Evidence of Late Paleocene - Early Eocene hyperthermal events in biosiliceous sediments of Western Siberia and adjacent areas

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Abstract

Changes in diatom and silicoflagellate assemblages from the terminal Paleocene-Early Eocene were analyzed for the first time from the biosiliceous sediments of North Eurasia in the Pechora Depression, northern and middle Transuralia, the Omsk Depression, and Mugodzhary (Russia). Two intervals of significant siliceous microfossil turnover were revealed. The first one correlated with the *Apectodinium hyperacanthum*+*Apectodinium augustum* dinocyst zones and is characterized by an increase in species diversity due to the invasion of Tethyan forms, occurrence of Cretaceous and Early Paleocene relicts and appearances of short-lived taxa with atypical morphology, and is interpreted as the PETM event. The second level corresponding to the second half of the Early Eocene (~ NP 12), is marked by a reappearance of some species characteristic of the transitional Paleocene—Eocene interval, first occurrences of two genera and a number of species and by a strengthened biosiliceous sedimentation indicating an increase in the productivity of the basin.

1. Introduction

The end of the Late Paleocene and most of the Early Eocene (from 58 to 51 Ma) belong to the warmest Cenozoic interval including episodes of so-called hyperthermal events recorded by isotope and other paleotemperature data (Zachos et al., 2008). The best-known and well studied is the ultrashort episode of global temperature increase at the Paleocene—Eocene boundary (PETM = Paleocene-Eocene Thermal Maximum) that was accompanied by a pronounced negative carbon isotope excursion (CIE) of the light isotope of carbon, regional changes in lithology, a significant restructuring of marine and continental biota with latitudinal and intercontinental migrations, and by the acceleration of evolutionary processes. For instance, it is revealed that the PETM event coincides with the *Apectodinium augustum* dinocyst zone. So far, hyperthermal events in the Early Eocene (ETM-2, EECO) have been much less studied (Sluijs et al., 2009; Vanhove et al., 2011).

In Western Siberia and adjacent regions the end of the Paleocene and the Early Eocene corresponded to the maximum development of the marine basin that connected the Tethys with the Arctic. The predominantly biosiliceous and terrigenous sedimentation and virtually complete absence of calcareous plankton puts a premium on studies of silicofossils. Being the dominant group of siliceous plankton, a biostratigraphy based on diatoms was developed by A.P. Jouse in the late 1940s. Subsequently the first zonations were elaborated using enormous amounts of factual material obtained during intense geological studies in Western Siberia (Rubina, 1973; Gleser, 1979; Strel'nikova, 1992). In recent years the range and age of these diatom zonal units have been refined through correlation with dinocyst zones and, in some cases, with other plankton groups in the boreal Paleogene reference sections (Iakovleva et al., 2000; Radionova et al., 2001; Oreshkina, Oberhansli, 2003; Oreshkina et al., 2004; Aleksandrova, Radionova, 2006; Oreshkina, Aleksandrova, 2007; Oreshkina et al., 2008; Akhmetiev et al., 2010; Aleksandrova et al., 2012). Our integrated biostratigraphic study revealed "critical" points in diatom and silicoflagellate evolution. The first one corresponds to the Paleocene—Eocene transition and is interpreted as a manifestation of the PETM event, whereas the later occurred in the second half of the Early Eocene and likely represents the EECO event. Here, we present a brief review of the siliceous plankton perturbations in the Paleogene setting of Western Siberia and adjacent area.

2. Materials and methods

Studied sections are located (Figs. 1, 2) in the Pechora depression (borehole 228/Inta), on the eastern slope of the Urals (borehole 19-U/Ust'-Manya, open pits Kamyshlov, Korkino, Chumlyak), in the Omsk Depression in southeastern Western Siberia (boreholes 8 and 10), and in the Mugodzhary (Emba and Kirgizskoe sections). Lithological succession consists of biosiliceous (diatomite, diatomaceous clay, opoka) and terrigenous sediments, representing deposition at high productive margins of inland marine basin. Samples (stratigraphic positions are indicated in Figs. 1, 2) were collected during 1997, 1999, and 2004 field seasons by the "Paleogene" team of the Geological Institute, Russian Academy of Sciences, Moscow; borehole material was provided by the Russian Geological Exploration regional departments. Standard diatom sample-processing procedures were employed (Jouse et al., 1974; Aleksandrova et al., 2012). Light microscope examination and photodocumentation were made by means of a Carl Zeiss Axiostar microscope and a Canon

