APPENDIX 4-O
KSM 2011 MEMO ON MITCHELL GLACIER SUB-GLACIAL DRAINAGE PATTERNS

Klohn Crippen Berger

DRAFT MEMORANDUM

TO:	Graham Parkinson	**DATE:**	August 12, 2011
FROM:	Andrew Hovey	**FILE NO:**	M09480A03.300
		LOG NO:	

SUBJECT: Stream flow beneath Mitchell Glacier – observations and estimated balance of source contributions

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This memorandum summarizes observations made while on site during recent drilling of the KCB 2011 holes on the Mitchell Glacier. These observations were recorded to improve the understanding of sources which contribute to Mitchell Creek beneath the glacier, and the potential alignment of the primary drainage channel beneath the glacier.

1. ESTIMATED BALANCE OF FLOW AT TOE OF MITCHELL GLACIER

A rudimentary water balance was undertaken for Mitchell Creek referenced to the point of discharge at the toe of the Mitchell Glacier. Flow in watercourses was visually estimated, from a distance. Flows disappearing below the lateral margins of the glacier were assumed to re-appear in Mitchell Creek at the Glacier toe. Weather conditions during the observation period were relatively warm, with slight rainfall in the days preceding; the proportions of flow in the water balance are expected to vary on a seasonal basis.

The estimated contribution of individual sources to total flow beneath the glacier is shown on Plate 1. Inputs to the water balance are as follows:

1. SOUTHERN RIDGELINE DRAINAGE [30% main water course + 20% smaller water course near toe]: A major drainage feature originates from the Snowfields site on the southern ridgeline and disappears beneath the southern side of the glacier. Although difficult to estimate from visual at a distance, flow in the southern ridgeline creek is approximately 30-80 L/s and is probably composed mainly of snow melt. During the drilling program, this was observed to change colour intermittently (from a distance - white to light brown, cascading flow), possibly due to sediment entrainment from slumping of the weathered surficial rock into the drainage line at higher elevations. The colour of this creek after the assumed slumping was similar to that of Mitchell Creek downstream of the glacier.

   Near where this creek reaches the glacier, it is joined by smaller creeks which originate from beneath the glacier. The area in which this occurs is in a small exposed depression (no ice cover). The collective creek discharge flows to the west, beneath the ice. The area where the creek disappears beneath the glacier appears to be collapsing (similar to the sinkhole near the toe), with the collapse oriented in an upstream direction (ie. towards the

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creek where it travels below the glacier). Plate 2 shows the estimated proportion of streamflow from individual sources in this area.

There are smaller drainage lines on the southern ridgeline near the toe of the glacier which disappear below the ice, near the main sinkhole near the toe. The collective flow from these creeks is discoloured (similar to Mitchell Creek). The contribution from these smaller creeks to total flow in Mitchell Creek at the Glacier toe is estimated 20%.

2. SOUTHERN RIDGELINE SEEPAGE [5%]: Seepage was observed where the southern ridgeline drainage from Snowfields flows beneath the ice, and appears to emerge at the contact between the weathered rock and intact rock. In this area, the rate of seepage appears negligible (few litres per second). Seepage along this contact probably occurs along the entire southern ridgeline (based on the presence of wet unconsolidated materials), and may be from groundwater and/or snow melt. Evidence of seepage was also observed on the northern ridgeline, however, this was mainly concentrated downstream of the Mitchell Glacier.

3. NORTHERN RIDGELINE DRAINAGE [two streams, estimated to comprise 10% and 20% of total flow in Mitchell Creek at the Glacier toe]: There are two drainage lines on the northern ridgeline which disappear below the glacier. Unlike the southern ridgeline creek, there is no well defined cave area into which these flow.

