Gold and PGE indicator mineral methods in mineral exploration

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Natural Resources Canada   Ressources naturelles Canada

Canada

Presentation Outline

- Gold deposit indicator minerals
  - gold grain morphology
  - gold grain compositions and inclusions
  - examples
- Platinum Group element deposit indicator minerals
  - PGM grain compositions
  - PGM morphology
  - examples
- Processing methods for gold and PGE indicator minerals

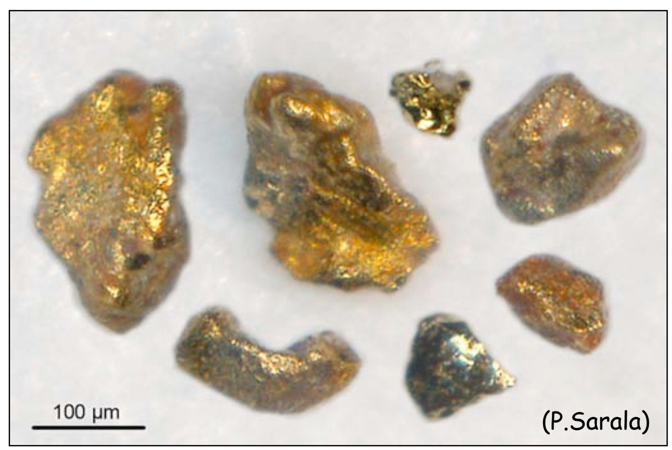
Gold Indicator Minerals

- Gold grains are the best indicator mineral for detecting the presence of gold deposits
- Sulphides (e.g., pyrite, pyrrhotite, arsenopyrite, chalcopyrite, sphalerite, galena)
- Platinum Group Minerals (PGM)
- Tellurides
- Scheelite, rutile
- Secondary minerals (e.g., jarosite, limonite, goethite, pyrolusite)

Gold Grain Characteristics

- Gold grain abundance and grain characteristics been applied systematically in the past 35 years in the search for sources
- Most common characteristics used: size, shape and chemical composition
- Because gold is malleable (H=2.5-3), gold grain shape and surface features will change as they are transported; changes function of distance and mode of transport

(D. Kelley)



(P.Sarala)

Gold Grain Morphology

- Grain shapes in streams are usually described in terms of their flatness, roundness, folding, and surface texture and these characteristics can be used to estimate the distance of transport
- Shape factor: Cailleux Flatness Index FI = a+b/2c
(a=long axis, b= intermediate axis, c= short axis dimensions of a grain)
- Flatness Index gradually increases with increasing transport distance downstream,
FI = 2 typical of bedrock deposits or gold grains close to source
FI = 45 grains transported several 10s km
- Software available to carry out automated morphological analysis of gold grains
- Alcoholic beverages available to study gold flake morphology

gold flakes in schnapps

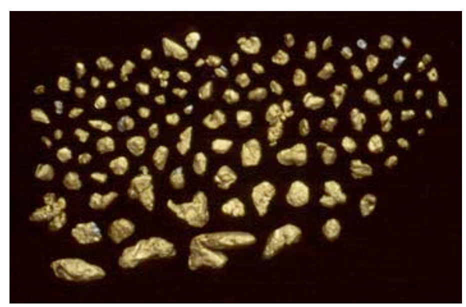
gold flakes in volka


gold flakes in champagne


gold flakes in sake

Gold Grain Morphology

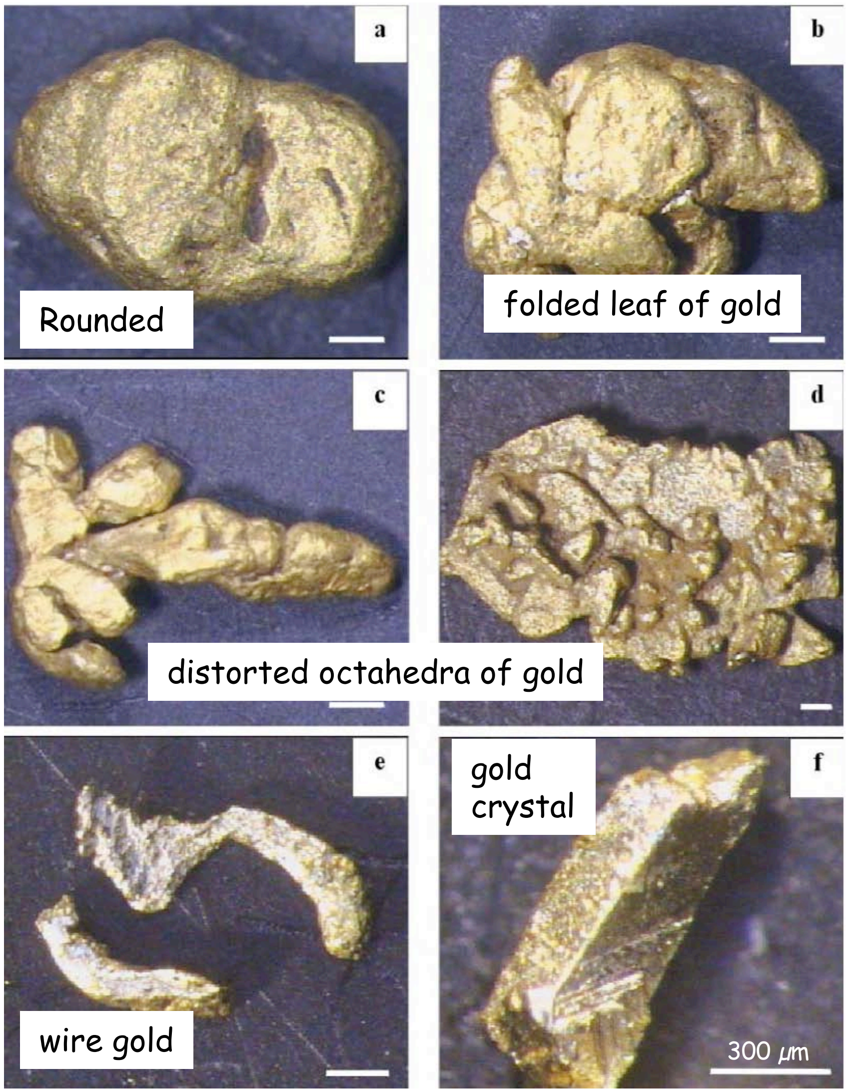
- Hammering and abrasion processes control grain shape and increase grain roundness
- Particle rounding results mainly from abrasion of particle edges and in-folding of delicate protrusions
- Roundness can be a more sensitive estimator for distances <5 km and less reliable than flatness for distances >5 to 10 km
- Gold grains in bedrock lateritic terrain change shape due to progressive chemical weathering over time, from primary grains of irregular, dendritic and prismatic forms with sharp edges to grains with rounded edges and corrosion pits



(D. Kelley 2007)

