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Abstract

In May, 1985, a field camp was set-up at Fort Selkirk on the Yukon River to observe break-up. This particular location was chosen because historical records showed it to be a common site for ice jam formation. However, the break-up of 1985 proved to be very gentle: water levels and flows remained low; thermal leads opened up along the entire length of the reach; and the ice simply melted in place. Although this sequence of events precluded any observations of ice jam hydraulics, it did allow observations of the kind of break-up that does little damage through flooding and ice pressure. In this report we describe the attendant conditions that seem to favour a mild break-up, and point out certain factors that may be of special concern to understanding break-up in the Yukon River Basin.

1. Introduction

The objective of the Yukon Ice Seasonality Experiment (YISEX) is to gain an understanding of physical processes affecting ice cover on northern river and lake systems. As part of this work, we observed break-up on the Yukon River at Fort Selkirk (Figure 1) to find out if patterns of break-up within this climate and setting were similar to those that occur elsewhere in Canada (c.f. Beltaos, 1984). In particular, we planned to observe the formation and hydraulic features of an ice jam.

The main concern about ice jamming is that it can result in the flooding of communities along the river. Figure 2, taken below Fort Selkirk in May, 1966, illustrates the degree of flooding that can occur following an ice jam.

The Fort Selkirk site was chosen for three reasons. First, historical records (Underwood McLellen Ltd., 1983) show that ice jams formed here in 31 out of 43 years for which observations are available. Second, the existance of buildings for shelter and a servicable air strip simplified logistical problems. Third, its location downstream of two proposed hydro-development sites (Eagle's Nest Bluff on the Yukon River and Granite Canyon on the Pelly River) means that this reach could be affected by such development; for example, the construction of a reservoir might alter streamflow during spring, a critical factor at break-up.

However, despite historical trends, the 1985 break-up was mild along the entire river, and no jamming occurred at Fort Selkirk. According to the classification given by Deslauriers (1968) the low run-off, intense deterioration, and in-place melting of the ice cover observed in 1985 defines an "overmature" break-up; this is in contrast to the "premature" break-up which occurs with intense run-off and little prior deterioration of the ice cover. It was, however, the kind of break-up most northern residents prefer.

In this report we wish to (a) identify those factors that contributed to the mild break-up; and (b) apply certain ideas suggested by Beltaos (1984) to conditions along the Yukon River.

2. Study Area

The Yukon River between the Pelly and the White rivers is usually the last to clear of ice each year (Kent, 1982), and appears to be especially susceptible to ice jamming (Underwood McLellan Ltd., 1983).

Fort Selkirk itself is located on the Yukon River immediately below the mouth of the Pelly at an elevation of about 430 m. Here, the river is about 300 m wide, and has a surface slope of about 0.6×10^{-3}.

Ice jams typically form between the bend, located 1.5 km below the town, and Victoria Rock, 3.5 km below town, when broken ice is carried into the reach. Such floes may be derived from either the Pelly River or the Yukon River with the former being the greater source. When jamming occurs ice may back-up 2 km or more and the water level at the town site may rise 6 m within a few hours (Danny Roberts, Fort Selkirk, personnal communication).

3. Observations

The following activities were carried out: (a) velocity and ice thickness measurements were made at the Victoria Rock section; (b) a photographic station was set up on Victoria Rock; and (c) daily surveys of water level were made at various points along the study reach between the town site and Victoria Rock.

Figure 3 shows changes in ice cover that occurred over a one-week period during break-up. At the start of break-up (4 May) the surrounding land is almost clear of snow, and areas of ice deterioration and open water are beginning to appear on the river at mid-channel. One week later (13 May) the river is open to a width of about 100 m, and only grounded shore ice remains. Although some small floes were observed moving downstream, none were of sufficient width or thickness to jam.

Throughout this period the water levels were observed to remain constant at about 1.8 m below freeze-up levels. Hence, much of the existing ice cover remained beached on emergent shores or sand bars and thus simply melted in place.

