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Gold in eskers and gyttja overlying auriferous till, Regnault deposit, Quebec

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Abstract: The Regnault gold deposit in Quebec, Canada, was discovered by Kenorland Minerals North America Ltd in 2020 following identification of a gold-in-till dispersal train. In 2022, two non-traditional media – eskers and organic lake-bottom mud (gyttja) – were sampled to determine if they likewise contained gold anomalies that vectored the mineral deposit. Striking, coherent (mappable) anomalies exist in both media. The gold-in-esker dispersal train has a similar pathfinder element association as the gold-in-till dispersal train (e.g. Te, W) but contains approximately twice the gold (average 73 ppb Au) in the <63 µm fraction. It is hypothesized to be a meltwater-sorted version of the gold-in-till train, sourced from the erosional esker corridor some 3 km upflow. By contrast, the gold-in-gyttja dispersal train is substantially different to both the gold-in-esker and gold-in-till dispersal trains. It has lost significant association with pathfinder elements, contains an order of magnitude less gold (average 4.2 ppb Au), and is tentatively hypothesized to have a hydromorphic origin, sourced primarily from the gold-in-till dispersal train. The main takeaway from the study is that the sampling of any of these three media – eskers, gyttja or till – could have conceivably led to the discovery.

Keywords: drift prospecting; glaciofluvial; hydromorphic; lake sediments; till; gold

Supplementary material: Maps showing till, esker and gyttja geochemistry (Appendix 1) and plots of gyttja geochemistry v. water depth (Appendix 2) are available at https://doi.org/10.6084/m9.figshare.c.7235784

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Over the past several million years, multiple successive ice sheets have advanced and retreated over Fennoscandia and northern North America (De Schepper *et al.* 2014; Dalton *et al.* 2020), scraping the bedrock surface, transferring sediment from continent to ocean, releasing large amounts of meltwater and sculpting the landscape (Prest 1970). A transported sediment cover has been generated in the process that unconformably overlies bedrock in most places (Geological Survey of Canada 2014). It consists largely of glacier-deposited sediment (till), which in turn is locally overlain by deglacial meltwater deposits (e.g. esker complexes), all capped by a thin veneer of post-glacial organic material. The presence of this transported cover complicates gold exploration. However, work has shown that the till, in particular, can contain trails (dispersal trains) of gold that can be traced back to mineralized bedrock (Averill and Huneault 1991; McClenaghan and Cabri 2011). Till is in many ways an excellent sampling medium for gold exploration (McClenaghan 2001). It tends to be widespread, texturally homogeneous, enriched in local bedrock fragments and enriched in silt, the dominant grain size of most gold particles in orebodies and dispersal trains alike (Averill and Huneault 2016; Girard *et al.* 2021). Furthermore, gold-in-till dispersal-train planforms tend to be 10–100 times those of their bedrock sources (Cummings and Russell 2018), making them easier to detect geochemically. The collection of till-sample grids to search for auriferous dispersal trains has therefore become a routine practice during gold exploration, one that has contributed to multiple orebodies discoveries in glaciated terrain (McClenaghan *et al.* 2023).

Ideally, when attempting to image gold-in-till dispersal trains on a mineral exploration property, sample grids should be constructed so that they extend across the entire property and be free of gaps. In reality, such unbroken coverage can rarely be achieved and gaps are common. One of the reasons for this is the presence of younger sediment – such as glaciofluvial sand and gravel, glaciolacustrine clay, beach sediment, organic matter or otherwise – which almost always exists locally and in extreme cases can bury the entire property. Overburden drilling can be used to penetrate through younger sediment and sample till at depth (Skinner 1972), but it is costly. Another potential option would be to sample the younger sediment. For this to work, coherent (mappable) gold dispersal train – the 'geochemical anomalies' of interest in gold exploration – would need to extend from the auriferous till or bedrock into the younger sediment. Most media in glaciated terrain, including sediment, organic matter and water, are known to contain trace amounts of gold (e.g. Cook and McConnell 2001; Dunn 2007; Leybourne and Cameron 2010). But do these media ever contain coherent gold dispersal trains that 'vector' gold mineralization? Practice has shown that some do. For example, coherent gold dispersal trains have been documented in vegetation and humus in areas where these media rest directly on till that also contains a coherent gold dispersal train (Gleeson *et al.* 1989; Dunn, *et al.* 1991). Vegetation and humus are therefore sometimes sampled in lieu of till (Dunn 2007). Most other surficial media, by contrast, are generally avoided during property-scale gold exploration. Glaciolacustrine mud is universally avoided (e.g. Gleeson 1960), perhaps for good reason. (For clarity, mud is, by definition, equivalent to the term 'silt + clay': it refers to sediment particles with diameters <0.063 mm, irrespective of the composition of the particles (Folk *et al.* 1970; Lazar *et al.* 2015).) The particles that make up glaciolacustrine mud bodies form part of regional dispersal trains (Veillette *et al.* 2005) that are too large, distally sourced and complexly comingled to be of use in property-scale exploration. Post-glacial organic lake-bottom mud (gyttja) – the main target of 'lake-sediment' sampling campaigns (Cameron 1994) – can contain elevated levels of gold near auriferous till and bedrock (Hornbrook 1989) but gyttja is generally only sampled during regional surveys (one sample per lake is typical) because it is perceived to contain averaged geochemical signals from the entire lake catchment (Timperley and Allan 1974). Eskers are generally thought to be ineffective sampling media for gold exploration: their provenance is often perceived as uncertain and possibly far travelled (Krajick 2001), hydraulic sorting is thought to generate noisy data (Craigie 1993), and gold particles are hypothesized to bypass gravelly esker-depositing streams and deposit in fine-sand outwash (Averill 2001).

Published gold dispersal studies that are sufficiently large and multi-faceted to test these popular perceptions are scant. With a few notable exceptions (e.g. Dunn *et al.* 1991), most lack information on one or more key components of the system, such as the bedrock source, till dispersal train or younger media. As such, 'source-to-sink' gold dispersal and partitioning in glacial landscape media remains incompletely documented and incompletely understood. Companies have little recourse when attempting to interpret gold anomalies in surficial media other than till, an important consideration given that such media (e.g. sand, gravel) are almost invariably sampled during 'bag-and-shovel' till sampling campaigns and overburden drilling projects alike, whether advertently or inadvertently.

To help address this knowledge gap, samples from two media rarely targeted during property-scale gold exploration – organic lake-bottom mud (gyttja) and eskers – were collected at the Regnault gold deposit (hereafter 'Regnault'), Quebec, in the summer of 2022 (Fig. 1). Regnault was discovered in 2020 by Kenorland Minerals North America Ltd (hereafter 'Kenorland') following identification of a gold-in-till dispersal train (Fig. 2). The objective of the work in the summer of 2022 was to determine if similar gold dispersal trains existed in the esker and gyttja that likewise indicated the presence of nearby gold mineralization. This paper details the results of the work.

Background and previous work

General setting

The Frotet mineral exploration property is located 2 h north of Chibougamau, Quebec, in the Frotet–Evans greenstone belt, a *c.* 2.7-billion-year-old body of metavolcanic and metasedimentary rock surrounded by granitoid rock in the Superior Province of the Canadian Shield (Simard 1987; Gosselin 1996). Mineral exploration in the belt started in earnest in the 1950s and continues today. It has involved a combination of drift prospecting (e.g. till sampling, boulder tracing, lake-sediment sampling), geophysics, outcrop sampling and diamond drilling (Hawkins and Charbonneau 2020). Eskers and lake sediments near Regnault had not been sampled prior to summer 2022 and till near Regnault had not been sampled prior to Kenorland's involvement at Frotet (Hawkins and Charbonneau 2020). The Troilus gold deposit, located just north of the property, was discovered in the 1980s by tracing a trail of mineralized boulders back to source. During its lifetime from 1996 to 2010, the Troilus Mine produced two million ounces of gold and 70 000 tons of copper (Evans 2019).

The surficial sediment package at Frotet is somewhat typical of the Canadian Shield landscape: streamlined till with a silty fine-sand matrix is the dominant surficial material; sparse erratic boulders are ubiquitous; esker–outwash complexes are present; and rare glaciolacustrine mud is observed in low-lying areas and is suspected to underlie most swamps and lakes in the study area (Hardy 1976, 1982; Hawkins and Charbonneau 2020). Rogen moraine is present locally in esker corridors. The Sakami Moraine (7900 ^{14}C years BP) crosses the mineral exploration property between Regnault and Troilus (Hillaire-Marcel *et al.* 1981; Hardy 1982). Striations are ubiquitous on the bedrock surface near Frotet (Bouchard and Martineau 1985; Paradis and Boisvert 1995). Most are young, trend SSE (*c.* 210°) and are interpreted to have been generated following the last glacial maximum during deglaciation (Veillette 1989, 2004). Rare older striations in sheltered locations trend orthogonal to this (Paradis and Boisvert 1995) and are interpreted to have formed much earlier, possibly during ice-sheet build-up at the start of the last glaciation (Veillette 2004). The esker networks trend roughly parallel to streamlined till landforms (drumlins, crag and tails), which in turn trend roughly parallel to dominant (young) striations (Fig. 1).

Frotet is located in the boreal forest near the southern limit of sporadic discontinuous permafrost. A mixed, black-spruce-dominated forest with minor poplar, pine and birch tends to grow on till, whereas an open pine and birch forest tends to grow on well-drained sand and gravel (e.g. eskers). Slope gradients are gentle, drainage is poorly developed, and streams entering and exiting Lac Frotet are small (estimated discharges of several cubic metres per second (m^3 s^{-1}); negligible clastic input). The lake network drains northwestward towards James Bay via the Rupert River. Podzol soils are developed on till. These are characterized by B horizons that extend to depths of 0.5–2 m. Forest fires are common and have partially to completely burned most forest near Regnault over the past several decades (https://www.foretouverte.gouv.qc.ca/). Lac Frotet is a brown-water lake similar to those observed throughout Northern Quebec and Ontario, the colour a product of high concentrations of dissolved organic carbon (e.g. humic and fulvic acids) from decaying plant matter in watershed soils (e.g. Meyer-Jacob *et al.* 2020). Dominant winds blow eastward. No smelters exist nearby that could have introduced airborne metal contamination (e.g. Palmer *et al.* 2015).

