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Preliminary report on surficial geology investigations of La Biche River map area, southeast Yukon Territory[1]

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Abstract: As part of the Central Forelands NATMAP Project, field investigations of the surficial geology of the La Biche River map area (NTS 95 C), southeastern Yukon Territory, were initiated. The distribution of erratics and glacial geomorphology, notably extensive bedrock fluting fields, indicates that the area was largely occupied by Montane ice advancing from the west-southwest. Granite erratics were found in glaciofluvial and till deposits within the south-central area. These indicate the presence of westward flowing Laurentide ice ~30 km beyond previously proposed limits, suggesting a more extensive advance of Laurentide ice across the Mackenzie Mountains bounding the eastern study area. During deglaciation, retreating ice impounded the regional drainages, forming large, proglacial lakes.

Ice- and clay-rich glaciolacustrine sediments and extensive shale deposits have led to widespread mass movements at varied scales (local to tens of square kilometres). The surficial investigations includes mapping these features to provide a database for risk assessment.

Résumé : Dans le cadre du Projet de l'avant-pays central du CARTNAT, on a entrepris des études sur le terrain de la géologie de surface de la région cartographique de la rivière La Biche (95C), dans le sud-est du Territoire du Yukon. La répartition des blocs erratiques et la géomorphologie glaciaire, notamment les vastes zones de rainures glaciaires, indiquent que la région a été recouverte par des glaces subalpines qui avançaient de l'ouest-sud-ouest. On a trouvé des blocs granitiques erratiques dans les dépôts glaciolacustres et les tills dans la région du centre sud. Ils indiquent la présence de glaces laurentidiennes à écoulement vers l'ouest à environ 30 km au-delà de la limite proposée précédemment, ce qui porte à croire que l'Inlandsis laurentidien s,est avancé plus loin sur les monts Mackenzie qui bordent la partie est de la région d'étude. Durant la déglaciation, la glace en retrait a bloqué le drainage régional, ce qui a formé de vastes lacs proglaciaires.

La présence de sédiments glaciolacustres riches en glace et en argile ainsi que de vastes dépôts de shale a entraîné des mouvements de masse généralisés à diverses échelles (allant d'une échelle locale à plusieurs dizaines de kilomètres carrés). L'étude de la géologie de surface inclut la cartographie de ces éléments aux fins de l'assemblage d'une base de données pour l'évaluation des risques.

[1] Contribution to the Central Forelands NATMAP Project

INTRODUCTION

The Central Forelands NATMAP Project includes mapping the surficial geology of the La Biche River map area NTS 95 C (Fig. 1). Research topics include the detailed mapping of glacial geomorphology, stratigraphy, geochronology, and till dispersal related to the interaction of Laurentide, Montane, and Cordilleran ice sheets along the Liard Plateau and southern Mackenzie Mountains, Yukon Territory, and Northwest Territories. Final results will be displayed on a 1:250 000 scale map of surficial geology. Mapping will also document the distribution and type of mass movements within the region, noting areas of potential hazard for future development. Databases produced from this study will be compatible with bedrock maps and geophysical databases under a GIS standard.

Initial field investigations began in the 1999 field season. Access to the field area was by canoe, paddling from Jackpine Lake down the Whitefish River to the Beaver River and then south beyond the map area (Fig. 1). Foot traverses were made from the shore at selected sites, whereas detailed observations and sediment samples were collected from exposed sections along the rivers.

A review of the current literature and regional Quaternary history along with preliminary field observations are presented here.

PHYSIOGRAPHIC SETTING

The La Biche River map area lies mostly within the Liard Plateau, bounded to the west by the Hyland Plateau, to the north and east by the Mackenzie Mountains, and farther east by the Interior Plains (Mathews, 1986). The landscape is characterized by discontinuous, north-trending ridges and valleys, on a gently rolling, heavily wooded terrain; maximum relief is ~1200 m (Fig. 1). The region is drained by the Beaver and Whitefish rivers and their tributaries, which drain southeastward to the Liard River and then north to the Mackenzie River. Along the eastern section of the map area lie the Kotaneelee and Liard ranges, the southern extension of the Mackenzie Mountains. Together with the La Biche Range, they represent three southward-plunging anticlinal structures, with summits exceeding 2400 m a.s.l. (Fig. 1). A series of smaller rivers (La Biche, Kotaneelee, Chinkeh) are aligned with the ridges and fed by trellis drainage networks. In places, this north-south alignment is disrupted and the rivers cross upland ranges through deeply incised canyons (Fig. 1). These diversions, and the stretch of the Beaver River that flows through a deeply incised canyon in the western map area, are thought to be the result of glacial damming and meltwater diversion (A. Duk-Rodkin, pers. comm., 1999). To the north, the Kotaneelee and La Biche ranges merge with the southern part of the Tlogotsho Plateau, where rivers drain northward into the South Nahanni River.

