Sample Processing Methods for Recovery of Indicator Minerals

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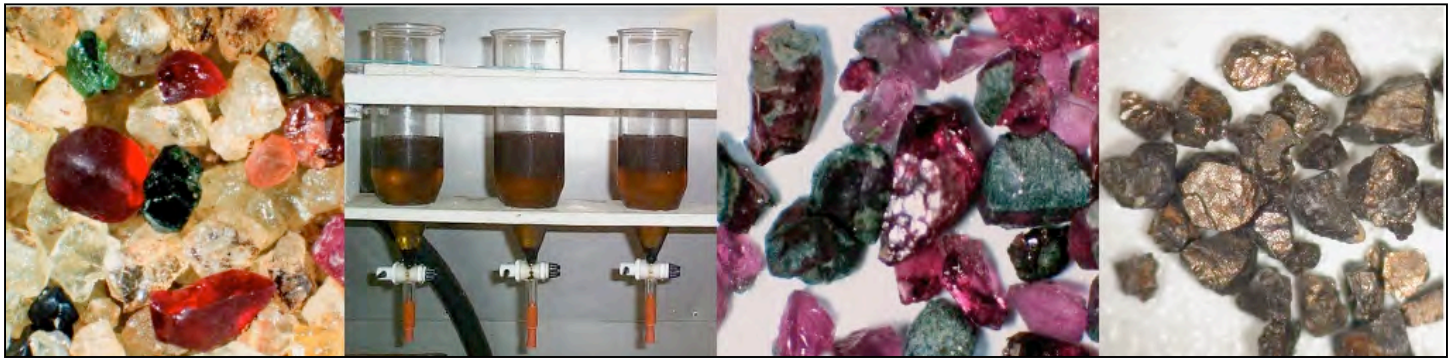
Geological Survey of Canada

Exploration 07 Workshop 3
Indicator Mineral Methods in Mineral Exploration
September 9, 2007

INDICATOR MINERALS

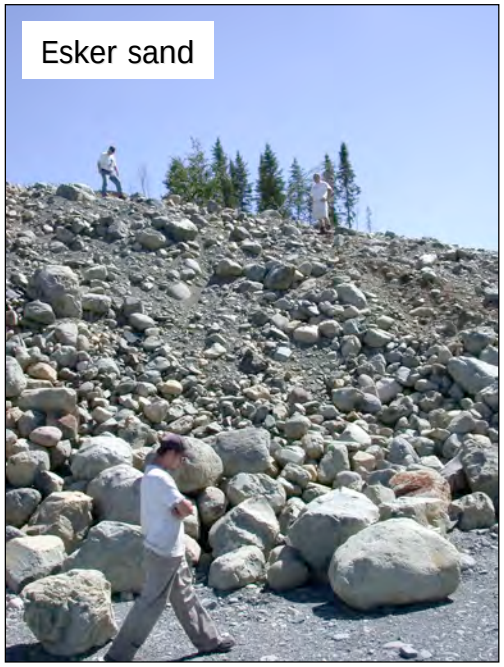
Physical Characteristics:

- Occur mainly in host rock
- Visually and chemically distinct
- Moderate to high density
- Silt to coarse sand-sized (0.10 to 2.0 mm)
- Survive weathering
- Survive clastic transport



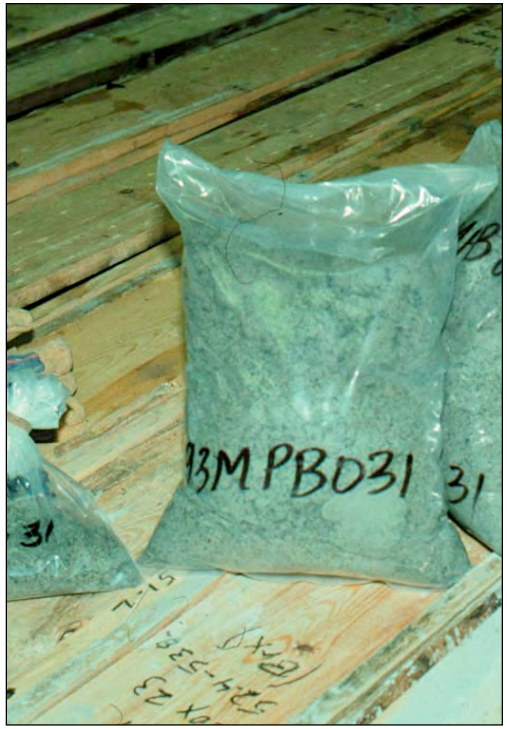
SAMPLE MEDIA

- Stream sediments
- Shoreline/beach sediments
- Glaciofluvial (esker) sediments
- Till
- Eolian sediments
- Laterite, regolith
- Float cobbles & boulders



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

SAMPLE WEIGHT

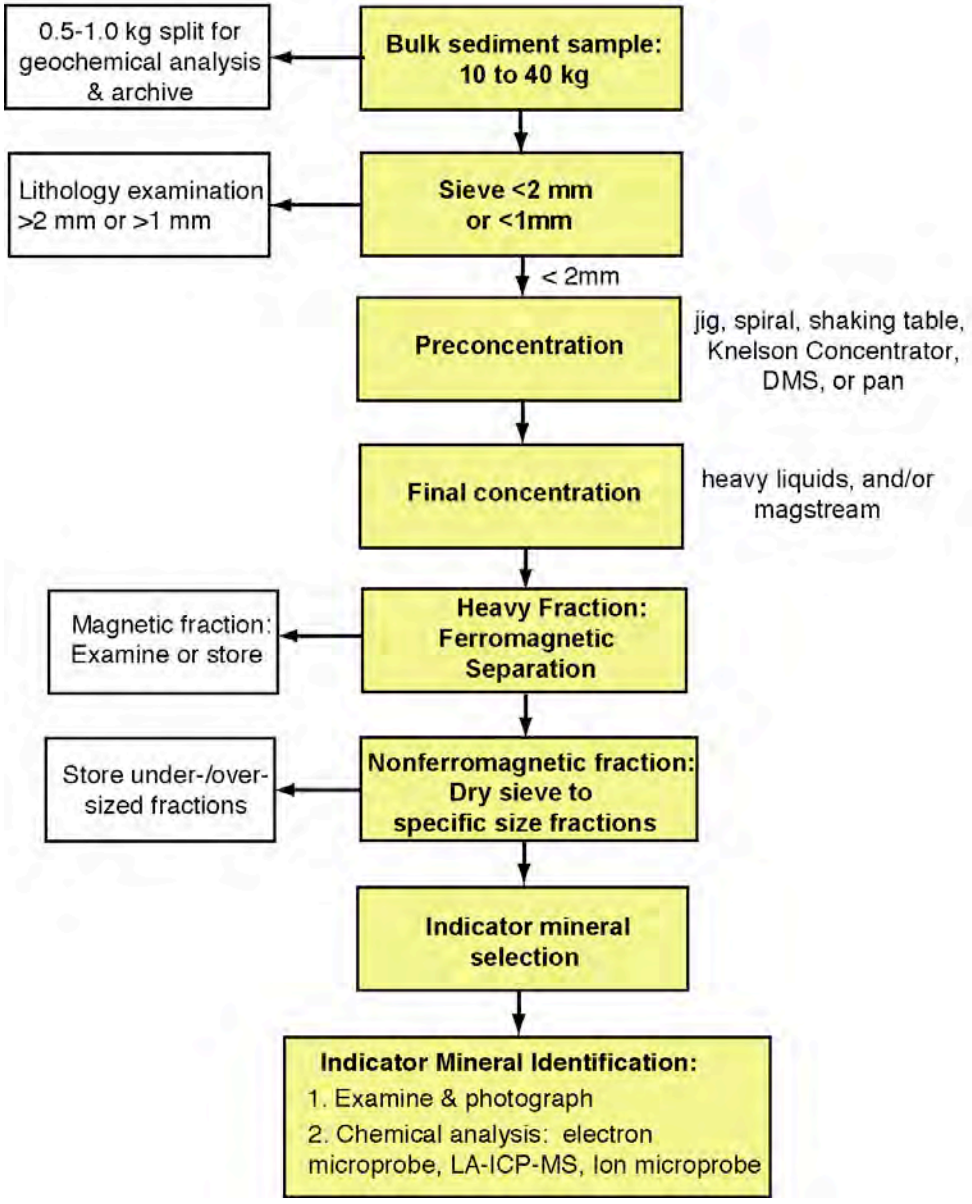
Example: till samples from glaciated terrain

