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Stratigraphy / Stratigraphie

A new Paleogene micropaleontological and palaeogeographical data in the Petchora Depression, northeastern European Russia

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Abstract – A new bore-hole from the Petchora Depression (northeastern Europe) yielded a rich Paleocene–Eocene record which allowed, for the first time, the study of dinoflagellate cysts in the whole Polar and Pre-Polar Ural region. The simultaneous occurrence of dinoflagellates in the whole section, benthic foraminifera in the Palaeocene part and diatoms in the Eocene section permits a high-resolution biostratigraphy. The lithological and micropalaeontological analyses suggest the existence of a marine basin in the Polar and Pre-Polar Ural area and its constant communications with the west Siberian epicontinental sea during the Thanetian–Ypresian. © 2000 Académie des sciences / Éditions scientifiques et médicales Elsevier SAS

Paleogene / northeastern Europe / stratigraphy / dinoflagellates / diatoms / benthic foraminiferas / palaeogeography

Résumé – Nouvelles données micropaléontologiques et paléogéographiques du Paléogène de la dépression de Petchora, Nord-Est de la Russie européenne. Un nouveau sondage carotté dans la dépression de Petchora (Europe du Nord-Est) a révélé une longue séquence d'âge Paléocène–Éocène, qui a permis l'étude, pour la première fois, de kystes de dinoflagellés dans toute la zone de l'Oural polaire et pré-polaire. La répartition simultanée des dinokystes dans toute la section, des foraminifères benthiques dans la partie paléocène et des diatomées dans la section éocène a conduit à définir une biostratigraphie à haute résolution. L'analyse lithologique et micropaléontologique suggère l'existence d'un bassin marin dans la région de l'Oural polaire et pre-polaire et de communications constantes avec la Sibérie occidentale pendant le Thanétien–Yprésien. © 2000 Académie des sciences / Éditions scientifiques et médicales Elsevier SAS

Paléogène / Europe du Nord-Est / stratigraphie / dinoflagellés / diatomées / foraminifères bentiques / paléogéographie

Version abrégée

Les premières découvertes de sédiments d'âge Paléogène, contenant des assemblages de radiolaires et de diatomées, dans la partie nord-est de la Russie européenne (toundra de la Grande Terre et de l'Oural polaire) [6, 10, 28], puis l'analyse lithologique de ces dépôts terrigènes et siliceux du Paléogène de l'Europe du Nord-

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Est [1, 2, 3], conduisent à exclure le nannoplancton et les foraminifères planctoniques comme outils biostratigraphiques. La zone de l'Oural polaire était interprétée comme une région de sédimentation continentale [18, 24, 29].

Les travaux sur les sédiments mésozoiques–cénozoiques du bassin Arctique [12, 13] ont mis en évidence l'influence des eaux arctiques. Pendant le Paléocène–Éocène, le détroit de Turgay et la mer de Sibérie occidentale participaient d'un système de communication permanente entre le bassin Arctique et l'océan mondial. L'influence de chaque source dans cet échange de masses d'eau n'était pas établie.

Le sondage n° 228, localisé dans la dépression de Petchora (vallée de Lemva) (*figure 1*), zone de l'Oural occidental polaire, présente 360 m de sédiments crétacés–tertiaires. Deux formations lithologiques ont été identifiées dans l'intervalle paléogène : Kirshorskaya et Voravogskaya (*figure 2*). La partie inférieure de la formation Kirshorskaya (357,0–297,0 m), discordante par rapport aux grès du Crétacé, se compose d'argiles à aleuronite et de gaizes sableuses avec quartz et glauconite. La partie supérieure (297,0–274,8 m) est une alternance d'argiles et d'argiles gaizeuses avec des intercalations de grès et d'aleuronite. La formation Voravogskaya (274,8–86,0 m), discordante sur la formation précédente, comprend des diatomites et des argiles à diatomées.

1. Dinoflagellés

Leur répartition dans toute la partie paléogène a permis de reconnaître ici différentes zones. Six zones de dinoflagellés, déterminées par la présence de marqueurs stratigraphiques, ont été comparées par la suite avec les zonations européennes [9, 23] (*figure 3*) :

• la zone à *A. margarita* (357,0–287,0 m), déterminée par la présence de *Deflandrea denticulata*, correspond à la même zone ouest-européenne (NP8 et P4 (pars)) et, par conséquent, un âge Thanétien lui est attribué ;

• la zone à *A. hyperacanthum* (287,0–284,2 m) est déterminée par la première apparition d'*A. homomorphum* (Europe occidentale : NP9 (pars) et P4(pars)–P5(pars) [23] ; cette partie de la formation Kirshorskaya est datée du Thanétien par l'assemblage à *A. hyperacanthum*.