Rocks in the area range in age from Proterozoic argillites to intrusive Upper Cretaceous syenite and Tertiary trachyte deposits (Douglas, 1976). Cretaceous sedimentary rocks, including those of the Garbutt, Scatter, and Lepine formations, outcrop in the synclinal basins and troughs in the eastern half of the map area (Stott, 1960; Douglas, 1976). To the west, the geology is dominated by Paleozoic strata including members of the Fantasque, Mattson, and Besa River formations (Harker, 1963; Douglas, 1976), much of which are shale-rich.

PREVIOUS WORK

Following original reconnaissance studies within the broader study area, subsequent investigations were driven by the search for mineral and hydrocarbon resources. Kindle (1944) traversed the Nelson, Liard, and Beaver rivers where he made observations on the geological structure and composition and noted the potential for oil-bearing strata in the region. Hage (1945) focused on the Cretaceous record around Fort Liard and the Liard and La Biche ranges. Patton (1958), working for British American Oil Company, described the geological succession from a site just north of the La Biche map area. Operation Mackenzie, initiated in 1957, involved a geological reconnaissance of the southwestern District of Mackenzie of which a prime objective was to map the geological stratigraphy and assess the economic possibilities of the area for oil, gas, coal, and minerals (Douglas, 1958, 1959). Subsequent reports were prepared by Douglas and Norris (1959) on the overall geology of the La Biche and Fort Liard map areas including the first detailed geological map of the La Biche map sheet, by Stott (1960) on the Cretaceous rocks around Fort Liard and the Kotaneelee river, and by Harker (1961, 1963) on the Carboniferous and Permian strata of the southern Mackenzie Mountains including all of the La Biche River map area.

Evidence of extensive glaciation in the southern Yukon Territory has been known since the late 1800s (Dawson, 1889; McConnell, 1890; Russell, 1890; Hayes, 1891). Evidence of multiple glaciations in the central Yukon Territory was recorded by McConnell (1903) and then formally documented and interpreted by Bostock (1966). Four glaciations were recognized: Nansen (oldest), Klaza, Reid, and McConnell (youngest). The two oldest glaciations were the most extensive (Jackson et al., 1991). Associated glacial landforms and deposits of the two oldest glaciations are often subdued and difficult to differentiate, and much of their surficial record is simply classified as ‘pre-Reid’ glaciation. On the basis of paleomagnetic and radiometric techniques, the Klaza Glaciation is dated >790 ka and the Nansen Glaciation, at >1.08 Ma (Naeser et al., 1982; Jackson et al., 1990). Dates on tephras overlying deposits of the Reid Glaciation provide a minimum age of 80 ka; the Reid Glaciation is generally considered to be Illinoian (Hughes et al., 1989; Jackson et al., 1990). The Reid Glaciation extended to limits between those of the pre-Reid and McConnell glaciations. The most recent glaciation, the McConnell Glaciation, is Late Wisconsinan and considered to be the least extensive regional ice advance (Klassen, 1987; Matthews et al., 1990; Jackson and Harington, 1991; Jackson et al., 1991).

