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Pre-Tommotian age of the lower Pestrotsvet Formation in the Selinde section on the Siberian platform: carbon isotopic evidence

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Abstract – Carbon isotopic data from the Selinde section in the southeastern part of the Siberian platform area are correlated with the reference isotopic profile from the Lower Cambrian stratotype sections of the Lena–Aldan region, but also show additional $\delta^{13}C$ excursions unrecognized there. The chemostratigraphic correlation suggests that the geological and fossil record of the lower Pestrotsvet Formation in the Selinde section has a deeper history than the stratotype region. This conclusion is important for both constraining the age of the earliest Cambrian marine transgression on the Siberian platform and providing a clearer understanding of the pace and order of early Cambrian geochemical and biological events.

Keywords: Cambrian, Precambrian, carbon, isotope ratios, stratigraphy.

1. Introduction

The Siberian platform is one of the few places in the world where the Cambrian Period is comprehensively represented by carbonate fossiliferous strata that are little affected by subsequent metamorphism. For purpose of precise correlation, carbon isotopic stratigraphy is the most suitable method in combination with biostratigraphy. Despite promising results (Knoll *et al*. 1995; Kaufman *et al*. 1996), doubts have been expressed about the potential of this technique for correlation within the Lower Cambrian strata of the Siberian platform (Khomentovsky, 1997; Zhuravlev, 1998). Insufficient data and sparse or discontinuous sampling represent major difficulties for chemostratigraphic correlation. As the Lower Cambrian is known to exhibit relatively high-frequency oscillations in $\delta^{13}C$ (Brasier *et al*. 1994; Brasier & Sukhov, 1998), geological sections may be difficult to correlate accurately unless an appropriate density of sampling is achieved.

Ever since the Tommotian Stage was first defined (Rozanov *et al*. 1969), there has been considerable discussion on the correlation of the lowermost Tommotian *Nochoroicyathus sunnaginicus* Biozone and on the age of sub-Tommotian fossiliferous beds. These sub-Tommotian beds are often referred to as the Manykajan or Nemakit-Daldynian Stage, with the lower boundary at the base of the *Anabarites trisulcatus* Biozone and upper boundary at the base of the Tommotian Stage (Missarzhevsky, 1989; Rozanov *et al*. 1992; Khomentovsky & Karlova, 1993). The term Manykajan Stage tends to be more in use in English, as more euphonious, despite priority issues favoring the Nemakit-Daldynian Stage (Khomentovsky & Karlova, 2002). They are roughly synonymous, and since neither is formally accepted, we use the term Manykajan Stage herein.

The Tommotian Stage was based on a stratotype section ('Dvortsy') on the Aldan River (Rozanov & Missarzhevsky, 1966; Rozanov *et al*. 1969, 1992). A second section, downstream at Ulakhan-Sulugur, was proposed as a candidate stratotype for the global Precambrian–Cambrian boundary (Cowie & Rozanov, 1983). The proposed boundary was placed within the uppermost Ust'-Yudoma Formation, about 1.5 m below the Pestrotsvet Formation (Rozanov *et al*. 1969, 1992). However, rich fauna, including one archaeocyath species that is diagnostic of the basal Tommotian

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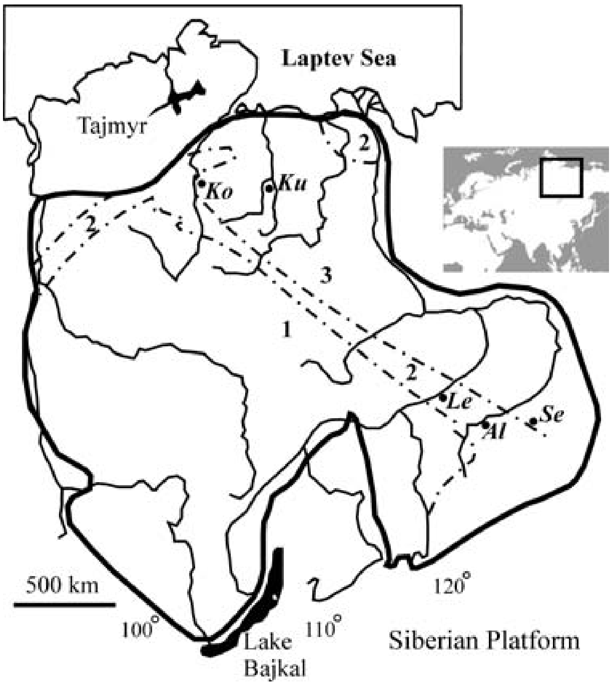


