig. 2). The profile shows six major negative excursions with a peak-to-peak amplitude of 6–10 ‰ and a conspicuous rising trend of δ^{13}C through the Sukharikha Formation with 15 ‰ difference between the minimum − 8.6 ‰ and maximum + 6.4 ‰. Major minima in the Sukharikha Formation are named 1n–6n; major positive peaks alternating with them are given their own numbers 1p to 7p in the same ascending order (Fig. 2). Peak 1p occurs at the boundary between the Sukharikha and Izluchin formations. The upper boundary of the Sukharikha Formation is marked by peak 7p followed by a fast drop of values from + 0.7 ‰ to − 1.7 ‰ in the Krasnoporog Formation (Figs 2 and 5). This boundary is constrained between samples A300 and A301 situated 10 cm apart at 543 m from the bottom of the Sukharikha Formation.

The profile through the Sukharikha Formation shows that the lowermost Cambrian carbon isotope signature has a complex pattern. There are three negative excursions, 1n–3n, ranging from less than − 8 ‰ to − 4 ‰ in the lower Sukharikha Formation, and each of them can be potentially recognized as the Precambrian–Cambrian boundary excursion. According to the chemostratigraphy, the Precambrian–Cambrian boundary can be placed as low as the absolute minimum, 1n, in this series of oscillations. The lowest value, − 8.6 , occurs at the level of sample A51, 62.5 m above the base of the Sukharikha Formation. There are, however, no diagnostic fossils from this level: the first skeletal remains (identified as *Anabarites* (?) from thin sections of samples) occur 240 m above the base (380 m below the top) of the formation (Rowland *et al.* 1998). This is the position of the Precambrian–Cambrian boundary proposed by Rowland *et al.* (1998) on the basis of biostratigraphy. It is possible to place this level between trough 2n and peak 3p of the isotope profile, because of the discrepancy between thicknesses of the Sukharikha Formation measured to be 619 m by Rowland *et al.* (1998) and 543 m herein (Fig. 2).

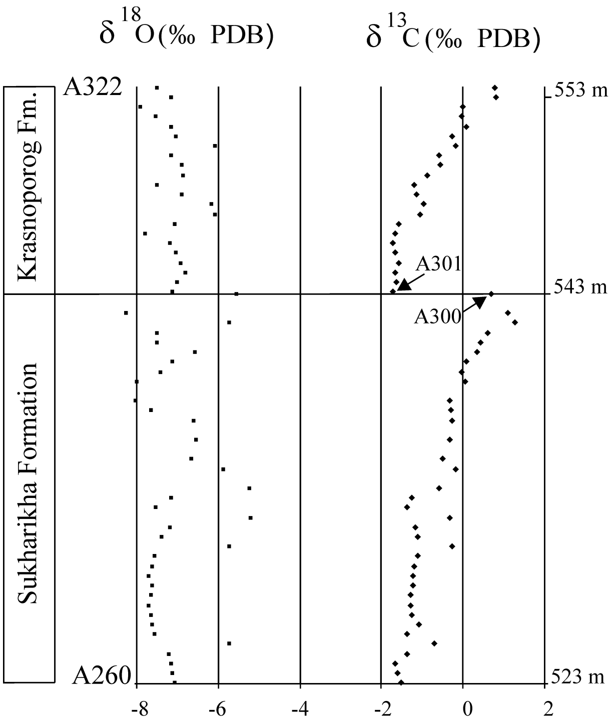


Figure 5. Carbon and oxygen isotope profiles through the sequence boundary between the Sukharikha and Krasnoporog formations between samples A260 and A322 (collected with 0.5 m intervals).

