

# Interprétation des amas de sulfures massifs stériles dans les districts miniers de VMS

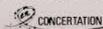
PROJET CONSOREM  
2013-08

17 novembre – Atelier CONSOREM

Dominique Genna



AGNICO EAGLE



URSTM/UQAT



GLENCORE



UQAC

UQAM

# Problématique

- Comment interpréter la présence d'amas VMS stériles aux premiers stades de l'exploration d'un secteur?

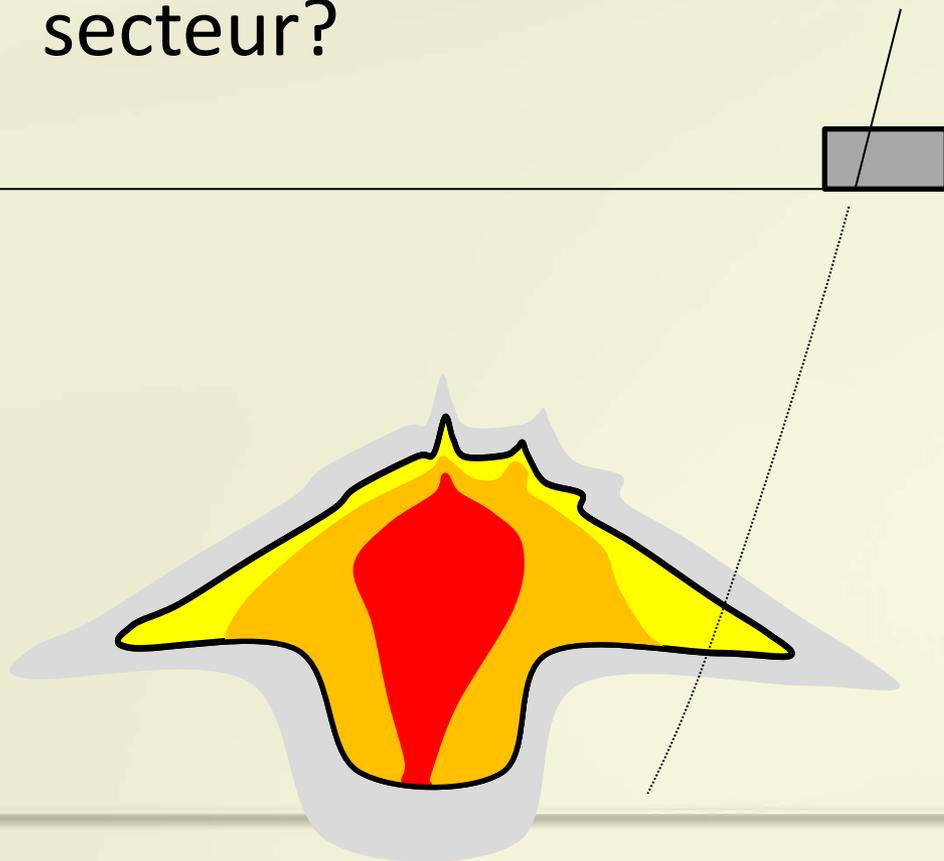
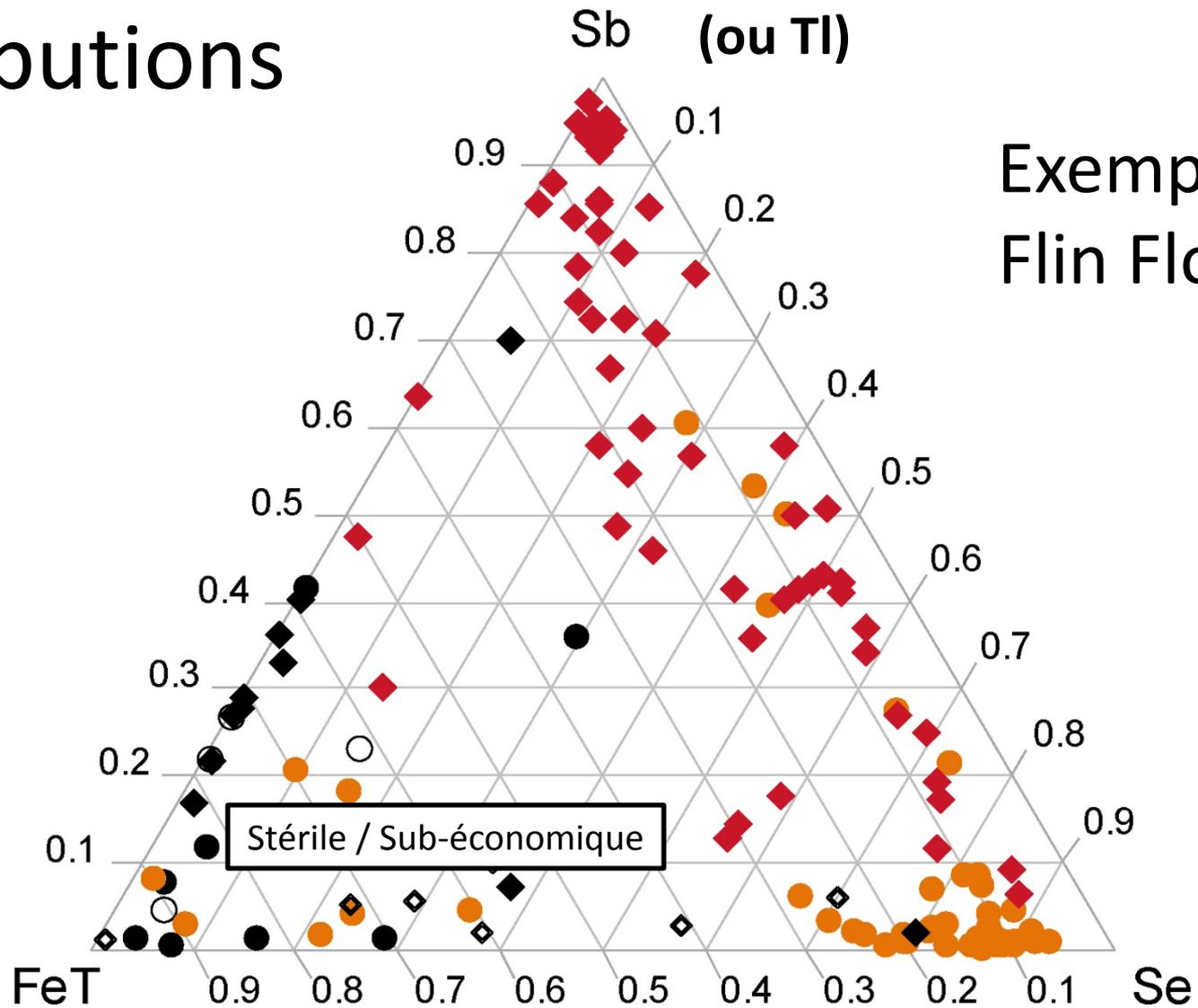


Figure A2.16b. Vamp Lake (Hudvam), diamond drill core CON36, 742 ft. Massive

# Contributions

Exemple  
Flin Flon



**Indices et gisements stériles**

- ◆ affinité zincifère
- affinité cuprifère

**Gisements économiques**

- ◆ riche en zinc
- riche en cuivre

# Plan de la présentation

- Objectifs et méthodologie
- Généralités sur les VMS et solubilité métaux
- Éléments traces
  - Matagami, à l'échelle du grain
  - Flin Flon, roche totale
- Pourquoi est-ce que Sb/Tl et Se fonctionnent?
- Limitations et recommandations

# Objectifs

- Facteurs contrôlent la présence de minéralisations
- Relation entre les amas stériles et amas économiques
- Développer des outils pour déterminer la présence de minéralisations économiques

# Défis

- Trouver des données (Stérile = \$ inintéressant  $\neq$  travaux)
- Package d'éléments analysés + méthodes d'analyses

# Méthodologie

- Revue de littérature
- Compilation de données
  - Flin Flon – CGC
  - Chimie des sulfures massifs sous-marins modernes
  - Matagami (Glencore)
  - Hackett-River (Glencore)
  - Kuroko
  - Brunswick...
- Étude: Relation entre chimie des sulfures et la fertilité

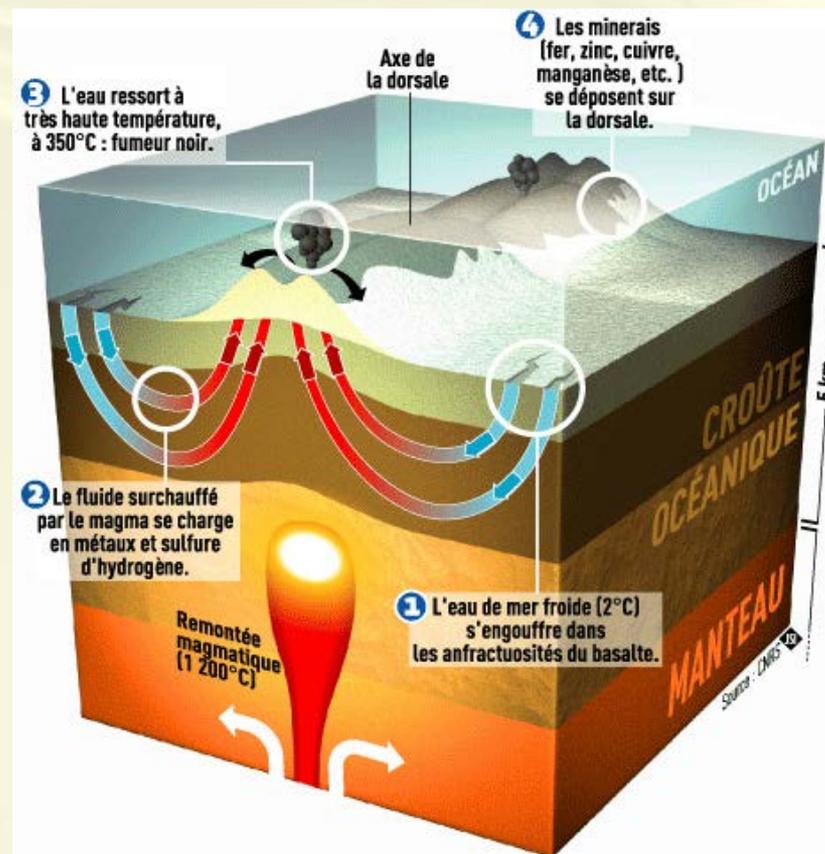


# Généralités sur les VMS

- Gisements polymétalliques (Cu, Zn, Pb, Au, Ag...)
- Contexte sous-marin en extension
- 3 paramètres de contrôle:
  - Perméabilité structurale
  - Apport illimité en eau
  - **Source de chaleur**