Discovery of Regnault

Kenorland's multi-year till sampling programme at Frotet started in 2018 (Charbonneau and Gallardo 2019). Approximately 8000 till samples have been collected since this time and several pencil-shaped metal-in-till anomalies (dispersal trains) have been identified, termed the Troilus, Cressida, Chatillion, La Fourche and Regnault target areas (Hawkins and Charbonneau 2020). Follow-up work is ongoing at each of these areas but is most advanced at Regnault. The Regnault gold-in-till dispersal train (Fig. 2) was first identified during Kenorland's maiden till sampling campaign in 2018. At this stage, only five contiguous samples along a single sampling fence hinted at its presence (14–41 ppb Au). It was further delineated during follow-up sampling in 2019, 2020 and 2021. Approximately 500 <63 µm till sample stations now exist over the Regnault till anomaly, with samples spaced roughly equidistantly at *c.* 75 m. The train is defined by: (1) elevated Au, Te, W, Ag, K, Rb, Ba, Tl, Ca and Sr in the <63 µm fraction of the till (B horizon, 30 g aliquots, aqua regia, inductively coupled plasma mass spectrometry (ICP-MS)), with peak gold concentrations (>98th percentile) between 110 and 560 ppb, which is somewhat typical of coherent gold-in-till trains down-ice of mineralized bedrock in the Abitibi (e.g. McClenaghan 2001); (2) tens to hundreds of gold grains in 10 kg C horizon till samples, most which are silt sized and have pristine to modified shapes, which is again typical (Fig. 3; e.g. McClenaghan 2001; Girard *et al.* 2021); and (3) a mineralized-boulder train at surface (Hawkins and Charbonneau 2020). The gold-in-till train is 1 km wide and extends at least 7 km down-ice, to the southern edge of the mineral exploration property. In an across-flow direction, metals are most concentrated in the axis of the dispersal train and decrease laterally away from this. Gold and W form the largest, most coherent dispersal trains in till. Concentrations of Au and W in <63 µm till samples peak in the

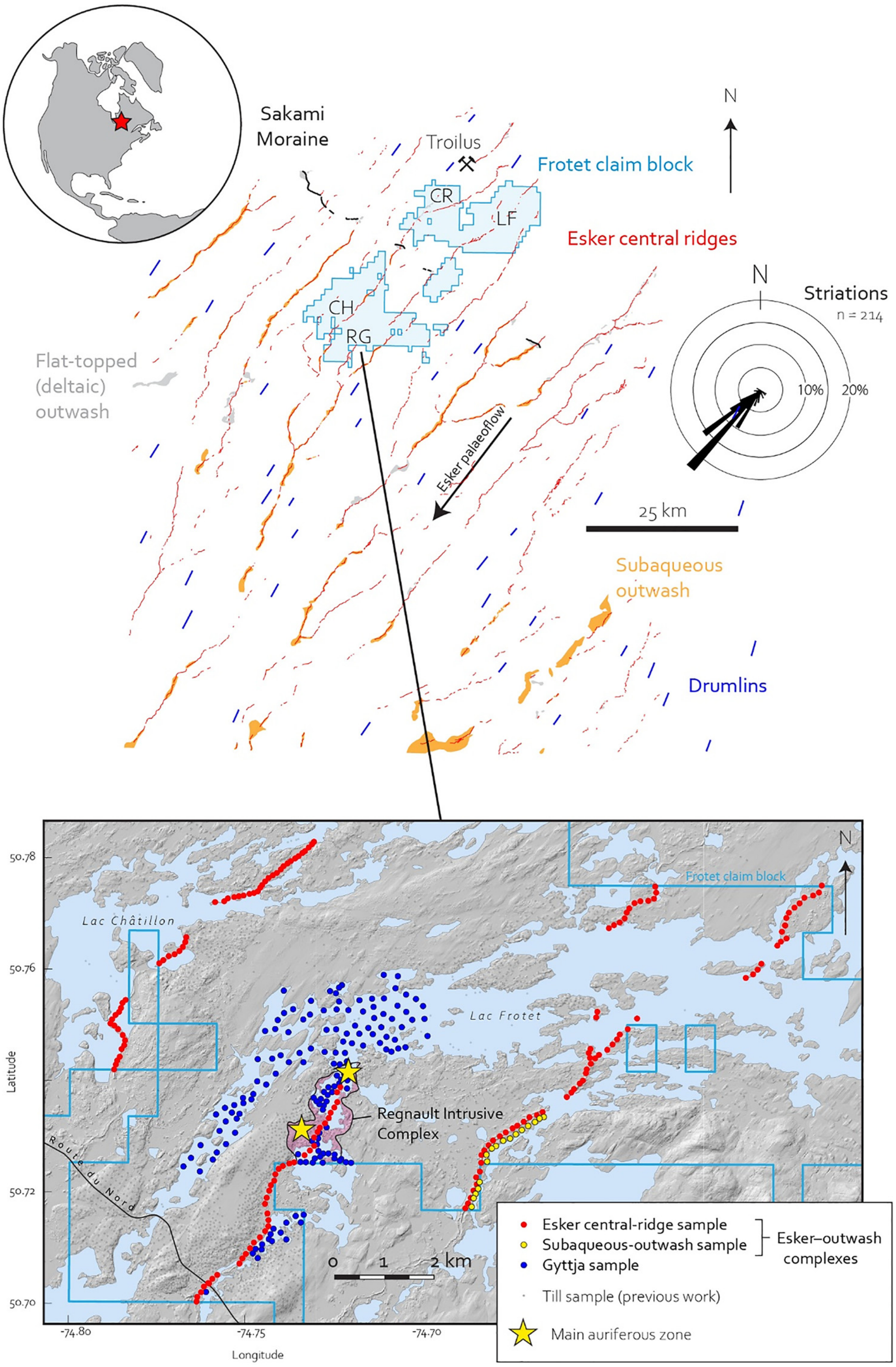

Fig. 1. Location of the esker and gyttja samples collected in summer 2022 near the Regnault gold deposit, Frotet Property, Quebec. Till samples collected previously by Kenorland shown for context. CR, LF, CH and RG refer to the Cressida, La Fourche, Chatillon and Regnault metal-in-till anomalies, respectively (Hawkins and Charbonneau 2020). Striations from Paradis and Boisvert (1995). Background is a hillshaded digital elevation model made from light detection and ranging data.

first 3 km of the train – peak gold concentrations (>98th percentile) are between 100 and 560 ppb in the core of the train – and decrease down-ice to the edge of the mapped train. By contrast, concentrations of Te, Ag, Ca, K, Rb, Ca, Sr and Tl are elevated for the first 3–4 km then fade into geochemical background down-ice of this. The length of the train therefore varies from 3 to >7 km depending on the element in question.

After the Regnault gold-in-till train was delineated, geophysical data were collected and chargeability anomalies were identified at the head of the train, beneath Lac Frotet (Hawkins and Charbonneau 2020). Drill testing of these anomalies in 2020 led to the discovery hole, which intersected 29 m of mineralized rock containing 8.47 $g\ t^{-1}$ Au. Assessment of the gold mineralization is ongoing. It appears largely restricted to a diorite body cut by porphyritic dyke swarms, the Regnault Intrusive Complex (Mathieu and MacDonald 2022), with minor mineralization extending out into the surrounding volcanic rocks. Approximately 84% of the gold in the twinned discovery hole is contained within Au–Ag–Te minerals (Shimada *et al.* 2022). The gold mineralization tends to be high-grade, quartz-vein-associated, correlated with Te and Ag, and confined to several steeply dipping, east–west-trending shear zones that cross-cut the diorite, termed R1, R2, etc. (Hawkins and Charbonneau 2020). These zones are characterized by moderate to high strain, biotite–carbonate ± silica–chlorite alteration, minor disseminated pyrite, and trace chalcopyrite. The mineralized zones are suspected to subcrop beneath the lake and likely have east–west strike lengths of *c.* 200–1000 m.

With regards to the suite of elements that form coherent till dispersal-trains at Regnault (Au, Te, W, Ag, K, Rb, Ba, Tl, Ca, Sr),

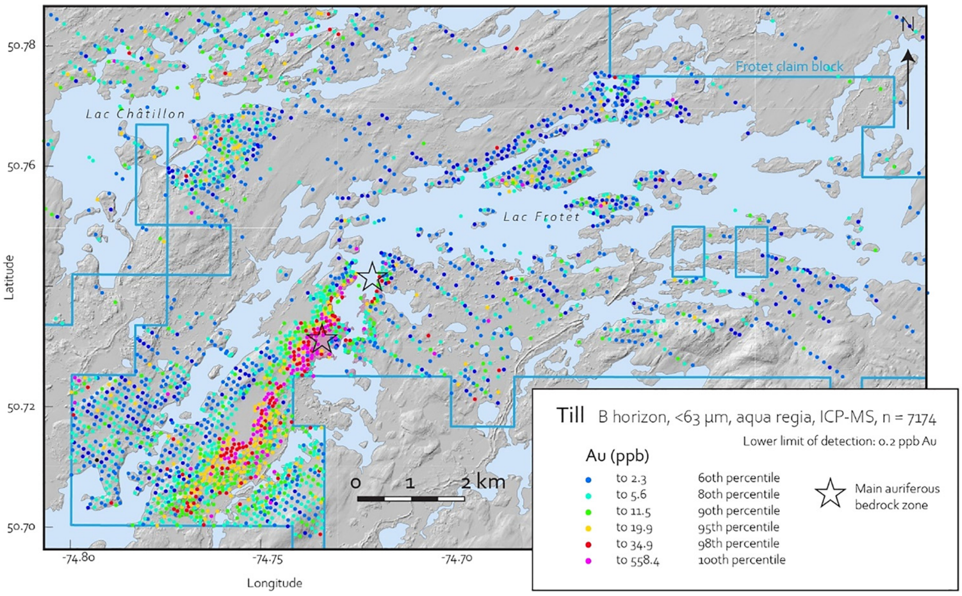

Fig. 2. Gold in till at Regnault, based on previous sampling conducted by Kenorland between 2018 and 2021 (Hawkins and Charbonneau 2020). Note the coherent dispersal train down-ice of Regnault, the identification of which led to the discovery. Background is a hillshaded digital elevation model made from light detection and ranging data.

Te and Ag are known to occur with Au in the aforementioned Au–Ag–Te minerals (Shimada *et al.* 2022); W may be associated with scheelite, which is suspected to be present locally in gold-mineralized veins as an inconspicuous white mineral that fluoresces under ultraviolet light; K, Ba, Rb and Tl may be associated with biotite, the main alteration mineral at Regnault (Hawkins and Charbonneau 2020); and Ca and Sr may be related to carbonate minerals in veins and alteration haloes.