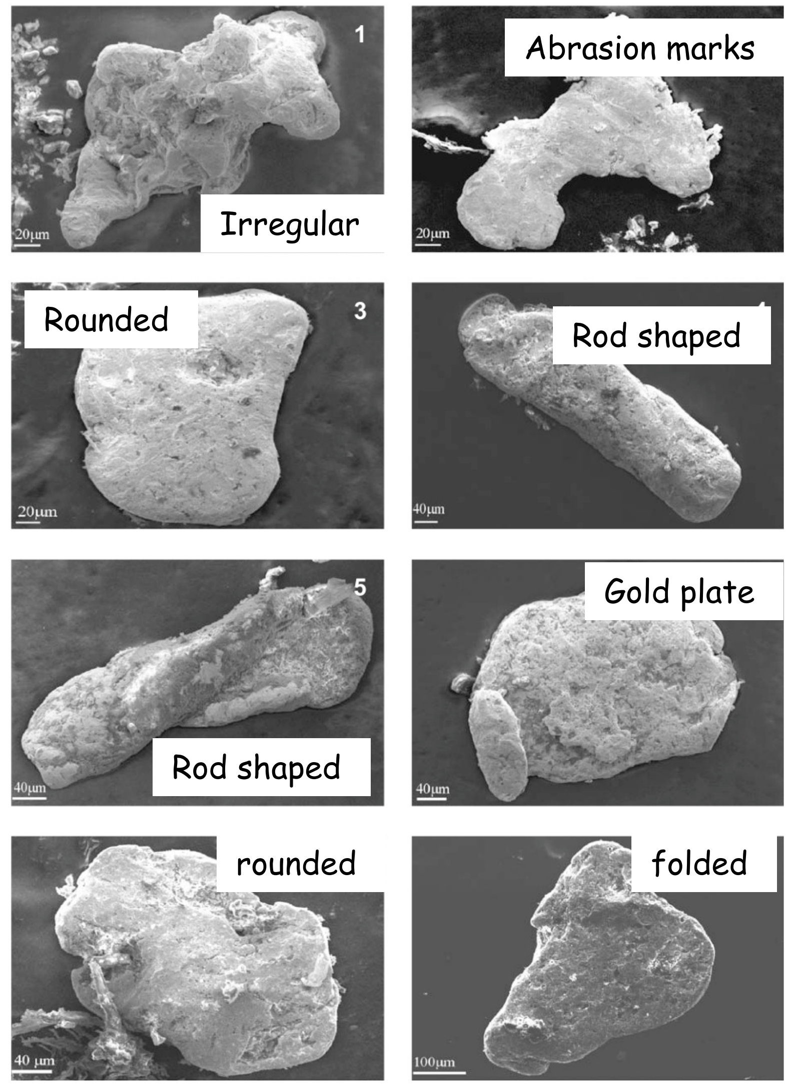
Gold Grain Morphology

Placer gold grains, San Luis Range, Argentina



(Marquez-Zavalia et al. 2004)

Placer gold grains, East Sudetic Foreland, Poland



(Wierchowiec, 2002)

Gold Grain Morphology

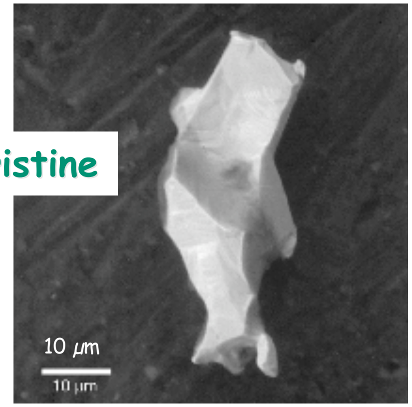
• DiLabio (1990) classification scheme describes conditions and surface textures of gold grains related to glacial transport distance

• **Pristine gold grains:**
- Primary shapes and surface textures
- Appear not to have been damaged in transport
- Angular wires, rods and delicate leaves that once filled in fractures, occurred as crystals with grain molds, and as inclusions in sulphides

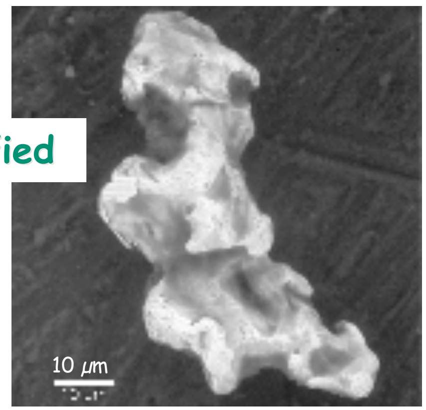
• **Modified gold grains:**
- Some primary surface textures
- Edges and protrusions have been damaged during transport
- Commonly striated.
- Irregular edges and protrusions are crumpled, folded and curled
- Grain molds and primary surface textures preserved on protected faces of grains

• **Reshaped gold grains:**
- Primary surface textures destroyed
- Original grain shape no longer discernible
- Flattened to rounded resulting from folding of leaves, wires, rods
- Surfaces may be pitted from impact marks from other grains
- Surfaces are not leached of silver in most cases in glaciated terrain

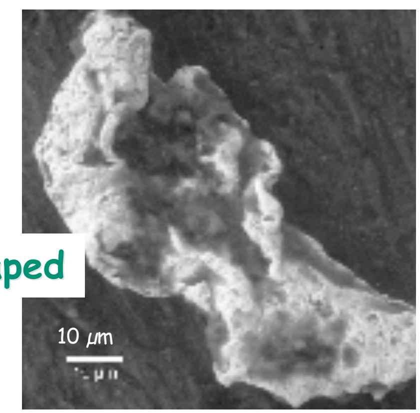
Pristine



Modified



Reshaped



Increasing transport distance

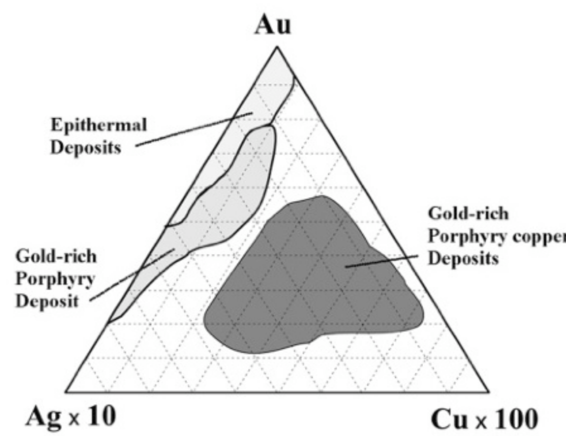
(McClenaghan 2001)

Gold Grain Composition

- Compositional studies identify different populations within/between samples and potential bedrock sources
- Compositions most commonly characterized using EMP analysis for Au, Ag, Pt, Pd, Cu, Hg, Pb, Bi As, Fe, and Te. Gold content expressed at wt.% or fineness in parts per thousand (e.g. 985)
- Large numbers of grains should be analyzed to characterize compositional variation; different deposit types do not always have unique signatures
- Large volumes of gold grain compositional data have been published for various types of lode and placer deposits worldwide (see reference list)
- Trace element analysis by gold grains by LA ICP-MS for elements such as Mo, Bi, Te, Sb, and Sn allows for more specific fingerprinting of groups of gold grains or deposit types
- Placer gold grains exhibit Au-enriched, Ag-depleted rims typically 1 to 20 μm thick that surround the grain core; may form by the leaching of Ag or by overgrowth of higher fineness gold subsequent to deposition

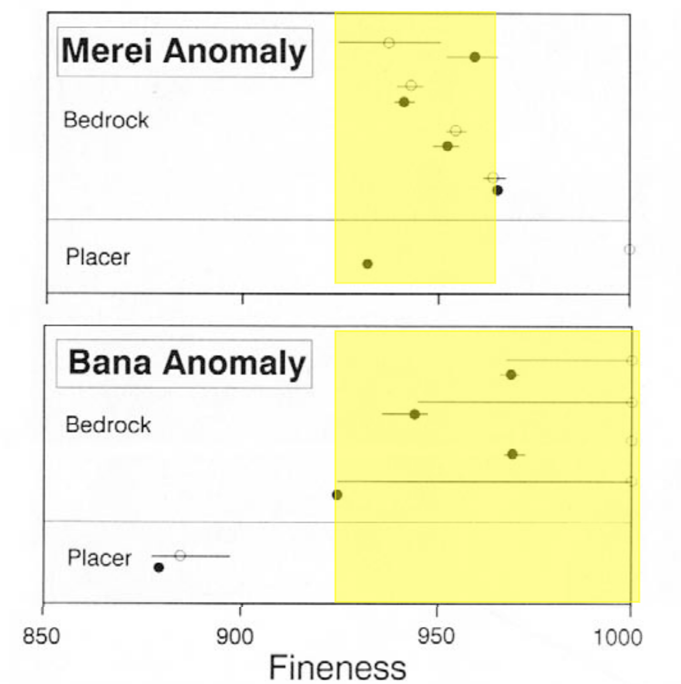
Composition of Au from different deposit types

(Townley et al. 2003)



