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Scanning Electron Microscopy of Vostok Accretion Ice

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Lake Vostok is a 230 km-long, ~670 m-deep, freshwater lake with an area of ~14,000 km^2 that lies under ~4 km of ice at Vostok Station, Antarctica. Accretion ice (lake water frozen onto the bottom of the ice sheet), which has been recovered by coring through the ice sheet to within 120 m above the lake surface is of interest because of the discovery of microorganisms [1]. However, it is unclear whether the microorganisms were ever alive in the ice or in the lake. Here we use a SEM and controlled sublimation to show unusual inorganic features in a triple junction in Vostok ice.

Our ~6 cm thick ice specimen, from a depth of 3550 m, contained three grains and a triple junction. The specimen was cut into three sections perpendicular to the ice core axis. In one of these sections, using optical microscopy, a dark feature was observed to be present along the triple junction, although it could not be clearly imaged. The surface of each section was shaved flat with a razor blade under a HEPA-filtered, laminar-flow hood, frozen onto a brass plate and mounted onto a cold stage. The specimens were held at 158 K ± 5 K and examined at 10 kV using a JEOL 5310LV SEM, equipped with a PGT IMIX energy dispersive x-ray spectrometer (EDS) system utilizing a pure germanium, aluminum-coated polyimide thin-window detector. Secondary electrons were used for imaging. Further details are given in [2].

Each of the sections were allowed to sublimate either in a cold room at 253 K or in the SEM at 158 K for several hours and examined in the SEM. In each section, unusual microstructural features were observed lying along the triple junctions. These consisted of either a large aggregate of crystals or a “stem and leaf” type structure (FIG. 1). The latter structures also appeared to be composed of individual crystals. EDS showed that the features were composed predominantly of S, Mg, and O, with smaller amounts of Ca and Na being observed occasionally (FIG 2). A small carbon peak was also sometimes observed on the spectra, which may have come wholly or partly from the SEM diffusion pump oil. The ratios of the integrated intensities of the S and Mg peaks from the different "stem and leaf" features analyzed varied from 1.12 to 4.18. That is, they did not correspond to the ratios for sulfates or the sulfide of magnesium. However, absorption effects due to the geometries and orientations of the features with respect to the EDS detector are likely the cause of this wide range of values from the "stem and leaf" features and the difficulty of fitting the ratios to one of the salts.

A thin filament was observed along one of the grain boundaries (FIG 1). Rapid heating and cooling of the specimen by the electron beam and the sublimation of the ice from beneath the filament probably caused the partial detachment of the filament from the grain boundary EDS showed that the filament contained the same elements as the stem and leaf feature (Figure 2c). This filament is similar in appearance to filaments observed in other Antarctic ice and probably forms by the coalescence of impurities in the grain boundary, which are left behind as the ice sublimates [2].

How the unusual morphology of these features, particularly the leaf and stem feature, could form by precipitation (either solid state or liquid state) or by solute rejection during the freezing of water is not obvious, although it is likely that they formed by the latter process. It is worth noting, as a piece to this puzzle, that the diameters of the water-veins that exist along triple junctions in ice increase and their freezing temperatures decrease due to impurities [3].

References

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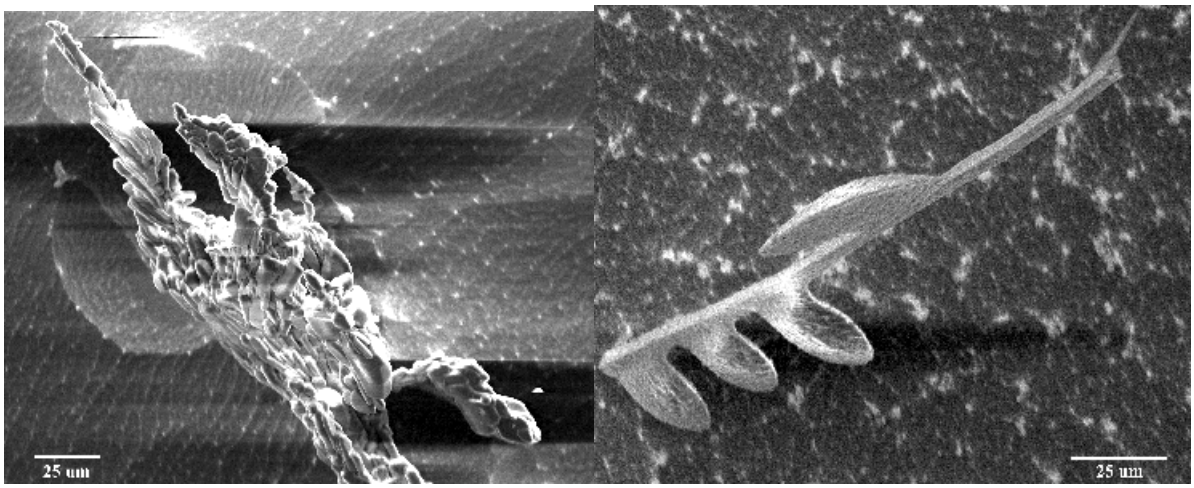
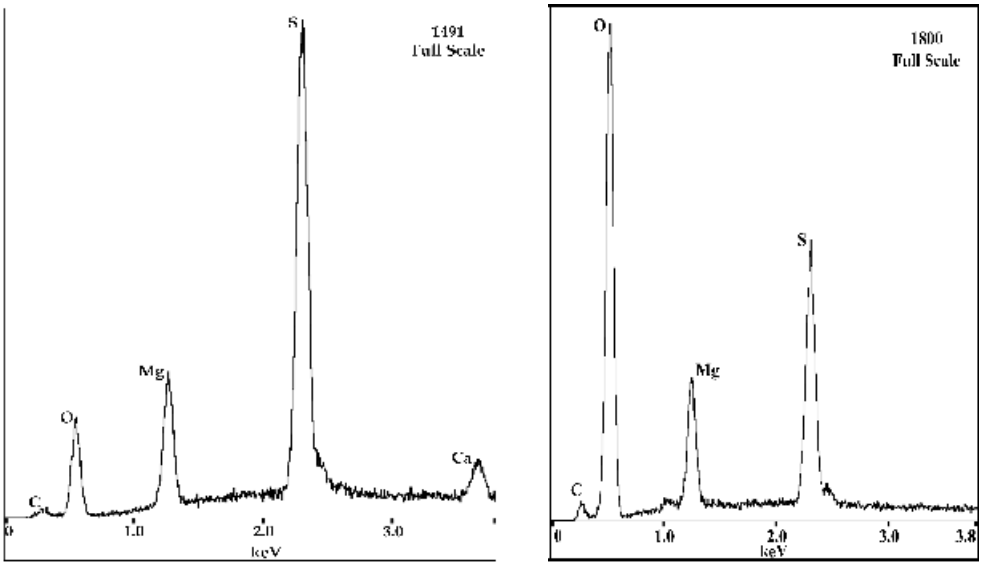


(a) (b)

FIG. 1. Secondary electron image showing (a) crystalline aggregate; and (b) “stem and leaf” feature in a triple junction in Vostok accretion ice.



(a) (b)

FIG. 2. Typical EDS spectra from: (i) “leaf” and “stem” structure; and (iii) filament above triple junction showing that all contain Mg, S, and O.

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