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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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.
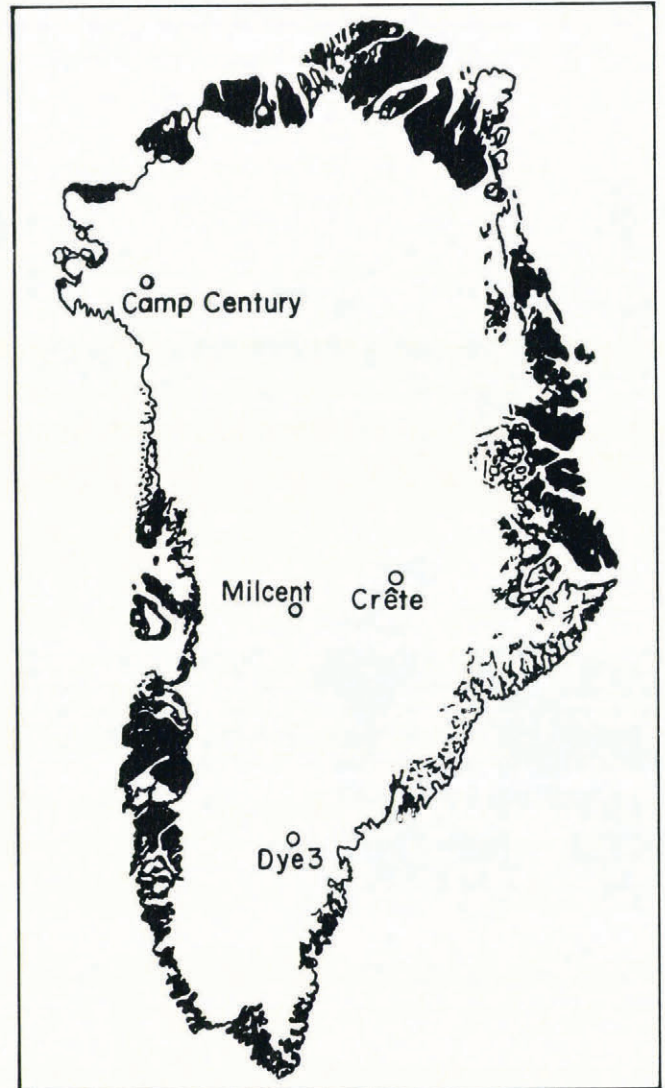

Fig. 1. Map of Greenland showing the location of Crête.