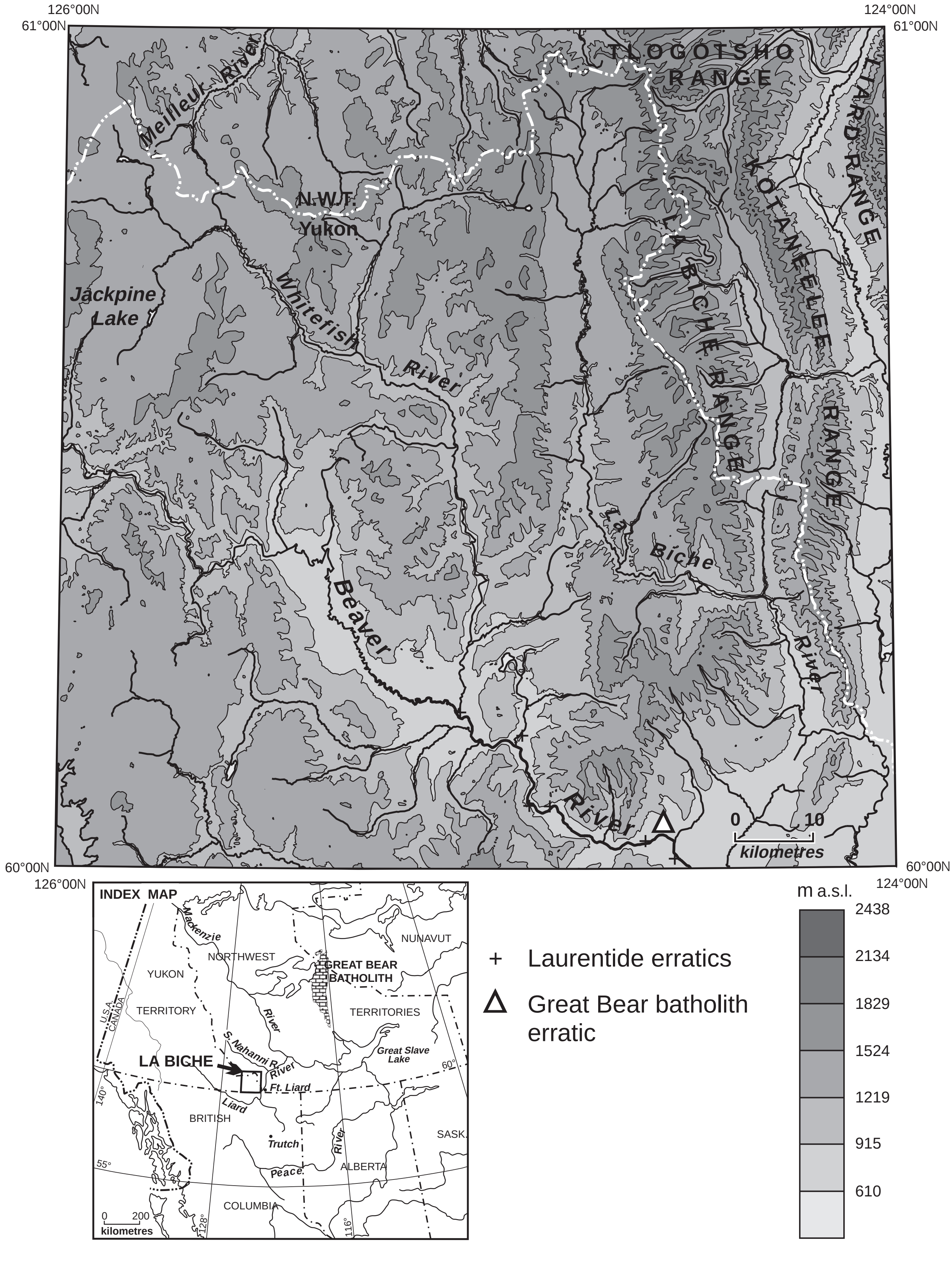

Figure 1. *Location and physiography of the La Biche River map area (NTS 95 C).*

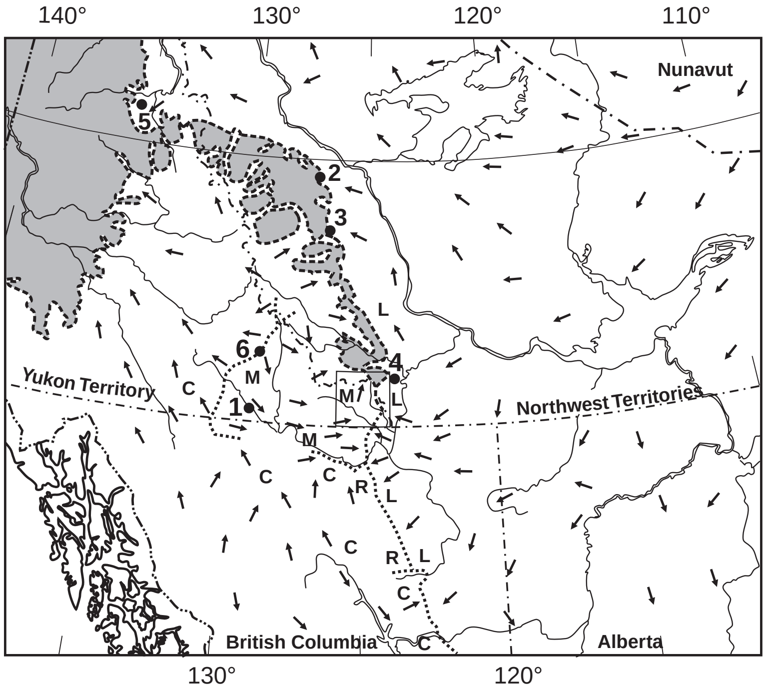

Figure 2.

Regional glacial limits based on those published by Mathews (1986), Duk-Rodkin and Hughes (1991), Catto et al. (1996), Duk-Rodkin et al. (1996), Duk-Rodkin (1999), and Duk-Rodkin and Lemmen (in press). Maximum advances are not considered to be coeval across the region. Arrows illustrate generalized ice-flow patterns; dotted lines approximate divides within the ice sheets; drift sheets are identified by provenance: C = Cordilleran ice; R = local Rocky Mountain ice; M = local montane ice; and L = Laurentide Ice Sheet. Shading shows terrain that remained largely ice-free during the last glaciation. The La Biche River map area (box) is situated at the junction of Laurentide and montane ice masses and is suggested to have supported ice-free areas in its northern margins. Numbers refer to sites discussed within the text.