• la zone à *A. augustum* (284,2–271,4 m), caractérisée par l'apparition d'*A. augustum*, est équivalente à son homologue européenne ; en Europe occidentale, elle correspond à NP9 (pars) et P5(pars)–P6(pars) ; elle est attribuée au Thanétien terminal–Yprésien basal (l'intervalle compris entre 271,4 et 267,1 m n'a livré aucun marqueur stratigraphique : *A. augustum* a disparu, alors que le marqueur suivant n'est pas encore présent) ;

• la zone à *W. meckelfeldensis* (267,1–216,2 m) (apparition du marqueur *W. meckelfeldensis*) permet, dans la partie inférieure de la formation Voravogskaya comme en Europe occidentale, de dater ces sédiments de l'Yprésien (NP10(pars)–NP11(pars)) ;

• la zone à *D. varielongitudum* (216,2–175,0 m), entre les premières apparitions de *D. varielongitudum* et *Ch. coleothrypta*, [23] confirme, comme en Europe occidentale, l'âge Yprésien (NP11(pars)–NP12(pars) ;

• la zone à *Ch. coleotrypta* s.l. (175.0–86.0 m), distinguée par la première apparition du marqueur, correspond partiellement à la zone *Ch. coleothrypta* s.str. de Powell [23] (NP12(pars)) ; la présence d'*A. diktyoplokum* et de *Ch. coleotrypta* subsp. *rotundata*, dans la partie supérieure de la séquence, permet d'élargir l'intervalle stratigraphique (NP12–NP13) et de l'attribuer à l'Yprésien supérieur.

2. Foraminifères agglutinés

Les assemblages des foraminifères agglutinés reconnus dans la formation Kirshorskaya incluent les taxons qui caractérisent les associations paléocènes (Thanétien) de la Sibérie occidentale [22].

3. Diatomées

Quatre zones sont déterminées dans la formation Voravogskaya (*M. uralensis*, *C. payeri*, *P. gracilis* et *G. polyactis*). Elles correspondent aux zones établies dans la mer de Kara [11, 26] (NP11–NP13) et confirment l'âge Yprésien de la formation Voravogskaya.

La succession lithologique de la carotte n° 228 prélevée dans la dépression de Petchora est similaire à celle décrite en Oural oriental et en Sibérie occidentale, où l'on observe également le remplacement vertical des argiles gaizeuses du Paléocène par les diatomites de l'Éocène. Les gaizes et les argiles gaizeuses de la formation Kirshorskaya (357,0–274,8 m) semblent refléter la transgression du Thanétien, tandis que l'intervalle de la formation Voravogskaya entre 274,8 et 267,1 m correspond à la régression de l'Yprésien basal. La discontinuité à la limite entre les deux formations et l'absence des zones de Dinoflagellés à *Gl. ordinata* et à *W. astra*, établies en Europe occidentale, suggèrent que les diatomites de la formation Voravogskaya (267,1–86,0 m) appartiennent à la deuxième phase transgressive, d'âge Yprésien. Les enregistrements de cette transgression, accompagnée par une bio-silicification intensive [27], sont connues dans les régions voisines, dans le Nord de l'Oural polaire et en Paï-Hoï [20, 28]. Les assemblages de microorganismes, déterminés dans la carotte n° 228, sont similaires à ceux de Sibérie occidentale. Ainsi, les diatomées *Pyxilla gracilis*, *Coscinodiscus payeri* et *M. uralensis* sont largement distribuées dans la région adjacente. Comme les espèces de Dinoflagellés *Cerodinium markovae*, *Wetzeliella coronata* et *Soaniella granulata* étaient considérées précédemment comme endémiques de la Sibérie, leur présence ici suggère une communication permanente entre les bassins marins du Petchora et de Sibérie occidentale pendant le Paléocène récent–Éocène ancien.