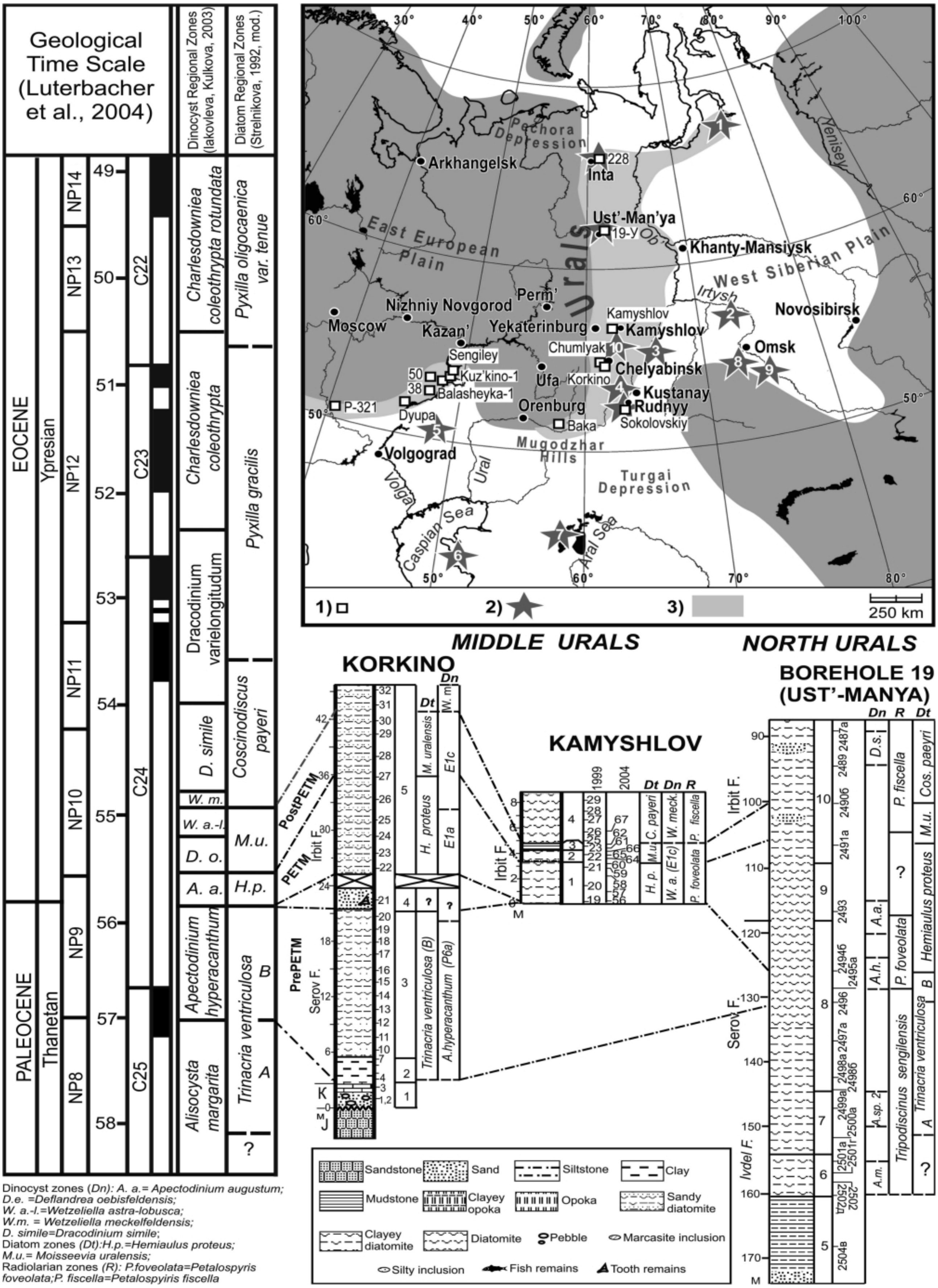


Figure 1: Paleogeographic reconstruction for the PETM interval in boreal Eurasia; overview of studied or discussed sections; diatom based correlation of the most representative sections: 1)- Studied and discussed sections with the PETM diatom zones; 2) - sections with *Apectodinium hyperacanthum* + *Apectodinium augustum dinocyst* zones: 1, 2- Iakovleva, Kulkova, 2002; 3, 4 – Vasil'eva, 2000; 5 - Vasil'ieva, Musatov, 2010 ; 6, 7- Iakovleva, Heilmann-Clausen, 2007; 8, 9 - Iakovleva et al., 2011; 10 - Vasil'eva, Malyshkina, 2008; 3) - biosiliceous sedimentation.

