The Khos-Nelege section of the Ogon'or Formation: a potential candidate for the GSSP of Stage 10, Cambrian System

NADEZHDA P. LAZARENKO, IVAN Y. GOGIN, TATYANA V. PEGEL & GALINA P. ABAIMOVA

The International Subcommission on Cambrian Stratigraphy (ISCS) has recommended a subdivision of the Cambrian System into four series and ten stages. The first appearance datum (FAD) of the cosmopolitan agnostoid trilobite *Lotagnostus americanus* has been chosen as a good indicator for the base of the uppermost Cambrian stage (Stage 10). The Khos-Nelege section located in the north-eastern Siberian Platform (Western Yakutia, Russia) is proposed as the Global Standard Stratotype Section and Point (GSSP) for the base of the 'Cambrian Stage 10'. The proposed GSSP coincides with the FAD of *L. americanus* at 339 m above the base of the Ogon'or Formation. The section fulfills the geological and biostratigraphical requirements for a stratotype and the GSSP horizon can be constrained by a number of auxiliary marker taxa. The first appearance of *L. americanus* is an easily recognizable level in the Cambrian which can be recognized from all major Cambrian continents, including Baltica, Laurentia, Avalonia, South China and Australia.
• Key word: Cambrian, Stage 10, trilobite, GSSP, *Lotagnostus americanus*, Russia.

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Subdivision of the Cambrian System into series and stages that can be applicable in a global scale is among major objectives of the International Subcommission on Cambrian Stratigraphy (ISCS) for a number of years. The absence of internationally recognized global standard for the Cambrian System partly a consequence of different stratigraphical approach developed historically by researches working in different regions, but also reflects faunal provincialism resulted the scarcity of suitable biostratigraphical markers applicable for intercontinental correlation at the Stage level. However, current progress in research on Cambrian trilobite biostratigraphy in combination with chemostratigraphy improved significantly long-range correlation of the regional Cambrian chronostratigraphic units (Babcock *et al*. 2005).

The ISCS came to the conclusion that the Cambrian System subdivision into four series and ten stages, looks as the most practical strategy (Babcock *et al.* 2005). So far, only four stages have been formally named and formally approved by the Commission on Stratigraphy IUGS. These are the Fortunian Stage (= base of Terreneuvian Series and Cambrian System), the Drumian Stage, Guzhangian Stage and the Paibian Stage (= base of Furongian Series). Apart from the Paibian, the two succeeding stages (Cambrian Stage 9 and 10) in the Furongian Series remain to be defined. In addition, in 2010, Duibian B section in Zhejiang, China was chosen by the ISCI as GSSP for the base of the Cambrian Stage 9 (= Jiangshanian Stage) defined by the FAD of the agnostoid trilobite *Agnostotes orientalis*. However, this decision is still awaiting ratification from the Commission on Stratigraphy IUGS. Babcock *et al.* (2005) suggested that the FAD of the agnostoid trilobite *Lotagnostus americanus*, may be the best choice for defining the base of the Cambrian Stage 10, which is the only Furongian Stage remaind awaiting for formal designation (Fig. 1).

The main objective of this paper is to present updated and refined documentation for a stratigraphic sequence through the upper part of the Furongian Series in the Khos-Nelege section which is presented as a GSSP candidate for

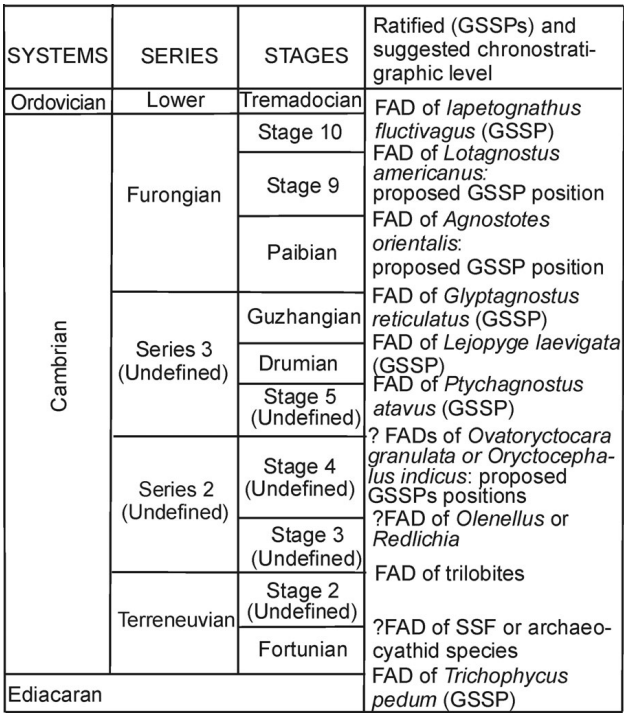

Figure 1. Chart showing working model for the global chronostratigraphical subdivision of the Cambrian System, indicating the position of the Cambrian Stage 10 and its lower boundary (modified from Babcock *et al.* 2005).

designation of the Cambrian System 'Tenth' Stage, defined by the FAD of the agnostoid trilobite *Lotagnostus americanus*.

Motivation for selection of the boundary level and of the potential stratotype section

Lotagnostus (Lotagnostus) americanus (Billings) is easily recognizable agnostoid taxon, which was recently revised by Peng & Babcock (2005). It was demonstrated that a number of species, including *Lotagnostus asiaticus* Troedsson, *L. xinjiangensis* Zhang, *L. punctatus* Lu, *L. trisectus* (Salter), *L. obscurus* Palmer and *Goniagnostus verrucosus* Rusconi represent junior objective synonyms of *Lotagnostus americanus*, thus presently this trilobite species is documented from almost all major Cambrian paleocontinents, which makes it a valuable tool for global correlation.

The diagnostic characteristics of *Lotagnostus americanus* include: lengthwise partition of the axis into three parts; pleurae with distinct scrobiculae; cephalon with a narrow roll-shaped border; a pentagonal anterior glabellar lobe; F3 curved backwards; node on the main glabellar lobe occupying the most elevated part of the cephalon; elongated basal lobes; presence of a preglabellar furrow; a long pygidial axis; medially effaced F1; broad border furrow; and presence of posterolateral marginal spines. Based on these criteria, *L. obscurus* Palmer should be excluded from the synonymy of *L. americanus*, because it has a nonscrobiculate surface and a short pygidial axis with a rounded posterior termination. This suggests that *Lotagnostus obscurus* has the closest affinity to the subgenus *Lotagnostus* (*Eolotagnostus*) Zhou.

Lotagnostus americanus has a short stratigraphic range in the late Furongian and is a common taxon in the open shelf lithofacies (Peng & Babcock 2005 and references therein) (Fig. 2).

Presently, occurrences of *L. americanus* are documented from Quebec, Newfoundland, Precordilleran Argentina, Sweden, China, Kazakhstan (Malyi Karatau), Kyrgyzstan (north Tien Shan), Australia, Avalonia (England and Wales), and Siberia (Babcock *et al.* 2005, Geyer & Shergold 2000, Peng & Babcock 2005, Peng *et al.* 2005) and it can be identified with precision using multiple lines of evidence. *Lotagnostus americanus* is widely used as the index taxon in Siberia, China and Scandinavia (Lazarenko *et al.* 2008, Peng & Babcock 2005, Terfelt *et al.* 2008). The early representatives of *Lotagnostus* emerged at the time, when *Eurudagnostus* and *Oncagnostus* (O*ncagnostus)* went into extinction or were in terminal decline, and the agnostoid genus *Trilobagnostus* had just appeared (Ergaliev & Ergaliev 2008, Terfelt *et al.* 2011, Lazarenko *et al.* 2008).

Lotagnostus (*Lotagnostus*) *americanus* occupied an intermediate position in the evolution of *Lotagnostus*. Species of *Lotagnostus* (*Eolotagnostus*), which differ in having poorly scrobiculate cephalic pleurae (sometimes pygidial pleurae too) and a rounded posterior termination of a relatively short pygidial axis, appeared earlier in the sequence than the first representatives of *Lotagnostus* (*Lotagnostus*) and *Lotagnostus* (*Distagnostus*). For instance in China *Lotagnostus* (*Eolotagnostus*) occurs at the Furrongian *Lotagnostus* (*Eolotagnostus*) *decorus-Kaolishaniella* Biozone and *Probilacunaspis nasalis-Peichiashania chunanensis* Biozone (Peng 1992), whereas in Kazakhstan (Malyi Karatau) it is documented from the *Lotagnostus* (*Eolotagnostus*) *scrobicularis-Jegorovaia* Biozone (upper Aksayan Regional Stage) (Ergaliev & Ergaliev 2008).

