# The Blackwater gold-spessartine-pyrolusite dispersal train, British Columbia, Canada: Influence of sampling depth on indicator mineralogy and geochemistry

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New Gold Inc. (New Gold), a Canadian mining company with operations in four countries, holds a highly prospective property known as Blackwater in south-central British Columbia, Canada (Fig. 1). This large property contains two significant Au-Ag deposits, Blackwater in the east and Capoose to the west (Fig. 2).

In 2011, New Gold collected 12 samples of alluvial gravel from first- and second-order drainages downslope from the Blackwater deposit and submitted these samples to the Ottawa laboratory of Overburden Drilling Management Limited (ODM) for heavy indicator mineral testing. As expected, the samples yielded only low levels of gold grains because ~90 percent of gold particles are, by nature, only of silt size (Averill 2001) and this hinders their settling to such a degree (Stokes' Law) that they are expelled rather than concentrated by high-energy, gravel transporting streams. However, some samples were found to be distinctly anomalous in another, coarser grained indicator mineral – spessartine – a manganiferous garnet ($Mn_3Al_2(Si0_4)_3$) which occurs in the altered host rocks of both the Blackwater (Simpson *et al.* 2012; Christie *et al.* 2014) and Capoose (Andrew 1988; Awmack *et al.* 2010) deposits.

Based on the positive spessartine response obtained from the gravel, a systematic indicator mineral survey was conducted in 2012 across much of the Blackwater property. Most of the samples collected were of till rather than gravel because till is unsorted and its matrix, though silt–biased, also contains sand grains of all sizes. Therefore samples collected within the mineral dispersal trains of any Blackwater- or Capoose-type mineralized zones on the property would be expected to contain both fine gold and coarse spessartine grains. The program was very successful, with large, strong gold-spessartine dispersal anomalies identified at both deposits along with other indicator mineral anomalies.

The Blackwater and Capoose deposits have only thin till cover but the till in some parts of the property is thick, potentially compromising the effectiveness of surface sampling. Therefore, in 2013, the till in these thickly covered areas was sampled from top to bottom by reverse circulation drilling. As well, four test holes were drilled on the Blackwater gold-spessartine dispersal train to investigate its subsurface mineralogy, geochemistry, and continuity.

The results obtained from the drilling and sampling programs would normally be confidential for an extended period but in recognition of their scientific importance and geochemical significance New Gold has authorized their early publication. Therefore, in this paper, the signature of the Blackwater dispersal train is described in more detail. In particular, it is shown that the mineralogy and geochemistry of the anomalous till samples are dependent to a significant degree on whether the samples were collected at surface or from the drillholes, i.e., whether the sampled till was oxidized or unoxidized.


**Fig. 1.** Location of the Blackwater property.

## PHYSIOGRAPHY AND QUATERNARY GEOLOGY

New Gold's Blackwater property is ~110 km southwest of the town of Vanderhoof (Fig. 1) on Highway 16, the northern Trans-Canada route, from which it is accessed by forest service roads. Physiographically it is located in the hilly terrain of the Nechako Plateau (Fig. 2). This plateau is part of the larger Interior Plateau of the Canadian Cordillera, which lies between the Rocky Mountains to the east and the Coast Mountains to the West (Fig. 1).

The Blackwater Au-Ag deposit lies on the northern slope of Mount Davidson, one of two peaks of the Fawnie Range on the property (Fig. 2). The Capoose deposit lies atop the other peak, Fawnie Nose. The base of Mount Davidson is ~1500 m above sea level. Its peak is at 1800 m and the Blackwater deposit is at 1600 m, well down the slope.

In the Late Pleistocene, the Blackwater area was glaciated repeatedly by the Cordilleran Ice Sheet, which migrated northeastward from the high mountains of the Coast Range. The last glacial event was the Fraser Glaciation from ca. 25,000 to 10,000 years ago (Fig. 3; Clague 1989) during which the ice sheet reached its most easterly limit. The direction of ice flow was

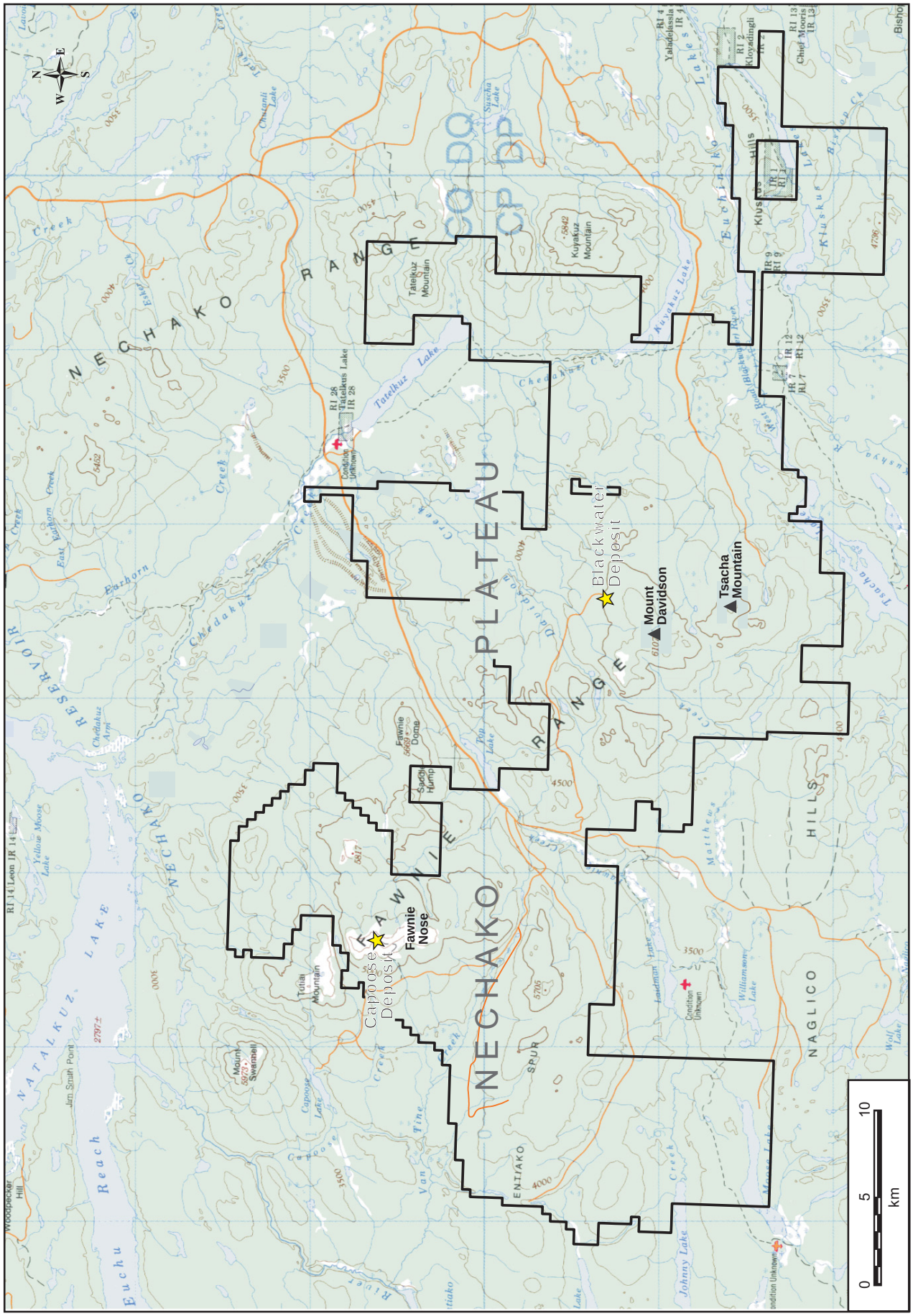


**Fig. 2.** Topography and physiography of the Blackwater property.

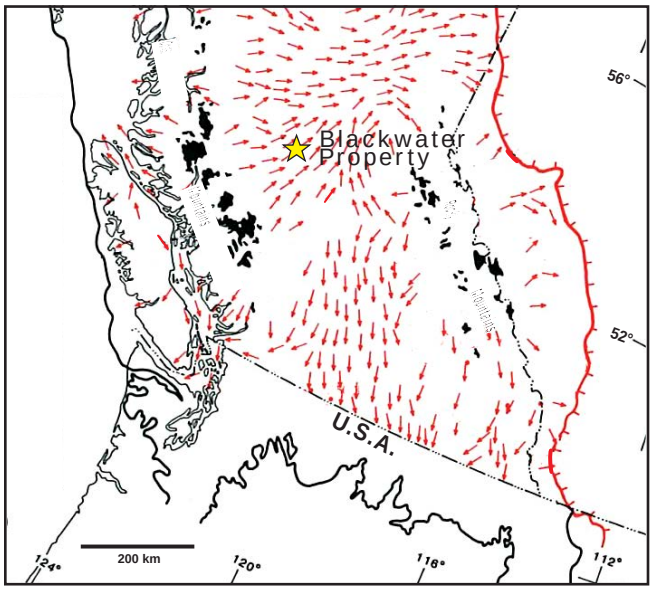


**Fig. 3.** Maximum extent and final flow directions in the Cordilleran Ice Sheet in south-central British Columbia. Modified from Clague (1989).

060°, which is recorded in the orientations of numerous drumlins, particularly in the lee of the mountains (Plouffe *et al.* 2004). Most of the till in the area is related to the Fraser Glaciation but a possibly older till horizon has been identified to the north (Plouffe & Levson 2001). The till is only 2 to 30 m thick over most of the Blackwater deposit (Fig. 4) but thickens rapidly downslope (i.e. glacially down-ice) to as much as 100 m (Fig. 5).