Powershot A 640 digital camera. SEM examination was carried out with an MV 2300 microscope at the Geological Institute RAS.

3. Results

3.1 PETM event

The transitional Paleocene-Eocene interval is most completely represented in the sections of Middle Transuralia. Here, the transgressive sediments of the Serov and Irbit formations, mainly represented by diatomites and diatomaceous clay, can be sampled in the Kamyshlov, Korkino, and Chumlyak quarries (Figs. 1, 3). Assemblages of the diatom zone *Trinacria ventriculosa* (B) with excellently preserved valves are characterized by a high taxonomic diversity, including the regional first ap-

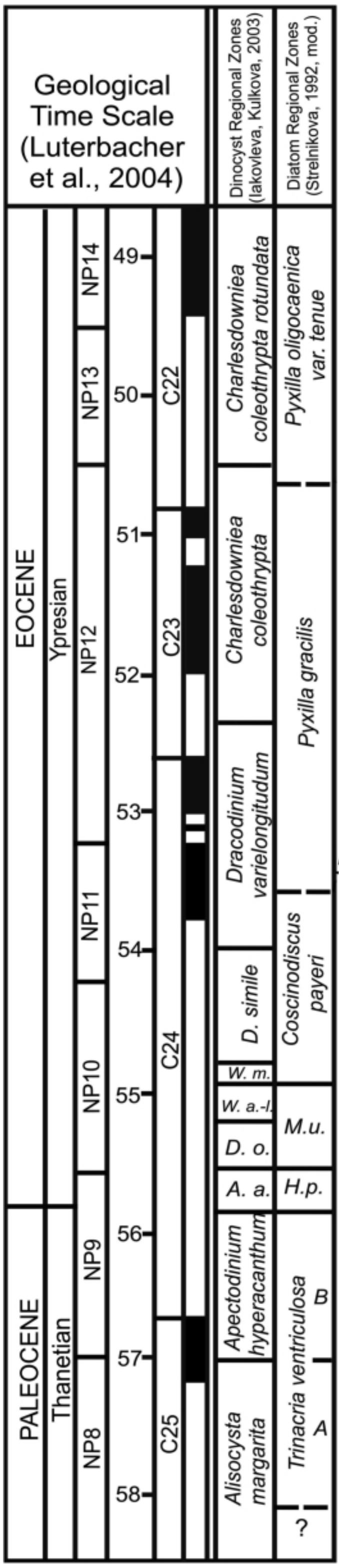
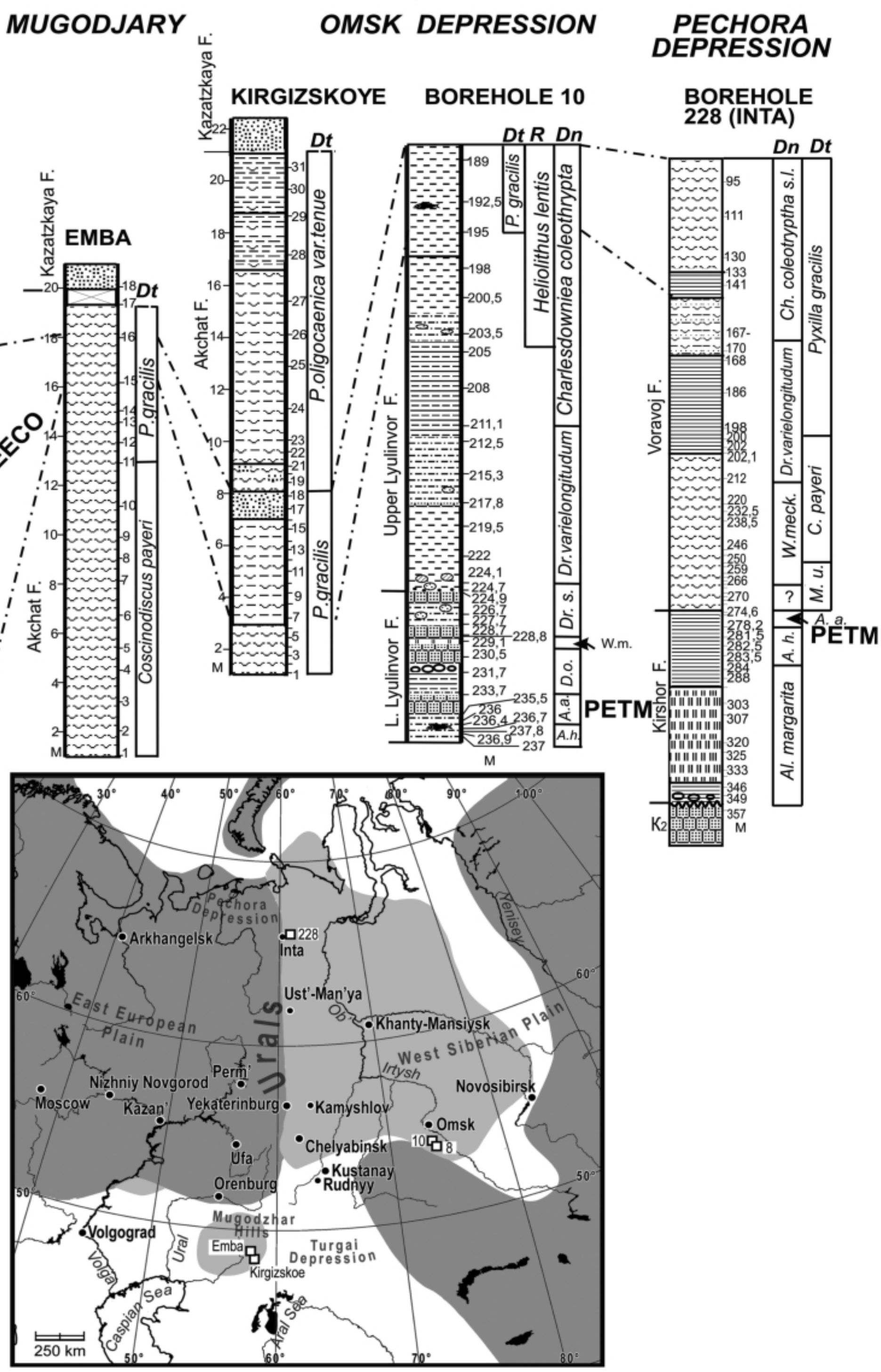


