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RADIO SOUNDINGS ON TRAPRIDGE GLACIER, YUKON TERRITORY, CANADA

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Abstract. As part of a program to study surge-type glaciers, a radar-depth survey, using a frequency of 620 MHz, has been made of Trapridge Glacier, Yukon Territory. Soundings were taken at 26 locations on the glacier surface and a maximum ice thickness of 143 m was measured. A rapid change in surface slope in the lower ablation region marks the boundary between active and stagnant ice and is suggestive of an "ice dam" or the water "collection zone" postulated by Robin and Weertman for surging glaciers.

Résumé. *Sondages radio sur le Trapridge Glacier, Territoire du Yukon, Canada.* Dans le cadre d'un programme d'étude des glaciers à crue, une prospection radar en profondeur dans une fréquence de 620 MHz, a été conduite sur le Trapridge Glacier, Territoire du Yukon. Les échos ont été recueillis en 26 points sur la surface du glacier et on a mesuré une épaisseur maximum de glace de 143 m. Un changement rapide dans la pente de la surface dans la zone inférieure d'ablation marque la limite entre la glace active et la glace stagnante, et suggère un "barrage de glace" ou un "bassin collecteur" d'eau dont Robin et Weertman postulèrent l'existence pour des glaciers à crue.

Zusammenfassung. *Radarecholotungen am Trapridge Glacier, Yukon Territory, Kanada.* Als Teil eines Programmes zum Studium von Gletschern des Surge-Typs wurde eine Radar-Auslotung des Trapridge Glacier im Yukon Territory durchgeführt. Die Messfrequenz betrug 620 MHz. Die Lotungen an 26 Stellen auf der Gletscheroberfläche ergaben eine Maximal-Dicke von 143 m. Ein jäher Wechsel der Oberflächenneigung im unteren Ablationsgebiet kennzeichnet die Grenze zwischen aktivem und stagnierendem Eis; er lässt einen "Eis-Damm" oder die "Sammelzone" des Wassers vermuten, wie sie von Robin und Weertman für ausbrechende Gletscher postuliert werden.

INTRODUCTION

Trapridge Glacier (lat. 61° 14′ N., long. 140° 20′ W.) is a small valley glacier in the Steele Creek drainage basin, Yukon Territory, Canada (Fig. 1). Identified by Post (1969) as a surge-type glacier, it is located in a region of intense surge activity: the neighbouring Steele, Hodgson, Hazard, Backe and Rusty Glaciers are all known to surge.

Evidence for a surge of Trapridge Glacier is quite extensive. Collins (1972) referred to unpublished photographs of Wood, taken in 1939, which show little crevassing of Trapridge Glacier. Photographs in 1941 show extensive crevassing and Sharp (1947) remarked that his "Glacier 13" was advancing rapidly. Sharp's "Glacier 13" is Trapridge (formerly "Hyena") Glacier. Air photographs of 1951 show extensive crevassing but those of 1967 show a healed surface. From this evidence, it would appear that the most recent rapid advance of Trapridge Glacier occurred about 1940. Annual surveys, begun in 1969, of 26 marker poles on Trapridge Glacier give a maximum flow rate of 20.5 m/year during the quiescent stage of the surge cycle (Collins, 1972).

