

Diatom turnover in the early Paleogene diatomite of the Sengiley section, Middle Povolzhie, Russia: A response to the Initial Eocene Thermal Maximum?

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ABSTRACT

The lower Paleogene sequence in the Middle Povolzhie (Ulyanovsk-Saratov syncline) of Russia is dominated by a terrigenous-rich siliceous facies with abundant and well-preserved siliceous plankton. Calcareous microfossils are virtually absent. The diatom successions of the Sengiley diatomite are correlated to diatom assemblages of the Fur Formation (Denmark) and the Polosataya Formation (Kazakhstan), and are calibrated to calcareous nannofossil and dinocyst zonations. The *Trinacria ventriculosa* Zone, which is found in the lower part of the Sengiley diatomite (Kamyshin Formation), is age equivalent to the upper part of calcareous nannofossil zones NP8 through NP9a. The upper part of the Sengiley diatomite ((Kamyshin Formation; *Hemiaulus proteus* Zone) can be correlated to the uppermost part of the *Apectodinium augustum* dinocyst Zone, which corresponds to the NP9b calcareous nannofossil Subzone, in which the globally observed negative carbon isotope excursion (CIE) occurs.

A major floral turnover in the upper third of the Sengiley diatomite is characterized by a succession of bioevents, including first appearances at generic and specific levels. Quantitative diatom analyses show pronounced compositional changes: (1) the decline of the meroplanktonic *Pyxidicula* group, typical of neritic conditions (2) the increase of the *Paralia* group, a marker for the proximity of the shoreline, and (3) a relatively high abundance of pelagic cosmopolitan species. Grain size analyses show an increase in terrigenous input in the upper part of Sengiley diatomite. The floristic and lithologic shifts indicate changes from stable, highly productive neritic conditions during a sea-level lowstand (Phase 1) to the onset of a transgression (Phase 2), which is followed by a highstand (Phase 3). The highstand phase coincides with enhanced exchange between the Tethys and the adjacent epicontinental seas. The diatom bioevents in Phases 2 and 3 in the Sengiley section are most probably coeval to the well-documented biotic changes of the Initial Eocene Thermal Maximum (IETM).

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INTRODUCTION

During the Thanetian, the Ulyanovsk-Saratov syncline was the proximal part of a gulf from the northern Peri-Tethys (Radionova et al., 1999). Sediments accumulating in the gulf consisted of diatomites and cherts, partly enriched in terrigenous components, with abundant diatoms, radiolaria, and silicoflagellates (Fig. 1).

One of the most important upper Paleocene–lower Eocene reference sections is a ~26 m-thick sequence near the village of Sengiley, consisting of pure, homogeneous diatomites. The stratigraphic study of Sengiley diatoms was pioneered by Jousé (1949, 1979, 1982). The Sengiley assemblages were investigated by many other authors (Gleser et al., 1977; Gleser, 1979; Strelnikova, 1992; Gleser, 1994, 1995; Khokhlova and Oreshkina, 1999). Due to the lack of calcareous plankton and paleomagnetic stratigraphy, the common approach to dating the Sengiley diatomite has been to correlate the observed diatom assemblages with diatom zones from areas where calibration with calcareous nannoplankton zones is possible.

The Sengiley diatom flora is similar to assemblages in sediments deposited at high latitudes of the Southern Hemisphere, such as the Falkland Plateau (Deep Sea Drilling Project [DSDP] Site 327A; Gombos, 1976), the South Atlantic (DSDP Site 700; Fenner, 1991), the Cape Basin (DSDP Site 524; Gombos, 1984),

the East Indian Range (DSDP Site 214; Jousé, 1982; Mukhina, 1976), and the eastern Indian Ocean (Ocean Drilling Project [ODP] Site 752; Fourtanier, 1991). Such nearly global correlations help to date Sengiley diatom successions, and place them in the late Paleocene (Selandian–Thanetian) to early Eocene (NP5–NP10).

Radiolarian data (Kozlova, 1994; Khokhlova and Oreshkina, 1999), also based on the correlation of regional zonal divisions with pelagic zones, constrain the age of Sengiley diatomite to the equivalent of calcareous nannofossil zones CP3–CP8 (NP4–NP9). Our reexamination of the diatom successions will attempt to confine the stratigraphic position of the diatom assemblages in this area more rigorously, using new data from key sections in the neighboring regions of the northern Peri-Tethys. In addition, we intend to reconstruct the paleoenvironments using the relative abundance of dominant diatom groups and grain size distribution.

GEOLOGICAL SETTING AND STRATIGRAPHY

The Paleocene–Eocene sedimentary section (~300 m thick) in the Ulyanovsk–Saratov syncline in the middle Volga area (Fig. 1), includes five lithological units: (i) the lower Syzran Subgroup (100 m thick, Danian); (ii) the upper Syzran Subgroup (30 m, Selandian); (iii) the Saratov Formation (70 m, Thanetian–