Figure 2: Paleogeographic reconstruction for the EECO interval; overview of studied sections; diatom based correlation of the most representative sections. Legend see Fig. 1.



pearance of such genera as *Fenestrella* (*F. antiqua* (Grunow) Swatman, *F. barbadensis* Greville, *F. russica* Swatman), *Craspedodiscus* (*C. moelleri* A. Schmidt), *Podosira* (*P. anissimovae* (Gleser et Rubina) Jackovshchikova et Strelnikova, *Moisseevia* (*M. uralensis* (Jouse) Strelnikova), *Pseudotriceratium* (*P. chenevieri* (Meinster) Gleser, *P. fallax* Grunow), *Solium* (*S. exsculptum* Heiberg), and significant radiations of *Anaulus* (*A. weyprechtii*, *A.* spp.), *Hemiaulus* (*H. inaequilaterus* Gombos, *H. subacutus* Grunow, *H. incurvus* Shibkova, *H. polymorphus* var. *frigida* Grunow, *H. affinis* Grunow, *H. peripterus* Fenner), *Trinacria* s.l. (*T. cornuta* (Greville) Ross et Sims, *T. regi-*

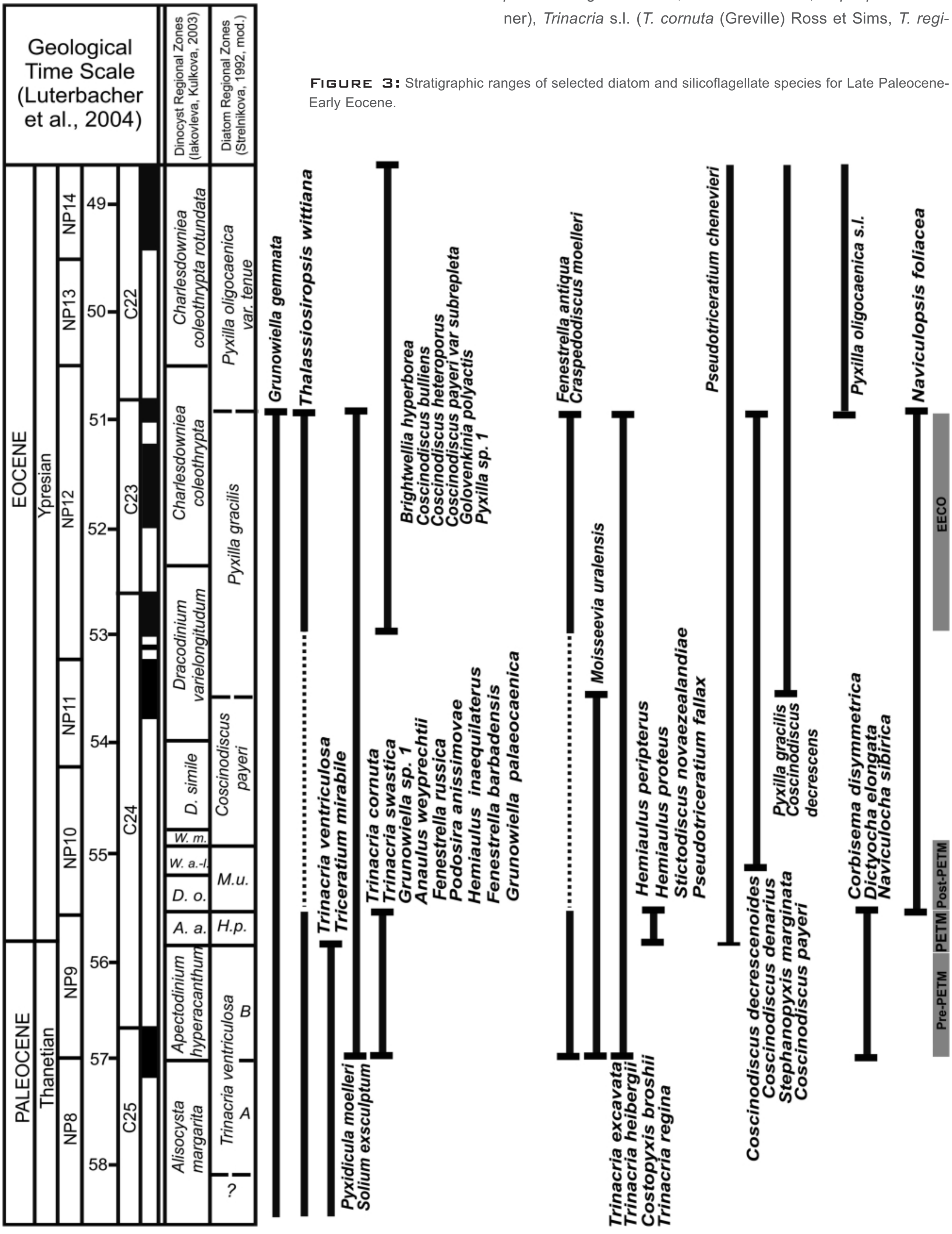


Figure 3: Stratigraphic ranges of selected diatom and silicoflagellate species for Late Paleocene-Early Eocene.

