

Quantifying Fluvial Sediment Transport by Anchor Ice

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LONG TERM GOALS

Our long-term goal is to understand how anchor ice rafting acts a sediment transport and dispersal agent. Ice rafting is the transport of rock (of all sizes) by floating ice. Sediment is ice rafted by river, lake and sea ice that forms annually. Anchor ice is a type of ice that forms on the beds of rivers, lakes and seas. When anchor ice is released from the bed, it carries entrained sediment to the surface. This entrained sediment may be widely dispersed as the floating anchor ice drifts under the influence of wind and currents.

OBJECTIVES

Our objective in this study is to determine if anchor ice rafting is a significant sediment transport mechanism in rivers. Rivers and other natural, turbulent water bodies do not freeze from the surface downward. Instead, the first ice to form in turbulent water are millimeter-sized crystals (frazil) that are suspended in the flow. When frazil adheres to the bed, it forms, by definition, anchor ice. Once formed, anchor ice masses can grow rapidly to cover large areas of the bed. Anchor ice usually forms at night, and is released from the bed in the morning. This released anchor ice floats to the surface, forming anchor ice runs (Figure 1). The released, floating anchor ice frequently contains entrained sediment (Figure 2); in rivers this sediment is ice rafted downstream as the released anchor ice drifts with the surface currents. There are many anecdotal observations of anchor ice rafting in fluvial systems, but there are not enough quantitative measurements to determine if anchor ice rafting is an important sediment transport mechanism in mid- and high-latitude rivers.

APPROACH

We will make observations and measurements of anchor ice formation and ice rafting on a 500 m long study reach of the Laramie River in southeastern Wyoming. The study reach is close to the University of Wyoming so daily observations can be made during periods of anchor ice formation. Preliminary observations (in 1993 and 1995) have shown that anchor ice is common in the Laramie River during freezeup periods. The Laramie River is relatively small; it is approximately 10 m wide and up to 1.5 m deep with winter discharges of 0.6 to $1.4 \text{ m}^3 \text{ s}^{-1}$ (20 to 50 cubic feet per second). The small size of the river makes it relatively safe for us to wade when ice is present, and should enhance our ability to observe the effect of anchor ice on all areas of the river bed.

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Figure 1. Oblique aerial image of an anchor ice run on the Laramie River in November 1993. Masses of released anchor ice are seen floating down the middle of the open water channel. The anchor ice masses in the foreground are ~ 0.5 m in diameter.

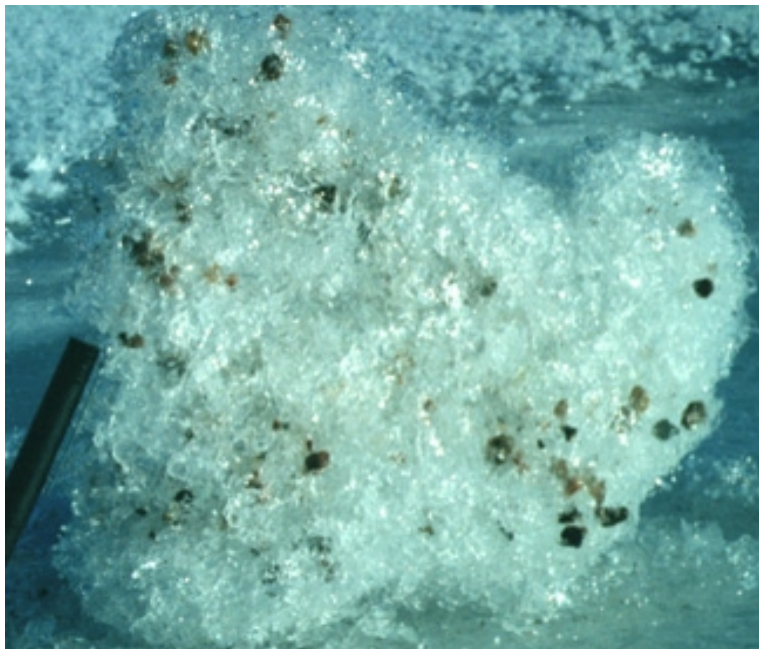


Figure 2. Floating anchor ice sample retrieved from the Laramie River during preliminary studies in November 1993. The sediment concentration is 34 g l^{-1} of ice. Pen in lower left corner for scale.

To determine the importance of anchor ice rafting, it is necessary to determine the amount of anchor ice that forms, the amount and type of sediment that is incorporated into anchor ice, and the distance that released anchor ice masses travel before entrained sediment is released. The diurnal formation and release of anchor ice make daily observations necessary. When anchor ice is present, we will sample the ice for sediment concentration, map the distribution of anchor ice in the study reach, and measure flow conditions where anchor ice deposition occurs. In addition, we will correlate anchor ice formation events (time and relative intensity) with local meteorological conditions. Air and water temperatures at the study reach will be recorded. A broader range of meteorological conditions will be retrieved from data recorded at an airport located 10 km northeast of the study reach. During the first field season, we plan to make relatively simple observations and measurements. The results from the first year's field work will be used to plan the following two field seasons.