Figure 1. Map of the Siberian platform with location of sections referred to in the text. Sections: Al, Aldan; Ko, western Anabar region (Kotuj and Kotujkan rivers); Ku, Bol'shaya Kuonamka; Le, Lena (middle reaches); Se, Selinde. Facies belts: 1, lagoonal; 2, transitional; 3, normal-marine.

N. sunnaginicus Biozone, has been found within glauconitic grainstones of the uppermost Ust'-Yudoma Formation (Khomentovsky & Karlova, 1993). Uncertainties concerning the age of the Ust'-Yudoma–Pestrotsvet contact are related to the possibility that the fossils may have fallen down solution fissures from the overlying Pestrotsvet Formation during the Cambrian transgression. Sedimentological arguments in favour of (Khomentovsky, Val'kov & Karlova, 1990; Khomentovsky & Karlova, 1993) and opposing (Rozanov *et al*. 1992; Zhuravlev, 1998) this interpretation have not yet led to a consensus. According to Rozanov *et al*. (1992) and Zhuravlev (1998), the hiatus between the Ust'-Yudoma and Pestrotsvet formations is contained within the *N. sunnaginicus* Biozone, but Khomentovsky & Karlova (1993) suggested its pre-Tommotian age. Chemostratigraphic correlations with the northern part of the Siberian platform support the notion of a long-lasting hiatus at Ulakhan-Sulugur (Kaufman *et al*. 1996; Kouchinsky *et al*. 2001).

The present paper deals with a previously described section (Val'kov, 1976, 1982, 1987; Voronova *et al*. 1983; Repina, Borodaevskaya & Ermak, 1988; Missarzhevsky, 1989, 1993; Khomentovsky & Karlova, 1993) situated in the uppermost reaches of the Selinde River, a small right tributary of the Uchur River, in the Uchur–Maya region of the southeastern part of the Siberian platform (Fig. 1). Cropping out at the southern slope of the Ket-Kap Range, 13 km SE of the town Mar-Kyuel', the section exposes two formations: the younger Pestrotsvet Formation separated from the older Ust'-Yudoma Formation by an erosional surface (Val'kov 1976, 1982, 1987; Repina, Borodaevskaya & Ermak, 1988) that is considered to be a sequence boundary. The lowermost part of the Pestrotsvet Formation contains transgressive deposits of sedimentary cycle C1.1, which has been traced across the Siberian platform (Zhuravlev, 1998). The Selinde section is important for its location only about 200 km southeast of the Tommotian Stage stratotype area on the Aldan River. However, in contrast to these Aldan sections, which are situated in the Cambrian transitional facies belt with barrier-reef buildups, the Selinde section belongs to the deeper-water normal marine facies belt (Rozanov & Zhuravlev, 1992; Fig. 1). Although the Selinde section contains numerous skeletal fossils, the latter are strongly facies-dependant and therefore difficult to correlate with the stratotype sections. Consequently, biostratigraphical correlation of the lower Pestrotsvet Formation and its equivalents across the Siberian platform is uncertain (Val'kov 1976; Khomentovsky & Karlova 1994). Carbon isotopic stratigraphy proves helpful in resolving this difficulty.