Université du Delaware

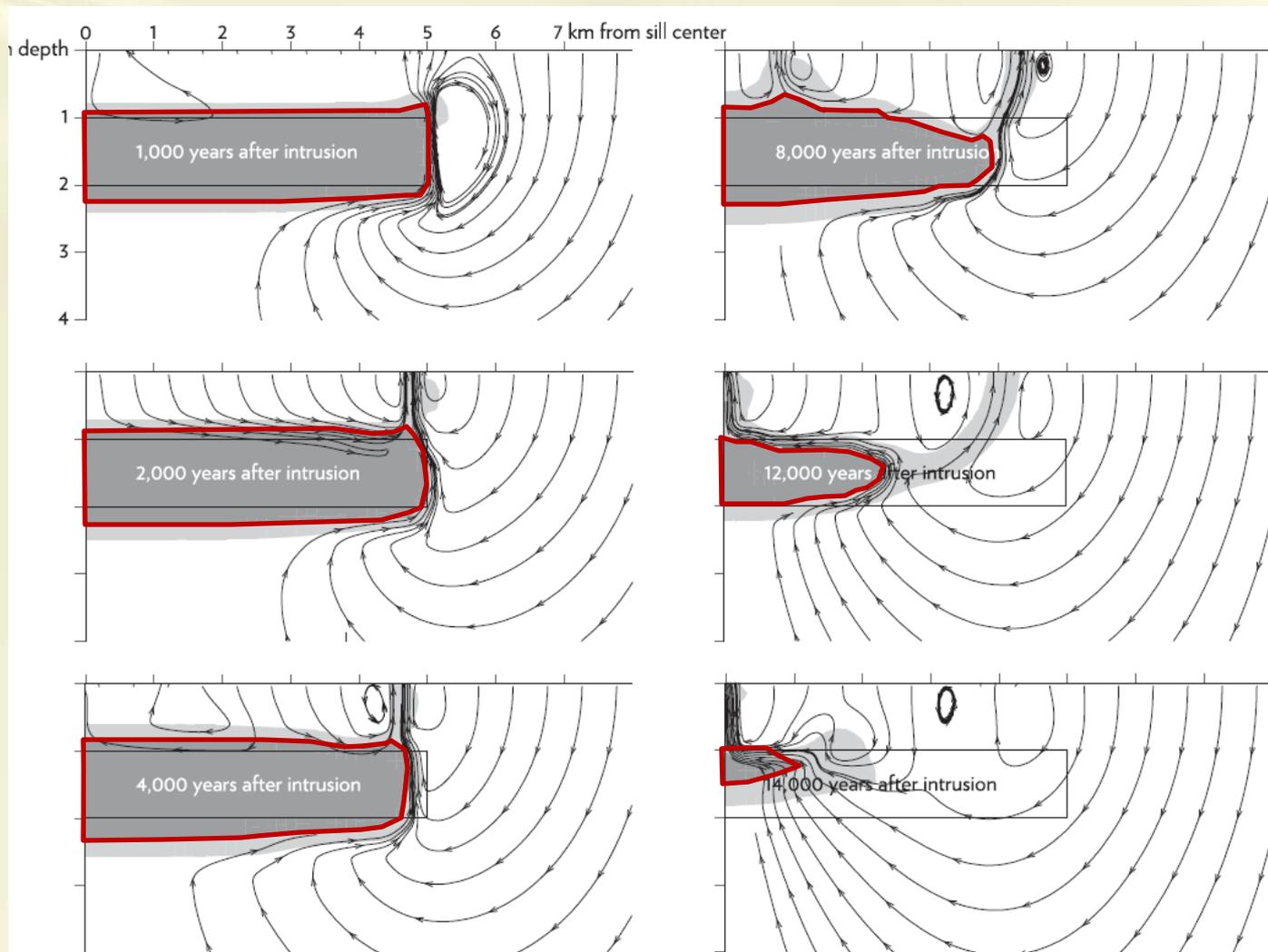


# Source de chaleur – Intrusion synvolcanique

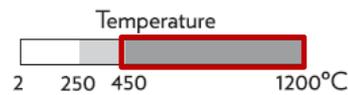
- Profondeur
  - Gradient géothermique

**T° max**
- Taille
  - Durée Du système hydro. (refroidissement)

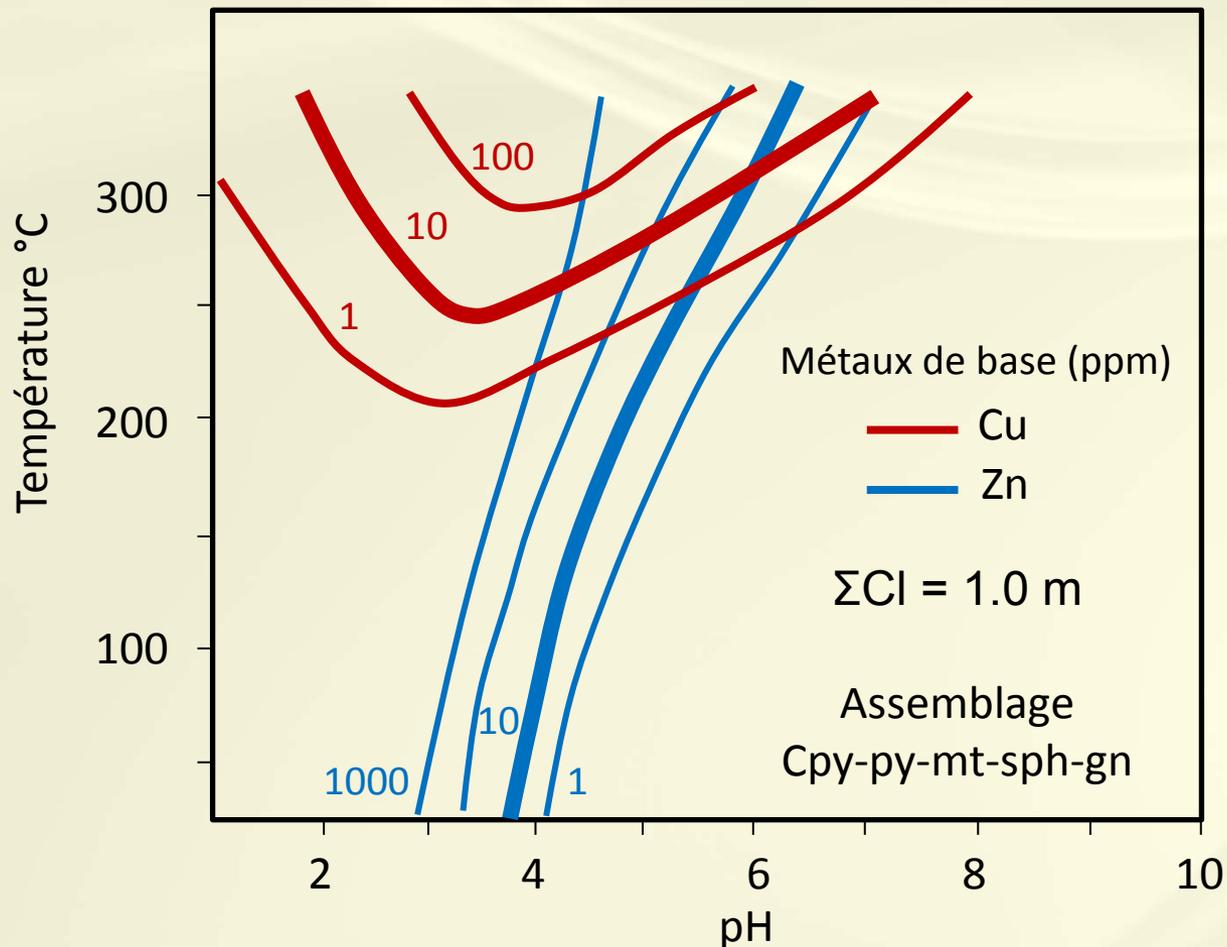
**temps**
- Source métaux



Carr et al. 2008



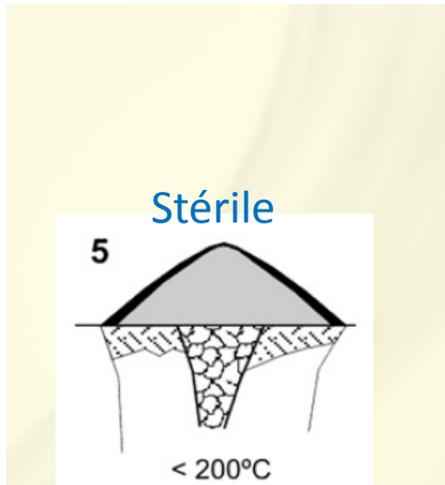
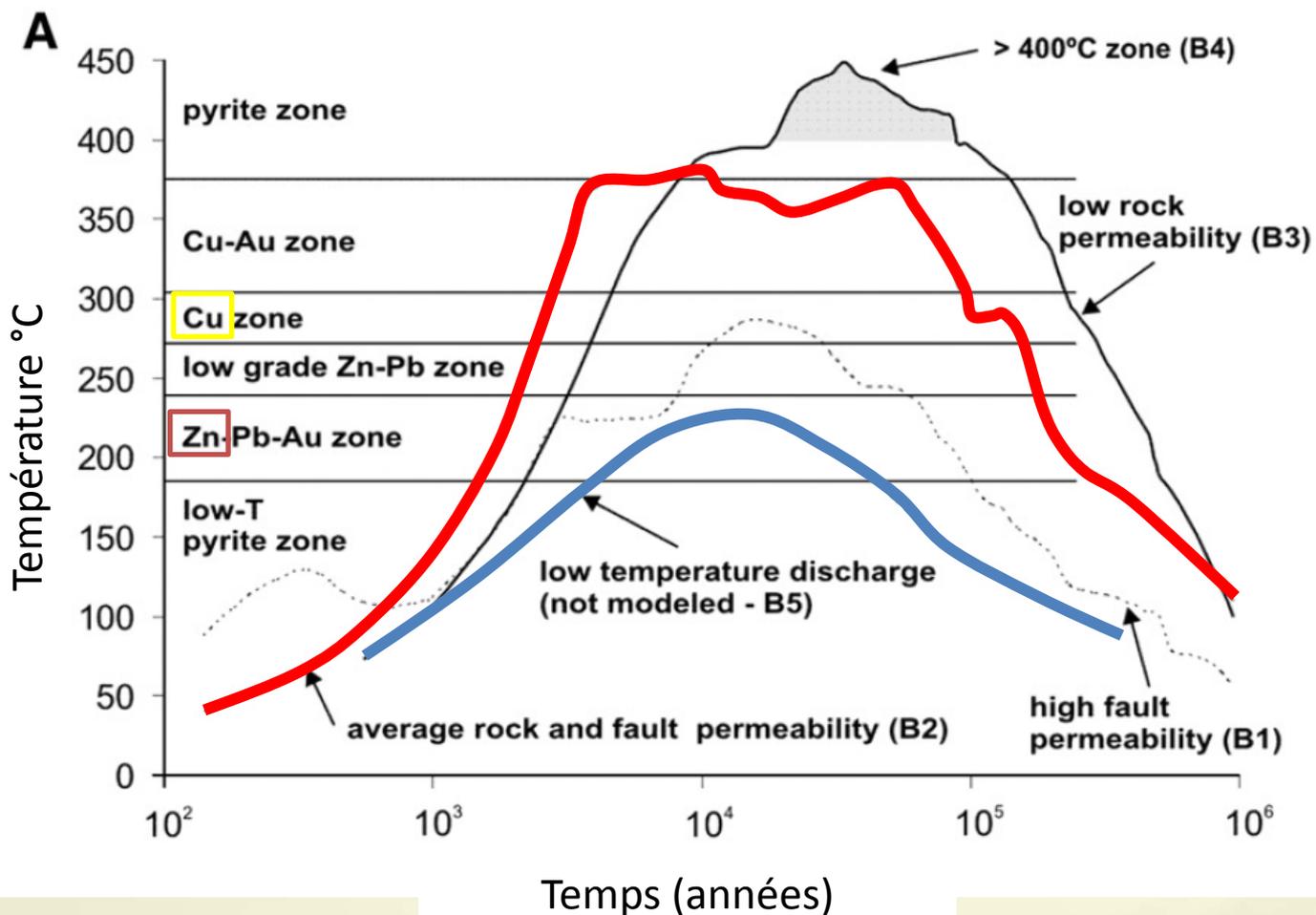
# Importance de la température: Solubilité des métaux



Lydon, 1988  
dans Franklin et al. 2005

# Pourquoi des gisements stériles?

- Système hydrothermal trop faible
- Système hydrothermal trop fort



Schardt and Large, 2009



# Éléments traces

## Généralités

### État des connaissances et pistes

Qu'est-ce qu'on recherche?

- Des preuves de l'efficacité du système hydrothermal pour le transport des métaux économiques (Cu, Zn)
  - Recherche d'éléments qui ont des comportements similaires, mais qui sont peut-être plus « mobiles » (dispersion plus large) et susceptibles d'être fixés dans les sulfures non économiques.

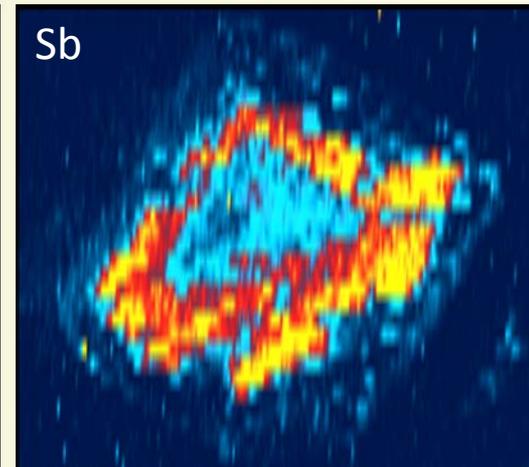
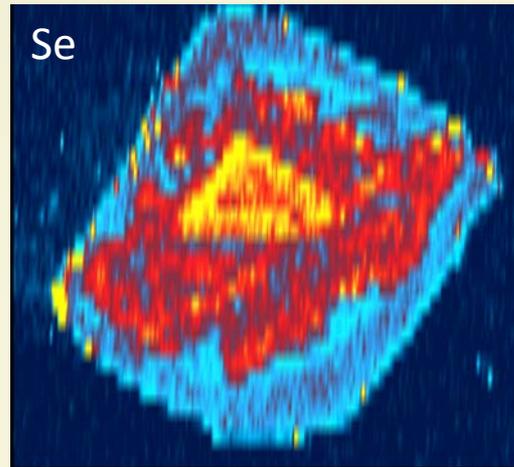
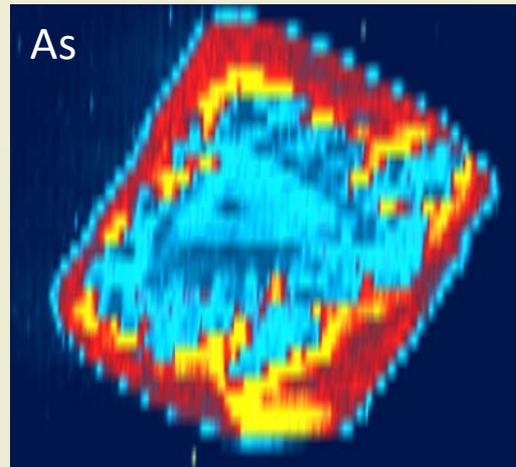
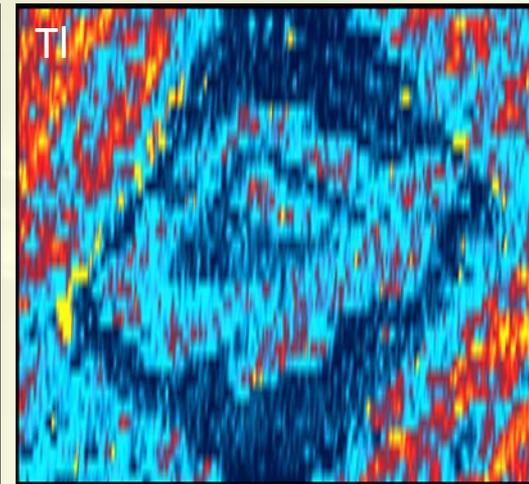
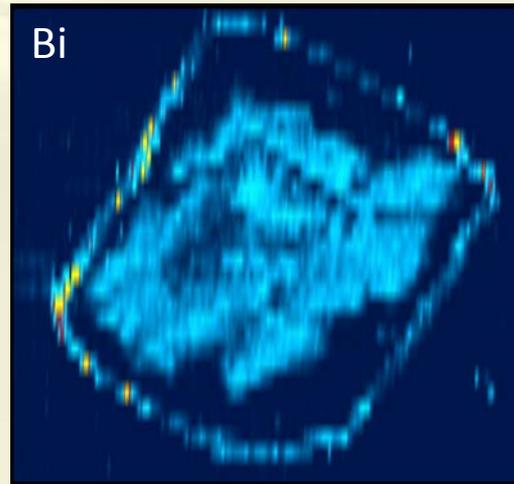
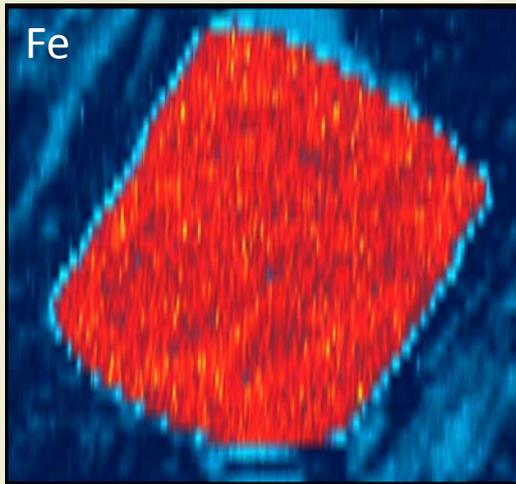
LFSE
  Transition
  Base Metals

