Current Research (2017) Newfoundland and Labrador Department of Natural Resources
Geological Survey, Report 17-1, pages 119-134

QUATERNARY MAPPING AND TILL GEOCHEMISTRY, WOODS LAKE, WESTERN LABRADOR (NTS MAP AREAS 23I/03, 04, 05, 06, 23I/11 AND 12)

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ABSTRACT

*Surficial-geological mapping and till-geochemistry sampling were completed in the western portion of the Woods Lake map area in western Labrador. This collaborative project is between the Geological Survey of Canada and the Geological Survey of Newfoundland and Labrador as part of the Geo-mapping for Energy and Minerals-2 program. The project was developed to better understand ice-flow patterns of the Labrador ice centre, characterize glacial landscapes and to determine glacial dispersal, sediment transport and deposition of glacial material northwest of the Smallwood Reservoir. This area was chosen as a focus for surficial mapping as there is a paucity of bedrock outcrops, and an understanding of the complex glacial-dispersal patterns from the Labrador ice centre would provide insight into glacial dispersal from source rocks and mineralized outcrops. A total of 54 till samples were collected for geochemical analysis from mudboils in discontinuous permafrost terrain, and hand-dug holes in non-permafrost regions. Mapping observations, such as surficial units (*e.g.*, till veneer, bedrock, glaciofluvial sediment) and surficial landforms (*e.g.*, crag-and-tail forms, flutings, ribbed terrain) were recorded at each sample station. Observations of landforms and striae indicate a complex glacial history along with a minimum of three different ice-flow directions and four glacial events.*

INTRODUCTION

Surficial geological mapping and sampling were carried out in the western portion of the Woods Lake map area (NTS 23I, scale 1:250 000) in Labrador as part of the GEM-2 Hudson-Ungava Surficial Mapping Program. The survey, jointly between the Geological Survey of Canada (GSC) and the Geological Survey of Newfoundland and Labrador (GSNL), is part of a three-year investigation into the surficial sediments overlying the 'Core Zone', a north–south-trending belt of Archean rocks centred between the Torngat Orogen to the east and the New Québec Orogen to the west. Surficial studies were undertaken to better understand the glacial ice-flow events that sculpted the landscape of NTS map area 23I. This investigation relied on surficial mapping, glacial-sediment sampling, ice-flow chronology and till-geochemistry studies. A separate, parallel study in map area 23P (Lac Résolution), located entirely in Québec, is the focus of a Ph.D. dissertation detailing glacial-sediment sampling, 10Be cosmogenic analysis, Optically Stimulated Luminescence (OSL) sampling, and detailed surficial mapping from 2014–2016 in order to determine ice-flow chronology, basal ice regime, and to understand the genesis and evolution of the Labrador ice centre (Rice *et al.*, *in press*).

The eastern quadrants of NTS map area 23I were mapped by surficial geologists at the Geological Survey of Canada from 2014 to 2016. The Labrador component of the research program mapped and sampled an area north of the Smallwood Reservoir on the western half of NTS map area 23I (23I/03-06, 23I/11 and 12) during the summer of 2016 (Figure 1). Surficial maps (1:50 000 scale) have been completed by Liverman *et al.* (2007a, b, c, 2010) on map sheets to the northwest, and by Batterson (2001a, b, c, d) and Batterson and Taylor (2004) on map sheets to the northeast.

Results from this 2016 survey will provide insight into the glacial history and sediment dispersal of the region, presenting surficial maps and improved resources for mineral exploration in this poorly understood area of Labrador, and serve as a framework for further studies in the region.

LOCATION, ACCESS AND PHYSIOGRAPHY

The survey area is located north of the Smallwood Reservoir, east of Menihek Lakes and west of Michikamau Lake (Figure 1). The centre of the study area is 90 km southeast of Schefferville, and is located within NTS 1:50 000 map areas 23I/03–06, 23I/11 and 12. Due to a lack of trans-