L'étude des Diatomées et des Dinoflagellés permet d'interpréter les paléoenvironnements du bassin marin de la dépression de Petchora. La dominance des écogroupes « *Deflandrea* » et « Wetzeliellielloideae » et, par-fois, des genres *Areoligera*, *Glaphyrocysta* et *Spiniferites* indique la présence de conditions lagunaires dans le bassin du Petchora pendant le Thanétien–Yprésien. Les associations éocènes de Diatomées sont caractérisées par la prédominance d'espèces méroplanctoniques et tychopélagiques, ce qui est typique des environnements de plate-forme continentale (conditions épicontinentales).

Nos résultats lithologiques et paléontologiques permettent d'établir une paléogéographie du Paléogène de la zone de l'Oural polaire et pré-polaire, différente de celle admise précédemment [18, 24]. Nous proposons que la sédimentation dans la dépression de Petchora et en Sibérie occidentale au Thanétien–Yprésien se soit produite dans un bassin (*figure 4*).

1. Introduction

The first discoveries of Paleogene sediments in northeastern European Russia (Great Land Tundra and Polar Ural regions) were made forty years ago: only two outcrops with radiolaria and diatoms assemblages were described [28], then two bore-holes (Laya and Saroda River regions) yielded sediments with benthic foraminifers and radiolaria of Paleocene age [5, 10]. Afterwards, Afanasieva characterized Paleogene and Neogene sediments in northeastern Europe (Polar and Pre-Polar Ural area) [1–3]. The lithological analysis indicated a terrigenous and siliceous sedimentation during the Paleogene in northeastern Europe. This excluded any stratigraphical use of calcareous nannoplankton and planktonic foraminifers in this northern area. Furthermore, detailed palaeogeographical reconstructions for the Paleogene of the Petchora Basin (Polar Ural region) were missing or the Polar Ural region was interpreted as an area of continental sedimentation [18, 24].

Increasing interest for the Mesozoic–Cenozoic history of the Arctic basin during the last two decades required more detailed investigations of the regions opened to the Polar area [12, 13, 17]. The aim of these studies was to obtain evidence of the influence of Arctic waters on the sedimentation, whereas no connection between the Arctic Basin and the Pacific Ocean existed during the Paleogene. The communications between the Arctic Basin and Atlantic Ocean were difficult and only possible through a complex system of straits [17, 18]. During the Paleogene, the Turgay Strait and the West Siberian epicontinental basin participated in a system of permanent communications between the northern basin and the open ocean allowing water exchanges between the Arctic and Tethys basins. It is, however, very difficult to distinguish the influence of each source in this watermass exchange. The problem can nevertheless be addressed by the precise study of the Paleogene marine sections in the Petchora Depression (Polar Ural area), which is directly connected to the Amerasian Basin by the Kara Sea.

The purpose of this paper is to present new data, obtained from the marine Paleogene section of borehole No. 228 in the Petchora depression (*figure 1*) based on the study of dinoflagellate cysts, benthic foraminifers and diatoms and to interpret the palaeogeographic environment of this area during the Early Paleogene.

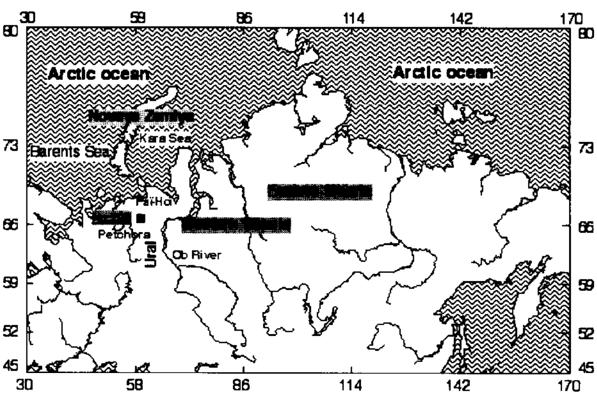

Figure 1. Geographical map of Russia showing the location of borehole No. 228.

Figure 1. Carte géographique de la Russie, avec la localisation de la carotte n° 228.

2. Geographical location and lithology

Bore-hole No. 228 is located in the western Polar Ural area, Lemva River region (66.3° N, 60.8° E) (*figure 1*). It revealed a rich Cretaceous–Tertiary record (360 m in thickness) overlain by 86 m of Pliocene–Quaternary sediments. The stratigraphical description of the Cretaceous interval can be found in Oreshkina et al. [21]. Only the Paleogene section is considered in the present study. Two lithological formations in the Paleogene interval were identified: Kirshorskaya (Paleocene) and Voravogskaya (Eocene) [2].