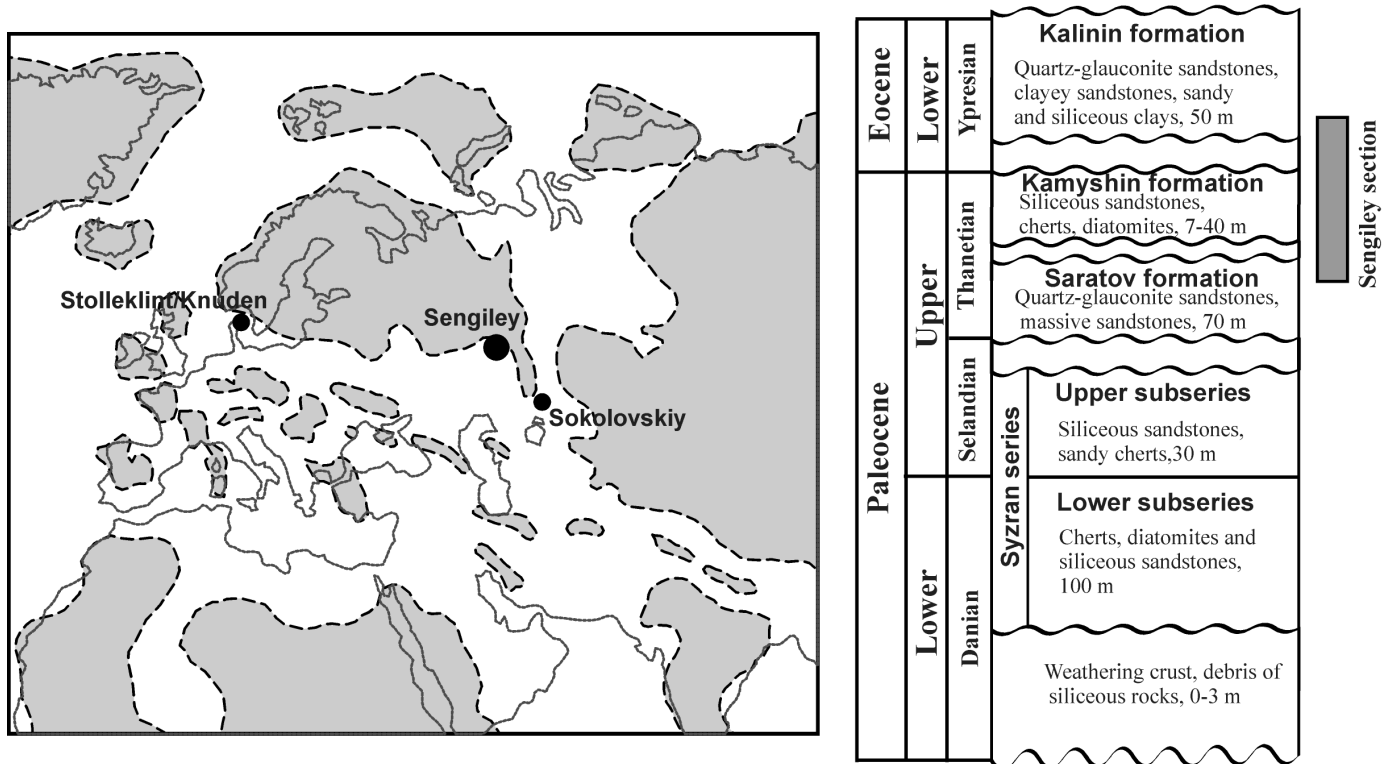


Figure 1. Location of the Sengiley section (Russia), and the correlative sections of the Stolleklint-Knuden (Denmark) and Sokolovskiy (Kazakhstan), shown in the paleogeographic setting of the area in the latest Paleocene. The figure on the right shows the Tertiary succession in the Ulyanovsk-Saratov syncline together with the stratigraphic position of the Sengiley section (shaded area).

ian); (iv) the Kamyshin Formation (7–40 m, Thanetian); and (v) the Kalinin Formation (50 m, Ypresian).

The Sengiley section (Figs. 1, 2) is located 7 km northwest of the village of Sengiley (Fig. 1) and is presently located ~400 m above sea level. Three depositional cycles are recognized in a well-exposed quarry at the hill Granoye Ukho. In this outcrop, Cretaceous deposits (Maastrichtian) are overlain by a rhythmically layered terrigenous-siliceous sequence (30–40 m), attributed to the Saratov Formation. This unit is represented by alternating dark-gray, silicified, thin-layered glauconitic sandstones and siliceous clays with chert nodules. Preliminary sampling of diatoms and dinocysts from this series has shown that diatoms

are poorly preserved and cannot be identified. The samples yield dinocysts typical of the *Alisocysta margarita* Zone, a time equivalent to calcareous nannofossil zone NP8 (Aleksandrova, 2001, personal commun.).

The overlying Sengiley diatomite is ascribed to the Kamyshin Formation and is ~26 m thick. It is divided into two parts. The lower part (some 19 m thick), is made up of white, massive diatomite with many grayish intercalations, in places with glauconite. Samples 109–72 from the lower part display well-preserved diatoms, silicoflagellates, and radiolarians. The upper 6–7 m interval is composed of light-gray, massive, clayey diatomite, resting conformably on the underlying sequence.

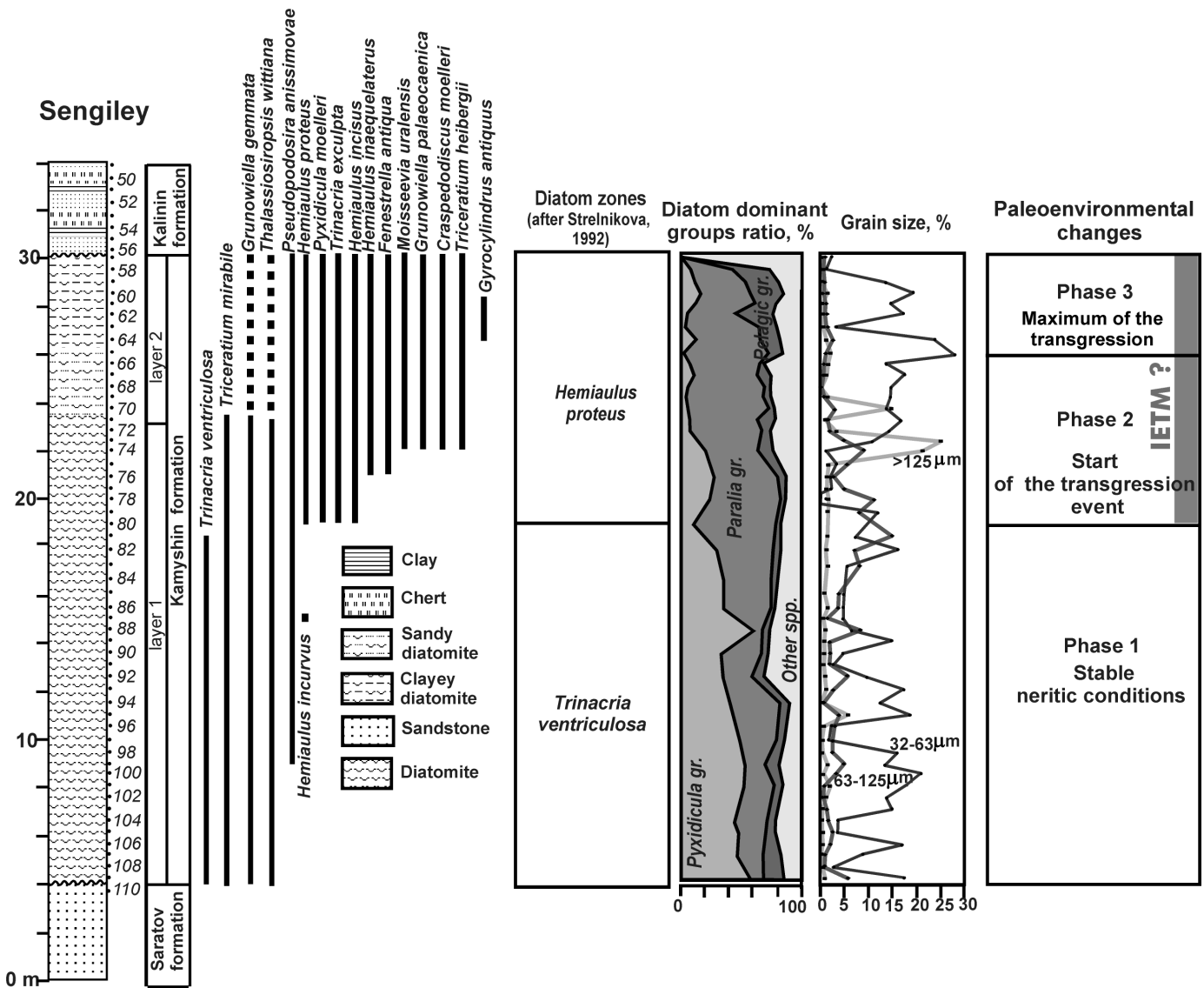


Figure 2. Stratigraphic ranges of selected diatom species in the studied Sengiley section, including the first appearances of the genera *Fenestrella*, *Moisseevia*, *Craspedodiscus*, and *Gyrocyllindrus*. Also included are the biozonation, the relative abundances of dominant diatom taxa, grain size changes, and a summary of the paleoenvironmental interpretation. Stratigraphic interval in m is indicated on the left of the lithologic column, sample number on the right.