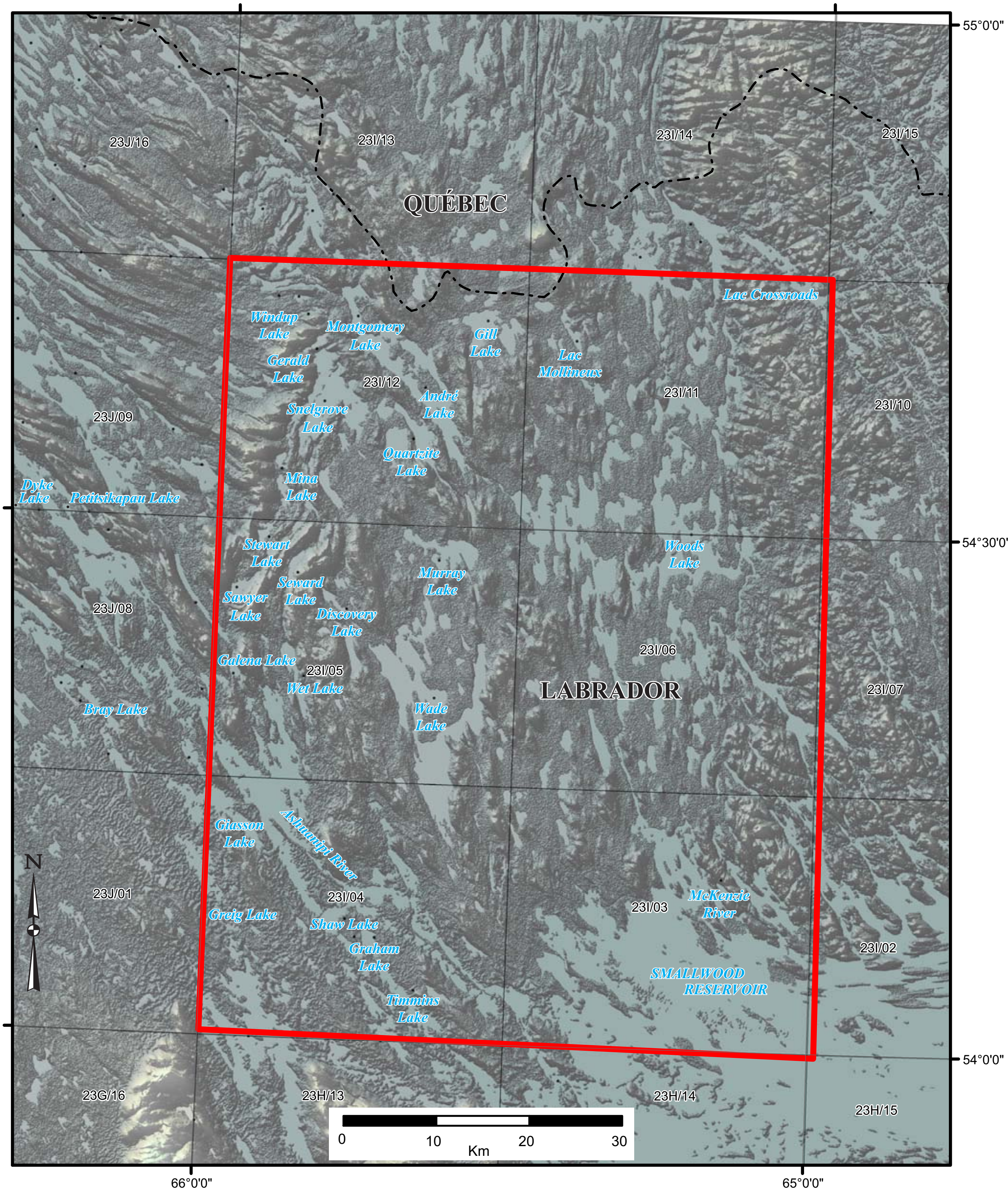

Figure 1. *Map showing location of lakes and the Smallwood Reservoir. The study area (NTS 23I/03–23I/06, 23I/11 and 23I/12) is outlined in red.*

portation infrastructure, a helicopter was used to access sample locations.

The southwestern quadrant of the survey area (23I/03–06) is dominated by lowland fens surrounded by highland bedrock ridges. The eastern limb of a fold closure in bedrock in the northwest corner of the Woods Lake map area (23I/05), defines the northeast–southwest orientation of bedrock ridges in this area. On the western edge of the study area (23I/03 and 23I/06), elevated ridges of exposed granite bedrock topographically dominate the region. Drainage in the study area flows southeastward through NTS map areas 23J and 23I toward the Smallwood Reservoir. The Ashuanipi River also flows through 23I/04 toward the Smallwood Reservoir. Larger bodies of water include Wade Lake (23I/04, 23I/05), Andre Lake (23I/12), and Woods Lake (23I/06) (Figure 1). Changing water levels in the Smallwood Reservoir resulting from the operation of the Churchill Falls hydroelectric generating project have obscured some of the primary landforms and modified shorelines in the NTS 23I/02-06 map areas.

BEDROCK GEOLOGY

The study area is underlain by two distinct bedrock zones (Figure 2): the Labrador Trough (comprising the Kaniapiskau Supergroup) to the west; and the Core Zone (comprising Archean rocks and the De Pas batholith) to the east.

The Paleoproterozoic (~2.17 to 1.87 Ga) Kaniapiskau Supergroup consists of three sedimentary and volcanic cycles (Wardle and Bailey, 1981; Clark and Wares, 2005; J. Conliffe, personal communication, 2016).

- Cycle 1 consists of coarse-grained conglomerates of the Seward Group (Unit P2ac, centre of map), the shale and siltstone of the Menihek Formation (Unit P2sh) and Le Fer Formation (Unit P2st) underlie the northwestern NTS map area 23I/12 and the southwestern NTS map area 23I/04, and the Denault and Fleming formations' dolomite and chert (Unit P2d) outcrop on the western portion of the map in Figure 2; in NTS map areas 23I/04-05 and 23I/12.
- Cycle 2 outcrops in the western portion of Figure 2 (in NTS map areas 23I/04-05 and 23I/12) and includes the Wishart Formation quartzites and Sokoman Formation iron formation (Unit P2i), the Nish Formation volcanic rocks (Unit P2amv) and the flysch rocks of the Menihek Formation (Unit P2sh). North of the map in Figure 2, through NTS map areas 12I/12-13, volcanic and sedimentary rocks of the Doublet Group (UnitP2pmv) occur, and are intruded by the Wakuach Gabbro of the Montagnais Group (Unit P2ga).
- Cycle 3 includes the Tamarack Formation (Unit P2as), which outcrops in the southwest of the map area in NTS map area 23J/01.

The central study area, east of the western shore of Wade Lake (Figure 1), is underlain by Neoarchean metatonalites and tonalite gneisses (Unit ANtgn) and granitic gneisses (Unit ANggn) of the Core Zone. These units have been thrust uncomformably against the Kaniapiskau Supergroup to the west of Wade and Gill lakes with cataclastic deformation in bedrock around the faults (Wardle and Doherty, 1978). The Neoarchean Core Zone units are bounded to the east by the De Pas batholith (Unit P2cg).

MINERALIZATION

Mineral occurrences throughout the area are summarized in Table 1 and individual occurrences are located on Figure 2.

QUATERNARY HISTORY

ICE-FLOW HISTORY

A.P. Low of the Geological Survey of Canada (GSC) was the first to recognize that disintegration of the continental ice sheets began in this general area of Labrador, suggesting it as "a place of significant ice buildup and dispersal" (Low, 1896). Several other later studies (Harrison, 1952; Henderson, 1959; Kirby, 1961, 1966; Hughes, 1964) presented ice-flow work summarized in the Glacial Map of Canada (Prest *et al.*, 1968; Figure 3) indicating a prominent flow that converged on Ungava Bay to the north, and divergent flow that was toward the Labrador Sea in the east, St. Lawrence River in the south and Hudson and James bays to the west from the horseshoe-shaped Labrador–Québec ice divide (Klassen and Thompson, 1987).

Klassen and Thompson (1989, 1990; *see* also Thompson and Klassen, 1986 and Klassen 1999) further clarified ice-flow trends from striae observations and dispersal patterns from glacial erratics. Their findings suggested five phases of glacial flow: 1) the oldest movement to the northeast, only evident in eastern Labrador; 2) northeastern and southwestward radial flow out from the axis of the Labrador Trough that eroded and transported material >100 km; 3) secondary radial north-northwestward flow to the north of the study area and south-southeastward flow in the south 4) an eastward erosive flow and landforms suggesting the possibility of ice streaming; and 5) a non-erosive, northeastern younger flow possibly resulting from a short-lived cold-based ice sheet (Klassen, 1999). Subsequent detailed studies of striation data, clast fabrics and dispersal trains by Liverman and Vatcher (1992, 1993) confirmed these regional-

