Glacial dispersal trains in North America

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\textbf{ABSTRACT}

A map depicting glacial dispersal trains in North America has been compiled from published sources. It covers the Canadian Shield, the Arctic Islands, the Cordillera and Appalachian mountains, and Phanerozoic sedimentary basins south of the Shield. In total, 140 trains are portrayed, including those emanating from major mineral-deposit types (e.g. gold, base metal, diamondiferous kimberlite, etc.). The map took 10 years of on-and-off work to generate, and it culls data from over 150 years of work by government, industry, and academia. It provides a new tool to help companies find ore deposits in Canada: the trains are generally a better predictor of dispersal distance and direction than striations and streamlined landforms, the data typically depicted on surficial-geology maps, including the Glacial Map of Canada. It also gives new insight into sedimentation patterns and processes beneath ice sheets, a sedimentary environment that, because of its inaccessibility, remains poorly understood and controversial.

\textbf{1. Introduction}

Clastic dispersal trains – hereafter referred to simply as dispersal trains – are trails of mud, sand and/or gravel particles (clasts) that were eroded from a bedrock source, transported one or more times downflow (but not necessarily downslope) by a geophysical fluid (air, water or glacier ice), and, ultimately, deposited and preserved in the stratigraphic record (Dilabio \& Coker, 1989; Kujansuu \& Saarnisto, 1990; McClenaghan, Bobrowsky, Hall, \& Cook, 2001; Paulen \& McClenaghan, 2017). Although the term has commonly been used to describe linear or fan-shaped trails of sediment (e.g. Dilabio, 1990; Dyke \& Morris, 1988; Flint, 1947), we use it here in the broader sense (e.g. Klassen \& Thompson, 1993) to describe trails of sediment of any shape or size, from pencil-shaped trails a few meters long to ovoid trails a few thousand kilometers in extent. Every clastic particle on Earth forms part of a dispersal train thus defined, though most trains are too dilute or too indistinct to map out and trace back to source. The term can be used in any depositional setting (e.g. fluvial, eolian, turbidite, etc), but it is most commonly used in glaciated terrain. In these settings, former glaciers performed most of the sedimentary and geomorphic work, and the dispersal trains generated as a result provide insight into glacier behavior. In terms of applied science, dispersal trains are an important component of mineral exploration: identification of trails of ore particles in glacial sediment has commonly led to the discovery of mineral deposits in the bedrock beneath.

Herein, we present the first compilation of glacial dispersal trains from across North America (Main Map). It builds upon previous regional and thematic compilations (e.g. Armstrong \& Kjarsgaard, 2003; Batterson \& Liverman, 2000; Cummings, 2018; Dyke \& Dredge, 1989; Flint, 1947; Klassen \& Thompson, 1993; Lamothé, 1992; Levson, 2001; McClenaghan \& Peter, 2015; Parent, Paradis, \& Boisvert, 1995; Shilts, 1982) and, in doing so, captures over 150 years of work by geological surveys, mineral exploration companies, and academic researchers. The map can be seen as a counterpart to other continent-scale glacial maps (e.g. Flint, 1945; Fortune, 1995; Prest, Grant, \& Rampton, 1968; Shaw, Sharpe, \& Harris, 2010), and significant insight can be obtained by superimposing and viewing these maps in conjunction. It provides mineral exploration companies with a new tool to help find ore bodies in glaciated parts of North America, and will hopefully foster discussion over how ice sheets interact with the lithosphere and mobilize sediment over large temporal and spatial scales.

\textbf{2. Methods and software used}

The mapping procedure was straightforward. First, published literature was searched, portions of the gray literature notwithstanding (e.g. mineral assess-
ment reports). Second, figures that depict well-delineated glacial dispersal trains with identified bedrock sources were digitized and georeferenced using a computer mapping program (ArcGIS) and a standardized projection (Lambert conformal conic) and datum (NAD83). Adobe Illustrator was used to draft the final paper copy map (PDF file), and ArcGIS was used to generate the final digital map (kmz file). The following were not included on purpose: glacial dispersal trains that were not constrained by significant field sampling, including those mapped primarily by visual means using remotely sensed imagery (e.g. Dyke & Morris, 1988; Ross, Campbell, Parent, & Adams, 2009); trains that were mapped by exclusively sampling sediment that was reworked from till, including lake sediment, glaciofluvial sediment (e.g. eskers), or stream sediment; surface trains (Abitibi region notwithstanding); till trains lacking an identified bedrock source (e.g. Ruler kimberlite indicator mineral (KIM) train (Armstrong, 2009); Williams Lake heavy mineral train (Kjarsgaard, Plourde, Knight, & Sharpe, 2014); Churchill KIM trains (Strand, Banas, Burgess, & Baumgartner, 2008, 2009); Thompson Nickel Belt chrome diopside train (Averill, 2011; Grunsky & Baumgartner, 2008, 2009); Thompson nickel belt chrome diopside trains from the McGerrigle Mountains in the Gaspé (Charbonneau & David, 1993), the Boothia Peninsula (Tremblay, Ryan, & James, 2007), and the Otish Mountains—Lac Mistassini area in central Quebec (Bouchard & Martineau, 1984; Veillette, 2004). Readers are encouraged to consult the original references (Appendix 1) for more information on these regions. For trains defined by multiple components derived from a single bedrock source (e.g. multiple geochemical elements), only one component was digitized.