The Paleogene sediments in bore-hole No.228 (357.0–86.0m) are divided into three main units (*figure 2*) from the base to the top (Afanasieva and Lutikov, Geological Survey of Vorkuta, pers. comm.):

- the lower Kirshorskaya formation (357.0–297.0 m) overlies, after lithological discordance, the Upper Cretaceous gaize sandstones; the bottom part is composed by siltstone clay, the upper one, by grey sandy gaize with quartz sandstone, glauconite and vegetal detritus;
- the upper Kirshorskaya formation (297.0–274.8 m): this is an alternation of grey and green-grey clay and gaize clay with intercalations of sandstone and siltstone.
- the Voravogskaya formation (274.8–86.0 m) overlies with discordance the Kirshorskaya formation; it is composed of diatomite and diatomite clay; a bed of sandy

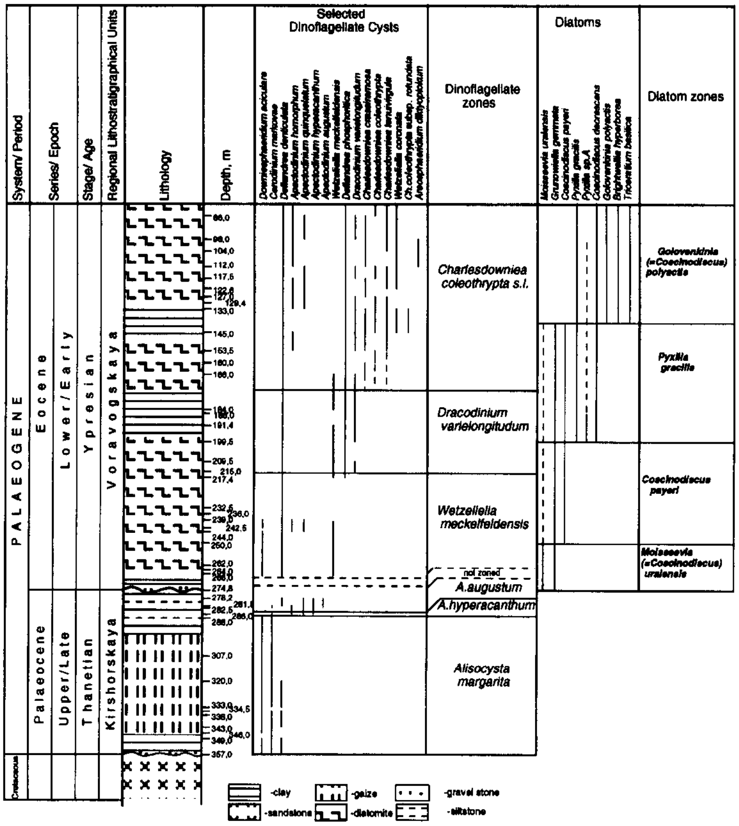

Figure 2. Sedimentological log and stratigraphical ranges of selected dinoflagellate cysts and diatoms in the studied section of bore-hole No. 228.

Figure 2. Lithologie et répartition stratigraphique des kystes de dinoflagellés et des diatomées sélectionnés dans la section de la carotte n° 228.

glauconite clay with gravel stone is recognised at the base of the formation.

3. Stratigraphical results

3.1. Dinoflagellate cysts

Dinoflagellate cysts are identified in the whole sequence and allow a precise biostratigraphy of the studied record. The presence of stratigraphical markers from Dinoflagellate zonations of other regions permits to identify six dinoflagellate zones. The defined biostratigraphy, hence, can be compared with compilated Paleogene dinoflagellate cysts Biozonation of Powell [23], calibrated with calcareous nannoplankton and planktonic foraminiferal biozonations, and the interregional paleogene dinoflagellate zonation of Costa and Manum [9] (*figure 3*). The dinoflagellate zones from the Petchora section can be also compared with regional Paleogene dinoflagellate zonations of Russia [4, 15, 29].