The evolutionary lineage of the genus *Lotagnostus* terminated with *L. hedini*, which is the index-species of a biozone designated for the uppermost Furongian in China (West Zheijang, Peng 1992) and in Kazakhstan (upper part of Batyrbaian Regional Stage of Malyi and Bolshoi Karatau ranges) (Ergaliev & Ergaliev 2008). In the Batyrbai section of the Malyi Karatau Range, Kazakhstan, *Lotagnostus hedini* occurs in the upper part of the *Proconodontus notchpeakensis* conodont zone (Apollonov & Chugaeva 1983). In the Dadoushen section, Duibian, China, *Lotagnostus hedini* occurs together with the conodonts *Eoconodontus notchpeakensis* and *Cordylodus proavus.*

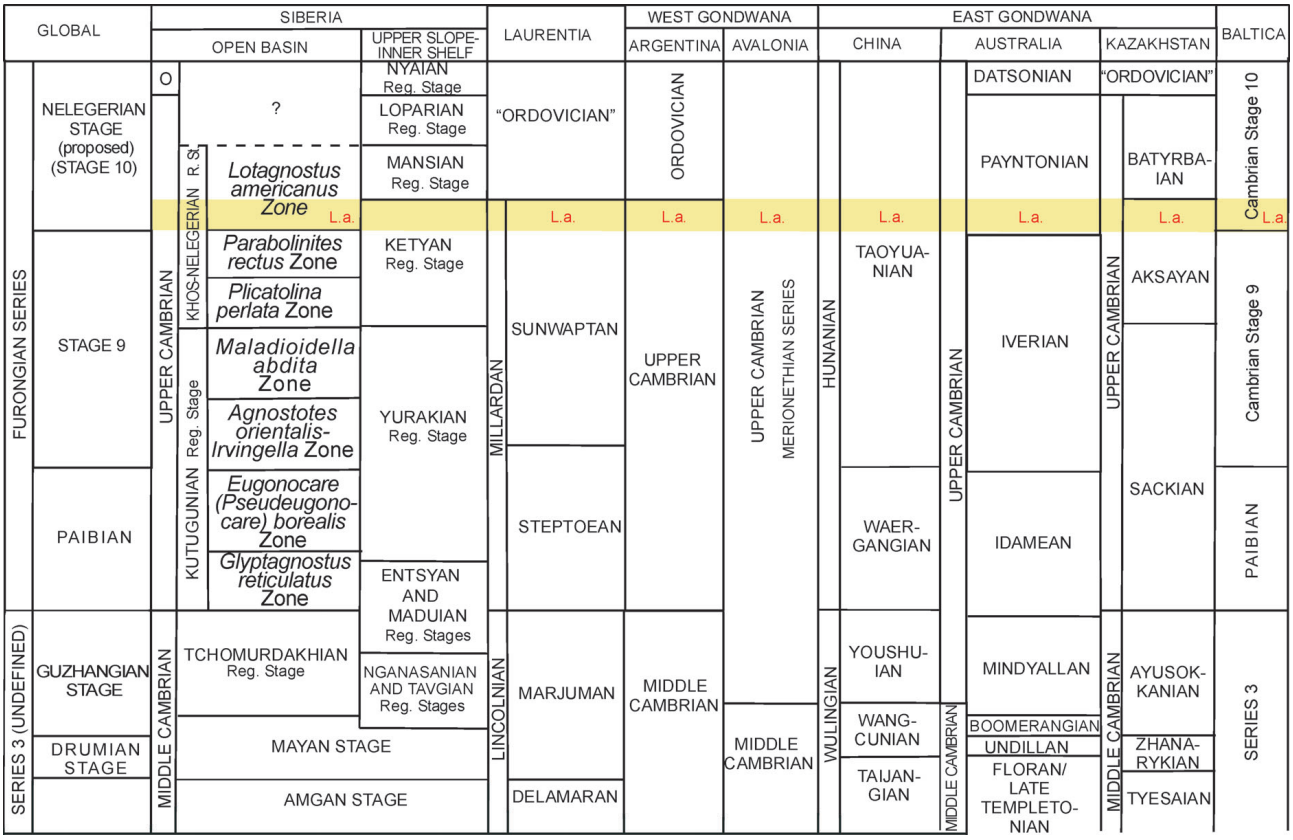

Figure 2. Correlation chart of the upper part of the Cambrian showing the global Cambrian stages compared to regional usage in major areas of the world. The presence of *Lotagnostus americanus* in a region is indicated by symbol L.a. Chart is compiled from numerous sources, summarized principally in Geyer & Shergold (2000) and Peng *et al.* (2004).

In the same area, the species *Lotagnostus americanus* (= *L. punctatus)* is common in underlying strata (Lu & Lin 1989).

The global correlation of the FAD of *L. americanus* is supported by data on the polymerid trilobites. In Scandinavia, *Lotagnostus americanus* ranges through the *Ctenopyge tumida, C. affinis, C. bisulcata* and *C. linnarssoni* biozones, which are correlated with the *L. americanus* to lower *Trilobagnostus holmi* agnostoid biozones (Terfelt *et al.* 2008, 2011). In South China, *L. americanus* is characteristic for the *L. americanus* (= *L. punctatus*) Biozone and *L. americanus* (= *L. punctatus*) – *Hedinaspis regalis* Biozone (Lu & Lin 1989, Peng 1992). The first occurrence of the polymerid trilobites *Ctenopyge* (*Mesoctenopyge*), *Macropyge*, *Peltura* in Scandinavia (Terfelt *et al.* 2011), *Promegalaspides*, *Skljarella* in Western Yakutia, Russia (Lazarenko *et al.* 2008), *Saukia*, *Niobella*, *Hedinaspis, Skljarella* in Kazakhstan (Ergaliev 1983, Ergaliev & Ergaliev 2008), *Niobella*, *Hedinaspis, Skljarella* in China (Peng 1992) was documented close to the FAD of *L. americanus*.

The Cambrian sections of the Tuora-Sis Ridge represent a part of the Siberian platform carbonate cover, formed in the large Yudoma-Olenek Basin. The basin is contured by thick reef deposites in its western and northern margins. Significant depths and uniform sedimentational settings of basin and deep ramp characterized the region in the Middle-terminal Late Cambrian. Selection of a GSSP in the basis of slope deposit from low palaeolatitudes such as the Siberian Platform, is desirable because it allows correlation with strata deposited in both open-shelf and basinal areas of low or high palaeolatitudes. Slope areas are characterized by a combination of shelf-dwelling taxa and basin-dwelling taxa. A combination of cosmopolitan agnostoids (which have intercontinental correlation utility) shelf-dwelling polymerids (which mostly allow for intracontinental correlation) and pan-tropical polymerids (which allow for limited intercontinental correlation), constitute a tool box facilitating precise correlation of the base of the *Lotagnostus americanus* Zone between Siberia, South China, Gondwana, Laurentia, Baltica, and the Kazakh terranes.

Potential stratotype section

Selection of the the Khos-Nelege section as the potential GSSP for the base of the Cambrian Stage 10 is well supported by the analysis of new and previously accumulated data on the palaeontology and biostratigraphy of the Furongian

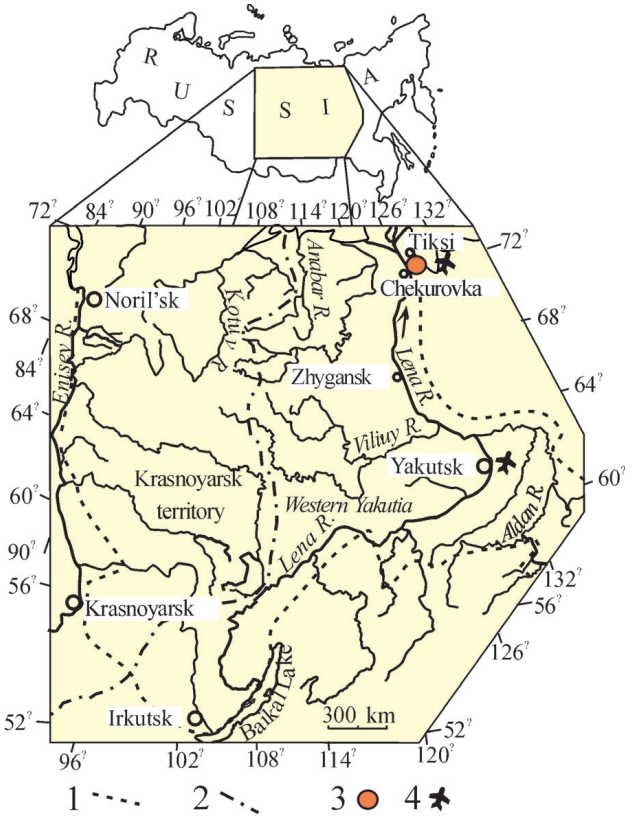

Figure 3. Location map of the Siberian Platform showing the position of the Khos-Nelege reference section. 1 – the Siberian Platform boundary; 2 – the boundary between Krasnoyarsk territory and Western Yakutia; 3 – the Khos-Nelege reference section (from Lazarenko *et al.* 2008), 4 – the airports.

