GEOLOGICAL FIELDWORK

Late Wisconsinan McConnell ice-flow and sediment distribution patterns in the Pelly Mountains, Yukon

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ABSTRACT

Late Wisconsinan McConnell glaciation (ca. 24-11 ka) occurred in four phases in the Pelly Mountains of southern Yukon. Phase 1 marked the onset of ice accumulation in cirques above 1524 m above sea level (a.s.l.). These local glaciers expanded and fed valley glaciers that extended into the surrounding lowlands (after 26.3 ka). At glacial maximum or phase 2, the development of ice-divides to the east and south of the Pelly Mountains permitted Cordilleran ice lobes to invade the lesser glaciated Pelly Mountains, which resulted in up-valley ice-flow. This ice-flow arrangement continued into early deglaciation (phase 3), a period characterized by re-advances of the invading ice lobes. Following retreat of the ice lobes from the Pelly Mountains, some local cirque glaciers above 1600 m a.s.l. resumed limited down-valley flow (phase 4).

For drift prospecting purposes, the dominant glacial dispersion trajectory in these high relief areas is controlled by the last phases of ice-flow (either phase 3 or 4).

RÉSUMÉ

La glaciation McConnell du Wisconsinien tardif (de 24 à 11 ka environ) s'est déroulée en quatre phases dans les monts Pelly, au sud du Yukon. La phase 1 correspond au début de l'accumulation de glace dans les cirques situés à plus de 1524 m d'altitude. Ces glaciers locaux ont pris de l'expansion et ont alimenté des glaciers de vallée qui s'étendaient au-delà du front des montagnes dans les basses terres avoisinantes (après 26,3 ka). Au maximum glaciaire, soit la phase 2, l'apparition de lignes de partage glaciaire à l'est et au sud des monts Pelly a permis à des lobes glaciaires de la Cordillère d'envahir les monts Pelly, moins englacés, ce qui a causé de l'écoulement glaciaire vers l'amont des vallées. Cette configuration de l'écoulement glaciaire s'est poursuivie jusqu'au début de la déglaciation (phase 3), période caractérisée par de nouvelles avancées des lobes glaciaires envahissants. Après le recul des lobes glaciaires dans les monts Pelly, certains glaciers locaux à plus de 1600 m se sont remis à s'écouler, de façon limitée, vers l'aval des vallées (phase 4).

Aux fins de la prospection glacio-sédimentaire, il faut savoir que, dans ces régions de relief élevé, la trajectoire dominante de dispersion glaciaire semble dépendre de la dernière phase d'écoulement glaciaire (phase 3 ou 4).

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INTRODUCTION

Predictive models of glacial dispersion and paleo-ice dynamics are an important component of mineral exploration in glaciated terrain. Exploration programs that utilize soil geochemistry and boulder tracing benefit from a comprehensive understanding of ice sheet models and the interplay between distinct ice accumulations throughout the many phases of a glaciation. Furthermore, empirical evidence regarding the nature of subglacial processes cannot be undervalued. Glacial erosion, transport and deposition are reflected in the clastic sedimentology of Quaternary sediments and sedimentary successions. A detailed understanding of the complexities of these processes is beneficial for the effective application of drift prospecting techniques.

Mineral exploration in the Seagull Creek drainage of the Pelly Mountains (Fig. 1) provides a good example of the challenges that are faced while drift prospecting in mountainous terrain. Since the 1980s, prospecting for a lode source for gold-bearing float boulders in Seagull Creek has been hindered by thick glacial deposits in the valley bottom. In 2003, Kennedy and Bond (2004) indicated that the last phase of ice movement in Seagull Creek was up-valley. This realization had important ramifications for the interpretation of previously collected geochemical and geophysical data from Seagull Creek. The glacial history of Seagull Creek is consistent with findings in the Lapie River drainage to the north where Plouffe (1989), and Plouffe and Jackson (1992) provided evidence for late glacial up-valley ice movement by the Selwyn Lobe of the Cordilleran ice sheet. This was restated in a broader context by Jackson and MacKay (1991) who suggested that ice-flow in some mountainous areas of southern Yukon could have been in the opposite direction to that of the modern drainage. These ice-flow complexities, and their potential implications to mineral exploration, provide the impetus for developing a clearer understanding of the glacial history, particularly processes of glacial erosion, transport and deposition, within the Pelly Mountains. In 2004, a study was initiated to further understand the late Wisconsinan McConnell glacial history within the Pelly Mountains. Results from this work are presented in this paper and have direct implications for drift prospecting in previously glaciated regions of Yukon and in other areas of the Cordillera where ice-flow reversals may have occurred.

PHYSIOGRAPHY, DRAINAGE AND BEDROCK GEOLOGY

The Pelly Mountains are located in south-central Yukon and form a physiographic divide between the Pelly River drainage to the north and the Nisutlin, Big Salmon and Liard river basins to the south (Fig. 1). Summits within the highland reach elevations of 2404 m (7887 ft). Narrow, steep-sided valleys characterize drainages flowing north out of the Pelly Mountains, whereas main valleys draining to the south have a broader character. The area investigated for this study included the central part of the Pelly Mountains (Fig. 1).

REGIONAL BEDROCK GEOLOGY

The geology of the Pelly Mountains includes rocks of Yukon-Tanana Terrane in the northwest, rocks of the Cassiar Platform through the central part of the range and displaced Yukon-Tanana Terrane rocks in the southeast. The Tintina Fault forms an important geological boundary between rocks of Cassiar Platform and those of the Yukon-Tanana Terrane. The study area is mostly underlain by rocks of the Cassiar Platform, which consist of a thick succession of Cambrian through Mississippian limestone and sandstone that represent one billion years of sediment accumulation off the margin of ancient North America (Tolbert, 2000; Gordey and Makepeace, 2003). The platform has since been folded and faulted into the 70-km-wide and 600-km-long massif of the Pelly Mountains. This assemblage of sedimentary rocks was intruded by granitic rocks in the Cretaceous.

REGIONAL QUATERNARY GEOLOGY

Yukon has been glaciated numerous times since the late Pliocene (Froese et al., 2000; Duk-Rodkin and Barendregt, 1997; Duk-Rodkin et al., 2001; Jackson et al., 1991). Centres of ice accumulation included: the St. Elias, interior Coast and Cassiar mountains in southern Yukon; the Pelly and Selwyn mountains in eastern Yukon; and the Ogilvie and Wernecke mountains in central Yukon. Ice from each of these accumulation zones flowed radially outward into lowland areas. Thickening ice masses on the landscape developed into separate ice lobes that eventually merged to form a continuous carapace of ice across southern and eastern Yukon (Fig 2; Jackson et al. 1991). This ice mass formed the northern extent of the Cordilleran ice sheet (Fulton, 1991). The limited ice extent in central Yukon is likely to be a function of aridity (Armentrout, 1983; Ward and Jackson, 1992).