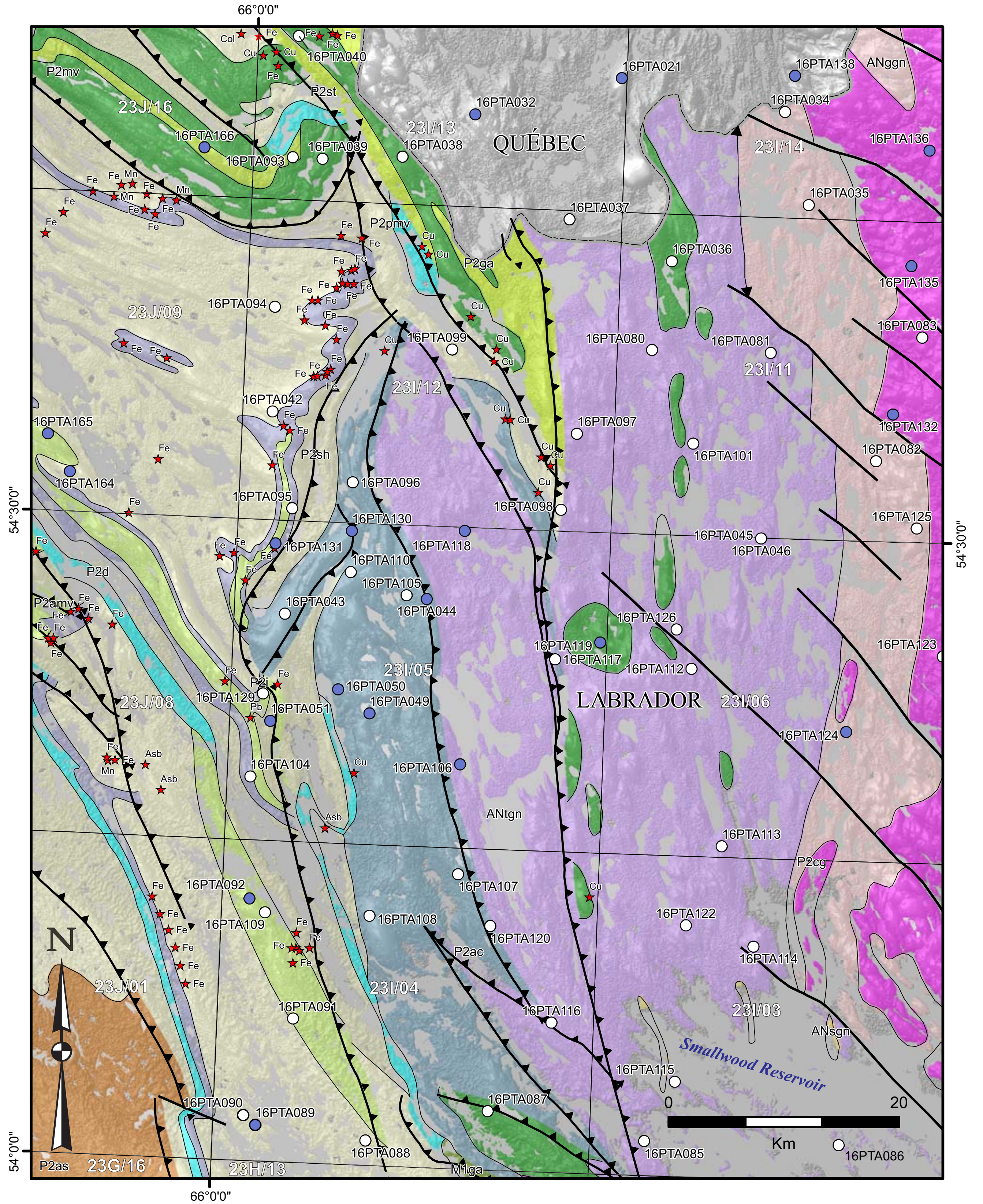

Figure 2. *1:400 000-scale bedrock-geology map of Labrador from Wardle* et al. *(1997), showing mineral occurrences listed in the legend. Sample sites are indicated by a white dot; observations are indicated by a blue dot.*

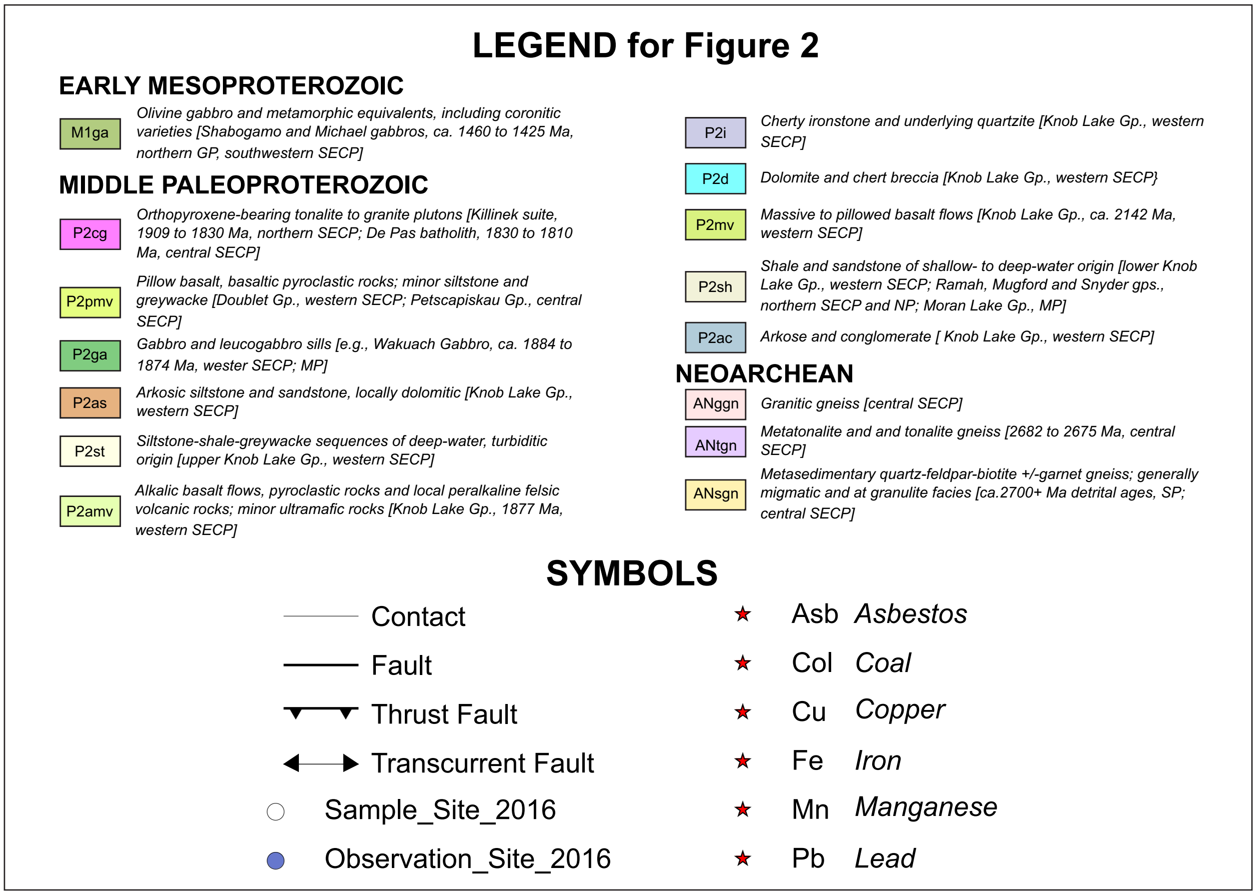

Table 1. Summary of mineral occurrences in the study area (Wardle, 1977; Swinden, 1991; Swinden and Santaguida, 1995; Conliffe, 2014, 2015)