Gold Grain Composition

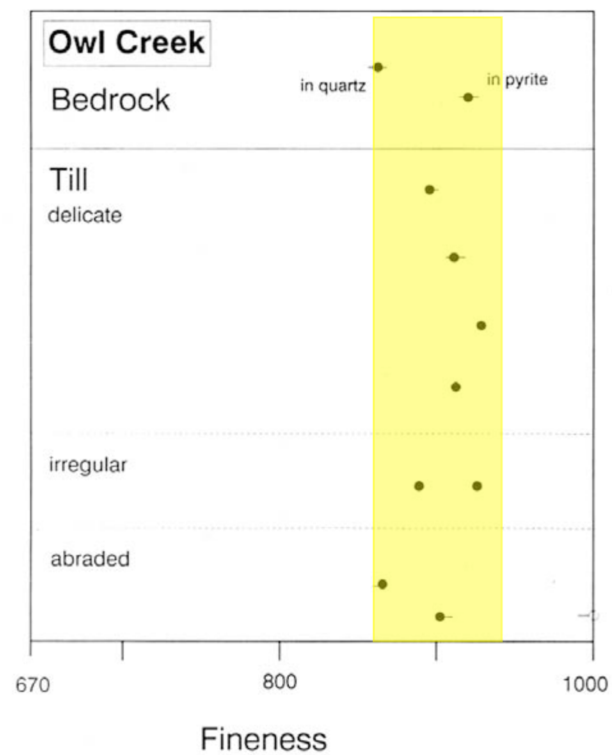
Stream placers, Ivory Coast



● Grain core
○ Grain rim

Gold grain core and rim compositions in bedrock and local placers

Owl Creek Au Mine, Timmins, Canada



Gold grain core compositions in bedrock and till down-ice

(Grant et al. 1991)

Gold Grain Inclusions

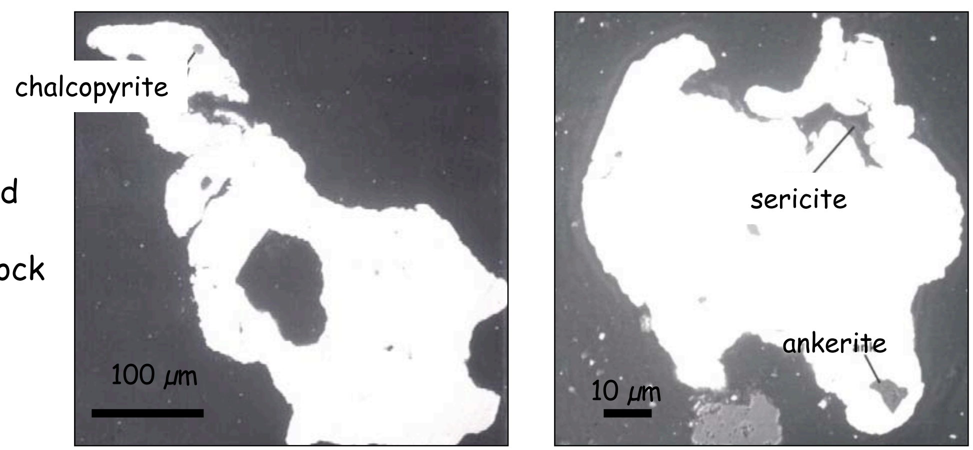
• Micro-inclusions in gold grains can provide information on ore and gangue minerals present in the bedrock source and thus provide a signature of the deposit type or even a specific gold deposit

• For example, enargite inclusions may indicate a high sulphidation epithermal source; argentite inclusions may indicate mesothermal gold

• Inclusion abundance may decrease due to post depositional alteration/ weathering in the surficial environment and/or due to physical grain degradation with increasing transport

• Inclusion mineralogy (stable versus unstable in surface weathering environment) may indicate distance of transport

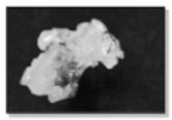
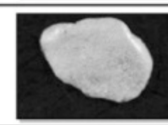
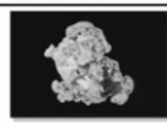
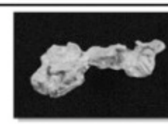
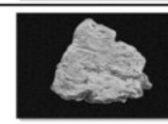
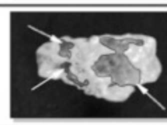
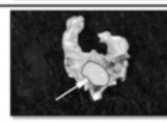
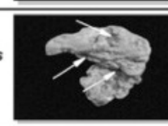
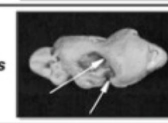
Placer deposit, French Guiana:
Presence of unstable primary inclusions and gangue minerals in gold grains indicates grains actively being shed from local bedrock source



(D. Kelley, 2007)

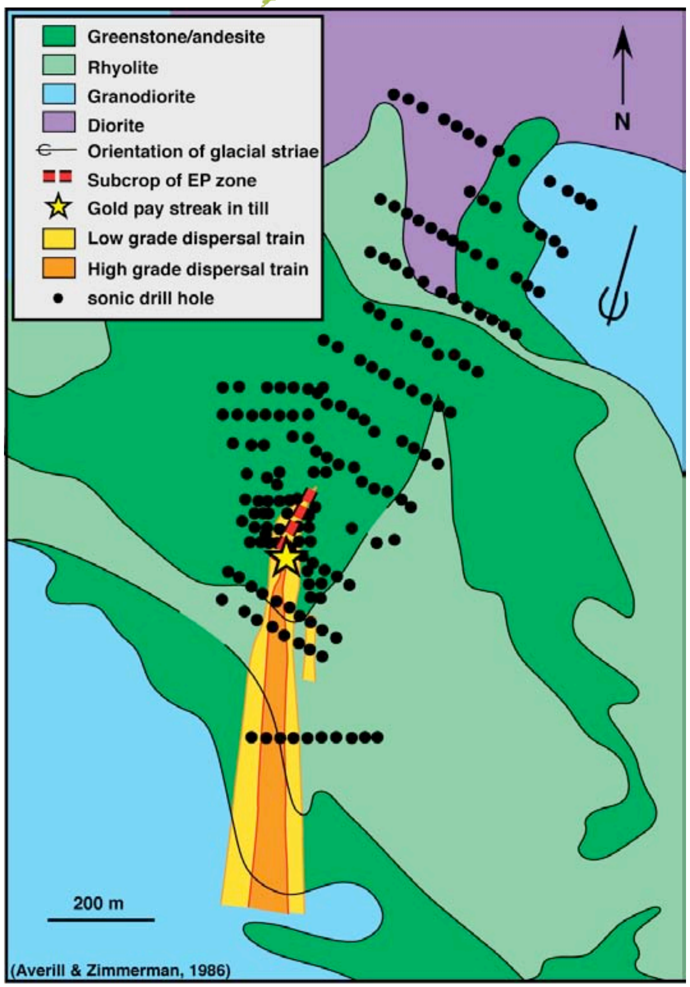
Gold Grain Characteristics

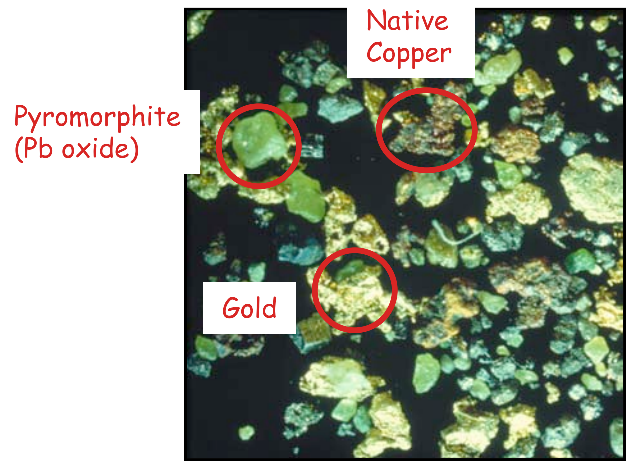
Gold grains in stream sediments, Antena District, Chile

Distance to the source	0-50 m	Increasing distance from source → 50-300 m	> 300 m
General shape			
Outline			
Surface			
Primary crystal imprints		*Diffuse Evidence*	*Absent*
Associated minerals	*Quartz and Fe Oxides* 	*Fe Oxides* 	*Limonites* 
Flatness index	1-3.6	2.1-6	3.0-7.5

(Townley et al. 2003)