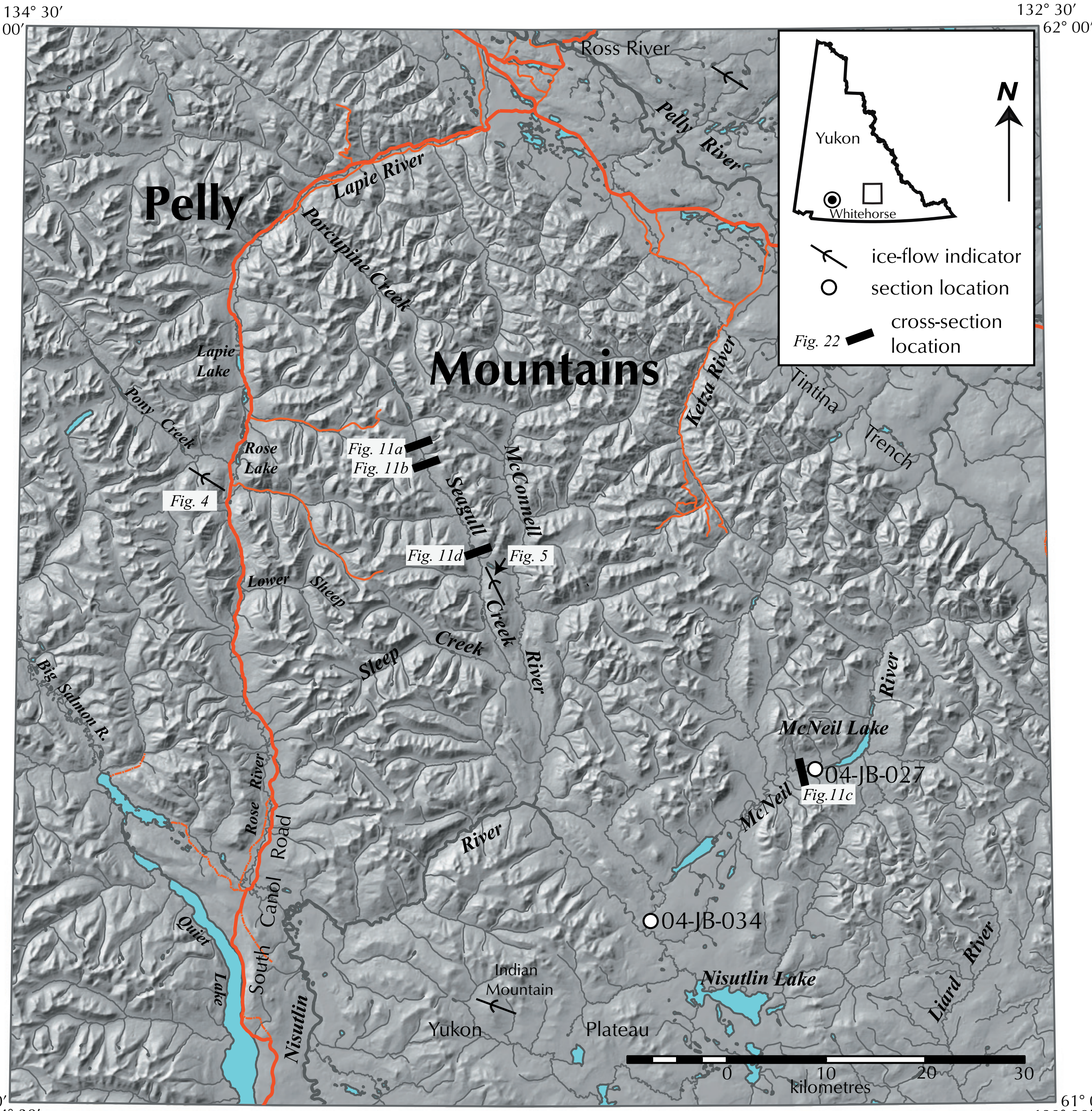


Figure 1. *Location map of the study area within the Pelly Mountains.*

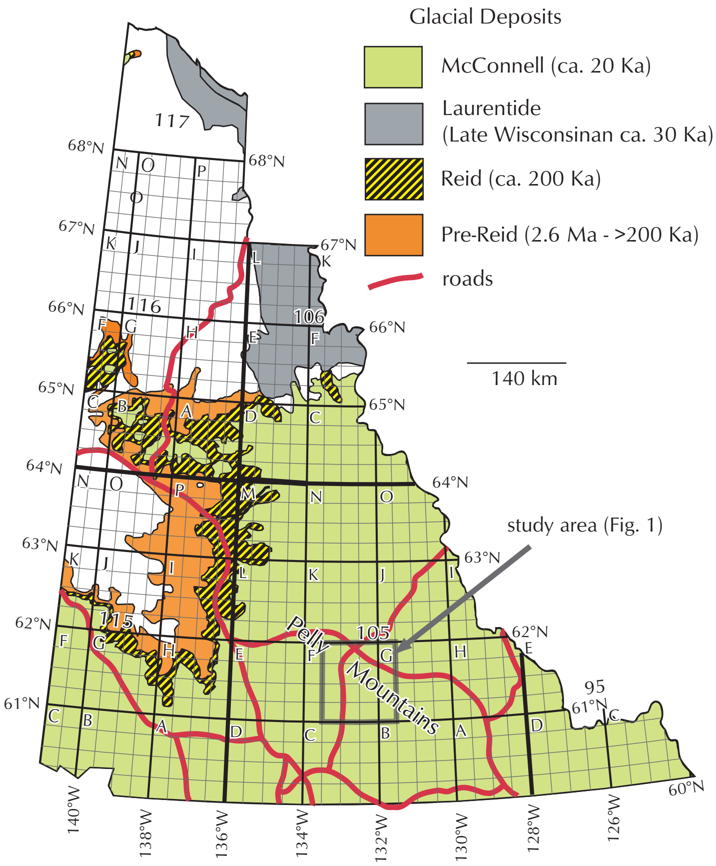


Figure 2. *Glacial limits map of Yukon (after Duk-Rodkin, 1999).*

The current study area lies entirely within the late Wisconsinan McConnell glacial limit (Fig. 2). There is little evidence of prior glacial or interglacial deposits in this area. Where pre-McConnell organic material has been identified, pollen assemblages suggest that a cooler climate was associated with the onset of glaciation approximately 29 600 years BP (Matthews et al., 1990). In the Tintina Trench, at the foot of the Pelly Mountains, bone-bearing gravel beneath McConnell till was dated at 26 350 ±280 BP, suggesting ice had not yet expanded out of the Pelly Mountains by this date (Jackson and Harington, 1991). Similarly, McConnell glaciers had not yet inundated the Watson Lake area in southeast Yukon by 23 900 ± 1140 BP (GSC-2811; Klassen, 1987). The retreat of ice from glacial maximum had begun by 13 660 ± 180 BP (GSC-1110) according to a radiocarbon age near the terminus of the St. Elias Mountains piedmont lobe complex (Rampton, 1971). A radiocarbon age of 10 700 BP from macrofossils in Marcella Lake (Kettlehole Pond), southern Yukon, suggests ice-free conditions by this date (Anderson et al., 2002).

RESULTS

GEOMORPHOLOGY

The identification of landforms used to reconstruct ice-flow during the last glaciation in the study area was completed using existing surficial geology maps (Jackson, 1993a,b,c,d) and new air photo interpretation. Landforms such as ice marginal melt-water channels, kame terraces and moraines were used to reconstruct ice-flow patterns and the style of ice retreat (Fig. 3). Four distinct phases of the McConnell glaciation were recognized in the Pelly Mountains (discussed later), although not all phases of the glaciation are well represented in the landform record. In many cases, later stages of a glaciation are preferentially preserved, which provides important information about late-stage ice-flow, but little about earlier ice-flow phases such as glacial maximum and the onset of glaciation. The reconstruction of glacial maximum depended on the identification of high-elevation landforms such as crag-and-tail features.

Glacial landforms above 1524 m (5000 ft) above sea level

Glacially streamlined crag-and-tail landforms occur near the summit of a 1524-m a.s.l. plateau west of Rose Lake, near the drainage divide within the Pelly Mountains (Fig. 4). The orientation (302° trend) and morphology of these bedforms suggests ice was moving northwest, an orientation nearly perpendicular to the Rose River valley (Fig. 1). Meltwater channels mapped by Jackson (1993a)

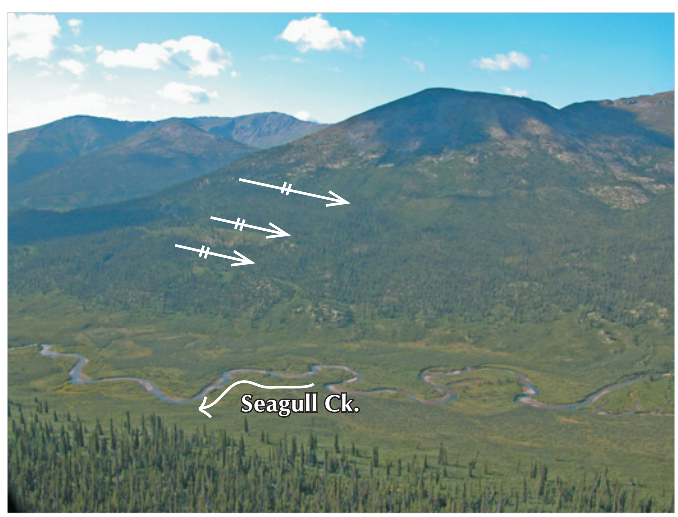


Figure 3. *Flights of meltwater channels descending up the Seagull Creek valley (arrows) indicate a former ice front retreating down-valley. View is to the southwest. Seagull Creek flows to the left.*

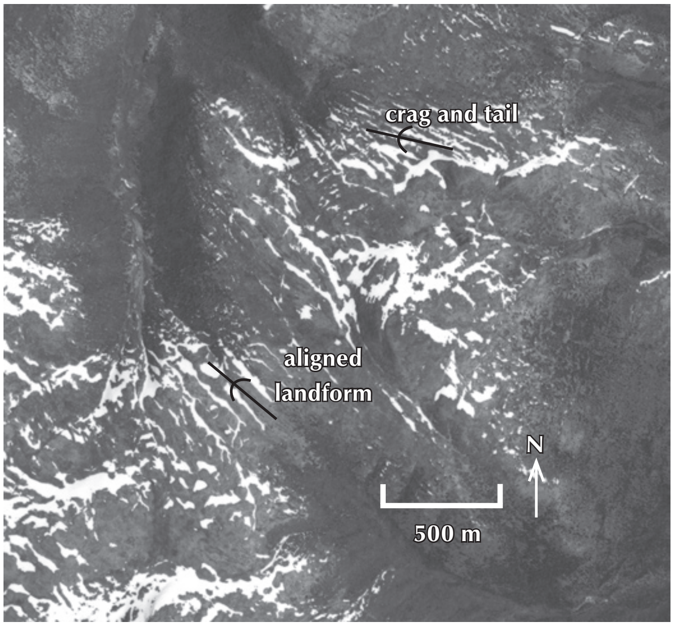


Figure 4. *Crag-and-tail landforms near Rose Lake at 5200 ft (1524 m). The ice direction that created these landforms was to the northwest.*

