Till Geochemistry and Indicator Mineral Methods for Exploration in Glaciated Terrain

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Exploration 07  Workshop 2
Exploration Geochemistry: Basic Principles and Concepts
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Drift prospecting is a common mineral exploration method in glaciated terrain.

Method dates back to observations of boulder transport in 1700s.

In the 20th century, method has contributed to significant discoveries including base metals deposits at Outoukumpu, Finland, the Buchans and Bathurst VMS camps, U deposits in the Athabasa Basin, Au deposits in the Abitibi Greenstone Belt and diamond deposits in northern Canada.

Multiple glaciations the Quaternary period (last 1.9 Ma).

Deposits sampled for mineral exploration are largely Late Wisconsinan (100,000 yrs).

Late Glacial Maximum (LGM): 18k - 20k yrs BP.
GLACIATED TERRAIN

Northern hemisphere

South America

Areas covered by Pleistocene ice sheets
- Kimberlite deposits

Existing glaciers
Area of former glaciation (conjectural in some sectors)
Alpine Glaciers

- Mountainous terrains
- e.g. North & South American Cordillera

Continental Glaciers

- Moderate relief terrains
- e.g. Central & Eastern North America, Fennoscandia
SAMPLE MEDIA IN GLACIATED TERRAIN

• Till:
  - geochemistry and indicator minerals
  - reconnaissance to local scale

• Stream sediments:
  - geochemistry, indicator minerals, water
  - reworked glacial sediments (shield), glacial seds+ bedrock (Cordillera)
  - reconnaissance to local scale

• Modern lake sediments:
  - geochemistry
  - organic lake sediments, water
  - reconnaissance to regional scale

• Soils:
  - selective leach analytical methods
  - for thick drift areas with no till
  - Scale depends on size of target

• Vegetation:
  - geochemistry
  - local scale only
GLACIATED VS UNGLACIATED REGIONS

GLACIATED

• Soil development shallow ~1 m

UNGLACIATED

• Soils can be developed to depth >100 m (regolith)

Northern Ontario, Canada

Western Australia

(Shilts, in Menzies, 1996)
## GLACIATED VS UNGLACIATED REGIONS

### GLACIATED
- Material dispersed by glacial processes (mechanical processes)

- Dispersal patterns **not** confined to a drainage basin except in mountainous regions with valley

- Minerals of different bedrock sources can be intermixed in glacial sediments (e.g. ultramafic & granitic)

- Sediments still contain minerals that are usually broken down in the first stage of weathering (e.g. carbonates, sulphides, olivine, pyroxene)

### UNGLACIATED
- Material in situ or remobilized by fluvial, eolian, or chemical processes

- Dispersal confined to a drainage basin

- More likely to have minerals of a single bedrock source

- Most of these minerals have been destroyed by soil forming processes and weathering

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(Shilts, in Menzies, 1996)
GLACIAL TRANSPORT

(Boulton 1996)
TILL DEPOSITION

- Lodgement
- Meltout
- Deformation
- Sublimation

(Bennett & Glasser, 1996)
TILL

- Sediment deposited directly by ice
- Very poorly sorted
- Clay to boulder sized material
- Texture reflects source material bedrock, recycled preglacial and/or glacial sediments
- Transport distance, few m to 100 km
VARIATIONS IN ICE FLOW PATTERNS

Probable directions of ice flow at the Late Wisconsin glacial maximum

(Fulton 1989)
INDICATORS OF ICE FLOW DIRECTION

**Erosional**
- Roches moutonées
- Whalebacks
- Rock drumlins
- Flutings
- Grooves
- Striations

**Depositional**
- Drumlin ridges
- Fluted till plain
- Till clast fabric
- Dispersal train

**Combined**
- Crag and tail
- Bullet-shaped boulders
- Boulder pavements
• Oriented landforms visible on topographic and geological maps and air photographs

• Morphology strongly influenced by bedrock topography

• Typically occur in groups, showing a characteristic pattern on maps and air photographs

• Accentuated by vegetation and drainage

• Provides a general impression of regional flow directions

(Ryder, 1995)
LARGE ICE FLOW INDICATORS

Till ridges

Roche moutonnée

Crag and tail
STRIATIONS

- Erosional marks on bedrock surface made by sole of glacier
- Most convenient and reliable means of determining ice-flow trends
CLAST ORIENTATION