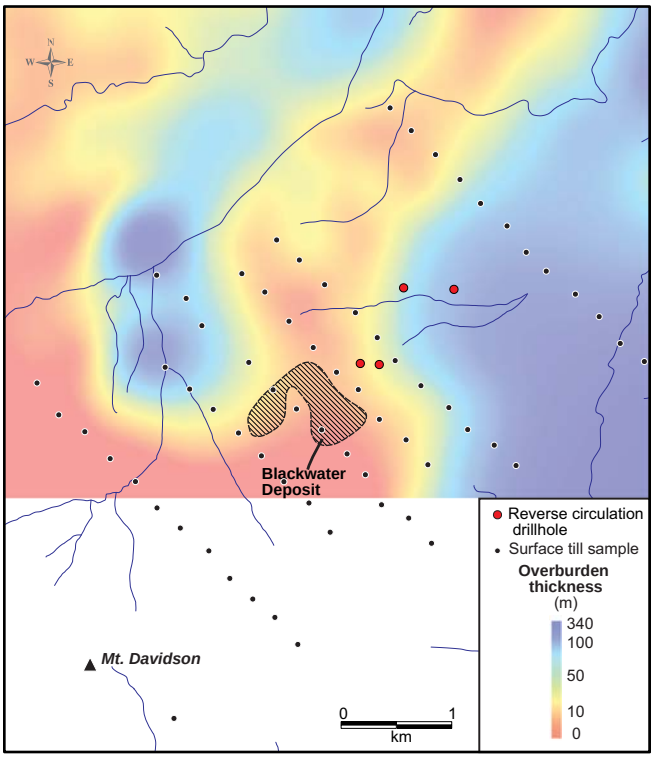


**Fig. 5.** Overburden thicknesses in the vicinity of the Blackwater deposit. Overburden thickness was determined from vertical condemnation holes drilled by New Gold. The locations of the 68 relevant surface till samples and four investigative reverse circulation drillholes are also shown.

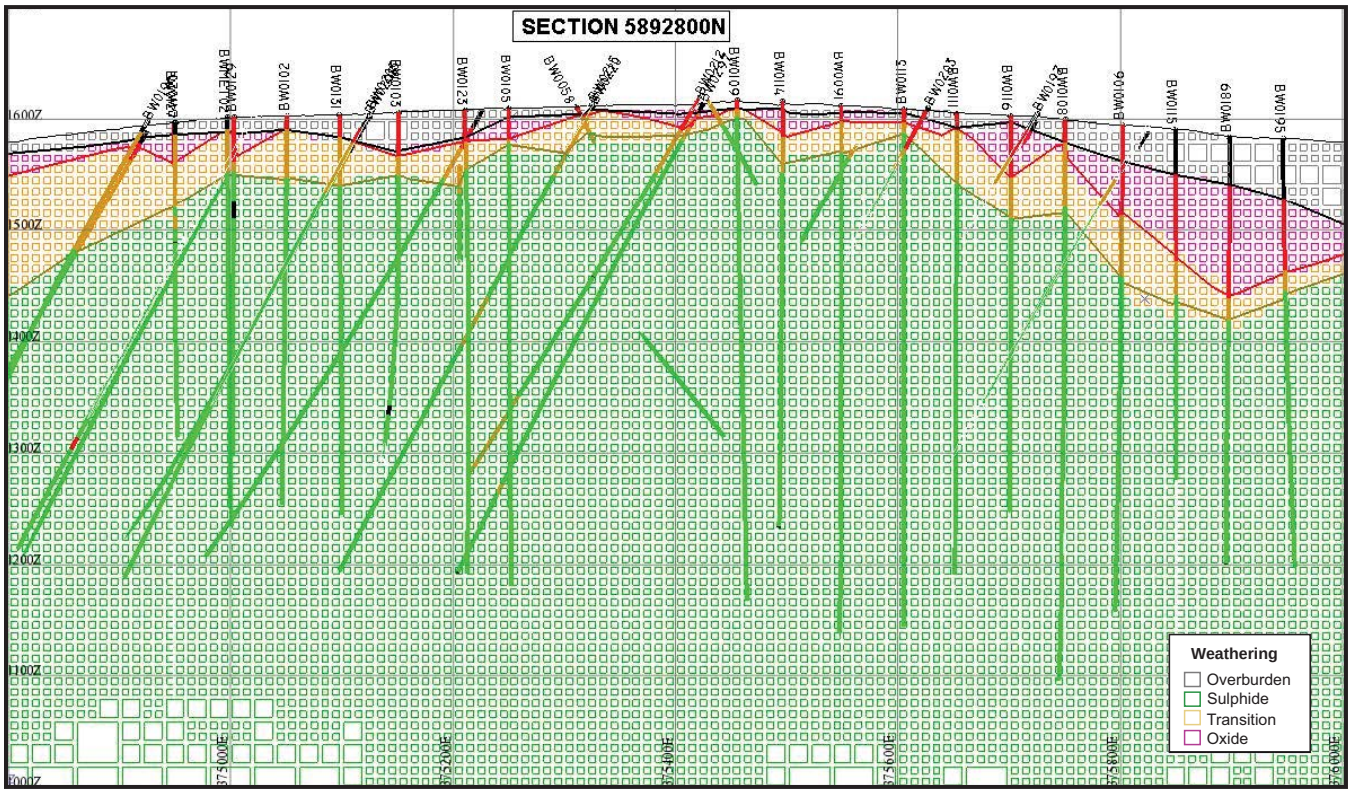


**Fig. 4.** East-west vertical longitudinal section through the Blackwater deposit showing the thickness of glacial till cover and depth of preglacial supergene alteration. Source: Simpson *et al.* (2012).

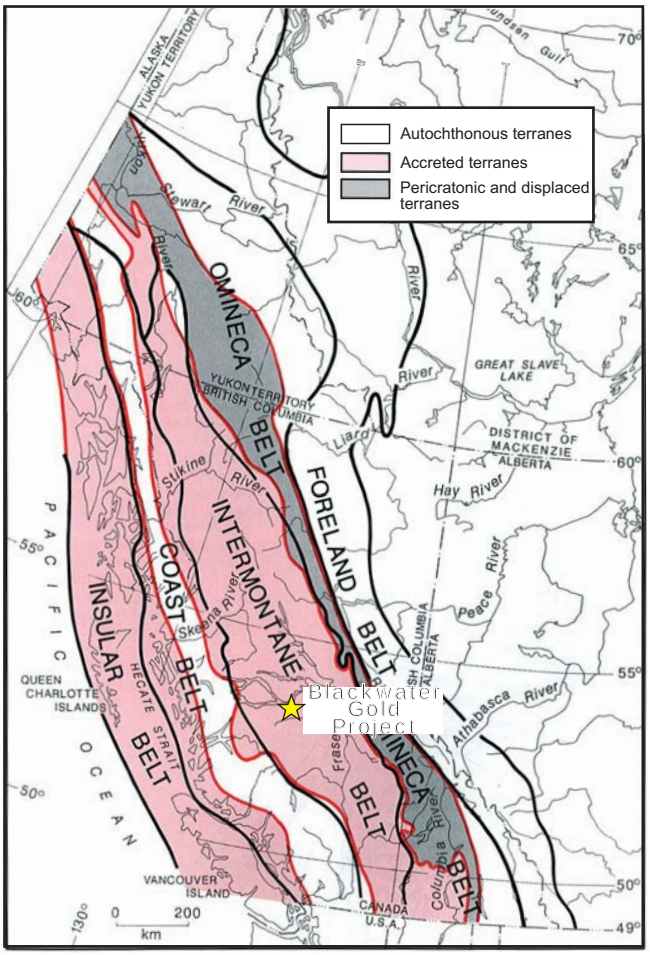


**Fig. 6.** Morphogeological belts and terranes of the Canadian Cordillera. Source: Gabrielse *et al.* (1991).

## GEOLOGICAL SETTING

The Blackwater property is located centrally within the Intermontane Belt of the Western Cordillera (Fig. 6). It covers part of a structurally raised block or horst, the Nechako uplift. Within this uplifted block allochthonous, mainly submarine volcanic rocks of the Middle Jurassic and granitoid plutons of the Late Cretaceous are exposed in windows within a regionally extensive cover of autochthonous, terrestrial, Eocene and Miocene volcanic rocks (Diakow *et al.* 1997).

The Early to Middle Jurassic volcanic rocks were accreted tectonically from the ancestral Pacific Ocean onto the North American protocontinent in the Middle Jurassic (Monger & Price 2002) during construction of the Cordillera (Fig. 6). Diakow *et al.* (1997) assigned them to the bimodal Hazelton Group, which consists of typical island arc rhyolite flows and volcaniclastic sedimentary rocks of the Entiako Formation overlain by submarine basalt flows of the Naglico Formation. The northeastern slope of Mount Davidson, as far west as the Blackwater deposit, is underlain by the Entiako Formation (Fig. 7). On both the western slope and foot of the mountain, these older rocks are largely covered by Eocene andesitic to rhyolitic flows and tuffs of the Ootsa Lake Group.

The Blackwater deposit does not crop out; its geology is known only from drilling. The deposit occurs within and is hosted by an isolated, 2 km wide zone of rhyolitic to andesitic volcanic and volcaniclastic rocks of the Late Cretaceous Kasalka Group (Fig. 7). The Capoose deposit occurs in a similar setting. Regionally, the Kasalka Group is restricted to isolated volcanic centres, mostly at high elevations as at Blackwater and Capoose.