Samples 71–58 from this interval contain well-preserved diatoms, silicoflagellates, and radiolarians.

The diatomites are unconformably overlain by the Kalinin Formation (11 m in thickness) which is represented by alternating brownish green clays, grayish-green siliceous sandstones, brownish sandy cherts, and dark gray cherts (Samples 56–42). No microfossils have been found in this unit.

MATERIAL AND METHODS

In 1994, the Sengiley section was sampled for microfossils studies during the field trip of the Geological Institute, Russian Academy of Sciences and the Simbirsk Geological Survey. Sample locations with a sampling interval of ~0.5 m are shown in Figure 2.

We used a standardized procedure of laboratory treatment and diatom slide preparation (Jousé et al., 1974). Species identifications were checked at 1250× magnification. Of 67 samples processed, 51 yielded siliceous microfossils, while 17 were barren. In order to calculate the relative abundance of dominant diatom species, 300–350 diatom valves were counted in each sample. For grain size analyses, 5 g of sediment was disaggregated in distilled water mixed with 3 ml of 10% H₂O₂ and placed on a shaker for several days. Then, the samples were wet sieved. Subsequently the different size fractions were dried and weighed.

DIATOM BIOEVENTS

Almost all the samples from the Sengiley diatomite contain abundant and excellently preserved diatom and silicoflagellate assemblages (>65 diatom species and ~10 silicoflagellate species, Fig. 4). The diatom and silicoflagellate floral lists with basionyms, synonyms and stratigraphic occurrences are given in Khokhlova and Oreshkina (1999). The stratigraphic framework of the Sengiley diatomites is based on the diatom zonation for Northern latitudes after Strelnikova (1992).

The *Trinacria ventriculosa* Zone, corresponding to calcareous nannofossil Zones NP8–NP6 after Strelnikova (1992), is recognized in the lower part of the diatom sequence (Samples 109–80). The zonal assemblage consistently includes *Triceratium mirabile* Jousé, *Grunowiella gemmata* (Grunow) Van Heurck, *Thalassiosiropsis wittiana* (Pantocsek) Hasle, *Trinacria ventriculosa* (Schmidt) Gleser, and *Pyxidicula ferox* (Greville) Strelnikova et Nikolaev. In the upper part of the zone, sporadic *Hemiaulus incurvus* Shibkova are found and *Pseudopodosira anissimovae* (Gleser et Rubina) Strelnikova first appears.

The *Hemiaulus proteus* Zone, corresponding to calcareous nannofossil zone NP 9 after Strelnikova (1992) is recognized in the upper part of the diatomite sequence (Sample 80–56). Its base coincides with the first appearance of *Hemiaulus proteus* Heiberg, but upsection a number of new taxa gradually appear (Fig. 2). Simultaneously, the abundance of *Thalassiosiropsis wittiana* and *Triceratium mirabile* declines to a few specimens. The genus *Hemiaulus* becomes more diverse, as *Hemiaulus proteus*

Heiberg, *H. inaequilaterus* Gombos, and *H. incisus* Hajos successively have their first appearances. In the genus *Grunowiella*, the species *G. palaeoceanica* Jousé has its lowest occurrence. A turnover in the genus *Pyxidicula* occurred, as evidenced by the upsection decline of this genus and the first appearance of *Pyxidicula moelleri* (Schmidt) Strelnikova et Nikolaev.

A remarkable feature of this assemblage is the appearance of a taxon identified as *Triceratium heibergii* Grunow sensu Gombos (1984). Its relict morphologic features resemble those of the early Paleocene species *Trinacria heibergiana* (Grunow) Gleser. Characteristically, its stratigraphic range is limited to short interval within calcareous nannofossil zone NP9 (Gombos, 1984).

There is also a turnover in taxonomic composition at the generic level. Several new genera appear, such as *Craspedodiscus*, *Fenestrella*, *Moisseevia*, and *Gyrocyllindrus*. The last two genera are monotaxic and short-lived. The genus *Moisseevia* represented by *M. uralensis* (Jousé) Strelnikova (1997) was described based on a revision of the species *Coscinodiscus uralensis* Jousé from Paleogene localities in the Russian territory, including the Sengiley diatomite. This taxon has features in common with both the planktonic genus *Coscinodiscus* and the benthic genus *Aulacodiscus*. The identity of this taxon as *Coscinodiscus josefinus* Grunow (1884) is suggested by Gleser and Stepanova (1994) and Strelnikova (1997) in marine deposits of the Barentz sea near Frantz-Josef Land. Homann (1991), in her monograph on diatoms of the Fur Formation, Denmark, placed *Coscinodiscus josefinus* Grunow in synonymy of *Aulacodiscus suspectus* Schmidt (1876). These taxons look identical, but no formal comparison of holotypes has been carried out.

The genus *Gyrocyllindrus* Strelnikova et Nikolaev, 1995 (= *Cylindrospira* Mitlehner, 1995) can be distinguished by its particular morphology, which renders it similar to genera that belong to different orders. It shows similarity to *Cerataulina* Peragallo, the freshwater genus *Aulacoseira* Thwaites, and the fossil tubular genera *Gladius* and *Pyxilla* (Strelnikova and Nikolaev, 1995; Mitlehner, 1995). Only the presence of the linking, flattened pads on top of the valve make it possible to tentatively attribute it to the order *Biddulphiales* (Strelnikova and Nikolaev, 1995; Mitlehner, 1995). *Gyrocyllindrus antiquus* has an extremely short stratigraphic range. It was endemic to the European part of the northern Peri-Tethys, as it has been reported only from two localities, the Fur Formation in Denmark and the Sengiley diatomite. In conclusion, the Sengiley section exhibits a significant turnover in the diatom taxonomy in the upper part of the diatomite sequence.