Elongated pebbles in till: measure strike and dip (50-100)

Bullet shaped boulder in till: measure boulder orientation & its striations
ICE FLOW RECONSTRUCTION

Western Abitibi Greenstone belt:
W, SW, SE ice flow

(Veillette and McClenaghan, 1996)
GLACIAL DISPERSAL TRAINS

• Larger than their bedrock source, easier target to find

• Size and shape of train controlled by:
  - orientation of ice flow
  - size & erodibility of bedrock source
  - influence of topography on ice flow
  - till thickness, number of till units

• May be affected by post-depositional processes
MAPPING DISPERSAL

Clast fraction (5+ mm)
- Boulders
- Cobbles
- Pebbles

Heavy minerals (0.25-2.0 mm)

Till matrix (<0.063 mm)
- Geochemistry for specific elements
IDEAL MODEL OF GLACIAL DISPERSAL TRAIN

PLAN VIEW

Cross section

LONGITUDINAL SECTION
MODEL OF GLACIAL DISPERSAL TRAIN

(Shilts, 1976)
WADDY LAKE, SASKATCHEWAN

- Archean volcanic-hosted Au deposit
- Ribbon-shaped train
- Indicator minerals: pyromorphite (Pb-PO$_4$), gold and native grains
- Dispersal distance >500 m
HALFMILE LAKE ZN-PB-CU DEPOSIT, BATHURST, NEW BRUNSWICK

- VHMS Cu-Pb-Zn deposit
- Ribbon-shaped train, ENE ice flow
- Matrix geochemistry: Sn <0.063 mm fraction
- Dispersal distance ~500 m

Parkhill & Doiron (2003)
EAST KEMPTVILLE TIN MINE, NOVA SCOTIA

- Tin deposit hosted in granite
- Fan-shaped dispersal train
- Two ice flow phases, SE, SW
- Matrix geochemistry: Sn <0.063 mm
- Dispersal distance >50 km
MODEL OF MULTI-PHASE GLACIAL DISPERSAL

(Stea, 2007)
TILL SAMPLING STRATEGIES

(backhoe trenching)

(hand-dug holes)

(portable drills)

(reverse circulation or sonic drills)

(clay and silt)

(younger till)

(older tills)

(organic beds)

(McMartin and McClenaghan, 2001)
PERMAFROST TERRAIN: MUDBOILS

I. McMartin

Sample here
FORESTED AREAS

Black-brown organic mineral soil

Orange-brown, highly oxidized Fe & Mn-rich B horizon

Grey, unoxidized C horizon

I. McMartin
HAND EXCAVATION

- Till at surface
- Flanks of bedrock outcrop
- Road cut exposures
- Lake, river exposures along shorelines
TRENCHING

PORTABLE SOLID STEM AUGER
HOLLOW-STEM AUGER

WET-ROTARY DRILL

R. Paulen
ROTASONIC DRILL

- overburden 10 to 125 m thick
- stony/bouldery till
- detailed stratigraphy
- continuous 9 cm core
- high costs
REVERSE CIRCULATION DRILL

- Overburden 10 to 125 m thick
- Stony/bouldery till
- Tricone bit
- Mud and chip slurry
- Clay-sized material lost

Tricone bit
+10 mesh on screen for logging
Sample recovered in bucket
TILL SAMPLE WEIGHT

Sample weight depends on analytical methods:

- Till geochemistry - 2 to 5 kg
- Indicator minerals - 10 to 50 kg
  - Clay-rich till, sand content <20%, 25 to 50 kg sample
  - Sandy-till, sand content >30%, 10 to 25 kg sample

40 kg sample

10 kg sample
SAMPLE PROCESSING & ANALYSIS FLOWSHEET

0.5-1.0 kg split for geochemical analysis & archive

Lithology examination >2 mm or >1 mm

Bulk sediment sample: 10 to 40 kg

Sieve <2 mm or <1 mm

Preconcentration

< 2 mm

Jig, spiral, shaking table, Knelson Concentrator, DMS, or pan

Final concentration

Heavy liquids, and/or magstream

Magnetic fraction: Examine or store

Heavy Fraction: Ferromagnetic Separation

Nonferromagnetic fraction: Dry sieve to specific size fractions

Store under-/oversized fractions

Indicator mineral selection

Indicator Mineral Identification:
1. Examine & photograph
2. Chemical analysis: electron microprobe, LA-ICP-MS, ion microprobe
**INDICATOR MINERALS**

