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Publications in this series have not been edited; they are released as submitted by the author.

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Introduction

Collection and processing of bulk sediment samples for isolating kimberlite indicator minerals and other economic heavy minerals using gravity/density separation methods is a standard mineral exploration protocol employed in Canada and elsewhere (Towie and Seet, 1995; Gent et al. 2011; McClenaghan, 2011; Plouffe et al., 2013). Typically large amounts of material (10-30 kg; 5 gallon pail) are required for each sample, particularly in reconnaissance-scale studies (i.e., distal to source) where indicator minerals may be scarce (≤1 grain per 10 kg of bulk sediment). The implication of this is that remote field sample collection can often be logistically limited based on aircraft payload restrictions, and incur additional processing costs associated with larger volumes of material. Were there practical methods available to provide concentrates of heavier mineral fractions (e.g., specific gravity >2.8) at the point of field collection (or at a central remote basecamp), it would be deemed advantageous to both enhancing the number and range of indicator minerals collected from a region and in different deposit types, and enable a greater number of samples to be collected within operational payload weight restrictions. The use of a method to concentrate samples in the field could not discard potential minerals of interest, from any size fractions, nor induce significant breakage of them. The study reported here tests whether a simple mechanical spiral separator (helical screw), designed for amateur gold exploration can be reliably used to produce a concentrate of heavier minerals from three different types of unconsolidated deposits known to contain abundant kimberlite indicator minerals, and one non-glacial gravel deposit known to contain placer gold. Results from this assessment will determine if this same field-portable spiral separator could be used on Banks Island, Northwest Territories, to increase the potential for kimberlite indicator mineral recovery from drift and unconsolidated bedrock samples.

Sediment Concentration Techniques

Standard suites of kimberlite indicator minerals (KIMs) are distinguished by having specific gravities (SG) ≥3.2, while gold has an SG of 19.3. These values contrast with the likes of feldspar (orthoclase; 2.56), quartz (2.65), calcite (2.71), mica (biotite; 2.82) and many carbonate minerals that often comprise the largest proportion of non-clastic glacial sediment matrices. Processing of samples for KIM recovery thus utilizes these density differences (amongst other properties) as a means of progressively reducing the volume of bulk samples by gravity and density separation into smaller and smaller concentrates from which individual KIMs are visually picked (McClenaghan, 2014). Following particle disaggregation, samples are sieved to remove coarser material (i.e., gravel, >2 mm). They are then processed through one or a variety of preconcentrators, including the likes of gravity shaking tables to yield density separations, after which the sediments may be subjected to micropanning, or heavy liquid separations to produce greater or specific density fractionations (McClenaghan, 2014).

Spiral Concentrator

On an industrial scale, gravity separation is widely utilized in the mining industry to produce mineral concentrates of various grades, through a variety of mechanical devices (Burt and Mills, 1984). One such apparatus is a spiral concentrator which consists of one or more helical profiled troughs supported on a central column (Fig. 1; Wills, 1984; Silva, 1986). A slurry is introduced into the top of a vertical spiral concentrator where denser particles sink to the bottom of the sluice faster. Heavy minerals experience more drag, hence travel slower, moving towards the center of the spiral, while lighter minerals remain on the outside (Atasoy and Spottiswood, 1995). At the base of the spiral concentrator, cutters or fences (splatters) draw off different density components producing a heavier mineral concentrate. Spiral concentrators can sustain recoveries of heavy minerals from 3 mm down to 75 microns, and can be adjusted for varying degrees of refinement (roughers, cleaners, or scavengers), and can accommodate feed rates from 0.5 to 4 tons per hour depending on the size, shape and density of materials being concentrated (Silva, 1986). Given their size, mechanical design and operational requirements, spiral concentrators would not be tenable instruments for use in field exploration operations.

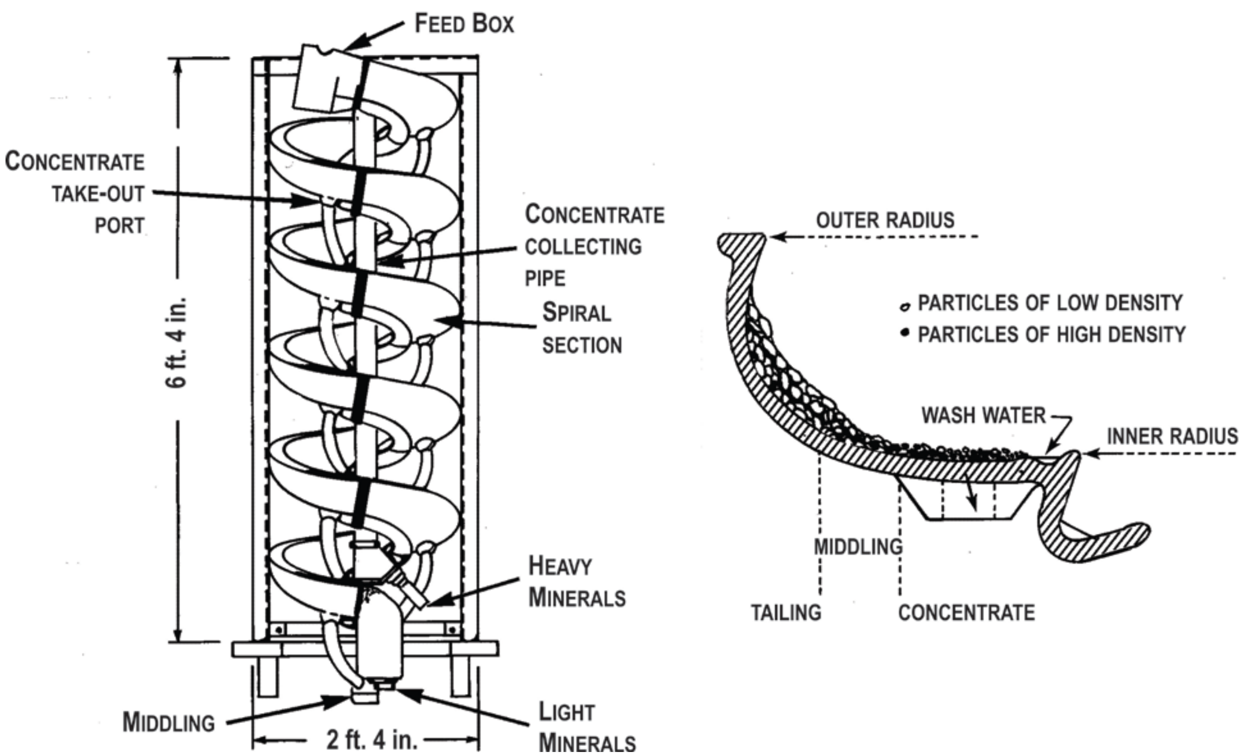

Figure 1. Plan (left) and cross sectional (right) views of a Humphries spiral concentrator showing accumulation of higher density minerals on the inside of the spiral (from Wills, 1984).

Rotating Spirals

Rotating spirals (a.k.a. gold wheel or gold screw) are a variation of the spiral concentrator that employs a flat, inclined, circular rotating table, into which a spiral pattern has been cut (or rubber bars affixed), and a wash water bar mounted on a frame running laterally from one side to the center (Fig. 2). When operating, the rotating table can be pitched at different angles and run at different speeds, with raw material fed in at the left side (table spinning clockwise). Less dense tailings are washed over the bottom lip, while concentrates are carried along the spirals towards the middle and a central discharge hole. Material is concentrated by gravity separation and fluid forces. Wash water forces light material downward over the rotating spirals, while centrifugal forces of the rotating table force heavier materials into the troughs of the spirals. Spirals can also vary in height (akin to tapered riffles on shaking tables), getting progressively thinner as the material approaches the center discharge point (Silva, 1986). Refinement of the concentrate is generally achieved through variations in the wash water flow rate and inclination of the table. Rotary tables are considered very efficient cleaners, but their low material capacity and load rate greatly limits their use as roughers (Maurice and Mercier, 1986; Silva, 1986), and therefore are unlikely to be usefully employed in a field-type environment.

