Till Geochemistry and Indicator Mineral Methods for Exploration in Glaciated Terrain

M. Beth McClenaghan
Geological Survey of Canada

Exploration 07 Workshop 2
Exploration Geochemistry: Basic Principles and Concepts
September 8, 2007
GLACIATED TERRAIN

• 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 Athabasca 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

- Areas covered by Pleistocene ice sheets
- Kimberlite deposits

South America

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

Legend:
- Existing glaciers
- Area of former glaciation (conjectural in some sectors)
**GLACIATION**

**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

(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
LARGE ICE FLOW INDICATORS

- 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
STRATIFICATIONS

- 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

Long section

Ice flow (Miller 1984)
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
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

- Hand-dug holes
- Backhoe trenching
- Portable drills
- Reverse circulation or sonic drills

Legend:
- Clay and silt
- Older tills
- Younger till
- 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

R. Paulen
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

Bulk sediment sample: 10 to 40 kg

Sieve <2 mm or <1mm

<2mm

Preconcentration

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

Indicator mineral selection

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

Store under-/oversized fractions
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

---

**STEP 2**

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

---

Cement mixer

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
Dense media separator

Spiral concentrator

Shaking Table

Knelson concentrator
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
- Magnetic separator

**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

- 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

Mineral grains mounted for probe analysis

Pyrite framboid with laser ablation pits

Electron microprobe (EMP)

LA-ICP-MS, CODES
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 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
**Lac des Iles, NW Ontario**

**Chromite in 0.25-0.5 mm fraction**

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

**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
ACKNOWLEDGMENTS

• Stu Averill, Overburden Drilling Management Ltd.
• Chris Benn, Bill Coker, BHP Billiton Exploration
• Marja Lehtonen, Geological Survey of Finland
• Isabelle McMartin, Geological Survey of Canada
• Roger Paulen, Alberta Geological Survey
• Alain Plouffe, Geological Survey of Canada
• Pertti Sarala, Geological Survey of Finland
• R. Stea, Consultant
• Pam Strand, Shear Minerals
• Harvey Thorliefson, Minnesota Geological Survey
FURTHER READING: DRIFT PROSPECTING

Drift Prospecting
(DiLabio and Coker 1989)

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

Glacial Indicator Tracing
(Kujansuu and Saarnisto 1990)

Drift Exploration in Glaciated Terrain
(McClenaghan et al. 2001)