HFSE
  Noble Metals

REE
  Volatile

H																		He
Li	Be											B	C	N	O	F	Ne	
Na	Mg											Al	Si	P	S	Cl	Ar	
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu				
Ac	Th	Pa	U															

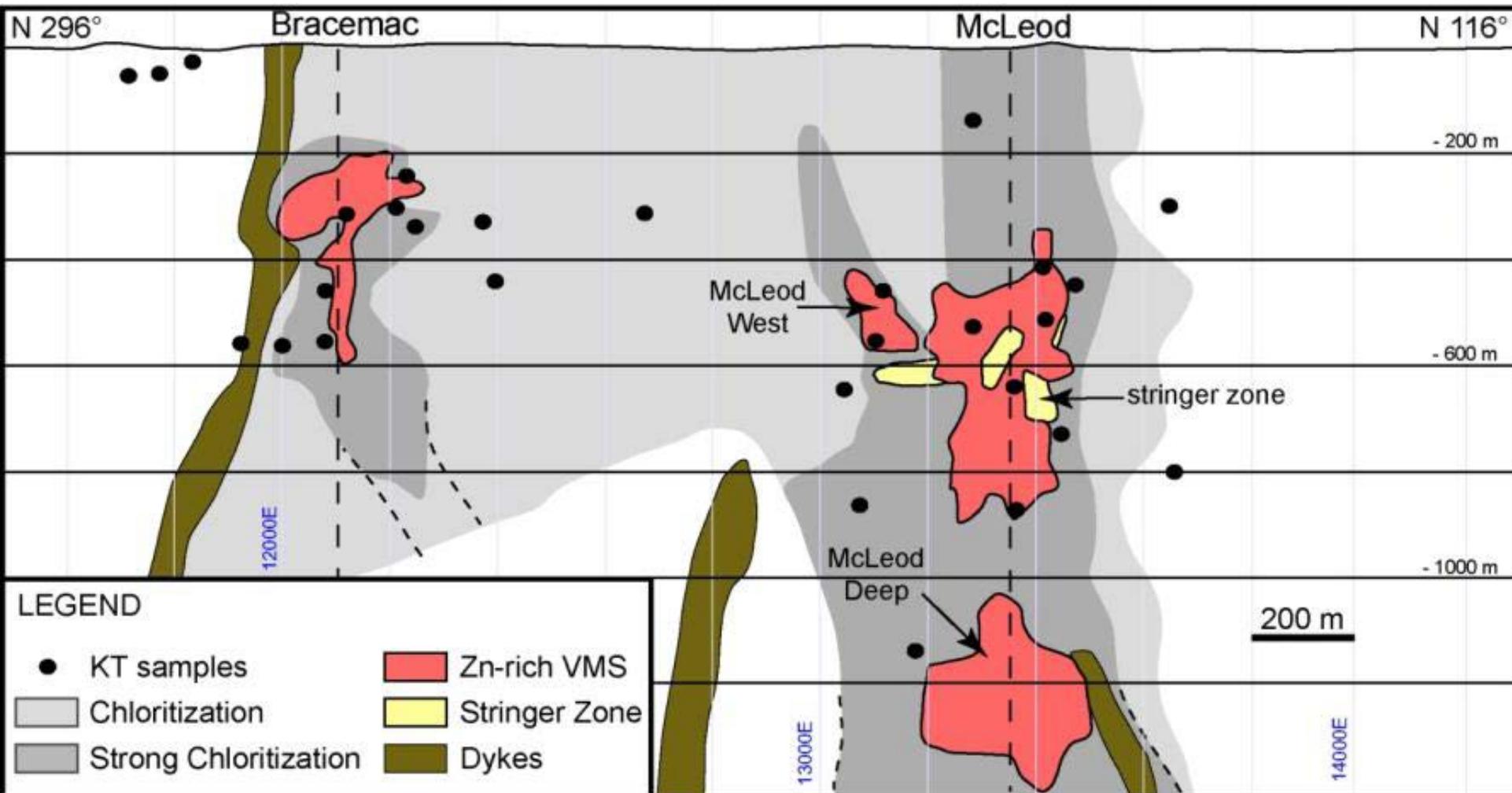
# Exemple de la signature des pyrites



Genna, PhD

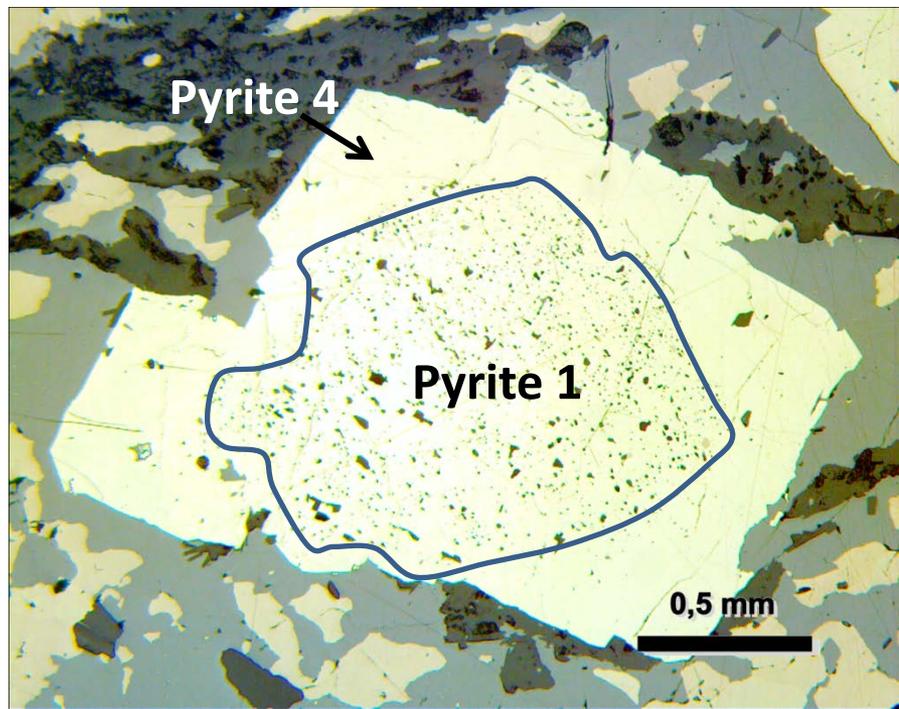
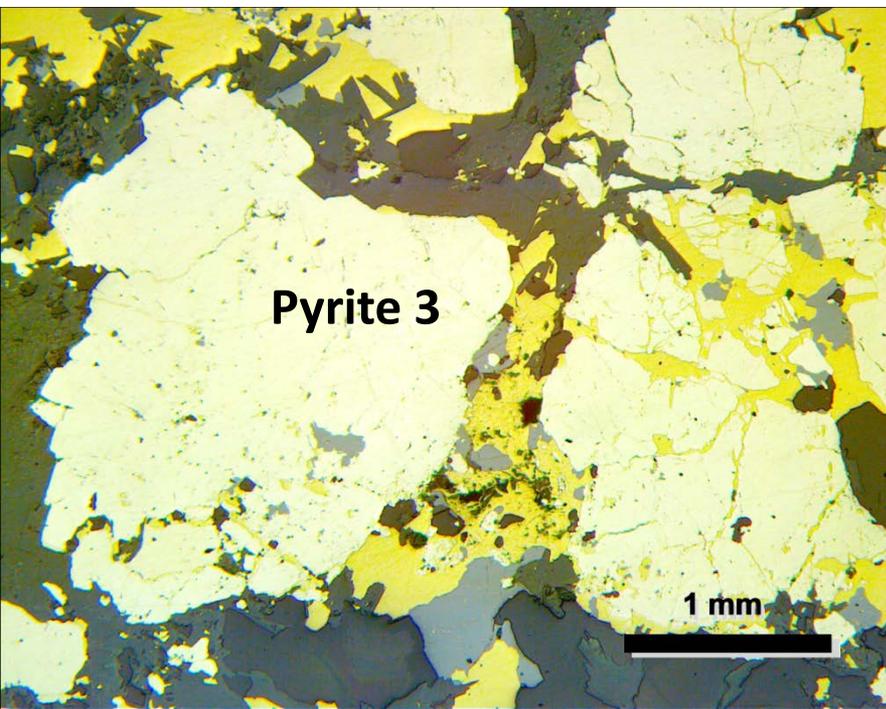
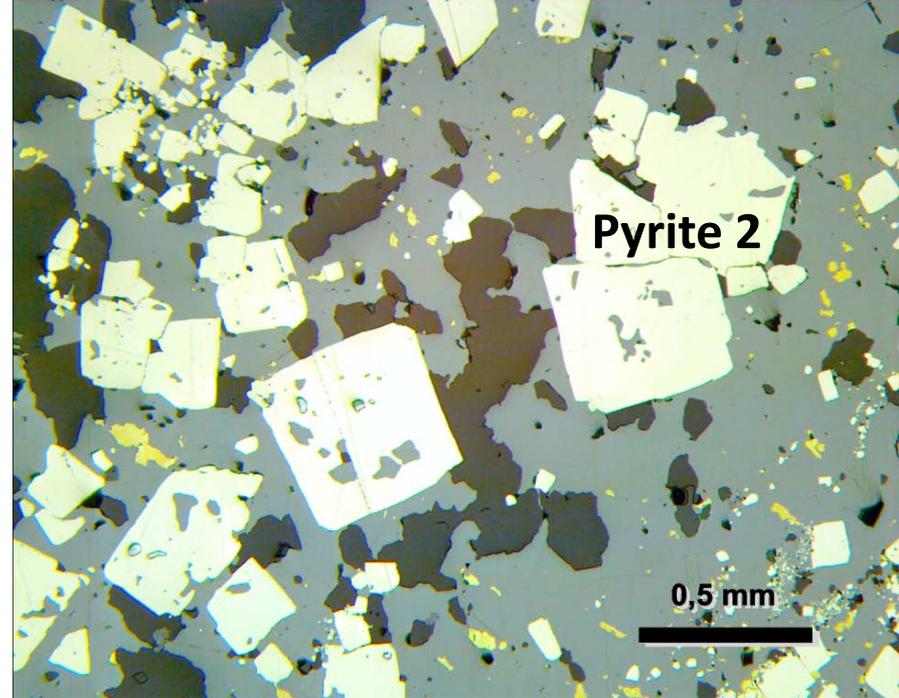
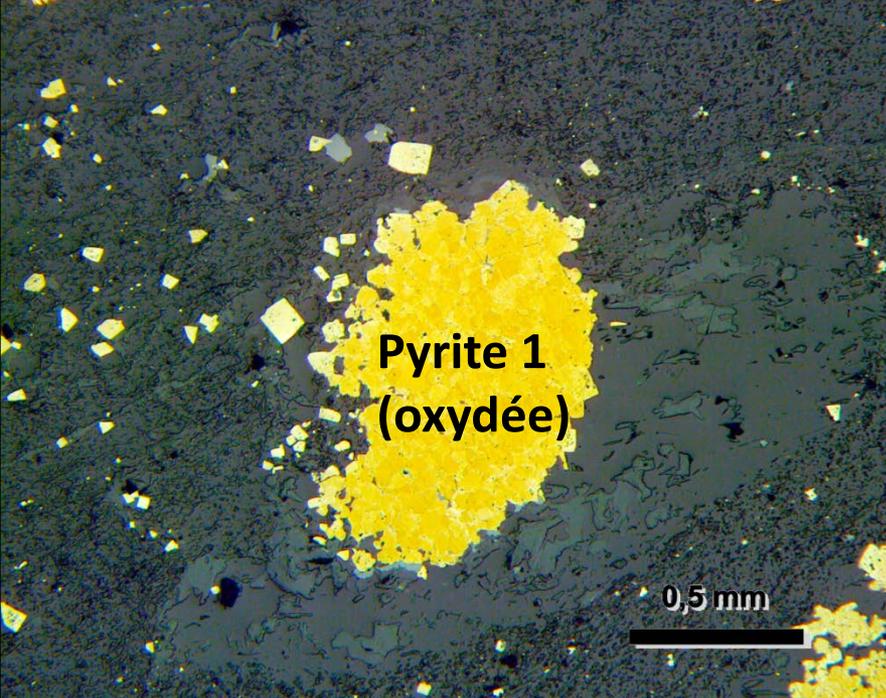
Bracemac-McLeod Matagami

