Stratigraphical evidence of environmental change in Lake Baikal, associated with recent changes in climate

A.W. Mackay, R.J. Flower & R.W. Battarbee

Final Report to the Leverhulme Trust on Grant: F.134 AZ

February 1996

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RECENT ENVIRONMENTAL CHANGE IN LAKE BAIKAL,
EASTERN SIBERIA, WITH SPECIAL REFERENCE TO THE
SEDIMENTARY DIATOM RECORD

by

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February 1996
## CONTENTS

1. Introduction 3  
2. Specific Achievements 5  
3. Results 6  
4. Research Conclusions 7  
5. Overall Evaluation of the Study 8  
6. Publications 9  
7. General references 11  
8. Acknowledgements 11  
9. Appendices:  

   $^{210}$Pb, diatom, metal and carbonaceous particle analyses  

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.1</td>
<td>Radiometric dating</td>
<td>13</td>
</tr>
<tr>
<td>9.2</td>
<td>Diatom stratigraphies</td>
<td>53</td>
</tr>
<tr>
<td>9.3</td>
<td>% dry weight</td>
<td>73</td>
</tr>
<tr>
<td>9.4</td>
<td>% LOI 550 °C</td>
<td>74</td>
</tr>
<tr>
<td>9.5</td>
<td>Trace metal profiles</td>
<td>75</td>
</tr>
<tr>
<td>9.6</td>
<td>Carbonaceous particles</td>
<td>76</td>
</tr>
</tbody>
</table>

Reprints of major publications  

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.7</td>
<td>Recent environmental change</td>
<td>82</td>
</tr>
<tr>
<td>9.8</td>
<td>An improved box corer</td>
<td>87</td>
</tr>
<tr>
<td>9.9</td>
<td>Crateriportula gen. nov.</td>
<td>97</td>
</tr>
<tr>
<td>9.10</td>
<td>British research on Baikal</td>
<td>102</td>
</tr>
<tr>
<td>9.11</td>
<td>Review of Foged collection of Baikal diatoms</td>
<td>108</td>
</tr>
<tr>
<td>9.12</td>
<td>Re-evaluation of endemic Cyclotella spp.</td>
<td>157</td>
</tr>
</tbody>
</table>
I. INTRODUCTION

Lake Baikal is the world's largest standing body of freshwater and is internationally famous for its rich and largely endemic flora and fauna (Kozhov 1963). Despite its isolated location in SE Siberia, effluent from the large wood pulp precessing factory on the lake's southern shore and from the major inflow, the Selenga River (Fig. 1) give cause for concern about the present and future state of the lake ecosystem. Atmospheric pollution has been mounting since the late 1970s and this possesses an additional contamination threat to the lake. Pollution impact on the biota of the lake is often cited as causing declining endemic white fish stocks and the spread of viral distemper within the Baikal seal population (Galazii 1991). However, these biological changes are not necessarily directly related to water pollution (Grachev 1994).

One way to assess the impact of water pollution on the Lake Baikal ecosystem is to examine long term records of biological change and water pollution. Such an approach using documentary data is inapplicable for Lake Baikal because records are inadequate. An alternative source of long term environmental information lies in the sub-aquatic sediments deposited in the Baikal basin. By examining biological and chemical records in the recently deposited lake sediments, trends in environmental change can be reconstructed for the lake over the past 100 years or more. This palaeolimnological approach to understanding recent environmental change and pollution impacts in Lake Baikal was the basis of a three research programme begun in 1992 by ECRC staff following financial support from the Leverhulme Trust.

A primary focus of the Lake Baikal palaeolimnological investigation is the sedimentary diatom record. Diatoms form a very important part of the Lake Baikal ecosystem; they are planktonic algae that are sensitive indicators of water quality, particularly of nutrients. Because their siliceous skeletons preserve well in sediment, time trends in diatom species abundance changes in sediments can be very diagnostic of ecological change, ecosystem disturbance, and of pollution trends. Recent lake sediments also contain a direct pollution record that can be revealed by geochemical analysis, especially for trace metals (Zn and Pb) and carbonaceous particles (derived from fossil fuel combustion). High resolution techniques of biological and geochemical analysis of surficial sediment, together with radio-isotope measurements to provide sediment dates, have not been employed in Lake Baikal palaeoenvironmental studies.

In the first year of the investigation 1992/93 a single sediment core was collected using a novel sediment box corer, especially developed for coring Baikal sediments (Flower et al. 1995b). The resulting core was analysed for diatoms, trace metals, carbonaceous particles and magnetic properties. The results of this pilot study were given in our previous report to the Leverhulme Trust (Mackay et al. 1993) and they formed the basis of a recent publication in The Holocene (Flower et al. 1995a). In the final two years of the study many more cores were collected and analysed; the achievements of this latter study are as follows:
2. SPECIFIC ACHIEVEMENTS:

1. Twenty short sediment cores were retrieved from the three main sub-basins of Lake Baikal during the 1993 field season using a variety of sediment coring techniques. Locations of these cores are shown in Fig. 1. Most of sediment cores were obtained using the Baïkal box corer (Flower et al. 1995b) but several were collected with a modified Glew tube corer (Glew 1991).

2. Six of the twenty-five cores were selected for radio-metric dating, performed by Dr P.G. Appleby (University of Liverpool).

3. Twenty cores were sub-sampled at between 2-10 mm intervals and analysed for diatoms and for lithostratigraphic changes (performed by Dr A.W. Mackay, ECRC).

4. Trace metal and carbonaceous particle analyses were carried on the six cores used for radio-metric dating by Dr J.L. Boyle (University of Liverpool) and by Dr N.L. Rose (ECRC), respectively.

5. All the sedimentary diatom data were entered on the computer database 'Amphora' maintained by the ECRC. Numerical analysis of these data was carried out using multivariate techniques available in CANOCO (ter Braak, 1988).

6. During the course of the study we collaborated closely with several Russian scientists at the Limnological Institute Irkutsk. As a result of the project, one of these (Dr. A.E. Kuzmina, a diatom specialist) spent two months in London working collaboratively on Baikal diatoms in the ECRC laboratories. Furthermore, Drs Flower & Mackay attended and contributed to two workshops held at the Limnological Institute, Irkutsk, during 1993 and 1994.

7. Open lectures about the results of sediment studies in Lake Baikal have been given by both Drs. Mackay and Flower:
   - Royal Zoological Society (1993)
   - Fifth Workshop on Diatom Algae, Irkutsk (1993)
   - Dept. Geography, UCL, guest lecture (1993)
   - British Diatom Meeting (1993)
   - International Conference on Lake Baikal as a Natural Laboratory for Global Change, Irkutsk (1994)
   - 13th International Diatom Symposium, Italy (1994)
   - Dept. Geography, University of Manchester, guest lecture (1995)
   - Royal Society sponsored workshop on British research on Lake Baikal, including a press release 'Lake Baikal- a clean bill of health?, (September 1995).
3. RESULTS

The results of the study are given in the Appendices which contain sediment dating results, summary diatom profiles for all the sediment cores analysed, together with trace metal and carbonaceous particle data. These data are the basis of a substantial research paper being prepared by Dr A.W. Mackay for publication in *The Philosophical Transactions of the Royal Society*.

Results of the initial single core study (Flower et al. 1995a), the development of a new box corer (Flower *et al.* 1995b), an overview of British research on Lake Baikal (Flower 1994), a new diatom genus (Flower & Hakansson 1994), a review of Baikal diatoms (Foged, ed. by Flower & Hakansson 1993) and a taxonomic re-evaluation of endemic *Cyclotella* spp are all included as published papers in the Appendices too.

As a result of the Leverhulme grant for Lake Baikal research, eight papers have already been published in scientific journals or conference proceedings and five more are being prepared (see below).
4. RESEARCH CONCLUSIONS

The main conclusions of the three year research programme are:

1. The sediment accumulation rate measured in cores of deep water sediment varies between about 0.1 and 0.26 cm yr⁻¹, so that the last one hundred years is usually represented by upper 10 cm or less of surface sediment. Only one core (BAIK22) showed a higher rate of sediment accumulation and this is probably caused by a turbidite deposit (slumped sediment).

2. Endemic diatom species *Aulacoseira baicalensis* and *Cyclotella minuta* dominate the sedimentary assemblages in all cores examined. Down-core variations in these two taxa occur throughout the lake and provide a way of biostratigraphically correlating cores. The proportions of these and other diatom taxa change through time in all the cores examined.

3. In most of the sediment cores there are no sustained changes in the proportions of cosmopolitan diatom species or those species thought to indicate increased pollution (*Stephanodiscus*, *Synedra* and *Nitzschia* species). Although some preservational problems were encountered with weakly silicified taxa such as the *Nitzschia* species, there is no diatom sedimentary evidence of any widespread recent enrichment of Lake Baikal.

4. Diatom species changes in sediment cores from near the Selenga delta, the main inflow to Lake Baikal, do indicate some enrichment during the 20th century. For Lake Baikal as a whole, this effect appears to be only of significance for the region near the Selenga River inflow and probably reflects increasing water pollution from urbanization and population growth in the extensive river catchment.

5. Atmospheric pollution indicators, carbonaceous particles and trace metals were present in all cores examined. Significant contamination by the former typically begins in the late 1930s. Trace metal contamination is less clear but lead concentration increases over approximately the last 100 years and zinc shows slight enhancement in the last decade. **None of these contamination changes are on a time scale that is compatible with the changes in sedimentary diatom frequencies.**

6. The sedimentary record of endemic planktonic diatoms in Lake Baikal indicates that the main body of the lake is still pristine and that contamination by pollutants is as yet insufficient to disturb the open water planktonic diatom communities. However, long-term changes (beginning before the 20th century period) in the sedimentary diatom record do indicate that the open water Lake Baikal ecosystem is not stable but is undergoing gradual change. One cause of such change is climate variability.
5. OVERALL EVALUATION OF THE STUDY

We regard the palaeoenvironmental assessment of pollution impact and biological changes in Lake Baikal as being very successful. We have not only shown that pollution is highly unlikely to account for the long term shifts in sedimentary planktonic diatom abundances, but also that Lake Baikal surface sediments can be used for monitoring atmospheric pollution trends. In this latter respect we hope that high resolution sediment sampling will become routinely employed for monitoring the state of Lake Baikal.

Staff at the Limnological Institute, Irkutsk, have reproduced sediment box-core and we look forward to further collaboration with them under the aegis of 'BICER' (Baikal International Centre for Ecological Research) agreement. This agreement, undertaken between Britain (administered by The Royal Society of London), the Limnological Institute (Irkutsk) and several other independent countries, to promote international research on Lake Baikal was fundamental to the smooth running of our project and has helped synergize other research initiatives on this lake.

We have developed good efficient working relations with our Russian colleagues despite inevitable but minor logistic difficulties during the project. These did not interfere with the main thrust of our research but opportunities to develop a sampling strategies for shallow water benthic diatom communities were compromised. Nevertheless, tenure of the Leverhulme award has enabled us to propose two follow-up projects:

i. **The incidence of species endemicity in shallow water diatom communities in Lake Baikal.**

ii. **The potential of Lake Baikal sediment cores for reconstructing climate during the Holocene period.**

These research proposals are currently under consideration for funding by Department of the Environment (UK), as part of the Darwin Initiative Biodiversity Programme, and by the Natural Environmental Research Council (UK), respectively.
8. PUBLICATIONS

Full list of (a) papers and (b) reports already published:

Published papers:


Reports:


Important publications directly resulting from this project are reproduced in full in the Appendices. In addition to these published papers, we have just organised a workshop (26th February 1996) for other UK scientists with whom we have shared our sediment core material. This workshop has enabled co-ordination of results and to refine the structure of five future research papers:

1. The spatial and temporal distribution of fossil fuel derived pollutants in the recent sediments of Lake Baikal, eastern Siberia (Principal author: N.L. Rose, ECRC).

2. Trace metal profiles in the recent sediments of Lake Baikal, eastern Siberia. (Principal author J.F. Boyle, University of Liverpool).


7. GENERAL REFERENCES


8. ACKNOWLEDGEMENTS

Field work facilities at Irkutsk and on Lake Baikal were kindly provided by Prof. M.A. Grachev, Director of the Limnological Institute, Irkutsk. Dr Y.E. Likhoshway at the Limnological Institute gave invaluable help during several stages of the project. Don Monteith, Jim Chambers, Nick Granin, Alexei Grachev, Eugene Berzukova and Joan Lees all made major contributions to the field work on Lake Baikal. Prof. H.J.B. Birks advised on statistical procedures. The Royal Society under the 'BICER' programme facilitated travel arrangements, and provided some of the equipment needed for deep-water coring.
9. APPENDICES

1. Results for Lake Baikal sediment core analyses:
   - sediment dating (PG. Appleby)
   - sedimentary diatoms (A.W. Mackay)
   - trace metals (J.F. Boyle)
   - carbonaceous particles (N.L. Rose)

2. Published Research Papers

   Recent Environmental Change in Lake Baikal

   An improved box corer

   Crateriportula gen. nov.

   British research on Baikal

   Review of Foged collection of Baikal diatoms

   Re-evaluation of endemic Cyclotella spp.
Radiometric Dating of Lake Baikal Sediment Cores

Methods

Sediment cores from six locations in Lake Baikal:

<table>
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<th>Core</th>
<th>Location</th>
<th>Water Depth</th>
<th>Core Date</th>
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<tr>
<td>BIK6</td>
<td>South basin</td>
<td>1420 m</td>
<td>1992</td>
</tr>
<tr>
<td>BIK19</td>
<td>Selenga ridge</td>
<td>342 m</td>
<td>1993</td>
</tr>
<tr>
<td>BIK22</td>
<td>Middle basin</td>
<td>1624 m</td>
<td>1993</td>
</tr>
<tr>
<td>BIK25</td>
<td>Academician ridge</td>
<td>342 m</td>
<td>1993</td>
</tr>
<tr>
<td>BIK29</td>
<td>North basin</td>
<td>920 m</td>
<td>1993</td>
</tr>
<tr>
<td>BIK38</td>
<td>South basin</td>
<td>600 m</td>
<td>1994</td>
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were sent to the Liverpool University Environmental Radiometric Laboratory for dating by $^{210}$Pb and $^{137}$Cs. Dried sediment samples from each core were analysed for total $^{210}$Pb, $^{226}$Ra and $^{137}$Cs by direct gamma assay using Ortec HPGe GWL series well-type coaxial low background intrinsic germanium detectors (Appleby et al. 1986). Background radiation was suppressed passively by housing the detectors in lead castles with 100mm thick walls lined with 3mm copper, and actively by using sodium iodide (NaI(Tl)) escape suppression shields. Before counting samples were packed and sealed for 3 weeks to allow equilibration between $^{226}$Ra, $^{222}$Rn and $^{214}$Pb. $^{210}$Pb was determined via its gamma emissions at 46.5 keV, and $^{226}$Ra by the 295 keV and 352 keV $\gamma$ rays of the daughter radionuclide $^{214}$Pb. $^{137}$Cs was measured by its emissions at 662 keV. The absolute efficiency of each detector was determined from a series of calibrated sources of known activity. Corrections to each count were made for the effect of self absorption of low energy $\gamma$ rays within the sample (Appleby et al. 1992).

Results

The results of the radiometric analyses are given in Table 1 and shown graphically in Figs.1-3. Table 2 gives values of a number of parameters characterising the record of fallout radionuclides in each core, including the unsupported $^{210}$Pb inventory, mean $^{210}$Pb flux and $^{137}$Cs inventory.

Lead-210 Activity

Total $^{210}$Pb (Figs.1a-f) reaches equilibrium with the supporting $^{226}$Ra activity at depths ranging from 6 cm in BIK25 to 16 cm in BIK22. In three cores (BIK6, BIK19 and BIK25), the maximum $^{210}$Pb activity in the profile occurs just below the surficial sediments, at a depth of 1-2 cm, but beneath this level declines more or less exponentially with depth. In the
other three cores (BIK22, BIK29 and BIK38) the $^{210}$Pb activity has its maximum value in the top-most sample, though in each of these cores the $^{210}$Pb profile has features indicating irregularities in the sediment record. These are relatively minor in BIK29 and BIK38, but in BIK22 there are large non-monotonic variations in $^{210}$Pb activity that would appear to record major departures from the normal process of sediment accumulation.

**Dating by $^{210}$Pb**

Dates were calculated using both the CRS and CIC $^{210}$Pb dating models (Appleby & Oldfield 1978) and the results are shown in Fig. 4. The apparently significant increase in sedimentation rates in BIK6, BIK19 and BIK25 during the past 10 years suggested by the CRS model (Figs. 4a, b & d) arise from the depressed $^{210}$Pb activities in the surficial sediments of these cores. Since these features may to some extent be the result of post-depositional redistribution due to e.g. physical mixing or chemical remobilisation, corrections have been calculated to take account of this possibility.

**BIK6**

The surficial zone of reduced $^{210}$Pb activity is of depth 1.5 cm. Beneath this level, unsupported $^{210}$Pb activity in BIK6 (Fig. 2a) declines more or less exponentially with depth and there is little significant difference between the two dating models. Both indicate a more or less constant sedimentation rate since ca.1900, with a mean value of 0.021±0.002 g cm$^{-2}$y$^{-1}$ (0.093±0.009 cm y$^{-1}$). This is very comparable to the values determined by Edgington et al. (1991) for cores 88/1 (0.022 g cm$^{-2}$y$^{-1}$) and 88/2 (0.018 g cm$^{-2}$y$^{-1}$) from a similar location in the South Basin. A small but apparently significant change in the slope of the $^{210}$Pb profile below ca.9 cm suggests that accumulation rates before 1900 may have been lower than those prevailing during the past 90 years.

**BIK19**

The surficial zone of reduced $^{210}$Pb activity is of depth 2 cm. Beneath this level unsupported $^{210}$Pb activity (Fig. 2b) declines more or less exponentially with depth and although there appear to have been some significant fluctuations in short-term sedimentation rates during the past ca.100 years, the two $^{210}$Pb dating models give similar estimates for the mean accumulation rate. The overall mean value of 0.017±0.002 g cm$^{-2}$y$^{-1}$
(0.076±0.009 cm y\(^{-1}\)) is very comparable to that determined by Edgington et al. (1991) for their core 88/5 (0.017 g cm\(^{-2}\)y\(^{-1}\)) from a similar location. Two other cores in their study (88/3 and 88/4) located progressively nearer to the Selenga delta gave significantly higher accumulation rates (0.025 g cm\(^{-2}\)y\(^{-1}\) and 0.043 g cm\(^{-2}\)y\(^{-1}\) respectively).

**BIK22**

Because of the non-monotonic features in the \(^{210}\)Pb profile (Fig. 2b), this core could not be dated using the CIC model (Appleby & Oldfield, 1983). The zone of irregular \(^{210}\)Pb activity, extending down to 11.5 cm, almost certainly record periods of very rapid sedimentation and is most probably due to turbidity currents caused by sediment slumping on the steeply shelving sides of the basin. The mean post-1950 sedimentation rate of 0.057 g cm\(^{-2}\)y\(^{-1}\) is nearly three times that for BIK6. Using the simple CRS model, the major episodes of rapid sedimentation (at core depths 2.1 cm and 7.25 cm) are dated ca.1985 and ca.1960. Below 11.5 cm (dated 1921) there does however appear to have been a much quieter period of at least 70 years during which sedimentation rates were relatively constant at about 0.011±0.002 g cm\(^{-2}\)y\(^{-1}\), significantly lower than in BIK6.

Since the unsupported \(^{210}\)Pb inventory of BIK22 (Table 2) is about 50% higher than the average value for all Baikal cores, it would appear that the conditions of the CRS model are only partially fulfilled at this site and that the higher sedimentation rates in recent decades have also given rise to a higher \(^{210}\)Pb flux. Assuming that the \(^{210}\)Pb flux during the period of normal sedimentation prior to these events was typical of the other cores, revised dates can be calculated using the methods indicated in Oldfield & Appleby (1984). These date the transitional level at 11.5 cm depth to 1934. The mean sedimentation rate above that level is calculated to be 0.052 g cm\(^{-2}\)y\(^{-1}\), nearly 5 times the pre-1934 value, though the \(^{210}\)Pb flux increases only by a factor of 1.6, to 198 Bq m\(^{-2}\)y\(^{-1}\). There is little effect on the dates of the events recorded at 2.1 cm and 7.25 cm, which are revised to 1986 and 1962 respectively. Fig. 4c plots both the raw CRS model \(^{210}\)Pb dates and the revised dates. The sedimentation rates shown are those given by the revised chronology.

**BIK 25**

Sedimentation at this core site (located on Academician Ridge)
appears to have been relatively slow, with \(^{210}\text{Pb}\) equilibrium being achieved at a depth of only 6 cm. Beneath the \(^{210}\text{Pb}\) maximum at 1.25 cm, unsupported \(^{210}\text{Pb}\) activity (Fig. 2d) declines more or less exponentially with depth. Since the mean post-1900 sedimentation rate calculated using the CRS model (0.0076±0.0014 g cm\(^{-2}\)y\(^{-1}\)) is significantly lower than that given by the CIC model (0.0110±0.0013 g cm\(^{-2}\)y\(^{-1}\)), there may have been a small increase in accumulation rates during this period, particularly during the past 40 years.

Core BIK29

Sedimentation rates at this location (centre of the North Basin) are a little higher than at BIK25 (Academician Ridge), \(^{210}\text{Pb}\) equilibrium occurring at a depth of about 10 cm. Although there is no evidence of significant mixing of the surficial sediments, there is a slight flattening of the profile above 4 cm depth (Fig. 2e) that could indicate either partial mixing, or a small fluctuation in the sedimentation rate. There are a number of small features in the unsupported \(^{210}\text{Pb}\) profile that suggest a slightly irregular sediment record and as a result CIC model dates are a little erratic compared to those determined by the CRS model. Sedimentation rates calculated using the CRS model (Fig. 4e) show a slight secular increase during the past 130 years, from a 19th century value of 0.0088±0.0004 g cm\(^{-2}\)y\(^{-1}\) to a post-1950s value of 0.011±0.001 g cm\(^{-2}\)y\(^{-1}\).

Core BIK38

Unsupported \(^{210}\text{Pb}\) activity (Fig. 2f) declines more or less exponentially with depth, though there are a number of features on the profile that suggest small irregularities in the sediment record. The CIC and CRS models give similar estimates of the mean sedimentation rate for the past 60 years, the average from both methods being 0.014±0.002 g cm\(^{-2}\)y\(^{-1}\) (0.066±0.009 cm y\(^{-1}\)). Both models also suggest lower sedimentation rates prior to this, with a mean value of for the preceding 100 years of 0.0095±0.0010 g cm\(^{-2}\)y\(^{-1}\) (0.033±0.004 cm y\(^{-1}\)).

Artificial Fallout Radionuclides

\(^{137}\text{Cs}\) was recorded in all six cores down to depths ranging from ca. 5 cm in BIK25 to ca. 10 cm in BIK22. In two cores (BIK6 and BIK19) maximum \(^{137}\text{Cs}\) activity occurs beneath the topmost layer, at depths similar to those of the \(^{210}\text{Pb}\) maximum. In BIK25, BIK29 and BIK38, \(^{137}\text{Cs}\) activity
declines smoothly with depth from a maximum value at the surface. In BIK22 there is a major sub-surface irregularity in $^{137}$Cs at 2-4 cm that coincides with a similar irregularity in $^{210}$Pb activity.

**Dating by $^{137}$Cs.**

Dating by $^{137}$Cs would appear to have little value in Baikal sediments. In the three cores with sub-surface $^{137}$Cs peaks, the $^{210}$Pb dates for these features are 1984 (BIK6), 1981 (BIK19) and 1977 (BIK22), and it would appear more likely that these features are caused by irregularities in the sediment record.

An alternative guide to the 1963 level in cores with no clear record of the fallout maximum is the depth containing 50% of the fallout inventory. Fig. 4 compares these dates with those determined by $^{210}$Pb and in all cases the $^{137}$Cs date is significantly younger than the $^{210}$Pb date. This would appear to support the inference in Edgington et al. (1991) of a ~20 year residence time for $^{137}$Cs in the water column.

**Dating by $^{241}$Am**

Traces of $^{241}$Am were recorded in three cores (BIK6, BIK19 and BIK38) though the records were not sufficiently clear to allow accurate determination of the 1963 level.

**Radionuclide Inventories**

Unsupported $^{210}$Pb inventories in the cores (Table 2) range from 2260-5980 Bq m$^{-2}$. The mean value of 3970 Bq m$^{-2}$ represents a $^{210}$Pb flux of 124 Bq m$^{-2}$ y$^{-1}$. The highest value occurs in BIK22 and probably reflects enhanced inputs caused by turbidity currents. The lowest values occur in BIK25 (Academician Ridge) and BIK38 (SE margin of South Basin), both of which may be expected to be subject to sediment erosion. $^{210}$Pb inventories at the other three sites are all relatively close to the mean.

$^{137}$Cs inventories are more variable than those of $^{210}$Pb, ranging from 570 Bq m$^{-2}$ in BIK25 to 2570 Bq m$^{-2}$ in BIK19. The highest value occurs in BIK19 on the Selenga Ridge, and presumably reflects enhanced inputs from the catchment via the Selenga River. Since BIK22 does not contain an enhanced $^{137}$Cs inventory, the turbidity currents appear to have transported sediments that predate the transfer of the bulk of the fallout $^{137}$Cs to the bed of the lake.
Tabulated Core Chronologies

Mean sedimentation rates for each core given in Table 3, and detailed core chronologies in Table 4.

The results given for cores BIK6, BIK19 and BIK29 have been based primarily on the CRS model in view of the apparent uniformity of the \( ^{210}\)Pb flux at these sites. Since there is no evidence of any major change in overall accumulation rates in recent years the most likely cause of the reduced surface activities in BIK6 and BIK19 is mixing and the tabulated values incorporate corrections for this process. Application of a mixing model increases CRS model ages below the mixing layer by just 2 years in the case of BIK6 and 4 years for BIK19.

Although there are no means for validating the CRS model in BIK22, there is at present no alternative. Table 4 does include both the raw CRS model dates and the corrected values based on the assumption of an enhanced \( ^{210}\)Pb flux above 11.5 cm.

The validity of the CRS model is less certain for BIK25 where the reduced \( ^{210}\)Pb inventory of the core may indicate some post-depositional erosion. Mixing is again the most likely cause of the reduced \( ^{210}\)Pb activity in the surficial sediment. The effect of mixing is more significant in this core because of the lower accumulation rate and mixing models suggest that CRS model ages below the surficial layer should be increased by about 6 years. When these corrections are made there is relatively little divergence between the CRS and CIC model. The divergence has been further reduced by using a mean sedimentation rate determined from both models to calculate dates below 3 cm.

The reduced \( ^{210}\)Pb inventory in BIK38 (located on the steeply shelving SE corner of the South Basin) may again indicate some post-depositional erosion of sediment. Above 4 cm (dated 1930) there is little difference between the CRS and CIC models. Dates below this level are those given by a mean sedimentation rate determined from both models.
References


# Table 1  
Lake Baikal: Radiometric Data

## (a) Core BIK6

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>$^{210}$Pb Concentration (Bq kg$^{-1}$ ±)</th>
<th>$^{226}$Ra Concentration (Bq kg$^{-1}$ ±)</th>
<th>$^{137}$Cs Concentration (Bq kg$^{-1}$ ±)</th>
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## (b) Core BIK19

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### Table 2  Radionuclides Inventories of Baikal Sediment Cores

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<td>Bq m$^{-2}$ ±</td>
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<td>BIK19</td>
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<td>BIK25</td>
<td>2259 ± 113 70 ± 4</td>
<td>573 ± 32</td>
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<td>BIK29</td>
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### Table 3  Mean Sedimentation Rates in Lake Baikal

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<tr>
<td>BIK19</td>
<td>0.017 ± 0.002</td>
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<tr>
<td>BIK22</td>
<td>0.052 ± 0.002 (post-1934)</td>
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<td>0.011 ± 0.002 (pre-1934)</td>
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23
### Table 4  
**Lake Baikal $^{210}$Pb chronology**

(a) Core BIK6

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<th>Date (AD)</th>
<th>Age (yr)</th>
<th>Sedimentation Rate (g cm$^{-2}$ yr$^{-1}$)</th>
<th>cm yr$^{-1}$</th>
<th>± (%)</th>
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Table 4 (cont.)

