ON THE HYDROGRAPHIC MECHANISM OF THE SO-CALLED BROWN ZONES ASSOCIATED WITH TIDAL GLACIERS

By

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The presence of zones of muddy, ice-free water at the sea faces of tidal glaciers has been recorded from Alaska (Gilbert, 1910), and from Spitzbergen (Stott, 1936). In view of their great significance in local ecology an understanding of the causes of these so-called "Brown Zones" seemed desirable and the problem of their establishment was first attacked hydrographically by the Oxford University Expedition to Spitzbergen, in 1933.

The present work was carried out in West Greenland, on two fjord-glaciers, Eqip Sermia and Kangilerngatâ Sermia, in Atâ Sound, the north-east corner of Disko Bay (Figure 96), in the summer of 1936. The authors take this opportunity of expressing their gratitude for the permission and help given to them by the Danish Administration of Greenland, without which the work would of course have been impossible.

Methods. It was not always possible or advisable to manoeuvre the small 20-foot motor boat, used for the work, through the close brash ice that surrounded the brown zone, and it was therefore necessary to choose days on which the brash ice was at its thinnest. The graphs published here were made from data taken on three separate days, one at Kangilerngatâ and two at Eqip. The closing water-bottle used was lent by the Admiralty, in London. The salinities were estimated by titration against silver nitrate, using Knudsen burettes.

The Brown Zones. Each of the glaciers has one brown zone at its face; the topographical relations of brown zone, brash ice, glacier, and the fjord water outside, are shown in the sketch-map (Figure 97). Inside the zone itself there is a surface current away from the ice, with a speed of about half a knot. The water is very muddy, of a coffee colour, and on reaching the surrounding brash ice, disappears under it, so that the boundary of the zone is clearly marked. Planktonic Crustacea, whose normal upper limit of vertical distribution is at a depth of between 15 and 25 metres, are found at the surface in the brown zone, in considerable numbers, a condition that makes the zone an important feeding area of the Kittiwake and other sea-birds. From the fact that the Kittiwake are always crowded together immediately under the face of the glacier, it is inferred that the water rises up the face of the ice itself. Unfortunately it is not possible to work a hydrographic station nearer than 100 yards from the glacier. The distance, at Eqip, from the ice cliff to the end of the brown zone is about 250 yards.