# Bracemac-McLeod

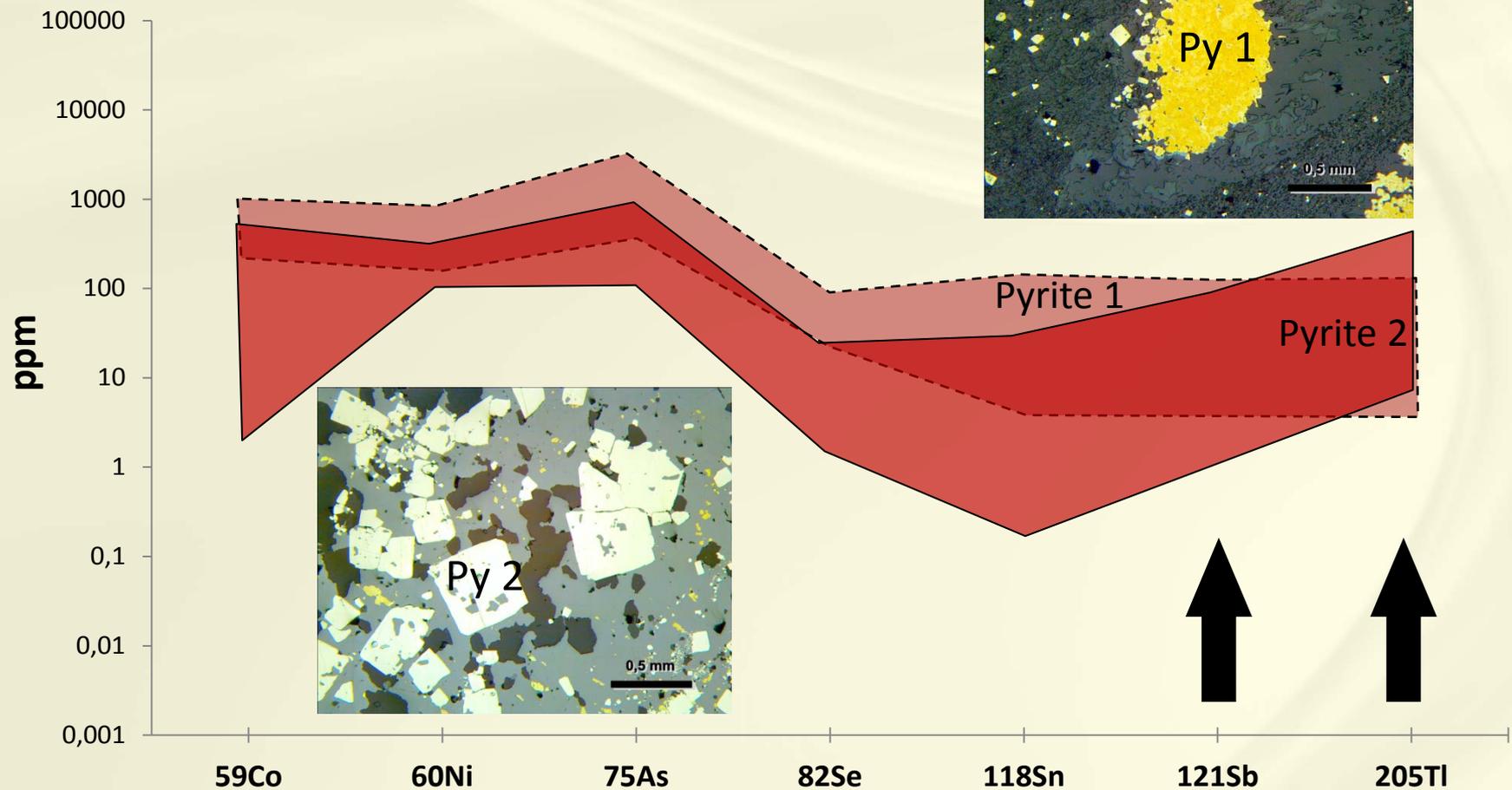


Xstrata Zinc-Donner Metals

**3.73 Mt @ 9.60% Zn and 1.26% Cu (BRC and MC measured and indicated)**  
**0.24 Mt @ 0.96% Zn and 1.25% Cu (MC copper stringer zone-indicated)**  
**2.63 Mt @ 8.78% Zn and 1.31% Cu (MC Deep inferred)**