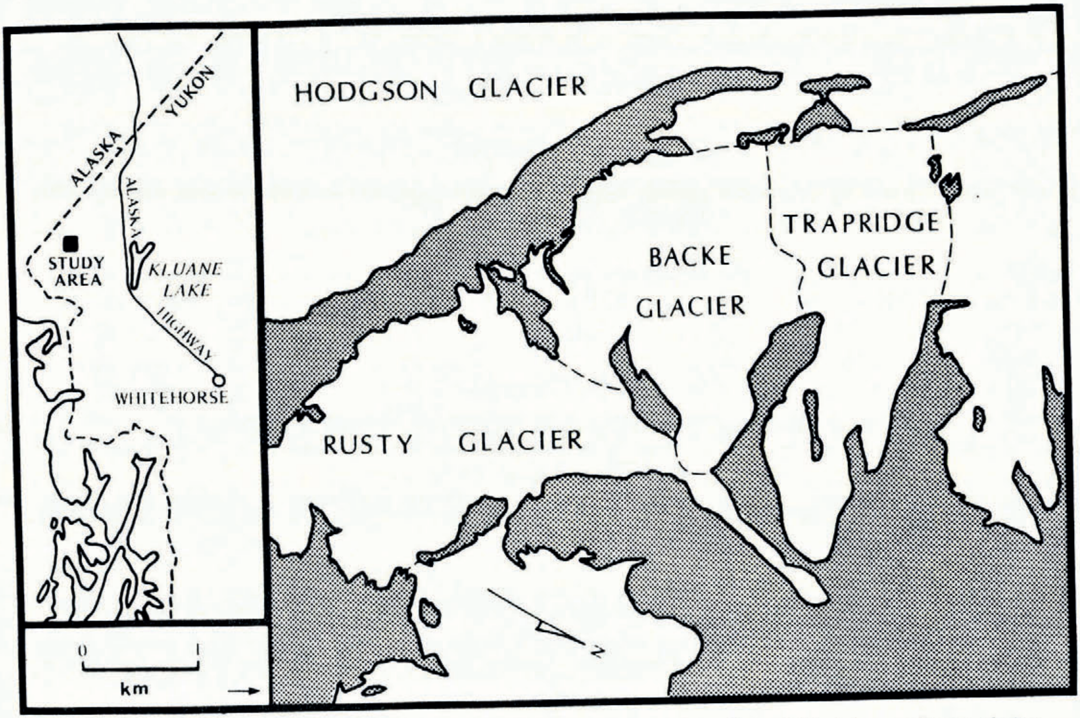

Fig. 1. Location map of Trapridge Glacier. Dashed lines indicate approximate flow divides between adjacent glaciers.

Geophysical studies consisting of radio echo soundings and deep ice-temperature measurements were initiated in 1972. The purpose of the radio-sounding survey was to provide information on channel geometry, to guide the selection of thermal-drilling sites, and to field test, in cold glacier ice, the 620 MHz sounder designed by Goodman (1970).

There has been a great deal of controversy concerning the optimum frequency for radio echo soundings. Workers in Greenland and Antarctica (Evans and Smith, 1969; Gudmandsen, 1969) have advocated low frequencies and accepted the resolution loss to gain increased penetration. For temperate and thin polar glaciers it is possible to design high-frequency equipment with excellent time and spatial resolution. Macroscopic losses in ice are practically frequency independent until nearly 1 GHz, but the volume scattering increases with frequency (Smith and Evans, 1972). Such scattering causes signal loss and a clutter of return echoes which could limit the utility of high-frequency systems. However, the increase in resolution and the ability to focus the power (a narrow beam-width antenna reduces the volume scanned) compensates for the scattering losses and gives a strong return echo.

Apparatus and field procedures

The radar echo sounder used for the present measurements (Fig. 2) was a subsystem of a more elaborate device described by Goodman (1975); the computer analysis and positioning systems were not used. This equipment weighed about 150 kg and was movable by man-drawn sleigh. Table I summarizes the radar characteristics. The transmitter produces a "sync" pulse which can be used either as an external trigger or as an input to the oscilloscope. While initially the external mode was used, it was found more convenient to use internal triggering and to scale the time differences from the resulting display. A typical display is