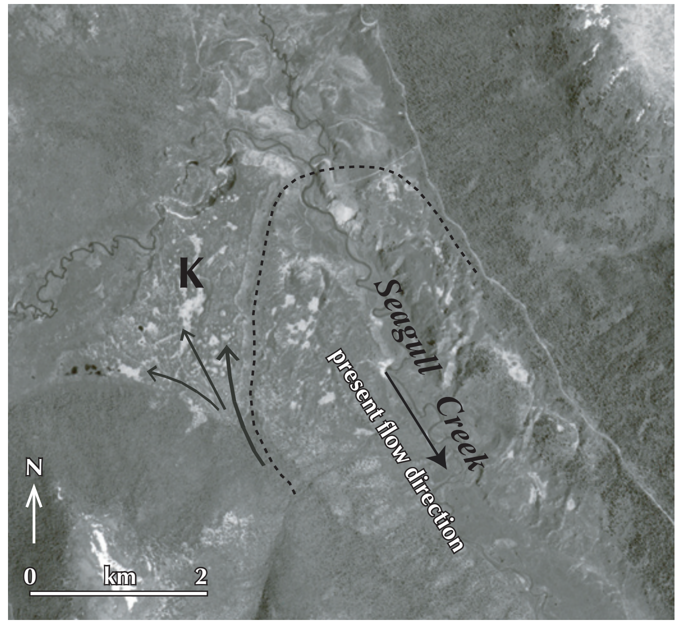


Figure 5. *A kame terrace (K) and moraine (dashed line) mark a recessional position of the Cassiar lobe that flowed up Seagull Creek. Seagull Creek is presently flowing south-southeast.*

spill over this plateau and indicate that during early deglaciation, ice was thicker on the south side of the plateau than the north. This supports a northwest-flowing ice mass at or near glacial maximum within the western part of the study area.

Meltwater channels breaching passes above 1524 m between the Seagull Creek and Rose River valleys have paleo-flow trajectories toward the west, suggesting ice was thicker to the east. Likewise, between Seagull and Porcupine creeks, meltwater flow at high elevations was to the north.

Further east, similar meltwater channel orientations were observed. At the headwaters of a south-flowing tributary to the McNeil River, lateral meltwater channels at 1600 m elevation breach a pass and extend north into the Ketza River.

Glacial landforms below 1524 m (5000 ft) a.s.l.

Many depositional and erosional landforms within the Pelly Mountains are remnant from the latest period of the McConnell deglaciation, when ice was thinner and dominantly confined to local valleys. Morainal landforms and associated lateral meltwater channels are plentiful and well preserved. Deposits from local alpine glacial activity are also present.

Seagull Creek valley provides an example of remnant landforms preserved at these elevations. Multiple moraine complexes and erosional meltwater channels are present (Fig. 3). In the upper reaches of the drainage, a kame terrace and moraine complex clearly reflect a former ice front from an up-valley-flowing glacier (Kennedy and Bond, 2004; Fig. 5). Up-valley-trending moraines and meltwater channels were also documented in other valleys within the study area, and include extensive moraine deposits near Rose and Lapie lakes (Fig. 6) and at the headwaters of the McNeil River.

Glaciolacustrine deposits are widespread in many of the upper valleys of the study area. Drainage outlets for these lakes were northward and often dissected the moraine complexes mentioned above. The thickness and distribution of glacial lake sediment is variable and likely depends on how long the lake existed and the height of its outlet. For example, in upper Seagull Creek, glaciolacustrine sediments are <1 m thick and extend to 60 m above the valley bottom, whereas in the neighbouring upper McConnell River valley, glaciolacustrine sediments are 10 to 20 m thick and blanket slopes 90 m above the valley bottom (Kennedy and Bond, 2004; Jackson, 1993c).

Locally derived down-valley-trending moraines were observed in many cirques within the study area. The

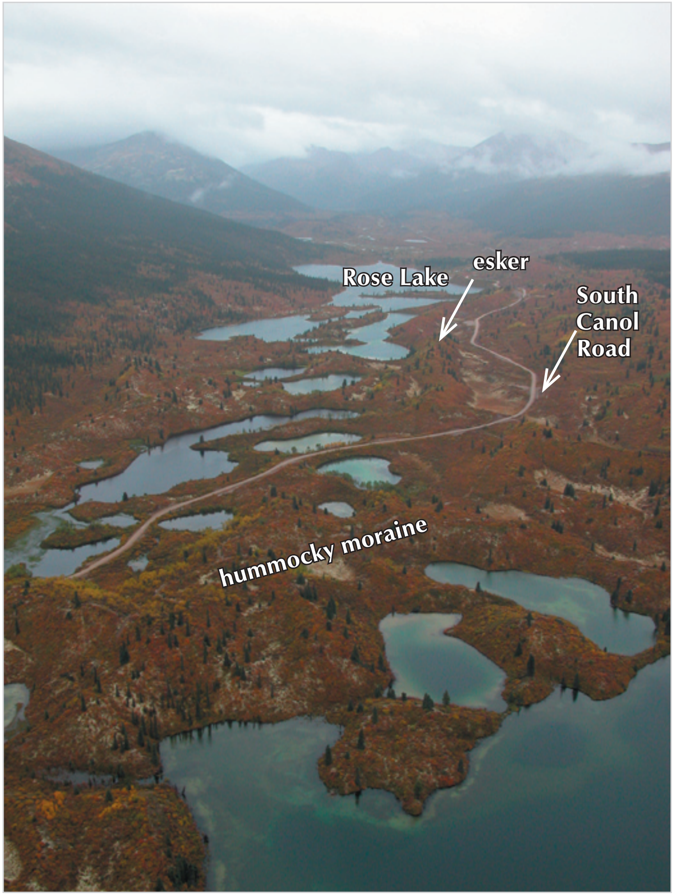


Figure 6. *Hummocky moraine near Rose Lake shows typical ablation sediment accumulations found at drainage divides in the study area. View is to the south.*

distance of these moraines from their source accumulation area is commonly limited to 1 to 2 km. The exception to this is Sleep Creek, a large east-trending tributary to lower Seagull Creek and the McConnell River. Local moraine and till from Sleep Creek are found in the McConnell River valley, approximately 20 km from its headwaters.

QUATERNARY STRATIGRAPHY

Quaternary stratigraphic observations were used to advance our understanding of the sequence of ice-flow patterns representing various phases of glaciation. Likewise, the sub-glacial processes associated with each glacial phase were identified and characterized. Ultimately, these data were used to develop a model for glacial dispersion in the mountain valleys.

Information such as texture, colour, cohesion, structure, till fabric, till geochemistry and pebble lithology were collected at natural exposures. Till fabric analyses were based on the measurement of 50 clasts (n = number of clasts) using the long-axis of elongated pebbles to determine orientation and dip. Fabric results also list the mean orientation from the population of measured clasts (V1) and the statistical significance or reliability of the data (S1). Statistical significance was measured between 0 and 1, where 1 corresponds to perfectly aligned data and 0 corresponds to perfectly random data. Fabric data with significance values of less than 0.5 were considered unreliable as indicators of flow direction.

Till geochemistry and pebble lithology samples were collected from the clastic units in order to characterize source areas. An initial assessment of this data set indicated that no unique clast lithologies or geochemical fingerprints were present to assist in characterizing the respective glacial units. This result may be due to the uniformity of the underlying bedrock in the study area. Further analysis of these data sets are required.

The term diamict is used widely in the sedimentology descriptions. It is used as a non-genetic descriptive term for any poorly-sorted gravel-sand-mud mixture. For example, a till is a diamict with a glacial origin, whereas a colluvium can also be a diamict but is derived from slope-related processes.

Exposed glacial sediments studied in the Pelly Mountains were deposited during the late Wisconsinan McConnell glaciation. Where multiple tills were identified, there was no conclusive evidence, in the form of paleosols or organic material from previous interglacials for example, that suggested pre-McConnell deposits were present. Erosion and reworking of non-glacial and older glacial deposits during the McConnell glaciation, however, cannot be ruled out.

Quaternary sections that depict the glacial history and stratigraphy of the study area are presented below and illustrated in Figures 7a and 7b. Figure 1 shows the locations of the sections.

04-JB-027

This section is situated on the McNeil River immediately downstream from McNeil Lake (Fig. 1) and is illustrated in Figure 7a. The 27-m exposure contains outwash gravel at the base of the section overlain by multiple till units, which are in turn capped by a thin glaciolacustrine deposit.