Location	Till Texture	Weight (kg)	>2 mm Clast (kg)	Liquid Light fraction (g)	Magnetic fraction (g)	Non-mag fraction (g)
Thompson Ni Belt	silty sand	15	3	105	36	48
Sudbury-N. Rim	sand	15	6	403	13	19
Timmins Au camp	silty sand	12	2	320	5	28
Timiskaming kimberlite field	silty sand	10	1	377	22	36
Northern Alberta	clay	67	2	1235	6	12

Suggested till sample weights:

- Sandy material, 10 to 25 kg
- Clay-rich material, 25 to 50 kg

GENERALIZED FLOWSHEET



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 (0.01 to 2.0 mm)

Density Separation

- Jig, wheel
- Pan
- Spiral separator
- Dense media separator (DMS)
- Shaking table (Wilfley table)
- Knelson Concentrator

STEP 3: PRECONCENTRATION

Panning

- Oldest recovery method for indicator minerals
- Pan shaken sideways in circular motion
- Heavy minerals sink, light minerals rise
- Size range: silt to sand sized mineral grains

Advantages:

- Field or lab-based operation
- Inexpensive, reduces shipping costs
- Recovers silt-size precious & base metals minerals
- Can be used in combination with other preconcentration methods

Disadvantages:

- Slow
- Dependent on experience & skill of operator
- Consistent personnel required to pan


B. Coker


W. Spirito

STEP 3: PRECONCENTRATION

Spiral concentrator

- Recovers heavy minerals ~SG ≥ 3
- Stainless steel bowl with ribs that form spiral
- Bowls spins, water sprays, grains move up in spirals
- Water washes light minerals down
- Heavy minerals travel up to central opening, collected in container behind bowl
- Heaviest minerals recovered first

Y. Maurice

Advantages:

- Fast if sample is sandy
- Field or lab-based operation
- Inexpensive, reduces shipping costs
- Recovers indicator minerals across broad size range, from silt-sized precious & base metals to sand size

P. Sarala

Disadvantages:

- Dependent on experience & skill of operator
- Lower density threshold variable
- Some loss of heavy minerals
- Slow if sample is clay-rich

STEP 3: PRECONCENTRATION

Knelson Concentrator

- Centrifugal separator, rotating bowl with rings
- Originally designed for recovery of gold
- Modified 3” version recovers heavy to moderately heavy minerals
- Slurry forced outward & upward under centrifugal force
- Slurry fills rings on cone wall, heavy minerals concentrate in rings

M. Lehtonen

Advantages:

- Moderate cost
- Field or lab-based operation
- Field based reduce shipping costs

Knelson Gravity Solutions website

Disadvantages:

- Lower size limit 0.25 mm, does not recover silt-size precious or base metal minerals
- Lower density threshold ~3.2, resulting in loss of moderately heavy minerals, greater loss for coarser (>0.5 mm) material

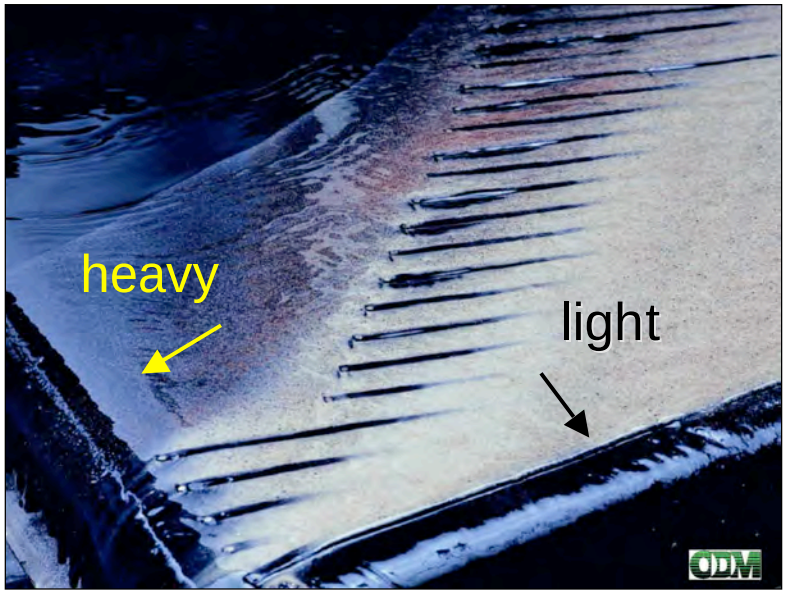
STEP 3: PRECONCENTRATION

Shaking (Wilfley) Table

- <2 or <1 mm fraction processed
- Table with riffles, shakes sideways
- Heavy minerals ride across top of table
- Light minerals across bottom of table

Advantages:

- Recovers broadest size range of indicator minerals from silt to sand size (0.1-2.0 mm)
- Recovers broad spectrum of indicator mineral species, including precious & base metals, kimberlites, U
- Moderate cost
- Pan preconcentrates for precious & base metals
- Well established & widely used method



Disadvantages:

- Some coarse heavy minerals lost during tabling
- Table operator requires experience
- Consistent personnel required to operate table

STEP 3: PRECONCENTRATION

Mineral Services Canada

Dense Media Separator (DMS)

