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Carbon isotope stratigraphy and the problem of a pre-Tommotian Stage in Siberia

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Abstract – Carbon isotopic oscillations are useful to elucidate the stratigraphy and biogeochemical events around the Precambrian–Cambrian transition. New isotopic data from the Manykaj and Emyaksin formations of the eastern Anabar Uplift (Siberia) help to correlate the Lower Cambrian and Neoproterozoic–Cambrian transitional beds across the Siberian Platform. The similarity of trends and amplitudes of the carbon isotopic curves, together with biostratigraphic and sequence-stratigraphic markers from the Anabar Uplift, provide a precise correlation with the southern part of the Siberian Platform. Diagenesis of argillaceous limestones of the Emyaksin Formation has apparently not affected the primary isotopic variations. The resulting curve is nearly identical in sections about 100 km apart in the Tommotian–Atdabanian portion of the formation. Relatively frequent and pronounced isotopic oscillations in the lower beds of the Emyaksin Formation fit between features I and II of the southern Siberian isotopic reference scale but are undetected therein owing to the depositional hiatus at the base of the Tommotian Stage in its type section. This confirms the transgressive onlap from the north suggested by previous studies, and makes the appearance of the Cambrian skeletal fossils on the Siberian Platform less abrupt. The hiatus in the south appears to embrace at least two biostratigraphic zones as recognized in the north. The case is strengthened for a pre-Tommotian Cambrian Stage in Siberia, the biostratigraphic framework for which has been elaborated earlier.

1. Introduction

The transition between the Proterozoic and Phanerozoic Eons has long been recognized as one of the most significant boundaries in geological and biological history. In most places on Earth, the transitional strata contain major hiatuses, and the Cambrian sedimentary sequence typically begins with a transgressive sequence over eroded Neoproterozoic or older strata.

Whereas this condition has simplified mapping of the Precambrian–Cambrian boundary in many parts of the world, it has also greatly obscured the details of the processes surrounding the 'Cambrian explosion'. Important events are hidden in hiatuses, and the correlation of various time-transgressive units has been wanting. Attempts within the Precambrian–Cambrian Boundary Working Group of the IUGS to define a stratotype section and point for the boundary were initially focused on the richly fossiliferous basal Cambrian carbonates on the Siberian Platform and in China. The presence of considerable hiatuses in these regions, however, eventually turned attention to the more complete clastic sequences of southeastern Newfoundland. In 1992, a stratotype section and point in the Chapel Island Formation at Fortune Head, Newfoundland, at the first appearance of the trace fossil *Phycodes pedum* (Narbonne *et al.* 1987), was ratified by the International Subcommission on Cambrian Stratigraphy (Landing, 1994).

Correlation into this massive clastic unit from elsewhere is an intricate task, given its poor fossil characterization (Rozanov *et al.* 1997) and low potential for palaeomagnetic, geochemical and microfossil correlation (Strauss *et al.* 1992*a*). Recent advances in physical correlation methods, however, have increased the possibilities of a truly integrated stratigraphy within strict temporal constraints and led to considerable improvements in the regional and global correlation of the Precambrian–Cambrian boundary beds (e.g. Bowring *et al.* 1993; Brasier *et al.* 1994*b*; Isachsen *et al.* 1994; Kaufman *et al.* 1996).

The global correlation of the boundary beds is still problematic, however, the difficulties being related to the assessment of stratigraphic discontinuities and diachronism of boundaries between geological formations, aggravated by the strong facies dependence of

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trace and body fossils in this interval (Lindsay *et al.* 1996). A particularly crucial question is the nature of the sub-Tommotian succession on the Siberian Platform (Rozanov, 1995; Knoll *et al.* 1995*b*, 1996; Landing, 1995, 1996; Kaufman *et al.* 1996).

Historically, the basal Cambrian boundary on the Siberian Platform was defined at the base of the Tommotian Stage (Rozanov *et al.* 1969; Khomentovsky & Karlova, 1993). The Dvortsy section, stratotype of the Tommotian Stage, is situated in the southern part of the craton on the Aldan River, *c*. 40 km upstream from the Ulakhan-Sulugur section, previous candidate for the Precambrian–Cambrian boundary stratotype (Fig. 1). Published correlations with the Newfoundland stratotype (Narbonne *et al.* 1987; Landing, 1994; Zhuravlev, 1995) suggest that the basal Cambrian sequences include sub-Tommotian strata of the Siberian Platform. These beds are often referred to as the Nemakit-Daldynian or Manykaian Stage, in Siberia commonly attributed to the top of the Vendian System (Val'kov, 1987; Missarzhevsky, 1989; Rozanov *et al.* 1992; Khomentovsky & Karlova, 1993). Moreover, there is no consensus on the upper boundary of this stage and the lower boundary of the Tommotian, nor on the biostratigraphic correlation of the transitional beds across the Siberian Platform. The differences between associations of the earliest skeletal fossils in these beds may be explained by differences in preservation, palaeogeographic and facies distribution, or in evolution.