In southern Yukon Territory within the Liard Lowland (Fig. 2, site 1), Klassen (1978, 1987) described a stratigraphy of four tills. Whereas the most recent of these tills (Till D) correlates with the McConnell Glaciation, the others date from the time between the Reid and pre-Reid glaciations, suggesting that they were deposited by more regionally restricted glaciations. Potassium-argon dating of interstratified basalts constrain the oldest till (till A) as >545 ka and <604 ka, and the second oldest till (till B) as >232 ka (Klassen, 1987). Radiocarbon dates of >30 000 BP (GSC-2949) and 23 900 ± 1140 BP (GSC-2811) from the Tom Creek silt between the uppermost and second till (till C) led Klassen (1987) to suggest that the penultimate glaciation was of Early Wisconsinan age. However, in the absence of a more precise age constraint, till C may be coeval with the Reid Glaciation of the central Yukon Territory.

Within the northeast Mackenzie Mountains there is widespread geomorphic evidence for two montane glaciations that are tentatively correlated with the Reid and McConnell glaciations (Duk-Rodkin and Hughes, 1991). Of these two advances, the Reid Glaciation was more extensive, as it was in the central Yukon Territory (Duk-Rodkin and Hughes, 1991). In addition to the geomorphic evidence, Duk-Rodkin and Hughes (1992) and Duk-Rodkin et al. (1996) documented stratigraphic evidence of six till deposits within the Canyon Ranges of the northeastern Mackenzie Mountains (Fig. 2, site 2). The lower five tills were deposited by montane glaciations and the ages are in part constrained by paleomagnetism as early Matuyama (<2.58 Ma), late early Matuyama (Olduvai Subchron 1.95–1.77 Ma), Middle Pleistocene (Matuyama/Brunhes ±0.78 Ma), Brunhes (<0.78 Ma), and Reid Glaciation (Illinoian; Duk-Rodkin et al., 1996). The sixth, uppermost till, which dates to the Late Wisconsinan, contains diagnostic Canadian Shield granite erratics, making it a Laurentide deposit. The fact that Laurentide erratics are not found in any of the deposits below this strongly suggests that the Late Wisconsinan advance was the most extensive continental advance westward into the Mackenzie Mountains. Within the eastern Carcajou Range of the Mackenzie Mountains (Fig. 2, site 3), Duk-Rodkin (pers. comm., 1999) reports finding granite erratics on surfaces up to 1500 m a.s.l. Hage (1945) reports granite erratics on top of Sawmill Mountain (1150 m a.s.l.; Fig. 2, site 4).

Little investigation of the Quaternary glacial record has been conducted in the Interior Plains region adjoining the La Biche River map area. Instead, interest has focused on the region adjacent to the Mackenzie River as part of the assessment and development of the Mackenzie Valley Transportation Corridor. In their mapping of the surficial geology of the upper Mackenzie and lower Liard rivers, Rutter and Boydell (1973) and Rutter (1974) documented deposits they ascribed to two Laurentide glaciations. The older of these is a grey-black, stony till exposed along tributaries of the Mackenzie River. Erratics on summits found up to 1500 m a.s.l. in the eastern Mackenzie Mountains are attributed to this advance. Overlying the lower till and separated by deposits of stratified sands and gravels is what Rutter (1974) termed deposits of the ‘Classical’ Wisconsin limit: a light grey-brown, stony till, accumulations of which are largely restricted to elevations below 670 m a.s.l. (Rutter and Boydell, 1973). Erratics deposited by this advance are found up to 1300 m a.s.l. around Wrigley Lake, south of the Carcajou Mountains (Fig. 2, site 3), but to 1500 m a.s.l. farther south, where they become inseparable from those of the penultimate glaciation (Rutter, 1974). In light of recent investigations by Duk-Rodkin and Hughes (1991, 1992) and Duk-Rodkin et al. (1996) along the eastern Mackenzie Mountains, the uppermost Laurentide erratics are considered to be from the last glaciation (Late Wisconsinan). Thus, the age and extent of the two tills described by Rutter and Boydell (1973) remain to be clarified.

Surface exposure ^{36}Cl dating of erratics indicates that the Laurentide maximum was attained about 30 ka (Duk-Rodkin et al., 1996), which correlates well with sub-Laurentide till radiocarbon dates of 36 900 ± 300 BP (GSC-2422) and 34 220 ± 120 BP (TO-124) from the Bonnet Plume Basin, north of the Mackenzie Mountains (Fig. 2, site 5; Hughes et al., 1981; Schweger and Matthews, 1992). The presence of Laurentide moraines and outwash deposits within mountain valleys that were subsequently overrun, or incised by montane ice, shows that the montane ice attained its maximum Late Wisconsinan limits after the Laurentide Ice Sheet (Duk-Rodkin and Hughes, 1991, 1992; Duk-Rodkin et al., 1996). This is broadly correlated with the McConnell Glaciation, which attained its maximum extent around 23 000 BP (Matthews et al., 1990; Duk-Rodkin et al., 1996). During this time, the ice-free terrain between the two ice masses (Fig. 2) developed small cirque glaciers and upland icefields (Duk-Rodkin and Hughes, 1991; Duk-Rodkin et al., 1996).

