Till Geochemistry and Indicator Mineral Methods for Exploration in Glaciated Terrain

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Geological Survey of Canada

Exploration 07 Workshop 2
Exploration Geochemistry: Basic Principles and Concepts
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GLACIATED TERRAIN

- Drift prospecting is a common mineral exploration method in glaciated terrain

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

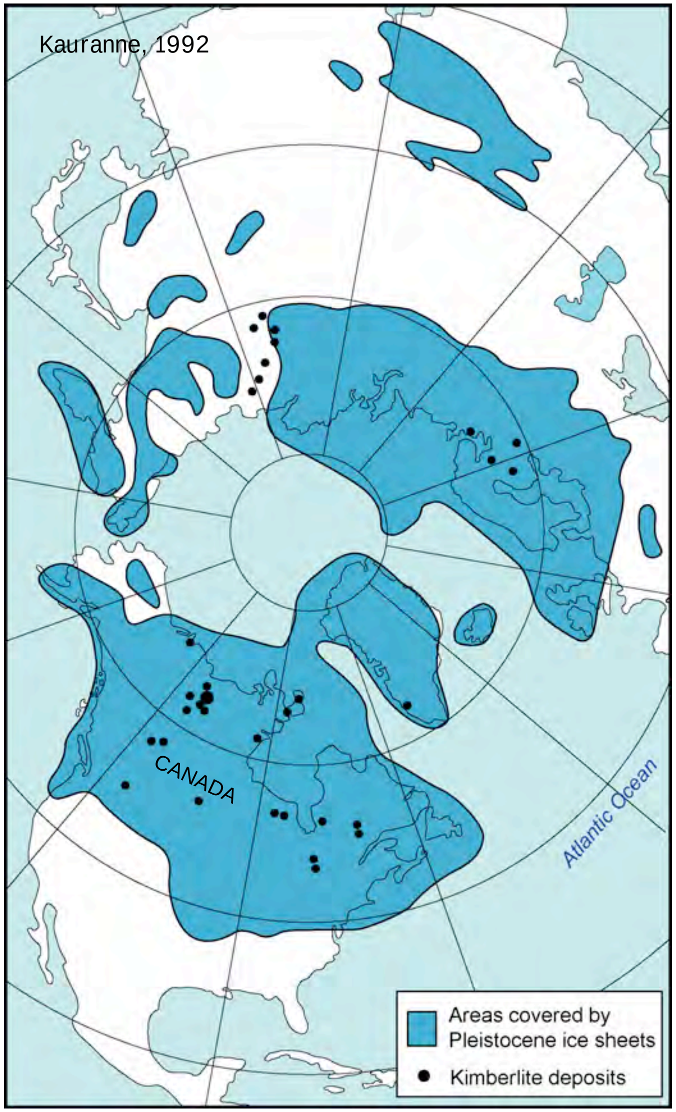
- In the 20th century, method has contributed to significant discoveries including base metals deposits at Outoukumpu, Finland, the Buchans and Bathurst VMS camps, U deposits in the Athabasa Basin, Au deposits in the Abitibi Greenstone Belt and diamond deposits in northern Canada

- Multiple glaciations the Quaternary period (last 1.9 Ma)

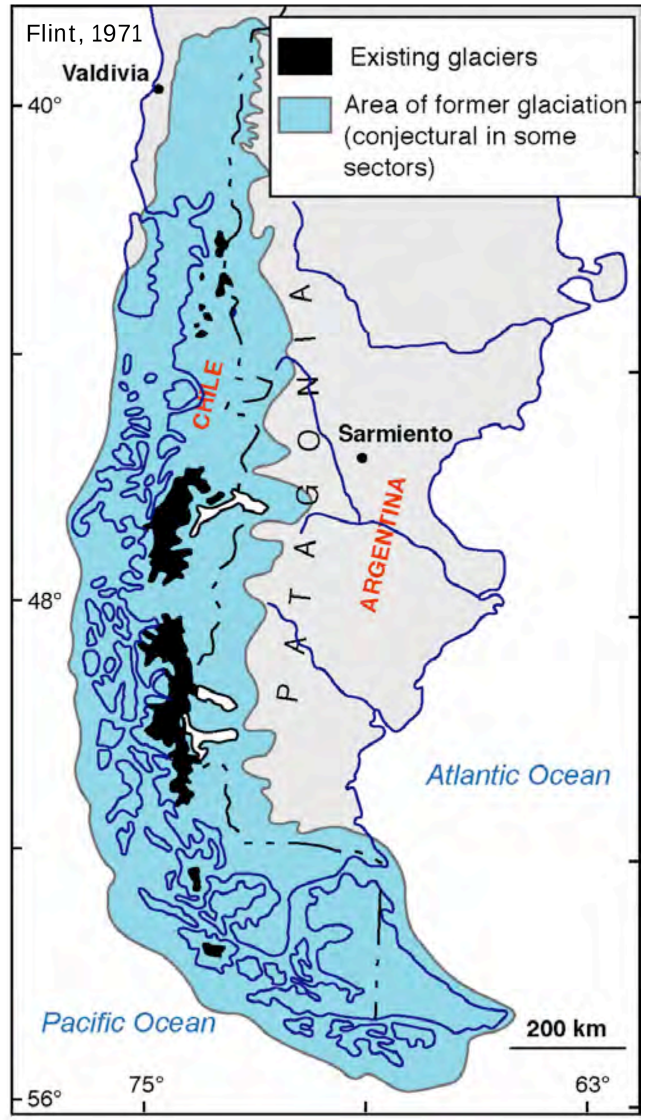
- Deposits sampled for mineral exploration are largely Late Wisconsinan (100,000 yrs)

- Late Glacial Maximum (LGM): 18k – 20k yrs BP

GLACIATED TERRAIN



Northern hemisphere



South America

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

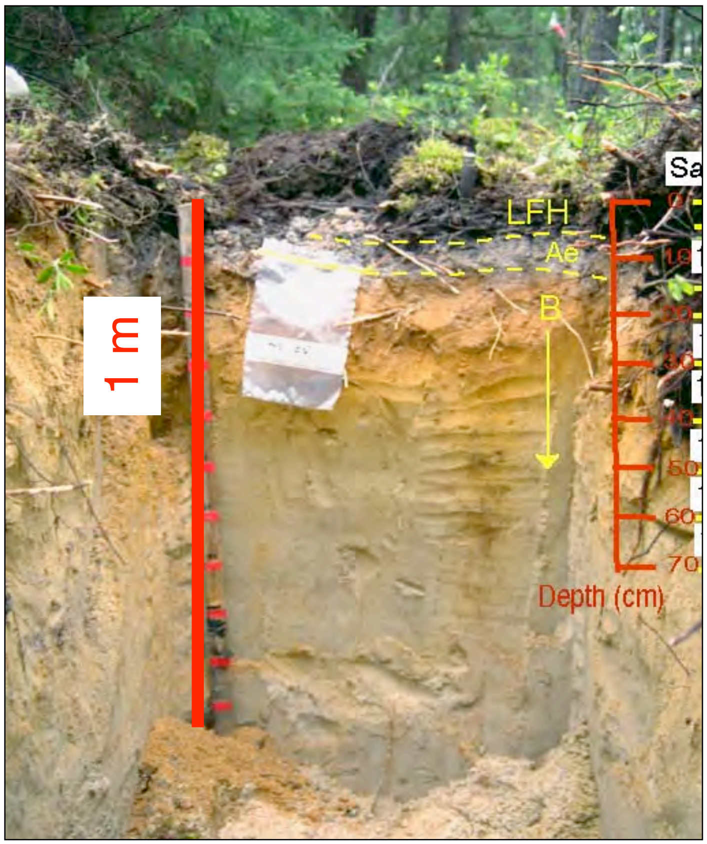
GLACIATED VS UNGLACIATED REGIONS

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

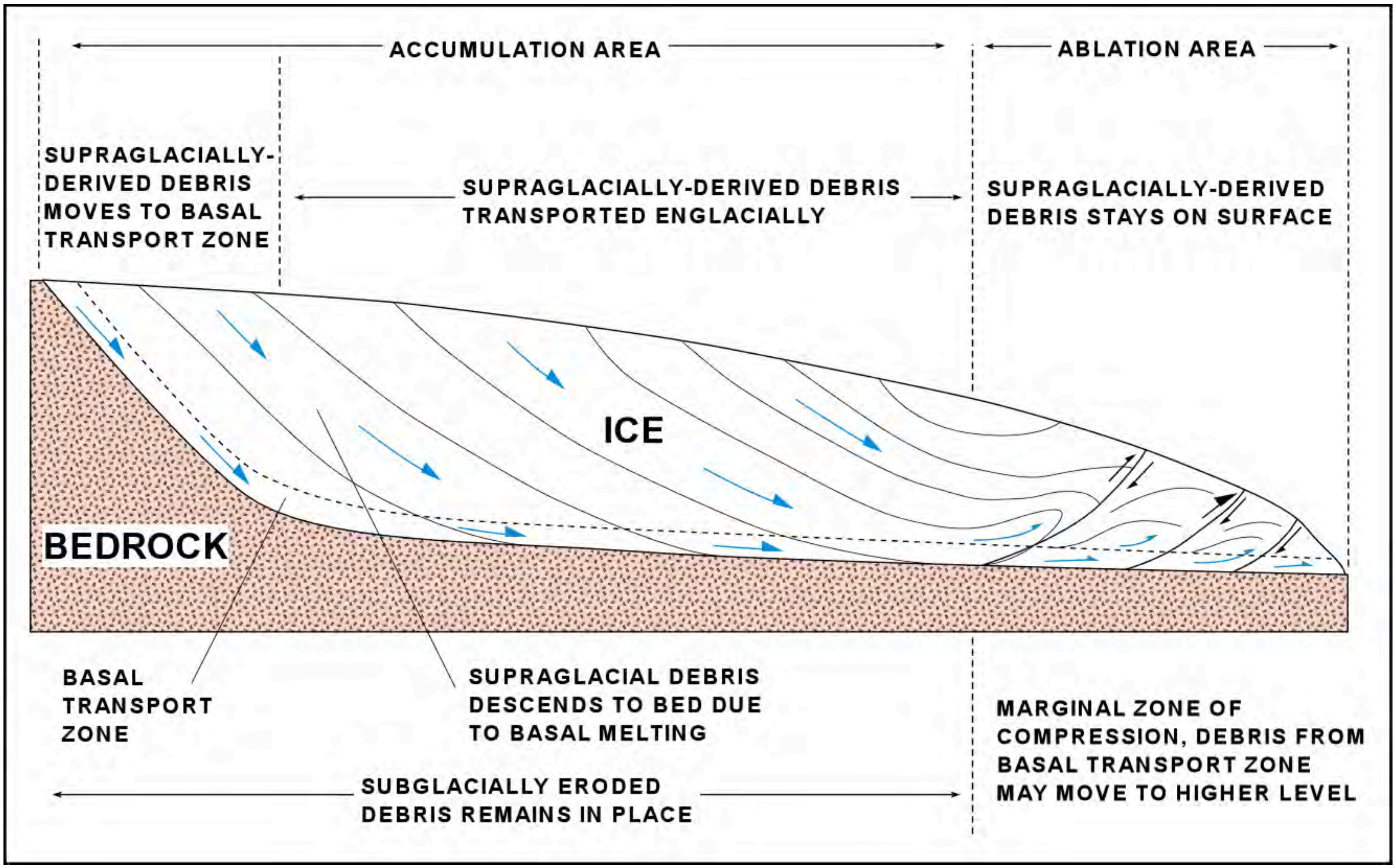
- Material dispersed by glacial processes (mechanical processes)
- Dispersal patterns not confined to a drainage basin except in mountainous regions with valley
- Minerals of different bedrock sources can be intermixed in glacial sediments (e.g. ultramafic & granitic)
- Sediments still contain minerals 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)

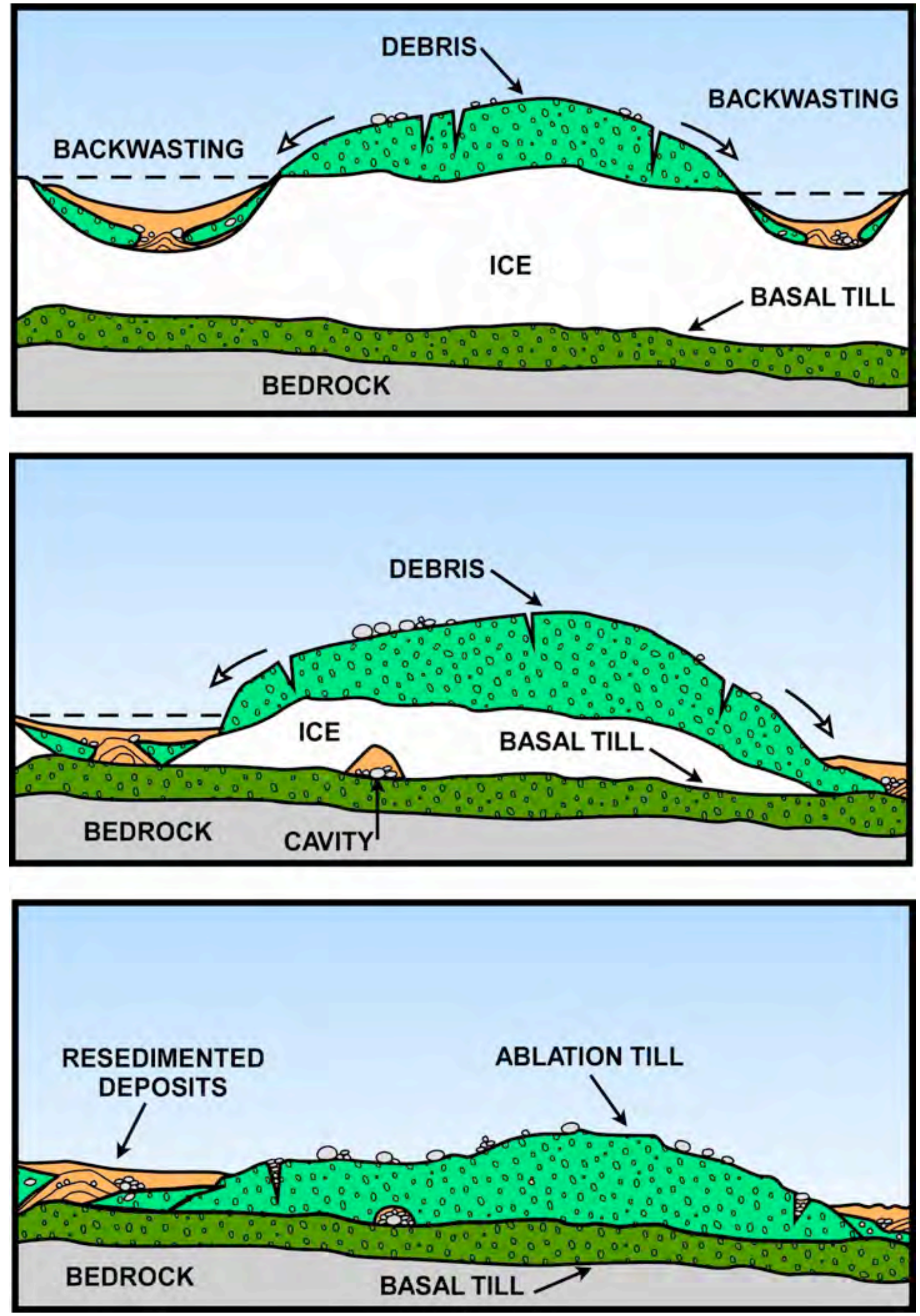
GLACIAL TRANSPORT



(Boulton 1996)

TILL DEPOSITION

- Lodgement
- Meltout
- Deformation
- Sublimation



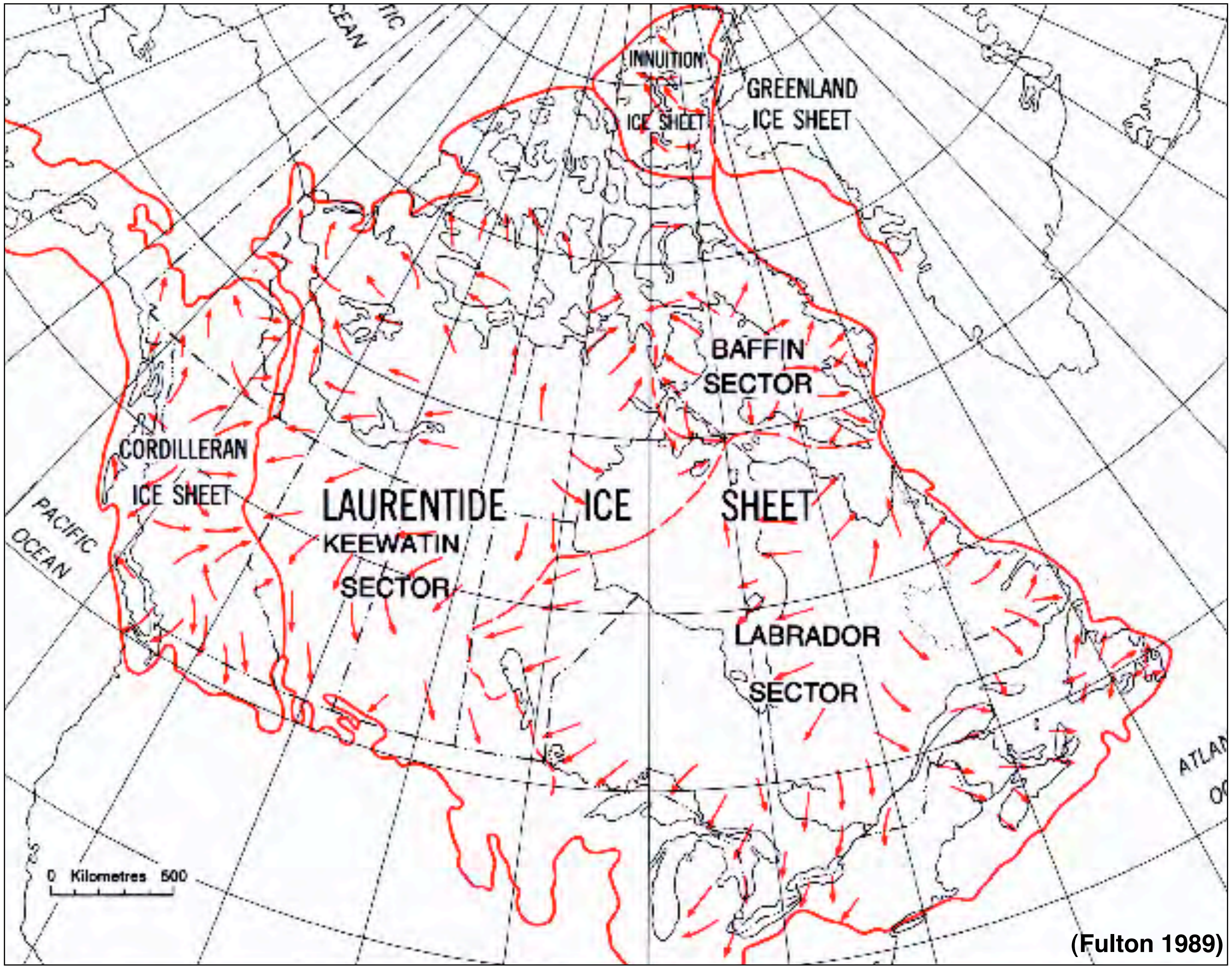
(Bennett & Glasser, 1996)

