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Dispersal Trains Produced by Ice Streams: An Example from Strange Lake, Labrador, Canada

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ABSTRACT

Large tracts of northern Canada were impacted by a large number of land-terminating and marine-terminating palaeo-ice streams during deglaciation of the Laurentide Ice Sheet. In soft-bedded areas, subglacial landforms can be used to map the spatial extent of ice stream tracks (e.g., mega-scale glacial lineations, ice stream shear margin moraines). Over hard-bedded areas, the geomorphic imprint of ice streams is less obvious. However, sediment dispersal trains, coupled with erosive corridors of streamlined terrain, provide a potentially powerful means of identifying 'hard-bedded' ice streams. The Strange Lake dispersal train, in northern Quebec and Labrador, has a remarkably linear, ribbon-like dispersal pattern trending more than 40 km down ice from a mineralized rare earth element (REE) peralkaline intrusion. The train was originally attributed to a consistent regional ice flow regime of the Laurentide Ice Sheet. Recent mapping of Laurentide Ice Sheet streams places the Strange Lake train directly within the Kogaluk River ice stream, one of a number of ice streams that operated near the centre of the Labrador dome and drained into the Atlantic Ocean. There are numerous mega-scale glacial lineations (up to 5 km long, with length: width ratios exceeding 12) within the mapped dispersal train. The dispersal train shows a remarkably linear consistency with REE element concentrations in till tens of kilometres down-ice from the mineral source, a phenomenon similarly observed with carbonate dispersal trains formed by ice streams in Nunavut. Thus, while drift prospecting methods have traditionally considered long term steady-state ice flow as the primary method for transporting glacial debris from a mineralized source, we argue that changes in glacial erosion, transport distances and diffusion rates are factors that should be considered when mapping and interpreting glacial dispersal trains in palaeo-ice stream corridors. Identification of ice-stream corridors in northern Canada may provide additional insight into many indicator mineral anomalies, which have no identified source.

INTRODUCTION

Ice streams are now recognized as prominent features of continental ice sheets that played a vital role in flow dynamics and mass balance (e.g., Evans et al., 2008; Stokes et al., 2016). Ice streams are corridors within an ice sheet that flow more rapidly than the surrounding ice; they act as arteries to discharge large amounts of ice over large distances and are the source of well-defined tracts of far-travelled, or exotic debris (e.g. Dredge, 2000; Ross et al., 2009). Few studies have focussed on dispersal patterns down ice of mineralized rocks that have been formed or modified by ice streams, in part because former ice stream tracts were not previously recognized or identified in the northern hemisphere, most notably in areas covered by the Laurentide Ice Sheet in Canada. An inventory of Laurentide Ice Sheet ice streams recently published by Margold et al. (2015a) should provide the impetus to re-examine many unexplained or unsourced glacial dispersal trains in northern Canada, with a better understanding of glacial context (cf. Margold et al., 2015b). One example of metal-rich debris dispersed by an ice stream is the plume of metal-rich till down-ice of the Strange Lake rare earth element deposit in eastern Canada (Batterson and Taylor, 2009). The ice stream produced elongate streamlined landforms enriched in debris from the deposit for more than 70 km down ice (northeast) of the deposit (Figure 1).

Location and Geological Setting

The Strange Lake deposit is located at the Quebec-Labrador border, 250 km northeast of the iron mining town of Schefferville, Quebec, and 125 km west of the Voisey's Bay nickel operations in Labrador (see inset, Figure 1). The area is accessible only by helicopter or fixed-wing aircraft and an overland route to the deposit from the coast is being considered should the deposit be developed. Till dominates the surficial geology, with organic material deposited in the low-lying areas. Till thickness is variable, ranging from a veneer (less than 2 m) to over several metres in places. The dispersal train is bounded to the north and south by eskers deposited by meltwater during regional deglaciation. Bedrock outcrops are rare and constitute less than 1% of the surficial terrain (Batterson, 1989).

The Strange Lake complex of peralkaline granitic rocks is one of the world's largest deposits of yttrium (Y) and zirconium (Zr), with varied and complex mineralogy (Zajac, 2015). The intrusive complex is hosted within Paleoproterozoic gneiss and associated rocks consisting of variably migmatized mafic gneiss to the east and quartz monzonite intruded to the west (Ryan et al., 1988)