2. Material and methods

The material was obtained during an expedition to Siberia in 2002 by Vladimir Pavlov and Anatolij Val'kov. The sampled succession of carbonates represents predominantly variegated limestones with variable amounts of clay of the Pestrotsvet Formation succeeding dolomites of the Ust'-Yudoma Formation. Samples were cut and their polished cleaned sections examined with a light microscope. Rock powder was obtained with a Dremel MiniMite micro-drill tool from areas selected for their micritic composition. The amount of powder prepared for a single analysis was 200–400 μg. One to three spots were analysed from each sample. The control duplicates are situated ~ 1 cm apart. Carbon isotopes in calcite from the samples were analysed with Finnigan MAT 253 equipped with Gasbench II at the Department of Earth and Space Sciences, University of California, Los Angeles. The carbon isotopic composition is defined as a deviation in parts per thousand of the ratio $^{13}C/^{12}C$ between a sample and a standard expressed in the conventional $\delta^{13}C$ notation relative to V-PDB. Secondary standards used are NBS-19 and IAEA-CO-1, and an internal laboratory standard CARM-1. The accuracy of the analyses was better than $\pm$ 0.1 ‰ for carbon. Tables of measurements are available upon request from Artem Kouchinsky.

3. Biostratigraphy and correlation

There are two suggested interpretations of the stratigraphical position of the lower beds of the Pestrotsvet

Formation in the Selinde section. Since an erosional surface regarded as a sequence boundary separates the Ust'-Yudoma and Pestrotsvet formations, and since the lowermost beds of the Pestrotsvet Formation contain many fossils in common with the stratotype and other sections on the Lena and Aldan rivers, the base of the Pestrotsvet Formation has been suggested to be of the same age as at 'Dvortsy' (Repina, Borodaevskaya & Ermak, 1988; Khomentovsky & Karlova, 1993, 1994). By contrast, Val'kov (1976, 1978, 1982, 1987) placed the base of the Tommotian Stage about 20 m above the Ust'-Yudoma–Pestrotsvet contact. In this interpretation, the base of the Pestrotsvet Formation is regarded as diachronous between 'Dvortsy' and Selinde.

Lower Cambrian biostratigraphy of the southeastern Siberian platform, including the Tommotian and younger stratotype sections, is based mainly on archaeocyaths and trilobites (Rozanov & Zhuravlev, 1992; Rozanov *et al*. 1992). Archaeocyaths are very rare in the lower part of the Pestrotsvet Formation in the Selinde section, and some of their reported occurrences in this section contradict carbon isotopic correlation with the stratotype region. Fragments of archaeocyaths are reported from the 2.7 m level by Khomentovsky & Karlova (2002). Such forms from the *Dokidocyathus regularis* Biozone as *Nochoroicyathus mirabilis* and *Cambrocyathellus tschuranicus* are found at the 5 m level (Korshunov, Repina & Sysoev, 1969). Repina, Borodaevskaya & Ermak (1988) encountered undetermined archaeocyaths at the ~21 m level; based on the earliest skeletal problematic fossils they assigned lower 28.5 m of the Pestrotsvet Formation to the *N. sunnaginicus* Biozone. The beginning of the next biozone (*Dokidocyathus regularis* Biozone) is situated at the base of Bed 24 (nomenclature from Repina, Borodaevskaya & Ermak, 1988; Fig. 2), which is about 28 m above the base of our measured section and corresponds to the lowermost part of Member 9 in an alternative scheme proposed by Val'kov (1982) (Fig. 2). The base of the following Member 10 is equivalent to the base of Bed 31 (Repina, Borodaevskaya & Ermak, 1988) and occurs at the 61 m level in our section. It contains fossils typical of the succeeding *Dokidocyathus lenaicus* Biozone (Repina, Borodaevskaya & Ermak, 1988), which extends to about the 87 m level in our section. Identifiable trilobites of the first Atdabanian Biozone, *Profallotaspis*, are reported from the base of Bed 37 (Member 11) at 87 m, but the first trilobites in thin-sections are found below, in Bed 36 (Repina, Borodaevskaya & Ermak, 1988) at the top of Member 10. The traditionally used *Fallotaspis* Biozone refers to the occurrence of '*Fallotaspis sibirica*' and '*Fallotaspis explicata*', which have been shown to represent the genus *Repinaella* (Gerd Geyer, pers. comm. 2005). Accordingly, the name of the next biozone is given as '*Fallotaspis*' herein (Figs. 2, 3). The uppermost beds of the Selinde section (Beds 46–54) are characterized by trilobites and archaeocyaths of the *Pagetiellus anabarus* Biozone of the Atdabanian Stage (Repina, Borodaevskaya & Ermak, 1988).