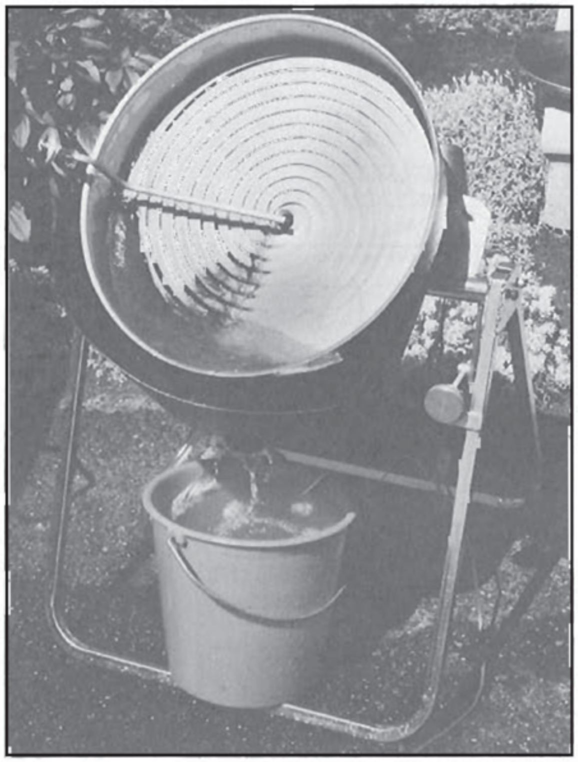

Figure 2. Gold screw spiral concentrator (from Maurice and Mercier, 1986).

Spiral Helixes

Spiral helixes are another concentrator device, consisting of an inclined cylinder lined with spirals along the inside (analogous to a hollow Archimedes screw), which depending on size and mechanics, can be used as both roughers and cleaners (Silva, 1986). Material is fed through a hopper into the clockwise rotating cylinder at a midway point. Wash water mixes with the sediments and carries the lighter material over top of the spirals where it is discharged out the back (lower) end. Centrifugal force and gravity push heavier minerals into the troughs between spirals where they are then carried upwards to the front of the helix and discharged into a collector. Secondary wash water streams behind (up) from where the material is introduced can further prevent moderately heavy grains from discharging, and pitch of the cylinder can be increased or decreased to affect relative concentration.

The device used in this study was a portable, battery powered spiral helix concentrator called the Mountain Goat Trommel (Fig. 3). It consisted of a 4 inch diameter spiral barrel, 17 inches long, inclined at 6.5°, with ¼ inch deep spirals that are spaced ¾ inch apart. The wash water sprayer-equipped hopper which sits behind the apparatus feeds material into the barrel 4 inches below the top, and the sprayer bar extends down the barrel another 10 inches. The water sprayer is fed by a bilge pump capable of recirculating 750 gallons (~2800 litres) per hour. The Mountain Goat Trommel is reported to be able to process 2 cubic yards (1.5 m^3) of placer gravel, producing as little as 10 pounds of concentrates in 8 hours (Camel Mining Products, 2016). The unit weighs 8.2 kg, measures 80x40x60 cm and is powered by a rechargeable 12 volt battery.

Figure 3. Mountain Goat Trommel spiral helix. Concentrated sediments are collected in the black pan at the back of the trommel, and then emptied into a separate sample bag.

Methodology

Field Sample Collection

This study set out to test the efficiency and accuracy of the Mountain Goat Trommel to produce concentrates of heavier minerals from three different types of sediments known to contain KIMs, and a fourth deposit known to contain placer gold. The area of sample collection was in southeastern Buffalo Head Hills, Alberta (57°N; 116°W), at a site with a long history of kimberlite exploration, scientific study, and documentation of 41 kimberlitic intrusions (Fenton and Pawlowicz, 1997; Friske et al., 2003; Prior et al., 2005, 2009; McClenaghan et al., 2008; Eccles, 2011; Paulen and McClenaghan, 2015).

The first sample site was a prominent esker situated in the Sawn Lake map sheet (NTS 84B/13; Trommelen et al., 2006), in which McClenaghan et al. (2008) documented the presence, mineralogy and chemistry of a kimberlite cobble(s). The esker is ~2 km long, and is exposed along a road in an aggregate pit that has dug into it, leaving faces up to 8 m high. It is comprised of planar and minor trough cross-bedded gravel and sand, and generally coarsens upwards from well-sorted medium-grained sand to coarse granular, pebbly sand. Ten 5-gallon pail samples (14SUV01##) were collected from a coarse granular, pebbly sand unit, ~1 m below the top of the esker – the same unit in which McClenaghan et al. (2008) had recovered a kimberlite cobble (Fig. 4).

Figure 4. Borrow pit exposure of esker where samples were collected 1 m below the upper surface (excavation site at top of slope behind truck), Buffalo Head Hills, Alberta.

The second sample site was from the same location that the Alberta Geological Survey till sample NAT95-134 (Fenton and Pawlowicz, 1997) was collected, which turned out to be immediately glacially down-flow of the K4 kimberlite complex. Two different samples were collected from this site. The first was a basal till exposed along the sloped banks of a 4 m high road cut. The till was a dark grey-brown, dense silty-clay with 5-10% indurated clast content (mainly igneous (granitic) and minor metamorphic, limestone, sandstone, chert and quartzite clasts; Fig. 5). Ten 5 gallon pail samples (excluding larger cobbles and boulders; 14SUV02##) were collected from 0.5-1.0 m depth (2.5-3 m below top of the road cut). The second sample collected from this site (14SUV03##) was a glaciofluvial gravelly-sand with abundant sub-rounded to sub-angular cobbles (granite, limestone, sandstone, quartzite; Prior et al., 2005). The glaciofluvial deposit is situated ~1.5 m below the surface (3.5 m below the top of the road cut), and was dug to a depth of 1 m (4.5 m below the top of the road cut; Fig. 6). Ten 5 gallon pail samples (excluding cobbles and boulders) were collected from this deposit.

Figure 5. Road cut site of till and glaciofluvial samples 14SUV02 and 14SUV03. Till sample collected from 0.5-1.0 m depth. Shovel length 1.2 m. White specks within the till are carbonate clasts.

