The Precambrian – Cambrian Boundary in Siberia

by A. Yu. Rozanov

For more than ten years, the difficult problem of the Precambrian-Cambrian boundary has been intensely studied by a Working Group of the IUGS Subcommission on Precambrian Stratigraphy together with IGCP Project 29. Candidates for the stratotype boundary have been narrowed to localities in China, Newfoundland, and Siberia. Although there are, naturally, arguments for and against each section proposed, it is expected that a final choice will be made within the near future. In this article, the author describes key sections in Siberia, Kazakhstan and Mongolia, including one of the main boundary candidates on the Aldan River of Western Siberia, in the Ulakhan-Sulugur section at the base of the *Aldanocyathus sunnaginicus* zone of the Tommotian stage.

Fundamental Considerations

Since the Precambrian-Cambrian boundary is rather special, suggestions have long been made for its establishment based on geological or physical characteristics rather than on purely palaeontological criteria. However, it is now clear that only biostratigraphical criteria will lead to a solution of this problem. With such profound differences between late Precambrian and Cambrian biotas, it was necessary to accept the principle that "the Precambrian-Cambrian boundary stratotype point should be placed as close as is practicable to the base of the oldest stratigraphical unit to yield Tommotian (*sensu lato*) fossil assemblages" (Cowie, 1978). This principle was based on the idea that the boundary should be along the base of the first zonal assemblage bearing abundant skeletal fossils, in this case archaeocyathids, gastropods, hyolithids, tomotoids and brachiopods (e.g. Rozanov, 1966, 1967; Rozanov *et al.*, 1969).

The appearance of a wide variety of skeletal fauna in the early Tommotian does not, of course, mean that those groups arose here for the first time. This was the time when many groups of animals first developed the ability to form skeletons, although the cause of this instantaneous geological phenomenon is not yet clear.

There are also certain interesting connections with global abiotic changes associated with the transition from the Vendian to the Cambrian. These include a decrease in dolomite accumulation, a sharp drop in stromatolite formation, the first widespread appearance of red biogenic limestones, and a global accumulation of phosphorite – the largest and richest deposits in the U.S.S.R., Mongolia and China are Tommotian (Fig. 1). Although the causes for these events are not yet clear, the finding of what is regarded as the earliest rich Tommotian association in a

particular section does not lead us to suspect a migration effect or the presence of another rich assemblage in older layers elsewhere.

Of course the process of skeletalization, in the broad sense, was probably prolonged. Moreover, there was first a long period (probably the major part of the Vendian) when all skeleton formation was just partial scleritization of certain body-parts, and only in the Tommotian (or a little earlier in a few groups) did the formation of "real" skeletons begin, for example, in molluscs and brachiopods.

Palaeogeographic considerations are also of great importance (Fig. 1). By the early Tommotian, the palaeogeographic situation was such that normal marine carbonate sedimentation was localized primarily in eastern Siberia. Consequently, sections with the richest faunas are located there, and it is there that the centres of origin and initial diversification of a number of skeletal-forming groups were located.

Figure 1: Tommotian palaeogeography: 1 – volcanic rocks; 2 – land; 3 – dolomites; 4 – evaporites; 5 – limestones; 6 – terrigenous rocks. Open circles – archaeocyathids; solid triangles – rich associations of small shelly fossils (SSF); open triangles – poor associations of SSF; open squares – *Platysolenites*; solid squares – the richest deposits of Tommotian phosphorites. PL-region of *Platysolenites* distribution, and TR-region of rich Tommotian associations of SSF.

The other basic consideration in establishing a boundary stratotype concerns the kind of section in which a specific level can be established. Almost all the scientists involved in the discussions agree on the importance of monofacial continuity of section and the presence of the maximum possible number of features for correlation. A minority view is that the boundary should be drawn along the base or the top of layers that reflect some global abiotic event, such as glaciation or palaeomagnetic reversal.

In Russian literature the sections in the northern part of the Siberian Platform in the Anabar Massif, the Olenek Uplift and on the Igarka-Norilsk dislocation along the Sukharikha River have long been considered as locations for a possible stratotype (Fig. 2). These sections, especially in Anabar, were regarded as suitable because it is here that the type section of the Nemakit-Daldyn horizon is located (Fig. 3). Moreover, these sections appear to be more monofacial than the Aldan River sections in the southern Siberian Platform, and a number of scientists believe that a rich skeletal fauna of the pre-Tommotian age is present (e.g. Valkov, 1975, 1978. Missarzhevskiy, 1982).