4. Chemostratigraphy and correlation

The upper portion of the carbon isotopic curve from the Selinde section (Fig. 2) clearly matches the Siberian carbon isotopic reference profile obtained from the Lena–Aldan region 200–400 km NW (Brasier *et al*. 1994), with cycles II–IV recognized (Fig. 3). In the reference profile, the lowermost Tommotian biozone of *Nochoroicyathus sunnaginicus* is preceded by a positive carbon isotopic peak I in the upper Ust'-Yudoma Formation (Fig. 3). The lower boundary of this biozone is marked by positive values in the uppermost Ust'-Yudoma Formation: up to ~0.8‰ at 'Dvortsy' (Magaritz, Holser & Kirschvink, 1986; Magaritz *et al*. 1991) and 1.5–2.5‰ at Ulakhan-Sulugur (Magaritz, 1989; Magaritz *et al*. 1991; Brasier, Khomentovsky & Corfield, 1993), whereas values around 0‰ occur at the base of the Pestrotsvet Formation in both sections. The high positive values in the Ulakhan-Sulugur section are missing from the 'Dvortsy' section above peak I reported from both sections (Magaritz, 1989; Magaritz *et al*. 1991). This is consistent with the presence of discontinuities and condensed intervals in them (Ivanovskaya, 1980; Rozanov, 1984). The hiatus between the Ust'-Yudoma and Pestrotsvet formations, according to Rozanov *et al*. (1992) and Zhuravlev (1998), is contained within the *N. sunnaginicus* Biozone. Khomentovsky & Karlova (1993) suggested it to be pre-Tommotian, because the apparent karstic origin of the basal Tommotian fauna in the uppermost Ust'-Yudoma Formation implied that it was derived from the base of the Pestrotsvet Formation.

Despite the obvious similarity of carbon isotopic profiles in the upper part of the Pestrotsvet Formation in the Selinde and Lena–Aldan regions, the lower beds of the Pestrotsvet Formation in these two areas exhibit very different isotopic signatures (Fig. 3). In the Selinde section, positive and frequently oscillating values are preceded by a trough and another positive peak in the lowermost beds of the Pestrotsvet Formation. These effects are missing from the lower Pestrotsvet Formation of the stratotype sections on the Aldan River. For lack of isotopic data from the underlying Ust'-Yudoma Formation at the Selinde section, it is not possible to compare the isotopic record with that from the same formation in the Lena–Aldan region. However, it is possible to conclude on an older age of the lowermost Pestrotsvet Formation in the Selinde section from presence of the positive excursion not found in other sections of this formation in the Lena–Aldan region. Although there is an apparent similarity with excursion I from the Lena–Aldan region (Fig. 3) known to be pre-Tommotian (Magaritz, Holser & Kirschvink, 1986; Magaritz *et al*. 1991; Brasier *et al*. 1994), our plausible interpretation is different. We