(b) Core BIK19

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Base of mixing zone?
(c) Core BIK22

(i) Raw CRS model chronology

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(c) Core BIK22 (Cont)

(ii) Corrected chronology

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Onset of rapid sedimentation

- 11.50 3.05 1934 59 3
- 12.00 3.18 1922 71 4
- 12.50 3.31 1910 83 4
- 13.00 3.45 1898 95 6 0.011 0.040 ~18%
- 13.50 3.59 1885 108 7
- 14.00 3.73 1872 121 10
- 14.50 3.87 1859 134 12

27
Table 4 (cont.)
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Lake Baikal

Total $^{210}$Pb Activity versus Depth

Core BIK6

$^{210}$Pb Activity (Bq kg$^{-1}$)

Depth (cm)
Lake Baikal

Total $^{210}\text{Pb}$ Activity versus Depth

Core BLK25

$^{210}\text{Pb}$ Activity (Bq kg$^{-1}$)

Depth (cm)
Lake Baikal

Total $^{210}$Pb Activity versus Depth

Core BIK29

$^{210}$Pb Activity (Bq kg$^{-1}$)

Supported $^{210}$Pb

Depth (cm)
Fig. 1f

Lake Baikal

Total $^{210}$Pb Activity versus Depth

Core BIK38

$^{210}$Pb Activity (Bq kg$^{-1}$)

Depth (cm)
Fig. 2a

Lake Baikal

Unsupported $^{210}\text{Pb}$ Activity versus Depth

$^{210}\text{Pb}$ Activity (Bq kg$^{-1}$)

Depth (cm)

Core BIK6
Lake Baikal

Unsupported $^{210}\text{Pb}$ Activity versus Depth

Core BIK19
Fig. 2c: Lake Baikal

Unsupported $^{210}\text{Pb}$ Activity versus Depth

Core BIK22

$^{210}\text{Pb}$ Activity (Bq kg$^{-1}$)

Depth (cm)
Fig. 2d

Lake Baikal

Unsupported $^{210}\text{Pb}$ Activity versus Depth

Core BIK25

$^{210}\text{Pb}$ Activity (Bq kg$^{-1}$)

Depth (cm)
Unsupported $^{210}\text{Pb}$ Activity versus Depth

Fig. 2e

Lake Baikal

Unsupported $^{210}\text{Pb}$ Activity versus Depth

Core BIK29
Fig. 2f

Lake Baikal

Unsupported $^{210}\text{Pb}$ Activity versus Depth

Core BIK38
Lake Baikal

$^{137}$Cs & $^{241}$Am Activity versus Depth

Core BIK6

Radiocaesium Activity (Bq kg$^{-1}$) vs Depth (cm)

$^{137}$Cs
$^{241}$Am
Fig. 3b

Lake Baikal

$^{137}$Cs Activity versus Depth

Core BIK19

Radiocaesium Activity (Bq kg$^{-1}$) vs Depth (cm)
Fig. 3c: Lake Baikal

$^{137}$Cs Activity versus Depth

Core BIK22

Radiocaesium Activity (Bq kg$^{-1}$) vs. Depth (cm)
Lake Baikal

$^{137}$Cs Activity versus Depth

Core BIK25

Radioactivity Activity (Bq kg$^{-1}$) vs Depth (cm)
Lake Baikal

$^{137}$Cs Activity versus Depth

Core BIK29
Lake Baikal

$^{137}\text{Cs}$ Activity versus Depth

Core BIK38

Radiocaesium Activity (Bq kg$^{-1}$) vs. Depth (cm)
Lake Baikal Core BLK6
Depth versus Age

Fig. 4a

Depth (cm)

Age (y)

Sed Rate (g cm$^{-2}$ y$^{-1}$)

- $^{137}$Cs/$^{241}$Am Date
- CIC $^{210}$Pb Dates
- CRS $^{210}$Pb Dates
- CRS Sedimentation Rates
Lake Baikal Core BIK19
Depth versus Age

Fig. 4b

Depth (cm)

Age (y)

Sed Rate (gcm$^{-2}$y$^{-1}$)

- $^{137}$Cs Dates
- CIC $^{210}$Pb Dates
- CRS $^{210}$Pb Dates
- CRS Sedimentation Rates
Lake Baikal Core BIK22
Depth versus Age

- **137Cs Dates**
- **CRS 210Pb Dates (raw)**
- **CRS 210Pb Dates (corr)**
- **CRS Sedimentation Rates**
Lake Baikal Core BIK29
Depth versus Age

- $^{137}$Cs Dates
- CIC $^{210}$Pb Dates
- CRS $^{210}$Pb Dates
- CRS Sedimentation Rates

Depth (cm) vs. Age (y)

Sed Rate (g/cm$^2$·y$^{-1}$)
Lake Baikal Core BIK38
Depth versus Age

Fig. 4f

- Depth (cm)
- Age (y)

- \(^{137}\)Cs Dates
- \(^{210}\)Pb Dates
- CRS \(^{210}\)Pb Dates
- CRS Sedimentation Rates
BAIK 25
Academic Ridge
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**BAIK 27**

north basin
northern basin.
LAKE BAikal SEDIMENT CORES:
TRACE METAL STRATIGRAPHIES

SEDIMENT RATES:
BIK38  BIK6  BIK19  BIK22  BIK25  BIK29

TRACE METAL CONCENTRATIONS:
Fe (black) Mn (grey) mg/g

DIATOMS COUNT 10^6/g

LEAD /g

Copper /g

Zinc /g
LAKE BAIKAL SEDIMENT CORES: SCP STRATIGRAPHIES

Lake Baikal (Bk 6) 1992
Carbonaceous Particle Concentration and Flux Profiles

![Graph showing carbonaceous particle concentration and flux profiles over time. The x-axis represents time in years (e.g., -1992, -1985 ± 1, etc.), and the y-axis represents sediment depth in cm. The graph includes data points for various years, indicating changes in particle concentration and flux over time.](image-url)
Lake Baikal (BIK 19)
SCP Concentration and Flux Profile

Sediment Depth (cm)

Conc (μM L⁻¹)

Flux (μmol m⁻² yr⁻¹)

- 1993
- 1985 ± 2
- 1977 ± 2
- 1966 ± 2
- 1955 ± 2
- 1943 ± 4
- 1933 ± 7
- 1900 ± 13
- 1878 ± 23
- 1857 ± 23
Lake Baikal (BIK 22)
SCP Concentration and flux profiles

![Diagram of SCP Concentration and flux profiles for Lake Baikal (BIK 22).](image)
Lake Baikal (BIK 25)
SCP Concentration and Flux Profile

- 1993
- 1977 ± 2
- 1990 ± 2
- 1957 ± 3
- 1610 ± 7
Lake Baikal (BIK 29)
SCP Concentration and Flux Profile

[Graph showing sediment depth (cm) against concentration (g/m²) and flux (mm/cm²-yr) for various dates.
- 1993
- 1986 ± 2
- 1979 ± 2
- 1957 ± 2
- 1954 ± 3
- 1936 ± 4
- 1916 ± 7
- 1893 ± 15
]
Sedimentary records of recent environmental change in Lake Baikal, Siberia

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Received 20 January 1995; revised manuscript accepted 8 February 1995

Abstract: Lake Baikal is the world's largest freshwater lake and is internationally famous for its rich and largely endemic biota. Concern about this unique ecosystem has grown since the late 1970s but whether recent biological changes result from natural fluctuations or pollution is unclear. One way of discriminating between these processes is to examine records of recent change in radiometrically dated deep-water sediment cores. Here we use high-resolution diatom analysis of one core to show that abundances have not changed significantly over recent decades. By contrast, we demonstrate that the lake is contaminated by atmospheric pollutants and has experienced a small qualitative change in soil derived magnetic minerals. Sedimentary lead concentrations show an increasing trend in the c. 150-year core sequence and spheroidal carbonaceous particles (SCPs) contaminate post-1930 sediment. Although we provide no evidence that twentieth-century pollution has affected the endemic planktonic diatoms in the central western region of southern Lake Baikal, longer trends in species abundances could be related to naturally occurring climatic cycles or to global warming.

Key words: Palaeolimnology, radiometric dating, diatoms, trace metals, magnetic minerals, carbonaceous particles, SCP, Lake Baikal.

Introduction

Pollution threats to Lake Baikal are well known and biological concern has centred principally upon declining endemic white fish stocks and the spread of viral distemper within the Baikal seal population (Galazii, 1982; 1991; Massey-Stewart 1991). Recent changes in the lake are thought by some (Galazii, 1982; 1991) to reflect widespread deterioration in lake-water quality, one likely cause being waste from the Baikalsk pulp mill on the lake's southern shore (Manella et al., 1990). Although local water quality problems are acknowledged, an alternative view is that pollution problems are overstated and that some recent ecological changes are attributable to natural variation or to factors unrelated to pollution (Grachev et al., 1989; Grachev 1994). Support for either of these opinions can be obtained from examining long-term (10 to 100 years) records for the lake. Documentary sources are inadequate for this time span, but trends in environmental change can instead be assessed from the biological and chemical records in recent sediments (Battarbee, 1991). Because diatom algae form a very important part of the Baikal ecosystem, are excellent water-quality indicators and their siliceous frustules preserve well, sedimentary diatom analysis can reveal much about environmental change (Bradbury et al., 1994). Furthermore, lake sediments can also contain pollutants and a chronology dependent on short-lived radioisotopes such as 206Pb. High-resolution techniques to reveal records of environmental change have not previously been employed together in Lake Baikal and this paper reports the results from the first of a suite of more than 25 cores collected from throughout the lake during 1991/2.

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In September 1992 a novel box-corer (Monticelli et al., 1993; Flower et al., 1995) was used to collect an undisturbed surface sediment core (BIK6) from 1420 m of water in Lake Baikal's southern basin (Figure 1). This core location was selected because its proximity to the outflowing River Angara must minimize any local effects from river inflows. The 120-mm-long core constitutes an upper 35 mm of brown oxic material overlying grey un laminated sediment. Subsampling was at 2-mm intervals in the upper 30 mm and then at 5 mm.

Thirteen sediment samples from BIK6 were analysed for $^{210}$Pb, $^{226}$Ra, $^{137}$Cs and $^{144}$Am by gamma spectrometry using a low background intrinsic germanium detector (Appleby et al., 1986) for sediment dating. Dates were calculated using both the CRS and CIC $^{210}$Pb dating models (Appleby and Oldfield, 1978). Diatom analysis was undertaken on untreated sediment samples, except for washing in dilute hydrochloric acid before mounting on glass coverslips before examination using a Leitz SM LUX microscope at x1000 magnification. Diatom identifications follow Flower (1993a) and standard floras. Geochemistry was according to standard techniques with biogenic silica by alkali digestion (Mortlock and Froelich, 1986) and spheroidal carbonaceous particle (SCP) analysis generally follow Thompson and Oldfield (1986) but omitting the initial dry ashing stage. Magnetic measurements and spherical carbonaceous particle (SCP) analysis generally follow Thompson and Oldfield (1986) and Rose (1991) respectively.

Results and discussion

There is little significant difference between the two sets of dates calculated using the CRS or CIC dating models. Both models indicate an essentially constant sediment accumulation rate of $c.$ 0.8 mm yr$^{-1}$ (c. 20 mg dry sediment cm$^{-2}$ yr$^{-1}$) for BIK6. This rate lies within the known rate range of deep-water sediment cores from Lake Baikal (Edgington et al., 1991). The dates quoted here are calculated using the CRS model.

Diatom analysis (Figure 2a) shows no major changes in species abundances throughout the estimated 146-year sediment sequence in BIK6. The assemblage is dominated at all

![Figure 1](https://example.com/figure1.jpg)  
*Figure 1 Lake Baikal showing the location (latitude 51° 48' 36" N, longitude 104° 51' 36" E) of the BIK6 sediment core, collected from a water depth of 1420 m, near the mouth of the outflowing Angara River. Principal regional industrial centres are Angarsk, Irkutsk, Ulan Ude, Selenginsk and Baikalsk; the latter two are notable sources of pulp and paper processing effluent.*
There is no clear evidence in BIK6 of any twentieth-century response to nutrient enrichment, but the sediment record does show increasing contamination by spheroidal carbonaceous particles (SCPs). SCPs are derived solely from high-temperature fossil-fuel combustion (Griffin and Goldberg, 1981) and contaminate BIK6 sediment from 5.5-6.0 cm depth or the late 1930s (Figure 2d). SCP concentrations increase sharply in the late 1970s, reaching a maximum of 2530 particles g⁻¹ dry sediment at the core top (1992), representing a SCP accumulation rate of 67 particles cm⁻² yr⁻¹. This is similar to rates measured in much smaller lakes on the western fringe of Europe (Rose, 1991). The BIK6 SCPs flux is however considerably higher than that in nearby highland lakes (Flower et al., 1994) and could indicate that local emissions are an important source of these particles for Lake Baikal.

Geochemical analysis of BIK6 shows clear changes in the trace metal concentrations (Figure 3) but, compared with SCPs, evidence for recent contamination is unclear. Trace metals are supplied from terrestrial and atmospheric sources, and are affected by diagenesis and residence time effects. Nevertheless, Pb concentration generally increases up-core peaking around 40 mm depth. Ni, Cu and Zn show elevated concentrations in the top 1 cm, but Fe and Mn show most change, reflecting metal cycling and the well-known oxidized surface of Baikal deep-water sediment (Libovich, 1984). They increase strongly above 3.5 cm (1965), coinciding with the visual change from grey to brown sediment. The common base cations, Mg, Al, K and Na and biogenic silica show an increasing trend down-core with lower values in the upper 30 mm where Fe, Mn and C concentrations are higher.

The upper section of BIK6 gives clear evidence of both Mn and Fe enrichment and co-enrichment by Co and Ni, typical of fast growing Mn oxides (Calvert and Price, 1970; Granina, 1992). For Ni and Co any pollution-derived proportion is masked by diagenesis, but this is not the case for Pb, Zn and Cu. The latter two metals increase at the core top by 40-60%, well within the oxidized layer, and thus should not be influenced by the deeper recycling. Pb, on the other hand, rises irregularly from the core base. Interpretation of these changes must take account of Baikal's great water depth. Although sediment trapping and phytoplankton sampling indicate that some particles sink >1000 m in several months (Wong, 1991 D.H. Jewson, pers. comm.), trace metals may have much longer residence times.

A water column residence time of not more than 20 years has been calculated for atmospherically supplied 137Cs to Baikal (Edgington et al., 1991). The sedimentary record must therefore constitute a strongly damped response to trace metal pollution unless rapid vertical transport by particulates occurs. The sharp surficial peaks in Cu and Zn are more easily explained by changing transport mechanisms within the lake. The long term trend in Pb increase is, on the other hand, better explained by changing supply. Atmospherically derived Pb typically shows a nineteenth-century increase at remote sites (Evans and Rigler, 1985) and marked post-1930 increases in more heavily affected lakes (Goldberg et al., 1981). This pattern is muted but discernable in BIK6, indicating a combination of low-level contamination and residence time effects.

Magnetic properties of lake sediment can reflect past changes in sediment supply and sources (Dearing, 1992). Selected magnetic profiles for BIK6 (Figure 3b) show markedly different trends in concentrations of paramagnetic susceptibility (χ₀) and canted antiferromagnetic (HIRM) minerals. The main features are a sharp up-core increase in χ₀
are calculated from $^{206}$Pb measurements using the CRS model. Dates are calculated from $^{206}$Pb measurements using the CRS model.

from about 35 mm, coinciding with the transition from anoxic to oxic sediment, and a gradual increase in HIRM from about 80 mm. The $\chi$ change may be of diageneric origin, resulting from the partial dissolution of ferrimagnetic minerals in the anoxic zone (Anderson and Rippey, 1988) and reprecipitation of paramagnetic Fe-bearing minerals above. HIRM mainly reflects the presence of goethite and haematite, and the lack of change around 35 mm indicates that these minerals are resistant to dissolution. If the dissolution process at the reducing front has been constant over time then the upcore increase in these minerals during the twentieth century could indicate increased supply from weathered surface soils. The change is largely qualitative, not being linked to increased sediment accumulation rate.

**Conclusion**

The sedimentary profiles in BIK6 indicate only small changes in sediment supply over the last c. 150 years, but provide clear evidence of recent contamination by SCPs and Pb, derived from either local or long-distance pollution sources. Possible large regional point sources of these pollutants are two major pulp mills, one built at Baikalsk in 1963 and another at Selenginsk on the main inflow to Lake Baikal (see Figure 1). However, the increasing regional growth and industrialization represented by these installations post-date the early Pb and SCP increases in BIK6. These increases must therefore reflect other regional and/or remote pollution sources. The Selenga River is another major pollution source (Popovskaya and Kuzmina, 1988; Mnatsakanian, 1993) and nutrient enrichment has caused eutrophic problems since the 1970s (Popovskaya and Kuzmina 1988; Tarasova and Meshcheryakova, 1992). This river usually contributes some 250 tonnes of phosphate-P annually (Tarasova and Meshcheryakova, 1992) with extreme floods doubling this quantity (Sorokovikova et al., 1994). Even so, the volume of Lake Baikal (23 000 km$^3$) is such that the increase in total annual P supply will only cause a theoretical increase in lake-water P concentration at the nanogram level.

There is no doubt that Lake Baikal receives effluent from the Selenga River and from Baikalsk and elsewhere, but there is so far no firm evidence that these cause anything other than local water-quality problems. If increasing twentieth-century pollution were ecologically significant throughout the lake then it might be expected that this would be reflected in the diatom record, possibly by a proliferation in cosmopolitan species. The diatoms in BIK6 and in other cores from deep-water locations in southern Lake Baikal (A. Mackay, in prep.) suggest otherwise. The past distributions of diatom taxa and the strong correlation of BIK6 diatom assemblage PCA scores with time indicate that a small but gradual floristic change was already under way by the mid-nineteenth century. Correlating this ecological change (as PCA axis 1 scores) with the environmental variables, sediment geochemistry and magnetic values, using CANOCO (ter Brak, 1987), identified Pb, Mn and HIRM as significant (at $p = > 0.01$).

Despite these correlations, proof of any causality is lacking. There is no evidence that current Pb concentrations in Lake Baikal (0.01-0.58 µg L$^{-1}$ particulate; Potyomkina et al., 1994) are ecologically important. Similarly, a link between small changes in magnetic minerals and diatoms is unlikely. The Mn profile is diageneric and therefore unrelated to floristic change. Particulate contamination post-dates diatom species shifts by more than 100 years. Consequently, BIK6 provides no evidence that twentieth-century pollution has had any significant widespread effect on the planktonic diatom flora of the west central region of southern Lake Baikal. Exactly why the recent sedimentary diatom assemblages have undergone gradual change, from *C. minut"A. baicalensis*, remains unclear. Natural long-term periodicity in the endemic diatom communities and/or the influence of climate, possibly mediated through changes in lake circulation, are plausible causes. Testing these hypotheses awaits high-resolution diatom and geochemical analysis of securely dated longer sediment sequences from deep-water locations in Lake Baikal.

**Acknowledgements**

Facilities and support provided by The Limnological Institute, Irkutsk, under the directorship of Professor M. Grachev, made this project possible. Special thanks go to the crew and scientific staff, headed by Professor V. Drukker, on R.V. *Vereshchagin*, for invaluable help with fieldwork. We thank Dr Y. Likhoshway for useful discussions on Lake Baikal diatoms. Professor R.W. Battarbee made constructive comments on the manuscript and Professor H.J.B. Birks provided help and advice on statistical analysis of the data. This work was funded by The Leverhulme Trust under grant no. F134AZ. Travel arrangements were facilitated and partly funded by The Royal Society, London, under the ‘BICER’ agreement.
The design and performance of a new box corer for collecting undisturbed samples of soft subaquatic sediments

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Received 26 January 1995; accepted 2 March 1995

Key words: box corer, Lake Baikal, ²¹⁰Pb sediment dating

Abstract

The 'Baikal' sediment box corer represents an innovation in design of the closing mechanism and involves a single, thin, and flexible stainless steel blade rather than closing jaws. With this light-weight box corer only a relatively small cross-sectional area is offered to the sediment, allowing easier penetration. The closure blade is propelled smoothly across the base of the box in a downwardly convex path by a set of constant force springs. Depending on choice of blade-release mechanisms, the corer can either be triggered immediately as the support cable slackens, after a delay of a few seconds, or immediately upon retrieval. The box corer has been used successfully to sample poorly consolidated sediments in freshwater lakes over a depth range of 8 to 1624 m. Cores of deep-water surficial sediment from Lake Baikal were tested for representativity and replicability by profiling natural and artificial radioisotopes and lithostratigraphic features.

Introduction

Sediment box corers offer several advantages over conventional narrow tube gravity and piston corers for sampling in situ sediments. They collect relatively large samples and sediment disturbance is minimized because the surface area of sediment sampled is also much larger. Crusius & Anderson (1991) showed convincingly that high-porosity lake sediment can undergo 'lateral thinning' and sediment can escape during narrow tube gravity coring of surficial sediment. This phenomenon is reviewed elsewhere (Blomqvist, 1991) but opinions differ as to the precise mechanisms (Wright, 1993) or the extent (Cumming et al., 1993) of this lateral loss of sediment. Different coring techniques will undoubtedly affect lateral loss but friction between the inside corer walls and the sediment will always exert some downward pressure on the sediment being cored. Clearly, instruments which minimize these frictional effects by sampling a relatively large area or sample by freezing sediment in situ must be preferred.

Tube gravity corers typically collect a sediment area of some 20 to 30 cm² (e.g. Glew, 1989, 1991), an order of magnitude less than that normally sampled by box corers. Despite this potential advantage of box corers, most are heavy (often exceeding 150 kg) and primarily deployed with powerful aboard ship lifting gear to collect large samples of marine sediment. Some instruments are equipped with a jaw-closing arrangement that offers a large cross-sectional area to the sediment, making corer penetration difficult in some sediments (cf. Boland & Rowe, 1989). In others, the box enters the sediment before single (Reineck, 1963) or paired (Peters et al., 1980) jaws close the box as the instrument is lifted. Small jaw-closing devices or grab samplers (e.g. Ekman, 1911) are much lighter, but are rarely satisfactory in deep water (see Bouma, 1969; Blomqvist, 1990) and usually sample only the upper few cm of sediment. Only the 'long' box corer (Kögler, 1963), modified with a steel-armed core catcher curtain (Werner, 1973), does not use closing jaws of some sort.
We have designed a new type of light-weight box corer (Fig. 1) incorporating a thin stainless steel cutting blade operated by constant force ('tensator') springs to close the sample box base. It therefore offers a relatively small cross-sectional area to the sediment surface and energy for blade closure is independent of the cable lifting force (unlike the Reineck and Kogler corers) or of passively sliding ballast weights (cf. Gomex corer, Boland & Rowe, 1989). With an instrument weight of only 13.5 kg, its primary use is to collect undisturbed samples of poorly consolidated surficial sediment to a depth of up to 35 cm whilst retaining an intact sediment-water interface. Minerogetic sediments require extra ballast to achieve satisfactory sample depth, and up to 18 kg of lead ballast can be added if required. A choice of trigger mechanisms is incorporated into the device so that timing of blade release and box closure can be varied. The closure blade and lid form a virtually water-tight seal at the box base and top, respectively. Unless only a very small plug of sediment is collected, leakage is minimal (when the corer is standing on deck).

The Baikal box corer can be operated by hand in shallow water to sample soft, fairly organic sediment. But it is primarily designed for deep-water sampling with a winch and has been used successfully to 1600 m depth. Small variations of entry angle to the sediment (up to 20°) can usually be compensated for during subsequent piston coring within the box. Alternatively, all problems associated with ship drift are eliminated if the corer is deployed through the ice on a frozen lake surface using a light-weight winch system. The Baikal box corer closing mechanism is subject to a pending patent (British Patent Office application number 9301913.1), but reproduction of the instrument will normally be granted on application to the authors under conditions fixed by University College London. Alternatively, it is commercially available (Duncan & Associates, Grange Over Sands, Cumbria LA11 7AF, UK).

**Corer construction and operation**

The Baikal box corer consists of a rectangular sampling box, 20 × 12 × 50 cm deep, which can be closed at the base by a thin (0.2 mm) stainless steel blade and at the top by a hinged lid (Fig. 1). To enable visual examination of sediment samples the wider two sides of the box are constructed of 10 mm plexiglas (later replaced by 5 mm polycarbonate Lexan) and the other two arc of 5 mm brass plate. The lower outer edges of each side are bevelled at 70° to a sharp cutting edge to aid sediment penetration. The box is subrounded by two vertical supporting arms, one of which serves to locate the blade release and energizing mechanism and the tensator springs. At their distal ends these arms are attached to the trigger release mechanism above which is a shackle for cable attachment. These arms therefore provide a symmetrical A-frame from which the box is suspended. Three stainless steel tensator springs, located on an axle attached to the 'active' side of the box, drive the stainless steel closure blade when the device is triggered.

The horizontal tensator shaft at the top of the box is supported by brackets attached to the plexiglas side walls. The free end of each tensator spring (each providing a pulling force of approximately 40 N) is attached to a priming bar (Fig. 1). This bar forms the upper edge of a 0.3 mm sliding stainless steel plate, which at its lower end is continuous with the 0.2 mm flexible stainless steel closing blade. The plate is kept in vertical alignment by guide channels running along the outer edges of the box side. At the lower end of the box, the channels end 10 cm above the corer base, where the wall is interrupted by a horizontal slit to permit entry of the closing blade into the sample box. At this point the external guide channels feed into channels machined into the inner walls of the plexiglas sides. This provides a continuous path for the closing blade to travel from its vertical cocked position, through the horizontal slit, into the box. In the box, the blade is guided in an arcuate path to finally abut on the passive brass inner side, so closing the box base. Release of the stainless steel blade also causes the top hinged lid to close passively. When seated, the lid is held tightly closed by magnetic strips.

The release mechanism is located at the apex of the supporting arms and can be varied to permit blade release either immediately as the cable slackens (type 1 mechanism), after a few seconds delay (type 2 mechanism), or as the corer is lifted (type 3 mechanism). Each method depends upon an upward movement of the releasing lever (Fig. 1) to trigger the corer. This angled lever is pivoted about its middle and fixed centrally and inwardly at the top of the support arm on the tensator side (Fig. 2). The lower arm of this lever has a hook which retains the priming bar on the blade propulsion assembly when in the cocked position. Essentially, the releasing mechanism consists of brass rod (190 × 10 mm) located in the apex tube. Movement of the releasing rod is restricted by upper and lower flanges which allow the rod to slide over 60 mm
under tension provided by two vertical 3 mm diameter springs which link the upper flange to the fixed apex tube (Fig. 2). A support cable is attached to the distal end of the rod with a swivel shackle. When suspended, the corer weight overcomes the tension in the rod springs and the lower end of the apex tube rests on the lower flange. In this position the metal block (type 1 closing mechanism, Fig. 2 left) attached to the rod’s proximal end, is raised above the releasing lever. When the corer weight is transferred from the support cable to the sediment, the releasing rod is pulled down by the two vertical springs. This pushes the metal block down to engage the releasing lever and trigger the corer.

Time-delayed triggering of the corer (type 2 mechanism) entails a vertical piston assembly attached to the distal end of the rod (Fig. 2, right). This assembly is held in position by two arms attached to the apex tube. The piston is housed in a 100 x 50 mm cylinder and has a rubber O-ring seal. When immersed, piston speed can be adjusted by altering the diameter of a bypass vent within the piston (Fig. 2). This mechanism effectively dampens movement of the releasing rod and therefore delays raising of the releasing lever...
Fig. 2. Alternative releasing mechanisms for the Baikal Box corer. A weighted catch system (left) controls blade release and lid closure only when withdrawal of the corer from the sediment begins; transferring corer weight from the sediment to the supporting cable enables the releasing rod to lift, triggering the corer (type 3 trigger mechanism, see text). Delayed blade release and lid closure is similar to that described in Fig. 1 but employs a damping piston (right) to retard box closure by several seconds following transfer of corer weight from the supporting cable to the sediment (type 2 trigger mechanism, see text).

by a few seconds (settings of 2 to 5 seconds are usually appropriate).

Triggering mechanism type 3 omits the piston assembly and incorporates a weighted catch, so when the corer is suspended and cocked, the releasing rod is held in its lower position by the catch hooked onto the upper flange (Fig. 2, left). Also, a differently shaped metal block is used on the releasing rod so that when the supporting cable slackens the weighted hook swings back, allowing the rod to lift 60 mm when cable tension is re-established. This movement lifts the releasing lever and so triggers the corer. Type 3 firing mechanism ensures that the corer box remains open in the sediment until the initial pull upwards causes immediate closure.

Ballast is unnecessary for sampling poorly consolidated sediment, but to aid corer penetration in more compacted material, lead weights (140 x 110 x 10 mm) can be attached to the box sides using pairs of stainless steel studs (Fig. 1). Up to eight (four on each side) of these 2.25 kg plates can be added to the corer, bringing the maximum weight of the whole box-corer assembly to about 32 kg. To aid sediment penetration, the lowest two lead plates are positioned 15 cm above the corer base and have bevelled lower edges. Alternatively, ballast weights can be re-configured as four downwardly pointed lead-filled stainless steel tubes supported by 20 cm long arms, bolted to the box corer sides (Fig. 3). These act as stabilizers but will impede sediment penetration of the box (a sliding support frame is under development by Duncan & Associates). A pressure release pipe is located on the outside of the box and links the box volume below the closure blade to the open water above the box. This allows the corer to be pulled from the sediment without subjecting the blade and sampled sediment to excessive back pressure. Laboratory tests using a water tank and simulated lake sediment showed that there is a significant difference between lift (kg) necessary to pull-out the corer, depending on the pressure release pipe being open or closed. With the pipe open, pull-out force was equivalent to 18.8 kg (S.D. = 0.6, n = 3) and closed,
21.4 kg (S.D = 2.1, n = 4). It became apparent that the duration of lift was more important than the lift weight per se. In a second test the time taken for the embedded corer to move upwardly 25 mm, when subjected to a lift force of 22 kg, was measured. With the pipe open, pull took 15.2 s (S.D = 1.7, n = 4) and closed, 20.0 s (S.D. = 4.1). In these tests the means are significantly different (at $P < 0.1$ and $<0.05$, respectively, $t$ test). It is noteworthy that significance is not high and that S.D.s are relatively large and variable, reflecting the inherent variability of even simulated sediment, despite careful sediment mixing and allowing exactly 24 hours between tests.