BIOSTRATIGRAPHIC CORRELATION

The diatom successions from the Sengiley section reveal affinities to assemblages reported from sediments in the Southern Ocean, and resemble diatom associations from neighboring regions of the northern Peri-Tethys, especially the Fur Formation in northern Denmark (Homann, 1991; Fenner, 1994;

Mitlehner, 1996), the Sambiiskaya Formation in the Kaliningrad Region, Russia (Strelnikova et al., 1978), the Veshenskaya and Buzinovskaya Formations, the Voronezh depression (Strelnikova, 1992), the Polosataya Formation in the Sokolovsky quarry, the Turgay basin (Radionova et al., 2001), and the Serovskaya/Irbitskaya Formations on the eastern slope of the Sub-Polar Urals (Kozlova and Strelnikova, 1984). Only from the Fur Formation, Denmark and the Polosataya Formation in the Sokolovsky quarry (Kazakhstan), however, are data from other plankton groups such as dinocysts (in the Fur Formation) and calcareous nannoplankton and dinocysts (in the Sokolovskiy quarry) available to construct a biostratigraphic age model, making it possible to correlate these regional zonations to pelagic zonations.

A correlation of the Sengiley diatom successions with diatom assemblages from the StolleKlint-Knuden sections, Fur Formation, and Polosataya Formation in the Sokolovsky quarry is presented in Figure 3.

A virtually identical set of species in samples from the Fur Formation and the Sengiley diatomite and, in particular, the

presence of stratigraphic key species such as the short-lived *Gyrocylindrus antiquus* (= *Cylindrospira simsii* Mitlehner, 1995) along with *Craspedodiscus moelleri*, *Hemiaulus proteus*, and *Moisseevia uralensis*, make it possible to correlate the upper part of the Sengiley sequence, in which the *Hemiaulus proteus* Zone is recognized, reliably with the lower part of the StolleKlint/Knuden section. This interval corresponds to the dinocyst *Apectodinium augustum* Zone and Viborg Zone 6 (Heilmann-Clausen, 1985, 1995).

The intervals of biogenic silica accumulation in the Sengiley section and the StolleKlint-Knuden section do not completely coincide. In the StolleKlint-Knuden section, the lower part of the *Apectodinium augustum* Zone, which is characterized by the *Apectodinium* spp. acme, there are no diatoms. The upper part of the StolleKlint-Knuden section, representing Viborg Zone 7 (= *Glaphirocysta ordinata*), is not represented in the Sengiley section.

Correlation with the Sokolovsky quarry section (Radionova et al., 2001) is less reliable due to differences in the diatom floras, with the diatoms from the Sokolovsky section indicating

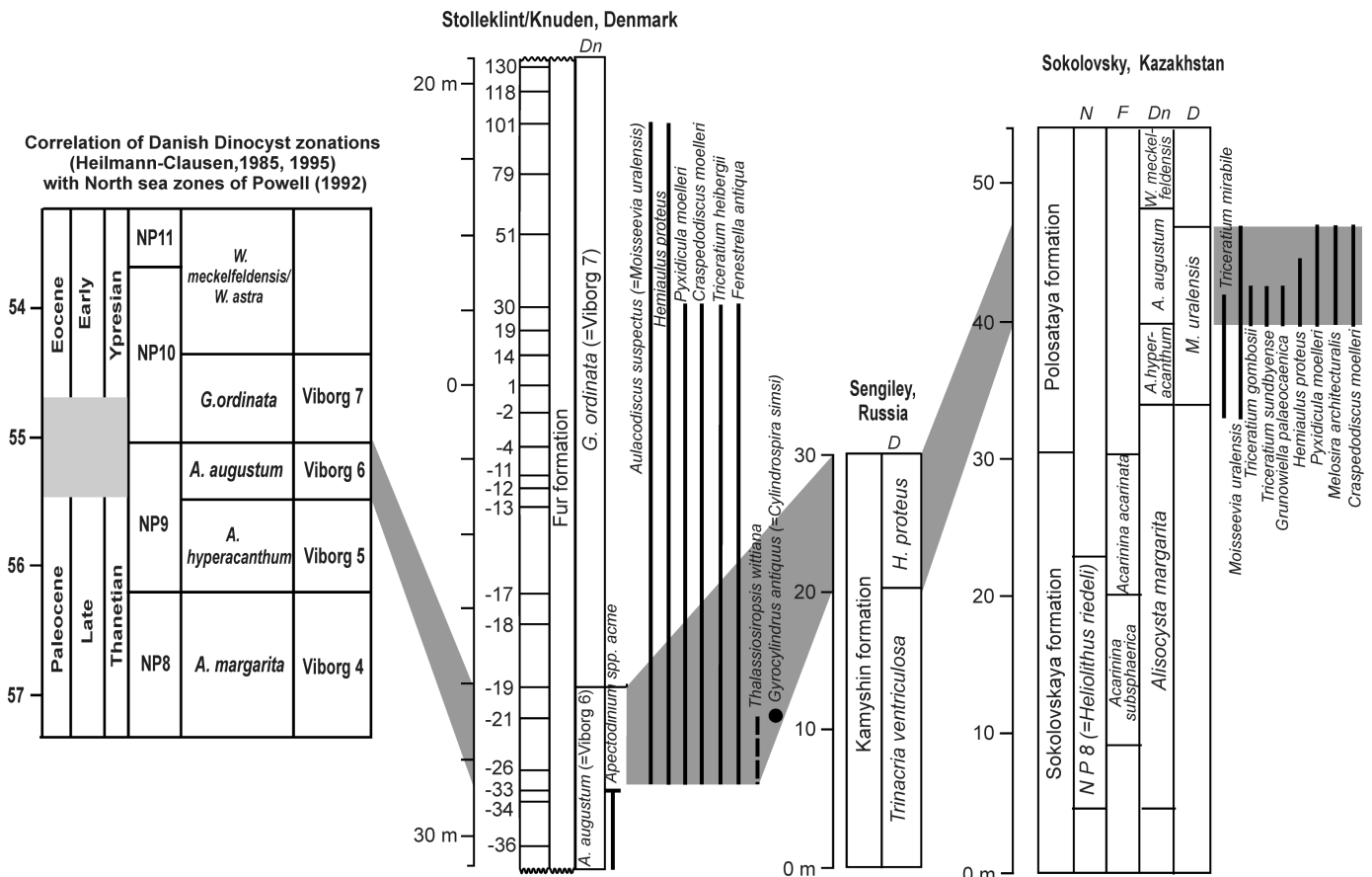
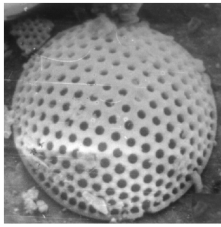
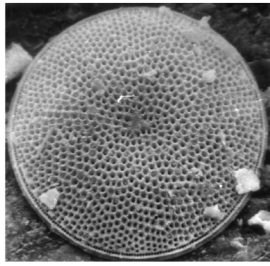