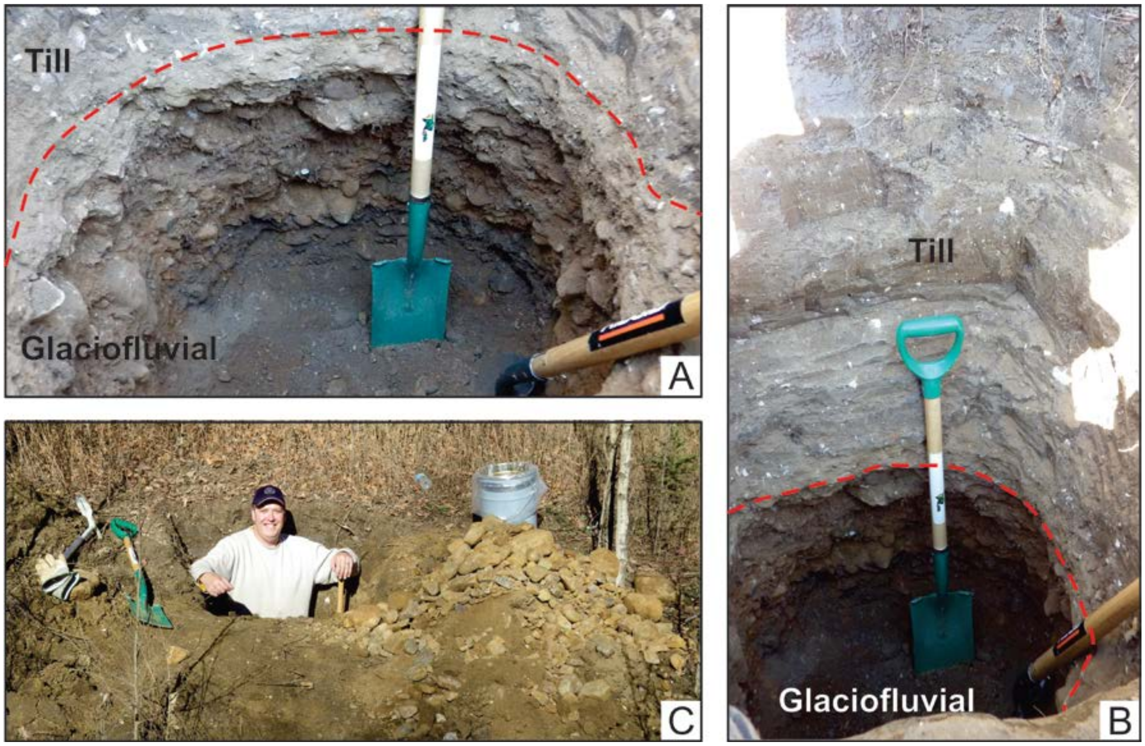

Figure 6. Glaciofluvial sediment sample 14SUV03. (A) Contact between till and gravelly-sand glaciofluvial sediments. (B) Depth of pit exposing 1.5 m of till overlying 0.5 m of excavated glaciofluvial sediments. (C) Two metre deep pit from which the till and glaciofluvial samples were dug. Collection of oxidized sub-rounded to sub-angular cobbles and boulders at right were discarded from the glaciofluvial sediments.

The third sample site was situated 12 km west of the till and glaciofluvial sample site (14SUV02 and 14SUV03), along the east side of a gravel road. Below approximately 1 m of dark, dense till, lays conspicuously orange-stained gravelly-sand and cobbles (Fig. 7). Cobbles are sub-rounded to well rounded, and comprise predominantly quartzite and chert. No Canadian Shield erratic material is found within these gravels and they are thus considered to be non-glacial, possibly Tertiary fluvial gravels derived from the Cordillera to the west (Paulen et al., 2006, in press; Trommelen et al. 2006). Four 5 gallon pails were filled with this material (14SUV04##).

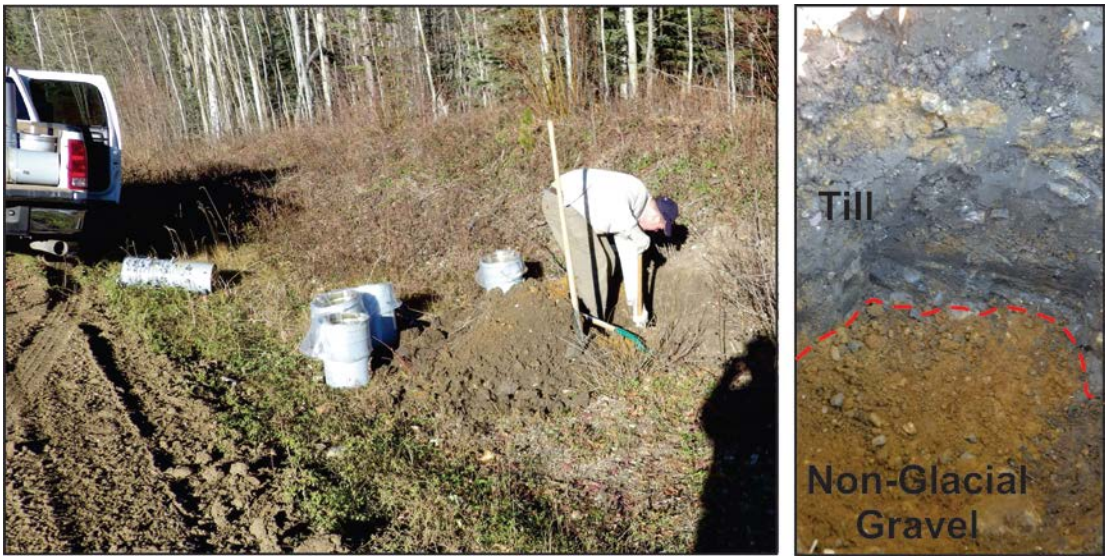

Figure 7. Site of the non-glacial gravel sample 14SUV04. Darkly orange-stained gravelly sand is exposed below 1 m of dark grey till.

Mountain Goat Trommel Processing

Sample pails were shipped to the Geological Survey of Canada, Calgary office for processing using the Mountain Goat trommel (Fig. 8). The study design involved processing two pails of each of the glacial sediment samples (14SUV01, 14SUV02, and 14SUV03), and 1 pail of the non-glacial gravel sediment (14SUV04) at each of three different trommel barrel pitches. The default pitch was 6.5° and by adjusting the screws at the base of the rear legs, pitches of 10° and 12.5° (maximum extension) were used. The speed of rotation of the trommel was held to be constant (the battery was fully charged each day), as was the water flow rate. The sump pump drew water from a large reservoir, and was screened from intake of silt and sand particles by a mesh filter (Fig. 3). Sediment was first sieved through a large diameter 4 mm sieve to remove coarser material. The <4 mm sediment was then introduced into the hopper ½ cup at a time, and the hopper was allowed to completely clear before additional sediment was added; it would take approximately 1 hour to empty a 5 gallon bucket sample. The entire <4 mm diameter sediments from each bucket was processed as one sample. The concentrate was collected at the top of the spiral helix into a tray that was periodically emptied into a small sample bucket. Reject tailings material was discharged at the lower end of the spiral helix, and were collected in a clean 5 gallon bucket from which waste water was allowed to overflow back in to the sump reservoir (Fig. 3). This ensured that while all sand and some coarser silt was retained in the tailings bucket, fine silt and clay was largely decanted. At least one pail of tailings sediments from each of the 3 glacial sediment samples was run a second time through the trommel, from which a secondary concentrate was collected. Smaller primary and secondary concentrate samples were further hand washed through sieves in the lab to isolate the <2 mm and >0.063 mm (sand-sized) fractions (Table 1).

The cohesive, over-consolidated, fine-grained nature of the till samples (14SUV02) were immediately recognized to be problematic and could not be run through the trommel without first being disaggregated. Till samples were soaked overnight in concentrated solutions of Calgon® (a water softener containing zeolite and polycarboxylate), and then thoroughly mixed using an electric paint mixer bar. While these pretreatments provided a significant measure of particle disaggregation, visual inspection of material collected in the tailings bucket indicated that the disaggregation was incomplete and agglomerated fine and coarser particles still remained. Larger clasts within the till samples were picked out by hand and excluded from the trommel processing.