The velocity field across the Victoria Rock section on 4 May and the the distribution of ice on 4, 7 13,14, and 17 May are shown in Figure 4. The discharge is 414 m^3/s. An important feature is the pronounced velocity core, approximately 60 m in width, located about 90 m from the right bank. About 80% of the total discharge occurs within this narrow core.

The opening of the river is clearly associated with this velocity core. For example, on 4 May the ice cover is markedly thinner above the core. By 7 May a 60 m wide lead has opened; and by 14 May only shore ice remains. This pattern of thermal lead development was observed along the entire reach.

4. Discussion

Beltaos (1984) lists several factors which contribute to the character of break-up; his list provides a useful framework for discussing the 1985 break-up.

Antecedent Conditions - A comparison of data published by the Canadian Climate Program (1982) and the Water Survey of Canada (1983) with observations obtained in 1984-85 (Alford and

Carmack, 1985) shows that the winter of 1984-85 was characterized by a late freeze-up, by above average air temperatures, and by above average snowfall. These factors led to an ice cover that was 30 to 40% thinner than average throughout the river basin.

Hydrologic Conditions - An important consideration in the Yukon River Basin is the marked difference in elevation between the snow pack (which supplies the run-off) and the ice cover of the river. There is also a large horizontal distance separating the snow pack and the river. Hence, these two components may experience widely different air temperatures during any given spring. In turn, this may effect a significant time lag between ice melting and the increase in runnoff.

Meteorological Conditions - In combination with the above the different meteorological variables (i.e solar radiation, air temperature, rainfall) may affect the ice cover differently than the snow pack. It is the experience of the second author that water levels in the Yukon River do not begin to rise in spring until the air temperatures at 1200 m increase above $0^{o}C$, and that the rise will be especially rapid if accompanied by rainfall; on the other hand, the deteoriation of the ice cover is strongly dependant on solar radiation. In 1985 there was sufficient solar radiation at lower elevations to melt the ice cover, but insufficiently high air temperatures and rainfall at higher elevations to melt the snow pack and increase runoff.

Geomorphic Conditions - Sand bars and emergent banks are ubiquitous in the Yukon River. Hence, the grounding of floes in shallow water is an important mechanism for the initiation of jams. However, the unusually thin ice cover in 1985 meant that floes, having a shallower draft, were less likely to ground in shallow portions of the river. Also, because the water level remained low, much of the potential ice supply remained beached and melted in place.

Hydraulic Conditions - The velocity core described above effects differential heating of the overlying ice by the conductive transfer of heat from the flow. Such heating, which occurs when solar radiation warms the underlying water above the freezing temperature, allows the formation of open leads which offer channels for the passage of floes. At Fort Selkirk in 1985 the leads opened so quickly and the incoming floes were so small that there was little chance of jamming.

To estimate the relative importance of thermal lead formation, we follow Baines (1961) and Ashton (1980) and note that the flux of heat from a river to its ice cover is given by $H_i = C_n\ (k\ T_w/D)\ R_e\ P_r^{1/3}$, where C_n is a shear coefficient (0.023 for pipe flow), R_e is the Reynolds Number (U_o D/v), P_r is the Prandtl Number (13.6 for water at 0 ^oC), k is the thermal conductivity (0.564 W/m^{o}C), v is the kinematic viscosity (1.787 x 10^{-6}), T_w is water temperature, D is the depth, and U_o is the mean velocity. For conditions near the core, and supposing T_w = 0.02 ^oC, we obtain H_i = 346 W/m^2. This flux is sufficient to melt approximately 0.09 m of ice per day, close to the observed rate. Away from the velocity core the heat flux is less.

5. Recommendations

Clearly, the break-up of an ice-covered river is an extremely complex event (see Figure 5, for schematic representation). However, the above observations suggest a direction of study which seems especially relevant to understanding break-up on the Yukon River; namely, to quantify how differing meteorological conditions affect the release of runoff from high elevations and, at the same time, control the rate of ice cover deterioration. Such work would likely require the efforts of a multi-discilpinary team covering the areas of hydrology, climatology, hydraulics, and ice physics.