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

R. Paulen

VARIATIONS IN ICE FLOW PATTERNS



Probable directions of ice flow at the Late Wisconsin glacial maximum

INDICATORS OF ICE FLOW DIRECTION

Erosional

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

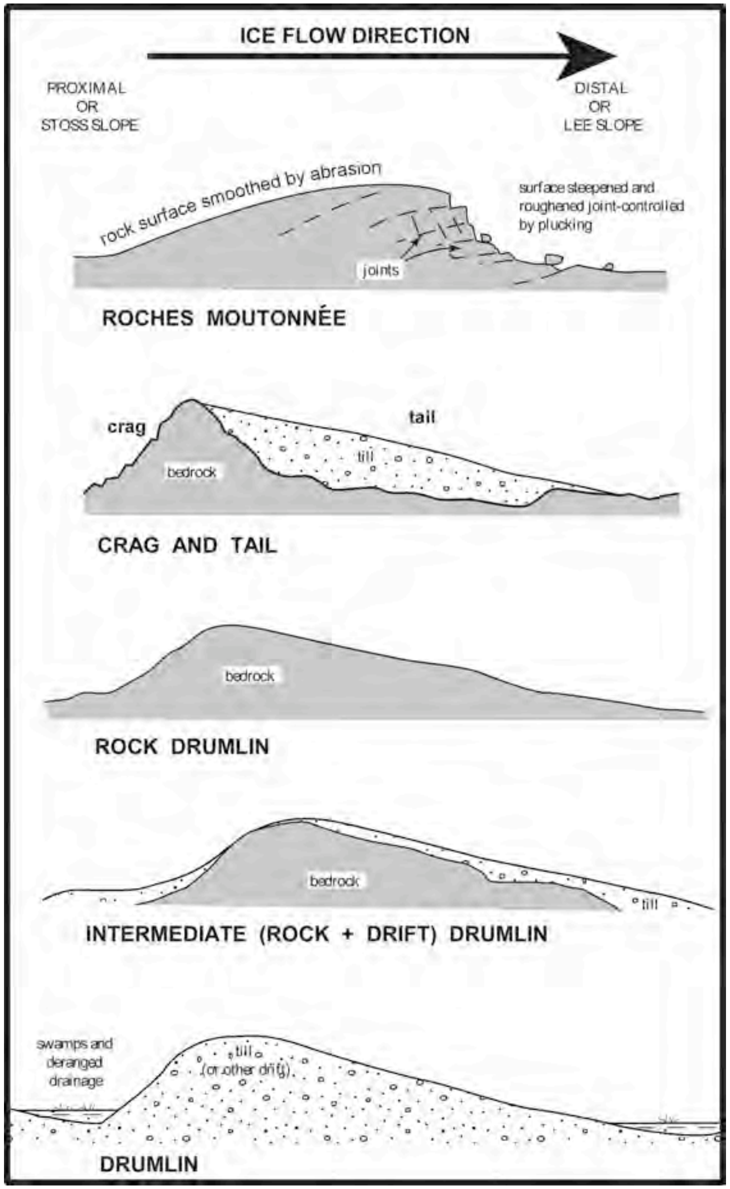
Depositional

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

Combined

- Crag and tail
- Bullet-shaped boulders
- Boulder pavements

LARGE ICE FLOW INDICATORS

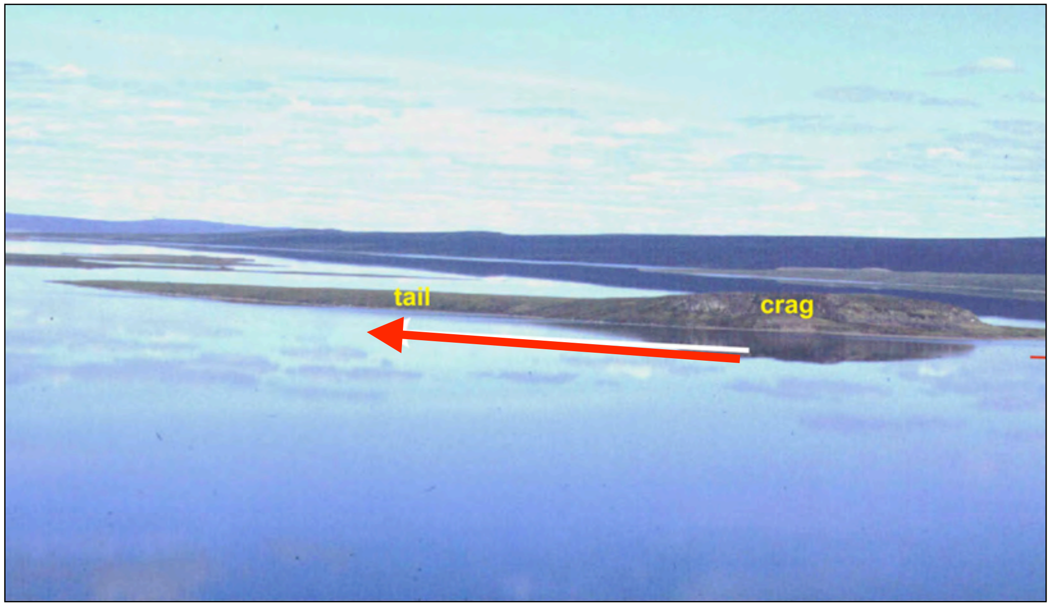


(Ryder, 1995)

- 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

LARGE ICE FLOW INDICATORS

Crag and tail



I. McMartin

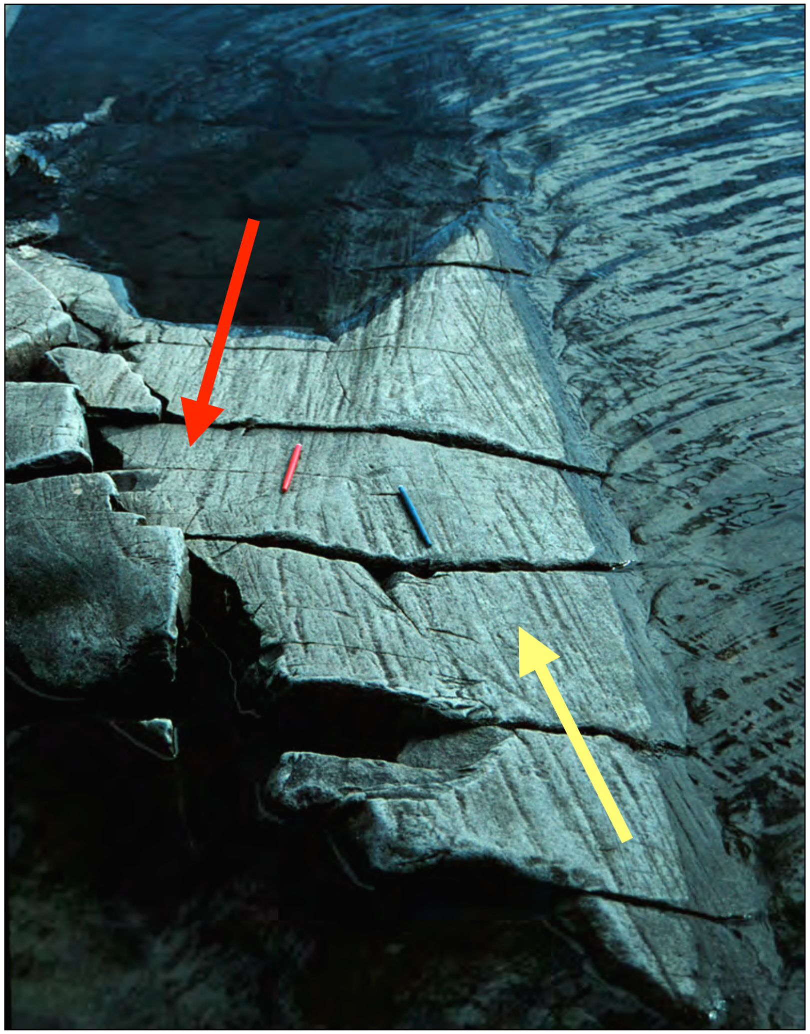
Till ridges

R. Paulen

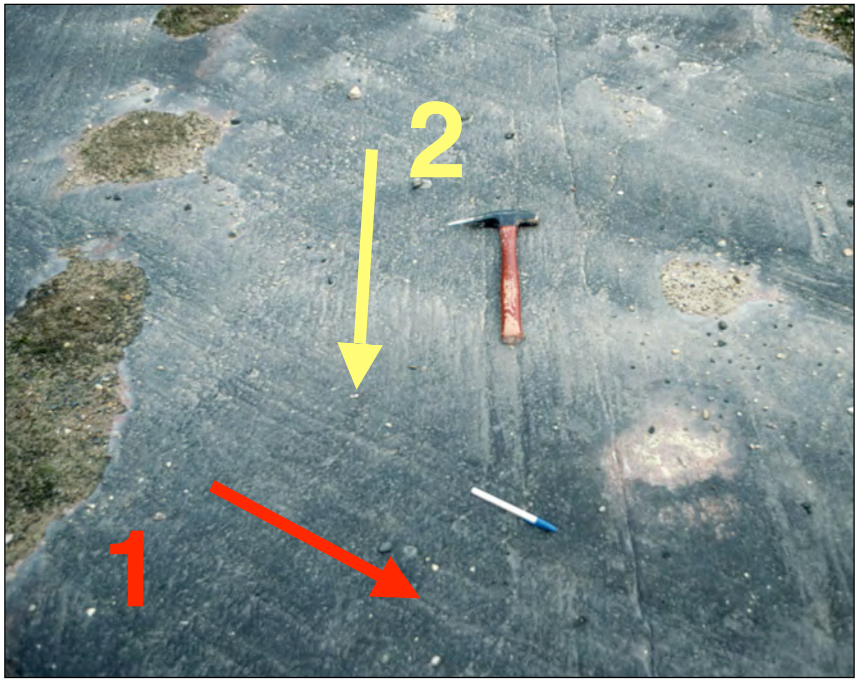
Roche moutonnée

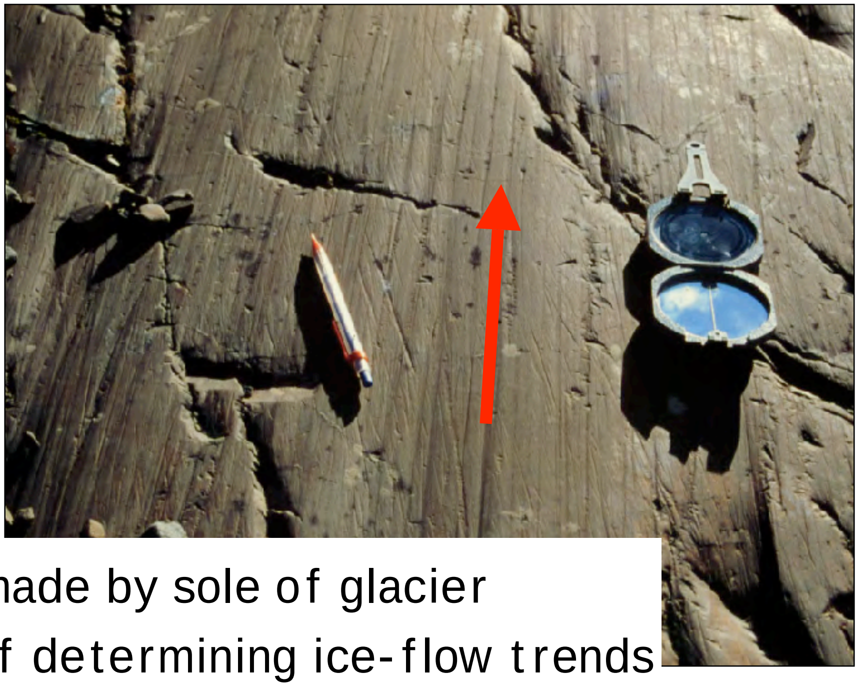
I. McMartin

STRIATIONS



I. McMartin



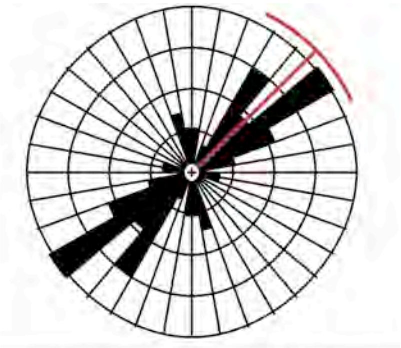


- Erosional marks on bedrock surface made by sole of glacier
- Most convenient and reliable means of determining ice-flow trends

CLAST ORIENTATION

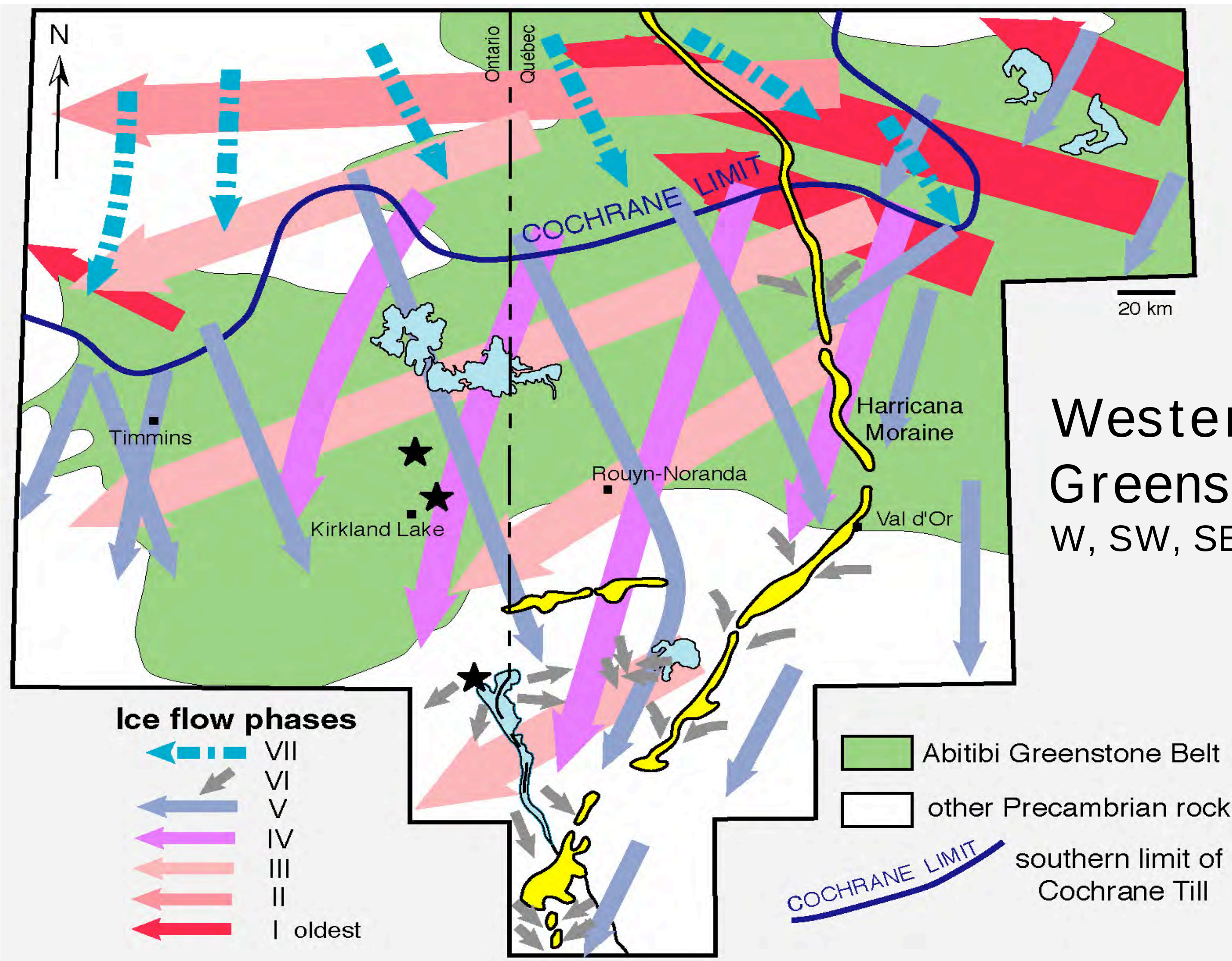
R. Paulen

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



Bullet shaped boulder in till:
measure boulder orientation & its striations

ICE FLOW RECONSTRUCTION



(Veillette and McClenaghan, 1996)

Western Abitibi Greenstone belt:

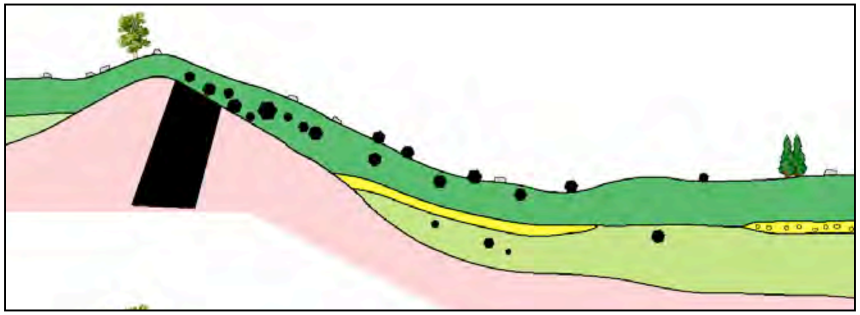
W, SW, SE ice flow

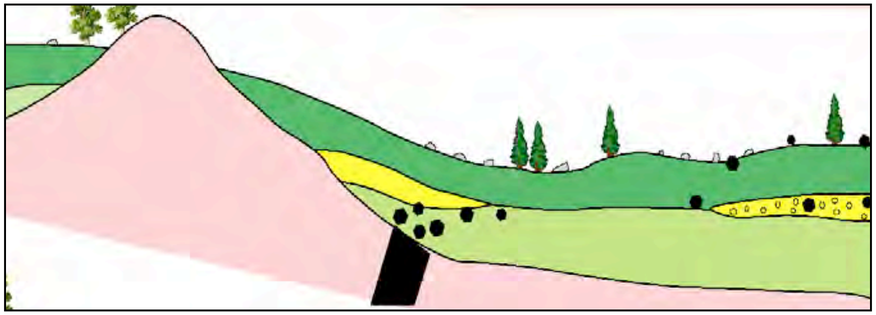
GLACIAL DISPERSAL TRAINS

- Larger than their bedrock source, easier target to find

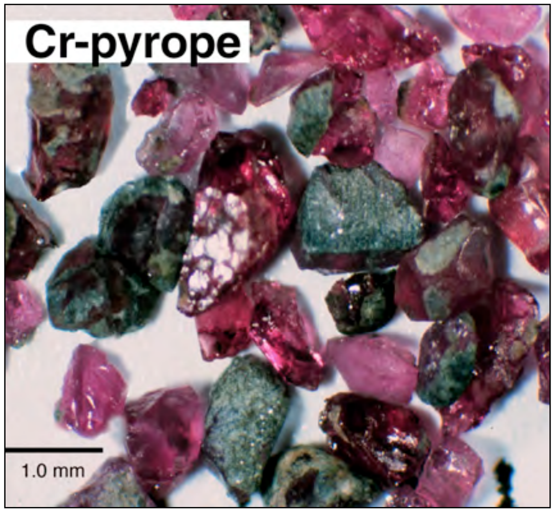
- Size and shape of train controlled by :
    - orientation of ice flow
    - size & erodibility of bedrock source
    - influence of topography on ice flow
    - till thickness, number of till units