It is significant that the transition from the Nemakit-Daldyn stage to the Tommotian stage takes place in limestones that are only slightly dolomitized. The basal 1.5 m of the lowest Tommotian zone (Aldanocyathus sunnagicus) are light-coloured limestones of the upper part of Sukharikha Formation, while the upper 0.9 m is represented by red argillaceous limestones typical of the Tommotian and Atdabanian strata of the Krasny Porog Formation. This section is, however, located in a region in the far north to which access is very difficult. Although it is not, therefore recommended as a possible type-section, it is of great importance because it indicates that the analogous succession of assemblages at the Precambrian-Cambrian boundary in the dolomites of the Aldan River is a reflection of general, not local, conditions.

On the Olenek Uplift (Fig. 2) there are also very interesting sections in which the transition from the Precambrian to the Cambrian is observed in terrigenous-carbonate facies (Rozanov, 1976, Missarzhevskiy, 1980). The lower zone of the Tommotian stage can be readily established here by non-archaeocyathan fauna, and in the underlying rocks Anabarites and Cam-brotubulus are present. In addition, the rocks of the Al. sunnaginicus zone contain acritarcha typical of the Lontova level of the East European Platform (see Sokolov and Fedonkin, this issue of Episodes). Further down section in the Kotlin level, acritarchs, and below these vendotaenids, and a rich Vendian-Ediacaran fauna have been

Figure 2: Locations of key areas discussed in this paper. 1 – Sukharikha River; 2 – Anabar region; 3 – Olenek Uplift; 4 – Tommot; 5 – Ulakhan-Sulugur section.

discovered (Rozanov & Sokolov, 1982). However, this section not only has some deficiencies but is also situated in a region that is very difficult to reach. Nevertheless, the presence of both rich Vendian and Tommotian faunas, together with acritarchs typical of the East-European Platform make this a good supplement to the Aldan River section, and we can estimate the possibilities of intracontinental correlation for the Vendian and early Cambrian.

The suggestion to use a section in the Anabar Uplift as a stratotype has caused some debate. In the best outcrops, it is possible to observe an upward transition from dolomites of the Starorechinskaya Formation with Yudomian phytolites,

SIBERIAN				PLATFORM		WEST MONGOLIA (KHASAGT-KHAYRKHAN RIDGE)		SOUTHERN KAZAKHSTAN (MALY KARATAU RIDGE)		CHINA	
LENA-ALDAN REGION				WEST ANABAR REGION							
ATADABIAN STAGE	Fanscyathus lermontovae Zone	Judomia Zone	PEREKHOD FM.		Judomia Zone	Alataucyathus jarochevitschi Tabulacyathellus bidzhaensis - Pretiosocyathus subtilis	SALANGOL FM.	Rhombocorniculum cancellatum Zone	SHABAKTY FM.	QI'ONGZHUSI STAGE	
	Nochoroicyathus kokoulini Zone										
	Porocyathus pinus Zone	Pagetielius anabarus Zone									Hebediscus prianabarus Pseudojudomia
	Retecoscinus zegebarti Zone	Fallotaspis Zone Profallotaspis jakutensis Zone									Fallotaspis Profallotaspis
TOMIMMOT STAGE	Dokidocyathus lenaicus - Tumuliolynthus primigenius Zone		PESTROTSVET		Latouchella korobkovi- Anabarella plana Zone	Stenothecoides	FORMATION	Bercutia cristata Zone	FORMATION	MEISHUCUN STAGE	
	Dokidocyathus regularis Zone	Lapworthella bella Subzone									
		Lapworthella tortuosa Subzone									
	Aldanocyathus sunnagininus Zone bed N8										
VENDIAN	Cambrotubulus sp., Hyolithellus sp., Chancelloria sp.		YUDOMA FORMATION		Nemakit-Daldyn Horizon (stage)	Anabarites trisulcatus Zone	TSAGANOLOM FORMATION	Protohertzina anabarica Zone	FORMATION	KYRSHABAKTY FORMATION	SINIEN

Figure 3: Correlation of the Precambrian-Cambrian boundary deposits of the southern and northern Siberian Platform with those of Kazakhstan, Mongolia, and China.