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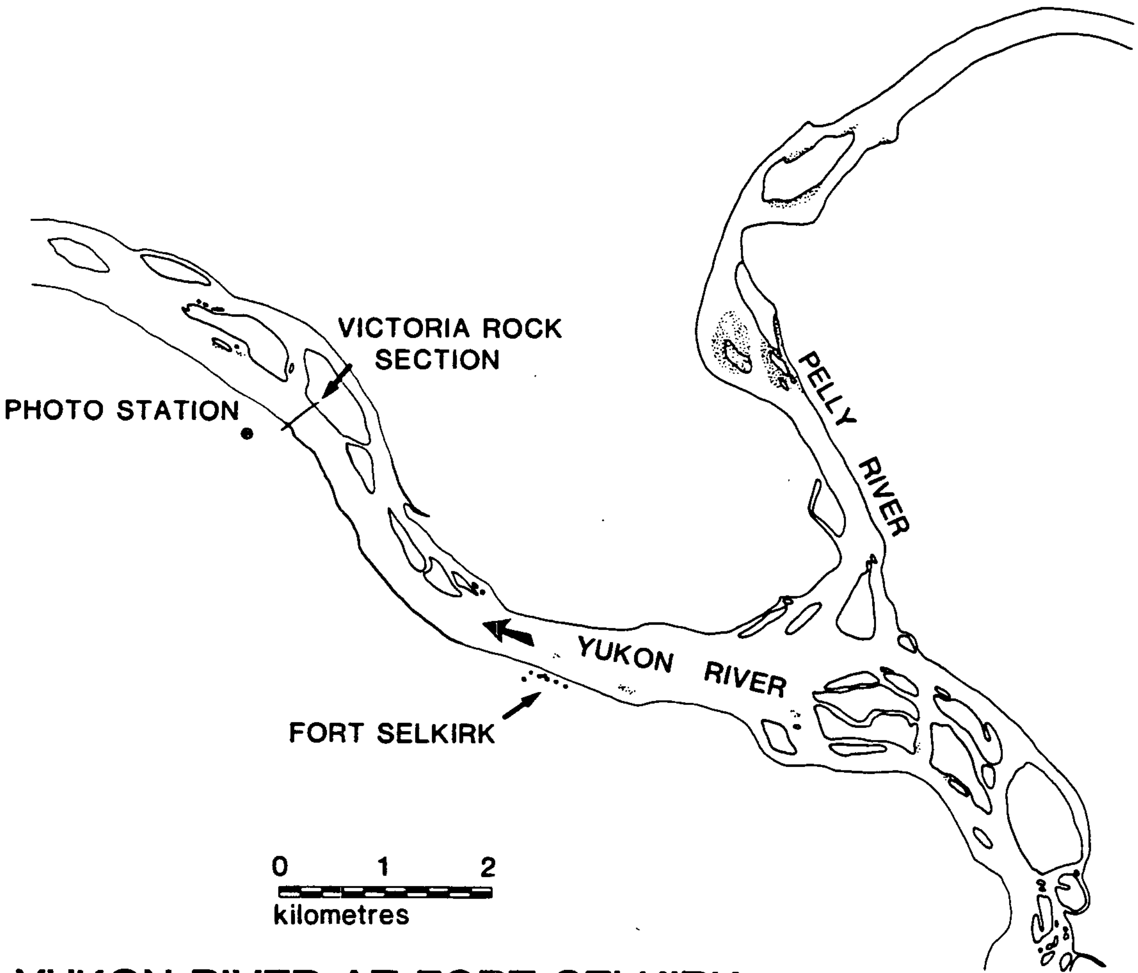

YUKON RIVER AT FORT SELKIRK

Figure 1 Study area: the Yukon River at Fort Selkirk.

Figure 2 Photograph of grounded ice following a ice jam on the Yukon River between the Pelly and White rivers.