The *Alisocysta margarita* zone (357.0–287.0 m) (*figure 2*), determined by the presence of *Deflandrea den-*

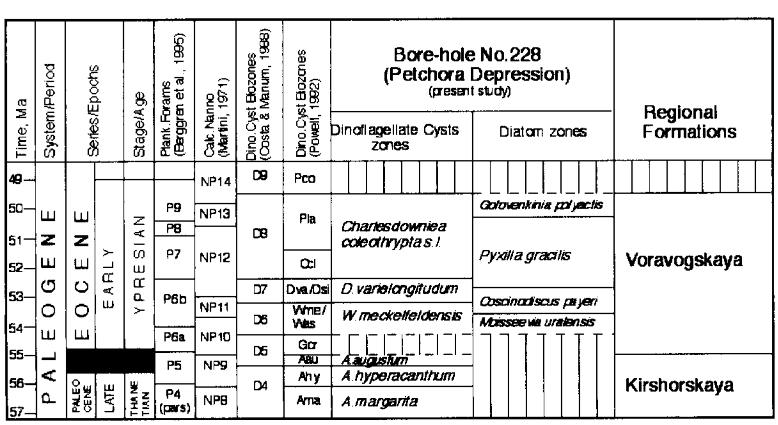

Figure 3. Correlation between the present determined biostratigraphy and biozonations in western and northwestern Europe.

Figure 3. Corrélation entre la biozonation proposée ici et les biozonations de l'Europe occidentale et nord-occidentale.

ticulata, is a similar zone to that described in western Europe [14, 23]. The biozonal limits are the first occurrences of *Deflandrea denticulata* Alberti and of *Apectodinium homomorphum* (Deflandre & Cookson) Lentin & Williams. According to Powell [23], the *A. margarita* zone corresponds to dinoflagellate zone D4 (pars) of Costa and Manum [9] and is calibrated with nannoplankton zone NP8 of Martini [19] and planktonic foraminiferal zone P4 (pars) [6] (*figure 3*). Hence, the sediments of the Kirshorskaya formation in the interval of 357.0–287.0 m are of Thanetian age (Late Paleocene).

The *Apectodinium hyperacanthum* zone (287.0–284.2 m) (*figure 2*), recognized in the Petchora section, is dominated by the genus *Apectodinium*. It corresponds to the west European *A. hyperacanthum* [23] and to the northwestern dinoflagellate zone D4 (pars) [9] (*figure 3*). The zonal body is between the first occurrences of *Apectodinium homomorphum* and *Apectodinium augustum*. In western Europe this zone is calibrated with nannoplankton zone NP9 (pars) and planktonic foraminiferal zones P4 (pars)-P5 (pars) (*figure 3*). Consequently, the Kirshorskaya formation sediments (287.0–284.2 m) can be attributed to the Thanetian (NP9(pars)).

The *Apectodinium augustum* zone (284.2–271.4 m) (*figure 2*) is equivalent to the west European *A. augustum* zone [23] and to D5a zone of Costa and Manum [9] (*figure 3*). The base is determined by the first occurrence of *A. augustum* (Harland) Lentin and Williams. According to Powell [23] this zone is calibrated with nannoplankton zone NP9 (pars) and planktonic foraminiferal zones P5 (pars)–P6 (pars). Therefore, the Petchora section interval of 284.2–271.4 m can be attributed to the Uppermost Thanetian–Lowermost Ypresian.

The section interval between 271.4 and 267.1 m did not, however, reveal any stratigraphical markers: *Apectodinium augustum* disappeared and the next marker had still not occurred.

The *Wetzeliella meckelfeldensis* zone is recognized in the interval 267.1–216.2 m (*figure 2*). This zone is equivalent to the west European *W. meckelfeldensis* and the northwestern sub-zone D6b (pars) [9, 23]. It is defined by the first occurrence of *W. meckelfeldensis* Gocht in the section. According to Powell [23], it is correlated in western Europe with the nannoplankton zones NP10 (pars)–NP11 (pars) and planktonic foraminiferal subzone P6b (pars) (*figure 3*). Consequently, the age of the Voravogskaya formation sediments (267.1–216.2m interval) is Ypresian.

The *Dracodinium varielongitudum* zone is recognized between 216.2 and 175.0 m (*figure 2*) and has a similar composition as in western Europe. The biozonal boundaries are the first occurrences of *D. varielongitudum* (Williams & Downie) Costa & Downie at the bottom and *Charlesdowniea coleotrhypta* (Williams & Downie) Lentin & Vozzhennikova at the top. Powell [23] correlates this zone with the nannoplankton zones NP11(pars)–NP12(pars) and planktonic foraminiferal zone P7 (pars) (*figure 3*).