Occurrence Name	MODS Reference	Status	Host Formation (Group)	Host Rock(s)	Major Commodity	Accessory Commodities
Sawyer Lake	023I/05/Fe001	Developed Prospect	Sokoman (Knob Lake)	BIF	Fe	
Galena Lake	023I/05/Pb001	Prospect	Nimish (Knob Lake)	Basaltic volcanics	Pb	Zn, Cu, Ag
Montgomery Lake	023I/12/Cu006	Prospect	Menihek (Knob Lake)	Siltstone quartzite and shale	Cu	Au
Montgomery North	023I/12/Cu011	Showing	Menihek (Knob Lake)	Siltstone quartzite and shale	Cu	
Andre Lake No 1	023I/12/Cu001	Showing	Menihek (Knob Lake)	Siltstone quartzite and shale	Cu	
Andre Lake No 2	023I/12/Cu002	Indication	Le Fer (Knob Lake)	Biotite phyllite and schist	Cu	
Andre Lake East No 1	023I/12/Pyr001	Indication	Thompson Lake (Doublet)	Black slate	Pyr	
Andre Lake East No 2	023I/12/Pyr002	Indication	Thompson Lake (Doublet)	Grey slate	Pyr	

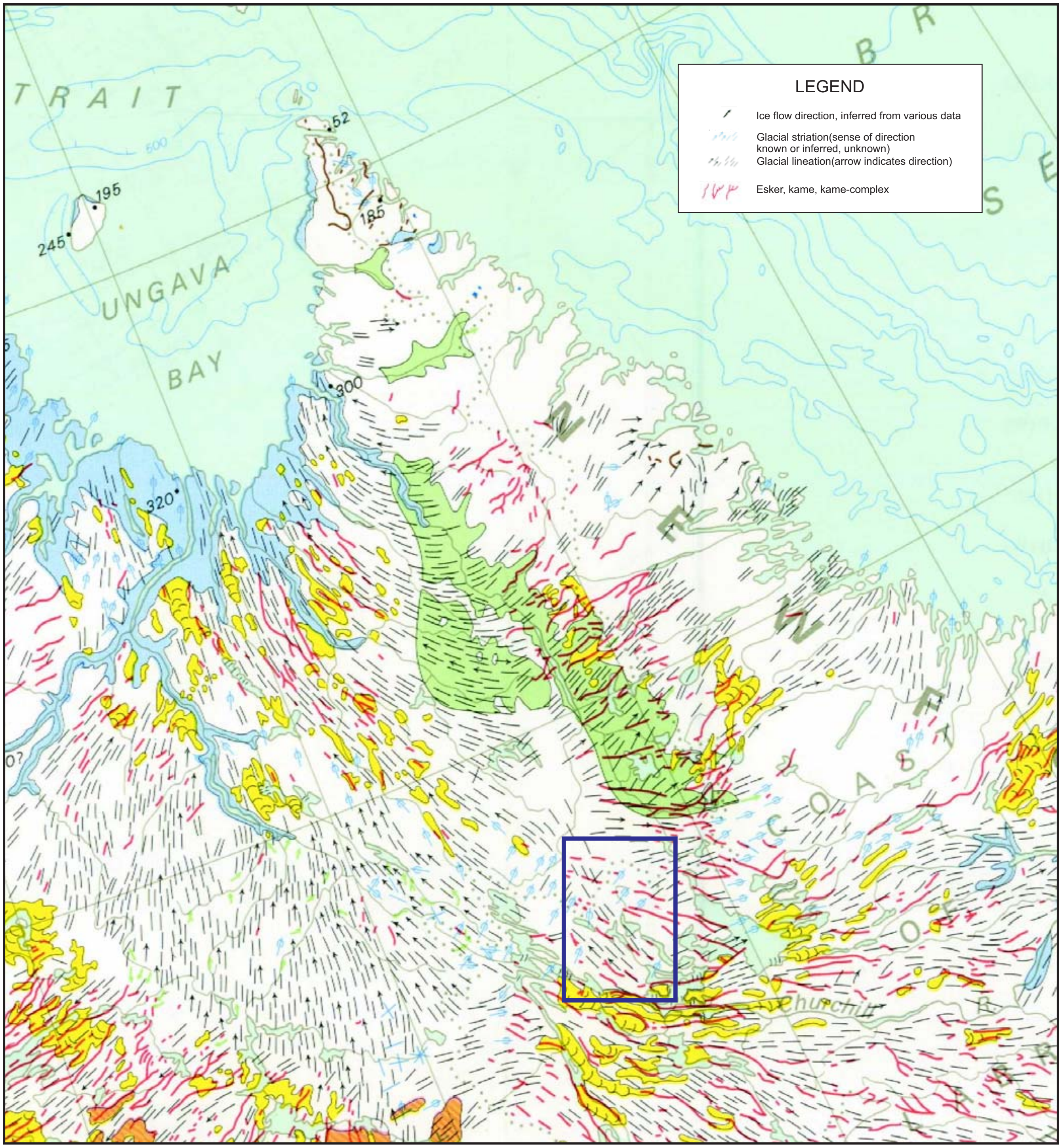

Figure 3. *The Québec and Labrador portion of the Glacial Map of Canada (Prest* et al.*, 1968). Approximate location of study area is outlined by the blue box.*