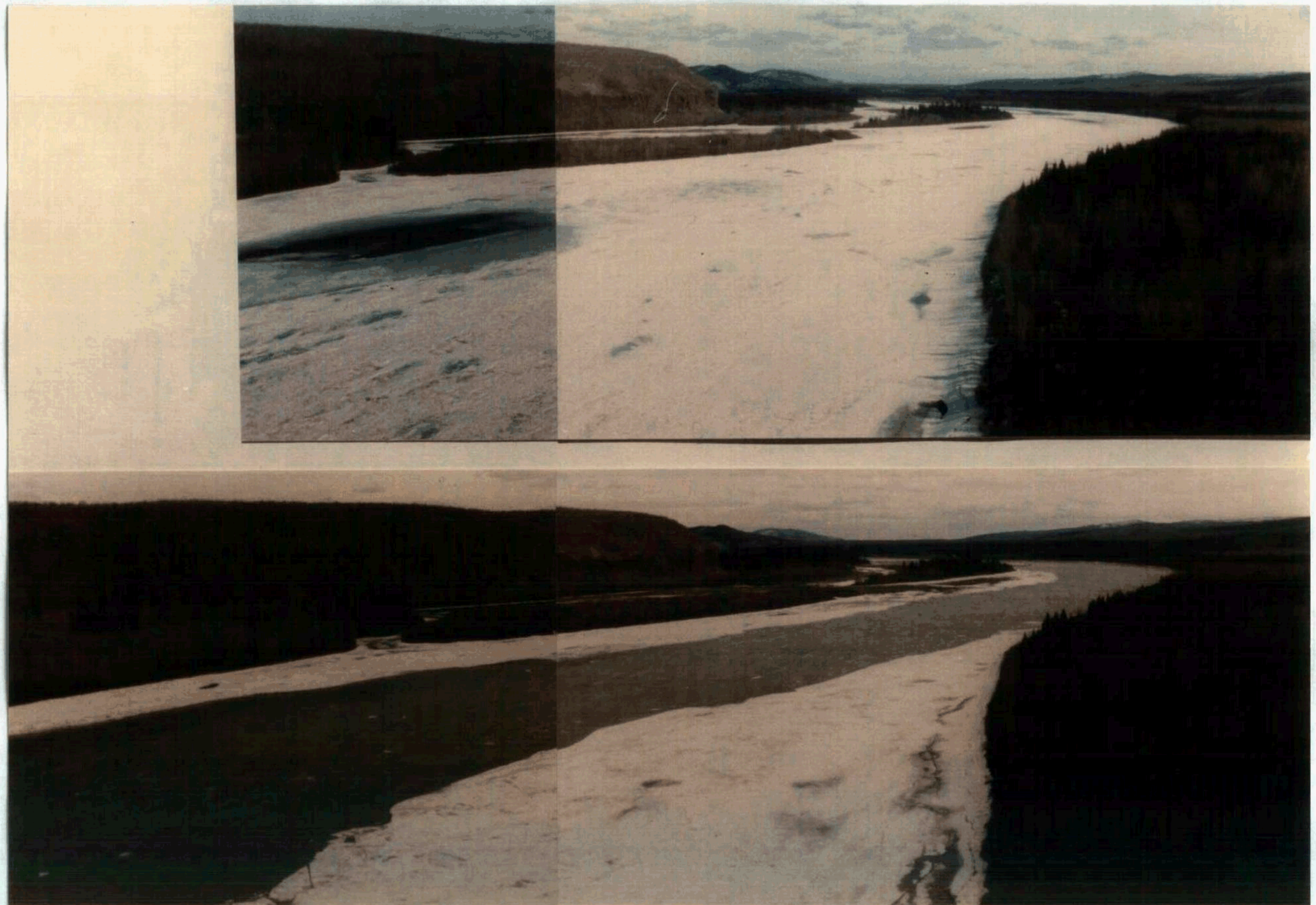

Figure 3 Photograhs of the study reach taken from the top of Victoria Rock on 4 May and 13 May.