It is important to note that whereas an aqua region digestion was used on all surficial sediment (till, esker, gyttja), a multi-acid digestion was used on pulverized bedrock samples. This likely generated some discrepancies in geochemical signatures and associations when comparing bedrock with surficial sediment (e.g. Table 1).

Methodology

Between 7 and 10 July 2022, lake-sediment sampling was conducted from a motorboat using a standard Hornbrook sampler (Fig. 4), which returned fist-sized samples of organic-rich lake-bottom mud (gyttja) – 150 lake-sediment samples and 8 field duplicates were collected. Because the Canada Centre for Mineral and Energy Technology lake-sediment standards are no longer available, 8 OREAS-46 till standards (certified value of <2 ppb Au) were inserted into the sample sequence, for a total of 166 samples. Sample-site spacing was roughly 200 m and followed an equidistant grid. Water depth was determined using a Deeper Smart Sonar PRO +2. Sample magnetic susceptibility, a proxy for siliciclastic sediment content in lake sediments (Blumentritt and Lascu 2014), was determined using a GF Instruments SM-20 meter. Field data were entered into Fulcrum, a field data collection app, using cell phones. Samples were shipped to Bureau Veritas Mineral Laboratories Canada (Bureau Veritas), where they were oven dried at 60°C, ashed at 475°C and sieved to <63 µm to obtain 30 g aliquots that were digested in modified aqua regia (1:1:1), and then analysed using ICP-MS (package AQ 252-EXT). The ICP-MS analyses were conducted using an Elmer Elan 9000 or an Agilent 7900. The laboratory also performed internal quality control: they analysed seven OREAS-262 standards, seven DS11 standards and seven blanks with the batch of esker samples in addition to six pulp duplicates. Loss-on-ignition (LOI), a proxy for organic matter content (Coker and Nichol 1975), was requested but was not recorded: the dried samples were not weighed prior to ashing. To prevent incorporation of any nuggety, friable, metal-rich Fe–Mn precipitates which may have been present in the gyttja (e.g. Terasmae 1971; Kerkermeier 2013), sample pulverization – a step typically performed on dried lake-sediment samples prior to sieving (e.g. Bourdeau and Dyer 2023) – was not requested for the Regnault lake-sediment samples. Similarly, in an attempt to further reduce nugget effect and bring the gyttja data more in line with the till and esker data, lake-sediment samples were sieved to <63 µm, not the more conventional <177 µm commonly used on lake sediments (Bourdeau and Dyer 2023).

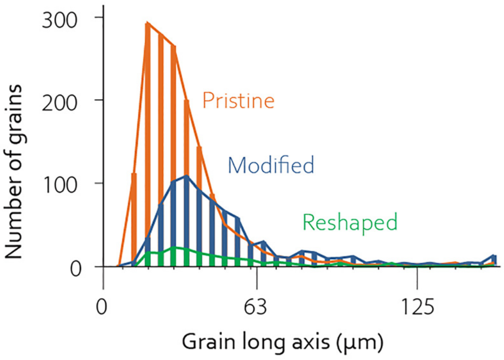

Fig. 3. Gold grain shape and size based on 59 samples collected from the Regnault gold-in-till dispersal train (Fournier and Girard 2021). Note the preponderance of pristine shapes and silt-sized gold particles, as is typically observed in coherent gold dispersal trains developed in till down-ice of auriferous bedrock.

Following lake-sediment sampling, esker sampling was conducted on foot between 11 and 19 July 2022. A motorboat was used to access eskers. Dutch augers or shovels were used depending on moss thickness and difficulty of penetration. Hubco bags were used and were filled completely. Samples were on average 1.3 kg. Cobbles and most pebbles were handpicked and discarded. One hundred and seventy-six esker samples were collected in addition to 8 field duplicates, and 8 OREAS-46 till standards were inserted into the sample sequence for a total of 192 samples. Esker-ridge crestlines were targeted (90% of samples), with flanking outwash sampled along a portion of one esker (10% of samples) in addition to the central ridge. Samples were collected from the B soil horizon (25–100 cm depth). Down-esker sample spacing was *c.* 150 m.

Table 1. Spearman correlation coefficients (r_s) between gold (Au) and other elements that form coherent dispersal trains (Te, Ag, W, K, Ba, Tl, Rb, Ca and Sr) downgradient of mineralization and alteration at Regnault

Element and method detection limit	Mineralized bedrock (>1 ppm Au)	Regnault dispersal trains				Frotet property		
		Head of gold-in-till train	Gold-in-till train	Gold-in-esker train	Gold-in-gyttja trains	All till samples	All esker samples	All gyttja samples
	$n = 2744$	$n = 100$	$n = 487$	$n = 20$	$n = 39$	$n = 7167$	$n = 176$	$n = 148$
	Au	Au	Au	Au	Au	Au	Au	Au
Au (0.2 ppb)	1	1	1	1	1	1	1	1
Te† (0.02 ppm)	0.81	0.68	0.45	0.83	0.39	0.03	0.14	0.18*
Ag† (2 ppb)	0.76	0.27*	0.2	0.32*	−0.43*	0.1	0.05	−0.37
W‡ (0.1 ppm)	0.06	0.72	0.58	0.59	0.03*	0.16	0.39	−0.03*
K§ (0.01%)	−0.31	0.15	0.26	0.85	−0.11*	0.06	0.16	−0.2
Ba§ (0.5 ppm)	−0.39	0.17	0.25	0.84	−0.12*	0.07	0.03	−0.12*
Tl§ (0.02 ppm)	−0.02	0.1	0.11	0.6	0.12*	0.06	0.07	0.06*
Rb§ (0.1 ppm)	−0.31	0.02*	0.08	0.79	−0.12*	0.09	0.09	−0.2*
Ca$^{\|}$ (0.01%)	−0.25	0.36*	0.22	0.91	−0.1*	0.15	0.17	−0.25
Sr$^{\|}$ (0.5 ppm)	−0.34	0.36*	0.34	0.81	−0.15*	0.17	0.07	−0.29

*Result is not significant ($p > 0.05$).

†Associated with gold (Au)- and silver (Ag)-bearing tellurium (Te) minerals in the twinned discovery hole, Regnault (e.g. Shimada *et al.* 2022).

‡Possibly associated with scheelite, which is present locally in mineralized veins at Regnault as a white mineral that fluoresces under ultraviolet light.

§Possibly associated with biotite, a common alteration mineral at Regnault (e.g. Hawkins and Charbonneau 2020).

$^{\|}$Possibly associated with carbonate minerals in mineralized veins and associated alteration zones.

Field data were entered into Fulcrum using cell phones. Samples were shipped to Bureau Veritas, where they were oven dried at 60°C then sieved to <63 µm to obtain 30 g aliquots that were digested in modified aqua regia (1:1:1), and then analysed using ICP-MS (package AQ 252-EXT). The laboratory also performed internal quality control: they analysed 6 OREAS-262 standards, 6 DS11 standards and 11 blanks along with the batch of gyttja samples, in addition to 6 pulp duplicates. The regional esker network was mapped using light detection and ranging (LiDAR) DEMs (1 m resolution) obtained from Quebec's Forêt Ouverte website (https://www.foretouverte.gouv.qc.ca/).

A variety of software programs (ArcGIS, ioGAS, Excel, Adobe Illustrator) were used to perform exploratory data analysis and to plot results. Results below the method detection limit were plotted as half the method detection limit value.

In addition to the esker and gyttja samples, 23 grain-size samples were collected on 19 July 2022 from the heart of the Regnault gold-in-till dispersal train for a fourth-year-student project at Carleton University (Gledhill 2022). The samples were primarily till, but also included several gravelly esker-ridge samples and two glaciolacustrine mud samples. The grain-size results provide basic information on surficial-sediment texture at Regnault and are included here accordingly. The samples were processed by Thomas Gledhill (the fourth-year student) at the Geological Survey of Canada's Sedimentology Laboratory in Ottawa, Canada. Each sample was split into two fractions: sand plus granules (0.063–4 mm) and mud (<0.063 mm). Camsizer and Beckman-Coulter particle size analysers were used to determine the grain size of the former and latter, respectively. Results were treated statistically using Gradistat software and plotted using ioGAS.

Fig. 4. Hornbrook sampler used to collect gyttja at Regnault. See Bourdeau and Dyer (2023) for further details on this type of sampler.

Results

Field observations

The three eskers sampled in summer 2022 form individual branches of a single regional tree-shaped network (Fig. 1). In concert, the branches pass directly over all major metal-in-till anomalies on the property, most of which (Troilus, Cressida, La Fourche) lie *c.* 20 km upflow of the study area. The esker branch in the middle – the main focus of the study – originates within the study area, beneath Lac Frotet, and passes directly over the Regnault gold-in-till anomaly before merging with the other esker branches south of the mineral exploration property. All the eskers sit in zones of thin, patchy till – which are here referred to using the non-genetic term ‘esker corridors’ (also known as ‘meltwater corridors’) – a characteristic trait of Shield eskers (e.g. Knight 2018). Local scallops along corridor edges have similar amplitudes and wavelengths as esker meanders and are suspected to have formed by gradual, lateral combing of sinuous streams beneath the glacier, perhaps in a fashion akin to the lateral combing of meandering river channels across fluvial floodplains (Fig. 5). Geomorphologically, the esker complexes can be subdivided into two main elements: (1) a central-ridge element, commonly gravelly, interpreted to be a subglacial-stream deposit (the ‘esker’ *sensu stricto*); and (2) broader sediment bodies that flank the central ridge, commonly sandy, interpreted to be outwash deposited where the subglacial streams debouched, expanded and decelerated into standing water at the ice front (Fig. 6). Time-transgressive ice-front retreat is hypothesized to have superimposed the latter over the former (e.g. Brennand 2000). Sample pits dug into crestlines of esker ridges typically revealed clast-supported, rounded to subangular pebble gravel with rare cobbles and small boulders, although fine to coarse sand and pebble gravel with fine sand matrix was observed locally (Fig. 7). Grain-size analyses (Gledhill 2022) show that a prominent silt peak in till samples is attenuated in esker gravel samples, presumably because most mud bypassed through subglacial meltwater conduits as suspended load (Fig. 8). This silt peak is observed again in glaciolacustrine mud, the distal equivalent of the esker systems (e.g. Antevs 1922). B soil horizons were generally well developed at esker-ridge crest sample stations; these were commonly orange-brown to red-brown, iron-rich and indurated. By contrast, geochemical samples from flanking outwash bodies were much finer grained and better sorted, typically consisting of well-sorted finer sand that was smooth to auger, although pebble gravel was also rarely observed.