Final samples to be analyzed for kimberlite indicator mineral contents included 1 raw (unprocessed) sample, for each of the 3 trommel pitches (6.5/10/12.5°), a primary concentrate (first sample run through the trommel) and a primary tailings discard (Table 1). Secondary concentrates – produced by re-running the primary tailings back through the trommel again, were collected for several samples, but owing to budget restrictions, none were submitted for KIM processing. These samples could be tested in the future if warranted.

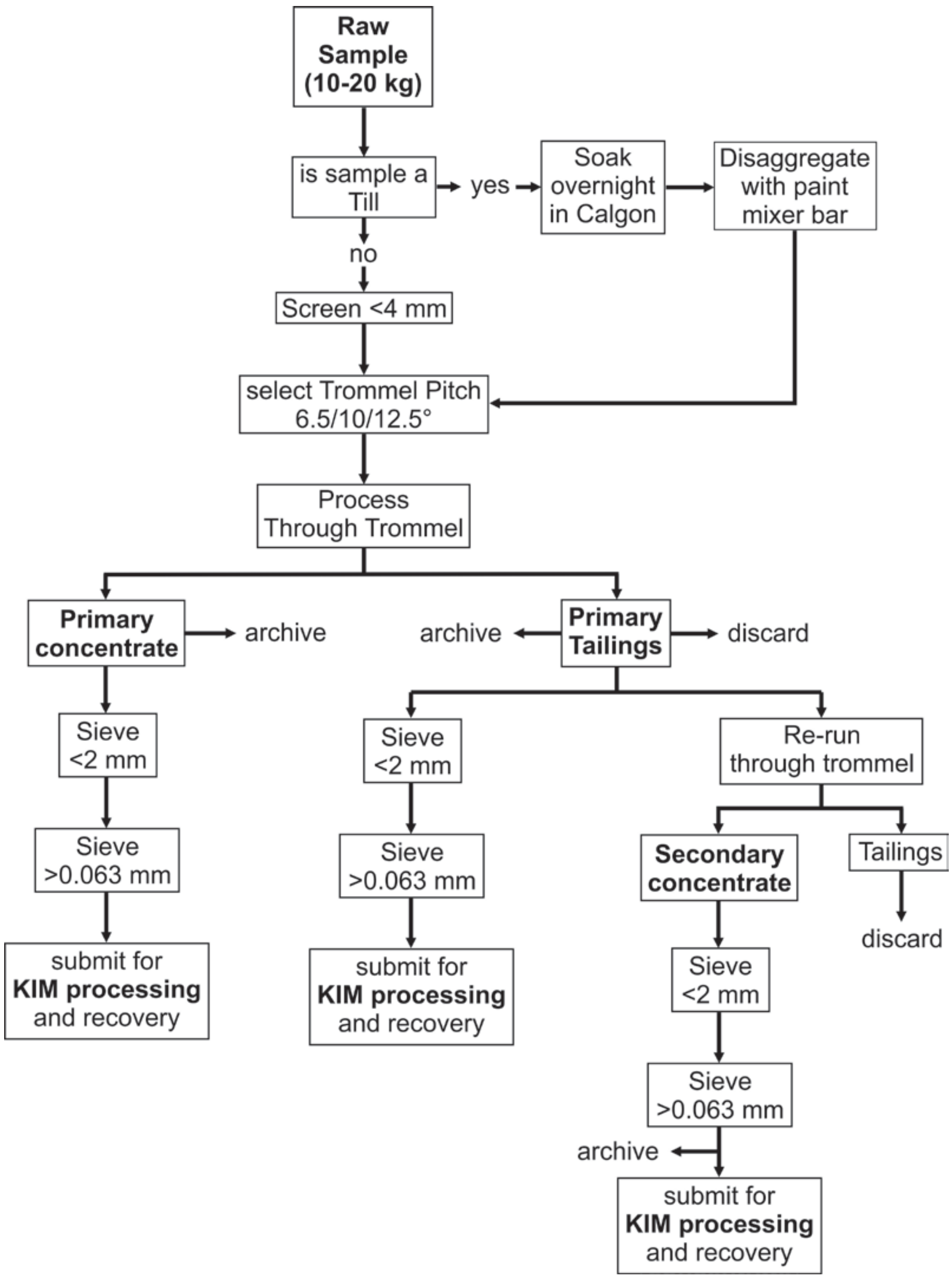

Figure 8. Flow chart outlining the sequence of steps for sample processing and analysis.

Table 1. Summary of sediment types, sample weights, and trommel processing methods utilized

Sample Type	ESKER										
Sample #	**14SUV0105**	**14SUV0101**	**14SUV0101**	**14SUV0102+09**	**14SUV0108**	**14SUV0108**	**14SUV0106**	**14SUV0103**	**14SUV0103**	**14SUV0110**	**14SUV0110**
Field Sample Weight (kg)	31.200	31.978	31.978	69.400	36.061		36.061	32.205	32.205	33.566	
Gravel (>4 mm) Weight (kg)		4.987		12.927	5.897		5.670	5.443		5.216	
Trommel Pitch (°)		6.5	6.5	6.5	10	10	10	12.5	12.5	12.5	12.5
Material Size Processed	Unprocessed	<4 mm	<4 mm	<4 mm	<4 mm	<4 mm	<4 mm	<4 mm	<4 mm	<4 mm	<4 mm
Material Produced	Bulk	Primary Concentrate	Primary Tailings	Primary Concentrate	Primary Concentrate	Secondary Concentrate	Primary Concentrate	Primary Concentrate	Primary Tailings	Primary Concentrate	Secondary Concentrate
Sieved and Washed	no	no	no	no	yes	yes	yes	yes	no	yes	yes
Gravel (2-4 mm) Weight (kg)	7.1[a]				0.113	0.059	0.088	0.046		0.075	0.053
Size Fraction	<2 mm	<4 mm	<4 mm	<4 mm	.063 - 2 mm	.063 - 2 mm	.063 - 2 mm	.063 - 2 mm	<4 mm	.063 - 2 mm	.063 - 2 mm
Wet weight (kg) submitted for KIM processing	24.1	15.880	20.410	24.270					29.030		
Dry weight (kg) submitted for KIM processing					1.247	[1.134][b]	[0.85][b]	0.397		0.450	[0.274][b]

Sample Type	TILL				
Sample #	**14SUV0202**	**14SUV0206**	**14SUV0206**	**14SUV0210**	**14SUV0205**
Field Sample Weight (kg)	27.700	24.721	24.721	27.896	27.216
Trommel Pitch (°)		6.5	6.5	10	12.5
Material Size Processed	<2 mm	Unprocessed	Unprocessed	Unprocessed	Unprocessed
Material Produced	Bulk	Primary Concentrate	Primary Tailings	Primary Concentrate	Primary Concentrate
Sieved and Washed	no	yes	no	yes	yes
Gravel (2-4 mm) Weight (kg)	1.3[a]	0.271		0.067	0.025
Size Fraction	<2 mm	.063 - 2 mm	<4 mm	.063 - 2 mm	.063 - 2 mm
Wet weight (kg) submitted for KIM processing	26.4		7.940		
Dry weight (kg) submitted for KIM processing		1.191		0.261	0.096