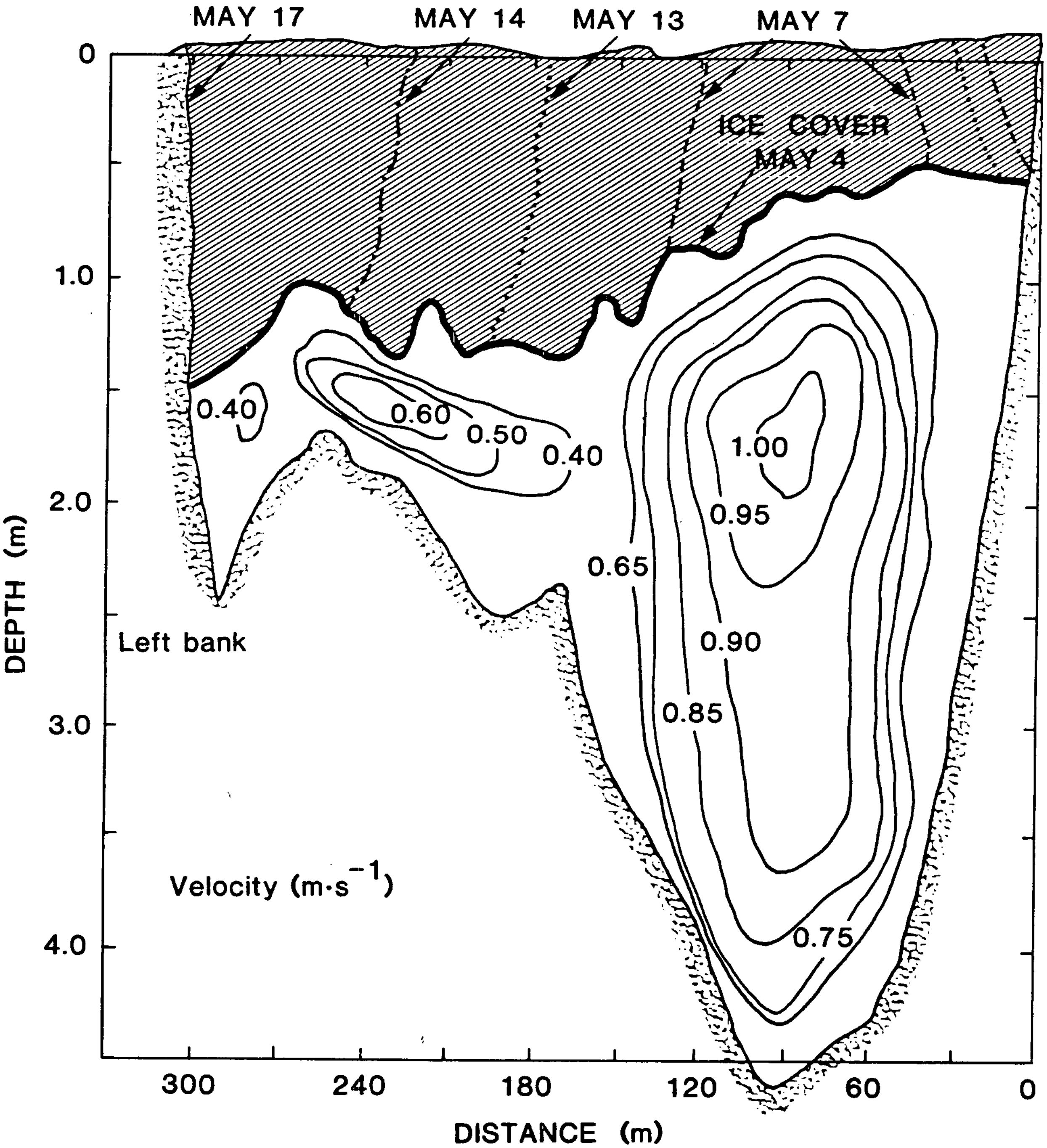

Figure 4 Section at Victoria Rock showing velocity on 4 May, and ice cover on 4, 7, 13, 14, and 17 May, 1985.