The retreat of the Laurentide Ice Sheet was interrupted by a brief readvance, the Katherine Creek Phase (Duk-Rodkin and Hughes, 1991), dating at ca. 22 000 BP (Duk-Rodkin et al., 1996). The Laurentide Ice Sheet then retreated eastward, forming a margin along the central Mackenzie River channel by ca. 12 000 BP (Dyke and Prest, 1987). Retreat of the Cordilleran and montane ice was considered to be rapid, with much of it disappearing by ~13 000 BP (Jackson, 1987; Jackson et al., 1991), although the retreat history remains poorly constrained.

GLACIAL GEOMORPHOLOGY

Most of the Liard Plateau is covered by a till veneer or blanket derived from montane ice that flowed from the northeastern dome (Logan Dome; Dyke, 1990) of the Cordilleran Ice Sheet during the last glaciation. Few sections of thick (>2 m) till were observed and thus much of the bedrock structure is visible on airphotos. Bedrock exposures are rare, however, except along drainage channels, where they occur along steep banks or cliff faces. Although the La Biche and Kotaneelee ranges were not investigated last summer, airphoto interpretation suggests that their lower slopes are largely covered by till veneer whereas their upper slopes, much of which extend above the treeline, are covered by colluvial deposits or exposed bedrock. On the basis of airphoto interpretation of the glacial geomorphology (meltwater channels, moraines, deltas, and kame deposits) by the author and by A. Duk-Rodkin (pers. comm., 1999), Laurentide ice may have advanced as far west as the central La Biche Range. This represents a westward extension of Laurentide ice beyond that proposed by earlier authors (e.g. Prest et al., 1968; Rutter, 1980; Dyke and Prest, 1987) who suggested that much of the region between the La Biche and eastern Liard ranges remained ice-free. Field investigations in the summer of 2000 will address this matter by examining glacial deposits for Laurentide erratics and determining their elevational limits along the La Biche and Kotaneelee ranges.

Mature cirques are prominent in the Tlogotsho and northern La Biche and Kotaneelee ranges. Less well developed cirque basins are found along higher terrain in the central La Biche and Kotaneelee ranges. No cirques in the study area currently support glaciers. Dyke (1990), working around Frances Lake, Yukon Territory (Fig. 2, site 6), documented widespread cirque glaciation. He indicated that cirque glaciers must have been active through much of the Quaternary, and that during the McConnell Glaciation these basins were inundated by ice flowing southeastward from the Logan Dome (Fig. 2). He also documented widespread growth and retreat of cirque glaciers during the last 450 years, when a number of neoglacial moraines formed. In the La Biche River map area, prominent nested moraines can be found at the mouths of and downvalley from many cirques. Future field investigations will examine these to determine whether they represent a neoglacial advance or are recessional deposits from local alpine glaciers formed during the breakup of the regional McConnell and Laurentide ice cover.

Diagnostic pink granite Laurentide erratics were found along the lower Beaver River at several locations (Fig. 1). Rare, well rounded granite cobbles were found within a 3 m exposure of glaciofluvial gravels overlying bedrock at the confluence of the Beaver and Whitefish rivers. South of there, granites were found sporadically along the riverbank, but were not identified in sections (2–4 m) of fluvial gravels and floodplain deposits into which the modern Beaver River has incised. This suggests that these fluvial materials postdate the retreat of Laurentide ice and were probably deposited by montane ice that was retreating westward. Approximately 15 km downriver from the confluence of the Beaver and Whitefish rivers, large (>1 m) granite boulders were found on the surface (~480 m a.s.l.) of a prominent ridge extending northeastward up a side valley (Fig. 1). The ridge is apparently composed of till in which granite erratics are abundant. This establishes a minimum upper limit and position for Laurentide ice in the southern field area. Farther downriver, granite erratics were found in all till sections along the river (Fig. 1) and become the dominant rock type. The thickness of the surficial deposits also increases to the southeast, and much of the lower areas are covered by a till blanket (>2 m). Near the south end of the map area, a distinctive 'piano-key' granite erratic was found. It is similar to diagnostic erratics found in Laurentide deposits northeast of Trutch, British Columbia (Fig. 1), which are considered to have been derived from the Great Bear Batholith (Fig. 1; M. Cecile, pers. comm., 1999).

