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In geomorphology, an *ice plateau* is defined as an ice-covered highland area whose upper surface is nearly level and whose sides slope steeply to lowlands or the ocean. A striking example of such a landform is the high ice plateau on the Juneau Icefield. This ice plateau is located in northwestern British Columbia close to the U.S. border between Atlin and Juneau, Alaska. From this flat, high ice plain at an elevation of 1875 m fall the Llewellyn, Tulsequah, and Matthes glaciers. Our most interesting observation about this ice plateau is that the present-day surface ice movement is largely independent of the subglacial topology, as revealed by geophysical measurements.

The Juneau Icefield is the fifth-largest icefield on the North American Continent (Figure 1). This temperate to sub-Arctic glacier complex lies along the longitudinal axis of the Boundary Range, straddling the international border. The Juneau Icefield encompasses 4000 km^2 of interconnected glacial tributaries and highland névé zones, representing the most heavily glaciated sector along the axis of the Coast Ranges. The highlands of the icefield have the appearance of being ice-flooded, with a much larger percentage of névé exposed than nunataks. The uppermost snowfields crest at 1830 to 1980 m. The highest peaks reach elevations over 2440 m. Relative to the surrounding terrain, the high ice plateau of the Juneau Icefield is flat, with no more than ±30 m of ice surface relief over an area of some 50 km^2. The Llewellyn Glacier flows north-northeast from the high ice plateau, falling about 30 m / km toward Atlin Lake through the Atlin Wilderness Park in British Columbia; the Tulsequah Glacier flows east-southeast from the high ice plateau, falling about 80 m / km into the Tulsequah River Valley of British Columbia; the Matthes Glacier flows south-southwest from the high ice plateau, falling about 34 m / km into Alaska, joining the Taku Glacier, a tidewater glacier that flows south to the Taku Inlet.

The high ice plateau links some of the world's most famous glacial complexes (Figure 1). Lying southeast of the high ice plateau, the Taku system includes, among others, the Matthes, Mendenhall, Herbert, Norris, and Eagle glaciers, as well as its namesake, the Taku Glacier (Miller 1960). The Taku Glacier is unique in that it is at present the only advancing glacier in the region, largely as a result of its extensive ice-covered highlands compared to other tidewater glaciers (Pelto and Miller 1990). Lying northeast of the divide, the Llewellyn glacial system includes many branches. The main Llewellyn Glacier is a historically popular tourist destination accessed via Atlin, British Columbia, and is renowned for its rapid recession during the past century. The Tulsequah Glacier system includes Tulsequah Lake, a body of water impounded by the glacier, which drains periodically in a catastrophic manner (Marcus 1960).

Curiously, the high ice plateau of the Juneau Icefield has the geographic distinction of being the true (i.e., most southern) headwaters of the Yukon River. The Yukon River flows some 3200 km north and west from Atlin Lake to the Bering Sea. Atlin Lake's most southern water source is on the high ice plateau of the Juneau