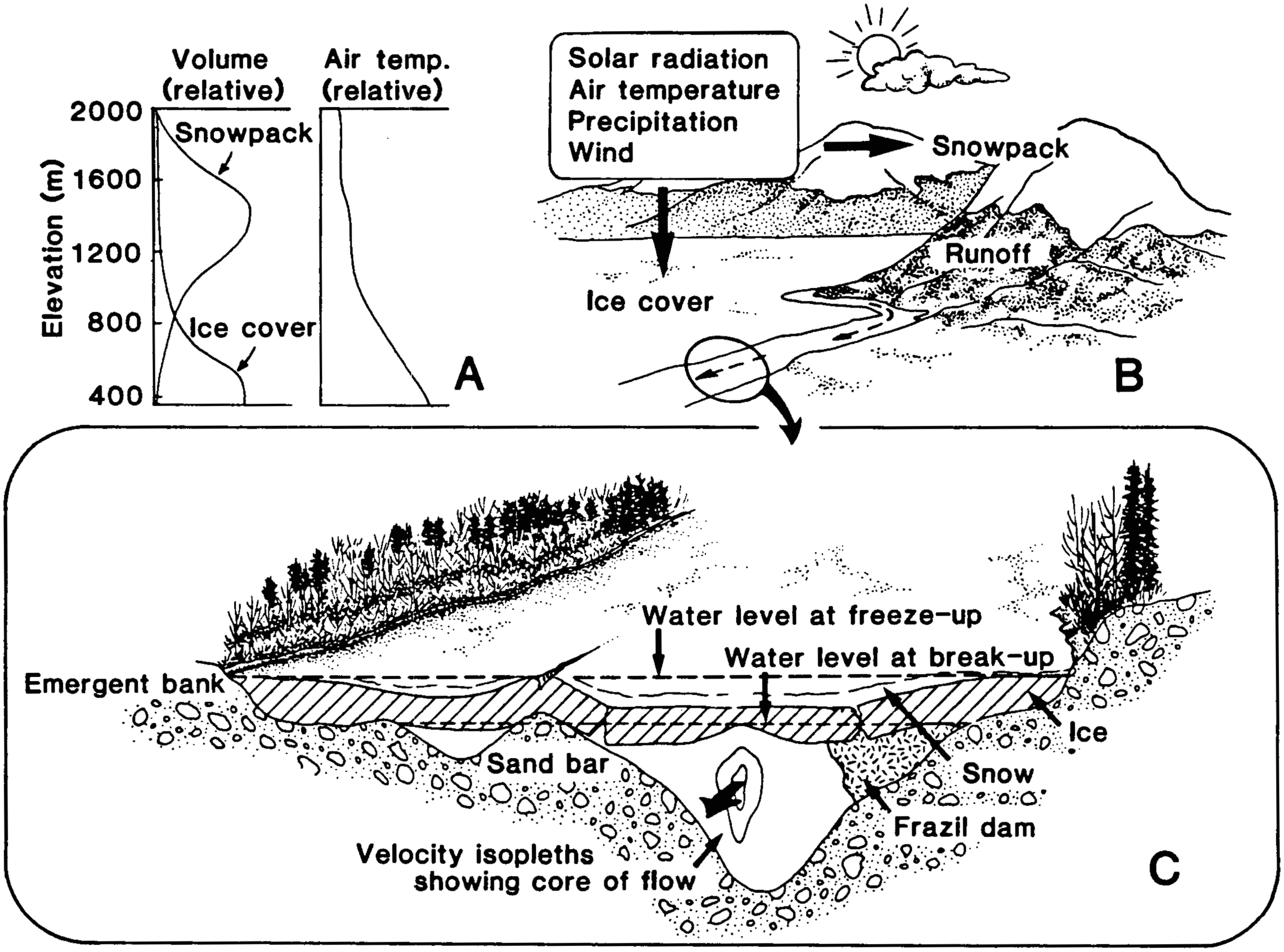

Figure 5 Sketch of parameters affecting break-up in the Yukon River Basin showing: (A) that ice-cover and snowpack occur at different elevations; (B) that different meteorological conditions are obtained; and (C) hydrological conditions of importance.