Study of particulate material in sea ice in the Fram Strait – a contribution to paleoclimatic research?

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Sea ice is a well documented transport agent of finegrained debris in the shallow Arctic Shelf regions (Barnes et al. 1982; Clark & Hanson 1983). However, its importance to Arctic deep sea sedimentation is not fully understood (e.g. Clark & Hanson 1983). To more fully understand the present day or 'interglacial' sediment flux from sea ice in the Arctic Ocean, we have analysed the debris flux through the Fram Strait. The area was selected due to its importance as the main pathway of sea ice exchange between the Arctic Ocean and the world oceans, with sea ice draining from most of the shelves fringing the Arctic Ocean.

The wide shallow shelf areas outside Alaska, Canada and the USSR, are important source areas of clastic entrainment into the sea ice. Off the Alaskan coast studies have documented entrainment of suspended sand and silt from the water column into anchored ice down to 20 m water depth (Kempema et al. unpublished). Further off shore there are several entrainment processes, of which the most important is incorporation during the initial ice cover formation from frazil ice under conditions of high turbulence (Osterkamp & Gosink 1984; Larsen 1980). The sea ice acts as a sediment trap of eolian sediments, which is reckoned as a minor contributor to the total sediment input to the central Arctic Basin (Darby et al. 1974). Off river outlets significant amounts of sediments are trapped in the sea ice, but are of minor importance for remote material transportation (Larsen 1980; Barnes et al. 1982; Osterkamp & Gosink 1984).

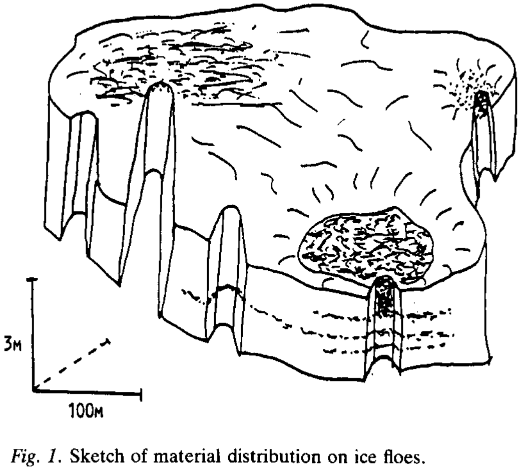

Fig. 1. Sketch of material distribution on ice floes.

When considering the overall ice movement (Hibler 1979) and deduction of long term ice motion (Colony & Thorndike 1985) based on short time observations, the most probable source areas for turbid sea ice in the eastern Fram Strait are the Eurasian parts of the shallow Arctic Ocean Shelves. To the west, multiyear ice dominates with clastic source areas in the Canadian part.

The investigated area in the Fram Strait is mainly along transects at 80°N from Spitsbergen towards Greenland and return at 79°N, where 13 ice core samples from both first year and multiyear ice were collected.

In general, the material was concentrated on the surface in meltwater ponds, topographic lows and widespread on the ice surface (Fig. 1), with the highest concentrations in the ponds. In addition, distinct turbid layers were detected within the ice column. The material concentration was calculated as the ratio of filtered material weight to ice volume (mg/l and mg/dm^3). The highest concentrations appeared in the upper 100 cm, and ranged up to 3,000 mg/l in turbid ice. In white/clean ice the concentrations were low, only 0–20 mg/l. An example of concentration ranges is shown in Fig. 2. The turbid ice contained mainly clastics, while biogenic material dominated in white ice samples. On average 20% of total sampled ice volume contained sediment debris. Due to preferential samplings a ratio less than 10% should be more realistic.

Generally 30–60% of bulk material in turbid ice is less than 2 µm, with only minor grains coarser than 63 µm (Fig. 2). Median grain sizes appear within two intervals, 3–6 µm and less than 2 µm. In comparison, the median grain sizes on the shelves vary from 30 µm (Beaufort and Chukchi Seas) to less than 2 µm (e.g. Naidu 1974; Logvinenko & Ogorodnikov 1980; Naugler et al. 1974; Holmes & Creager 1974). Most noticeable is the Laptev Shelf, where more than 70% of the shelf contains median grain sizes less than 8 µm (Holmes & Creager 1974).

The mineral assemblage consists of clay minerals (smectite, chlorite, kaolinite and illite) in addition to quartz and feldspars. This is in good accordance with bottom surface samples in the Fram Strait. There is no apparent variation in the mineral distribution neither lateral nor vertical. A similar assemblage is characteristic of most of the Mesozoic and Tertiary rocks in Svalbard (Bjærke & Dypvik 1977), but restricted exposure of smectite bearing rocks in the archipelago suggests contribution from other sources.

The organic assemblage consists mainly of diatoms of marine, brackish and freshwater origin, and in some cores tracheid tissue from plants, probably coniferous wood, the latter apparently

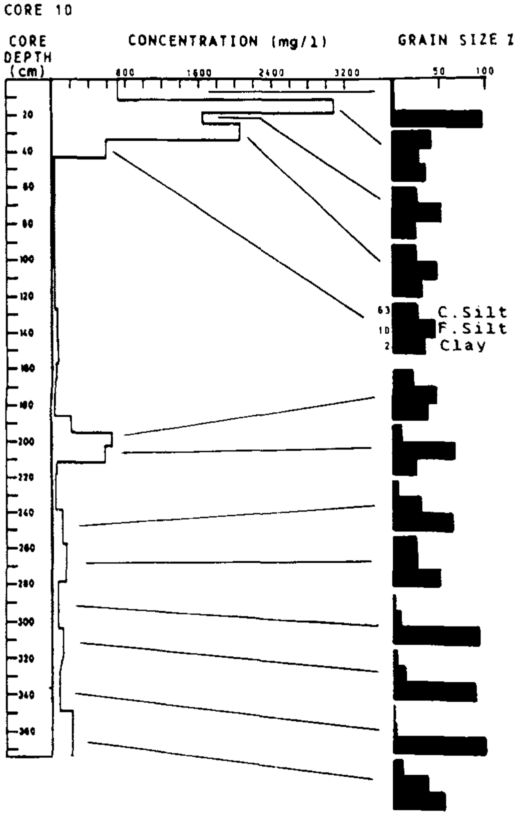

Fig. 2a. Example of material-concentration diagram and grain size distribution (coarse silt, fine silt and clay on histograms, respectively) in one ice core. For location, see Fig. 2b.