To operate the corer, the closure blade assembly is raised manually by sliding the priming bar up the active side support arm. The tensators are rolled out and put under tension, and the stainless steel plate and box closure blade are held vertically beneath the priming bar by the releasing lever. At the same time, the lid is lifted and latched to the support arm. In deep water, the corer is lowered by winch at moderate speed and cable length monitored. When within some 50 m of the sediment surface the winch is slowed. Best results are often obtained by using the hand operation option (depending on winch type available) to lower the corer through the last few 10 s of metres to the sediment at a rate of about 1 m s$^{-1}$ or less.

The box corer penetrates the surficial sediment to a depth determined by the corer momentum and the sediment density. When the corer weight is transferred from the cable to the sediment, the corer is tripped according to the particular trigger mechanism used and the priming bar is released. Release allows the tensators to recoil, pulling the steel plate/blade assembly downwards so that the flexible closure blade cuts through the sampled sediment and closes the box base.

Field trials

The box corer was first tested in an English, eutrophic, 8 m deep, artificial lake where it successfully retrieved samples of undisturbed surficial sediment to a depth of c. 30 cm. The corer (without ballast) was operated by hand from an inflatable boat. However, compared with gravity and piston corers used at the same site, the Baikal corer more frequently retrieved samples with disturbed sediment/water interfaces. This disturbance resulted from sediment degassing and, because the box corer has a much greater sediment sampling area, there is a proportionally greater chance of encountering interstitial gas pockets.

The box corer has had much more extensive use in Lake Baikal, for which it was primarily designed, and has collected a suite of deep-water cores for diatom analysis (Mackay et al. in prep.). The instrument performed best in very calm conditions with delayed closure of the corer (mechanism 2), with the piston release set to about 5 s. When retrieved on ship, the box corer was sub-sampled by conventional piston coring (Blomqvist & Bostrom, 1987), using a 78 mm diameter plexiglas tube pushed into the undisturbed sediment in the box centre. Poorly consolidated, fine-grained material usually comprises the surface 3-4 cm of Lake Baikal sediment and this is very easily disturbed by slight turbulence. Although some surface disturbance always occurs near the box walls, in successful cores
Table 1. Results from the radiometric analysis of BIK6, a short core of surficial sediment collected from Lake Baikal in September 1992 using the Baikal box corer.

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>210Pb Conc. (Bq kg⁻¹)</th>
<th>137Cs Conc. (Bq kg⁻¹)</th>
<th>241Am Conc. (Bq kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Mass</td>
<td>± Unsupported</td>
<td>±</td>
<td>±</td>
</tr>
<tr>
<td>0.10</td>
<td>0.014</td>
<td>559.2 ± 16.1</td>
<td>499.5 ± 16.3</td>
</tr>
<tr>
<td>1.10</td>
<td>0.162</td>
<td>622.7 ± 22.4</td>
<td>559.1 ± 22.7</td>
</tr>
<tr>
<td>1.70</td>
<td>0.264</td>
<td>609.3 ± 26.8</td>
<td>540.4 ± 27.3</td>
</tr>
<tr>
<td>2.30</td>
<td>0.377</td>
<td>483.5 ± 19.4</td>
<td>431.2 ± 19.6</td>
</tr>
<tr>
<td>3.25</td>
<td>0.575</td>
<td>403.9 ± 10.9</td>
<td>356.4 ± 11.1</td>
</tr>
<tr>
<td>4.25</td>
<td>0.808</td>
<td>275.3 ± 12.2</td>
<td>231.6 ± 12.4</td>
</tr>
<tr>
<td>4.75</td>
<td>0.935</td>
<td>221.2 ± 8.4</td>
<td>173.9 ± 8.5</td>
</tr>
<tr>
<td>6.25</td>
<td>1.333</td>
<td>165.6 ± 7.8</td>
<td>117.6 ± 8.0</td>
</tr>
<tr>
<td>7.25</td>
<td>1.588</td>
<td>120.5 ± 8.4</td>
<td>76.8 ± 8.6</td>
</tr>
<tr>
<td>8.25</td>
<td>1.854</td>
<td>98.0 ± 6.5</td>
<td>50.1 ± 6.7</td>
</tr>
<tr>
<td>9.25</td>
<td>2.132</td>
<td>92.6 ± 11.5</td>
<td>55.8 ± 11.7</td>
</tr>
<tr>
<td>9.75</td>
<td>2.275</td>
<td>81.3 ± 7.1</td>
<td>31.6 ± 7.2</td>
</tr>
<tr>
<td>11.50</td>
<td>2.798</td>
<td>50.5 ± 5.1</td>
<td>8.3 ± 5.3</td>
</tr>
</tbody>
</table>

The high degree of similarity between these two cores is clearly shown in Fig. 4c by plotting BIK34 values (mean = 20.4%, SD = 8.0, n = 41) against those of BIK35 (mean = 19.8%, SD = 7.8, n = 41). Regression analysis of these results reveals a highly significant correlation (r = 0.93, P < 0.001) between the two profiles and the regression line deviates from the 1:1 line by <1.0%.

Simple regression analysis is an informative way to compare two profiles, but time-ordered stratigraphic data are not independent samples. Another comparison that overcomes this problem is 'sequence-slotting' (Gordon & Birks, 1974). Here sample sets are grouped into a single joint sequence so that discordance (psi) between sequences is minimized. Performing this test on cores BIK34 and 35 (H. J. B. Birks, pers. comm.) gives a psi value of 0.56. Standardizing the data to zero mean, so that the comparison is carried out according to curve shape rather than size, reduces psi only slightly. Also, constraining the data by making the top samples synchronous makes no difference to psi. Psi values can vary from zero, for a perfect match, to infinity and values less than unity can be considered to be very low, indicating a good match; the psi value of 0.56 is different from random expectation at P < 0.01.

The profiles of weight loss at 550 °C show an upwardly increasing trend in each core (Fig. 4b). Depth equivalent values in the lower part of BIK34 and 35 are very similar and differ by <±1%. However, above 2.5 cm depth values are consistently higher in BIK34. Again, plotting BIK34 values (mean = 10.3%, SD = 3.1, n = 41) against those of BIK35 (mean = 9.6%, SD = 1.8, n = 41) gives a high correlation (r = 0.9, P < 0.001) for the core section below 2.5 cm, with little difference from the 1:1 line (Fig. 4c). The figure clearly shows the dissimilarity of values in the upper 2.5 cm of each core and if these data are included in the regression the correlation coefficient falls to 0.51. This difference is also demonstrated by the sequence-slotting test: when the 550 °C weight loss data are included, psi rises to 1.42 and constraining the top samples further increases this value.

Discussion

Compared with conventional jaw closing box corers, the Baikal corer offers a relatively small cross-sectional area to the sediment surface. This permits the instrument to be light-weight, yet it will penetrate typically 15–30 cm depth of soft sediment, using only a small amount of ballast where necessary. Energy to close the box is provided in a controlled manner by tension springs and release can be timed according to several mechanisms. The depth of sediment collected is usually adequate for large or oligotrophic smaller lakes to provide full sediment inventories of natural radionuclides, such as 210Pb, which are important for establishing recent core chronologies. The corer design...
Fig. 4. Sediment core replicability: sedimentary profile of percentage dry weight (a) and weight loss at 550 °C (b) in two sediment cores (BIK34 and 35) from 1400 m depth in the south basin of Lake Baikal. The two cores were collected with the Baikal box corer operated through the ice-covered lake in March 1994 and where a surface distance of 15 m separated the two core locations. There is a close correspondence between percentage dry weight measurements made on equivalent depth samples in cores BIK34 and 35 (c) but for weight loss at 550 °C measurements (d) note that values above 2.3 cm depth are consistently and disproportionately higher in BIK 34 than in BIK 35 (see text).
should be equally effective for sampling 'soft' marine sediments but construction should be strengthened.

The Baikal box corer has performed efficiently for surficial sediment sampling in Lake Baikal during calm water or ice-over conditions during 1992–94. This routine usage indicated, however, that the sediment sample size area could be increased by changing the box dimensions and that penetration efficiency improved by using stronger and thinner box walls. Increasing instrument size always increases handling difficulties, but field-trials with the box corer modified with lateral walls of 5 mm polycarbonate and incorporating a slightly larger box area under way. This modification provides for 329 cm² of sampled surface sediment with a cross-sectional box area (below any ballast weights) of 36.5 cm². This represents a box to sample area ratio of 1:8 and compares favourably with that in popular tube cores. For example, the small piston corer (Mackereith, 1969) commonly uses 9 mm plexiglas tubes, 59 mm internal diameter, representing a cross-sectional tube area to sample area ratio of 1:1.4. The Baikal box corer therefore offers a five-fold improvement in the relative surface area of sediment sampled. Very wide diameter, thin walled tube cores of course also offer a better sample area ratio but experience has shown that in deep-water locations, increasing tube diameter leads to core wash-out during retrieval.

Despite the successful operation of the Baikal box corer, the instrument has several shortcomings that limit its performance. It will not collect sediment with substantial quantities of sand and the stainless steel closure blade could be damaged if stones are encountered. Deepwater sediment in Lake Baikal contains diatom remains and clays but little organic matter and, as a result, it has a very cohesive texture beneath the top few cm. With shorter sediment samples (< c. 12 cm in depth), slight rotational movement of the sampled sediment sometimes occurs. This is caused by the movement of the closure blade, and although the rotation could be compensated by appropriate positioning of the subsequent piston core, the problem could prevent successful coring of particularly 'sticky' sediments. Equipping the Baikal box corer with two opposing closure blades could possibly solve this occasional problem. Another sedimentological difficulty concerns the hard iron/manganese 'pan' in the oxidized microzone found in surface sediment of some lakes. Several box cores from Lake Baikal were disturbed by inversion of the surface sediment by corer-penetration shock and by fracturing of this pan. Another problem is that occasionally the corer falls over during sampling and if the instrument is to be deployed in less calm or marine conditions or for sampling denser sediment then some sort of supporting frame would be needed to ensure a good recovery rate of intact cores.

When deploying the Baikal box corer, the conditions (weather, location, sediment type, and winch type used) will determine which particular blade-release mechanism is appropriate. Release mechanism 1 is probably least satisfactory generally, but it could be employed in conditions where the ship is undergoing significant movement (due to wind or current). Use of the 'damper' device to delay closure a few seconds works best in our experience, for it allows the corer time to sink into the sediment and closure is effected before retrieval. Calm conditions, however, are required for optimum performance of this mechanism. When the corer is used from an ice platform, controlled closure timing is not always necessary. Indeed, the trigger damper assembly can freeze-up when removed from the water. With a fixed coring platform, box closure on retrieval is perhaps to be preferred, but if a winch is employed the corer should, initially, be lifted very slowly.

Sub-sampling the retrieved sediment sample by using a wide diameter piston corer gently pushed into the sediment minimizes smearing and compaction. Disturbance effects are further reduced by trimming each sediment slice on extrusion. In contrast to observations made with hand inserted core tubes without pistons (Chant & Cornett, 1991), no significant core shortening by sediment loss or sediment dewatering occurred with Lake Baikal sediment during the sub-sampling or by subsequent extrusion. However, piston-core extrusion of organic-rich lake sediments can result in some 8% loss of length due to dewatering, water being preferentially pushed out of the sediment (R. J. F., unpubl. data). Piston coring always has some risks for micro-stratigraphy compared with sub-sampling by sediment freezing. The Baikal box corer has been successfully sub-sampled using a modified liquid nitrogen coldfinger technique (Pollingher et al., 1992) in the field, but the sediment reveals no visual laminations (Flower, 1994). Immediate sub-sampling of the box is not always appropriate if activities at the mud-water interface need to be viewed and monitored.

In the validation and replication tests applied to the Baikal box cores, the BIK6 radiometric data, especially that of 241Am, all confirm that the corer collected very recent and undisturbed sediment. The evidence concerning core replicability is more equivocal; the per-
Acknowledgments

Engineer M. Town kindly provided many innovative design ideas and also helped construct the box corer using workshop facilities at University College London. Engineers at LINNA, Angarsk (Siberia) also provided helpful discussions and suggested several modifications to the instrument. We are indebted to the crews of the RVs Vereschagin and Titov for their patience and help with use of this new box corer in Lake Baikal during 1992 and 1993. Basic costs of building the corer were provided under a UCL Departmental Equipment grant and field-work trials in Russia where organized through M. Grachev, Director of the Limnological Institute, Irkutsk (Siberia), under the International 'BICER' agreement. Invaluable help in the field was provided by Dr N. Granin and others. H. J. B. Birks advised on numerical core-comparison techniques. The referees made useful improvements to the manuscript. Travel arrangements were facilitated by L. Mole and funding was kindly provided by The Royal Society, London and The Leverhulme Trust (under grant F134AZ). Artwork is by Guy Baker (UCL).

References


CRATERIPORTULA GEN. NOV., A NEW GENUS WITH CLOSE AFFINITIES TO THE GENUS STEPHANODISCUS

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Examination of material from Lake Baikal revealed several species of the genus Stephanodiscus Ehrenberg in addition to the common genera Cyclotella (Kütz.) Bréb. and Aulacoseira Thwaites. One of the diatoms found closely resembled the recently described taxon, S. inconspicuus Mak. & Porn. (in Makarova & Pomazkina 1992). This diatom has several unusual features which makes us question its inclusion in the genus Stephanodiscus. On the basis of our investigation we have erected a new genus Crateriportula Flower & Håkansson nov. gen. into which we have transferred S. inconspicuus as the type species.

INTRODUCTION

In material from Lake Baikal we have found a diatom taxon which under the light microscope might be considered to be a small Stephanodiscus species. Recently, Makarova & Pomazkina (1992) validly described a new Stephanodiscus, S. inconspicuus Mak. & Porn, also from Lake Baikal. From the available illustrations and description we are certain that all the features of this new Stephanodiscus species are in accordance with those observed in our species. However, it is our opinion that several of the distinctive characteristics have not been recorded in any known Stephanodiscus species and we therefore propose that a new genus Crateriportula be erected. We were not able to check the type material, but we assume that our material is conspecific with Stephanodiscus inconspicuus, Mak. & Porn., 1992. Therefore, we are retaining the epithet inconspicuus.

MATERIAL AND METHODS

Surface sediment samples as well as samples from cores were lightly acid cleaned and prepared for LM and SEM investigation (see Håkansson 1984).
Diagnosis

**Crateriportula** Flower et Håkansson, gen. nov.


**Typus generis:** *Crateriportula inconspicua* (Mak. et Ponn.) Flower et Håkansson nov. stat.

**Type slide:** Russia, Lacus Baical, VII, 1988, G.V. Pomazkina. In Instituto Limnologiae Sect. Sibiriae Russian Acad. Sci. (Irkutsk) conservatur.

Valve circular, concentrically undulate. In the central area a few scattered puncta of variable size; in the marginal area short striae and interstriae. At the distal end of every interstria a short, stout spine occurs. Beneath some spines a crater-like opening of a mantle fultoporula. The crater-like opening of the rimoporula is positioned in the ring of spines but slightly internal to the ring. Each areola provided internally with a cribrum consisting of a few (rarely 2, 3-7) pores. The central fultoporula is situated very near the junction of the valve face and the mantle.

**Crateriportula inconspicua** (Mak. et Ponn.) Flower et Håkansson comb. nov. Figs 1-12


**Type slide:** Russia, Lacus Baical, VII, 1988, G.V. Pomazkina.

**Type locality:** Southern part of Lake Baikal.

Valve circular, slightly concentrically waved, with a diameter between 6 and 10 mm. The marginal area has short striae and interstriae, 15-16 in 10 µm. At the end of every interstria a short, stout spine occurs. Beneath some of the spines a crater-like opening of the mantle fultoporula occurs. In the central area are several puncta of differing size. There are no interstriae on the very short mantle. The valve face fultoporula is very near the valve face edge and internal to the ring of mantle fultoporulae. All fultoporulae have 3 satellite "pores" or laterisquamae (see Flower 1993 for a definition of this term). The rimoporula lies just beyond the ring of the spines on the mantle and opens into an external crater-like opening.

**OBSERVATIONS**

*Crateriportula inconspicua* has a slight elevation or depression on the central area of the valve. Some puncta differing in size are arranged in no special order on the valve face (Figs 4-6, 8, 9). Usually, the marginal striae starts with a single areola, then is continued with two or three areola rows reaching on to the very short mantle. Within the mantle zone, however, areolae are scattered, their distribution having no clear pattern (Figs 4 & 7). Areolae on the valve face are of two types, one has the usual simple and round external aperture (Fig. 7 arrow a) and one has a round or oval aperture and occurs in a crater-like depression (Figs 5 & 7b). The striae are divided by slightly elevated interstriae which broaden towards the mantle (Figs 4-6). It is not clearly visible if every interstria continues down to the valve edge; it seems as if this is only the case with the interstriae associated with the rimoporula (Figs 4, 5, 7). At the end of most interstriae, located around the valve face-valve mantle junction, there are short, robust spines. They can be broken or detached.
**Crateriportula gen. nov.**

Figs 1-7. *Crateriportula inconspicua*. Figs 1-3. LM. Scale bar (Fig. 3) = 10 µm. Figs 4-7, SEM. Scale bars = 1 µm.

Figs 1-3. Different valves observed in the light microscope. Fig. 4. External view of a slightly tilted valve, the opening of the rimoportula (arrow a). Fig. 5. External view of a frustule, the opening of the rimoportula (arrow a) and the opening of the "displaced" or valve face fultoportula (see text and arrow b). Fig. 6. On this external view the remnants of the spines (arrow a), the openings of the mantle fultoportulae (arrow b), the opening of the rimoportula (arrow c) and the opening of the "displaced" fultoportula (arrow d). Fig. 7. Detail of Fig. 5, showing the two types of valve face areolae, type 1 are simple round apertures (arrow a) and type 2 are sub-round and the aperture occurs in a crater-like depression. Also note the stout spines, also located within depressions or recesses, and the external opening of a mantle fultoportula (arrow c).

leaving a remnant (Fig. 6, arrows a). These spines are not quite regularly spaced due to the irregular arrangement of the mantle fultoportulae on the narrow mantle area (Figs 4-6). Each spine is located on the valve face in a shallow depression (Fig. 6, arrows a). A fultoportula opening is associated with every 3-4th spine but the aperture does not lie directly beneath each spine but is always off-set a little to one side (Fig. 6,
arrows b). Occasionally, a marginal fultoportula opening is not associated with a spine (Fig. 7, arrow c). The openings of the fultoportulae occur in crater-like depressions (Figs 4–7); their arrangement is very unlike the tubular openings typical of species in the genus *Stephanodiscus*. The external, crater-like, opening of the rimoportula occurs at the end of an interstriae without a spine (Figs 4 & 5, arrow a; Fig. 6, arrow c). The distal part of the mantle is devoid of areolae but possesses rather irregularly spaced vertical grooves, up to about 7 per valve (Figs 4 & 9, arrows b on Fig. 9).

Internally, the fultoportulae are usually furnished with two laterisquamae (Figs 8–10). There seems to be only one valve face fultoportula with up to three laterisquamae (Figs 10, 11 arrows b) but sometimes only a single laterisquama is present (Figs 8, 9 arrow c). This central fultoportula gives the impression of being a "displaced" marginal process (arrow b, Fig. 5 where the external opening is visible). Interestingly, this fultoportula lies exactly opposite the rimoportula (Figs 8–10), a characteristic also found in species of the genera *Stephanodiscus*, *Cyclotella* and *Cyclostephanos*. Internally, the rimoportula is sessile and the direction of the slit-like aperture is approximately parallel to the valve perimeter (Figs 8–10, 12). The internal areolae are domed and covered by only a few (2–7) relatively large cribral pores, some having the appearance of a ring of pores around a slightly raised central pore (Fig. 12).

DISCUSSION

Under the light microscope *Crateriportula inconspicua* appears very similar to some of the small species in the genus *Stephanodiscus*. However, study in more detail under the electron microscope (SEM) revealed many features atypical for *Stephanodiscus*. On the other hand, some of the morphological features seen in *C. inconspicua* seem to be shared by both *Cyclostephanos* and *Stephanodiscus*. We know that in *Stephanodiscus* species, during different life-cycle stages, the valve face central area can have less areolae (Håkansson & Meyer 1994) but in all cases there is a clear central fasciculate area. Furthermore, in *Stephanodiscus* the external openings of the mantle fultoportulae are slightly thickened and the rimoportula possesses a tubulus of differing length. These features are all different in *Crateriportula inconspicua* and, as far as we know, the internal structure of the cribrum is also different from those in *Stephanodiscus* where finer poroids are the rule. On the other hand, the cribrum structure in *Cyclostephanos invictus* (Hohn et Hellerman) Theriot, Stoermer et Håkansson (Theriot, Stoermer & Håkansson 1987) appears somewhat similar to that in *Crateriportula inconspicua*. Other species in *Cyclostephanos* of course have several features which differ from our newly described genus; particularly in the structure of marginal features.

It is known that a range of variation in each feature is to be expected and not all members of a genus should be expected to possess all features. However, in the new genus *Crateriportula* we can clearly recognize several very distinct and unique morphological features that cannot easily be considered as part of the normal range of expected variation, e.g. i) crater-like external openings of the marginal as well as the valve face fultoportulae and of the rimoportula; ii) the single valve face fultoportula near the valve face/mantle mantle junction which gives the impression of a "displaced" marginal fultoportula; iii) the very short, marginal radiate striaion; iv) scattered areolae of different size on the valve central area; v) two types of areolae on the valve face; vi) scattered areolae on the mantle; vii) spines located in shallow depressions. Although the basic structural arrangement or "Bauplan" of *Crateriportula* can be described as stephanodiscoid we believe that the sum of the differences in morphological detail are sufficient to warrant the creation of a new genus.

*Stephanodiscus inconspicuus* as described by Makarova & Pomazkina (1992) should therefore be transferred to the newly erected genus *Crateriportula*. As far as we know the taxon is endemic to modern day Lake Baikal. Little is known of its distribution in lake sediments. The sedimentary diatom record in Lake Baikal extends back to at least the Miocene period and so offers an unparalleled opportunity to study
Figs 8–12. Crateriportula inconspicua. SEM. Scale bars: Figs 8–11 = 1 µm; Fig. 12 = 0.5 µm. Figs 8, 9. Internal view with the “displaced” fultoportula (arrow a) with a single laterisquama, located opposite the rimoportula (arrow b). In Fig. 8 the rimoportula is located between two mantle fultoportulae. Fig. 9 The rimoportula (arrow a) is located besides a mantle fultoportula. Also note the small grooves (usually 6–8 in number) on the external edge of the mantle (arrows b). Fig. 10. Internal view with the “displaced” fultoportula with three laterisquamæ (arrow a). Fig. 11. Detail of the same specimen showing the mantle fultoportula with two laterisquamæ (arrow a) and the “displaced” fultoportula with three laterisquamæ. Fig. 12. Detail of the features and placement of the rimoportula and the distinctive cribra over the areolae.

do the phylogeny of this new genus over a geological time-scale. Questions about whether Crateriportula represents a relic of a more widespread and species rich genus, a persistent but always rare group, an aberrant form, or even the beginning of a newly differentiated taxon (cf. Theriot 1992) await further evidence from the fossil record. Ongoing palaeolimnological studies at the Limnological Institute (Irkutsk) and elsewhere should soon reveal answers to some of these questions.
ACKNOWLEDGEMENTS

We want to thank Ms Patricia Sims for her kind and expert help at the scanning electron microscope, Mr R. Ross for the Latin description, Professor F. E. Round and Mr R. Ross for critical reading of the manuscript and making valuable suggestions. R.J.F. is grateful for discussions with Drs Y. Likhoshway and A. Kuzmina. We wish to thank also the Universitets och Högskolelämnet and The British Council for their financial support. The Royal Society and the “BICER” initiative made visits by one of us (R.J.F.) to Lake Baikal possible.

REFERENCES


Introduction
Lake Baikal is possibly the world's most remarkable freshwater lake (Figs 1-3). It is certainly the largest in volume (23,000 km$^3$), the deepest (maximum depth is 1632 m) and probably the most ancient. Nevertheless, from a biological point of view its most interesting aspect is the endemic flora and fauna. Many of the species of animals and plants occurring in Lake Baikal today are found nowhere else in the world. Especially remarkable is the unique and diverse deep-water fauna which is maintained by the circulation of oxygen-rich water to the greatest depths in the lake. This water mixing is the prime feature that sets Lake Baikal apart from other deep freshwater lakes; for example, lakes Tanganyika and Malawi in the African rift system possess anoxic deep-water (Beadle 1974). Despite the fascination of Lake Baikal's biota, its isolated location in southeastern Siberia, combined with restricted access caused by political tensions, has until recently largely prevented international research on the lake.

This situation changed markedly when former President Gorbachev introduced glasnost and perestroika to the former Soviet Union. Rapid changes in attitude occurred and, in 1990, an international centre was created to foster collaborative research on Lake Baikal, following a founding conference in the Siberian town of Irkutsk. Funding for this centre was and is international; it involves five founder member countries, USA, Britain, Belgium, Japan, and Switzerland acting in conjunction with the Russian Academy of Sciences. “BICER”, or the Baikal International Center for Ecological Research is linked directly with the Limnological Institute at Irkutsk. The Director of this institute is Dr M. A. Grachev who is also the chairman of the BICER international committee. BICER acts by promoting and facilitating research by visiting...
FIG. 2. Views of Lake Baikal in the southern basin. Above: RV Timor in Peshnya Bay, a popular but little-developed summer resort on the western shore. Note the sandy-gravel and rocky intershore with virgin coniferous woodland on mountain slopes facing the lake. Photograph by D. Amorosa. Below: Conifer pollen accumulations on the surface of the southeast region of the lake, following several days of very light winds preceding 5 July 1993. Photograph by R. J. Flower.

FIG. 3. A large pulp mill is a major pollution source on the southern shore of Lake Baikal. The industrial complex generates significant atmospheric as well as waterborne pollution. The photograph (by R. J. Flower) was taken in July 1993.

scientists from the founder countries, in co-operation with Russian scientists, as well as providing support for materials and equipment for the Limnological Institute. This latter support is increasingly valuable now that political and economic turmoil are destabilizing the Russian science infrastructure in general and research funding in particular.

BICER and British contributions to research on Lake Baikal

The on-going British effort in BICER was initiated and is administered by The Royal Society, London. This activity has been aided by grants from British Petroleum and the Foreign and Commonwealth Office. Since its beginning a little over three years ago the initiative has been remarkably successful in stimulating and co-ordinating research in a number of widely different fields of freshwater biology and limnology. Research so far includes investigations of visual pigments in deep-water fish (cotooids) by Drs J. K. Bowmaker and D. M. Hunt (Institute of Ophthalmology, University of London), phytoplankton taxonomy and ecology by Drs R. J. Flower (University College London), D. H. Jewson (Freshwater
The current pollution status of Lake Baikal

Although Russian scientists have been systematically describing Lake Baikal's impressive array of endemic species for the past 100 years or so, much of the international research effort is now focused on environmental change over a variety of time-scales. American research centres upon the geological record of climatic change contained in some 10 m of lacustrine sediments which lie at the bottom of modern Lake Baikal. There is, however, increasing international concern about very recent changes in the lake's unique ecosystem that could be linked with the effects of water pollution from catchment effluents and atmospheric contamination. Warnings so far have centred upon declining endemic whitefish stocks in the south basin and the spread of viral distemper within the Baikal seal population (Grachev et al. 1989). These recent changes in the lake ecosystem are thought by some to reflect deterioration in lake water quality (Galazia 1991), and one principal cause is believed to be waste from a large pulp mill (Fig. 4) at Baikalisk on the southern shore of Lake Baikal. Whilst local water quality problems are acknowledged, other scientists firmly believe that the pollution problem has been overstated (Grachev 1991). To resolve these opinions it is necessary to show if the ecology of Lake Baikal has changed in a sustained manner over a time period that is compatible with known pollution sources. Probably the best way to do this is to measure structural changes in the lake's ecosystem, by monitoring changes in species abundances over sufficiently long periods of time.

Assessing recent biological change

Monitoring studies of the phytoplankton in Lake Baikal's southern basin indicate that several species have increased in abundance since the mid
FIG. 5 above: A sediment box-corer (see Fig. 6 on facing page) being retrieved after sampling surface sediment living under 1200 metres of water in the southern region of the central basin of Lake Baikal. Coning, in July 1991, was from the R V Time, in cooperation with Dr V. Tkachenko as second from the rear; she is a senior scientist at the Limnological Institute, Irkutsk.