scale trends but noted directional variations in areas of high relief. Previous studies that focused on deglaciation patterns within northern Québec and Labrador were mainly interpretations of glacial lineations identified from aerial photographs, resulting in the Glacial Map of Canada (Prest *et al.*, 1968; Figure 3). Two main glacial landform patterns resulting from the retreat of the Late Wisconsinan Laurentide Ice Sheet were identified from Prest's map and later, delineated from satellite imagery (Prest, 1970; Boulton *et al.*, 1985; Dyke and Prest, 1987; Klassen and Thompson, 1993; Kleman *et al.*, 1994). The patterns consist of a radial esker and drift lineation swarm tracing inward from the peripheries of the Labrador Peninsula (Klassen and Thompson, 1993), and the Ungava Bay landform swarm (Prest *et al.*, 1968) of lineations and eskers that converge toward Ungava Bay. Kleman *et al.* (1994) suggested that the aforementioned glacial landforms are not the result of the Late Wisconsinan ice retreat. Rather, the Ungava Bay lineations and esker swarms were pre-Wisconsinan relict landforms that were preserved in a later, dry-based glacial environment (Kleman *et al.*, 1994). This suggestion was based on spatial correlations of ice-flow lineations from the Glacial Map of Canada (Prest *et al.*, 1968; Figure 3) and identifying temporal relationships of landforms based on their appearance (*i.e.*, eroded or fresh) in aerial photographs (Kleman *et al.*, 1994). Subsequent ice-flow indicator mapping by Veillette *et al.* (1999) provided a more detailed understanding of ice-flow patterns in northern-central Québec during the last glacial event, reiterating the validity of previous timelines for deglaciation in Labrador. Later studies of aerial photographs and satellite-image interpretation along with groundtruthing transects resulted in the postulation of a more northerly, cold-based ice-dispersal centre during the Late Wisconsin, and an ice-stream flow convergence toward and north of Ungava Bay (Jansson *et al.*, 2002, 2003). Clarhall and Jansson (2003) suggested that there was a temporal shift from warm-based subglacial conditions to non-erosive cold-based ice, based upon observations from field and aerial photographs taken at Lac aux Goélands in northeastern Québec. Recently, fieldwork by the GSC in the Lac Résolution (NTS map area 23P) and Woods Lake (NTS map area 23I) regions of Québec and Labrador identified complex subglacial regimes, ice-flow chronologies, and enigmatic regions of minimal glacial erosion (McClenaghan *et al.*, 2014, 2015a, b; Rice *et al.*, 2016). These complexities are part of the issues concurrently being addressed by J. Rice at the University of Waterloo, using ground-mapping observations, ^{10}Be cosmogenic analysis of till, bedrock and boulders, geochemical and indicator-mineral sampling, and Optically Stimulated Luminescence (OSL) dating. The results of this collaborative research between the GSC, GSNL and the University of Waterloo will provide much-needed field-based evidence needed to constrain, validate, and clarify current chronological ice-flow hypotheses relating to the buildup, migration and disintegration of the Labrador ice cente. A preliminary model for ice-flow history (Rice *et al.*, 2016) based on the field data from the 2014–2016 field seasons is presented (Figure 4).

Ice flow through NTS map areas 23P and 23I was characterized by four main events: 1) a consistent, strong erosive-flow event from the southwest responsible for shaping large-scale land forms; the timing of this flow phase is unknown (Veillette *et al.*, 1999); 2) an earlier radial-flow phase from somewhere within the central De Pas batholith; 3) a later radial flow phase, after the ice centre had shifted westward; and 4) deglacial phases consisting of first ice streams to the Labrador coastline and last flow in the final deglacial landsystem. The oldest event was consistently observed in multiple stoss-and-lee landforms and striation measurements throughout the study area. The radial-flow events and their chronologies were documented using cross-cutting striation relationships and faceting/truncation of glacial erosion surfaces (*cf.*, McMartin and Paulen, 2009). The former ice streams are evident in megascale glacial lineations and large-scale, bi-lobate constructional landforms on the eastern edge of the study area and in the Smallwood Reservoir area (Paulen *et al.*, 2015). The deglacial landsystem flowsets are generally localized, topographically controlled and often parallel to major esker systems and former meltwater conduits.

SURFICIAL GEOLOGY

Reports from early excursions by Low (1896) describe the geology, landscape, and botany in several regions of the Labrador Peninsula, including glacial features near the present day Smallwood Reservoir. Low (*op. cit.*) mentions (page 161) exposed terraces along the shores of Lake Michikamau (eastern Smallwood Reservoir) as well as boulder-strewn shorelines, water-eroded flat-topped islands and drift-covered mounds having westward-facing embayments. In the early 1950s, Henderson (1959) mapped the surficial geology of west-central Labrador, covering Astray and Dyke lakes to the north of the study area and the Ashuanipi River within the study area. Douglas and Drummond (1955) are credited with the first comprehensive surficial map of Labrador; they produced a broad classification map using air photographs, and compiled information from earlier surveys. Henderson (1959) reported abundant moraine material that had been slightly molded by ice and eroded by water during ice-flow and glacial-landform investigations. He also discussed the origin of the large central Labrador esker complexes and mentioned the lack of transverse eskers outside these complexes. Ives (1956) brought attention to ‘rippled till’ west of the survey area near Bray Lake, and discussed the geomorphological relationship of the till with the numerous eskers in the area. Cowan (1967) studied the relationship of ribbed moraine to fluted ground moraine and the interdependence of subglacial channels, eskers, esker fans and moraines (Figure 5); similar relationships between erosion and deposition are thought to exist in the current study area.

Liverman and Vatcher (1992) mapped features to the northwest of the current survey area, which included subglacial channel features, southeast-oriented landforms, and till fabrics in sections that coincide with mean regional transport directions. Field observations by Liverman and