na Heiberg, *T. heibergii* Kitton, *Trinacria excavata* Heiberg, *T. gombosii* Fenner), *Grunowiella* (*G. palaeocaenica* Jouse, G. sp.1), and *Pyxidicula* (*P. moelleri* (A. Schmidt) Strelnikova et Nikolaev. The diversity of background species greatly increased.

The zonal index species occurs in the *Hemiaulus proteus* Zone; at its base *Trinacria mirabile* Jouse, *Trinacria ventriculosa* A. Schmidt, *Thalassiosiropsis wittiana* (Pantocsek) Hasle have their last occurrences. Silicoflagellate assemblages are marked by the presence of extreme morphotypes. In addition to the characteristic species of this interval such as *Dictyocha elongata* Gleser, *D. precarentis* Bukry, and the *Corbisema disymmetrica* Bukry group, there is the appearance of the new taxon *Naviculocha sibirica* Oreshkina and Radionova described in Aleksandrova et al. (2012) which combines the morphological features of *Naviculopsis* and *Dictyocha*. The *Moisseevia uralensis* Zone represents the termination of the PETM and transition to the Early Eocene complexes. The taxonomic diversity sharply decreases and is typified by Early Eocene *Coscinodiscus denarius* A. Schmidt, *C. payeri* Grunow, and *C. decrescenoides* Jouse.

