SIR, *Depth of water-filled crevasses that are closely spaced*

I agree with the conclusion of Robin's letter. Another way to reach his conclusion is as follows. Consider material that contains an infinite row of parallel cracks. Let the spacing d between the cracks be much smaller than the length L of the cracks. The stress analysis of this problem when the outer boundary of the material is subjected to a uniform stress is given in Sneddon and Lowengrub (1969 p. 57–62), in Isida (1973), and in Tada and others (1973, p. 12.1). The result of this analysis is that the stress singularity that exists at the crack tips is approximately the same as that for an isolated crack whose length is equal to the spacing d between the parallel cracks. Thus if an applied tensile stress T is applied (in a direction normal to the plane of the cracks) at the outer boundary, the stress singularity is such that the tensile stress at distance r ahead of a crack tip is of the order of $T(d/r)^{\frac{1}{2}}$ where $0 \leqslant r \ll d$. The stress singularity at the tips of the set of parallel cracks of length L and spacing d is approximately the same as that for a set of parallel cracks of length d and spacing d (or of larger spacing).

For a set of closely spaced crevasses of spacing d and length L ($d \ll L$) the stress singularity at the crevasse tips, by analogy with the results just mentioned, is a tensile stress ahead of the crack that is approximately equal to $(T+p-\rho_i gL)(d/r)^{\frac{1}{2}}$ where ρ_i is the ice density and g is the gravitational acceleration so that $\rho_i gL$ is the ice overburden pressure at the tips of the crevasses, T is the longitudinal tensile stress present in the glacier, and p is the water pressure at the bottom of the crevasses. If no water is present ($p = 0$), a tensile stress singularity is present if L is smaller than $T/\rho_i g$. Thus because of the presence of a high tensile stress at the crevasse tips, closely-spaced water-free crevasses can penetrate a glacier until their depth reaches Nye's value of $L = T/\rho_i g$. Deeper penetration is not possible in this case because a *compressive* stress singularity then would come into existence. For completely water-filled crevasses, $P = \rho_w gL$ where ρ_w is the density of water. Since $\rho_w > \rho_i$, a tensile stress singularity exists if $T \geqslant 0$ for *all* values of L. Thus, as concluded by Robin, a set of closely spaced water-filled crevasses should be able to penetrate to the bottom of a glacier.

Departments of Materials Science and Geological Sciences,
Northwestern University,
Evanston, Illinois 60201, U.S.A.
J. WEERTMAN
8 January 1974

REFERENCES

Isida, M. 1973. Method of Laurent series expansion for internal crack problems. (*In* Sih, G. C., *ed. Mechanics of fracture. 1. Methods of analysis and solutions of crack problems.* Leiden, Noordhoff, p. 56–130.)

Sneddon, I. N., *and* Lowengrub, M. 1969. *Crack problems in the classical theory of elasticity.* New York, John Wiley and Sons, Inc.

Tada, H., *and others.* 1973. *The stress analysis of cracks handbook, by H. Tada, P. C. Paris and G. R. Irwin.* Hellertown, Pa., Del Research Corporation.

SIR, *Ice volcanoes in Ozero Baykal*

I have read with great interest the article of R. K. Fahnestock and others (1973) published in your *Journal*. My interest may be ascribed to the fact that about forty years ago I observed similar formations in Ozero Baykal (Tsurikov, 1939). At that time the first frosts and the freezing of the lake were separated by a considerable gap of time. A peculiar ice foot similar to the one described by Fahnestock and others (1973) as "shore-fast ice" formed at the lake's south-eastern shores. The local inhabitants name these ice formations "sokuy". This term has been preserved in the Russian scientific language (Botkin, 1900; Shostakovich, 1908; Tsurikov, 1939). "Sokuy" is composed of one or several ice ridges facing the lake with steeper and at times vertical slopes. The ridge heights amount to 5.5–6.5 m.

Among the ridge summits close to the lake's margin one observes the so-called "sopki" which resemble "cone-shaped ice hills which are hollow within and open to the Baykal. The outer features of these ice hills resemble ice marquees" (Tsurikov, 1939). At times the latter are spaced at a sufficient distance from one another and in other instances they are grouped together. In some areas, close to the shores where "sokuy" is not formed "sopki" are encountered as isolated hills. At times they are 6 m high.

Unfortunately, all Russian scientists (Botkin, 1900; Shostakovich, 1908; Tsurikov, 1939) observed these "sopki" in winter when the lake is completely frozen. The origin of these ice bodies remained unknown. However, Lieutenant Botkin (1900) believed that the formation of these bodies might be regarded as a result of freezing of splashes of interfering waves. Only now, following the publication of the paper by R. K. Fahnestock and others who observed the eruption of ice volcanoes in Lake Erie, is it finally clear that the "sopki" of Baykal are of a similar ice "volcanic" origin.

It appears that the ice foot of the "sokuy" type and ice volcanoes are formed not only close to the shores of Erie and Baykal. They ought to be observed in all sufficiently deep lakes in which, owing to intense mixing, complete freezing strongly lags behind the first frosts. It may be expected that these formations may be built up beneath those shores where the prevailing winds develop most severe disturbance.

Okeanograficheskaya Komissiya Akademii Nauk S.S.S.R.,
ul. Vavilova, 44, Moskva, V-333,
117333, U.S.S.R.
3 April 1974

V. L. Tsurikov

REFERENCES

Botkin, A. 1900. *Materialy dlya izucheniya ozera Baykal* [*Materials for the study of Ozero Baykal*]. St. Petersburg, Izdaniye Morskogo ministerstva, p. 1–33.

Fahnestock, R. K., *and others.* 1973. Ice volcanoes of the Lake Erie shore near Dunkirk, New York, U.S.A., by R. K. Fahnestock, D. J. Crowley, M. Wilson and H. Schneider. *Journal of Glaciology*, Vol. 12, No. 64, p. 93–99.

Shostakovich, V. B. 1908. Led na ozere Baykal [Ice of Ozero Baykal]. *Lotsiya ozera Baykal. Chast' II. Fiziko-geograficheskiy ocherk Baykala* [*Pilot of Ozero Baikal. Pt. II. Physico-geographical sketch of Baykal*]. St. Petersburg, Izdaniye Glavnogo Gidrograficheskogo Upravleniya.

Tsurikov, V. L. 1939. Nablyudeniya nad ledyanym pokrovom yuzhnogo Baykala v 1934 godu [Observation of the ice-cover of southern Baykal in 1934]. *Trudy Baykal'skoy Limnologicheskoy Stantsii*, Tom 9, p. 23–43.