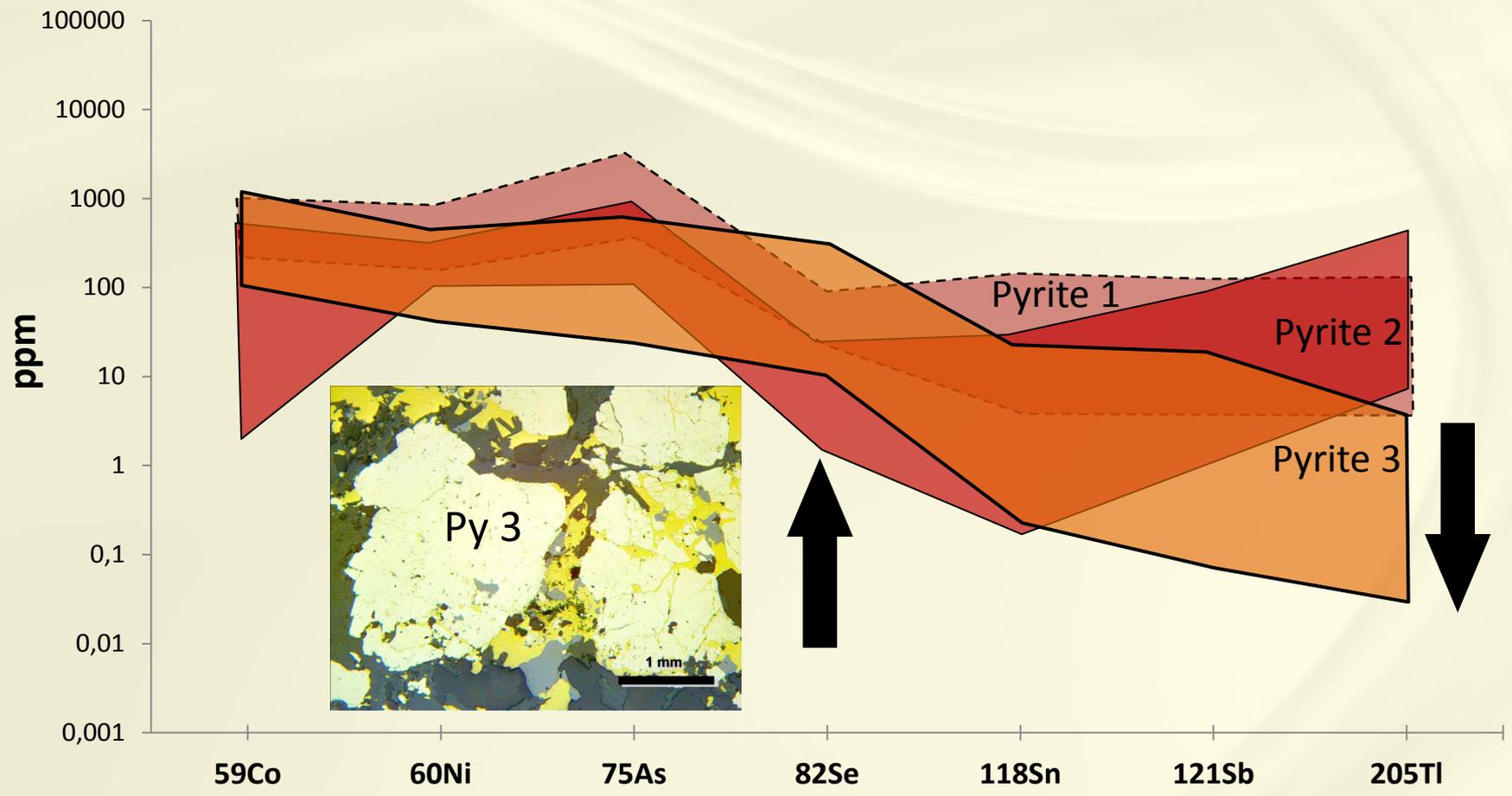


# Fluide riche en Zinc: Sb et Tl



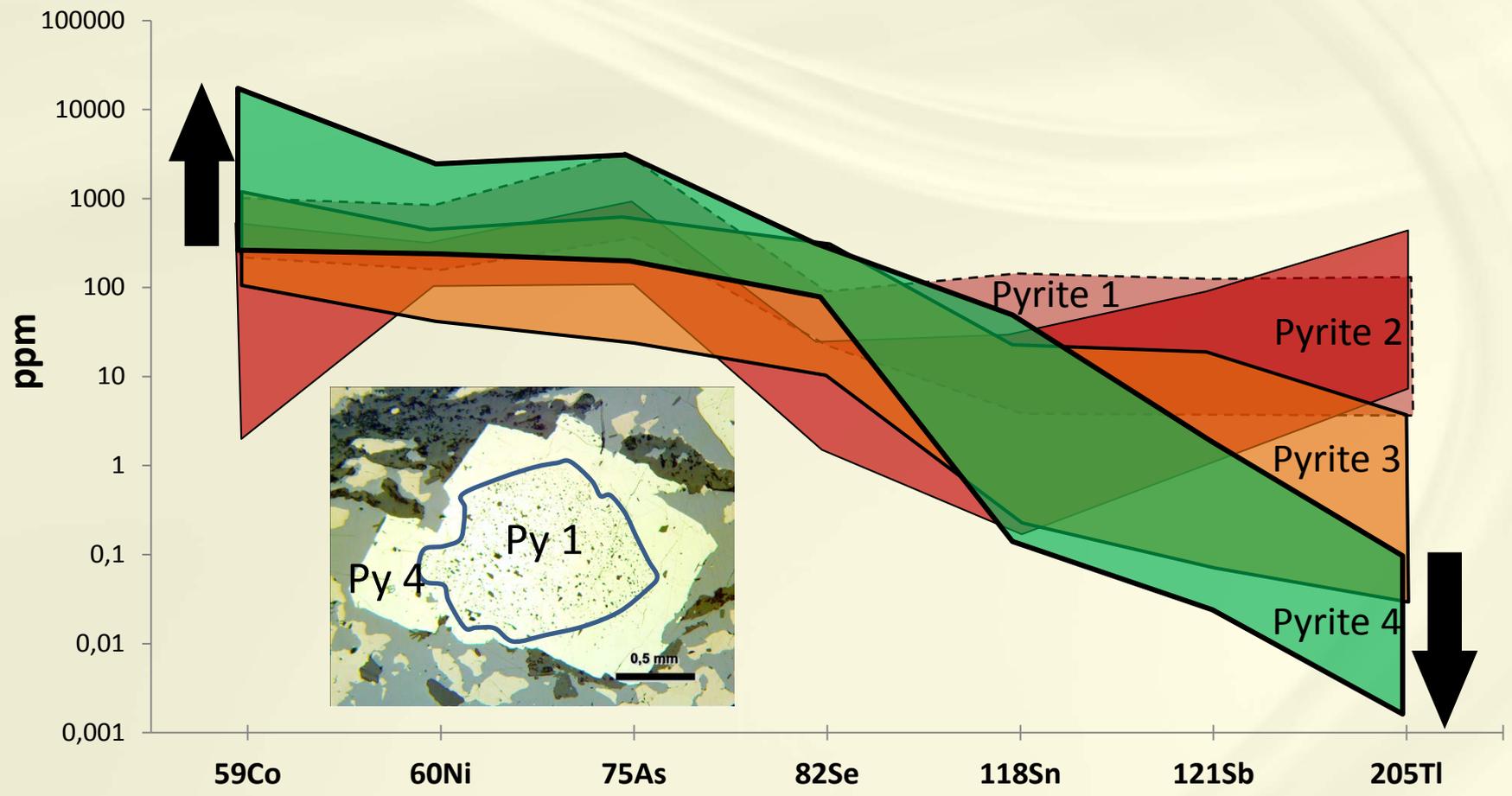
Genna, PhD

# Fluide riche en Cuivre: Se



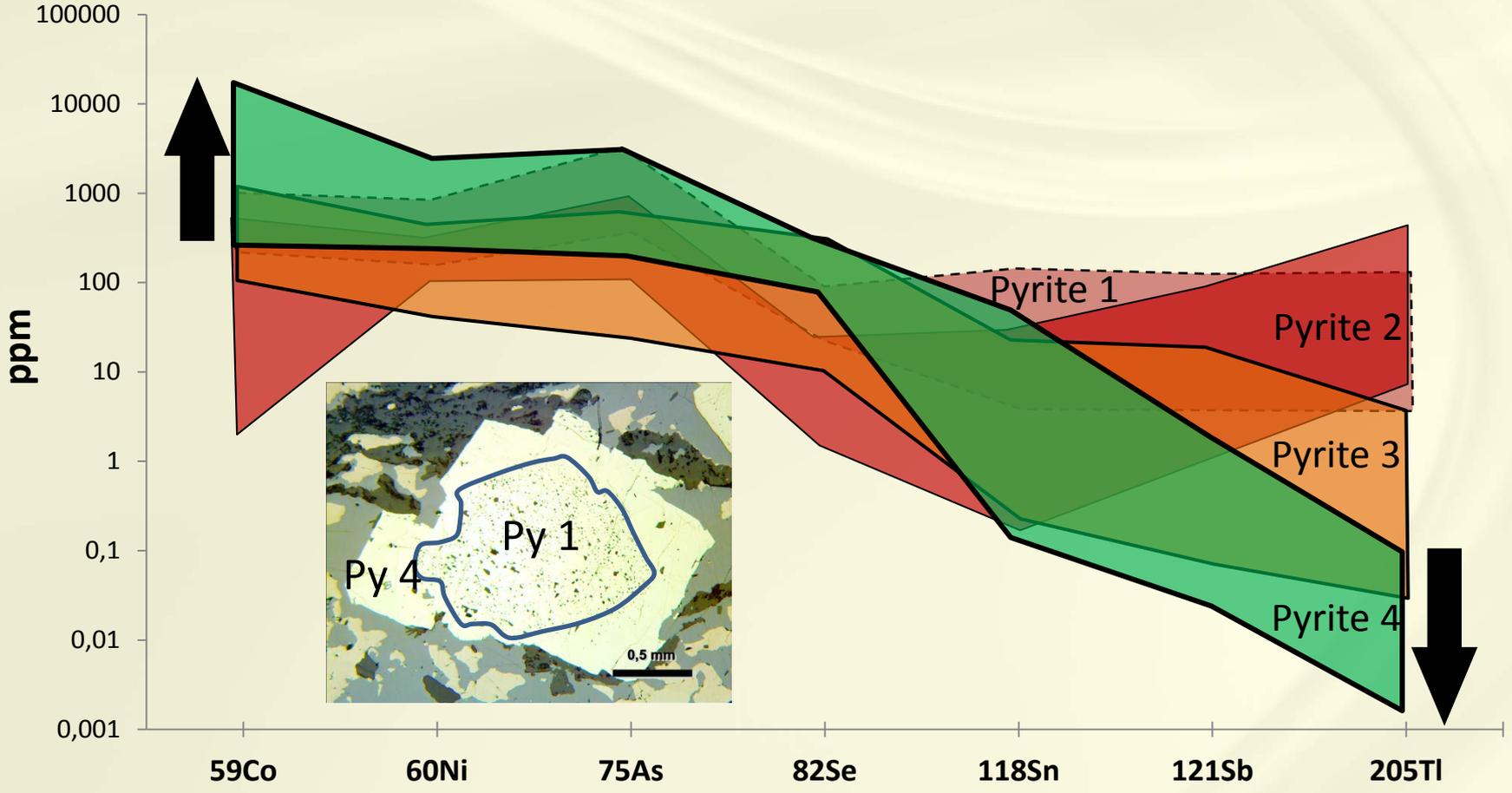
Genna, PhD

# Surcroissance métamorphique: Co-As



Genna, PhD

Intéressant, mais non applicable à l'exploration  
Approche: roche totale



LFSE
  Transition
  Base Metals

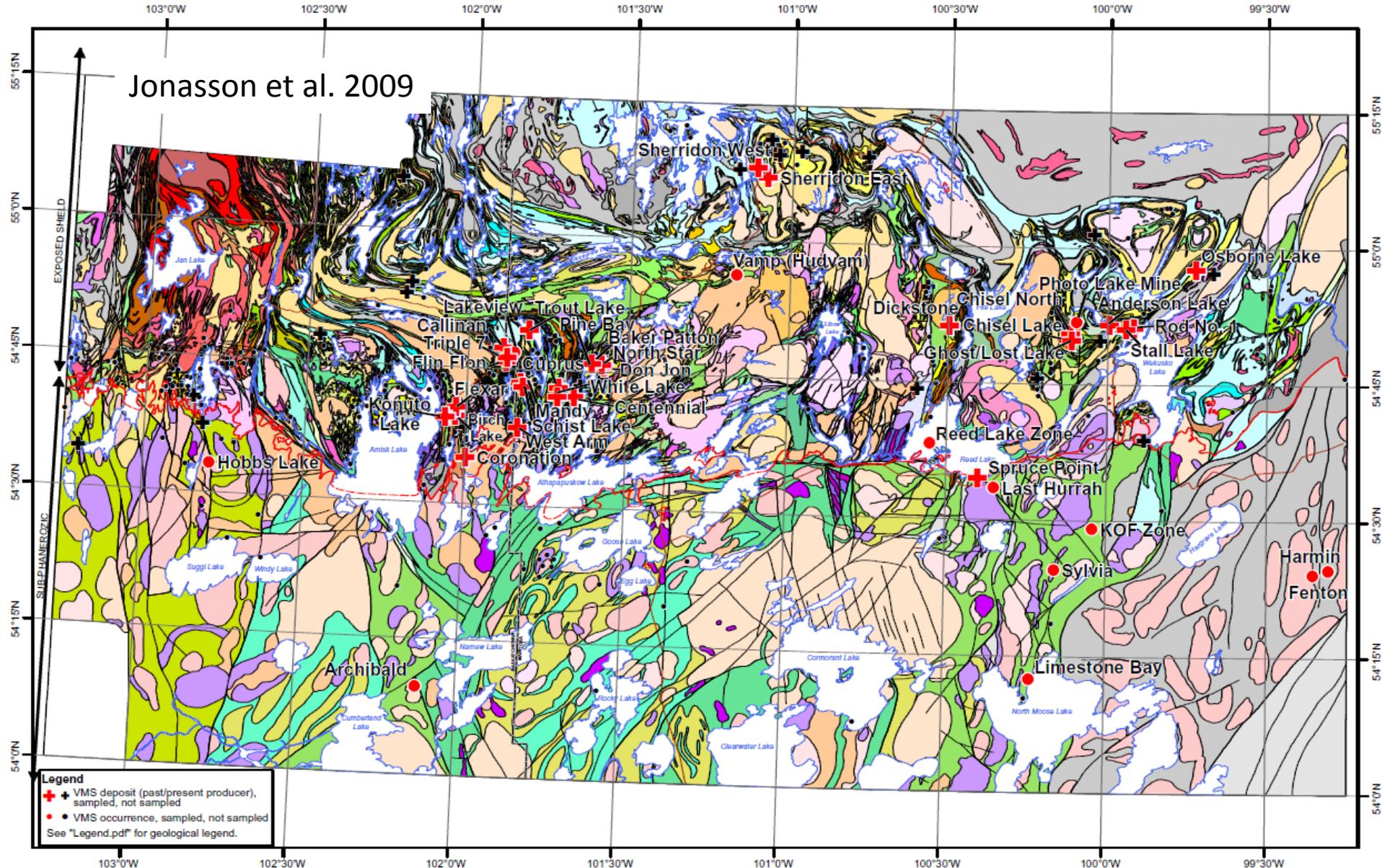
HFSE
  Noble Metals

REE
  Volatile

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu			
Ac	Th	Pa	U														

# Application Flin Flon, Manitoba - Saskatchewan

Jonasson et al. 2009



Base Map: NATMAP Shield Margin Project Working Group,  
 1998: Geology, NATMAP Shield Margin Project area, Flin Flon Belt, Manitoba-Saskatchewan;  
 Geological Survey of Canada, Map 1968A, Manitoba Energy and Mines Map A-98-2, Sheets 1 to 7,  
 Saskatchewan Energy and Mines Map 258A-7, scale 1:100 000.

0 2.5 5 10 15 20 25  
 Kilometres

# Application Flin Flon, Manito

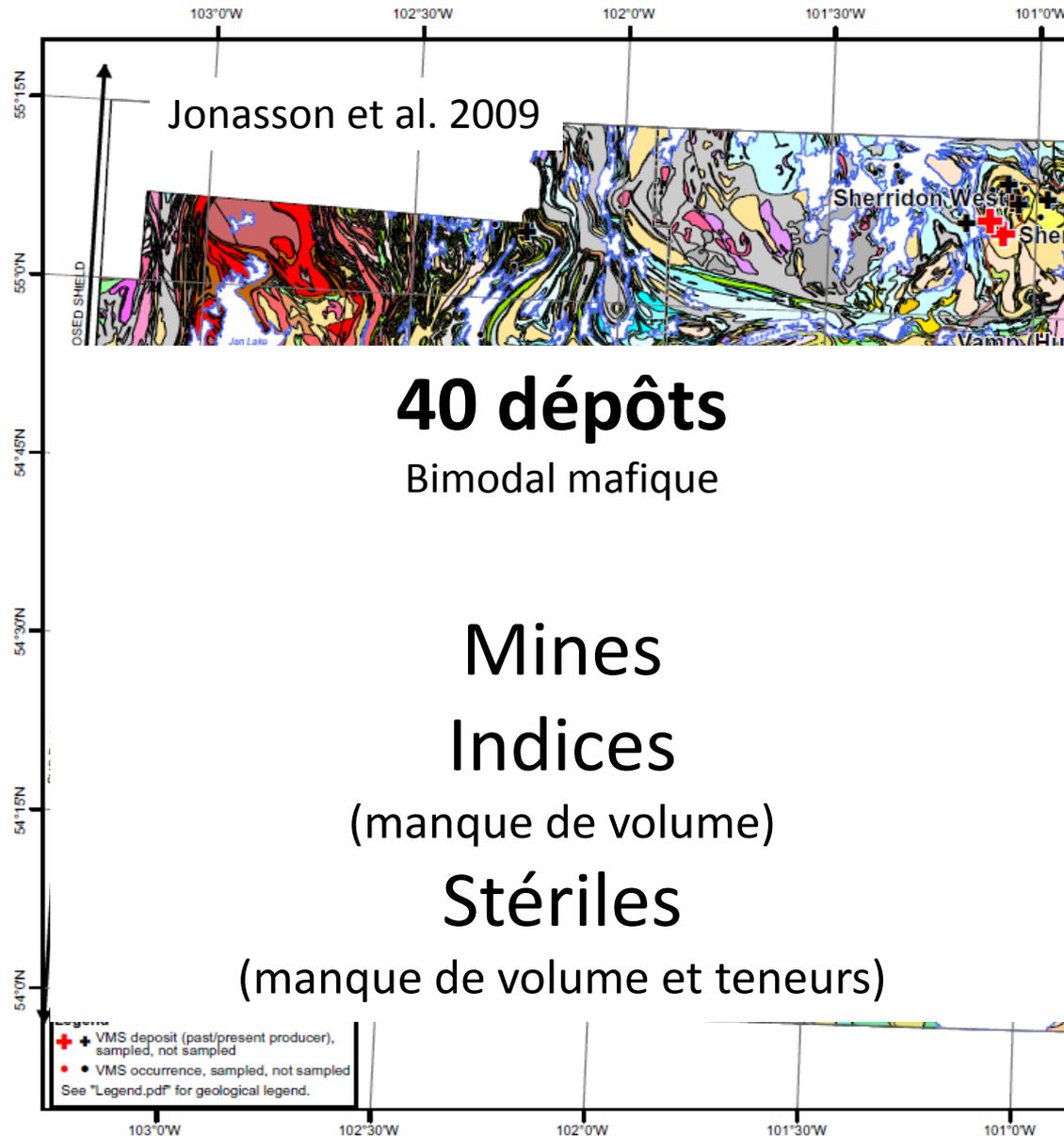


Table 1. Summary of deposit and sample locations included in the Flin Flon belt database.

Location	Status	Easting Nad 83 Zone 14	Northing	Number of Samples
<b>Table A1: Flin Flon Area</b>				
Baker Patton	Occurrence	332777	6071846	7
Birch Lake	Past producer	304312	6061329	10
Callinan	Present producer	314247	6075256	11
Centennial	Past producer	328322	6065079	5
Coronation	Past producer	306399	6052750	8
Cuprus	Past producer	325201	6067017	15
Don Jon	Past producer	334384	6071188	1
Flexar	Past producer	304674	6063047	14
Flin Flon	Past producer	314554	6072383	30
Konuto Lake	Past producer	302487	6061226	9
Lakeview	Occurrence	316402	6074096	1
Mandy	Past producer	317656	6068060	12
North Star	Past producer	334026	6071615	7
Pine Bay	Past producer	331862	6071731	18
Schist Lake	Past producer	317995	6067167	15
Triple 7	Present producer	314790	6074114	8
Trout Lake	Present producer	319303	6078732	4
West Arm	Past producer	317012	6058816	12
White Lake	Past producer	324921	6065046	8
Vamp (Hudvam)	Occurrence	361129	6089875	8
<b>Table A2: Snow Lake</b>				
Anderson Lake	Past producer	436296	6079569	7
Chisel Lake	Past producer	427947	6076770	5
Chisel North	Present producer	428353	6077865	19
Ghost/Lost Lake	Past producer	428545	6076599	13
Osborne Lake	Past producer	453599	6090808	10
Photo Lake Mine	Past producer	429534	6080154	13
Rod No. 1	Past producer	441002	6078983	9
Stall Lake	Past producer	439455	6078749	9
<b>Table A3: Subphanerozoic</b>				
Archibald	Occurrence	296179	6005951	9
Fenton	Occurrence	476962	6028306	6
Harmin	Occurrence	480087	6029232	6
Hobbs Lake	Occurrence	254820	6051700	4
KOF Zone/ Farewell Lake	Occurrence	432561	6037945	2
Last Hurrah	Occurrence	412778	6046488	4
Limestone Bay	Occurrence	419718	6007294	2
Reed Lake Zone	Occurrence	399904	6055620	7
Sylvia	Occurrence	424860	6029595	9
<b>Table A4: Sherridon</b>				
Sherridon East	Past producer	367546	6109796	11
Sherridon West	Past producer	365531	6111976	5
<b>Table A5: Four Mile</b>				
Dickstone	Past producer	404026	6079619	3
Spruce Point	Past producer	409446	6048716	2

Base Map: NATMAP Shield Margin Project Working Group,  
 1998: Geology, NATMAP Shield Margin Project area, Flin Flon Belt, Manitoba-Saskatchewan;  
 Geological Survey of Canada, Map 1968A, Manitoba Energy and Mines Map A-98-2, Sheets 1 to 7,  
 Saskatchewan Energy and Mines Map 258A-7, scale 1:100 000.