Fig. 6 on facing page: Left: a deep-water box-corer developed at University College London and the Limnological Institute, Irkutsk. This corer has successfully retrieved undisturbed surface sediment samples from a depth of 1420 m in the southern basin of Lake Baikal. The core assembly is about 1 m in height. Right: a frozen core of lacustrine sediment obtained by coring in 156 m depth of water through ice-covered Lake Baikal in March 1991. Following sample retrieval using the box-corer, the sediment was frozen with liquid nitrogen. Note the oxidized iron and manganese microzones at the sediment surface and the abrupt change to grey anoxic sediment at about 4.5 cm depth.
1970s (Kozhova 1987). However, biological records are generally incomplete, are representative of too short a time period, or/and are of insufficient quality to determine whether significant shifts in species abundances have taken place. One way of assessing ecosystem change over a longer time period is of identifying any contamination by chemical pollution is to examine biological and chemical records preserved in recent lake sediments. All lake basins gradually accumulate sediment, and analysis of sediment cores allows past changes in the lake ecosystem to be detected and dated. One of the main techniques used is diatom analysis. Diatoms are siliceous algae which, in Lake Baikal phytoplankton, are very important primary producer organisms. They are also excellent indicators of water quality. Because their skeletons preserve well, changes in the relative abundances of diatom species in a sediment core can be very diagnostic of ecological change.

The diatom flora of Lake Baikal

In any study of structural ecology or palaeoecology, the quality of information obtained is fundamentally dependent on accurate and precise taxonomy. Fortunately, diatoms have been well studied in this lake with collections beginning in 1877 (Gutwinski 1890). Two major papers on the identification and taxonomy of Lake Baikal diatoms by Skvortzow & Meyer (1928) and Skvortzow (1937) then appeared, followed by a series of ecological and taxonomic studies by A. P. Skabichevsky (see Skabichevsky 1960). Many endemic diatoms were described in these papers; the diatom phytoplankton is dominated by endemic Aulacoseira baicalensis (Meyer) Simonsen and several endemic Cyclotella taxa, including C. minuta (Skv.) Antipova (Fig. 4).

Despite the relative wealth of taxonomic work on Baikal's diatom flora, many problems remain and new species are being described continuously (e.g. Marakova & Pomazkina 1992). Even Aulacoseira baicalensis is not adequately described, with the first paper on variation in cell ultrastructure being only very recently published (Likhoshway et al. 1992). Furthermore, there appears to be some morphological overlap of this species with a more cosmopolitan species, A. islandica. Initial results of ongoing genetic research on the analysis of RNA gene sequence (Sherbakova 1993), however, indicates that genotypes of these two taxa are clearly distinct.

Recent sedimentary diatom records in Lake Baikal

Although diatoms in Lake Baikal sediments have been studied since the 1930s, the focus was on describing taxa. Only later were biostratigraphic studies combined with those of taxonomy (Cherevinskova 1973). Such studies were however concerned with species changes over thousands rather than tens of years, and in any case the type of coring apparatus used caused the very surface sediments to be lost. These most recently deposited sediments are of course crucially important in any study of recent changes. Collecting undisturbed surface sediment samples at water depths of more than 1 kilometre is not easy and requires specialized corers. Several types of box-corers with closing tops and bottoms have been developed by staff at the Limnological Institute, Irkutsk and at University College London (Figs 5, 6). Undisturbed samples of surficial sediment have been retrieved by these corers and the presence of radio-isotopes of recent origin confirm the recent nature of these sediments (Edgington et al. 1991; Monteith et al. 1993). Diatom analysis of several cores taken from a variety of depths in Lake Baikal's southern basin using these box-corers, is now underway in both Irkutsk and UCL. Most recently, frozen cores have been obtained by freezing samples of sediment within a box-corer using liquid nitrogen (Fig. 6). Results of core analyses will be published later.

Future research and aspects of particular interest

Despite the economic and political problems in Russia today it is anticipated that British research initiated under the BICER agreement will increase. Further phytoplankton research with special reference to life cycles, taxonomy and periodicity is planned and work on deep-water ctenophora fish is continuing. Recent palaeoecology of the Lake Baikal system is underway following successful pilot studies in 1992, with the initial aim of collecting a suite of cores from all three of the lake's main basins. Analysis of these cores should provide an accurate assessment of the lake's current ecological status and demonstrate the impact (if any) of pollution-linked changes, where they are strongest and when these effects began. British research projects planned for the future include collection of remote-sensing data of high resolution, to help examine how phytoplankton blooms are initiated spatially and how crops are distributed throughout the lake's three basins. Fundamental to all these studies is good taxonomy and correct identification of species. These are well established for many invertebrate and vertebrate groups but not for algae, particularly for the diatoms and picophytoplankton. Much more research is required, however, before morphological algal species types can be underpinned by genetic identities.

An area requiring inspirational development concerns the occurrence of endemic species; the significance of endemism in ancient lakes is still far from clear despite a recent international conference on the subject.
LAKE BAIKAL SEDIMENT CORES: DIATOM STRATIGRAPHIES
southern basin

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<th>Depth (cm)</th>
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below 7.5 cm, no diatoms are present
middle basin
For Lake Baikal, the lake's great age can only be part of the answer, and the speciation mechanisms of different groups are not necessarily similar. The unique deep-water amphipod fauna comprises over 40 endemic genera (Kozlov 1963) but whether this radiation is the result of allopatric speciation through geographical separation or sympatric speciation by neighbouring populations remains an area of dispute. Some recent workers favour the former mechanism (see Fryer 1991, for a succinct discussion of the issues). Despite this opinion, it remains difficult to reconcile Lake Baikal's fairly uniform and stable (over recent geological times) deep water environment with Mayr's explanation of allopatric speciation resulting from localization of populations by "extrinsic barriers" (Mayr 1963). Perhaps the debate will be aided by research into the genetics of amphipod speciation currently in progress at the Limnological Institute in Irkutsk.

The endemic diatom flora raises other issues. Common endemic planktonic diatoms number probably less than 10 species and so are much less diverse than many animal groups in the lake. Diatoms require some relationship with the photosynthetic or euphotic zone, where water turbulence is a key factor controlling species occurrence and periodicity. Environmental instability of Lake Baikal's surface waters extends to a longer time-scale. The Baikal region was never glaciated but peri-glacial conditions occurred during the Pleistocene Period (Velichko et al. 1984) and must have caused, inter alia, major variations in the persistence of ice cover and lake-water turbulence. Another difference between the diatom flora and the endemic faunas in Lake Baikal is that an excellent fossil record of diatom plankton communities is preserved in deep-water sediments. Modern endemic species have been reported from Miocene sediments (e.g. Belova et al. 1983) but identifications are unsubstantiated and are now thought to be unreliable (G. Khursevich, pers. comm.). Close scrutiny of the fossil diatom record, combined with careful and consistent discrimination of taxa using both morphological and genetic criteria, is therefore required before sensible speculations about the origin of modern diatom species and communities can be made for Lake Baikal.

In addition to its remarkable endemic biota, Lake Baikal possesses many other notable features, not least of which is its catchment, 540,000 km² in area. This offers many varied opportunities for more applied research. The current extent of background deposition of atmospheric pollutants in the Baikal region has implications for lake-water quality and is partially known from direct measurements (Kokorin & Politov 1991). However, the ecological impacts and time trends in deposition loadings can be best estimated from the analysis of sediment cores taken from small lakes in the mountain ranges in the immediate vicinity of Lake Baikal. This work is in its initial stages (Flower et al. 1993) but results so far show that a soft-water mountain lake near the southeastern shore of Lake Baikal has been contaminated by trace metals since approximately the 1940s.

Taking a wider perspective, virtually all spheres of energy production, agriculture and exploitation of mineral reserves within the Baikal catchment are inefficiently developed. Whether or not these operations are affecting the biota of Lake Baikal remains unclear, but there is great scope for innovations and improvements to pollution controls. The region's spectacular lake scenery and extensive wilderness areas are its greatest resource and eco-tourism must offer great potential for the cash-starved local economies. However, this industry will not thrive unless development is reconciled with maintaining natural ecosystems. Lake Baikal has been proposed as a World Heritage Site and recognition is based on the assumption that it suffers from little or no pollution. Any regional development must therefore proceed in an environmentally sensitive manner based on sound policies developed from appropriate research and concurrent impact assessments.

Acknowledgements

I wish to thank the Royal Society and Dr M. A. Grachev, Director of the Limnological Institute, Irkutsk, for making this report possible by stimulating international research on Lake Baikal. I am very grateful to all the staff at the Limnological Institute who have facilitated fieldwork visits to Lake Baikal and surrounding areas, Dr Y. Likhoshway, Dr A. Kuzmin and Ms G. Nagornaya deserve particular thanks. Mr L. U. Mole at The Royal Society London provided invaluable support with logistics and travel arrangements. ECRC colleagues Mr D. Monteith and Dr A. Mackay have also contributed to this work. This paper has benefitted from discussions with many people including Dr D. Shcherbakov (Irkutsk), Dr D. H. Jewson (Ulster), Prof. R. W. Battarbee (UCL), Mr S. Politov (Moscow) and Dr J. Talling (FBA). Art work is by Mr T. Aspden.

BICER publications

The following are research publications and reports resulting directly from the BICER scheme operated by The Royal Society of London.


Bowmaker J. K., Govardovskii, V. I., Shukolyukov, S. A., Zueva, L. V.,


General references:


SOME DIATOMS FROM SIBERIA
ESPECIALLY FROM LAKE BAIKAL

Niels Foged†

edited by
H. Håkansson and R. J. Flower

In 1975 Niels Foged travelled through the former Soviet Union (FSU) and collected diatoms from several localities. In 1986 he began working on this material but was unable to finish the manuscript before he died in January 1988. His study is of particular interest because he collected from Lake Baikal, the world's largest freshwater lake, famous for its abundance of endemic species. His samples provide a record of the abundance of the species at a point in time during which this scientifically important lake was receiving effluents and which were possibly changing its water quality. The changes may be sufficient to alter the balance between the endemic and cosmopolitan diatoms which Lake Baikal supports. Any evidence about past diatom floras is valuable to scientists studying recent environmental change in this lake as well as elsewhere in the FSU.

We have not changed the text (apart from minor editorial corrections) of Foged's manuscript but we have had to reconstruct his figures. We have also left his names for the taxa but added (in square brackets) what are, in our opinion, the currently accepted names. This is especially necessary for some taxa belonging to *Cyclotella*, *Aulacoseira*, *Fragilaria* and *Opephora*. Classification is to a degree subjective and sometimes scientists use different names for the same taxon; where the current name is in doubt we give an alternative. The most difficult part in preparing the manuscript was deciding upon the magnification of the diatom figures. Niels Foged mostly used 1500× magnification, but sometimes he would use 1200×, 1000× or 2000× and precise information about magnifications used for particular photographs is lacking. We therefore omit scale-bars and suggest that the reader should refer to the measurements given in the text for each photograph.

On examining Foged's slides in the archives at the Botanical Museum in Copenhagen we found several more undescribed taxa and located later material collected by Foged in the FSU together with more field notes. If enough archived data becomes available then its value for monitoring ecological change can be significant. In this respect, one of us (RJF) re-sampled diatom communities in 1992 from three of the locations where Foged collected in 1975. It is hoped to publish at a later date the results of floristic comparisons between these collections. Photographs of Foged's sampling sites on Lake Baikal are given in the Appendix.

We wish to thank all the people without whose help it would never have been possible to complete this manuscript. Mona Nissen and Sören Håkansson typed most of the manuscript, and Lotte Foged helped us as much as possible with details of the collecting sites and transcribed her husband's handwritten notes. Ruth Nielsen, the curator in the Botanical Museum in Copenhagen where all the Foged diatom material is available for research, was indefatigable in finding solutions to problems which...
arose during this work. It was a great pleasure to work at the Museum with all this support. A grant from The British Council and the Swedish Academy of Sciences to foster co-operation between British and Swedish scientists made our work possible.

INTRODUCTION

The diatom flora of Siberia is little known outside the former Soviet Union (FSU). This is due to several exceptional circumstances: particularly its huge size, but also the extreme climate and the very low density of population which consists mainly of peoples outside the large European and Asiatic culture groups. During the last 200 years – especially most recently – a considerable immigration from the European part of the U.S.S.R. has taken place. Because of the inhospitable conditions, the population is chiefly concentrated in a few large towns and agricultural areas in the southern part of Siberia; the major part of the country is still very sparsely populated. The towns and communication systems are concentrated around the points of exploitation of the region's huge natural resources. Scientific investigations of the natural environment have been chiefly performed by specialists from the European part of the U.S.S.R. The results of this work are published mainly in Russian, very often without a summary in a W. European language. This still causes communication difficulties between E. and W. European scientists.

It is, however, not surprising that the first paper on the Siberian diatom flora concerned Lake Baikal, the biggest freshwater lake in the world. The lake is 30,500 km² in area, 620 km long up to 75 km wide, up to 1940 m deep and contains the major part of the earth's standing freshwater. Associated with its age (it dates from the Tertiary period), its fauna and flora are extraordinary, including a series of endemic species and even endemic genera. In certain respects its biology can be compared with other ancient lakes like Ochrid (Yugoslavia) and Tanganyika (Africa).

Algal collections began in Lake Baikal in 1877 (P. Dybrowski) and in 1890-91 the Polish scientist R. Gutwinski published treatises on the diatoms in this material. Papers by Dorogaiski (1904, Observera Dorogaiski ska! kontrolleres evt i bibliografien eller i Skvortzow, 1937), Meyer (1922) and Wislouch (1924) followed. Later, a series of major and minor papers was published on diatoms and other algae in Lake Baikal, the most important being Skvortzow and Meyer (1928) which reported a total of 450 diatom taxa of which 160 were new. Skvortzow's 1937 treatise, based on a single sample from a depth of 33 m in the lake, recorded 304 taxa of which 148 were new. This huge wealth of species in a sub-arctic freshwater lake is remarkable. More recent analyses of diatom material from other arctic localities have much less diversity. A single bottom sample from 15.5 m depth in a large lake on The Northern Slope of Alaska (70° 01'N. lat. 153° 36'W. long.) had only 30 new species out of a total of about 400 diatom taxa recorded (Foged 1971). The uniqueness and diversity of the Lake Baikal diatom flora can be compared with those from elsewhere (e.g. Foged 1953, 1955, 1958, 1971, 1972, 1973 and 1981).

After the paper of Skvortzow (1937) a series of chiefly minor treatises on the diatom flora of Lake Baikal were published. Especially during the years after 1950, a series of short papers on the diatom florals of other Siberian localities was published in the Russian language in journals edited by Akademia Nauk, SSSR, Moskva. The titles of the papers available to me are given in the References at the end of this paper.

MATERIAL

Samples were collected during a tour along the Transiberian Railway in 1975 [see appendix Figure 1 and 2].
24.8.1975 Chabarowsk. The river Amur at the sports ground.
No. 1 and 2: Scrapings from rocky surface. Green alga.

28.8.1975 Lake Baikal [see Appendix figure] at the Limnological Institution:
No. 3: Scrapings from quay poles.
No. 4: Green algae on stones in the surf.
Lake Baikal [see appendix figure] at the parking place at the change-over between the lake and the
River Angara.
No. 5: Scrapings from concrete of the quay, green algae in the wash of the waves.
No. 6: Scrapings from a stone picked up from the water at a short distance from the coast. Green
algae.
Wheel track with oozing water near the meteorological station:
Nos 7 and 8: Green algae

Note: Skvortzow (1937, p. 293) states the average temperature of Lake Baikal is 3.2°C, in January
0°C and in September 8.6°C. The lake is ice covered c. 6 months of the year. The site is at 51°31'-55°46' N. lat., 103°44' - 109°57' E. long.

29.8.1975 Irkutsk at the monument for the railway:
No. 9: A piece of Elodea and scrapings from concrete steps in the Angara river.

1.9.1975 Novosibirsk. A reservoir with water from the river Ob:
No. 10: Surface sand
No. 11: Scrapings from a floating stick. Green algae.

RESULTS

Achnanthes Bory

A. borealis A. Cleve
A. Cleve 1895, p. 23, pl. 1, figs 24, 25; Sabelina et al. 1951, p. 224, pl. 126, fig. 2; Foged 1971b, p. 927, pl. 8, fig. a,b; 1974, p. 23, pl. 36, fig. 11; 1977, p. 21, pl. 14, figs 3, 4; 1981, p. 44.

Fig. 42: 26 x 14 µm, No 06 Baikal-Angara.
Oligohalobe (indifferent) pH? Circumpolar.

First recorded, described and named by A. Cleve 1895 (p. 23, pl. 1, figs 24, 25) from Swedish
Lapland, where "both valves have not been seen together, but are found in the same sample". Because
of this A. Cleve-Euler (1953, p. 55) refers it to A. elliptica (Cleve) A. Cleve-Euler (1932, p. 35).

In Foged 1971b, p. 927, pl. 8, fig. 3a, b (20 x 9 µm; a: 18 striae, b: more than 25-26 striae in
10 µm) the two valves belong to the same cell. In sample No 06/1975 from the Baikal region both
valves of the same cell are seen, but the rapheless valve, Fig. 42, almost covers the raphe valve with
the very dense striae. Previously the species was observed by me in sample No 341/1959 from SW
Greenland, and was recorded from 3 localities in Iceland (Foged 1974), from 6 localities in Ireland
(Foged 1974) and in a bottom sample from Alaska (Foged 1981). It seems to be a widespread
circumpolar species, presumably up to now overlooked or confused with A. oestrupii (A. Cleve) Hust.
Hustedt (1930-66, II, p. 429) writes: "Die raphenlose Schale (Fig. 24) gehört vielleicht zu A. oestrupii
(A. Cleve) Hust." Because of the size of the valves in this material, the species here recorded should
perhaps be separated as a forma baikalensis f.o. nov.

A. calcar Cleve
Krypt II p. 412, fig. 866; Sabelina et al. 1951, p. 225, fig. 127; Foged 1971b, p. 927; 1981, p. 44, pl.
13, fig. 2; Patrick & Reimer 1966, p. 281

Fig. 52: 14 x 8 µm, No 06 Baikal-Angara.
Oligohalobous (indifferent), alkaliphilic. N temperate zone.
A. clevei Grun.
Hustedt 1930-66, II, p. 391, fig. 839 a, b; Sabelina et al. 1951, p. 215, pl. 118, fig. 2; Foged 1971b, p. 928, pl. 1, fig. 5a, b; Patrick & Reimer 1966, p. 267, pl. 17, figs 21, 22.
Nos 05, 06 Baikal–Angara.
Oligohalobous (indifferent), alkaliphilic.

fo. nov.?
Fig. 44: 27 × 10.5 µm, No 06.
Closely related to A. clevei Grun. var. balconica Hustedt fo. rostrata Hustedt 1945.

A. hauckiana Grun. [= A. delicatula ssp. hauckiana (Grun.) Lange-Bertalot in Krammer & Lange-Bertalot 1991.]
Hustedt 1930-66, II, p. 388, fig. 834; Sabelina et al. 1951, p. 212, pl. 115, fig. 1; Foged 1971b, p. 929; Patrick & Reimer 1966, p. 267, pl. 17, figs 25-32.
No 06 Baikal-Angara.
Mesohalobous. Cosmopolitan?

[Because of complicated taxonomy in the Achnanthes lanceolata-complex, we have not changed any names (see Round et al. 1990 and Krammer & Lange-Bertalot 1991)].

A. lanceolata (Bréb.) Grun.
Hustedt 1930-66, II, p. 408, figs 863a-d; Schmidt et al. (1874-1959), pl. 411, figs 20-31; Sabelina et al. 1951, p. 221, pl. 124, fig. 1; Foged 1971b, p. 930, pl. 8, figs 4a, b, 6a, b; 1981, p. 49, pl. 12, figs 11, 12, 24; Patrick & Reimer 1966, p. 269, pl. 18, figs 1-10.
Nos. 02, 04, 05, 06, 07, 08 (common), 10, 12.

Fig. 21: 19 × 8 µm No 08. Fig. 50: 17 × 8 µm No 05.
Fig. 51: 20 × 8 µm No 09. Fig. 25: 17 × 9 µm No 05 var.?
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

A. lanceolata var. ellipica Cleve
Hustedt 1930-66, II, p. 410, figs 863 n, o; Schmidt et al. 1874-1959, pl. 411, figs 43, 44; Sabelina et al. 1951, p. 223, pl. 124, fig. 6; Foged 1971b, p. 930; 1981, p. 49.
Nos 05, 06, 08 Baikal-Angara.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

var. rostrata (Østrup) Hustedt
Hustedt 1930-66, II, p. 410, figs 863 i-m; Sabelina et al. 1951, p. 222, pl. 124, fig. 4; Foged 1981, p. 49.

Fig. 28: 24 × 6.5 µm, No 06 ?, Fig. 38: 21 × 7 µm, No 06 Baikal–Angara.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

var. ventricosa Hustedt. [= - - var. elliptico-lanceolata (Schaar.) Ross.]
Hustedt 1930-66, p. 409, figs 863 e, f.

Fig. 43: 35 × 10 µm, Nos 08, 09 Angara.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

A. lapponica Hustedt. [= A. laevis istrup. in Lange-Bertalot & Krammer 1989. A. quadratarea (Ost.) Ross]
Nos 04, 05, 06 Baikal and Baikal–Angara.
Halophobous, acidophilic. Europe, Greenland, Alaska, USA.
A. \textit{latrostrata} Hustedt
Hustedt 1930-66, II, p. 392, fig. 840; Schmidt \textit{et al.} 1874-1959, pl. 410, figs 6, 7, 63-66; Sabelina \textit{et al.} 1951, p. 215, pl. 118, fig. 1; Patrick & Reimer 1966, p. 281; Foged 1971b, p. 930; 1981, p. 50, pl. 10, figs 20, 21; pl. 12, figs 19, 20; pl. 13, fig. 9.

Fig. 26: 12 x 6 µm, No 06 Baikal–Angara.


A. \textit{minutissima} Kütz.
Hustedt 1930-66, II, p. 376, fig. 849; Schmidt \textit{et al.} 1874-1959, pl. 410, figs 49, 50; Sabelina \textit{et al.} 1951, p. 206, pl. 111, fig. 3; Patrick & Reimer 1966, p. 253, pl. 16, figs 9, 10; Foged 1971b, p. 931; 1981, p. 50.

Nos 09, 11 (common) Angara–rkutsk. Reservoir at Ob.

Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

A. \textit{peragalli} Brun & Héribaud.
Hustedt 1930-66, II, p. 412, fig. 865; Schmidt \textit{et al.} 1874-1959, pl. 411, figs 8-16; Sabelina \textit{et al.} 1951, p. 225, pl. 126, fig. 4; Patrick & Reimer 1966, p. 274, pl. 19, figs 1, 2; Foged 1971b, p. 930; 1981, p. 51, pl. 13, fig. 3.

Nos 04, 06 Baikal, Baikal–Angara.


A. \textit{profunda} Skvortzow
Skvortzow 1937 p. 312, pl. 5; Sabelina \textit{et al.} 1951, p. 226, pl. 127, fig. 3.

No 06 Baikal–Angara.

Oligohalobous.

A. \textit{striata} Skvortzow & Meyer
Skvortzow & Meyer 1928, p. 10, pl. 1, fig. 23; Skvortzow 1937, p. 312, pl. 5, figs 11, 12, 45-47.

Nos 05, 06, Baikal–Angara.

Figs 47, 48: 18 x 10 µm, No 05 (the same cell)

[Differences from \textit{A. clevei} in the “nonpunctate striae of the lower part of the valve” (Skvortzow & Meyer 1937)].

Oligohalobous.

\textit{Amphora} Ehr. 1840

A. \textit{costulata} Skvortzow
Skvortzow 1937, p. 342, pl. 12, fig. 1; Sabelina \textit{et al.} 1951, p. 416, pl. 258, fig. 6.

Fig. 128: 23 x 6 µm, No 06 Baikal–Angara.

\textit{A. costulata} Skv. has no dorsal area and 11 striae in 10 µm (Krammer 1980, p. 212).

Oligohalobous.

A. \textit{inariensis} Krammer
Krammer 1980, p. 211, figs 21-24, 36, 37, 43-45.

Fig. 126: Cell: 20 x 8 µm, No 12 Reservoir Ob.

\textit{A. inariensis}: closely related to \textit{A. pediculus}. “The transapical striae in \textit{A. pediculus} are however relatively coarsely punctate. In \textit{A. inariensis} no puncta are visible.”

Oligohalobous (indifferent), pH-circumneutral.

A. \textit{montana} Krasske
Hustedt 1937-39, p. 413, pl. 24, figs 6-8; Krasske 1932, p. 119, pl. 2, fig. 27; Patrick & Reimer 1975, p. 80.

No 07 Angara.

Oligohalobous (indifferent), alkaliphilic, aerophilic.
A. ovalis Kütz.
Hustedt 1930, p. 342, fig. 628; Schmidt et al. 1874-1959, pl. 26, figs 116-111; Sabelina et al. 1951, p. 415, pl. 258, fig. 1; Patrick & Reimer 1975, p. 68, pl. 13, figs 1, 2; Krammer 1980, p. 208, figs 3, 5, 6-11; Foged 1971, p. 933; 1981, p. 54, pl. 45, figs 1, 2.
NoS 05, 10, 12 Baikal–Angara, and reservoir Ob.
Fig. 94: 38 × 27 μm No 12.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

var. libyca (Ehr.) Cleve [= A. libyca Ehr.]
Hustedt 1930, p. 342; Sabelina et al. 1951, p. 416, pl. 258, fig. 3; Krammer 1980, p. 209, figs 4, 12-20; Foged 1971b, p. 933; 1981, p. 54, pl. 45, fig. 3.
NoS 04, 12 Baikal, reservoir Ob.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

var. pediculus Kütz. [= A. pediculus (Kütz.) Grun.]
Hustedt 1930, p. 343, fig. 629; Sabelina et al. 1951, p. 416, pl. 258, fig. 4; Patrick & Reimer 1975, p. 69, pl. 13, figs 5a-6b; Krammer 1980, p. 214, figs 38-40, 42, 47, 48 as A. pediculus (Kütz.) Grun.;
Foged 1971b, p. 733; 1981, p. 54, pl. 45, fig. 10.
NoS 04, 05, 11 Baikal, Baikal-Angara, reservoir Ob.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

A. siberica Skv. & Meyer 1928 p. 36; 3:168
Skvorzov 1937, p. 342, pl. 12, fig. 26; Sabelina et al. 1951, p. 418, pl. 260, fig. 1; Stoermer & Yang 1951, p. 406, figs 11 a, b; Patrick & Reimer 1975. Nos 06, 10, 12 (very common) Baikal–Angara, reservoir Ob.
Fig. 86: cell 23 × 14.5 μm No 06.
A. siberica seems to be rather closely related to A. inariensis Krammer 1980, p. 211, but also to
Amphora libyca Ehr. in Krammer 1980, p. 209, figs 4, 12-20.
Oligohalobous (indifferent), alkaliphilic. Siberia and N. America.

Asterionella Hassall 1855

A. formosa Hassall
Hustedt 1930-66, II p. 251, fig. 729; Schmidt et al. 1874-1959, pl. 269, figs 20, 21; Sabelina et al. 1951, p. 153, pl. 85, fig. 1; Patrick & Reimer 1966, p. 159, pl. 9, figs 1-3; Foged 1971b, p. 934; 1981, p. 56.
NoS 01(?), 09, 10 Amur, Angara-Irkutsk, reservoir Ob.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

Berkella Ross & Sims 1978
According to Round et al. (1990) and Krammer & Lange-Bertalot (1986), the genus Berkella Ross & Sims should be combined with Frustulia.

B. linearis Ross & Sims [= Frustulia spicula (Amossé) Carter]
Ross & Sims 1978, p. 156, figs 20-27; Foged 1979, p. 29, pl. 17, fig. 4; 1981, p. 56, pl. 16, figs 5, 6; 1985a, p. 17, pl. 3, fig. 7.
Syn. Frustulia spicula var. alpina Amossé.
NoS 05, 07 (very common), 08, 09, 10 Baikal–Angara, Angara, Angara-Irkutsk, reservoir Ob.
Fig. 53: 43 × 8.5 μm, No 09.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan (?).
Caloneis Cleve 1891

*C. bacillum* (Grun.) Mereschk.
Hustedt 1930, p. 236, fig. 360; Sabelina *et al.* 1951, p. 390, pl. 238, fig. 1; Patrick & Reimer 1966, p. 586, pl. 54, fig. 8; Foged 1971b, p. 934, pl. 9, fig. 11; 1981, p. 57.

Nos 08, 09, 10, 12 Angara, reservoir Ob.
Fig. 30: 27 × 6 µm No 10, fig. 55: 36 × 7.5 µm No 12.

*C. schumannianna* (Grun.) Cleve
Hustedt 1930, p. 239, fig. 369; Sabelina *et al.* 1951, p. 393, pl. 242, fig. 1; Patrick & Reimer 1966, p. 587, pl. 4, fig. 10; As *C. limosa* (Kutz.) Patr.; Foged 1959, p. 50; 1981, p. 59, pl. 17, fig. 16; pl. 18, fig. 8; pl. 19, figs 8, 9; 1971b, p. 936, pl. 8, fig. 2; pl. 9, fig. 12.

No 12 Reservoir Ob.

*C. silicula* (Ehr.) Cleve
Hustedt 1930, p. 236, fig. 362; Patrick & Reimer, p. 583, pl. 54, fig. 3 (as *C. ventricosa* (Ehr.) Meister).