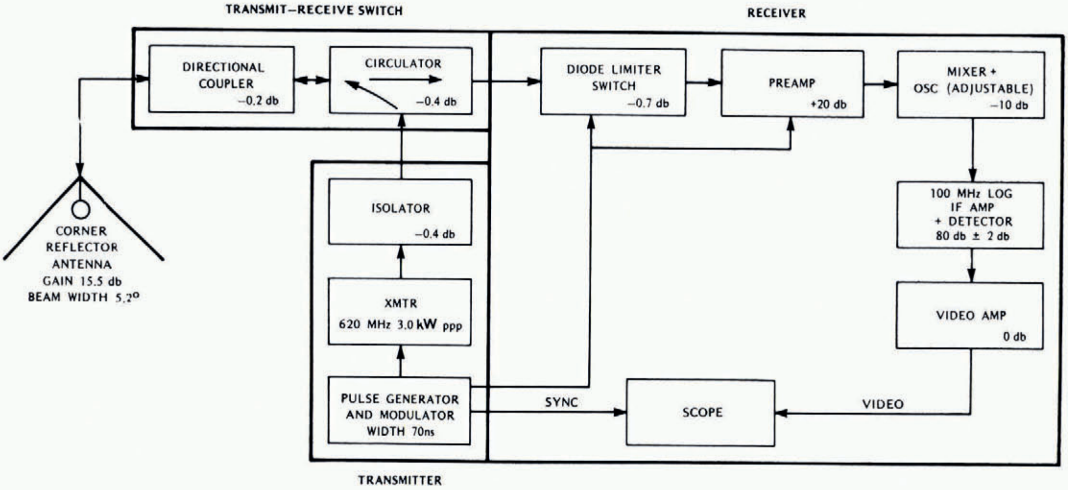

Fig. 2. Block diagram of radar set.

illustrated in Figure 3. The differences between the results from Norway using 480 MHz (Smith and Evans, 1972) and the results from Trapridge Glacier at 620 MHz (Fig. 3) are clear evidence of the ability of a high-resolution system to reduce interference caused by scattering from intraglacial structures. Short pulse lengths and a wide band width were used so the highest possible resolution was achieved. The zero delay was calibrated using a small dipole placed in the beam of the antenna. The delay between the trigger point and the dipole echo was measured and, after correcting for cable delays, the intrinsic equipment delay was found to be 80 ns, which corresponds to depth correction of 7 m.

The radio soundings on Trapridge Glacier were performed at 26 sites, established either at surveyed stakes (Collins, 1972) or at intermediate locations determined by chaining. In order to discriminate against reflections from the valley walls, two soundings were made at each site: one with the antenna rotated in a horizontal plane by an angle of 90° from the other. Most spectra were uncomplicated and no difficulty was experienced in identifying the bottom return echo. The radar echoes obtained on the lower part of the glacier provide some evidence

TABLE I. CHARACTERISTICS OF THE HIGH-RESOLUTION RADAR

Transmitter		
Frequency	620	MHz
Peak pulse power	3	kW
Repetition rate	2 000	pulses/s
Antenna beam width	5.2°	
Antenna gain	15.5	db
Pulse width	70	ns
Receiver		
Gain	90	db
Noise	6	db above thermal
Dynamic range	90	db
Band width	30	MHz
Overload recovery	150	ns
System		
Performance	169	db
Minimum range	30	m
Range resolution	2.5	m

