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SIR,

River-ice mounds on Alaska's North Slope

The U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) was contracted by the U.S. Department of Interior, Fish and Wildlife Service (FWS) to conduct water-availability studies in the Arctic National Wildlife Refuge (ANWR) during March 1988. The objective was to identify the presence of unfrozen water beneath selected rivers and lakes in the ANWR using a UHF short-pulse radar mounted to a helicopter. It was generally believed before the study by both CRREL and FWS personnel that unfrozen water would be found only in the *aufeis*-formation zones down-river of the known water sources (hot springs) and in the deeply cut coves of the foothills defining the southern boundary of the coastal plain. If unfrozen water did exist beneath the shallow streams of the flood plain and coastal deltas, it would be a "needle in a haystack" for our low and slow airborne radar to find. Instead, however, we were confronted with myriads of ice mounds, most existing as small ridges and often grouped in twos and threes, throughout the entire length of all the major rivers, with about 70% of them containing unfrozen water. Generally, these mounds rose 2–3 m above the level of the surrounding ice sheet. Drilling into two of these mounds revealed water under pressure.

The major waterways studied were Canning, Tamayariak, Katakturuk, Sadlerochit, Hulahula, Okpilak and Jago Rivers, and Itkilyariak and Okerokovik Creeks, shown in Figure 1. We used topographic maps to identify our positions in general and a satellite-based Global Positioning System (Mororola Mini-Ranger) to define the end points of our transects. A full data report is being published through CRREL (Arcone and others, 1989) in which the transects are *approximately* placed on 1955 USGS topographic maps. We were based at Barter Island where the USGS coordinates for the aircraft hangar agreed with our GPS reading to within 3" of latitude and longitude. Most of our radar profiles deliberately traversed the mounds.

The radar equipment we used was an Xadar control unit mated to a GSSI Model 3102 antenna unit mounted off the skids of a Bell Long Ranger helicopter. Details of this equipment and its operation for river-ice surveying have been discussed recently in this journal (Arcone and Delaney, 1987). The graphic output is a horizontal composition of thousands of echo scans (~30/cm) wherein darkness is proportional to signal intensity, the horizontal axis is proportional to distance, and the vertical axis to time of return. Helicopter altitude was generally 4–6 m and flight speed about 5 m/s. Fluctuations in altitude and helicopter clutter are apparent in the radar data.

Figure 2a is a photograph of one of the mounds encountered on Sadlerochit River. These mounds were 2–3 m