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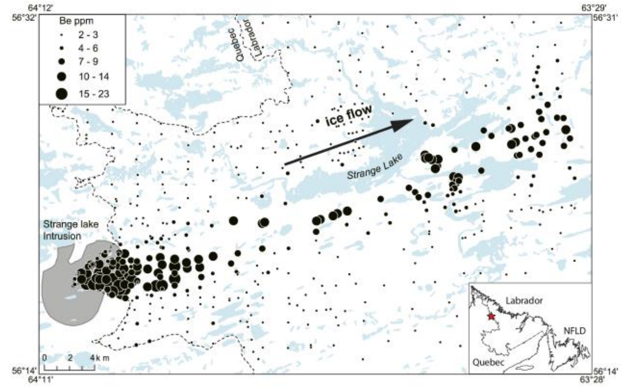

Figure 1: Ribbon-shaped glacial dispersal train of beryllium (Be) content in the <0.063 mm fraction of till trending northeast from the Strange Lake rare earth element deposit in eastern Canada (modified from Batterson and Taylor, 2009).

STRANGE LAKE DISPERSAL TRAIN

The Strange Lake Zr–Nb–Y–Be–REE deposit was discovered by the Iron Ore Company of Canada in 1979 by following up a combined regional fluorine-in-water and uranium-in-lake sediment anomaly, published by the Newfoundland and Labrador Department of Natural Resources (Geological Survey of Canada, 1979).

High density till sample surveys (one sample site per 1.97 km^2) were carried out by the Newfoundland Geological Survey Branch during the summers of 1983 and 1984 (Batterson, 1989). The results of this survey defined a remarkable linear dispersal train, which maintained a width comparable to the outcrop of the source rock along its length. Single-element geochemical patterns for ore-related elements (Y, Zr, Nb, Be, La) defined a ribbon-shaped dispersal train continuous for at least 40 km down-ice from the peralkaline complex (Figure 1). A re-analysis of the till samples was undertaken in 2009 (Batterson and Taylor, 2009), with a much larger suite of elements, and with an objective to improve the geochemical accuracy.

Airborne gamma-ray spectrometry surveys conducted in the Lac Brisson region (Geological Survey of Canada, 1980) showed a subdued signal over part of the deposit itself and a very long equivalent thorium (eTh) ribbon extending more than 60 km to the northeast. The strong Th signal was attributed to glacial dispersion of radioactive and geochemically anomalous boulders and till (Figure 2). The western part of the deposit was covered by nonradiometric overburden dragged in by the ice sheet from the unmineralized country-rocks west of the peralkaline complex (Zajac, 2015).

CONTINENTAL ICE STREAMS

Palaeo-ice streams generally form mega-scale glacial lineations under two main subglacial settings: 1) An unlithified, soft sediment bed of till that was modified subglacially into elongate landforms and megaridges through mechanisms of erosion, accretion, deformation or a combination thereof (Evans and Rea, 1999; Spagnolo et al., 2016); 2) An indurated bedrock surface, considered as 'hard bed' conditions (Bradwell et al., 2008), whereby elongate subglacial forms have been constructed on bedrock surfaces. Ice streams can occur in former and current continental ice sheets within bedrock structural channels around the margins as outlet glaciers and as arteries extending well back into ice sheets (Margold et al., 2015b). Evidence of fast glacier flow can be deduced from glacial landforms. Large groups of long streamlined forms (megaflutings and mega-lineations) that sometimes are juxtaposed with areas devoid of such features represent relatively fast and slow former ice flow, respectively. Mega-scale glacial lineations are typically identified from various types of imagery and are most commonly expressed as clusters of glacial lineations with relatively high length to width ratios.