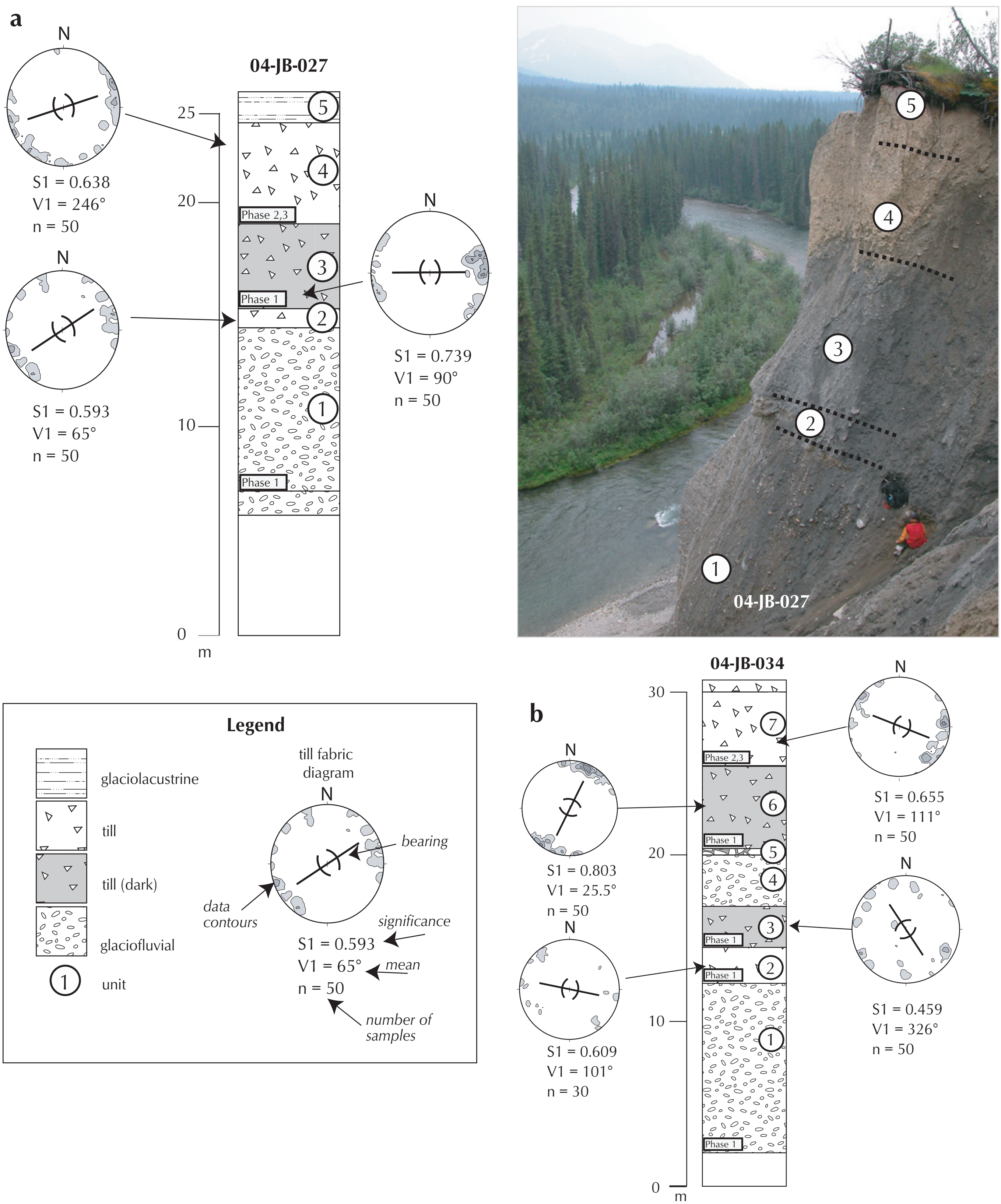


Figure 7. (a) *Stratigraphic section 04-JB-027 consists of stacked glacial deposits. The exposure is located west of McNeil Lake along the McNeil River.* ***(b)*** *Stratigraphic section 04-JB-034 on the lower McNeil River near its junction with the Nisutlin River. A similar stratigraphy to 04-JB-027 is recorded at this site.*

Unit 1 is outwash gravel that has a paleo-flow structure concurrent with the modern McNeil River. Importantly, the unit coarsens upward from a well-sorted pebble gravel into a boulder-dominated gravel at the contact with unit 2 till. Unit 1 is interpreted as advance outwash gravel originating from Pelly Mountain glaciers.

Units 2, 3 and 4 consist of a series of stacked diamicts (Fig. 7a). Unit 2 is a coarse-textured, cemented diamict in gradational contact with unit 1. Based on this relationship, unit 2 is interpreted to be till derived from a local glacier that advanced down-valley. The southwest-trending pebble fabric suggests that unit 2 was sourced from the upper McNeil River. The contact between units 2 and 3 is gradational. Unit 3 is a cohesive, matrix-dominated dark grey diamict. It contains many polished, striated and faceted clasts and has a well-defined fabric that is oriented east-west (90°). On this basis, it is interpreted to be a lodgement till. Its fabric parallels a nearby tributary valley entering the McNeil River, suggesting that unit 3 may have originated from west-trending ice-flow (Fig. 1). Unit 4 is a cohesive olive-grey diamict that weathers beige (Fig. 7a). The mean orientation of the clast fabric within this unit is 246°. It is also interpreted to be till because of its well-aligned fabric (S1=0.638; Fig. 7a). It is capped by a laminated silty-clay deposit containing drop-stones, which is interpreted to be a glaciolacustrine unit (unit 5) that formed in a lake proximal to the ice front following deposition of unit 4 and recession of ice from the immediate area. Unit 4, the upper-most ice-deposited unit, can also be correlated with up-valley-trending meltwater channels within the valley. The presence of the glaciolacustrine silt and the meltwater channels in this part of the McNeil River drainage suggest that unit 4 is derived from an up-valley-flowing glacier.

04-JB-034

This section is located on the lower McNeil River, 1 km above its confluence with the Nisutlin River and is illustrated in Figure 7b. The 31.5-m exposure consists of a stacked sequence of glacial outwash and till and is similar to section 04-JB-027.

Unit 1 is poorly stratified, coarse gravel with diamict lenses. Boulders within this unit are angular and locally derived. It is interpreted as an ice proximal proglacial outwash. No paleo-flow measurements were taken from this unit.

Unit 2 is a cohesive, clast-rich diamict in gradational contact with Unit 1. Clast fabric within this unit has a well-aligned orientation of 101° (Fig. 7b). This unit's proximity to the underlying outwash and its clast fabric suggest that it is a till originating from a local glacier flowing out of the Pelly Mountains from the northwest.

Unit 3 is a cohesive, matrix-supported, dark grey diamict. Smearing and reworking of unit 2 into unit 3 in a southward trajectory suggests that the contact between units 2 and 3 is erosional. The clast fabric from unit 3 has no well defined orientation (Fig. 7b); however, the presence of southward-oriented erosional smearing suggests that it was deposited from a glacier originating in the Pelly Mountains. A well-sorted sandy gravel unit (unit 4) and a discontinuous, stony diamict to muddy cobble gravel unit (unit 5) overlie unit 3. The coarse texture and muddy matrix of unit 5 is indicative of a debris-flow deposit and/or a high-energy muddy stream. Based on this reconstruction, units 4 and 5 were likely deposited in an ice proximal environment.

Unit 6 is a compact and cohesive diamict containing well-polished, striated and faceted clasts. The clast fabric within this unit is strongly aligned parallel to the McNeil River valley (205.5°; Fig. 7b). It is interpreted as a lodgement till that was deposited by a glacier flowing out of the McNeil River valley.

Unit 7 is a compact, matrix-supported diamict that is also interpreted as a lodgement till based on a well-aligned clast fabric (291°; Fig. 7b). The source of this upper-most ice-flow deposit is perhaps best shown by the orientation of glacially streamlined crag-and-tail landforms on top of Indian Mountain (located 13 km to the southwest of this section; Fig. 1) that trend at 290° and were created by ice flowing to the northwest into the Pelly Mountains. Unit 7 is interpreted to be correlative with these surficial features based on its stratigraphic position. This unit is capped by non-cohesive gravel-rich ablation sediment that extends to the top of the section.

DISCUSSION

MCCONNELL GLACIAL HISTORY

The late Wisconsinan McConnell glacial history of the Pelly Mountains can be separated into four phases based on changes in regional ice-flow direction and ice dynamics.

McConnell advance: Phase 1

Initial ice-flow within the Pelly Mountains is from the accumulation and advance of local valley glaciers (Fig. 8a) out of the mountains and into neighbouring lowlands such as the Tintina Trench and the upper Nisutlin River area. On the north side of the Pelly Mountains, local ice from the Lapie River flowed eastward into Tintina Trench prior to the arrival of the Selwyn lobe of the Cordilleran ice sheet (Plouffe, 1989; Fig. 8a). The timing of this advance into Tintina Trench post-dates 26.3 ka (Jackson and Harington, 1991). Likewise, stratigraphy in sections 04-JB-027 and 04-JB-034 on the south side of the mountains suggests that local ice advanced down the McNeil and McConnell rivers after an initial phase of glaciofluvial deposition (Figs. 7a and 7b). The clast fabric and structural data suggests that the lower tills deposited at these sections originated locally from Pelly Mountain glaciers. Deposition of multiple till units in this period could be controlled by the physiography, given that multiple valleys converge on a similar location. This would funnel glaciers into the area at slightly different times and allow for till stacking to occur. In addition, glaciofluvial deposits separating units 3 and 6 at section 04-JB-034 suggest that these valley glaciers may have advanced, retreated slightly and re-advanced at the mountain front during this time (Fig. 7b).