The Canadian Geographer / Le Géographe canadien 43, no 1 (1999) 99–104

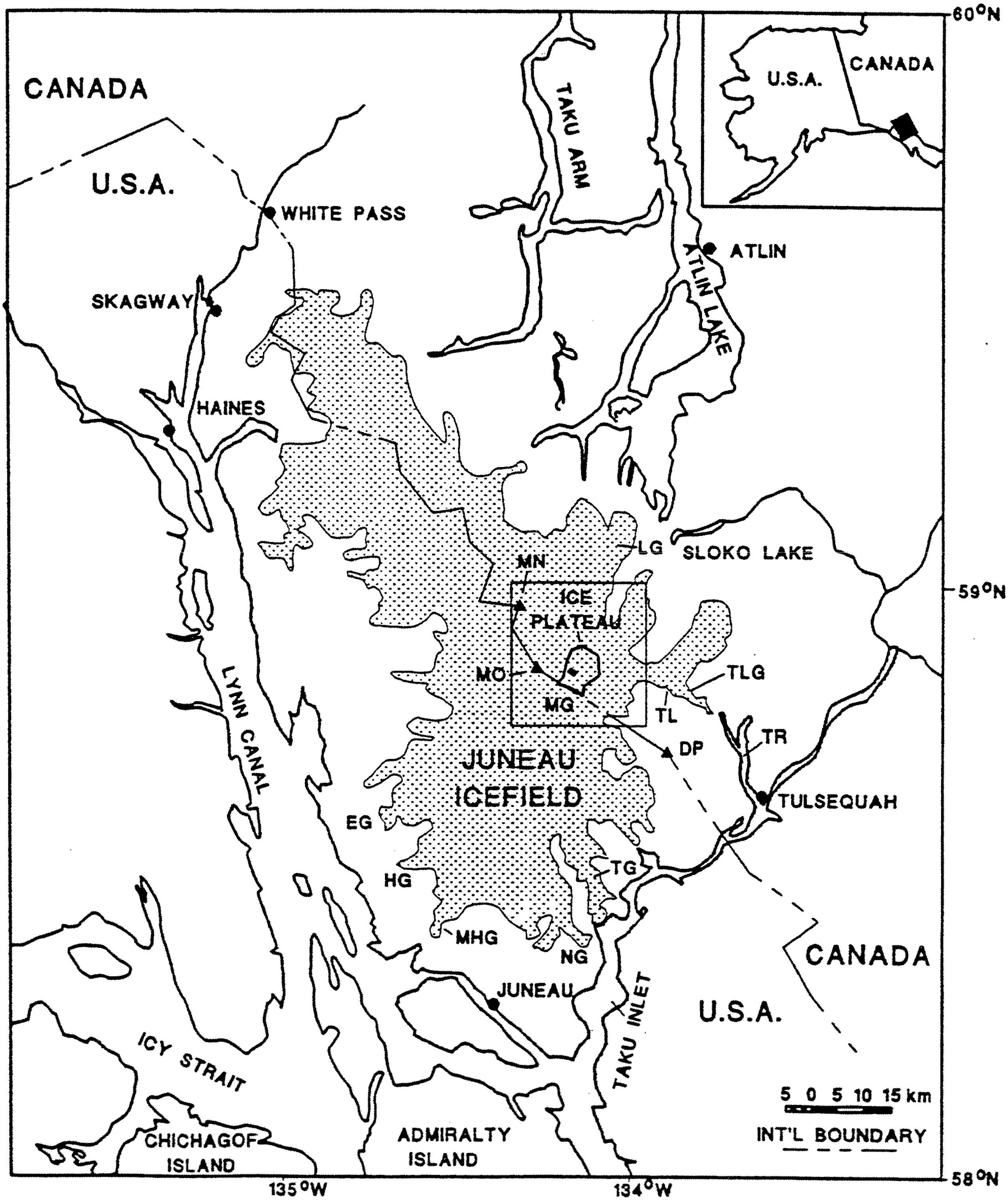

Figure 1

General map of the Juneau Icefield region. The stippled area is the Juneau Icefield. The inset rectangle indicates the location of the study area shown in shaded relief in Figure 2. Mountains (triangles) are DP, Devils Paw; MO, Mount Ogilvie; MN, Mount Nesselrode. Glaciers include EG, Eagle Glacier; HG, Herbert Glacier; MHG, Mendenhall Glacier; NG, Norris Glacier; TG, Taku Glacier; TLG, Tulsequah Glacier; LG, Llewellyn Glacier; MG, Matthes Glacier. TR is the Tulsequah River; TL is Tulsequah Lake.

Icefield. On the other hand, meltwater on the southern and western edges of the Ice Plateau flows a few tens of kilometres into Pacific Ocean saltwater in the Taku Inlet via the Tulsequah and Taku drainage systems.

The high ice plateau is of considerable climatological and glaciological interest, lying on the boundary between the moist Maritime Polar and the dry Continent Polar weather systems. Ice movement is theoretically very slow on the crest of a divide and, being in the upper névé zone, little ablation occurs to balance the snowfall. In an average mass balance year on the Taku Glacier system, nearly 3×10^8 m^3 of ice surplus occurs, a striking effect of the snowfall and low ablation on the higher levels of the system (Miller 1963).

Thus, a long record of annual ice accumulation may be preserved in the ice stratigraphy on the high ice plateau. Ice cores from a future borehole on the ice plateau might provide information on the climate at this unique location for the last hundreds to thousands of years.

Field Investigation

During the 1997 summer field season, a grid of 30 survey stations was established on the high ice plateau in order to locate exactly the ice-flow divide between the Llewellyn and Matthes glaciers, part of a larger investigation to study in detail the high ice plateau's suitability as a site for a future research borehole. Geodetic Global Positioning System (GPS) measurements were used to measure surface ice velocity. A rectangular grid of 30 stakes, at a spacing of 300 m, was placed transverse to the longitudinal axes of the Llewellyn Glacier to the north-northeast and the Matthes Glacier to the south-southwest (Figure 2). Relative to a base station on a nearby bedrock nunatak, geodetic measurements using GPS provided stake locations accurate to 0.01 m and elevations accurate to about 0.05 m. Over a nine-day period, the horizontal movement of the slowest stake was 0.06 m, and the horizontal movement of the fastest stake was 0.77 m. The stakes were initially surveyed on August 4, 1997, and resurveyed on August 13, 1997.