4. SUPRA-GLACIAL STREAMS and MELTING AT ICE-ROCK CONTACT [ie. glacial melt-water, 10%]. Have a widespread distribution across the glacier, flowing WSW (towards toe). Flow is channelized, but tended to bifurcate and change path on a daily basis. Smaller streams tended to flow into crevasses across the glacier, probably becoming englacial (ie. flowing though ice mass). May report to base of glacier? Surface streamlines tended to converge in the sinkhole near the toe of the glacier, and became englacial through crevasses; given ice thickness at the cave is less, flow to the sinkhole area likely reports to the base of the glacier.

   During warmer parts of the day (~20-25°C), streams had flows up to approximately 4L/s; flow receded to <0.5L/s overnight. Flow in the supra-glacial streams is derived from melting of the glacier surface.

   No evidence of standing or flowing water was encountered at the ice-rock interface beneath the glacier during drilling at KC11-42 and KC11-43, however, there is likely to be some melting of ice at this contact. Standing/flowing water beneath is likely to be channelized by the morphology of the bedrock surface, and therefore, only encountered in localized areas. Melting of ice may be exacerbated toward the toe, where pyrite oxidation rates are likely to be highest.

5. It was estimated that approximately 5% of flow beneath the glacier is from upstream areas (combination of seepage and meltwater at ice-rock interface). Drilling in the likely vicinity of the primary sub-glacial channel was constrained by safety considerations (ie. crevassing).

2. DRAINAGE ALIGNMENT BENEATH THE MITCHELL GLACIER

The estimated alignments of drainage channels beneath the Mitchell Glacier are shown in Plate 3. These alignments were selected based on the following:

- It is assumed that significant flow occurs from the southern ridgeline drainage where it flows beneath the glacier and the toe.
- Sub-glacial creek alignments will be controlled by bedrock morphology and ice conditions. On the south side of the valley downstream of the glacier the lower slopes tended to be somewhat 'hummocky', which may deflect the drainage more toward the centre of the valley, rather than running directly along the south side.
- Most supraglacial runoff disappeared through crevasses in the sinkhole area near the Glacier toe. A dendritic drainage pattern could be seen on the glacier surface within the sinkhole area when viewed from the air during hot weather, however, this meltwater did not flow over the edge of the glacier (ie. became englacial). Meltwater is therefore expected to join the sub-glacial stream primarily near the glacier toe via the sinkhole.
- A large sub-glacial channel does not appear to have been intersected in any of the Mitchell Glacier holes (a dry cavern was intersected on the McTagg West Glacier – the contact was very apparent when drilled through).
- The secondary drainage alignments shown on Plate 3 may be morphologically as significant as the primary drainage, however, the amount of water flowing in these is expected to be less. The alignment of any channel from the north ridgeline is speculative, but it is expected the drainage from upglacier follows the valley bottom.

3. RECOMMENDATIONS

It is understood an understanding of differences in water quality from the Snowfields site and up-glacial areas on the KSM property is required to assist with characterization of background water quality and delineation of sources of acidity in Mitchell Creek downstream of the glacier toe. The following may assist with meeting these goals, and may been at least partially covered during baseline monitoring completed by Rescan:

- Recover water quality samples for analysis from the various drainage lines at the southern side of the glacier, where the stream from the Snowfields property disappears beneath the glacier. The 5%, 10% and 15% creeks shown on Plate 2 originate from beneath the glacier, whereas the 70% creek originates from the Snowfields site.
- More detailed ice radar transects are recommended to assist with defining bedrock morphology beneath the glacier and therefore, the location of the sub-glacial creek. Results from these surveys would also assist with optimizing locations for the sub-glacial inlets under the block cave mining scenario.

- Based on observations and the findings of the ice radar transects, drill a borehole to intersect the primary sub-glacial drainage to facilitate water sampling. Given crevassing is more frequent above the inferred alignment of the primary drainage, it may be necessary to complete an inclined borehole for this purpose.
- If water is encountered at the ice-rock interface in any up-glacier boreholes drilled for geotechnical assessment, samples will be recovered for analysis using bailers.