The first positive values in the rising trend from the Ust'-Yudoma Formation of the southeastern Siberian platform constitute peak Z (Brasier *et al.* 1994). In the Sukharikha section similar positive values are reached at peak 2p. Peaks 3p and 4p are of a similar magnitude, however (*c.* + 2 ‰), and are thus also candidates for peak Z (Fig. 3). It is not possible to make a definitive correlation of them because of the lack of adequately dense profiling through the Ust'-Yudoma Formation and the scarcity of fossils in the Sukharikha Formation (Khomentovsky & Karlova, 2002). Peak 4p is the highest possible position of Z, though, because it is followed by high positive values of peak 5p that are unknown below cycle I of the uppermost Ust'-Yudoma Formation and are identified in pre-Tommotian strata elsewhere on the Siberian platform (Kaufman *et al.* 1996; Kouchinsky *et al.* 2001, 2005; Fig. 3). On the other hand, there is a closer similarity of peaks 2p and 3p with positive peaks from the upper Manykaj Formation tentatively correlated with Z and I by Knoll *et al.* (1995b) and Kaufman *et al.* (1996) (Fig. 3). The high positive values + 4.6 ‰ and + 6.4 ‰ of peaks 5p and 6p, respectively, are similar to those of oscillations known from the Siberian platform in the lower Pestrotsvet Formation of Selinde (Kouchinsky *et al.* 2005), the lower Emyaksin Formation of the Bol'shaya Kuonamka sections (Kouchinsky *et al.* 2001), the Medvezhin Formation of western Anabar (Kaufman *et al.* 1996), and the upper Kessyusa Formation of the Olenyok uplift (Knoll *et al.* 1995a).

Results obtained from the uppermost Sukharikha Formation suggest that there are a negative excursion, 6n, and a positive peak, 7p, below the drop of values through the base of the Krasnoporog Formation (Fig. 2). The latter feature has apparently no exact match elsewhere, but it may be interpreted as a truncated uppermost pre-Tommotian excursion. The corresponding interval appears to be better preserved in the lower Pestrotsvet Formation of the Selinde section (Kouchinsky *et al.* 2005; Fig. 3). Data from the Lena–Aldan region, the lower Pestrotsvet Formation of Selinde (Kouchinsky *et al.* 2005), and the lower Emyaksin Formation of the Kuonamka sections (Kouchinsky *et al.* 2001) suggest that fast dropping values occur in the lower part of the *N. sunnaginicus* Biozone of the Tommotian Stage. Unlike the sequence boundary between the Ust'-Yudoma and Pestrotsvet formations in the Lena–Aldan region, there is no evidence of erosion or any hiatus between the Sukharikha and Krasnoporog formations at the same sequence boundary, although a change in colour and lithology occurs (Rozanov *et al.* 1969, 1992; Rowland *et al.* 1998; personal observations by Vladimir Pavlov in 2004). This seems to be in agreement with observations by Rowland *et al.* (1998) of stylolitic dissolution surfaces within the upper part of the Sukharikha Formation. Consequently, peak 2p seems to be the lowest possible location of excursion Z; peak 5p is tentatively correlated herein with excursion I', and peaks 6p–7p are within the I'n series of oscillations, where the upper peak 7p is truncated at the sequence boundary (Kouchinsky *et al.* 2001, 2005).

The second rising trend of δ^{13}C is observed through the Krasnoporog and lower Shumny formations (Figs 2 and 3). It comprises four major excursions with six maximums that may be correlated with peaks II–VII of the reference profile from the southeastern Siberian platform (cf. Brasier *et al.* 1994). The δ^{13}C signature known from the Tommotian–Botomian stages of the Siberian platform can be readily recognized in the Krasnoporog Formation. Peak II marks the *Dokidocyathus regularis* Biozone of the Tommotian Stage. The subsequent oscillations with positive peaks III–VII extend this record into the Botomian Stage, represented by the lower part of the Shumny Formation. Although the Lower Botomian peak VII can be identified in this portion, the higher isotopic record is more difficult to recognize from scattered values (Figs 2 and 3).