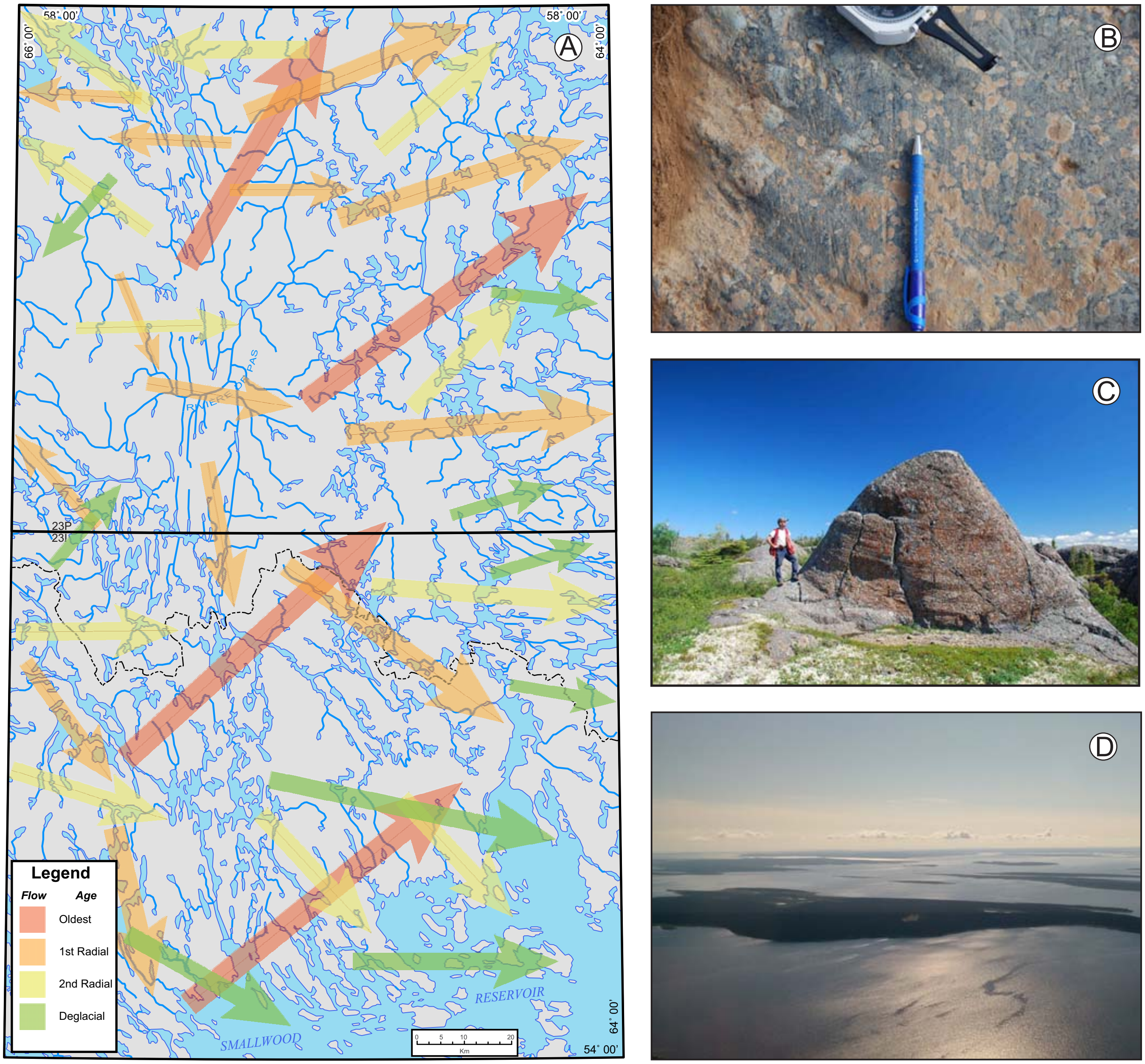

Figure 4. *A) Preliminary, simplified ice-flow model for northern Labrador; based on striation data (Rice* et al.*, 2016); B) Example of outcrop-scale ice-flow indicators near Cavers Lake west of NTS map area 23I/12; C) Conglomerate with large wrap-around striations and rat tails near Mina Lake in the southwest corner of NTS map area 23I/12; D) Large mega-scale landforms in the Smallwood Reservoir in NTS map area23I/02.*

Vatcher (1993) indicate that the moraines near Petitsikapau Lake are composed of diamicton, have a veneer of gravel and were deposited by northeastward-flowing ice. Much of this detail is represented in the GSC Map 1814A (1:100 000 scale) compiled by Klassen *et al.* (1992) from aerial-photograph interpretation and ground observations by Klassen and Thompson (1990), and detailed 1:50 000-scale Government of Newfoundland and Labrador maps of NTS 23J/09 (Map 2007-33), 23J/10 (Map 2007-34), 23J/15 (Map 2010-26), and 23J/16 (Map 2007-35) were published by Liverman *et al.* (2007a, b, c, 2010).

TILL GEOCHEMISTRY AND INDICATOR MINERALS

Klassen and Thompson (1987) used clast dispersal of unique rock types to determine glacial ice-flow directions in central Labrador. They were able to trace out a glacial his-

Figure 5. *Aerial photograph reproduced from Cowan (1967, Plate 6, page 49) showing the relationship between subglacial chutes, eskers, moraines and outwash in the Shoal Lake area.*

tory north of the current study area using Martin Lake rhyolite (a felsic phase of the Wakuach Gabbro (Wardle *et al.*, 1982; J. Conliffe, personal communication, 2016)) and nepheline syenite as indicator units. Additionally, geochemical data and striae measurements were used to further refine ice-flow directions (Klassen and Thompson, 1987). Studies of glacial dispersal from the Strange Lake alkaline complex in northeast Labrador (Batterson, 1989) demonstrated that clast dispersal and geochemical patterns can be used to infer glacial-transport distances in areas where units of distinct geological composition contrast with the surrounding bedrock.

Klassen and Thompson (1990) reported dispersal trends in central Labrador till samples in GSC Open File 2170; Klassen and Knight (1995) reported the re-analysis of several of these samples using new analytical methods. Sample spacing was one per 4–25 km^2 in areas of known mineral occurrences, but lower (one sample per 100–200 km^2) elsewhere (Klassen and Knight, 1995). In another regional study, Klassen (1999) looked at clast dispersal and geochemical trends from the Ashuanipi (metamorphic) Complex in western Labrador, eastward across the Labrador Trough into the current study area. Liverman *et al.* (1993) reported the till geochemistry of NTS map areas 23J/09 and 23J/16 having 2 x 4 km grid spacing, and identifying two major ice-flow directions (east and northeast) around Martin Lake.

McConnell and Ryan (1994) collected both till and glaciofluvial samples in eastern Labrador in a survey targeting diamonds and indicator minerals, and reported no indication of kimberlitic or lamproitic potential. A reconnaissance survey for kimberlite-indicator minerals was carried out by Brushett and Amor (2013) in western Labrador, focusing on eskers west and south of the study area. Very few kimberlite-indicator minerals were recovered; however, results suggested the presence of base-metal mineralization west and south of the current survey area (Brushett and Amor, 2013). Preliminary results from GSC observations in 2014 from 107 field stations and 36 till samples indicate enriched values for Au, Co, Cr, Cu, Ni, Sb, and Zn over the Doublet Zone mafic volcanic rocks in the northern NTS map area 23I/12, Laporte Zone sedimentary rocks immediately north of the Doublet Zone and metagabbro units that intrude through the Core Zone Archean rocks on the southern portion of the map sheet (23I/04, 23I/05 and 23I/06) (McClenaghan *et al.*, 2016a, b).

