NOTES

Gas Loss from a Temperate Glacier[1]

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1. Introduction

The gas enclosed in the ice of a temperate-zone glacier, Storbreen in the Jotunheimen district of Norway, has been systematically examined (COACHMAN ET AL., 1956). In this study samples of ice were taken from the glacier surface in a longitudinal line from the firn area to the terminus. Ice thus sampled has both a gradient in age and a gradient in depth of passage in the glacier interior. The results showed:

1. The pressure on the gas was near atmospheric when the ice was formed, but increased to three times atmospheric going down the glacier toward the terminus. However, the pressures were not equal to the estimated hydrostatic ice load in the glacier interior.
2. Oxygen was specifically lost from the gas, the O_2 content varying from about that of the atmosphere when the ice was formed (19.5—21.9 volume-per cent) to values averaging 10—12 per cent in the terminal ice, with occasional bubbles as low as 4.8 per cent.

The mechanism by which the O_2 loss could take place was not apparent. Gas diffusion through the ice is exceedingly slow (SCHOLANDER ET AL., 1953; HEMMINGSEN, 1958). Furthermore, the oxygen tension in the terminal ice samples was only one-half that of the atmosphere, and in this case diffusion would take place from the atmosphere into the ice. The loss of O_2 through bacterial decomposition of organic matter appeared unlikely because of the lack of increase in CO_2 and lack of sufficient amounts of contaminants in the ice.

In April 1957, Storbreen was re-examined for composition of the enclosed gas. In addition to analyses for O_2, N_2, and CO_2, the argon content of the gas was determined by mass spectrometry, giving a clue to the mechanism of oxygen loss.

2. Results

The measurements for gas pressure, gas quantity, and ice density showed the same results as the previous survey (COACHMAN ET AL., 1956), that is, the gas pressure increased going from the formation area to the terminus, and there was no indication of a general loss of gas from the glacier.

The composition analyses (Fig. 1) showed: (1) the oxygen content was reduced during the life of the entrapped gas in the glacier, from values approximately those of air to one-half of these; (2) the argon values were reduced from approximately those of air to one-half those of air; and (3), the CO_2 values were three times those of air in the upper ice and close to those of air in the ice lower down.

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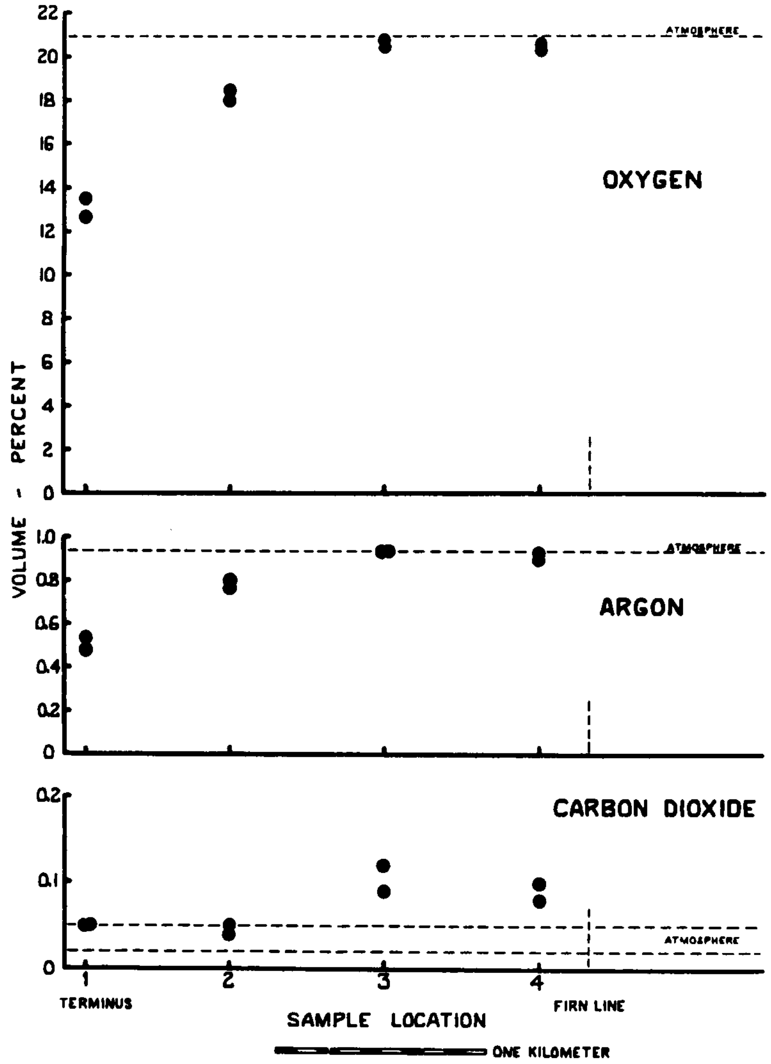

Figure 1. Content of oxygen, argon, and carbon dioxide in entrapped glacier gas at different sample locations. In the carbon dioxide plot the two horizontal dashed lines delimit the accuracy of analysis.

3. Discussion

Bader (1950) conducted a microscopic examination of the ice of the temperate Malaspina Glacier in Alaska. His investigations were made during the summer and the majority of the bubbles in the ice had a "bag" of water associated with them. He concluded that, under certain conditions of ice movement, the water of a "water bag" may be pressed into the inter-granular boundary layer between two ice crystals, and that therefore dense glacier ice may not be completely impermeable to water. Bader also measured the gas pressure in the ice as 1 1/2 to 2 1/2 atmospheres, only a small fraction of the theoretical ice load in the glacier interior.

When air dissolves in water the components dissolve in proportions different from those present in atmosphere. For example, oxygen, which comprises about 21 per cent of atmosphere, is 34.9 per cent of air dissolved in equilibrated water at 0° C. Likewise, argon and carbon dioxide, 0.94 and 0.03 per cent of atmosphere respectively, comprise 1.86 and 1.75 per cent of air dissolved in water (HOCK ET AL., 1952; *Handbook of Chemistry and Physics*, 36th ed., 1954—55).

Storbreen ice has been observed during the months of March and April; i.e., at a time too cold to have water associated with the bubbles. However, most of the bubbles in Storbreen ice are spherical and quite variable in size, undoubtedly the result of melting during the summer.

It would seem that in temperate glacier ice during the summer there is often melting around the bubbles, in which case water will be associated with each bubble. It is suggested that there are then slight movements of this water out through the capillary-like intercrystal spaces, helped by the gas over-pressure in the bubbles. Those gas components which are more soluble will then be preferentially removed in the water and, at least from the surface ice, may be totally removed from the glacier. The gas itself cannot escape because of capillary forces in the very fine liquid channels.

The fact that large quantities of argon together with the oxygen are lost from the glacier gas clearly indicates that some physical process, rather than oxidation, is responsible for the loss of oxygen. This was already indicated by the lack of sufficient amount of oxidizable material in the ice. The loss of argon strongly supports the idea of a primary, slow loss of meltwater around the bubbles, which takes place by leaking through the capillary spaces between the ice crystals and is activated by the bubble pressure. The gas cannot follow because of capillary forces in the minute intercrystal spaces.

Such a progressive melting and leaking would remove preferentially those gases which are most soluble; i.e., CO_2, O_2, and A_r leaving behind a mixture increasingly richer in N_2. Also, by the same process, the bubble pressures would gradually decrease to values less than those inferred from the weight of the ice. Calculations show that the proposed explanation can account for at least the major part of the changes which have been found to take place in the ice as the glacier ice proceeds toward the terminus.

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