In some areas, dispersal trains were omitted on purpose to prevent visual confusion from excessive overlap. Examples include the Lake Melville region in Labrador (Batterson, Simpson, & Scott, 1988; Klassen & Thompson, 1993), the McGerrigle Mountains in the Gaspé (Charbonneau & David, 1993), the Boothia Peninsula (Tremblay, Ryan, & James, 2007), and the Otish Mountains—Lac Mistassini area in central Quebec (Bouchard & Martineau, 1984; Veillette, 2004).

The grain-size nomenclature used to describe dispersal trains in the past has commonly been confusing and inaccurate, in part because multiple grain-size classification schemes have existed over the years (Roderick, 1966). For clarity, we use the Udden–Wentworth grain-size scale herein (Table 1), the standard scale used by geologists today (e.g. Boggs, 2011). The only exception is that we define the clay–silt boundary as 0.002 mm, not 0.004 mm. Glacial geologists and mineral exploration geologists typically use the 0.002 mm (2 μm) boundary (e.g. Shilts, 1996) because there is often a stronger chemical contrast at this level (Roderick, 1966), especially for some elements of economic interest (e.g. Cu, Zn).

Two main types of glacial dispersal trains are reported in the literature, boulder trains and till dispersal trains (Figure 1). These categories are retained here for the sake of continuity. Boulder trains are trails of large, distinct particles, typically boulders but sometimes also cobbles and pebbles, which are sparsely distributed across the surface of the landscape. Till dispersal trains are trails of distinct mud (i.e. clay and/or silt), sand, or gravel particles within till. They are typically defined by (1) the geochemistry of the silt plus clay fraction (<63 μm) or clay fraction (<2 μm) of the till (or, less commonly, by the sand plus mud fraction of the till), (2) by the mineralogy of the sand and visible silt particles in the till (e.g. gold grains, kimberlite indicator minerals), and/or (3) by the lithology of the gravel clasts in the till. For simplicity, the rare trains on the map that consist of clastic particles in ‘glacial drift’ (i.e. till plus sand and gravel

| Grain-size nomenclature used in this paper. |
|---------------------------------------------|
| Gravel                                      |
| Boulder                                    |
| 1.25–6 cm                                  |
| Cobble                                     |
| 6.4–25.6 cm                                |
| Pebble                                     |
| 4 mm–6.4 cm                                |
| Granule                                    |
| 2 mm–4 mm                                  |
| Sand                                        |
| Very coarse                                |
| 1 mm–2 mm                                  |
| Coarse                                     |
| 0.5 mm–1 mm                                |
| Medium                                     |
| 0.25 mm–0.5 mm                             |
| Fine                                       |
| 0.125 mm–0.5 mm                            |
| Very fine                                  |
| 0.063 mm–0.125 mm                          |
| Mud                                         |
| Silt                                        |
| 0.002 mm–0.063 mm                          |
| Clay                                        |
| <0.002 mm                                  |
reworked from till), such as the Omar train (Prest, Donaldson, & Mooers, 2000) and the various trains emanating from the Otish Mountains area in Quebec (Veillette, 2004), are lumped into the latter category. Boulder trains may or may not be associated with till dispersal trains, and vice versa.

3. Conclusions

The map presented herein represents the first synthesis of dispersal trains from across glaciated North America. It will hopefully foster discussion and provoke debate. It should not be considered as the definitive, final product. Rather, like all maps, it is highly simplified and it is a work in progress. Dispersal trains from published literature were undoubtedly missed. All of the trains portrayed remain incompletely understood and require further study. To improve subsequent versions, authors could search the gray literature (e.g. mineral assessment reports, provincial government reports, theses, etc) more thoroughly to find additional trains; integrate in-house data from mineral exploration companies (there is a large amount of privately held data within industry); plot trains that lack known bedrock sources; depict the internal heterogeneity of trains; plot overlapping trains; and plot multiple components (e.g. multiple pebble lithologies, multiple geochemical elements) derived from individual bedrock sources. When integrated with existing data (e.g. Prest et al., 1968), these trains are key to understanding how the cryosphere interacts with the rest of the Earth system over geological time.

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