Figure 4: General view of the Ulakhan-Sulugur section on the Aldan River. Light-colored dolomites at water level belong to Yudoma Formation. Brick-red limy mudstones in lower half of section belong to the Petrotsvet Formation, and the overlying white carbonates to the Tulmudur Formation. Height of cliffs about 300 m. (Photo by W.H. Fritz)

Figure 5: Close-up of bed 8 (marked by pencil in lower part of photo) in the upper Yudoma Formation Ulakhan-Sulugur section. (Photo by W.H. Fritz)

through the thinly interbedded terrigenous and carbonate rocks of the Nemakit-Daldyn Formation with its poor fauna, to vari-colored carbonates, which contain a typical Tommotian fauna (Fig. 3). First, Savitskiy (1959, 1975) assigned all the Nemakit-Daldyn Formation to the Cambrian and stood his ground for a very long time, considering the Nemakit-Daldyn horizon (defined on the basis of the Formation) to be pre-Tommotian. Then Zhuravleva (1975) proposed that the Nemakit-Daldyn horizon corresponds to the Sunnagin horizon of the southeastern Siberian Platform. By 1969, a strong belief had developed that all the Nemakit-Daldyn Formation was pre-Tommotian in age (Missarzhevskiy in Rozanov et al., 1969).

Later work by B.B. Shishkin (1974) and others showed that the upper 11 m of the Nemakit-Daldyn Formation contains a number of fossils, such as *Cambrotubulus decurvatus*, *Conotheca* sp., *Circotheca* sp., *Hyolithellus* sp., *Anabarites* sp. and unidentified gastropods. This fauna made it possible to suggest that the upper part of the formation belongs to the Tommotian. The consensus in 1979 was that these Anabar sections correlated with those of the southeastern Siberian Platform, the latter being considered the type-sections.

The composition of the fauna of the upper part of the Nemakit-Daldyn Formation is, however, too poor to allow firm conclusions to be drawn. Precisely for this reason V.V. Missarzhevskiy has stated that these beds belong to older, pre-Tommotian deposits, which he called the Manykai stage. The concept of the Manykai stage and its subdivision into zones is based on the correlation of sections between the Kotuykan and Fomich rivers. According to this view, the Koril limestone marker-bed is considered constant in lithology and thickness (5-10 m) over the vast region adjacent to the Anabar Uplift, whereas the overlying beds are diachronous. Thus, faunal complexes, which were previously considered to be of the same age (Rozanov et al., 1969), are now regarded as being superimposed on each other (Missarzhevskiy, 1982). The main objection to this concept is that the correlation of sections is unproved and that the zonal subdivision in the new stage cannot be observed in any of the sections known today.

The Southeastern Siberian Platform

There has been a long history of intense study of the Aldan River sections (Fig. 1) (e.g. Rozanov et al., 1969; Cowie and Rozanov, 1973). Here numerous outcrops extend over 100 km and expose the transition from the Precambrian to the Cambrian (Figs. 4, 5, 6). The section at Ulakhan-Sulugur was chosen as the key section for two reasons. First, it was here that the rich fauna of the upper part of the Yudoma Formation was first discovered and, second, in the lowest part of the outcrop the boundary can be observed over a lateral distance of 1300 m. (The Ulakhan-Sulugur section will be visited by Excursion 053 of the 1984 Geological Congress).

A short description of the boundary strata of the Ulakhan-Sulugur section follows, beginning at the river level and continuing stratigraphically upwards (Figs. 5, 6):

Yudoma Formation

1. Yellowish and light-grey, fine-grained, laminated dolomites with lenses of oncolitic limestones.
2. Medium-grained, laminated light-grey dolomites, brecciated in the lower half, oolitic in the upper part.
3. Fine-grained, light-grey, oolitic dolomites with a thin layer of becciated dolomite in the upper part.
4. Fine-grained, thick- to thin-bedded, light-grey dolomites.
5. Yellowish-grey dolomitic breccias, with oolites.
6. Dolomite.
7. Dolomitic breccia with oolites and/or oncolites.

In Beds 1-7 fragments of *Chancelloria*, probably *Cambrotubulus* and the microphytolite *Nubecularites abustus* Z. Zhur. occur. (In the type-section of the Tommotian stage at Dworts, upstream from Ulakhan Sulugur, older beds crop out and *Chancelloria*, *Hyolithellus*, and *Cambrotubulus* have been discovered 20 m below the base of the Cambrian).