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
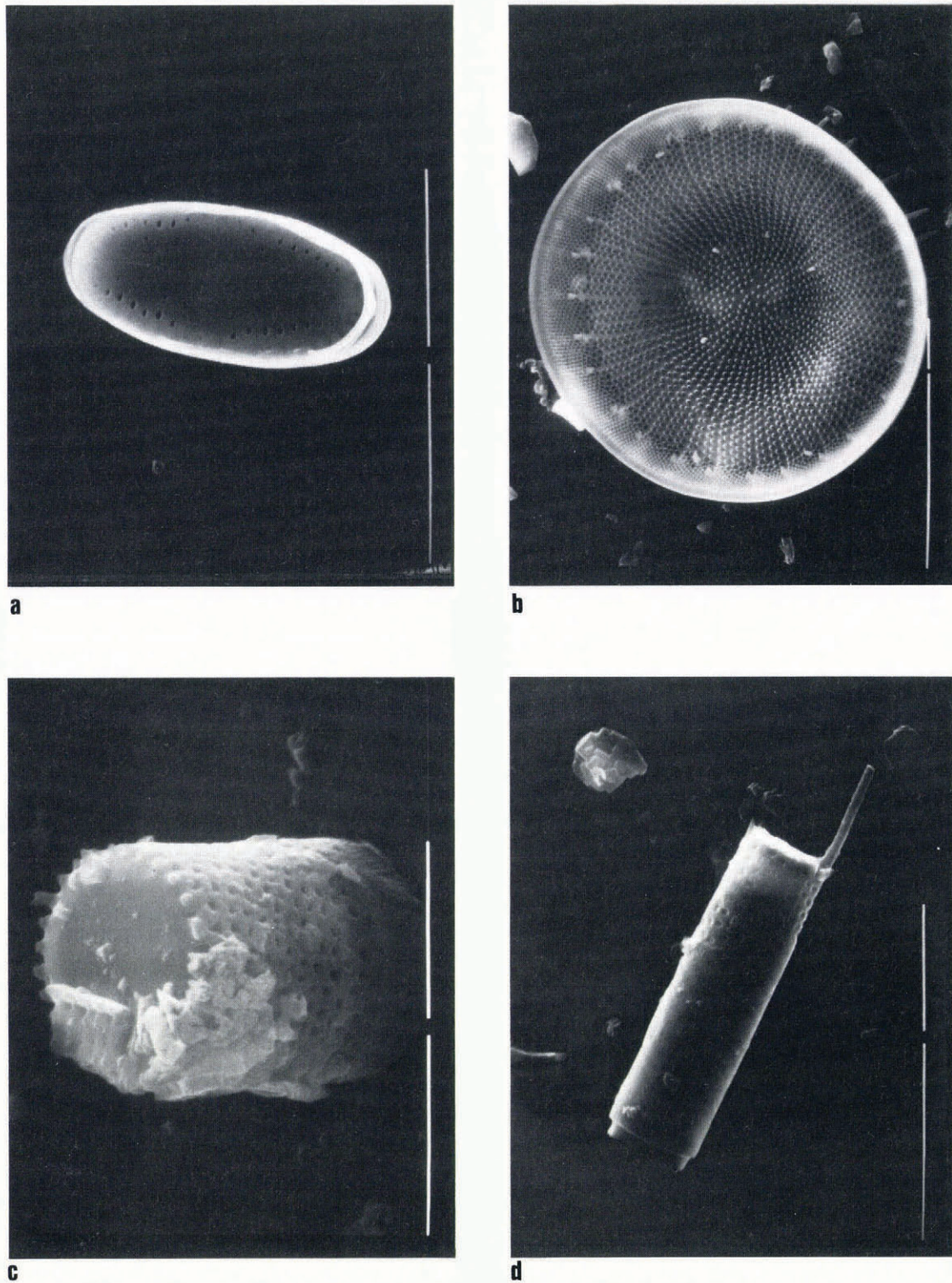
Fig. 2. SEM micrographs of diatoms found in the 1784 spring abundance maximum. (a) Navicula mutica *var.* cohnii, *a species commonly found in soils and other aerophytic habitats. (b)* Stephanodiscus niagarae, *(c)* Melosira italica, *and (d)* M. granulata. *The gap between the two horizontal lines at the bottom of the pictures is 0.5 µm wide.*

spring are carried in an ascending flow along a north-easterly path that intersects Greenland before descending and heading south over the Atlantic Ocean. We note, however, that the species found in our samples are very similar to those illustrated by Kolbe (1957), which are believed to be derived from Africa.

It is hard to see how diatoms and particles could arrive in such well co-ordinated peaks over such a short seasonal time-scale (Fig. 3) unless they came from the same general region under the influence of the same general wind patterns. This idea is supported by the observation that the ratio of diatoms to insoluble particles in the two spring peaks is equal within the experimental uncertainty. This suggests that study of diatoms in Greenland ice could eventually help elucidate the origin of the dust in the spring peaks.