Comparison with synchronous assemblages from sections of the Kamyshin Formation in the central Volga region located at the same latitude, indicates certain differences within the general trends. For instance there is a higher species diversity and abundance of *Anaulus*, *Fenestrella*, and *Coscinodiscus* in the Transuralian sections. The *Trinacria* s.l., *Hemiaulus*, *Stephanopyxis*, *Eunotogramma*, *Paralia*, and *Anuloplicata* genera are less representative than in the Volga region sections. The lack of PETM markers, namely, *Trinacria cancellata* (Greville) Sims et Ross, *Cylindrospira simsii* Mitlehner and pennate *Navicula*-type diatoms in the central Volga region is remarkable. *Grunowiella* sp. A, *Stictodiscus novaezealandiae* Grunow, *Pseudotriceratium fallax*, *P. chenevieri*, *Fenestrella russica*, *F. barbadensis*, and the silicoflagellate *Naviculocha sibirica* mentioned above, are found only in the Transuralian sections. The revealed differences suggest an occurrence of regional circulation systems in the West Siberian Sea-Strait and in the “Russian Sea” of the Volga region. Structural distinctions are recorded as well. The most significant is the declined proportion of the *Paralia/Anuloplicata* group compared to the Volga sections, which evidently resulted from an overdeepened shelf on the eastern slope of the Urals.

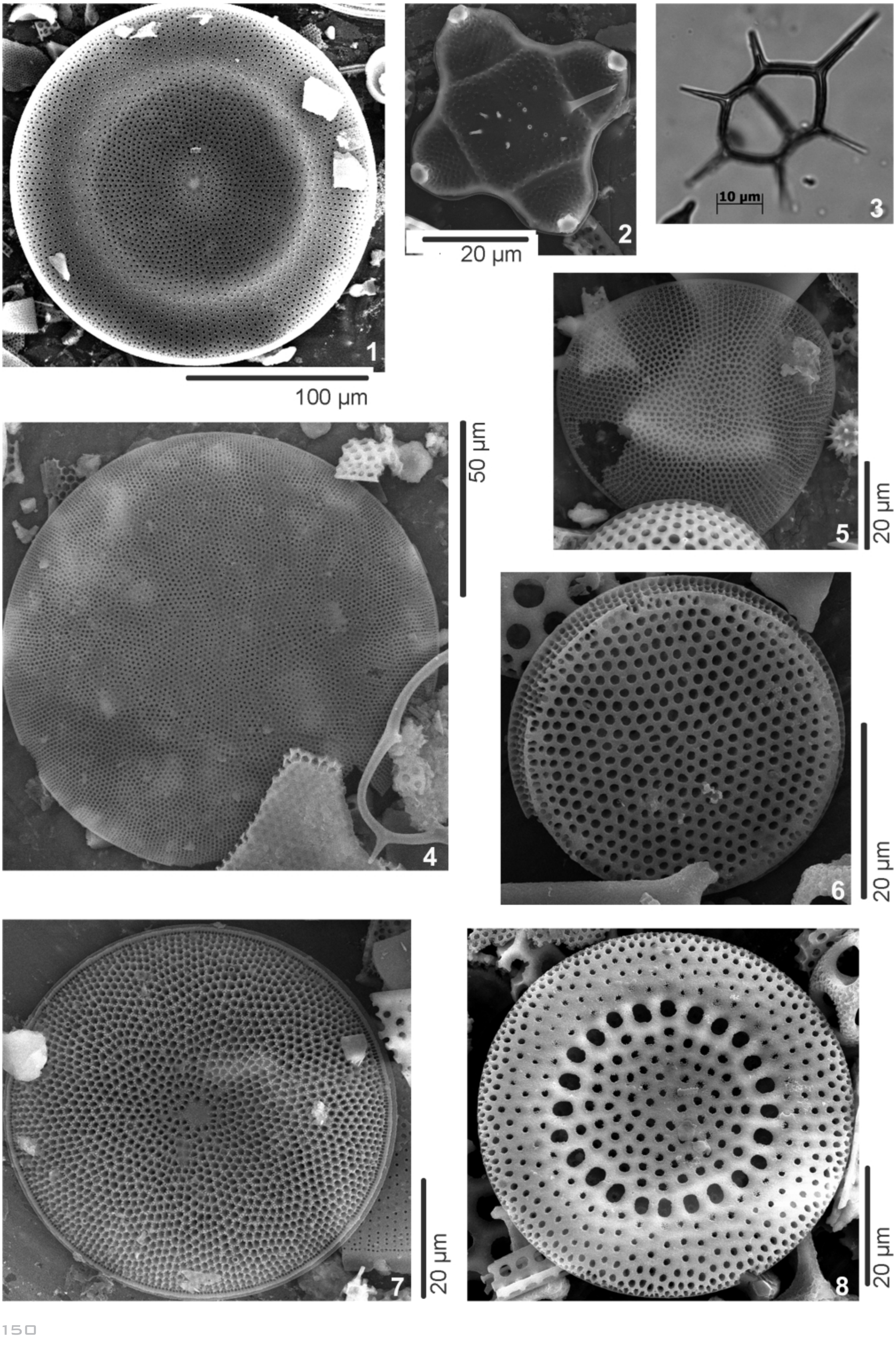
In the northern Urals, in borehole 19A (Ust’-Man’ya), the *Apectodinium augustum* dinocyst zone corresponds to the *Hemiaulus proteus* diatom zone with a similar species composition, however, with considerably less diverse concomitant species compared to the assemblages of the central Transuralian sections. In the Pechora Depression on the western slope of the Polar Urals (borehole 228/Inta) biosiliceous sedimentation is recorded above the PETM interval starting with the *Moisseevia uralensis* diatom zone recognized at the base of the Voravozh Formation (Fig. 2). The PETM interval corresponds to the *Apectodinium augustum* dinocyst zone distinguished in the dark grey clays of the underlying Kirshor Formation (Iakovleva et al., 2000).