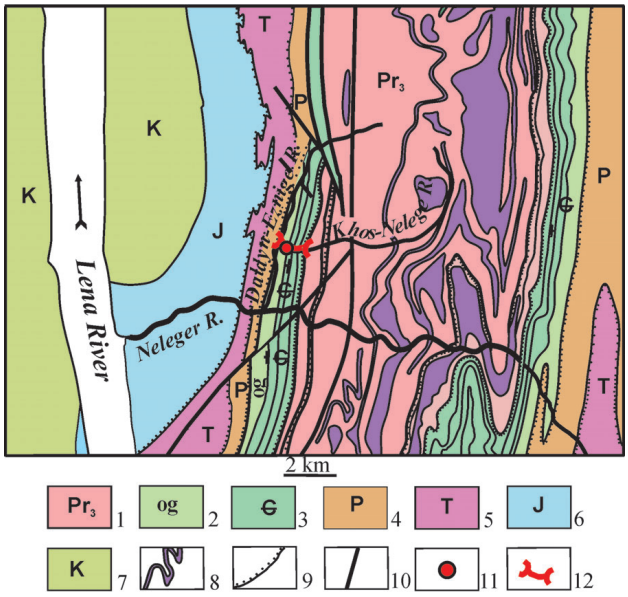

Figure 4. Geological map and location of the section proposed as a stratotype for the Nelegerian Stage lower boundary (the Khos-Nelege reference section, Western Yakutia, Russia). 1 – Upper Proterozoic; 2 – upper part of the Cambrian, Ogon'or Formation; 3 – middle and lower part of the Cambrian; 4 – Permian; 5 – Triassic; 6 – Jurassic; 7 – Cretaceous; 8 – sills of basic rocks; 9 – disconformity; 10 – tectonic disturbances; 11 – stratotype section; 12 – the reference section of the Cambrian open basinal deposits along the Khos-Nelege River (from Lazarenko *et al.* 2008).

deposits across the northeastern Siberian Platform (*e.g.* Lazarenko 1966, 1973; Lazarenko *et al.* 2008; Lazarenko & Nikiforov 1972; Lazarenko & Pegel 2001).

The Khos-Nelege section is located in the Lower Lena River basin, at approximately 25 km north-east of the Chekurovka village and at about 60 km south-west of the town Tiksi in north-west Yakutia, Russia (Fig. 3). It can be reached by helicopter from Tiksi in twenty minutes. The Khos-Nelege River is part of the Neleger River system, which is a confluent to the Lena River (Figs 4, 5). The Neleger River dissects the Tuora-Sis Ridge (northeastern part of the Verkhoyansk Ridge) from the east to the west. The section is located on a public land under permanent protection by the government of the Republic of Sakha (Yakutia). This will ensure unrestricted free access to the site for research purposes.

The Ogon'or Formation in the Khos-Nelege section is a thick, mostly monotonous succession of rhythmically alternating limestones, calcareous argillites and fine siliciclastic sediments deposited in a distal slope environment (outer fan to basin transition). The strata strike at about 295–305° and dip at about 55–60°. Soft-sediment deformation, truncation surfaces and slide surfaces are rare throughout the section and absent near the proposed GSSP. The proposed GSSP position for the base of the Cambrian Stage 10 defined by the FAD of *L. americanus*, is at 339 m above the base of the Ogon'or Formation (Figs 6, 7). This level is within a continuous succession of foliated silty mudstones with thin lenticular limestone interbeds.

Trilobite biostratigraphy

Trilobite biostratigraphy of the Ogon'or Formation in the measured section (Figs 6, 8) exhibits a complete, tectonically undisturbed marine succession from the uppermost part of the Drumian Stage (the lowermost 10 m of the Ogon'or Formation below the base of the *Lejopyge laevigata* Biozone) and up to the Cambrian Stage 10 (Nelegerian Stage of Lazarenko *et al.* 2008) marked by the FAD of *L. americanus.*

Specimens of *L. americanus* were sampled from at least 21 horizons over the interval almost 90 m thick in the Khos-Nelege section (at 339 m, 349 m, 357 m, 362.2 m, 362.6 m, 366.3 m, 368.3 m, 369 m, 370.3 m, 370.7 m, 374.4 m, 375.3 m, 382 m, 382.15 m, 384 m, 393.35 m, 395 m, 391.7 m, 401.7 m, 421.35 m and 421.4 m above the base of the Ogon'or Formation, respectively). At the lowest 10 m of the sampled interval (339 m and 349 m)

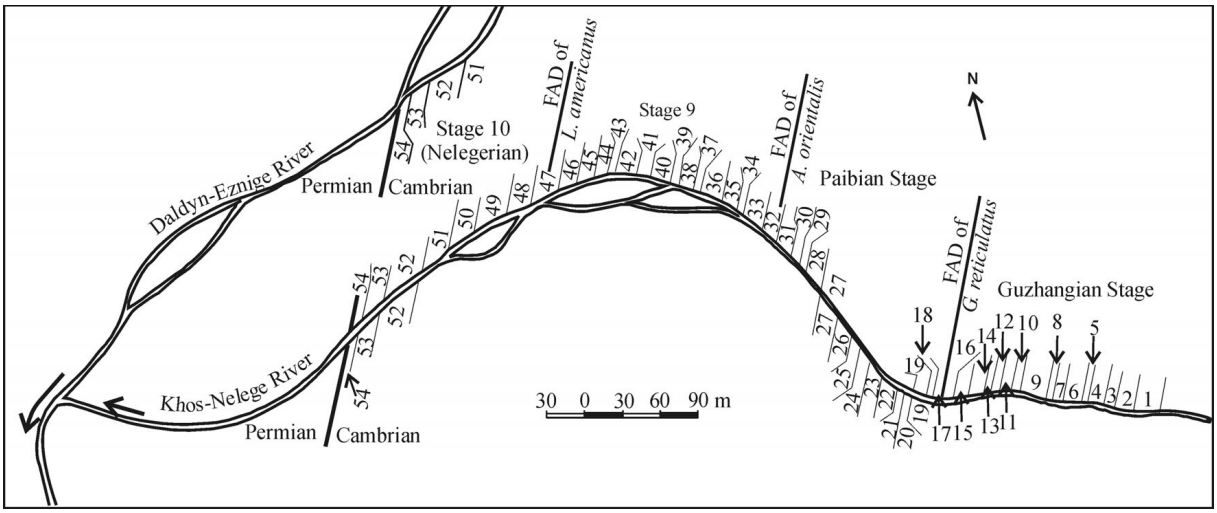

Figure 5. Position of global correlative levels of the Furongian Series and Proposed GSSP for the base of the Stage 10 (Nelegerian) (coinciding with the FAD of *Lotagnostus americanus)* in the beds of the Ogon'or Formation in the Khos-Nelege section (modified from Lazarenko *et al.* 2008).