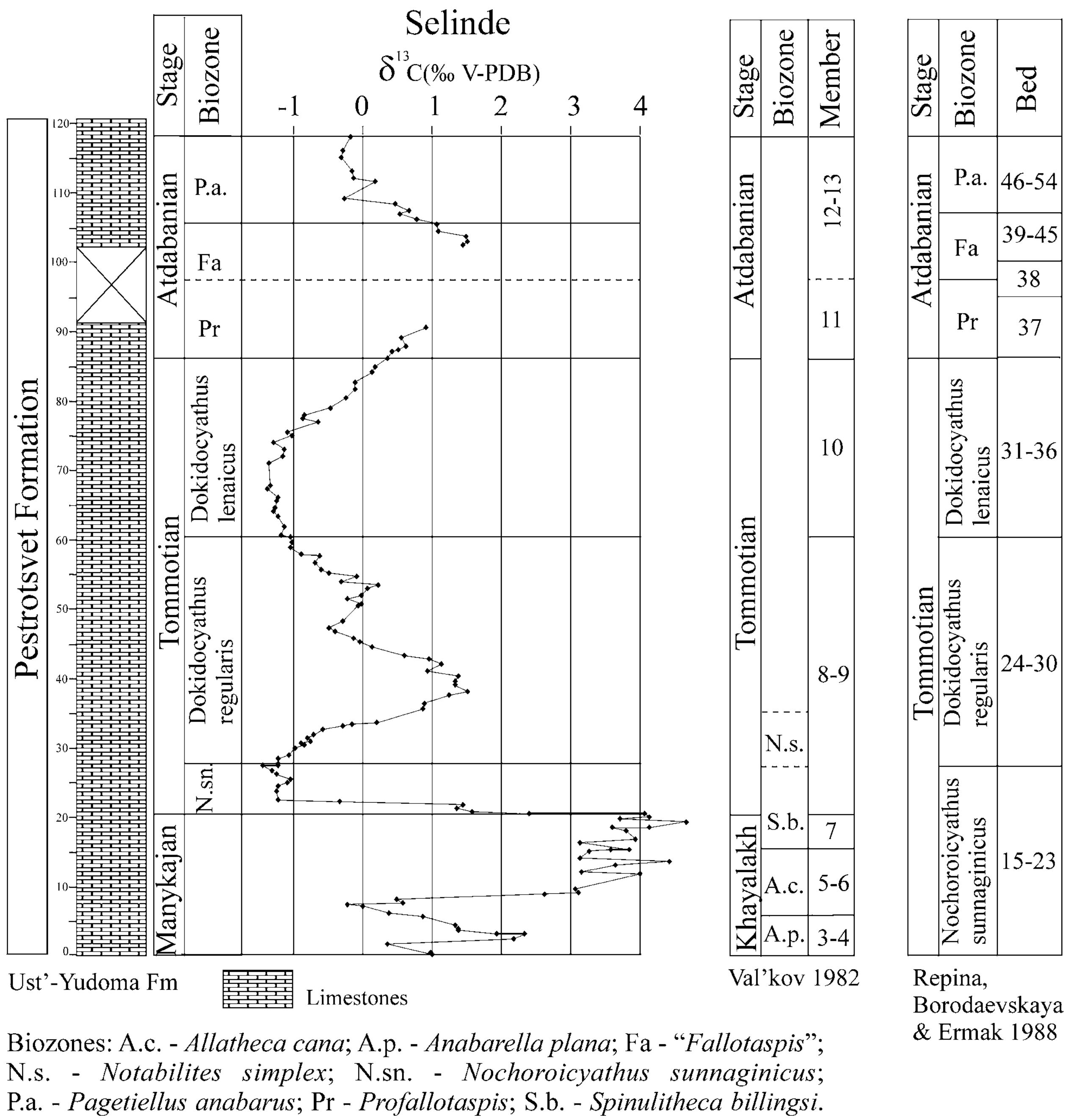
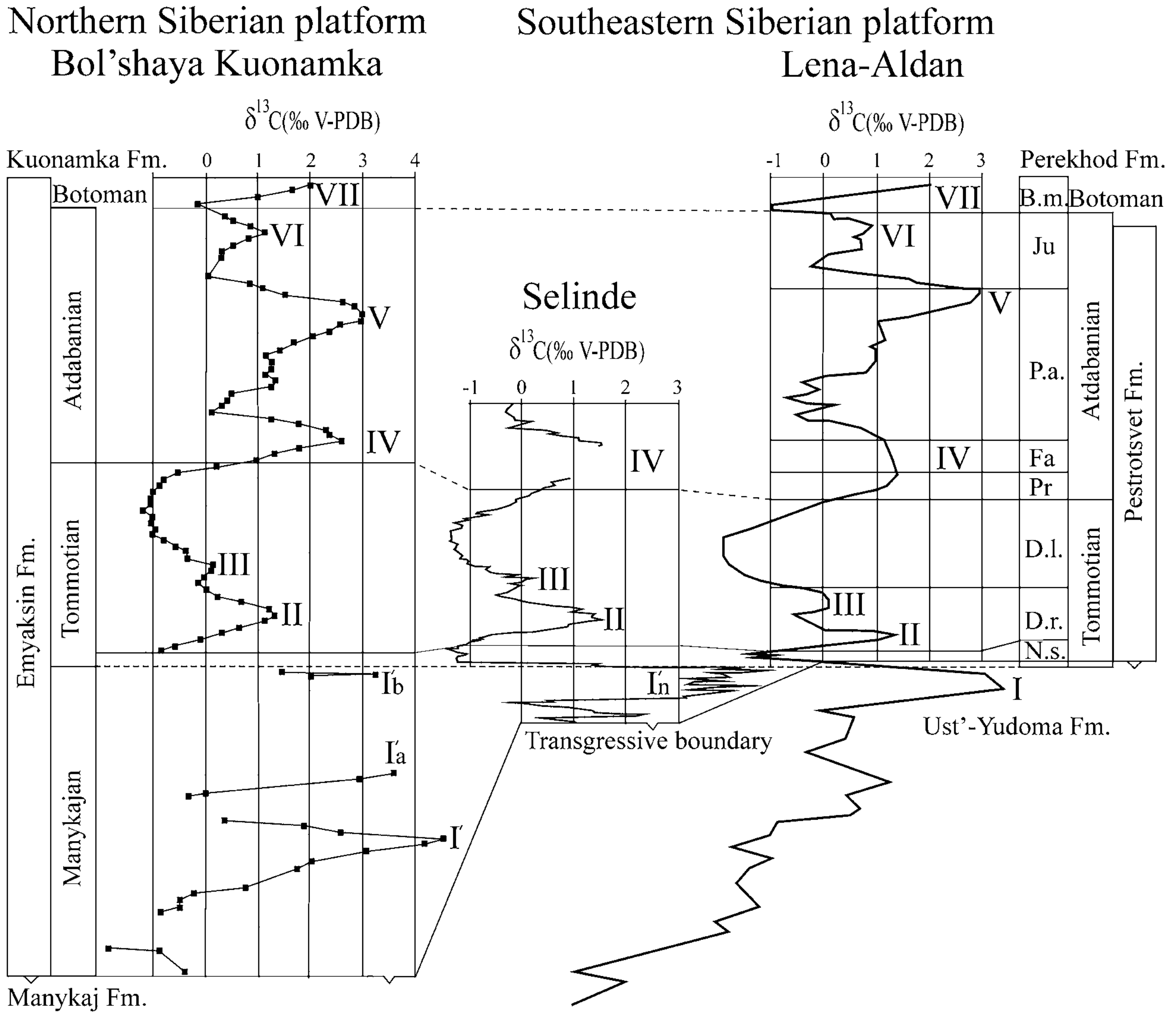