In the lake-sediment survey, organic lake-bottom mud was recovered at all sample stations. It was invariably dark olive brown, soft and gel-like, structureless and unscented (Fig. 9). Following conventional practice in glaciated North America (Coker *et al.* 1979; cf. Hansen 1959; Stankevica 2020), it is herein referred to as gyttja (‘yit-cha’), a catch-all term of Swedish origin used to describe post-glacial organic mud recovered from lake bottoms. Previous work suggests gyttja from Canadian Shield lakes commonly consists of some combination of diatoms, pollen, cyanobacteria, spore cases, faecal matter, inorganic grains, and organic fronds and fibres, all set in a mush of organic material, clay minerals, and Fe and Mn hydroxides (e.g. Dunn 1980). The gyttja recovered from Lac Frotet was remarkably homogeneous in appearance and texture, irrespective of water depth or geographic location. However, subtle differences were noted. In the deepest parts of the lake (>15 m depth), the gyttja had a soupier consistency and was consequently harder to recover in the Hornbrook sampler. In very shallow water (<3 m depth) within tens of metres of the shoreline it contained rare charcoal fragments, rare visible woody fragments and rare ‘grit’ (dispersed silt and sand grains). In shallow water (<5 m) the sampler often encountered rocks which were in places clearly visible as boulders in sonar. Multiple attempts routinely had to be made at a given station, and in some cases no sample could be collected. By contrast, in deeper water (>5 m) the lake bottom was invariably smooth in sonar and the sampler invariably penetrated gyttja. Rarely, in shallow water, compact light grey silty siliciclastic mud (interpretation: glaciolacustrine mud) was recovered at the base of the sampler beneath thin gyttja. This was discarded; the only material analysed geochemically was gyttja. No other types of sediment (siliciclastic sand, etc.) were retrieved in the sampler.

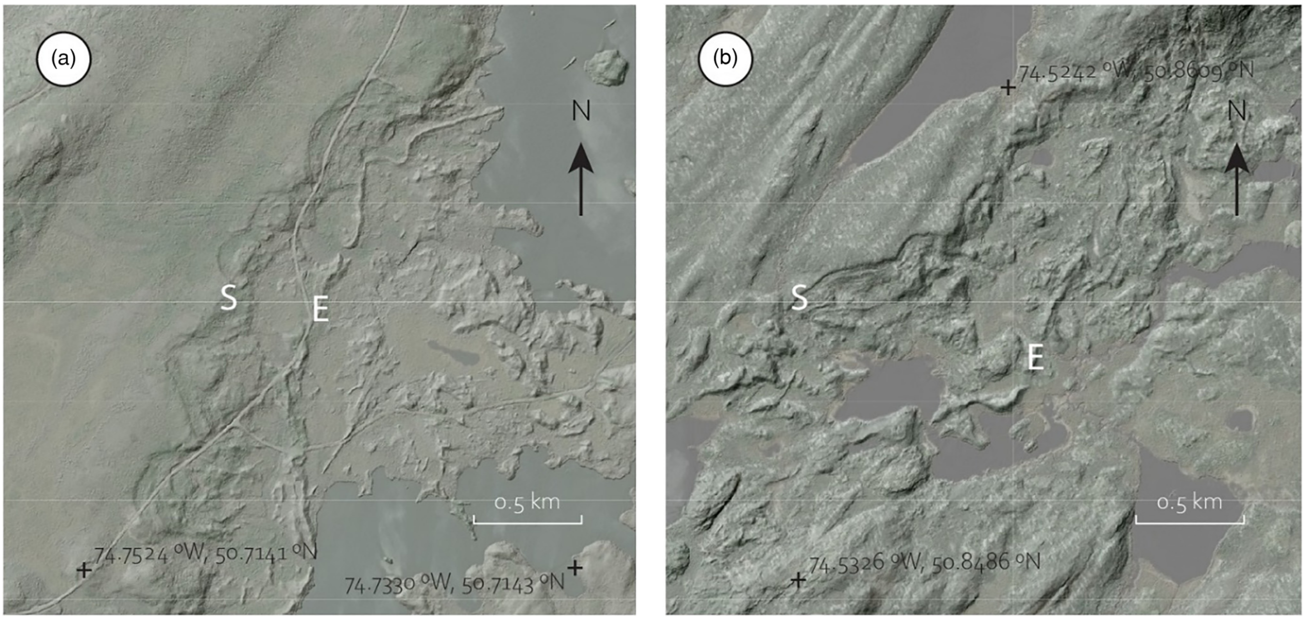

Fig. 5. (**a** and **b**) Scallops (S) developed along esker-corridor margins adjacent to sinuous esker segments (E) at two locations in the Regnault study area. In both cases, smooth streamlined till is present on the left-hand side of the image and the rough esker corridor is present on the right-hand side. Field visits indicate that scallops are erosional features carved into till, not retrogressive slump scars like those documented along other esker-corridor margins elsewhere (e.g. McWade *et al.* 2017). Background is a hillshaded digital elevation model made from light detection and ranging data.

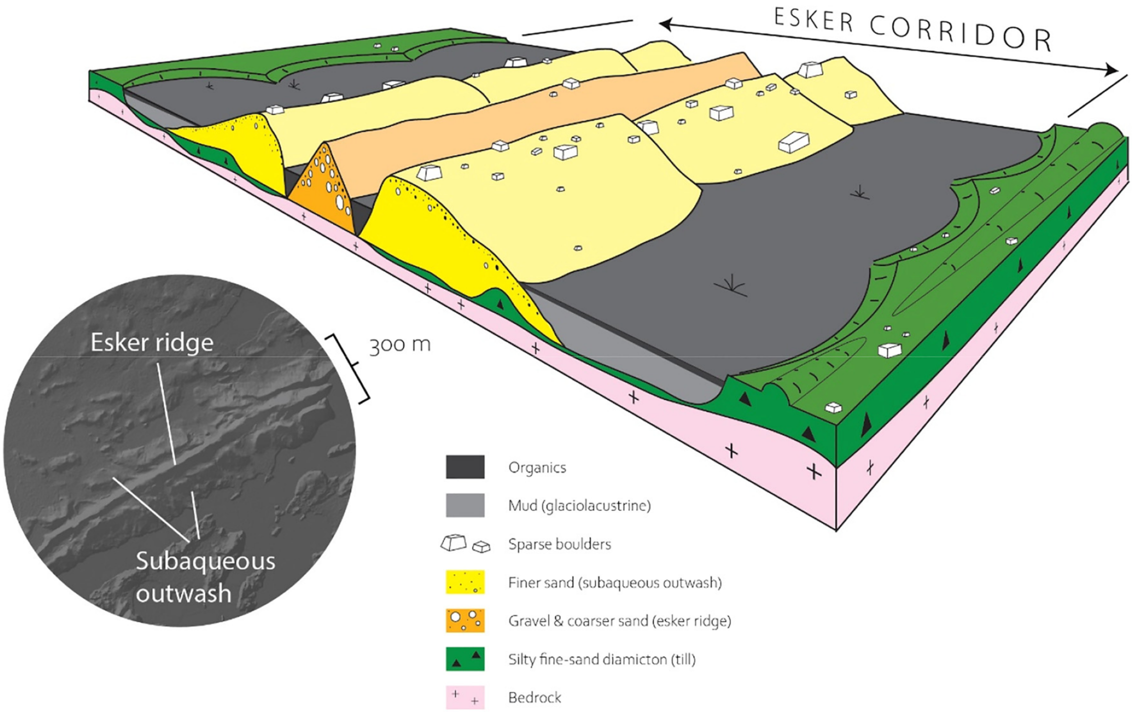

Fig. 6. Conceptual diagram of esker–outwash complexes at Regnault, showing their relationship with erosional esker corridors and till, which they stratigraphically overlie, and glaciolacustrine mud and organic matter, which they stratigraphically underlie. Gyttja in adjacent lakes (not illustrated) can be considered the lacustrine equivalent of the post-glacial terrestrial organic matter depicted here.

Quality control

Analysis of blanks yielded values for gold and key pathfinders that were invariably below method detection limits, whereas analysis of geochemical standards generally yielded values for gold and key pathfinders that were close to expected values and within tolerance limits (Fig. 10). Analysis of field duplicates generally yielded values for gold and key pathfinders that lacked statistical significance ($P > 0.05$).

Geochemistry

Striking geochemical anomalies, each defined by multiple contiguous gold-rich samples, are observed in both esker and gyttja at Regnault (Figs 11, 12). They are spatially associated with the gold-rich till and bedrock and are interpreted to be gold dispersal trains sourced from these media.

The gold-in-esker anomaly consists of a cluster of 20 contiguous gold-rich samples whose mappable edge is roughly defined by the 26 ppb Au contour (Fig. 11). The anomaly starts 3 km downflow of the head of the gold-in-till dispersal train and the auriferous bedrock, and continues downflow at least another 2.5 km to the edge of the property. Gold is distributed relatively homogeneously from sample to sample within the anomaly and has average and maximum concentrations of 73 and 614 ppb Au, respectively. By comparison, the gold-in-till dispersal train ($n = 487$) has a mappable edge approximated by the 16 ppb Au contour and has average and maximum gold concentrations of 23 and 558 ppb, respectively. Some of the elements that form coherent dispersal trains in the till at Regnault also form coherent dispersal trains in the esker (W, Te), whereas others do not (Ag, K, Ba, Rb, Tl, Ca, Sr) (Supplementary data, Appendix 1).

Two gold-in-gyttja anomalies are observed (Fig. 12). Both are centred over the gold-in-till anomaly in shallow water (<4 m) and have mappable edges approximated by the 4.2 ppb Au contour. The first consists of 24 contiguous samples centred over auriferous bedrock at the head of the gold-in-till dispersal train. Gold is distributed relatively homogeneously from sample to sample within the anomaly and has average and maximum concentrations of 5.6 and 22.8 ppb Au, respectively. The second anomaly consists of 15 contiguous samples located 3 km SW of auriferous bedrock over the outer edge of the gold-in-till train. Gold is distributed relatively homogeneously from sample to sample within the anomaly and has average and maximum concentrations of 5 and 17.9 ppb Au, respectively. The substrate beneath the auriferous gyttja is unknown: it could be bedrock, till, esker-outwash, glaciolacustrine mud or some combination. However, till and/or glaciolacustrine mud are prime candidates: isolated boulders (erratics) are common in both of the shallow-water gold-in-gyttja anomaly areas – they formed a hazard during the boat work – suggesting that till and/or bedrock may form the substrate locally, whereas glaciolacustrine mud was recovered in the Hornbrook sampler below gyttja at one station in between the two anomalies. Relative to the gold in the till and esker anomalies, gold in the gyttja anomalies has a much lower average and maximum concentration and is largely ‘decoupled’ from pathfinders (e.g. W, Te), both geographically (Supplementary data, Appendix 1) and in data space (Table 1). In stark contrast to gold, whose concentrations peak in shallow water, most other metals in gyttja tend to increase in concentration with water depths of 5–10 m, the estimated thermocline depth, then flatline or decrease slightly in concentration below this (Supplementary data, Appendix 2). This trend is often observed irrespective an element’s geochemical affinity (e.g. siderophile, chalcophile, lithophile) or mobility during weathering. There is no correlation between gold concentration and gyttja magnetic susceptibility (Supplementary data, Appendix 2).