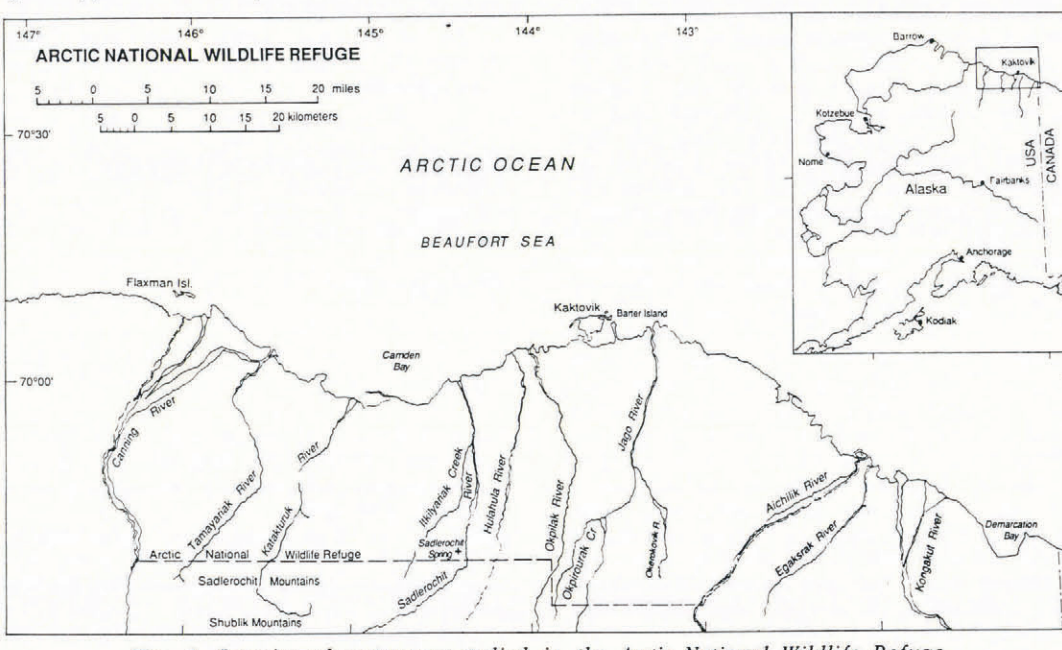

Fig. 1. Location of waterways studied in the Arctic National Wildlife Refuge.

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a

b

Fig. 2. a. Ice mound on Sadlerochit River, on 27 March 1988. b. Same mound as in (a) showing split along the crest after snow was removed.

high, 10–20 m wide, and 30–40 m long, with the long axis in the stream-channel direction. Most mounds, including these, were split along the top-surface long axis as seen in Figure 2b (a second mound can be seen in the background). A typical radar profile taken purposely over the ridges of several mounds along a 120 m reach of Hulahula River is shown in Figure 3. The vertical dashed lines are event markers entered on the magnetic tape when the antenna passed over a mound. In this figure, the ice surface, sub-surface water, and inter-mound sub-ice gravel bottom reflections are identified. The water reflection is easily identified by its strong intensity, estimated from the oscilloscope trace at ~30 dB greater than the ice-surface reflection in some cases. This is due to a weakening of the surface reflection by a layer of snow or an intensification of the water reflection by a focusing effect of the mounds. Given the size, homogeneity, and low-loss dielectric properties of the mounds, it is plausible that both the mounds and their associated unfrozen water could be inventoried with airborne SAR imagery as has been done with lakes (Mellor, 1985).

The sources of water for these mounds are not certain at this time. There appear to be two explanations. The data from a radar survey around two mounds suggest isolated thaw bulbs which could be related to the channel geometry and river-flow regimes. A second possibility is that deep aquifers exist beneath the stream bed, implying that many of the mounds may be connected. If true, such aquifers and pressure must extend the length of all these rivers, as mounds existed in their coastal deltas.

Leffingwell (1919) briefly described these features in Canning River and ascribed their origin to hydraulic pressure caused by retarded flow. A computer review of the CRREL Cold Regions Bibliography Data Base using key words that could describe these river-ice mounds uncovered CRREL Draft Translation 399, *Siberian naleds* (Alekseev and others, 1973). This translation described a river-ice mound, similar to the features we observed on the rivers in the ANWR, and referred to them as "naled-heaving hummocks" because of their formation in the river. Individual contributors to this translation often referred to these river hummocks as mixed naleds, the term "mixed" being associated with the source of water(s) for the