The details of the phase 1 ice-flow and the extent of ice originating from individual cirques cannot be clearly defined, and is therefore assumed to largely resemble the current fluvial drainage.

McConnell glacial maximum: Phase 2

At the height of the McConnell glaciation, ice-flow in the Pelly Mountains was controlled by ice-divides associated with the Selwyn and Cassiar lobes of the Cordilleran ice sheet (Fig. 8b). Local ice accumulations within the Pelly Mountains remained sufficiently thin to permit Cordilleran ice to advance into the mountains from the south (Cassiar lobe) and east (Selwyn lobe). By glacial maximum, the massif was largely overridden and incorporated into the neighbouring ice lobes. Cordilleran ice within the Pelly Mountains reached a minimum elevation of 1676 m (5500 ft) and was >600 m thick. High-elevation landforms within the McConnell and McNeil river drainages suggest ice-flow was directed by underlying topography. In contrast, west of the Rose River valley, ice-flow had less topographic control (Fig. 8b). Topographically uncontrolled ice-flow was likely restricted to the southern parts of the Pelly Mountains where the Cassiar lobe was thicker. Further northwest, the ice sheet thinned and became valley controlled. Selwyn lobe ice-flow along the northeastern margin of the Pelly Mountains extended above the mountain summits adjacent to the Tintina Trench and flowed to the northwest. The orientation of high-elevation meltwater channels in this area suggests ice flowed perpendicular to the valleys entering Tintina Trench during glacial maximum (Fig. 8b).

McConnell early deglaciation: Phase 3

Well-defined, up-valley-trending moraine and meltwater channels identified in upper Seagull Creek suggest that retreat of the Cassiar lobe from the southern Pelly Mountains was punctuated by re-advances and prolonged recessional pauses (Fig. 8c). Similar extensive hummocky moraine accumulations were observed at drainage divides of many of the main valleys draining south out of the study area. Whether or not these landforms are chronologically correlative is uncertain; however, it does imply that ice in each of the valleys was influenced by similar climate fluctuations and ice responses. It also suggests a relative lack of local ice in the Pelly Mountains at this time. Glaciation of the Glenlyon Range to the northwest at glacial maximum could be an analogue for the Pelly Mountains in early deglaciation (Ward and Jackson, 1992). Local cirque glaciers in the Glenlyon Range advanced <3 km at glacial maximum and in most areas did not converge with the Selwyn Lobe that invaded the upland. Aridity likely played an important role in limiting the extent of local cirque glaciers (Ward and Jackson, 1992).

The cumulative evidence from the Pelly Mountains suggests that the Selwyn and Cassiar lobes responded to similar climatic shifts during deglaciation (Plouffe, 1989; Kennedy and Bond, 2004). Likewise, comparable deglacial characteristics are documented for paleo-glaciers in the Logan Mountains to the east (Dyke, 1990), in the Whitehorse map area to the west (Bond, 2004) and the Anvil District to the north (Bond, 1999). This evidence suggests that frontal retreat was the dominant recessional process, which contradicts Jackson's (1994) proposal for wholesale stagnation of the Selwyn Lobe at the end of the last glaciation. Jackson did recognize, however, that uniform stagnation could not explain the glacial lake that existed in the Lapie River valley. To account for this, he concurred with Plouffe (1989) and suggested that the Selwyn lobe re-advanced into the mountains. This growing body of evidence from southern Yukon suggests that deglaciation was an active period of ice-flow

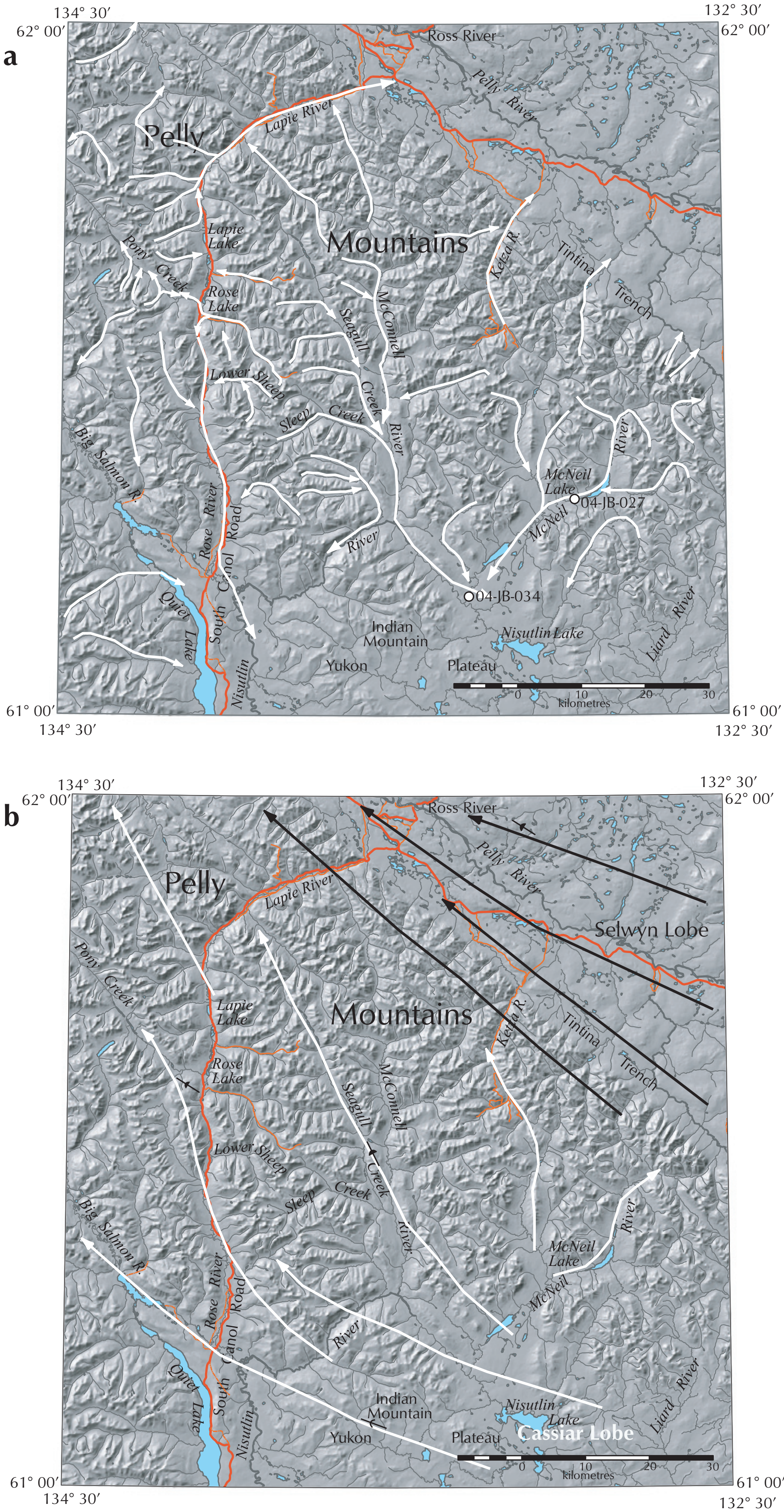
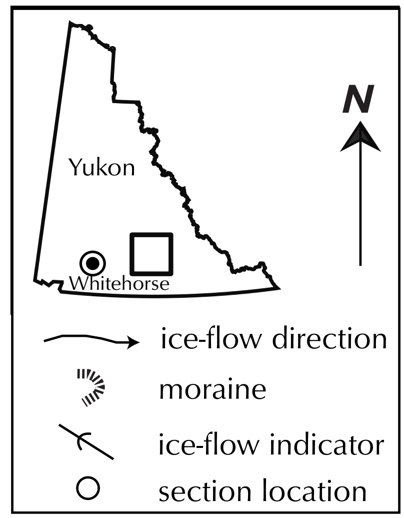


Figure 8. *Phases of the McConnell glaciation in the Pelly Mountains.* ***(a)*** *Phase 1: glacial onset characterized by local ice-flow;* ***(b)*** *Phase 2: glacial maximum ice-flow reconstruction, where flow originates from the Cassiar and Selwyn lobes of the Cordilleran ice sheet.*