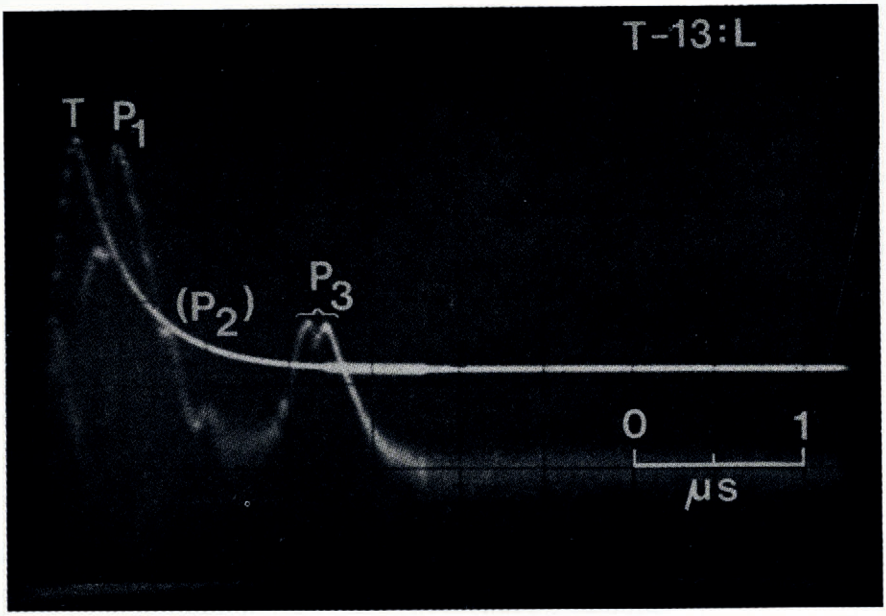

Fig. 3. A typical echogram from Trapridge Glacier survey (site T-13): T = trigger pulse; P_1 = surface return; (P_2) = intraglacier structure; P_3 = bottom return. The vertical scale is the logarithm of the amplitude. Although no precise calibration was made, each vertical scale division is approximately a decade.

TABLE II. RADIO-SOUNDING DATA

Station identification	*Map location*	*Depth* m	*Remarks*
T-1	≃ 40 m SE of Q	67	
T-2	Q	69	
T-3	≃ 60 m WNW of Q	97	
T-4	≃ 140 m N of Q	?	no apparent reflection
T-5	≃ 180 m SW of Q	108	
T-6	≃ 230 m NW of R	108	
T-7	≃ 100 m NW of R	124	
T-8	R	143	some internal structure
T-9	≃ 130 m WSW of R	131	
T-10	≃ 180 m SW of R	72	
T-11	≃ 300 m SSW of R	96	multiple bottom structure
T-12	≃ 200 m S of R	94	
T-13	≃ 90 m SE of R	131	
T-14	≃ 100 m E of R	107	double bottom peak
T-15	M	93	multiple bottom structure
T-16	L	73	crevasse zone; multiple peaks
T-17	J1	93	double peak
T-18	KX	97	
T-19	J2	101	internal structure; crevasses
T-20	14	117	
T-21	12	106	
T-22	1	80	internal structure
T-23	H3	79	
T-24	H	75	
T-25	G	71	
T-26	≃ 100 m E of G	<35	depth less than minimum

for glacial intrastructure which may be due to compressive and emergent flow in this region. There is, however, no indication of any features similar to the extensive intraglacial horizons that have been observed in temperate glaciers (Goodman, 1975). Spectra from each site were photographically recorded for further analysis.