# Application Flin Flon

Jonasson, I.R., Ames, D.E., and Galley, A.G., 2009. Sulphide ore geochemistry database for volcanogenic massive sulphide deposits of the Paleoproterozoic Flin Flon Belt and Sherridon area, Manitoba and Saskatchewan; Geological Survey of Canada, Open File 5432, 1 Cd-ROM.

- 400 analyses de roche totale des zones minéralisées de 40 gisements ou indices
- Sélection de 150 analyses de sulfures massifs (> 90%). Validé par les photos
- Échantillons ne sont pas représentatifs des dépôts

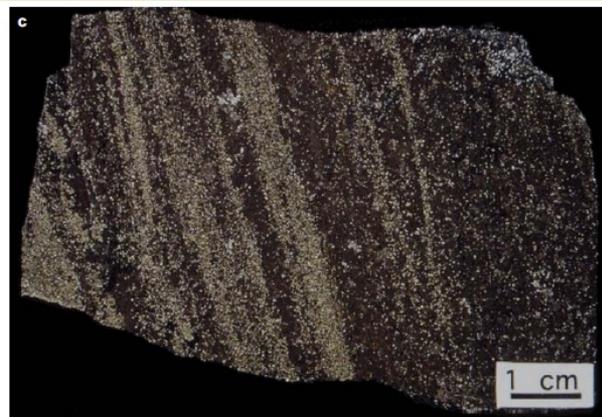


Figure A2.3c. Callinan deposit, 1600 m level, #7 lens. Massive sulphide composed of banded sphalerite/pyrite ore with siderite or ankerite, recrystallized mylonite. Sample 00GIA-CALL-531.1A3.

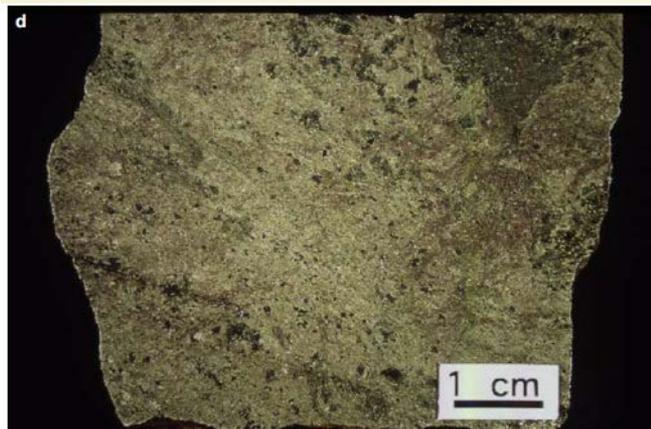


Figure A2.5d. Coronation deposit. Massive pyrrhotite/chalcocopyrite/magnetite catclasite. Sample 00GIA-CRON-529D.

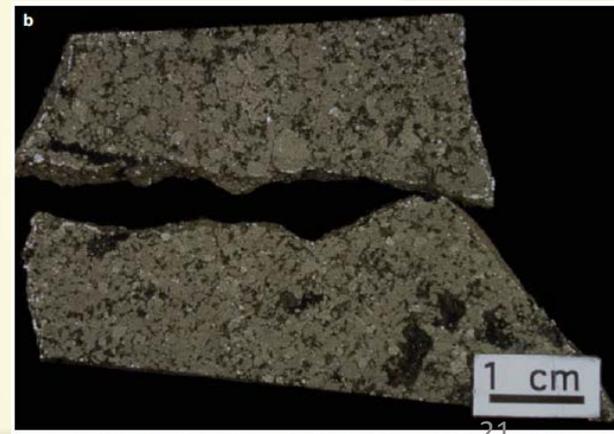


Figure A2.16b. Vamp Lake (Hudvam), diamond drill core CON36, 742 ft. Massive sphalerite/chalcocopyrite buckshot pyrite; recrystallized pyrite/chlorite. Sample 00GIA-VAMP-554D.

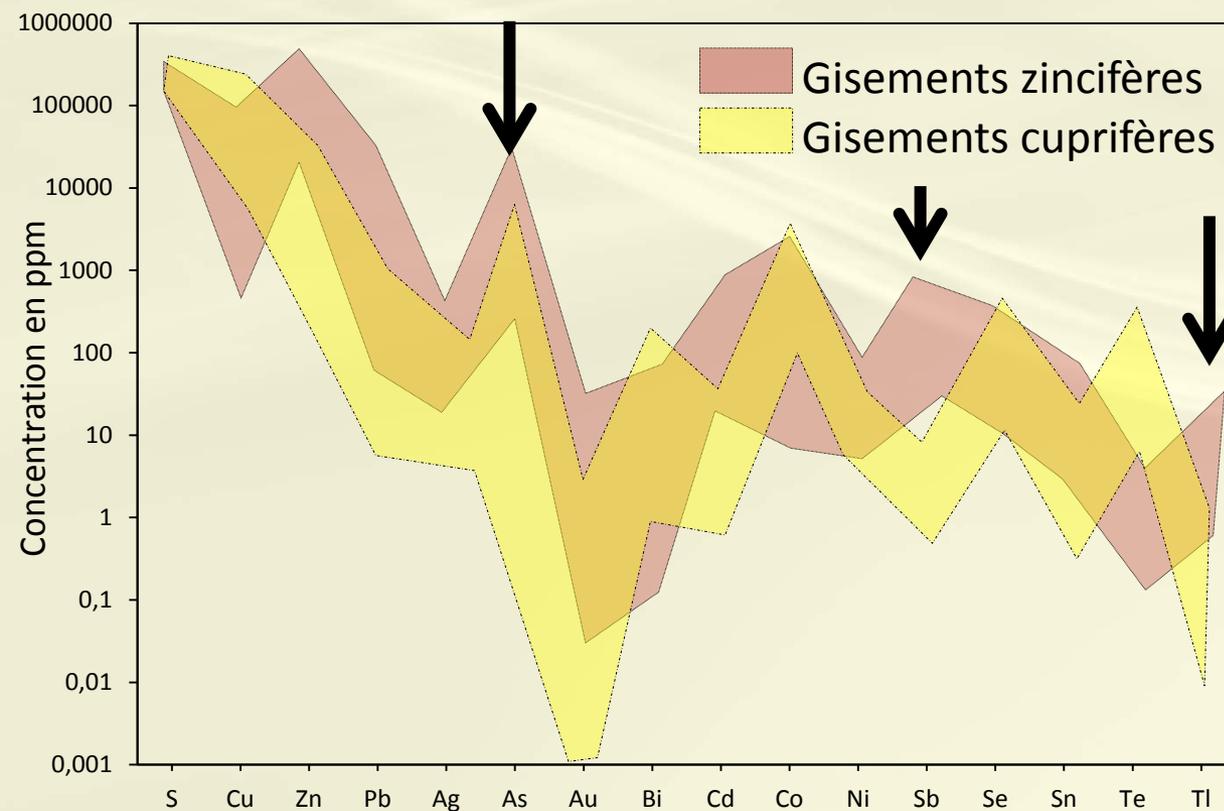


# Méthodologie

- 60 éléments analysés
- Méthodes d'analyses:
  - ICP-AES (majeurs) – Fusion Li-tétraborate
  - ICP-MS (mineurs et traces) – 4 acides
  - INAA (As, Au, Hg, Se)
  - S et CO<sub>2</sub>

**Table 2.** Geochemistry methodology, source, and detection limits.

Element	Method.Lab	Detection Limit
		(%)
SiO <sub>2</sub>	ICP. GSC	0.5
TiO <sub>2</sub>	ICP. GSC	0.02
Al <sub>2</sub> O <sub>3</sub>	ICP. GSC	0.2
Fe <sub>T</sub>	ICP. GSC	0.04
MgO	ICP. GSC	0.04
CaO	ICP. GSC	0.01
Na <sub>2</sub> O	ICP. GSC	0.03
K <sub>2</sub> O	ICP. GSC	0.05
Cu	ICP. GSC	0.001
Zn	ICP. GSC	0.001
Pb	ICP. GSC	0.001
Mn	ICP. GSC	0.001
CO <sub>2,T</sub>	chemistry.GSC	0.1
P <sub>2</sub> O <sub>5</sub>	ICP. GSC	0.01
S <sub>T</sub>	chemistry.GSC	0.02
Total	calculated	-
LOI	chemistry.GSC	-
		(ppm)
Ag (ppm)	ICP. GSC	0.5
As	INAA. Act labs	0.5
Au (ppb)	INAA. Act labs	5 ppb
Ba (ppm)	ICP. GSC	20
Bi	ICP. GSC	0.2
Cd	ICP. GSC	0.2
Co	ICP. GSC	5
Cr	ICP. GSC	10
Cs	ICP. GSC	0.02
Ga	ICP. GSC	0.1
Hf	ICP. GSC	0.05
Hg	INAA. Act labs	1
In	ICP. GSC	0.05
Mo	ICP. GSC	0.2
Nb	ICP. GSC	0.05
Ni	ICP. GSC	10
Rb	ICP. GSC	0.05
Sb	ICP. GSC	1
Sc	ICP. GSC	0.5
Se	INAA. Act labs	3
Sn	ICP. GSC	0.5
Sr	ICP. GSC	10
Ta	ICP. GSC	0.05
Te	ICP. GSC	0.2
Th	ICP. GSC	0.02
Tl	ICP. GSC	0.02
U	ICP. GSC	0.02
V	ICP. GSC	5
Y	ICP. GSC	0.1
Zr	ICP. GSC	0.5
		(ppm)
La (ppm)	ICP. GSC	0.1
Ce	ICP. GSC	0.1
Pr	ICP. GSC	0.02
Nd	ICP. GSC	0.1
Sm	ICP. GSC	0.02
Eu	ICP. GSC	0.02
Gd	ICP. GSC	0.02
Tb	ICP. GSC	0.02
Dy	ICP. GSC	0.02
Ho	ICP. GSC	0.02
Er	ICP. GSC	0.02
Tm	ICP. GSC	0.02
Yb	ICP. GSC	0.02
Lu	ICP. GSC	0.02
REE <sub>T</sub>	calculated	-



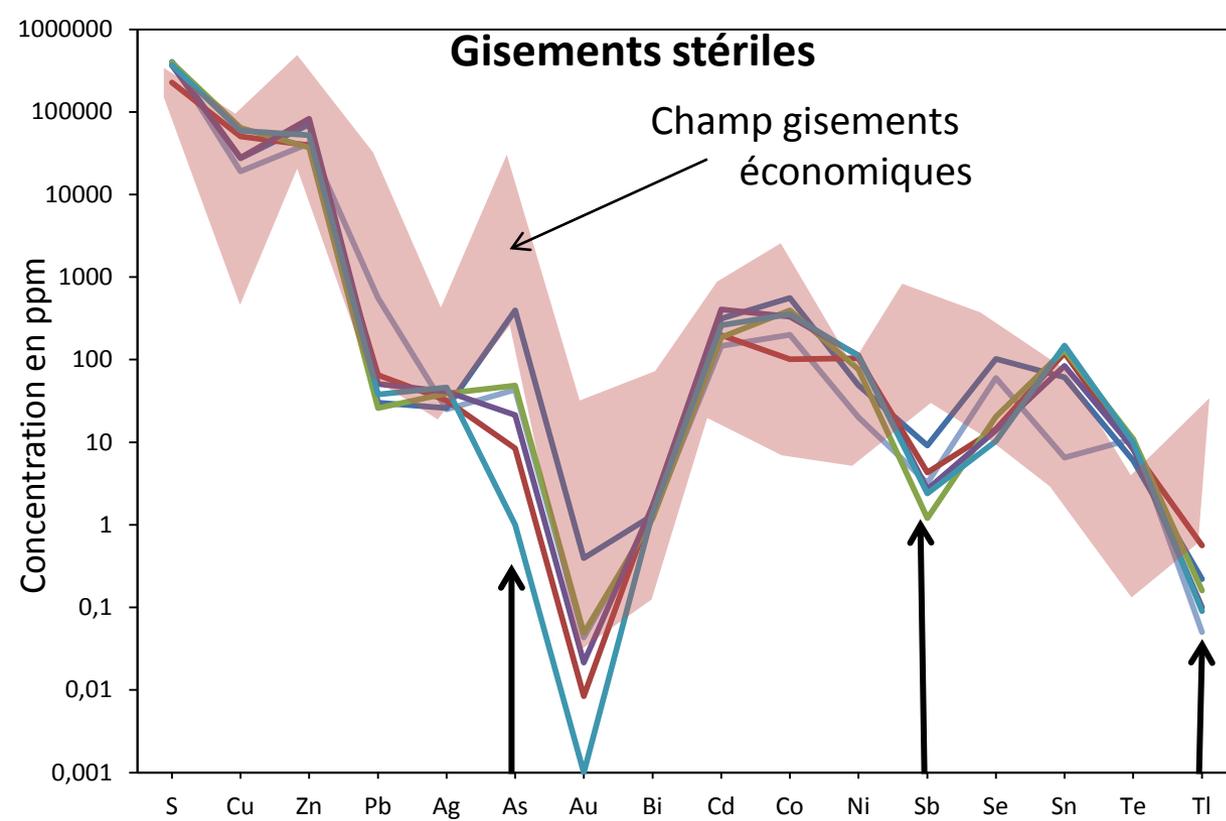
Pourquoi ces éléments?

Éléments présents en traces dans les pyrites des systèmes VMS (Genna, 2009; Genna, PhD en cours)

Ordre des éléments?