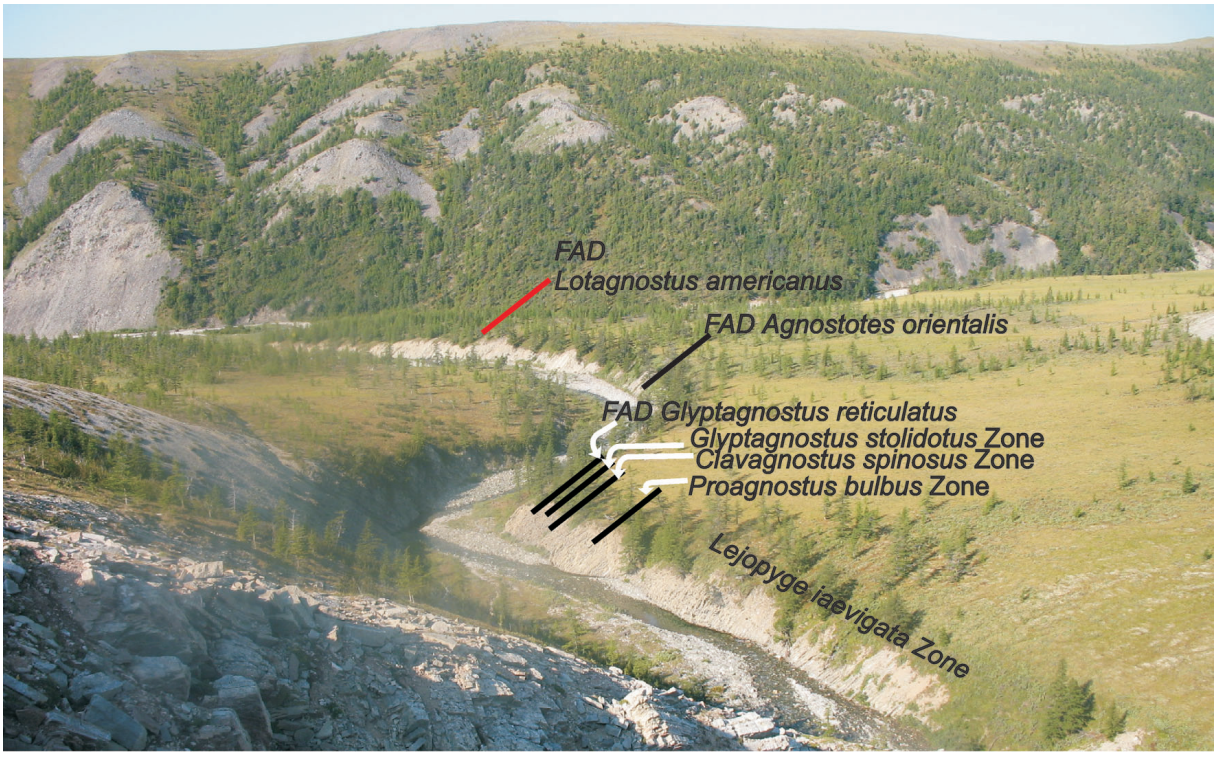

Figure 6. View of the right bank of the Khos-Nelege River showing deposits of the Ogon'or Formation with proposed GSSP for the base of the Nelegerian Stage (coinciding with the FAD of *Lotagnostus americanus*). Underlying sediments are compared with Stage 9 (which base coincides with the FAD of *Agnostotes orientalis*), the global Paibian Stage (which base coincides with the FAD of *Glyptagnostus reticulatus*), and the Guzhangian Stage (which base coincides with the FAD of *Lejopyge laevigata*) (from Lazarenko *et al.* 2008).

L. americanus is relatively rare. Numerous disarticulated cephala and pygidia of the species occur at: 357 m, 362.2 m, 370.3 m, 375.3 m, 382.15 m, 391.7 m and 421.35 m, respectively. A complete range of *L. americanus* cannot be determined at Khos-Nelege, because the top of the section is cut by the unconformity.

Observed ranges of agnostoids and polymerid trilobites across the stratigraphical interval including the proposed GSSP are summarized in Fig. 8. The new material, obtained from the Ogon'or Formation in the Khos-Nelege section together with a comprehensive revision of previously assembled collections revealed that the specimens

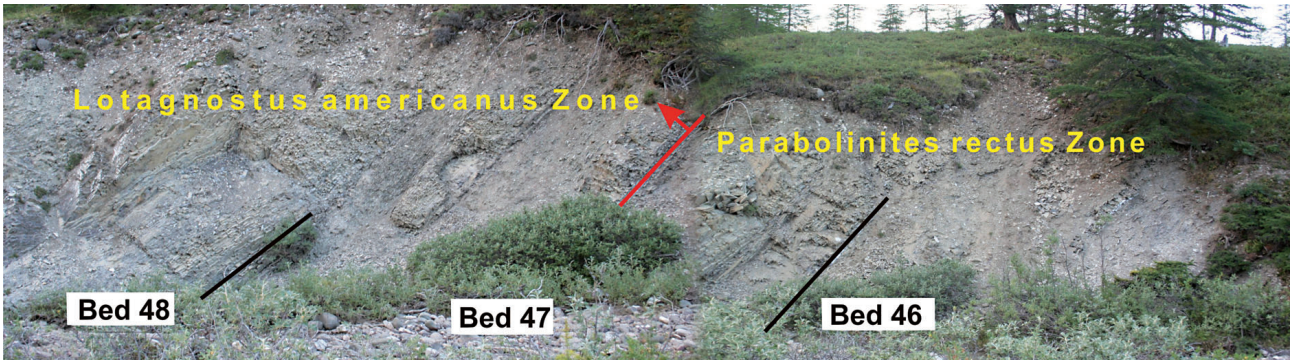

Figure 7. The FAD of *Lotagnostus americanus* (marked by the red line) at 339 m above the base of Ogon'or Formation in the Khos-Nelege reference section (from Lazarenko *et al.* 2008).

previously identified as *Lotagnostus hedini* (Lazarenko *et al.* 2008, pl. 21, figs 1, 5; pl. 23, figs 3, 4; Figs 19, 25), should be re-assigned to *Lotagnostus (Eolotagnostus)* and their closest relative is *Lotagnostus* (*Eolotagnostus*) *agnostiformis* Apollonov & Chugaeva. These specimens are the first representatives of the genus *Lotagnostus* in the Ogon'or Formation and they occur at 18 m below the FAD of *L. americanus.* In Kazakhstan, *Lotagnostus* (*E.*) *agnostiformis* occurs in the *Lotagnostus* (*Eolotagnostus*) *scrobicularis-Jegorovaia* Biozone (Ergaliev & Ergaliev 2008). This biozone is of similar age to the *Lotagnostus* (*Eolotagnostus*) *decorus-Kaolishania* Biozone of South China, which is stratigraphically below the *Lotagnostus* (*Lotagnostus*) *punctatus-Hedinaspis regalis* Zone (Peng 1992).

In addition to *L. americanus*, a number of other biostratigraphically informative trilobite taxa, which are useful for intercontinental correlations, are present near the proposed stage boundary in the Khos-Nelege section (Figs 9, 10). For instance, *Trilobagnostus rudis* (Salter) occurs at 40 m above the FAD of *Lotagnostus americanus*. In Scandinavia, the FAD of this species is documented at the base of the *Lotagnostus americanus* Biozone (Terfelt *et al.* 2011). *Skljarella* cf. *marinae* Petrunina occurs in the lower half of the *Lotagnostus americanus* Biozone above the first occurrence of *Lotagnostus (E.) agnostiformis. Skljarella marinae* Petrunina, first described from the Dobrinskiy Regional Stage of the Altai-Sayan Region. It can be correlated to the lower part of the Batyrbai Regional Stage (uppermost Furongian) of Malyi Karatau in Kazakhstan (*Trisulcagnostus trisulcus-Saukiella* and *Lotagnostus* (*Eolotagnostus*) *scrobicularis-Jegorovaia* biozones). The genus *Eurycarina* Ivshin *in* Petrunina is common in the Zolotokitatskii Regional Stage and sporadically occurs in the Dobrinskii Regional Stage in the Altai-Sayan Region (Petrunina & Gabova 2008), which is equivalent to the upper part of Aksayan and the lower part of Batyrbaian regional stages in Kazakhstan. In the Ogon'or Formation section, different species of this genus occur below the *Lotagnostus americanus* Zone. *Promegalaspides pelturae* and *P. kinnekullensis* occur at the FAD of *Lotagnostus americanus* in the Ogon'or Formation, and in Scandinavia they are found within the lower *Trilobagnostus holmi* Biozone (Terfelt *et al.* 2011). In the Khos-Nelege section, *Macropyge* (*Aksapyge*) *transita* occurs at 55 m above the base of the *Lotagnostus americanus* Biozone. In Kazakhstan, it is widespread in the upper part of the *Hedinaspis sulcata* Biozone (the upper part of the Aksayan) (Apollonov *et al.* 1984).