Since diatom searches in ice cannot be automated, they are very time-consuming and our preliminary study covered only 2 years of ice core. Because of the possible importance of our findings, it is, nevertheless, essential that more extensive measurements be carried out to verify that dust and diatom concentrations co-vary in time over longer sections of ice core covering more years of snow accumulation.
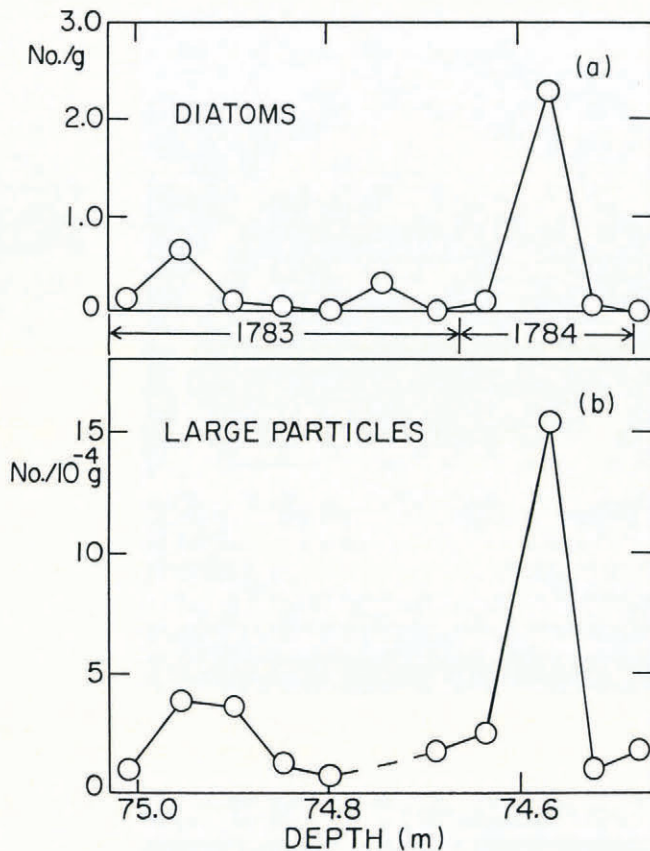
Fig. 3. (a) Concentration of diatoms and diatom fragments in the Crête ice core as a function of time of deposition. Only diatoms whose largest linear dimension is greater than or equal to 10 μm were counted. Since each sample represents a fraction of a year, the number of diatoms in each is not large and in some cases it is zero. Note that since snowfall is not constant throughout the year, one cannot treat the time-scale as linear.

(b) Concentration of insoluble microparticles in the Crête ice core as a function of time of deposition. In our work (Gayley and Ram, 1985), we measured the size distribution of insoluble microparticles in the radius range 0.05–1.31 μm. Only those particles in our largest radius range, 0.38–1.31 μm, were included in this study, since they are closer in size to the diatoms. The qualitative features of the curve remain unchanged when all particles are used rather than the larger ones. The dashed line indicates a region where particle measurements were not made (the particle distribution on the filter was not uniform), although the diatom content was determined.

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SIR,

In-situ measurements of electrical conductivity and pH in core samples from a glacier in Spitsbergen, Svalbard

The Japanese Arctic Research Project in the Svalbard region, in the Arctic, began in the early summer of 1987. The object was to clarify fluctuations in past and present sedimentary environments which would help us to forecast future features of the Earth's environmental system. An ice core gives us various information on the past. The precise details of this project together with information on the coring site have already been reported by Watanabe and Fujii (1988).

At the top of a glacier in Spitsbergen, we were able to obtain complete ice-core samples down to the bedrock at 85.6 m depth. In the lower part of the core, at 75.33 m depth, there is a band of organic matter, which possibly corresponds to a layer formed during warmer decades. Because of logistic limitations, we were unable to bring back all the core samples in a frozen condition and parts of the core had to be left behind. It is desirable to carry out certain of the analyses *in situ* throughout the whole core. One of the successful field measurements reported here is d.c. conductivity on the solid core samples (Neftel and others, 1985); this represents the acidity of the cores. We have used the measurements of electrical conductivity (EC) and the pH values of the liquid phase of the whole ice core to give us basic information on the coring field and to help us to consider, *in situ*, the chemical composition of the cores and the values of EC and pH that would represent the local sedimentary environment (Delmas and others, 1982; Kamiyama and others, 1987).

METHODS AND MATERIALS

By coring at the top of a glacier, the whole core from the surface to the bottom was obtained with individual core lengths of *c.* 60 cm. Each sample was examined visually to determine the stratigraphy, and contained bubble and dust features. Some of the core samples were prepared so that they could be carried back to the home laboratory in a frozen condition. Some of the others were used for the determination of density and crystal structure. The remainder were converted into the liquid phase as follows.

The surface of each sample was scraped carefully with a knife after being cut with a band saw into suitable shapes. The decontaminated samples were put into pre-cleaned 1 litre bottles, which were immersed in warm water so the contents could become liquid. The melted samples were then put into other pre-cleaned 100 ml bottles; these were then used for the determination of both EC and pH.