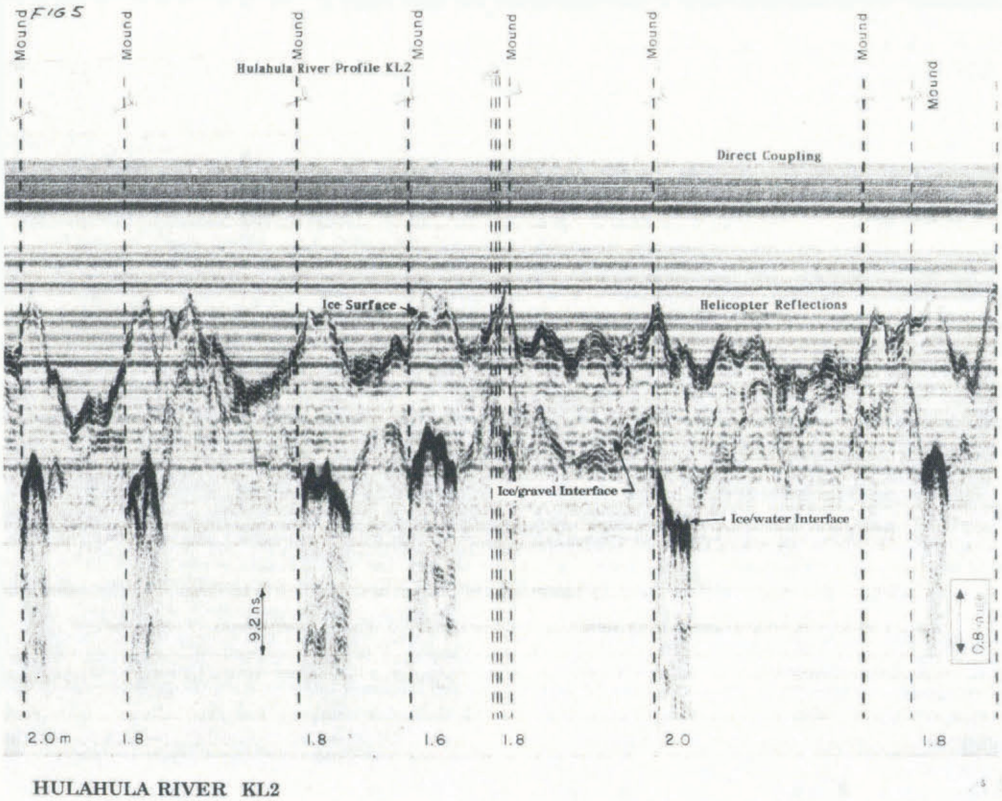

Fig. 3. Short-pulse radar profile taken along the ridges of eight consecutive mounds in Hulahula River. Numbers at the bottom are approximate depths in meters of water under the ridges as interpreted using the ice-depth scale on the graph. "KL2" is one of about 100 such profiles compiled in a CRREL report.

hummock formation. However, no one actually formulated or documented the process that describes their development. Based on English abstracts of untranslated Russian literature, there appears to be additional documentation on the occurrence of river-ice mounds.

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1 November 1988

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SIR,

Seasonal variations in diatom abundance and provenance in Greenland ice

Seasonal variations in insoluble particle concentrations with large spring peaks have been observed by Hammer (1977) and Thompson (1977) in Greenland ice cores, and the phenomenon has been used for ice-core dating. The origin of the dust in the peaks is, however, still unknown. Gayley and Ram (1984) have found diatoms, mainly of fresh-water origin, in a section of ice core from Crête, central Greenland (lat. 71°N., long. 37°W.; Fig. 1). We have now measured the time variation of the diatom concentration in a 2 year section of this ice and found that diatom abundances also exhibit seasonal changes with a spring maximum that coincides with the dust maximum. In this letter, we would like to suggest the possibility that diatoms could be used as tracers for the source of dust in ice cores.

The ice we studied was a 2 year section of 200 year old ice from Crête. The ice was divided into ten samples and, as described previously (Gayley and Ram, 1984), diatoms were recovered from each sample by filtration of ice melt water through a 13 mm diameter Nuclepore membrane filter with pore-size diameter of 0.08 μm for each of the samples. The typical mass of water filtered per sample was 30 g. Using a Scanning Electron Microscope (SEM), we determined the concentration of diatoms and diatom fragments whose largest linear dimension was greater than or equal to 10 μm.

All of the diatoms that could be clearly identified were of fresh-water origin. Genera observed include *Achnanthes, Amphora, Eunotia, Fragilaria, Melosira, Navicula, Nitzschia, Pinnularia,* and *Stephanodiscus*. Many of the specimens present were fragmented, and could only be identified to genus. Complete specimens included both species commonly found in soils and other aerophytic communities (e.g. *Navicula mutica* var. *cohnii*; Fig. 2a), and species which grow only in plankton communities (e.g. *Melosira italica*, Fig. 2c; *M. granulata*, Fig. 2d). Some planktonic species (e.g. *Stephanodiscus niagarae*; Fig. 2b) were surprisingly well preserved.