**Definition:** Mineral that suggests the presence of a deposit, alteration or lithology

**Physical Characteristics:**
- Occur mainly in host rock
- Visually and chemically distinct
- Moderate to high density
- Silt to medium sand-sized (0.10 to 2.0 mm)
- Survive weathering
- Survive clastic transport
COMMON INDICATOR MINERALS

- Gold grains (Au)
- Native copper (Cu)
- Kimberlite indicator minerals
- Platinum Group minerals (PGM)
- Sulphide minerals
- Metamorphosed massive sulphide minerals- e.g. gahnite
- Magmatic Ni-Cu-PGE minerals
- Scheelite (W)
- Cassiterite (Sn)
- Cinnabar (Hg)
- Fluorite, topaz (F)
- Uranium minerals
- Rare earth element (REE) minerals

- May be recovered from same heavy mineral concentrate, depends on processing methods used
- Selected from sample all at same time, or during re-examination
SAMPLE PROCESSING

- Reduce sample volume
- Recover heavy mineral fraction
- Reduce volume of heavy mineral fraction to examine
- Recover & analyze indicator minerals

10 to 40 kg sample

10s to 1000s indicator mineral grains
STEP 1

Disaggregate & homogenize

H. Thorleifson

Cement mixer

STEP 2

Screen off gravel fraction
- >4 mm (5 mesh)
- >2 mm (10 mesh)
- >1 mm (20 mesh)
- Retain gravel for pebble counts

Stainless steel sieves
STEP 3: PRECONCENTRATION

Size Screening
- silt to very coarse sand (0.1 to 2.0 mm)

• Density Separation
  - Jig, pan, spiral, wheel
  - Dense media separator (DMS)
  - Shaking table (Wilfley table)
  - Knelson Concentrator

• Magnetic Separation
  - Separate ferromagnetic fraction
STEP 4: FINAL CONCENTRATION

- Preconcentrate (step 3) further processed using heavy liquid.
- Exact separation at a specific density, light minerals float, heavy minerals sink.

- Heavy liquids commonly used:
  - Methylene iodide (MI) $SG=3.3$
  - Diluted MI $SG=3.2$
  - Tetrabromoethane (TBE) $SG=2.96$
  - Na-polytungstate $SG\ 2.82-2.95$

- Lower limit for kimberlite indicator minerals is $SG\ 3.2$, to include Cr-diopside and forsteritic olivine.
STEP 5: REMOVAL OF FERROMAGNETIC MINERALS

Purpose: reduce volume of material to examine for indicator minerals

Hand magnet

STEP 6: ADDITIONAL PROCESSING

Purpose: reduce picking volume & time

• Sizing, e.g. 0.25-0.5 mm; 0.5-2.0 mm
• Magnetic susceptibility (paramagnetic separation)
• Magstream

Magnetic separator

Carpco magnetic separator
STEP 7: INDICATOR MINERAL SELECTION

- Visual identification of possible & probable indicator minerals using binocular microscope
- Grain morphology & surface textures: binocular microscope, SEM
- Examine entire HMC or portion (normalize to full weight HMC)
- Select indicator minerals for chemical analysis
**STEP 8: MINERAL CHEMISTRY**

- Quantitative major & trace element analysis
- Confirm visual mineral identification, evaluate deposit grade, deposit genesis & alteration
- e.g. kimberlitic chromite & Mg-ilmenite difficult to identify visually
- Mount & polish selected grains (25 mm epoxy mounts)
- SEM, EMP, LA-ICP-MS, SIMS
KIMBERLITE MINERAL CHEMISTRY

Mg-ilmenite

Garnets

Eclogitic garnets

Chromite

Also discrimination plots for olivine, Cr-diopside...
**INDICATOR MINERALS**

**Surface Features**

Kelyphite rims (k) on Cr-pyrope

**Grain Shape**

- Pristine gold grains
- Modified gold grains
- Reshaped gold grains

Increasing transport distance

(DiLabio, 1990)
**INDICATOR MINERALS**

**Grain size**
- Visible gold grains in till, Pamour Mine, No. 5 open pit, Timmins
- Grains fine sand to silt sized
- Most grains <50 µm
- Typical of Archean quartz vein-hosted lode gold deposit