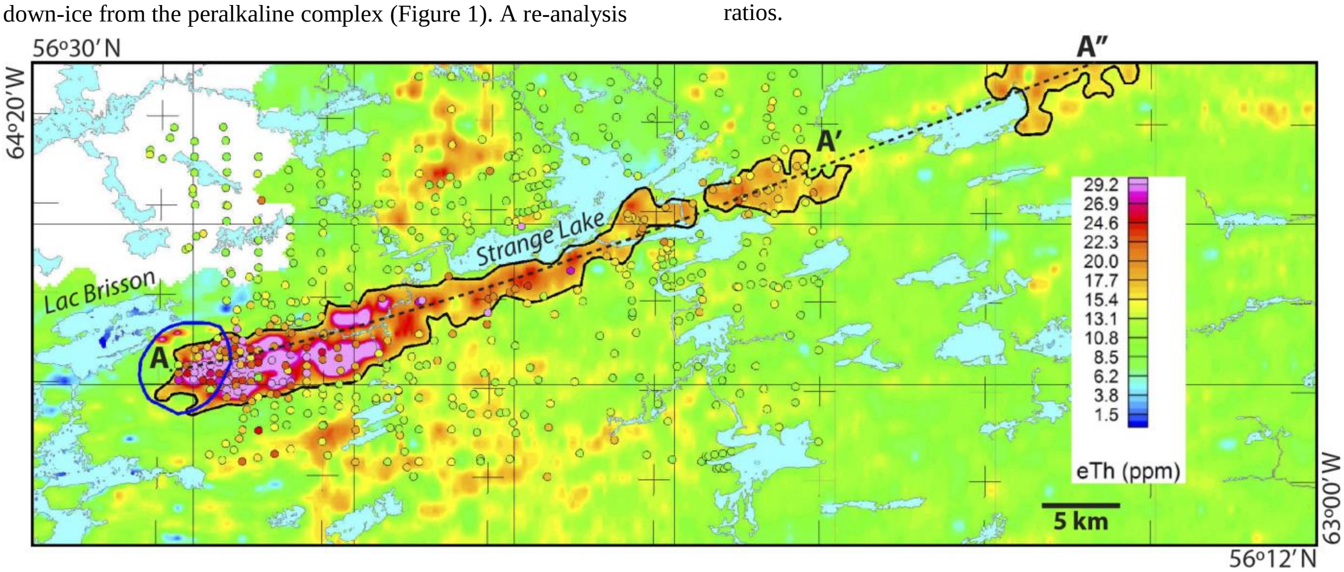

Figure 2: The Strange Lake till survey (dots) from Batterson and Taylor (2009) overlain on the airborne gamma-ray spectrometry survey data (Geological Survey of Canada, 1980), using the same colour values for Th and eTh. The Strange Lake deposit is outlined in blue and the dispersal train is outlined in black. The dashed line A-A' and A-A" refers to Th profile transects (Figures 5 and 6).

Examination of satellite imagery and digital elevation models (DEM) of the Strange Lake deposits and dispersal train provide strong evidence of a former ice stream on a hard bed (Figure 3). The outcrops form spectacular crag-and-tail landforms and there are a number of low-relief flutings with length to width ratios exceeding 12. Margold et al. (2015a) also mapped the Kogaluk River ice stream (IS #187) within the study area which places the Strange Lake REE deposit within the trunk of the ice stream.

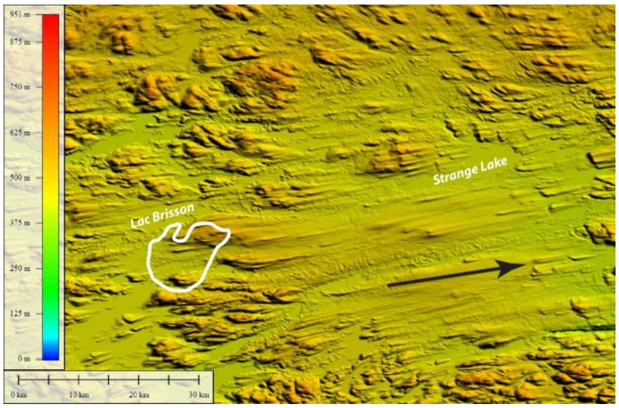

Figure 3: Shuttle Radar Topographic Mission (SRTM) DEM image of the Strange Lake deposit (outlined in white) and mega-scale glacial lineations from the Kogaluk River ice stream that eroded the deposit from left to right (black arrow) and created an elongated dispersal train (see Figure 2).

DISCUSSION AND SUMMARY

Glacial debris eroded from a discrete bedrock source is deposited down-ice in what is commonly referred to as a glacial dispersal train (DiLabio, 1990). Dispersal trains are hundreds to thousands of times larger than their bedrock source, and therefore provide ideal targets for mineral exploration. Typically, in continental glacial settings, steady-state or relatively sluggish ice flow creates an abundance of dispersed debris that decreases with increasing distance down-ice such that a plot of abundance versus distance down ice commonly approximates a negative exponential curve (Shilts, 1976; Figure 4). Within an ice stream, the concentration gradient of dispersed debris decreases linearly down-ice (Figures 5 and 6) and not exponentially, as the result of rapid ice flow transporting debris far from source with little dilution (e.g., Klassen, 1997; Dredge, 2000; McClenaghan and Paulen, 2017). Distribution patterns from ice streams in northern Canada may provide additional insight into many unexplained indicator mineral anomalies, the bedrock sources of which have not yet been discovered.