8. With traces of slight reworking the surface of the preceding bed is conformably overlain by a laterally

impersistent layer of glauconitic-calcareous sandstones, with an admixture of quartzose material and abundant fossils. This layer is proposed as the base of the Cambrian. *Aldanocyathus* cf. *virgatus* (Zhur.); *Spinulitheca kuteinikovi* (Miss.), *Turcutheca crassecochlia* (Sys.), *Laratheca nana* Miss., *Exilitheca multa* Sys.; *Bemella jacutica* (Miss.), *Aldanella rozanovi* Miss., *Philoxenella* ex gr. *spiralis* Vost., *Barskovia* sp., *Hyolithellus tenuis* Miss., *Torelliella curva* Miss., *T. cf. lentiformis* (Sys.), *Cambrotubulus decurvatus* Miss., *Coleoloides trigeminatus* Miss., *Tiksitheca licis* Miss., *Sunnaginia imbricata* Miss., *Sachites sacciformis* Mesh., *Chancelloria* ex gr. *lenaica* Zhur. et Korde, and *Nubecularites abustus* Z. Zhur.

9. Light-grey laminated dolomites and sandy brecciated dolomites.
10. Light-grey, coarse-bedded, sugary dolomites with thin layers of sandy dolomite. *Turcutheca crassecochlia* (Sys.) fragments of brachiopods and the microphytolite *Nubecularites abustus* Z. Zhur. occur.
11. Light-grey, sugary, cross-bedded dolomites, with thin layers of sandy and brecciated dolomite.

Pestrotzvet Formation

12. Grey limestones, sometimes tinged with green or pink, highly glauconitic. At the base of the bed there is much clastic material, and the top of the underlying Yudoma Formation is uneven and pocketed. Small bioherms with archaeocyathids occur throughout the entire bed: *Archaeolynthus polaris* (Vol.), *Cryptoporocyathus junicanensis* Zhur., *Dokidocythus* sp., *Aldanocyathus sunnaginicus* (Zhur.), *A. virgatus* (Zhur.), *A. belvederi* (Roz.), *Nochoroicyathus aldanicus* Zhur., *Paranacyathus tschuranicus* (Zhur.), *Okulitchicyathus disciformis* (Zhur.); hyolithes: *Exilitheca multa* Sys., *Turcutheca crassecochlia* (Sys.), *Laratheca nana* Miss., *Spinulitheca kuteinikovi* (Miss.), *Allatheca* sp.; molluscs: *Aldanella rozanovi* (Miss.), *B. parula* Miss., *B. septata* (Miss.); skeletal problematica: *Hyolithellus tenuis* Miss., *H. vladimirovae* Miss., *Torelliella lentiformis* (Sys.), *T. curva* Miss., *Coleolella billingsi* Miss., *Cambrotubulus decurvatus* Miss., *Coleoloides trigeminatus* Miss., *Coleolus trigonus* Sys., *Tommotia admiranda* (Miss.), *Camenella garbowskae* Miss., *Sachites sacciformis* Mesh., *Sunnaginia imbricata* Miss., *Tumulduria incompta* Miss., *Fomitichella* sp., *Chancelloria* ex gr. *lenaica* Zhur. et Korde; algae: *Renalcis jacuticus* Korde.
13. Argillaceous red and cherry-red, bedded limestones with admixture of glauconite in the lower part of the bed. Hyolithes: *Spinulitheca* sp., *Allatheca corrugata* Miss., *A. concinna* Miss., *Laratheca annae* (Sys.), *Laratheca nana* Miss.; Molluscs: *Bemella jacutica* (Miss.), *B. septata* (Miss.), *Igorella monstrosa* Miss., *Latouchella korobkovi* (Vost.), *Anabarella indecora* Miss., *Aldanella rozanovi* Miss., *Heraulitpegma sibirica* (Miss.); skeletal problematica: *Anabarites* sp., *Coleolella billingsi* Miss., *Coleoloides trigeminatus* Miss., *Tommotia kozlovskii* (Miss.), *T. plana* (Miss.), *T. admiranda* (Miss.), *Camenella garbowskae* (Miss.), *Lapworthella* cf. *tor-tuosa* Miss., *Sachites saccifor* Mesh. have been defined from the lower half of the bed.
14. Red argillaceous bedded limestones, with rare thin layers of grey and greenish-grey limestones. Numerous bioherms with archaeocyathids occur throughout the entire bed.

Figure 6: Stratigraphic column of the Ulakhan-Sulugur section.