(McClenaghan, 1999)
QUALITY CONTROL

• QC program indicator mineral processing & analysis as outlined in “Mineral Exploration Best Practices Guidelines” in Canada

• Tour heavy mineral processing and picking labs

• Use blanks, field duplicates, spiked samples, repick ~5-10%

• Use same/similar labs for duration of project to allow comparison of results over several batches/years

• Report raw counts, as well as normalized counts

• Report indicator mineral abundances with respect to sample weight for interpretations on maps, figures etc..., e.g. 100 grains/10 kg
Mineral Exploration Best Practices Guidelines

**Sampling Methods**
- Appropriate, sufficient material collected
- Drill logs/field notes
- Photographic record

**Sample security**
- Secure storage, and shipping

**Sample preparation**
- Till matrix geochemistry- sieving
- Indicator mineral processing & recovery of heavy minerals
- Indicator mineral selection
- Methods appropriate, quality control monitored

**Analysis & Testing**
- Till matrix - geochemical analysis
- Mineral chemistry analysis
- Methods appropriate, quality control monitored
Key Lake area, uranium deposits

- Fan shaped dispersal train defined by boulders, till geochemistry & indicator minerals
- Train separated by 13 km gap from bedrock source
- Indicator minerals: niccolite (NiAs), hematite
- Till Geochemistry: U, Ni, As
STRANGE LAKE, LABRADOR

Strange Lake peralkaline granite, F-rich phases
• >40 km ribbon-shaped dispersal train defined by till geochemistry
• Indicator minerals: F, Nb, Ta, REE-rich minerals
e.g. fluorite, pyrochlore, zirconosilicates, monazite
• Till geochemistry: Be, La, Nb, Pb, Th, U, Y, Zr

Pyrochlore (Nb, F)

(www.Webmineral.com)

(Pyrochlore (Nb, F)

(DiLabio, 1982)
**LAC DES ILES, NW ONTARIO**

**Chromite in 0.25-0.5 mm fraction**

- *Cr-andradite (Cr-bearing garnet)*

- Indicator minerals: Cr-andradite, chromite, PGM minerals

**Lac des Iles Platinum mine**

- >5 km ribbon-shaped dispersal train defined by till geochemistry & indicator minerals
- Indicator minerals: Cr-andradite, chromite, PGM minerals

*(Barnet & Averill, in press)*
KIMBERLITE INDICATOR MINERALS

- Cr-pyrope
- Cr-diopside
- chromite
- Mg-ilmenite
- Olivine
- E-garnet
LAC DE GRAS, NWT

- Lac de Gras kimberlite field
- >100 km dispersal fan defined by indicator minerals in till
- Indicator minerals: Cr-pyrope, Cr-diopside, chromite, Mg-ilmenite, olivine, and diamond
- Regional survey, 10 to 15 km spacing
RANCH LAKE, NWT

- Ranch Lake kimberlite
- ~70 km dispersal train defined by indicator minerals in till
- Indicator minerals: Cr-pyrope, Cr-diopside, olivine, chromite

(McClenaghan et al., 2002)
SUMMARY

- Ice flow mapping and reconstruction of ice flow history key part of till sampling program, local or regional scale

- Glacial dispersal mapped using different size fractions: ore boulders or distinct lithology; indicator minerals; till matrix geochemistry

- Dispersal train shape reflects net result of all ice flow events; train may initially be intersected anywhere along its length, may not be complete, concentrations not always highest at head

- Indicator minerals are rugged, easily recovered heavy minerals. Recovery methods exploit mineral size, density and magnetic characteristics

- Various processing methods available, methods used will depend on: cost, number of samples, survey location, time frame to obtain results

- Mineral abundance, chemistry, shape, surface features may provide important information about bedrock source, including style of mineralization, host lithology, alteration, or grade, as well as distance of glacial transport

- Broad range of indicator mineral species can now be recovered, allowing exploration for a wide range of deposit types using the same samples

- Commercial labs now offer a range of analytical methods for till matrix geochemistry as well as indicator mineral processing, selection and analysis

- Optimal approach is to use both till geochemistry and indicator minerals methods
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FURTHER READING: DRIFT PROSPECTING

Drift Prospecting
(DiLabio and Coker 1989)

Drift Exploration in the Canadian Cordillera
(Bobrowsky et al. 1995)
FURTHER READING: DRIFT PROSPECTING