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NSERC-CMIC Mineral Exploration Footprints Project Contribution 065.

**Glacial dispersion of indicator minerals and geochemical pathfinders from the Canadian Malartic gold deposit Val d'Or, Quebec: Testing legacy data and new indicators**

By

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A thesis presented to the Department of Earth and Environmental Sciences in fulfillment of the requirement for the degree of Bachelor of Science in Earth Science - Geology Specialization

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**Abstract**

The Canadian Malartic Gold Mine is located in Malartic near Val d'Or, Quebec. It is an open pit mine targeting disseminated, low grade, native gold found in metasediments and intrusions. This study focuses on defining the distal footprint of the gold deposit within the surficial sediments. There are two main objectives; 1) determine whether legacy surficial geochemistry data can be used today and; 2) assess whether rutile and hyperspectral imaging can be used to trace Malartic-type gold deposits in glacial sediments. A total of 47 samples were taken in 2015 to test the Cadillac data and to initiate the rutile and hyperspectral study. Data exploration techniques, such as Q-Q plots and GIS mapping, were used to analyze the Cadillac data and compare with the 2015 data. Testing tungsten-rich rutile as an indicator mineral relied on using gold (Au) and tungsten (W) as a geochemical proxy until a heavy mineral study is completed and microprobe analysis determines the rutile composition. Hyperspectral imaging was done at the University of Alberta on pebbles from 10 kg surficial till samples.

Results show that despite issues and limitations associated to the Cadillac data, such as lack of grain size data and different analytical techniques used, the data can still be useful. It will, however, require careful levelling and material type differentiation before it can be used to its fullest potential. One important issue was identified related to material type; field work verified that till, the target sample media, is discontinuous across the study area and is clearly missing at some of the Cadillac sampling sites. Therefore, a portion of the results in the database reflect the geochemistry of sediments other than till; in this case probably glaciolacustrine sediments. The Cadillac project reports, now in scanned pdf format, will be valuable in finding more information regarding the database samples as they contain enough description of the samples to differentiate till from glaciolacustrine mud.

Similar Au and W dispersal patterns suggest W-rich rutile may be useful as a proxy for Au content in the till. Hyperspectral results have revealed the occurrence of metasediments with a signature similar to that currently associated with the Malartic footprint. However, it is unclear whether this signature is unique to Malartic or if other bedrock sources located up-ice of the deposit could have a similar signature. Additional work needs to be done on the different bedrock types located up-ice of the deposit for a better understanding of the hyperspectral signature in the area.

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# 1.0 Introduction

## 1.1 Project Rationale

As deposits are found in Canada, the mineral exploration industry has to adapt to find deeper, buried, and lower grade ore deposits. The Footprints Project is a collaboration between the Canadian Mining and Innovation Council and the Natural Sciences and Engineering Research Council of Canada to find new ways of integrating different exploration techniques and data to define mineral deposit footprints. Bedrock footprints of ore deposits can extend into surficial sediments through many processes including Quaternary glacial processes. Dispersal patterns from glacial erosion and transport can potentially produce larger footprints within the surficial sediments compared to the bedrock footprint (Averill, 2001). This study will focus on defining the surficial footprint around one of the Footprints Project's 3 locations; the Canadian Malartic gold deposit in Québec. (NSERC-CMIC, 2016).

Malartic is a well explored area within the Abitibi that has old databases of geochemistry available for use. Before legacy data can be modeled and integrated with new data, it must be explored and analyzed to determine whether or not it meets current standards.

Contrary to diamond exploration in Canada, geochemical pathfinders and mineral assemblages for gold deposits are poorly developed. Obviously, gold grains are the primary indicator mineral for gold mineralization (McClenaghan & Cabri, 2011). However, within the Abitibi, gold grains could come from a variety of sources. Developing geochemical pathfinders and indicator mineral suites for the Canadian Malartic Gold Mine could prove useful while searching for other Malartic type deposits within the Abitibi. Other methods such as hyperspectral imaging (SWIR; short wave infrared) can be tested as potential exploration tools for Malartic type deposits as well. Hyperspectral imaging has been done on bedrock from the Malartic deposit (Lypaczewski, et al., 2015) so Malartic is a good location for preliminary testing on till pebbles.

## 1.2 Geological Setting

Malartic is a town about 25 km west of Val-d'Or in Québec on the Superior Province. It sits on the Cadillac-Larder Lake Tectonic Zone (CLLTZ) which is an east-west trending fault zone with a steep dip (Helt, et al., 2014). The CLLTZ is a gold-bearing feature which runs from

Matachewan in Ontario to just past Val-d'Or where it ends at the Grenville Province (Wares & Burzynski, 2011). This zone also marks the boundary of the Abitibi and Pontiac Subprovinces. The Abitibi to the north is composed of alternating meta-igneous and metasediments, whereas the Pontiac to the south is made up of mostly metasediments. The southern most portion of the Abitibi Subprovince is the Piché Group. It is composed of talc-chlorite-carbonate schists formed from highly deformed and altered volcanics and forms the CLLTZ (Wares & Burzynski, 2011). The Pontiac Subprovince to the south also has a metamophic grade increasing southward from upper greenschist along the CLLTZ to amphibolite. Specifically, a garnet-in isograd occurs just south of the Malartic deposit and a staurolite-in isograd occurs another 1.7km south of the garnet-in isograd (Helt, et al., 2014). Both the Piché Group and the Pontiac Group have undergone felsic-intermediate intrusions and alterations associated with faulting (Helt, et al., 2014). Figure 1 shows the geologic setting and location of the Malartic property.

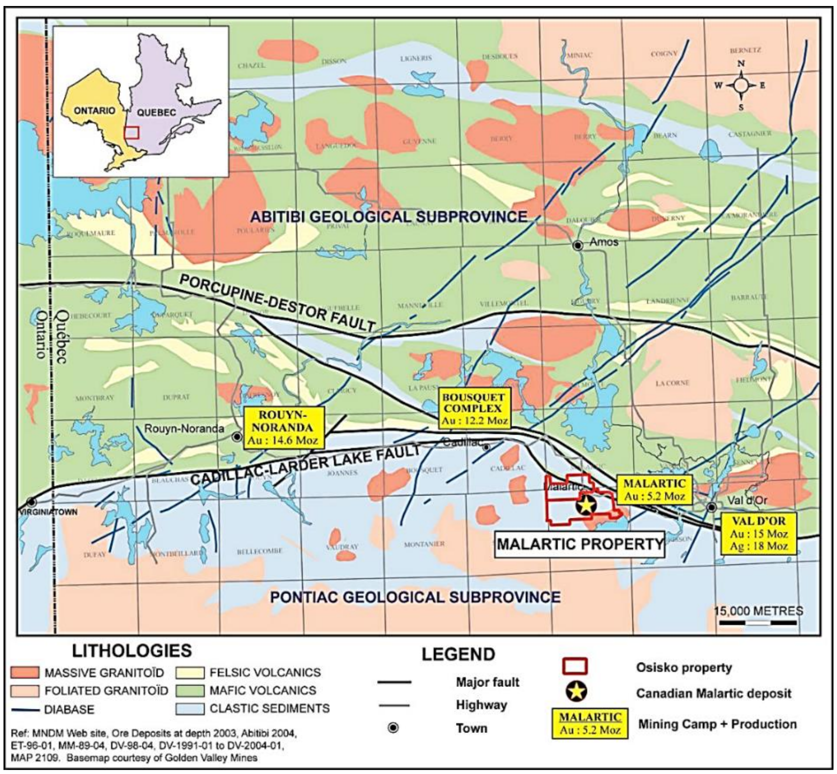



**Figure 1:** Regional Geology in the Malartic area. (Wares & Burzynski, 2011)

### 1.3 Canadian Malartic Gold Mine Geology and History

Mineralization occurs in the metasediments of the Pontiac Group and in porphyry intrusions which occur throughout the region. The Canadian Malartic Gold Mine was originally an underground mine following small veins of high grade (>3g/t) gold from 1935-1965 with several other mines also operating in the area until 1979. In May 2011 it was reopened as an open pit targeting low grade (approx. 0.5-2.0g/t) gold found in the metasediments of the Pontiac Group and porphyry intrusions. The gold occurs as small inclusions within disseminated pyrite crystals as a result of hydrothermal alteration. (Wares & Burzynski, 2011)

## 1.4 Previous Surficial Geology Work in the Area

### *1.4.1 Surficial Geology Map*

The Geological Survey of Canada released a surficial geology map covering the study area (Veillette 2004). The map shows the distribution at the surface of subglacial till, coarse glaciofluvial sediments, and glaciolacustrine fine sediments in the study area (Figure 2). Most of the surface till occurs to the southwest of the open pit. The rest of the study area has relatively thick glaciolacustrine and glaciofluvial sediment cover reaching up to 13 meters. This is an important complication for drift prospecting in the area; drilling is required to collect till samples across most of the study area. The map also includes ice flow direction indicators and an interpretation of the glacial history of the area. According to Veillette (2004), there are two main ice flow events that need to be considered; 1- An older southwest-trending ice flow phase which was continuous through the Abitibi, and 2- A second ice flow phase which developed as part of an interlobate system that formed the Moraine d'Harricana located east of Malartic. The lobe over Malartic flowed to the southeast (Veillette, 2004). The presence of the interlobate moraine indicates a thinner, weaker flow in the Malartic area during the second ice flow phase, which developed during deglaciation of the region. Most striations in the region indicated by Veillette (2004) record the second, south-southeast ice flow direction. Two markings with overlapping striae roughly 20 km from Malartic indicate an older ice flow trending southwest and south-southwest while both show a south-southeast flow direction in the second phase. It is proposed that ice flow in the region would have transitioned through time from southwest to southeast. One implication of this ice flow history is dispersal patterns may exhibit a fan shape showing provenance from the old southwest flow phase and the counter clockwise shift of ice flow ending in a southeast direction (seen in Figure 2 inset). Finally, secondary dispersal may have occurred through meltwater erosion and deposition of glaciofluvial sediments such as eskers and other related sediment deposits.