The *Charlesdowniea coleothrypta s.l.* zone is recognized in the top interval studied (175.0–86.0m) (*figure 2*). It is characterized by the first appearance of the zone marker. The *Ch. coleothrypta s.l.* zone partially corresponds to the west European *Ch. coleothrypta s. str.* zone (nannoplankton NP12 (pars) and foraminiferal P8 (pars) stratigraphical interval) (*figure 3*). However, except the marker and accompanying taxa, *Ch. coleothrypta rotundata* (Châteauneuf and Gruas-Cavagnetto)) Lentin and Vozzhennikova and *Areosphaeridium diktyoplokum* (Klumpp) Stover and Williams are also present. According to Châteauneuf and Gruas-Cavagnetto [8], *Ch. coleothrypta rotundata* appears stratigraphically higher in west Europe. This is the reason why the *Ch. coleothrypta rotundata* zone is identified in the Paris Basin in the NP12-NP14 interval [7]. According to Powell [23] *A. diktyoplokum*, another key species of the studied interval, occurs for the first time within the *Pentadinium laticinctum* zone (NP12-NP13). In the southern former Soviet Union, stratigraphical frameworks of the *Ch. coleothrypta s.l.* zone are allocated to the NP12-NP14 nannoplankton interval [4]. Considering these correlations the sediments between 1 675.0–86.0 m can be dated as Late Ypresian.

3.2. Benthic foraminifers

The associations of agglutinate foraminifers are established for the 325.0–307.0 and 286.0–274.8-m intervals of the Kirshorskaya formation. The associations include the following species: *Haplofragmoides peripheroexcavatus* Subbotina, *Trochammina pentacamerata* Lipman, *Cyclammina coksuvorovae* Ushakova and *Verneuilinoides paleogenicus* Lipman. This assemblage is analogous to those described from the western Siberian Paleocene sediments and dated as Thanetian [22].

3.3. Diatoms

Four biozones are determined in the studied section (*figure 2*). These zones are correlated with the diatom zonation of Strelnikova [26] for northern latitudes with the indirect correlation with nannoplankton and planktonic foraminifers zonations.

1. The *Moisseevia* (= *Coscinodiscus*) *uralensis* zone is determined for the interval between 274.8 and 250.0 m by the presence of marker *Moisseevia uralensis* (Jouse) Strelnikova. It corresponds to the similar zone established in Strenikova's zonation [26] and attributed to the Ypresian.
2. The *Coscinodiscus payeri* zone (250.0–212.0 m). The base of this zone is marked by the occurrence of *C. payeri* Grunow. This zone corresponds to the same one of Strelnikova [26] (NP11–NP12 zones).
3. The *Pyxilla gracilis* zone (212.0–133.0 m) is determined by the first occurrence of *Pyxilla gracilis* Tempere and *Coscinodiscus decrescens* Grunow. In the scheme of Strelnikova [26] this zone corresponds to NP12-NP13 zones.

4. The *Golovenkinia (= Coscinodiscus) polyactis* zone is distinguished in the interval between 133.0 and 86.0 m. *Golovenkinia polyactis* (Grunow) Strelnikova and *Brightwellia hyperborea* Grunow appear and *Grunowiella gemmata (Grunow)* Van Heark, *Triceratium basilica* Brun and *Coscinodiscus payeri* disappear at the base of this zone. According to correlation with Strelnikova's scheme [26] and with the *B. hyperborea* zone of Kara Sea [11] the *Golovenkinia polyactis* zone corresponds to NP13 zone.

It can be noted that the diatom succession from the bore-hole No. 228 is very similar to those of Kara Sea [11] and of eastern Ural region and western Siberia [26].

4. Discussion and palaeogeographical conclusions

The lithological succession in bore-hole No. 228 in the Petchora Depression is similar to those described in eastern Ural and western Siberia sequences. In these adjacent regions the vertical replacement of the Paleocene gaize-clay formation by the Eocene diatomites is also observed.