- <2 or <1 mm fraction processed
- Fed into ferrosilicon solution, SG 3.1
- Heavy minerals spin to outside of column, light minerals in middle of column, heavy minerals collected at base

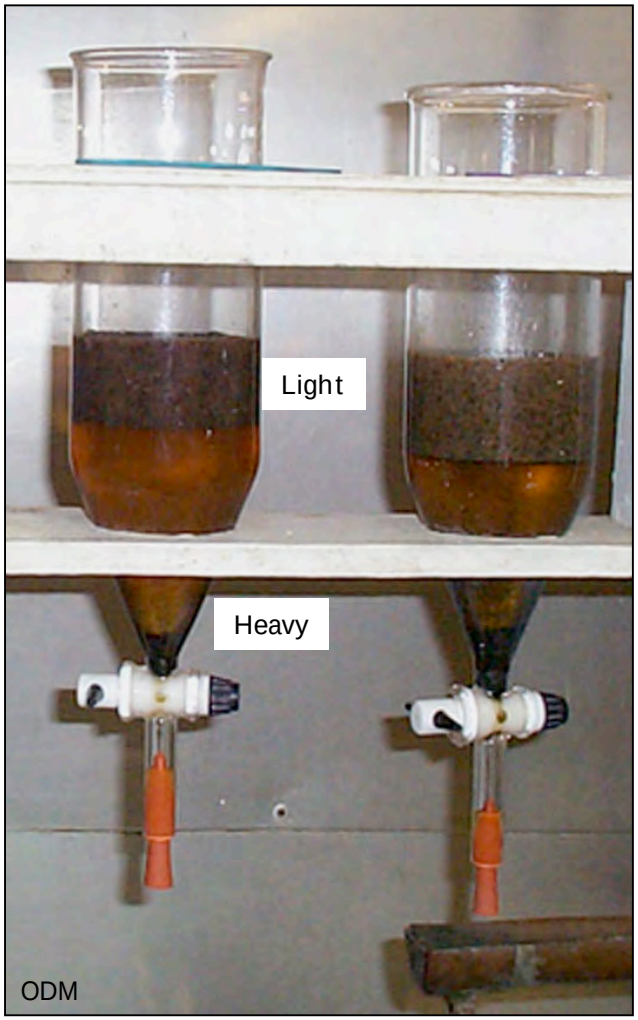
Advantages:

- Fast
- Density settings checked daily
- Not operator dependent
- Use for recovery of kimberlite indicator minerals

Disadvantages:

- Higher cost
- Lower size limit: 0.3 mm
- No recovery of silt-size precious & base metals

STEP 4: FINAL CONCENTRATION



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

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

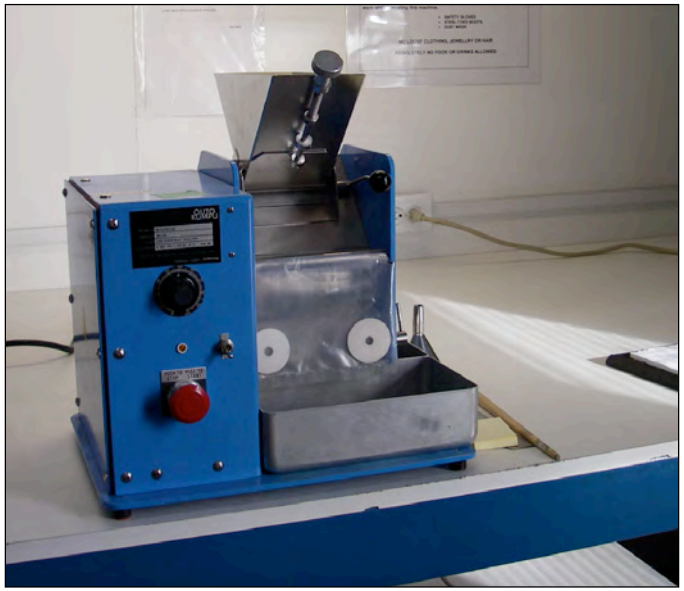
  - Diluted MI SG=3.2

    Lower limit for kimberlite indicator minerals is 3.2, to include Cr-diopside and forsteritic olivine

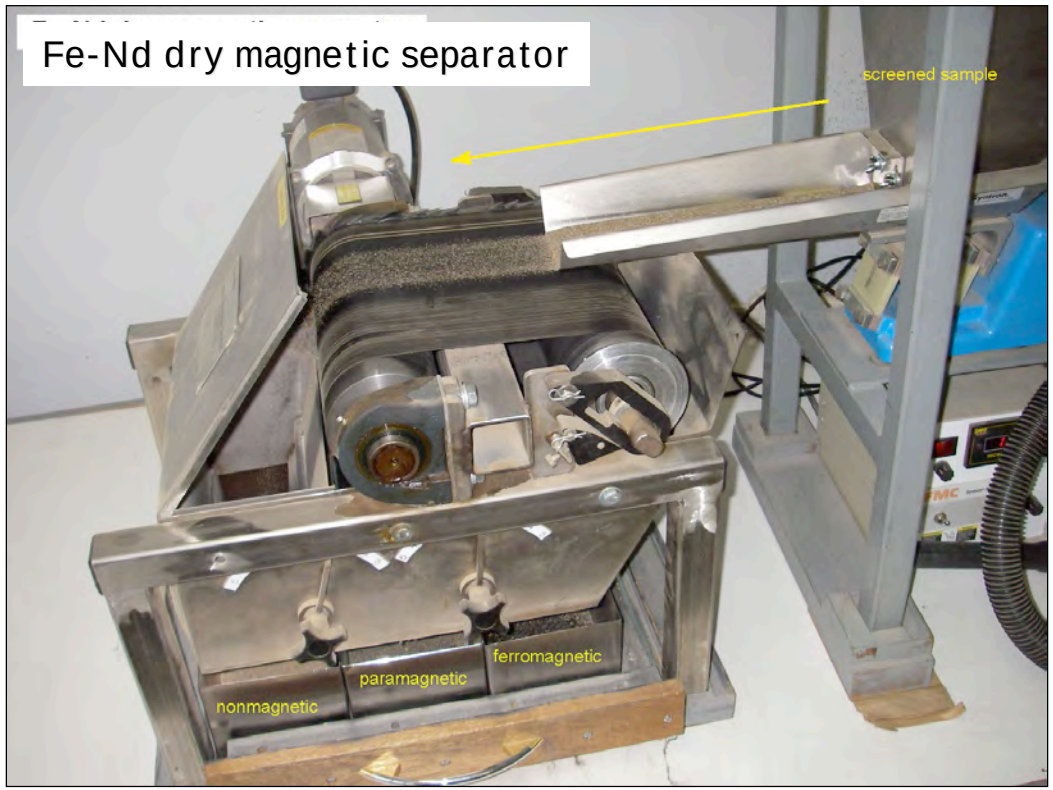
STEP 5: REMOVAL OF FERROMAGNETIC MINERALS