- 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)

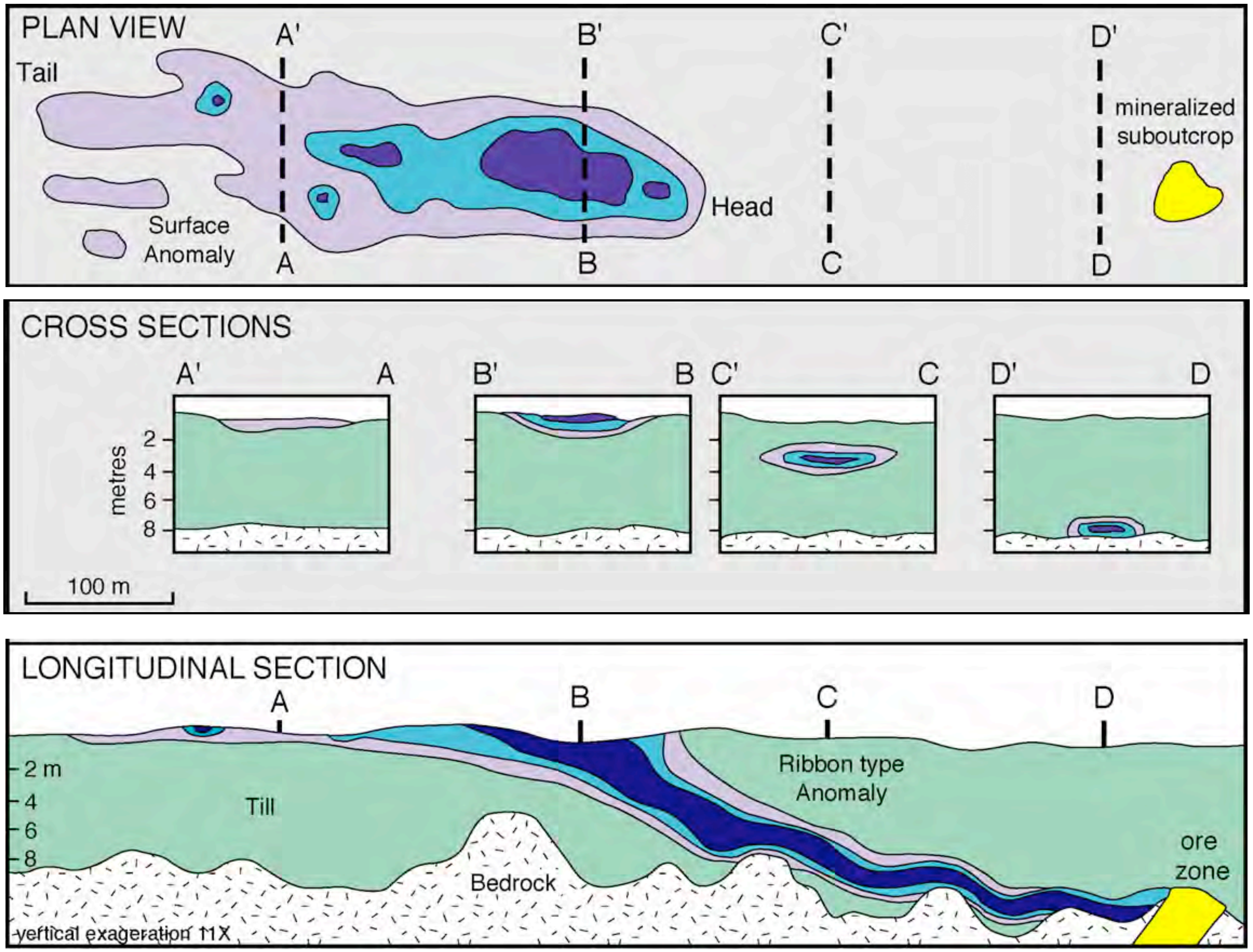
- Geochemistry
for specific elements

IDEAL MODEL OF GLACIAL DISPERSAL TRAIN

Plan view

Cross section

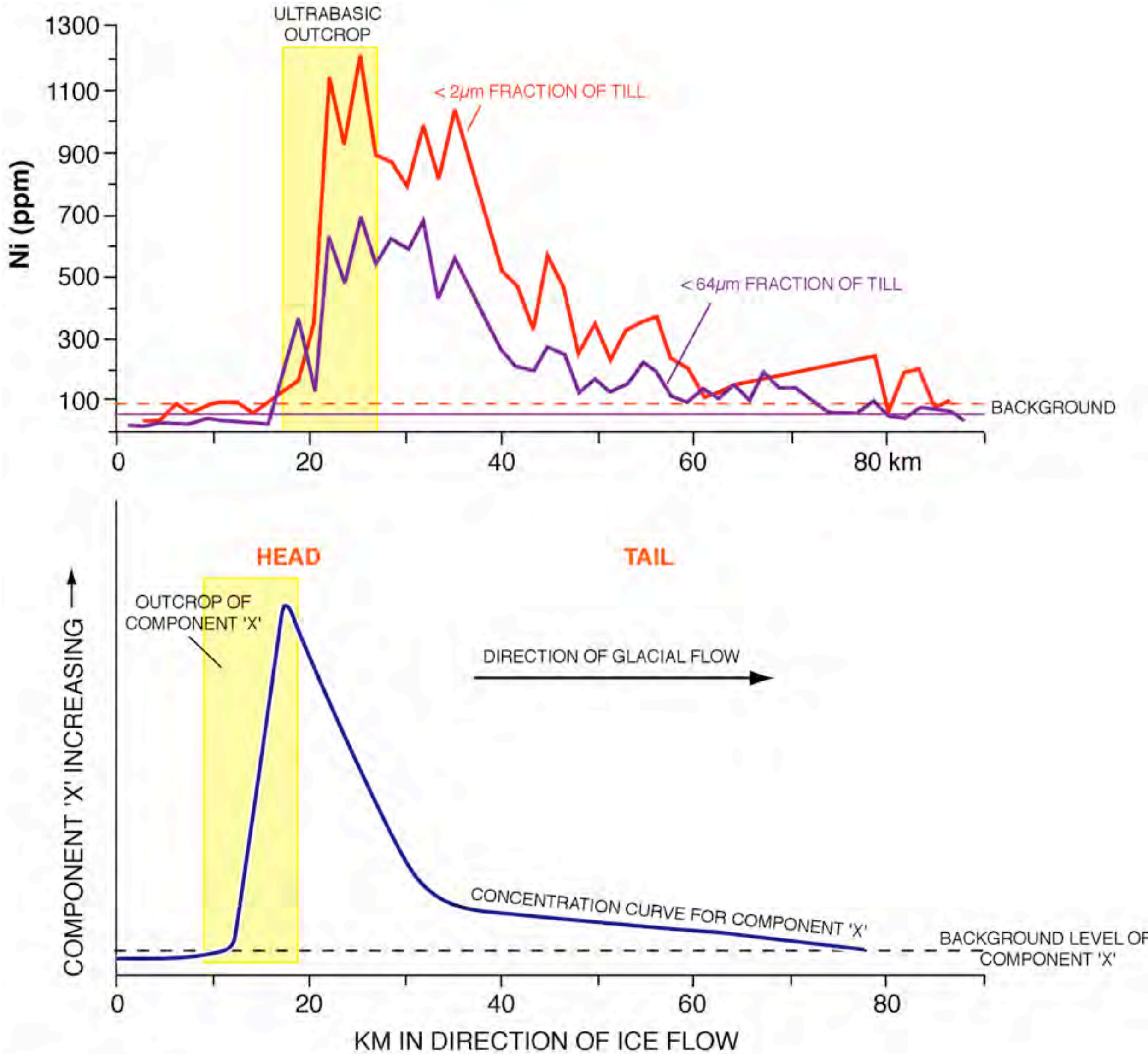
Long section



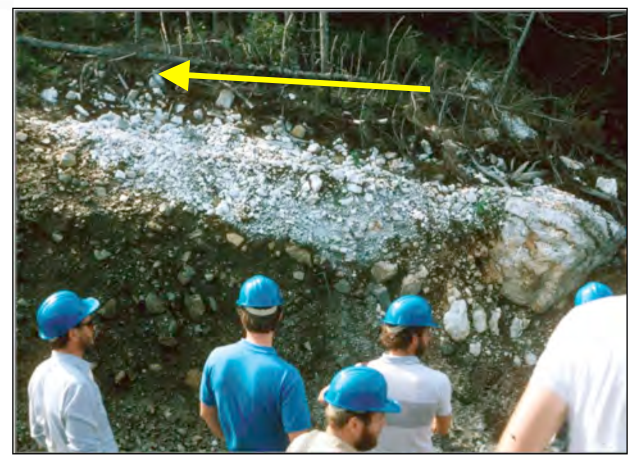
(Miller 1984)

Ice flow

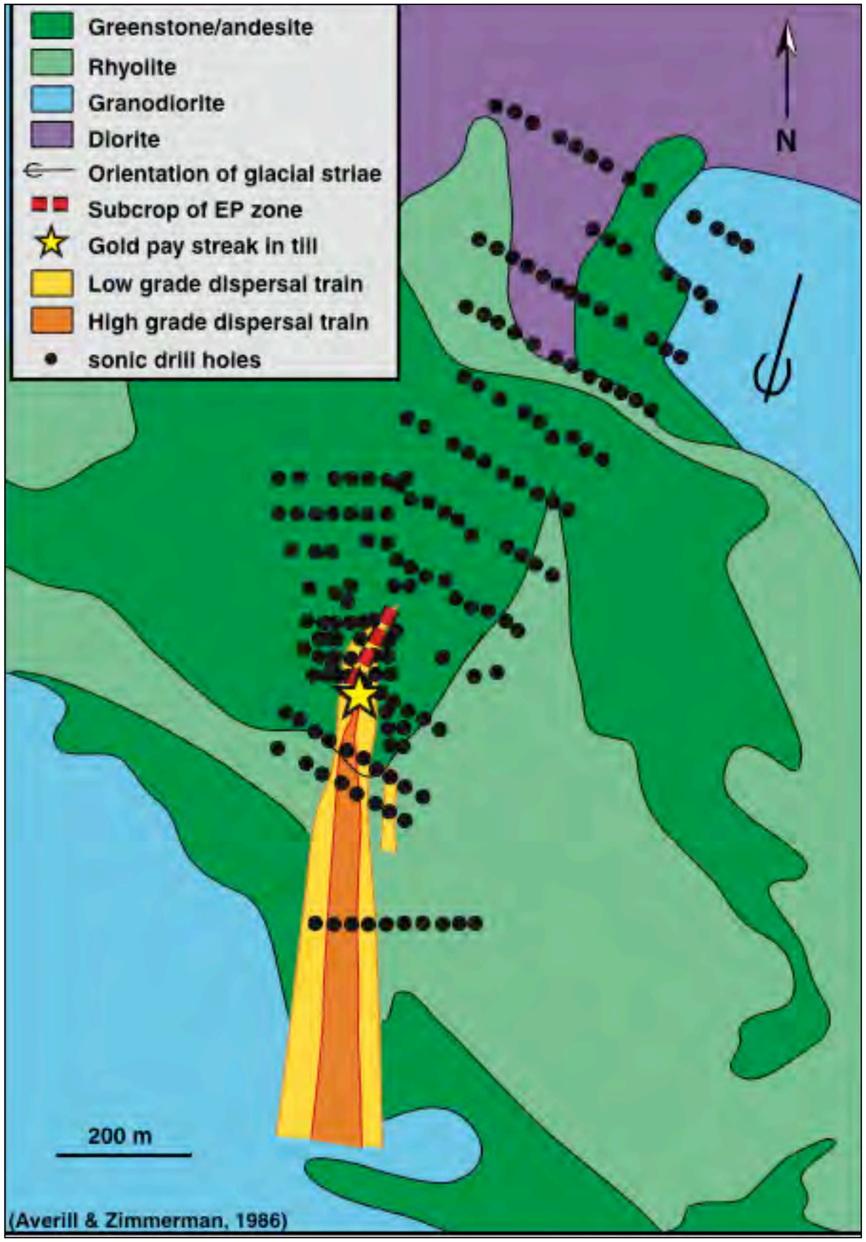
MODEL OF GLACIAL DISPERSAL TRAIN



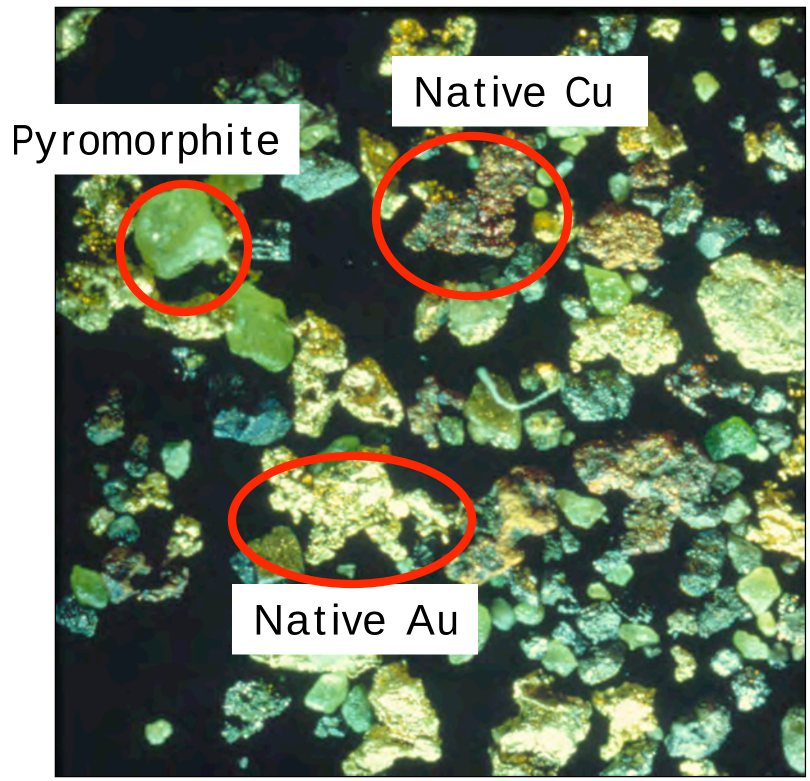
(Shilts, 1976)



WADDY LAKE, SASKATCHEWAN

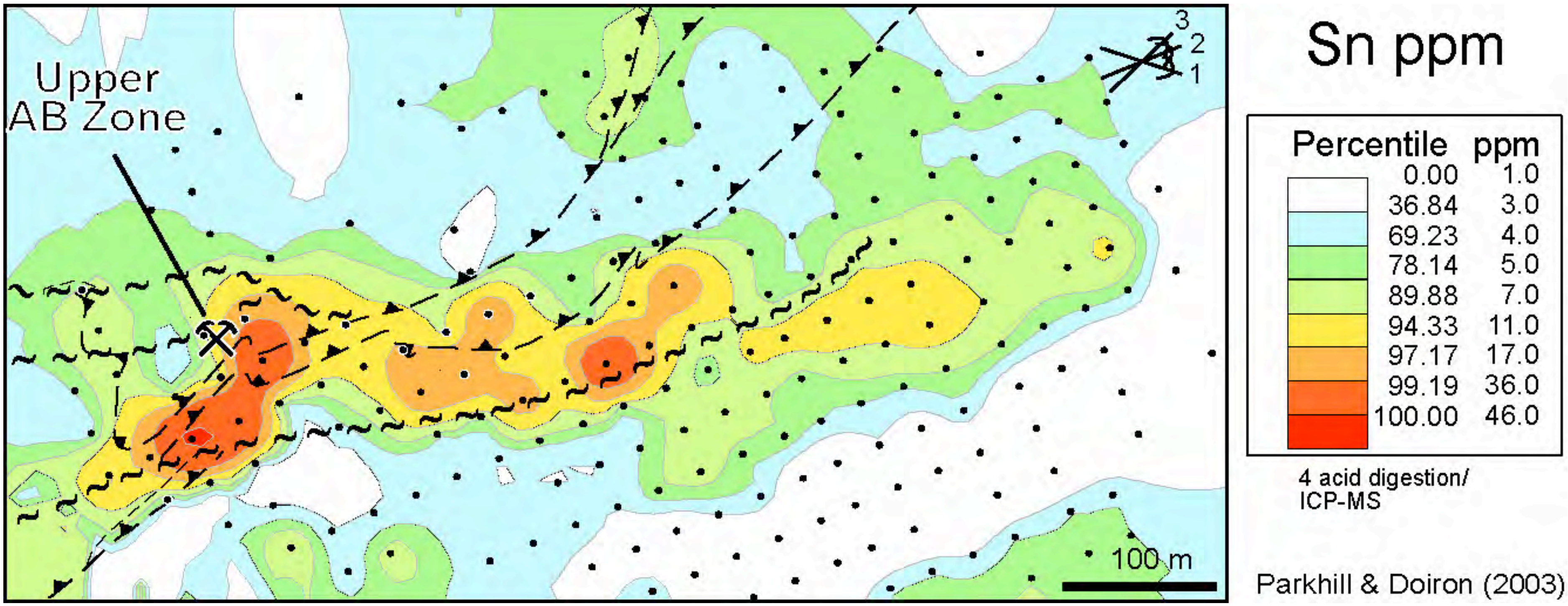


- Archean volcanic-hosted Au deposit
- Ribbon-shaped train
- Indicator minerals: pyromorphite (Pb-PO_4), gold and native grains
- Dispersal distance >500 m