Two geophysical methods, seismic reflection and gravity, were also employed to determine the thickness of the ice on the plateau. The seismic reflection survey took advantage of the surveyed grid, with geophones and shots placed along surveyed lines. An L-shaped geophone spread was employed to ensure three-dimensional coverage. The records were all of high quality, and the reflecting events from the base of the ice were easily picked. A seismic ice velocity of 3660 m / s was used to convert seismic reflection times to ice thickness and to locate subglacial reflection points. Thirty gravity measurements were made on the survey grid as well. Conventional gravity corrections were applied to the measurements, including drift, free-air, Bouguer, latitude, and terrain reductions. The high ice plateau provided an exceptional environment for gravity interpretation in that considerable seismic control on the ice thickness existed and the bubbly glacial ice itself is virtually homogeneous in density, eliminating the possibility of shallow anomalous densities above the base of the glacier. The subglacial topographic model of the divide shown in Figure 3 is consistent both with the seismic reflection control points and with the gravity measurements. For complete technical details of the geophysical surveys and interpretation, see Sprenke et al. 1997.

Subglacial Morphology and Ice Movement

The geophysical results show that the high divide is a locality of surprisingly rugged subglacial topography, not at all what one might surmise from the featureless flat plain of the ice surface. Below the ice, the divide appears as a saddle-shaped morphology with an ice thickness of 925 m at the centre of the saddle. A central bedrock trough bounded by 45-degree slopes shows a relatively flatter bottom, widening toward the Llewellyn Glacier side. A tributary subglacial trough trends up the neve field along the northeastern slopes of Mt. Ogilvie.

Surprisingly, the ice velocity vectors, which range up to 8 cm / day, trend parallel to the topographic divide, in an east-southeast direction, perhaps into the Tulsequah system, despite the subglacial topography appearing to have a steep wall in that direction. On the other hand, a tributary subglacial valley appears to be going up to the northwest into the icefield northwest of Mt. Ogilvie, suggesting that ice flow from that direction is important in understanding overall ice movement in the divide. Although the surface ice flow vectors are unrelated to the bedrock topography, they appear strongly correlated with the slope of the ice surface (Figure 3). Apparently, ice moving downslope from the Mt. Ogilvie area is pushing the surface ice at the divide to the east into the Tulsequah drainage.

The ice flow velocity minimum (about 7 mm / day) is located in the southeastern corner of the grid, some 700 m distant from the bedrock topographic divide indicated by the geophysical surveys. Here, the ice travelling transverse to the older bedrock channels is perhaps slowed by the steep southeastern walls of the older glacial trough. Here the ice is about 600 m thick, some 300 m thinner than at the topographic divide.