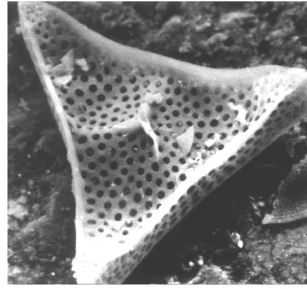
Figure 3. Correlation of the Sengiley section with the StolleKlint-Knuden and Sokolovsky sections. For the StolleKlint-Knuden section, the dinocyst zonation (Dn) is after Heilmann-Clausen (1985, 1995). Stratigraphic ranges of selected diatoms are after Homann (1991). For the Sengiley section, diatom (D) zonation is after Strelnikova (1992). For the Sokolovsky section, nannofossil (N), foraminifera (F), dinocystes (Dn), and diatom (D) zonations are after Radionova et al. (2001). The grey-shaded intervals indicate the correlation by diatoms.



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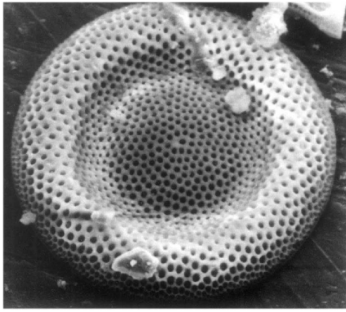
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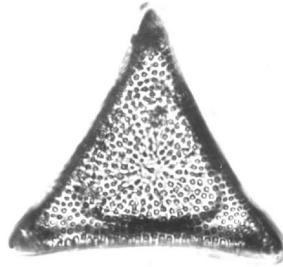
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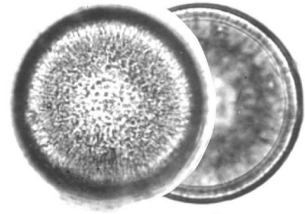
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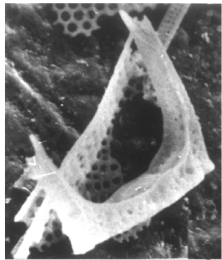
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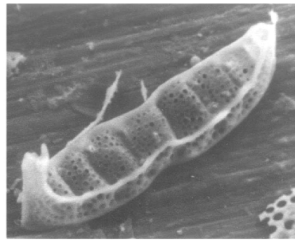
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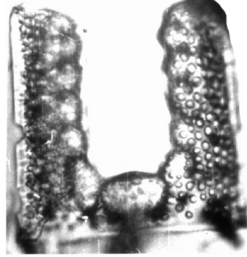
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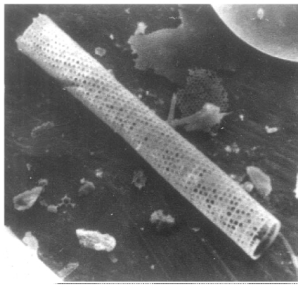
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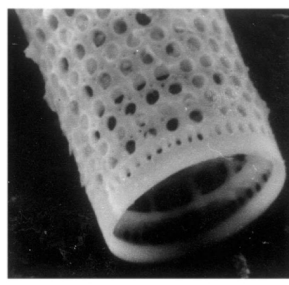
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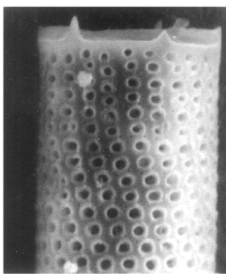
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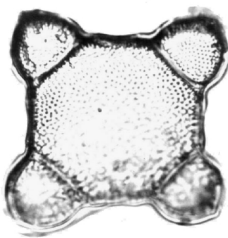
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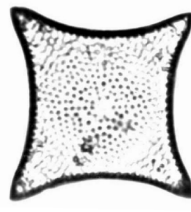
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more offshore paleoenvironments. The data generally suggest that the diatom assemblages of the upper part of the *Moisseevia uralensis* Zone of Radionova et al. (2001) in the Sokolovskiy section can be correlated with the *Hemiaulus proteus* Diatom Zone in the Sengiley section. Particularly, the occurrences of *Craspedodiscus moelleri*, *Hemiaulus proteus*, *Moisseevia uralensis*, and *Triceratium mirabile* suggest biostratigraphic equivalence. The presence of dinocysts corresponding to those in the *Apectodinium augustum* Zone in the Sokolovskiy quarry section also suggests correlation with the lower part of the StolleKlint-Knuden section in Denmark (Fig. 3).

Radionova et al. (2001) noted the similarity of the Sokolovskiy diatom assemblages to those from ODP Site 752 in the eastern Indian Ocean (Fourtanier, 1991). This deep-sea section, which recovered Paleocene-Eocene transitional strata, provides data to correlate diatom and nannoplankton assemblages directly with the negative carbon isotope excursion (CIE), and benthic extinction event (BEE) (Nomura, 1991). The Paleocene-Eocene boundary has been placed at the lower boundary of the carbon isotope excursion. These events thus coincide with boundaries of Subzones B and C of the *Hemiaulus incurvus* diatom Zone (upper part of CP8), as proposed by Fourtanier (1991). Characteristically, *Triceratium mirabile* from ODP Site 752, has a dashed range just above the CEE and BEE events. This provides indirect evidence that, in the Sengiley section, the Paleocene-Eocene biotic crisis correspond roughly to the *Trinacria ventriculosa*–*Hemiaulus proteus* zonal boundary, which would make this equivalent to the Paleocene-Eocene boundary.

Stratigraphic assignment of the lower part of the Sengiley section, corresponding to the *Trinacria ventriculosa* Zone, is more questionable. The Sengiley diatomite might correspond to the entire *Apectodinium augustum* dinocyst Zone, but possibly also covers the upper part of the *Apectodinium hyperacanthum* dinocyst Zone. These stratigraphic data constrain the phase of considerable taxonomic rearrangement to the top of the *Apectodinium* spp. acme and the upper limit of the *Apectodinium augustum* Zone. According to the data of Egger et al. (2000) on the Anthering section in Austria and Heilmann-Clausen and Schmitz (2000) data on Danish sections in Olst-Hinge in eastern Jylland and in the DGI 83 101 borehole in Osterrenden, Store Bolt, the level of the global negative carbon isotope excursion (CIE) corresponds to the upper part of the *Apectodinium augustum* Zone (= NP9b).

PALEOENVIRONMENTAL CHANGES

In general, the taxonomically rich diatom associations of the Sengiley diatomite are typical of epicontinental seas, as they are dominated by neritic diatoms. This category of diatoms is represented by meroplanktonic, tychoipelagic, and benthic species.