In addition to the lithological and palaeontological characteristics given above, palaeomagnetic data from the Aldan and Lena sections make it possible to create a preliminary palaeomagnetic standard for the Upper Yudomian, Tommotian and Atdabanian stages (Kirschvink and Rozanov, 1979, 1984). Recent analyses of iridium (Nazarov et al., 1983) show an increased content associated with the bottom of bed 8. However, so far this has only been ascertained in one section, and the importance of this phenomenon is not yet clear. However, if it does reflect some global event it would provide a good additional criterion for establishing this boundary.

A review of geochronological data shows that, as elsewhere, only approximate ages can be given, and these are of no use for precise correlation. Trace fossils are also relevant to problems of sedimentology and ecology, but they can not be used for exact zonal correlation either.

Correlation with Other Asian Sections

IGCP Project 29 has stimulated the study of the boundary problem in many countries, and many new results and comparative data have been obtained, especially from candidate sections on the Asian continent (Figs. 1, 3). A brief review of some of these follows.

Recent studies of the Maly Karatau in southern Kazakhstan, very successfully carried out by Missarzhevskiy and Mambetov (1981; see also Korolev and Ogurtsova, 1983 - Ed.), have made it possible to distinguish a succession of fossil assemblages at the Precambrian-Cambrian boundary that is easily compared with those of the Siberian Platform (Fig. 3). For example, the Upper Precambrian Protohertzina anabarica zone in the upper part of the Kyrshybakty Formation is comparable with the Nemakit-Daldyn stage, and *P. unguliformis* Miss. is also found. The next assemblage (zone of *Pseudorthotheca costata*) occurs in the main part of the phosphoric Chuluktai Formation and contains well known Siberian genera such as *Tiksitheca*, *Conotheca*, *Allatheca*, *Hyalolithellus*, *Protohertzia*, *Fomitchella*, *Kijacus* and *Anabarites*, which permit comparisons with the early Tommotian assemblages of the Siberian Platform.

A detailed description is also available of the deposits at the Precambrian-Cambrian boundary in western Mongolia (Fig. 2), where they are characterized by a rich fauna (Rozanov, 1982). Here in the upper part of the Yudomian stromatolites and microphytolites occur, and rich associations of small shelly fossils in the Tommotian make correlation possible with the Siberian Platform. The lower part of the section here is called "the beds with *Tiksitheca licis*-*Maikhanella multa*." This part contains *Tiksitheca licis* Miss., *Cambrotubulus decurvatus* Miss., *Anabarites trisulcatus* Miss., *Rozanoviella atipica* Miss., *Sachithes sacciformis*

Mesh., tommotiids and others. These rocks may also be compared with the *Al. sunnaginicus* zone and the lower part of *D. regularis* zone, which is substantiated by the presence in the overlying beds of *Ilsanella compressa*, together with numerous molluscs such as *Latouchella*, *Anabarella* and *Barskovia*, and the Siberian zonal species *Lapworthella tortuosa*.

This Mongolian section is of interest not only because it is possible to recognize the same level chosen as the Precambrian-Cambrian boundary on the Aldan River, but also because it contains the fauna observed in sections of both China and the Siberian Platform together with its surrounding folded regions.

Key sections of southern China have been studied in detail in recent years (Yin Jicheng et al., 1980; Luo Huilin et al., 1982; see also Xing Yusheng et al., 1982 - Ed.). Earlier, Qian Yi (1977) and Zhong Hua (1977) concluded that the lower stage of the Cambrian (Meishucun) corresponded generally to the Tommotian and, consequently, that their lower boundaries could be correlated (Fig. 3). Chinese scientists subsequently proposed the idea of an older age for the Meishucun stage in part or as a whole. In the author's opinion this is incorrect, and the general correlation between the base of the Meishucun and the base of the Tommotian is certain.

The interpretation of the upper part of the Meishucun stage also changed significantly, and the lower part of the Qiongzhusi Formation was sometimes included in it and sometimes not. It is interesting to note that the lower part of the latter formation contains the fauna that appear in the upper half of the Atdabanian stage in Siberia and on the East European Platform. Moreover, as more of the fauna of the lower Meishucun stage are studied, more elements in common with Siberia and Mongolia are being found.

Tommotian deposits can thus be distinguished with precision in Asia, and this has led to strong suggestions for the choice of the Precambrian-Cambrian boundary stratotype in this part of the world (Cowie and Rozanov, 1983).

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