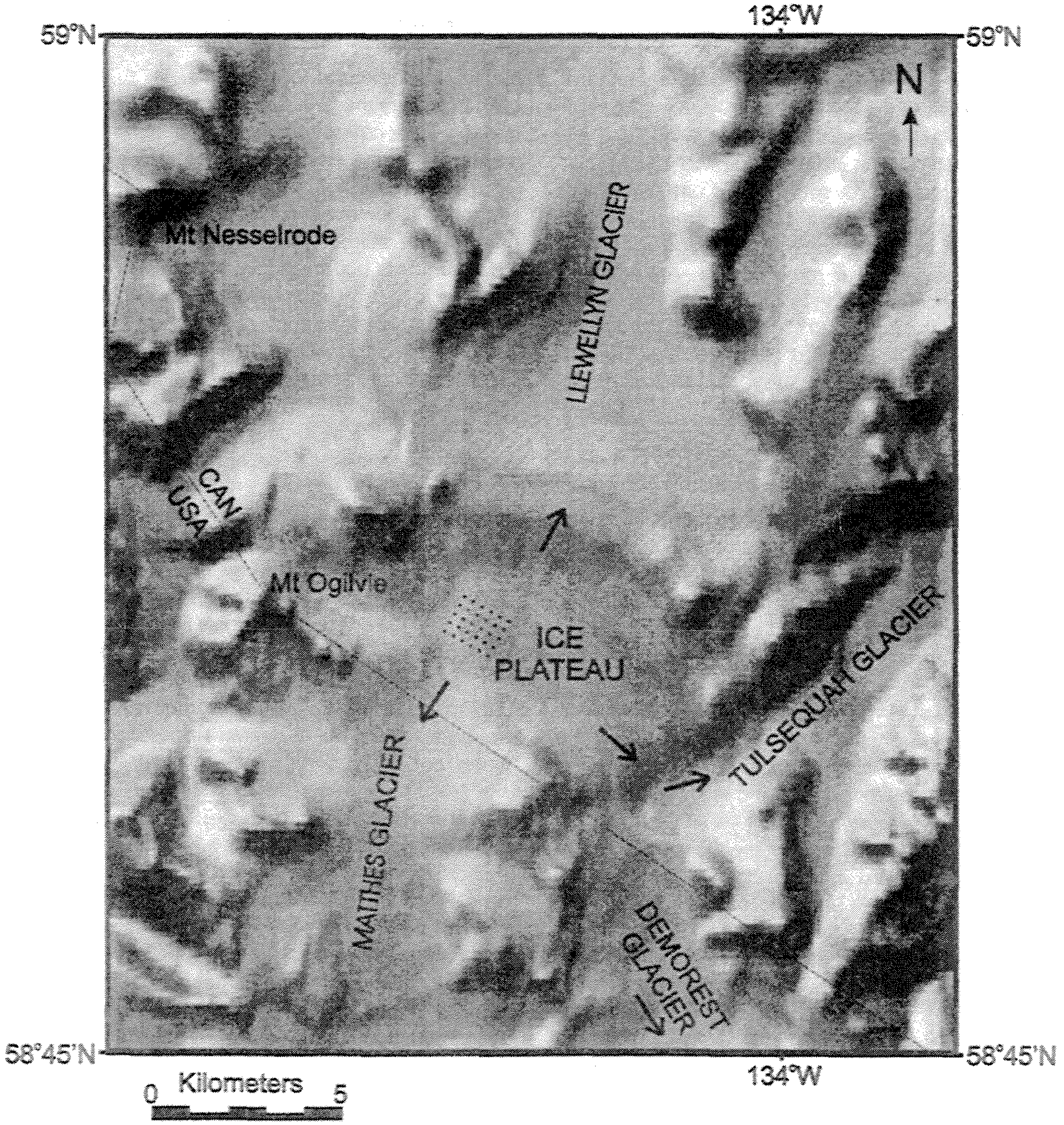

Figure 2
The high ice plateau of the Juneau Icefield and vicinity. The dots show the location of the GPS survey grid, established in the 1997 field season, the study area for the geophysical surveys described in this report. The arrows indicate general direction of surface ice flow. See Figure 1 for location.

Conclusion

The high ice plateau of the Juneau Icefield is a high plain of low relief from which three major glaciers flow. We have discovered that below the featureless, relatively flat ice plain, a rugged, saddle-shaped bedrock morphology exists, including glacial troughs cut by the Llewellyn and Matthes glaciers, with side slopes up to 45°. We have also found that present-day surface ice movement on the high ice plateau is largely independent of the subsurface morphology as the ice, up to 950 m thick, moves from the slopes of Mt. Ogilvie parallel to the divide and transverse to the Matthes and Llewellyn Glacial channels toward the Tulsequah Glacier. The surface ice velocity is consistent with the gentle slope of the present-day ice surface.