Discussion

How was the gold-in-esker dispersal train generated?

The Regnault esker sits in a corridor of thin, eroded till and the gold-in-esker anomaly shows geochemical similarity with the head of the

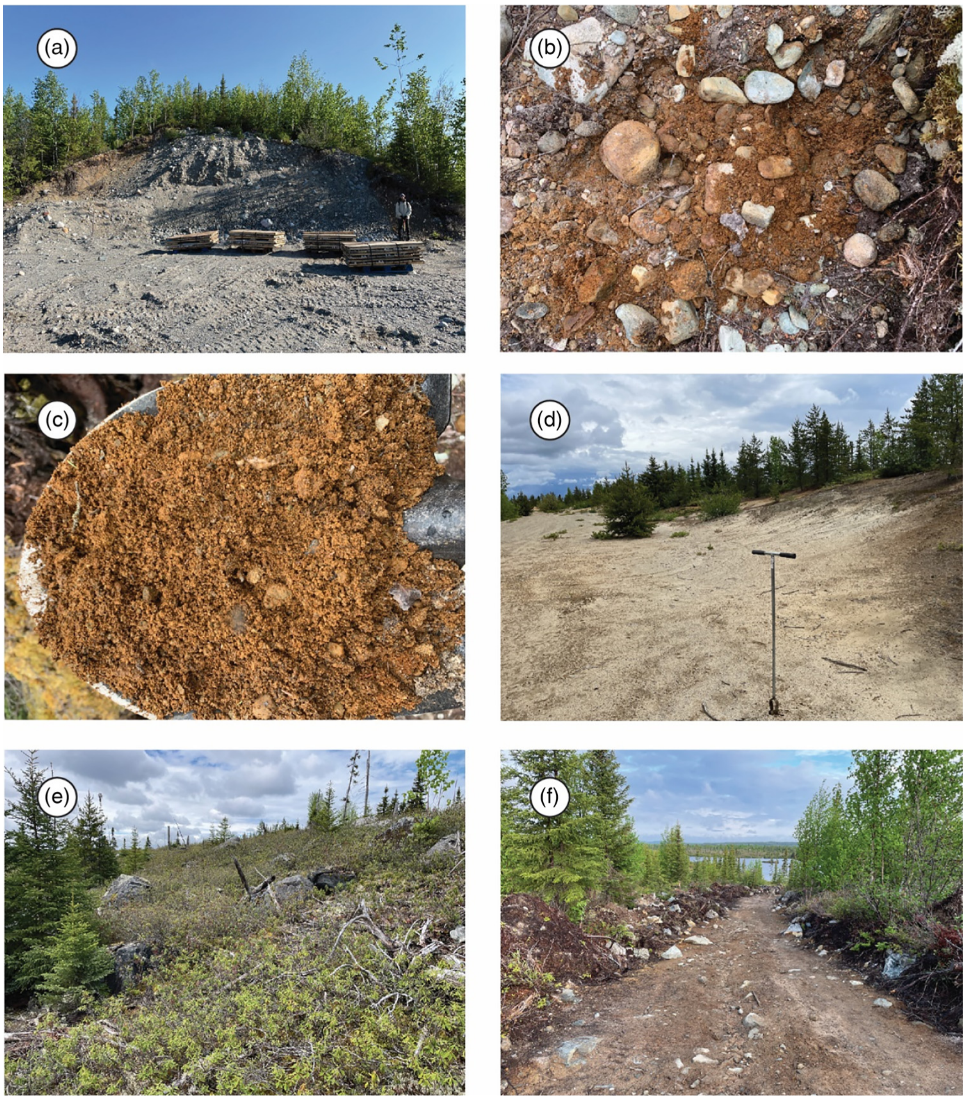

Fig. 7. (**a**–**e**) Photos of eskers sampled in summer 2022; (**f**) photo of a road excavated in till. (**a**) Cross-section of a representative gravelly esker central-ridge element, Châtillon Camp. (**b** and **c**) Representative pebbly gravel from esker ridge-crest sample stations. The pebbles in (b) are 2–3 cm in diameter. (**d**) An anomalous esker central-ridge element composed of well-sorted sand. This photo is from the upflow portion of the westernmost esker sampled. A host of anomalous metals are concentrated here (see Supplementary data, Appendix 1), possibly reflecting a grain-size control or, alternatively, sourcing from Cressida and Troilus till anomalies (this could be a terminal fan deposited close to the ice front but still within the channelized portion of the system – essentially outwash masquerading as an esker ridge). (**e**) Sparse angular boulders on sandy outwash, a common phenomenon at Regnault. (**f**) Road constructed directly on till at Frotet Camp, eastern fringe of the Regnault Intrusive Complex. Till on the property has a silty fine-sand matrix (e.g. Fig. 8), typical of most Canadian Shield tills.

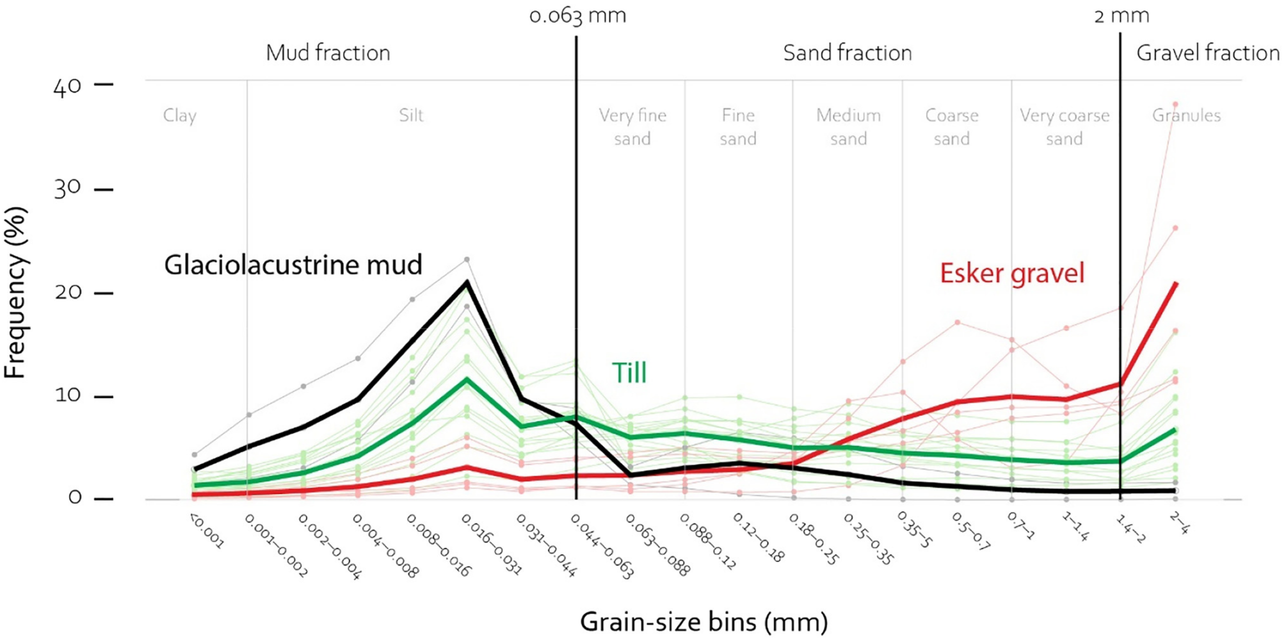

Fig. 8. Grain-size distributions (<4 mm fraction only) of esker-ridge gravel ($n = 5$), till (diamicton *sensu* Hambrey 1994; $n = 16$) and glaciolacustrine mud ($n = 2$) collected over the Regnault gold-in-till dispersal train in summer 2022. Thicker lines are average values. Modified from Gledhill (2022).

Fig. 9. Representative photos of gyttja recovered from Lac Frotet, summer 2022. (**a**) Sample 3422661, 2.4 m water depth. (**b**) Sample 3422611, 4.1 m water depth. Hansen (1959) argues that brown-water lakes (e.g. Lac Frotet) generate brown-ish gyttja, and that both lake water and gyttja gain their colour from dissolved organic carbon (humic acid) influx from catchment soils.

gold-in-till anomaly. As such, the esker is interpreted to have been erosionally sourced from the till by subglacial meltwater during deglaciation, a standard interpretation of how eskers form (e.g. Shilts 1984; Cummings *et al.* 2011). Post-glacial weathering and soil formation changed the nature of the sampled esker material, but not sufficiently to alter its gold content or its pathfinder element association, which remains roughly similar to that of the till (Table 1; Supplementary data, Appendix 1). The geochemical anomaly in the esker is therefore largely clastic and is interpreted to reflect a two-stage dispersal process: first, glacier ice eroded bedrock and dispersed the gold downflow, generating the pencil-shaped gold-in-till train, and second, meltwater eroded the till and dispersed the gold downflow, generating the gold-in-esker train (Fig. 13). The till and esker are suspected to have formed in rapid succession (several thousand years?) during deglaciation given that eskers are deglacial and that all other ice-flow proxies – the streamlined landforms, till dispersal trains and dominant striations – trend parallel to eskers, suggesting they formed under a similar gradient dictated by glacier-ice-surface slope (e.g. Shreve 1985). The paucity of Ca and Sr in esker v. till may reflect dissolution of calcite in cold subglacial meltwater, which can be aggressive towards carbonates (e.g. Anderson 2007), or post-glacial leaching of calcite from the well-drained soils (e.g. Shilts 1973). The more erratic distribution of K, Ba, Rb and Th in the esker v. till may reflect hydraulic sorting and partial bypassing of biotite through gravelly esker-depositing streams to sandy outwash and proglacial mud. Biotite is an important reservoir of these trace elements (Hinton 1972; Simmons 1999; Baidya *et al.* 2024), is nearly completely digested in aqua regia (Church *et al.* 1987), and should readily travel in suspension in meltwater given its flakey shape and reduced settling velocity (Komar and Reimers 1978). Whereas bypassing of gold particles through gravelly esker-depositing streams to fine sand proglacial outwash may occur in some cases (e.g. Averill 2001), the enrichment of gold in the esker v. till at Regnault suggests the opposite occurred here, and that selective sorting led to concentration of the silt-sized gold in the gravelly esker ridge, not depletion.

