Journal of Glaciology, Vol. 34, No. 117, 1988

CORRESPONDENCE

The Editor,
Journal of Glaciology

SIR,

Ice rafting: an indication of glaciation?

Interpreting the Cenozoic climatic and oceanographic history of the Arctic Ocean basin and surrounding coastal areas depends largely on our ability to interpret the sedimentary record that accumulated on its floor. This ability relies on the adequacy of models for sediment supply used in the interpretation of sediment cores. There is general agreement that much of the sediment was supplied by ice rafting, and that periods of more or less sea-ice cover alternated with periods of drifting icebergs (both from glaciers and from ice shelves), but how these cycles relate to timing of glaciations on surrounding continents is under debate (Herman and Hopkins, 1980; Hopkins and Herman, 1981; Spjeldnaes, 1981; Clark and Hanson, 1983; Minicucci and Clark, 1983). As Spjeldnaes (1981), we question the models of sediment supply and the use of two particular criteria to recognize the contribution by icebergs as opposed to that by sea ice: coarse-sediment texture and presence of shallow-water micro-faunas. Until recently, nobody had looked into sea ice for its sediment texture and content, and the contribution by sea ice therefore has been misjudged.

There seems little doubt among most workers that drop stones represent drifting icebergs. Some sedimentologists (Clark and Hanson, 1983; Minicucci and Clark, 1983), however, believe that more subtle textural criteria give clues of the two different ice types and transport mechanisms under question here, and seem convinced that sand in ice-rafted deposits records drifting icebergs. If sand-size particles include shallow-water foraminifers, these are thought to have been "gouged up" by glacial ice and rafted to the deep sea (Herman and Hopkins, 1980). Some even go so far as to differentiate the mud fraction of cores into four types, where dominance of silt reflects icebergs and dominance of clay a sea-ice cover (Clark and Hanson, 1983; Minicucci and Clark, 1983). Sand/silt/clay ratios extracted from their published histograms are plotted on a ternary diagram in Figure 1.

Recent studies in the Beaufort Sea indicate that turbid (sediment-bearing) sea ice can transport considerable quantities of sediment indistinguishable by texture and micro-fossils from that presumed to record glacial climate in the deep basin. The mechanism of sediment entrainment leading to turbid ice is very different from any of the classic entrainment mechanisms (e.g. Kindle, 1924), which in fact are of little importance for Beaufort Sea ice rafting (Reimnitz and Barnes, 1974). Turbid ice forms from rising frazil-ice crystals originally suspended in supercooled water during freeze-up storms (Barnes and others, 1982). Frazil ice scavenges particulate matter and plankton from the water column and directly from the sea floor (Osterkamp and Gosink, 1984; Reimnitz and Kempema, 1987; Reimnitz and others, 1987; Kempema and others, unpublished). The resulting ice canopy contains finely disseminated sediment in those upper parts that formed from frazil slush after the storm subsided (Fig. 2). Turbid ice generally includes small patches of coarser material, such as granules, pebbles, mollusk shells, plant material, kelp, sticks, etc., raised to the surface by masses of anchor ice (ice that accretes on a substrate submerged in either quiet or turbulent supercooled water and that remains attached to the substrate) (Reimnitz and others, 1987). Lastly, this ice also carries neritic ostracodes and foraminifers (Briggs, 1983, unpublished). Sand/silt/clay ratios for sediment samples, both from newly formed frazil ice at freeze-up and from the surface of turbid ice as concentrated by summer melting (Kempema and others, unpublished), are plotted in Figure 1. The sand fraction of two composite anchor-ice samples collected at

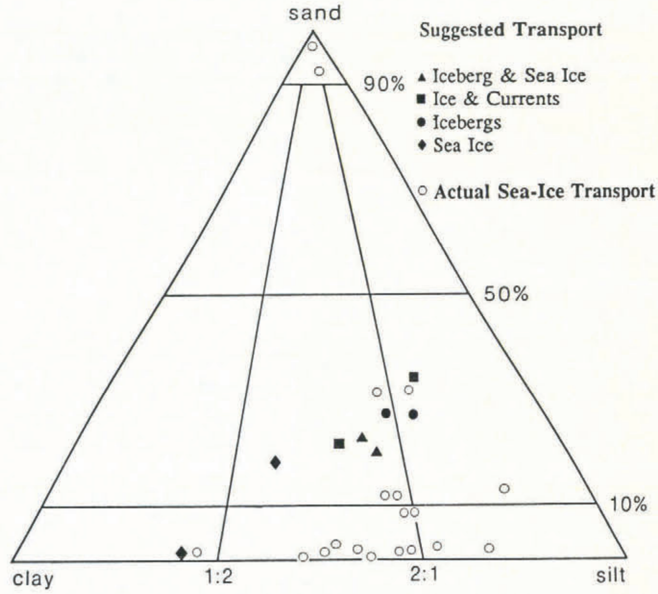

Fig. 1. Sand/silt/clay ratios attributed by Clark and Hanson (1983) and Minicucci and Clark (1983) to four dominant modes of deposition under the influence of ice, and those actually measured in floating sea ice (Kempema and others, unpublished). The two coarse samples at the very top become mixed with finer fractions in the drifting/settling process.