Figure 2. Carbon isotopic profile from the Selinde section with references to stages and biozones. The Manykajan Stage used herein is roughly synonymous to the Nemakit-Daldynian Stage, but neither is formally accepted.

suggest that we are dealing with a younger interval of prominent excursions preserved in this section and also reported from the northern part of the platform between isotopic peaks I and II. This conclusion is in agreement with Val'kov's (1976, 1978, 1982, 1987) suggestions that the lowermost 20 m of the Pestrotsvet Formation in the Selinde section contain fossils older than those from the base of the same formation in the stratotype sections on the Aldan River. The Pestrotsvet Formation does not contain recognized hiatuses comparable to that between Pestrotsvet and Ust'-Yudoma formations. Since the boundary between these two formations is erosional, it is not possible to warrant the completeness of the isotopic record through this boundary. Carbon isotopic oscillations in the lower 20 m of the Pestrotsvet Formation are unlikely to be diagenetic artifacts. They are situated within the same geological formation and limestone lithologies as the Tommotian–Atdabanian isotopic signature that is known to correlate well with the reference section and across the Siberian platform.

A correlation of carbon isotopic profiles across the Siberian platform has been proposed previously for the Lower Cambrian (Kouchinsky *et al.* 2001; Fig. 3). The upper part of the carbon isotopic profile from the Bol'shaya Kuonamka section in northern Siberia (Fig. 1) matches oscillations of the reference profile,



Biozones: B.m. - *Bergeroniellus micmacciformis*; D.l. - *Dokidocyathus lenaicus*; D.r. - *Dokidocyathus regularis*; Fa - "*Fallotaspis*"; Ju - *Judomia*; N.s. - *Nochoroicyathus sunnaginicus*; P.a. - *Pagetiellus anabarus*; Pr - *Profallotaspis*.