The gaizes and clays of the Kirshorskaya formation probably reflect the Thanetian transgression (section interval between 357.0 and 274.8 m), whereas the Voravogskaya formation between 271.4 and 267.1 m could possibly reflect the Early Ypresian regression. The discontinuity at the boundary between the Kirshorskaya and Voravogskaya formations and the lack of the lowermost Eocene dinoflagellate zones, defined in western Europe — the *G. ordinata* and *W. astra* zones [9, 23] would imply that the diatomites and diatomite clays of most of the Voravogskaya formation (266.0–86.0 m) belong to the second transgressive phase identified, the Ypresian transgression. Remains of this second transgression, followed by the intensive bio-silicification [27] are recognised in the adjacent regions in the north of the Polar Ural [28] and in the Paï-Hoï [20]. The presence of diatoms in the sediments in the Vishera River region, southward of the studied area, allows us to assume that the marine basin existed at that time as far as the Mid Ural region [25].

The microbiota assemblages, determined in bore-hole No. 228, reveal a broad similarity with western Siberian assemblages. Hence, the diatoms *Pyxilla gracilis*, *Coscinodiscus payeri* and *Moisseevia uralensis* are widely distributed in this adjacent region. The dinoflagellate species *Cerodinium markovae* (Vozzhennikova) Lentin and Williams (Paleocene), and *Wetzeliella coronata* Vozzhennikova and *Soaniella granulata* Vozzhennikova (Eocene) were previously considered as western Siberian endemics. Their occurrence in the studied section suggests, however, that stable communication existed between the Petchora and western Siberia marine basins during Late Paleocene–Early Eocene.

The results of the diatom and dinoflagellate study allow then to interpret the Petchora marine basin palaeoenvironmental conditions during the Early Paleogene. The dominance in the dinoflagellate assemblages of the ecogroups '*Deflandrea*' (*Deflandrea* and *Cerodinium*) and 'Wetzelielloideae' (*Apectodinium* and *Wilsonidium* in the Thanetian, *Wetzeliella*, *Dracodinium* and *Charlesdownlea* in the Ypresian) with, sometimes, the participation of *Areoligera*, *Glaphyrocysta* and *Spiniferites* genera, indicates shallow-water settings and a possible existence of lagoon and estuarine conditions in the Petchora marine basin during the Thanetian-Ypresian interval. The Eocene diatom associations, recognized in the studied record, are characterized in general by the predominance of meroplanktonic and tychopelagic species typical for epicontinental conditions. The increase of open sea diatoms, indicating the maximum transgressive event is observed in the *Golovenkinia polyactis* zone interval (Late Ypresian).

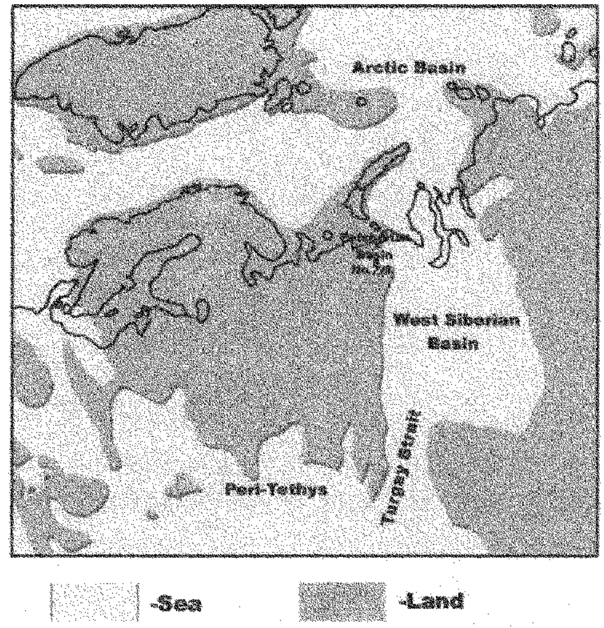

Figure 4. Paleogeographic reconstruction of the Arctic, Petchorian and Siberian Basins during the Thanetian–Ypresian.

Figure 4. Reconstitution paléogéographique des bassins Arctique, Sibérien et de Petchora pendant le Thanétien–Yprésien.

Hence, our lithological and palaeontological results permit the modification of the Paleogene palaeogeographical model of Polar and Pre-Polar Ural area, previously proposed by Shatsky [24], Ziegler et al. [30], Marincovich et al. [18] and Kazmin and Natapov [16]. We assume that the Thanetian–Ypresian sedimentation in the Petchora Depression and western Siberia happened in one marine basin (*figure 4*).

In conclusion, the geological investigations of the Paleogene Petchora Depression provide new data to characterize the Paleogene Arctic history such as the exact times of different seaway connections, and to reconstruct the palaeogeography of northern Russia and the whole Arctic Basin area.

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