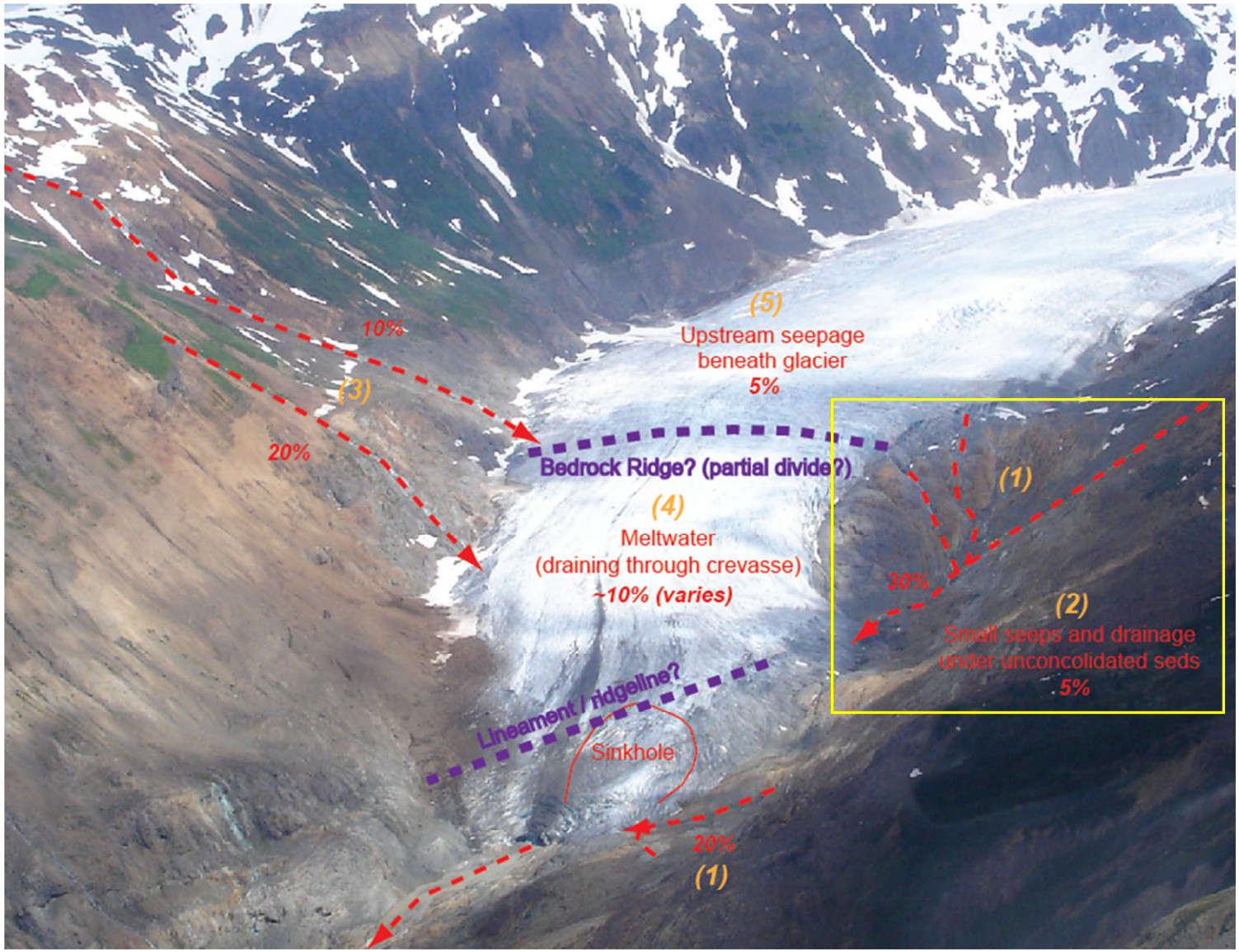

Plate 1. Estimated contribution of individual sources to flow in Mitchell Creek at the toe of Mitchell Glacier.