Knoll *et al.* (1995*b*) and Kaufman *et al.* (1996) applied integrated biostratigraphy, sequence stratigraphy and chemostratigraphy to solve this issue, coming up in support of the northern Siberian sequences being more complete than the ones in the south, as earlier suggested by Missarzhevsky (1983, 1989).

We present here new data from the Anabar Uplift, northern part of the Siberian Platform, showing that the middle and upper parts of the Emyaksin Formation can be correlated precisely with the Tommotian to lower Botomian sequences in the south of the platform with the help of carbon isotope curves.

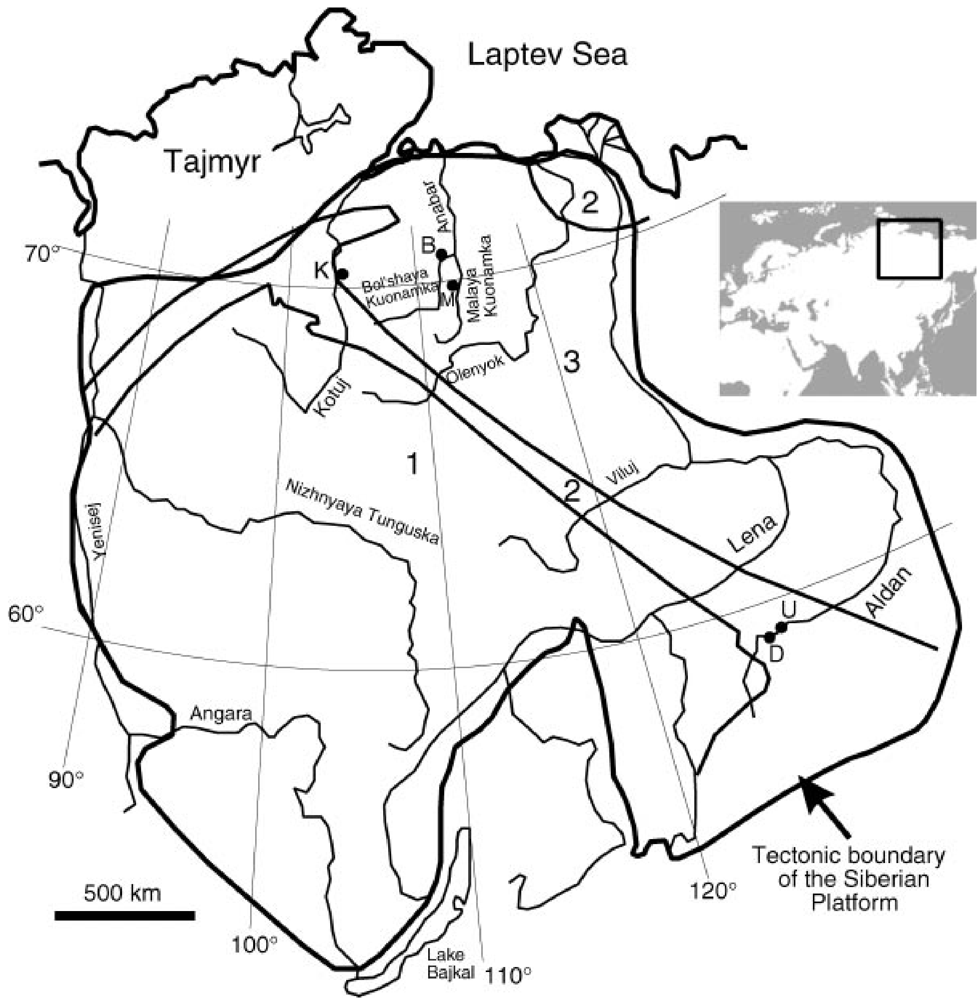

Figure 1. Map of the Siberian Platform with localities discussed in the text. B – Bol'shaya Kuonamka sections (96-4, 5, 5a, 6); M – Malaya Kuonamka section (96-3); K – Kotuj section (see Kaufman *et al.* 1996); D – Dvortsy section; U – Ulakhan-Sulugur section. 1 – lagoonal facies zone (Turukhano–Irkutsk–Olekma); 2 – transitional facies zone; 3 – open-marine facies zone (Yudoma–Olenyok).

The isotopic curves in the lower Emyaksin Formation display several positive excursions that appear to have been unrecognized in other parts of the platform, suggesting that sedimentation was here more complete and includes at least two biostratigraphic zones not represented in the south. The underlying Manykaj Formation, separated from the Emyaksin by a sequence boundary, represents the earliest part of the Cambrian Period and can be correlated with the Ust'-Yudoma Formation in the southeastern part of the Siberian Platform.

