My article on mass budget terms was written to stimulate discussion so that a proper conceptual framework can be evolved. I believe that Dr. Glen has definitely contributed to this aim, and I would welcome further discussion.

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7 February 1963

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SIR,

Observations of rapid water-level fluctuations in ice sink-hole lakes, Martin River Glacier, Alaska

During the summer of 1962 a series of rapid fluctuations of water levels in ice sink-hole lakes was observed on the Charlotte Lobe of the Martin River Glacier which is located in south-central Alaska, lat. 60° 28′ N., long. 144° 10′ W., approximately 97 km. east of Cordova (USGS Cordova B–1 Quad.). This glacier is unusual in that the outer 11 km. is covered with ablation till ranging from less than 0·3 to more than 6 m. thick and averaging about 0·7 m. The marginal zone, which is up to 4 km. wide, is characterized by numerous ice sink-holes most of which have standing water in them. These sink-holes average 250 to 300 m. in diameter and 30 to 90 m. in depth.

Investigation of the Charlotte Lobe is being undertaken by members and students of the Department of Geology, University of North Dakota and is financed by a grant from the National Science Foundation.

On 28 June Lake A (Figs. 1 and 2) was at 190 m. elevation and had a maximum depth of approximately 28 m. while Lake B at 213 m. elevation had a maximum depth of approximately 29 m. (personal communication from W. M. Laird and S. J. Tuthill). The water level in both of these lakes rose as much as 1 m. after prolonged rainy periods, but did not lower appreciably after subsequent dry periods.

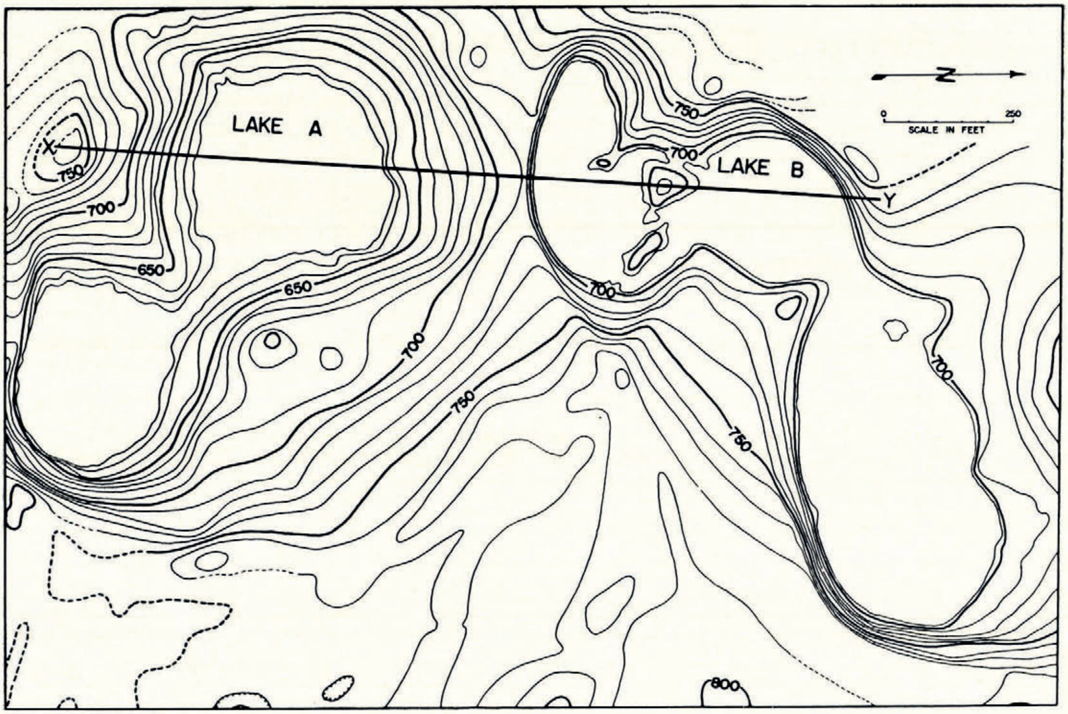

Fig. 1. Topographic map of described portion of ice sink-hole lake area, Charlotte Lobe, Martin River Glacier, showing line of cross-section

On 28 July after a week of warm, clear weather the level of Lake A was observed to have dropped about 1 m., but the numerous strand lines indicated that the lowering had not been sudden. On the following two days one of three streams discharging from tunnels at the terminus of the Charlotte Lobe some 1,600 m. down-glacier from the lakes became very silty and its volume increased four to five times. This stream was still silty on 31 July, but it had diminished to near-normal flow.