No 12 reservoir Ob.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

[For the following varieties no new names can be given, because we do not know what Foged had seen (eds comment).]

*C. arcus* (Ehr.) Kütz.
Hustedt 1930-66, II, p. 179, fig. 684 a, b; Sabelina *et al.* 1951, p. 138, pl. 76, fig. 1; Patrick & Reimer 1966, p. 132, pl. 4, fig. 20 (as *Hannaea arcus* (Ehr.) Patr.). Foged 1971b, p. 37; 1981, p. 60.

Nos 03, 04, 12 Baikal, reservoir Ob.
Fig. 24: 52 × 7 µm 16-17 striae in 10 µm No 04.
var. *linearis* Holmboe
Hustedt 1930-66, II, p. 180, fig. 684c; Sabelina *et al.* 1951, p. 138, pl. 7, fig. 8; Foged 1981, p. 61, pl. 5, fig. 15.
Nos 01, 03 (common), 04 (dominant), 05, 06, 07, 09, 10 Amur, Baikal, Angara, reservoir Ob.

*Cocconeis* Ehr. 1834

*C. pediculus* Ehr.
Nos 09, 09 Irkutsk–Angara, reservoir Ob.
Fig. 49: 29 x 20 µm No 09.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

*C. placenta* Ehr.
Hustedt 1930-66, p. 347, figs 802 a, b; Schmidt *et al.* 1874-1959, pl. 192, figs 1-4; Sabelina *et al.* 1951, p. 190, pl. 103, fig. 1; Patrick & Reimer 1966, p. 240, pl. 15, fig. 7; Foged 1971b, p. 938, pl. 7, fig. 16; 1981, p. 61, pl. 13, figs 13, 14.
Nos 03, 04, 05, 06, 07, 09 (dominant) Baikal–Angara, Angara–Irkutsk.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

var. *baikalensis* Skvortzow
Skvortzow 1937, p. 310, pl. 5, figs 7, 8 (non Skvortzow & Meyer 1928, pl. 1, fig. 25).
Nos 03, 06, 09 Baikal–Angara–Irkutsk.
Fig. 46: 19 x 11 µm No 06.
Oligohalobous (indifferent), alkaliphilic.

var. *euglypta* (Ehr.) Cleve
Hustedt 1930-66, II, p. 349, fig. 802c; Sabelina *et al.* 1951, p. 192, pl. 103, fig. 5; Patrick & Reimer 1966, p. 241, pl. 15, fig. 1; Foged 1971b, p. 938, pl. 7, fig. 12 a, b; 1981, p. 61.
No 11 reservoir Ob.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

var. *lineata* (Ehr.) Cleve
Hustedt 1930-66, II, p. 348, fig. 802d; Sabelina *et al.* 1951, p. 191, pl. 103, fig. 4; Foged 1971b, p. 938; 1981, p. 62.
Nos 02, 03, 09, 10 (common). Amur, Baikal, Angara–Irkutsk, reservoir Ob.
Fig. 29: 30 x 24 µm No 10 ?; Fig. 41: 35 x 25 µm No 09
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

*C. thumensis* A. Mayer
Hustedt 1930-66, II, p. 346; 1945-50, p. 347, pl. 35, figs 37-40; Sabelina *et al.* 1951, p. 193, pl. 105, fig. 1; Patrick & Reimer 1966, p. 244; Foged 1971, p. 938, pl. 7, fig. 9; 1981, p. 62, pl. 13, fig. 10.
No 06 (?) Baikal–Angara.
Oligohalobous (halophobe), alkalibiontic. (Hustedt 1957 p. 243).

*Cyclotella* Kütz. 1833

*C. baikalensis* Skvortzow et Meyer fo. *ornata* Skvortzow [= *C. ornata* (Skv.) Flower].
Skvortzow & Meyer 1937, p. 305, pl. 2, figs 4, 8, 9, 11-13, 16; Sabelina *et al.* 1951, p. 99, pl. 55, fig. 2a, b.
Nos 03, 04, 05, 06, 09 Baikal, Baikal-Angara, Irkutsk-Angara.
Fig. 1: diam 47 µm No 05; Fig. 2: diam 28 (x 26) µm No 05.
Fig. 3: diam 37 (x 34) µm No 06; Fig. 9: diam 30 (x 29) µm No 05.
Skvortzov 1937, p. 305. C. baikalensis is a very variable species and seems to comprise several different forms.

Oligohalobous (indifferent), alkaliphilic?

C. iris Brun & Héribaud
Brun & Héribaud 1893, p. 224, pl. 6, fig. 1; Schmidt et al. (1874-1959), pl. 222, figs 37, 39; Cleve-Euler 1951, p. 5; Fig. 67; Schimarski 1973, pl. 3, figs 1-3; Reichardt 1984, p. 24, pl. 2, fig. 38.
Nos 03, 04, 05, 06, 09 Baikal, Baikal-Angara, Irkutsk-Angara.

Fig. 13: diam 15-16 µm No 06. Fig. 14: 13 x 10.5 µm No 05.
Oligohalobous (indifferent), alkaliphilic.

[New research shows, that this species is C. minuta (Skv.) Antipova, see Flower et al. 1993]

C. meneghiniana Kütz.
Hustedt 1930-66, I, p. 341, Fig. 174. Schmidt et al. 1874-1959, pl. 181, fig. 91; pl. 222, fig. 35;
Sabelina et al. 1951, p. 94, pl. 50, fig. 1a, b; Foged 1981, p. 64, pl. 2, figs 12, 13.
Nos 01, 02 Amur.
Halophilic, alkaliphilic. Cosmopolitan.

Cymatopleura W. Smith 1851

C. elliptica (Bréb.) W. Smith var. constricta Grun.
Skvortzow 1937, p. 357, pl. 18, fig. 10.; Hustedt 1930, p. 428; Fig. 624; Foged 1981, p. 64.
Nos 06, 12 Baikal–Angara, reservoir Ob.
Fig. 160: 58 x 17-19 µm No 12.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

C. solea (Bréb.) W. Smith [= C. librile (Ehr.) Pant.].
Hustedt 1930, p. 425; Fig. 823a; Sabelina et al. 1951, p. 537, pl. 338, fig. 1; Foged 1971b, p. 940, pl. 20, fig. 14; 1981, p. 64, pl. 50, fig. 2.
Nos 09, 10, 11, 12 Angara–Irkutsk, reservoir Ob.
Fig. 161: 120 x 18-25 µm No 10.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

Cymbella

C. acuta (A. Schmidti) Cleve
P. T. Cleve 1894-95, p. 164; Cleve-Euler 1955, p. 145; Figs 12, 13; Schmidt et al. 1874-1959, pl. 71, figs 75-78; Manguin 1960, p. 86, pl. 20, fig. 1 a-c; Patrick & Reimer 1975; p. 35. pl. 5, fig. 1; Foged 1981, p. 65.
Fig. 137: 52 x 18 µm 9-10 striae in 10 µm No 05 Baikal–Angara
Oligohalobous (indifferent), alkaliphilic. Europe, N. America.

C. affinis Kütz.
Hustedt 1930, p. 363; Fig. 671; Schmidt et al. 1874-1959, pl. 9, fig. 29; pl. 71, figs 28, 29; Sabelina et al. 1951, p. 448, pl. 278, fig. 5; Patrick & Reimer 1975, p. 57, pl. 10, fig. 7; Foged 1959, p. 68, pl. 9, figs 1-3; 1971b, p. 940, 1981, p. 65, pl. 46, fig. 16; pl. 50, figs 4-5.
Nos 11, 12 reservoir Ob.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.
C. cistula (Hempr.) Kirchner
Hustedt 1930, p. 363; Schmidt et al. 1874-1959, pl. 71, figs 21, 25; Sabelina et al. 1951, p. 450, pl. 279, fig. 3; Patrick & Reimer 1975, p. 62, pl. 18, figs 3, 4; Foged 1959, p. 69; 1971b, p. 941, pl. 18, fig. 1; 1981, p. 67, pl. 47, figs 2, 3, 5-7.
Nos 01, 04, 05, 06, 09 Amur, Baikal, Baikal–Angara, Irkutsk–Angara.
Fig. 129: 36 x 15 µm 10 striae in 10 µm No 01; Fig. 133: 43 x 13 µm No 09.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

C. cuspidata Kütz.
Hustedt 1930, p. 357; Schmidt et al. 1874-1959, pl. 9, figs 50, 53-55; pl. 374, figs 13, 14; Sabelina et al. 1951, p. 442, pl. 274, fig. 1; Patrick & Reimer 1975, p. 39, pl. 6, figs 2, 3; Foged 1959, p. 69; Foged 1971b, p. 941, pl. 18, figs 16, 18, 20; pl. 19, fig. 1; 1981, p. 67, pl. 48, figs 3-7; Skvortzow 1937a, p. 345, pl. 13, fig. 1.
Nos 10, 12 reservoir Ob.
Fig. 76: 38 x 14 µm No 12 sensu Schmidt et al. 1874-1959, pl. 374, figs 13, 14 and Patrick & Reimer 1975, pl. 6, fig. 3; Fig. 130: 46 x 20 µm No 10 sensu Hustedt 1930; Fig. 650.

C. cymbiformis (Ag. ?Kütz.) Van Heurck
Hustedt 1930, p. 362; Fig. 672; 1955, pp. 50, 51, figs 13-16; Schmidt et al. 1874-1959, pl. 376, figs 26-28; Sabelina et al. 1951, p. 449, pl. 278, fig. 4; Patrick & Reimer 1975, p. 54, pl. 10, figs 3, 4; Foged 1959, p. 69, pl. 9, fig. 9; 1971b, p. 941, pl. 18, figs 2-4.
No 09 Angara–Irkutsk.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.
Patrick & Reimer 1975, p. 54: Single isolated stigma on ventral side of central area.

C. helvetica Kütz.
Hustedt 1930, p. 364; Fig. 678; Schmidt et al. 1874-1959, pl. 10, fig. 18; Sabelina et al. 1951, p. 452, pl. 281, fig. 3; Patrick & Reimer 1975, p. 64; Foged 1959, p. 71; 1981, p. 70, 1985a, p. 24, pl. 6, fig. 15.
Nos 05, 11, 12 Baikal–Angara, reservoir Ob.
Fig. 147: 70 x 13 µm No 11.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

var. compacta (Østrup) Hust. [in Krammer & Lange-Bertalot (1986) included in nominate variety.]
Nos 02, 10, 11, 12 Amur, reservoir Ob.
Oligohalobous (indifferent), alkaliphilic.

C. hustedtii Krasske
Hustedt 1930, p. 363, fig. 674; Schmidt et al. 1874-1959, pl. 380, figs 25-32; Skvortzow 1937b, p. 343, pl. 12, fig. 15; pl. 13, fig. 16; Sabelina et al. 1951, p. 449, pl. 279, fig. 8; Patrick & Reimer 1975, p. 27, pl. 4, figs 2a-3b; Foged 1959, p. 72; 1981, p. 70; 1985a, p. 25, pl. 6, fig. 6.
Nos 11, 12 reservoir Ob.
Fig. 77: 24 x 9 µm No 11.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan?

C. lanceolata (Ehr.) Kirchner
Hustedt 1930, p. 364, fig. 679; Schmidt et al. 1874-1959, pl. 375, figs 4, 5; Sabelina et al. 1951, p. 451, pl. 281, fig. 1; Patrick & Reimer 1975, p. 52, pl. 10, fig. 11; Foged 1959, p. 72; 1971b, p. 942; 1981, p. 71.
Nos 10, 11, 12 reservoir Ob.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

*C. naviculiformis* Auerswald
Hustedt 1930, p. 356, fig. 653; Schmidt *et al.* 1874-1959, pl. 377, figs 15-20; Sabelina *et al.* 1951, p. 441, pl. 273, fig. 4; Patrick & Reimer 1975, p. 31, pl. 4, fig. 9; Foged 1959, p. 73; 1971b, p. 942, pl. 18, figs 14, 15; 1981, p. 73, pl. 50, fig. 9.
No 10 (?) reservoir Ob.

*C. prostrata* (Berkeley) Cleve
Hustedt 1930, p. 357, fig. 659; Sabelina *et al.* 1951, p. 443, pl. 275, fig. 1; Patrick & Reimer 1975, p. 40, pl. 6, fig. 4; Foged 1959, p. 74; 1981, p. 74.
Fig. 131: 55 × 19 µm No 11 reservoir Ob.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

*C. sinuata* Greg. [Kociolek & Stoermer (1987) erected the new genus *Reimeria* with the type: *R. sinuata* (Greg.) Kociolek & Stoermer] Hustedt 1930, p. 361, fig. 668a, b; Sabelina *et al.* 1951, p. 447, pl. 278, fig. 2a, b; Patrick & Reimer 1975, p. 51, pl. 9, figs 3a-4b; Foged 1959, p. 74, pl. 10, fig. 6; 1971b, p. 943; 1981, p. 75, pl. 46, fig. 17; pl. 50, fig. 15.
Nos 03, 04, 05, 06 Baikal, Baikal–Angara.

*fo. ovata* Hustedt. [= *R. sinuata* *fo. ovata* ————??]
Hustedt 1930, p. 361, fig. 668c; Sabelina *et al.* 1951, p. 448, pl. 278, fig. 3; Patrick & Reimer 1975, p. 65; Foged 1971b, p. 943, pl. 19, fig. 7; 1981, p. 75.
Nos 04, 06, 09.
Fig. 127: 16 × 5 µm No 06.
Oligohalobous (indifferent), pH circumneutral. Cosmopolitan.

*C. stuxbergii* Cleve.
P. T. Cleve & Grun. 1880, p. 13, pl. 1, fig. 10; Cleve 1894-95, I, p. 173, pl. 5, fig. 2; Wislouch 1924, figs 2, 3; Cleve-Euler 1955, p. 164, figs 1252a, c (as var. *genuina*); Sabelina *et al.* 1951, p. 450, pl. 280, fig. 1; Musafarov 1958, p. 311, pl. 15, fig. 7; Foged 1981, p. 75, pl. 50, fig. 1; Schmidt *et al.* 1874-1959, pl. 380, figs 2, 3
Nos 03, 04, 05, 06, 09 Baikal, Baikal–Angara, Irkutsk–Angara.
Fig. 134: 60 × 28 µm No 05.
Oligohalobous (indifferent), alkaliphilic. Eurasia, Alaska, Afghanistan.

*Cymbella stuxbergii* var. *intermedia* Wislouch
Wislouch 1924, p. 170, fig. a-e; Cleve-Euler 1955, IV, p. 164, fig. 1252d; Manguin 1960, p. 280, pl. 6, fig. 2.
Nos 05, 11 Baikal–Angara, reservoir Ob.
Fig. 97: 66 × 13 µm 8-9 striae in 10 µm No 11.
Oligohalobous (indifferent), alkaliphilic. Europe, N. America.

var. *sibirica* (Grun.) Wislouch
Cleve 1894-95, I, p. 173, pl. 5, fig. 2; Cleve-Euler 1955, IV, figs 1252e, f; Manguin 1960, p. 281, pl. 3, fig. 8; Foged 1981, p. 75, pl. 50, fig. 1.
Nos 05, 06 Baikal–Angara.
Fig. 135: 96 × 24 µm 12 striae in 10 µm No 05.
Oligohalobous (indifferent). Eurasia, N. America.
C. tumida (Bréb. ex Kütz.) Van Heurck
Hustedt 1930, p. 366, fig. 677; Schmidt et al. 1874-1959, pl. 10, figs 28-30; Sabelina et al. p. 453, pl. 283, fig. 1; Patrick & Reimer 1975, p. 58, pl. 10, fig. 8; Foged 1959, p. 75, pl. 10, fig. 4

Nos 01, 02 (common), 03, 07, 09, 10, 11, 12 Amur, Baikal, Angara-Irkutsk, reservoir Ob.

Fig. 90: 38 x 11 µm, 12 striae in 10 µm No 12. Fig. 178: 78 x 18 µm 9 striae in 10 µm No 01. Fig. 132: 52 x 17 µm, 11 striae in 10 µm No 01.

Patrick & Reimer 1975, p. 58: “Isolated stigma present, opening on ventral side of the central area and penetrating laterally across central nodule, terminating on the dorsal side of the central nodule.”

Fig. 178: Near Cymbella mexicana (Ehr.) Cleve var. kantschadica Grün; Foged 1981, p. 72, pl. 30, fig. 2; Patrick & Reimer 1975, p. 59, pl. 12, figs 1, 2. “Central area small, ovoid, with isolated stigma in the middle.” Foged 1981, pl. 50, fig. 2 thus must be C. tumida. Vide Helmcke & Krieger IX plate 897; C. tumida (Bréb) Van Heurck.

Oligohalobous (indifferent), pH-indifferent.

C. turgida (Greg.) Cleve (= Enyonema elginensis (Krammer) D. G. Mann (1990 in Round et al.))
Hustedt 1930, p. 358, fig. 660; Schmidt et al. 1874-1959, pl. 10, figs 59-53; pl. 373, figs 8, 9; Sabelina et al. 1951, p. 444, pl. 275, fig. 2; Patrick & Reimer 1975, p. 65; Foged 1959, p. 75; 1971b, p. 943, pl. 18, figs 5, 10; 1981, p. 75, pl. 46, fig. 2.

Nos 03, 04, 05, 06, 09, 10 Baikal–Angara, reservoir Ob.

Fig. 91: 37 x 10 µm No 09.

Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

C. ventricosa (Ag.) Kütz. (= C. minuta Hilse)
Hustedt 1930, p. 359, fig. 661; Schmidt et al. 1874-1959, pl. 9, fig. 32; pl. 72, fig. 11; Sabelina et al. 1951, p. 444, pl. 276, fig. 1; Foged 1959, p. 75, pl. 10, fig. 11; 1971b, p. 944, pl. 18, figs 8, 9; 1981, p. 76.

Syn: C. minuta Hilse ex Bréb. var. silesia (Bleich) Rabh. Patrick & Reimer 1975, p. 49, pl. 8, figs 7a-10b.

Nos: 01, 02 (fairly common), 03, 04, 05, 06, 09, 10, 11, 12 Amur, Baikal–Angara, reservoir Ob.

Fig. 89: 16 x 7 µm No 04.


Diatoma A.P. de Candolle 1805

D. elongatum (Lyngbye) Ag. (= D. tenue Ag.)
Hustedt 1930-66, II, p. 99, figs 629a,b; Schmidt et al. 1874-1959, pl. 268, figs 37-39, 41-45, 47-50; Sabelina et al. 1951, p. 127, pl. 67, fig. 1; Patrick & Reimer 1966, p. 109, pl. 2, fig. 6 (as D. tenue Ag. var. elongatum Lyngbye); Foged 1971b, p. 945; 1981, p. 77, pl. 4, fig. 1.

Fig. 17: 78 x 3.5 µm No 09 Angara–Irkutsk.

Halophilic pH circumneutral, alkaliphilic. Cosmopolitan?

var. tenue (Ag.) Van Heurck [included in the nominate var.]
Hustedt 1930-66, II, p. 100, fig. 629d-g; Schmidt et al. 1874-1959, pl. 268, figs 40, 46, 51-53, 58-67; Sabelina et al. 1951, p. 122, pl. 67, fig. 4a, b; Patrick & Reimer 1975, p. 108, pl. 2, fig. 5 (as Diatoma tenue Ag.); Foged 1981, p. 77, pl. 4, fig. 2.

Nos 01, 04, 09 Amur, Baikal–Angara–Irkutsk.

Fig. 18: 24 x 6 µm No 04.

Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

D. vulgare Bory
Hustedt 1930-66, II, p. 96, figs 628a-d; Schmidt et al. 1874-1959, pl. 268, figs 3-6; Sabelina et al. 1951, p. 121, pl. 66, fig. 3a, b; Patrick & Reimer 1966, p. 109, pl. 2, fig. 9; Foged 1981, p. 78.
Nos 02, 09 (fairly common), 10, 11 Amur, Angara–Irkutsk, reservoir Ob.
Fig. 40: 34 \times 10 \mu m No 10.
Oligohalobous (indifferent), alkalibiontic. Cosmopolitan.

var. producta Grun.
Hustedt 1930-66, II, p. 98, figs 628c, f; Schmidt et al. 1874-1959, pl. 268, figs 7-10; Sabelina et al. 1951, p. 121, pl. 66, fig. 6; Patrick & Reimer 1966, p. 109 (included in D. vulgare Bory).
Nos 01, 12 Amur, reservoir Ob.
Oligohalobous (indifferent), alkalibiontic.

Didymosphenia M. Schmidt 1899.

D. dentata Dorog var. subcapitata Skvortzow & Meyer
Skvortzow 1937, p. 349, pl. 14, fig. 15.
Fig. 93: 74 \times 28 \mu m 10 striae in 10 \mu m No 05 Baikal–Angara.
Oligohalobous (indifferent).

D. geminata (Lyngbye) M. Schmidt
(Schmidt et al. 1874-1959, pl. 214, figs 7-9; Hustedt 1930, p. 367, fig. 682).
Nos 03, 04, 05, 06, 09 Baikal, Baikal–Angara, Irkutsk–Angara.
None of the specimens recorded in this material can be identified with typical specimens from other localities. The material comprises many variations, among which the varieties and formae mentioned below are identified according to Skvortzow 1937, Skvortzow and Meyer 1928 together with Schmidt et al. 1874-1959, p. 244.
They are all oligohalobous (indifferent), pH-circumneutral.

var. baikalensis Skvortzow & Meyer fo. curvata Skv. & Meyer.
Fig. 103: 74 \times 32 \mu m 10 striae in 10 \mu m No 06.
Fig. 104: 90 \times 35 \mu m 8 striae in 10 \mu m No 05.

var. sibirica (Grun.) M. Schmidt fo. curvata Skv. 1937, p. 350, pl. 14, figs 8, 20.
Fig. 92: 80 \times 30 \mu m 9-10 striae in 10 \mu m No 04.
Fig. 105: 82 \times 30 \mu m 9-10 striae in 10 \mu m No 04.
Fig. 115: 63 \times 28 \mu m 10 striae in 10 \mu m No 05.

var. stricta M. Schmidt fo. baikalensis Skv. & Meyer 1928, pl. 2, fig. 136; Skvortzow 1937, pl. 10, fig. 13.
Fig. 116: 172 \times 42 \mu m No 05.

Diploneis Ehr. 1840

D. elliptica (Kütz.) Cleve
Hustedt 1930-66, II, p. 690, fig. 677a; Schmidt et al. 1874-1959, pl. 7, figs 29, 32; Sabelina et al. 1951, p. 253, pl. 141, fig. 4; Patrick & Reimer 1966, p. 414, pl. 38, fig. 10; Foged 1971b, p. 975, pl. 12, figs 1-3; 1981, p. 79.
No 10 (?) reservoir Ob.
Oligohalobous (indifferent), alkaliphilic.

D. ovalis (Hilse) Cleve
Hustedt 1930-66, II, 671, figs 1065a-c; Sabelina et al. 1951, p. 249, pl. 139, fig. 3; Foged 1971b, p. 946; 1981, p. 80, pl. 14, fig. 5
Nos 02, 09, 12 Amur, Angara–Irkutsk, reservoir Ob.
Fig. 54: 34 \times 17 \mu m No 12.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.
Epithemia Bréb. 1838

E. muelleri Fricke [= E. goeppertiana Hilse]
Hustedt 1930, p. 384, fig. 728; Schmidt et al. 1874-1959, pl. 251, figs 20-24; Sabelina et al. 1951, p. 481, pl. 310, fig. 2a, b; Patrick & Reimer 1973, p. 178, pl. 23, fig. 6; Foged 1959, p. 79; 1981, p. 82.

No 12 reservoir Ob.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

Eunotia Ehr. 1837

E. diodon Ehr. (seems to be very problematic)
Hustedt 1930-66, II, p. 276, fig. 742 (?); Schmidt et al. 1874-1959, pl. 270, figs 14-18 (?); Sabelina et al. 1951, p. 175, pl. 93, fig. 1; Patrick & Reimer 1966, p. 204, pl. 12, fig. 7 (?)

Nos 02, 12 Amur, reservoir Ob.
Fig. 32: 28 × 13-15 µm No 02.
Halophobous, acidophilic. Cosmopolitan.

Fragilaria Lyngbye 1819

F. capucina Desmar.
Hustedt 1930-66, II, p. 144, figs 659a-c; Schmidt et al. 1874-1959, pl. 298, figs 14, 17-22, 29, 30; Sabelina et al. 1951, p. 127, pl. 69, fig. 2; Patrick & Reimer 1966, p. 118, pl. 3, fig. 5; Foged 1971b, p. 947; 1981, p. 91; 1985a, p. 31, pl. 2, fig. 3.

Nos 06, 10 Baikal–Angara, reservoir Ob.
Fig. 36: 41 × 5 µm No 06.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

var. mesolepta Rabh.
Hustedt 1930-66, II, p. 145, figs 659h, i; Schmidt et al. 1874-1959, pl. 298, figs 16, 23-28, 37-41; Sabelina et al. 1951, p. 128, pl. 69, fig. 4; Patrick & Reimer 1966, p. 119, pl. 3, fig. 6; Foged 1981, p. 92, pl. 4, fig. 12.

No 02 Amur.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

F. construens (Ehr.) Grun. [= Staurosira construens (Ehr.) Williams & Round (1987)]
Hustedt 1930-66, II, p. 156, fig. 670a-c; Schmidt et al. 1874-1959, pl. 296, figs 25-30, 44; Sabelina et al. 1951, p. 133, pl. 74, fig. 3; Patrick & Reimer 1966, p. 125, pl. 4, fig. 4; Foged 1971b, p. 948; 1981 p. 82, pl. 5, fig. 2.

Nos 03, 12 Baikal, reservoir Ob.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

F. intermedia Grun. [= F. vaucheriae (Kütz) B. Petersen]
Hustedt 1930, p. 139, fig. 130; 1930-66, p. 152; Fig. 666; Sabelina et al. 1951, p. 129, pl. 70, fig. Foged 1981, p. 93, pl. 4, figs 10, 11.

Nos 01, 03, 05, 09 Amur, Baikal, Angara–Baikal, Angara–Irkutsk.
Fig. 19: 25 × 4 µm No 09.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

F. pinnata Ehr. [= Staurosirella pinnata (Ehr.) Williams & Round (1987)]
Hustedt 1930-66, II, p. 160, fig. 671; Schmidt et al. 1874-1959, pl. 297, figs 47-50, 52-54; pl. figs 47-68, 70-74; Sabelina et al. 1951, p. 135, pl. 75, fig. 1. Patrick & Reimer 1966, p. 127, pl. 4 10; Foged 1971, p. 948; 1981, p. 93, pl. 4, fig. 21; pl. 5, fig. 3

No 09 Angara–Irkutsk.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.
F. vaucheriae (Kütz.) B. Petersen
B. Petersen 1938, p. 167, fig. 1; Patrick & Reimer 1966, p. 120, pl. 3, figs 14, 15; Foged 1971b, p. 948.
Nos 02, 12 Amur, reservoir Ob.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

Gomphoneis Cleve 1894
G. elegans (Grun.) Cl. var. quadrirunctata Skv. & Meyer
Nos 05, 06 Baikal–Angara.
Fig. 102: 35 × 10 µm No 05.
Oligohalobous (indifferent), alkaliphilic.

Gomphonema Ag. 1824
G. acuminatum Ehr.
Hustedt 1930, p. 370, fig. 683; Schmidt et al. 1874-1959, pl. 72, fig. 10; pl. 239, figs 1-4, 11-15; pl. 240, figs 1-6; Sabelina et al. 1951, p. 460, pl. 287, fig. 1; Patrick & Reimer 1975, p. 112, pl. 15, figs 2, 4, 7; Foged 1959, p. 75; 1981, p. 95, pl. 52, figs 6, 9.
Nos 01 Amur.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

var. brebissonii (Kütz.) Cleve [included in nominate var. by Krämer & Lange-Bertalot 1986]
Hustedt 1930, p. 370, fig. 685; Schmidt et al. 1874-1959, pl. 233, figs 7-10; Sabelina et al. 1951, p. 460, pl. 287, fig. 2; Patrick & Reimer 1975, p. 116, pl. 15, fig. 8; Schmidt et al. 1874-1959 G. brebissonii Kütz; Foged 1959, p. 75; 1981, p. 95; pl. 53, fig. 19.
Nos 02, 10 Amur, reservoir Ob.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

var. coronata (Ehr.) W. Smith
Hustedt 1930, p. 370, fig. 684; Sabelina et al. 1951, p. 460, pl. 287, fig. 2; Foged 1981, p. 96, pl. 52, fig. 8.
Nos 01 Amur.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

var. trigonocephala (Ehr.) Grun.
Hustedt 1930, p. 371, fig. 686; Schmidt et al. 1874-1959, pl. 239, figs 15-17; Proskhina-Lavrenko 1950, p. 293, pl. 8, fig. 18; Foged 1981, p. 96, pl. 52, fig. 7.
Nos 01, 02 Amur.
Fig. 107: 25 × 7.5, 12 striae in 10 µm No 01.
Fig. 85: 25 × 8 µm No 02. Transition to var. brebissonii
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

var. turris (Ehr.) Wolle [in Krämer & Lange-Bertalot (1986) as G. angur var. turris (Ehr.) Lange-Bertalot.]
Hustedt 1930, p. 372, fig. 687; Proskhina-Lavrenko 1950, p. 293, pl. 90, fig. 1; Sabelina et al. 1951, p. 461, pl. 287, fig. 4; Patrick & Reimer 1975, p. 114, pl. 16, fig. 6; Foged 1981, p. 96, pl. 52, fig. 10.
Nos 01 Amur.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

G. alaskaensis Manguin
Manguin 1960, p. 981, pl. 3, fig. 9.
No 05 Baikal-Angara.
Closely related to G. ventricosum Greg.
Oligohalobous (indifferent), alkaliphilic?