Meroplanktonic species are distinguished by their ability to produce resting spores, enabling them to survive environmental stress, such as extreme seasonal changes. Among this group of diatoms, representatives of the genus *Pyxidicula* [*P. ferox* (Greville) Strelnikova et Nikolaev, *P. turris* (Greville et Arnott) Strelnikova et Nikolaev, *P. corona* (Ehrenberg) Strelnikova et Nikolaev, *P. moelleri* (A. Schmidt) Strelnikova et Nikolaev] and the closely related genus *Costopyxis* [*C. antiqua* (Jousé) Gleser] are predominant. Representatives of other meroplanktonic diatoms are also common: *Briggera sibirica* (Grunow) Ross et Sims, *Stellarima microtrias* (Ehrenberg) Hasle et Sims, and *Fenestrella antiqua* (Grunow) Swatman. The group of so-called extinct spore-genera *Odontotropis* (*O. cristata* Grunow, *O. carinata* Grunow), *Pterotheca* (*P. kittoniana* Grunow, *P. major* Jousé), *Pseudopyxilla* [*P. rossica* (Pantocsek) Forti], *Kentrodiscus* (*K. fossilis* Pantocsek), and *Xanthiopyxis* spp., which are represented only by resting spores, is also taxonomically diverse.

In the group of tychoipelagic and benthic species, *Paralia sulcata* (Ehrenberg) Cleve, is characteristic of present-day diatom assemblages of near-shore environments. Extinct species of this genus, such as *Paralia grunowii* Gleser and *P. selecta* (A. Schmidt) Gleser, and taxonomically related species of the fossil genus *Anuloplicata* [*A. concentrica* (Grunow) Gleser, *A. ornata* (Grunow) Gleser] are predominant in samples from the Sengiley section. *Hyalodiscus radiatus* (O'Meara) Grunow, *Aulacodiscus distinguendus* Hustedt, *A. probabilis* Schmidt, *A. schmidtii* Witt, *Pseudopodosira westii* W. Smith, *P. anissimovae* (Gleser et Rubina) Strelnikova, *Pseudostictodiscus angulatus* Grunow, *Ratrayella oamaruensis* (Grunow) De Toni, *R. rotundata* (Shibkova) Gleser, *Rhaphoneis morsiana* Grunow, *R. simbirskiana* Grunow, *Actinoptychus* spp., *Arachnoidiscus* spp., and *Rutilaria* sp. are also common.

Trinacria [*T. ventriculosa* (A. Schmidt) Gleser, *T. excavata* (Ehrenberg) Grunow, *Tr. regina* Heiberg], *Trinacria exculpta* Heiberg, *Eunotogramma weissii* Ehrenberg, and *Trochosira spinosa* Kitton, which are fully planktonic but gravitate toward the near-shore zone, are important components of the flora.

Figure 4. Diatom marker-species of the Sengiley section. A: *Pyxidicula moelleri* (Schmidt) Strelnikova et Nikolaev, sample 58. B: *Moisseevia uralensis* (Jousé) Strelnikova, sample 58. C: *Triceratium heibergii* Grunow sensu Gombos, 1977, sample 58. D: *Thalassiosiropsis wittiana* (Pantocsek) Hasle, sample 100. E: *Craspedodiscus moelleri* Sample 58. F: *Trinacria ventriculosa* (Schmidt) Gleser, sample 103. G: *Pseudopodosira anissimovae* (Gleser et Rubina) Strelnikova, sample 100. H: *Hemiaulus inaequilaterus* Gombos, sample 64. I: *Hemiaulus proteus* Heiberg, sample 58. J: *Hemiaulus incurvus* Shibkova, sample 85. K: *Hemiaulus curvatus* Strelnikova, sample 67. L, M, Q: *Gyrocyllindrus antiquus* Strelnikova et Nikolaev, sample 62. N: *Hemiaulus incisus* Hajos, sample 58. O: *Grunowiella gemmata* (Grunow) Van Heurck, sample 100. P: *Grunowiella palaeocaenica* Jousé, sample 58. R: *Trinacria exculpta* (Heiberg) Hustedt, sample 67. S: *Trinacria regina* Heiberg, sample 61. T: *Triceratium mirabile* Jousé, sample 98. Scale bar indicates 10 μ m.

Pelagic species, which, as a rule, have a subglobal distribution constitute a relatively small group. These are the previously mentioned *Triceratium mirabile* Jousé, *Grunowiella gemmata* (Grunow) Van Heurck, *G. palaeocaenica* Jousé, *Thalassiosiropsis wittiana* (Pantocsek) Hasle, *Hemiaulus incurvus* Shibkova, *H. proteus* Heiberg, *H. inaequilaterus* Gombos, *H. incisus* Hajos, *Triceratium heibergii* Grunow sensu Gombos, and representatives of the genera *Coscinodiscus*, *Craspedodiscus*, *Moisseevia*, *Proboscia*, and *Rhizosolenia*.

Within the Sengiley sequence there are quantitative trends in the proportion of dominant diatom groups (Fig. 2, Table A1): The *Paralia-Anuloplicata* and *Pyxidicula* groups. The lower part of the diatom sequence is dominated by the meroplanktonic *Pyxidicula* assemblage (Fig. 2, Table A1) and their close environmental counterparts, such as *Trochosira*. This floral composition suggests that paleoenvironmental conditions were stable, in a neritic setting (Phase 1). Pelagic constituents are *Triceratium mirabile* and *Grunowiella gemmata*, *Thalassiosiropsis wittiana*.

The middle part of the sequence shows a gradual increase in the tychopelagic *Paralia-Anuloplicata* group and their environmental counterparts, such as the genus *Pseudopodosira*, with a decreasing abundance of the genus *Pyxidicula*. In the upper part of the sequence the relative abundance and species richness of the pelagic diatoms and silicoflagellates increased (Phases 2 and 3), and the short-lived, endemic species *Gyrocyllindrus antiquus* with its unusual morphological features appeared. Sporadic freshwater forms similar to the genera *Navicula* and *Aulacoseira* are present, and the relative abundance of the benthic genera *Raphoneis*, *Rutilaria*, and *Pseudostictodiscus* increases toward the upper part of the Sengiley diatomite. Grain size analysis shows an increase in terrigenous input in the upper part of the Sengiley section (Fig. 2, Table A2).

The changes in the diatom assemblages in the Sengiley diatomites, i.e., a change in the ratio of the dominant *Pyxidicula-Paralia* groups with a concurrent increase in the relative abundance and species richness of pelagic taxa, reflect the global biotic crisis at the Paleocene-Eocene boundary (Fig. 2). The assemblage characteristic of relatively stable paleoenvironmental conditions in the near-shore zone of an epicontinental basin, dominated by the characteristic neritic genus *Pyxidicula* (Phase 1 in Figure 2), is replaced by an assemblage dominated by *Paralia sulcata* and a group of species closely related to this taxon in ecological characteristics.