Presently there are two key individuals on this project: Neil Humphrey (PI) and Ed Kempema (postdoc). We share the responsibilities of managing this project and on deciding what instrumentation and methods should be used in the field study. Ed Kempema manages the day-to-day tasks of the project: establishing the study reach, maintaining instruments, routine data and sample collection, etc. We will bring a graduate student into the program in 2000.

WORK COMPLETED

We have identified and surveyed a study reach along the Laramie River and have installed instrument arrays for monitoring river bed, water and air temperatures along with river stage. We have obtained a current meter for measuring unidirectional current velocities. This will allow us to measure stream discharge and to measure water velocity in areas where anchor ice forms on the bed. We are presently in a 'stand-by' mode, waiting for the beginning of ice formation in the river. This project started in April 1999, so we have not yet collected any ice-related data.

Although we have not collected any field data for the present study, we have re-evaluated the results of the 1993 and 1995 preliminary studies. We used these preliminary results to plan the sampling program for the upcoming field season.

RESULTS

We do not have any significant results to report because we have not begun winter field work.

IMPACT/APPLICATIONS

We will document the type and volume of sediment ice rafted downstream in one small river. This information will be used to determine if ice rafting is an important component of the overall transport regime in rivers that have seasonal ice formation. Important expected results of our study include: (1) development of instruments for sampling anchor ice and entrained sediment; (2) improvement in our understanding of anchor ice/sediment interactions and anchor ice rafting; and (3) development of a predictive framework for assessing anchor ice rafting of sediment.

TRANSISTIONS

Anchor ice rafting may potentially play a significant roll in redistributing contaminated sediment in high-latitude rivers that drain into the Arctic Ocean. At this point, almost nothing is known about anchor ice rafting in fluvial environments, so it is ignored as a sediment transport mechanism. We expect that the results of this study will be valuable for researchers working on sediment transport problems in rivers with seasonal ice growth. Also, the results of this study may lead to new insights on anchor ice growth and ice rafting in marine and lacustrine settings.

RELATED PROJECTS

1 – Anchor ice formation and anchor ice rafting of sediment are not limited to fluvial environments. Project personal, working with Erk Reimnitz and Peter Barnes (U.S. Geological Survey), submitted a paper (see publications) on the results of a study of anchor ice formation in the nearshore zone of southwestern Lake Michigan. This study found that anchor ice forms regularly on nearshore sand and gravel during the winter. Release of anchor ice from the lake bed carries entrained sediment to the water surface, where it is ice rafted offshore. The drifting ice melts in warm water in the middle of the lake and drops the entrained sediment in deep water. This sand sized material is permanently removed from the sediment starved nearshore zone during the winter months. This observation of nearshore sediment loss by anchor ice rafting contradicts earlier studies that suggested ice protects the beach and nearshore zone from erosion during the winter.

2 – In December 1998, Ed Kempema participated in the EU INTERICE II experiments at the Hamburg Model Ship Basin in Hamburg, Germany. Kempema worked with Dirk Dethleff (GEOMAR, Kiel, Germany) on a series of tank experiments that modeled frazil entrainment into the water column in Langmuir Cells in the ocean. Langmuir Cells are wind- and wave-induced, counter rotating helical vortices that form in the surface layers of lakes and seas. The experiments showed downwelling at surface convergent zones in Langmuir Cells entrained frazil down into the water column. The frazil in the water column collects both suspended and bed sediment. This sediment is buoyantly carried to the water surface and incorporated into the growing ice cover. Kempema presented the results of these experiments at the 4th International Conference on Environmental Radioactivity in the Arctic in September 1999.

PUBLICATIONS

Kempema, E.W., Reimnitz, Erk, and Barnes, P.W., (submitted 8/99), Anchor ice formation and ice rafting in southwestern Lake Michigan, *Journal of Sedimentary Research*, 49 p.

Dethleff, Dirk, Kempema, E.W., Kuhlmann, Gesa, and Neis, Hartmut, 1999, Laboratory experiments on the entrainment of Novaya Semlya dumping bay sediments into newly forming sea ice – with applications to nature. (extended abstract) In: Strand, Per and Jolle, Torun, *The Fourth International Conference on Environmental Radioactivity in the Arctic*, Edinburgh, Scotland 20-23 September 1999. The Scientific Committee on the International Conference on Environmental Radioactivity in the Arctic. p. 8-11.