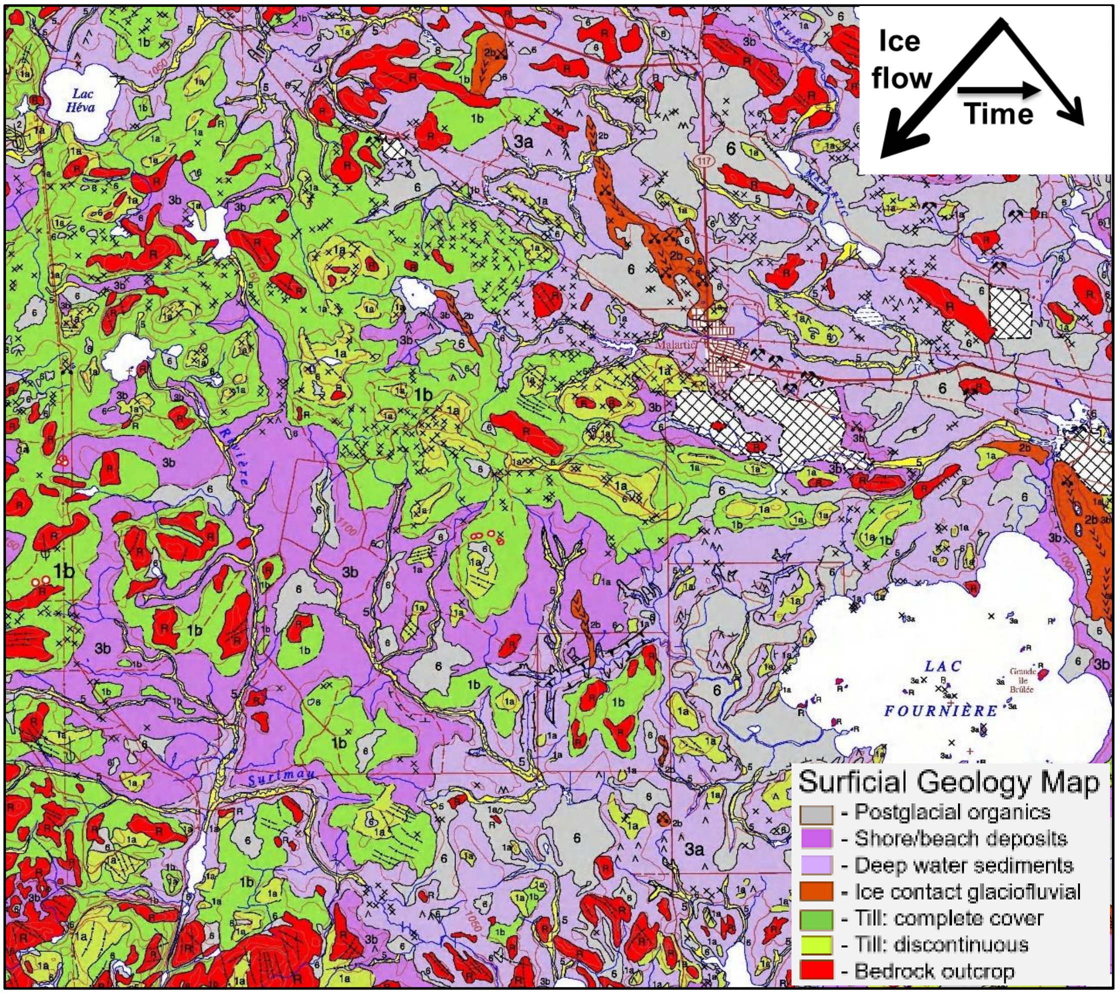



**Figure 2:** A portion of the surficial geology map produced by the GSC. Also the two main ice flow phases and their relative chronology for the Malartic region. (modified from Veillette 2004)

### *1.4.2 Groundwater Flow*

Certain geochemical pathfinders in surficial sediments may not be stable in the postglacial surficial environment and may move with groundwater creating dispersal patterns that may significantly overprint and alter the ones from glacial processes. It is thus useful to consider groundwater flow dynamics in drift prospecting studies as it may help explain complex patterns that cannot be explained otherwise. Groundwater in the region flows to the northeast as indicated on groundwater maps of the Abitibi (Groupe de recherche sur l'eau souterraine (GRES) - UQUAT, 2013). At a local scale, mining and other activities may have affected this general pattern, but it is assumed that groundwater has flowed to the northeast for most of postglacial times. Since the direction of ice flow phases is quite different than that of groundwater flow, we can assume that it is possible to confidently identify the main process responsible for dispersal patterns in the study area.

### *1.4.3 The Cadillac Project*

The Cadillac Project was a drilling program conducted by the Ministère de l'Énergie et des Ressources Naturelles du Québec (MERNQ) between 1971-1972. Of the 7000 samples collected during the project, 436 samples were taken in the Malartic area as shown in Figure 3. Portable hammer drills were used to sample the till between overlying glacial lake sediments and the underlying bedrock. Till samples were generally taken at regular, 0.5-1.0km intervals. The initial publication with geochemical results from these samples was on paper. Since then, the database has been digitized into excel spreadsheets and is now available on the Système d'Information Géominière du Québec (SIGÉOM), which is the main data repository system used by the MERNQ. There are a few potential problems associated with this data that need to be assessed before its use. One is the very regular spacing of till samples reported in an area where till is known to be discontinuous. There is also no description of the material type sampled making it impossible to identify sampling media other than till, such as glaciolacustrine mud, for example. The digitization process itself is a point of concern as there is often a certain proportion of error introduced in any data format transfer operation.

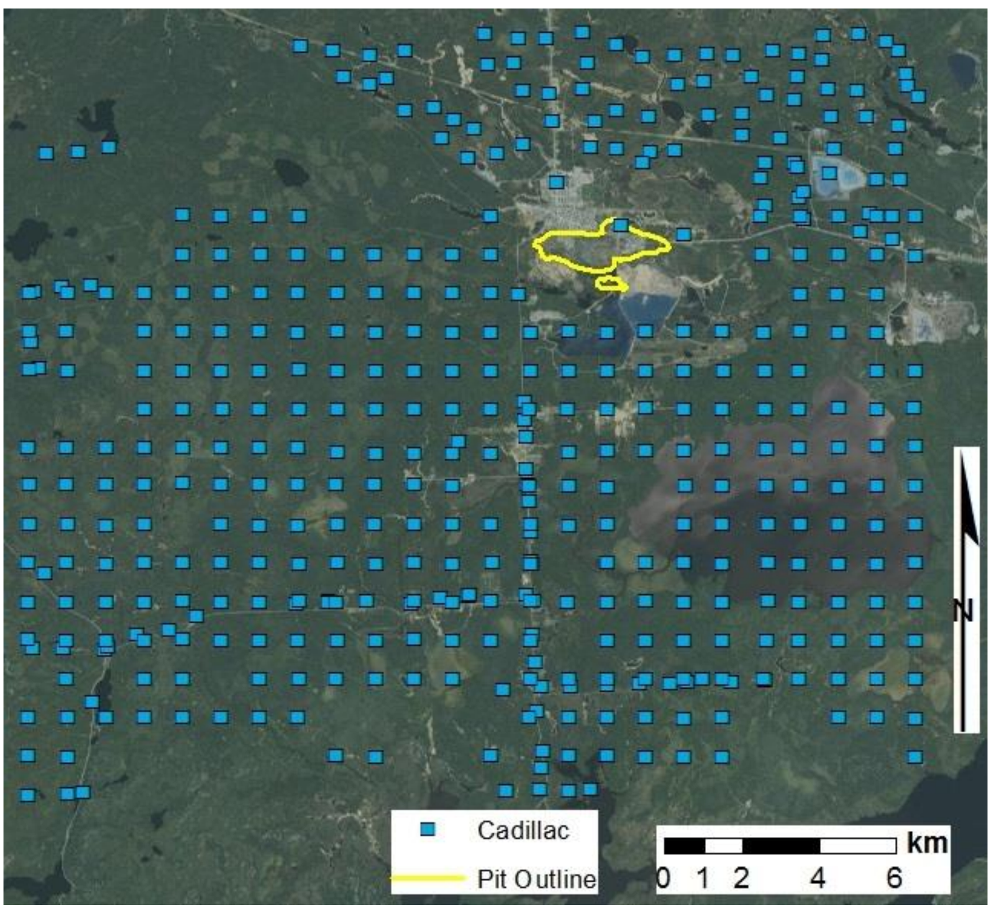



**Figure 3:** Cadillac Project sample locations in Malartic area, solid yellow outline represents pit location. (SIGÉOM, 2015)

### 1.5 Project Goals

There are two objectives that are being addressed in this study.

First and foremost is to determine whether surficial geochemistry data from the Cadillac Project (1970s) can be used today. The data has a very consistent distribution of till sample collection points and no recorded clay content to normalize the data with. It is an old dataset that has been digitized since it was published and very little is known about material types. If validated, it is a large database that would be valuable for finding indicator minerals and geochemical pathfinders for the Malartic deposit.

The second objective is to assess whether rutile and hyperspectral imaging can be used to trace Malartic-type gold deposits in glacial sediments. Although the use of gold grains is the primary form of surficial exploration for gold deposits where bedrock is overlain with till (McClenaghan & Cabri, 2011), there is potential for using other minerals such as sulphides, sheelite, and rutile as indicators as well (McClenaghan & Cabri, 2011; Clark & Williams-Jones, 2004). The first method is to use a specific composition of rutile as an indicator. Rutile is much more abundant in comparison to Au and it may also be better at fingerprinting specific mineralization footprints. This may be quite useful in a region such as the Abitibi where gold grain counts may be high in general with as many as 20 gold grains per 10 kg till sample (Averill, 2001). Rutile has been shown to have compositions with higher Tungsten (W) content in mesothermal gold deposits (Clark & Williams-Jones, 2004). Analyzing the dispersal patterns and tungsten rich rutile in the till around the Malartic deposit may help to refine exploration methods for other low-grade, mesothermal, gold deposits within the Abitibi. Au and W geochemistry will be used as a proxy for W rich rutile and correlating W rich rutile with higher Au levels in the till. Hyperspectral imaging is another innovative approach that has yet to be tested for prospecting in surficial sediments. This thesis will test if the hyperspectral signature of the Malartic deposit is reflected in the surface till.