The Kasalka succession at the Blackwater deposit is much disrupted by faulting but primarily consists of massive to brecciated porphyritic andesite overlain successively by massive to laminated rhyodacitic tuff and heterolithic volcaniclastic breccia (Petersen *et al.* 2013). Gold mineralization is present in all lithologies but occurs mainly in the tuff and volcaniclastic breccia in association with sericite-silica alteration and 1–5% pyrite ± sphalerite. The sulphides occur mainly as disseminated grains but locally with quartz in stockwork veins (Looby *et al.* 2013; Petersen *et al.* 2013). The sericitic alteration appears to be superimposed on an earlier potassic hornfels that, in the outboard andesite, is recorded as replacement of primary hornblende phenocrysts by biotite + spessartine garnet ± pyrrhotite (Looby *et al.* 2013). Spessartine, however, also occurs in the sericitic alteration zone (Petersen *et al.* 2013), where it has been observed in quartz-garnet-pyrite veinlets and appears to envelop pyrite grains that contain micron-scale gold inclusions (Looby *et al.* 2013), suggesting a late rather than early paragenesis.

Gold at Blackwater occurs mainly as micron-sized native grains and silver as argentite; visible gold is rare and restricted to quartz-pyrite veins (Petersen 2013). The mineralization has been determined to be epithermal and of the Zn-rich intermediate sulphidation variety (Petersen 2013; Looby *et al.* 2013; Petersen *et al.* 2013) although it is rather atypical of this style of alteration (Looby *et al.* 2013) due to the presence of spessartine garnet, a paucity of As, and the apparent absence of adularia. Recent work by New Gold has established a continuum between the Blackwater mineralization and porphyry-style mineralization on Tsacha Mountain, south of Mount Davidson (Fig. 2; M.A. Petersen, pers. comm. 2015).

## FOOTPRINT OF THE BLACKWATER DEPOSIT

The Blackwater deposit is large with a NI43-101 compliant proven and probable mineral reserve of 8.17 Moz gold and 60.8 Moz silver in 344 Mt grading 0.74 g/t Au and 5.5 g/t Ag (Christie *et al.* 2014). Its subcrop beneath the till, i.e., the area exposed to glaciation, measures ~300 x 1000 m based on a 0.3 g/t Au cut-off (Figs. 5, 7). Therefore, despite its relatively low grade, the deposit and its alteration zone would be expected to be well reflected in the till, both mineralogically and geochemically. Both primary and secondary indicator minerals could be present because 10 to 100 m of the former (preglacial) supergene oxide cap remains over most of the deposit (Fig. 4).

## METHODS

### Sample collection

In the surface sampling program in 2012, samples of till were collected at 300 m intervals on lines oriented northwest-southeast, orthogonal to the northeast ice-flow direction. The locations of the 68 samples collected closest to and/or glacially in line with the Blackwater deposit are shown in Figure 7. The line spacing for these samples varied from 1500 m for the most distal sample sites to 500 m over the deposit, providing coverage at a density of ~2 to 6 samples per km$^2$.

ODM, with assistance from New Gold, collected samples from hand-dug pits at a depth 0.5 to 1 m within the C-horizon

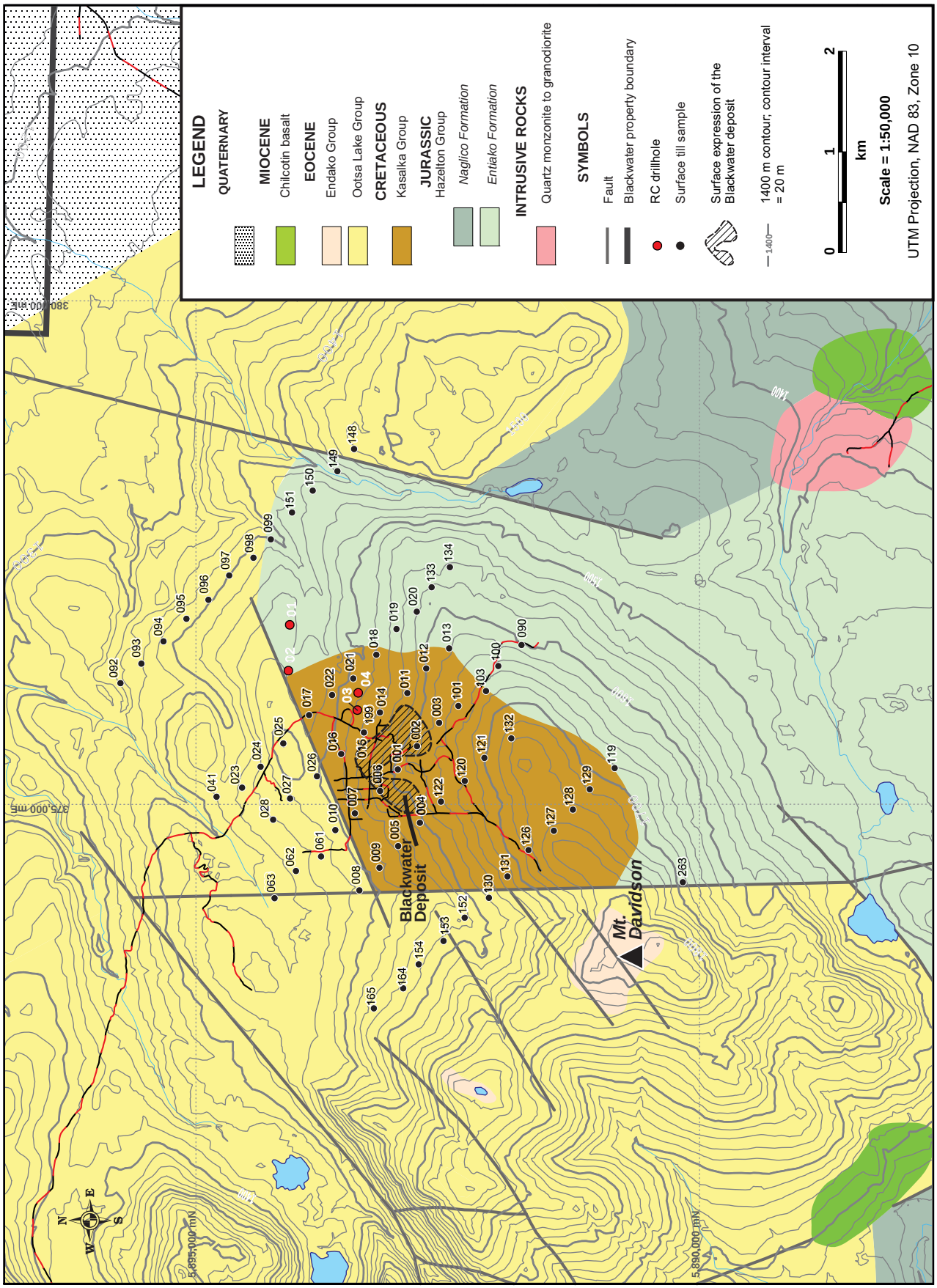


**Fig. 7.** Locations of the surface till samples and reverse circulation drillholes in relation to the underlying rock formations. Bedrock geology modified from Massey *et al.* (2005) and Simpson *et al.* (2012).


**Figure 8.** Typical till sample pit. The sample is normally collected at a depth of 0.5 to 1 m from the C-horizon of the soil profile which is less oxidized than the overlying B-horizon but still depleted of sulphide minerals as illustrated by the extracted heavy mineral concentrate. At this site, which is not on the Blackwater property, duplicate 10 kg samples of sieved till matrix were taken for quality control. Source: ODM archives.

of the soil profile (Fig. 8). The till in the C-horizon is less oxidized than that in the B-horizon but the only sulphide mineral that survives to any degree is chalcopyrite (Averill 2001, 2013a), increasing the dependence of indicator mineral surveys on gold grains and chemically resistant oxide and silicate minerals. The samples were rubbed through an 8 mm sieve to obtain 12 to 13 kg of -8 mm material, sufficient to yield ~10 kg of -2 mm till matrix for indicator mineral processing at the laboratory.

The RC drilling program in 2013 used a rig that was purpose-built for efficient, continuous sampling of unconsolidated surficial sediments of any consistency and bedrock of any hardness. All holes were logged and sampled by ODM. In till sections, 10 kg samples of wet-screened -2 mm material, which includes fine drill cuttings from the till clasts in addition to the matrix of the till, were collected over intervals ranging from 1 m in thin sections to 2 to 3 m in sections over 20 m thick. The till below a depth of 2 to 3 m was found to be unoxidized and thus not depleted in sulphide mineral grains. Seventy-one till samples were obtained from the four holes drilled down-ice from the Blackwater deposit, with Hole 01 abandoned at a depth of 43.5 m without reaching bedrock.

### Sample processing

In ODM's mineral extraction laboratory, the oxidized surface samples were processed to extract (a) the specific gravity (SG) >3.2 heavy mineral fraction for indicator mineral study; and (b) a large, ~30 g subsample of the -0.063 mm silt + clay fraction for geochemical analysis. The heavy mineral concentrates (HMCs) were not analyzed because, with the till being oxidized and depleted of sulphides, they would contain negligible base metals and gold only in the form of liberated grains, most of which were observed during processing and physically measured to determine their Au value.

A second, lower density concentrate of SG 2.8 to 3.2 had been prepared from the 12 gravel samples collected in 2012 to check for possible jarosite dispersal from the supergene zone of the Blackwater deposit because jarosite is a key indicator mineral at the glaciated Pebble porphyry Cu-Au deposit in Alaska (Kelley *et al.* 2011). Only a few jarosite grains were found; therefore, preparation of the low-density concentrates was discontinued.

SG >3.2 HMCs were also prepared from the odd-numbered and bottom samples collected from the drillholes. Since the till at depth was unoxidized and sulphide-bearing, the HMCs rather than the -0.063 mm till fines were analyzed geochemically. Only the -0.25 mm fraction of the concentrates was analyzed; the coarser, 0.25 to 2 mm fraction was reserved for indicator mineral determination.

