Journal of Glaciology, Vol. 9, No. 57, 1970

FINGER-RAFTING IN FRESH-WATER ICE: OBSERVATIONS IN LAKE SUPERIOR

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ABSTRACT. Finger-rafting, similar to that reported in sea ice, is common in thin (2–15 mm) new ice on Lake Superior. It is produced by wind traction alone; neither wave action nor brine is necessary for its initiation or propagation. Fingers have been observed to progress at rates of 0.5–5 cm/s.

RÉSUMÉ. *"Doigts de glace flottants" dans la glace d'eau douce: observations dans le Lake Superior.* La formation de "doigts de glace flottants" semblables à ceux connus dans la glace de mer est courante dans la glace nouvelle mince (2–15 mm) du Lake Superior. Elle est produite par la seule traction par le vent; ni l'action des vagues, ni celle du sel ne sont nécessaires pour le déclenchement et la propagation de ce phénomène. On a observé la progression de ces "doigts" à une vitesse de 0,5–5 cm/s.

ZUSAMMENFASSUNG. *"Finger-rafting" in Süsswasser-Eis: Beobachtungen im Lake Superior.* "Finger-rafting" (Bildung von fingerartigen Riss-Systemen), ähnlich dem bei Meereis bekannten, tritt häufig in dünnem (2–15 mm) neuem Eis am Lake Superior auf. Es entsteht allein durch den Zug des Windes; weder Wellen noch Salzwasser sind zur Einleitung und Ausbreitung nötig. Die Finger schreiten, wie beobachtet wurde, mit Geschwindigkeiten von 0,5–5 cm/s fort.

FOR the past $4\frac{1}{2}$ years I have been living on the shore of Lake Superior and driving to work each day for 8 km along the shore of the lake to Duluth. Each winter I have been intrigued by very curious and regular fracture patterns that form when the ice is thin, and I recently wrote to W. F. Weeks of the U.S. Army's Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, for information on these features. He told me of the name of this effect, finger-rafting, and kindly referred me to several papers in this *Journal*. On looking at these papers I find that, with the exception of melt-water pools on old sea ice, little mention has been made of finger-rafting in fresh-water lakes (Weber, 1958), and it therefore might be appropriate to describe some observations of this phenomenon from Minnesota.

Finger-rafting is very common in Lake Superior; I have observed it many times each winter (Figs. 1–4). As reported by others (Weeks and Anderson, 1958; Dunbar, 1960, 1962) it forms only in very thin

Fig. 1. Active finger-rafting; Lake Superior shore at Lakewood district, Duluth, Minnesota. View to south-west; thrusting is on-shore under south breeze. 16 March 1970. Ice is 3–8 mm thick, thrusting rate 2–5 cm/s.

ice; my estimates of thickness from land-based observations (within 1–20 m) are 2 to 15 mm. It probably can form in as thin ice as can transmit thrusting. Fresh-water ice thicker than about 2 cm appears to break irregularly.

Most fingers seen range from 0.5 to 3 m wide and 2 to 10 m long, but they vary considerably in size, and there appears to be some weak correlation between width of fingers and thickness of ice. The narrowest I have seen (about 3–10 cm) occurred in extremely thin and fragile ice (2–3 mm), whereas the wider ones (up to 10 m) occur in ice between 1 and 2 cm thick. The smaller fingers in thinner ice are also shorter, about 0.5–1.5 m long. On 16 March 1970, I observed one perfectly straight rift about 100 m long, and one finger that was 50 m long by 1 m wide—all in ice that ranged from 3 to 8 mm in thickness that was undergoing thrusting at the time. On several occasions the fingers have been observed to show a gentle curvature, probably produced by continued thrusting as the ice raft rotated with respect to the wind. Thrust-fingers trending in markedly different directions have been seen in the same area on many occasions. This probably results from changes in wind direction, but I have no direct observations to support this assumption.

The thin ice has typically formed on a still night and the rise of a breeze the next morning appears to initiate thrusting. Although I have not seen the process start, I have observed (10 February, 16 and 17 March 1970) the thrusting in action, the fingers being shoved forward by traction from a light breeze at a rate ranging from about 0.5 to 5 cm/s. Shoving from a thicker mass of ice up-wind does not appear to be necessary, although the fast ice along the shore acts as a buttress. Most observations have been at temperatures only a few degrees below freezing ($-6°$ to $-1°C$). As the overthrust plates impinge on the shore ice or rocks their leading edge breaks up into irregular plates that tinkle as they slide back onto the advancing ice. Although the thrusting appears to take place at a very constant rate, twice I have observed it to cease abruptly (within about 1 s).