Hand magnet

Purpose: reduce volume of material to examine for indicator minerals



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

Paramagnetic separation:

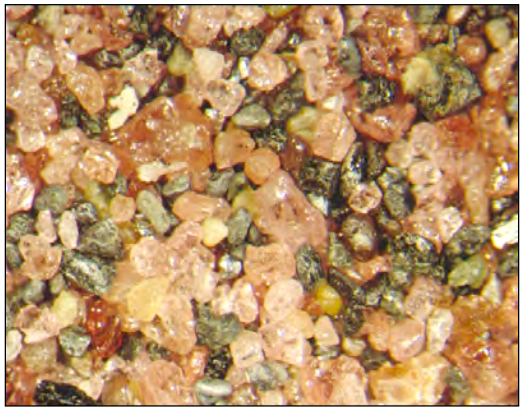
- Non paramagnetic (e.g. diamond, olivine)
- Weakly paramagnetic (e.g. pyrope garnet, Cr-diopside, olivine)
- Moderately paramagnetic (e.g. Cr-spinel)
- Strongly paramagnetic (e.g. Mg-ilmenite)

Carpco magnetic separator

STEP 6: ADDITIONAL PROCESSING

Magstream magnetic separator:

- Gravity (& magnetism) used to separate heavy minerals
- Fluid with high SG used, e.g. SG 3.1
- Fluid spins, magnet on outside of tube
- Heavy minerals concentrate on outside of tube (e.g. oxides, Fe-almandine)
- Light minerals concentrate on inside of tube (e.g. CPX, pyrope)
- Used to separate similar looking Fe-rich almandine from E-garnets prior to indicator mineral selection

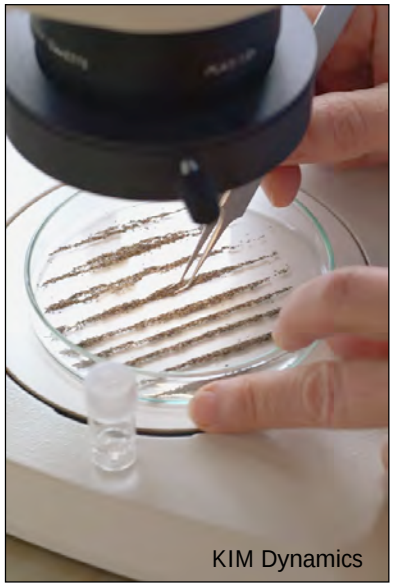


Till heavy mineral concentrate containing abundant orange Fe-rich almandine that may be misidentified as E-garnet

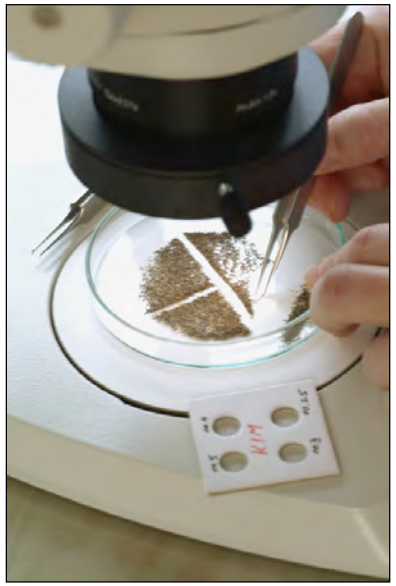
STEP 7: INDICATOR MINERAL SELECTION

- 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

Spiral



Lines

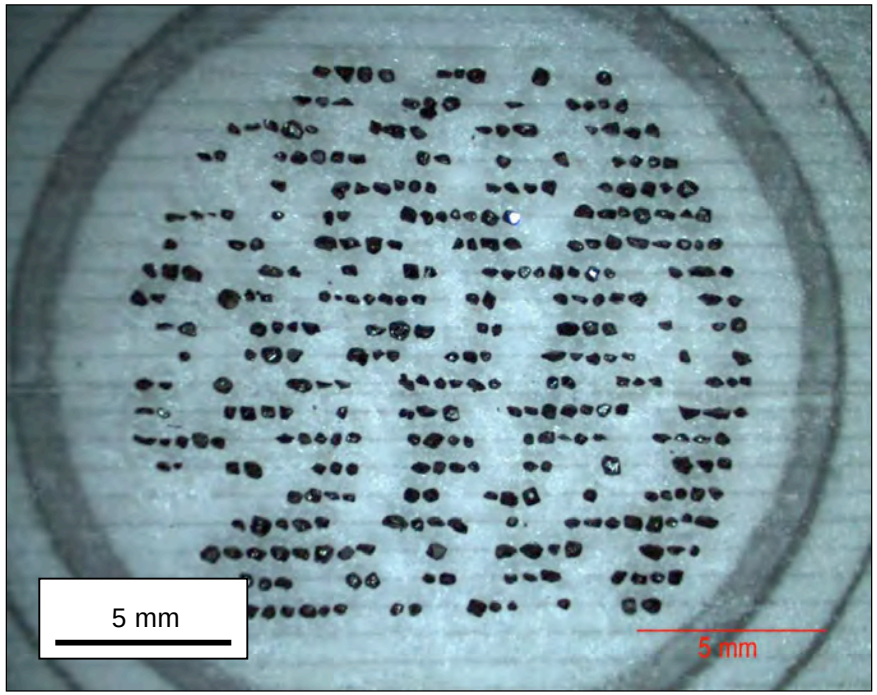


Quarters

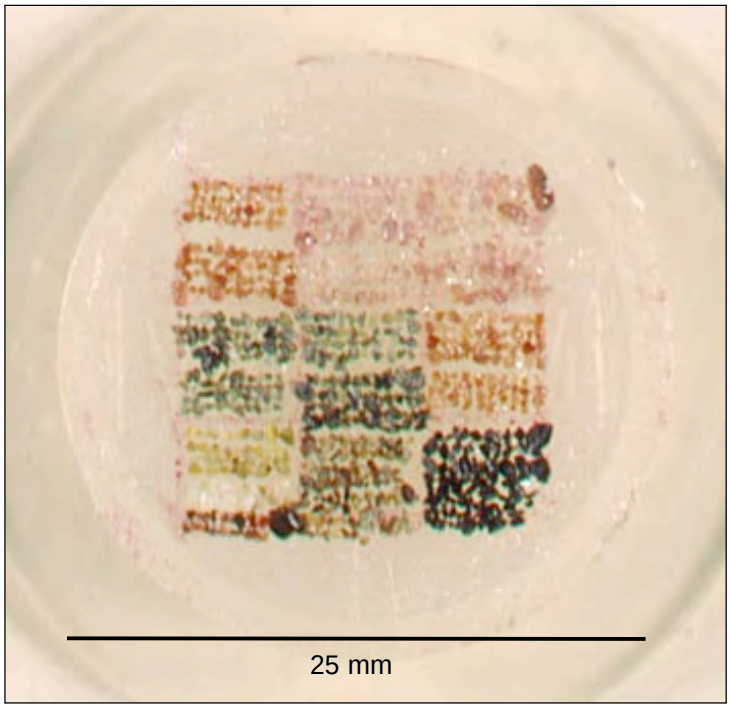
STEP 8: MINERAL CHEMISTRY

- Confirm visual mineral identification, evaluate grade, genesis or alteration
- Mount & polish grains (25 mm epoxy mounts)
- Mounting technique and polishing crucial steps
- Quantitative major & trace element analysis: SEM, EMP, LA-ICP-MS, SIMS
- Examples of the application of mineral chemistry data:
  Bill Griffin, Herman Grütter