The HMCs were extracted from the till samples using a well established process involving successive separations by tabling, heavy liquids, magnetism, paramagnetism, and sieving to produce 0.25–0.5 mm, 0.5–1 mm, and 1–2 mm nonferromagnetic heavy mineral fractions with the finest, 0.25–0.5 mm fraction further separated into four subfractions of varying paramagnetic susceptibility to facilitate indicator mineral identification. The gold grains were counted after the first separation (i.e. tabling), then returned to the table concentrate. The gold-grain counts were not normalized because the sample weights were relatively constant.

### Indicator mineral identification

All six nonferromagnetic heavy mineral fractions were thoroughly examined for indicator mineral grains by experienced mineralogists using a binocular microscope with scanning electron microscope (SEM) support to resolve any questionable grains. The number of grains of each indicator mineral in each of the three particle size ranges was either counted or estimated, depending on the number of grains present. For key minerals, either all of the grains or representative populations were put in vials to form an organized grain library. The overall mineralogy of each concentrate was also recorded systematically, mainly to identify any major changes in till provenance that might suggest the presence of more than one till horizon.

### Sample analysis

All geochemical analyses were performed by Actlabs Limited in Ancaster, Ontario. The same analytical methods were used to analyze the -0.063 mm fines from the surface samples and the -0.25 mm HMCs from the drillhole samples. Au and As were determined by instrumental neutron activation (INA) analysis using a large split of the available sample material to ensure that most or all of the gold grains were represented. No pulverizing was required; therefore the gold grains remained intact. Base metals and other potential indicator elements were determined on a small split by inductively coupled plasma (ICP) analysis following aqua regia digestion.

## RESULTS

### Indicator mineralogy of the surface till samples

The surface sampling identified and outlined a strong indicator mineral dispersal train down-ice from the Blackwater deposit (Fig. 9). This dispersal train, hereinafter called the Blackwater train, is defined equally well by gold (Fig. 9A) and spessartine (Fig. 9B) grains although the margins of the spessartine train are more diffuse. The trend of the train is 060°, matching the azimuth of ice flow at the end of the Fraser Glaciation (Fig. 3). The train is ribbon-shaped and ~1300 m wide, or 300 m wider than the 1000 m footprint of the deposit at a 0.3 g/t Au cutoff grade. This suggests that the train reflects both the eco-

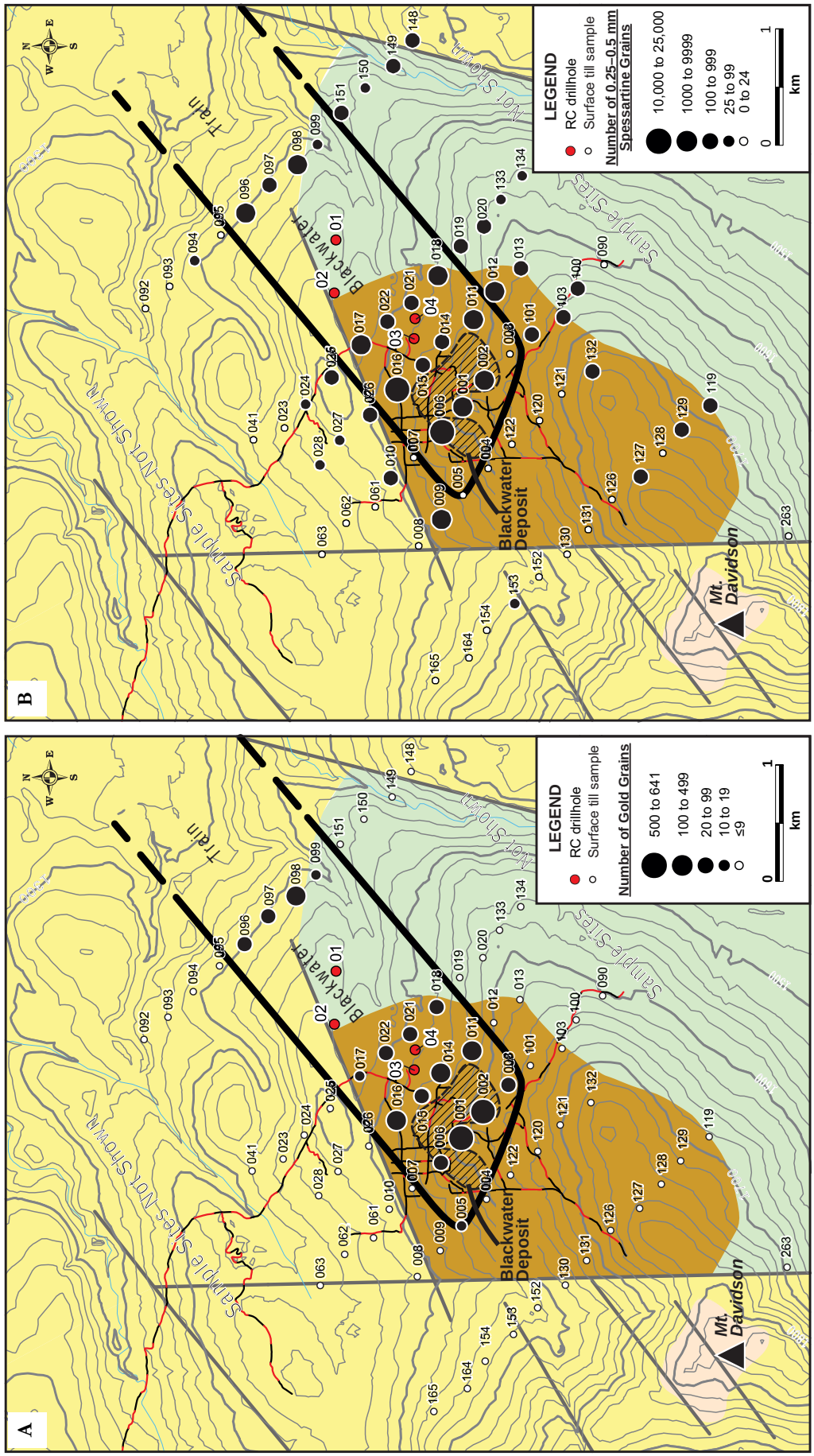


**Fig. 9.** Concentrations of **(A)** gold and **(B)** 0.25–0.5 mm spessartine grains in the surface till samples. See Figure 7 for bedrock lithologies.

**Table 1.** Indicator mineralogy and -0.063 mm geochemistry of the surface till samples collected along the Blackwater train. Only the four central samples on each line across and up-ice from the train are shown.

| Distance Down-Ice from Centre of Deposit (m) | Sample No. | No. of Gold Grains | | | | % Pristine or Modified | No. of Spessartine Grains (0.25–0.5 mm) | Geochemistry of -0.063 mm Fraction | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | ppb | ppm | | | | | | | | % |
| | | Total | Pristine | Modified | Reshaped | | | Au | Ag | As | Cu | Zn | Pb | Cd | Mo | Mn | S |
| -1500 | 152 | 1 | 0 | 0 | 1 | 0 | 15 | < 2 | < 0.2 | 7 | 8 | 50 | 11 | < 0.5 | 3 | 317 | 0.02 |
| | 130 | 4 | 0 | 3 | 1 | 75 | 9 | < 2 | < 0.2 | 15.5 | 13 | 62 | 14 | < 0.5 | 4 | 427 | 0.01 |
| | 131 | 1 | 0 | 0 | 1 | 0 | 8 | < 2 | < 0.2 | 47.1 | 13 | 61 | 9 | < 0.5 | 3 | 372 | 0.05 |
| | 126 | 1 | 0 | 0 | 1 | 0 | 6 | < 2 | < 0.2 | 19.6 | 24 | 78 | 9 | < 0.5 | 2 | 676 | 0.03 |
| -500 | 005 | 10 | 2 | 6 | 2 | 80 | 16 | < 2 | < 0.2 | 7.7 | 6 | 52 | 13 | < 0.5 | < 2 | 234 | 0.01 |
| | 004 | 5 | 3 | 1 | 1 | 80 | 5 | < 2 | < 0.2 | 18 | 20 | 91 | 18 | 0.6 | < 2 | 768 | 0.01 |
| | 122 | 1 | 0 | 0 | 1 | 0 | 0 | 8 | 0.8 | 12 | 18 | 207 | 31 | 1 | 4 | 393 | 0.02 |
| | 120 | 3 | 0 | 0 | 3 | 0 | 13 | < 2 | < 0.2 | 10.5 | 13 | 56 | 7 | < 0.5 | 3 | 474 | 0.01 |
| 0 | 006 | 62 | 20 | 41 | 1 | 98 | 25,000 | 37 | < 0.2 | 32 | 39 | 1620 | 49 | 8.5 | < 2 | 1210 | 0.01 |
| | 001 | 641 | 180 | 446 | 15 | 98 | 2000 | 74 | < 0.2 | 26.1 | 25 | 266 | 71 | 1.4 | < 2 | 676 | 0.01 |
| | 002 | 561 | 287 | 257 | 17 | 97 | 1000 | 42 | < 0.2 | 31.4 | 18 | 118 | 47 | 1 | < 2 | 506 | 0.01 |
| | 003 | 23 | 3 | 17 | 3 | 87 | 3 | 11 | < 0.2 | 21.6 | 11 | 95 | 10 | 0.6 | < 2 | 547 | 0.01 |
| +500 | 016 | 119 | 29 | 78 | 12 | 90 | 12,000 | 34 | 1.5 | 57.8 | 7 | 761 | 70 | 0.9 | < 2 | 612 | 0.01 |
| | **015** | 26 | 8 | 18 | 0 | 100 | 800 | < 2 | < 0.2 | 12.8 | 24 | 125 | 17 | 0.6 | < 2 | 1140 | 0 |
| | 014 | 151 | 68 | 78 | 5 | 97 | 500 | 19 | < 0.2 | 11.7 | 10 | 120 | 26 | 0.6 | < 2 | 475 | 0.01 |
| | 011 | 214 | 148 | 66 | 0 | 100 | 2500 | 14 | < 0.2 | 24.9 | 18 | 208 | 66 | 2.7 | < 2 | 1020 | 0 |
| +1000 | 017 | 11 | 6 | 5 | 0 | 100 | 1500 | < 2 | 0.6 | 9.5 | 5 | 158 | 79 | 0.5 | 2 | 195 | 0.01 |
| | 022 | 23 | 6 | 17 | 0 | 100 | 250 | 15 | 0.7 | 14.3 | 8 | 123 | 32 | < 0.5 | < 2 | 395 | 0.02 |
| | 021 | 44 | 17 | 25 | 2 | 95 | 400 | 13 | 0.2 | 8.8 | 9 | 133 | 20 | 0.6 | < 2 | 326 | 0.01 |
| | 018 | 58 | 21 | 35 | 2 | 97 | 1200 | 36 | 0.3 | 7.5 | 8 | 101 | 45 | 0.6 | < 2 | 325 | 0.01 |
| +2500 | 096 | 32 | 0 | 16 | 16 | 50 | 2500 | < 2 | 0.3 | 9.4 | 12 | 70 | 21 | < 0.5 | < 2 | 266 | 0.01 |
| | 097 | 28 | 0 | 12 | 16 | 43 | 800 | 7 | 0.3 | 9 | 12 | 115 | 25 | < 0.5 | 3 | 270 | 0.01 |
| | 098 | 162 | 19 | 82 | 61 | 62 | 2000 | 9 | 0.3 | 6.8 | 12 | 100 | 45 | < 0.5 | 2 | 300 | 0.01 |
| | 099 | 14 | 0 | 2 | 12 | 14 | 18 | 7 | 0.4 | 5.6 | 18 | 72 | 8 | 0.5 | 3 | 373 | 0.01 |

