LETTER

Algal ice-binding proteins change the structure of sea ice

Krembs et al. (1) reported that extracellular polymeric substances (EPS) produced by a sea ice diatom, *Melosira*, created convoluted ice-pore morphologies in sea ice, potentially increasing its habitability and primary productivity. The activity was reduced by heat treatment and glycosidase treatments, suggesting that a glycoprotein was involved. Based on our previous work (2), it is very likely that the active substance is an ice-binding protein (IBP).

All sea ice diatoms examined so far secrete similar ~25 kDa IBPs that bind to ice, distorting its shape as it grows (2). Similar proteins are found in ice-adapted bacteria and fungi (3) and even a sea ice amphipod that presumably acquired the gene from a diatom by horizontal transfer (4). Such proteins also have the ability to change the structure of sea ice. We recently identified another IBP secreted by an Antarctic euryhaline chlorophyte, *Chlamydomonas* sp. Its sequence bears no resemblance to the diatom IBPs, but it has similar effects on ice, resulting in the formation of highly irregular shapes (5). At natural concentrations, the *Chlamydomonas* IBP causes sea ice to freeze with a very fine structure composed of small brine pockets (Fig. 1) that trap brine and slow its drainage (Fig. 2) (5). Krembs et al. (1) attributed the reduced porosity of EPS sea ice to pore clogging by the EPS. Our results (5) suggest that the main factor in the case of *Chlamydomonas* is the highly irregular shape imposed on ice by the IBPs (Fig. 2 *Inset*).

Various functions have been proposed for ice algal IBPs, including antifreeze activity, inhibition of the recrystallization of ice (which can damage cell membranes), and attachment to ice. Together, these studies (1, 5) point out a possible function of algal IBPs, retention of a liquid environment, without which survival is difficult.

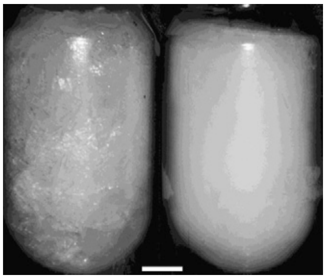

Fig. 1. Effect of ice-binding proteins (IBP) on freezing of seawater medium. Seawater medium (*Left*) and seawater medium with IBP (*Right*) are shown in centrifuge tubes after expulsion of most of the brine by centrifugation. IBP ice has a finer, more homogeneous appearance, apparently caused by smaller brine pockets (5). (Scale bar: 1 cm.) Reproduced from ref. 5 with permission from John Wiley & Sons, Inc. (Copyright 2009).

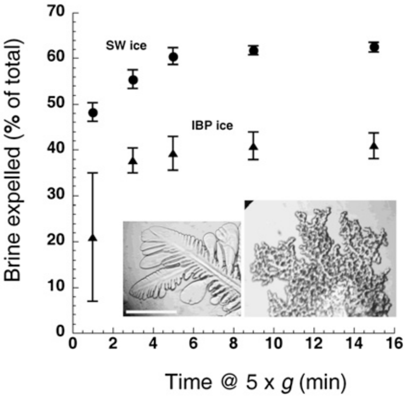

Fig. 2. Effect of IBP on brine retention by frozen seawater. Seawater medium samples containing semipure IBP at close to actual concentration and without IBP were frozen overnight at −6.0 °C and subjected to increasing centrifugation; the cumulative amount of expelled brine was measured. Values indicate mean ± SD (n = 3). (*Inset*) Photos of ice dendrites grown in seawater (*Left*) and IBP ice (*Right*). As the IBP dendrites grow and become densely packed, they appear to trap small pockets of water between the branches (5). (Scale bar: 1 mm.) Reproduced from ref. 5 with permission from John Wiley & Sons, Inc. (Copyright 2009).

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1. Krembs C, Eicken H, Deming JW (2011) Exopolymer alteration of physical properties of sea ice and implications for ice habitability and biogeochemistry in a warmer Arctic. *Proc Natl Acad Sci USA* 108:3653–3658.
2. Janech MG, Krell A, Mock T, Kang JS, Raymond JA (2006) Ice-binding proteins from sea ice diatoms (Bacillariophyceae). *J Phycol* 42:410–416.
3. Raymond JA, Janech MG (2009) Ice-binding proteins from enoki and shiitake mushrooms. *Cryobiology* 58:151–156.
4. Kiko R (2009) Acquisition of freeze protection in a sea-ice crustacean through horizontal gene transfer? *Polar Biol* 32:393–398.
5. Raymond JA, Janech MG, Fritsen CH (2009) Novel ice-binding proteins from a psychrophilic Antarctic alga (Chlamydomonadaceae, Chlorophyceae). *J Phycol* 45:130–136.

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The author declares no conflict of interest.

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