Glaciated terrain: Waddy Lake, Central Canada

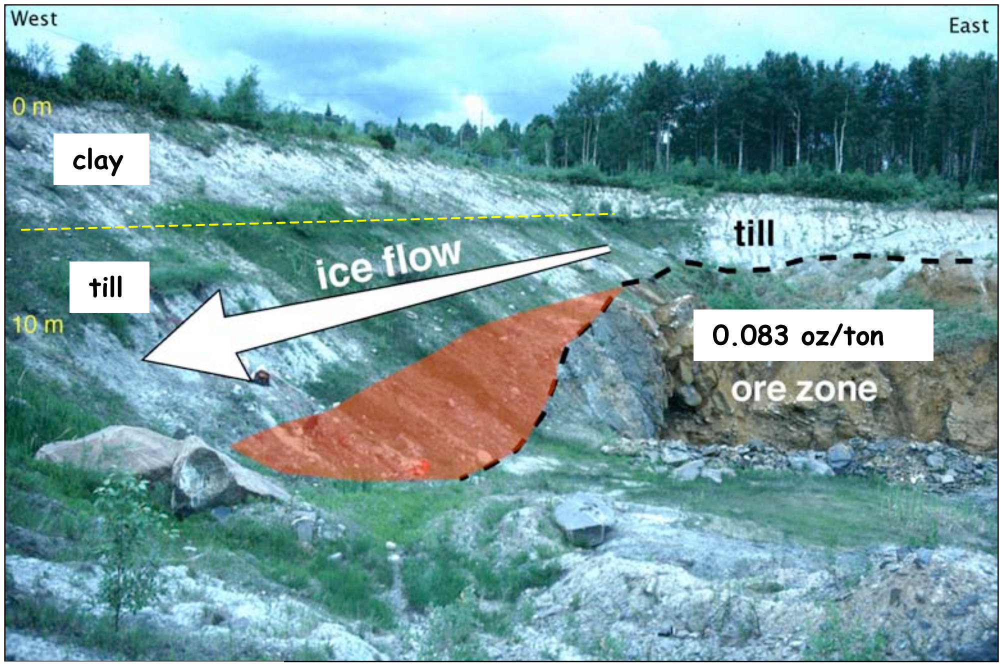




EP Gold Zone, Waddy Lake, Saskatchewan

- Lode gold hosted in quartz veins, in places supergene cover
- Exploration challenge: thick (up to 15 m) glacial sediment cover
- Discovered using gold grains in till; initially panned grains from till, follow up with overburden drilling & systematic till sampling
- >400 m ribbon-shaped train defined by indicator minerals and till geochemistry
- Indicator minerals: gold, native copper, galena, chalcocite- galena, pyromorphite, bornite, molybdenite

Glaciated terrain: Timmins, central Canada



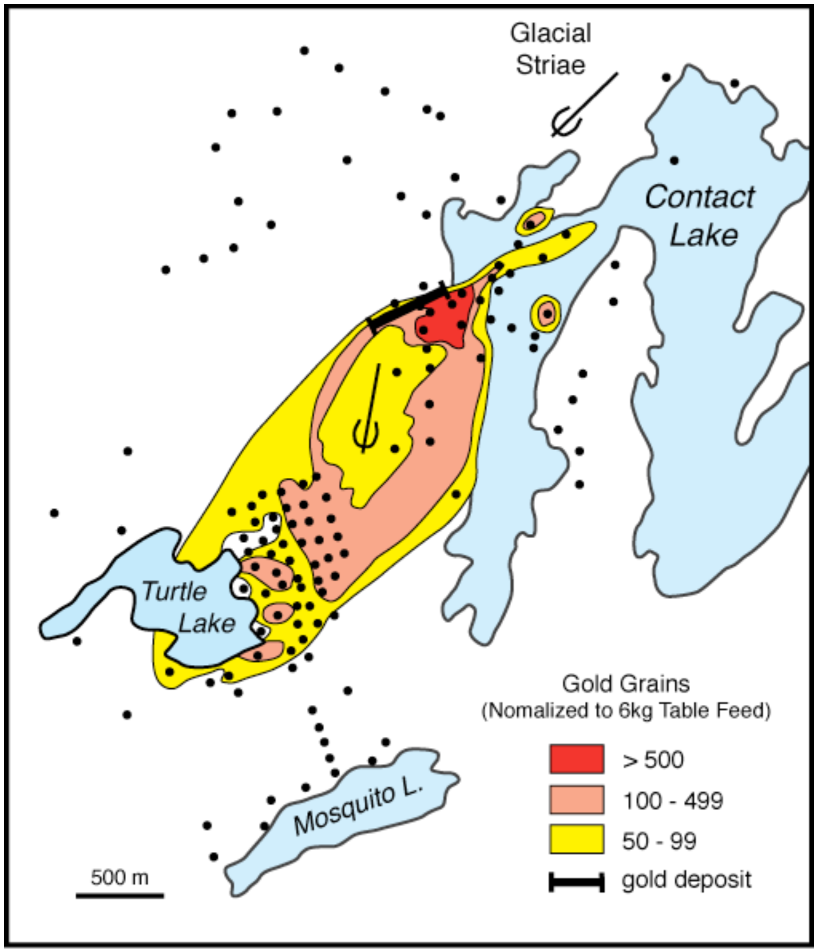
(McClenaghan, 1999)

Pamour Au Mine, Timmins, Canada

- Lode gold in quartz veins, associated with shear zone
- Exploration challenge: thick (10-30 m) glacial sediment cover, till overlain by thick glaciolacustrine clay

- Gold grain abundance, shape and size range in till proximal to bedrock source documented
- Maximum 880 gold grains/10 kg + pyrite
- Most gold grains pristine shape
- Most gold grains <50 µm
- Strong till geochemical signature

Glaciated terrain: Contact Lake, Canada



(Chapman et al., 1990)

Bakos Au deposit, La Ronge Belt,Saskatchewan

- Lode gold in quartz veins, associated with shear zone
- Exploration challenge: thick glacial sediment cover; 2 phases of ice flow and 2 till units

- Regional till survey to follow-up gold lake sediment anomalies
- Gold grain abundance in till defined glacial dispersal train down-ice
- Highest concentration near bedrock source
- up to 2751 gold grains/6 kg
- pristine to reshaped grains
- grains 20 to 400 µm in size, most < 100 µm
- 2.5 km transport distance
- Lake sediment and till sampling results led to discovery of deposit 3 years later

Tropical Terrain: French Guiana

(R. Brommecker, 2003;
D. Kelley, 2007)

Cokioco and Wayamaga gold placers, NW French Guiana

Exploration Challenges:
- Location of lode sources unknown
- Extensive vertical weathering and erosion
- Geomorphology of region is dynamic
- Lode source may not be in current placer drainage

- Detailed gold grain study- shape, size, fineness, inclusions
- Actively shedding lode source likely proximal to Wayamaga
- Cokioco source likely very far or eroded away

	Cokioco	**Wayamaga**
Grain Morphology	Fully reshaped	Modified/reshaped
Grain Size	125-300 um	50-150 um
Leaching of Ag	Complete (1000)	Thin rim/absent (988)
Inclusions	Stable or entrained grains	Unstable primary minerals

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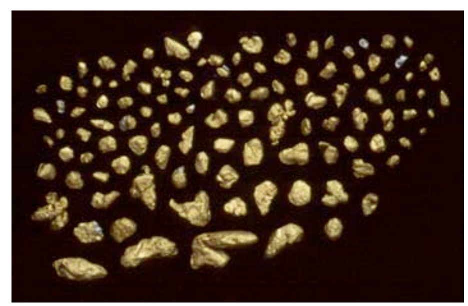
Gold Deposit Indicator Mineral Summary

- Gold is best indicator of its own deposits
- Recovered from broad range of sediment types: eolian, stream, lateritic soil, glacial
- **Size range:** 10 µm to 2.0 mm routinely recovered
- **Recovery methods:** panning, table, jig, spiral, Knelson concentrator
- **Composition:** varies with deposit type, mainly Au and Ag

- trace element concentrations used to fingerprint source
- characterized by EMP and LA ICP-MS
- inclusion mineralogy provides clues to source and distance of transport