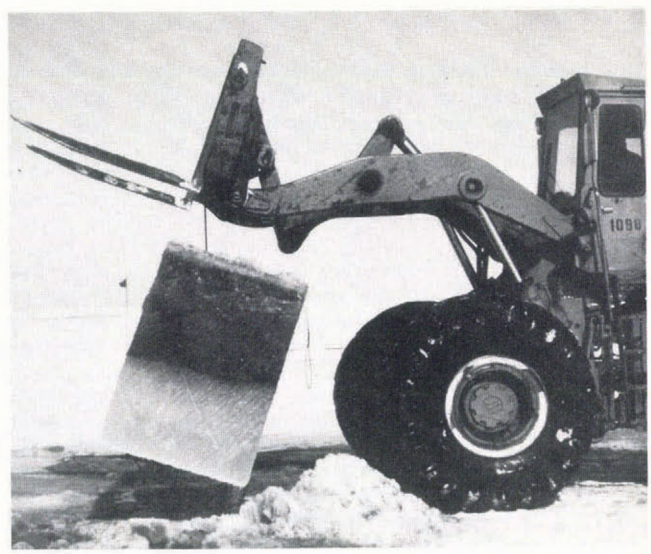

Fig. 2. Block of seasonal fast ice, including turbid ice formed from sediment-bearing frazil during a few days at freeze-up. (Photograph by G. Meltveldt, University of Alaska.)

the time of freeze-up plot at the very top of Figure 1. Clasts of cobble size do occur in turbid ice but representative samples of the very coarse components are not available. This floating seasonal ice canopy, although having never physically contacted the sea floor as massive ice, may carry over 1000 m^3/km^2 of sediment, or 16 times more than the annual sediment supply by rivers feeding the same area (Reimnitz and Kempema, 1987). In some winters, the turbid ice canopy extends as a contiguous band from shore to the 20 or 30 m isobath, and in patches across the entire shelf (Barnes and others, 1982; Reimnitz and Kempema, 1987; Kempema and others, unpublished).

The texture of mud carried by turbid sea ice today is indistinguishable from the mud texture of deep Arctic Ocean cores attributed to glacial conditions (Fig. 1). The patchy coarse components entrained into sea ice by anchor ice become homogenized in the common settling process after release from drifting floes into deep water. Therefore, not even a sandy texture and drop stones can be used as sole criteria for glacial conditions. Also, drifting sea ice imparts striations on rocks in the coastal zone (Dionne, 1985), on boulders embedded in firm mud at 10 m water depth (Reimnitz and others, unpublished), may shatter them (Josenhans and others, 1985), and possibly produce fracture faces on quartz grains (Hodel and others, 1988). Most damaging to the theory that certain surface features and shapes of drop stones are unique to glacial conditions is the fact that pebbles lifted by anchor ice today, and then are rafted by sea ice, include Flaxman lithologies (Hopkins and Herman, 1981) with "glacial striations". Lastly, icebergs impacting the bottom produce gouges but are highly unlikely to entrain shallow-water organisms (Kempema and others, unpublished). However, frazil ice scavenging suspended matter from supercooled water is an effective mechanism to enrich sea ice with planktonic foraminifers and diatoms, as found in the Antarctic (Garrison and others, 1983; Dieckmann and others, 1986; Spindler and Dieckmann, 1986; Sullivan and others, 1986), and confirmed by our unpublished laboratory experiments. Similar mechanisms lift shallow shelf micro-organisms off the bottom and incorporate them into the sea ice (Briggs, 1983, unpublished; Reimnitz and others, 1987; Kempema and others, unpublished). The occurrence of such micro-fossils, along with plant debris and mollusks, in cores to over 1000 m water depths on the continental slope off northern Alaska (personal communication from E. Brouwers, 1983) suggest modern sea-ice transport of shelf sediments to the deep ocean. Ice-rafted components, such as drop stones, sand, and shallow-water benthic organisms in sediment cores of the Arctic Basin therefore are not necessarily an indication of glaciation on the surrounding continents. They are incorporated, moved, and released more effectively by short-lived and more quickly recycled sea ice.

Branch of Pacific Marine Geology,
U.S. Geological Survey,
Menlo Park,
California 94025, U.S.A.

ERK REIMNITZ
EDWARD W. KEMPEMA

2 November 1987

REFERENCES

Barnes, P.W., Reimnitz, E., *and* Fox, D.J. 1982. Ice rafting of fine-grained sediment, a sorting and transport mechanism, Beaufort Sea, Alaska. *Journal of Sedimentary Petrology*, 52(2), 493-502.