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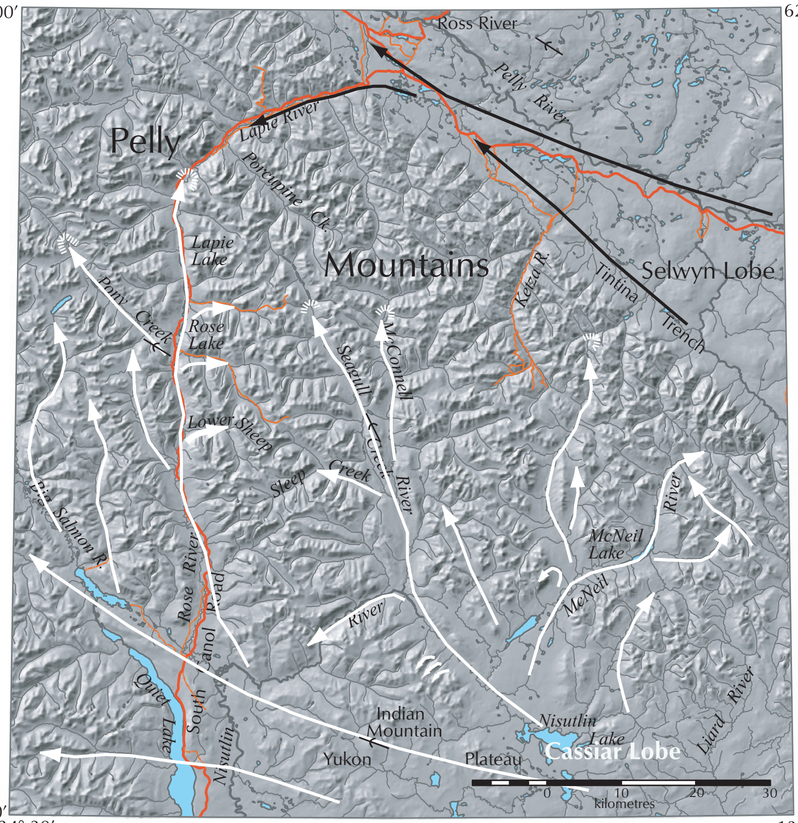

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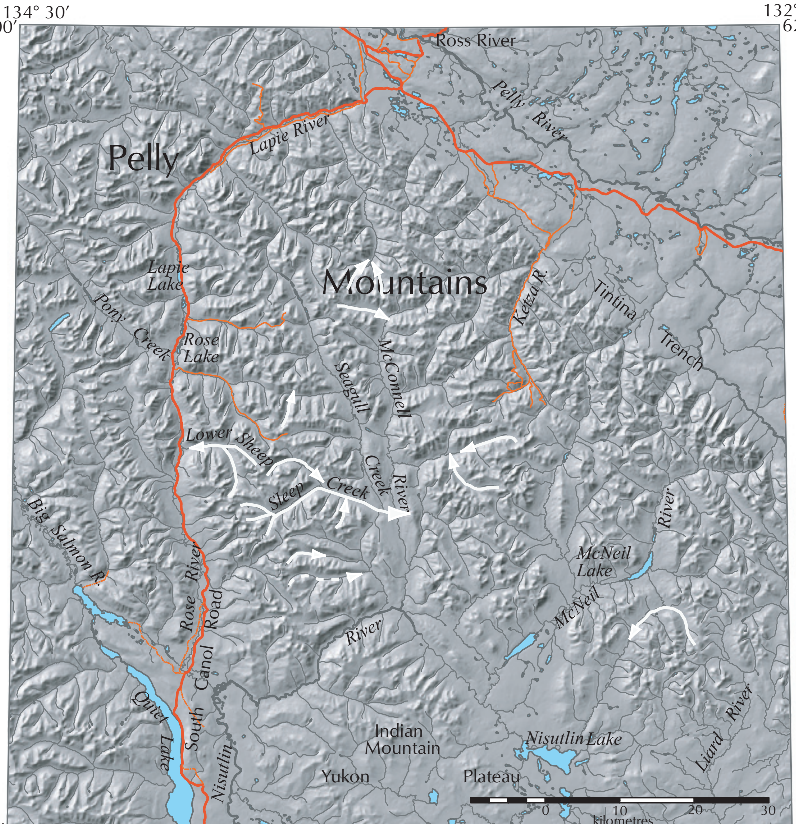

Figure 8. *(continued) Phases of the McConnel glaciation in the Pelly Mountains. **(c)** Phase 3: early deglaciation characterized by the retreat and periodic re-advance of Cordilleran ice; **(d)** Phase 4: Late McConnell to early Holocene re-advance of local cirque glaciers.*

characterized by a combination of frontal retreat, dynamic equilibrium or recessional stand-stills, and re-advances. In terms of climate reconstructions, this evidence shows that deglaciation continued to be interrupted by periods of renewed precipitation and/or cooler temperatures.

McConnell late deglaciation: Phase 4

A re-activation of local glaciers at the highest elevations was the final phase of glacial activity in the Pelly Mountains (Fig. 8d). The timing of this re-advance relative to the retreating Cordilleran ice sheet is uncertain. Evidence from Sleep Creek shows that ice flowed freely into the McConnell River valley, which suggests the northern margin of the Cordilleran ice sheet was at least as far south as the Sleep Creek outlet. The extent of this local re-advance was limited to <5 km in most drainages with the exception of Sleep Creek where glaciers advanced over 20 km (Fig. 8d). This may have been due to a lingering ice cap that spanned the drainage divide between Sleep Creek and lower Sheep Creek. The cirques associated with these known moraines typically exceed 1600 m (5250 ft) a.s.l. Air photo interpretation of the surficial geology in this region indicates extensive glacial erosion within the limit of this re-advance, but no field-based exposures were documented to verify this.

GLACIAL PROCESSES AND IMPLICATIONS FOR DRIFT PROSPECTING:

The four-phase model proposed for the McConnell glaciation in the Pelly Mountains has implications for mineral exploration. Previous exploration projects in Seagull Creek valley assumed down-valley dispersion for mineralized float. Up-valley ice-flow dominated phases 2 and 3 of the last glaciation, however, which resulted in the reworking and redistributing of phase 1 sediment in the opposite dispersal direction (Fig. 9). In other words, the down-valley direction would be the likely source for anomalous sediment and float samples. In the hypothesized dispersal diagram (Fig. 9), a remnant geochemical anomaly may be preserved down-valley from mineralized outcrop if reworking of phase 1 sediment is incomplete. The amount of sediment reworking and erosion by successive ice-flow phases is the pivotal question in determining the dominant glacial sediment dispersion direction. To address this question, four Pelly Mountain valley profiles are described below. These field-based profiles show the distribution of surficial sediment within a typical valley cross-section, and thereby provide a clearer understanding of the degree of deposition and inferred erosion.

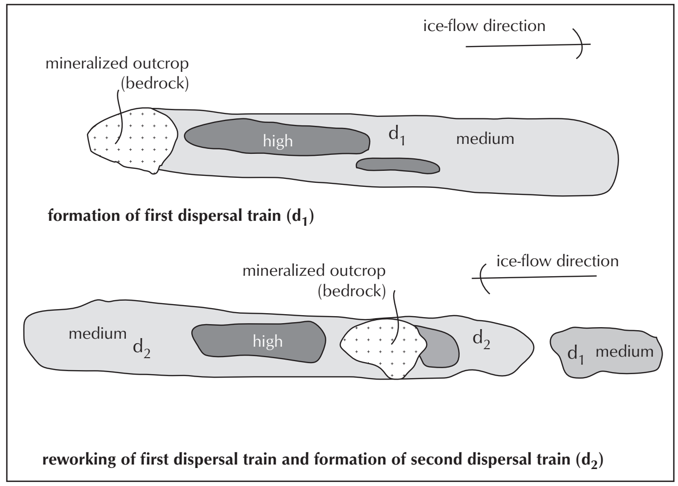

Figure 9. *A glacial dispersion model for the Pelly Mountains. This model is most applicable for the upper reaches of the southward draining valleys that experienced ice-flow reversals during phases 2-4 of the McConnell glaciation.*

The surficial geology shown in the following diagrams is based on field observations within the McNeil River, Seagull Creek and Rose-Lapie Lakes valleys. These diagrams illustrate the general characteristics of the surficial geology and its variability within a valley cross-section. These profiles are not necessarily applicable to a particular property, but can be used as a guide in the construction of new profile models that reflect the unique surficial attributes observed at that property. The general location of these cross-sections is shown in Figure 1.

Upper Seagull Creek

The surficial sediment distribution in upper Seagull Creek reflects the staggered retreat of the Cordilleran ice sheet from the Pelly Mountains. Multiple thick moraine complexes deposited during recessional pauses are separated by zones of thinner surficial cover where glacial retreat was relatively constant and rapid (Fig. 10). Two profiles have been constructed to illustrate the surficial sediment distribution in each of these zones.

Surficial geology profile 1 (Fig. 11a) illustrates an area within the Seagull Creek valley where phase 3 glaciers retreated relatively constantly and rapidly. Glacial deposits are thin (<4 m) on the valley sides and bottom (Fig. 10).