2. Material and methods

The material was obtained during a 1996 field expedition along the Malaya Kuonamka and Bol'shaya Kuonamka rivers, Anabar Uplift, Siberia, in which AK, SB, VVM, SP and AKV participated. The samples derive from sections 96–4 (Manykaj Formation), 96–3, 96–5, 96–5a, and 96–6 (Emyaksin Formation) (Fig. 1). The localities belong to the Yudoma–Olenyok open-marine facies basin (Rozanov & Zhuravlev, 1992). The succession of samples covers the entire Emyaksin Formation (mainly argillaceous carbonates) and the upper part of the Manykaj Formation (predominantly sandstones and carbonates with varied amount of siliciclastic material). Some intervals are covered (cf. sections 96–5 and 96–5a in Fig. 2) or contain unsuitable lithologies with abundant siliciclastic material (cf. section 96–4 in Fig. 2). Samples were cut, and their polished sections examined with a light microscope. Rock powder was obtained with a microdrill from the areas selected for their micritic composition. The amount of powder prepared for a single analysis was *c.* 100 µg. One to three spots were analysed from each sample (duplicates are mostly from sections 96–4, 5 and 5a). Carbon isotopes in calcite from the samples were analysed with a Finnigan MAT 252 equipped with an automated online Kiel Device at the Department of Geology and Geochemistry, Stockholm University. The carbon isotope composition is defined as a deviation in ‰ 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. The accuracy of the analyses was always better than ± 0.1‰. Here we report the preliminary data of the analyses. Tables of measurements are available from the British Library Document Supply Centre as Supplementary Publication no. SUP 90489 (6 pages); details of how to obtain a copy are given in the Acknowledgements.

3. Biostratigraphic and sequence-stratigraphic markers

The Manykaj Formation contains a biostratigraphic marker, a distinct association of calcareous tubular anabaritids ('marker' in Fig. 2). It is distinguishable across the Siberian Platform and represents the sub-Tommotian biostratigraphic zone *Angustiochrea lata* (Val'kov, 1975; Vasil'eva & Rudavskaya, 1989).

The lowermost Emyaksin Formation contains transgressive deposits of sedimentary cycle C1.1 distinguishable across the Siberian Platform (Zhuravlev, 1998). Val'kov (1975, 1987) defined the *Anabarella plana* (mollusc) and *Allatheca cana* (hyolith) biozones in the lower part of the Emyaksin Formation (sections 96–5, 96–5a). They are situated below the *Allatheca anabarica* (hyolith) Biozone. Val'kov (1975, 1987) believed the latter to be Tommotian in age, whereas he regarded the *Anabarella plana* Biozone as pre-Tommotian and the *Allatheca cana* Biozone as occupying an intermediate position.

In the southern part of the Siberian Platform, archaeocyaths allow correlation within the Tommotian and later stages (Rozanov & Zhuravlev, 1992). In contrast, there are no archaeocyaths in the Emyaksin Formation. Earliest skeletal fossils other than hyoliths have not been sufficiently studied in the region and cannot at present be used for a convincing biostratigraphic correlation across the Siberian Platform. The Tommotian–Atdabanian biostratigraphic zones in sections 96–3 and 96–6 are based on hyoliths. These fossils have been extensively studied in the region by Val'kov (1975, 1987) and may be correlated with the stratigraphic charts of Sysoev (1972) for the northern slope of the Aldan Shield. However, correlation across the Siberian Platform using hyoliths is not as good for the Tommotian as for the Atdabanian (Val'kov, 1993). Hyolith biozones are indicated in Figures 2–4.

The upper biostratigraphic boundary in section 96–6 provides the most important anchor point for the carbon isotopic curve. It is defined quite clearly in the eastern Anabar area by the second trilobite biozone of the Botomian Stage, *Bergeroniellus expansus*, represented by the lowermost black shale bed of the Kuonamka Formation (Bakhturov, Evtushenko & Pereladov, 1988). The maximum flooding on the Siberian Platform is attributed to this biozone (Zhuravlev, 1998). Trilobites allow correlation of the lowermost part of the *B. expansus* Biozone with the *Bergeroniellus gurarii* Biozone in the stratotype area in the south of the craton. The uppermost part of the Emyaksin Formation belongs to the lowermost Botomian *Calodiscus–Erbiella* Biozone, which may be correlated with the *B. micmacciformis–Erbiella* Biozone of the stratotype area (Fig. 4).

4. Carbon isotopic chemostratigraphy

Organic matter tends to be enriched in the light isotope of carbon (^{12}C) compared to the ambient inorganic matter, mainly as a result of fractionation by primary producers (Holser *et al.* 1988; Schidlowski & Aharon, 1992). Depending on the cycling of organic carbon (influenced, for example, by the relative rate of burial of organic material), ambient isotopic ratios