## 2.0 Research Methodology

### 2.1 Methods

Testing the validity of the Cadillac data will rely on fieldwork done in 2015, maps produced in ArcMAP, and data exploration analysis techniques (Q-Q plots) (Grunsky, 2010). Careful examination of the database preparation and structure will be performed. Mapping specific anomalies (Au and W) will demonstrate patterns within the database linked to the Malartic deposit. These patterns in the Cadillac data will be compared with geochemistry patterns seen in the 2015 data for similarities. Leveling and methods to identify anomalies will be explored as well.

Investigating W-rich rutile as an indicator for Malartic type deposits will rely on 2015 fieldwork. Based on the dominant ice flow in the region, W-rich rutile is expected to occur in the till to the southwest of Canadian Malartic. Till samples will provide geochemistry that will be used to plot Au and W patterns in the area as a proxy for W-rich rutile.

To test hyperspectral imaging as a potentially useful exploration tool, clasts from an esker and two draping fan units will be compared. Figure 4 shows the extrapolated esker path moving from northwest to southeast across the mine site as well as the sample locations (2 samples located at the southwest site). It is expected that more of the esker pebbles will show a hyperspectral signature similar to the Malartic deposit rocks compared to the fan because the sediment facies of the esker core is thought to be related to high energy meltwater flow, likely involving direct bedrock erosion across the Malartic footprint area, and rapid deposition. The draping fan may have formed through more complex processes leading to a more heterogenous pebble provenance and thus composition. Imaging will also be done on the clasts from the till surface samples.

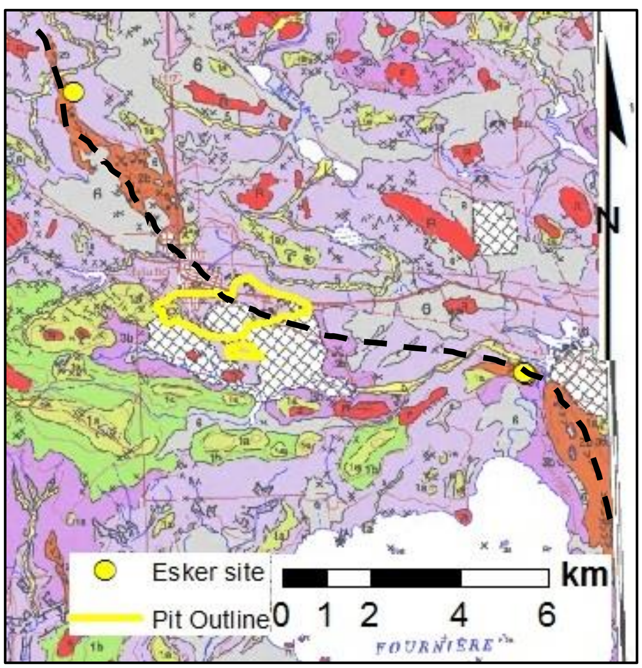



**Figure 4:** Surficial geology map with extrapolated esker path (dotted black) moving from northwest to southeast.

### 2.2 Sample Collection

In May and June of 2015, field work was done in the Malartic region. Surface samples, drill samples, and esker/draping fan samples were taken (Figure 5).

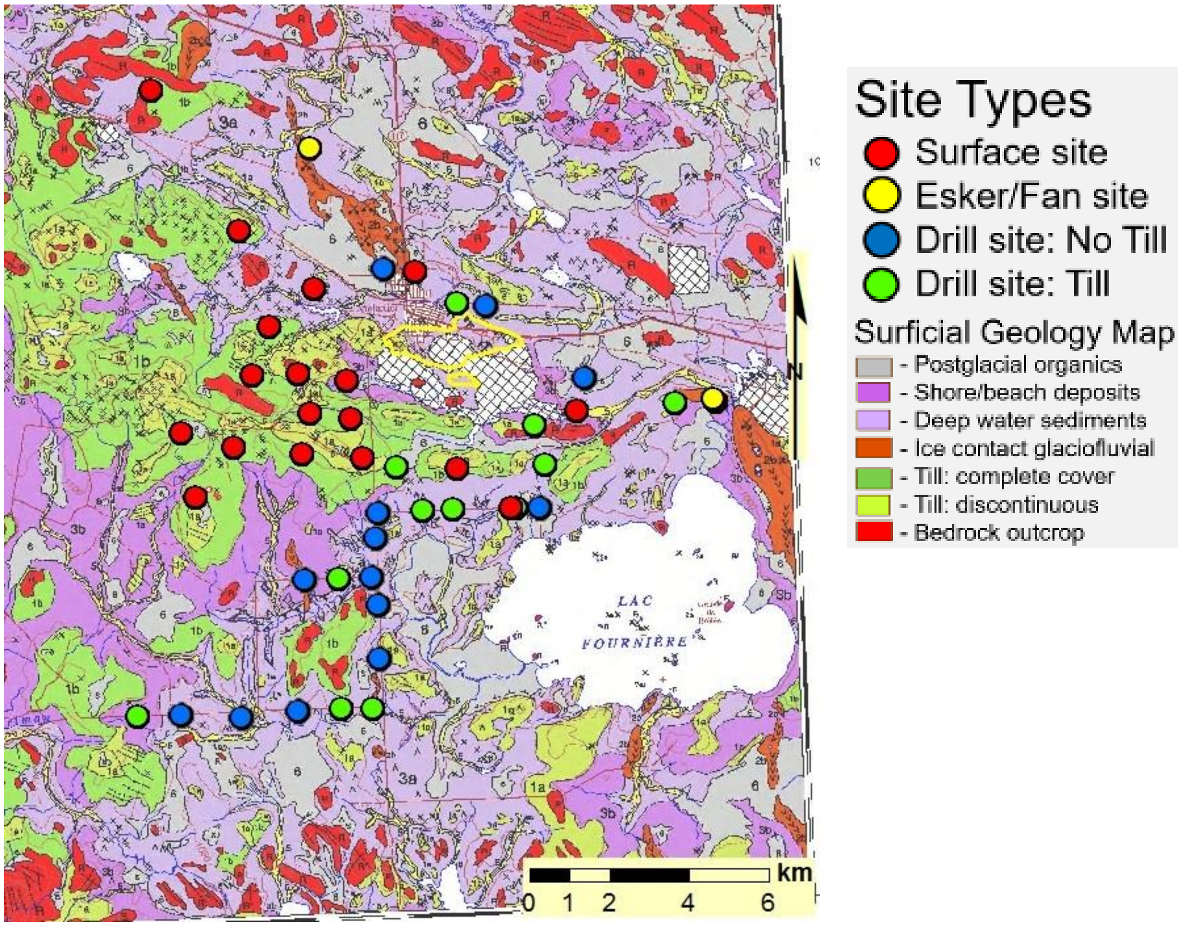



**Figure 5:** All 2015 sample locations.

### *2.2.1 Surface Samples*

The surface samples were all till material and were located mostly to the southwest of the mine as this is the area with the most uncapped till. Since the primary ice flow direction in the area was to the southwest, indicator minerals are predicted to occur more in the till in a southwest direction from the mine site. Some samples were located to the south and southeast to cover other possible vectors of dispersion, as well as in the up ice directions to determine background composition. McMartin and Campbell (2004) recommend sampling in the C-horizon (>75cm) but above the water table. The region around Malartic has a very high water table in the spring which made it difficult to obtain a deep sample without flooding the hole before till could be collected. As a result, surface material sampling generally began in the lower B horizon at a depth of 40 cm where the till transitioned from red weathered material to green-gray unweathered till (Figure 6). In total, 18 surface till samples were collected with an average weight of 12.6kg, a minimum of 8.8kg, and a maximum of 15.5kg.

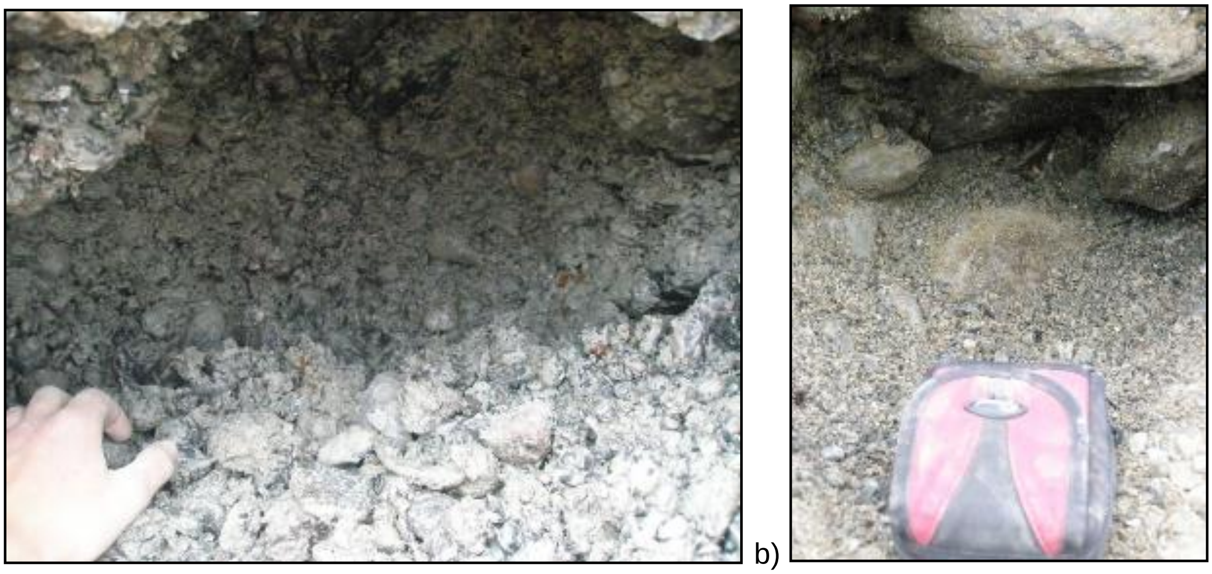

**Figure 6:** Soil horizons showing the transition from the weathered upper B horizon to the grey/green lower B/upper C horizon.