- **Surface features and shape:** provide information on transport distance
- Reference list



(D. Kelley, 2007)

PGE Deposit Indicator Minerals

Common heavy indicator minerals for Ni-Cu-PGE mineralization:

	Indicator Mineral	Chemical Composition	Indicator Elements
	* occur in other unmineralized ultramafic rocks		
	hercynite	$FeAl_2O_4$	Al
	olivine *	$(Mg,Fe)SiO_4$	Mg
Stu Averill's talk	orthopyroxene*	$(Mg,Fe)_2Si_2O_6$	Mg
	low Cr-diopside	$Ca(Mg,Cr)Si_2O_6$	Mg, Cr
	chromite *	$(Fe,Mg)(Cr, Al)_2O_4$	Cr, Mg, Al (-/+Zn)
	uvarovite	$Ca_3Cr_2Si_3O_{12}$	Cr
	Cr-rutile	$(Ti, Cr)O_2$	Cr
	chalcopyrite	$CuFeS_2$	Cu, S
	loellingite	$FeAs_2$	As
	rammelsbergite	$NiAs_2$	Ni, As
This talk	sperrylite	$PtAs_2$	Pt, As
	PGE alloys	PGE	PGE

(Averill, 2001)

PGE Deposit Indicator Minerals

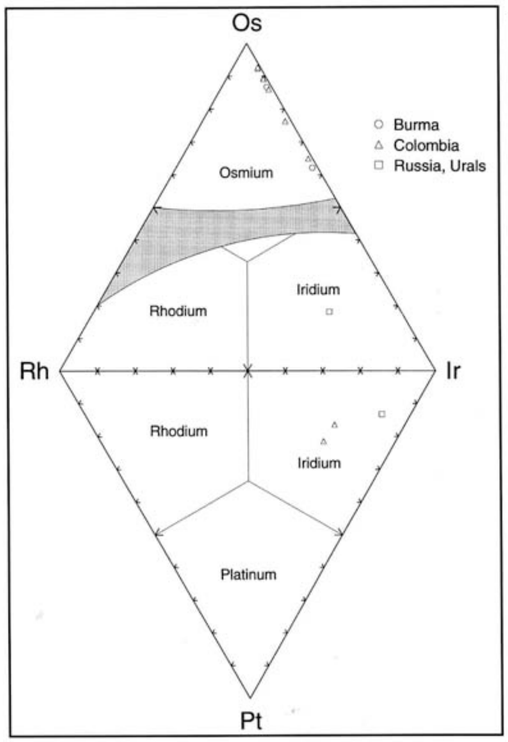
Arsenopalladinite	$Pd_8(As,Sb)_3$
Atheneite	$(Pd,Hg)_3As$
Bowieite	Rh_2S_3
Braggite	(Pt,Pd,Ni)S
Cooperite	PtS
Cuproiridsite	$CuIr_2S_4$
Cuprorhodsite	$CuRh_2S_4$
Erlichmanite	OsS_2
Ferronickelplatinum	(Ni,Fe)Pt
Genkinite	$(Pt,Pd)_4Sb_3$
Geversite	$PtSb_2$
Hollingworthite	RhAsS
Hongshiite	PtCu
Irarsite	IrAsS
Iridarsenite	$IrAs_2$
Iridium	Ir
Isoferroplatinum	Pt_3Fe
Isomertieite	$Pd_{11}Sb_2As_2$
Kashinite	Ir_2S_3
Keithconnite	Pd_3Te
Kotulskite	PdTe
Laurite	RuS_2
Malanite	$CuPt_2S_4$
Mertieite-II	$Pd_8(Sb,As)_3$
Osmium	Os
Platarsite	PtAsS
Platinum	Pt
Pt-Fe alloy	Pt-Fe
Rhodplumsite	$Rh_3Pb_2S_2$
Ruthenarsenite	RuAs
Rutheniridosmine	(Os,Ir,Ru)
Ruthenium	Ru
Sperrylite	$PtAs_2$
Stibiopalladinite	Pd_5Sb_2
Tetraferroplatinum	Pt Fe
Tolovkite	IrSbS
Tulameenite	Pt_2FeCu
Platinian Copper	Cu,Pt
Gold	Au
Rhodian Pentlandite	$(Fe,Ni,Rh)_9S_8$
Rhodian Pyrrhotite	(Fe,Rh)S
Undefined PGM	
Undefined PGE-oxides	

- Platinum Group Minerals (PGM) and gold are important indicators of PGE deposits

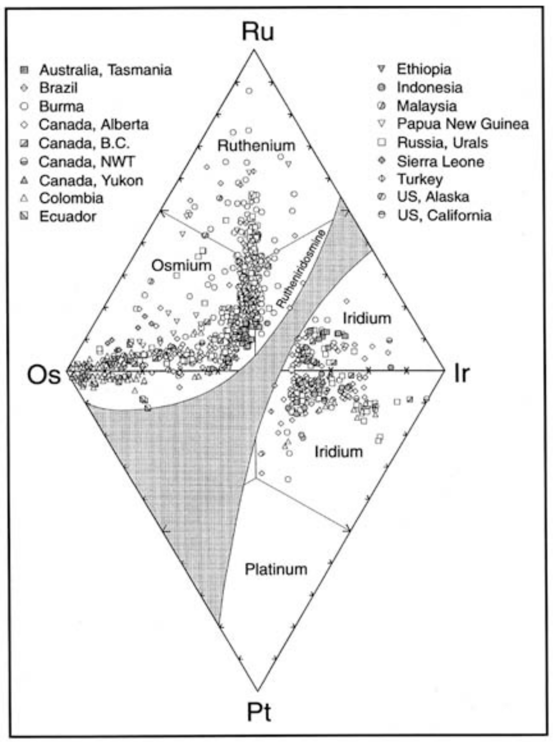
- List of the more common PGM documented in lode deposits and placers (Cabri et al. 1996)

PGM Composition

Os-Ir-Ru-Pt



Os-Ir-Rh-Pt

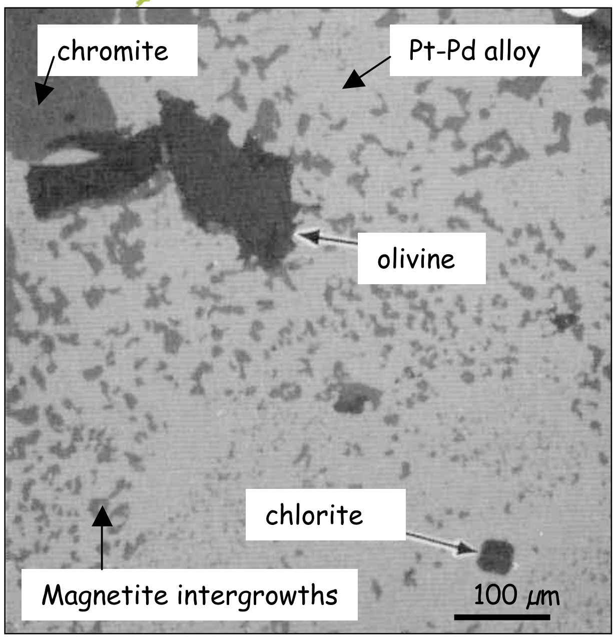


(Cabri et al. 1996)