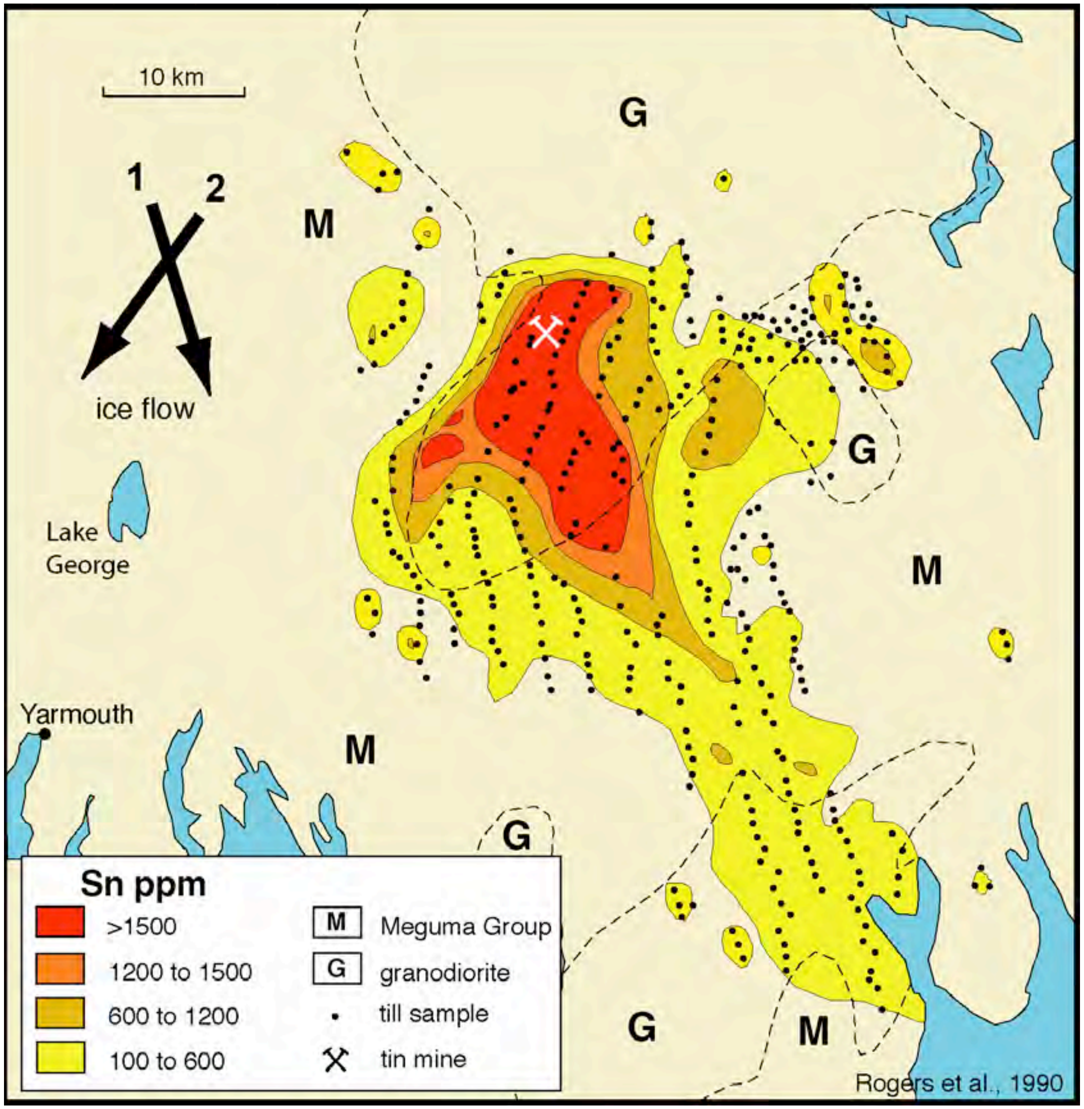
ODM

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

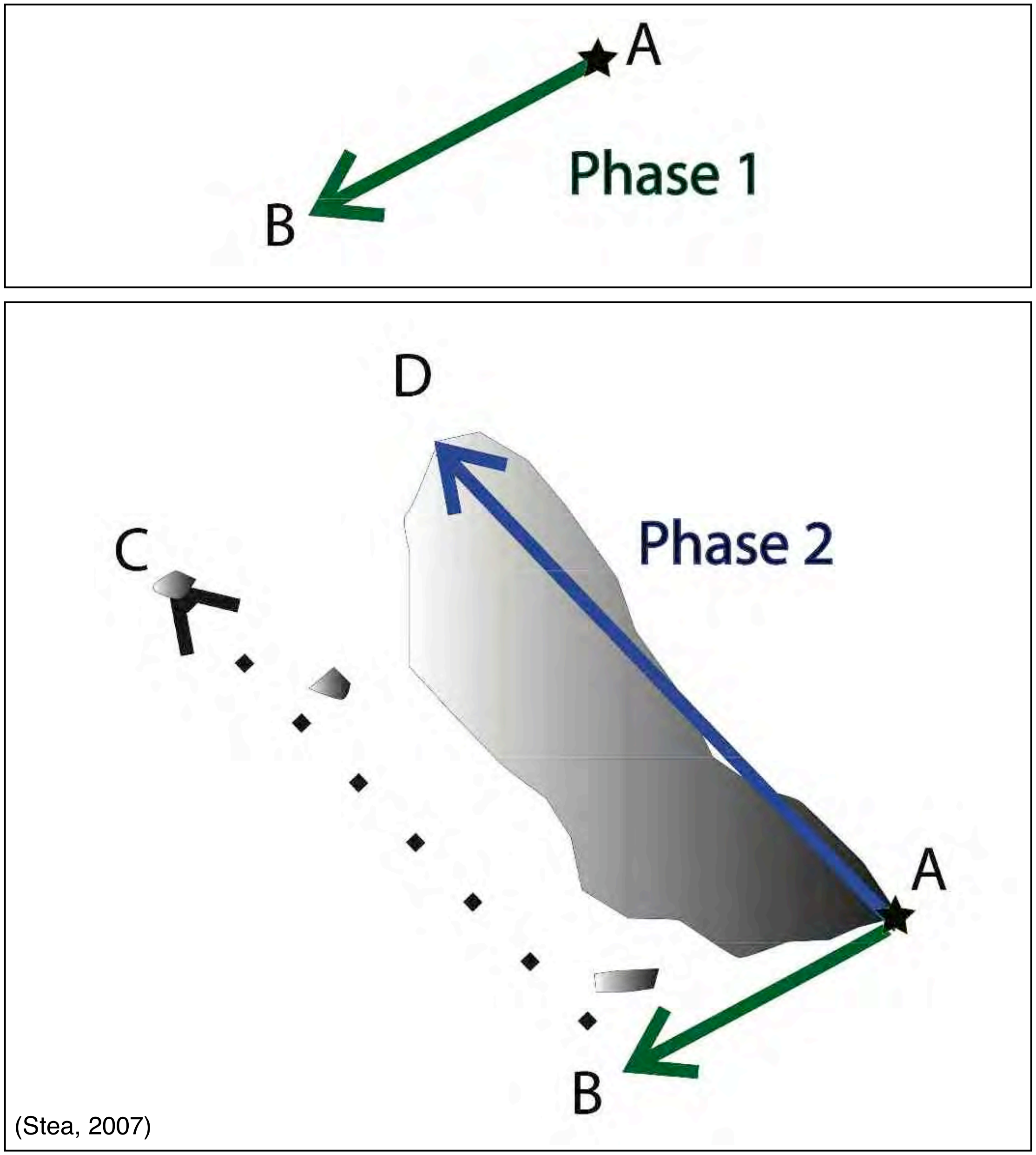


- Tin deposit hosted in granite
- Fan-shaped dispersal train
- Two ice flow phases, SE, SW
- Matrix geochemistry:

Sn <0.063 mm

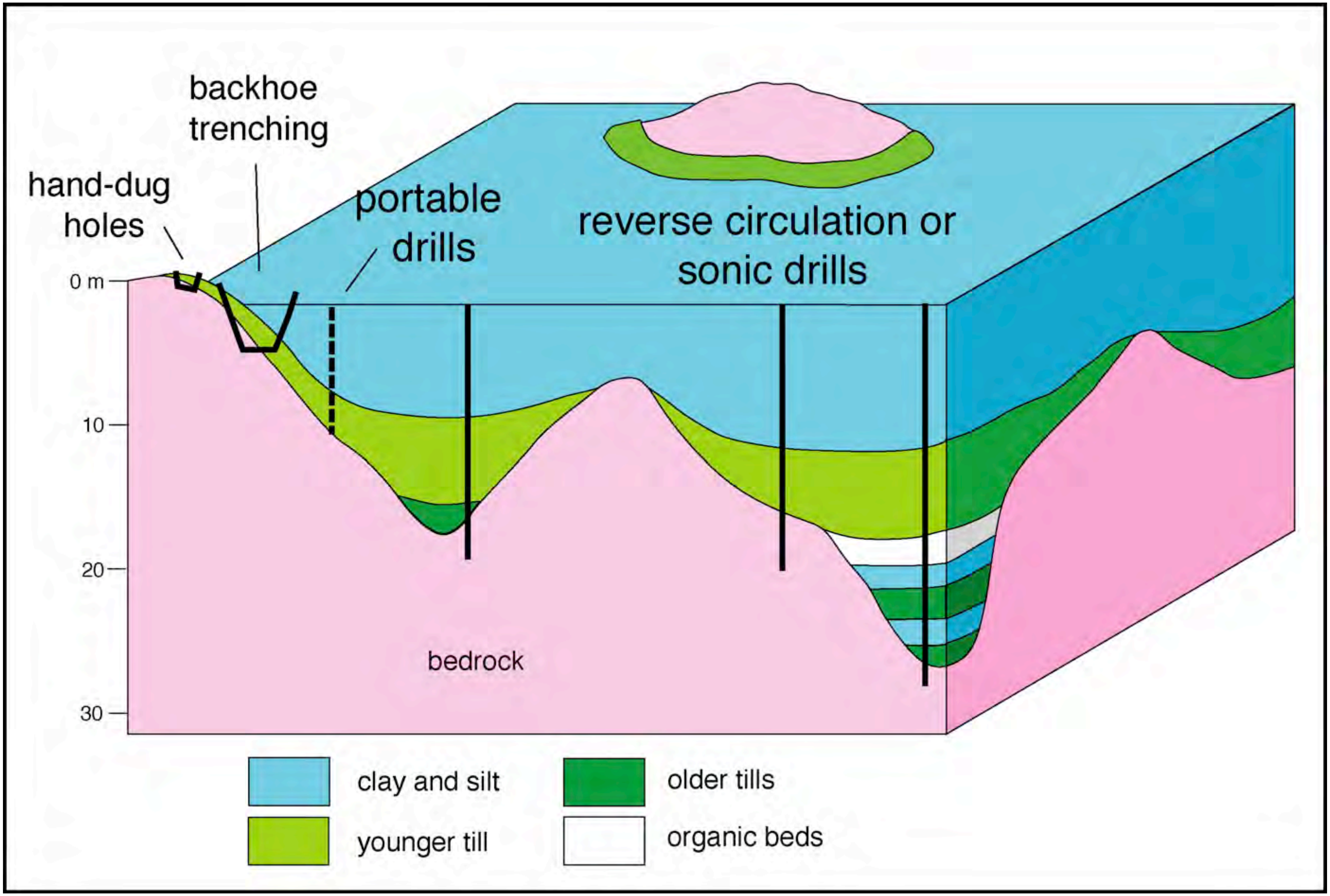
- Dispersal distance >50 km

MODEL OF MULTI-PHASE GLACIAL DISPERSAL

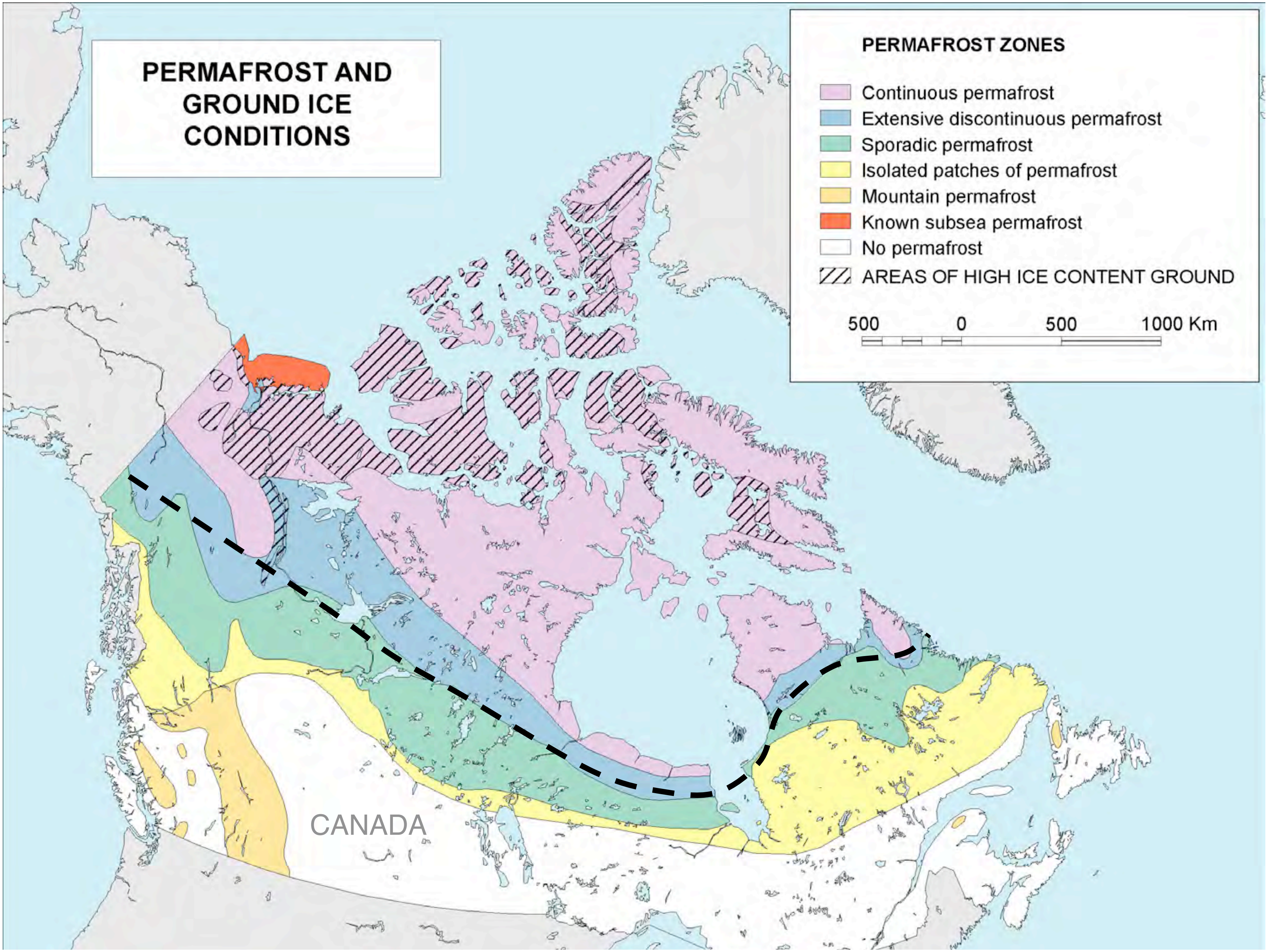


(Stea, 2007)

TILL SAMPLING STRATEGIES

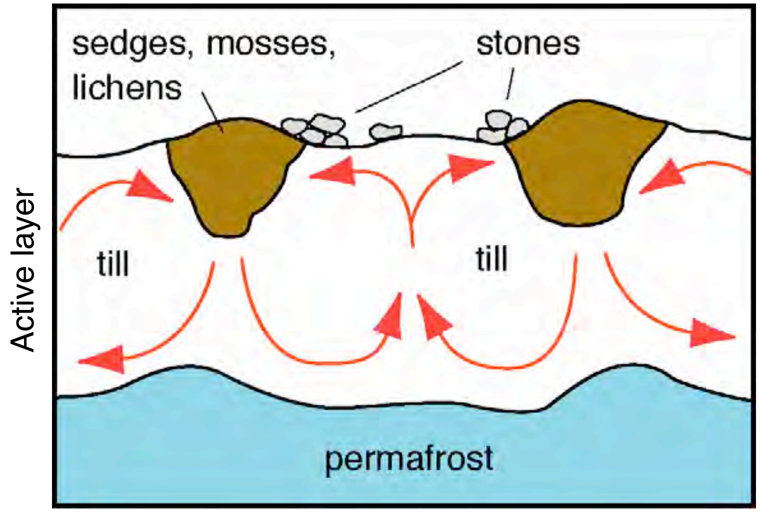


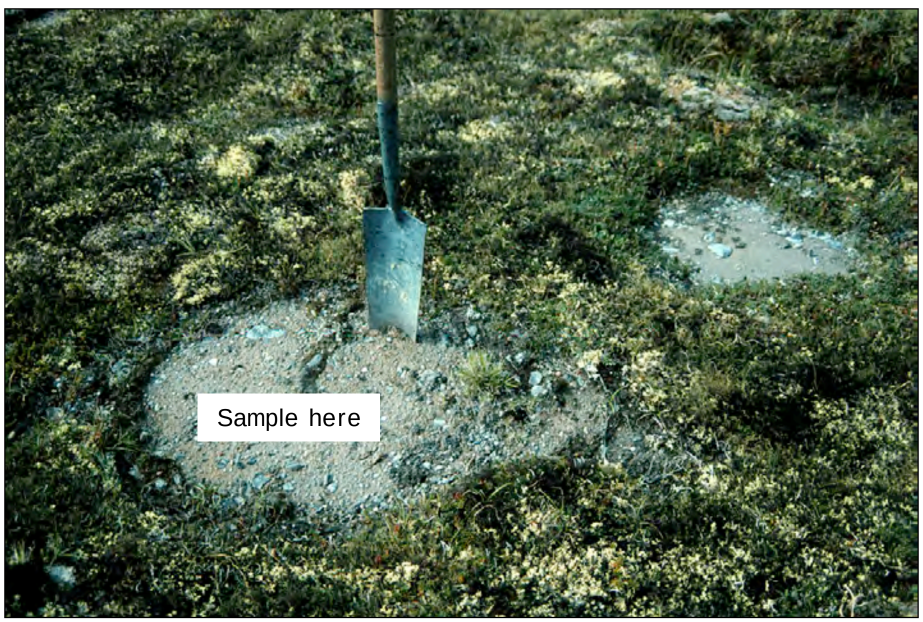
(McMartin and McClenaghan, 2001)



PERMAFROST AND GROUND ICE CONDITIONS
PERMAFROST ZONES
Continuous permafrost
Extensive discontinuous permafrost
Sporadic permafrost
Isolated patches of permafrost
Mountain permafrost
Known subsea permafrost
No permafrost
AREAS OF HIGH ICE CONTENT GROUND
500
0
500
1000 Km
CANADA