nomic core and lower grade margins of the deposit.

Sixteen samples were collected within the main part of the Blackwater train, four on each of four lines across the train (Fig. 9A). Of these, twelve were collected from 0 to 1000 m down-ice from the centre of the mineralized zone and the other four were collected 2500 m down-ice. All sixteen yielded significantly anomalous levels of gold grains, with the counts ranging from 10 to 641 grains per sample (Fig. 9A, Table 1). In contrast, the samples collected alongside and up-ice from the train consistently yielded <10 and mostly 0 to 5 grains, with the exception of sample No. 005 which was collected on the alteration envelope 500 m up-ice from the centre of the mineralized zone and yielded 10 gold grains. The four most distal samples on the dispersal train, on the line 2500 m down-ice from the deposit, still yielded from 14 to 162 grains (Table 1), suggesting that the total detectable length of the train is at least 3 km.

Approximately 90% of the recovered grains were silt-sized (Fig. 10) as expected because (a) most gold grains crystallize at this size in bedrock; and (b) the grains retain their sizes during glacial transport due to their malleability; i.e., they are deformed, not comminuted during transport (Averill 2001, 2013b). This is readily seen in Figure 10 where the gold grains in the most distal gold-rich sample, No. 098, which was collected 2500 km down-ice, have the same particle-size distribution as two gold-rich samples collected close to (sample No. 011) or directly over (sample No. 001) the deposit.

In the twelve samples collected within 1000 m of the deposit, 95 to 100% of the gold grains are either pristine or only partly modified (Table 1). In contrast, only 14 to 62% of the gold grains in the four distal samples, which were collected 2500 m down-ice, are of these morphologies. The rest are fully reshaped, reflecting the progressive grain modification that occurs with increasing transport distance (Averill 2001).

Three of the seventeen auriferous samples that define the Blackwater train (Fig. 9A), samples 003 and 005, which are beyond the economic limits of the mineralized zone, and sample No. 099, collected on the distal line, 2500 m down-ice, were not significantly anomalous in spessartine (Fig. 9B), yielding only 3 to 25 grains of 0.25–0.5 mm size (Table 1), which is only marginally above the regional spessartine background of 0 grains. The other fourteen samples yielded from 250 to 25,000 grains, with the highest counts being closest to the deposit. Due to the much higher concentration of spessartine grains than gold grains in the Blackwater train, the train should be detectable for a considerably greater distance using spessartine, possibly as far as 10 km down-ice from the Blackwater deposit.

While the highest spessartine concentrations occur within the limits of the gold dispersal train, significantly anomalous responses were obtained up to 1 km outboard on either side of the gold train and 1.5 km further up-ice on the southeastern side (Fig. 9B). The distribution of the outlying anomalous sam-

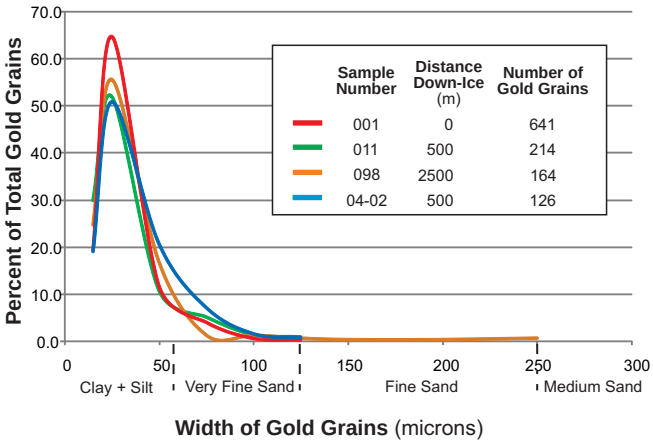


**Fig. 10.** Gold particle-size distribution in three oxidized, gold-rich surface till samples and in an unoxidized till sample from reverse circulation drillhole No. 04.

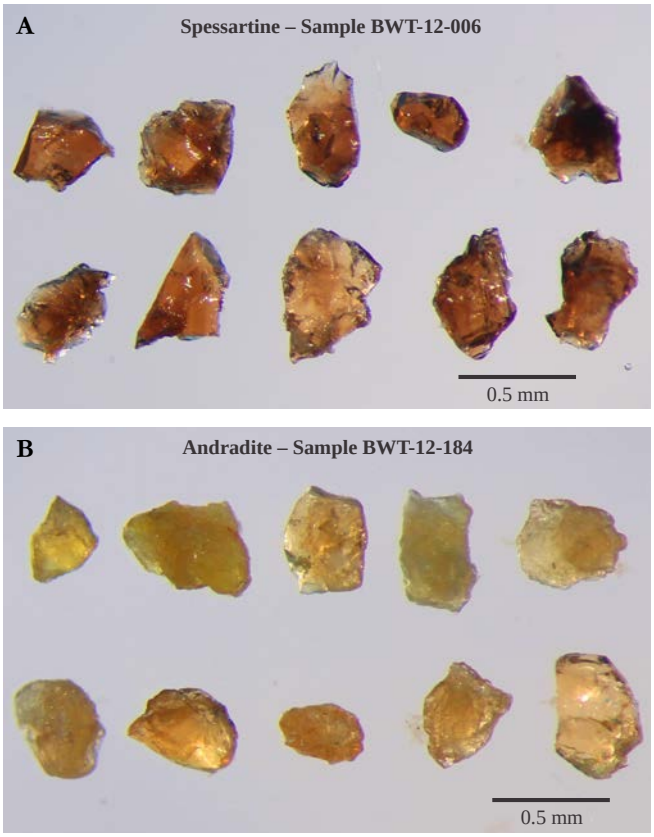


**Fig. 11.** Binocular microscope photographs of representative **(A)** spessartine and **(B)** andradite garnet grains from selected till samples.

ples relative to the Kasalka Group volcanic rocks suggests that all of the spessartine is derived from these rocks and thus that additional zones of spessartine alteration occur beyond the immediate alteration envelope of the Blackwater deposit.

The spessartine occurs as rather bland orange-brown grains (Fig. 11A) rather than as euhedral crystals, reflecting the relatively low temperatures and pressures of the near-surface environment in which it crystallized. Despite their blandness, the spessartine grains are readily recognizable in most of the HMCs due to an absence of almandine garnet, which reflects the essentially unmetamorphosed condition of even the oldest, Early Jurassic volcanic rocks in the Blackwater district. On some parts of the property, however, another variety of garnet, andradite, is very abundant in the till. This andradite is also a key indicator mineral, being derived from either skarns (Dawson & Kirkham 1996) or the propylitic alteration zones of porphyry Cu deposits (Averill 2011). Therefore it is critical that the spessartine and andradite grains in the till be differentiated. The only significant difference is that the andradite grains are of a slightly paler yellow-brown colour (Fig. 11B). Andradite occurs at much lower concentrations than spessartine in the study area, impeding its recognition, and it is probable that some grains were misclassified as spessartine.

### Geochemistry of the -0.063 mm fraction of the surface till samples

The Au, Ag, As, Cu, Zn, Pb, Cd, Mo, Mn, and S analyses obtained from the -0.063 mm fines of the 24 surface till samples collected within and directly up-ice from the gold grain dispersal train (Fig. 9A) are presented in Table 1. The Blackwater deposit contains three main metals, of which two, Au and Zn, are the most strongly anomalous elements in the dispersal train. They were detected in all samples collected within 1000 m of the deposit. The third metal, Ag, is not anomalous in the till, probably because in the mineralized zone it occurs mainly as argentite (Petersen *et al.* 2013), a sulphide mineral ($Ag_2S$), and the sampled till was oxidized and sulphide minerals were depleted. The oxidation is also reflected in very low-S analyses of 0–0.05%. The till samples that were collected no more than 1000 m down-ice from the centre of the deposit are also weakly anomalous in Pb, and those collected within 500 m are weakly anomalous in As, Cd, and Mn but not in Cu or Mo. The elevated Mn probably reflects the high concentration of spessartine garnet in the till.