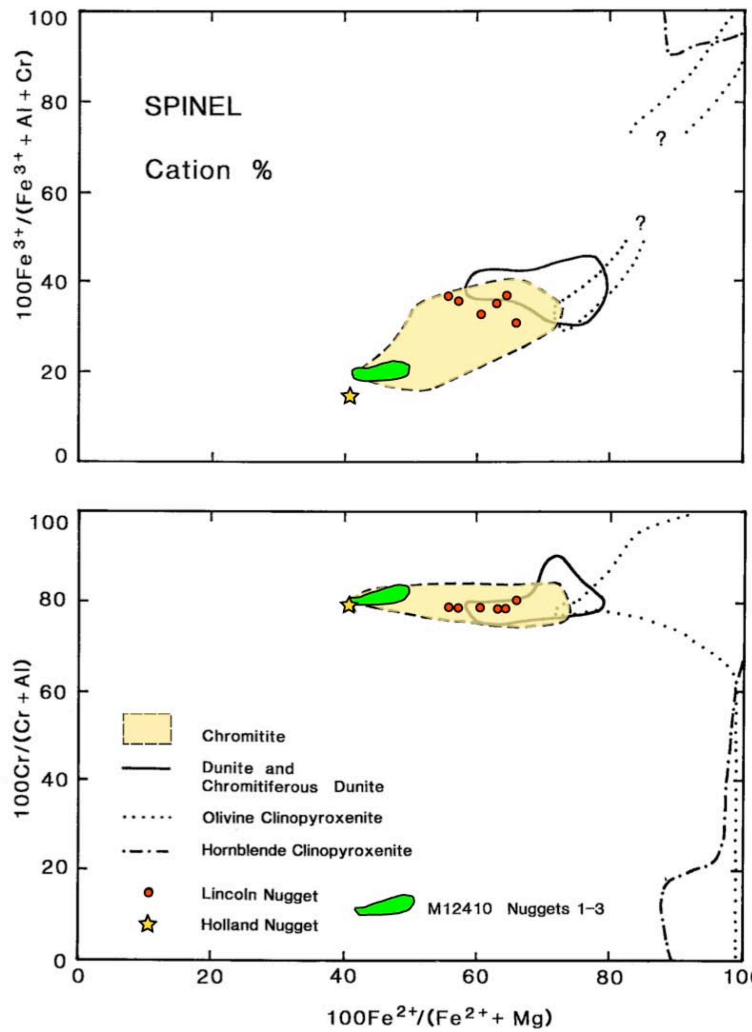
- last years 40 years, PGM grain compositions have been characterized and documented
- Quaternary diagrams for Pt-Ir-Os + Rhodium or Ruthenium (Cabri et al. 1996)
- PGM mineral chemistry provides a fingerprint to identify and compare grain populations and can be used to characterize bedrock source
- PGM minerals, especially Pt-Fe alloys, usually contain inclusions of other PGM
- Chromite most common non-PGM inclusion; others include magnetite, olivine, pyroxenes, micas, sulphides
- Mineral chemistry of inclusions and inter-growths provides information on bedrock

PGM Inclusions

Tulameen Pt Placer District, Canada



(Cabri et al. 1996)

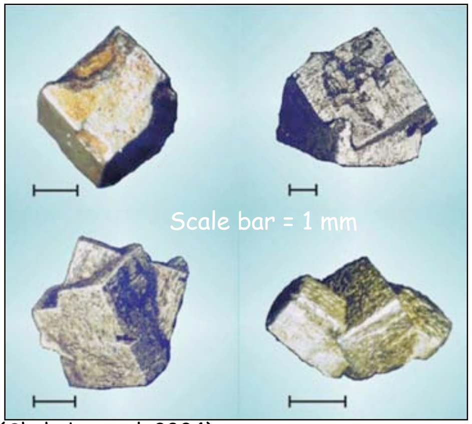


(Nixon et al. 1990)

- Chemistry of spinel and olivine intergrowths and inclusions used to determine bedrock source of placer PGM grains in streams
- Source determined to be chromitites in dunitic core of Tulameen Complex

PGM Grain Morphology

Crystal faces on Pt-FE alloy placer grains, Kondyor, Russia

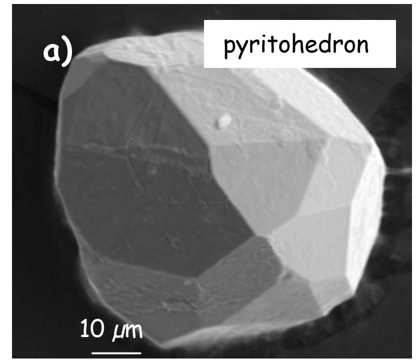


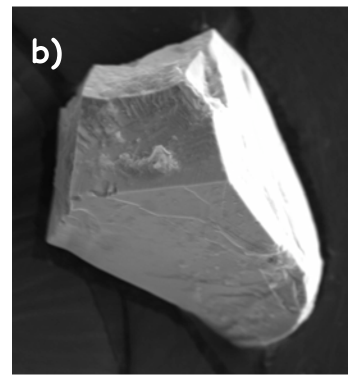
(Shcheka et al. 2004)

Rounded PGM placer grains, Tulameen, Canada

(B. McClenaghan)

Fresh crystal faces (a) and angular broken sperrylite grains (b) in till, Sudbury, Canada



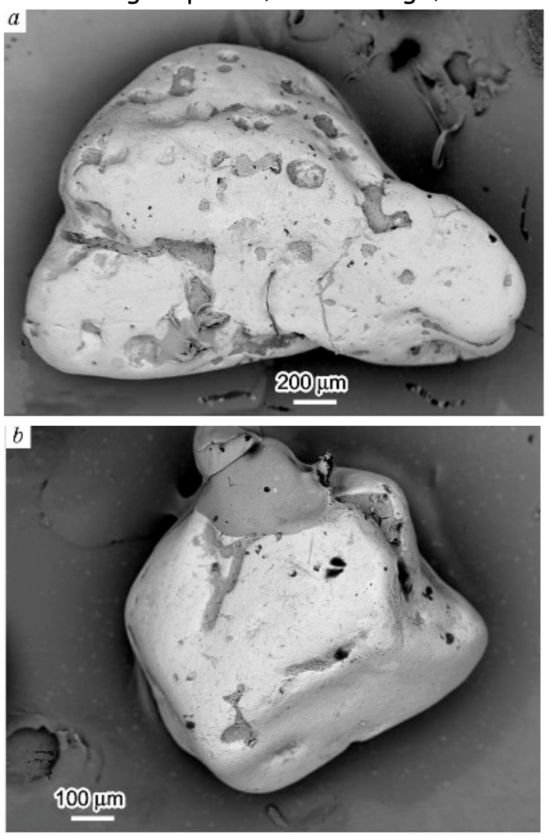


(McClenaghan et al. 2007)

- Morphology and size in surficial sediments depends on distance traveled from source
- No systematic classification scheme for morphology
- PGM hardness range 1.5 to >7, more common minerals >5
- Largest grains and best preserved crystal faces usually found closer to source rocks
- Variety of grain morphologies reported:
  - preserved crystal faces in stream placers
  - preserved crystal faces and angular broken grains in till
  - rounded PGM from placers