How was the gold-in-gyttja dispersal train generated?

Whereas the gold-in-esker train is essentially a meltwater-sorted version of the gold-in-till train, the gold-in-gyttja anomalies are substantially different. Previous workers have proposed different hypotheses to explain patterns of gold and trace metals in gyttja. The classic, hydromorphic hypothesis invokes weathering of labile minerals (sulfides) from catchment soils, advection of the metallic ions in groundwater to streams and lakes, and scavenging of the ions by organic matter (molecules, particles) and/or Fe and Mn hydroxides, causing settling and deposition in gyttja (Timperley and Allan 1974; Coker *et al.* 1979). A similar hydromorphic model has been proposed for gold in gyttja (Schmitt *et al.* 1993), whereby gold obtains mobility in groundwater by complexing with a ligand, is advected in groundwater in trace (ppt) concentrations, and is then scavenged aggressively once it enters the lake by organic matter, causing it to precipitate out rapidly (e.g. Coker *et al.* 1982; Schmitt 1993) and often in shallow water, given the lack of upward groundwater discharge beneath most lakes in glaciated terrain (Ogden 1986; Rogers *et al.* 1990; see also Klassen and Shilts (1982) for context). By contrast, other authors have suggested that clastic influx best explains patterns of gold and/or trace metals in gyttja (e.g. Dunn 1980; Turcotte 2012). Rogers (1988) and Rogers *et al.* (1990) document detrital gold grains in gyttja in Nova Scotia, in addition to detrital cassiterite, scheelite, wolframite and zircon.

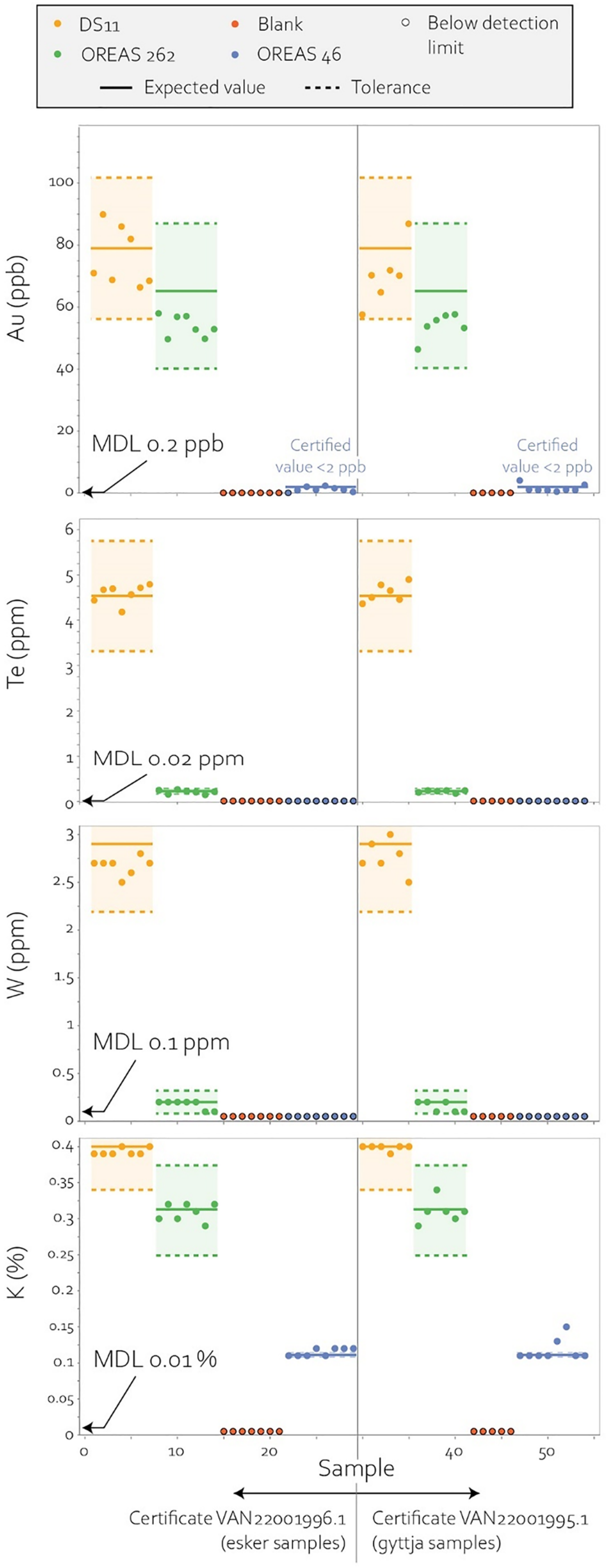

Fig. 10. Results for gold (Au) and several key pathfinder elements (Te, W, K) in certified reference materials, including the OREAS 46 standards inserted into the sample sequence, and the standards (OREAS 262, DS11) and blanks run internally by Bureau Veritas. Values below this limit are plotted as 0.5 × MDL (where MDL is the method detection limit). Expected values and tolerance limits for DS11 and OREAS 262 are from Bureau Veritas.

Turcotte (2012) documents a trend similar to that at Regnault in several Northern Quebec lakes: he reports an increase in metal concentration in gyttja to water depths of *c.* 5 m followed by flatlining of concentrations below this and, based on selective leach analysis, argues that the signature is largely clastic (gold was not investigated). By contrast, Coker *et al.* (1982) document a similar trend in Northern Ontario lakes but argue it is largely hydromorphic based on selective leach analysis. Terrestrial vegetation growing on auriferous till can have similar gold concentrations as nearby gyttja (e.g. Dunn *et al.* 1991; Schmitt 1993), and influx of this material into lakes could potentially explain auriferous gyttja. Forest fires are rarely mentioned, but they can burn off A horizons, expose mineral soils and charcoal to aeolian and stream action, and cause influx of particulate matter into lakes. Note that: (1) the Regnault area has burned multiple times in recent decades; and (2) the gyttja anomaly sits downwind of the till anomaly (Supplementary data, Appendix 1). As argued by Schmitt (1993), the gold-in-gyttja problem is a complex one, and multiple input pathways likely exist, with gold conceivably entering lakes as dissolved gold complexes, as gold adsorbed onto suspensates, as gold complexed in plant material or charcoal, and as clastic (free or occluded) gold (Fig. 14).

Which model, hydromorphic or clastic, best explains the geochemical patterns in gyttja at Regnault? It is tempting to argue for the involvement of hydromorphism at some point in the process. Several observations seem to support this, including: (1) the decoupling of gold in gyttja from other pathfinders, both geographically (Supplementary data, Appendix 1) and in data space (Table 1); (2) low average concentrations of elements commonly interpreted to reflect mineral-grain influx in gyttja relative to eskers and till (e.g. Al, Mg, Ti; see Dunn 1980; El Bilali *et al.* 2002; Trepanier 2007); (3) low average concentrations of some elements perceived as being immobile during weathering (e.g. Au, Nb, Pb, Sn, Ti; see Leybourne and Cameron 2010), which might be expected if hydromorphic influx dominated (Supplementary data, Appendix 1); and (4) the strong correlation of most elements with suspected seasonal thermochemical layering in Lac Frotet, including the concentration of redox-sensitive elements believed to be anoxia/suboxia proxies in profundal gyttja below the suspected thermocline (>5–10 m; e.g. Mo, V, U, Cr; see Tribovillard *et al.* 2006; Cole *et al.* 2017; Bennett and Canfield 2020; see Supplementary data, Appendix 2). However, one might equally argue that the general increase in concentration of most metals in gyttja with water depth (gold notwithstanding) has nothing to do with hydromorphic influx and thermochemical layering within the lake, but rather reflects basinward fining of detrital influx, given that the clay size fraction (<2 µm) is commonly enriched in a host of metallic elements, gold notwithstanding (e.g. Jenne 1977; Shilts 1995; Cummings 2023*a*). As is the case for most lake-sediment studies (e.g. Cameron 1994), it is not possible to conclusively determine whether anomalous metal contents in gyttja at Regnault were contributed by clastic or hydromorphic processes. More data would be required to obtain clarity on this (e.g. selective leaches of gyttja, scanning electron microscope (SEM) analysis to search for clastic gold, X-ray diffraction analysis, groundwater geochemistry, vertical profiling of lake-water pH, redox potential (*Eh*), dissolved O_2, temperature, conductivity, LOI, etc.). Irrespective of how the gold-in-gyttja anomalies at Regnault formed, the important point is that they exist, that they are centred over auriferous till and/or bedrock, and that similar gold-in-gyttja anomalies have been reported near mineralization elsewhere (Coker *et al.* 1982; Fox *et al.* 1987; Hornbrook 1989; Schmitt 1993).

Why ash gyttja?

Gyttja samples from Regnault were ashed to determine LOI, with the idea that this would provide insight into potential correlation between gold and organic content. While LOI ultimately could not be determined – the oven-dried samples were not weighed at the laboratory prior to ashing – the ashing may have had unintended consequences that improved results.