Dunbar (1960, 1962) has mentioned wave action as possibly being involved in the formation of finger-rafting. My observations in Lake Superior, however, show that waves are not a prerequisite; the phenomenon occurs in absolutely flat ice, in many cases far from any open water that might be a source of waves, and early in the day after a still night when no new waves of any consequence could be built up by the breezes observed to accompany this rafting. Furthermore, the width of the fingers is at least an order of magnitude less than the wave-length of any possible swell. The suggestion of Weeks and

Fig. 2. Finger-rafting in thin ice; Lake Superior shore at Lakewood district, Duluth, Minnesota. Ice is 3–4 mm thick, thrusting rate 0.5 cm/s. 16 March 1970. Open water in background, ice-covered shore in foreground.

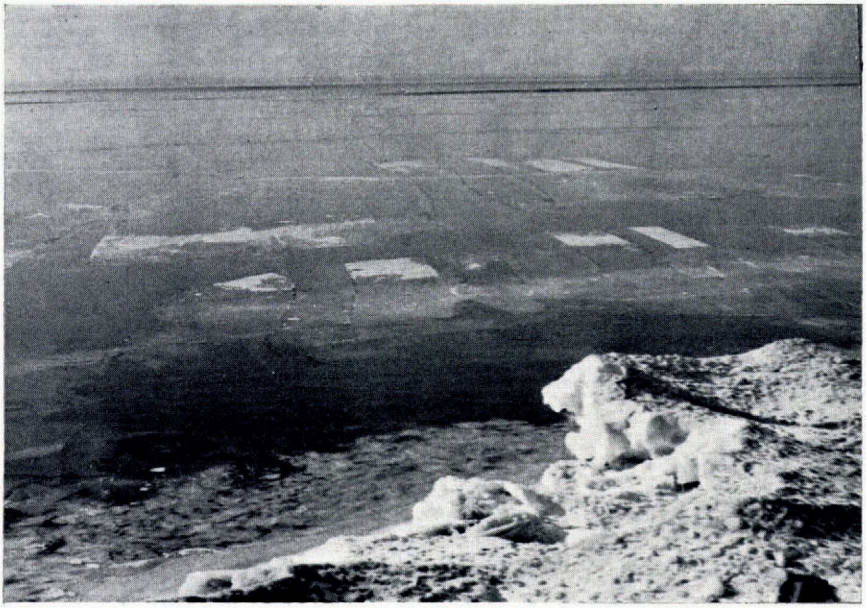

Fig. 3. Inactive finger-rafting thrust fractures; Lake Superior shore at Lakewood district, Duluth, Minnesota. 16 March 1970. Ice is 3–5 mm thick. White areas in thrust fingers appear to have air beneath them. Ice-covered shore rock in foreground.

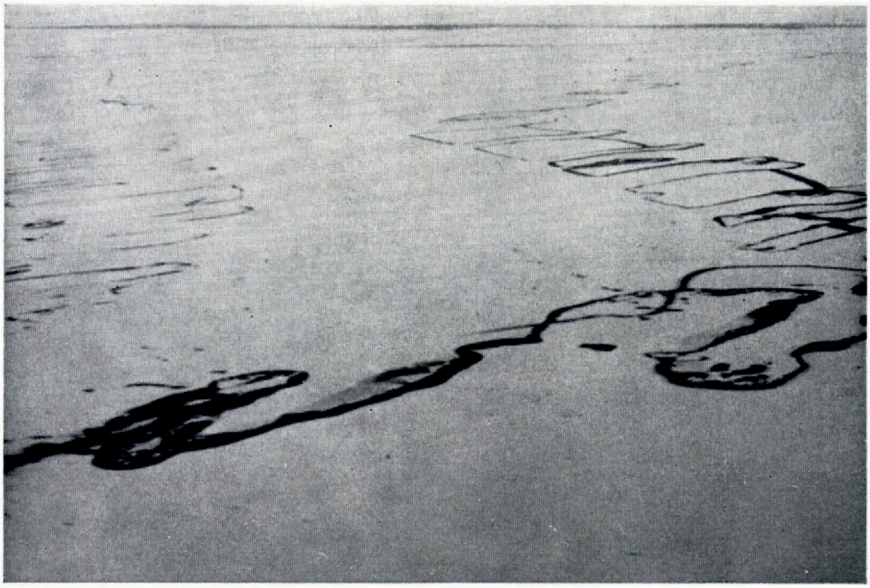

Fig. 4. Inactive finger-rafting fracture emphasized by new snowfall; Lake Superior shore, Lakewood district of Duluth, Minnesota. February 1970.

https://doi.org/10.3189/S0022143000022942 Published online by Cambridge University Press

Anderson (1958, p. 174) and Weeks and Kovacs (unpublished) that the brine leaking out of the overthrust sheet in sea ice helps to lubricate the thrust clearly is inapplicable to Lake Superior ice; the sheets apparently have an inherently very low frictional resistance. On one occasion, however, water was seen to leak up onto the ice surface just ahead of the fingers as advancing plates bowed down the underlying sheet.

MS. received 21 April 1970

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