Briggs, W.M., *jr.* 1983. Ice rafting of ostracodes and other microfauna, Beaufort Sea, Alaska. *Geological Society of America. Abstracts with Programs*, 15(6), 532.

Briggs, W.M., *jr.* Unpublished. Final Project Report, National Science Foundation, Polar Programs, Award No. DPP-81-06802.

Clark, D.L., *and* Hanson, A. 1983. Central Arctic Ocean sediment texture: a key to ice transport mechanisms. *In* Molnia, B.F., *ed. Glacial-marine sedimentation.* New York and London, Plenum Press, 301-30.

Dieckmann, G., Rohardt, G., Helmer, H., *and* Kipfstuhl, J. 1986. The occurrence of ice platelets at 250 m depth near the Filchner Ice Shelf and its significance for sea ice biology. *Deep Sea Research*, Pt. A, 33(2), 141-48.

Dionne, J.-C. 1985. Drift-ice abrasion marks along rocky shores. *Journal of Glaciology*, 31(109), 237-41.

Garrison, D.L., Ackley, S.F., *and* Buck, K.R. 1983. A physical mechanism for establishing algal populations in frazil ice. *Nature*, 306(5941), 363-65.

Herman, Y., *and* Hopkins, D.M. 1980. Arctic Ocean climate in late Cenozoic time. *Science*, 209(4456), 557-62.

Hodel, K.L., Reimnitz, E., *and* Barnes, P.W. 1988. Microtextures of quartz grains from modern terrestrial and subaqueous environments, North Slope of Alaska. *Journal of Sedimentary Petrology*, 58(1), 24-32.

Hopkins, D.M., *and* Herman, Y. 1981. Ice rafting, an indication of glaciation? *Science*, 214(4521), 688.

Josenhans, H.W., Barrie, J.V., Woodworth-Lynas, G.M.T., *and* Parrott, D.R. 1985. DIGS-85: Dynamics of iceberg grounding and scouring: observation of iceberg scour marks by manned submersible. *In 14th Arctic Workshop. Arctic Land-Sea Interaction. 6-8 November, 1985, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, Canada,* 92.

Kempema, E.W., Reimnitz, E., *and* Barnes, P.W. Unpublished. Sea ice sediment entrainment and rafting in the Arctic.

Kindle, E.M. 1924. Observations on ice-borne sediments by Canadian and other Arctic expeditions. *American Journal of Science*, 7, 251-86.

Minicucci, D.A., *and* Clark, D.L. 1983. A late Cenozoic stratigraphy for glacial-marine sediments of the eastern Alpha Cordillera, central Arctic Ocean. *In* Molnia, B.F., *ed. Glacial-marine sedimentation.* New York and London, Plenum Press, 331-65.

Osterkamp, T.E., *and* Gosink, J.P. 1984. Observations and analysis of sediment laden sea ice. *In* Barnes, P.W., Schell, D.M., *and* Reimnitz, E., *eds. The Alaskan Beaufort Sea: ecosystems and environments.* Orlando, FL, etc., Academic Press, 73-94.

Reimnitz, E., *and* Barnes, P.W. 1974. Sea ice as a geologic agent on the Beaufort Sea shelf of Alaska. *In* Reed, J.C., *and* Sater, J.E., *eds. The coast and shelf of the Beaufort Sea. Proceedings of a Symposium on Beaufort Sea Coast and Shelf Research.* Arlington, VA, Arctic Institute of North America, 301-51.

Reimnitz, E., *and* Kempema, E.W. 1987. Field observations of slush ice generated during freeze-up in Arctic coastal waters. *Marine Geology*, 77(3/4), 219-31.

Reimnitz, E., Kempema, E.W., *and* Barnes, P.W. 1987. Anchor ice, seabed freezing, and sediment dynamics in shallow Arctic seas. *Journal of Geophysical Research*, 92(C13), 14671-78.

Reimnitz, E., Kempema, E.W., Ross, R., *and* Minkler, P.W. Unpublished. Overconsolidated surficial deposits on the Beaufort Sea shelf. U.S. Geological Survey. Open-File Report 80-2010.

Spindler, M., *and* Dieckmann, G.S. 1986. Distribution and abundance of the planktic foraminifer *Neogloboquadrina pachyderma* in sea ice of the Weddell Sea (Antarctica). *Polar Biology*, 5(3), 185-91.

Spjeldnaes, N. 1981. Ice rafting, an indication of glaciation? *Science*, 214(4521), 687-88.

Sullivan, C.W., *and 6 others.* 1986. Physical and chemical modification of sea ice by ice algae. *EOS*, 67(44), 1006.

SIR,

Chernobyl fall-out on glaciers in the Austrian Alps

We have investigated the Chernobyl fall-out in 55 vertical snow profiles (359 samples) on Hintereisferner, Kesselwandferner (Oetztal Alps), Schaufelferner (Stubai Alps), and Gefrorene Wand Kees (Zillertal Alps). The results have been compared with those given by Pourchet and others (1988). The maximum measured gross ß-activity