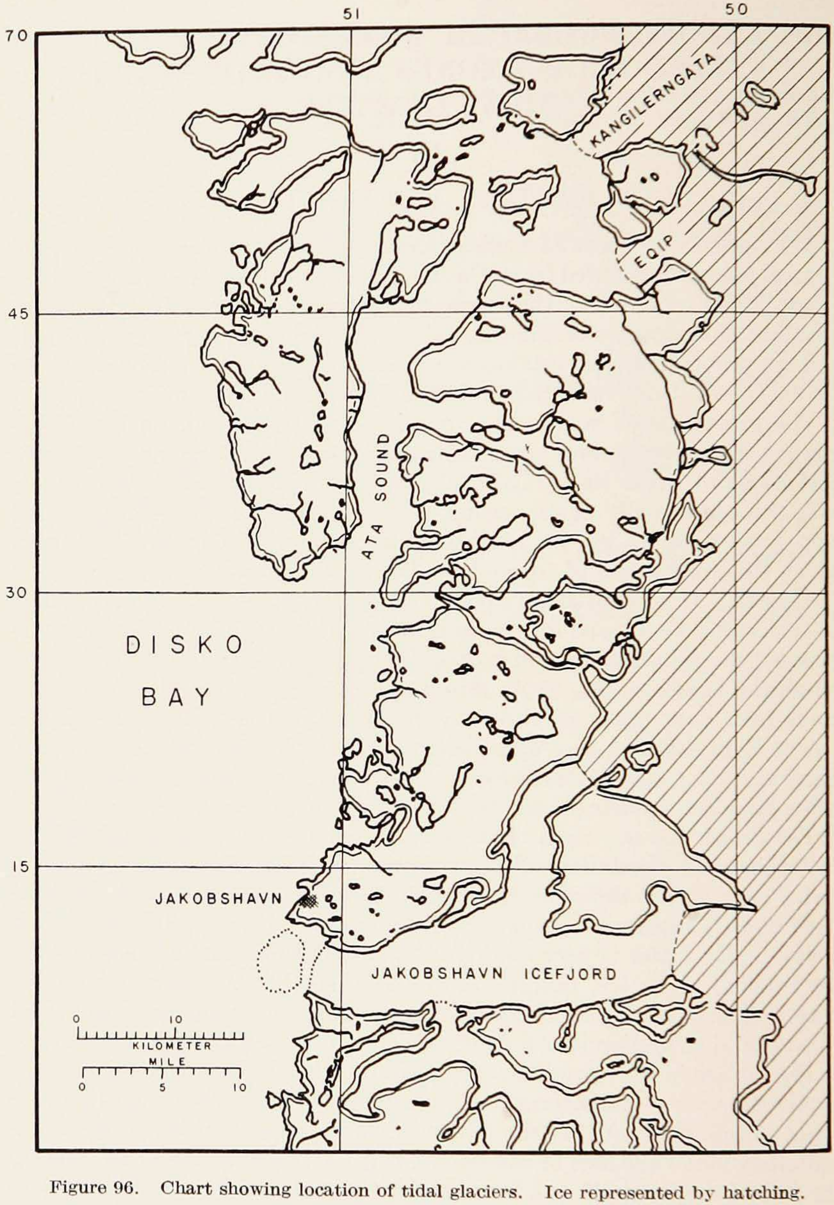

Figure 96. Chart showing location of tidal glaciers. Ice represented by hatching.

From observations made at the Nordenskiold Glacier in Spitzbergen, Stott, (1936) was led to the belief that the brown zone there was due to a drainage stream from the glacier, at or near the surface. The temperature, salinity, and density graphs, and the temperature-salinity correlation curves published here (Figures 98, 99) give no evidence whatsoever of such a stream entering the system, although the possibility is not excluded. Unfortunately the low and small range of temperatures met with in Greenland makes the density-salinity correlation curves useless, as far as the demon-

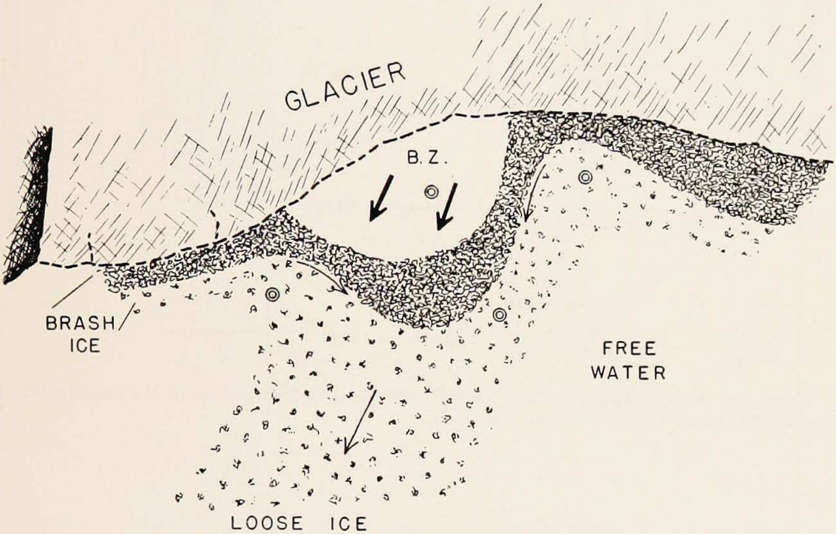

Figure 97. Sketch map of the Eqip Brown Zone, August 22, 1933. Points of observation indicated by double circles. Directions of surface movement by arrows. BZ = Brown Zone. Note absence of significant freshening of Brown Zone at this time shown in Figure 98.

stration of freshening along isopycnic surfaces is concerned. The σ_t-S curves are all virtually coincident, rectilinear and of the same slope. The negligible difference in salinity between the surface and the deeper layers within the area of the Brown Zones at Kangerlingata on August 3, and at Eqip on August 22 (see tables and Figure 98) shows an absence of significant freshening in the ascending motion which must be assumed to be associated with these zones, while the high surface salinities in themselves exclude the possibility of a fresh drainage stream entering at the top. It is therefore evident that the existence of the brown-zone can not be dynamically dependent upon the presence of a glacier stream entering at any level within the area of the zone itself. That a freshening *may* occur also within the Brown Zone as shown by the observations at EQIP on August 9, thus seems merely an incidental