5. Biostratigraphic *v.* chemostratigraphic correlation with the Lena–Aldan region

A diverse complex of archaeocyaths with six species of the *Nochoroicyathus sunnaginicus* Biozone was reported from the uppermost 2 m of the Sukharikha Formation by Rozanov *et al.* (1969). Subsequent publications by other workers (Luchinina *et al.* 1997; Rowland *et al.* 1998; Khomentovsky & Karlova, 2002) refer to this initial report, but do not confirm the presence of archaeocyaths independently. According to Khomentovsky & Karlova (2002) the lower Tommotian boundary cannot be established biostratigraphically in the Sukharikha section, because there are no diagnostic fossils belonging to the underlying pre-Tommotian *Purella* Biozone there. On the contrary, archaeocyaths are well known from the lower 20 m of the Krasnoporog Formation (Rowland *et al.* 1998). The *Nochoroicyathus sunnaginicus–Dokidocyathus regularis* boundary in the Sukharikha section is indicated 1 m above the base of the Krasnoporog Formation (Rowland *et al.* 1998) by the first appearance of archaeocyaths *Robustocyathus robustus*, *Dictyocyathus translucidus*, *Cambrocyathellus tschuranicus*, and *Paranacyathus tuberculatus* of the *Dokidocyathus regularis* Biozone. In contrast, chemostratigraphic correlation with the stratotype section suggests that the boundary is to be set at least as high as 3.5 m above the base (Figs 2, 3). According to the same data, the *Dokidocyathus lenaicus* Biozone begins at 18.5 m, but biostratigraphically it has been located at 11 m by Rowland *et al.* (1998). The Tommotian–Atdabanian boundary has been placed at 12.5 m above the base of the Krasnoporog Formation with the first Atdabanian archaeocyaths *Rotundocyathus dotatus* and *Pliocyathus* cf. *Pliocyathus platyseptatus* at this level (Rowland *et al.* 1998). Chemostratigraphy indicates that the boundary is located no lower than 50 m above the base of the formation (Figs 2, 3). The uppermost part of the Krasnoporog Formation contains archaeocyaths of the *Carinacyathus squamosus–Botomocyathus zelenovi* Biozone, belonging to the Botomian Stage (Rozanov *et al.* 1992). Trilobites of the Shumny Formation span the interval beginning with the *Calodiscus–Erbiella* Biozone of the Botomian Stage (Luchinina *et al.* 1997) and extending into the *Tomagnostus fiss*us*–Paradoxides sacheri* Biozone of the Middle Cambrian (Rozanov *et al.* 1992). Chemostratigraphic correlation with the Lena–Aldan region places the Atdabanian–Botomian boundary within the lowermost Shumny Formation, higher than suggested by the biostratigraphy (Figs 2, 3).

Brasier *et al.* (1994) first noticed that chemostratigraphic and biostratigraphic boundaries do not always coincide between sections of the Lena–Aldan region of the Siberian platform. Diachroneity of biostratigraphic boundaries can be explained by faunal migrations or facies unsuitable for preservation of index fossils. A concurrent explanation of chemo- and biostratigraphic boundary mismatch is a possible geochemical diachroneity, but the latter is more difficult to explain, because the sections discussed belong to the same epicontinental basin of the Siberian platform with surface ocean environments. Although absolute magnitudes of oscillations vary from one section to another depending on local facies and diagenetic overprint (see profiles through the Tommotian–Botomian interval in Fig. 3), a characteristic signature produced by trends in changes of $\delta^{13}C$ in the surface ocean can be used for intrabasinal and, probably, for global correlation. Hence, chemostratigraphy may well indicate that the first appearances discussed above are earlier in the Sukharikha section than in the Lena–Aldan region.

6. Conclusions

Analysis of the carbon isotope profile through the Sukharikha section in the northwestern margin of the Siberian platform reveals seven major oscillations within the Sukharikha Formation followed by four major oscillations in the Krasnoporog and lower Shumny formations (Figs 2, 3). The evidence suggests that the $\delta^{13}C$ negative anomaly characteristic of the Precambrian–Cambrian boundary beds elsewhere is recorded also in the Sukharikha section. There is a prominent negative shift in the lowermost Sukharikha Formation followed by a rising trend with secular oscillations towards highly positive excursions in the upper parts of the formation. The rising trend within the Sukharikha Formation comprises the negative excursions 1n–6n and positive excursions 1p–7p in ascending order. Three prominent positive oscillations in the upper Sukharikha Formation, peaks 5p–7p, precede excursion II of the Krasnoporog Formation. These peaks appear to be represented fragmentarily in other sections of the northern Siberian platform within the interval containing the I' and I'n series of oscillations (Kaufman *et al.* 1996; Kouchinsky *et al.* 2001, 2005). Peak 7p seems to be truncated at the sequence boundary between formations, suggesting a certain hiatus in accumulation. The second rising trend of $\delta^{13}C$ is observed through the Krasnoporog and Shumny formations and comprises four major excursions with six maximums identified as peaks II–VII in the Tommotian–Botomian interval of the reference profile from the southeastern Siberian platform (cf. Brasier *et al.* 1994; Fig. 3). Chemostratigraphic correlation within the Siberian platform likely indicates that the first appearances of zonal index complexes of archaeocyaths are older in the Sukharikha section than in the Lena–Aldan region.

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