The trilobite assemblage of *L. americanus* Biozone in Khos-Nelege suggests a close palaeobiogeographic link with Baltica. Taxa in common include *Lotagnostus americanus*, *Trilobagnostus rudis*, *Promegalaspides kinnekullensis*, *P. pelturae*, and representatives of the genera *Parabolinites*, *Parabolinella*, *Macropyge*, and *Niobella*. Moreover, the presence of *Neoagnostus*, *Ketyna* (= *Kujandaspis*), and *Skljarella* in this zone indicate clear links with other parts of Siberia, as well as with South Kazakhstan and China.

In the Khos-Nelege section the FAD of *L. americanus* occurs in an interval marked by a distinct change in taxonomic composition of polymerid trilobite fauna (see Fig. 8). At approximately 10 m below the FAD of *L. americanus*, the species ranging upwards from the *Plicatolina perlata* Biozone disappear and the first representatives of the genera *Skljarella*, *Westonaspis* and *Promegalaspides*, which is particularly common in the *L. americanus* Biozone, appear. A similar change has been documented at the base of the *Lotagnostus americanus* Biozone in Scandinavia. In underlying the *Ctenopyge spectabilis* Biozone the first representatives of *Peltura*, *Macropyge* appear, whereas at the base of *L. americanus* Biozone the first occurrence of *Sphaerophthalmus* and *Parabolinites* was reported (Terfelt *et al.* 2011). In South China *Charchaqia*, *Hedinaspis*, *Macropyge* and *Niobella* first appear at about the same level (Peng 1992).

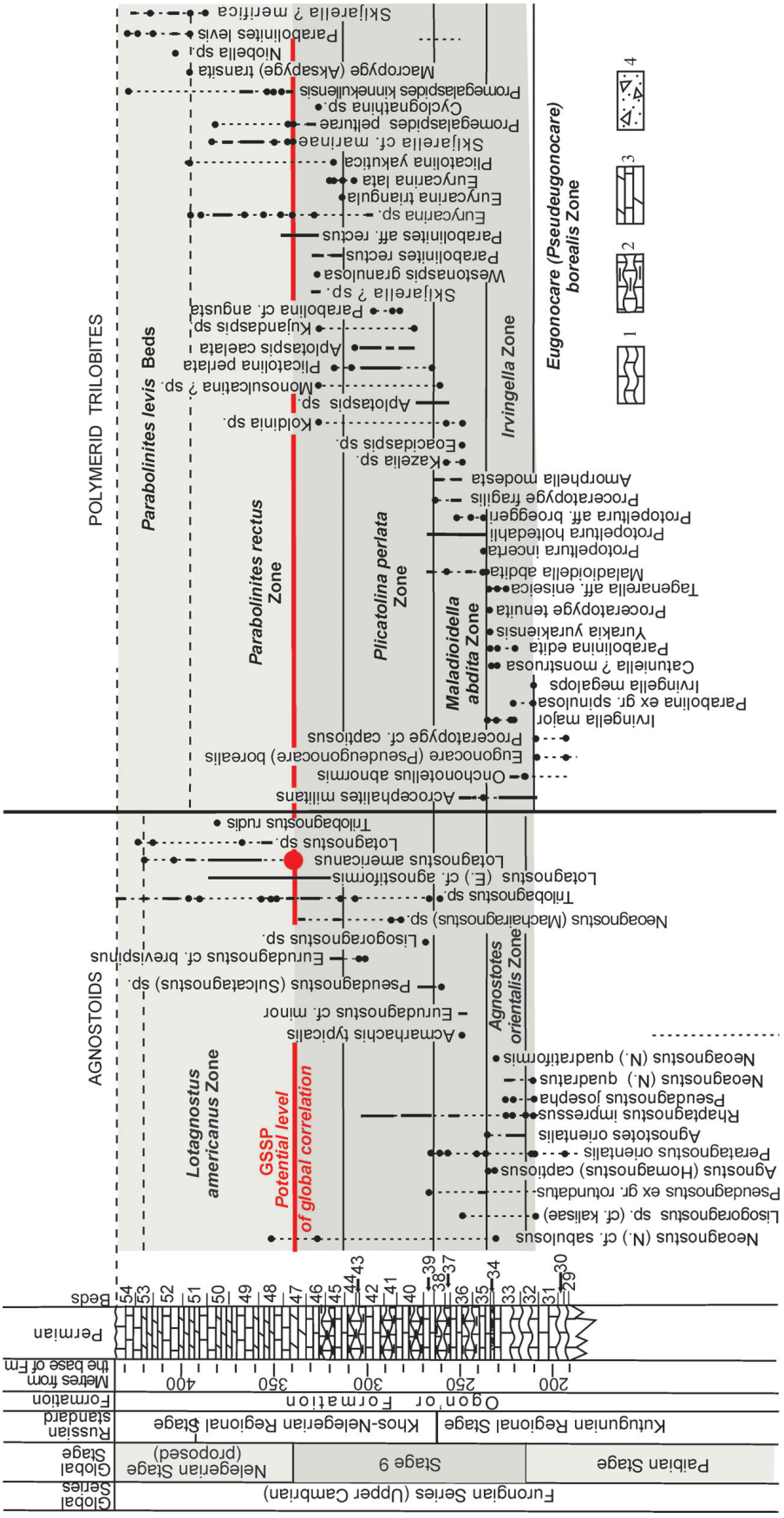

Figure 8. Stratigraphical distribution of agnostoids and polymerid trilobites in the upper part of the Furongian Series in the Ogon'or Formation, Khos-Nelege reference section: 1 – dark-gray wavy limy flagstone (mud-wackestone) with greenish siltstone and black argillaceous laminaes; 2 – gray-greenish argillaceous-dolomitic wackestone with gray silty lens-nodular limestone; 3 – alternation of marl, argillite and lens-nodular wackestone; 4 – carbonate breccia.