The Au and Zn geochemical anomalies are shown in Figure 12A and 12B, respectively. Although both elements are anomalous for 1000 m down-ice from the centre of the Blackwater deposit, the highest Au response — directly over the deposit — is just 74 ppb, and the highest Zn response — also directly over mineralization — is 1620 ppm. The frequency of gold grains in the anomalous samples is sufficient (Fig. 9A, Table 1) for one or more grains to be present in the ~30 g aliquot of -0.063 mm fines that was analyzed, especially as most of the grains were also finer than 0.063 mm (Fig. 10). Therefore most and probably all of the Au anomalies were caused by this particulate gold rather than by Au chemically adsorbed by clay minerals or limonite. However, an outlying, 39 ppb Au anomaly obtained from sample 154, collected west of the Blackwater deposit, may be due to adsorbed Au because no gold grains were observed in this sample.

### Till stratigraphy of the reverse circulation drillholes

Two RC drill holes were originally planned along the axis of the Blackwater train to investigate the train at depth: a proximal hole ~600 m down-ice from the centre of the gold deposit and a more distal hole ~1700 m down-ice. However, the original distal hole, Hole 01, was abandoned in till at 43.5 m due to drilling issues and a 70.4 m replacement hole, Hole 02, was drilled further west off the axis of the train. In addition the planned proximal hole, Hole 03, encountered only 1.6 m of till and was replaced by a 40 m hole to the east, Hole 04.

A longitudinal section of the Blackwater train from the gold deposit northeastward through Hole 04 to Hole 02 is shown in Figure 13. The overburden forms a distinct wedge; its thickness increases rapidly downslope to the northeast along the Blackwater train, from <5 m thick over the Blackwater deposit to 70.4 m at Hole 02, ~1300 m down-ice. Nevertheless it consists entirely of till and this till is of a relatively uniform texture and composition, suggesting that it was all deposited during the Fraser Glaciation.

The depth of oxidation in the three deep drillholes varies from 1.8 to 5.0 m. Below this depth the till is as fresh as when it was deposited ~10,000 years ago, although it contains some highly oxidized clasts derived from preglacially saprolitized bedrock. It typically consists of 20 to 40% pebble- to boulder-size clasts in a matrix dominated by silty to sandy rock flour but locally by clay. This clay is grey-brown and is probably derived from organic-rich glaciolacustrine sediments of the same colour that were intersected within the till on the western part of the property. The clast lithologies indicate a mostly local provenance; 90 to 100% are volcanic and <10% are granitoid,

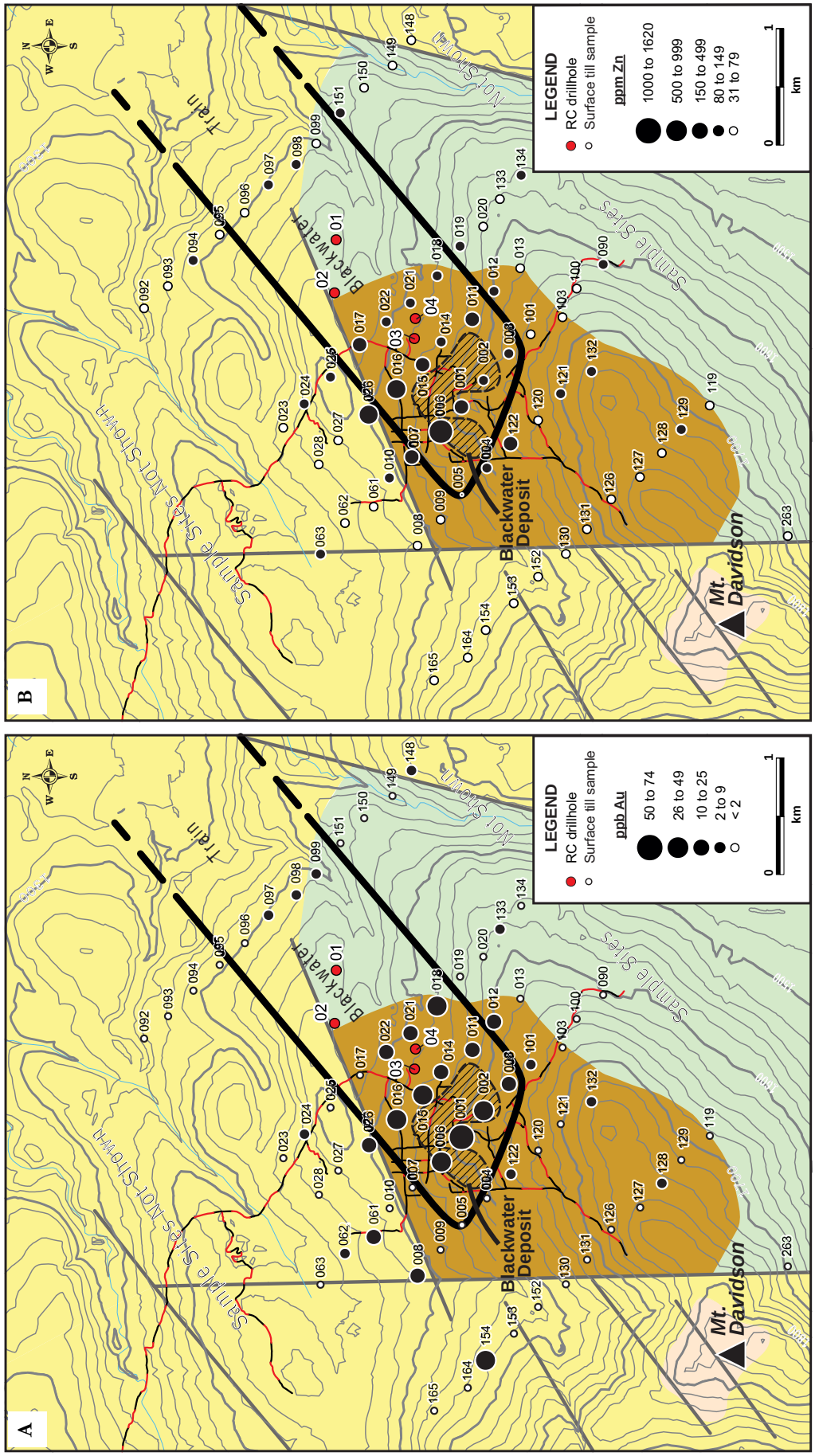


**Fig. 12. (A)** Au and **(B)** Zn analyses for the -0.063 mm fraction of surface till samples. See Figure 7 for bedrock lithologies.

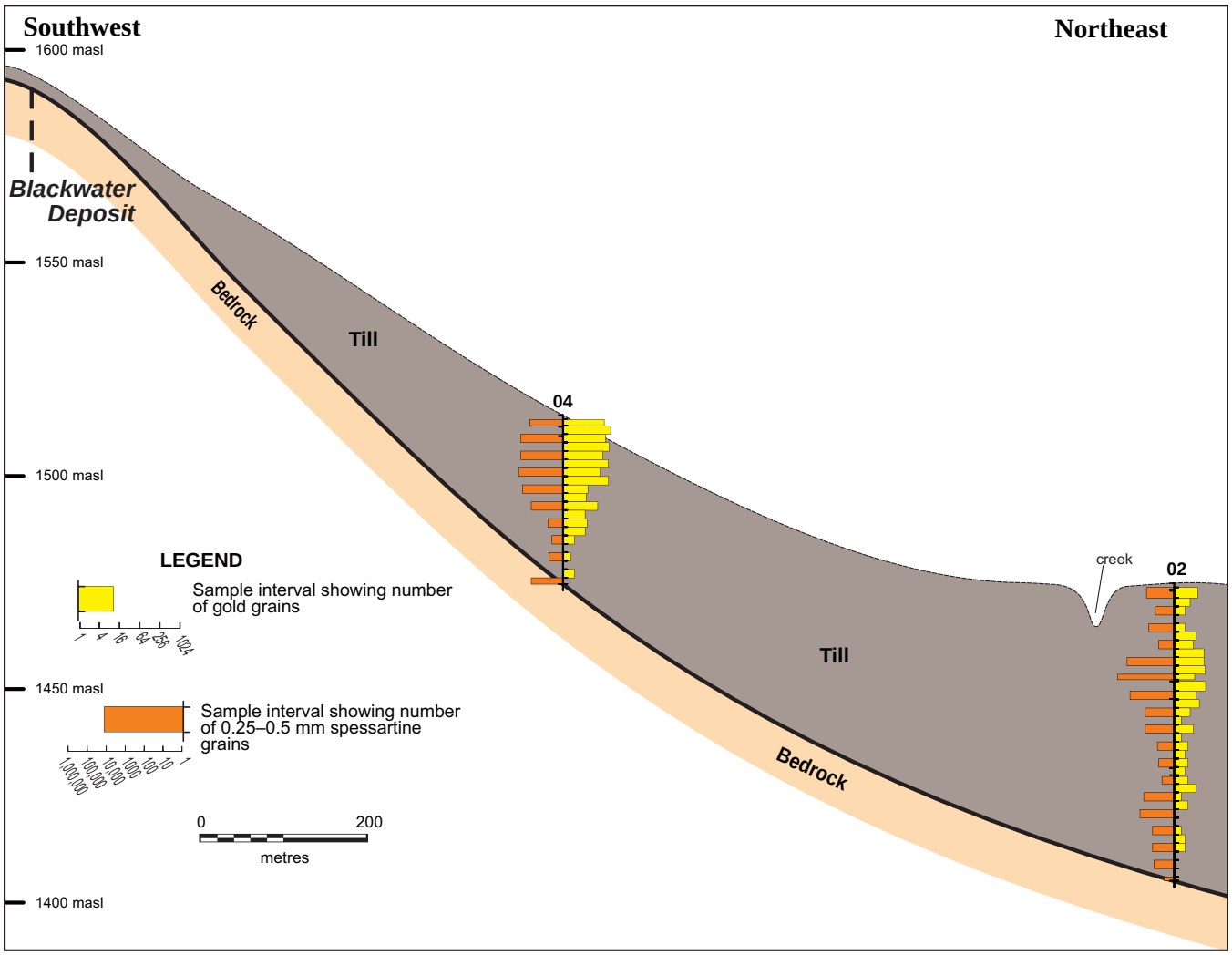


**Fig. 13.** Longitudinal section of the Blackwater train through reverse circulation drillholes No. 04 and 02.

even though a large pluton, the Laidman Batholith, is present just 10 km up-ice.