G. angustatum (Kütz.) Rabh.
Hustedt 1930, p. 373, fig. 690; Schmidt et al. 1874-1959, pl. 234, figs 20-25, 31-35; Patrick & Reimer 1975, p. 125, pl. 17, figs 17-19; Foged 1959, p. 76; 1981, p. 96, pl. 54, fig. 12.
No 10 reservoir Ob.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

G. angustatum var. linearis Hustedt
Hustedt 1930, p. 373, fig. 692; Sabelina et al. 1951, p. 463, pl. 288, fig. 6.
No 08 Angara.
Oligohalobous (indifferent), alkaliphilic.

var. obtusata (Kütz.) Grun.
Schmidt et al. 1874-1959, pl. 234, figs 29, 30; Sabelina et al. 1951, p. 463; Patrick & Reimer 1975, p. 126, pl. 17, fig. 21.
No 09 Angara-Irkutsk.
Oligohalobous (indifferent), alkaliphilic.

var. producta Grun.
Hustedt 1930, p. 373, fig. 693; Schmidt et al. 1874-1959, pl. 234, fig. 26; Sabelina et al. 1951, p. 463, pl. 288, fig. 7; Patrick & Reimer 1975, p. 127, pl. 17, fig. 22; Foged 1959, p. 76; 1981, p. 97, pl. 53, figs 4-6, 8.
Nos 07, 08 Angara.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

var. sarcophagus (Greg.) Grun.
Hustedt 1930, p. 273, fig. 691; Sabelina et al. 1951, p. 463, fig. 288; Patrick & Reimer 1975, p. 128, pl. 17, fig. 28; Foged 1981, p. 97.
No 07 Angara.
Fig. 113: 26 x 6 µm No 07. Possibly transition to var. producta.
Oligohalobous (indifferent), alkaliphilic.

G. augur Ehr. var. gautieri Van Heurck
Hustedt 1930, p. 372, fig. 689; Schmidt et al. 1874-1959, pl. 240, figs 13-17; Sabelina et al. 1951, p. 462, pl. 287, fig. 8.
No 02 Amur.
Oligohalobous (indifferent), alkaliphilic (pH-circumneutral?)

G. constrictum Ehr.
Hustedt 1930, p. 377, fig. 714; Schmidt et al. 1874-1959, pl. 247, figs 3-11; Sabelina et al. 1951, p. 468, pl. 292, fig. 3; Patrick & Reimer 1975, p. 118, pl. 16, fig. 3 (as G. truncatum Ehr.); Foged 1979, p. 76; 1971, p. 948; 1981, p. 98, pl. 54, figs 3-5.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

var. capitata (Ehr.) Cleve
Hustedt 1930, p. 377, fig. 715; Schmidt et al. 1874-1959, pl. 247, figs 12-16, 21, 24, 25; Sabelina et al. 1951, p. 469, pl. 292, fig. 5; Patrick & Reimer 1975, p. 119, pl. 16, fig. 4 (as G. truncatum var. capitatum (Ehr.) Patr.); Foged 1959, p. 76; 1971b, p. 748, pl. 19, fig. 23; 1981, p. 98, pl. 52, fig. 3; pl. 54, figs 7-9.
Nos 01, 09 Amur, Angara-Irkutsk.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.
fo. curta Grun.
Schmidt et al. 1874-1959, pl. 247, figs 26-28.
Fig. 125: 15 x 7 µm, Fig. 121: 24 x 8 µm No 09 Angara-Irkutsk
Oligohalobous (indifferent), alkaliphilic.

fo. turgida Ehr.
Schmidt et al. 1874-1959, pl. 247, fig. 29.
Fig. 123: 22 x 9 µm No 09 Angara-Irkutsk
Oligohalobous (indifferent), alkaliphilic.

var. cuneata Fricke
Schmidt et al. 1874-1959, pl. 247, figs 22, 23.
Fig. 118: 31 x 11 µm, Fig. 120: 39 x 10 µm No 02 Amur
Oligohalobous (indifferent), alkaliphilic.

G. gracile Ehr.
Hustedt 1930, p. 376, fig. 702; Patrick & Reimer 1975, p. 31, pl. 17, figs 1-3; Foged 1971b, p. 949; 1981, p. 98, pl. 53, figs 15, 16, 18.
No 01 Amur.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

G. intricatum Kütz. [= G. angustatum Agardh (Krammer & Lange-Bertalot, 1986).]
Hustedt 1930, p. 375, fig. 697. Schmidt et al. 1874-1959, pl. 234, figs 47-50, 58; pl. 235, figs 15-17, 34-39; pl. 236, figs 1-8; pl. 247, figs 34-38; pl. 248, figs 23-25; Sabelina et al. 1951, p. 465, pl. 289, fig. 6; Patrick & Reimer 1975, p. 134, pl. 18, fig. 1; Foged 1971b, p. 949; 1959, p. 77; 1981, p. 99, pl. 53, figs 2, 3.
No 04 Baikal.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

var. pumila Grun.
Hustedt 1930, p. 375, fig. 699; Schmidt et al. 1874-1959, pl. 234, figs 56, 57; pl. 266, figs 32, 33; Sabelina et al. 1951, p. 465, pl. 289, fig. 8; Patrick & Reimer 1975, p. 135; Foged 1959, p. 77; 1981, p. 99.
Nos 04, 05 Baikal, Baikal–Angara.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

G. lanceolatum Ehr. [= G. gracile Ehr. (Krammer & Lange-Bertalot 1986)]
Hustedt 1930, p. 376, fig. 700; Schmidt et al. 1874-1959, pl. 238, fig. 35; Sabelina et al. 1951, p. 465, pl. 290, fig. 1; Patrick & Reimer 1975, p. 131, pl. 17, fig. 6 (as G. grunowii Patr.); Foged 1959, p. 77; 1971b, p. 949; 1981, p. 99, pl. 52, fig. 5; pl. 53, fig. 17.
No 02, 04, 07, 12 Amur, Baikal, Angara, reservoir Ob.
Fig. 124: 34 x 8 µm No 07.

G. longiceps Ehr. var. montana (Schum.) Cleve
Hustedt 1930, p. 375, fig. 707; Schmidt et al. 1874-1959, pl. 238, figs 1-11; Patrick & Reimer 1975, p. 121, pl. 16, fig. 7 (as G. montanum Schum.); Foged 1971b, p. 950, pl. 19, fig. 16; 1981, p. 100, pl. 53, fig. 1.
Fig. 111: 38 x 8 µm No 01 Amur.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

G. olivaceoides Hustedt. [= G. olivaceum (Hornemann) Bréb. var. minuissima Hustedt (Krammer & Lange-Bertalot 1986)]
Hustedt 1945-50, p. 397, figs 9-12; Patrick & Reimer 1975, p. 144, pl. 18, fig. 21a, b; Foged 1959, p. 78; 1971a, pp. 269-281, 3 pb; 1971b, p. 950, pl. 5, figs 1-3; pl. 19, figs 18, 19; 1981, p. 100, pl. 54, figs 19, 22.

Nos 03, 04, 05, 06, 09 Baikal, Baikal–Angara, Irkutsk–Angara.

Fig. 101: 19 × 5 µm No 04, Fig. 112: 31 × 6 µm No 04,

Fig. 109: 25 × 7 µm No 05, Fig. 110: 28 × 7 µm No 04.

Oligohalobous (indifferent). Eurasia, N. America.

G. olivaceum (Hornemann) Bréb.

Hustedt 1930, p. 378, fig. 719; Schmidt et al. 1874-1959, pl. 233, figs 9-16; Sabelina et al. 1951, p. 471, pl. 295, fig. 1; Patrick & Reimer 1975, p. 139, pl. 18, figs 13, 14; Foged 1971b, p. 950, pl. 19, fig. 16; 1981, p. 101, pl. 52, fig. 12; pl. 53, fig. 20.

Syn: Gomphoneis olivacea (Lyngbye) Dawson (Lange-Bertalot 1978, p. 407, figs 1, 2.)

Nos 03, 09, 10, 11 Baikal, Angara–Irkutsk, reservoir Ob.

Oligohalobous (indifferent), alkaliphilic. Cosmopolitan?

var. micropus (Kütz.) Cleve [included in nominate var. by Krammer & Lange-Bertalot 1986]

Hustedt 1930, p. 372, fig. 713a; Schmidt et al. 1874-1959, pl. 234, figs 1-15, 18, 19; Sabelina et al. 1951, p. 462, pl. 288, fig. 3; Patrick & Reimer, p. 122, pl. 17, figs 7-12; Foged 1959, p. 78; 1981, p. 101.

Nos 01, 02, 04, 05, 07, 09, 10, 11 Amur, Baikal–Angara, reservoir Ob.


G. parvulum (Kütz.) Kütz.

Hustedt 1930, p. 372, fig. 713b; Schmidt et al. 1874-1959, pl. 234, figs 16, 17; Sabelina et al. 1951, p. 462, pl. 288, fig. 3; Patrick & Reimer 1975, p. 122; Foged 1959, p. 78; 1981, p. 101; 1985a, p. 33, pl. 7, fig. 6.

Nos 02, 08 Amur, Angara.

Fig. 122: 18 × 6 µm No 08.

Oligohalobous (indifferent), alkaliphilic.

G. quadripunctatum (Istrup) Wislouch.

Wislouch 1924, p. 166, figs 5a-c., 6 (as G. olivaceum var. quadripunctata Istrup); Proschkina-Lavrenko 1950, p. 298, pl. 93, fig. 12; Sabelina et al. 1951, p. 21, pl. 294, fig. 3; Patrick & Reimer 1975, p. 145, pl. 18, 19.


Nos 03, 04, 05, 06, 09 Baikal, Baikal–Angara, Irkutsk–Angara.

Fig. 99: 53 × 15 µm No 06 12 striae, Fig. 100: 26 × 8 µm No 04 14 striae, Fig. 106: 46 × 12 µm No 04 12 striae, Fig. 96: 52 × 14 µm No 04 12 striae.

Fig. 95: 30 × 12 µm No 06 14 striae, Fig. 114: 41 × 13 µm No 05 12-13 striae.

Oligohalobous (indifferent), alkaliphilic?

var. hastata Wislouch

Skvortzow 1928, p. 312, fig. 7; Sabelina et al. 1951, p. 470, pl. 294, fig. 4.

No 09 Angara–Irkutsk.

Oligohalobous (indifferent), alkaliphilic?

G. venricosum Greg.

Hustedt 1930, p. 377, fig. 716; Schmidt et al. 1874-1959, pl. 216, figs 9-12; Sabelina et al. 1951, p. 469, pl. 292, fig. 6; Patrick & Reimer 1975, p. 137, pl. 19, fig. 2; Foged 1981, p. 101, pl. 52, figs 4, 14; pl. 53, fig. 21.

Nos 03, 04, 05, 06, 09 Baikal, Baikal–Angara, Angara–Irkutsk.
Diatoms from Siberia, especially Lake Baikal

**Gyrosigma Hassall 1845**

*G. kützingii* (Grun.) Cleve [= *G. spencerii* (Qucet) Griffith & Henfrey (Krammer & Lange-Berlalot 1986)]

Hustedt 1930, p. 224, fig. 333; Sabelina *et al.* 1951, p. 403, pl. 247, fig. 3; Patrick & Reimer 1966, p. 315, pl. 23, fig. 4 (as *G. spencerii* (Quc.) Griff & Henfr.); Foged 1981, p. 102, pl. 17, fig. 3.

No 09 Angara–Irkutsk.

Oligohalobous (indifferent), alkaliphilic. Eurasia, N. America, New Zealand.

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**Hantzschia Grun. 1877**

*H. amphioxys* (Ehr.) Grun.

Hustedt 1930, p. 394, pl. 747; Schmidt *et al.* (1874-1959), pl. 329, figs 11, 12, 15-20; Sabelina *et al.* 1951, p. 491, pl. 310, fig. 1; Foged 1959, p. 82; 1971b, p. 951; 1981, p. 102; 1985a, p. 35, pl. 7, figs 8, 9; pl. 20, fig. 6.

Nos 02, 04, 07, 08, 10 Amur, Baikal, Angara, reservoir Ob.

Fig. 154, 37×8 µm No 07


var. *maior* Grun.

Hustedt 1930, p. 394, fig. 749; Schmidt *et al.* (1874-1959), pl. 329, fig. 5; Sabelina *et al.* 1951, p. 491, pl. 310, fig. 4; Foged 1959, p. 80; 1981, p. 103, pl. 56, figs 1, 2, 4.

Nos 07, 08, 10 Angara, reservoir Ob.


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**Melosira Ag. 1834**

[Most of the following *Melosira* species are transferred to the genus *Aulacoseira* Thwaites].

*M. ambigua* (Grun.) Müller [= *Aulacoseira ambigua* (Grun.) Simonsen].

Hustedt 1930-66, I, p. 256, fig. 108; Sabelina *et al.* 1951, p. 88, pl. 45, fig. 5; Foged 1981, p. 104, pl. 1, fig. 12.

No 12 reservoir Ob.

Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

*M. baikalensis* (Meyer) Wislouch [= *Aulacoseira baikalensis* (Meyer) Simonsen].

Wislouch 1924, p. 165; Skvortzow & Meyer 1928, p. 4, pl. 1, fig. 1; Skvortzow 1937, p. 302, pl. 1, figs 1, 2; Hustedt 1942, p. 386, fig. 466; Sabelina *et al.* 1951, p. 81, pl. 42, fig. 4.

Nos 03, 04, 05, 06, 09, 10, 12.

Fig. 4: width 12 µm No 06; Fig. 7: width 10.5 µm No 05 Sporangial form; Fig. 15: width 16 µm No 09.

Oligohalobous (indifferent), alkaliphilic?
$M.\ grana/ata$ (Ehr.) Ralfs [= $Aulacoseira \ grana/ata$ (Ehr.) Simonsen]
Hustedt 1930-66, I, p. 248, figs 104a-c; Skvortzow 1928, p. 400, pl. 1, fig. 2; Sabelina et al. 1951, p. 84, pl. 44, fig. 1; Foged 1959, p. 36; 1971b, p. 951, pl. 6, figs 1, 2; 1981, p. 104, pl. 1, figs 3, 4, 7.
Nos 01, 02, 04, 05, 09, 09, 12 Amur, Baikal, Baikal-Angara, Irkutsk-Angara, reservoir Ob.
Fig. 5: width 14 µm No 10.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.
var. $angustissima$ Müller [= $Aulacoseira \ grana/ata$ (Ehr.) Simonsen var. $angustissima$ (Ehr.) Simonsen]
Hustedt 1930-66, I, p. 250, fig. 250, fig. 104d; Sabelina et al. 1951, p. 86, pl. 44, fig. 3; Foged 1981, p. 105.
Nos 02, 10, 12 Amur, reservoir Ob.
Fig. 6: width 5 µm, No 05.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

$M. \ varians$ Ag.
Hustedt 1930-66, I, p. 240, fig. 100; Schmidt et al. (1874-1959), pl. 178, figs 1, 2, 7-24, 38, 39; pl. 183, fig. 10; Sabelina et al. 1951, p. 78, pl. 40, fig. 3; Foged 1959, p. 36; 1981, p. 106, pl. 1, fig. 6.
Nos 01, 02 (common), 03, 09, 09, 11, 12 Amur, Baikal, Angara Irkutsk, reservoir Ob.
Fig. 8: width 14 µm No 02. (This figure is changed by the eds)
Fig. 10: width 11 µm No 03.

$Meridion$ Ag. 1834

$M. \ circulare$ (Grev.) Ag.
Hustedt 1930-66, II, figs 627a-f; Schmidt et al. (1874-1959), pl. 267, figs 34-39; Patrick & Reimer 1966, p. 113, pl. 2, fig. 15; Foged 1959, p. 38; 1981, p. 106, pl. 5, fig. 22.
Nos 01, 03, 04, 07, 08 Amur, Baikal-Angara.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.
var. $constricta$ (Ralfs) Van Heurck
Hustedt 1930-66, II, p. 93, figs 627g, h; Proschkina-Lavrenko 1950, p. 29, pl. 7, fig. 9; Patrick & Reimer 1966, p. 114, pl. 2, fig. 16; Foged 1981, p. 106, pl. 5, fig. 21.
Fig. 39: 41 x 6 µm No 08 Angara.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

$Navicula$ Bory 1824

$N. \ anglica$ Ralfs [= $N. \ pseudoanglica$ ? (Krammer & Lange-Bertalot, 1986)]
Hustedt 1930, p. 303, figs 530, 531; Skvortzow 1937a, p. 332, pl. 7, fig. 32; 1937b, p. 202, pl. 2, fig. 12; Sabelina et al. 1951, p. 322, pl. 184, fig. 1; Foged 1981, p. 107, pl. 38, fig. 9; 1971, p. 953.
Nos 06, 11 Baikal–Angara, reservoir Ob.
Fig. 70: 15 x 7 µm No 11.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

$N. \ bacillum$ Ehr. [= $Sellaphora \ bacillum$ (Ehr.) D. G. Mann]
Hustedt 1930 p. 280, fig. 465; Schmidt et al. (1874-1959), pl. 212, fig. 15; Patrick & Reimer 1966, p. 494, pl. 47, figs 4, 5; Foged 1959, p. 56; 1971b, p. 953, pl. 3, fig. 4; 1981, p. 108, pl. 38, figs 18, 19.
Nos 04, 10, 11, 12 Baikal, reservoir Ob.
Fig. 69: 29 x 8.5 µm No 12.

127
var. gregoriana Grun.
Hustedt 1930, p. 280, fig. 466; Schmidt et al. (1874-1959), pl. 396, figs 43, 44; Sabelina et al. 1951, p. 287, pl. 164, fig. 2; Foged 1981, p. 108.
Nos 10, 12 reservoir Ob.
Fig. 83: 54 x 14 µm No 10.
Oligohalobous (indifferent), pH circumneutral.

N. cinetia (Ehr.) Kütz.
Hustedt 1930, p. 298, fig. 510; Schmidt et al. (1874-1959), pl. 299, figs 26-30; Sabelina et al. 1951, p. 314, pl. 176, fig. 1; Foged 1959, p. 58; 1981, p. 109; Patrick & Reimer 1966, p. 516, pl. 49, fig. 8.
Nos 07, 09, 10 Angara, Angara-Irkutsk, reservoir Ob.
Fig. 67: 22 x 5 µm 14 striae in 10 µm No 07.
Halophilic, alkaliphilic. Cosmopolitan.

N. costulata Grun.
Hustedt 1930, p. 298, fig. 505; Schmidt et al. (1874-1959), pl. 398, figs 52, 53; Patrick & Reimer 1966, p. 535, pl. 51, fig. 9; Sabelina et al. 1951, p. 313, fig. 175; Foged 1981, p. 110, pl. 38, fig. 17.
No 11 reservoir Ob.
Oligohalobous (indifferent-halophilic), alkaliphilic.

N. cruciculata (W. Sm.) Donk. (forma)
Hustedt 1930-66, III, p. 318, fig. 1436a-b; Schmidt et al. (1874-1959), pl. 299, figs 24, 35; Patrick & Reimer 1966, p. 471, pl. 15, fig. 2; Foged 1981, p. 110, pl. 29, fig. 9.
Nos 05, 06 Baikal-Angara.
The forma recorded here is closely related to N. cruciculata var. obtusa as seen in Tynni 1975, pl. 4, fig. 74, and also to var. obtusa var. Grun.; Hustedt 1930, p. 284.
Mesohalobous, alkaliphilic.

N. cryptocephala Kütz.
Hustedt 1930, p. 295, fig. 496; Schmidt et al. (1874-1959), pl. 272, figs 35-37; Sabelina et al. 1951, p. 308, pl. 172, fig. 1; Patrick & Reimer, p. 503, pl. 48, fig. 3; Foged 1959, p. 59; 1971, p. 955; 1981, p. 110.
Nos 01, 04, 07, 08 (common), 09 (common), 10, 11, 12 Amur, Baikal-Angara, reservoir Ob.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.
var. intermedia Grun.
Hustedt 1930, p. 295, fig. 497b; Sabelina et al. 1951, p. 309, pl. 172, fig. 2; Foged 1959, p. 59, pl. 4, figs 9, 10; 1971, p. 955; 1981, p. 110, pl. 35, fig. 6.
Nos 01, 02, 04, 05, 06, 09, 11, 12 Amur, Baikal, Angara, reservoir Ob.
Fig. 61: 35 x 9 µm 13-14 striae in 10 µm No 12.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.
var. veneta (Kütz.) Rabh.
Hustedt 1930, p. 295, fig. 497a; Sabelina et al. 1951, p. 309, pl. 172, fig. 4; Patrick & Reimer 1966, p. 504, pl. 48, fig. 5; Foged 1959, p. 59, pl. 5, figs 1, 2; 1981, p. 111.
No 09 Angara Irkutsk.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

N. cuspidata Kütz. var. ambiguus (Ehr.) Cleve
Hustedt 1930-66, III, p. 62, fig. 1206b; Schmidt et al. (1874-1959), pl. 211, figs 42-47; Sabelina et al. 1951, p. 275, pl. 155, fig. 8; Foged 1959, p. 52; 1985a, p. 43, pl. 4, fig. 9; 1981, p. 111; Patrick & Reimer 1966, p. 464, pl. 43, fig. 10.
No 10 reservoir Ob.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

*N. decussis* Østrup

Østrup. 1910, p. 77, pl. 2, fig. 50; Schmidt et al. (1874-1959), pl. 398, figs 36; pl. 401, figs 12, 13; Foged 1959, p. 59, pl. 5, fig. 5; 1981, p. 111, pl. 32, fig. 13; Germain 1981, pl. 73, fig. 6.

Nos 10 (common), 11, 12 (common) reservoir Ob.

Fig. 65: 24 × 8 µm No 10.

Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

*N. gastrum* (Ehr.) Kütz. var. *exigua* (Greg.) Grun.

Cl.-Euler 1953, III, p. 147, fig. 801d, e.

Nos 10, 11, 12 reservoir Ob.

Fig. 82: 24 × 10 µm 12-13 striae in 10 µm No 12.

Oligohalobous (indifferent)

*N. gothlandica* Grun.

Hustedt 1930, p. 296, fig. 499; Schmidt et al. (1874-1959), pl. 272, figs 33, 34; Sabelina et al. 1951, p. 310, pl. 173, fig. 1; Patrick & Reimer 1966, p. 509, pl. 48, fig. 14; Foged 1981, p. 114.

No 09 Angara–Irkutsk.

Oligohalobous (indifferent), alkaliphilic. Eurasia, N. America.

*N. gracilis* Ehr. [= *N. tripunctata* (O. F. Muller) Bory in Krammer & Lange-Bertalot (1986)]

Hustedt 1930, p. 299, fig. 514; Sabelina et al. 1951, p. 315, pl. 177, fig. 3; Patrick & Reimer 1966, p. 513, pl. 49, fig. 3 (as *N. tripunctata* (O. F. Müller) Bory); Foged 1959, p. 60; 1971b, p. 957; 1981, p. 114; 1985a, p. 44, pl. 4, figs 6, 7.

Nos 03, 05, 11 Baikal, Baikal–Angara, reservoir Ob.

Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

*N. hungarica* Grun. [= *N. capitata* Ehr. var. *hungarica* (Grun.) Ross]

Hustedt 1930, p. 296, fig. 500; Schmidt et al. (1874-1959), pl. 402, fig. 65; Sabelina et al. 1951, p. 313, pl. 175, fig. 2; Patrick & Reimer 1966, p. 537, pl. 52, fig. 3 (as *N. capitata* Ehr. var. *hungarica* (Grun.) Ross); Foged 1959, p. 61; 1971b, p. 958; 1981, p. 115.

No 04 Baikal.

Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

var. *capitata* (Ehr.) Cleve [= *N. capitata* Ehr.]

Hustedt 1930, p. 296, fig. 508; Schmidt et al. (1874-1959), pl. 272, figs 41-43; Sabelina et al. 1951, p. 313, pl. 175, fig. 4; Patrick & Reimer 1966, p. 536, pl. 52, figs 1, 2 (as *N. capitata* Ehr.); Foged 1959, p. 61; 1981, p. 115.

No 12 reservoir Ob.

Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

*N. meniscusculus* Schum

Hustedt 1930, p. 301, fig. 517; Schmidt et al. (1874-1959), pl. 399, figs 30-33; Sabelina et al. 1951, p. 317, pl. 178, fig. 8; Patrick & Reimer 1966, p. 574; Foged 1981, p. 118, pl. 31, fig. 3.

No 04 Baikal.

Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

var. *uppsaliensis* Grun.

Patrick & Reimer, p. 519, pl. 49, figs 17, 18; Foged 1981, p. 118, pl. 31, figs 9, 10.

Fig. 64: 29 × 8 µm No 12 reservoir Ob.

Oligohalobous (indifferent), alkaliphilic. N. Europe, N. America.
N. mutica Kütz. [= Luticola mutica (Kütz.) D. G. Mann]
Hustedt 1930-66, III, p. 583, figs 1592a-f; Schmidt et al. (1874-1959), pl. 370, figs 23, 24; Sabelina et al. 1951, p. 280, pl. 159, fig. 1; Patrick & Reimer 1975, p. 454, pl. 42, fig. 2; Foged 1959, p. 55; 1981, p. 118.
No 08 Angara.

N. mutica var. cohnii (Hilse) Grun. [= Luticola cohnii (Hilse) D. G. Mann]
Hustedt 1930-66, II, p. 583, figs 1592g-m; Schmidt et al. (1874-1959), pl. 370, fig. 25; Sabelina et al. 1951, p. 280, pl. 159, fig. 3; Patrick & Reimer 1966, p. 454, pl. 42, fig. 3; Foged 1959, p. 55; 1981, p. 118.
No 01, 02 Amur.

var. goeppertiana (Bleisch) Grun. [= Luticola goeppertiana (Bleisch in Rabh.) D. G. Mann]
No 02 Amur.

N. neoventricosa Hust.
Hustedt 1930-66, III, p. 612, fig. 1612; Sabelina et al. 1951, p. 280, pl. 159, fig. 2; Foged 1981, p. 119, pl. 29, fig. 11.
Syn: Navicula mutica var. ventricosa (Kütz.) Cleve & Grun. 1880
Nos 07, 08, 09 Angara.
Fig. 68: 17 × 6 µm. No 08.

N. oppugnata Hust.
Hustedt 1945 p. 925, pl. 42, fig. 1; Foged 1974, p. 77, pl. 12, figs 5, 15; 1977, p. 83, pl. 28, figs 3, 4; Patrick & Reimer 1975; Lange-Bertalot 1985, p. 96, pl. 16, figs 8-11; Foged 1981, p. 119, pl. 31, fig. 8; pl. 35, fig. 8.
Nos 09, 10, 11, 12 Angara-Irkutsk, reservoir Ob.
Fig. 79: 43 × 10 µm. No 12.
Oligohalobous (indifferent), alkaliphilic. Europe, N. America.

N. paludosa Hust.
Hustedt 1957 p. 286; Foged 1981, p. 120, pl. 38, figs 6, 8.
Syn: N. lagerstedtii Cleve var. palustris Hust.; Hustedt 1934, p. 385; Schmidt et al. (1874-1959), pl. 400, figs 27-29; Foged 1959, p. 64.
No 04 Baikal.

N. placenta (Ehr.) Grun.
Hustedt 1930, p. 303, fig. 532; Schmidt et al. (1874-1959), pl. 272, figs 20-22; Sabelina et al. 1951, p. 323; Patrick & Reimer 1966, p. 523, pl. 50, fig. 1; Foged 1971b, p. 961, pl. 1081, fig. 121.
Nos 10, 12 reservoir Ob.
Fig. 62: 33 × 17 µm No 10.
Fig. 63: 39 × 17 µm 10-11 striae in 10 µm No 12.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

so. lanceolata Grun.
Hustedt 1930, p. 304, fig. 535; Sabelina et al. 1951, p. 323, pl. 185, fig. 4.

130
No 12 reservoir Ob.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

*fo. latiuscula* (Grun.) Meister
Hustedt 1930, p. 304, fig. 534; Sabelina *et al.* 1951, p. 323, pl. 185, fig. 3; (Vide Patrick & Reimer 1966, p. 523); Foged 1981, p. 121.

No 10 reservoir Ob.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

*fo. rostrata* A. Mayer
Hustedt 1930, p. 304, fig. 533; Sabelina *et al.* 1951, p. 323, pl. 183, fig. 2; Foged 1971, p. 961, pl. 13, fig. 13; 1981, p. 121, pl. 32, fig. 7.