Flow direction of the montane ice across the western and central map area are readily recognized from extensive flutings and drumlinoid ridges (Fig. 3). Cross-sections through several such ridges along the Whitefish River show them to be cored by bedrock overlain by a till veneer. The ridges are on the order of tens of metres wide, tens to hundreds of metres long, and upward of 10 m high. Thus, during the last glaciation, montane ice apparently flowed east-southeastward from the Logan Dome, sweeping south of latitude 60°N, then east-northeastward as it was deflected by the Laurentide Ice Sheet (Fig. 2; Dyke, 1990; Jackson et al., 1991; Duk-Rodkin, 1999). On the basis of this reconstruction, it is suggested that a distinctive suite of igneous erratics found along a 20 km stretch of the Whitefish River is derived from an outcrop of Cretaceous syenite located to the southwest along the west-central margin of the map area (Douglas, 1976). Identification of the erratics is currently underway and they will be compared with those sampled from the actual outcrops following the 2000 field season. Further investigation and mapping of this erratic flow path across the map area will help constrain the local glacial history.

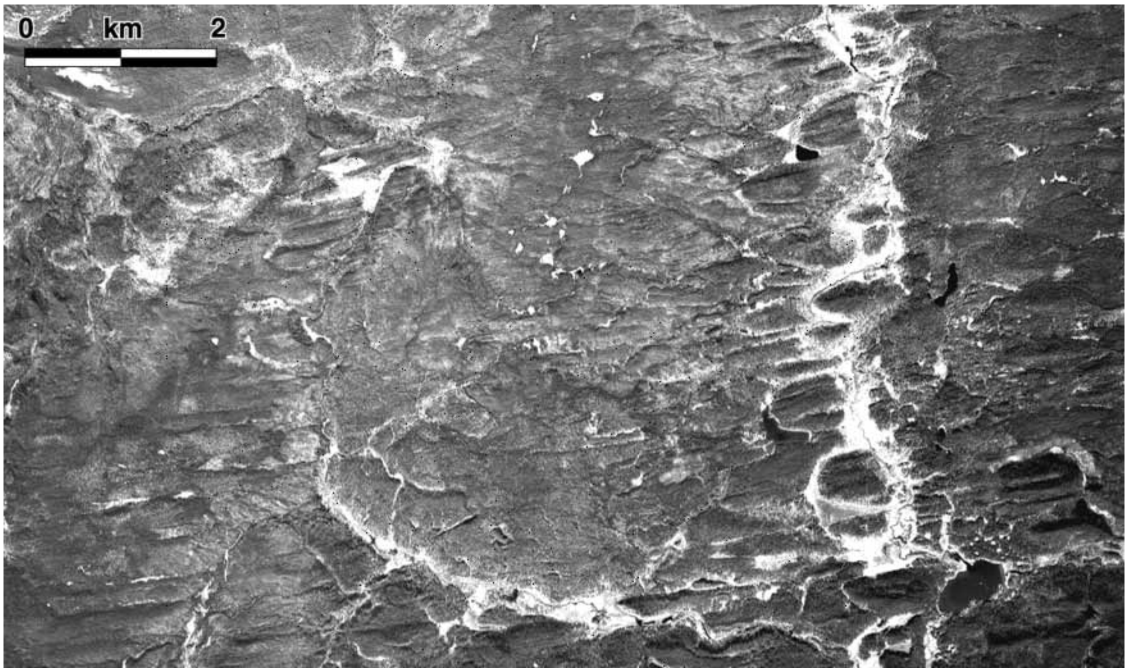

Figure 3. *Cropped airphoto illustrating the extensive flutings and drumlinoid ridges found throughout the western half of the map area. Ice flow was from west to east (left to right). NAPL A17437-185.*

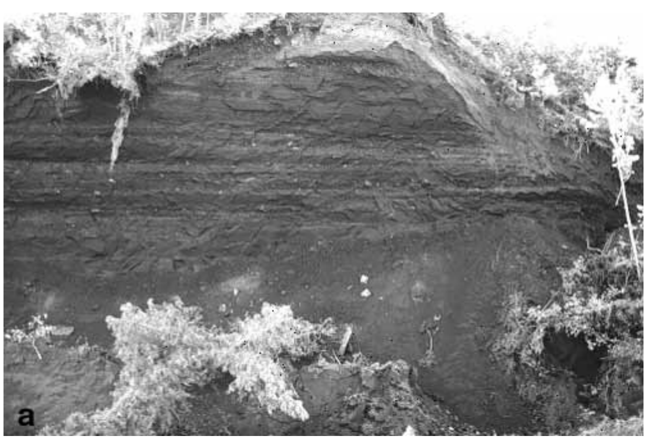

Figure 4. a) *Clay-rich, glaciolacustrine sediment containing numerous ice-rafted clasts. Section is approximately 4.5 m high.* ***b)*** *A 7 m section of glaciolacustrine sediment. The upper 3 m are dark, clay-rich sediment; the middle 2.5 m are pale, well sorted, medium sand; the lower 1.5 m are dark, clay-rich sediment. The entire section is devoid of clasts. Discrete ice lenses were observed throughout the lower clay-rich sediment. The deposit itself is frozen up to half way through the middle sand unit, which allows the sand unit to be considerably undercut before it fails. Note the 'drunken' forest formed as the trees are tilted on the surficial material, which is deforming downslope.*