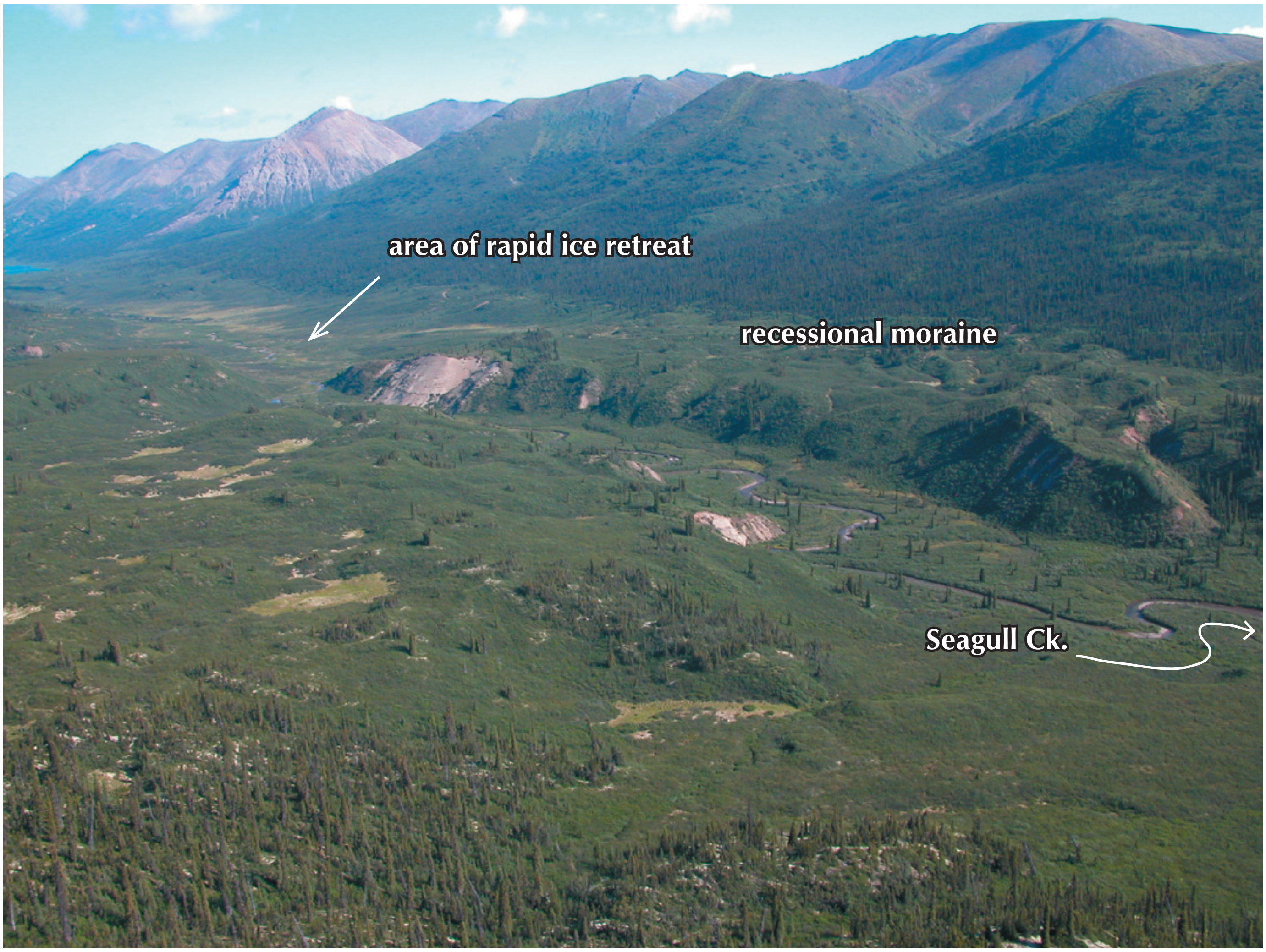

Figure 10. *A view to the northeast up Seagull Creek showing the surficial sediment variability that is typical in the Pelly Mountains. In the foreground is a recessional moraine/kame accumulation with thicknesses exceeding 30m. In the background is an area of thin glacial cover (<4 m) indicative of clean glacial retreat.*

Surficial geology profile 2 (Fig. 11b) illustrates a cross-section through a moraine complex in the Seagull Creek valley. A kame terrace is visible on the valley side and thick ablation sediment overlies basal till in the valley bottom. A deep incision by the modern creek is common (Fig. 10).

Lower McNeil River

The surficial geology in valleys of lower elevation have fewer moraines, which suggests that the Cordilleran ice sheet retreated more uniformly during the later stages of retreat from the Pelly Mountains.

In profile 3 (Fig. 11c), sediment accumulations are relatively thin on valley benches (<4 m) compared to thick accumulations in valley bottoms (>30 m) where sediment stacking occurred. Earlier glacial deposits are likely eroded from the benches by later ice-flow, whereas deposition dominates in valley bottoms and earlier deposits are preserved.

Glaciolacustrine deposits

The down-valley retreat of ice in many Pelly Mountain valleys caused ponding of fluvial and glaciofluvial drainage against the ice front. As a result, glaciolacustrine sediment was deposited into pro-glacial lakes. Controls on

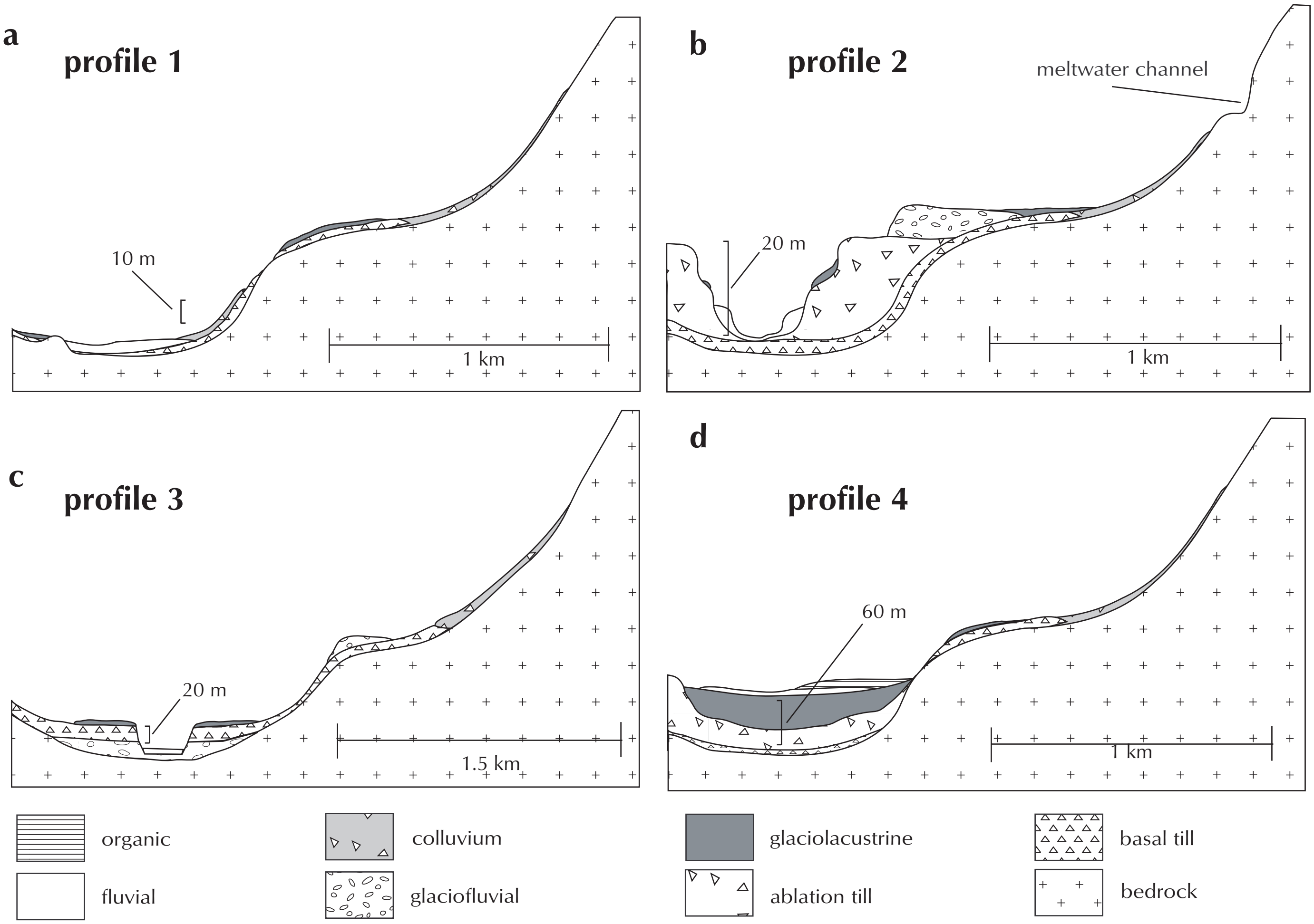

Figure 11. *Surficial geology profiles of* ***(a)*** *upper Seagull Creek;* ***(b)*** *middle Seagull Creek;* ***(c)*** *McNeil Lake area- and* ***(d)*** *lower Seagull Creek.*

the extent of glaciolacustrine sedimentation in a given valley depended on the elevation of the lake outlet, the subglacial hydrology and perhaps the style of ice retreat. Where lake outlets were relatively high, there are thicker and more widespread glaciolacustrine deposits than in drainages having lower outlets. A lower outlet may have allowed for greater circulation of water through the valley, thereby permitting sediment to be carried through in suspension. As ice retreated further down-valley, glacial lakes would have grown in extent, assuming drainage outlets remained constant. These lakes would have lasted through a significant period of deglaciation and would undoubtedly have left behind thick glaciolacustrine sediments over the valley bottoms. While some glaciolacustrine deposits are thick, particularly in the upper-reaches of the main valleys, they are not longitudinally continuous into the lower valley reaches. Reasons for this distribution of glaciolacustrine deposits are uncertain, however, and could be explained by the style or rate of ice retreat.