#### *2.2.2 Drill Samples*

Drill sites were all located on areas where glacial lacustrine material was at the surface. Drilling was done with a Pionjar Hammer Drill, the size of which restricted sampling to roadways on and off the mine property. The same method was used as during the Cadillac Project; the material at the overburden-bedrock interface was sampled. Samples collected were sorted into till, glaciolacustrine mud, and 'other' material which was mostly sands. In some cases there was a thin enough layer of till that the sampler was filled with mud on the top and till in the bottom. In these cases the mud and till were separated into different bags. A total of 26 sites were drilled at depths ranging from 1.22m to 13.1m with a mean of 5.67m. One of these sites was located at a surface sample site for comparison, this sample will be excluded from the drill site total bringing it to 25 sites.

#### *2.2.3 Esker/Fan Samples*

The esker and one of the draping fan samples were taken from a gravel pit used by Canadian Malartic to the east of the main pit. The esker sample was clast supported with clay coatings on the clasts (Figure 7a). The draping fan unit overlay the esker, was weakly imbricated, and had a sandy matrix (Figure 7b). Although the esker core was not located to the northwest of the mine, a draping fan deposit was sampled to compare lithologies and geochemistry of material upstream and downstream of the mine property.



a) b)

**Figure 7:** Draping fan and esker photographs from locations east of main pit; a) esker sample showing clasts with clay coating, b) draping fan showing weak imbrication from top right to bottom left

## 2.3 Sample Processing

### *2.3.1 Surface Samples*

The surface samples taken during field work have been sieved into 4 fractions, each with a different purpose. The >8mm fraction is for clasts counts to confirm the primary ice flow dispersion direction (southeast) suggested by Veillette (2004), for lithology comparisons, and for hyperspectral imaging. The categories of sorting are: metasediment, mica-rich metasediments, igneous, quartz veins, and miscellaneous. There was an average of 284 clasts per sample with a maximum of 512 and minimum of 56. The 8-2mm fraction has been archived. Grains between 2mm and 63μm have been sent for heavy mineral content (HMC) (rutile, Au) which was not complete at the time of writing. The <63μm portion was analyzed for geochemistry as well as laser diffraction, using a Fritsch Analysette 22, for grain size distribution. Geochemistry was performed at Saskatchewan Resource Council (SRC). All sieving and laser diffraction was done at the University of Waterloo.

### *2.3.2 Drill Samples*

The drill samples are about 50-100 grams each and were analyzed for geochemistry. They were first sieved (wet or dry depending on material type) at 63μm and weighed at the University of Waterloo. Laser diffraction (Fritsch Analysette 22) was performed on most samples for grain size distribution before shipping. However, 6 samples did not have enough material to do both laser diffraction and geochemistry, no laser diffraction was performed on these samples. Only the <63μm portion of the samples were sent and analyzed by SRC. 2 SRC packages were run for geochemistry: ICMPS1 and Au1. ICPMS1 is a “sandstone exploration” package. This analysis includes partial and total digestion of the samples. Partial digestion uses a mix of $HNO_3$:HCl, total digestion uses HF:$HNO_3$:$HClO_4$ followed by dissolution in dilute $HNO_3$. Au1 is a standard fire assay using $HNO_{3-}$ and aqua regia. (Saskatchewan Resource Council, 2015)

#### ***2.3.3 Esker/Fan Samples***

The esker and draping fan samples were treated the same as the surface samples with sieving at screen sizes of 8mm, 2mm, and 63µm. Laser diffraction was performed on the <63µm fraction. SRC ran geochemistry on the <63µm fraction. The 2mm–63µm fraction was sent for HMC. Once the clasts (>8mm) for these samples were sorted into intrusive or metasediment they were shipped to the University of Alberta where Philip Lypaczewski took hyperspectral images of them using Short Wave InfraRed – SWIR (1000-2500nm wavelength) (Lypaczewski, et al., 2015).

## 3.0 Results and Discussion

### 3.1 The Cadillac Data

#### ***3.1.1 Field Observations: Collocated Site Lithology Comparison***

Depths reported from the Cadillac Project were consistent with depths found during 2015 sampling. However, the Cadillac Project reports a till sample at every site at even intervals whereas clear evidence for discontinuous till was found during field work in 2015. Of the 25 sites drilled, only 12 recovered till. Nine of the remaining samples were glaciolacustine muds and the last 4 were generally sandy. This means only 48% of drill locations were till. Figure 8 shows the 2015 drill sites overlain with the Cadillac data points. A few notable areas are circled where 2015 drilling found glaciolacustrine material in the vicinity of a Cadillac project ‘till’ sample site.

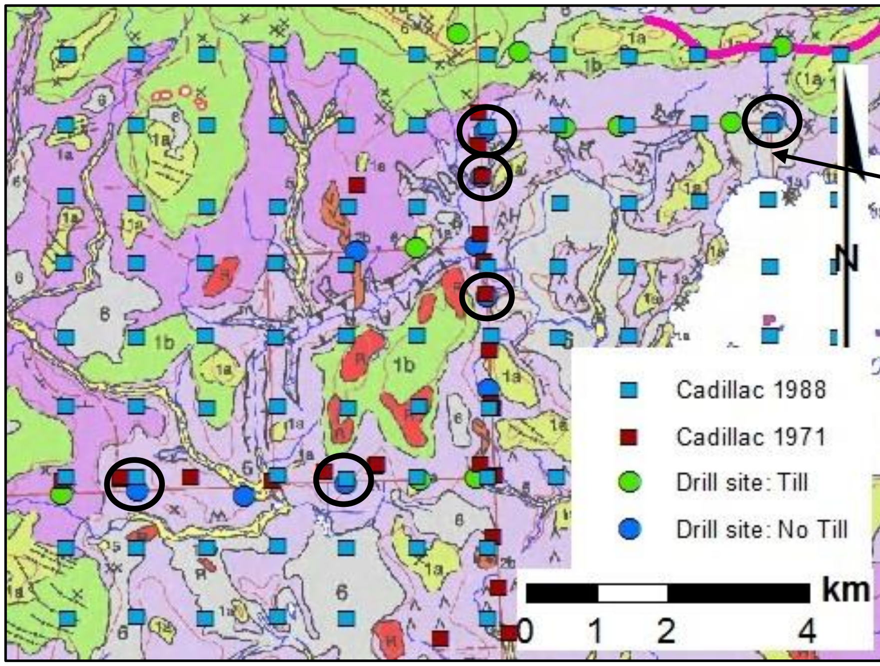



**Figure 8:** Cadillac and 2015 drill site comparison.

**Figure 9:** Glaciolacustrine material seen to directly overlie bedrock with no till in between near a Cadillac 'till' sample.

Figure 9 shows a location where glaciolacustrine mud directly overlies bedrock outcrop (seen in top left) with no till in between. However, a Cadillac 'till' sample is indicated nearby.

However, original reports may have more information than was transcribed into the digital database. The 1971 database, for example, has several sheets that have the data points with a number beside it indicating material type as clay, till, and possibly till.

### *3.1.2 Processing of Cadillac Samples (from Reports and Dataset)*

Processing of samples taken in 1971 involved sieving at 177µm. The finer fraction was digested in hot $HNO_3$ for half an hour before Cu, Zn, Pb, Ni, Co, Mn, and Ag were determined by atomic absorption (LaSalle, et al., 1982). The >177μm material was split at a density of 2.85g/cm$^3$. The <2.85g/cm$^3$ had atomic absorption performed providing the same 7 elements as in the fine fraction. The >2.85g/cm$^3$ was grinded and sieved before also undergoing atomic absorption (unknown, n.d.). Then x-ray fluorescence provided Rb, Sr, Y, Zr, Nb, and Mo on the remaining >2.85g/cm$^3$ material (Kish, et al., 1979). In 1985, the remaining fine fraction material from sampling was analyzed for Au, As, Sb, and W by neutron activation analysis (LaSalle & Henry, 1987). There have been no reports or record of methods found for the 1988 dataset.

### *3.1.3 Database Collection, Structure, and Description*

There are a total of 555 samples in the Cadillac database for the Malartic area. All of the samples are labelled as being taken with a pionjar (a portable hammer drill) and are invariably described as till material. Each sample in the database has the sample ID, coordinates, basic description (grain size fraction), depth, loss on ignition, and geochemistry of the material sampled. The mean depth to bedrock was 5.96 m with a range of 0-30.6 m. There are a few different parameters that the database can be divided and regrouped according to. The first is by year (Figure 10).

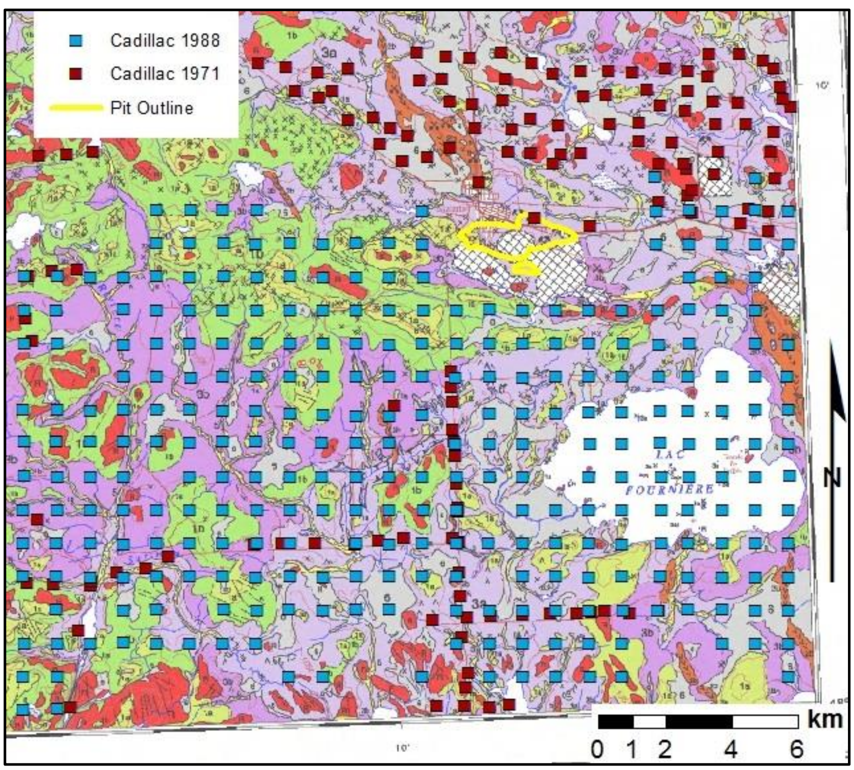



**Figure 10:** Cadillac database split by year into 1988 and 1971 datasets.

The 1988 samples are all labelled as fine fraction till samples. There are a total of 293 samples in the 1988 database and each has geochemistry on 47 elements.