On the following morning, 1 August, when Lake A was discovered to have drained completely, it became evident that there was a direct connection between the lakes and the outlet stream. In the site of

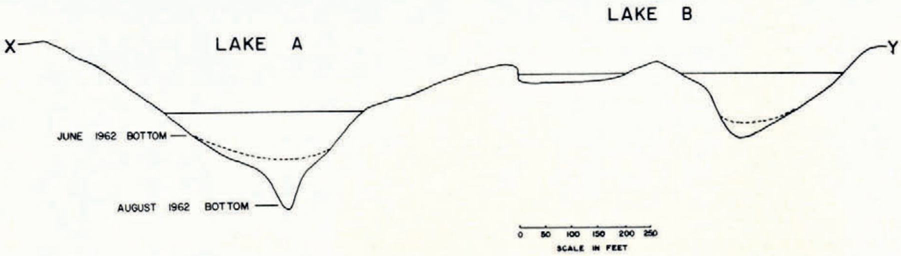

Fig. 2. Cross-section of Lakes A and B showing pre-drainage and post-drainage profiles

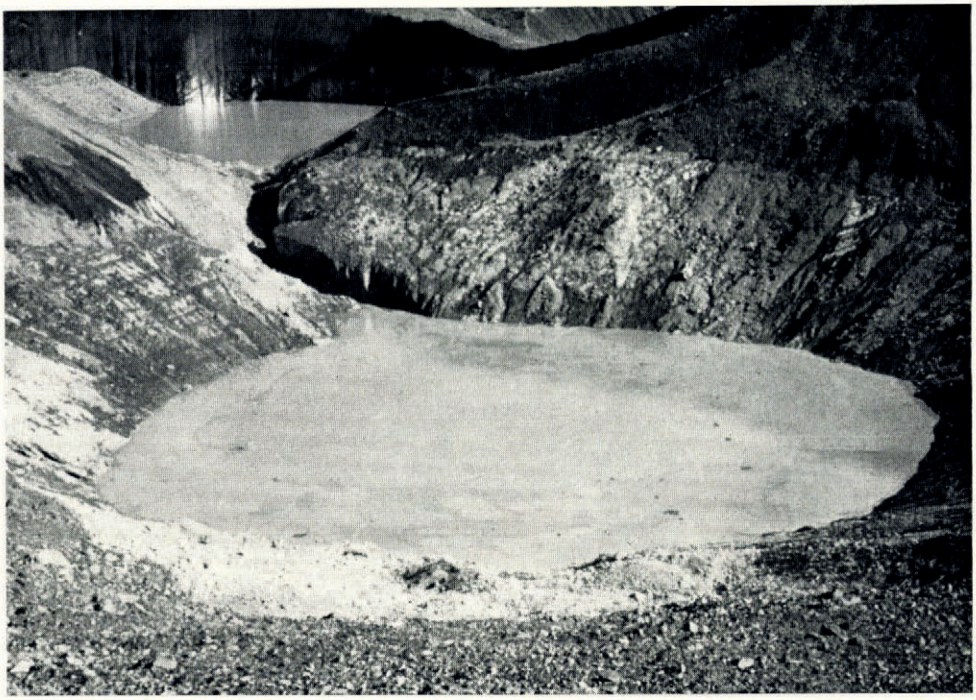

Fig. 3. Lake A refilling after having been completely drained less than one hour before. Diameter of lake at this water level is about 80 m.

the former lake there was a hole 25 m. deep in the center of a conical depression which, in turn, was some 60 m. below the level of the highest strand line and some 100 m. below the relatively flat stable upland surrounding the depression (Figs. 2 and 3). The sediments that had previously settled in the lake basin as a result of slumping from the sides and rim of the sink-hole were completely flushed out and the ice bottom was further deepened. At the same time, Lake B level was noted to have dropped about 1 m.

The following morning, 2 August, Lake A was about half full again. Shortly after a series of sharp cracking noises was heard in the ice, the lake was observed to be draining again. It drained completely in about 15 min. The cracking was presumably the result of the sudden release of water pressure in the depression; ice fragments stranded at higher levels in the sink-hole revealed that the lake had been draining at the time of our arrival. Concentric fractures dipping 30° to 45° into the ice wall were subsequently noted in the dry sink-hole.

Lake B was also draining at this time. Its level dropped about 5 m. during the four hours that it was observed on 2 August. The lake drained through a conical depression similar to the one in Lake A. An outlet stream was observed in the bottom of a newly exposed moulin 25 m. deep at the north-western edge of the lake and adjacent to the central depression (Fig. 2).

The moulin was separated from the main conical depression by an ice sill. From the roar at the bottom it was obvious that the moulin was still draining. This roaring suddenly ceased and within 35 min. the water in the moulin rose to within 15 m. of the level of the water in the central depression, and then it drained at a rate of 2 m./min. until the water level was 25 m. below the level of the central lake. After several surges and drainings the water finally drained completely. Rough calculations indicate that Lake A drained at a rate of about one million gallons per minute.

Apparently, Lake A, Lake B, and the moulin adjacent to Lake B are all connected to the same subglacial drainage tunnel; the rise of the water in all these depressions was caused both by blocking of the drainage tunnel down-glacier from Lake A and, at least in part, by the hydrostatic head resulting from the higher level of Lake B. It is suggested that differential flow of the ice in the trunk glacier caused the opening and closing of the drainage tunnels by thrusting of the ice blocks in the brittle marginal zone. The depressions are approximately 335 m. from the present ice margin and although the ice thickness is not known, the stable character of the surface indicates that the ice is not appreciably active and therefore thin. The fluctuations in the sink-holes occurred after nine days of abnormally warm, clear weather. Increased flow of the active ice may have consequently resulted. From the study of earlier photographs of this ice lobe, it is evident that such fluctuations are common here and it is possible that in some of these lakes the fluctuations are an annual event.

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