PERMAFROST TERRAIN: MUDBOILS





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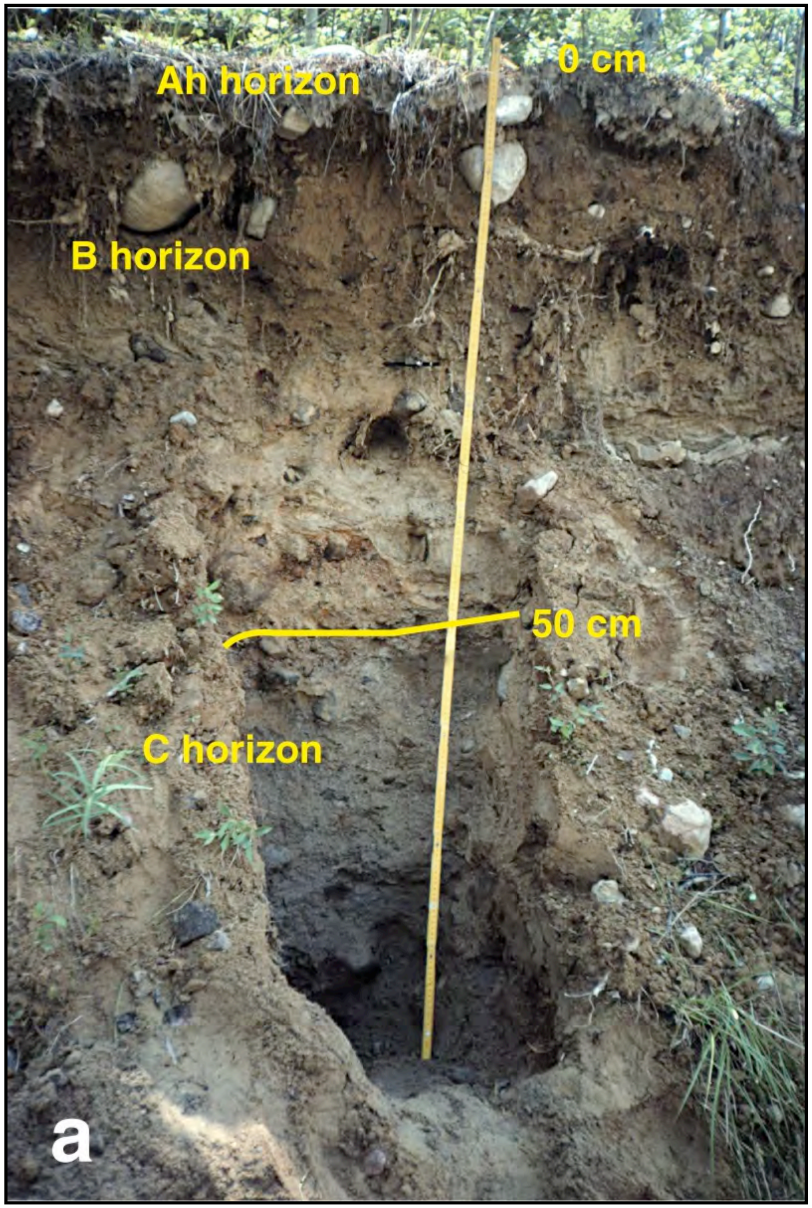
FORESTED AREAS



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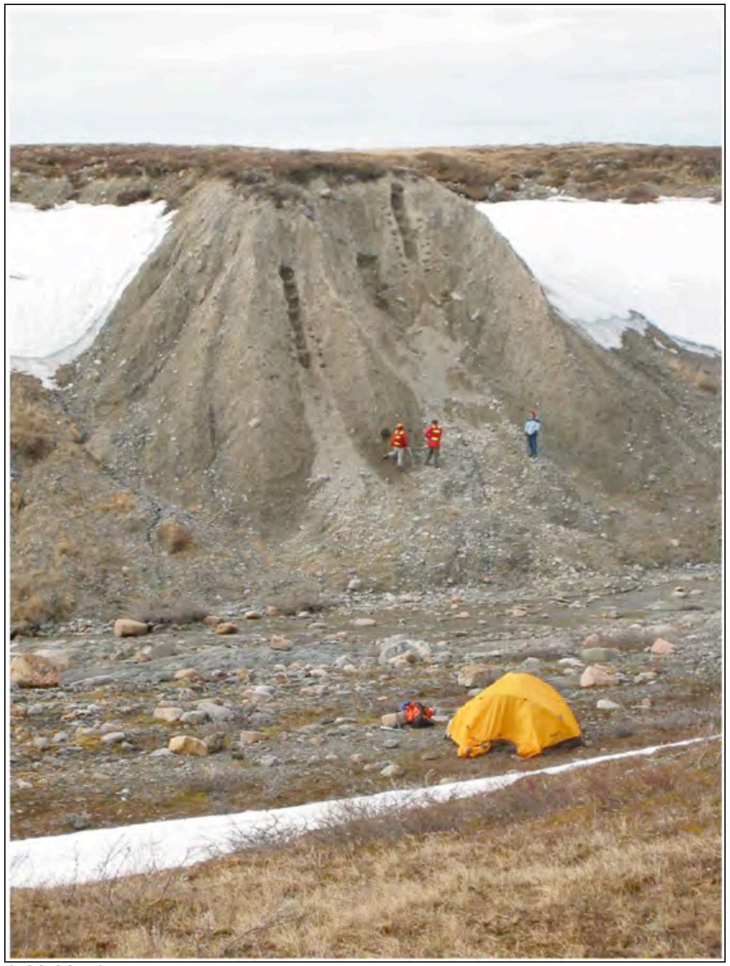
Black-brown organic mineral soil

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

Grey, unoxidized C horizon

HAND EXCAVATION

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



I. McMartin

I. McMartin

TRENCHING

PORTABLE SOLID STEM AUGER

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HOLLOW-STEM AUGER

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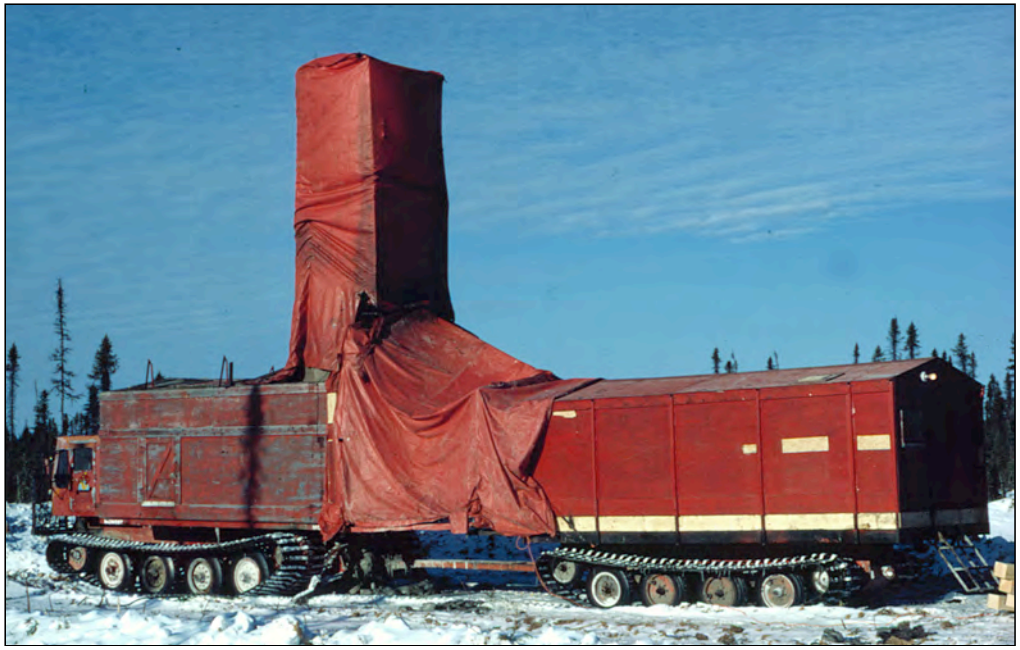
WET-ROTARY DRILL

R. Paulen

ROTASONIC DRILL



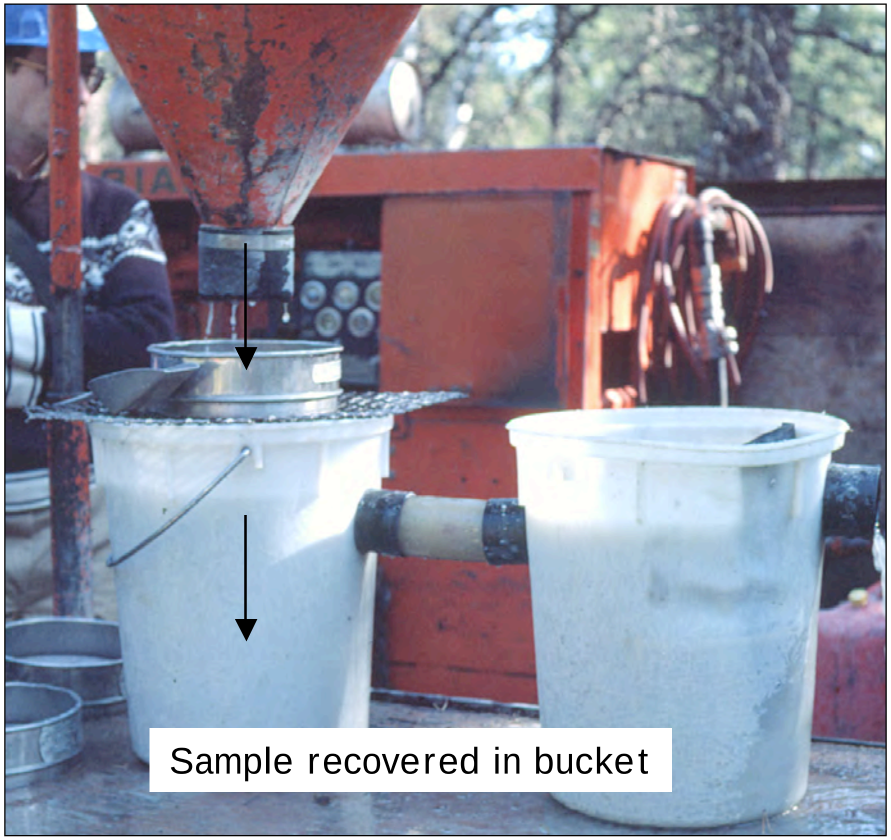
- overburden 10 to 125 m thick
- stony/bouldery till
- detailed stratigraphy
- continuous 9 cm core
- high costs

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

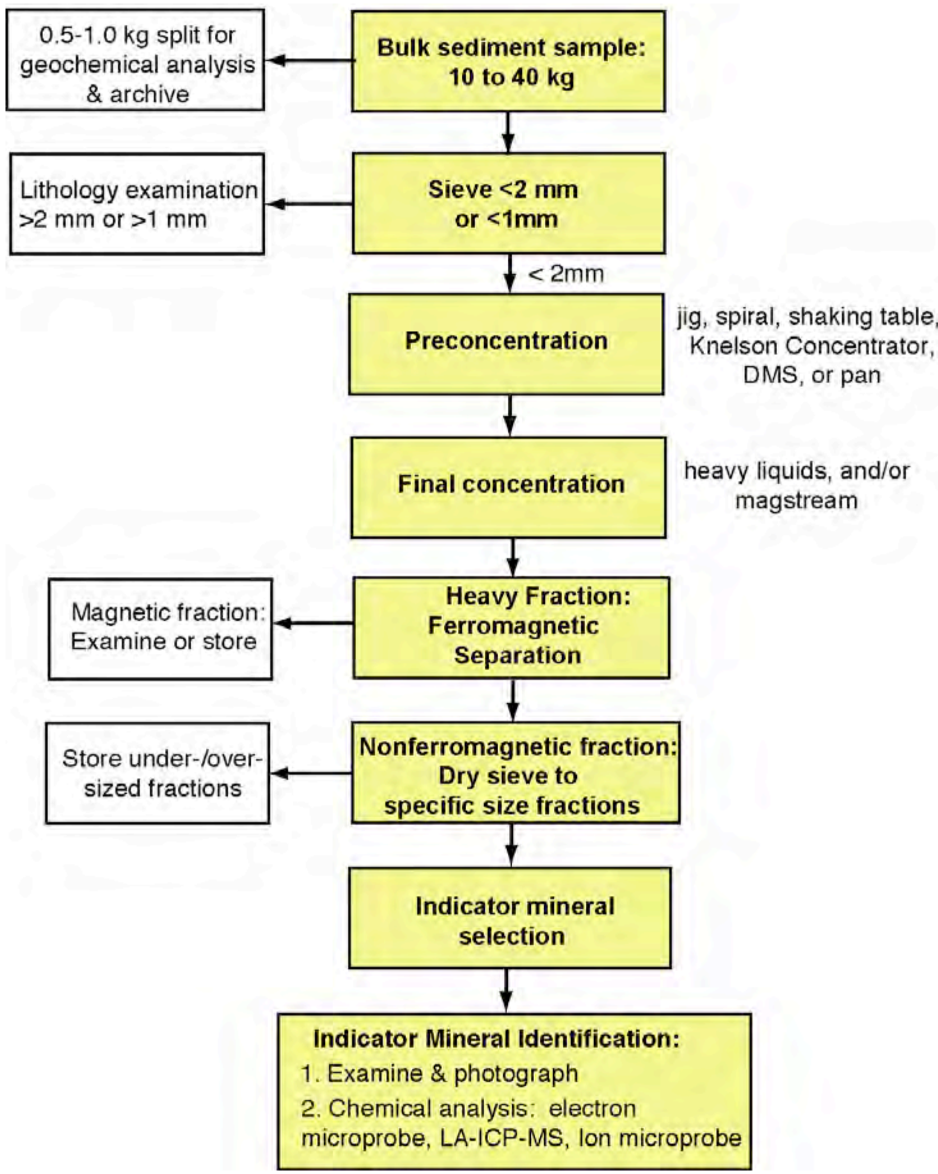
Sample weight depends on analytical methods:

- 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



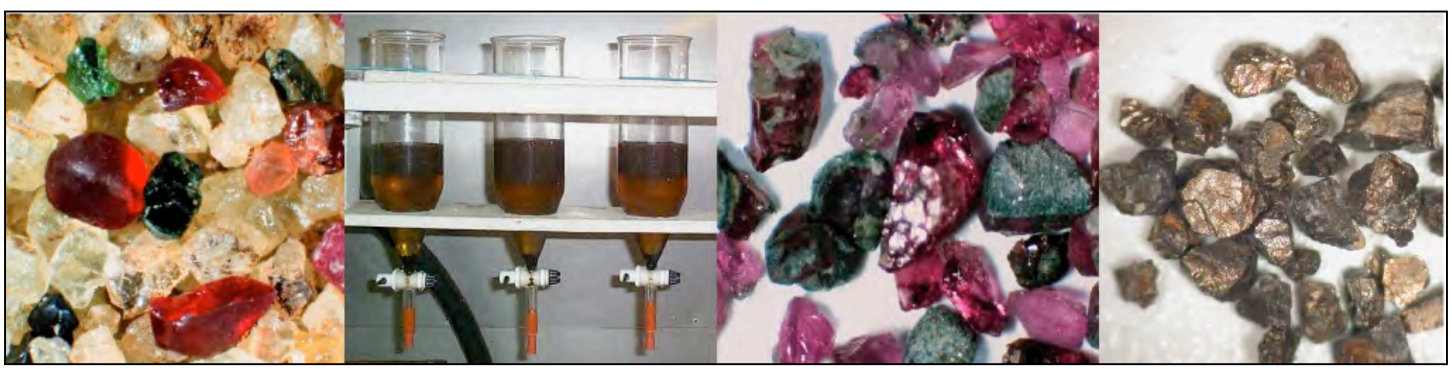
B. Coker

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

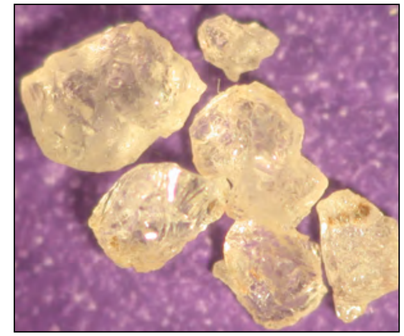


COMMON INDICATOR MINERALS

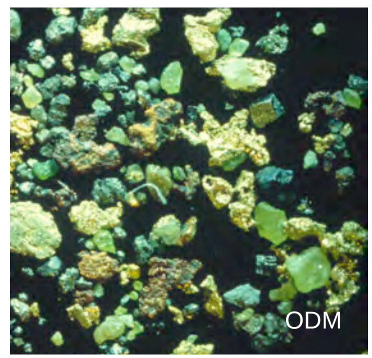
- Gold grains (Au)
- Native copper (Cu)
- Kimberlite indicator minerals
- Platinum Group minerals (PGM)
- Sulphide minerals
- Metamorphosed massive sulphide minerals- e.g. gahnite
- Magmatic Ni-Cu-PGE minerals
- Scheelite (W)
- Cassiterite (Sn)
- Cinnabar (Hg)
- Fluorite, topaz (F)
- Uranium minerals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