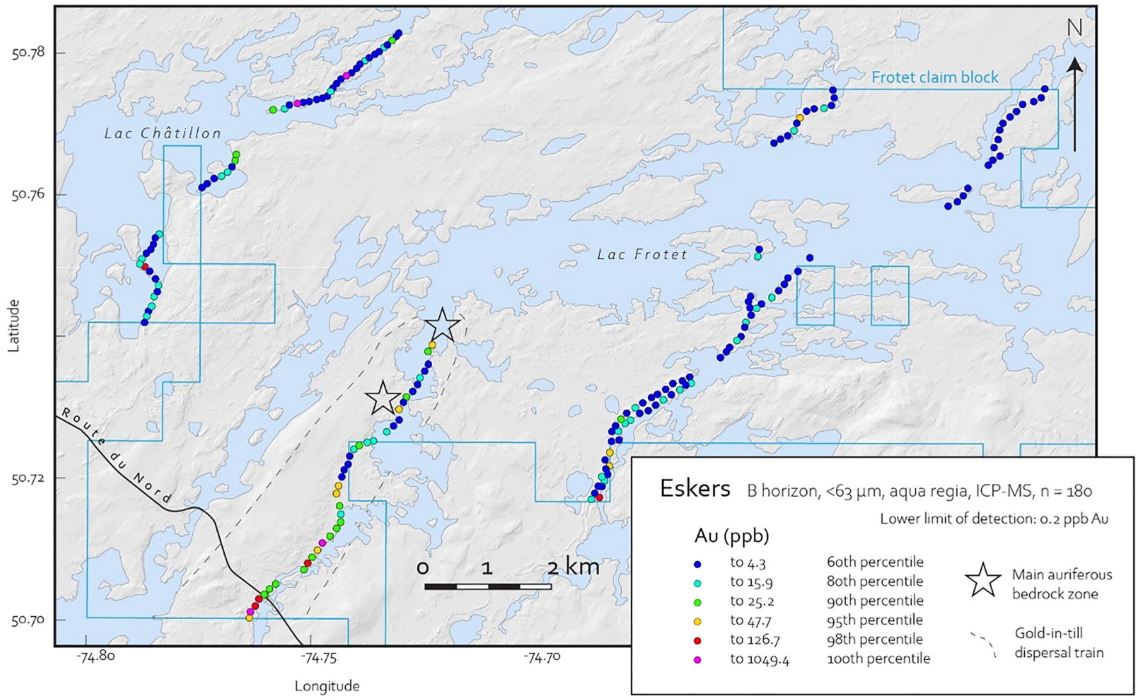

Fig. 11. Gold in eskers at Regnault. Note the coherent dispersal train that starts several kilometres downflow of the head of the gold-in-till dispersal train and auriferous bedrock and continues SW (downflow) to the edge of the exploration property. Background is a hillshaded digital elevation model made from light detection and ranging data.

Ashing volatizes organic compounds, leaving behind inorganic residue ('ash') that is enriched in most metals (Dunn 2007). Because of this, ashing was routinely performed on lake-sediment samples during the 1970s to raise element concentrations sufficiently above detection limits (e.g. Coker and Nichol 1975) prior to the advent of instrumental neutron activation analysis (INAA) in the 1980s. It is less commonly performed today – for example, gyttja samples collected during government surveys in Canada are typically not ashed (e.g. Bourdeau and Dyer 2023) – the idea presumably being that modern detection limits afforded by ICP-MS are sufficiently low and that the negative side effects of ashing (e.g. volatilization of Hg and partial volatilization of As; Dunn 2007) outweigh the benefits (e.g. concentration of metals). However, ashing has another, rarely mentioned, benefit: it allows samples to be sieved without having to first pulverize them. Dried gyttja samples become hard solid masses that must be broken down in some way prior to

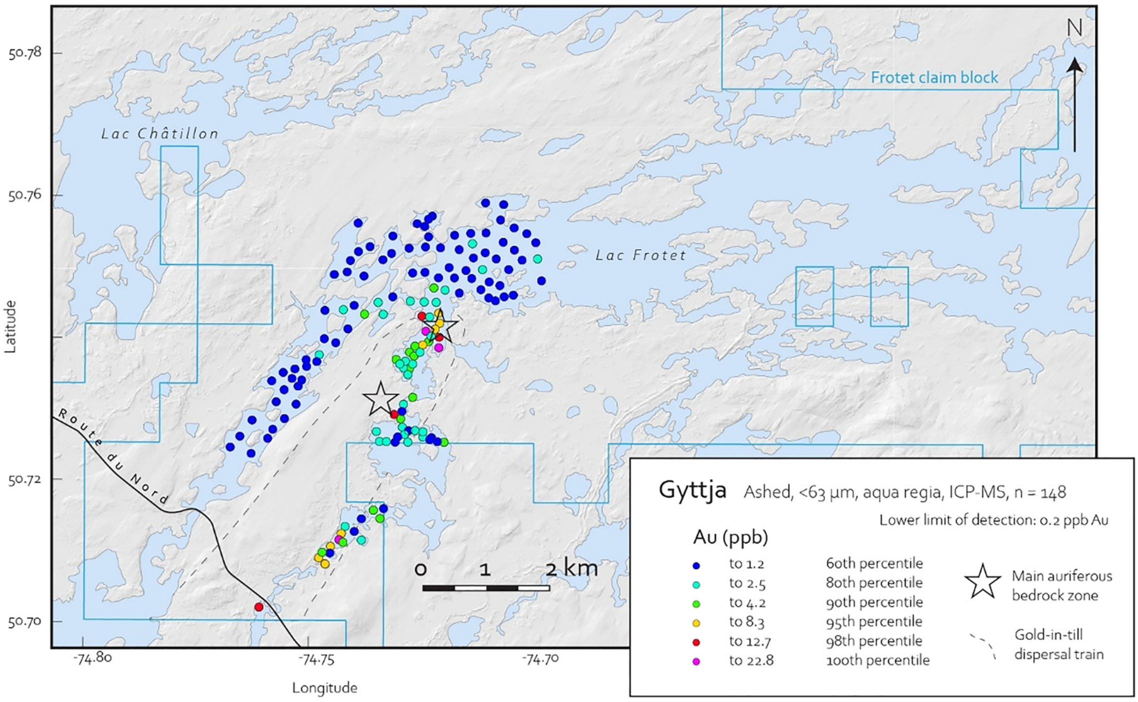

Fig. 12. Gold in gyttja at Regnault. Note the two clusters of anomalous gold values, one over the head of the gold-in-till dispersal train and auriferous bedrock and one 3 km SW of this over the outer edge of the gold-in-till dispersal train. Background is a hillshaded digital elevation model made from light detection and ranging data.

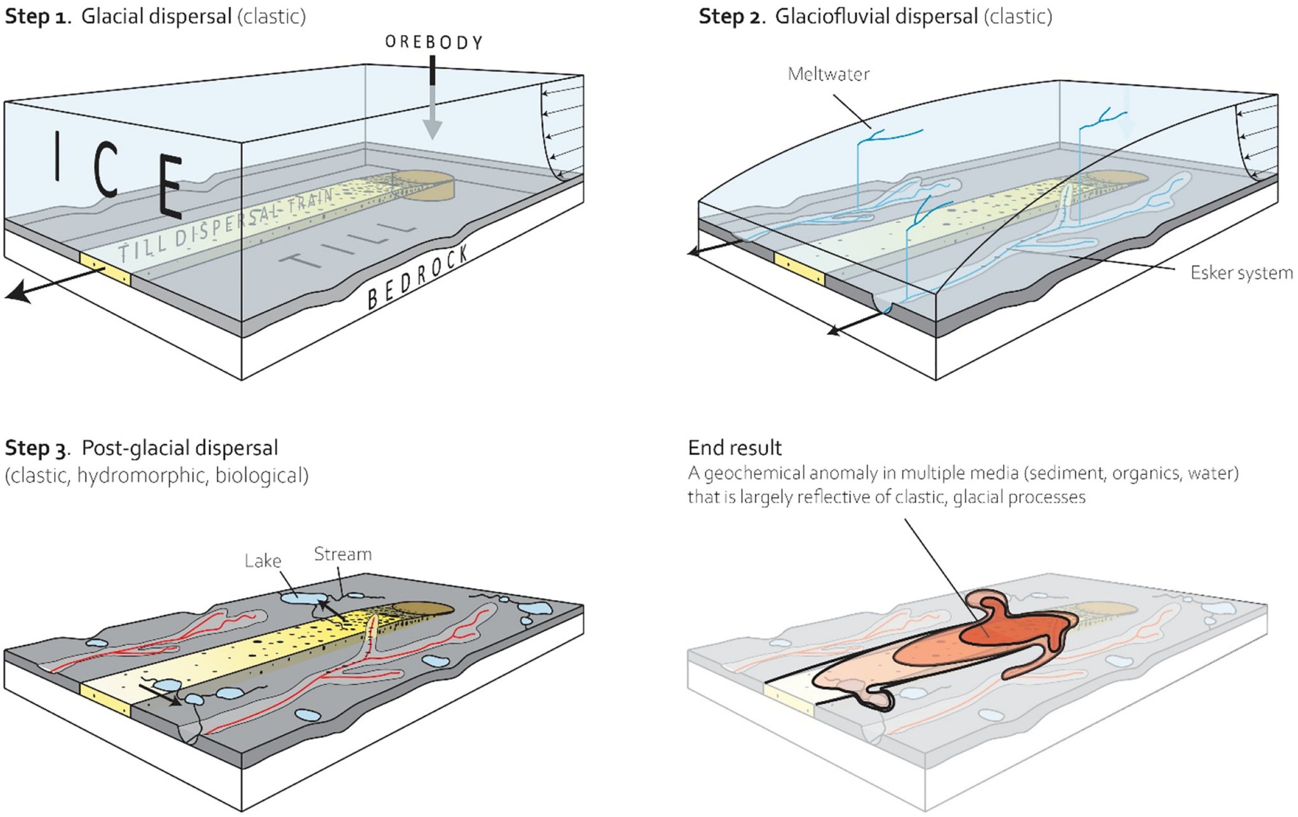

Fig. 13. Conceptual model of how coherent gold dispersal trains formed in till, eskers and gyttja down-ice of the Regnault deposit. Figure is based on results from Regnault study and is informed by previous work (e.g. Ermengen 1957; Cameron 1980, 1994; Coker *et al.* 1982; Fox *et al.* 1985, 1987; Hall *et al.* 1986; Hornbrook 1989; Rogers *et al.* 1990; Dunn *et al.* 1991; Schmitt 1993; Averill 2001; Dunn 2007; Leybourne and Cameron 2010; Cummings *et al.* 2011; Morris 2014; Cummings and Russell 2018).

sieving. Pulverization is usually employed to accomplish this (Bourdeau and Dyer 2023). While this avoids the need to ash, it has the potential to introduce unwanted nuggety material into the fine fraction. In particular, friable metal-rich sand- to gravel-sized Fe–Mn precipitates, which can abound in gyttja (Terasmae 1971; Kerkermeier 2013), could conceivably become comminuted and incorporated into the sieved fraction during pulverization, resulting in a noisy (nuggety) signal. If anything, ashing the Regnault gyttja samples instead of pulverizing them, and sieving them to <63 µm instead of the more standard <177 µm (e.g. Bourdeau and Dyer 2023), will reduce the nugget effect, an important consideration when exploring for a notoriously nuggety substance like gold.