Sample Type	GLACIOFLUVIAL											
Sample #	**14SUV0307**	**14SUV0302**	**14SUV0302**	**14SUV0304**	**14SUV0304**	**14SUV0305**	**14SUV0305**	**14SUV0306**	**14SUV0303**	**14SUV0303**	**14SUV0308**	**14SUV0308**
Field Sample Weight (kg)	35.000	34.473		36.287	36.287	36.061		37.195	32.432		35.607	35.607
Gravel (>4 mm) Weight (kg)		12.020		17.010		15.422		14.742	15.195		13.154	
Trommel Pitch (°)		6.5	6.5	6.5	6.5	10	10	10	12.5	12.5	12.5	12.5
Material Size Processed	Unprocessed	<4 mm	<4 mm	<4 mm	<4 mm	<4 mm	<4 mm	<4 mm	<4 mm	<4 mm	<4 mm	<4 mm
Material Produced	Bulk	Primary Concentrate	Secondary Concentrate	Primary Concentrate	Primary Tailings	Primary Concentrate	Secondary Concentrate	Primary Concentrate	Primary Concentrate	Secondary Concentrate	Primary Concentrate	Primary Tailings
Sieved and Washed	no	yes	yes	yes	no	yes	yes	yes	yes	yes	yes	no
Gravel (2-4 mm) Weight (kg)	18.5[a]	0.510	0.454	0.346		0.235	0.170	0.203	0.073	0.062	0.149	
Size Fraction	<2 mm	.063 - 2 mm	.063 - 2 mm	.063 - 2 mm	<4 mm	.063 - 2 mm	.063 - 2 mm	.063 - 2 mm	.063 - 2 mm	.063 - 2 mm	.063 - 2 mm	<4 mm
Wet weight (kg) submitted for KIM processing	16.5				16.783							18.597
Dry weight (kg) submitted for KIM processing		4.026	[2.551][b]	2.211		0.680	[0.510][b]	0.567	0.283	[0.170][b]	0.227	

Sample Type	PRE-GLACIAL GRAVEL				
Sample #	**14SUV0403**	**14SUV0402**	**14SUV0402**	**14SUV0401**	**14SUV0404**
Field Sample Weight (kg)	29.000	32.659		27.669	31.751
Gravel (>4 mm) Weight (kg)		11.340		10.659	10.886
Trommel Pitch (°)		6.5	6.5	10	12.5
Material Size Processed	Unprocessed	<4 mm	<4 mm	<4 mm	<4 mm
Material Produced	Bulk	Primary Concentrate	Secondary Concentrate	Primary Concentrate	Primary Concentrate
Sieved and Washed	no	yes	yes	yes	yes
Gravel (2-4 mm) Weight (kg)	11.2[a]	0.159	0.172	0.071	0.059
Size Fraction	<2 mm	.063 - 2 mm	.063 - 2 mm	.063 - 2 mm	.063 - 2 mm
Wet weight (kg) submitted for KIM processing	17.8				
Dry weight (kg) submitted for KIM processing		1.474	[1.417][b]	[0.51][b]	0.170

[a]Gravel weights for bulk samples screened by ODM comprise all material >2 mm.
[b]Samples for which dry weights are enclosed by square brackets (e.g., [1.417]) were processed by the trommel but not submitted for KIM recoveries.

Kimberlite Indicator Mineral Processing

Raw and variously processed samples were submitted to Overburden Drilling Management Ltd. (ODM) for their standard kimberlite indicator mineral processing and gold grain counting (Averill, 2001, 2007; McClenaghan, 2014). The entire contents of each sample were processed. Kimberlite indicator minerals were picked, or total numbers estimated from the final heavy liquid concentrates. Gold grains were counted from each of the 2 non-glacial gravel samples, and collected from the raw, unprocessed sample. ODM also reported gold grain counts from the three glacial sediment sample types.

Results and Discussion

Mountain Goat Trommel

A total of 19 different samples, concentrates and tailings were processed through the trommel; 7 esker (14SUV01), 3 till (14SUV02), 6 glaciofluvial (14SUV03) and 4 non-glacial gravel (14SUV04; Table 1). Initial sample weights ranged from 24-37 kg, from which primary concentrates of 15.88-0.096 kg were produced (Table 1). Table 2 presents concentrate weights normalized to 10 kg of <2 mm sized material sample weights for each of the different materials, and at each of the different trommel pitches. Where more than one sample was processed at a given trommel pitch, results are averaged. It was not possible to sieve the original till samples, nor practical to sieve the disaggregated slurry following pretreatment; primary concentrate masses for tills are thus presented as per 10 kg raw sample.

Highest concentrate weights correspond to lowest trommel pitches in all samples, after which there is an exponential decline in concentrate weights with increasing trommel pitch (Table 2). Highest concentrate weights were produced in the esker sample, at all pitches, and lowest concentrate weights were produced in the till samples (although the fact that gravel (>2 mm) material weights were not excluded in the till samples likely exaggerates this disparity).

Table 2. Primary Concentrate masses (kg), averaged to 10 kg of <2 mm sized material sample weights.

Material	Trommel Pitch (°)		
	6.5	10	12.5
Esker (14SUV01)	4.348[1]	0.347	0.154
Till (14SUV02)[2]	0.482	0.094	0.035
Glaciofluvial (14SUV03)	1.526	0.292	0.129
Pre-glacial gravel (14SUV04)	0.697	0.301	0.082

[1]Averaged to 10 kg of <4 mm sized material sample weights

[2]Till samples were not sieved, and are thus reported per 10 kg raw sample

Where primary tailings were re-run through the trommel (6 samples; 2 esker, 3 glaciofluvial, 1 non-glacial gravel), resultant secondary concentrate weights show a wide and inconsistent variation in comparison to the weights of the primary concentrates (Table 1). The non-glacial gravel sample 14SUV0402 produced almost the same weight of concentrates from the original sample (1.474 kg), as it did in the re-run of the primary tailings (1.417 kg). The esker sample 14SUV0110 and glaciofluvial sample 14SUV0303 produced the lowest percentage of secondary concentrates, although even with these, they were ~60% of the original sample concentrates. Secondary concentrate weights also followed the same exponential decreasing trend as trommel pitch increased. That so much material could be produced as a secondary concentrate from the original sample tailings argues that a potentially significant amount of material is either being lost in the initial processing run, or that the trommel is incapable of finely cleaning samples, and thus allows a larger variation in particle densities to be captured in the concentrate fraction. Regardless, a significant level of imprecision is suggested. Examination of the KIM contents of primary concentrates and tailings will help to resolve this.

Kimberlite Indicator Minerals

A total of 25 samples were processed by Overburden Drilling Management Ltd (ODM) for KIMs (Table 1), and gold grain contents (Table 3). One unprocessed, raw field sample of each of the different sediment types was submitted as a control against which the trommel-processed samples were compared. The highest concentration of KIMs was found in the glaciofluvial sediment, followed closely by the overlying till, and then at approximately half the abundance in the esker samples. KIMs within the largest sand fraction (1.0 – 2.0 mm) were only abundant in some of the glaciofluvial samples and generally absent or at trace levels in the other sediment types. Highest KIM abundances were found in the finest sand fraction (0.25 – 0.5 mm) in each of the glacial deposits (Table 3). Forsterite (FO; olivine) grains were the most abundant KIM recovered, although their over-representation in three glaciofluvial samples where estimated numbers range from 4700 – 63 000 clearly skew the data. Forsterite grains are also the most abundant large KIM grains recovered (1.0 – 2.0 mm; Table 3). Peridotitic garnet (GP) and chromite (CR) abundances are comparable, and also show increasing abundance in the finer sand fractions (Table 3). Chromites are the only potential KIM found in the non-glacial gravel deposit, although clearly other sources of chromites apart from kimberlites exist in the region. That no forsterite grains (otherwise abundant in all the 3 glacial deposits) are found in the non-glacial gravels further argues that these sediments formed as aggradational deposits from a Cordilleran (westward) source (Paulen et al., 2006, in press; Eccles, 2011), and that they had not eroded any of the 41 kimberlite bodies known to exist immediately east and north of this locality.