Within the 1971 sample descriptions, there is a fine fraction (FF), heavy fraction (FLo), and light fraction (FLé) each. They are all labelled 'till' but some of the samples are marked with a 'b' as well. An explanation of what the 'b' means has not been located in original papers. All of these samples are at depth so it likely means basal till as opposed to the other till samples which have shallow depths as well. Next, when sorted by coordinate sites, a grouping of the different size fractions is revealed. However not every size fraction is present at every location. The fine fraction has geochemistry on 11 elements, the heavy on 13, and the light fraction on 7. When coordinate duplicates are removed from the 1971 database, 143 sample locations are left of the original 262. Figure 11 is a flow chart of the database divisions with total sample numbers in brackets.

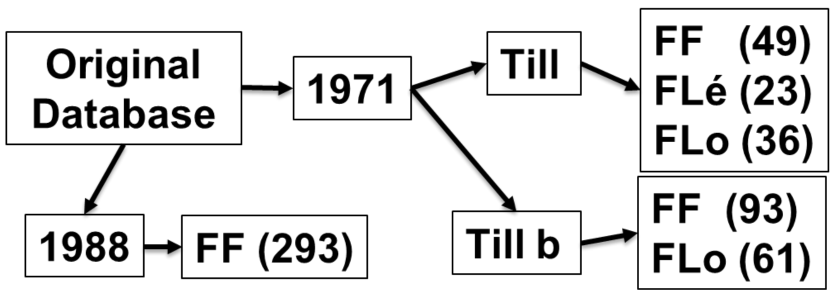



**Figure 11:** Flow chart of Cadillac database structure divisions. Number in brackets indicates how many samples are of that type. Fraction fine (FF), Fraction Légère (FLé), Fraction Lourdes (FLo). Till b means basal till.

#### *3.1.4 Geochemistry Levelling*

The Cadillac database has several datasets with varying years, analytical methods, detection limits, and procedures (cf. sect. 3.1.2). It may thus need to be levelled before it can be integrated and used as one (Grunsky, 2010). However, data should only be leveled when the material, preparation, and analytical methods are the same. Since little is known about the 1988 data, it is unwise to level and use this data. Here it will be levelled as a demonstration of the method only and the integrated data will not be used further. The 1988 dataset is exclusively the fine fraction of material (FF). This means that the 1971 fine fraction (FF) is the only data that can be levelled to the 1988 dataset. To begin, the sets are ordered in ascending geochemical value. The values from the larger dataset (1988) were ranked and then selected based on values from a random number generator. The two sets can then be plotted against each other. Figure 12 shows the resulting plot and clearly indicates that the 1971 values are systematically higher than the 1988 values. To level the 1971 to the 1988 dataset, the equation of the line of best fit needs to be brought to a slope of 1 with a multiplier (0.27037) and changed to pass through the origin by vertical shift (-0.4143). During generation of the linear trend line the outliers where ignored so that the majority of the sample points are levelled properly. However, the outliers were levelled with the rest so there is consistency within the dataset.

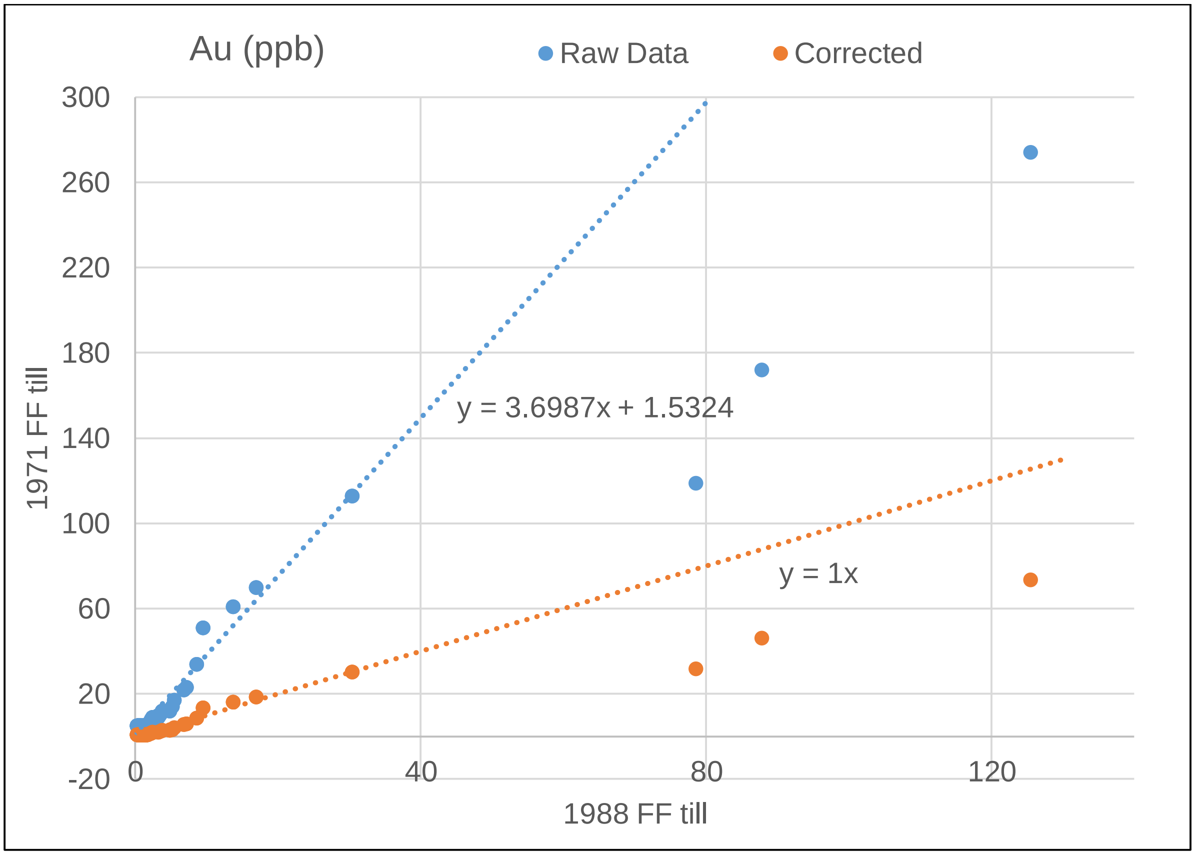



**Figure 12:** 1971 vs 1988 datasets plotted for levelling with linear trend lines in the same colour (top 3 anomalies excluded from trend line generation). Blue shows raw data plot, orange shows corrected data with a multiplier of 0.27037 and a vertical shift of -0.4143.

### 3.2 Rutile as an Indicator (W and Au as a proxy)

Tungsten (W) and Au are two useful pathfinders in this study. Rutile associated with mesothermal gold deposits is known to have an elevated W content (Clark & Williams-Jones, 2004) and is part of the bedrock footprint at Malartic. Q-Q plots for both Au and W were created from the 2015 datasets with the material type plotted in different colours (Figure 13). Note that all of the anomalies are till material. The highest 'other' red point is likely a reworked till sample with residual till geochemical properties. The anomalies from these plots were located on a map and highlighted (Figure 14).

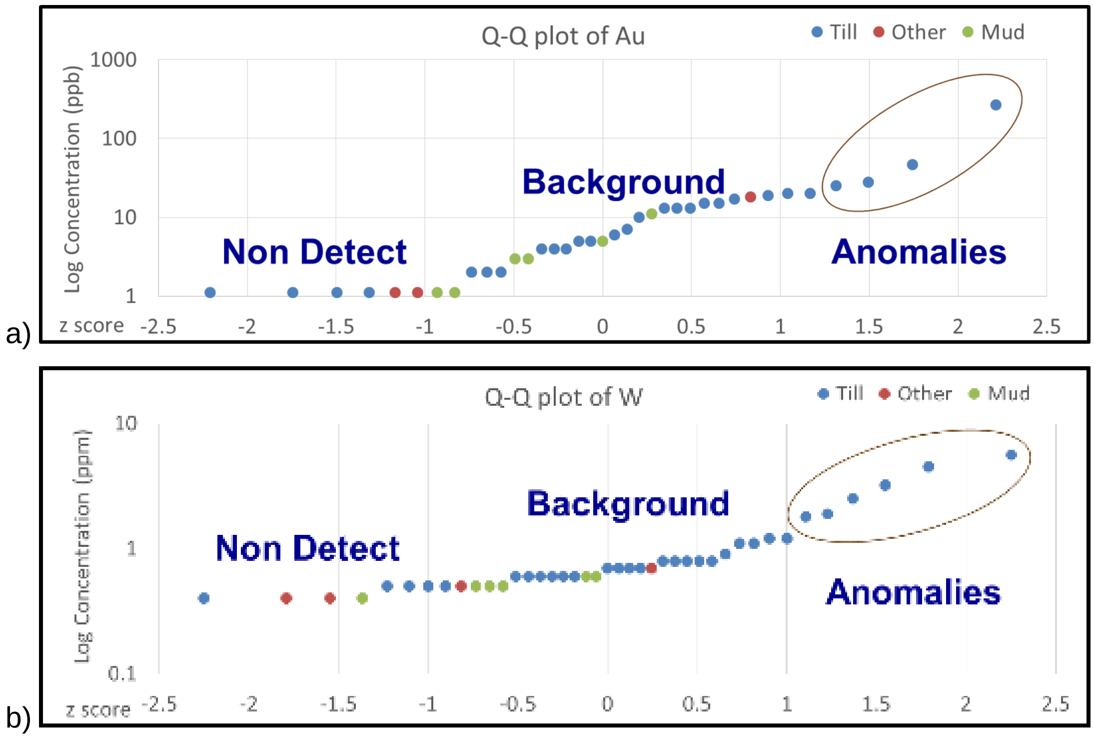



**Figure 13**: Q-Q plots of 2015 Au and W with different material types labelled. a) Au plot with 4 anomalies, b) W plot with 6 anomalies