In the Turgai Strait and southwards, in the mixed terrigenous-carbonate sedimentation area, the interval of the Paleocene—Eocene transition coincides with the occurrence of biosiliceous sediments corresponding to the *Trinacria ventriculosa* - *Hemiaulus proteus* zones. These sediments are recognized as the Polosataya Formation of the Sokolovskii quarry in Turgai (Radionova et al., 2001) and Tykbutak Formation in the Mugodzhary region (Glezer, 1979). Several localities of that age are known southwards as well, such as the "opokas" of the Suzak Beds (Teslenko, 1949) in the Tashkent depression and northwestern Fergana. Assemblages of similar composition were also recognized when drilling in southern Kazakhstan in the Ashchikol Lake region, western Chuiskaya depression, in dark grey clays with glauconite and sponge spicules and in the Karatau region, eastern Kyzylkumy, in greenish-grey clayey opokas (Shibkova, 1968).

It should be noted that the similarity of the taxonomic composition of the diatom floras from the inland basins of Western Siberia and the Russian platform with the tropical assemblages of the Indian and Atlantic oceans (Gombos, 1984; Fenner, 1991) was reported by Mukhina (1976), Jouse (1982), Strel’nikova (1992), and Glezer (1995). In particular, at the Paleocene-Eocene transition we observe the earlier stratigraphic appearance of some species initially known from the middle Eocene deposits of tropical regions. There are *Fenestrella barbadensis* Greville (1863) from Barbados, and *Stictodiscus novaezealandiae* Grunow (1889) from Oamaru, New Zealand.

3.2 EECO event

The Early Eocene was a time of maximum expansion of biosiliceous sediments in Western Siberia and adjacent regions of the Polar Cisuralia and northern Kazakhstan (Fig. 2). A significant enrichment of the diatom taxonomic composition (Figs. 3, 4) corresponds to the upper part of the *Pyxilla gracilis* zone (~ NP12 Nannoplankton zone) and is correlated with isotope excursions (EECO) to the upper part of the Ypresian. This level is well traced in Western Siberia, which served as the basis for the distinction of the *Coscinodiscus polyactis* A. Cleve-Euler (revised as genus *Golovenkinia* by Strelnikova, 1997) subcomplex in the upper part of the *Pyxilla gracilis* zone (Rubina, 1973) in one version of the West Siberian regional zonation. Compared to a homogeneous composition of assemblages of the previous *Coscinodiscus payeri* Zone and lower part of the *Pyxilla gracilis* zone bearing the index species, *Coscinodiscus payeri* Grunow, *Grunowiella gemmata* (Grunow) Van Heurck, *Pyxidicula moelleri* (A. Schmidt) Strelnikova et Nikolaev, and *Stephanopyxis marginata* Grunow, the interval discussed is marked by a considerably increased diversity owing to both reinvasion of some PETM reference species (*Craspedodiscus moellleri*, *Fenestrella antiqua*, *Thalassiosiropsis wittiana*) and regional first appearances of *Brightwellia* and *Golovenkinia* species - *Triceratium basilica* Brun, *Coscinodiscus decrescens* Grunow, *Pyxilla* sp. 1, and *Pseudotriceratium radiosoreticulatum* Grunow. The most taxonomically diverse assemblages were found in Mugodzhary in the Kirgizskoe and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Emba sections (northern Kazakhstan) where the sediments are represented by diatomites of the Akchat Formation. In the Pechora Depression (borehole 228) only reference species *Brightwellia hyperborea* Grunow, *Golovenkinia polyactis*, *Coscinodiscus decrescens* Grunow, and *Pyxilla* sp. 1 occur.