Mineral grains mounted for analysis



K. Gibbs

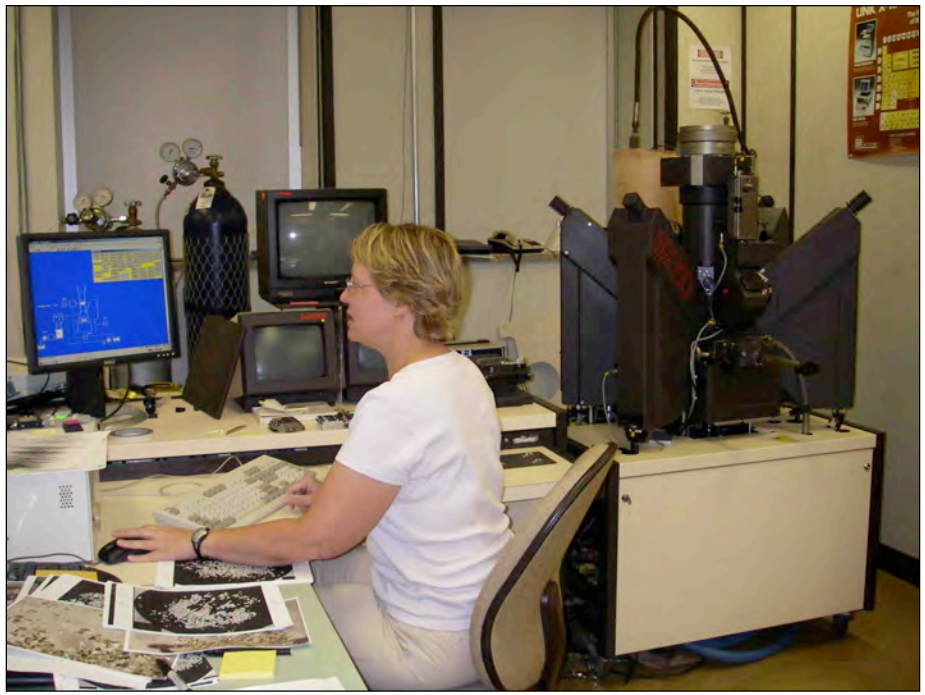


H. Thorliefson

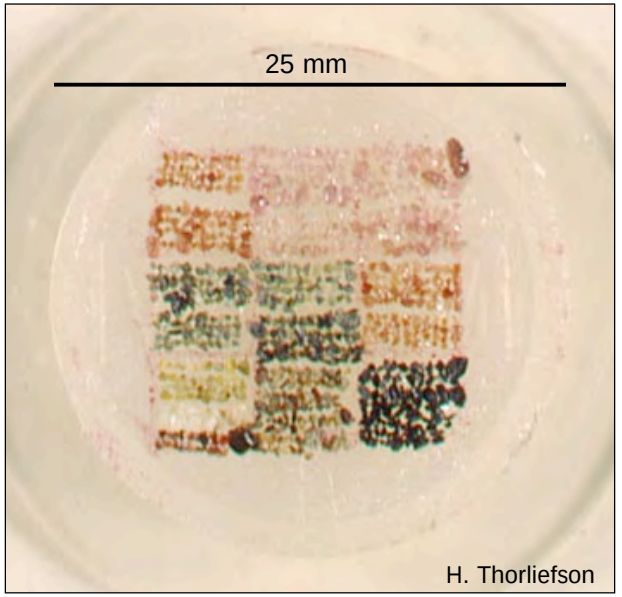
STEP 8: MINERAL CHEMISTRY

Electron microprobe analysis (EMP):

- Determines element concentrations in % to ppm range
- Target key locations within single mineral grain
- Beam width 5 μm



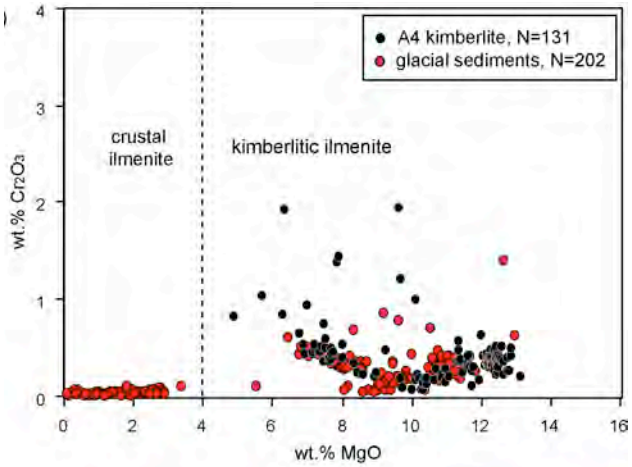
Electron microprobe (EMP)