CURRENT WORK

FIELD METHODS: OBSERVATIONS, SAMPLING AND ANALYSES

Field observations relating to surficial geology and outcrop-scale ice-flow indicators were made at 82 different field locations in Labrador during the 2016 summer field season. Sample sites were chosen based on the potential for mapping ice-flow indicators and bedrock prospectivity, and a sample spacing of approximately 10–12 km. Areas with a higher percentage of known mineral occurrences were sampled at 5–8 km spacing. A large part of the southern study area is dominated by forest or bog, which limited safe helicopter landings and even sampling distribution. In the northern study area, and at higher elevations where permafrost was discontinuous, mudboils were targeted for sample collection. Samples were collected ~0.2 m below the mudboil surface, following GSC till-sampling protocols defined by Spirito *et al.* (2011) and McClenaghan *et al.* (2013). Outside of regions characterized by discontinuous permafrost, samples were collected by hand-dug pits to depths below the oxidized soil profiles; specifically targeting C-horizon till. Larger clasts (>5 cm) were removed at the sample site by hand. Duplicate site samples were collected every 15 samples and the duplicate sample dug within 6 m of the original site. Blanks were inserted every 15 samples to monitor contamination during the sample preparation and analysis procedures. Care was taken in limiting cross-contamination by cleaning shovels between sites and double bagging saturated samples to ensure fines were not lost by desaturation of the sample initiated through vibration created during helicopter transport. Specific care was taken to exclude any surficial organics or overlying soil horizon material from collected samples and other general quality-assurance and quality-control guidelines outlined by Plouffe *et al.* (2013). A total of 54 geochemical samples of C-horizon material (till) were submitted to the Geological Survey of Newfoundland and Labrador's Geochemical Laboratory, in St. John's, for sample preparation and multi-element analysis; details of methods used are described in Open File NFLD 3273 (Brushett and Amor, 2016).

At the same sites, additional till samples were also collected for geochemical analysis, Munsell colour determination, grain-size determination, LOI and $CaCO_3$ measurement, and heavy mineral identification by the Geological Survey of Canada following methods described by McClenaghan *et al.* (2015a, b).

RESULTS

LANDFORMS

The surficial geology is characterized by bedrock outcrops, thin (*i.e.*, less than 2 m) till veneer, till blanket, and glaciofluvial deposits that include large esker systems. Landforms coincide with southeast and east-southeast ice-flow and where large-scale stoss-and-lee landforms are oriented to the northeast. Northeast- and southeast-trending striae were recorded at 14 sites; measurements were consistent with previous striae recorded in the region with older northeast (060°) and radial south (171° – older phase) and southeast (126° – younger phase) flow directions. The northwestern study area is dominated by bedrock, rocks from the Kaniapiskau Supergroup exposed at high elevations and surrounded by thin, till cover, oxidized soil, or lichen. Abundant meltwater channels have been eroded into the sides and valleys of bedrock uplands. Deeply incised channels (Plate 1A) are seen on the sides and tops of hills; U-shaped channels can be observed on lower slopes and valleys. In some areas within NTS map area 23I/05, the till has

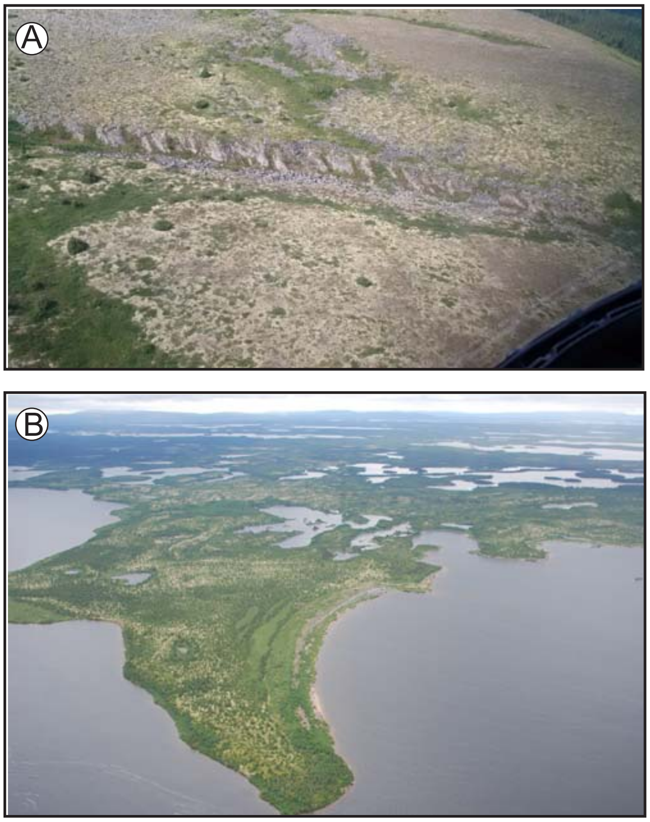

Plate 1. *A) Meltwater channel that incised the top of conglomerate bedrock unit (Seward Formation, photograph approximately 1 km from left to right); B) Raised shorelines from glacial Lake Low that winnowed sediments from a large esker junction in the southern Ashuanipi River (photograph 2 km from left to right).*

been eroded away from the bedrock leaving bedrock covered with a shallow soil profile and a thin organic mat with little or no surficial sediment. Till-covered landforms in the central regions of the study area are accentuated by surrounding fens that infill the low-lying regions separating the landforms. Metagabbro units covered by till veneer are observed east and northeast of Wade Lake (Figure 1). The eastern survey area is characterized by granitoid rock knobs of the De Pas Batholith flanked by thin, till veneer and till blankets toward lower elevations and in deeply incised valleys. In the southern study area, boulder lags are seen in low-lying areas along with strandlines (Plate 1B) and areas that have poorly sorted gravel marking the extent of a shallow glacial lake (tentatively named 'glacial Lake Low' after A.P. Low (Rice *et al.*, 2016). Streamlined landforms oriented to the southeast are also observed, where eskers and Rogen moraines extend into, and covered by, the Smallwood Reservoir area. To the southwest, fluted landforms rise above ribbed moraines, surrounded by eskers and esker complexes; much like the landscape near Bray and Shoal lakes described by Henderson (1959), Cowan (1967) and Liverman and Vatcher (1993) (Plate 2).