Nos 11, 12 reservoir Ob.
Fig. 66: 28 x 13 µm No 12.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

*N. protrata* (Grun.) Cleve
Hustedt 1930-66, Ill, p. 315, fig. 1433; Sabelina *et al.* 1951, p. 292, pl. 166, fig. 8; Patrick & Reimer 1966, p. 471, pl. 45, fig. 3; Foged 1981, p. 121, pl. 38, fig. 10.

Nos 10, 11, 12 reservoir Ob.

*N. pseudouscula* Hust.

No 10 reservoir Ob.
Oligohalobous (indifferent), alkaliphilic. Europe, N. America.

*N. pupula* Kütz. [= *Sellaphora pupula* (Kütz.) D. G. Mann]
Hustedt 1930, p. 281, fig. 467a; 1930-66, III, p. 120, figs 1254a-g; Schmidt *et al.* (1874-1959), p. 396, pl. 15, fig. 21; Sabelina *et al.* 1951, p. 287, pl. 165, fig. 1; Patrick & Reimer 1966, p. 495, pl. 47, fig. 7; Foged 1971b, p. 962; 1981, p. 126, pl. 38, fig. 20.

Nos 01, 08, 11, 12 Amur, Angara, reservoir Ob.

*fo. capitata* Skv. & Meyer
Hustedt 1930-66, III, p. 121, figs 1254i-m; Schmidt *et al.* (1874-1959), pl. 396, figs 22-25; Patrick & Reimer 1966, p. 496, pl. 47, fig. 8; Foged 1981, p. 122.

No 01 Amur.

*N. radiosa* Kütz.
Hustedt 1930, p. 299, fig. 513; Schmidt *et al.* (1874-1959), pl. 47, figs 50-92; pl. 395, figs 5, 6; Sabelina *et al.* 1951, p. 315, pl. 177, fig. 1; Patrick & Reimer 1966, p. 509, pl. 48, fig. 15; Foged 1959, p. 62; 1981, p. 123, pl. 32, fig. 1; pl. 35, fig. 5.

Nos 03, 04, 05, 06, 10 Baikal, Baikal–Angara, reservoir Ob.
Fig. 60: 53 x 9 µm No 04. (fo. *cymbulata*?)

*N. radiosa* var. *tenella* (Bréb. ex Kütz.) Cleve & Möller.
Syn.: *N. tenella* Bréb ex Kütz. 1849; Foged 1985a, p. 50.
No 09 Angara–Irkutsk.
**N. reinhardtii** Grun. var. *elliptica* Héribaud
Patrick & Reimer 1966, p. 517, pl. 49, fig. 13; Foged 1985a, p. 49, pl. 18, fig. 3.
Syn.: *N. reinhardtii* var. *ovalis* A. Mayer; Skvortzow 1928, p. 312, fig. 4; Economou-Amilli 1976, p. 71.
Nos 10, 11, 12 reservoir Ob.
Fig. 81: 34 x 16 µm 7-8 striae in 10 µm No 12.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

**N. tripunctata** (O. F. Müller) Bory
Patrick & Reimer 1966, p. 513, pl. 49, fig. 3; Lawson & Rushforth 1975, p. 37, pl. 24, fig. 7; Foged 1981, p. 127; 1985a, p. 50, pl. 19, fig. 5.
Nos 03, 04, 05, 09, 10, 11, 12 Baikal, Baikal–Angara, Angara, reservoir Ob.
Fig. 78: 53 x 10 µm 11 striae in 10 µm No 09.
Oligohalobous (indifferent to halophilic), pH-circumneutral to alkaliphilic.

**N. trivialis** Lange-Bertalot
Lange-Bertalot 1980, p. 31, pl. 1, figs 5-9.
Syn: *N. lanceolata* (Ag.) Kütz. 1834.
* N. lanceolata* (Ag.) Ehr. 1838.
* N. lanceolata* (Ag.) Kütz. 1844.
* N. gothlandica* sensu Germain 1964, pl. 1, figs 1-3.
Nos 10, 12 reservoir Ob.
Fig. 80: 31 x 7.5 µm No 12.
Oligohalobous (indifferent), alkaliphilic? Cosmopolitan.

**Neidium** Pfitzer 1871

**N. affine** (Ehr.) Pfitzer
Hustedt 1930, p. 242, fig. 376; Patrick & Reimer 1966, p. 390, pl. 35, fig. 2; Foged 1959, p. 50; 1971b, p. 967; 1981, p. 129.
No 07 Angara.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.
var. *amphirhynchus* (Ehr.) Cleve
Hustedt 1930, p. 243, fig. 377; Schmidt et al. (1874-1959), p. 49, figs 27-30; Sabelina et al. 1951, p. 378, pl. 230, fig. 4; Patrick & Reimer 1966, p. 391, pl. 35, fig. 3; Foged 1981, p. 129, pl. 19, fig. 16.
No 08 Angara.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

var. *longiceps* (Greg.) Cleve
Hustedt 1930, p. 244, fig. 378; Sabelina et al. 1951, p. 380, pl. 230, fig. 6; Patrick & Reimer 1966, p. 393, pl. 35, fig. 4; Foged 1981, p. 130.
Nos 07, 08 (common), 10 Angara, reservoir Ob.
Fig. 34: 38 x 6 µm No 07; Fig. 33: 37 x 8 µm No 08.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.
**N. bisulcatum** (Lagerst.) Cleve

Hustedt 1930, p. 242, fig. 374; Schmidt *et al.* (1874-1959), pl. 49, figs 15, 17; Sabelina *et al.* 1951, p. 378, pl. 229, fig. 1; Patrick & Reimer 1966, p. 377, pl. 36, fig. 5; Foged 1959, p. 51; 1971b, p. 968; 1981, p. 131, pl. 22, fig. 17; pl. 25, fig. 9; pl. 26, fig. 8; pl. 28, fig. 10.

Nos 07, 08 Angara.

Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

**N. dubium** (Ehr.) Cleve

Hustedt 1930, p. 246, fig. 384; Schmidt *et al.* (1874-1959), pl. 49, figs 7, 8, 11, 24-26; Sabelina *et al.* 1951, p. 383, pl. 233, fig. 3; Patrick & Reimer 1966, p. 404, pl. 37, fig. 5; Foged 1971b, p. 969, pl. 2, fig. 5; pl. 10, fig. 5; 1981, p. 132, pl. 25, fig. 6.

Nos 10, 12 reservoir Ob.

Fig. 35: 37 × 12 µm No. 10.


**N. iridis** (Ehr.) Cleve fo. *vernalis* Reichelt

Hustedt 1930, p. 245, fig. 380; Sabelina *et al.* 1951, p. 380, pl. 232, fig. 2; Patrick & Reimer 1966, p. 408; Foged 1971b, p. 970, pl. 9, fig. 15; pl. 10, fig. 3; 1981, p. 133.

Nos 07, 08, 09 Angara, Angara-Irkutsk.

Fig. 31: 54 × 12 µm No. 08.


**Nitzschia** Hassall 1845

**N. acicularis** (Kütz.) W. Smith

Hustedt 1930, p. 423, fig. 821; Schmidt *et al.* (1874-1959), pl. 335, figs 15-17; Sabelina *et al.* 1951, p. 532, pl. 336, fig. 3; Foged 1959, p. 87; 1981, p. 136, pl. 59, fig. 11.

No 09 Angara-Irkutsk.

Oligohalobous (indifferent), alkaliophilic. Cosmopolitan.

**N. acuta** Hantzsch [In Krammer & Lange-Bertalot 1988 *N. acuta.*]

Hustedt 1930, p. 412, fig. 790; Schmidt *et al.* (1874-1959), pl. 334, figs 25, 26; Grun. 1880, p. 90 as *N. acuta* Hantzsch ex Cleve; Foged 1971b, p. 972; 1981, p. 136, pl. 58, figs 6, 7 (as *N. acuta*).

Nos 02, 09 Amur, Angara-Irkutsk.

Oligohalobous (indifferent), alkaliophilic. Cosmopolitan.

**N. amphibia** Grun.

Hustedt 1930, p. 414, fig. 793; Schmidt *et al.* (1874-1959), pl. 348, figs 34-37; Sabelina *et al.* 1951, p. 519, pl. 328, fig. 1; Foged 1959, p. 83, pl. 12, fig. 10; 1971b, p. 972; 1981, p. 137, pl. 58, fig. 10; pl. 59, fig. 3.

Nos 07, 10, 11 Angara, reservoir Ob.

Fig. 146: 19 × 4 µm No. 07.

Oligohalobous (indifferent), alkaliophilic. Cosmopolitan.

**N. angustata** (W. Sm.) Grun. var. *acuta* Grun.

Hustedt 1930, p. 402, fig. 768; Schmidt *et al.* (1874-1959), pl. 331, figs 44, 45; Sabelina *et al.* 1951, p. 503, pl. 317, fig. 6; Foged 1959, p. 81; 1971b, p. 972; 1981, p. 137, pl. 57, fig. 5.

No 06 Baikal–Angara.

Oligohalobous (indifferent), alkaliophilic, Cosmopolitan.

**N. dissipata** (Kütz.) Grun.

Hustedt 1930, p. 412, fig. 789; Schmidt *et al.* (1874-1959), pl. 332, figs 22-24; Sabelina *et al.* 1951, p. 515, pl. 327, fig. 1; Foged 1959, p. 83; 1971, p. 972; 1981, p. 138; 1985a, p. 53, pl. 7, fig. 17.
N. *filiformis* (W. Sm.) Hust.
Hustedt 1930, p. 422, fig. 818; Sabelina *et al.* 1951, p. 531, pl. 335, fig. 4; Pernagallo 1897-1908, p. 283, pl. 72, fig. 18; Foged 1976, p. 40, pl. 22, fig. 4.

No 03 Baikal.
Mesohalobous.

N. *frustulum* Kütz.
Hustedt 1930, p. 414, fig. 795; Sabelina *et al.* 1951, p. 521; Schmidt *et al.* (1874-1959), p. 349, pl. 17, fig. 26; Foged 1959, p. 84, pl. 13, fig. 15; 1971b, p. 972; 1981, p. 138.

No 07 Angara.
Oligohalobous (indifferent to halophilic), alkaliphilic. Cosmopolitan.

N. *frustulum* var. *perpusilia* (Rabh.) Grun.
Hustedt 1930, p. 415; 1942, p. 133, figs 289-296; Sabelina *et al.* 1951, p. 52; Foged 1959, p. 85; 1977, p. 95, pl. 45, fig. 10.

Nos 04, 08 Baikal, Angara.

Fig. 138: 16 × 3 µm No. 08.
Oligohalobous (indifferent to halophilic), alkaliphilic. Cosmopolitan.

N. *gracilis* Hantzsch
Hustedt 1930, p. 416, fig. 794; Schmidt *et al.* (1874-1959), pl. 349, figs 34-37; Foged 1981, p. 139, pl. 59, fig. 1.

No 09 Angara-Irkutsk.
Oligohalobous (indifferent), pH-circumneutral. Cosmopolitan?

N. *hejleriana* Grun. [= *N. nana* Grun. (*Krammer & Lange-Bertalot, 1988.*)]
Hustedt 1930, p. 414, fig. 805; Lange-Bertalot 1976, p. 260, pl. 1, figs 20, 21.

Fig. 149: 88 × 5 µm 8-12 striae in 10 µm No 06 Baikal–Angara.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

N. *ignorata* Krasske
Hustedt 1930, p. 422, fig. 819; Foged 1959, p. 87; 1981, p. 139, pl. 58, fig. 4; pl. 59, fig. 2.

No 01 Amur.

N. *intermedia* Hantzsch
Lange-Bertalot 1976, p. 267, pl. 4, fig. 2; Foged 1959, p. 85, pl. 11, fig. 13; 1981, p. 139, pl. 58, figs 3, 8.

Fig. 143: 53 × 5 µm No 06 Baikal–Angara.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

N. *kuetzingiana* Hilse [= *N. pusilla* Grun. *emend. Lange-Bertalot.*]

No 09 (fairly common) Angara–Irkutsk.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

N. *linearis* W. Smith
Hustedt 1930, p. 409, fig. 784; Schmidt *et al.* (1874-1959), pl. 334, figs 22-24; Sabelina *et al.* 1951, p. 512, pl. 325, fig. 1; Foged 1981, p. 140; 1979, p. 88, pl. 42, fig. 12.

Nos 03, 05, 06, 07, 08 (common), 09, 10 Baikal–Angara, reservoir Ob.
Fig. 27: 14 x 7 µm No 06.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

*Pinnularia* Ehr. 1840

*P. borealis* Ehr.
Hustedt 1930, p. 326, fig. 597; Schmidt *et al.* (1874-1959), pl. 45, figs 15-21; Sabelina *et al.* 1951, p. 356, pl. 211, fig. 5; Patrick & Reimer 1966, p. 618, pl. 58, fig. 13; Foged 1981, p. 145, pl. 40, figs 6, 7.

No 01, 08 Amur, Angara.

*P. brevicostata* Cleve fo. *sensu* Foged 1971
Foged 1971, p. 974, pl. 16, fig. 16

Fig. 87: 62 x 12 µm 10 striae in 10 µm No 05 Baikal–Angara.
It is fairly similar to the forma from the deep lake in Alaska (sample No 25/1963 collected by C. Holmquist), but maybe it is also related to *P. microstauron*, which varies very much in size and outline.


*P. isostauron* (Ehr.) Cleve
Hustedt 1924, p. 572, pl. 20, fig. 5; Patrick & Frase 1961, p. 230; Foged 1981, p. 150, pl. 43, fig. 4.

Fig. 88: 60 x 12 µm 8-9 striae in 10 µm No 07 Angara.

*P. mesolepta* (Ehr.) W. Smith
Hustedt 1930, p. 319, fig. 575a; Schmidt *et al.* (1874-1959), pl. 45, figs 52, 53; Patrick & Reimer 1966, p. 600, pl. 55, figs 17, 18; Foged 1959, p. 65; 1971b, p. 976; 1981, p. 152, pl. 39, fig. 12.

No 01 Amur.

*P. microstauron* (Ehr.) Cleve
Hustedt 1930, p. 320, fig. 582; Schmidt *et al.* (1874-1959), pl. 94, figs 14, 16; Sabelina *et al.* 1951, p. 350, pl. 208, fig. 1; Patrick & Reimer 1966, p. 597, pl. 55, fig. 2; Foged 1959, p. 66, pl. 8, fig. 7; 1971b, p. 976; 1981, p. 152, pl. 41, fig. 9; pl. 43, figs 2, 3, 6; pl. 44, fig. 7.

No 07, 08, 10 Angara, reservoir Ob.

Fig. 71: 54 x 11 µm No 08, Fig. 73: 43 x 11 µm 10 striae in 10 µm No 10, Fig. 74: 62 x 12 µm No 07, Fig. 75: 49 x 9 µm 10-11 striae in 10 µm No 08.

var. *brebissonii* (Kütz.) Mayer
Hustedt 1930, p. 321, fig. 584; Schmidt *et al.* (1874-1959), pl. 44, figs 17, 18 (as *P. brebissonii* Kütz.); Sabelina *et al.* 1951, p. 350, pl. 208, fig. 4; Patrick & Reimer 1966, p. 614, pl. 58, fig. 6 (as *P. brebissonii* (Kütz.) Rabh.); Foged 1971b, p. 976; 1981, p. 152, pl. 39, fig. 15; pl. 40, fig. 8.

No 07, 08, 10 Angara, reservoir Ob.

Fig. 72: 34 x 8 µm No 08, Fig. 84: 33 x 8 µm 11-12 striae in 10 µm No 07.

fo. *diminuta* Grun.
Hustedt 1930, p. 322, fig. 585; Sabelina *et al.* 1951, p. 215, pl. 68, fig. 4; Patrick & Reimer 1966, p. 616, pl. 58, fig. 7 (as *P. microstauron* var. *diminuta* (Grun.) Cleve; Foged 1971b, p. 976; 1981, p. 154.

No 01 Amur.
P. viridis (Nitzsch) Ehr.
Hustedt 1930, p. 334, fig. 617a; Schmidt et al. (1874-1959), pl. 42, figs 11-14, 19, 21-13; Sabelina et al. 1951, p. 372, pl. 226, fig. 1; Patrick & Reimer 1966, p. 639, pl. 64, fig. 5; Foged 1971b, p. 978, pl. 16, fig. 7; pl. 17, fig. 3; 1981, p. 156, pl. 42, fig. 2; pl. 43, fig. 1.
No 08 Angara.

Rhoicosphenia Grun. 1860
R. curvata (Kütz.) Grun.
[According to Kranner & Lange-Bertalot (1986) this species should have the name R. abbreviata. Round et al. (1990), however, found that there are several races and would therefore temporarily retain the name R. curvata.]
Hustedt 1930, p. 211, fig. 311; Schmidt et al. (1874-1959), pl. 213, figs 1-5; Sabelina et al. 1951, p. 231, pl. 130, fig. 1; Patrick & Reimer 1966, p. 282, pl. 20, figs 1-5; Foged 1959, p. 47; 1971b, p. 973, pl. 19, fig. 25; 1981, p. 157, pl. 14, fig. 1.
No 03 (common), 04, 05, 06, 09, 11 (common), 12.
Fig. 22: 40 x 4-7 µm No 03, Fig. 23; 34 x 7 µm No 06.
Oligohalobous (indifferent to alkaliphilic), alkaliphilic. Cosmopolitan.

Rhopalodia O. Müller 1895
R. gibba (Ehr.) O. Müller
Hustedt 1930, p. 390, fig. 740; Schmidt et al. (1874-1959), pl. 253, figs 1-13; Sabelina et al. 1951, p. 485, pl. 305, fig. 2; Patrick & Reimer 1975, p. 189, pl. 28, fig. 1; Foged 1959, p. 80; 1971b, p. 979; 1981, p. 157.
No 01 Amur.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

var. ventricosa (Ehr.) Grun.
Hustedt 1930, p. 391, fig. 741; Schmidt et al. (1874-1959), pl. 253, figs 14-17; Patrick & Reimer 1975, p. 190, pl. 28, figs 3, 4; Foged 1981, p. 157, pl. 55, fig. 13.
No 01 Amur.
Oligohalobous (indifferent), alkalibiontic. Cosmopolitan.

Stauroneis Ehr. 1841
S. anceps Ehr.
Hustedt 1930-66, II, p. 771, fig. 1120a; Sabelina et al. 1951, p. 266, pl. 151, fig. 1; Patrick & Reimer 1966, p. 361, pl. 30, fig. 1; Foged 1959, p. 51; 1971b, p. 979, pl. 11, fig. 3; 1981, p. 158, pl. 20, fig. 8.
Nos 06, 07, 08, 10 Angara, reservoir Ob.
Fig. 59: 60 x 12 µm No 10.

S. anceps fo. gracilis Rabh.
Hustedt 1930-66, II, p. 771, fig. 1120b; Schmidt et al. (1874-1959), pl. 242, figs 7, 12; Sabelina et al. 1951, p. 266, pl. 151, fig. 2; Patrick & Reimer 1966, p. 361, pl. 30, fig. 2; Foged 1971b, p. 979, pl. 11, fig. 8; 1981, p. 158.
Nos 02, 07, 08 (common) Amur, Angara.
Fig. 57: 42 x 11 µm No 08.
Diatoms from Siberia, especially Lake Baikal

S. phoenicenteron (Nitzsch) Ehr.
Hustedt 1930-66, II, p. 766, fig. 1118a; Schmidt et al. (1874-1959), pl. 242, figs 13, 16; Sabelina et al. 1951, p. 264, pl. 150, fig. 2; Patrick & Reimer 1966, p. 359, pl. 29, figs 1, 2; Foged 1959, p. 51; 1971b, p. 980, pl. 11, figs 1, 2; 1981, p. 161, pl. 21, fig. 2.
Nos 08, 09, 10 Angara, reservoir Ob.
Fig. 58: 102 × 9 µm No 08.

Stephanodiscus Ehr. 1845
S. astraea (Ehr.) Grun. var. minutula (Kütz.) Grun. [= S. minutulus (Kütz.) Cleve & Möller]
Hustedt 1930-66, I, p. 369, figs 193d, e; Schmidt et al. (1874-1959), pl. 226, figs 5, 12-17; Sabelina et al. 1951, p. 102, pl. 57, fig. 2; Foged 1959, p. 37; 1971b, p. 982, pl. 7, fig. 3; 1981, p. 164, pl. 2, figs 18, 21.
Nos 01, 02, 04, 07, 10, 11, 12 Amur, Baikal, reservoir Ob.
Fig. 11: diam 12 µm No 01, Fig. 12: diam 9 µm No 04.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

Surirella Turpin 1828
S. angustia Kütz.
Hustedt 1930, p. 435, fig. 844; Schmidt et al. (1874-1959), pl. 23, figs 34, 35, 39-41; Sabelina et al. 1951, p. 553, pl. 351, fig. 4; Foged 1959, p. 87; 1971b, p. 982, pl. 23, fig. 4; 1981, p. 164, pl. 59, figs 14, 19.
Nos 01, 02, 04, 07 (common), 08 (dominant), 09, 10.
Fig. 155: 31 × 8 µm No 07.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

S. biseriata Bréb. var. bifrons (Ehr.) Hust.
Hustedt 1930, p. 443, fig. 833; Schmidt et al. (1874-1959), pl. 283, figs 3, 4; Sabelina et al. 1951, p. 548, pl. 347, fig. 3; Foged 1981, p. 165, pl. 61, fig. 2.
No 01 Amur.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

S. linearis W. Smith
Hustedt 1930, p. 434, fig. 837; Schmidt et al. (1874-1959), pl. 23, fig. 27; Sabelina et al. 1951, p. 551, pl. 350, fig. 1; Foged 1959, p. 88; 1971b, p. 983, pl. 5, fig. 8; pl. 21, fig. 5; 1981, p. 166, pl. 61, fig. 7; pl. 64, figs 4, 11.
Nos 01, 02 Amur.

var. helvetica (Brun) Meister
Hustedt 1930, p. 434, fig. 840; Sabelina et al. 1951, p. 551, pl. 351, fig. 3; Foged 1971b, p. 983, pl. 2, fig. 8; pl. 22, fig. 1; 1981, p. 167, pl. 62, figs 5, 8.
Fig. 159: 53 × 15 µm 30-35 alae in 10 µm No 10 reservoir Ob.

S. ovata Kütz.
Hustedt 1930, p. 442, fig. 864; Schmidt et al. (1874-1959), pl. 23, figs 49-55; Sabelina et al. 1951, p. 564, pl. 361, fig. 1; Foged 1959, p. 88; 1981, p. 168, pl. 63, fig. 11.
Nos 02, 04, 07 (fairly common), 09, 10 Amur, Baikal, Angara, reservoir Ob.
Fig. 156: 19 × 9 µm No 07.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.
var. pinnata (W. Smith)Brun
Hustedt 1930, p. 442, fig. 869; Sabelina et al. 1951, p. 564, pl. 361, fig. 2; Foged 1959, p. 88; 1971b, p. 984; p. 168, pl. 63, figs 7, 10; pl. 64, figs 7, 10.
Nos 01, 02, 07 (dominant), 08 (dominant), 09, 10 (common) Amur, Angara, reservoir Ob.
Fig. 158: 35 × 10 µm 60 alae in 100 µ No 07.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

S. tenera Greg.
Hustedt 1930, p. 438, fig. 853; Schmidt et al. (1874-1959), pl. 23, figs 7-9; Sabelina et al. 1951, p. 558, pl. 355, fig. 1; Foged 1959, p. 88; 1971b, p. 984; 1981, p. 169.
No 02 Amur.
Oligohalobous (indifferent), alkaliphilic. Cosmopolitan.

S. turgida W. Smith fo. obtusa Foged
Foged 1974, p. 110, pl. 36, fig. 8; 1981, p. 169, pl. 61, fig. 4.
Nos 01, 02 Amur.
Fig. 157: 29 × 15 µm 30 alae in 100 µ No 01.

Synedra Ehr 1830

S. rumpens Kütz.
Hustedt 1930-66, II, p. 207, figs 677a, b; Sabelina et al. 1951, p. 149, pl. 82, fig. 1; Patrick & Reimer 1966, p. 143, pl. 5, fig. 19; Foged 1981, p. 171.
Nos 01, 02 Amur.
Fig. 16: 73 × 4 µm No 01.
Oligohalobous (indifferent), pH-circumneutral. Cosmopolitan(?)

S. ulna (Nitzsch) Ehr.
Hustedt 1930-66, II, p. 195, figs 691A a-c; Schmidt et al. (1874-1959), pl. 301, figs 1-26; pl. 302, figs 1-17, 19-22; pl. 303, fig. 1; Sabelina et al. 1951, p. 144, pl. 79, fig. 1; Patrick & Reimer 1966, p. 148, pl. 7, figs 1, 2; Foged 1959, p. 41; 1981, p. 171, pl. 5, figs 12, 13.
Nos 01, 02, 03, 06, 09, 10, 11 Amur, Baikal, Angara-Baikal, Angara-Irkutsk, reservoir Ob.

var. aequalis (Kütz.) Grun.
Hustedt 1930-66, II, p. 199, fig. 691a-d; Schmidt et al. (1874-1959), pl. 303, fig. 3; Sabelina et al. 1951, p. 144, pl. 79, fig. 2; Foged 1959, p. 41; 1981, p. 171.
No 09 Angara-Irkutsk.

var. danica (Kütz.) Grun.
Hustedt 1930-66, II, p. 200, fig. 691a-f; Schmidt et al. (1874-1959), pl. 303, figs 6, 8; Sabelina et al. 1951, p. 144, pl. 79, fig. 5; Patrick & Reimer 1966, p. 151, pl. 7, fig. 10; Foged 1959, p. 42; 1981, p. 172; 1985a, p. 65, pl. 2, fig. 1.
Nos 01, 02, 09 Amur, Angara-Irkutsk.

S. vaucheriae Kütz.
Hustedt 1930-66, II, p. 194, fig. 689a-c. Schmidt et al. (1874-1959), pl. 305, figs 18-21; Sabelina et al. 1951, p. 142, pl. 78, fig. 8; Foged 1981, p. 172, pl. 4, fig. 14; pl. 5, fig. 25.
Nos 01, 03, 04, 05, 06 (very common), 09, 10, 12.
Fig. 20: 19 × 4.5 µm, No 03.
Fig. 37: 28 × 5 µm, 16 striae in 10 µm, No 03.
Concluding Comments

From the 1975 Lake Baikal samples the diatom list contains about 260 taxa. This list forms an important taxonomic record for Lake Baikal’s rocky shore in the Lisvianka region at that time. Interestingly, the samples are considerably less diverse than those described earlier by Skvortzow & Meyer (1928) and particularly by Skvortzow (1937). Furthermore, the latter two papers recorded that between 40 and almost 50% of the diatom taxa were endemic. This compares rather unfavourably with a low occurrence of these taxa, < 6% of the total number of taxa, in the present material. There are several possible reasons for these discrepancies. Foged’s samples were collected from surfaces in very shallow water in the surf zone whereas greater depths were sampled in the earlier work. In summer, the photic zone in Lake Baikal is in the order of 30m and endemic taxa are allegedly more common in the lower part of this zone. It is not surprising therefore that the 33m depth diatom sample examined by Skvortzow (1937) contained more species. Even so, the total of 148 new taxa described for this single sample is remarkably large and suggests the need for a very careful scrutiny of archived material before taxa can be regarded as truly endemic.