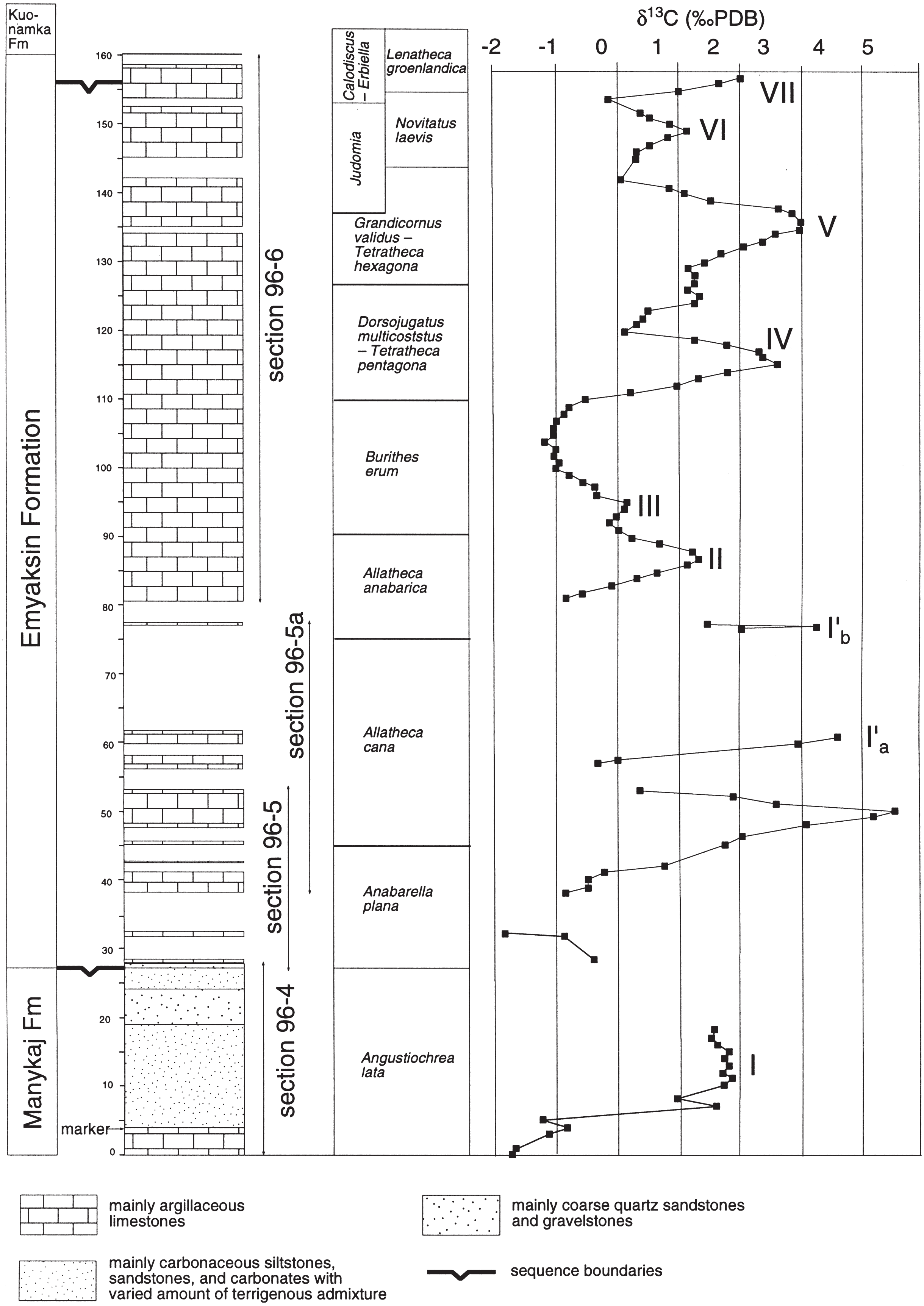

Figure 2. Composite $\delta^{13}C$ curve for the Bol'shaya Kuonamka sections.

may vary on a regional or global scale. Variations in the ratio of heavy (^{13}C) and light (^{12}C) stable isotopes of carbon recorded in organic matter, skeletons and sedimentary carbonates thus provide an important geochemical proxy and may be used in chemostratigraphy (Strauss *et al.* 1992*b*; Kaufman & Knoll, 1995). A number of isotopic curves have been published from the Neoproterozoic–Cambrian successions in Siberia and elsewhere in order to trace associated biogeochemical events and improve stratigraphic correlation (Magaritz, Holser & Kirschvink, 1986; Magaritz *et al.* 1991; Brasier *et al.* 1994*b*; Ripperdan, 1994; Kaufman & Knoll, 1995; Bartley *et al.* 1998). The upper Neoproterozoic to Lower Cambrian is characterized by a high amplitude of variation in the $\delta^{13}C$ curves in carbonates (Brasier *et al.* 1994*a*) with a diminishing trend from +11‰ in the Neoproterozoic to values close to 0‰ by the end of the Early Cambrian (Brasier & Sukhov, 1998). The cause of these oscillations is still obscure, but they appear to provide good tools for intra- and interbasinal correlation.

Chemostratigraphic data from the region of Bol'shaya and Malaya Kuonamka have been published by Brasier & Sukhov (1998) concerning mostly the Kuonamka Formation (Early Cambrian Botomian Stage to Middle Cambrian Amgan Stage) and the overlying Olenyok Formation (Middle Cambrian Mayan Stage). They also obtained results for the Manykaj and Emyaksin formations, but this information is too incomplete to be adequate. In one case there was found a prominent positive excursion in the Emyaksin Formation identified as peak I′, also found in the western Anabar region. Following Khomentovsky & Karlova (1993) and Landing (1996), this feature was believed by Brasier & Sukhov (1998) to accompany fossils of mid-Tommotian age.