The environmental affinity of *Paralia sulcata* is ambiguous. Although this species is characteristic of coastal near-bottom (benthic) environments, it can also be highly abundant in planktonic associations. According to McQuoid and Hobson (1998),

this species is easily detached from the substrate when vigorous mixing occurs in near-shore waters. An increasing abundance of this species is usually related to a transgressive phases in basin evolution. According to Zong (1997), *Paralia sulcata* is tolerant of a wide range in salinity (5%–35%) and depths (>1 m), but prefers warm water enriched in organic matter. Such environmental conditions occur during a transgressive phase, because organic matter is reworked from a previously exposed shelf area. A coarsening of grain size (samples 85–73) is in agreement with a strengthening of bottom currents at the beginning of the transgressive phase (Fig. 2, Table A2). These floral and lithological changes thus may reflect the onset (Phase 2) and the highstand (Phase 3) of a transgressive cycle in basin evolution as well as a warmer climate.

We thus suggest that the turnover in diatom flora in the Sengiley section, as in many other marine and on-land sections, is the local reflection of a global event, the Initial Eocene Thermal Maximum (IETM). The significant changes in composition and structure of diatom assemblages from epicontinental basins of the northern Peri-Tethys may reflect a more vigorous exchange of surface waters with the Tethys, possibly as a result of sea-level rise, as well as warming.

CONCLUSIONS

In the Sengiley section, the IETM is reflected in: (i) a considerable turnover of the diatom flora at generic and species levels (ii) the appearance of short-lived taxa (iii) showing both new and relict morphologic features due to peculiar paleoenvironmental conditions, and an increasing communication with neighboring epicontinental basins and the Tethys. These floristic changes are accompanied by changes in current dynamics (possibly as a result of sea-level rise) as documented by changes in grain size distribution.

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APPENDICES

TABLE A1. RELATIVE ABUNDANCE OF DIATOM GENERA IN THE SENGILEY SECTION

Samples no. and depth (m)	Number of counted diatoms	%																			
		Paralia+Anuloplicata	Actinocyclus	Rhaphones	Pseudopodosira	Hyalodiscus	Trochosira	Odontella	Pyxidicula	Pterotheca	Pseudopyxilla	Trinacria	Stellarima	Grunowiella	Coscinodiscus	Moissevia	Proboscia	Hemiaulus	Triceratium	Thalassiosiropsis	
58 (29.5 m)	340	35.6	0.0	0.9	17.1	1.2	2.4	0.0	6.8	1.5	0.0	0.9	0.3	11.8	0.6	1.2	0.0	17.6	0.0	0.0	
59 (29.0 m)	367	42.0	0.3	1.1	10.9	0.8	4.1	0.3	9.8	0.8	0.0	2.2	0.3	11.4	1.1	0.5	0.5	11.2	0.0	0.0	
60 (28.5 m)	358	40.0	0.0	0.0	7.8	0.3	3.1	0.0	17.0	0.8	0.3	1.7	0.0	4.2	0.6	1.1	1.1	17.9	0.3	0.0	
61 (28.0 m)	356	51.4	0.7	0.7	10.4	0.3	0.6	1.4	12.6	2.5	0.3	2.3	0.0	5.9	0.6	0.8	0.3	6.7	0.0	0.0	
62 (27.5 m)	368	43.4	0.0	0.8	15.8	0.5	1.6	0.8	6.0	1.6	0.0	2.2	0.0	13.6	0.8	0.3	1.4	7.1	0.0	0.0	
63 (27.0 m)	346	63.3	0.3	0.9	15.0	0.0	0.9	0.3	4.1	0.3	0.3	0.9	0.0	5.5	0.0	0.6	2.9	3.5	0.3	0.0	
64 (26.5 m)	357	53.9	0.7	0.3	7.3	2.2	3.9	0.0	11.8	0.6	0.4	2.5	0.3	2.8	0.8	0.8	1.4	7.3	0.3	0.0	
65 (26.0 m)	349	70.5	0.3	0.3	9.5	0.6	0.9	0.9	2.9	0.6	0.0	2.6	0.0	4.0	0.6	0.3	1.2	3.4	0.0	0.0	
66 (25.5 m)	368	58.2	2.2	0.5	7.9	0.3	9.0	0.5	7.3	1.9	0.5	7.6	0.0	1.1	0.0	0.3	0.8	1.1	0.0	0.0	
67 (25.0 m)	398	55.0	0.8	0.3	4.3	0.8	2.0	1.8	13.8	2.3	0.0	7.8	0.0	1.8	0.0	0.5	0.5	6.3	0.3	0.0	
68 (24.5 m)	357	63.8	1.4	0.3	3.9	1.7	7.6	1.1	7.3	1.4	0.6	3.1	0.0	0.3	0.0	0.6	0.8	2.8	0.3	0.0	
69 (24.0 m)	370	62.7	1.1	0.5	6.2	1.4	5.7	1.4	6.5	2.4	0.3	4.9	0.0	1.1	0.0	1.4	0.0	3.8	0.0	0.0	
70 (23.5 m)	358	67.6	1.1	0.3	4.2	2.2	4.2	1.7	8.10	2.0	0.3	4.2	0.0	0.8	0.0	0.6	0.6	1.4	0.0	0.0	
71 (23.0 m)	341	53.1	0.6	0.3	6.5	3.2	2.1	1.8	8.5	1.5	0.6	10.3	0.0	1.8	0.0	0.9	2.4	4.4	0.0	0.6	
72 (22.5 m)	372	59.4	0.8	0.0	5.4	2.5	4.8	0.8	8.9	4.0	0.8	4.8	0.0	1.1	0.0	0.8	1.6	2.4	0.0	0.3	
74 (21.5 m)	377	43.8	1.1	0.5	1.6	4.5	3.7	3.7	20.4	4.8	0.5	5.6	0.5	0.5	0.0	0.8	1.1	5.8	0.3	0.0	
76 (20.5 m)	384	48.2	0.0	0.0	2.9	3.4	1.6	1.6	28.4	0.0	1.0	3.7	0.3	1.6	0.0	0.0	0.8	3.4	1.3	0.3	
78 (19.5 m)	346	57.2	0.0	0.0	2.3	1.5	1.7	0.0	24.6	0.3	0.6	4.6	0.9	0.3	0.0	0.0	0.3	1.5	0.6	0.0	
80 (18.5 m)	370	68.1	0.0	0.0	6.5	2.2	0.5	0.0	10.3	0.5	0.0	5.1	0.5	0.3	0.0	0.0	0.5	1.6	1.7	0.3	
82 (17.5 m)	388	40.2	1.6	0.0	0.5	4.6	3.4	0.5	35.1	1.8	1.0	1.6	0.8	0.0	0.0	0.0	1.0	2.6	2.6	0.3	
84 (16.5 m)	332	36.1	0.3	0.0	0.9	3.3	5.4	0.6	37.1	1.2	0.6	3.0	0.9	0.0	0.0	0.0	0.9	0.9	3.3	1.5	
86 (15.5 m)	365	37.5	1.6	0.0	4.9	3.0	2.7	0.3	36.7	0.8	0.6	3.8	0.3	0.3	0.0	0.0	0.0	1.1	1.9	0.6	
88 (14.5 m)	369	6.8	0.5	0.0	3.0	4.6	3.8	2.7	58.3	1.6	0.3	5.4	1.4	0.3	0.0	0.0	0.5	2.2	2.7	3.4	
90 (13.5 m)	350	33.4	0.0	0.0	4.0	4.0	6.9	0.9	35.7	0.6	0.3	4.9	0.9	0.0	0.0	0.0	0.7	0.9	2.6	1.7	
92 (12.5 m)	346	19.7	0.0	0.0	2.0	7.5	8.7	1.2	35.6	0.3	0.0	2.6	7.5	0.0	0.0	0.0	0.9	1.7	5.5	0.9	
94 (11.5 m)	318	20.4	0.0	0.0	3.1	1.9	16.7	0.9	41.2	0.3	0.3	4.4	0.0	0.6	0.0	0.0	0.9	0.9	6.0	0.0	
97 (10.0 m)	339	26.8	0.3	0.0	0.3	2.7	4.1	0.3	49.6	1.8	0.0	3.2	0.3	0.9	0.0	0.0	0.3	1.2	3.8	0.9	
99 (9.0 m)	345	15.1	0.3	0.0	0.3	3.8	10.7	0.3	51.6	0.0	0.6	3.5	0.6	2.0	0.0	0.0	0.0	1.2	7.3	0.9	
101 (8.0 m)	342	23.1	0.0	0.0	0.0	2.3	3.2	0.0	53.5	0.3	0.6	2.9	1.2	2.1	0.0	0.0	0.6	3.5	1.2	1.8	
104 (6.5 m)	340	23.8	0.0	0.0	0.0	2.7	12.7	0.9	44.7	2.4	0.3	1.5	0.3	2.7	0.0	0.0	0.9	0.9	2.1	0.3	
105 (6.0 m)	332	22.6	0.6	0.0	0.6	2.4	7.5	1.5	49.4	0.6	0.3	3.0	0.3	3.0	0.0	0.0	0.6	1.8	3.3	0.6	
107 (5.0 m)	321	21.5	0.0	0.0	1.3	3.4	7.2	0.0	42.1	0.3	1.7	3.4	0.6	3.4	0.0	0.0	0.9	5.3	4.4	0.3	
109 (4.0 m)	321	8.4	0.0	0.0	1.0	3.4	3.4	0.6	57.3	0.9	0.6	3.4	0.0	5.6	0.0	0.0	1.6	3.1	5.3	2.5	