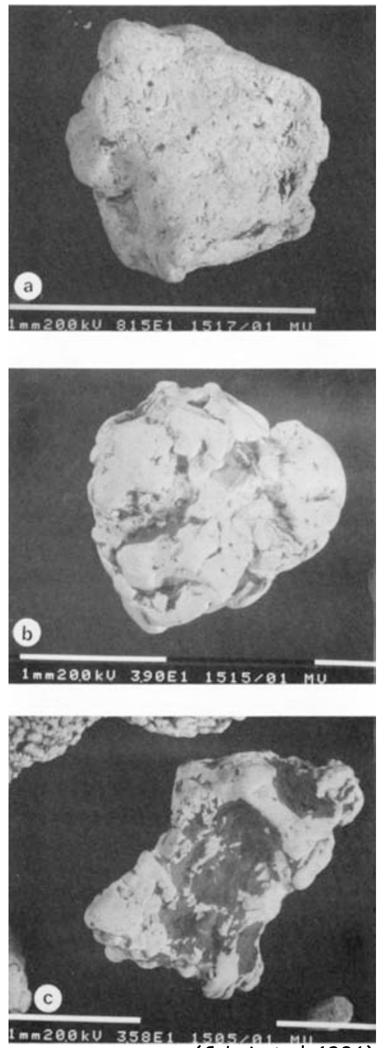
PGM Grain Morphology

Rounded PGM grains, Simonovsky Brook gold placer, Salair Range, Russia



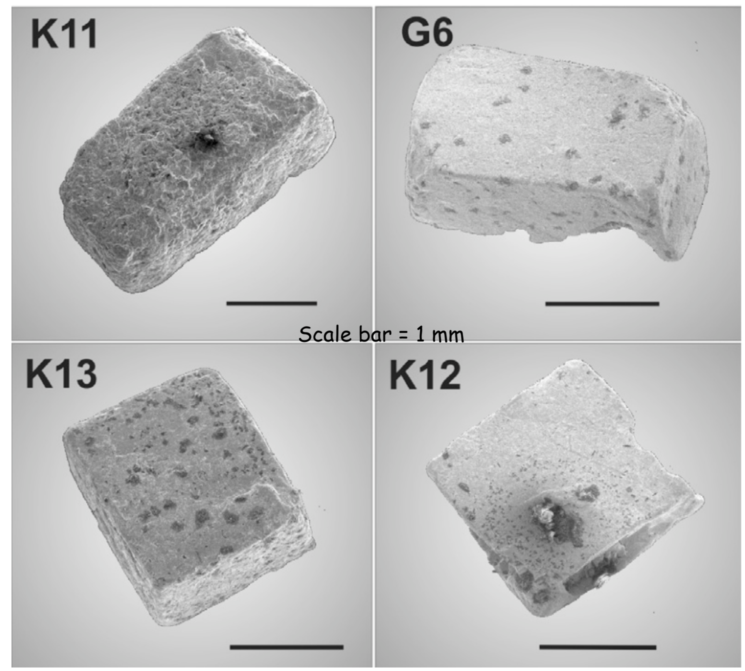
(Podlipsky et al. 2007)

Rounded Pt-Fe alloy grains Choco region, NW Columbia



(Cabri et al. 1996)

Ferroan-platinum grains from the Darya river, Russia



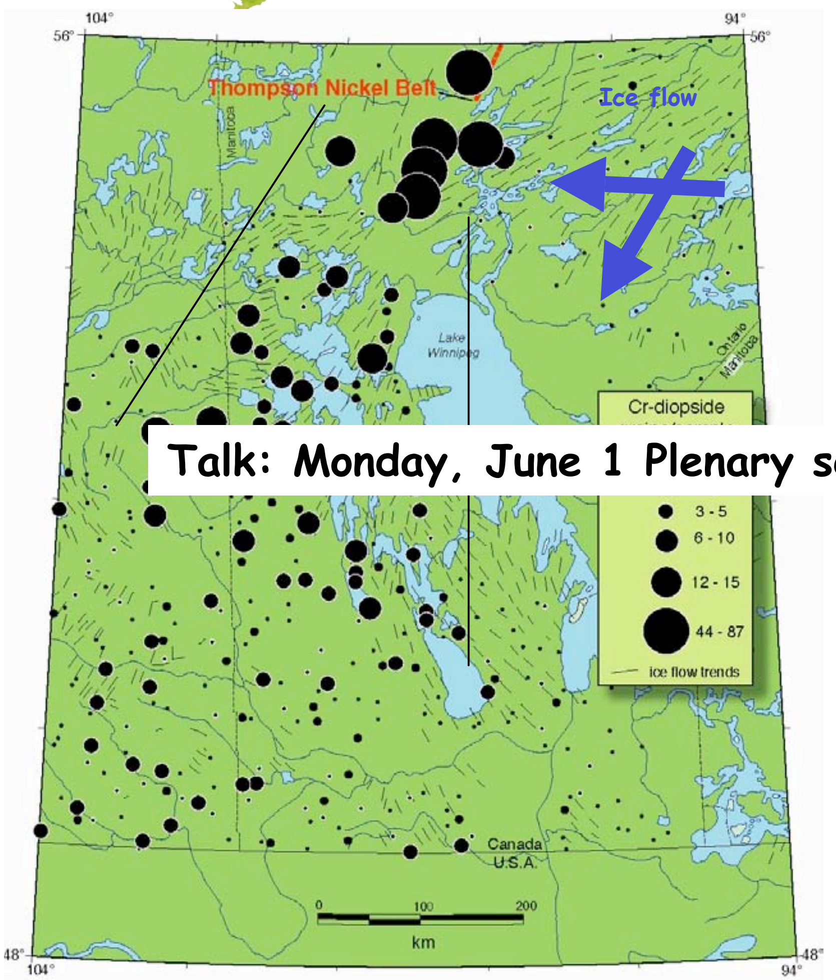
(Shcheka et al. 2004)

PGM Grains in Glacial Sediments

- Historically, report of PGM in glacial sediments (till) rare
- Where found, usually included only a few grains from samples collected <500 m from source
- Presence of as few as two PGM grains in a till sample is significant; likely indicates nearby (<500 m) PGE mineralization
- Recent years, much improved recovery and recognition of PGM grains in till
- Geochemical assay of till matrix (fire assay/ICP-MS) useful check on PGM content of sample

Some Recent Examples:
- Sudbury Ni-Cu-PGE deposits (Bajc & Hall 2000)
- Broken Hammer Cu-(Ni)-PGE deposit, Sudbury (McClenaghan et al. 2007)
- Magmatic Ni-Cu deposits, Thompson Nickel Belt (TNB) (talk, June 1 Plenary Session)
- Peregrine Diamonds' 2007 discovery of sperrylite grains in till, Baffin Island, Canadian Arctic

Glaciated terrain: Thompson Ni Belt, central Canada



Talk: Monday, June 1 Plenary session

(Matile & Thorliefson, 1997; Thorliefson & Garrett, 1993)

Thompson and Pipe magmatic Ni-Cu deposits

- Exploration challenge: thick glacial sediments, till overlain by glaciolacustrine clay
- >300 km plume defined by indicator minerals in till
- Indicator minerals: Cr-diopside, chromite, forsterite, enstatite, sulphides, sperrylite

(McClenaghan et al., 2007; 2009)

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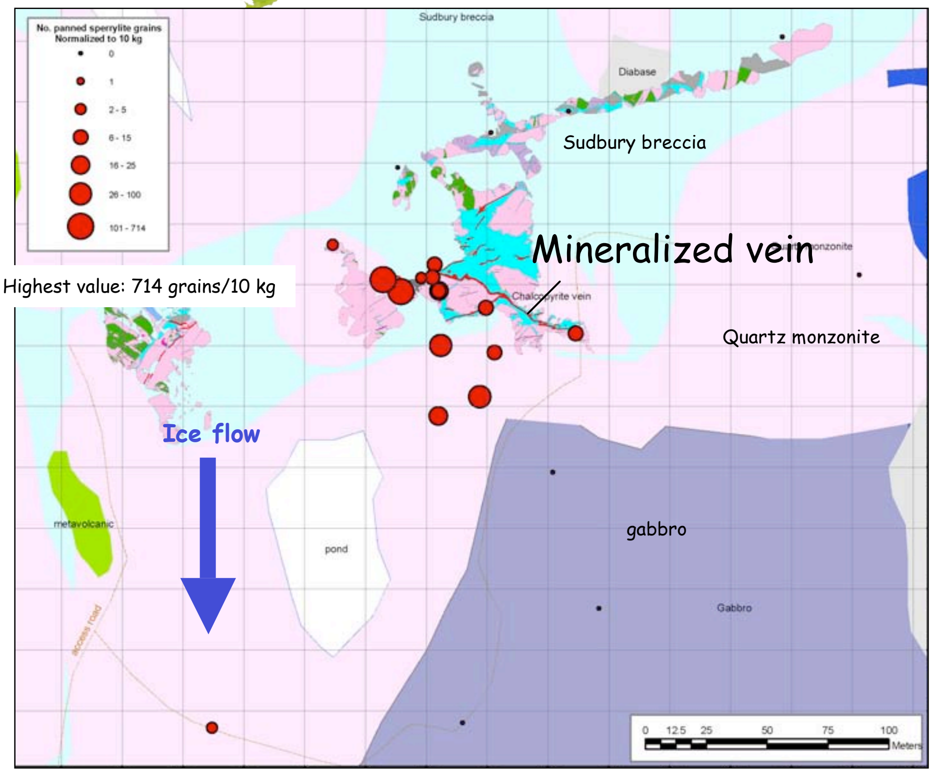
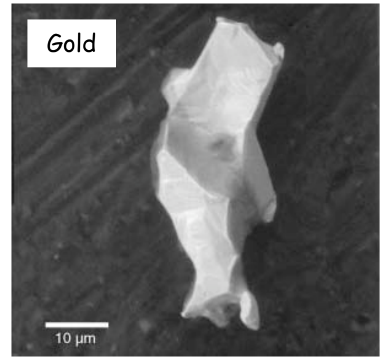
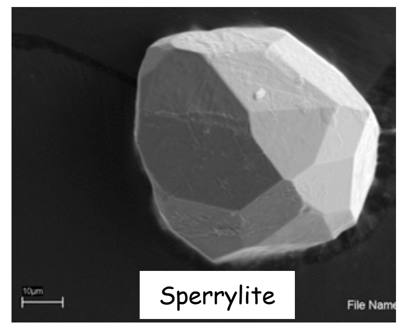
Glaciated terrain: Sudbury, Canada