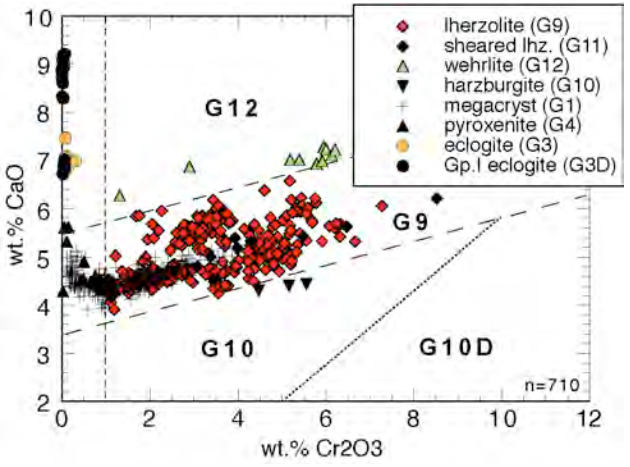
Mineral grains mounted for analysis

KIMBERLITE MINERAL CHEMISTRY

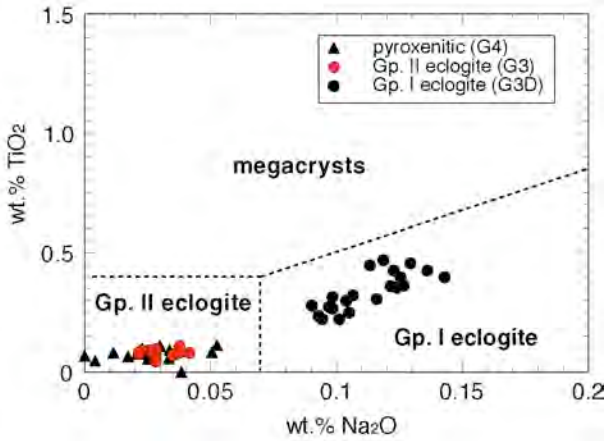
Mg-ilmenite



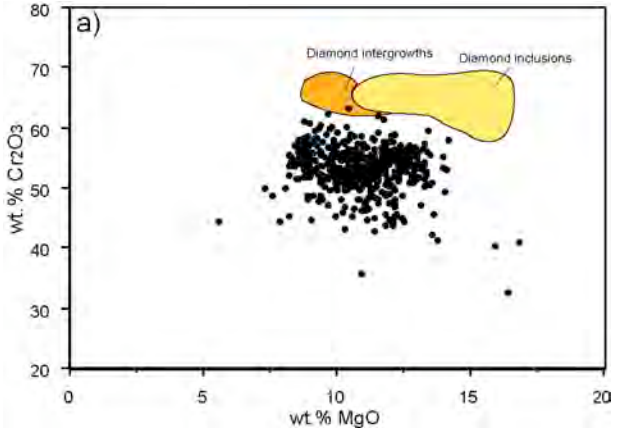
Garnets



Eclogitic garnets



Chromite



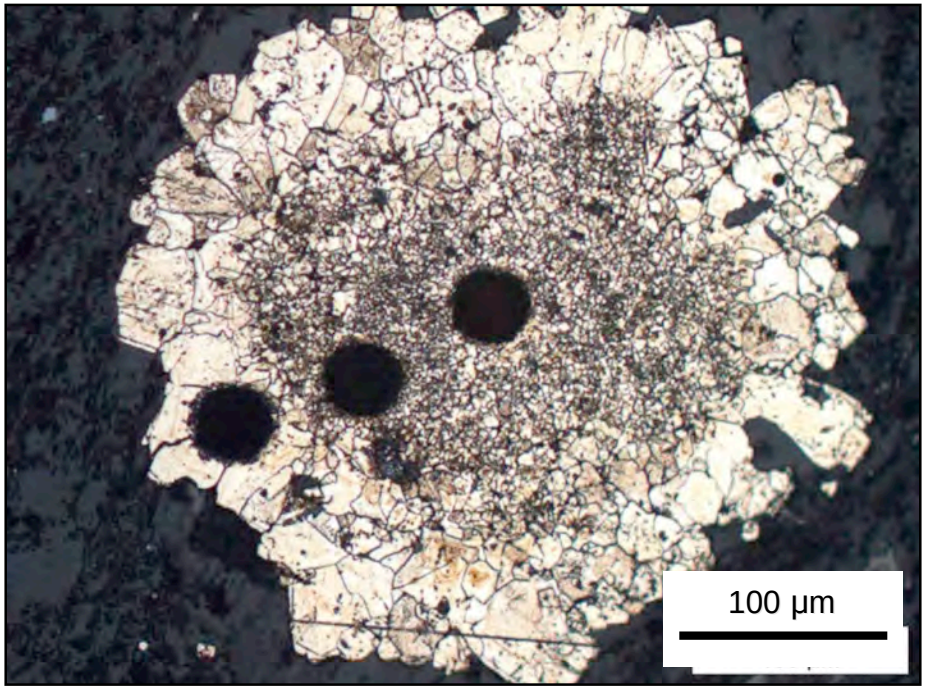
Also discrimination plots for olivine, Cr-diopside…

Step 8: Mineral chemistry

Laser Ablation ICP-MS (LA-ICP-MS):

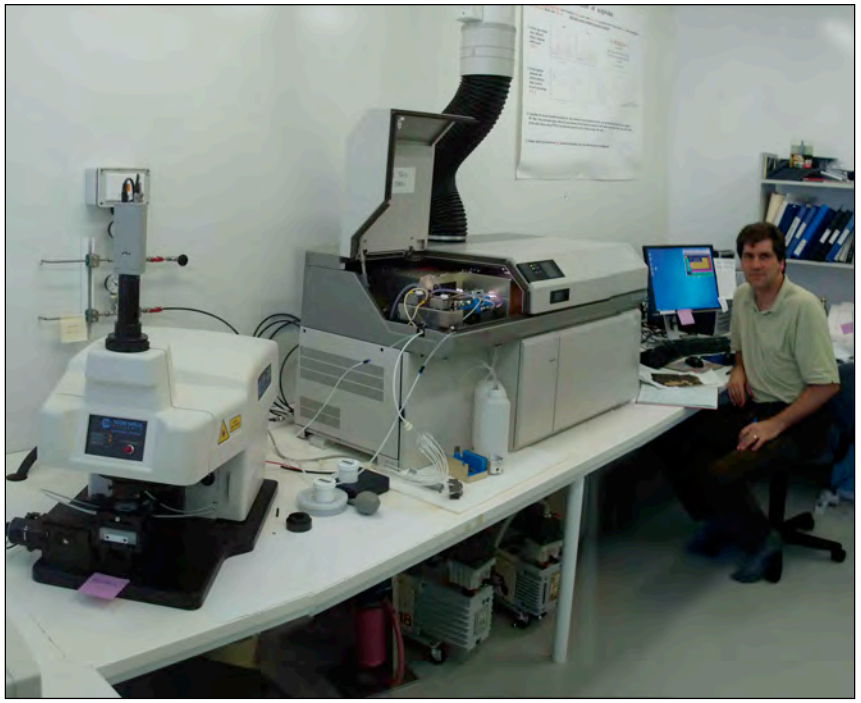
- Determines element concentrations in ppm-ppb range
- Target key locations within single mineral grain
- Beam width 30 to 50 μm