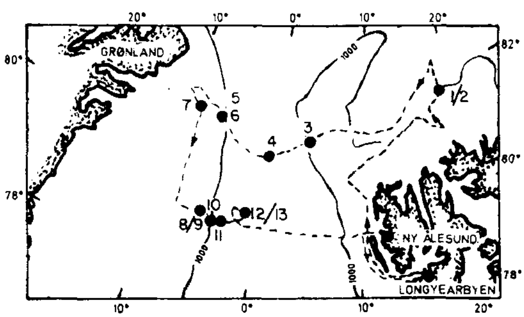

Fig. 2b. Locations of collected ice cores.

from floating timber. It reflects remote sources due to the absence of forests (trees) in Svalbard and Greenland.

Average sediment content in sampled turbid ice amounts to 195 mg/dm^3 (or 195 g/m^3). Sediment content in total sampled ice is 57 g/m^3, but should be lowered by a factor of 2 due to preferential samplings (i.e. 30 g/m^3). With an annual ice flux through the Fram Strait estimated to 5,000 km^3 (Vinje & Finnekåsa 1986), the annual sediment flux should amount to 15×10^7 tons. Assuming that the material is deposited within the Greenland Sea, with an areal extension of 10^6 km^2, ice rafted deposits represent 150 tkm^{-2} yr^{-1}. Assuming 80% water content in the sediments and 2.70 g/cm^3 sediment density, the corresponding sedimentation rate should be approximately 10 cm/ka. Average linear sedimentation rates in the Greenland-Norwegian Sea amount to 3.5 cm/ka during the Holocene (O-isotope stage 1) (Thiede et al. 1986), with a higher input in the Jan Mayen area. Application of this number indicates that the debris content of 57 g/m^3 in the sampled sea ice should obviously be lowered by a factor of approximately 6, if the total sediment volume is deposited within the Greenland Sea. The factor should be smaller if the deposition area is increased.

The results indicate transport of relatively large amounts of fine-grained sediments by sea ice within the present Arctic, provided by wide shallow shelf sources. In Arctic Ocean bottom sediments, Clark & Hanson (1983) have described interglacial sediments (type III) deposited from sea ice, which is in good accordance with the present sea ice debris in the Fram Strait (Fig. 3).

Studies of the turbid ice at various water depths (including anchor ice) off the Alaskan coast (Kempema et al. unpublished) have documented grain size distributions similar to all four deposition types of Arctic Ocean bottom sediments defined by Clark et al. (1980) and Clark & Hanson (1983). These are:

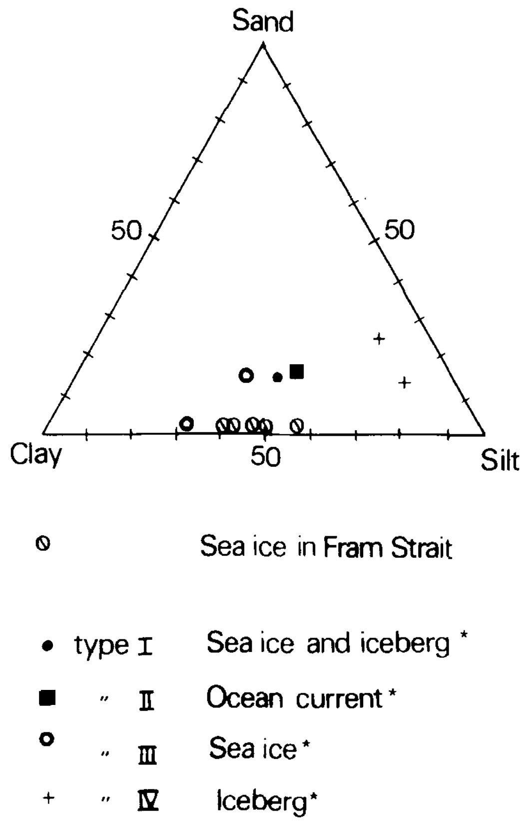

Fig. 3. Grain size distribution of sea ice samples in Fram Strait and Arctic Ocean bottom samples. (*sediment type and interpreted depositional environment from Clark et al. 1980).

mixed iceberg and sea ice transport (I), ice transported and current sorted (II), transported by sea ice (III) and transported by icebergs (IV).

A sea level drop will change the source areas and consequently the major entrainment processes. The present debris apparently originate on the wide, shallow Eurasian shelves. A lowering of sea level would give narrow shelves like the present Alaskan Shelf, leading to more coarse grained sources and to a minor difference between iceberg and sea ice transported sediments. This implies that sections of coarse clastics do not exclusively reflect iceberg rafting. Variations in sediment sequences in the Arctic Ocean bottom sediments may in part reflect variation in proximity to source areas and the source material, and not only increased iceberg activity.

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