The C-isotopic curve for the Emyaksin Formation presented here is very consistent in its upper part with the Siberian reference scale, obtained for the southern part of the craton about 1500 km away (Brasier *et al.* 1994*b*) (Fig. 4). The correlation of the curves is based on the close similarity in their trends and amplitudes and on the associated biostratigraphic and sequence-stratigraphic markers (see foregoing discussion and Brasier *et al.* 1994*b*). Cycles II–VII of the reference curve may be easily recognized in the most complete and uninterrupted succession of section 96–6 (Figs 2, 4). The data from this section confirm isotopically heavy values of C and several major oscillations in the Atdabanian and lower Botomian. The behaviour of the curve for the Emyaksin Formation in its Middle Tommotian–Atdabanian part is nearly identical in sections 96–3 (Malaya Kuonamka) and 96–6 (Bol'shaya Kuonamka), about 100 km apart (Figs 1, 4). The positive excursion VII of the isotopic reference scale (Brasier *et al.* 1994*b*) belonging to the Botomian *Bergeroniellus micmacciformis–Erbiella* Zone may be readily correlated with the uppermost excursion in section 96–6. The lowermost positive peak in section 96–6 is correlated with excursion II of the middle Tommotian *Dokidocyathus regularis* Zone. The positive excursion in the upper Manykaj Formation (section 96–4) is of the same magnitude (about +2‰) as the peak in the Koryl Member in the top of the Nemakit-Daldyn Formation on the Kotujkan River (Kaufman *et al.* 1996). Its stratigraphic position, however, rather supports its correlation with the next lower peak in the Nemakit-Daldyn Formation, which Kaufman *et al.* (1996) correlate with feature I of similar magnitude (about +3‰) in the uppermost Ust'-Yudoma Formation (Knoll *et al.* 1995*b*; Kaufman *et al.* 1996) (Fig. 3).

A noteworthy difference from the reference curve exists below peak II, in the lower *c.* 50 m of the Emyaksin Formation (Figs 2, 3). This interval crops out in sections 96–5 and 96–5a and is less densely covered by sampling owing to its poor exposure. The upper part of section 96–5a may be connected lithostratigraphically with section 96–6, and there is an approximately 5 m gap between them (Fig. 2). Three positive excursions (I', I'_a, I'_b) have been revealed in these sections. These excursions deserve a special consideration.

According to the reference scale, the lowermost Tommotian zone, *Nochoroicyathus sunnaginicus*, is preceded by a positive carbon isotopic peak I and shows generally low values of $\delta^{13}C_{carb}$ in its stratotype, whereas the lower boundary of the biozone is marked by higher positive values, 0.8‰ at Dvortsy (Magaritz, Holser & Kirschvink, 1986; Magaritz *et al.* 1991) and 1.5–2.0‰ at Ulakhan-Sulugur (Magaritz, 1989; Magaritz *et al.* 1991). In the Ulakhan-Sulugur section, positive values up to 2.5‰ are reported from the uppermost Ust'-Yudoma Formation, above peak I (Magaritz, 1989). They are missing from the Dvortsy section (Magaritz *et al.* 1991). This is consistent with the presence of discontinuities in these two Aldan sections (Ivanovskaya, 1980; Rozanov, 1984). The presence of peak II at the base of the Kuonamka section 96–6 and of at least three distinct positive excursions (I', I'_a, I'_b) in the underlying Emyaksin Formation in sections 96–5 and 96–5a (Figs 2, 3) suggests that they correspond to a missing or condensed part in the Aldan sections.

The lowermost positive peak in the Emyaksin Formation (in Figs 2 and 3 it belongs to section 96–5, but it is also present in section 96–5a) has the same magnitude (but shifted in absolute value) and biostratigraphic position as peak I′ reported from the Medvezhin Formation of the western Anabar region (Knoll *et al.* 1995*b*; Kaufman *et al.* 1996) (Fig. 3). This excursion was first discovered, but not named, by Pokrovsky & Missarzhevsky (1993) in the Medvezh'ya Formation. Peak I′ is there associated with facies comparable to those in the Emyaksin Formation (argillaceous limestones) and is followed by a significant