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

Kimberlite indicator minerals

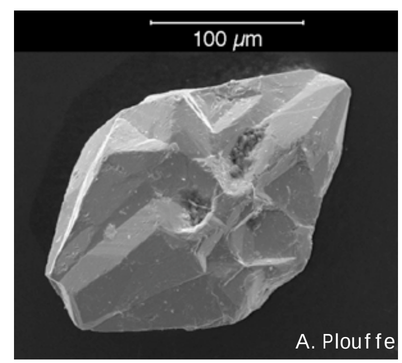


Topaz

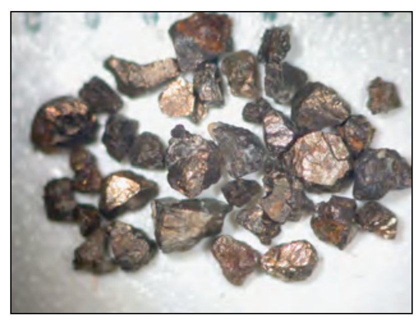


Gold, native copper, pyromorphite

Gahnite



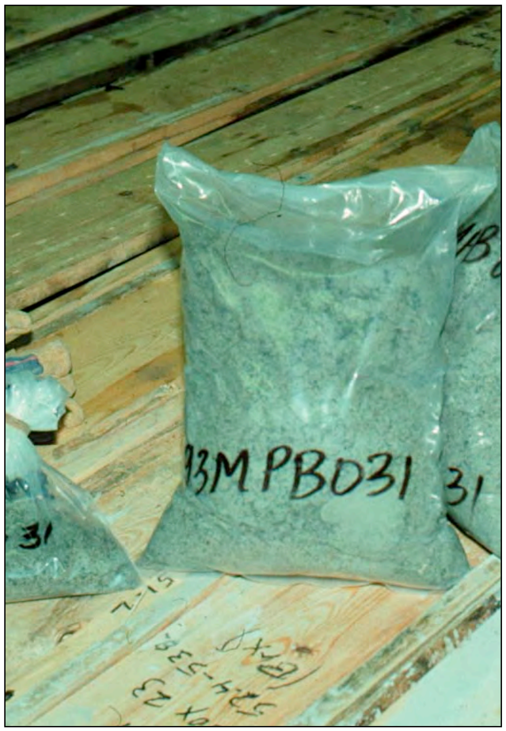
Cinnabar



Pentlandite

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

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

B. Coker

Dense media separator

Shaking Table

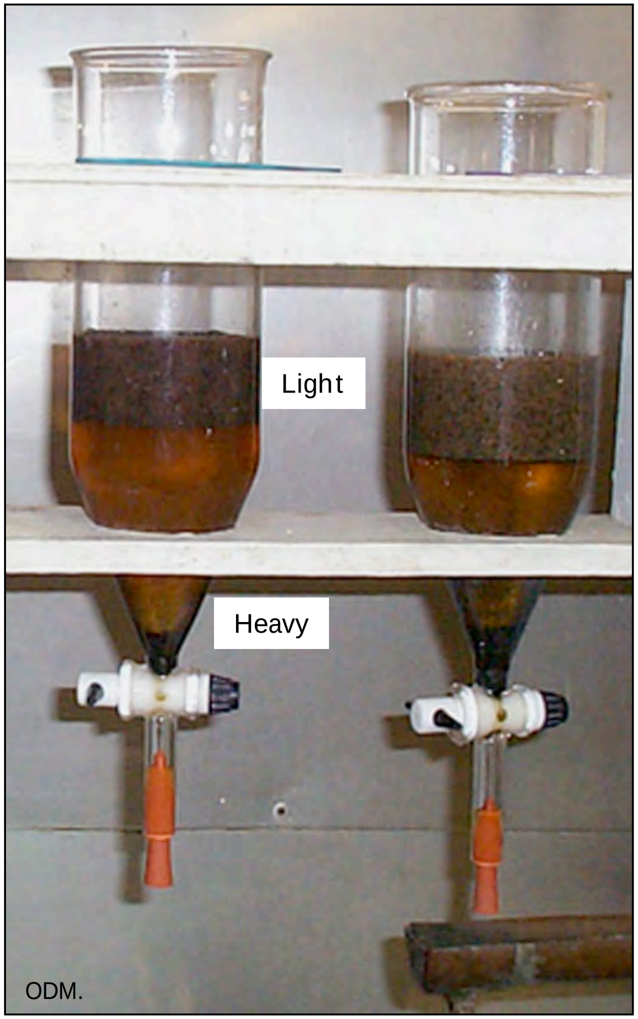
Spiral concentrator

Knelson concentrator

P. Sarala

M. Lehtonen

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

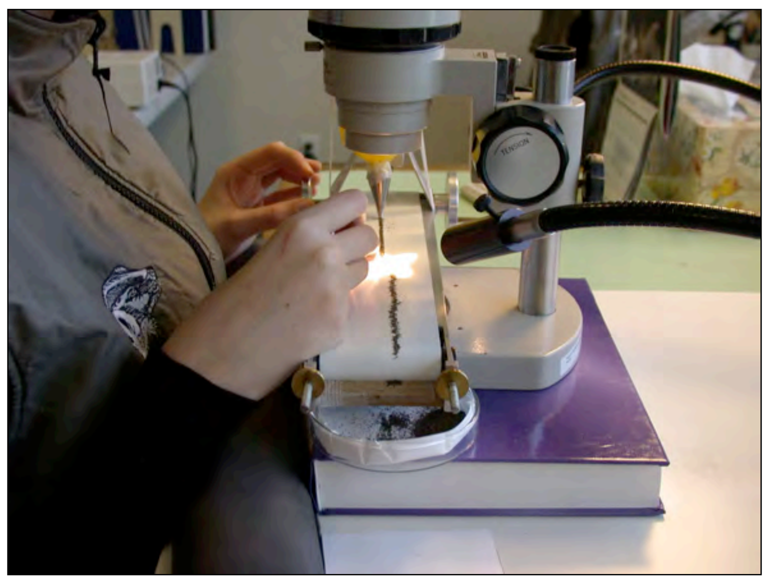
- Sizing, e.g. 0.25-0.5 mm; 0.5-2.0 mm
- Magnetic susceptibility (paramagnetic separation)
- Magstream

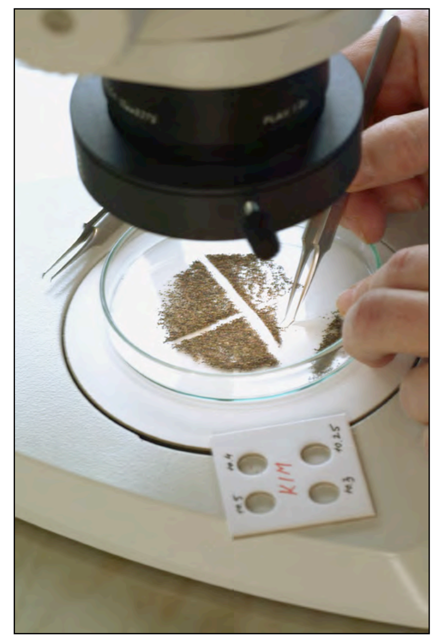

Carpco magnetic separator

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

ODM

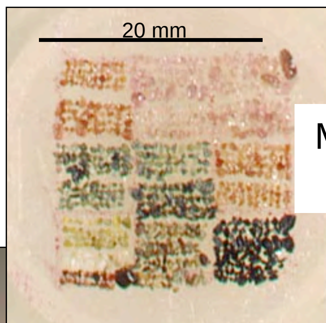




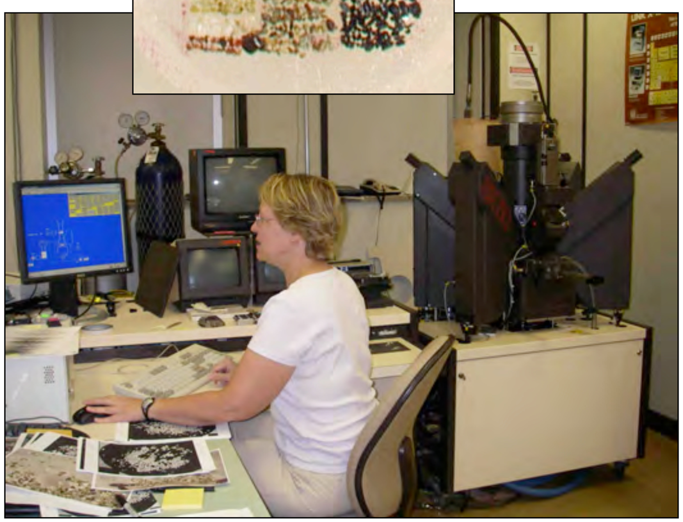
KIM Dynamics

STEP 8: MINERAL CHEMISTRY

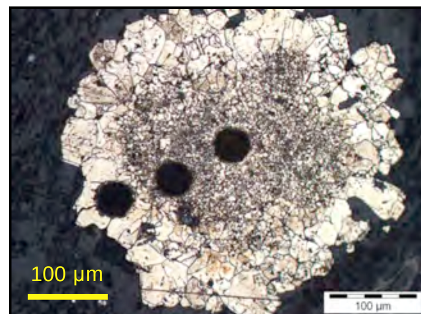
- Quantitative major & trace element analysis
- Confirm visual mineral identification, evaluate deposit grade, deposit genesis & alteration
- e.g. kimberlitic chromite & Mg-ilmenite difficult to identify visually
- Mount & polish selected grains (25 mm epoxy mounts)
- SEM, EMP, LA-ICP-MS, SIMS



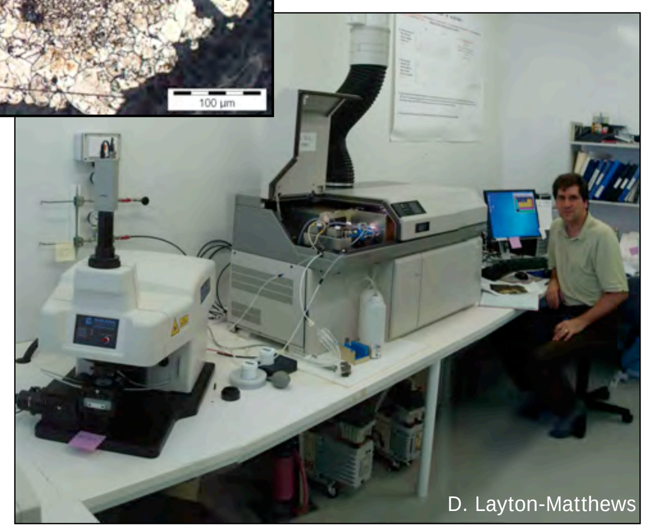
Mineral grains mounted for probe analysis



Electron microprobe (EMP)



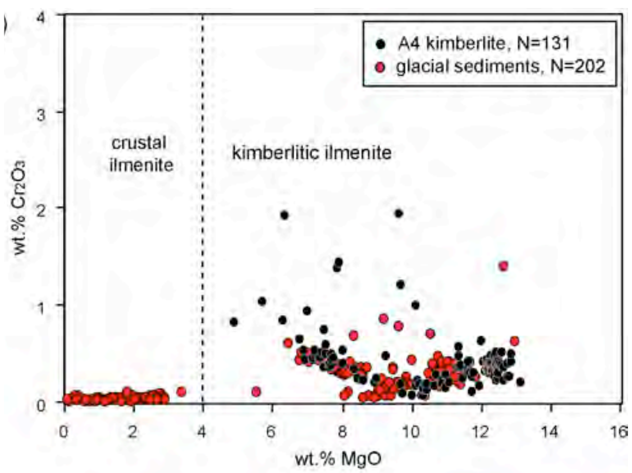
Pyrite framboid with laser ablation pits



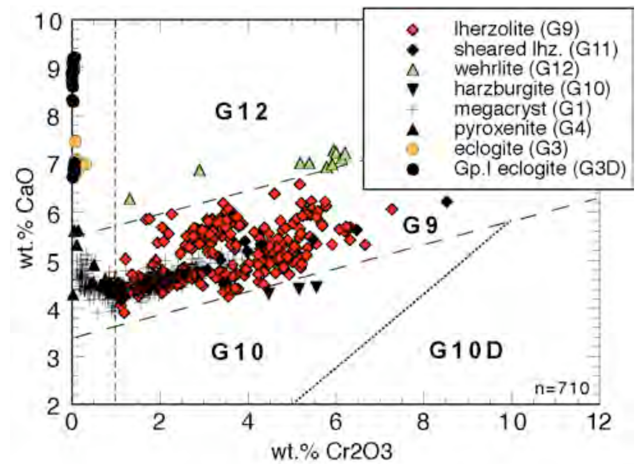
LA-ICP-MS, CODES

KIMBERLITE MINERAL CHEMISTRY

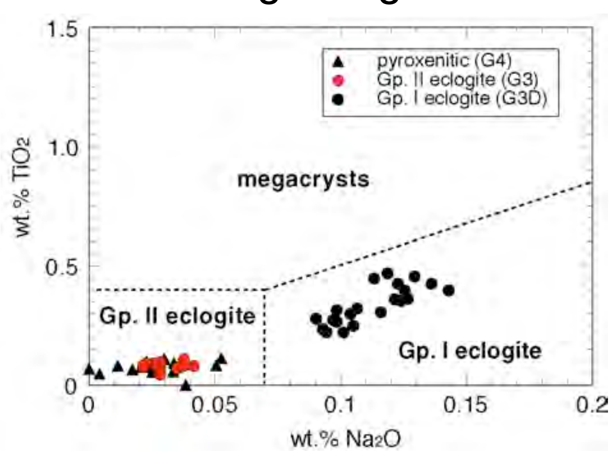
Mg-ilmenite



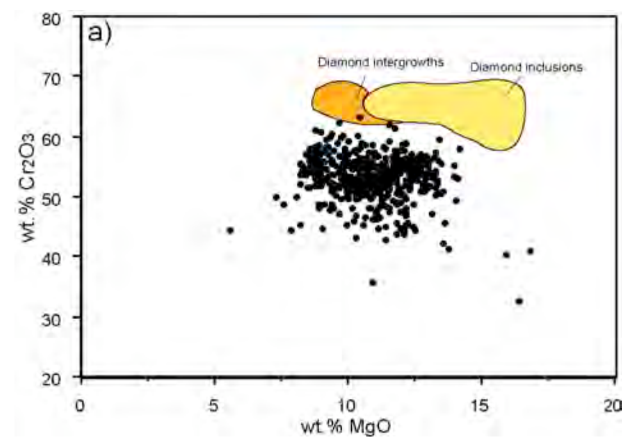
Garnets



Eclogitic garnets



Chromite



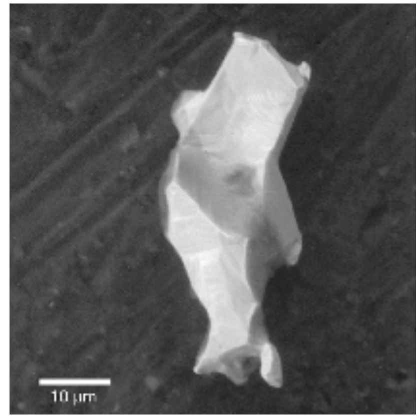
Also discrimination plots for olivine, Cr-diopside...

INDICATOR MINERALS

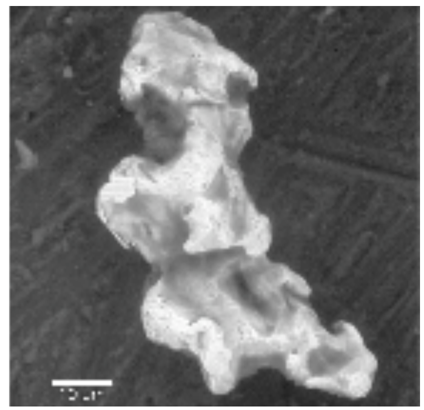
Surface Features

Kelyphite rims (k) on Cr-pyrope

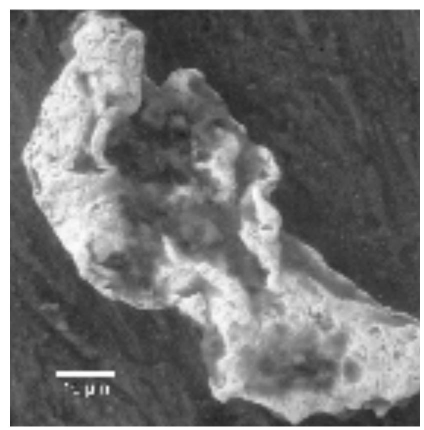
Grain Shape



Pristine gold grains



Modified gold grains

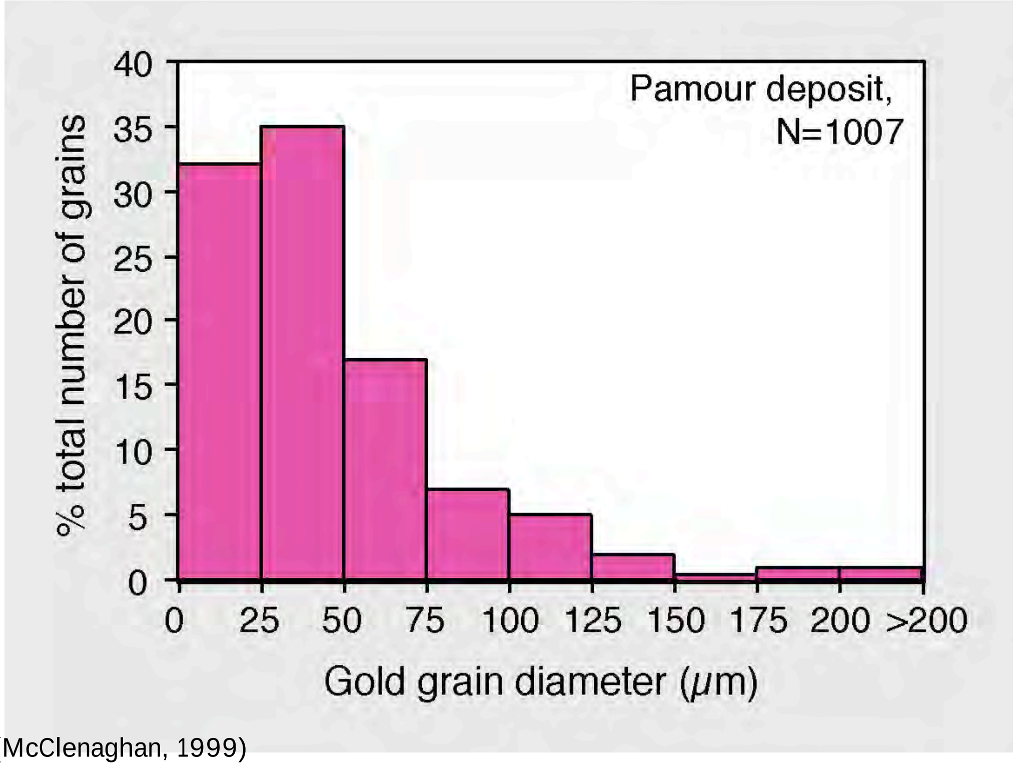


Reshaped gold grains

Increasing transport distance

(DiLabio, 1990)

INDICATOR MINERALS



(McClenaghan, 1999)

