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MOVEMENTS OF BRINE IN ICE

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Abstract

An explanation of the flowing of the brine downwards in sea ice is given in a form of a numerical example. The idea is applied to the growth of ice in general and to the motion of brine at the formation of white ice.

1. *Introduction*

It is well known that sea ice generally has inclusions of salt in the form of brine or maybe in addition it may have salty water and/or white ice on top of it. The salt has a tendency to move downwards. Some ideas are presented in this paper to explain the event.

2. *Theory*

Salt in a certain temperature is able to melt a certain amount of ice to form brine. In a given temperature $-\theta$ the volume of pure ice melted per mass of salt, κ, is in equilibrium with its surroundings. As an example the κ-curve for NaCl is given as a function of θ, MICHEL (1971). Now, if we have salt of mass m_s, then the corresponding volume and mass of pure ice melted are κm_s and $\rho_0 \kappa m_s$ respectively, where ρ_0 is the density of pure ice. The salinity of brine is thus

$$s = m_s/(m_s + \rho_0 \kappa m_s)$$

or

$$s = 1/(1 + \rho_0 \kappa). \tag{1}$$

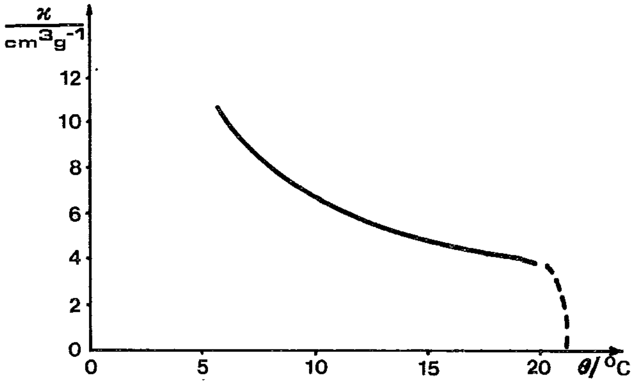

Fig. 1. Volume of melted pure ice produced per mass of NaCl given as a function of temperature.

Thus the salinity of brine decreases as the temperature increases. But this is just what happens in a cylindrical inclusion or pore, because, the temperature increases generally from the air temperature above the ice to the freezing temperature of water below the ice. This causes the salinity to become lower downwards in equilibrium condition according to the function plotted in Fig. 1 and Eqn. 1. But the density of more saline water in the upper part of the pore is higher than that of less saline water farther down. Therefore mixing takes place. Yet, the liquid constituents after mixing are no more in equilibrium in temperatures in question. To achieve the state of equilibrium some pure ice must be formed from brine in the upper part of the pore whilst in the lower part of it the opposite is true. Because the volume of ice needed for melting is larger than the volume of ice formed, the pore will be elongated downwards. In Table 1 a numerical illustration is given.

Table 1. An example of brine movement in ice.

θ/°C	κ/m^3kg^{-1}	s	$\bar{s}$	$\bar{\kappa}/m^3kg^{-1}$	$\Delta\kappa/m^3kg^{-1}$
15	0.0047	0.1912	0.1406	0.00679	−0.00209
10	0.0067	0.1423	0.1406	0.00679	−0.00009
5	0.0122	0.0835	0.1406	0.00679	0.00541

It is assumed that the temperatures given in the first column for equidistant layers lying beneath each other are −15, −10 and −5 °C respectively. The corresponding κ-values are found from Fig. 1. The salinity values s are obtained by using the formula (1). In this example it is assumed that the salinity values $\bar{s}$

after mixing are equal. The averaging is performed by Simpson rule. The obtained salinity corresponds to the $\bar{\kappa}$-value of the next column. Finally, the last column gives the excess $\Delta\kappa$ of κ, *i.e.* the excess of the pure ice volume/saltmass. This means freezing in the uppermost layer and melting in the lowermost one. It is observed that the pore will be elongated during the process, because $|\Delta\kappa|$ is smaller in the upper layer than in the lower one.

3. *Special cases*

The theory above is developed for the case of brine inclusions, but it is applicable in some special cases as well.

The mechanism of sea ice growth is well explained by PEYTON (1968). The temperature in the upper part of the dendrites may be lower than farther down, see Fig. 2. Therefore the exclusion of salt from the dendrites increases the salinity above more than farther down and the ice growth there may be correspondingly slower. The salinity down is lower partly due to diffusion and convection. The ice there will before long form a unified ice mass and the water in between will be trapped to constitute inclusions.

When water comes above the ice because of the weight of fallen snow, it moistens the snow above by salty water as consequence of the capillary phenomenon. When this water later freezes, the salt will mostly be separated from the show and collected just above the ice cover to form a layer of white ice saltier

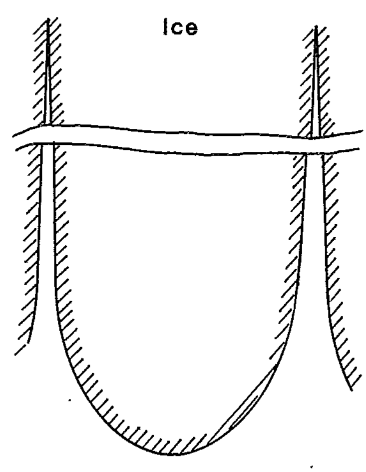

Fig. 2. Schematic representation of sea ice growth showing dendrites of pure ice and wedge shaped regions of liquid brine. After TILLER, (1963).

than the sea water. Because the distribution of salt may not be quite even, it will eventually form depressions with brine above. By cold weather, the brine will begin to penetrate downwards in a manner described earlier.

4. *Discussion*

The theory above may not be quite accurate because of omitting of the influence of densities in some places, but the main features may indeed be truthful. In the example above it was assumed that the salty water (brine) will be fully mixed during the process. This may not even be true because the process has not enough time to achieve an equilibrium state and the brine continues to clear its way downwards, eventually down to the water beneath the ice. In effect, the ice will become less salty on account of this process.

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