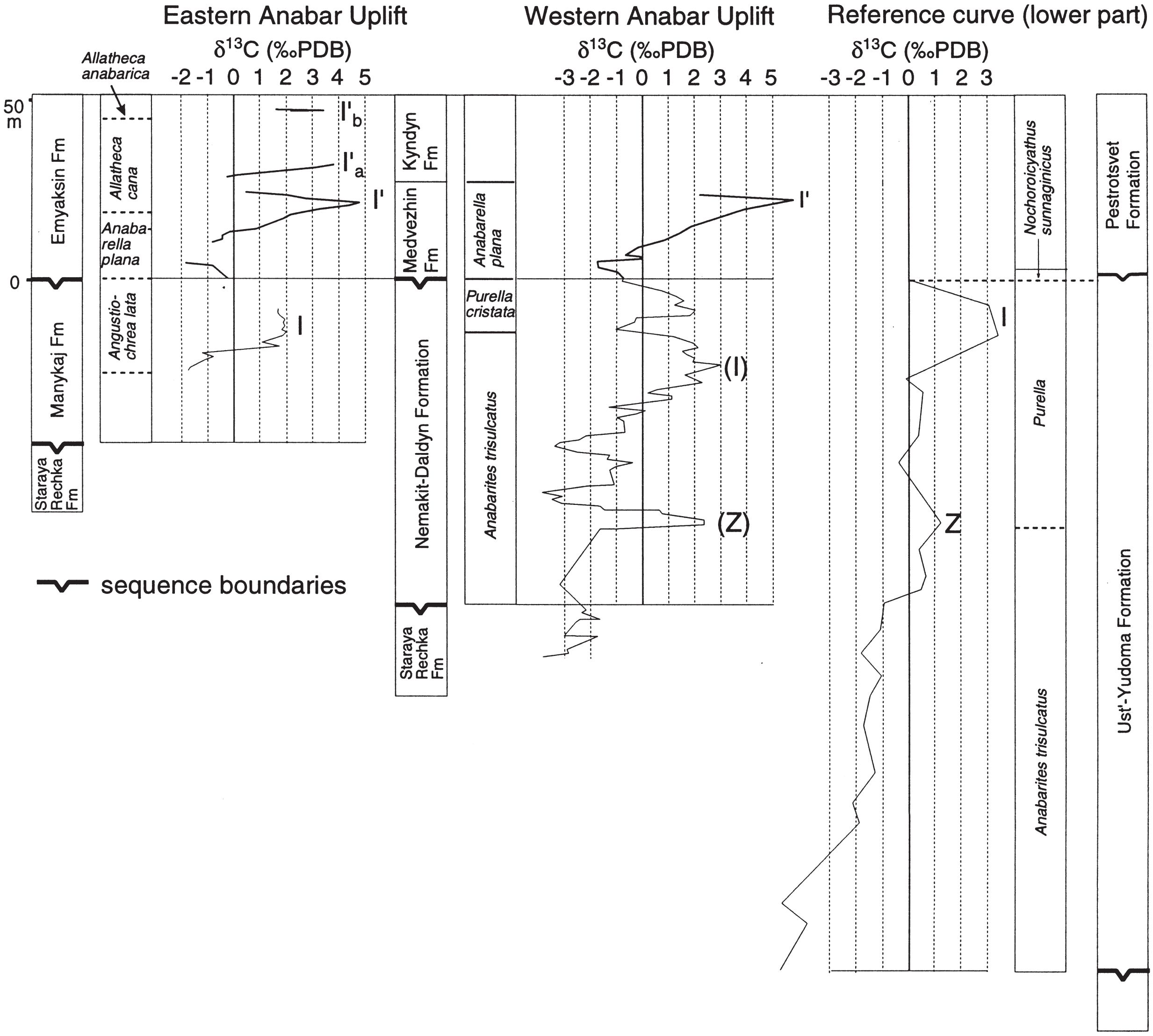

Figure 3. Comparison of Manykaian–Tommotian(?) $\delta^{13}C$ curves from the Eastern Anabar Uplift (this paper; lower part of the Bol'shaya Kuonamka sections; biostratigraphical scale adapted from Val'kov, 1975), Western Anabar Uplift (adapted from Kaufman *et al.* 1996), and the southern part of the Siberian Platform (reference curve, lower part; adapted from Brasier *et al.* 1994*b*). Vertical scale the same in all three columns.

change in lithology (oolite dolostones of the Kugda Formation). The other two peaks have not been captured in the Medvezh'ya Formation, probably because low sampling density and depositional hiatuses prevented the short-lived peaks from being expressed there. A peak similar to I′ has also been reported from the upper Kessyusa Formation of the Olenyok Uplift in Siberia (Knoll *et al.* 1995*a*).

Kaufman *et al.* (1996) correlated feature I′ with isotopic excursions of similar magnitude in India (Aharon, Schidlowski & Singh, 1987), Iran (Brasier *et al.* 1990), and Morocco (Tucker, 1986; Magaritz *et al.* 1991), though in Iran and Morocco there are, respectively, one and two additional later peaks of similar magnitude before the negative drop of values toward feature II. The isotopic record in all these sections is not continuous enough to provide a reliable correlation with the Siberian reference scale. In the case of our Kuonamka sections, the close match of the curves makes the correlation with the reference scale much more secure.