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

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

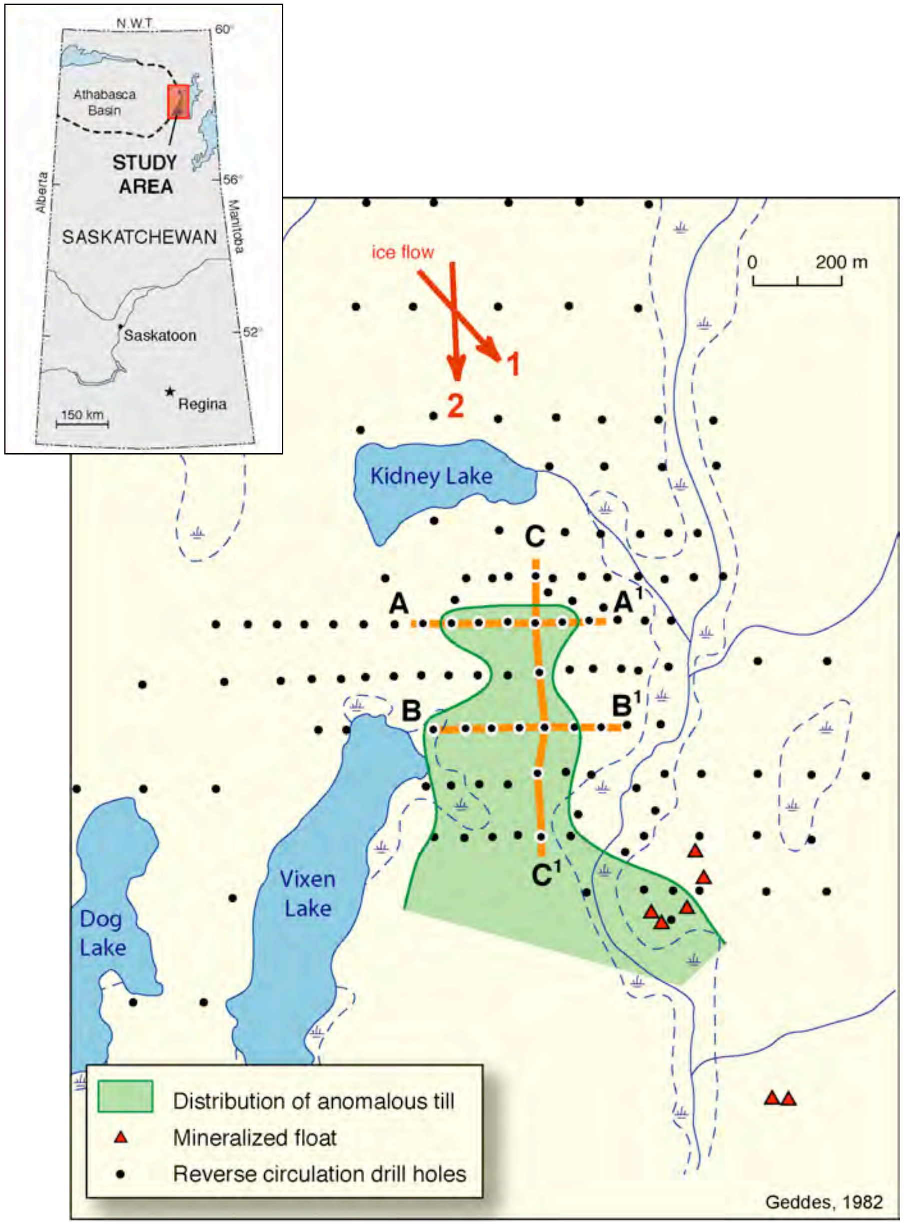
Sample preparation

- 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

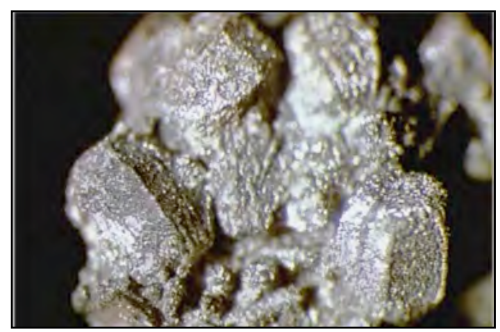
ATHABASCA BASIN, SASKATCHEWAN



Key Lake area, uranium deposits

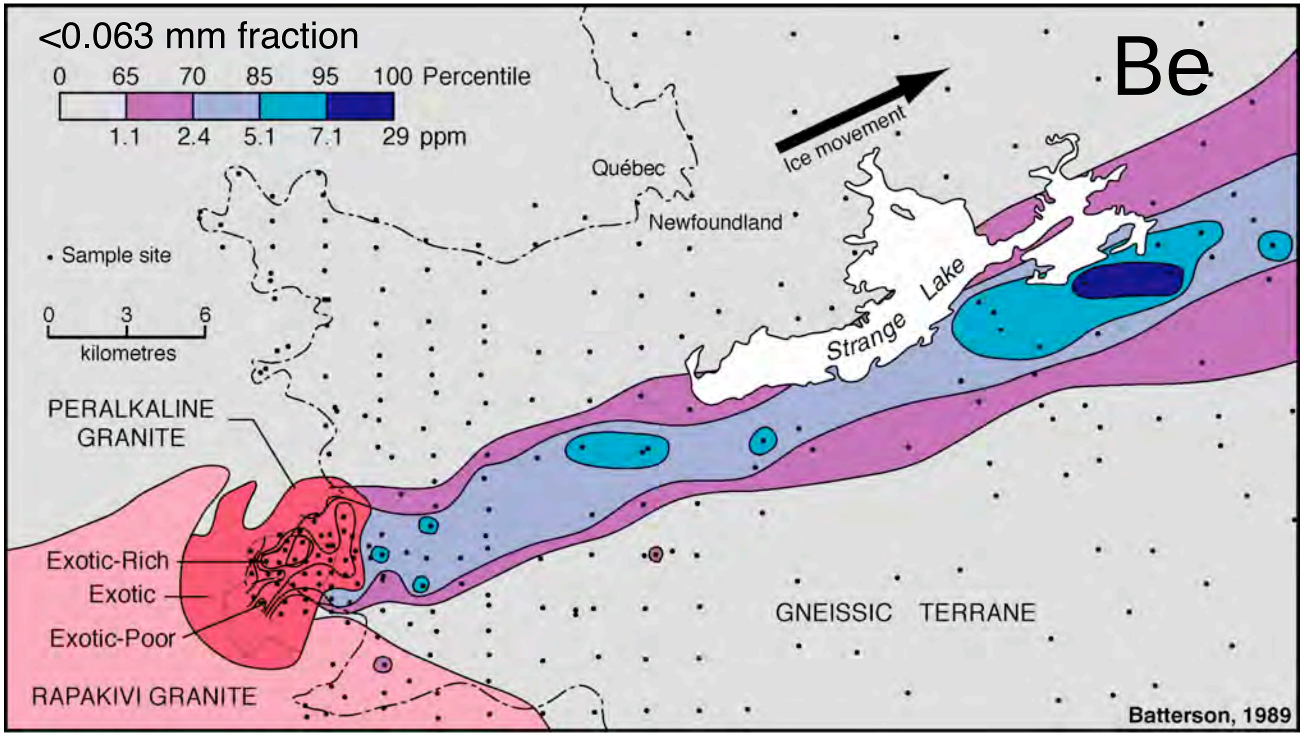
- Fan shaped dispersal train defined by boulders, till geochemistry & indicator minerals
- Train separated by 13 km gap from bedrock source
- Indicator minerals: niccolite (NiAs), hematite
- Till Geochemistry: U, Ni, As

Niccolite



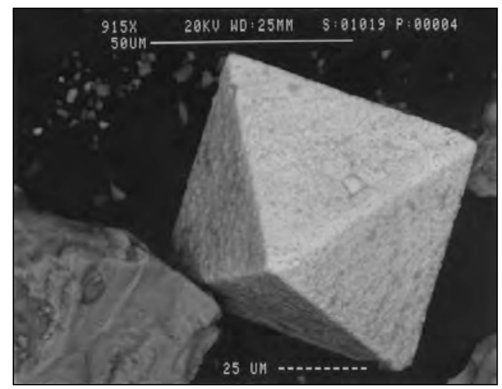
(Webmineral.com)

STRANGE LAKE, LABRADOR



Pyrochlore (Nb, F)

(www.Webmineral.com)



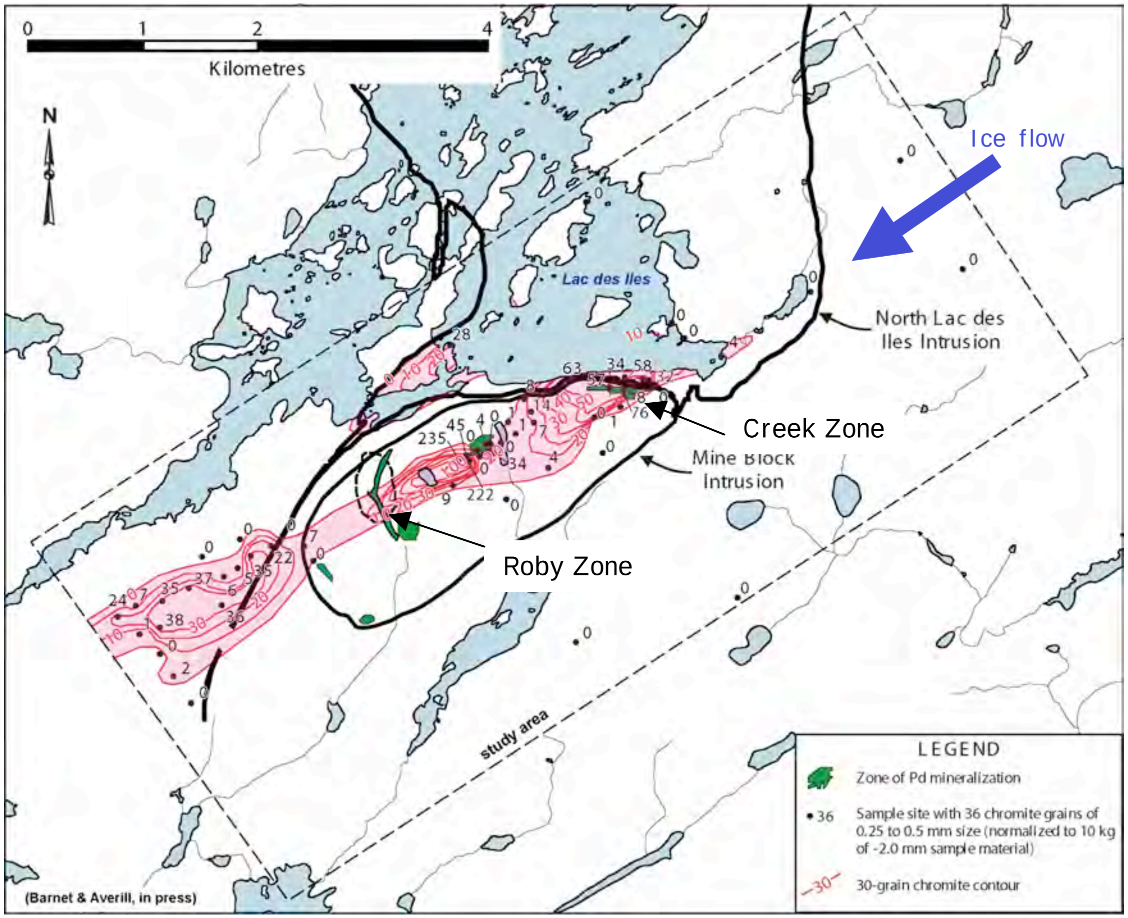
(DiLabio, 1982)

Strange Lake peralkaline granite, F-rich phases

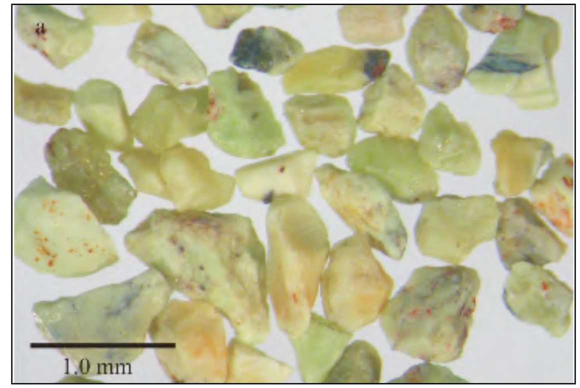
- >40 km ribbon-shaped dispersal train defined by till geochemistry
- Indicator minerals: F, Nb, Ta, REE-rich minerals
  e.g. fluorite, pyrochlore, zirconosilicates, monazite
- Till geochemistry: Be, La, Nb, Pb, Th, U, Y, Zr

LAC DES ILES, NW ONTARIO

Chromite in 0.25-0.5 mm fraction

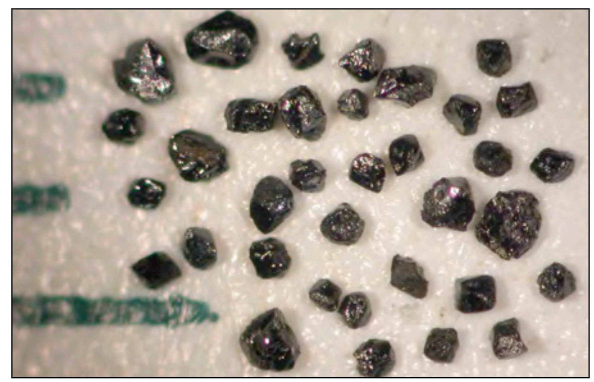


Cr-andradite (Cr-bearing garnet)



(Averill, 2007)

Chromite

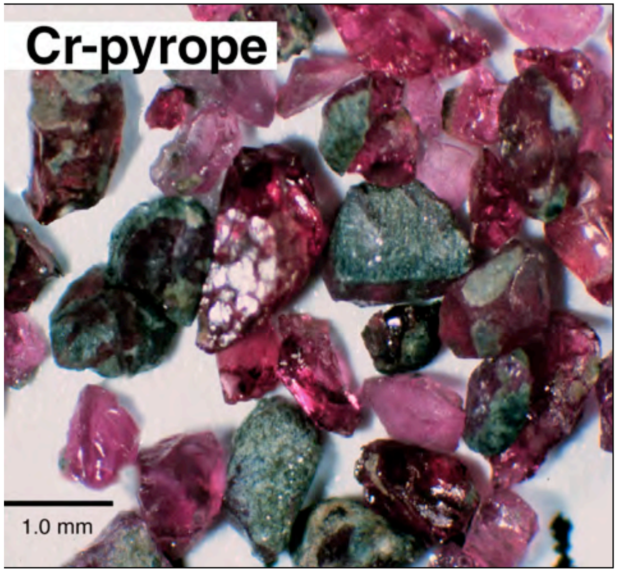


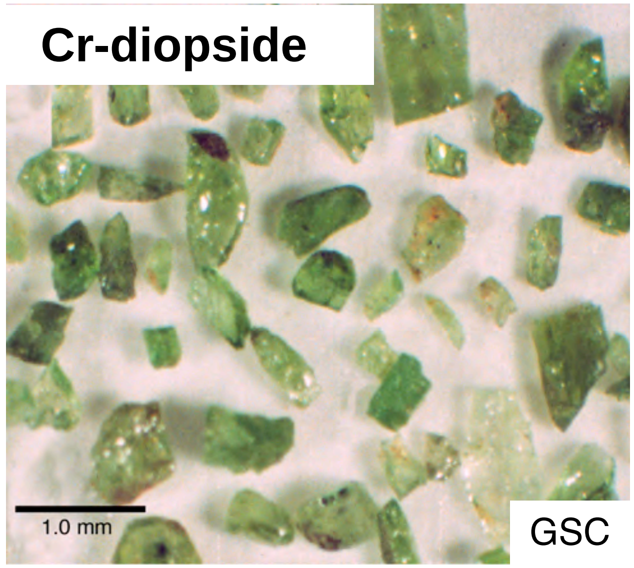
Lac des Iles Platinum mine

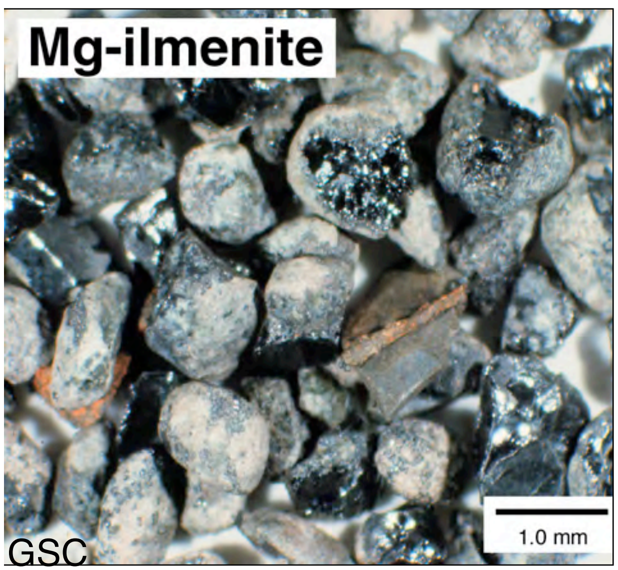
- >5 km ribbon-shaped dispersal train defined by till geochemistry & indicator minerals
- Indicator minerals: Cr-andradite, chromite, PGM minerals

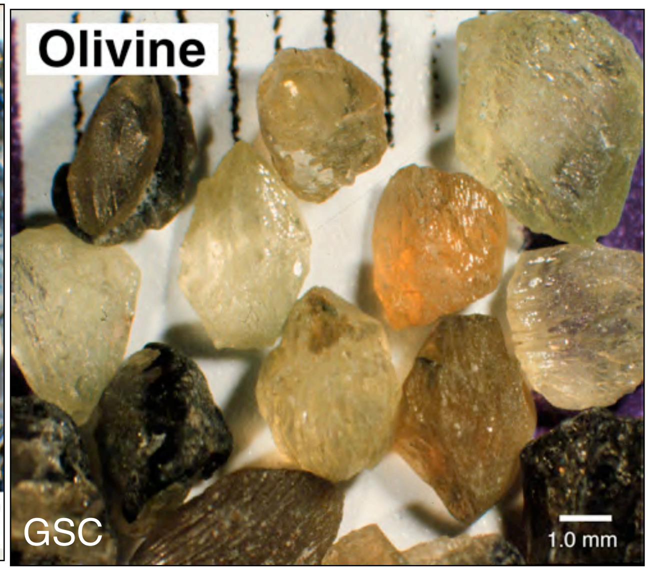
(Barnet & Averill, in press)

