Climate transitions and sediment transportation in the Arctic as revealed by mineralogical evidences from the late Cenozoic sediments in the Yermak Plateau and the central Arctic Ocean

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Objectives of this study

• Clay sedimentation and sediment component characteristics were used in this study to evaluate critical climate transitions and sediment distribution in the Arctic Ocean after Mid-Miocene Climate Optimum and Mid-Pliocene Global Warmth.

• This is based on the fact that clay sedimentation has a close relationship between ice-sheet evolution, sea-ice cover and sedimentary processes.

• Only recently, the very first deep sediment cores from the Arctic Ocean basins are recovered to focus on these objectives.
Drilling sites

IODP Arctic Coring
Expedition 302, Sites M0002 & M0004

ODP Leg 151, Site 911
The start of cooling after Middle Miocene Climate Optimum

Global climate evolution

Modern clay sedimentation

Surface water currents

[Map showing surface water currents in the Arctic region, including labels for Beaufort Gyre, Fram Strait, Yermak Plateau, and various landmasses such as Greenland, Franz Josef Land, and Novaya Zemlya. The map highlights the movement of water currents with arrows and points labeled M0002 & M0004.]
Central Arctic Ocean record (IODP Exp 302, ACEX)
Miocene intensification of glaciations

• In Middle Miocene ~ 13.9 Myr ago, the Earth’s climate cooled dramatically after an extended period of relative warmth. This key transition in the Earth’s climatic evolution marked the start of further cooling during late Cenozoic.

• This seems to coincide with the increased kaolinite occurrence in the central Arctic Ocean probably due to continental ice generation and increased erosion on land.

• This is consistent with higher chlorite and illite contents. Periodically high smectite contents may indicate turns to more open water conditions and interglacials (smectite content fluctuates between 2-37%).

• Our results present the value of reworked kaolinite and illite with the increased ice rafted debris for recognising an initiation of glaciations and the most probable sources for sediment material.
Yermak Plateau record (ODP Leg 151, Site 911)
Clay mineral distribution
Kaolinite versus TOC distribution
Clay analysis results

- The clay fraction input in the Yermak Plateau sediments during the Middle Pliocene warmth ~ 3.00 Myr can be mostly related to the transport mechanisms by sea ice and by oceanic currents.
- The smectite content shows an abrupt increase. This change can, however, be seen as a drop in the amount of kaolinite and organic carbon concentration.
- After that these values start to increase, most probably indicating high rates of reworked glacially eroded matter.
Heavy mineral data

The diagram shows the percentage distribution of pyroxene, amphibole, stable minerals, and opaque minerals with depth. The data is plotted against depth in meters, with mineral assemblages indicated vertically. The age in millions of years (Ma) is shown on the right side of the diagram.
Related heavy mineral information

- During the warm Pliocene, the fluctuating heavy minerals might reflect changes in the fresh-water input from the great Siberian rivers which would lead to changes in the supply of terrigenous material delivered to the shallow Arctic shelves by the rivers.
- Based on the occurrence of pyroxenes and amphiboles, the source area of the Yermak Plateau sediments is most likely the Laptev and Kara Seas, with some additional sediment influx from the Barents Sea.
- In general, the heavy mineral fluctuation can well reflects changes in the amount of sea ice formation which correlates with climate variations and the general the fresh-water input from the continent.
**Synthesis of the clay and heavy mineral studies**

<table>
<thead>
<tr>
<th>Age (Ma)</th>
<th>Mineral assemblage</th>
<th>Smectite &amp; illite indicating climatic variability</th>
<th>Reworked terrestrial material indicating climatic variability</th>
<th>Heavy minerals indicating variation in fresh-water input</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.78</td>
<td>III</td>
<td>Decrease of smectite / increase of illite indicating colder conditions</td>
<td>Increase of kaolinite and TOC indicating enhanced glacial erosion in the adjacent continents</td>
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<td>2.90</td>
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<tr>
<td>3.00</td>
<td>II</td>
<td>Increase of smectite / decrease of illite indicating warmer conditions</td>
<td>Decrease of kaolinite and TOC indicating reduced glacial erosion</td>
<td>Higher amount of heavy minerals indicating increased fresh-water input</td>
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<tr>
<td>3.10</td>
<td>I</td>
<td>Decrease of smectite / increase of illite indicating colder conditions</td>
<td>Increase of kaolinite and TOC indicating enhanced glacial erosion</td>
<td></td>
</tr>
</tbody>
</table>

Graph showing the relationship between ice volume and δ¹⁸O (%): 96-100, Pliocene optimum, M2-MG2, 0.39%
### Synthesis of Sediment Transportation

<table>
<thead>
<tr>
<th>Provenance</th>
<th>Source Area</th>
<th>Transport Agent &amp; Path</th>
<th>Site of Sedimentation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>East Siberian Traps</strong></td>
<td><strong>Kara Sea</strong></td>
<td><strong>Transpolar Drift (Siberian branch)</strong></td>
<td><strong>Yermak Plateau, Arctic Ocean</strong></td>
</tr>
<tr>
<td>- Yenisey river</td>
<td>- Smectite</td>
<td><em>Sea Ice</em></td>
<td></td>
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<tr>
<td></td>
<td>- Pyroxene</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>East Siberian Traps</strong></td>
<td><strong>Laptev Sea Western Part</strong></td>
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<td></td>
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<tr>
<td>- Khatanga river</td>
<td>- Smectite</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Siberian Platform</strong></td>
<td><strong>Laptev Sea Eastern Part</strong></td>
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<tr>
<td>- Lena river</td>
<td>- Amphibole</td>
<td></td>
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<tr>
<td></td>
<td>- Illite</td>
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<tr>
<td><strong>Russian Platform</strong></td>
<td><strong>Barents Sea</strong></td>
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<tr>
<td></td>
<td>- Organic carbon</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>- Kaolinite</td>
<td></td>
<td></td>
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<td></td>
<td>- Pollen</td>
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</tbody>
</table>
Conclusions

- The clay mineral assemblages and heavy mineral fluctuation can well reflect changes in the amount of sea ice formation which correlates with climate variations and the general the fresh-water input from the continent.
- Smectite has been transported mainly from the Kara Sea and Laptev Sea during the periods of more open water. It has accumulated on the Lomonosov Ridge and the Yermak Plateau from sea ice because of the warming effect West Spitsbergen Current.
- Clay mineral analysis is a good proxy when determining onset of glaciations, ice rafting and also land-sea linkages.