5. What is below the Tommotian?

Ulakhan-Sulugur on the Aldan River was one of the candidate stratotypes for the global Precambrian–Cambrian boundary (Cowie & Rozanov, 1983), the proposed stratotype boundary point being in the uppermost Ust'-Yudoma Formation, about 1.5 m below the Pestrotsvet Formation (Rozanov *et al.* 1969; Rozanov *et al.* 1992). A major problem (and probably the decisive one for the eventual rejection of this stratotype) with the Ulakhan-Sulugur section has been the uncertainties surrounding the Ust'-Yudoma–

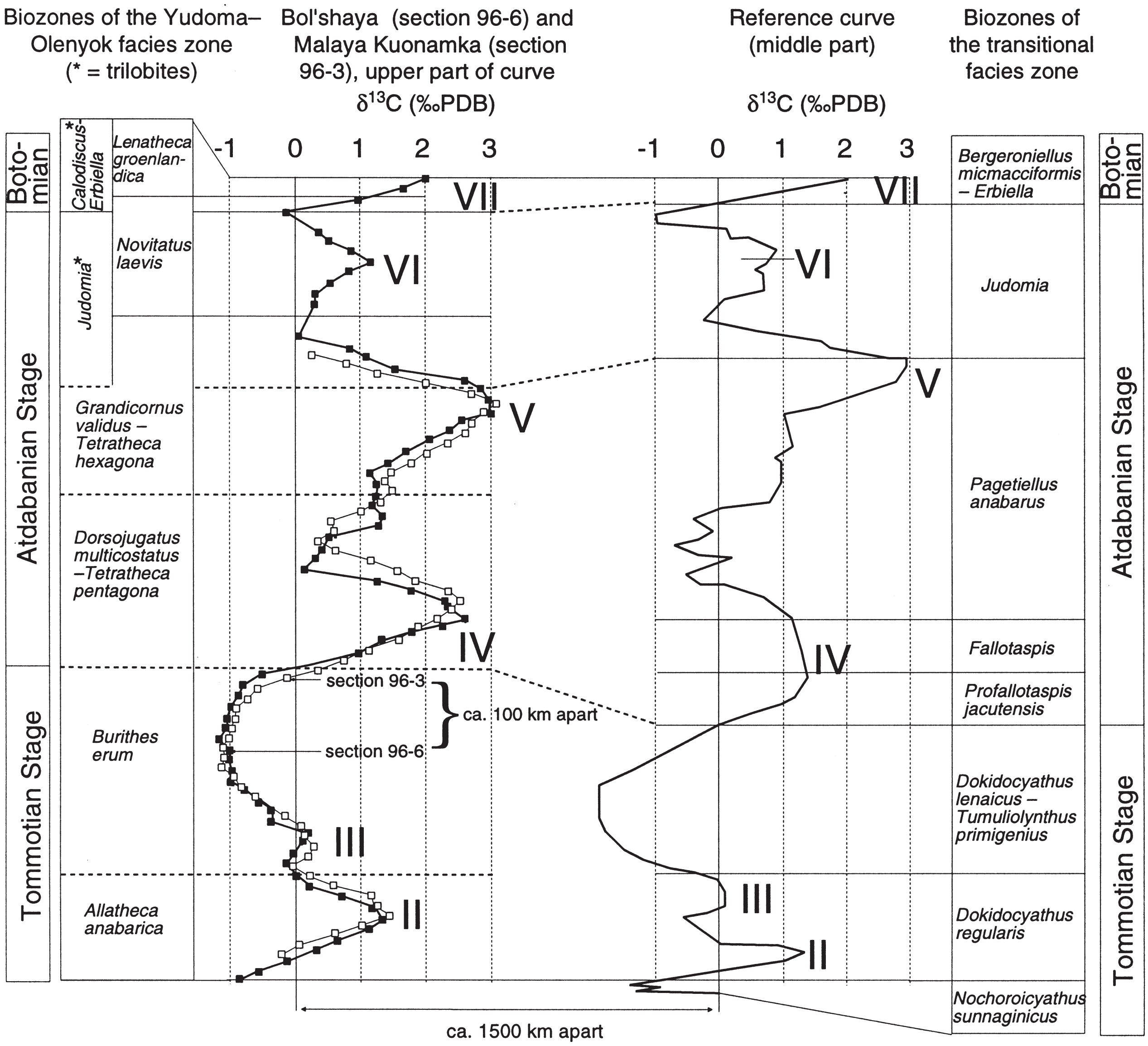

Figure 4. Proposed correlation of Tommotian–Botomian $\delta^{13}C$ curves from the Bol'shaya and Malaya Kuonamka sections (this paper) with the reference curve from the southern part of the Siberian Platform (adapted from Brasier *et al.* 1994*b*). Biozones of the Yudoma–Olenyok facies zone adapted from Pel'man *et al.* (1990) and Val'kov (1975; 1987; 1993); those of the transitional facies zone from Brasier *et al.* (1994*b*).