Improved methods stem from continued experimentation. Use of a standardized method to prepare lake-sediment samples for analysis (i.e. oven dry, pulverize, sieve to <177 µm, analyse; Bourdeau and Dyer 2023) has served Canadian governments well, allowing comparison of a large amount of data gathered over multiple decades from multiple regions. This alone is a good argument to continue with the method. However, it is debatable whether it is the best method for all applications, including gold exploration. Continued investigation of alternative methods, such as the one employed at Regnault (oven dry, ash, sieve to <63 µm, analyse), will be beneficial.

How should eskers be sampled during gold exploration and how should esker data be interpreted?

Gold dispersal trains in eskers have been reported at Regnault (this study) and at the Ti-pa-haa-kaa-ning (TPK) gold system in Northwestern Ontario (Morris 2014). On a first order, both have a strong spatial correlation with underlying auriferous till and bedrock. The head of the Regnault gold-in-esker anomaly is displaced downflow by 3 km relative to the gold-in-till anomaly; whether its downflow tail is displaced a similar distance beyond the edge of the till train is unknown. No details have been provided for the TPK train other than that it sparked the discovery. However, if previously published studies of siliciclastic-sediment dispersal in eskers v. till are representative (e.g. Hellaakoski 1931; Gillberg 1968; Bolduc 1992), it is possible that the Regnault and TPK gold-in-esker trains are similar in length to the till trains from which they were sourced but are shifted downflow. Eskers studied to date are not ‘regional dipsticks’ for mineral exploration. They do not provide drastically different information than the underlying till: previously documented dispersal trains of gravel, sand and mud in eskers tend not to overshoot the till dispersal trains from which they were sourced by more than several kilometres (Gillberg 1968; Cummings *et al.* 2011), even if the esker is hundreds of kilometres long (Bilak and Cummings 2021).

So how might this information impact esker sampling and data interpretation? Perhaps the most important takeaway is that esker sediments may potentially be sourced locally, for example within the bounds of the exploration property that is undergoing investigation. Identification of several contiguous ‘hot’ samples in eskers, like in any sampling medium (till, gyttja, etc.), should be seen as key to triggering follow-up work. Isolated hot samples should be treated with scepticism. For <63 µm, aqua regia, ICP-MS analysis of eskers in greenstone belts, ‘anomalous’ gold values in eskers may be slightly greater than those in till: 25 ppb Au defines the edge of the gold-in-esker anomaly at Regnault, whereas 12 ppb defines the edge of the gold-in-till anomaly. Sampling should target esker-ridge crests where possible, not outwash, and grain size (sand, gravel) should always be recorded as it may affect gold content

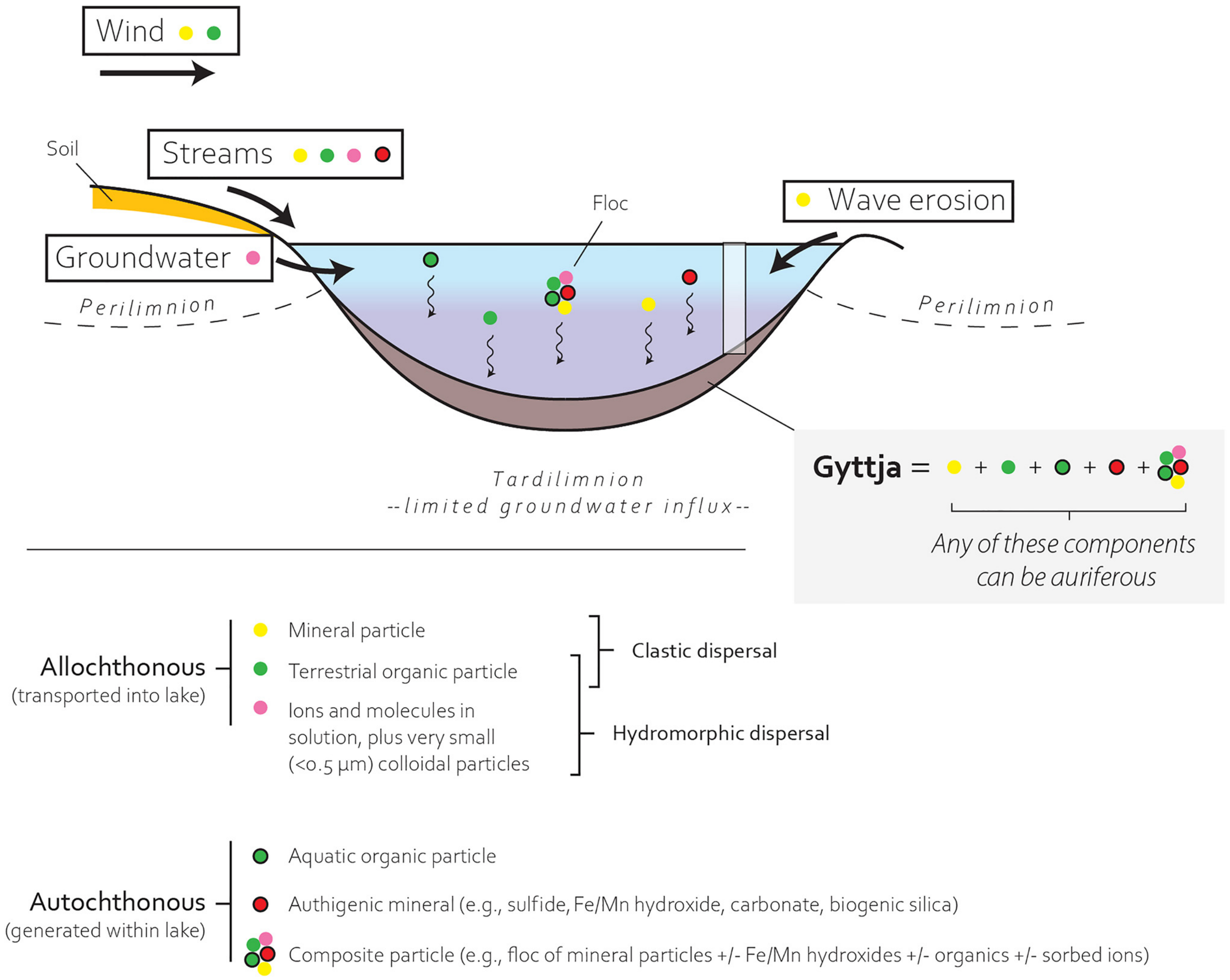

Fig. 14. Potential input pathways for gold and other metals in gyttja (cf. Schmidt 1956; Timperley and Allan 1974; Coker *et al.* 1979, 1982; Ogden 1986; Schmitt 1993; Cameron 1994).

(Averill 2001). For regional work, a down-esker sample spacing of 500 m may suffice; this spacing would have identified up to five anomalous samples along the Regnault esker. Esker sampling can be conducted inside or outside areas of extensive mud cover (e.g. Abitibi Clay Belt) and should provide roughly similar information as the underlying till several kilometres upflow of the sample point so long as esker crests protrude through the mud and are not blanketed by younger till (e.g. Cochrane Till). On exploration properties that are sufficiently large (e.g. >10 km in down-ice direction), one might simply consider integrating esker sampling into till-sampling programmes. Till fences could be extended across eskers using a standard spacing (e.g. 150 m). Additionally, eskers could be sampled in a down-esker direction using a slightly greater spacing of *c.* 300 m (this would have intersected eight ‘hot’ gold samples along the Regnault esker). LiDAR data can be used to vet and reclassify facies. Follow-up work should focus on till from the esker corridor from 0 to 5 km up-glacier of multi-sample gold-in-esker anomalies, using a grid of till samples to search for an upflow cut off.

How should gyttja be sampled during gold exploration, and how should gyttja data be interpreted?

As mentioned above, coherent gold anomalies in gyttja at Regnault and elsewhere are different to anomalies of other metals in gyttja (e.g. Coker *et al.* 1982). They tend to occur in shallow water (e.g. in the perilimnion region *sensu* Ogden (1986)), show a strong spatial correlation with auriferous till and bedrock (Fox *et al.* 1987), and display little correlation with organic content (LOI) or concentration of Fe or Mn hydroxides (Hornbrook 1989). If Regnault proves to be representative, gold may lose connection with its pathfinder elements in gyttja, more so than in till or eskers.

How might this impact gyttja sampling and data interpretation when searching for gold? Because gold anomalies in gyttja are so different from those of other trace elements (Coker *et al.* 1982; Fox *et al.* 1987), standard centre-lake government surveys may have missed many of them. Regional work should target both shallow- and deep-water gyttja and, as argued by Coker *et al.* (1982), and should adopt a relatively tight spacing – a 500 m spacing would have identified one anomalous gold sample at Regnault, whereas a 300 m spacing would have identified up to three contiguous anomalous samples. For property-scale work, as with eskers, gyttja could be integrated by simply extending till-sample fences or grids across lakes, using a similar sample spacing as the till samples (e.g. 150 m). Gold anomalies in gyttja may have a much lower concentration than those in till or eskers, so the gyttja results should be binned separately from the till and esker results before plotting. Follow-up work around gold-in-gyttja anomalies should focus on till from adjacent hillslopes, both up-glacier and down-glacier, in addition to nearby gyttja. LOI and magnetic susceptibility measurements should be performed on each sample as these are simple, crude ways of vetting siliciclastic v. organic content. Each sample should be photographed to ensure that gyttja was collected, not siliciclastic mud or sand.

Summary

Till is, and should remain for the foreseeable future, the primary surficial-sediment sampling target when performing property-scale gold exploration in glaciated terrain. However, the results of the Regnault study question longtime assumptions about whether other, younger media – in this case gyttja and eskers – are necessarily unsuitable for the task. Gyttja and eskers can contain coherent gold dispersal trains that 'vector' local mineralization. Additional case studies are required at other known coherent gold-in-till dispersal trains to determine whether the results of the Regnault study are representative and to further investigate the mechanisms of 'source-to-sink' gold dispersal and partitioning in all media in glaciated landscapes (till, gravel, sand, mud, organic matter and water).

Scientific editing by Scott Wood

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Author contributions **DIC**: conceptualization (supporting), formal analysis (lead), investigation (lead), methodology (lead), writing – original draft (lead), writing – review & editing (lead); **AO**: formal analysis (equal), investigation (equal), writing – review & editing (equal); **FM**: conceptualization (lead), funding acquisition (lead), methodology (equal), resources (lead), writing – review & editing (equal).

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Data availability Data are provided as Supplementary data, Appendices 1 and 2.

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