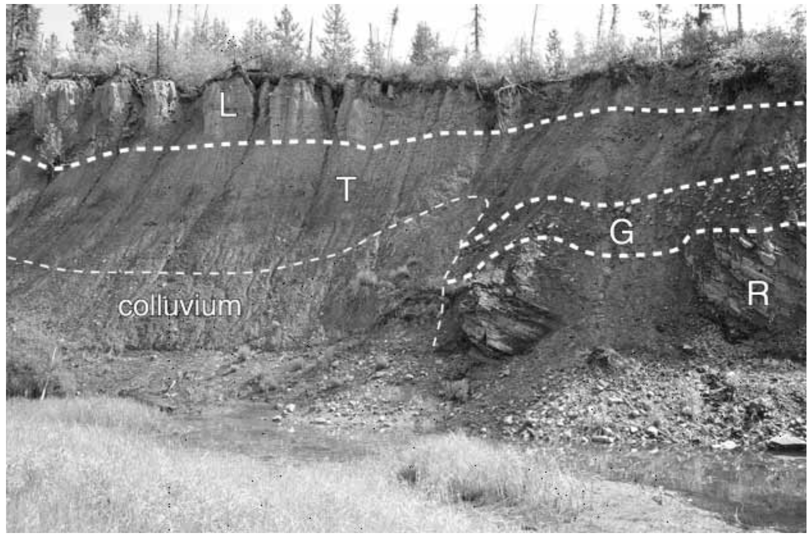

Figure 5.

Stratigraphic section along the Whitefish River. Shale (R) is overlain by up to 1.5 m of glaciofluvial gravels (G) that, in turn, are overlain by up to 4 m of montane till (T) capped by up to 2 m of glaciolacustrine sand (L). Much of the lower glaciofluvial and bedrock units on the left side of the image are obscured by colluvial deposits. Ice advanced from south to north (right to left) through this location.

STRATIGRAPHY

Glaciolacustrine sediments are found discontinuously along stretches of the Whitefish and Beaver rivers and their thickness locally exceeds 10 m (Fig. 4a). They are predominantly clay-rich, reflecting the abundance of shale within the surrounding bedrock, yet considerable textural variability exists. Other glaciolacustrine sediments were dominantly fine to medium sand (Fig. 4b) and the abundance of ice-rafted clasts within them varied considerably. The formation of proglacial lakes would have been increased by southward-retreating ice margins and much of the regional drainage would have been impounded. The discontinuous nature of the sediments likely reflects the breaching of successive topographic barriers and changes in the geometry of the retreating glaciers.

One stratigraphic section logged along the central Whitefish River illustrates the sequence of deposits related to the advance and retreat of montane ice within the valley (Fig. 5). Overlying the shale bedrock is 1–1.5 m of glaciofluvial gravels (mostly local sandstone) recording a paleoflow that was northward up the valley, opposite to that of the modern river (*glacial advance*). This unit is overlain by a 4 m thick, well indurated till containing numerous striated clasts of local lithology (*full glacial)*. Capping this is a 2 m thick blanket of sandy glaciolacustrine sediment containing abundant ice-rafted clasts (*glacial retreat*).

Several sections of well to poorly lithified, current-bedded gravels were found along a short stretch of the Whitefish River (lat. 60°36′N; long. 125°17′W). Their thicknesses range from <1 to 5 m and they are situated as little as 1 m above the modern river. They show a prominent orange staining. Sections are made up of alternating beds (2–18 cm thick) of poorly consolidated, well sorted, well rounded, fine to medium gravel and highly indurated, well sorted, coarse sand and fine gravel (Fig. 6). Clasts are mostly shale and sandstone. These sediments unconformably overlie the local Besa River Formation shale and siltstone bedrock. Similar types of poorly consolidated, possibly Tertiary gravel deposits with pronounced rust staining were described by Hage (1945) along the Petitot River east of Fort Liard. The only Tertiary materials identified in the La Biche River map area are intrusive trachyte dykes (Douglas, 1976). However, tertiary gravel units have been documented in the surrounding region (*see* Klassen, 1987; Duk-Rodkin et al., 1996). Samples of the deposits along the Whitefish River have been submitted for pollen analysis in an attempt to constrain their age.