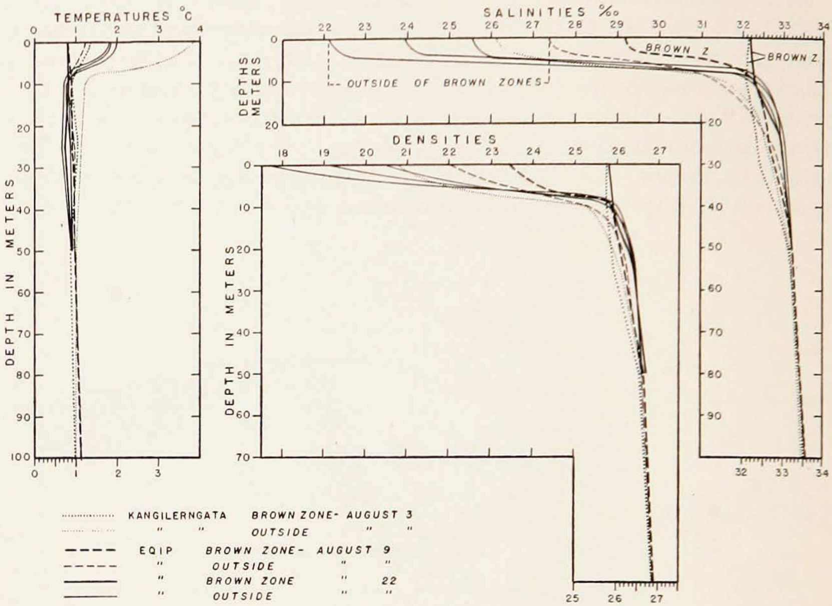

Figure 98. Temperature, Salinity and Density curves for stations inside (heavier lines) and outside (light lines) of Brown Zones.

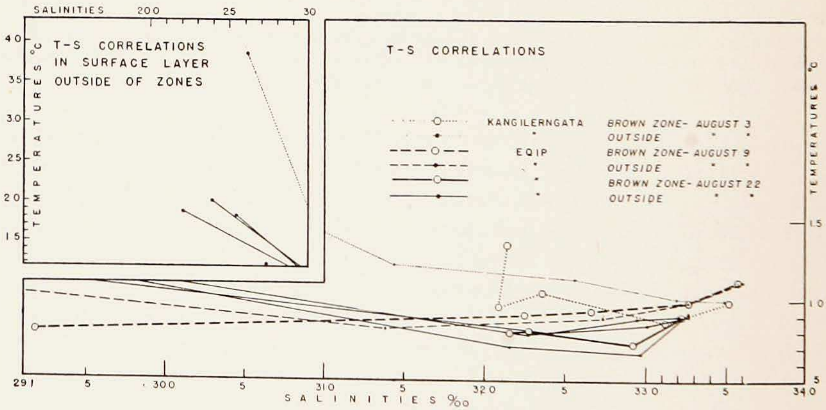

Figure 99. Temperature–Salinity correlation curves for stations inside and outside of Brown Zones.

and additional feature in this particular case but not a fundamental requirement for the existence of the zone as such. The primary force which causes the establishment of the equilibrium must therefore be sought outside of the Brown-Zone itself. Since the surface salinities observed immediately outside of the surrounding brash ice are in all instances (see tables and Figure 98) much lower than the surface salinities within the Brown Zones, it is obvious that the actual freshening is mainly or entirely introduced in or *via* the brash ice belt. The primary cause for the maintenance of the Brown Zone phenomenon is therefore to be found in the movement away from the

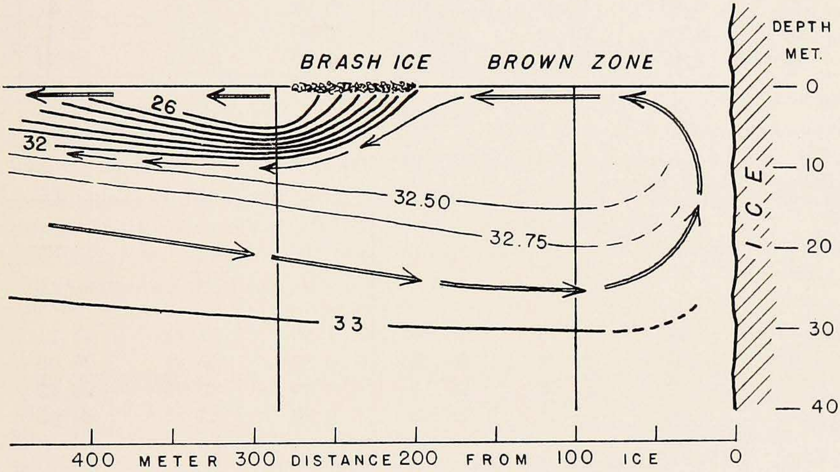

Figure 100. Indicated salinity profile (heavy isohaline for every 1 °/oo, from 26 °/oo to 33 °/oo, light isohalines for 32.5 and 32.75 °/oo) and vertical circulation at Eqip Brown Zone, August 22, 1933.

glacier of the fresh layer occurring in the brash ice belt, where it is probably mainly derived from the melting of the brash ice itself. The system thus established is diagrammatically illustrated in Figure 100.