Figure 3. Proposed correlation of the carbon isotopic profiles between northern Siberia (Bol'shaya Kuonamka) and southeastern Siberia (Selinde section and Lena–Aldan stratotype region). The Lena–Aldan isotopic profile is adapted from Brasier *et al.* (1994). The Manykajan Stage used herein is roughly synonymous to the Nemakit-Daldynian Stage, but neither is formally accepted.

but contains additional peaks in the lower part of the Emyaksin Formation. The base of the Emyaksin Formation represents the same sequence boundary as the base of the Pestrotsvet Formation. On the other hand, the stratigraphic record in the Emyaksin Formation of the Bol'shaya Kuonamka section extends further downwards than in the Selinde section. The lowermost positive peak in the Emyaksin Formation has the same magnitude and biostratigraphical position as peak I' reported from the Medvezhin Formation of the western Anabar region (Knoll *et al.* 1995; Kaufman *et al.* 1996; Fig. 1). This event is apparently missing from the lower part of the Pestrotsvet Formation in the southeastern part of the Siberian platform (Selinde and Aldan sections). Peak I' is characterized by a steady change of isotopic values without oscillations (Kouchinsky *et al.* 2001; Fig. 3). By contrast, Members 6 and 7 of the Selinde section exhibit frequent oscillations from +3 to +4.5‰ (Figs. 2, 3), implying that this protracted period of positive values represents a different event from peak I'. Two incompletely resolved excursions, named I'a and I'b, from a poorly exposed part of the Bol'shaya Kuonamka section possibly embrace this interval of frequent positive oscillations that is revealed in the Selinde section (Kouchinsky *et al.* 2001; Fig. 3). Collectively these oscillations recovered in the Selinde section and correlated with the oscillating positive values between peaks I' and II in the Bol'shaya

Kuonamka section can be preliminary named I'n series of oscillations (Fig. 3) until a complete continuous section through the entire interval is analysed.

The abrupt drop from +4 to −1‰ within the lower part of the *N. sunnaginicus* Biozone in the Selinde section (Fig. 2) represents a significant geochemical event rather than a hiatus, because transitional values are observed throughout the event. A hint of a similar rapid shift is contained within the Bol'shaya Kuonamka section (Fig. 3). High $\delta^{13}C$ values are also known from the early Cambrian of Morocco, India, Iran (Knoll *et al.* 1995), Mongolia (Brasier *et al.* 1996), and China (Zhang *et al.* 1997; Zhou *et al.* 1997; Li & Xiao, 2004), but these profiles are not sufficiently continuous to be unambiguously correlated with the Siberian sections. However, the fossil record does not contradict placement of these high positive excursions within the interval between peaks I and II of the Siberian isotopic reference scale.

5. Conclusions

The Selinde section is the most continuous outcrop of the Pestrotsvet Formation close to the established early Cambrian stratotypes of the Lena–Aldan region, but it represents more offshore normal marine facies. Carbon isotopic excursions unrecognized in the 'Dvortsy' and Ulakhan-Sulugur sections confirm, independently of fossils, a significant difference in age of the lower boundary of the Pestrotsvet Formation in the stratotypes and Selinde section. We conclude that the lowermost 20 m of the Pestrotsvet Formation in the Selinde section are older than the base of the same formation in the stratotype sections at the Aldan River, and they exhibit a large positive isotope excursion (up to +4.5‰) that is missing in the stratotype region. Together with previously published data from northern Siberia, the new information allows us to document the age and dynamics of the early Cambrian marine transgression. The transgression is associated with rapid shifts of $\delta^{13}C$ values from *c.* −2‰ to *c.* 5‰, which may be correlated at least on the Siberian platform. During this interval geochemical events recorded in the surface ocean sediments co-occurred with a rapid evolutionary radiation of benthic metazoans.

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