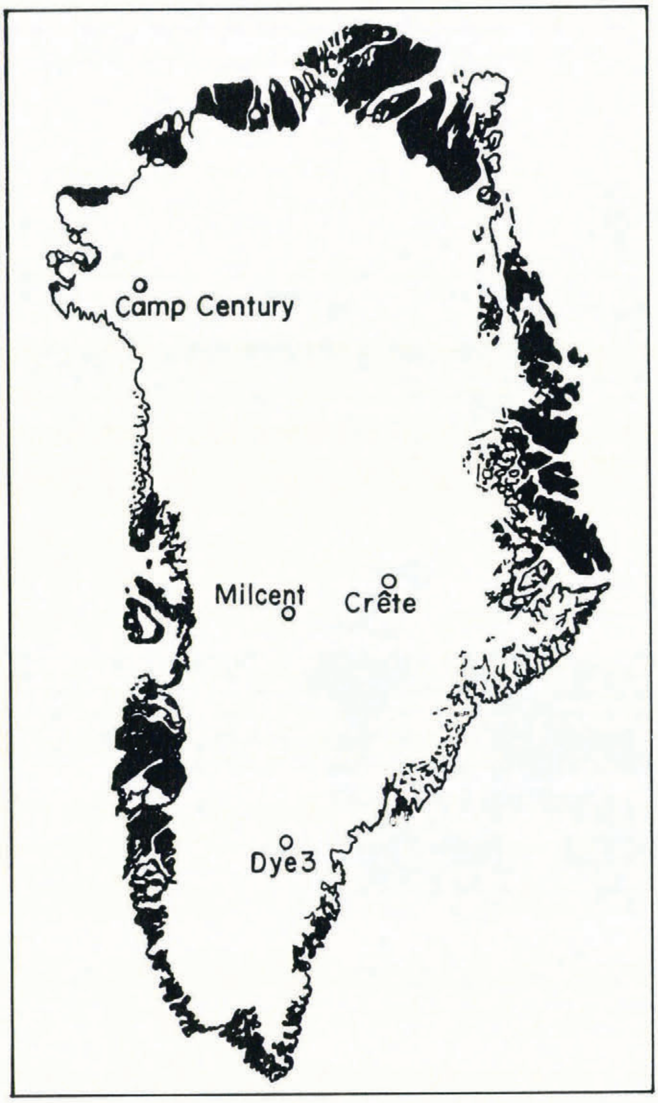

Fig. 1. Map of Greenland showing the location of Crête.

Figure 3 shows how the concentration of large insoluble particles and diatoms, and diatom fragments varied with time in the 2 year period, 1783–84. Both large particles and diatom concentrations exhibit simultaneous spring peaks in each of 2 years. Diatom remains in the smaller 1783 peak consist entirely of species derived from soil or aerophytic communities, plus a few badly fragmented and corroded specimens possibly derived from fresh-water diatomites. The larger 1784 peak contains, additionally, relatively large numbers of complete and well-preserved valves of planktonic species. The most probable sources of these specimens are shallow, productive lakes in semi-arid regions which undergo large periodic fluctuations in water level. Aeolian transport of fresh-water planktonic diatoms derived from such lakes in sub-Saharan Africa via the "Harmattan haze" has long been known (Kolbe, 1957).

The two conditions that are essential for atmospheric transport of planktonic diatoms from source regions are: (a) lowering of lake levels to the point where diatomaceous sediments are exposed, and (b) wind velocities high enough to entrain and transport particles as large as whole diatom valves. The presence of specimens of planktonic species in Greenland ice from a given year may thus provide a signal of both aridity and particularly active aeolian transport. Possible source areas that satisfy these conditions are sub-Saharan Africa, south-central Asia, and south-western North America.

The diatoms found in our present samples do not allow an unequivocal determination of source area. Most species which can be firmly identified have a wide geographic distribution. The presence of *Stephanodiscus niagarae*, a species particularly abundant in North America, supports the semi-arid south-western United States as a possible source. The work of Jackson and others (1973) suggests the possibility that dust storms originating in this region in the