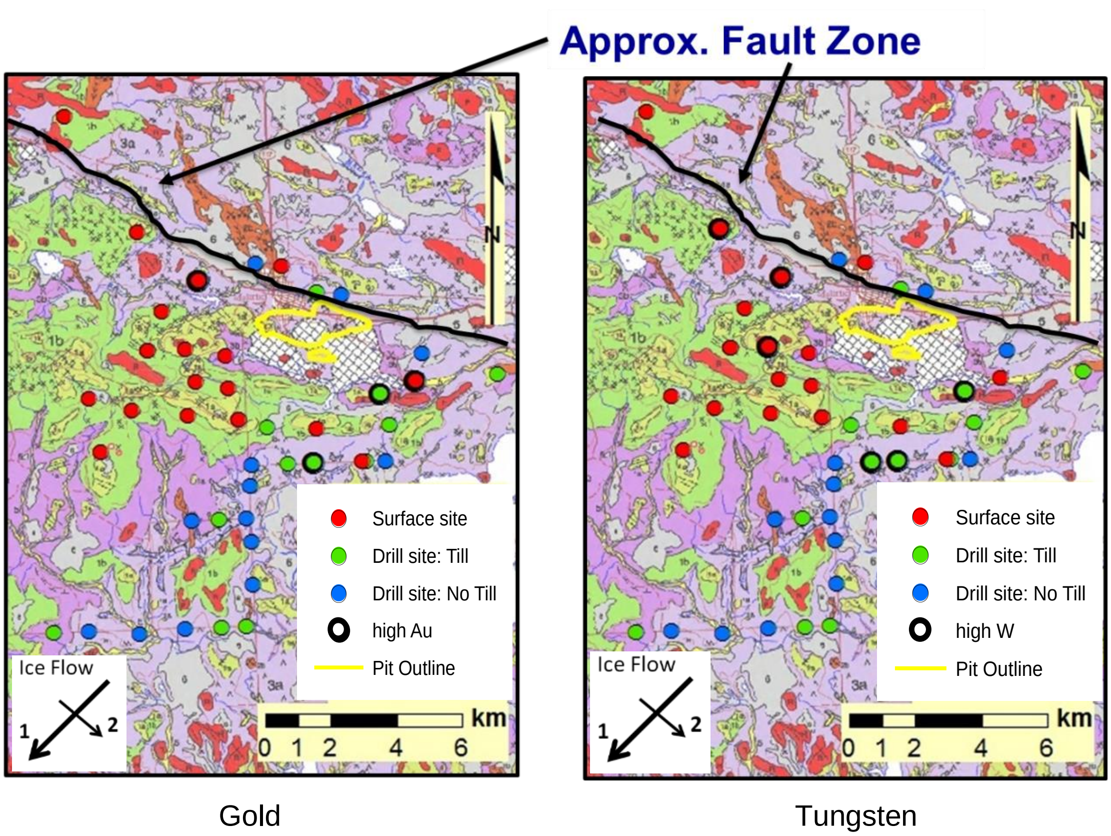



**Figure 14:** 2015 sample sites with Au and W anomaly locations outlined.

The area where both Au and W are anomalous is at most 3.2 km down-ice of the mine or the CLLTZ (the main footprint area).

The same analysis was performed on the 1988 dataset to see if similar anomalies and associated patterns occur with that data (Figures 15, 16).

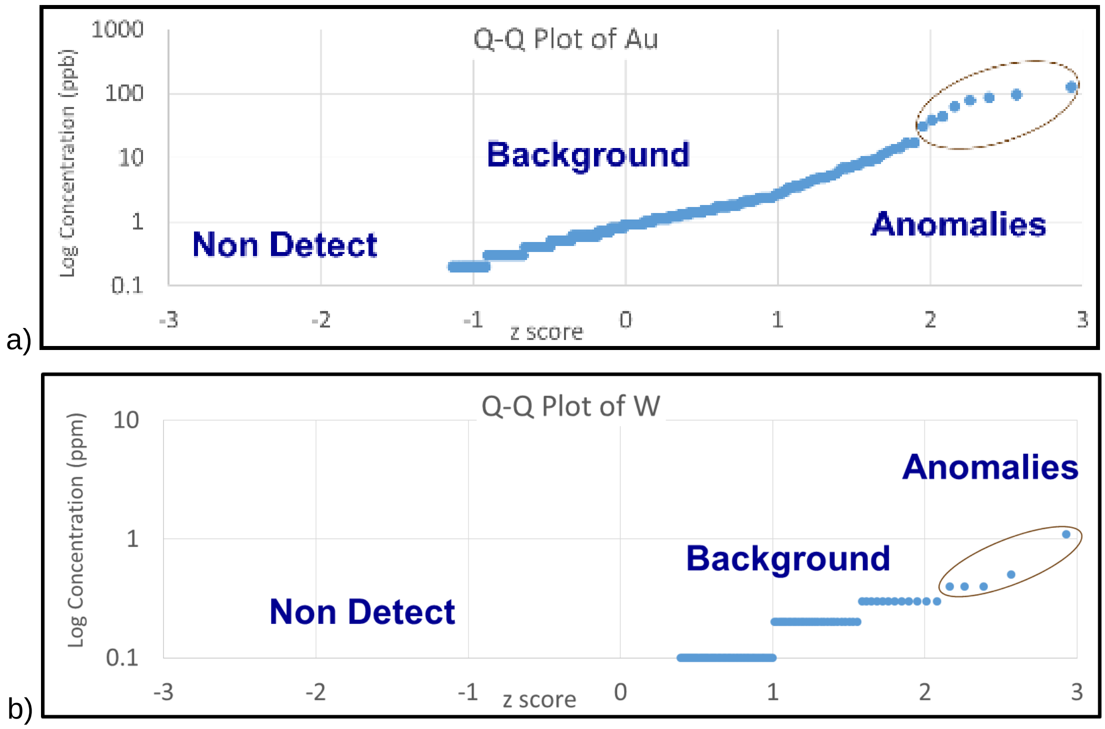
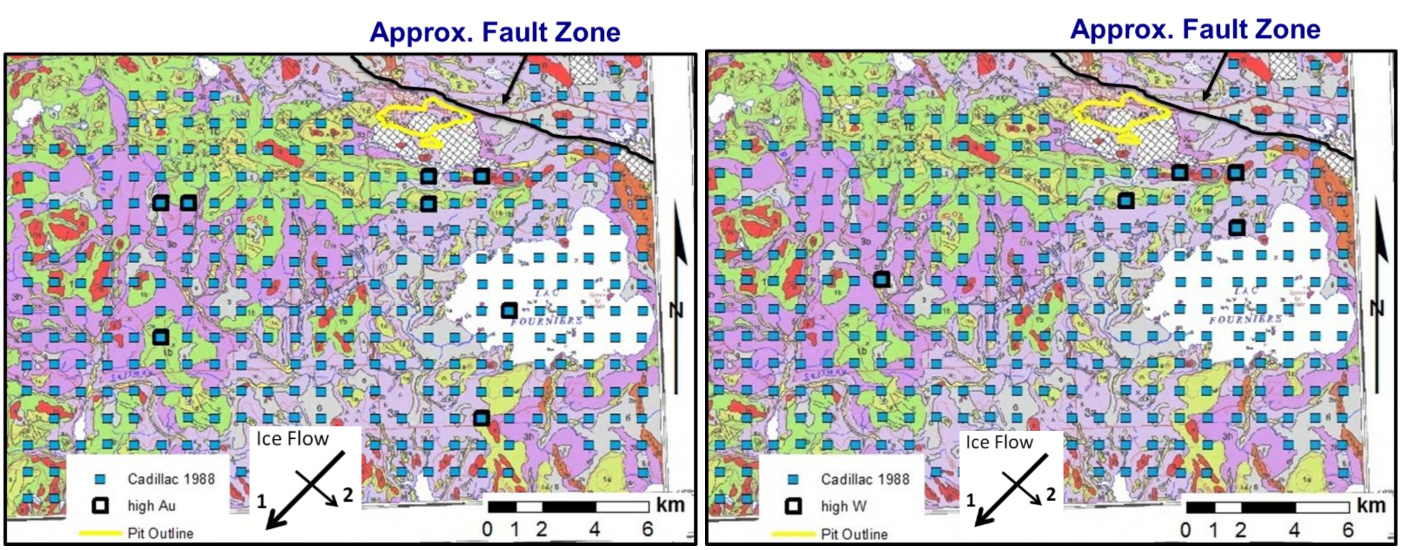



**Figure 15:** Q-Q plots of Au and W from Cadillac data. a) Au with 8 anomalies, b) W with 5 anomalies.




Gold Tungsten

**Figure 16:** Au and W anomaly locations from the 1988 Cadillac data shown in relation to the deposit and the CCLTZ.

There are a few more isolated Au anomalies in the Cadillac data than what is seen in the 2015 data, but the small group of three anomalous sites south of the mine is spatially consistent to a similar group of anomalies in the 2015 data (cf. Fig. 14). The W distribution is concentrated near the mine property and the CLLTZ with only one anomaly lying to the far southwest. Figures 14 and 16 show that the one place where Au and W anomalies are found in close spatial proximity is south and southeast of the mine. This suggests that a dispersal pattern extends from the main footprint zone in the direction of the youngest ice flow phase. This relative spatial consistency between the 1988 and 2015 data also suggest that the legacy data is valid and can be used in the project. Nonetheless, more data north of the fault is necessary, as well as results from heavy mineral concentrates (i.e. gold grains and rutile) to test this interpretation further.