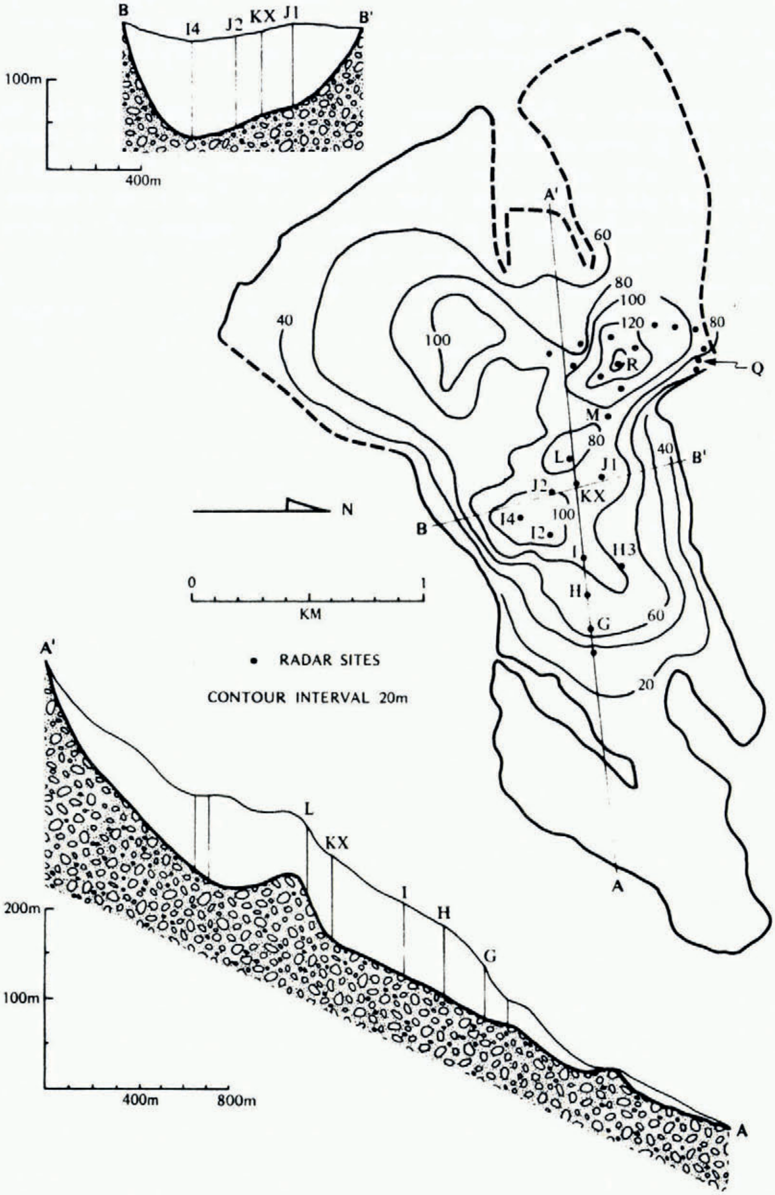

Fig. 4. Trapridge Glacier ice-thickness interpretation. The solid circles indicate sounding sites and the alphabetic identifications correspond to 1972 locations of the marker poles placed by Collins.

RESULTS

The measured ice thicknesses are presented in Table II. From these data, in combination with elevation survey results, a total of 18 longitudinal, transverse, and diagonal depth profiles were constructed and the bedrock topography deduced. The longitudinal profile is well established by the number of points along it and was used as a control for the transverse and diagonal profiles. Where interpolated curves from two or more profiles intersected, the mean depth was taken and each profile was readjusted accordingly. The largest discrepancy where two profiles intersected, was 10 m and this is an indication of the consistency, though not necessarily the accuracy, of the interpolation scheme. From the depth profiles ice thicknesses were contoured (Fig. 4).

The maximum measured ice thickness was 143 m recorded at stake R in the accumulation region. The bedrock high near stake L correlates with a crevasse field, the maximum observed flow velocity (Collins, 1972), and a rapid change in surface slope. Near stake G the flow is strongly emergent and below this point the glacier is inactive. The ice crest in this region does not appear to reflect bedrock topography and Collins (1972) suggested the presence of a dam of stagnant ice. Similar crests were predicted by Robin and Weertman (1973) in their recent surge theory; the zone near stake G might correspond to their "collection zone". The Robin–Weertman surge theory relies on certain stress conditions which favour basal water collection and is particularly useful in explaining surges of presumably temperate glaciers: Trapridge Glacier, however, is sub-polar. Ice-temperature measurements, to be published separately, indicate that below stake G the base of Trapridge Glacier is cold and therefore frozen to the bed, while above stake G a large "hotspot" exists. We therefore conclude that for this glacier the presence of basal water is thermally rather than mechanically controlled. Similar conclusions have been reached for the nearby Rusty Glacier (Classen and Clarke, 1971) and some form of thermally regulated water-film instability is therefore believed to control the surge behaviour of both glaciers.

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