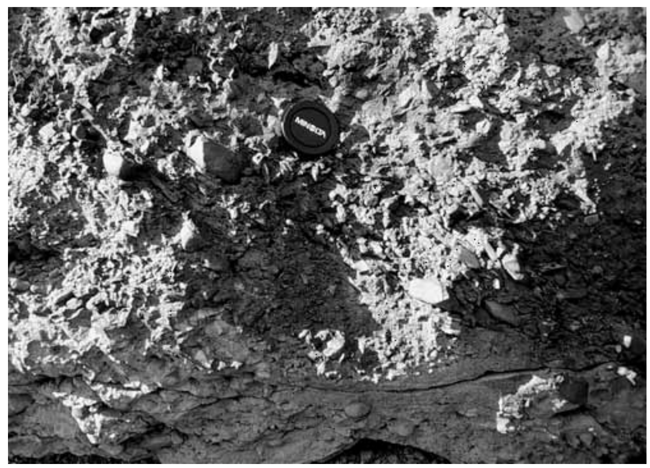

Figure 6. *Fluvial gravel unit (?Tertiary), with alternating lenses of poorly consolidated, well rounded, fine to medium gravel and well lithified, well sorted, coarse sand and fine gravel. Note lens cap for scale.*

MASS WASTING

The La Biche River map area is underlain by extensive shale deposits that seem highly susceptible to failure (Fig. 7a). Extensive glaciolacustrine deposits, sections of which are ice-rich, also seem highly susceptible to mass wasting (Fig. 7b) as do localized accumulations of till (Fig. 7c). Mass

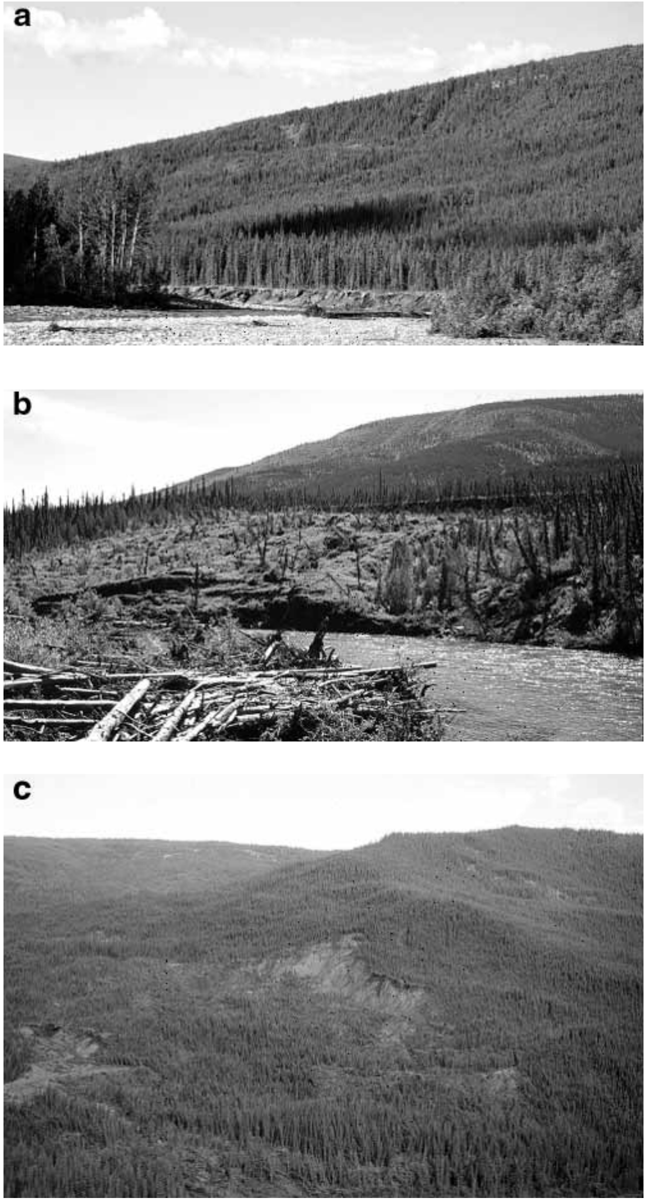

Figure 7. a) *Large (1.5 km wide) bedrock slump in shale-rich terrain along the Whitefish River.* ***b)*** *Extensive debris flows in glaciolacustrine sediment. The area of mass wasting is approximately 60 m wide and 100 m long. A prominent bench marks the upper limit of the glaciolacustrine deposit.* ***c)*** *Slump and debris flows in a thick (>10 m) till deposit along the lower Whitefish River. Failure may have occurred along a contact with underlying shale terrain. The feature is approximately 200 m wide.*

movements can be recognized from exposed scarp faces or from areas where the surface materials are either actively deforming or sliding over a failure plane, leading to the development of 'drunken' forests (Fig. 4b and 7b). Debris flows are the predominant form of mass movement active today; however, other examples range from large-scale slumps and earthflows to more localized mudflows and rockfalls. Although many of the larger mass movements apparently date from early postglacial times, there is widespread evidence of their recent and ongoing activity. They are considered to be a dominant geomorphic process active in the area today.

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