Basé sur le numéro atomique

# Gisements économiques Flin Flon



Indices  
Stériles  
Flin Flon

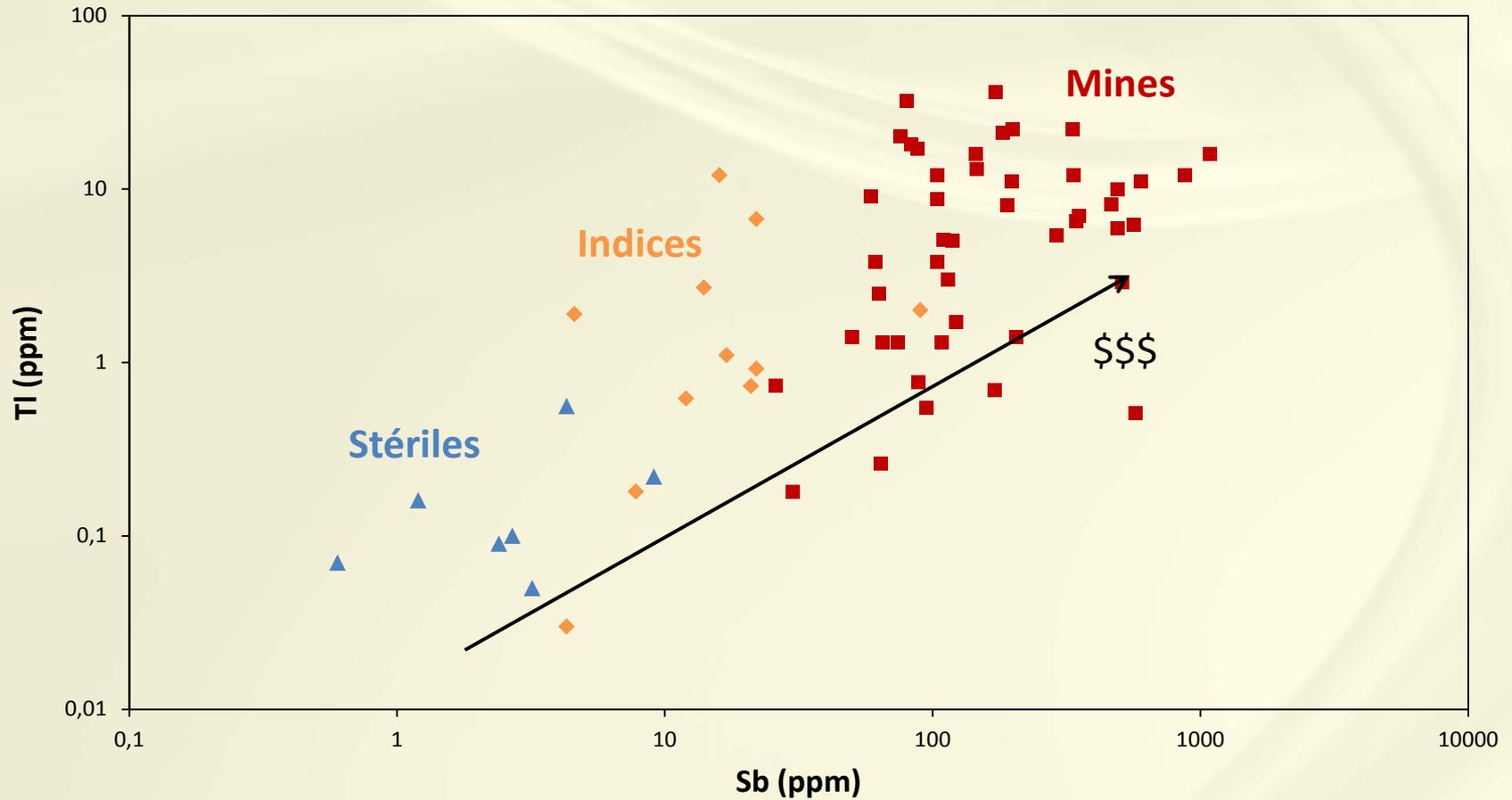
Vamp Lake  
Hudvam



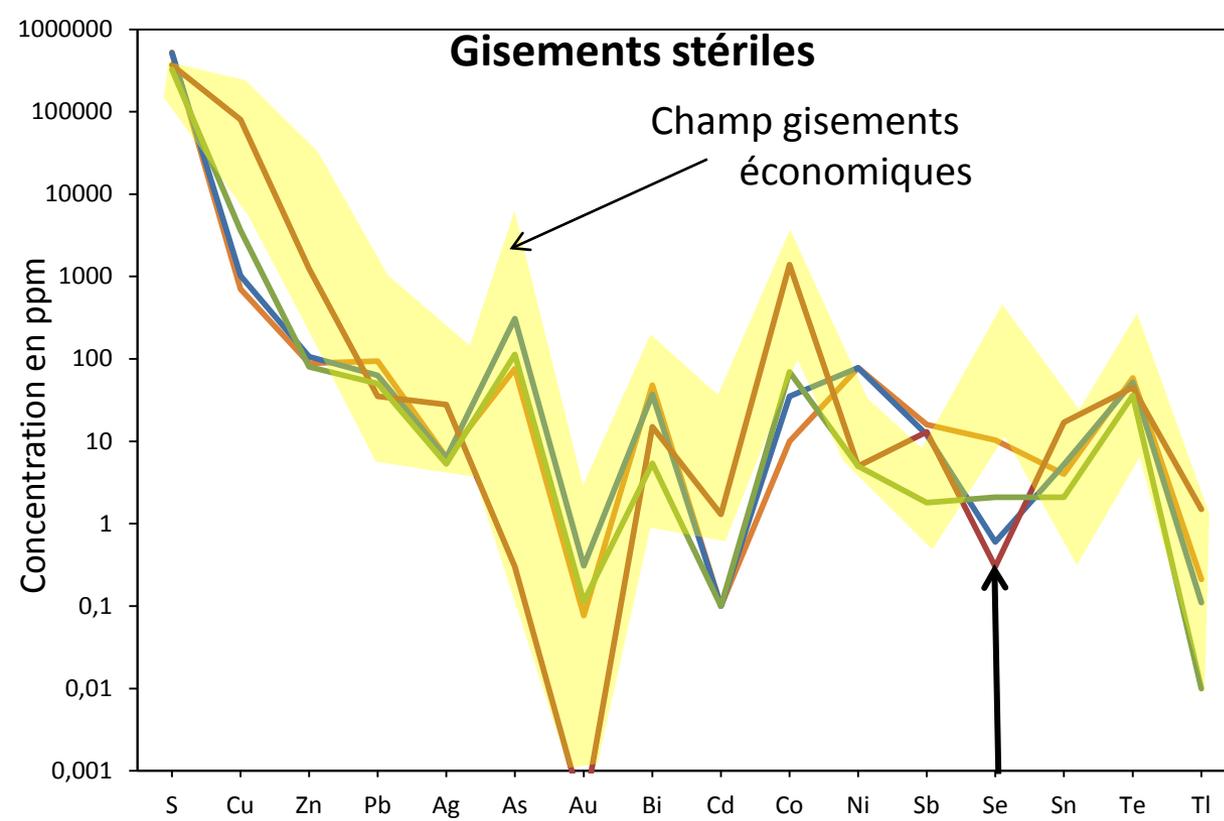
Figure A2.16b. Vamp Lake (Hudvam), diamond drill core CON36, 742 ft. Massive

Teneur en Zn

# Flin Flon – affinité zincifère







Indices  
Stériles  
Flin Flon

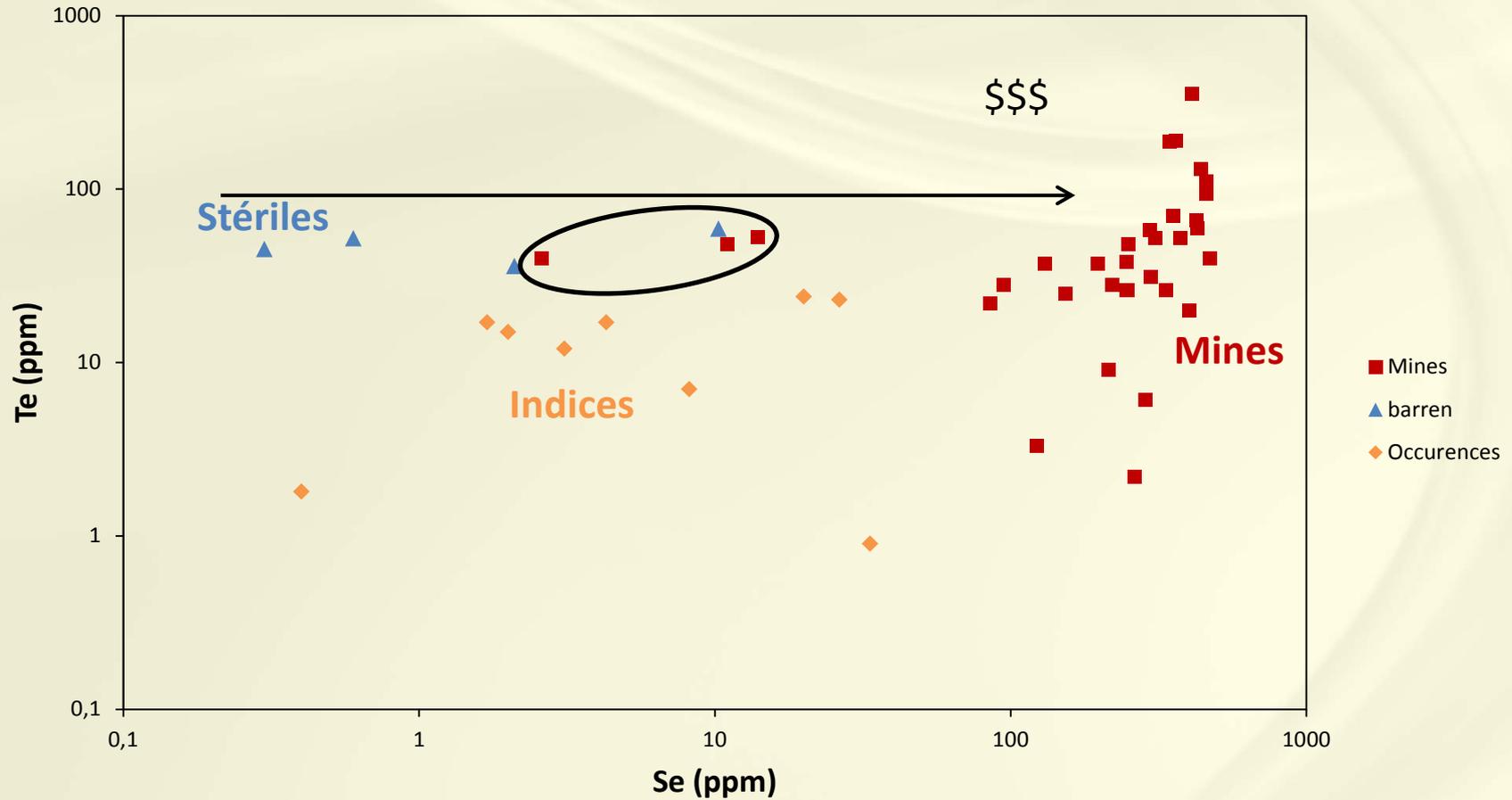
Baker Patton  
Sylvia  
Reed Lake



Teneur en Cu

Figure A2.1a. Baker Patton Cu deposit, surface trench sample. Very oxidized, pyrite-rich massive sulphide. Sample 06AV-501.

# Flin Flon – affinité cuprifère



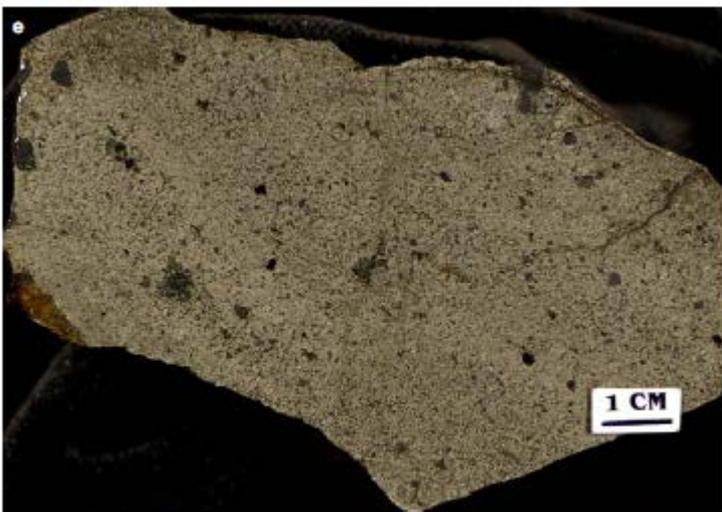


Figure A2.2e. Birch Lake deposit. Fine-grained massive pyrite-chalcopyrite massive sulphide. Sample 06AV-523.

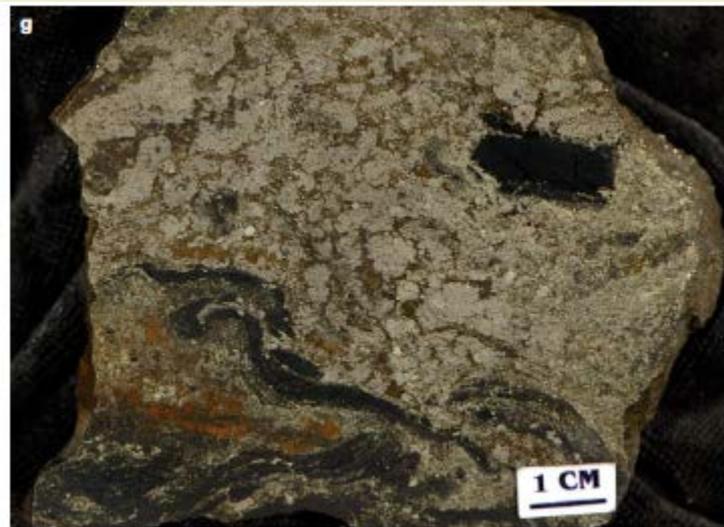


Figure A2.2g. Birch Lake deposit. Fine-grained pyrite-chalcopyrite massive ore with ~10% <1 cm diameter rock fragments. Sample 06AV-527.