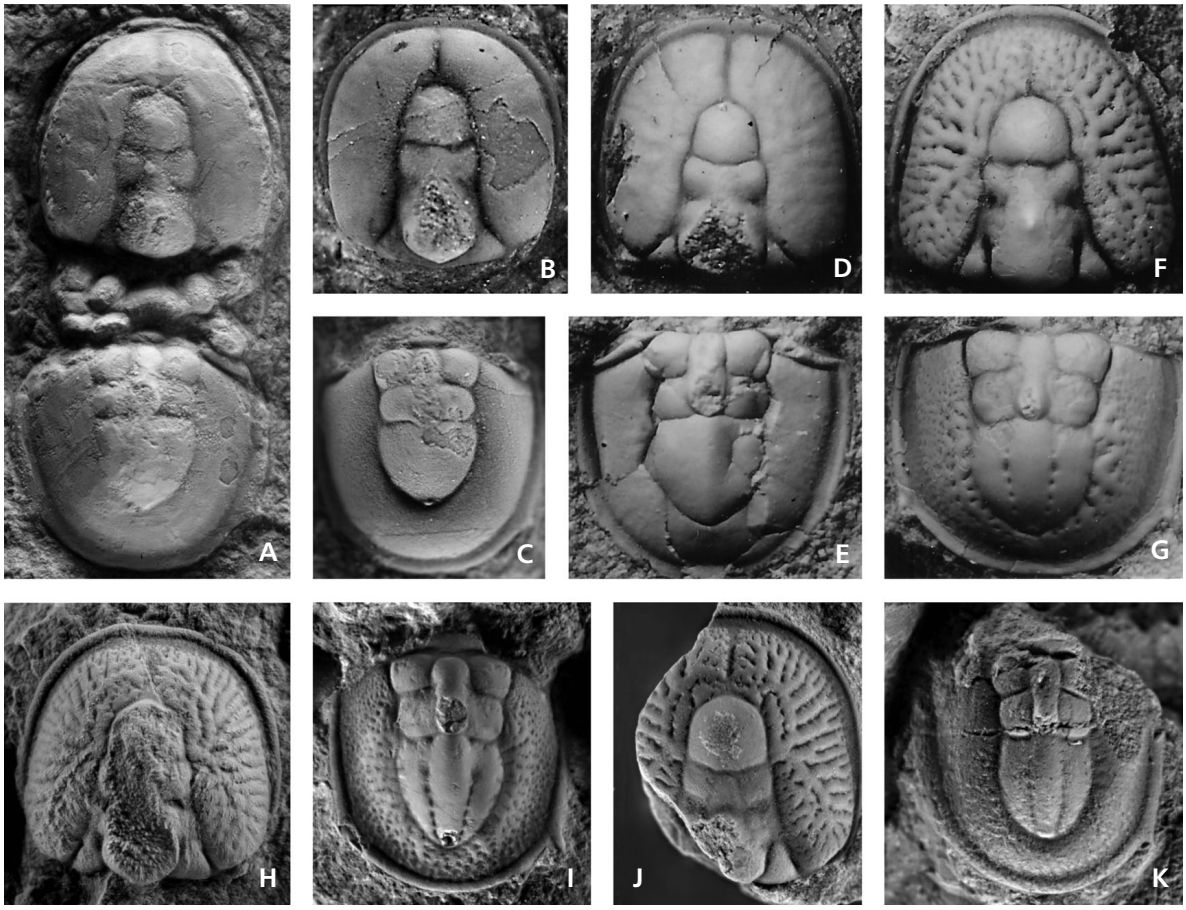

Figure 9. Key species of *Lotagnostus* used for recognition of the base of the Proposed Stage. All specimens are from the Khos-Nelege section, Western Yakutia, Russia; position of collections in metres (m) above the base of the Ogon'or Formation are indicated. • A–E – *Lotagnostus (Eolotagnostus)* cf. *agnostiformis* Apollonov & Chugaeva: A – exoskeleton, × 9.4, from 322 m; B – cephalon, × 20, from 322 m; C – pygidium, × 17.5, from 322 m; D – cephalon, × 12, from 335.6 m; E – pygidium, × 11, from 335.6 m. • F–K – *Lotagnostus (Lotagnostus) americanus* (Billlings): F – cephalon, × 9, from 357.6 m; G – pygidium, × 8, from 357.6 m; H – cephalon, × 6.4, from 397.5 m, I – pygidium, × 8, from 397.5 m, J – cephalon, × 7.5, from 398 m, K – pygidium, × 12.6, from 427 m.

Conodont biostratigraphy

Application of conodonts for the Cambrian biostratigraphy is relatively limited and increased only for the upper Furrongian, when euconodonts appeared and diversified. In the Khos-Nelege section the upper part of the Cambrian Stage 9 and the lower part of the Cambrian Stage 10 are characterized by conodont assemblages referred to the *Westergaardodina amplicava* Biozone (Fig. 11). Most of the conodont taxa first documented from the Cambrian Stage 9, including *Westergaardodina bohlini*, *W. amplicava*, *W. tricuspidata*, *C. bicostatus*, *Prooneotodus rotundatus*, *Prosagittodontus dunderbergiae*, *P. minutus*, *Problematoconites perforatus*, *Prooneotodus gallatini*, *Laiwugnathus laiwuensis expanses*, are transitional into the Cambrian Stage 10. Conodont assemblage of the Cambrian Stage 10 includes also *Westergaardodina* cf. *procera*, *W.* cf. *wimani*, *Viirodus* sp., *Muellerodus* sp., *Furnishina ovata*, *F. bicarinata*, *F.* cf. *alata*, *Bengtsonella triangularis*, *Proacontiodus multicostatus*, *Phakelodus tenuis.* This conodont assemblage shows distinct similarity to the assemblage characteristic of the *Westergaardodina amplicava* Biozone (the upper part of the Aksai Regional Stage, the *Hedinaspis sulcata* Trilobite Biozone) in the Batyrbai section of Malyi Karatau (Dubinina 2000). In Malyi Karatau, Kazakhstan, the first occurrence of euconodont is documented only from the base of overlying Batyrbai Regional Stage (Dubinina 2000), whereas they are not yet found in the Khos-Nelege section.

Brachiopod biostratigraphy

Brachiopods are present in the Khos-River section but they are rare, have long stratigraphic ranges and are known only from preliminary identifications. Only *Quadrisonia minor* and *Quadrisonia* sp. yet documented from the Ogon'or Formation, but they have long stratigraphical ranges and are considered here as biostratigraphically uninformative.

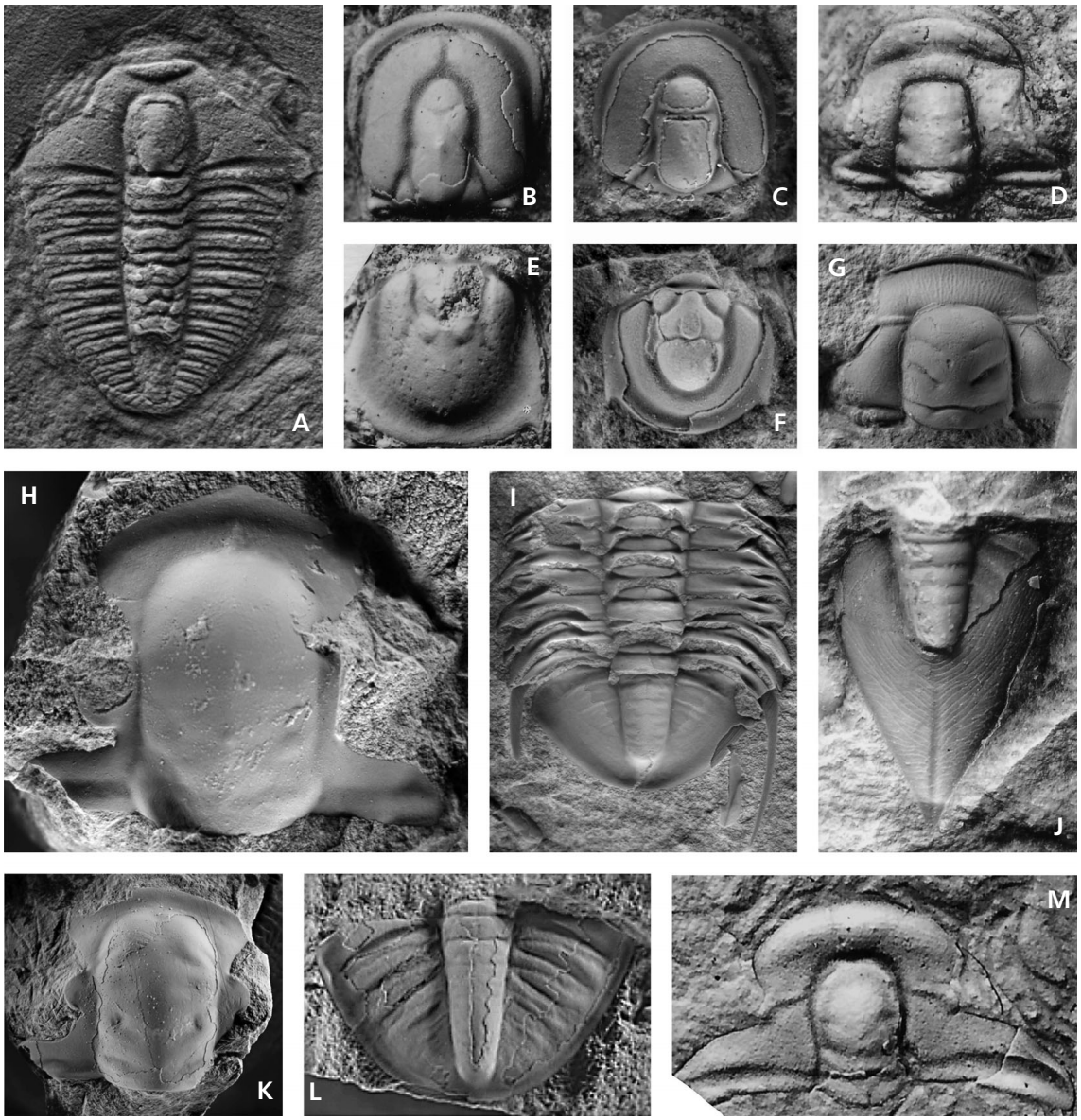

Figure 10. Key agnostoids and polymerid trilobites used for recognition of the base of the Proposed Stage. All specimens are from the Khos-Nelege section, Western Yakutia, Russia; position of collections in metres (m) above the base of the Ogon'or Formation are indicated. • A – *Eurycarina triangula* Lazarenko & Pegel, exoskeleton, × 14, from 313.6 m. • B, E – *Neoagnostus* cf. *sabulosus* Peng: B – cephalon, × 9.7, from 327 m; E – pygidium, × 9, from 327 m. • C, F – *Trilobagnostus rudis* (Salter): C – cephalon, × 14, from 381 m; F – pygidium, × 9, from 381 m. • D – *Kujandaspis* sp., cranidium, × 12, from 327 m. • G – *Parabolinites levis* Lazarenko, cranidium, × 6.6, from 398 m. • H, I – *Promegalaspides pelturae* Westergård: H – cranidium, × 6.8, from 382 m; I – thorax and pygidium, × 2.6, from 382 m. • J – *Macropyge (Aksapyge) transita* Apollonov & Chugaeva, latex cast from the imprint of pygidium, × 7, from 395 m. • K, L – *Promegalaspides kinnekullensis* Westergård: K – cranidium, × 3.4, from 339 m; L – pygidium, × 4.5, from 430.5 m. • M – *Skljarella* cf. *marinae* Petrunina, cranidium, × 11.8, from 364 m.