References


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NB: An Obituary for Niels Foged was published in *Diatom Research* Volume 3 (1), 169-174
Figs 1-3. Cyclotella baikalensis Skvortzow & Meyer, fo. ornata Skvortzow. Fig. 4. Aulacoseira baikalensis (Meyer) Simonsen. Fig. 5. Aulacoseira granulata (Ehr.) Simonsen. Fig. 6. A. granulata var. angustissima (Müller) Simonsen. Fig. 7. A. baikalensis (sporangial form). Fig. 8. Melosira varians Ag. Fig. 9. Cyclotella baikalensis Skvortzow & Meyer. Fig. 10. Melosira varians Ag. Figs 11, 12. Stephanodiscus minutulus (Ehr.) Ill & Møller. Figs 13, 14. Cyclotella Brun et Héribaud.
Figs 15-36. Fig. 15. Aulacosira baikalensis (Meyer) Simonsen. Fig. 16. Synedra rumpens Kütz. Fig. 17. Diatoma elongatum (Lyngbye) Ag. Fig. 18. Diatoma elongatum var. tenuis (Ag.) Van Heurck. Fig. 19. Fragilaria intermedia Grun. Fig. 20. Fragilaria vaucheriae Kütz. Fig. 21. Achnanthes lanceolata (Bréb.) Grun. Figs 22, 23. Rhoicosphercia curvata (Kütz.) Grun. Fig. 24. Ceratoneis arcus (Ehr.) Kütz. Fig. 25. Achnanthes lanceolata var. ? Fig. 26. Achnanthes laterostriata Hust. Fig. 27. Opephora marthi Heib. Fig. 28. Achnanthes lanceolata var. rostrata (Ostenp) Hust. Fig. 29. Cocconeis placenta var. linearis (Ehr.) Cl. Fig. 30. Caloneis bacillum (Grun.) Mereschk. Fig. 31. Neidium iridis fo. vernalis Reichelt. Fig. 32. Funnalia diodon Ehr. Figs 33, 34. Neidium affine var. longiceps (Grégo.) Cl. Fig. 35. Neidium dubium (Ehr.) Cl. Fig. 36. Fragilaria capucina Desmar.
Figs 37-58. Fig. 37. Synedra vaucheriae Kütz. Fig. 38. Achnanthes lanceolata var. rostrata (Ostr.) Hust. Fig. 39. Meridion circulare var. constricta (Ralfs) Van Heurck. Fig. 40. Diatoma vulgare Bory. Fig. 41. Cocconeis placentula var. lineata (Ehr.) Cl. Fig. 42. Achnanthes borealis A. Cleve. Fig. 43. A. lanceolata var. ventricosa Hust. Fig. 44. A. clevei var. balcanica Hust. f. nov.? Fig. 45. A. profunda Skv. Fig. 46. Cocconeis placentula var. baikalensis Skv. Figs 47, 48. Achnanthes striata Skv. & Meyer (the same cell). Fig. 49. Cocconeis pediculus Ehr. Figs 50, 51. Achnanthes lanceolata (Bréb.) Grun. Fig. 52. A. calcar Cleve. Fig. 53. Berkelia linearis Ross & Sims. Fig. 54. Diploneis ovalis (Hilse) Cl. Fig. 55. Caloneis bacillum (Grun.) Mereschk. Fig. 56. C. schumanniana var. biconstricta Grun. Fig. 57. Stauroeis anceps fo. gracilis Rabh. Fig. 58. St. phocenicerion (Nitzsch) Ehr.
Diatoms from Siberia, especially Lake Baikal
Figs 78-91. Fig. 78. *Navicula tripluncata* (O. F. Müller) Bory. Fig. 79. *N. oppugnata* Kütz. Fig. 80. *N. trivalis* Lange-Bertalot. Fig. 81. *N. reinhardii* var. *elliptica* Härth. Fig. 82. *N. gastrum* var. *exigua* (Greg.) Grun. Fig. 83. *N. bacillum* var. *gregoryana* Grun. Fig. 84. *Pinnularia microstauron* var. *brebissonii* (Kütz.) Hust. Fig. 85. *Gomphonema acuminata* Ehr. (transition between var. *trigonocephala* and *brebissonii*). Fig. 86. *Amphora sibirica* Skv. & Meyer. Fig. 87. *Pinnularia brevicostra* fo. *sensa* Foged 1971, pl. 16, fig. 16 (possibly also similar to *P. microstauron*?). Fig. 88. *P. isostauron* (Ehr.) Cleve. Fig. 89. *Cymbella ventricosa* (Ag.) Kütz. Fig. 90. *C. tumida* (Bréb. ex Kütz.) Van Heurck. Fig. 91. *C. turgida* (Greg.) Cleve.
Figs 92-102. Fig. 92. Didymosphenia geminata var. silicica f. curvata Skv. Fig. 93. D. dentata var. subcapitata Skv. & Meyer. Fig. 94. Amphora ovalis Kütz. Figs 95, 96, 98-100. Gloeohorma quadriradiata (Ost). Wisloch. Fig. 97. Cymbella stuxbergii var. intermedia Wisloch. Fig. 101. Gloeohorma olivaceoides Hutt. Fig. 102. G. elegans var. quadriradiata Skv. & Meyer.
Figs 103-114. Figs 103-105. Didimorpha geminata var. baikalensis fo. curvata Skv. & Meyer. Figs 106, 108, 114. Gomphonema quadrupunctata (Ostrup) Wislouch. Fig. 107. G. acuminatum var. trigonocepha (Ehr.) Grun. Figs 109, 110, 112. G. olivae-olivus Hert. Fig. 111. G. longiceps var. montana (Schum.) Cl. Fig. 113. G. angustatum var. sacrophagus (Grev.) Grun.
Figs 134-147. Fig. 134. Cymbella staeheliella Cleve. Fig. 135. C. staeheliella var. sibirica (Grun.) Wislouch. Fig. 136. C. tumida (Bréb. ex Kütz.) Van Heurck. Fig. 137. C. acuta (A.S.) Cl. Fig. 138. Nitzschia frustulum var. perpusilla (Rabh.) Grun. Figs 139, 144. N. dissipata (Kütz.) Grun. Fig. 140. N. palea var. debilis (Kütz.) Grun. Figs 141, 145. N. palea Hantzsch. Fig. 142. N. trilobellula var. victoriae Grun. Fig. 143. N. intermedia Hantzsch. Fig. 146. N. amphibia Grun. Fig. 147. Cymbella helvetica Kütz.
Figs 148-161. Figs 148, 150, 151. *Nitzschia recta* Hanstzh. Fig. 149. *N. heugleriana* Grun. Fig. 152. *N. linearis* W. Smith. Fig. 153. *N. parva* f. *torricola* Lund. Fig. 154. *Hanuthzia amphioxys* (Ehr.) Grun. Fig. 155. *Surirella angusta* Kütz. Fig. 156. *S. ova* Kütz. Fig. 157. *S. turgida* f. *obusa* Foged. Fig. 158. *S. ova* var. *pinnata* (W. Smith) Brun. Fig. 159. *S. linearis* var. *helvetica* (Brun) Meister. Fig. 160. *Cymatopleura elliptica* var. *constricta* Grun. Fig. 161. *C. solea* (Breb.) W. Smith.
Fig. 1. The 1975 diatom sample site locations in the former Soviet Union with inset showing details of the Lake Baikal sampling area.
Figs 2-5. Photographs of the sample site locations at Lake Baikal. Fig. 2. The rocky shore of Lake Baikal looking west from the quay near the then Limnological Station (now a museum). Fig. 3. The start of Lake Baikal outflow, the Angara River and the meteorological station. Fig. 4. Irkurstk, monument (to the builders of the Trans-Siberian Railway) steps to the Angara River. Fig. 5. The sandy shore of the reservoir fed by the River Ob at Novosibirsk.
A taxonomic re-evaluation of endemic Cyclotella taxa in Lake Baikal, Siberia

by

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With 34 figures and 1 table

In honour of Robert Ross on the occasion of his eightieth birthday

Abstract: Cyclotella taxa occurring in surface sediment samples from Lake Baikal are investigated using light and scanning electron microscopy. Original descriptions of Cyclotella baicalensis Skvortzow & Meyer and C. minutis (Skvortzow) Antipova are confirmed and additional morphological information is provided. Using differences in marginal structure, C. baicalensis f. ornata Skvortzow is raised to specific status. Comparison of marginal structures indicate that this taxon, C. ornata comb. nov., is more closely related to C. minutis than to C. baicalensis. The significance of these taxa in relation to endemism and recent environmental change in Lake Baikal is discussed.

Introduction

Lake Baikal is notable not only as the world's deepest and largest freshwater lake but also for its unique ecosystem which is characterized by a largely endemic flora and fauna. The biological uniqueness of Lake Baikal stems from both its great age and its unusual hydrological conditions, notably complex water circulation patterns, which prevent deepwater anoxia (Kozhov 1963). Until recently this great lake was unaffected by pollution but especially since the 1950s industry and urbanisation have developed markedly in the catchment (e.g. Galazii 1991). International concern about the Lake Baikal ecosystem led to the creation of the Baikal International Center for Ecological Research (BICER), see Maddox 1989 which was formally established in 1990 with The Royal Society being a founder member for the UK.

Lake Baikal is undoubtedly receiving industrial and urban effluents (Maatca et al. 1990, Grachev 1991) as well as pollutants from atmospheric deposition (Politov & Kokorin 1991). However, the extent to which the ecology of the lake is being affected by these processes is questionable (Grachev 1991). If pollution of Lake Baikal is eco-
logically significant then communities living in the lake will have responded by changes in species composition and abundance. Some of these changes can be established over a time scale of decades by using palaeolimnological techniques, most notably diatom analysis of recent dated sediment cores (e.g. Flower et al. 1987). Before such studies can be usefully undertaken an appropriate level of taxonomic information is required. Correct identification and discrimination of diatom taxa in sedimentary assemblages is fundamental to detecting floristic change.

Although diatom research in Lake Baikal began in a systematic way as early as the 1920s (e.g. Skvortzow & Meyer 1928) many taxonomic challenges remain, particularly in regard to the periphytic forms. Nevertheless, in terms of diatom productivity and sedimentary diatom accumulation it is endemic species of the planktonic genera, Aulacoseira and Cyclotella, that are most important. There is only one endemic Aulacoseira species, A. baikalensis (Meyer) Simonsen, whereas the genus Cyclotella is represented by several common species and forms. The taxonomic literature gives conflicting accounts of these ecologically important Cyclotella. This paper re-evaluates the taxonomy of common Cyclotella taxa in the lake as a necessary pre-requisite for using diatom analysis of recent sediments as a tool to identify recent changes in the lake ecosystem. As such, the paper represents the first publication on diatoms resulting directly from the 'BICER' agreement between The Royal Society, London, and the Siberian Limnological Institute, Irkutsk.

Methods

Surface sediment samples were collected for diatom analysis from several locations in Lake Baikal (Fig. 1) using a modified Glew core (Glew 1989). Cyclotella taxa were found in all four samples but small forms were more common in sediment from near Baikalsk in southern Baikal. Being very low in organic matter (≤ 5% loss on ignition at 550 °C) samples were stained for both LM and SEM microscopy by concentrated hydrochloric acid treatment only followed by several washings in distilled water. Photographs were taken using phase optics in a Zeiss 16 light microscope (LM) or by using either a Hitachi 721 or S 800 scanning electron microscope (SEM).

Diatom size frequency determinations were made by measuring 30 valve diameters in each 10 µm size class.

Results

Cyclotella baikalensis Skvortzow & Meyer

Figs 2, 3, 10–17
Proc. Sungsaree River Biol. Station 1 (5): 5, pl. 1, fig. 3 (1928), figs 2, 3, 10–17.

This diatom is rather uncommon in surface sediment samples but, being large and conspicuous, it is readily recognisable at low magnifications in LM. Cell diameters range from 80 µm to 150 µm, Skvortzow (1937) gives 10–113 µm. In LM the valve is more or less circular and characterized by a marked undulation within the central area (Fig. 2). A marginal ring of fine, regularly arranged radiating striae occupy about one third of the valve face. The central area is markedly colliculate and possesses a prominent punctum (the rimoportula) which is always located at the inner edge of the striated zone (Fig. 2, arrow a). This process always has the same orientation lying on the line bisecting the central area undulation. Numerous smaller puncta are scattered over the central area.

Fig. 1. The southern portion of Lake Baikal, Siberia, showing locations of surface sediment sampling points (1–5, sample depths 132, 134, 270, 827, and 1304 m, respectively).
(Fig. 2, arrow b). Phase-contrast optics more clearly reveal the puncta and some details of the marginal valve structure (Fig. 3).

In SEM details of external valve morphology including the colliculate external central area and external openings of some forty fultoportulacae are revealed (Figs 10, 11). Higher magnification of the central area (Fig. 12) shows the fultoportulacae apertures (Fig. 12, arrow b) as well as numerous smaller puncta and pits located in depressions (Fig. 12, arrow a). These latter structures do not communicate with the internal surface of the valve and in life are all probably covered by silica plates. The marginal radial striae are composed of striae and interstriae (Fig. 13), the latter are hyaline ridges on the mantle becoming colliculate on the valve face. The striae are multiseriate and are typically composed of 3 or 4 rows of areolae with those in the inner rows being smaller in diameter. There are no spines at the valve face/mantle junction. The circular external openings of the marginal fultoportulacae are present on most interstriae (Fig. 13).

Internally, the regularly arranged costae are confined to the mantle: longer thickened costae do occur but are infrequent (Fig. 14). The marginal fultoportulacae project centripetally, each with a simple outer collar around the elongated tube of the process (Fig. 16). A conspicuous single spartulate rimoportula occurs between the marginal costae and central fultoportulacae (Fig. 15). The central area of the valve is occupied by a group of fultoportulacae (Fig. 14) which are clearly composed of several sub-units. The interior openings of these fultoportulacae are short tubes surrounded by a pair of scale-
like, bi-lobed silica collars (Figs 14, 16). A fractured valve shows the internal structure of two central fultoportulae (Fig. 17). The process exists as a simple tube that narrows slightly as it passes from the external opening (arrow) through the double layered central area silica matrix. Towards its base the tube forms a double folded structure and the lumen is restricted giving the appearance of a reed valve arrangement. The two outer silica folds emerge on to the internal valve surface and form the pair of silica collars.

Sub-process parts of the central fultoportulae in *C. baikalensis* are rather different from those described previously for centric diatoms in general, Ross & Sims (1972) define the fultoportula as a process surrounded by 2–5 chambers or pores that probably open into the central tube. In this species there is no structural evidence of any sub-process structures that can be described as distinct chambers or pores. There is a small gap between the outer tube wall and each of the bi-lobed silica collars which could conceivably be called a pore but it is not morphologically comparable with the distinct satellite pores described in *C. comta* (see Ross & Sims 1972) for example. Furthermore, these small slit-like gaps do not link with the fultoportula tube lumen and it difficult to assign any possible functional significance to them. The internally projecting silica col-
Figs 18-21. Cyclotella ornata, SEM. Scale bars as marked. Figs 18, 19. External valve views showing the colliculate and undulate central area and marginal striae with short spines at the mantle valve face junction. Fig. 20. Detail of the valve mantle showing the striae and interstriae, interstriae on the mantle are frequently without fultoportulae openings. Note the valvocopula and opesia. Fig. 21. Detail of the central area showing external openings of the fultoportulae.

Tars around the fultoportulae complex seem to be undescribed sub-processes of unknown functional significance. It seems appropriate to name them as side-scales or laterisquamae, each laterisquam is a bilobed structure.

Cyclotella ornata (Skv.) Flower, comb. nov. Figs 4-6, 18-25.


This diatom is more common in surface sediment samples than C. baikalensis. Cell diameter ranges from about 30 to 80 µm (see Skvortzov 1937). In LM the valve is circular or nearly circular and characterized by fine marginal radiating striae occupying about one third of the valve face. The colliculate central area is markedly undulate and possesses a number of clearly visible puncta (Figs 4, 5). As in C. baikalensis, one prominent punctum (the rimoportula) is always located at the inner edge of the striated zone (Fig. 4) and the process has the same orientation to the central undulation. At a lower plane of focus in phase contrast optics, an irregular radial arrangement of silica struts (the shadow lines or 'schattenlinien') can be seen (Figs 5 arrowed, 6).
In SEM the external valve structure (Figs 18, 19) is similar to that of *C. baikalensis*, except that an irregular ring of spines is usually present on the valve/mantle junction. The marginal striated zone occupies about one third of the valve face. External openings of the marginal fultoportulae occur on the mantle on every one to five interstriae and compared with *C. baikalensis* they are more regularly arranged and relatively much more frequent. External openings of the central fultoportulae are scattered over the colliculate central area and vary between 5 and about 20 in number, depending on valve diameter (Fig. 21).

Internally, the broadly rounded rimoportula is located between the group of central fultoportulae and the alveoli (Fig. 22). The marginal alveoli are complex, being divided into marginal chambers (Lange & Syvertsen 1989) containing 2 to 6 short costae (4 inserted interstriae, Lange & Syvertsen 1989) bordered by thick elongated marginal costae (Fig. 23). The ratio of long to short costae is always < 1. One to five short costae occupy each chamber and all possess fultoportulae (Figs 23, 24). The marginal fultoportulae are short with a pair of laterisquamae orientated in the valvar plane. The laterisquamae are reflexed (Fig. 23) or folded, in an imbricate manner, around each fultoportula tube (Fig. 24). The central area fultoportulae generally possess oval apertures and the projecting tubes are surrounded by two laterisquamae (Fig. 25).

*Cyclotella minuta* (Skvortzow) Antipova Figs 7-9, 26-27

The diatom is easily the most common *Cyclotella* species in most surface sediment samples from southern Lake Baikal. The cell diameter (longest axis) range is 11–42 µm according to Antipova (1956) but in our material a few valves occurred with diameters < 11 µm, the smallest being 7 µm in diameter (see Fig. 34). In LM the valve is nearly always oval and characterized by very short marginal striation which occupies less than one third of the valve face (Figs 7, 8). The central area has a marked undulation and possesses a few (< 6) centrally located puncta. As in the other Baikal *Cyclotella* taxa, one prominent punctum (the rimoportula) is always located at the inner edge of the striated zone and is similarly orientated. At a lower plane of focus, in phase contrast optics, an inner marginal ring of black dots (the marginal fultoportulae) can be observed (Fig. 9).

In SEM the external valve (Figs 26, 27) has an undulate central area which is colliculate and contains the openings of the few central fultoportulae. These two figures show hypovalves but in Fig. 27 the larger epivalve is still in place; when only one valve remains attached to the tripartite girdle band complex it is always the hypovalve. Marginal striation differs from that in the previous taxa, with the striae and interstriae barely extending on to the valve face. Each interstria subtends a robust spine at the valve face/mantle junction (Fig. 28). Striae on the mantle are typically composed of four rows of areolae and these decrease to two or one row on the valve face. The interstriae are almost as wide as the striae and marginal fultoportulae openings perforate every second to eight interstriae. The spines are robust, firmly attached structures (as indicated by the broken spine base in Fig. 29), and form a very regular ring.

Internally, the alveoli and costae are confined to the valve mantle and the relatively large central area possesses an off-centre group of fultoportulae; the rimoportula lies in a location and orientation similar to that in previous taxa but it always lies in the longest axis of the valve (Figs 30, 31). Although the marginal alveoli are complex, there is usually only a single short costa within each marginal chamber (Figs 31, 32). The ratio of long to short marginal costae in *C. minuta* is always > 1 and most but not all short costae bear a fultoportula. The rimoportula is a sessile but fultoportula structure seems similar to that in *C. ornata* (Fig. 33). Both reflexed (Fig. 33, arrow a) and imbricate (Fig. 33, arrow b) laterisquamae can occur within the same specimen (Fig. 33). This difference in appearance could result from preparational procedures. In common with the other *Cyclotella* taxa, the girdle bands are solid and simple but are relatively broader; internally, the tripartite structure is not apparent (Fig. 31).
The first diatom collections from Lake Baikal were made in 1877 (Gutwlnski 1890) and described C. striata (Kuetz.) Grun. var. magna from Lake Baikal. This was followed by the important paper on the Baikal diatom flora by Skvortzow and Meyer (1928) which included descriptions of new species, perhaps most notably of Cyclotella baikalensis (synchronised with C. striata var. magna) and C. baikalensis forma minor. They differentiated the two taxa largely by size, the diameter of C. baikalensis was reported as 95–113 μm and that of the fo. minor as 27.5–51 μm.

Later, Skvortzow (1937) revised the formal description of C. baikalensis (a baikalensis) and extended the lower end of its valve diameter range to 10 μm. He described four new forms, C. baikalensis fo. typica Skv. (diameter 50–13 μm, note this latter figure is probably a typographical error), C. baikalensis fo. stellata (noted simply as larger than fo. typica), C. baikalensis fo. ornata (diameter 30–80 μm) and C. baikalensis fo. minuta (diameter 20–10 μm). Skvortzow had now recognised the taxonomic significance of the short dark lines marking the middle part of radiating striae (the 'schützenlinien') and used these to differentiate C. baikalensis fo. ornata. Interestingly, Skvortzow (1937) made no mention of C. baikalensis fo. minor described in his 1928 paper with Meyer. Comparison of the descriptions shows that the size range of C. baikalensis fo. minuta falls well below that of C. baikalensis fo. minor. According to Genkal (1950), Skachievsky (1960) believed that a C. baikalensis fo. minor was an entirely different taxon because the original figure showed the valve to be circular rather than oval. Although the forms minuta and minor are probably not synonymous, it is possible that the latter was merely a typographical error.

The most recent major taxonomic review of the C. baikalensis-C. minuta complex was undertaken by Genkal & Popovskaya (1990) and Genkal (1990). They used both LM and SEM to show that C. baikalensis fo. ornata is separated from the nominate type by the possession of thickened radial costae. They also showed that thickened radial costae were characteristic of C. minuta and that both taxa possess marginal spines. These observations led them to synonymize C. minuta with C. baikalensis fo. ornata.

Discussion

Distinctive morphological and size differences clearly separate the three common endemic Cyclotella taxa in Lake Baikal. In the absence of SEM, early workers (e.g. Skvortzow 1937) closely linked C. baikalensis with the forms ornata and minuta. They failed to recognise the significance of the marginal costae or 'schützenlinien' (see Håkansson & Carter 1990). Similarly for C. minuta, insufficient morphological detail regarding the costae and marginal processes led to its inclusion within C. baikalensis. However, specific status accorded to C. minuta by Aniţa (1956) accords with our observations, but the recent synonymy of this species with C. baikalensis fo. ornata (Genkal & Popovskaya 1990, Genkal 1990) does not. We believe that C. minuta and C. ornata require specific status since both differ markedly from C. baikalensis.

Although valve size and alveolar structure are the most significant features serving to separate C. baikalensis from C. ornata and C. minuta, marginal fultoportulae and internal rimoportulae are very different in structure in C. baikalensis compared with the other two taxa. Since differences between these processes probably reflect genotypic variation, process structure is a valuable characteristic for separating Cyclotella taxa (e.g. Battersby et al. 1984). Conversely, the similarity of fultoportula structure in C. minuta and C. ornata indicates that these two species are probably closely related. They are nevertheless
clearly distinguished as \( C. \text{minuta} \) possesses one spine per interstria, longer radiating striae on the mantle than on the valve face, different mantle arrangement of striae, fewer marginal siliques in each marginal chamber, lower ratio of long to short siliques, fewer central siliques and different shape and size. There are considerable differences in cell size ranges for the various common endemic Cyclotella taxa according to the data reported here and elsewhere (e.g. Zabotina et al. 1951). These must arise in part from sample bias, especially since previous studies were carried out on diatom samples spanning a 70 year period and compounded by the fact that this study uses surface sediment material rather than plankton samples. Although seasonality trends are lost by use of sediment samples and despite operation of taphonomic processes, examination of deposited diatoms can give a more complete picture of size variation and of ‘average’ abundance of particular taxa. This is because such samples contain an integrated assemblage of diatoms deposited from several crop years. Given the differences in sampling techniques and timing it is remarkable that Cyclotella cell size distributions are so similar (Fig. 34). This figure compares the size distributions of \( C. \text{minuta} \) measured in this study with those determined by Antipova (1956) from plankton samples. Both studies show that \( C. \text{minuta} \) cells with a diameter of around 20 \( \mu \text{m} \) are the most abundant. Furthermore, the point at which the size frequency distributions of \( C. \text{minuta} \) and \( C. \text{ornata} \) (Antipova uses \( C. \text{baciliformis} \) but the frequency data indicate she was measuring \( C. \text{ornata} \)) overlap is at about 30 \( \mu \text{m} \) in both studies. Overall, however, \( C. \text{minuta} \) was more abundant and reached a smaller size (<10 \( \mu \text{m} \)) in our sediment samples. It is tempting to speculate that the plankton sampling method caused the smallest forms to be missed.

Selected characteristics of the Cyclotella taxa are summarized in Table 1 which shows that separating \( C. \text{baciliformis} \) f. \( \text{ornata} \) sensu lato from \( C. \text{minuta} \) sensu lato has caused most taxonomic problems. Nevertheless, studies of phytoplankton ecology in Lake Baikal typically refer to only two Cyclotella taxa, \( C. \text{baciliformis} \) or \( C. \text{minuta} \) (e.g. Votintsev et al. 1975, Kozhova 1987). Without consulting original samples it is unclear in these cases whether abundances of \( C. \text{baciliformis} \) or more probably \( C. \text{ornata} \) were enumerated and so the taxonomic information is devalued. Identification difficulties have arisen for several reasons but mostly due to the failure to recognize the significance of the thickened internal costae. These are only conspicuous in \( C. \text{ornata} \) but smaller forms (25–35 \( \mu \text{m} \) diameter) of this species are difficult to distinguish from \( C. \text{minuta} \) using the size criterion alone. Also, differences in spine arrangement between these two undoubtedly closely related taxa are impossible to see in LM. The oval shape of \( C. \text{minuta} \), noted by Antipova (1936) and Skabichevskaya (1960), is not accorded taxonomic significance by Genkal (1990). Our study largely confirms the oval characteristic of \( C. \text{minuta} \) but its significance is unclear. Ellipsoidal centric diatoms are very unusual but do occur elsewhere; \( C. \text{iris} \) Brun & Heribaud, \( C. \text{austriaca} \) (Peragallo) Hust. and \( C. \text{schumannii} \) (Grun.) Håkansson are the other extant examples known to exhibit this condition (also see Mc Laughlin 1992).

All the common Cyclotella taxa in Lake Baikal show extreme endemism, occurring in no other lake, and perhaps even more remarkably they have been present in this lake since the late Miocene (according to Belova et al. 1983). In the past, however, these taxa occurred elsewhere and are apparently known from several fossil deposits in Russia (Loginova 1990). Endemism in Lake Baikal cannot therefore be explained simply by progressive and adaptive evolution as a result of the lakes great age and stable environment. In certain periods of its history other, more cosmopolitan, diatoms have dominated
the phytoplankton of Lake Baikal, in particular species of *Stephanodiscus* (Belova et al., 1983, Loginova & Khusevich 1990) and their occurrences are thought to indicate shifts in climate. Even so, the endemic *Cyclotella* taxa presumably persisted through these phases and today represent a relict flora that was formerly more widespread. Accordingly, they must have accumulated some genetic diversity over the past 7 or 8 million years but whether they have evolved physiologically is unknown. These taxa are undoubtedly well adapted to life in the lake but if water quality is now changing as a result of anthropogenic factors then a more cosmopolitan and less specialized taxa can be expected to proliferate. There is already some evidence for this from Lake Baikal phytoplankton records (Kozhova 1987). These show that *Nitzschia acicularis* and *Synechocystis* have become much more abundant in southern part of the lake since the mid 1970s.

Any sustained water quality changes in Lake Baikal can be revealed by analysis of the sedimentary diatom record but the application of environmental transfer functions to down core diatom assemblages remains a challenge for the future and its success will depend on precise taxonomy as well as accurate ecological information.

### Table 1. Summary of selected characteristics and size ranges of taxa within the *Cyclotella baikalensis*- *baicalensis* complex in Lake Baikal according to various workers.

<table>
<thead>
<tr>
<th>Central area folioporate</th>
<th>Radial valve</th>
<th>Diameter (μm)</th>
<th>Abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>C. baikalensis</em></td>
<td>irregular</td>
<td>50-120</td>
<td>common</td>
</tr>
<tr>
<td><em>C. baikalensis</em></td>
<td>uniform</td>
<td>30-80</td>
<td>common</td>
</tr>
<tr>
<td><em>C. baikalensis</em></td>
<td>uniform</td>
<td>10-20</td>
<td>common</td>
</tr>
<tr>
<td><em>C. baikalensis</em></td>
<td>uniform</td>
<td>11-42</td>
<td>common</td>
</tr>
<tr>
<td><em>C. minuta</em></td>
<td>central group</td>
<td>up to 60-80</td>
<td>common</td>
</tr>
<tr>
<td><em>C. minuta</em></td>
<td>short, uniform</td>
<td>7-35</td>
<td>common</td>
</tr>
<tr>
<td><em>C. minuta</em></td>
<td>longer, some thickened</td>
<td>25-80</td>
<td>not common</td>
</tr>
<tr>
<td><em>C. baikalensis</em></td>
<td>usually uniform</td>
<td>80-150</td>
<td>not common</td>
</tr>
</tbody>
</table>

**Acknowledgements**

I am indebted to the Royal Society, London, and Dr Graechen, The Limnological Institute, Irkutsk, Russia, for making field research in Lake Baikal possible under the "BICER" agreement. I am particularly grateful to Robert Ross for encouraging diatom research in Lake Baikal and for providing advice and access to his diatom samples collected from this lake. This paper is dedicated to him. I wish to thank sincerely Dr Ye. V. Likhanov and A. Kuzmina for their kind help throughout this study. Dr H. Håkanson gave invaluable advice on both the taxonomy and nomenclature of *Cyclotella* taxa and constructively criticized the manuscript. Patricia Sims very kindly helped with SEM photographs and also commented on the manuscript. The authors also wish to thank all those who helped with the field work, including Mr D. Altensteer, Mr A. Takahashi and the crew of the Orbsvcius, Dr A. Frenich, Dr J. Cameron and Ms O. Khusevich helped with and translated various key documents. Art work is by Mr T. Atepelen. This work was partially funded by the Leverhulme Trust under grant code P13442.

### References


SKVORTSOV, M. (1993): *Cyxotella baicalensis* sp. nov. - J. I. P. Flower, C. P. Elsington and M. O. Kuzovkin helped with technical work and critically commented on the manuscript. The authors also wish to thank all those who helped with the field work, including Mr D. Altensteer, Mr A. Takahashi and the crew of the Orbsvcius, Dr A. Frenich, Dr J. Cameron and Ms O. Khusevich helped with and translated various key documents. Art work is by Mr T. Atepelen. This work was partially funded by the Leverhulme Trust under grant code P13442.