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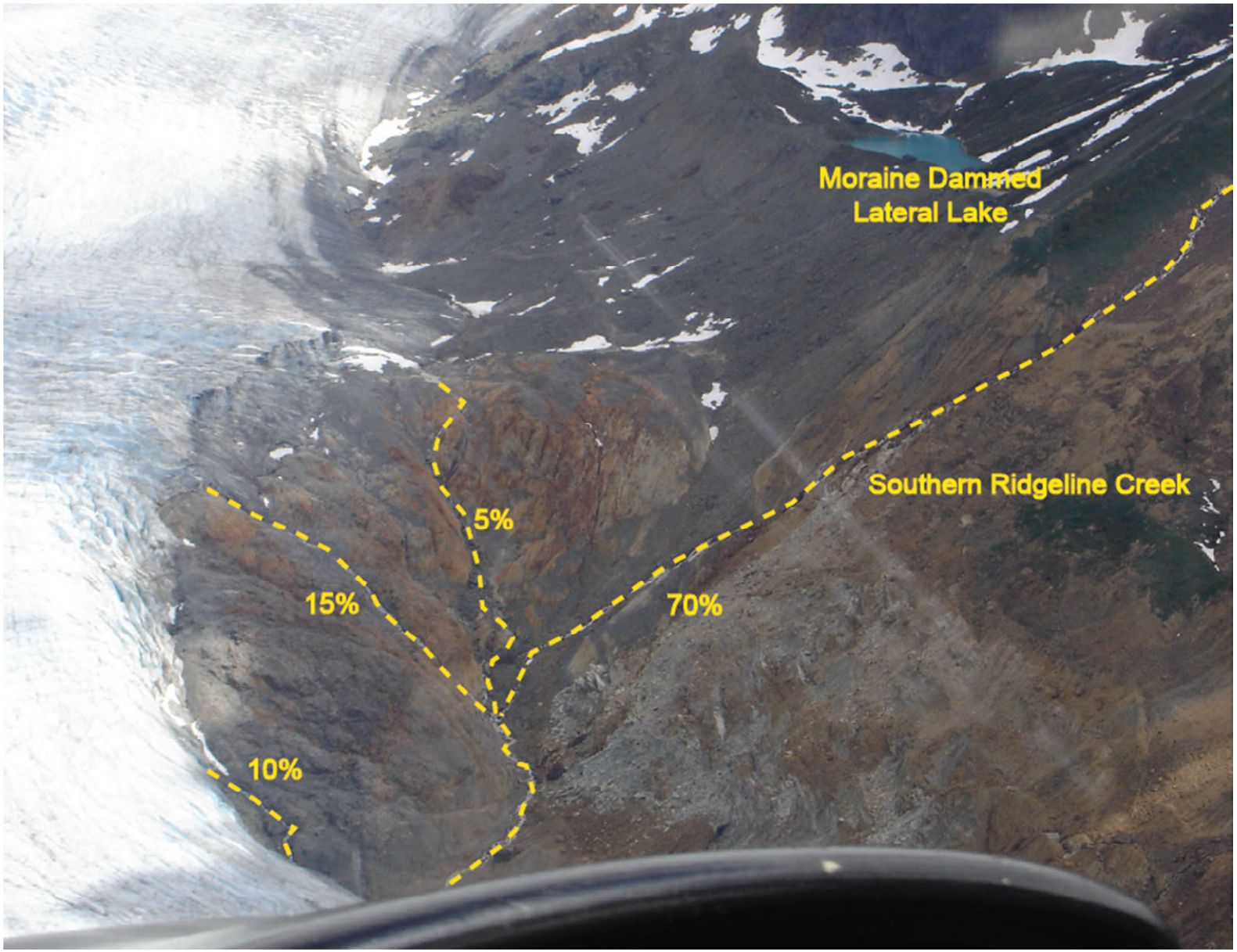

Plate 2. Southside of Mitchell Glacier, looking ENE. Estimated components of streamflow contribution to southern ridgeline drainage.