Pyrite framboid with laser ablation pits



D. Layton-Matthews

LA-ICP-MS, CODES



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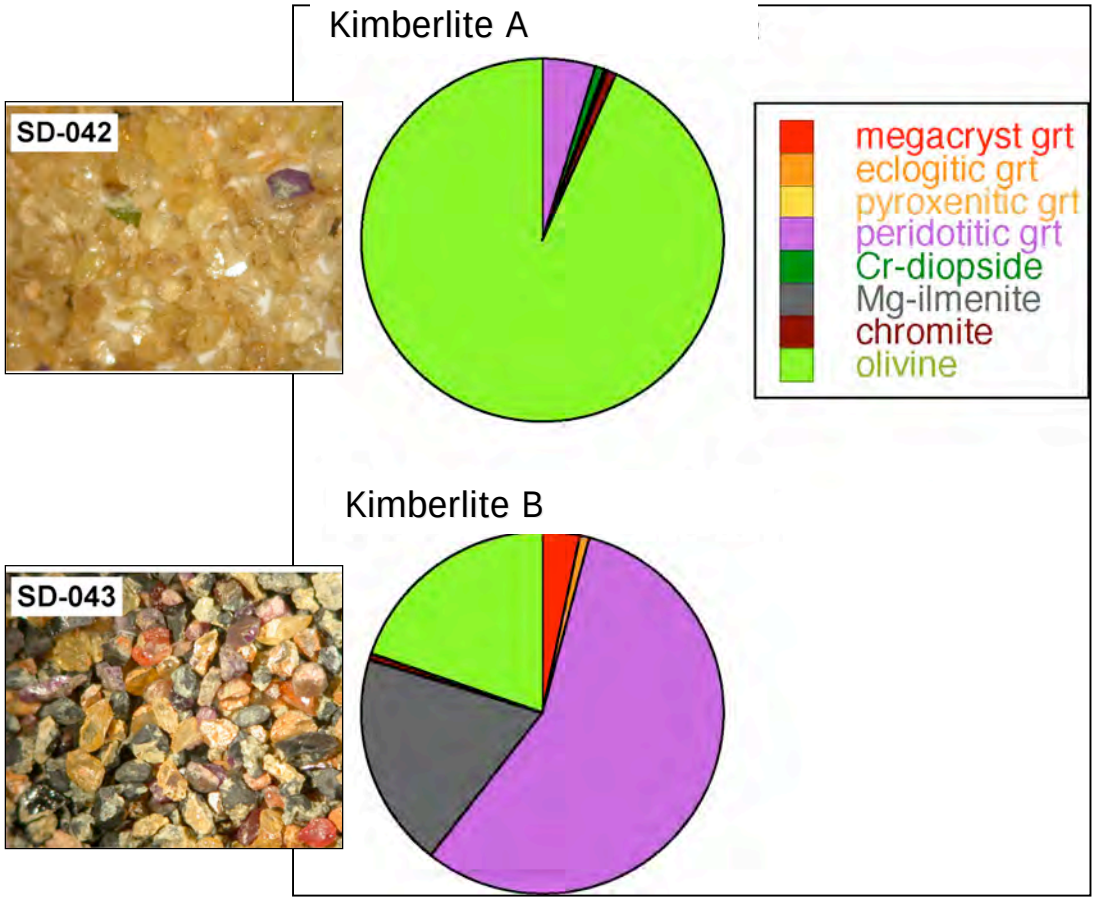
INDICATOR MINERAL FEATURES

Relative Abundance



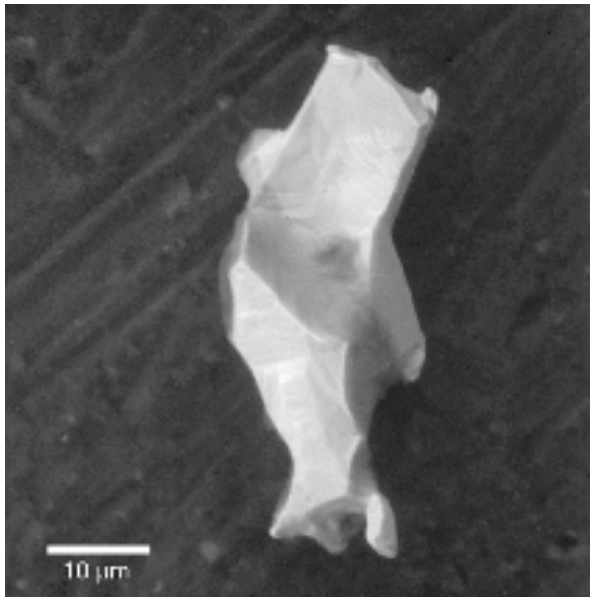
Grain Surface

Kelyphite rims (k) on Cr-pyrope

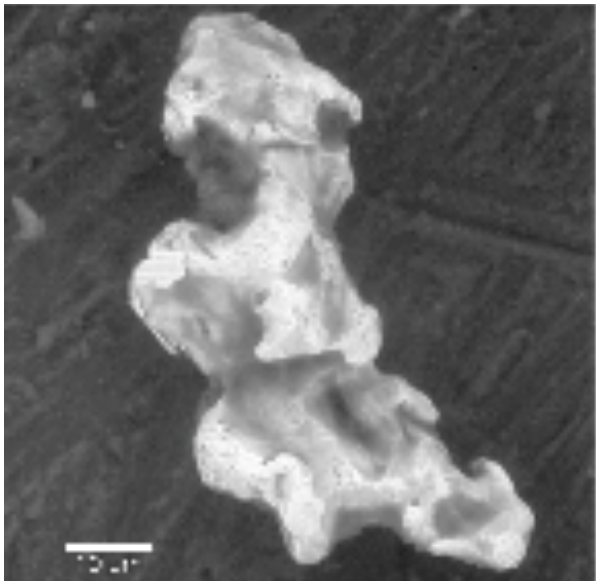
INDICATOR MINERAL FEATURES

Grain shape

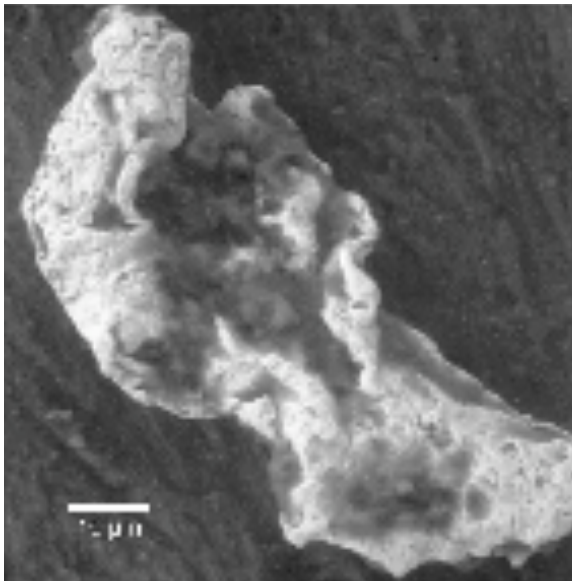
Gold grain shape classification scheme (DiLabio, 1990)