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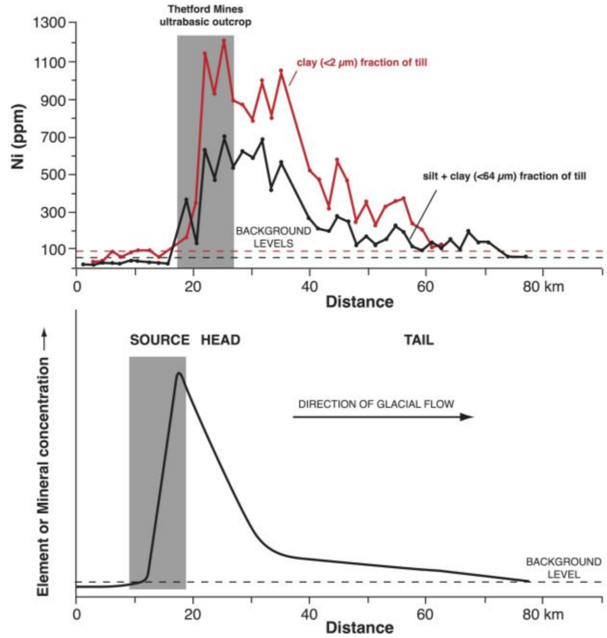

Figure 4: Plots of nickel abundance in till collected at surface in the Thetford Mines area, central Canada. Actual (top) and idealized (bottom) plots show the relationship between the source, head and tail of a dispersal train (modified after Shilts, 1976).

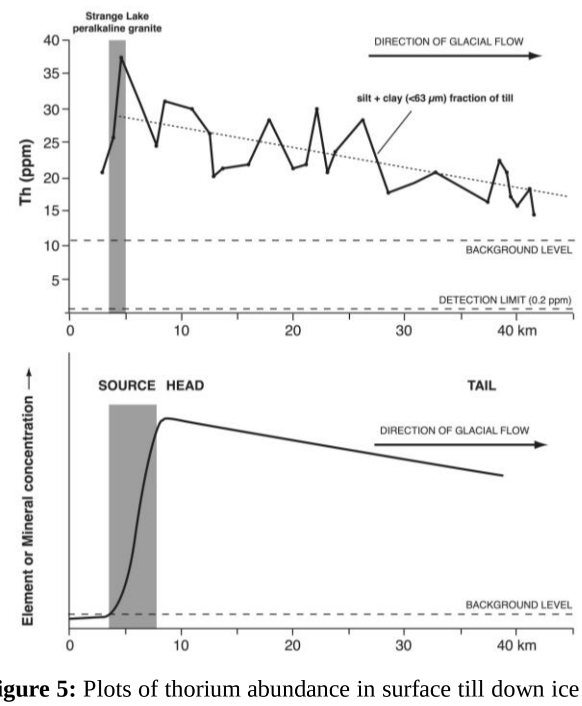

Figure 5: Plots of thorium abundance in surface till down ice of the Strange Lake deposit in eastern Canada (see A-A' in Figure 2) using data from Batterson and Taylor (2009), with the best-fit data curve shown as a dashed line The lower plot is an idealized glacial dispersal train, modified from Klassen (1997), that shows the relationship between the source, head and tail of a dispersal train formed by a palaeo-ice stream.

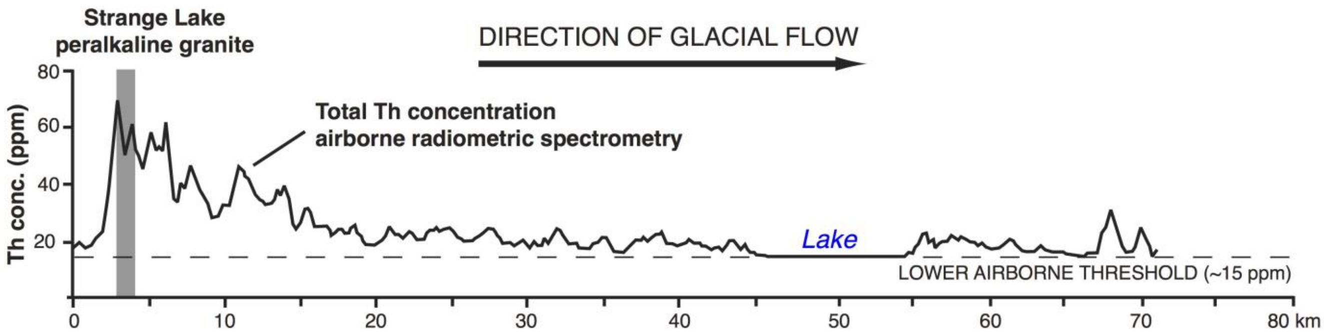

Figure 6: Plot of equivalent thorium concentrations along the dispersal train transect (see A-A” on Figure 2) from the airborne gamma spectrometry data (Geological Survey of Canada, 1980) down ice of the Strange Lake deposit. Elevated concentrations above 30 ppm likely reflect a total airborne signal from the concentration of mineralized boulders plus the enriched till.

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