## 3.3 Hyperspectral Imaging

### *3.3.1 Hyperspectral Imaging in Malartic*

The white micas in the Malartic deposit have a phengitic composition which has an absorption wavelength of 2195-2200nm in hyperspectral imaging (Lypaczewski, et al., 2015). Imaging was done on all of the 10 kg surface samples and on a subset of the esker/draping fan samples at wavelengths of 2190-2220nm. Figure 17 is the hyperspectral image of the large metasediment pebbles from the draping fan sample up gradient of Malartic as well as the colour scale used. Two ways of counting the portion of clasts over both 2205nm (the signature around the deposit area) and 2210nm (the signature specific to deposit) were used. The first calculated the number of pixels of clasts with colours indicating wavelengths over 2205/2210 and divided it by the total number of pixels with absorption wavelengths between 2190-2220nm. The second was by manual counting of the clasts. The amount of clasts with colours over 2205/2210 were divided by the total number of coloured clasts in the image. To test the different methods, the results were plotted against each other (Figure 18). It is clear that both methods generate similar result. For this study the pixel counting method was used.

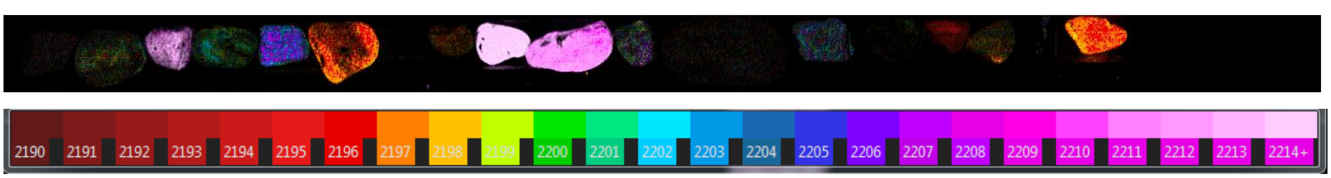



**Figure 17:** a) Hyperspectral image of draping fan sample, b) Colour scale bar. Large sized metasediment pebbles showing 3 above 2205nm wavelength.

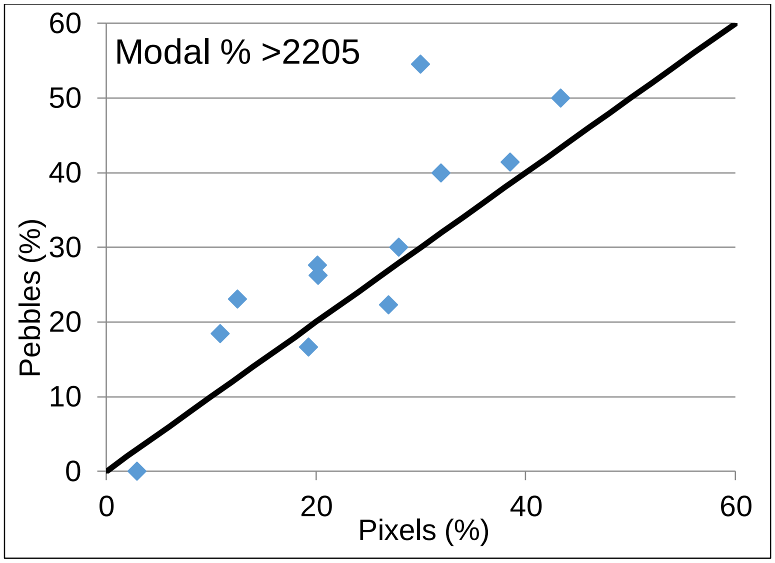



**Figure 18:** Pixel % vs Pebble %.  This shows the correlation between both methods.

### *3.3.2 Surface Till Samples*

Selected hyperspectral images on the clasts from the surface till samples are presented on Figure 19.  It shows the spatial distribution of the results. There is a cluster of samples with white micas southwest of the mine. This could represent a dispersal pattern associated to the older southwest ice flow phase; more samples are necessary to increase confidence in this interpretation.  It is worth noting that surface till sampling was biased to the southwest of the mine property due to glaciolacustrine cover and/or lack of till in the other directions. It will thus represent a challenge to collect more 10kg till samples to refine the pattern. Nonetheless, it is interesting that the apparent dispersal patterns from the pebble and hyperspectral data differ from the ones associated with the geochemical Au and W anomalies (cf. sect. 3.2). The pebbles appear to show greater inheritance from the older southwest ice flow phase, whereas the geochemical anomalies of the fine fraction seem to show a greater influence from the younger south and southeast flow phases. More research is necessary to understand this difference, but one possibility is a change in subglacial dynamics that would have led to differences in erosional mechanisms between the different ice flow phases. For example, quarrying/plucking could have been an important process during the southwest ice flow phase, generating large clasts, whereas abrasion could have been more dominant in the younger phases, thus producing stronger dispersion in the fine fraction.

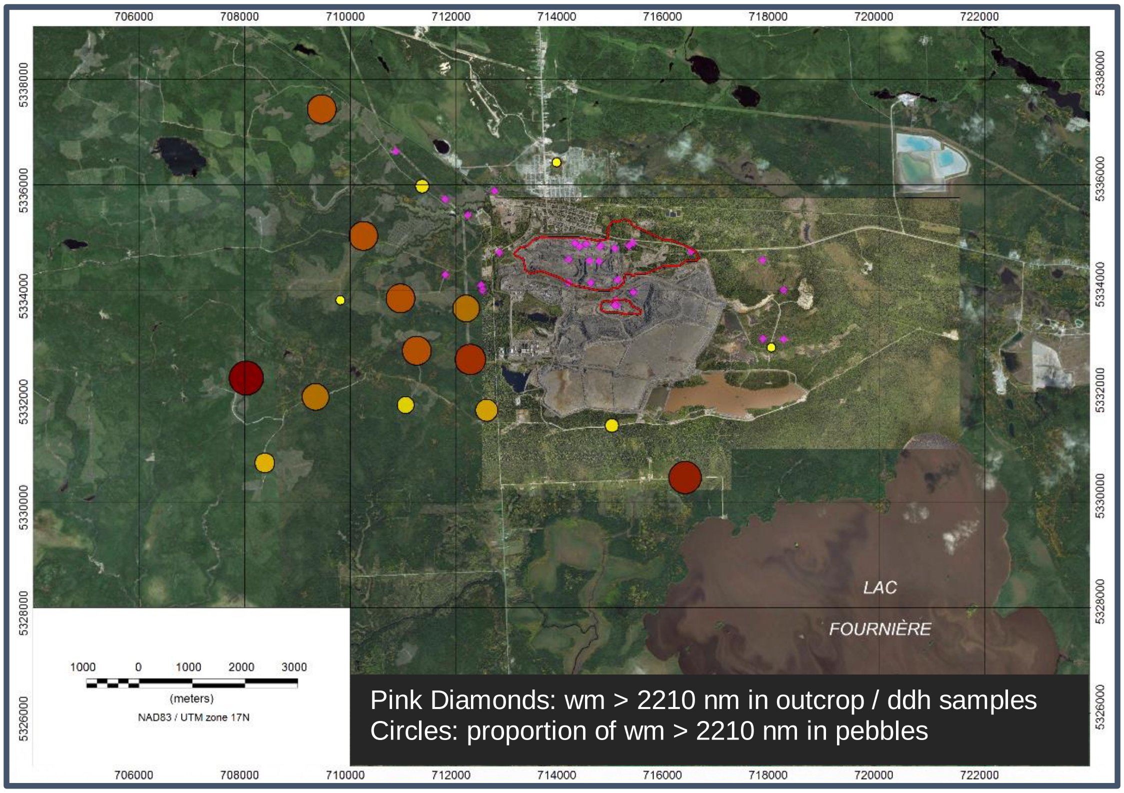
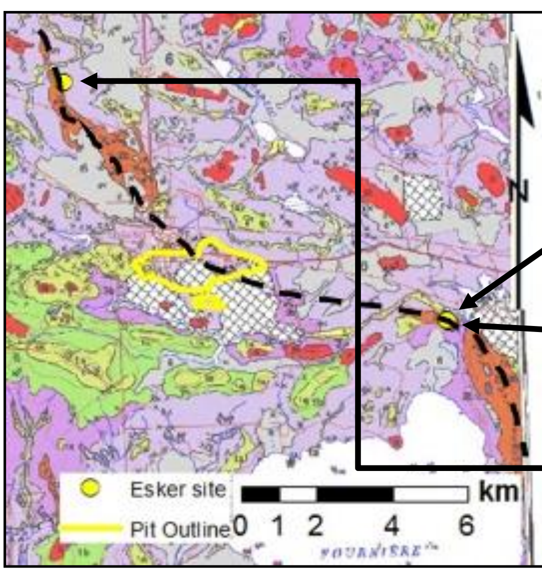



**Figure 19:** Hyperspectral on surface samples (>10kg) showing a weak pattern to the southwest, wm is white mica.

### *3.3.3 Esker, Draping Fan Samples*

The table in Figure 20 shows the pixel modal percent for the clasts above 2205 nm and 2210 nm in the different clast size and lithology fractions.




| Samples 18, 21, 47 | Modal % >2205 | Modal % >2210 | |
|---|---|---|---|
| 18_L_Int | 31.9 | 6.5 | Draping Fan |
| 18_L_Sed | 2.9 | 0.0 | |
| 18_M_Int | 20.1 | 5.3 | |
| 18_M_Sed | 19.3 | 2.1 | |
| 21_L_Int | 10.9 | 0.7 | Esker |
| 21_L_Sed | 30.0 | 6.5 | |
| 21_M_Int | 26.9 | 4.8 | |
| 21_M_Sed | 27.9 | 2.4 | |
| 47_L_Int | 12.5 | 0.8 | Draping Fan |
| 47_L_Sed | 43.3 | 33.7 | |
| 47_M_Int | 20.2 | 5.0 | |
| 47_M_Sed | 38.5 | 26.2 | |

**Figure 20:** Hyperspectral results for esker and draping fan locations using the pixel % method. L = large, M = medium, Int = intrusive, Sed = metasediment

It is shown that the metasediments in the esker have higher values than the metasediments of the collocated draping fan. However the intrusives of the draping fan are generally higher than the intrusives in the esker. Since the white micas of interest are in the metasediments, it can be stated that the metasediment comparison between the esker and collocated draping fan suggests the esker has the deposit signature and the draping fan does not.