Pristine



Modified

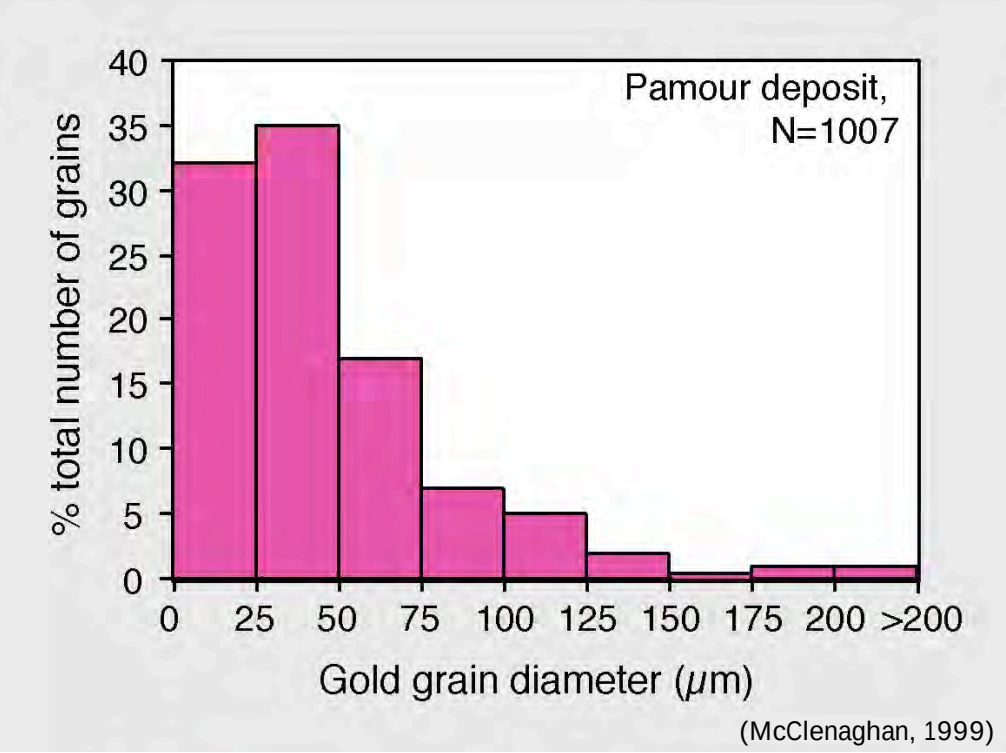


Reshaped

Increasing glacial transport distance

INDICATOR MINERAL FEATURES

Grain size



(McClenaghan, 1999)

Visible gold grains in till, Pamour Mine, Timmins:

- Gold grains fine sand to silt sized
- Most grains <50 μm
- Typical of Archean quartz vein-hosted lode gold deposits

QUALITY CONTROL

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

- Dictated in Canada by National Instrument 43-101

- 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

QUALITY CONTROL

Mineral Exploration Best Practices Guidelines:

- *Sampling*
- *Sample security*

- *Sample preparation (processing):*

- Indicator mineral spikes - oxides & silicates, laser etched & SEM photos;
- Diamond spikes- laser etched & SEM photos
- Density beads

- *Analysis & Testing (Indicator mineral picking):*

- Indicator mineral spikes - oxides & silicates, laser etched & SEM photos
- Diamond spikes- laser etched & SEM photos
- Repicking by another mineralogist within the lab
- Resubmit 5-10% of concentrates for re-picking

- *Analysis & Testing (Mineral chemistry analysis):*

- Analyze certified reference standards

QUALITY CONTROL

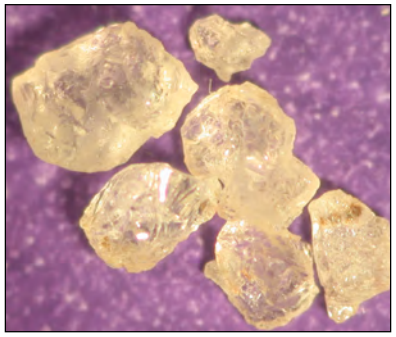
Things that can screw up your results….

- Sample tampering in the field (unsecured sample storage)
- Contamination/carry over in the field from equipment (e.g. dirty shovels)
- Contamination during sample processing: carry over from one sample to the next within your batch or another client's samples
- Indicator minerals lost during processing
- Indicator minerals missed during examination/selection

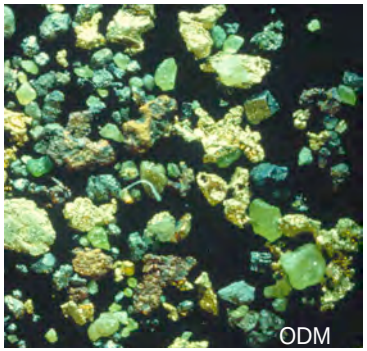
COMMON INDICATOR MINERALS

- 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

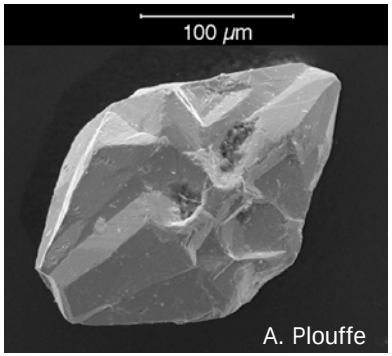
Kimberlite indicator minerals



Topaz

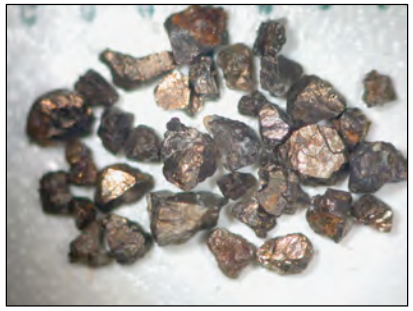


Gold, native copper, pyromorphite



Cinnabar

- 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



Pentlandite

SUMMARY

- 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 the bedrock source, including style of mineralization, grade, alteration as well as distance of transport from source

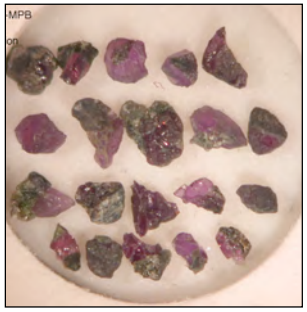
- Quality control essential to monitor during all phases of processing, mineral selection and analysis

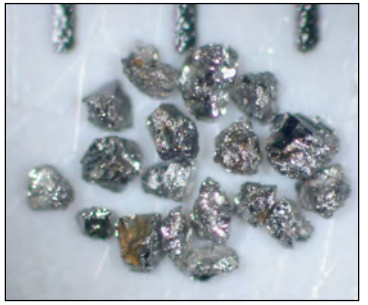
- Commercial labs now offer a range of indicator mineral processing, selection and analytical services

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

ACKNOWLEDGMENTS

- Stu Averill, Remy Huneault, *Overburden Drilling Management Ltd.*
- Chris Benn, Bill Coker, *BHP Billiton Exploration*
- Peter Friske, *Geological Survey of Canada*
- Kim Gibbs, *SGS Minerals*
- Maja Kiridzija, *KIM Dynamics Inc.*
- Peter Le Coutuer, *Vancouver Indicator Processors Inc.*
- Marja Lehtonen, *Geological Survey of Finland*
- Yvon Maurice, *Geological Survey of Canada*
- Maureen Morrison, *I & M Morrison Geological Services*
- Tom Nowicki, Mike Baumgartner, *Minerals Services Canada*
- Pertti Sarala, *Geological Survey of Finland*
- Pam Strand, *Shear Minerals*
- Harvey Thorliefson, *Minnesota Geological Survey*

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