Comparisons of KIM results from the raw field samples with various trommel-processed concentrates and tailings yield a wide variation in the number, size and types of KIMs, that isn't in all cases inconsistent with one and other. It is apparent, however, that even within the small aerial extent (<1 m^3) from which samples were collected in the three glacial deposits, there can be very significant variations in the relative abundance of KIMs. When computed as KIM grains per 10 kg of <2 mm sized sample material (excepting the trommel-processed till samples which are expressed per 10 kg raw sample), some of this variation is reduced (Table 3). However, particularly in the case of forsterite grains, where abundances in the glaciofluvial samples vary by 4 orders of magnitude (Table 3), this inter-deposit variability compounds the ability to directly test recovery methods.

In the esker samples (14SUV01) there are comparable, or even higher abundances of forsterite grains in the two samples processed by the trommel at 6.5° pitch when compared to the raw sample (50-78 KIMs/10 kg of <2 mm sample material; Table 3). At the same time, it is noted that in sample 14SUV0101 (6.5° pitch), there are approximately equal number of forsterite grains in the primary tailings (reject material), as there were in the primary concentrate. As the trommel pitch was increased to 10° and 12.5° there is a discernible decrease in forsterite grain recovery in the concentrates (15-4 KIMs/10 kg of <2 mm sample material; Table 3). That the primary tailings of sample 14SUV0103 had 40 KIMs/10 kg of <2 mm sample material (comparable to that of the raw sample – 14SUV0105) indicates that the lower primary concentrate recovery (11 KIMs/10 kg of <2 mm sample material) is not reflective of lower actual KIM content of this sample, but instead an imprecision to concentrate them. There does not appear to be any significant difference between trommel recovery precision in the 0.5-1.0 and 0.25-0.5 mm size fractions.

The most consistent deficiency in KIM recovery between the raw field samples and those processed by the trommel appear to be with the till samples (14SUV02; Table 3). Almost certainly a significant part of this reflects the inability to completely disaggregate the till samples prior to being processed by the trommel, versus more thorough methods of disaggregation employed by ODM. Concentrations of KIMs in the trommel samples are half to almost a tenth of those from the raw sample, and the deficiencies are most pronounced in the recovery of peridotitic garnets. While the weight of >2 mm sized material is unknown in the trommel-processed samples, by comparison, the raw sample processed by ODM only had ~5% material >2 mm that was removed

Table 3. Numbers of kimberlite indicator mineral grains from the four study sediment types in raw and variously trommel-processed samples.

Sample #	Trommel Pitch (°)	Processed Fraction	Field Sample <2 mm (kg)	Table Feed (kg wet)	Number of Kimberlite Indicator Mineral Grains																																				Total (KIMs)		Average # of KIMs per 10 kg of <2 mm sample material
					1.0 to 2.0 mm												0.5 to 1.0 mm												0.25 to 0.5 mm														
					GP		GO		DC		IM		CR		FO		GP		GO		DC		IM		CR		FO		GP		GO		DC		IM		CR		FO				
					E	P	E	P	E	P	E	P	E	P	E	P	E	P	E	P	E	P	E	P	E	P	E	P	E	P	E	P	E	P	E	P	E	P	E	P	E	P	
ESKER																																											
14SUV0105	Raw	Raw		24.1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	40	20	0	0	0	0	0	0	0	0	0	0	80	20	121	41	50
14SUV0101	6.5	Primary concentrate		10.9	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	40	20	1	1	0	0	0	0	0	0	0	0	40	20	82	42	75
14SUV0101	6.5	Primary tailings		16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	20	1	1	3	3	0	0	0	0	0	0	80	20	124	44	78
14SUV0102+09	6.5	Primary concentrate		20.1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	1	0	0	0	0	40	20	1	1	0	0	0	0	0	0	0	0	60	20	103	43	51
14SUV0108	10	Primary concentrate	30.051		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	15	0	0	0	0	0	0	0	0	0	0	30	20	45	35	15
14SUV0103	12.5	Primary concentrate	19.705		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	8	0	0	0	0	0	0	0	0	0	0	14	14	22	22	11
14SUV0103	12.5	Primary tailings		26.1	0	0	0	0	0	0	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0	0	40	20	0	0	0	0	0	0	0	0	0	0	60	20	104	44	40
14SUV0110	12.5	Primary concentrate	28.275		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	5	0	0	0	0	0	0	0	0	0	0	7	7	12	12	4
(Grain Total Numbers)															*7*	*7*					*1*	*1*					*228*	*128*	*3*	*3*	*3*	*3*							*371*	*141*	*613*	*283*	
TILL																																											
14SUV0202	Raw	Raw		26.4	1	1	0	0	0	0	0	0	0	0	2	2	14	14	1	1	0	0	0	0	9	9	40	20	80	20	0	0	0	0	0	0	60	20	40	20	247	107	94
14SUV0206	6.5	Primary concentrate	17.95		0	0	0	0	0	0	0	0	0	0	0	0	7	7	0	0	0	0	0	0	9	9	7	7	26	26	0	0	0	0	0	0	23	23	14	14	86	86	48
14SUV0206	6.5	Primary tailings		6.3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	3	3	5	5	0	0	0	0	0	0	1	1	17	17	28	28	44
14SUV0210	10	Primary concentrate	17.829		0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0	0	4	4	0	0	0	0	0	0	8	8	7	7	21	21	12
14SUV0205	12.5	Primary concentrate	14.691		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	0	0	0	0	0	0	0	0	5	5	5	5	14	14	10
(Grain Total Numbers)					*2*	*2*									*2*	*2*	*22*	*22*	*1*	*1*					*20*	*20*	*54*	*34*	*115*	*55*							*97*	*57*	*83*	*63*	*396*	*256*	
GLACIOFLUVIAL																																											
14SUV0307	Raw	Raw		16.5	2	2	1	1	0	0	0	0	0	0	9	9	11	11	0	0	0	0	0	0	40	20	30	20	30	20	0	0	2	2	0	0	20	10	40	20	185	115	112
14SUV0302	6.5	Primary concentrate	21.943		1	1	0	0	0	0	0	0	2	2	0	0	3	3	0	0	0	0	0	0	9	9	6	6	10	10	0	0	0	0	0	0	20	10	30	20	81	61	37
14SUV0304	6.5	Primary concentrate	18.931		0	0	0	0	0	0	0	0	0	0	18	18	2	2	0	0	0	0	0	0	7	7	800	20	6	6	0	0	0	0	0	0	5	5	4000	20	4838	78	2556
14SUV0304	6.5	Primary tailings		11.2	1	1	0	0	0	0	0	0	1	1	60	20	4	4	0	0	0	0	0	0	1	1	3000	20	5	5	1	1	1	1	0	0	4	4	60000	20	63078	78	56320
14SUV0305	10	Primary concentrate	20.404		0	0	0	0	0	0	0	0	0	0	1	1	4	4	0	0	0	0	1	1	4	4	17	17	1	1	0	0	0	0	0	0	4	4	6	6	38	38	19
14SUV0306	10	Primary concentrate	22.25		1	1	0	0	0	0	0	0	0	0	0	0	4	4	0	0	0	0	0	0	7	7	27	27	3	3	0	0	0	0	0	0	11	11	18	18	71	71	32
14SUV0303	12.5	Primary concentrate	17.164		0	0	0	0	0	0	0	0	1	1	30	20	1	1	0	0	0	0	0	0	3	3	1200	20	3	3	0	0	0	0	0	0	1	1	3500	20	4739	69	2761
14SUV0308	12.5	Primary concentrate	22.304		0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	9	9	2	2	0	0	0	0	0	0	0	0	4	4	3	3	20	20	9
14SUV0308	12.5	Primary talings		13.4	0	0	0	0	0	0	0	0	0	0	6	6	10	10	0	0	0	0	0	0	11	11	38	38	30	20	1	1	0	0	0	0	40	15	100	20	236	121	176
(Grain Total Numbers)					*5*	*5*	*1*	*1*					*4*	*4*	*124*	*74*	*41*	*41*					*1*	*1*	*91*	*71*	*5120*	*170*	*88*	*68*	*2*	*2*	*3*	*3*			*109*	*64*	*67697*	*147*	*73286*	*651*	
PRE-GLACIAL GRAVEL																																											
14SUV0403	Raw	Raw		17.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	20	0	0	40	20	22
14SUV0402	6.5	Primary concentrate	21.16		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	17	17	0	0	18	18	9
14SUV0404	12.5	Primary concentrate	20.806		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	2	2	1
(Grain Total Numbers)																									*1*	*1*											*59*	*39*			*60*	*40*	
					7	*7*	*1*	*1*					*4*	*4*	*133*	*83*	*63*	*63*	*1*	*1*	*1*	*1*	*1*	*1*	*112*	*92*	*5402*	*332*	*206*	*126*	*5*	*5*	*3*	*3*			*265*	*160*	*68151*	*351*	*74355*	*1230*	