Chemostratigraphy

The FAD of *Lotagnostus americanus* is not marked by a distinctive shift in carbon isotope values, although its position can be broadly recognized within a longer sequence of $\delta^{13}C$ values (Fig. 12). The FAD of *L. americanus* and the base of the proposed Nelegerian Stage is placed in a field of positive $\delta^{13}C$ values, which shows a gradual increase from +0.25 ‰ to +1.25‰. Strata in the upper part of the underlying Cambrian Stage 9 reach a minimum values of – 0.25‰. A small positive shift, which peaks at about + 0.5‰, is near the base of the Cambrian Stage 10. This is followed by small oscillations in the $\delta^{13}C$ curve through the overlying Cambrian Stage 10 with values ranging between +0.25‰ and +1.25‰. The most distinct position in the Furongian $\delta^{13}C$ curve is the onset of the SPICE excursion, one of the

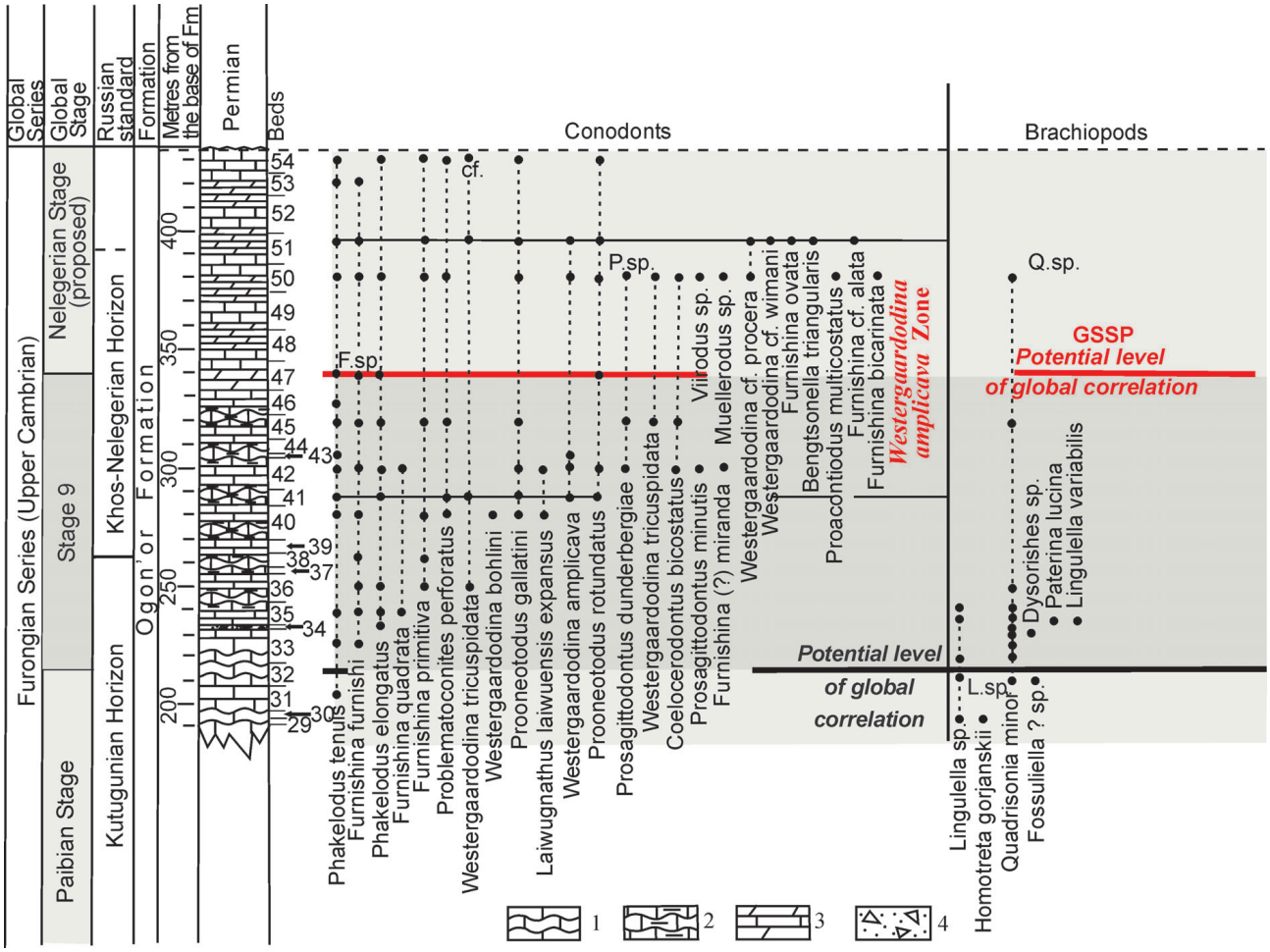

Figure 11. Stratigraphic distribution of conodonts and brachiopods in the upper part of the Furongian Series in the Ogon'or Formation, Khos-Nelege reference section. 1 – dark-gray wavy limy flagstone (mud-wackestone) with greenish siltstone and black argillaceous laminaes; 2 – gray-greenish argillaceous-dolomitic wackestone with gray silty lens-nodular limestone; 3 – alternation of marl, argillite and lens-nodular wackestone; 4 – carbonate breccia.

largest positive $\delta^{13}C$ excursions known from the Lower Paleozoic. In the proposed section of the Khos-Nelege it reaches peak values of about +4.5‰ and is located within the upper third of the Paibian Stage (about the middle of the *Eugonocare* (*Pseudeugonocare*) *borealis* Biozone) below the FAD of trilobites *Irvingella* and *Agnostotes orientalis.*

Sequence stratigraphy

Cambrian strata exposed along the Khos-Nelege section were mainly deposited in a deep-water, middle to distal slope environment setting stable for a substantial amount of time (see Fig. 12). Therefore, developmental phases of the sedimentary basin are not easily distinguishable in comparison with relatively shallow-water shelf successions. Deposition of the Ogon'or Formation took place well below storm wave base and there were no any significant change of lithofacies, submarine erosion or non-deposition caused by sea level fluctuations of eustatic or tectonic nature. The lower part of the Ogon'or Formation displays lithofacies transitional from an outer-fan fringe to outer-fan lobe, which was followed by gradual progradation of the slope during the rest of the late Cambrian.

Other regional sections and reasons for rejection

Lotagnostus americanus has been documented from a number of section in various parts of Siberia. Some of them are potentially useful for definition of the FAD of *Lotagnostus americanus.* In particular these include (1) the section of the Stepanovo Formation in the Trautfetter River basin, the south-western Taimyr Peninsula (Sobolevskaya *et al.* 1995), and (2) the section of the Dzhunyukan and Billyakh formations exposed along the Dzhunyukan River in Southern Verkhoyanie (Gogin 2009). However, these