However, high values in the metasediments were obtained from the draping fan sample located northwest of the mine. Since meltwater was flowing to the southeast in the study area, these clasts are unlikely to have been transported from the deposit. These problematic results could be explained in two ways; 1- poor lithological sorting or 2- phengitic micas occur northwest of the fault and the deposit. For the first potential cause, it is important to note that clasts from these samples were sorted on site in Malartic. Errors were likely made in differentiating fine grained extrusive rocks of the Abitibi from metasediments. The second potential cause is due to the lack of knowledge regarding the hyperspectral signature of lithologies north of the fault. It is possible that metasediments contain similar phengitic white micas in that area with implications for defining the footprint using hyperspectral imaging. Therefore, it will be important to investigate these issues.

### 3.4 Clast Counts

Figure 21 shows the initial clast count categories except for miscellaneous clasts. The varied metasediments were later combined for pie charts added over a bedrock geology map.

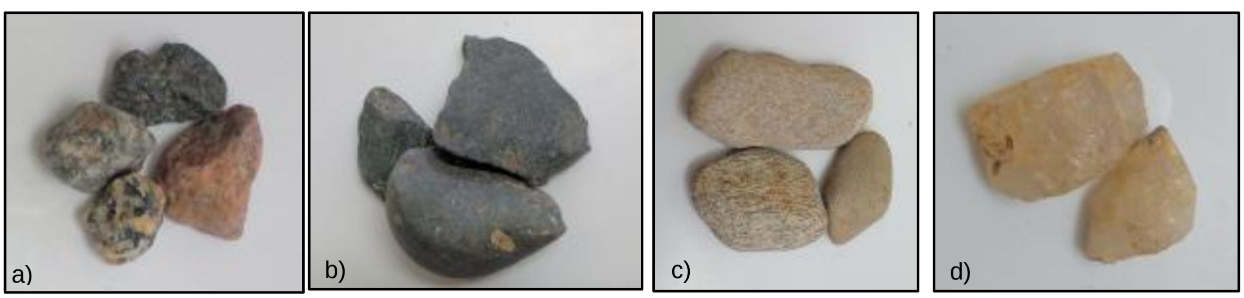



**Figure 21:** Clast sorting categories: a) Igneous, b) Metasediments, c) Mica-rich Metasediments, d) Quartz, and Miscellaneous (not shown). Metasediments (b and c) combined for pie charts.

There are two main things to note regarding the sorting. One is the distribution of quartz clasts. Quartz veins mineralized with Au are associated with fault zones and form higher grade stockworks near the northern edge of the Malartic property (Wares & Burzynski, 2011). Figure 22 shows the sorting results with quartz proportions higher than 2% circled in black. Their distribution forms a pattern elongated more or less parallel to the main bedrock structures and extends to the southwest and south.

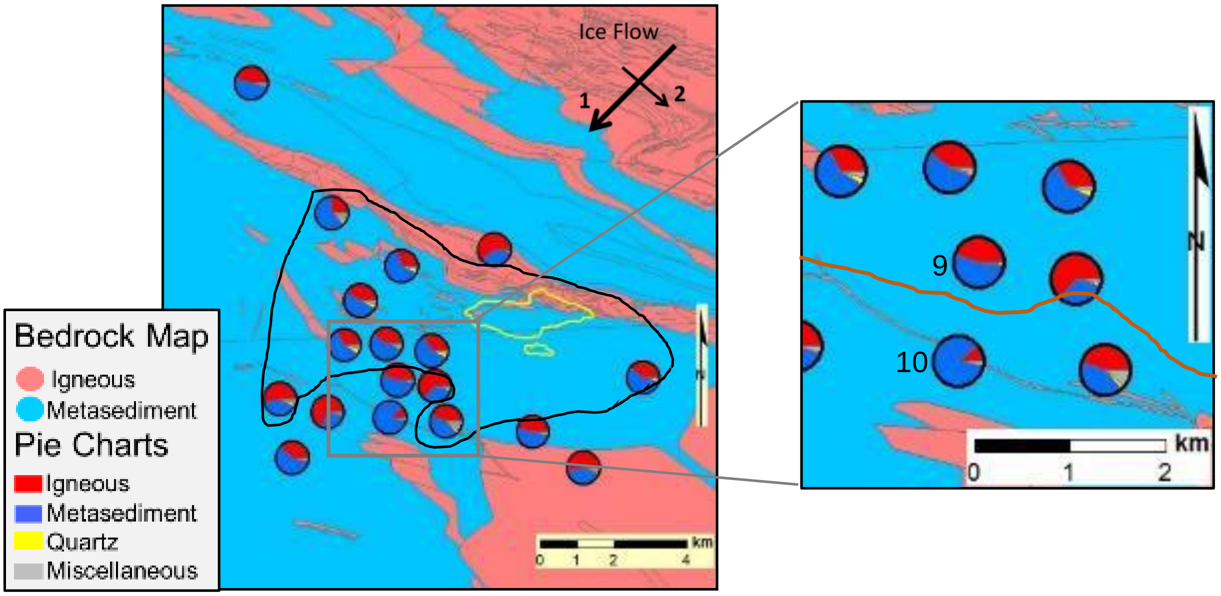



**Figure 22:** Clast counts on bedrock map with quartz proportions higher than 2% circled (black). Inset of surface site 9 and 10 with approximate staurolite-in isograd between (Brown). Bedrock map altered from SIGÉOM, 2016.

The second ice flow direction indicator is the presence of staurolite crystals in the metasediments. 2 of the 5 samples south of the staurolite-in isograd have staurolite in them, while none of the samples north of the isograd do. Clasts with staurolite crystals in them are seen in Figure 23.

**Figure 23:** Clasts with staurolite crystals.

Most notably are samples 9 and 10 which straddle the staurolite-in isograd. Sample 9 is to the north of the staurolite-in isograd and 10 to the south (Figure 22). In sample 9 there is no staurolite but in sample 10, staurolite is seen in 5% of metasediment clasts. These indicators confirm a southwest to south dispersal pattern of sediments.

## 4.0 Summary and Conclusion

The two objectives of this study are to; 1- determine whether surficial geochemistry data from the Cadillac Project (1970s) can be used today, and 2- assess whether rutile and hyperspectral imaging can be used to trace Malartic-type gold deposits in glacial sediments.

The Cadillac legacy data shows similar dispersal patterns in Au and W to the 2015 data. However, several ‘background’ results are from glaciolacustrine sediments rather than till. It will thus be useful to look carefully at the original reports and identify which samples were described as ‘mud’. This could be used to map discontinuities in the subsurface till unit. Dispersal patterns may be truncated due to till being absent in certain places. This could have implications on the final interpretation of dispersal patterns.  Unfortunately, reports or records of the methods used during the 1988 sampling have not been located.  Before levelling and integration of the 1971 and 1988 datasets can be confidently applied, these should be located.

Rutile as an indicator mineral shows promise when using Au and W as a proxy for the mineral itself.  Both Au and W are found near the CLLTZ and the deposit with anomalous values occurring in overlapping samples.  Further work performing heavy mineral content and microprobe analysis on the rutile grains will determine if a specific rutile composition is a potential indicator mineral at Malartic.  However, there are a few more variables to consider. The size of rutile grains in the source rocks and in the till may be small, which could limit the use of traditional indicator mineral grain picking. However, grain mount thin sections could be used to analyze the finest heavy mineral fractions. If W-rich rutile is identified in till down-ice of Malartic in the same locations as the W anomalies in the fine fraction, then W could be used with confidence as a proxy for rutile dispersion.

The hyperspectral imaging results are interesting since metasediments with phengitic white micas have been identified in till and in glaciofluvial sediments. However, better sample coverage and improved knowledge of the hyperspectral signature of lithologies north of the fault is necessary to draw conclusions on provenance and dispersal patterns.

The Canadian Malartic site has two objectives that are a part of the larger Footprints project. The first one is to define the alteration footprint of the deposit.  The second goal is to identify and characterize the secondary footprint in the surficial sediments.  This study has shown that the surficial sediments do show evidence of a surficial footprint, but more work needs to be performed to fully delineate patterns and to confidently relate them to Malartic as their main source zone. Additional glacial geology work is also necessary to improve understanding of subglacial processes and dynamics during the different ice flow phases which most likely controlled sediment dispersion.

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## Appendix

### Normalized results of clast sorting

| Sample | Igneous | Meta-sediments | Mica Rich Metased. | Qtz Veins | Misc |
|---|---|---|---|---|---|
| SS 1 | 30 | 34 | 29 | 4 | 3 |
| SS 2 | 64 | 26 | 6 | 2 | 3 |
| SS 3 | 34 | 32 | 27 | 4 | 3 |
| SS 4 | 39 | 27 | 29 | 1 | 4 |
| SS 5 | 54 | 25 | 13 | 3 | 5 |
| SS 6 | 45 | 32 | 9 | 2 | 11 |
| SS 7 | 42 | 29 | 21 | 4 | 4 |
| SS 8 | 34 | 29 | 28 | 5 | 5 |
| SS 9 | 45 | 43 | 9 | 1 | 1 |
| SS 10 | 11 | 21 | 64 | 0 | 3 |
| SS 11 | 27 | 45 | 16 | 3 | 10 |
| SS 12 | 68 | 21 | 6 | 0 | 4 |
| SS 13 | 53 | 34 | 6 | 1 | 5 |
| SS 19 | 46 | 37 | 12 | 0 | 5 |
| SS 22 | 39 | 36 | 21 | 3 | 1 |
| SS 23 | 40 | 34 | 20 | 2 | 4 |
| SS 48 | 46 | 42 | 8 | 1 | 4 |
| SS 49 | 61 | 29 | 9 | 2 | 0 |