[1]Abbreviations Used: KIM - Kimberlite Indicator Mineral; GP - purple to red peridotic garnet; GO - orange mantle garnet; DC - Cr-dopside; IM - Mg-ilmenite; CR - Chromite; FO - Forsterite

E - estimated; P - picked

prior to processing, so this is unlikely to significantly change the KIM concentration data from that calculated based on the total sample weight (Tables 1, 3). As was also seen in the esker samples, it is not that the actual abundance of KIMs in the till samples necessarily differ between individual samples. For example, in sample 14SUV0206 (6.5° pitch) the total abundance of KIMs in the primary concentrate and tailings would equal that in the raw sample (14SUV0202). Further, in sample 14SUV0206 there is a comparable abundance of KIMs in both the primary concentrate and the tailings; so again, the trommel is demonstrated to be an imprecise method for isolating KIMs. Recovery efficiency of KIMs from the till samples also notably declines as trommel pitch increases (Table 3).

The glaciofluvial samples provided the starkest differences in terms of KIM recoveries, but as previously discussed, are complicated by very large inter-sample variations in forsterite abundances. If the two most anomalous samples (14SUV0303 and 14SUV0304) are set aside, then KIM abundances in the trommel concentrates of the remaining 4 samples are significantly lower than in the raw sample (Table 3). As with till sample 14SUV0206, glaciofluvial sample 14SUV0308 has a comparable number of KIMs/10 kg of <2 mm sample material compared to the raw sample (n=112) when both the primary concentrate and primary tailings are combined (n=185). So, at least for this sample, differences in recovery do not reflect absolute KIM grain abundances, but instead demonstrate an imprecision of the trommel to concentrate KIMs (9 in the concentrate, 176 in the tailings). Perhaps the most damming evidence of concentrating imprecision by the trommel is with sample 14SUV0304 (6.5° pitch). While the trommel was able to concentrate 2556 KIM grains/10 kg of <2 mm sample material, it discarded more than an estimated 20 times that number of KIMs in the tailings (n=56 320; Table 3). Similar to that seen with the till samples, the trommel also appears to be less effective at recovering peridotitic garnets, which is curious as their specific gravity (3.5-3.8) is greater than that of forsterite (3.2-3.33; McClenaghan and Kjarsgaard, 2007), and would be expected to be more efficiently concentrated in a density separation device such as the trommel. As seen with the other types of deposits, trommel recovery efficiency also decreases with increasing trommel pitch (Table 3).

The only potential KIMs recovered in the non-glacial gravels are chromites. In the absence of absolute number comparisons (e.g., single sample concentrate + tailings) it is not possible to make direct comparisons on recovery efficiencies, other than to say that abundances of chromites in the two trommel-processed samples are 60 to 95% less than in the ODM-processed raw sample (Table 3).

Gold Grains

The non-glacial gravels were collected with the primary focus of testing the trommel's efficiency in recovering gold grains as these deposits were known to host gold (Rukhlov, 2011; Paulen et al., in press). Results are presented in Table 4, and show that gold grains are mostly absent or trace constituents (1 or 2 grains) in the three glacial sediment sample types and the two non-glacial gravel samples processed by the trommel, but are abundant (104 grains) in the raw non-glacial sediment sample processed by ODM. The disparity in gold grain abundance between the trommel-processed and ODM-processed non-glacial gravel samples suggests a significant failure of the trommel to concentrate fine (<100 µm) gold grains, the very material it is purported to be designed to do so. However, it must be recognized that the decision to wash the trommel concentrates through a 0.063 mm (63 µm) square mesh sieve (with a diagonal of 89 µm) may have caused a significant loss of finer gold grains. Measurements of individual gold grains recovered from all the samples are reported in Table 5. Only 3 gold grains with minimum planar axes >63 µm were recovered in the trommel-processed glaciofluvial samples (14SUV03), however, the four gold grains recovered from the trommel-processed esker and till samples have minimum (and maximum) planar axes <63 µm, which by rights could have permitted them to be lost through the sieve when washed. When examining the ODM-processed non-glacial gravel sample (14SUV0403), if the minimum planar axes length of 63 µm is used as a cut-off, then 54 of 104 gold grains (52%) would have potentially been lost had this sample been washed through the 63 µm sieve. Increasing the discrimination to the maximum sieve mesh diagonal length of 89 µm, would increase that to potentially 77 of 104 gold grains (74%), although it is unlikely given gold grain particle thicknesses of 15-25 µm that these would actually have passed through the sieve (Table 5). Unfortunately, no tailings were collected with the trommel-processed samples, so it cannot be determined if the gold grains had simply failed to be concentrated by the trommel. Regardless, that so many (~48%) of the gold grains in the ODM-processed non-glacial gravel sample are larger than the sieve mesh diameter, yet only 1 single gold grain of comparable (>63 µm) size was recovered from the two trommel-processed non-glacial gravel samples indicates that the Mountain Goat Trommel is ineffective in concentrating fine gold grains in unconsolidated sandy gravel.

Table 4. Visible gold grain counts and calculated PPB visible gold in test sample heavy mineral concentrates.