Frost-shattered and heaved bedrock blocks are abundant throughout NTS map area 23I/05. Occurrences on both sides of Wade Lake and south of Wade Lake toward the Smallwood Reservoir, and the Wet Lake area, are indicative of permafrost conditions persisting for some time, following deglaciation. Reworked and winnowed till mounds are observed east of Wade Lake and a thin lag of boulders occurs in the lowlands on the peninsula jutting into the Smallwood Reservoir area, southeast of Wade Lake, likely associated with glacial Lake Low.

Plate 2. *Photograph taken facing east toward Wade Lake (in the far background) with an esker and glaciofluvial outwash deposits in the foreground. Southeast-oriented streamlined landforms can be observed in the background (black arrows). The hummocky landforms to the east and west of the esker are also glaciofluvial deposits (photograph 3 km from left to right).*

TILL COMPOSTION AND GENERAL CLAST COMPOSITION

The dominant till composition is silty-sand matrix with 10–20% clasts, many of which are striated and faceted. Individual clasts originating from the Sokoman Formation iron formation (Unit P2i) were seen throughout the survey area. Striated and bevelled volcanic clasts, thought to originate from the Knob Lake Group, are also seen east of the survey area, as well as granites, gneisses, and gabbros originating from the central portion of the survey (Figure 2). Sedimentary clasts are more common on the western portion of the survey although dolomites and sediments are seen east of Wade Lake.

DISCUSSION

Landforms in the northwestern (NTS 23I/05 and 23I/12) survey area indicate an ice-erosional environment and abundant meltwater channels cut into the till and bedrock; a thin veneer of till covers most highland areas. Deeply incised bedrock channels are concentrated in Seward Formation (Unit P2ac) conglomerates. The interaction between preglacial tectonic structures and joints from glacial loading and unloading may have facilitated differential erosion of the channels by meltwater. The sparse till veneer in highland areas in 23I/05 may have been caused by meltwater erosion due to ablation of ice during glacial downwasting. Material from meltwater erosion was most likely funnelled to the southeast into kettle-pocked eskers and large esker junctions north of the Smallwood Reservoir area.

Ribbed moraines originating from the northwest of the study area in NTS map area 23J/08 occur in the southwestern survey area and are transverse to the last glacial event observed by Rice *et al.* (2016). There is a close spatial relationship between the ribbed moraine in the lower elevations and lateral eskers and esker complexes, and southeast-oriented fluted terrain at higher elevations. This pattern repeats at 8 to 10 km intervals covering the southwestern survey area. The central lowland area of the survey is considered to have been eroded preferentially, most likely due to the weak competence of the underlying Neoarchean units. Scattered till-covered hummocks in the lowlands may represent the remnants of a large till blanket that once covered the area. The abundant frost-shattered boulders around Wade Lake are most likely due to heaving of cataclastically deformed bedrock around the large north–south thrust structures on either side of the lake. Poorly sorted glacial sediments seen in hand-dug pits to the east of Wade Lake, around low-lying hills in the Smallwood Reservoir area and southwest of Shaw Lake are interpreted as nearshore lake sediments from the inundation of glacial Lake Low. Strandlines in glacial sediments, rounded boulder lags around the base of the hills and water-washed low-lying bedrock surfaces north of the Smallwood Reservoir also indicate winnowing during the inundation of a shallow glacial lake.

The sequence of glaciation and postglacial events for some of the landforms in the region can be inferred on the following:

1) Intense erosion as the earliest ice advanced into the region, with the preglacial rock surfaces and sediments removed.

2) Erosion of bedrock and till formation continued under ice cover during both radial flow phases.

3) As the ice retreated, deglacial landforms were created, with continued subglacial erosion and till deposition in the northwestern study area and moraine and esker formation in the southwestern areas (NTS 23I/04 and 23I/05).

4) With ice stagnation, some regions were washed by meltwater from the ablation of ice, and with final retreat from the lowlands, glacial Lake Low inundated the southern part of the region. Detailed air-photo interpretation of the survey area will clarify the relationships between separate landform occurrences.

Glacial dispersal in this area is expected to be relatively simple to characterize, given that the study area in Labrador occurs entirely east and south of the major ice-divide migration observed to the north (Rice *et al.*, 2016). In general, site observations of clasts note units most likely derived from the Kaniaskipau Supergroup east and southeast of known outcrop locations, supporting late eastward and southeastward ice-flow reconstructions. A more detailed investigation of the coarse fraction (0.5–2.0 mm) of till samples will be carried out by the GSC and will clarify preliminary ice-flow hypothesis with results expected in later this year. It is expected that geochemical dispersal trends from known mineralized units can determine difference in bedrock composition between Core Zone rocks and the Kaniaskipau Supergroup with the till matrix. Results from the fine (177 micron) fraction of Labrador till samples analyzed by GSNL should also be available later this year.

CONCLUSIONS

The western part of NTS map area 23I contains a spectacular record of glacial erosion and depositional features including glacially scoured bedrock, streamlined landforms, megascale glacial lineations, ribbed moraine, meltwater channels, eskers, and glaciolacustrine strandlines. Field-mapping observations suggest that channel formation in bedrock, north of the study area, is contemporaneous with esker formation and ribbed moraine formation in the southwestern study area. Detailed air-photo interpretation should clarify the spatial relationships of the surficial units. Till samples from NTS map area 23I are characterized as having a silty-sandy matrix containing 10–20% clasts, many of which are faceted and striated. In general, clast dispersal is consistent with reported ice-flow directions; geochemical analysis of the fine fraction and an additional analysis of the coarse fraction of the till matrix should further constrain the working ice-flow history model of the area.

ACKNOWLEDGMENTS

The surficial mapping survey is part of the GEM 2 Hudson–Ungava Project, under the scientific leadership of David Corrigan and surficial activity leader Beth McClenaghan, with GSC management support from Réjean Couture and Lila Chebab. This research benefitted from the support of the Polar Continental Shelf Program. Norpaq Aviation provided excellent and professional expediting services. Matt Pyne is thanked for his data collection and support through the project. Grant Hagedorn is thanked for his assistance in the field. Alain Rioux and Maxime Gauthier of Innukopters Inc. provided professional and efficient helicopter services. Special thanks to Clara Schattler of Gestion Porlier for superb accommodations and meals. James Conliffe is thanked for his critical review of the bedrock portion of the paper and his insights into the geology of the Kaniapiskau Supergroup. Stephen Amor is thanked for his critical reviews of this report and his management support. Wayne Tuttle is thanked for logistical support for Heather Campbell in Labrador. The authors are grateful to Terry Sears and Joanne Rooney of the Geological Survey of Newfoundland and Labrador for their expertise with the figures and layout and design of this paper. The manuscript was critically reviewed by David Huntley (GSC Vancouver), ESS Contribution No. 20160333.

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