### Indicator mineralogy of the till sections

Twenty samples were collected from the 40 m thick till section in the deposit-proximal drillhole, Hole 04. The top eleven samples, spanning 22.5 m, were all found to be anomalous, yielding from 10 to 126 gold grains, with an average of 68 grains (Fig. 13, Table 2). The next three samples, spanning 6 m, yielded nearly anomalous to weakly anomalous levels of 9 to 11 grains per sample, giving the gold dispersal train a remarkable total thickness of 28.5 m. The last six samples, spanning 11.5 m between the dispersal train and bedrock, yielded only background levels of 0 to 3 grains per sample. In neighbouring Hole 01, the single till sample obtained from the thin, 1.6 m till section yielded 32 gold grains.

Thirty-five samples were collected from the 70.4 m thick till section in Hole 02. The gold grain results obtained from this hole (Fig. 13) are similar to but weaker than those from Hole 04 because Hole 02 was drilled ~800 m further down-ice and off the axis of the dispersal train. As well, the nearest surface samples, Nos. 017 and 022 (Fig. 9A), yielded just 11 and 23 gold grains (Table 1).

In the drillhole, the main part of the gold dispersal train occurs in a 12 m interval between 17.5 and 29.5 m although the top sample in the hole, between 1.0 and 3.5 m, yielded 11 gold grains, supporting the weak surface anomaly (Fig. 9A). In the main anomalous zone (Fig. 13), seven successive samples yielded from 8 to 25 gold grains, averaging 17 grains. As in Hole 04, the anomalous zone is followed by a zone of elevated but sub-anomalous gold grain concentrations, then a thick zone directly above bedrock — in this case 14.9 m — of only background levels of 0 to 3 grains per sample. The gold grain response obtained from neighbouring Hole 01 was similar; it is not shown in Figure 13 because the hole was not completed to bedrock.

In the thick, unoxidized portion of the Blackwater train at depth, as in the thin, oxidized zone at surface, ~90% of the gold grains are silt sized (Fig. 10). Also as in the surface samples (Table 1), the proportion of pristine to modified grains is high in the proximal part of the train (Table 2) and lower in the distal part. Interestingly, however, the proportion of pristine to modified grains appears to decrease in the upper part of the train. In the top four anomalous samples collected from the train in Hole 04, for example, only 69 to 85% of the gold grains are pristine to modified, compared to 86 to 100% (mostly >90%) in the bottom seven samples (Table 2). This

**Table 2.** Indicator mineralogy and HMC geochemistry of the till samples from reverse cirvulation drillhole No. 04 proximal to the Blackwater deposit. Only the odd-numbered and bottom samples from the hole were tested for indicator minerals.

| Sample No. | End Depth (m) | No. of Gold Grains | | | | % Pristine or Modified | No. of 0.25–0.5 mm Mineral Grains | | | Geochemistry of the HMCs | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | ppb | ppm | | | | | | | | % |
| | | Total | Pristine | Modified | Reshaped | | Spessartine | Pyrolusite | Pyrite | Au | Ag | As | Cu | Zn | Pb | Cd | Mo | Mn | S |
| 04-01 | 2.5 | 65 | 23 | 22 | 20 | 69 | 400 | 0 | 0 | 2350 | 2.6 | 152 | 34 | 128 | 212 | 3 | 1.4 | 896 | 0.02 |
| 04-02 | 4.5 | 126 | 49 | 48 | 29 | 77 | | | | 11300 | 11.1 | 328 | 45 | 493 | 1150 | 4 | 5.5 | 12000 | 0.05 |
| 04-03 | 6.5 | 75 | 28 | 35 | 12 | 84 | 2,000 | 1,500 | 0 | 1870 | 19.4 | 863 | 119 | 3530 | 2280 | 6 | 17.3 | 14200 | 0.19 |
| 04-04 | 8.5 | 106 | 45 | 45 | 16 | 85 | | | | 725 | 17.2 | 856 | 122 | 1650 | 1980 | 9 | 15.5 | 20000 | 0.05 |
| 04-05 | 10.5 | 55 | 28 | 23 | 4 | 93 | 2,000 | 1,500 | 0 | 364 | 9.9 | 297 | 44 | 620 | 717 | 5 | 5.1 | 9940 | 0.01 |
| 04-06 | 12.5 | 97 | 56 | 35 | 6 | 94 | | | | 1330 | 40.7 | 418 | 86 | 915 | 2200 | 8 | 11.9 | 19500 | 0.02 |
| 04-07 | 14.5 | 42 | 24 | 16 | 2 | 95 | 3,000 | 6,000 | 30 | 420 | 19.1 | 614 | 74 | 1110 | 1350 | 7 | 17.1 | 18700 | 0.1 |
| 04-08 | 16.5 | 99 | 41 | 44 | 14 | 86 | | | | 613 | 17.7 | 311 | 51 | 879 | 863 | 5 | 11.9 | 13700 | 0.01 |
| 04-09 | 18.5 | 12 | 7 | 5 | 0 | 100 | 1,500 | 2,000 | 0 | 84 | 3.7 | 140 | 31 | 448 | 262 | 3 | 2.1 | 7640 | 0.14 |
| 04-10 | 20.5 | 10 | 3 | 6 | 1 | 90 | | | | 207 | 69.5 | 536 | 120 | 2260 | 1810 | 12 | 13.6 | 34500 | 0.01 |
| 04-11 | 22.5 | 33 | 25 | 7 | 1 | 97 | 300 | 60,000 | 15 | 1040 | 56 | 668 | 92 | 1920 | 1720 | 7 | 11.4 | 32000 | 0.02 |
| 04-12 | 24.5 | 9 | 4 | 4 | 1 | 89 | | | | 221 | 8.5 | 126 | 56 | 408 | 949 | 4 | 2.8 | 12400 | <0.01 |
| 04-13 | 26.5 | 11 | 5 | 4 | 2 | 82 | 15 | 5,000 | 20 | 288 | 16.9 | 119 | 67 | 985 | 974 | 5 | 7.3 | 18200 | 0.03 |
| 04-14 | 28.5 | 9 | 2 | 3 | 4 | 56 | | | | 495 | 10.4 | 92 | 43 | 427 | 494 | 6 | 3.4 | 10500 | <0.01 |
| 04-15 | 30.5 | 3 | 1 | 2 | 0 | 100 | 7 | 800 | 1 | 90 | 2.7 | 98 | 55 | 197 | 303 | 9 | 1.6 | 6000 | <0.01 |
| 04-16 | 32.5 | 1 | 1 | 0 | 0 | 100 | | | | <5 | 0.5 | 53 | 55 | 140 | 121 | 7 | 1.3 | 4580 | <0.01 |
| 04-17 | 34.5 | 2 | 1 | 1 | 0 | 100 | 12 | 300 | 0 | 105 | 1.4 | 83 | 82 | 147 | 247 | 9 | 1.7 | 12300 | <0.01 |
| 04-18 | 36.5 | 1 | 1 | 0 | 0 | 100 | | | | 478 | 2.9 | 125 | 102 | 197 | 285 | 11 | 2.5 | 20000 | 0.06 |
| 04-19 | 38.5 | 3 | 1 | 2 | 0 | 100 | 1 | 40 | 0 | 56 | 3.7 | 72 | 61 | 180 | 112 | 5 | 1 | 10900 | <0.01 |
| 04-20 | 40.0 | 0 | 0 | 0 | 0 | 0 | 300 | 1,500 | 0 | 144 | 6.1 | 114 | 67 | 306 | 326 | 7 | 3.8 | 12400 | <0.01 |

suggests that the till in the upper part of the dispersal train has a longer transport history, i.e., it was transported the same horizontal distance as the till in the lower part of the train but a greater vertical distance and in a longer period of time with the result that the gold grains are physically more mature. Another interesting feature is that in the thick, underlying zone, which has only background levels of 0 to 3 gold grains, 100% of the grains are pristine to modified rather than reshaped, suggesting that they too are related to the Blackwater deposit rather than to distal gold sources.

As previously noted, the concentration of spessartine and other potential indicator minerals other than gold was determined only for the odd-numbered and bottom samples collected from the till section in each drillhole. Spessartine levels in the unoxidized zone of the gold dispersal train at depth (Fig. 13, Table 2) mirror those of the oxidized zone at surface (Fig. 9B, Table 1). Most of the anomalous samples yielded >1000 grains of 0.25 to 0.5 mm size versus a background to slightly elevated concentration of 0 to 20 grains. The strongest response was 30,000 grains, mirroring the 25,000-grain peak in the surface samples. Spessartine levels in the train are not only much higher than gold grain levels, but also appear to decrease more slowly down-ice (Fig. 13). Therefore, in the subsurface as at surface, the Blackwater train should be detectable much further down-ice with spessartine grains than with gold grains.