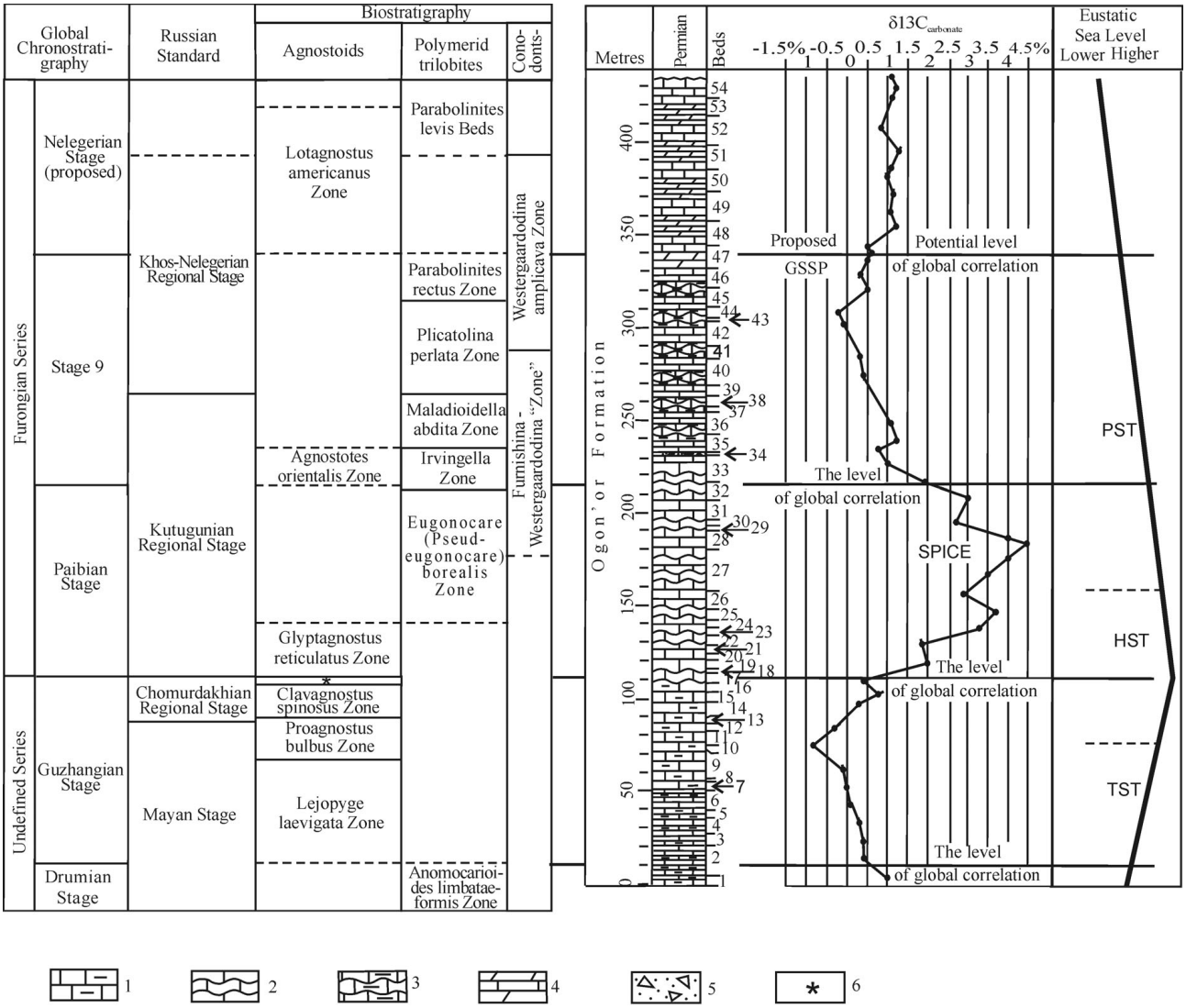

Figure 12. Summary of primary and secondary stratigraphic indicators for the base of the proposed Nelegerian Stage of the Cambrian System (modified from Lazarenko *et al*. 2008). 1 – alternation of dark-gray laminated mudstone to shale, with minor thin chert and pyrite, greenish terrigenious-carbonate siltstone and distal carbonate turbidite; 2 – dark-gray wavy limy flagstone (mud-wackestone) with greenish siltstone and black argillaceous laminas; 3 – greenish-gray argillaceous-dolomitic wackestone with gray silty lens-nodular limestone; 4 – alternation of marl, argillite and lens-nodular wackestone; 5 – carbonate breccia; 6 – *Glyptagnostus stolidotus* Zone.

sections are stratigraphically less complete and existing data on palaeontology and stratigraphy need to be upgraded to make them competitive candidates for the Cambrian Stage 10 GSSP definition.

Other extraregional sections

There are several Cambrian (Furongian) sections in Sweden and in South China, which can be considered as potential candidates for Cambrian Stage 10 GSSP defined by the FAD of *L. americanus* (Terfelt *et al.* 2008, Lu & Lin 1989, Peng 1992). However the upper Furongian sequence in Sweden (Scania) is poor in agnostoids whereas accompanying complexes of polymerid trilobites are largely endemic, or have limited geographical distribution.

The Duibian B section in a vicinity if the Duibian village, Jiangshan County, Zhejiang Province, China (Peng *et al.* 2009) has been voted by the ISCS as the GSSP for the Cambrian Stage 9. The adjacent profile, called the Duibian A section, exhibits one of the most complete Cambrian sequences in western Zhejiang, comprising strata, which extend from the Ediacaran to the Ordovician. It is located approximately 9 km north-east of the city of Jiangshan and was one of the candidate stratotype sections proposed for the base of the Ordovician (Peng *et al.* 2009). The Siyanshan Formation at the top of the Duibian A section is a highly fossiliferous unit rich in polymerids and

agnostoids. *Lotagnostus americanus* appears at the base of the Formation and in the upper 3 m contain *Lotagnostus hedini* in abundance, where it occurs together with the conodont *Cordylodus proavus* (Lu & Lin 1989). This section is inferior to the Khos-Nelege section as the Cambrian Stage 10 GSSP candidate, because the rocks underlying the FAD of *L. americanus* are poorly fossiliferous (only two horizons with *Macropyge longa* and *Pseudagnostus josepha*, respectively are indicated). Furthermore, the appearance of *L. americanus* coincides with a sedimentary change, suggesting an environmental change and possible biofacies shift (Peng *et al.* 2005, 2009).

The alternative proposals for global correlation levels defining the base of the upper stage of the Cambrian

Besides trilobites, several conodont levels have been suggested as possible markers to define the base of the Cambrian Stage 10. In particular, Miller *et al.* (2005) suggested the Lawson Cove section (Utah, USA) as the terminal Cambrian Stage GSSP candidate. The proposed horizon coincides with the FAD of *Cordylodus andresi* Viira and Sergeeva at the base of the *Cordylodus proavus* Biozone. Recently, Landing *et al.* (2010) proposed the level of the FAD of *Eoconodontus notchpeakensis* as the primary correlation point for the base of the Cambrian Stage 10 and suggested the Lawson Cove section as a potential stratotype.

Eoconodontus notchpeakensis occurs in the Dobryi Regional Stage of the Altai-Sayany Region and its FAD is recorded in the Loparian Regional Stage of the Kulumbe River (Siberian Platform) reference section, which exposes a typical inner-shelf sequence. Endemic species of trilobites *Dolgeuloma* and *Saukiella* are also present in these deposits. Reviews by Abaimova and Tolmacheva (Abaimova *et al.* 2008, Tolmacheva & Abaimova 2009) suggest that a part of the Mansian Regional Stage, the Loparian and the lower part of the Nyaian Regional Stages of the Siberian Platform can be correlated with the *E. notchpeakensis* Biozone. *E. notchpeakensis* is still unknown in the basinal settings around Siberia.

Dubinina (2009) suggested the Batyrbai section in Malyi Karatau (South Kazakhstan) as a potential GSSP of the Cambrian Stage 10 defined by the FAD of the conodont *Cordylodus proavus.* This species is geographically widespread and is found in all major Cambrian continents. On the Siberian Platform it is recorded only in inner-shelf sequences of the upper part of the Loparian Regional Stage close to the base of the Nyaian Regional Stage. *Cordylodus proavus* is accompanied here by the polymerids *Plethopeltides magnus*, *Nyaya nyaensis*, and *Eoapatokephalus nyaicus*. A precise trilobite based correlation with basinal sequences across Siberia within this interval proved difficult.

Conclusions

The Khos-Nelege section of the Ogon'or Formation at the Kharaulakh Mountains, Western Yakutia, Russia, is proposed as a candidate stratotype for the GSSP of Cambrian Stage 10, which is defined by the FAD of the agnostoid *Lotagnostus americanus.* The proposed name of the stage is Nelegerian after the Neleger River.

The proposed GSSP is at 339 m above the base of the Ogon'or Formation in the Khos-Nelege section. It fulfills all biostratigraphical, chemostratigraphical, paleogeographic, facies-relationship, and sequence stratigraphy requirements for the GSSP (Remane *et al.* 1996).

Nelegerian Stage is here proposed to be the uppermost of the three stages (Stage 10) of the Furongian Series of the Cambrian System.

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