In the Omsk Depression (boreholes 8 and 10) in the terrigenous Lulinvor Formation this interval is characterized by the appearance of a biosiliceous member up to 20 m thick with sponge spicules, diatoms, silicoflagellates, ebridians, and radiolarian fragments. The diatom assemblage contains *Golovenkinia polyactis* and indicates the attribution to the upper part of the *Pyxilla gracilis* zone.

4. Conclusions

Diatoms and silicoflagellates at the Paleocene—Eocene transition during the PETM event evolved according to the scenario common to other groups of microplankton, in particular to dinocysts and nannoplankton. This means the evolution at the generic level, appearance of short-lived species with atypical morphology, and reoccurrence of Early Paleocene and Cretaceous relicts. The question of warm-water species migrating into northern latitudes during the PETM, as has been established for dinocysts, is ambiguous with respect to diatoms and requires special study. It should be noted that similarity of the taxonomic composition of the diatom floras from the inland basins of Western Siberia and the Russian platform with the tropical assemblages of the Indian and Atlantic oceans (Gombos, 1984; Fenner, 1991) was reported by Mukhina (1976), Jouse (1982), Strel'nikova (1992), and Glezer (1995). Despite the occurrence of some species common with tropical assemblages of the World Ocean, there are regional differences in species composition including the presence of endemics, which can be likely explained by a specific regional current system and/or different parameters of water masses in the Volga region and West Siberian Sea-Strait.

Another peculiar response of the diatom flora to the PETM event is that the maximum taxonomic diversity falls in the upper part of the *Trinacria ventriculosa* zone, i.e. stratigraphically below the CIE event that is currently accepted as the Paleocene-Eocene boundary. The same regularity is recorded for other groups of marine biota in some regions of the Earth including Spitsbergen (Harding et al., 2011).

The available records of diatoms and silicoflagellates infer three stages of the Northern Peri-Tethys development at the Paleocene—Eocene boundary represented by major transgressive-regressive cycles, namely, (1) initial stage (pre-PETM) – transgression and warming; (2) the proper PETM event coinciding with the isotope excursion and new transgression (in some sections, for instance Korkino, there is evidence of ultra-short regression at the beginning of this event); and (3) terminal stage, post-PETM, representing the transition to the Early Eocene flora with notably decreased species diversity, occurrence of Early Eocene reference species, and a short-term regression followed by stabilization of the marine basin.

Rearrangement of diatom assemblages in the upper part of the Early Eocene (presumably EECO) shows similar trends, i.e. the enrichment of assemblages at the generic and specific level, and reappearance of forms characteristic of the PETM. The taxonomic and structural rearrangements of silicofossils well pronounced in the biosiliceous sedimentation area, are correlative with the appearance of hyperproductive biosiliceous facies in the regions with terrigenous and terrigenous-carbonate sedimentation.

Figure 4: Diatoms and silicoflagellates markers-species of the PETM and the EECO events from the sections of Western Siberia and adjacent areas: 1- *Craspedodiscus moelleri* A. Schmidt; 2 – *Solium exsculptum* Heiberg; 3 - *Naviculocha sibirica* Oreshkina and Radionova; 4 – *Fenestrella barbadensis* Greville; 5 - *Pseudotriceratium fallax* Greville; 6 – *Golovenkinia polyactis* (A. Cleve-Euler) Strelnikova; 7 – *Moisseevia uralensis* (Jouse) Strelnikova; 8 – *Brightwellia hyperborea* Grunow; 1,2, 7- Kamyshlov, sample 58; 3- Chumlyak, sample 121; 4 – Korkino, sample 17; 5 – Korkino, sample 15; 6, 8 – Kirgizskoye, sample 6.

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