While the Blackwater train in the subsurface is hosted by unoxidized till and the gold grains in this till are clearly derived from the Blackwater deposit, where the gold is closely associated with pyrite (Petersen 2013, Petersen *et al.* 2013, Looby *et al.* 2013), the till contains negligible pyrite. No sample from the 22.5 m thick section of the gold dispersal train in Hole 04 (Fig. 13) yielded more than 30 pyrite grains of 0.25 to 0.5 mm size and most samples yielded no pyrite (Table 2).

The paucity of pyrite in the unoxidized till is evidently due to preglacial oxidation of most of the hypogene sulphides in the supergene zone that caps the deposit because the till is anomalous not only in gold and spessartine but also in pyrolusite (Table 2), a supergene Mn-oxide mineral ($MnO_2$). In Hole 04, the top till sample was from the oxidized zone and, like all of the surface samples along the train (Fig. 9, Table 1), yielded no pyrolusite grains, whereas the next ten samples were from the unoxidized zone and yielded from 1500 to 60,000 grains between 0.25 and 0.5 mm, a response similar to that for spessartine. Moreover, many larger grains of pyrolusite, which is a coarse-biased mineral, were found in the 0.5–1 mm and 1–2 mm fraction of the HMCs. The indicated presence of pyrolusite in the oxidized cap of the Blackwater deposit contrasts with its absence in oxidized till and suggests that the preglacial climate was more arid.

### Geochemistry of the heavy mineral concentratess from the till sections

As previously mentioned, the -0.25 mm HMCs of the drilled till samples were analyzed instead of the -0.063 mm till fines because the unoxidized till at depth retains any heavy sulphide mineral grains that were dispersed during glaciation.

The Au, Ag, As, Cu, Zn, Pb, Cd, Mo, Mn, and S analyses obtained from the HMCs of the 20 samples collected from the 40 m thick till section in Hole 04 are shown in Table 2. The highest Au analyses, ranging up to 11,300 ppm, were obtained in the top half of the till section from the eleven samples having anomalous concentrations of gold grains. However, the observed gold grains were expected to collectively produce Au analyses only one tenth to one-fifth as high as the reported values, due to the very small average size of the grains (Fig. 10). Such a large discrepancy between the expected and actual Au analyses normally indicates that another auriferous mineral is present in the HMCs. Most commonly this mineral is pyrite, as in the dispersal train of New Gold's large Rainy River gold deposit in Ontario, where 90% of the Au occurs within pyrite grains and pyrite is so plentiful in the till that the HMCs are oversized (Averill 2013a).

As previously noted and reinforced by very low-S analyses of <0.01 to 0.19% for the HMCs from Hole 04 (Table 2), pyrite is rare in the Blackwater train but pyrolusite, a secondary mineral apparently derived from the supergene cap of the Blackwater deposit and a known scavenger of metals, is abundant and results in HMC Mn analyses of up to 34,500 ppm or 3.45%. To check the metal content of the pyrolusite, a hand-picked separate of the largest grains from the most pyrolusite-

**Table 3.** Geochemical analyses for pyrolusite grains separated from Sample 11 in Hole 04.

| Sample Number | Ag ppm | As ppm | Cu ppm | Zn ppm | Pb ppm | Cd ppm | Mo ppm | Ni ppm | Mn ppm | S % |
|---|---|---|---|---|---|---|---|---|---|---|
| 04-11 | 264 | 781 | 133 | 8660 | 2010 | 58.9 | 18 | 66 | 90400 | 0.04 |

rich sample in Hole 04, sample No. 11, was submitted for geochemical analysis (Table 3). This separate was too small for gold analysis but was found to be extremely anomalous in both Ag (264 ppm or 7.5 ounces per ton) and Zn (8660 ppm) and also, in the same manner as the -0.063 mm fines from the oxidized surface samples, significantly anomalous in As (781 ppm), Pb (2010 ppm) and Cd (58.9 ppm) but not in Cu (only 133 ppm) or Mo (18 ppm). These results strongly suggest that the unseen Au in the HMCs resides in the pyrolusite.

Pure pyrolusite contains ~60% or 600,000 ppm Mn, but the Mn analysis obtained from the pyrolusite separate was only 90,400 ppm (Table 3), indicating that the grains are very impure. Analysis of the HMC before the pyrolusite grains were removed yielded 32,000 ppm Mn, which suggests a pyrolusite content of ~35%. The HMC also returned 56 ppm Ag, 668 ppm As, 1920 ppm Zn, 1720 ppm Pb, and 7 ppm Cd, each of which is fully accounted for by the high pyrolusite content of the HMC.

## CONCLUSIONS

The till sampling performed near the Blackwater Au-Ag deposit successfully delineated a large, previously unknown indicator mineral dispersal train — the Blackwater train — directly down-ice from the deposit (Fig. 9). The sampling program was unusually comprehensive as it established not only the indicator mineralogy but also the geochemistry of the dispersal train, both at surface where the till is oxidized and in the subsurface where it is unoxidized.

The oxidized zone of the till was sampled for 2.5 km down-ice from the Blackwater deposit at a density varying from 2 to 6 samples per km$^2$. At this sample spacing, the Blackwater train was faithfully detected mineralogically for more than 2.5 km from source using either gold (Fig. 9A) or spessartine (Fig. 9B) grains; whereas it is was detected for only 1 km geochemically in the -0.063 mm silt + clay fraction of the till (Fig. 12). Moreover the Mn in the spessartine was detected only in the samples that were collected within 500 m of the Blackwater deposit; these proximal samples contained thousands of spessartine grains.

Gold grains are the best indicator of the Blackwater deposit because they reflect the actual mineralization; the spessartine grains reflect only its alteration envelope. Moreover, the gold grains are malleable and their morphologies change systematically along the train from pristine to reshaped (Table 1), providing a measure of their transport distance. In 10 kg samples, background levels of both gold and spessartine grains are near zero. At an anomaly threshold of 10 gold grains per sample, the dispersal train is probably detectable for at least 3 km down-ice. With spessartine its detectable length may be as much as 10 km because spessartine grains are much more abundant than gold grains within the train.

Gold grains (Fig. 9A) define a train that is ~1.3 km wide — similar to the width of the Blackwater deposit — and ribbon-shaped with straight, sharp, lateral boundaries and a clear cut-off at the deposit. Using spessartine (Fig. 9B), the axis of the train is unchanged but the lateral margins are diffuse and the width doubles. The spessartine train appears to originate entirely from the Late Cretaceous Kasalka volcanic rocks that host the Blackwater deposit, with its core reflecting the known spessartine-bearing alteration envelope of the deposit and the lower grade margins suggesting that the outlying Kasalka volcanic rocks contain other, similar alteration zones.

In the subsurface, the Blackwater train is up to 22.5 m thick and is elevated well above the bedrock surface (Fig. 13). Gold grain and spessartine levels are similar to those at surface (Fig. 9), suggesting that the train is detectable for the same distance down-ice in the subsurface. Although the till that hosts the gold and spessartine grains is unoxidized, and the Blackwater deposit, from which these grains are derived, contains ~1 to 5% pyrite (Petersen *et al.* 2013, Christie *et al.* 2014), the till contains negligible pyrite. This appears to be due to the presence of an oxidized, preglacial supergene cap on the primary pyritic mineralization (Fig. 4). Instead of pyrite, the unoxidized till contains pyrolusite, a heavy, supergene Mn-oxide mineral that is apparently derived from the oxidized cap of the Blackwater deposit. Except at the surface of the Blackwater train where any glacially dispersed pyrolusite grains in the till were consumed by post-glacial oxidation, pyrolusite is as abundant as spessartine (Table 2), constituting up to 35% of some HMCs.

The pyrolusite grains are remarkably enriched in scavenged Ag (256 ppm or 7.5 oz/ton), As (781 ppm), Zn (8660 ppm), Pb (2010 ppm), and Cd (58.9 ppm) (Table 3). The HMC analyses for these elements are roughly proportional to the percentage of pyrolusite in the HMCs. The pyrolusite was not analyzed for Au but apparently it is as enriched in this element as in Ag because the HMC Au analyses are five to ten times higher than expected from the recovered gold grains, 90% of which are silt-sized (Fig. 10) and thus make only a small contribution to the Au analyses.

Possibly the most unusual feature of the gold grain dispersal train is its rapid separation from bedrock in the down-ice direction (Fig. 13). In Hole 04, ~600 m down-ice from the centre of the Blackwater deposit, the base of the dispersal train, excluding the underlying zone of elevated but subanomalous levels of gold grains, is 17.5 m above bedrock and in Hole 02, ~800 m further down-ice, it is 50.9 m above bedrock. While this could suggest the presence at depth of an older, barren till horizon deposited by ice that flowed in a more easterly or northerly direction, only one till appears to be present because (a) macroscopically the till section is very homogeneous; (b) both the barren and auriferous till contain spessartine (Table 2, Fig. 13); and (c) while the barren till in Hole 04 contains only sparse gold grains, all of the grains are pristine (Table 2) and thus are probably derived from the Blackwater deposit.

The progressive separation of the gold-spessartine-pyrolusite dispersal train from bedrock with increasing distance from the Blackwater deposit is probably due to the englacial thrusting process described by Clayton & Moran (1974), which is also responsible for elevating mineralized boulders to surface down-ice from ore deposits. This upthrusting may have been accelerated by the steep drop-off in the bedrock surface down-ice from the Blackwater deposit (Figs. 5, 13). Similarly perched indicator mineral dispersal trains have been identified by RC drilling at Matagami and a few other mineral deposits that occur on bedrock-highs directly up-ice from deep bedrock valleys in the Abitibi Greenstone Belt of Eastern Canada (Averill 2003). None of these perched trains would have been recognized if only the bottom of the till section, commonly referred

to as "basal" till, had been sampled. As demonstrated by the Blackwater program, the top till samples from a drillhole can be more important than the bottom samples and the entire till section must be sampled to determine the limits and significance of a dispersal train.

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