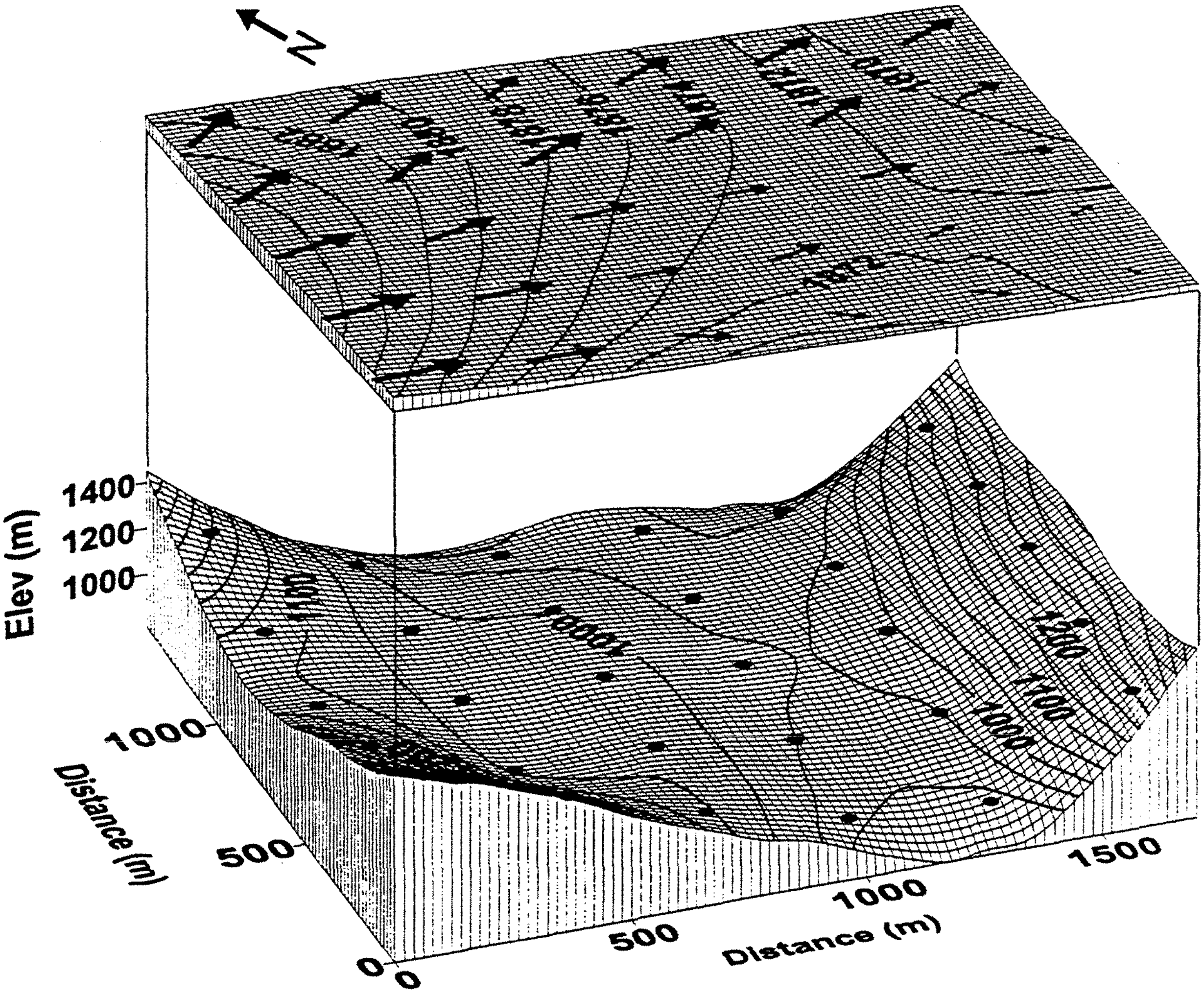

Figure 3
Surface and bedrock morphology of the high ice plateau on the Juneau Icefield. Upper surface shows the surface topography and the movement vectors in the area of the divide. Arrows indicate the magnitude and direction of the surface movement at each survey flag. Lower surface shows the subglacial valley at the divide, as determined by seismic and gravimetric methods.

Our results pose an interesting geomorphogenic scenario. The subglacial topography shows that, at lower ice levels, northerly and southerly trending troughs were cut into the topographic divide by the Llewellyn and Matthes glaciers. However, these old channels do not form the dominant control for the present-day easterly surface ice movement on the divide. The relatively high ice levels today allow ice from the slopes of Mt. Ogilvie to push ice from the high ice plateau toward the Tulsequah Glacier, moving the surface ice transverse to the old bedrock channels. A distinction needs to be made between the surface movement and the movement at depth. While the subglacial topography does not influence the surface movement at the grid, at some undetermined depth below the ice surface, the bedrock topography must control the direction of the ice movement.

We have also discovered that the present-day location of minimum ice flow velocity (7 mm / day) is displaced 700 m from the bedrock topographic divide. The ice thickness at this stalled ice is only 600 m, some 300 m less than that above the topographic divide, greatly reducing the ice stratigraphy that might be available in a future ice core. Furthermore, it is unlikely that the ice at the present-day location of stalled ice has been stalled in the past. The complicated present-day flow regime and the geomorphogenic history of the ice plateau will therefore require considerably more study before a research borehole can be intelligently located on the high ice plateau of the Juneau Icefield.

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