The upwelling water which replaces the melt-water, in the hypothetical beginnings of the brown zone in the Spring, might conceivably be in the form of a sheet, rising all along the face of the glacier. It is probable, on physical grounds alone, that such a sheet would soon take the line of least frictional resistance and form itself into a column. The presence of a drainage stream, however, be it never so small, would facilitate this process, by serving as a centre of concentration. Moreover, there are three other considerations which favour the belief that such a stream is present:—

1. The normality of a drainage stream; most glaciers possess one at least. (Gilbert, 1910; Von Engel in, 1911; Antevs, 1922.)

TABLE I

Eqip Glacier

August 9, 1936

Depth Meters	Brown Zone			Outside A		
	°C	°/₀₀S.	σ_t	°C	°/₀₀S.	σ_t
0	0.80	29.18	23.41	1.22	27.38	21.94
10	0.91	32.25	25.87	0.82	31.38	25.17
25	0.93	32.66	26.19	0.99	32.74	26,25
50	0.99	33.24	26.65	0.99	33.26	26.67
100	1.12	33.57	26.90	1.12	33.60	26.93

TABLE II

Eqip Glacier

August 22, 1936

Depth Meters	Brown Zone			Outside: A		
	°C	°/₀₀S.	σ_t	°C	°/₀₀S.	σ_t
0	0.80	32.16	25.80	1.86	22.11	17.71
10	0.81	32.28	25.895	0.80	32.41	26.00
25	0.73	32.92	26.41	0.89	32.95	26.42
50	0.90	33.22	26.63	0.90	33.21	26.63
Depth Meters	Outside: B			Outside: C		
	°C	°/₀₀S.	σ_t	°C	°/₀₀S.	σ_t
0	1.81	25.55	20.49	2.00	23.95	19.17
10	0.71	32.16	25.80	0.79	32.27	25.885
25	0.67	32.97	26.45	0.85	33.01	26.47
50	0.92	33.26	26.67	0.91	33.26	26.67

TABLE III

Kangilerngata Glacier

August 3, 1936

Depth Meters	Brown Zone			Outside A		
	°C	°/₀₀S.	σ_t	°C	°/₀₀S.	σ_t
0	1.35	32.14	25.74	3.85	26.13	20.79
10	0.96	32.09	25.735	1.22	31.44	25.19
25	1.05	32.36	25.94	1.13	32.56	26.09
50	0.87	33.12	26.56	1.01	33.19	26.61
100	0.99	33.51	26.87	1.00	33.49	26.85

2. The presence of the mud. It has been suggested that the vibration caused by a moving glacier might keep the bottom sufficiently stirred up to supply the mud. The muddy water at Eqip, however, is found at the surface and at 10 metres depth only, in the brown zone, and at 10 metres depth outside the zone, in the direction of the brown zone current; it is not found at 25 metres or lower either in the zone or out of it. It seems, therefore, that the turbidity is not due to a general stirring up of the bottom by water movement or any other phenomenon, but to the presence of a localised source, such as a drainage stream emerging from the glacier. The supply of mud need not be very great, since (Figure 100) a large amount of it may be kept in circulation by means of its sinking from the outgoing flow at the surface to the incoming and ascending flow underneath.

3. The position of the brown zone. The Eqip brown zone is well toward the north-west end of the glacier face. If there were no drainage stream to localise the zone, one would expect it to be found more nearly in the middle.

The authors are confident that further work will solve the problem of the implication of a drainage stream in the system. They wish to express their gratitude here to Dr. A. E. Parr for valuable suggestions and assistance in the presentation of the data.

SUMMARY

Investigation of the so-called Brown Zones (zones of upwelling water at the sea faces of tidal glaciers) at two glaciers in West Greenland has shown that the upwelling cannot be due primarily to drainage streams of fresh water from the ice, as previously suggested, but that there is reason to suppose that drainage streams, although insignificant in terms of volume, may play some part in the system. It is suggested that the maintenance energy requirements of the phenomenon are derived from the movement of melt-water away from the glacier, and not from the effects of a fresh water drainage stream emerging from the ice.

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