TABLE A2. GRAIN SIZE ANALYSIS OF THE DIATOMITE OF THE SENGILEY SECTION

Sample no. and depth (m)	Weight (g)	>125 μ m (%)	63–125 μ m (%)	32–63 μ m (%)
57 (30.0 m)	2.50	0.31	0.83	3.28
58 (29.5 m)	2.50	0.41	0.89	1.38
59 (29.0 m)	2.50	0.29	0.68	14.01
60 (28.5 m)	2.50	0.58	0.96	19.34
61 (28.0 m)	2.50	0.78	0.86	13.69
62 (27.5 m)	2.50	0.97	1.42	17.40
63 (27.0 m)	2.57	0.98	1.58	4.45
64 (26.5 m)	2.50	0.85	3.25	24.85
65 (26.0 m)	2.50	1.78	0.98	27.45
66 (25.5 m)	2.50	1.30	0.74	14.31
67 (25.0 m)	2.50	0.62	0.84	18.39
68 (24.5 m)	2.50	0.09	0.20	13.20
69 (24.0 m)	2.50	1.30	0.96	14.84
70 (23.5 m)	2.50	15.77	2.65	13.52
71 (23.0 m)	2.50	2.26	2.13	17.20
72 (22.5 m)	2.50	4.08	1.66	14.26
73 (22.0 m)	3.03	25.66	5.07	11.10
74 (21.5 m)	2.50	22.10	9.22	1.22
75 (21.0 m)	2.50	1.50	6.14	4.21
76 (20.5 m)	2.50	1.70	2.40	1.52
77 (20.0 m)	2.50	2.16	4.52	2.40
78 (19.5 m)	2.50	2.04	10.96	-5.49
79 (19.0 m)	2.50	7.65	7.65	11.68
81 (18.0 m)	2.50	1.87	30.12	7.21
82 (17.5 m)	2.50	1.21	6.68	16.81
83 (17.0 m)	2.50	1.25	7.61	5.88
85 (16.5 m)	2.50	1.10	8.83	4.61
86 (15.5 m)	2.62	1.85	3.51	4.90
87 (15.0 m)	2.50	0.46	1.73	5.28
88 (14.50 m)	2.50	0.80	8.44	6.64
89 (14.0 m)	3.06	1.01	2.30	15.79
90 (13.5 m)	2.44	1.04	2.38	5.06
91 (13.0 m)	2.98	0.10	2.42	3.40
92 (12.5 m)	2.64	1.23	5.98	9.88
93 (12.0 m)	2.70	5.25	13.05	5.61
94 (11.5 m)	2.69	0.45	0.87	12.46
95 (11.0 m)	2.79	5.86	3.53	18.67
96 (10.5 m)	2.54	1.19	3.43	3.12
97 (10.0 m)	3.50	0.70	1.62	2.06
98 (9.5 m)	3.40	0.72	3.29	16.40
99 (9.0 m)	2.72	2.02	4.65	14.11
100 (8.5 m)	2.73	0.55	3.66	20.81
101(8.0 m)	3.03	1.60	2.29	17.63
102 (7.5 m)	2.70	1.42	0.45	13.86
103 (7.0 m)	2.84	0.42	1.60	15.23
104 (6.5 m)	2.97	0.92	2.13	4.37
105 (6.0 m)	3.03	0.84	2.79	4.11
106 (5.5 m)	2.81	0.53	2.41	17.41
107 (5.0 m)	2.68	0.55	1.61	8.59
108 (4.5 m)	2.59	0.96	2.13	3.22
109 (4.0 m)	2.93	1.09	2.63	18.18

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