(McClenaghan et al., 2007)





Silt-sized

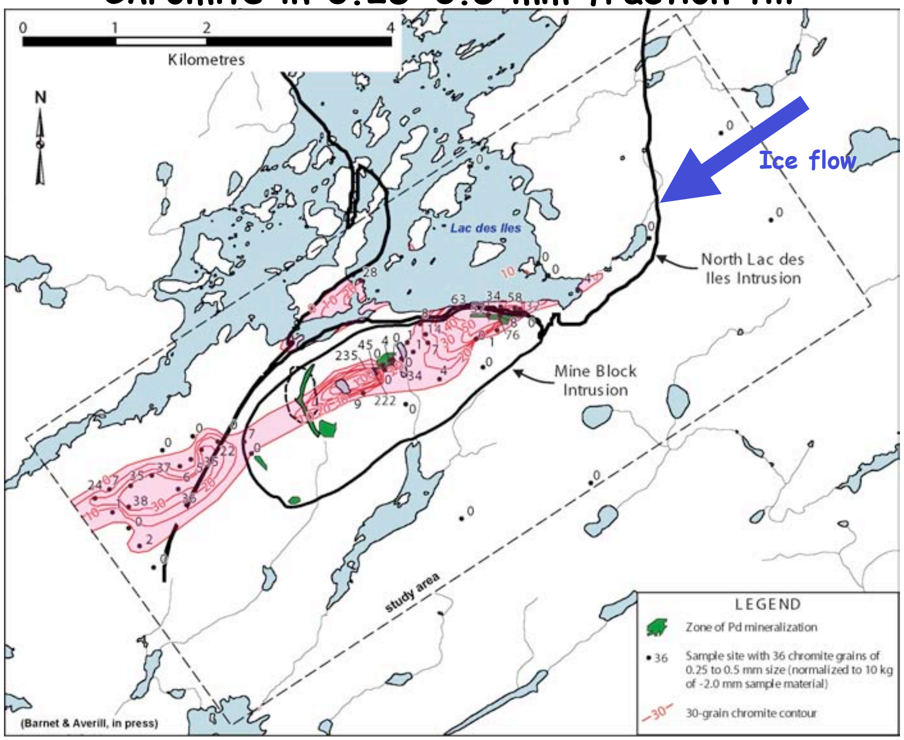
Sand-sized

Broken Hammer footwall Cu-PGE deposit

- Exploration challenge: thin till covered terrain
- >150 m dispersal, defined by indicator minerals and till geochemistry
- Indicator minerals: sperrylite ($PtAs_2$), gold, chalcopyrite, pyrite, others to be determined…

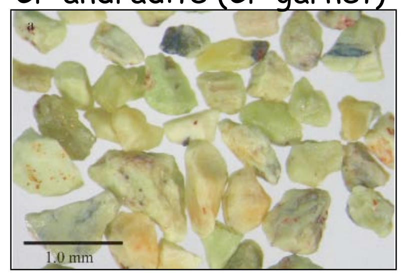
Glaciated terrain: Lac des Isles, Canada

Chromite in 0.25-0.5 mm fraction till



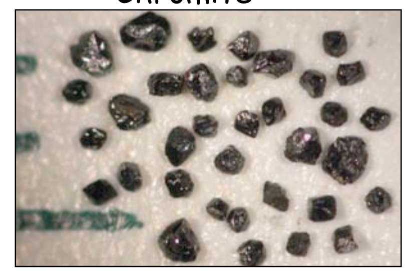
Barnet & Averill, in press
Searcy, 2001

Cr-andradite (Cr-garnet)



(Averill, 2007)

Chromite



Lac des Iles PGE Deposits

- Exploration challenge: till covered region
- >5 km ribbon-shaped dispersal train defined by indicator minerals and till geochemistry
- Background = zero chromite grains
- Maximum 235 chromite grains
- Indicator minerals: Cr-andradite, chromite, sperrylite ($PtAs_2$), stillwaterite (Pd_8As_3), native Pt

PGE Deposit Indicator Mineral Summary

- PGM and gold are important indicators of PGE deposits
- In addition, suite of oxides, silicate and metallic minerals (Averill and others)
- Recovered from broad range of sediment types: eolian, stream, lateritic soil, glacial
- **Size range:** 10 µm to 2.0 mm routinely recovered
- **Recovery methods:** panning, table, jig, spiral, Knelson concentrator
- **Composition:**

- broad range of minerals in PGM suite
- characterized by EMP and LA ICP-MS
- inclusion mineralogy provides clues to source and distance of transport

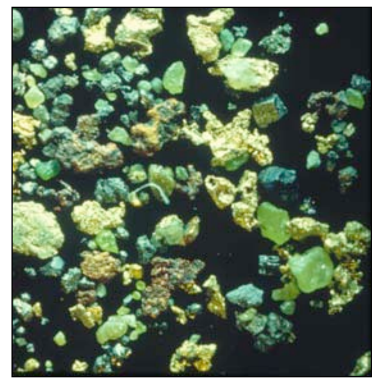
- **Surface features and morphology:** may provide information on relative transport distance, no systematic classification scheme
- Reference list

Recommendations for Exploration

- PGE indicator mineral suite identified
- Indicator minerals for a broad spectrum of commodities
- Recovered from <u>same</u> heavy mineral concentrate
- Use in combination with till geochemistry

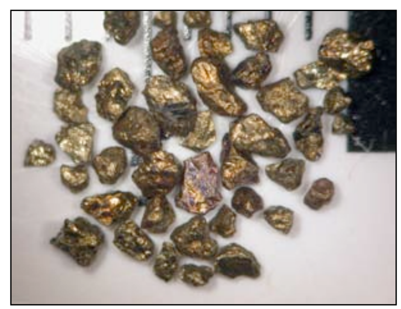
Common indicator minerals:

- Magmatic Ni-Cu-PGE minerals
- Platinum Group minerals
- Gold grains
- Kimberlite indicator minerals
- Sulphide minerals
- Metamorphosed massive sulphide minerals- e.g. gahnite
- Native copper
- Scheelite
- Cassiterite
- Cinnabar
- Fluorite, topaz
- Uraninite, thorianite



Gold, native copper, pyromorphite

Gahnite



Chlalcopyrite

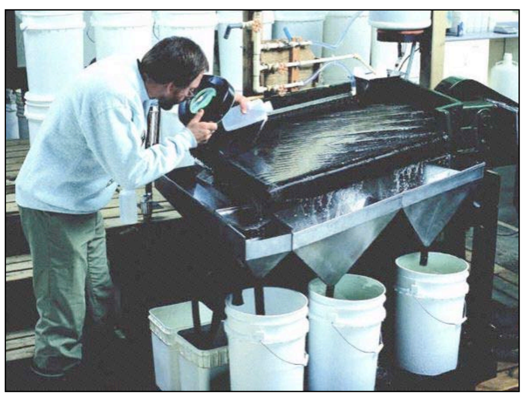
Kimberlite indicator minerals

Processing Methods

- Two-phased, to allow for the recovery of indicator minerals from two size fractions.

1) Silt-sized gold, PGM, and associated sulphide minerals recovered by panning
2) Coarser sand-sized gold, PGM, silicate and oxide indicator minerals recovered using table, jig, spiral, or Knelson concentrator

- Minerals examined and analyzed using scanning electron microscope (SEM), electron microprobe (EMP) and Laser ablation ICP-MS



Acknowledgements

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