Sample #	Trommel Pitch (°)	Processed Fraction	Field Sample <2 mm (kg)	Table Feed (kg wet)	Nonmag HMC Weight (g)	Number of Visible Gold Grains				Calculated PPB Visible Gold in Sample			
						Total	Reshaped	Modified	Pristine	Total	Reshaped	Modified	Pristine
ESKER													
14SUV0105	Raw	Raw		24.1	96.4	1	1	0	0	15.6	15.6	0	0
14SUV0101	6.5	Primary concentrate		10.9	155.2	0	0	0	0	0	0	0	0
14SUV0101	6.5	Primary tailings		16	64	0	0	0	0	0	0	0	0
14SUV0102+09	6.5	Primary concentrate		20.1	215.2	0	0	0	0	0	0	0	0
14SUV0108	10	Primary concentrate	30.051		594.7	0	0	0	0	0	0	0	0
14SUV0103	12.5	Primary concentrate	19.705		3.4	0	0	0	0	0	0	0	0
14SUV0103	12.5	Primary tailings		26.1	104.4	2	2	0	0	2.1	2.1	0	0
14SUV0110	12.5	Primary concentrate	28.275		3.4	0	0	0	0	0	0	0	0
TILL													
14SUV0202	Raw	Raw		26.4	105.6	1	1	0	0	44.9	44.9	0	0
14SUV0206	6.5	Primary concentrate	17.95		800.2	0	0	0	0	0	0	0	0
14SUV0206	6.5	Primary tailings		6.3	25.2	1	1	0	0	3.2	3.2	0	0
14SUV0210	10	Primary concentrate	17.829		73.6	1	1	0	0	<1	<1	0	0
14SUV0205	12.5	Primary concentrate	14.691		32.7	0	0	0	0	0	0	0	0
GLACIOFLUVIAL													
14SUV0307	Raw	Raw		16.5	66	1	1	0	0	22.7	22.7	0	0
14SUV0302	6.5	Primary concentrate	21.943		3069.1	1	1	0	0	<1	<1	0	0
14SUV0304	6.5	Primary concentrate	18.931		1499.1	0	0	0	0	0	0	0	0
14SUV0304	6.5	Primary tailings		11.2	44.8	0	0	0	0	0	0	0	0
14SUV0305	10	Primary concentrate	20.404		269	0	0	0	0	0	0	0	0
14SUV0306	10	Primary concentrate	22.25		157.5	0	0	0	0	0	0	0	0
14SUV0303	12.5	Primary concentrate	17.164		1.3	0	0	0	0	0	0	0	0
14SUV0308	12.5	Primary concentrate	22.304		3.5	1	1	0	0	1414.6	1414.6	0	0
14SUV0308	12.5	Primary talings		13.4	53.6	1	1	0	0	107.1	107.1	0	0
PRE-GLACIAL GRAVEL													
14SUV0403	Raw	Raw		17.8	71.2	104	91	13	0	3811.4	3692.8	118.7	0
14SUV0402	6.5	Primary concentrate	21.16		677.2	1	0	1	0	2.2	0	2.2	0
14SUV0404	12.5	Primary concentrate	20.806		10.1	0	0	0	0	0	0	0	0

Table 5. Visible gold grain dimensions

Sample #	Trommel Pitch (°)	Processed Fraction	Field Sample <2 mm (kg)	Table Feed (kg wet)	Nonmag HMC Weight (g)	Number of Visible Gold Grains				Dimensions (microns)		
						Total	Reshaped	Modified	Pristine	Thickness[1]	Width	Length
ESKER												
14SUV0105	Raw	Raw		24.1	96.4	1	1	0	0	20 C	75	125
14SUV0103	12.5	Primary tailings		26.1	104.4	2	2	0	0	5 C	25	25
										10 C	50	50
TILL												
14SUV0202	Raw	Raw		26.4	105.6	1	1	0	0	50 M	50	175
14SUV0206	6.5	Primary tailings		6.3	25.2	1	1	0	0	8 C	25	50
14SUV0210	10	Primary concentrate	17.829		73.6	1	1	0	0	3 C	15	15
GLACIOFLUVIAL												
14SUV0307	Raw	Raw		16.5	66	1	1	0	0	20 C	75	125
14SUV0302	6.5	Primary concentrate	21.943		3069.1	1	1	0	0	20 C	75	125
14SUV0308	12.5	Primary concentrate	22.304		3.5	1	1	0	0	25 M	125	200
14SUV0308	12.5	Primary talings		13.4	53.6	1	1	0	0	25 M	100	250
PRE-GLACIAL GRAVEL												
14SUV0402	6.5	Primary concentrate	21.16		677.2	1	0	1	0	20 C	75	125
14SUV0403	Raw	Raw		17.8	71.2	104		1	0	3 C	15	15
							6	1		5 C	25	25
							8	2		8 C	25	50
							3	2		10 C	25	75
							1			13 C	25	100
							12	1		10 C	50	50
							8	1		13 C	50	75
							4	1		15 C	50	100
							3			25 M	50	150
							2	1		15 C	75	75
							9	1		18 C	75	100
							7			20 C	75	125
								1		22 C	75	150
							2			25 M	75	250
							2			20 C	100	100
							3			22 C	100	125
							3			50 M	100	150
							2			25 M	100	175
							1			25 M	100	250
							3	1		25 C	125	125
							3			50 M	125	225
							1			25 M	150	150
							2			50 M	150	200
							2			25 M	150	275
							1			50 M	175	200
							1			50 M	200	200
							1			50 M	200	250
							1			50 M	300	375

[1]M - actual measured thickness of grains (microns); C - thickness of grain (microns) calculated from measured width and length

Conclusions

This comparative study was set up as both an operational test of the Mountain Goat Trommel in terms of whether it could be used as a field-portable device for roughing or concentrating a variety of unconsolidated glacial and non-glacial sediments, and whether the concentrates produced by this device reliably captured all types, sizes, and abundances of kimberlite indicator minerals and gold grains.

Unquestionably, in the four different types of sediments tested, the Mountain Goat Trommel produces a concentrate of sediments that represents a 42 to 99% (average 88 %) reduction in original (<2 mm particle size) sample mass. On its own, this offers significant benefits in terms of sample weight reduction, and the potential for processing larger volumes of material in the field to produce concentrates of what may be rare abundances of indicator mineral. However, it is the issue of accuracy and even precision of being able to concentrate mineral grains with specific gravities >3.2 (e.g., KIMs) that remains the most significant determinant of reliability and usefulness of this device.

The simplest observation is that the Mountain Goat Trommel does not preferentially exclude KIMs from the concentrates. In some cases the trommel can produce comparable or at least high numbers of KIMs in much smaller masses of concentrates. In other cases the trommel produces equal numbers of KIMs in the concentrate as in the tailings (14SUV0101 and 14SUV0206; Table 3), and in the case of the anomalous glaciofluvial samples 14SUV0304 and 14SUV0308, the tailings contain 95% and 97%, respectively, greater abundances of KIMs than the concentrates (Table 3). In light of this evidence, the trommel cannot be considered accurate or precise, and therefore is deemed an unreliable apparatus.

The study design utilized to test this device is not ideal. The inability to easily and fully disaggregate the till samples (14SUV02) is instructive for what kinds of sediments the trommel is and is not able to properly process. It appears best suited to coarser, unconsolidated materials, such as the esker, glaciofluvial sediments, and non-glacial gravels. The enormous inter-sample variability of KIM abundances in the glaciofluvial sediments likely makes comparisons of KIM recoveries between samples largely uninterpretable. Only those glaciofluvial samples for which the concentrate and tailings were analyzed (14SUV0304 and 14SUV0308) can be directly contrasted in terms of absolute recoveries. To improve upon this testing efficacy, various types of sediment samples known to contain no KIMs or gold grains (i.e, blanks), would have to be spiked with a variety of types, sizes, and numbers of KIMs/gold grains, and then separately processed through the trommel and ODM laboratory. Only then could absolute accuracy and precision be assessed.

Based on the results of this study, the Mountain Goat Trommel is deemed an inaccurate means of concentrating or roughing kimberlite indicator minerals from coarser unconsolidated sediments, and therefore will not be deployed in field operations by the GSC.

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