Pestrotsvet contact. A rich fauna, including one archaeocyath species, diagnostic for the basal Tommotian *Nochoroicyathus sunnaginicus* Biozone, has been found in glauconitic grainstones of the uppermost Ust'-Yudoma Formation (Khomentovsky & Karlova, 1993). This fauna may have been deposited there along karstic dykes from the overlying Pestrotsvet Formation during the Cambrian transgression, but sedimentological arguments in favour of (Khomentovsky, Val'kov & Karlova, 1990; Khomentovsky & Karlova, 1993) and opposing (Rozanov *et al.* 1992; Zhuravlev, 1998) its karstic nature have not yet led to a consensus.

The abrupt appearance of many taxa at the base of the Tommotian Stage in Siberia has been taken to reflect an initial radiation spanning the Cambrian evolutionary explosion (Rozanov *et al.* 1969; Rozanov, 1984; Rozanov *et al.* 1992). A more common interpretation assumes a sizeable hiatus at the base of the Tommotian in Siberia, which significantly misrepresents the rate of speciation (Khomentovsky & Karlova, 1993; Landing, 1994; Knoll *et al.* 1995*b*; Kaufman *et al.* 1996). Even so, there is considerable disagreement about the length of the hiatus (Landing 1996; Knoll *et al.* 1996).

If the Tommotian in its type area is underlain by a considerable hiatus, faunal sequences in other regions might show a more gradual appearance of 'Tommotian' taxa (Kaufman *et al.* 1996). According to Pel'man *et al.* (1990), the *N. sunnaginicus* Zone in the southern part of the craton may be subdivided into two or three parts by associations of earliest skeletal fossils, with the diversity increasing through the interval.

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. Based on their preferred correlations across the Siberian Platform, Kaufman *et al.* (1996) concluded that the sub-Tommotian hiatus between the Ust'-Yudoma and Pestrotsvet formations corresponds to at least 48 m of rock in the Kotujkan River section, incorporating one hiatus of unknown length. From the available radiometric data they estimated the missing interval in the south to represent at least several million years.

The new data from the Kuonamka rivers are in good agreement with these estimates. The maximum age of the lower Tommotian boundary was reported from the Kharaulakh section of northeast Siberia as 534.6 ± 0.4 Ma (535 Ma) by Bowring *et al.* (1993), measured on volcanic pebbles in a conglomerate underlying beds with lower Tommotian fossils. An age of 530.7 ± 0.9 Ma was reported from New Brunswick for strata correlated with the sub-Tommotian Manykaian Stage in Siberia (Isachsen *et al.* 1994). This correlation rests on an explicit assumption that the occurrences of Avalon key taxa are not controlled by lithofacies and environment, and must be considered uncertain. Nonetheless, the age of the lower Tommotian is not well constrained; it has been suggested to be considerably older (Zhuravlev, 1995) as well as considerably younger than 535 Ma (Landing *et al.* 1998). For the sake of comparison, we accept Kaufman *et al.*'s (1996) proposed range of 535–530 Ma for the lower boundary of the Tommotian. If the hiatus in the area of the Tommotian stratotype is pre-Tommotian, this estimate corresponds to the base of section 96–6 of the Emyaksin Formation. An absolute date of 522.8 ± 1.8 Ma from Australia has been interpreted as late Botomian (Jago & Haines, 1998), whereas Bowring *et al.* (1993) provided an age of *c.* 525 Ma for the Atdabanian–Botomian boundary. These dates may be regarded as an upper age limit of the Emyaksin Formation, 521–525 Ma. The duration of the interval covered in section 96–6 (79 m) is therefore 5–14 m.y. Assuming a steady rate of sedimentation (admittedly a dangerous assumption), the lower part of the formation (53 m), reflecting the record missing from the south, would have been deposited during a period of 3.4–9.4 m.y. If the hiatus in the south is accepted as spanning the lower Tommotian (Rozanov *et al.* 1992; Zhuravlev, 1998) and the lower boundary of the Tommotian being correlated with the base of the Emyaksin, the time interval for the hiatus would be 2.0–5.6 m.y. Both these estimates are consistent with those of Kaufman *et al.* (Kaufman *et al.* 1996) and suggest that the hiatus was too long to be considered intrazonal. The recognition of at least two biostratigraphic zones (Val'kov, 1975, Figs 2, 3) in the lower Emyaksin Formation supports this interpretation.

6. Conclusions

The carbon isotopic curves from carbonates in the eastern Anabar region are in excellent agreement with the Tommotian–Botomian part of the reference curve for southeastern Siberia and register significant and frequent changes below the first Tommotian positive peak. These fit between features I and II of the Siberian isotopic reference scale, but are undetected there owing to a depositional hiatus at the base of the Tommotian Stage in the southeastern part of the platform. This hiatus is associated with a transgressive boundary and merely suggests that accumulation of the Cambrian transgressive deposits began earlier in the Anabar region than in the area of stratotype. If the original definition of the lower Tommotian boundary in the uppermost Ust'-Yudoma Formation is accepted, this hiatus is intrazonal. However, it covers an interval of several, perhaps up to ten, million years and appears to correspond to at least two biostratigraphic zones in the eastern Anabar region. Thus it is more properly regarded as sub-Tommotian, representing the upper part of the Manykaian (or Nemakit-Daldynian) Stage.

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