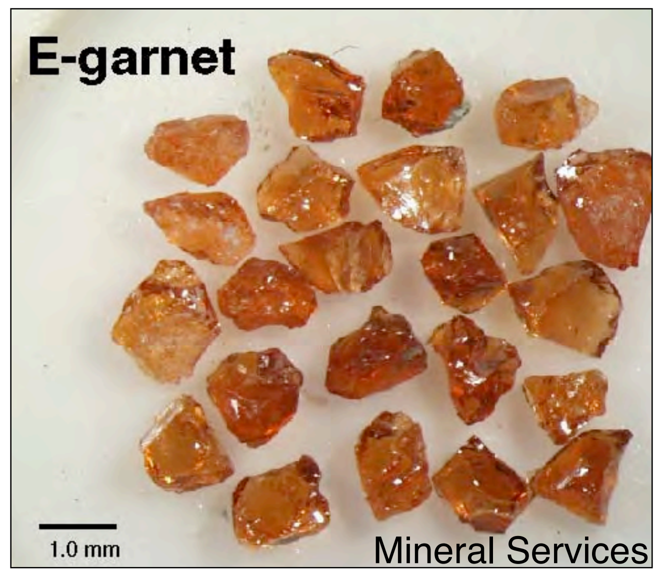
KIMBERLITE INDICATOR MINERALS





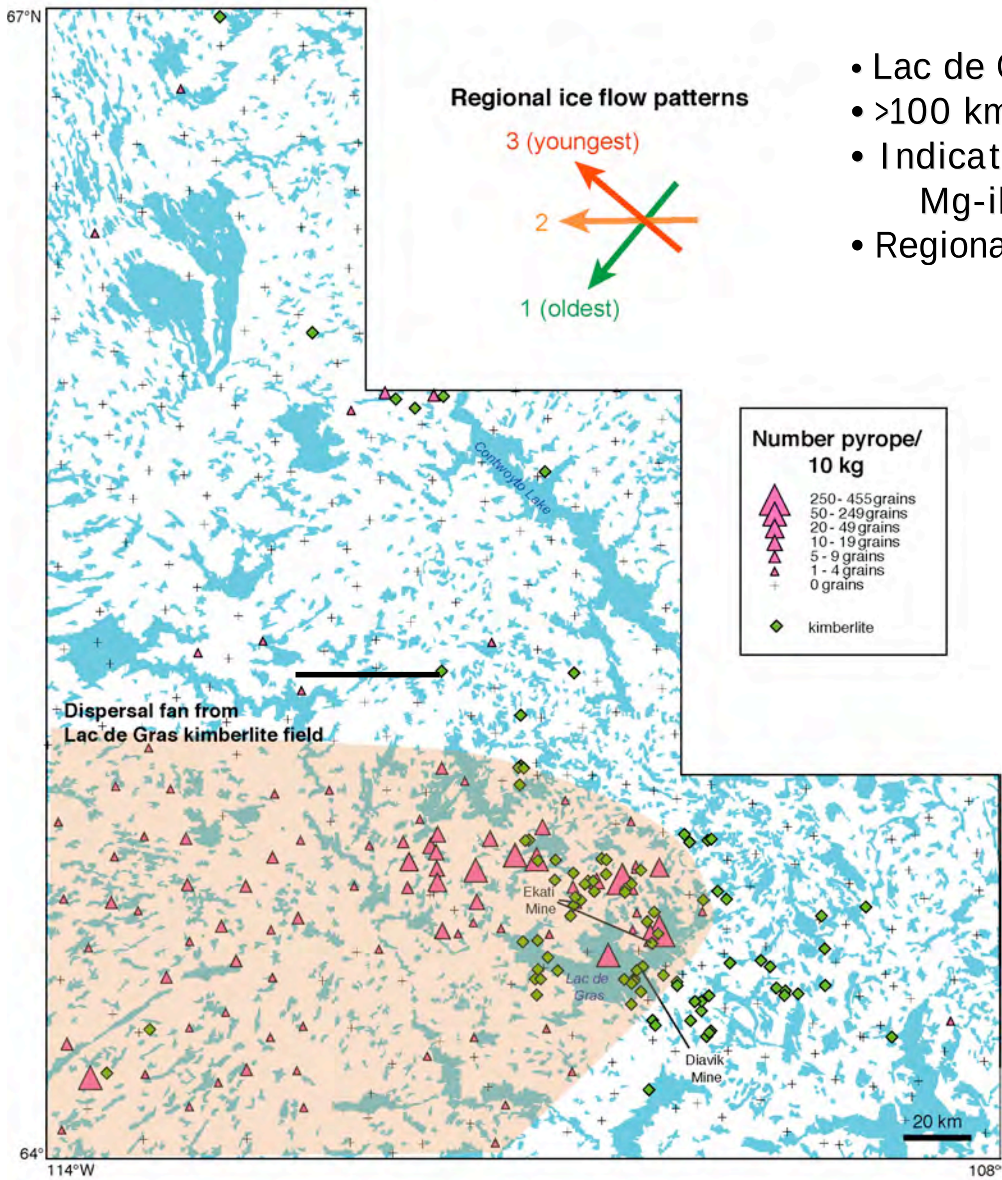




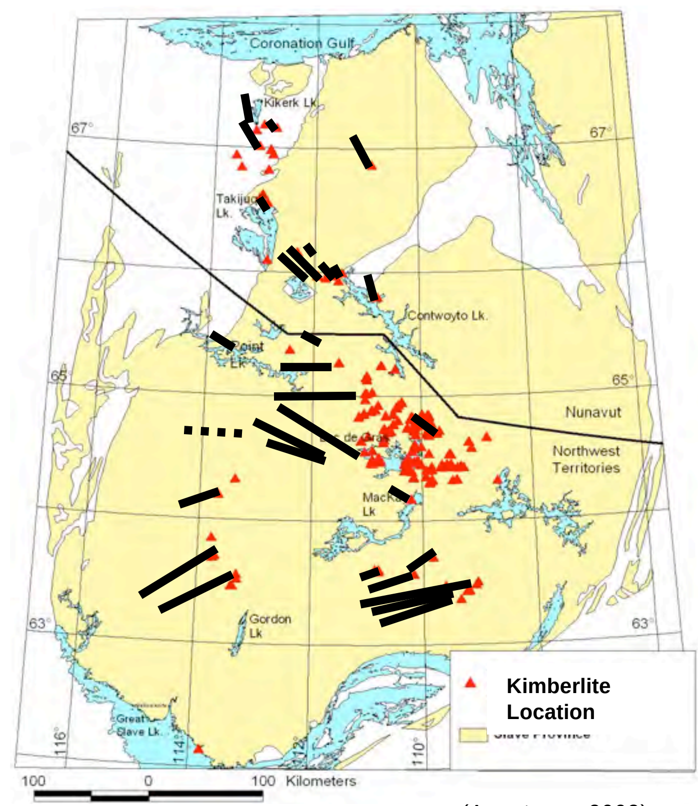


LAC DE GRAS, NWT

- 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

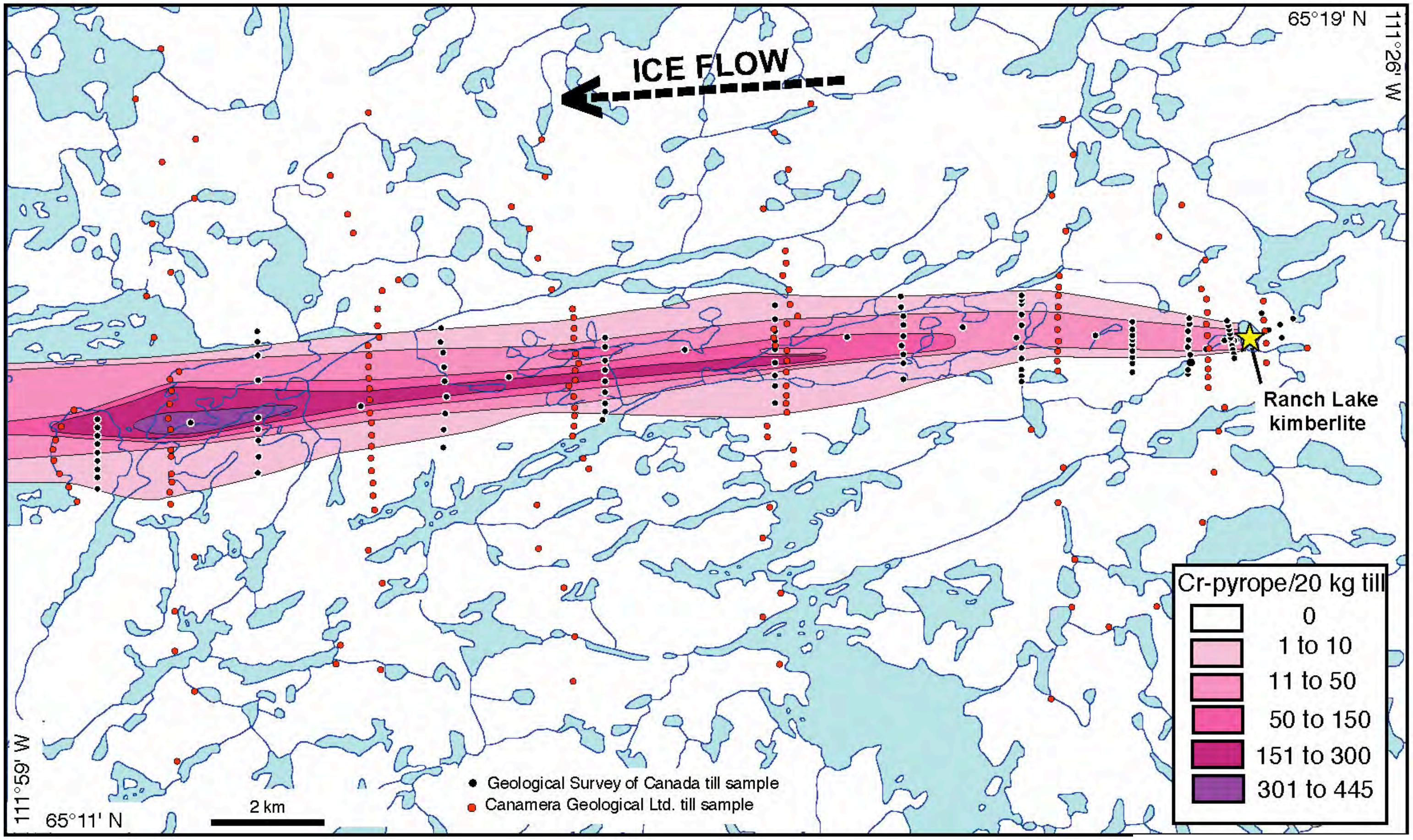


(Kerr, 2000)



(Armstrong, 2003)

RANCH LAKE, NWT



(McClenaghan et al., 2002)

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

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 <u>net</u> 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

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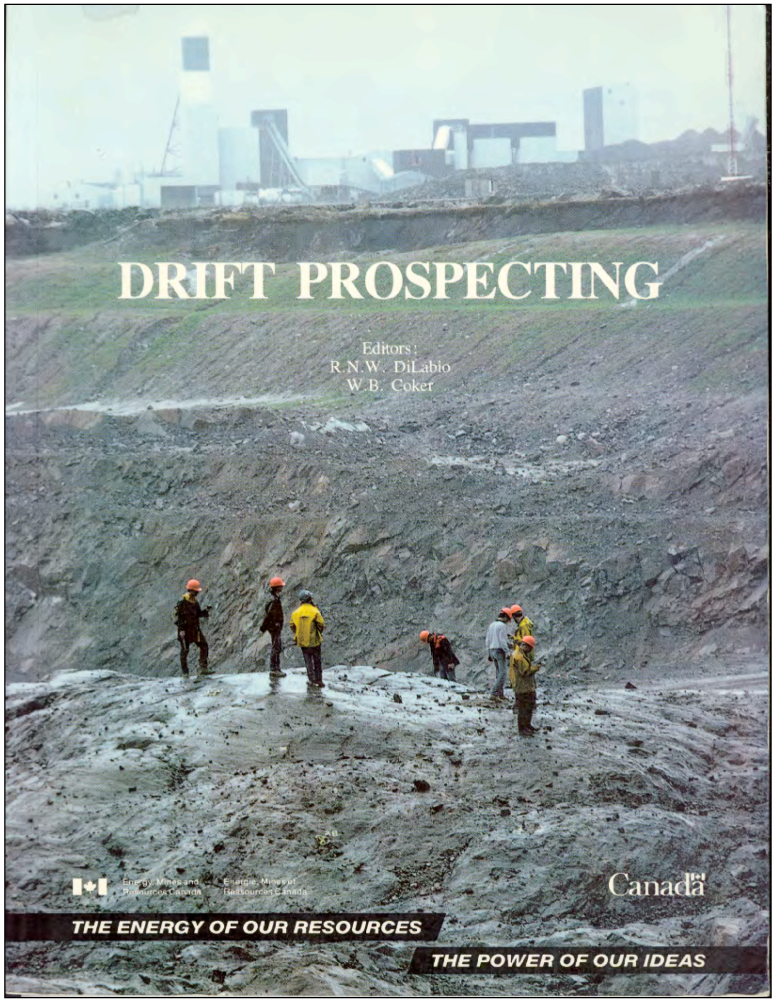
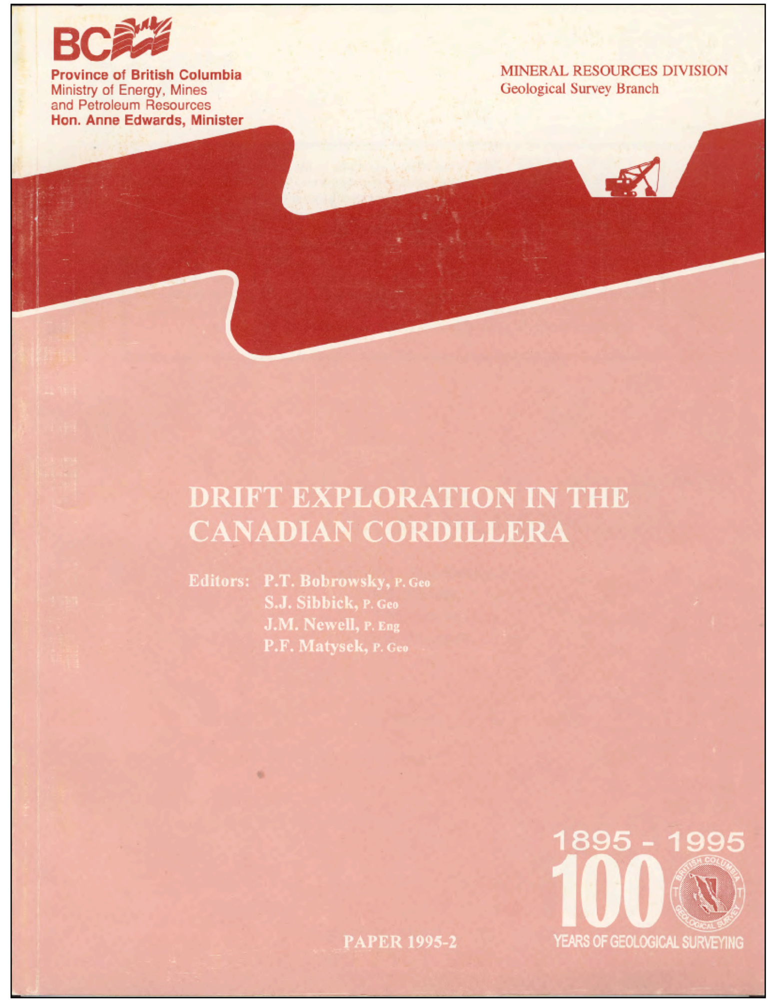
- Pertti Sarala, *Geological Survey of Finland*
- R. Stea, *Consultant*
- Pam Strand, *Shear Minerals*
- Harvey Thorliefson, *Minnesota Geological Survey*

FURTHER READING: DRIFT PROSPECTING

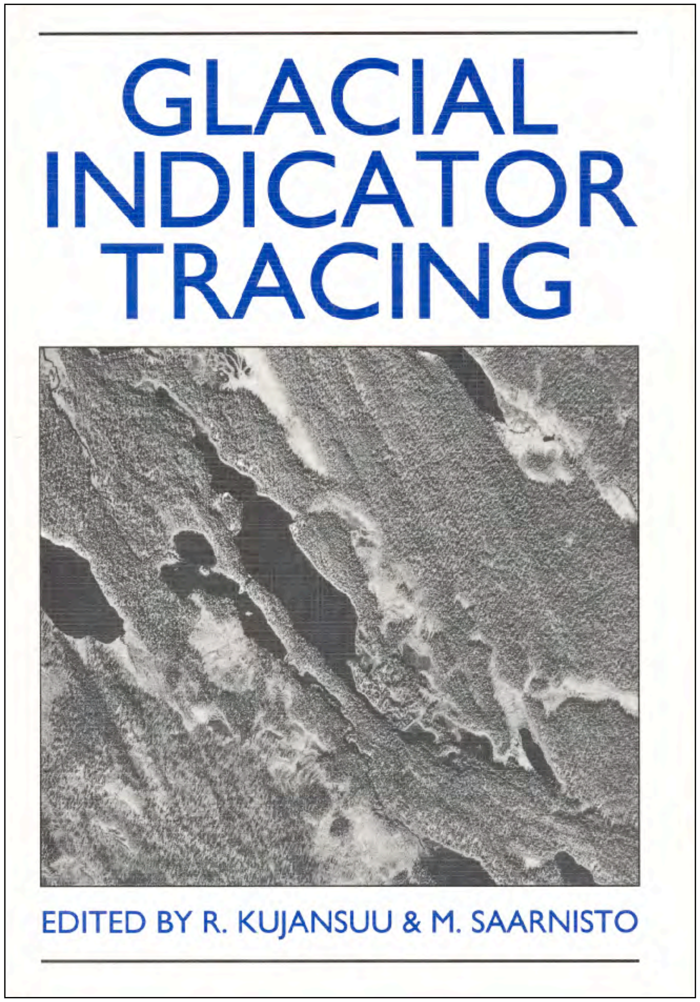


Drift Prospecting
(DiLabio and Coker 1989)

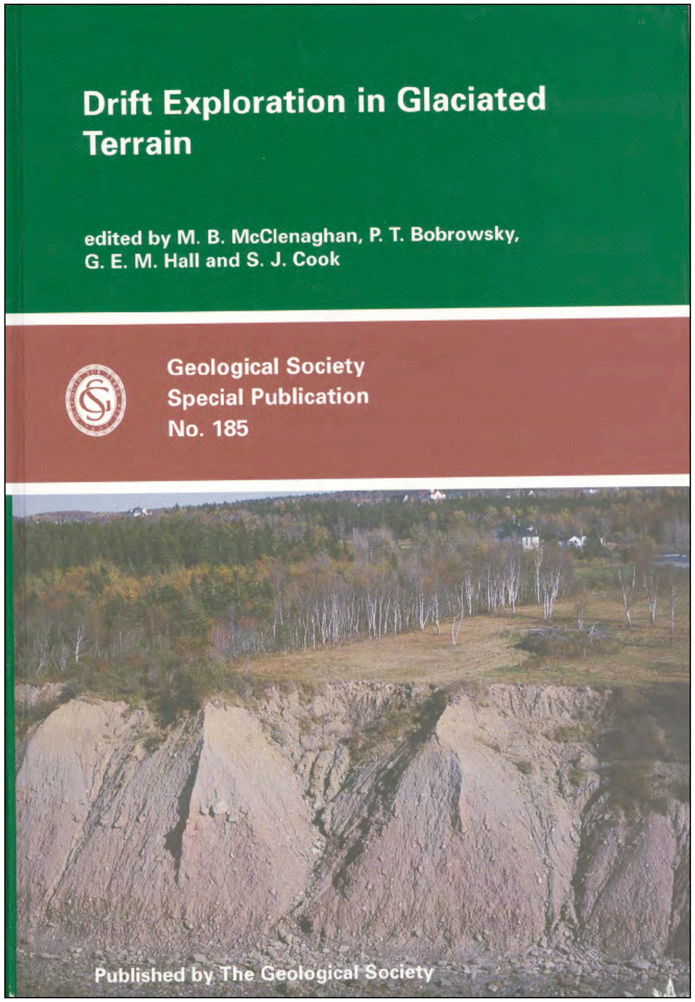


Drift Exploration in the Canadian
Cordillera (Bobrowsky et al. 1995)

FURTHER READING: DRIFT PROSPECTING



Glacial Indicator Tracing
(Kujansuu and Saarnisto 1990)



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