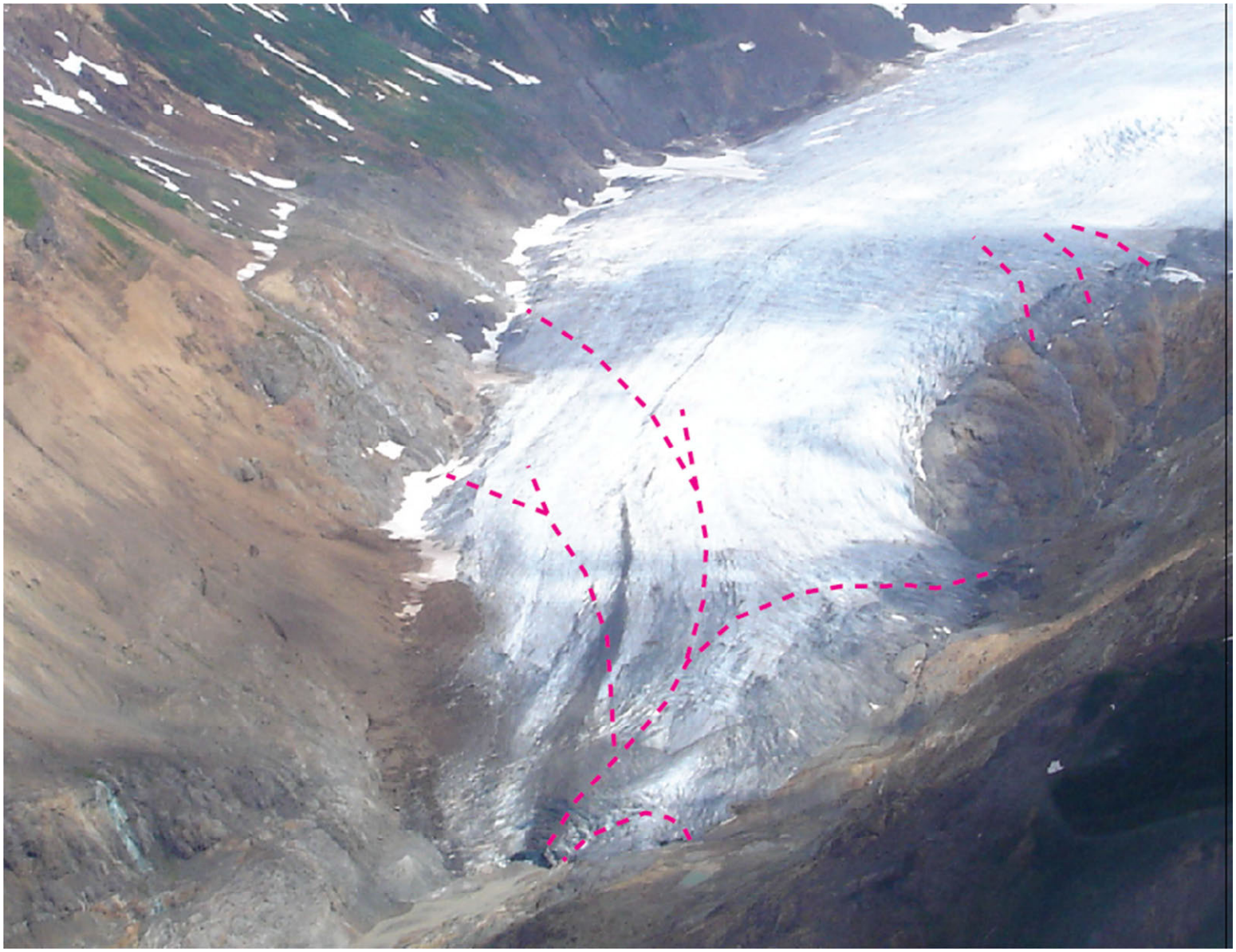

Plate 3. Estimated alignment of primary stream channels beneath Mitchell Glacier.