Sediment accumulations in profile 4 (Fig. 11d) are characterized by thick glaciolacustrine deposits that overlie till in the valley bottom. In some valleys, fluvial erosion has incised the thick glacial sediment package, whereas in others, like lower Seagull Creek, post-glacial stream base-level changes have not been sufficient to encourage fluvial incision. Surficial sediment thicknesses on the valley sides are considerably thinner compared to the valley bottom in this environment.

In terms of mineral exploration, glaciolacustrine sediment is not derived directly from local bedrock and therefore is a poor sample medium that should be avoided when conducting standard soil geochemistry surveys. In order to illustrate the geochemical variability between glaciolacustrine sediment and till, several samples from

Figure 12. *A surficial sediment profile in Seagull Creek valley showing a veneer of glaciolacustrine sand overlying a till. The gold concentrations from each unit show the geochemical variability within the surficial geology and highlights the need for surficial mapping early in the exploration process.*

Ross River Mineral's Tay-LP property in Seagull Creek were analysed (Fig. 12). Assays showed that the anomalous gold concentration present in the till is absent within the glaciolacustrine veneer. Standard B-horizon soil geochemistry techniques would therefore be misleading in this environment.

CONCLUSION

A proposed four-phase ice-flow model was developed to describe the McConnell glacial history for the Pelly Mountains. At the onset of glaciation, local valley glaciers advanced down-valley to the mountain front. By glacial maximum, the control on ice-flow shifted to ice-divides located south (Cassiar lobe) and east (Selwyn lobe) of the Pelly Mountains. This resulted in an ice-flow reversal into the mountains. During deglaciation, the neighbouring ice-divides continued to control ice-flow within the Pelly Mountains. The down-valley recession of glaciers was characterized by periods of rapid retreat and periodic up-valley re-advances or recessional pauses. Glacial lakes developed at the margin of the ice front where drainages were blocked. The final phase of ice activity in the Pelly Mountains was a resumption of ice-flow from local cirques above 1600 m a.s.l. This re-advance was limited to <5 km in most valleys and occurred after the invading ice lobes had retreated down-valley to the mountain fronts.

Future drift prospecting in the Pelly Mountains should consider ice-flow complexities that occurred in this area. Surficial geology investigations showed that the dominant glacial sediment dispersal trains were likely created by phases 3 and 4 ice-flow, which means that many valleys in the study area have up-valley-trending sediment dispersal records.

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REFERENCES

Anderson, L., Abbott, M., Finney, B. and Edwards, M.E., 2002. The Holocene lake-level history of Marcella Lake, southern Yukon Territory, Canada. *In:* The Geological Society of America Northeastern Section – 37th Annual Meeting, Springfield, Massachusetts, Session No. 19 Program Abstract.

Armentrout, J.M., 1983. Glacial lithofacies of the Neogene Yakataga Formation, Robinson Mountains, southern Alaska Coast Range, Alaska. *In:* Glacial-marine sedimentation, B.F. Molnia, (ed.), Plenum Press, New York, New York, p. 629-665.

Bond, J.D., 1999. The Quaternary history and till geochemistry of the Anvil District, east-central Yukon. *In:* Yukon Exploration and Geology 1998, C.F. Roots and D.S. Emond (eds.), Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada, p. 105-116.

Bond, J.D., 2004. Late Wisconsinan McConnell glaciation of the Whitehorse map area (105D), Yukon. *In:* Yukon Exploration and Geology 2003, D.S. Emond and L.L. Lewis (eds.), Yukon Geological Survey, p. 73-88.

Duk-Rodkin, A., 1999. Glacial limits map of Yukon Territory. Geological Survey of Canada, Open File 3694; Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada, Geoscience Map 1999-2, scale 1:1 000 000.

Duk-Rodkin, A. and Barendregt, R.W., 1997. Glaciation of Gauss and Matuyama age, Tintina Trench, Dawson area, Yukon. Canadian Quaternary Association Biannual Meeting, May 22-24, 1997, Université de Québec à Montréal, Montréal, Québec.

Duk-Rodkin, A., Barendregt, R.W., White, J.M. and Singhroy, V.H., 2001. Geologic evolution of the Yukon River: implications for placer gold. Quaternary International, vol. 82, p. 5-31.

Dyke, A., 1990, Quaternary geology of the Frances Lake map area, Yukon and Northwest Territories. Geological Survey of Canada, Memoir 426, 39 p.

Froese, D.G., Barendregt, R.W., Enkin, R.J. and Baker, J., 2000. Paleomagnetic evidence for multiple late Pliocene-early Pleistocene glaciations in the Klondike area, Yukon Territory. Canadian Journal of Earth Sciences, vol. 37, p. 863-877.

Fulton, R.J., 1991. A conceptual model for growth and decay of the Cordilleran Ice Sheet. Geographie physique et Quaternaire, vol. 45, no. 3, p. 281-286.

Gordey, S.P. and Makepeace, A.J. (comps.), 2003. Yukon Digital Geology, version 2. Geological Survey of Canada, Open File 1749, and Yukon Geological Survey, Open File 2003-9(D), 2 CD-ROMS.

Jackson, L.E., Jr. and Mackay, T.D., 1991. Glacial limits and ice-flow directions of the last Cordilleran Ice Sheet between 60 and 63 degrees north. Geological Survey of Canada, Open File 2329, scale 1:1 000 000.

Jackson, L.E., Jr. and Harington, C.R., 1991. Pleistocene mammals, stratigraphy, and sedimentology at the Ketza River site, Yukon Territory. Geographie physique et Quaternaire, vol. 45, p. 69-77.

Jackson, L.E., Jr., Ward, B., Duk-Rodkin, A. and Hughes, O.L., 1991. The last Cordilleran ice sheet in southern Yukon. Geographie physique et Quaternaire, vol. 45, p. 341-354.

Jackson, L.E., Jr., 1993a. Surficial Geology, Lapie Lakes, Yukon Territory. Geological Survey of Canada, Map 1790A, scale 1:100 000.

Jackson, L.E., Jr., 1993b. Surficial Geology, Bruce Lake, Yukon Territory. Geological Survey of Canada, Map 1791A, scale 1:100 000.

Jackson, L.E., Jr., 1993c. Surficial Geology, McConnell River, Yukon Territory. Geological Survey of Canada, Map 1793A, scale 1:100 000.

Jackson, L.E., Jr., 1993d. Surficial Geology, Lonely Creek, Yukon Territory. Geological Survey of Canada, Map 1796A, scale 1:100 000.

Jackson, L.E., Jr., 1994. Terrain inventory and Quaternary history of the Pelly River area, Yukon Territory. Geological Survey of Canada, Memoir 437, 41 p.

Kennedy, K.E. and Bond, J.D., 2004. Evidence for a late-McConnell re-advance of the Cassiar lobe in Seagull Creek, Pelly Mountains, central Yukon. *In:* Yukon Exploration and Geology 2003, D.S. Emond and L.L. Lewis (eds.), Yukon Geological Survey, p. 121-128.

Klassen, R.W., 1987. The Tertiary-Pleistocene stratigraphy of the Liard Plain, southeastern Yukon Territory. Geological Survey of Canada, Paper 86-17, 16 p.

Matthews, J.V., Schweger, C.E. and Hughes, O.L., 1990. Plant and insect fossils from the Mayo Indian Village section (central Yukon): new data on middle Wisconsinan environments and glaciation. Geographie physique et Quaternaire, vol. 44, p. 15-26.

Plouffe, A., 1989. Drift prospecting and till geochemistry in Tintina Trench, Southeastern Yukon. Unpublished MSc thesis, Carleton University, Ottawa, Ontario, 81 p.

Plouffe, A. and Jackson, L.E., 1992. Drift prospecting for gold in the Tintina Trench. *In:* Yukon Geology, vol. 3, Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada, p. 196-213.

Rampton, V.N., 1971. Late Quaternary vegetational and climatic history of the Snag-Klutlin area, Yukon Territory, Canada. Geological Society of America Bulletin, vol. 82, p. 959-978.

Tolbert, R.S., 2000. Assessment report on selective leach soil geochemistry and prospecting. Ross River Minerals Ltd., Assessment Report #94143, 17 p.

Ward, B.C., and Jackson, L.E., Jr. 1992. Late Wisconsinan glaciation of the Glenlyon Range, Pelly Mountains, Yukon Territory, Canada. Canadian Journal of Earth Sciences – Journal Canadien des Sciences de la Terre, 29 (9), p. 2007-2012.