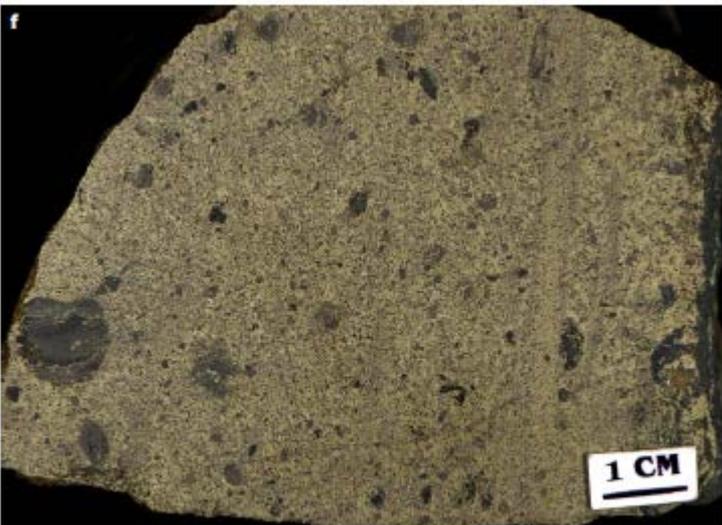


Figure A2.2f. Birch Lake deposit. Fine-grained chalcopyrite-pyrite ore with rounded fragments of wallrock. Sample 06AV-524.

# Birch Lake deposit

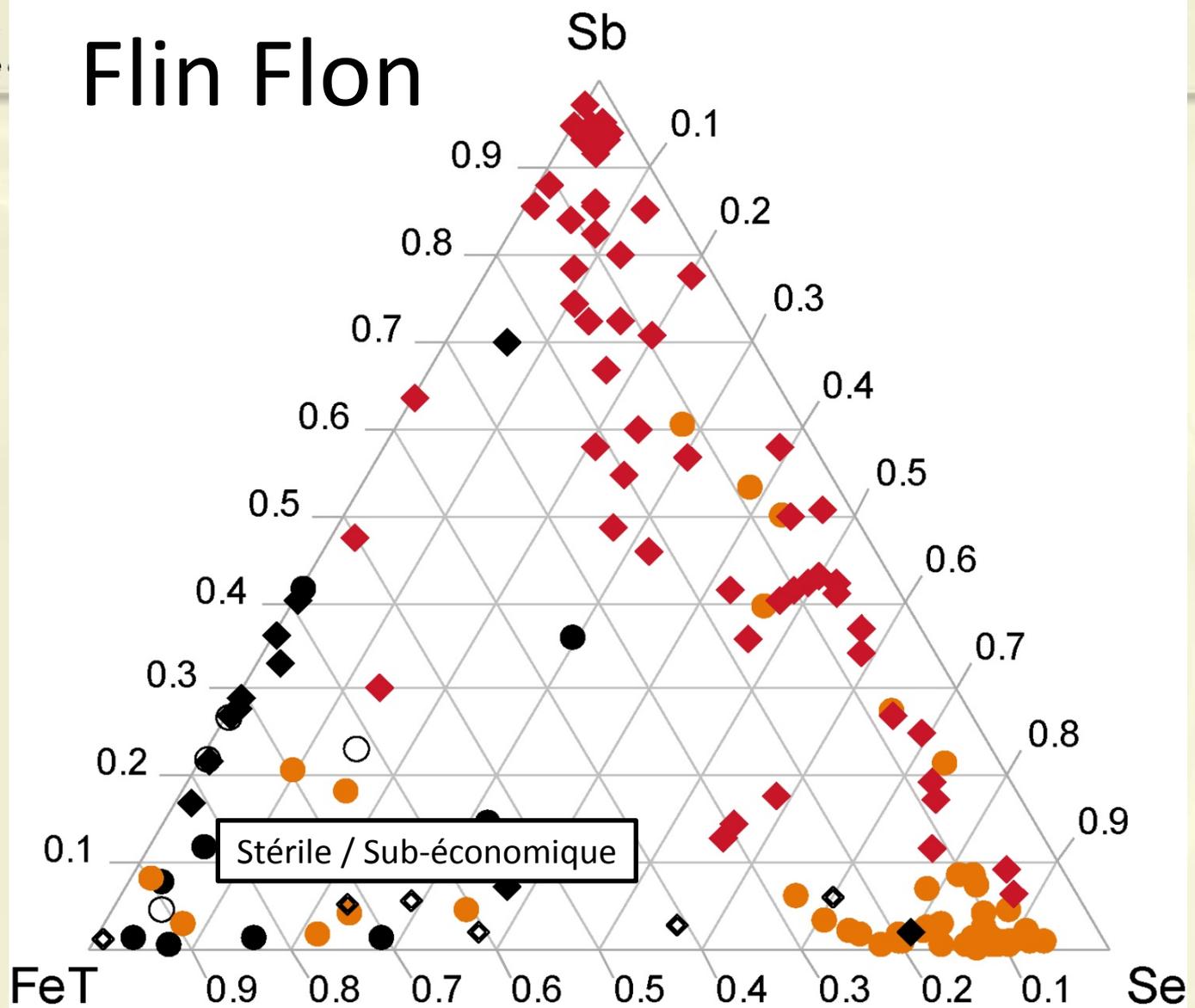
## 1957-1960

< 300 000 t

@ 4.11 ppm Ag, 6.21% Cu, Tr Zn

- Pyrite fortement dominante

# Flin Flon



## Indices et gisements stériles

- ◆ affinité zincifère
- affinité cuprifère

## Gisements économiques

- ◆ riche en zinc
- riche en cuivre

# Pourquoi est-ce que ça fonctionne?

- **Sb – Tl**

- Sidérophile/Chalcophile **ET** Lithophile

Noll et al. 1996

- Ex: {
- Tl → lithophile → séricite
  - Tl → chalcophile → sulfures

- Volatils

- Grande dispersion
- Problèmes analytiques

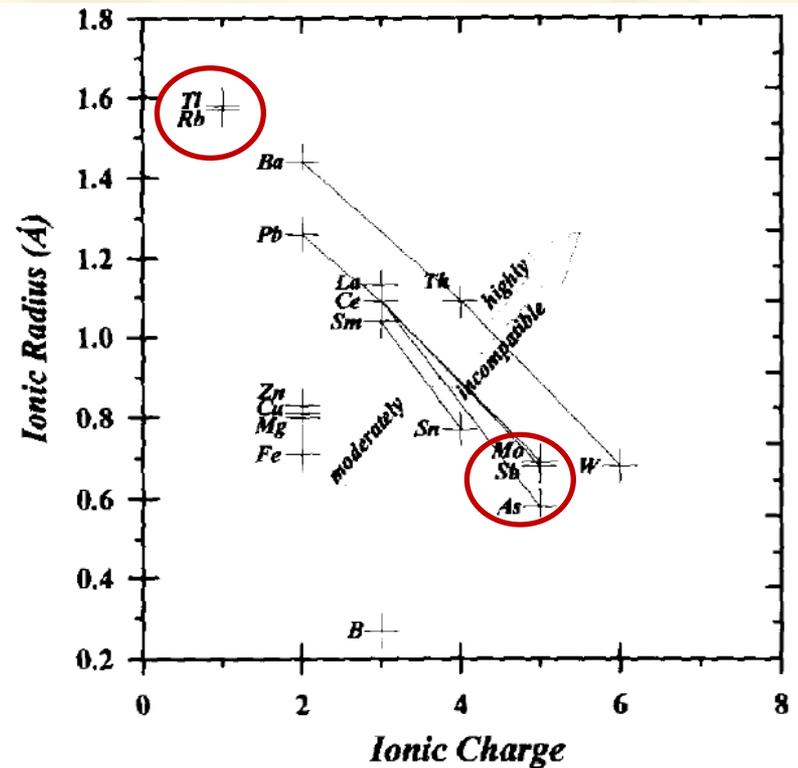
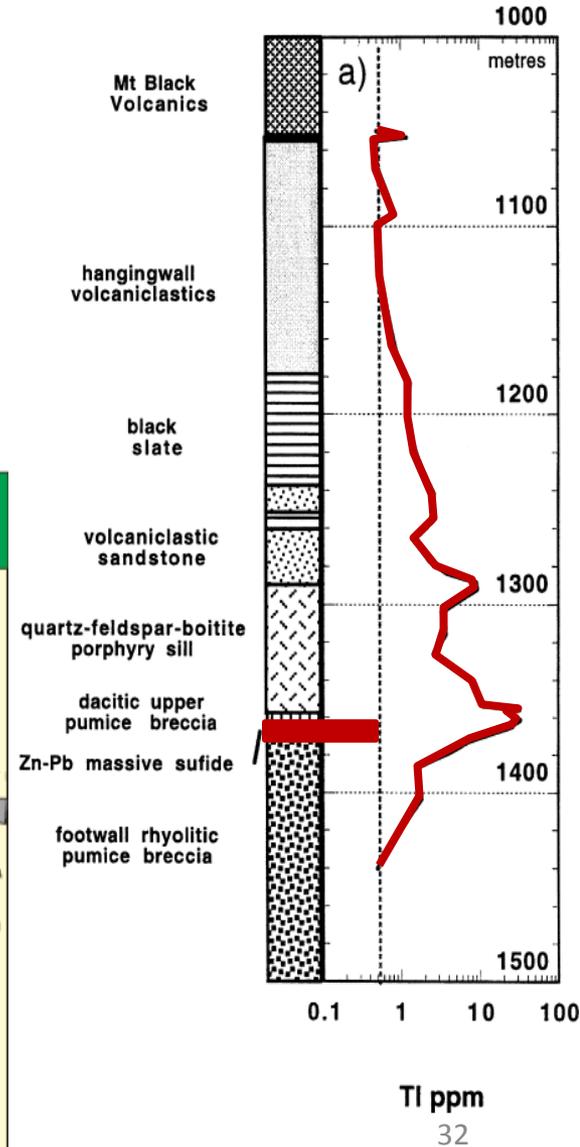
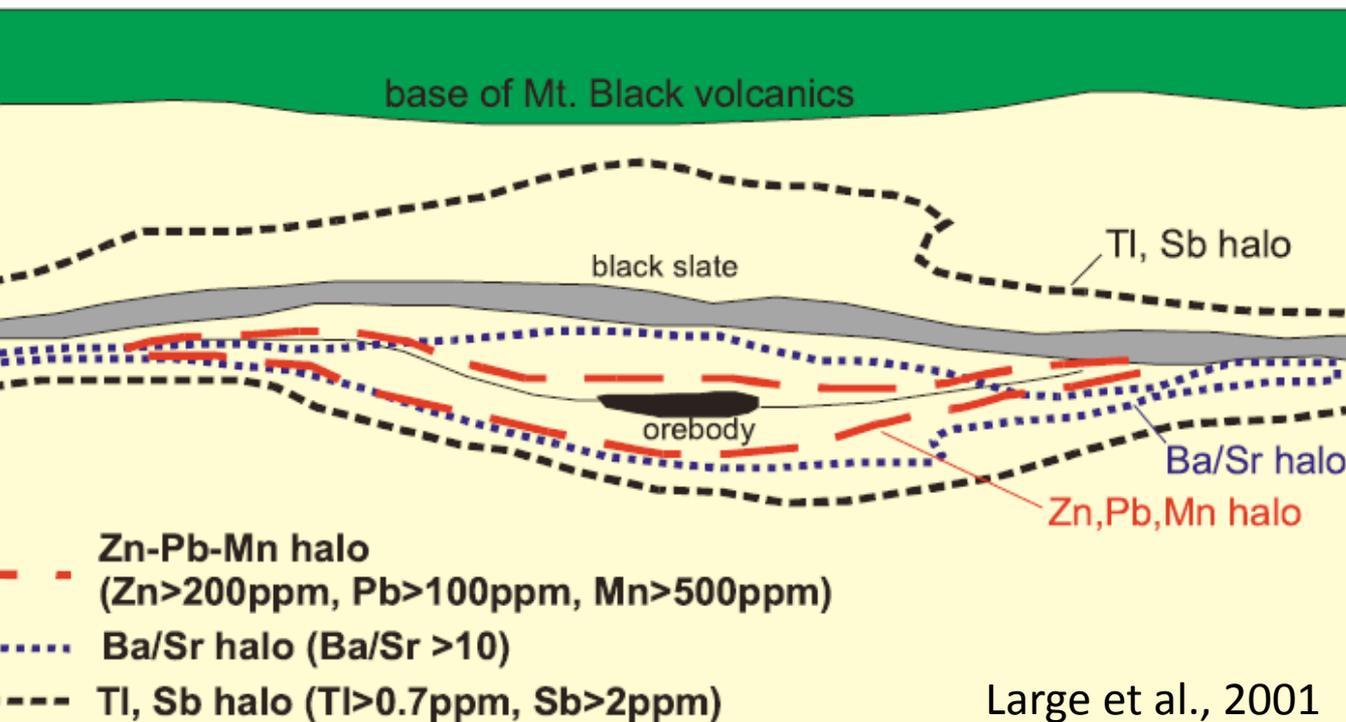
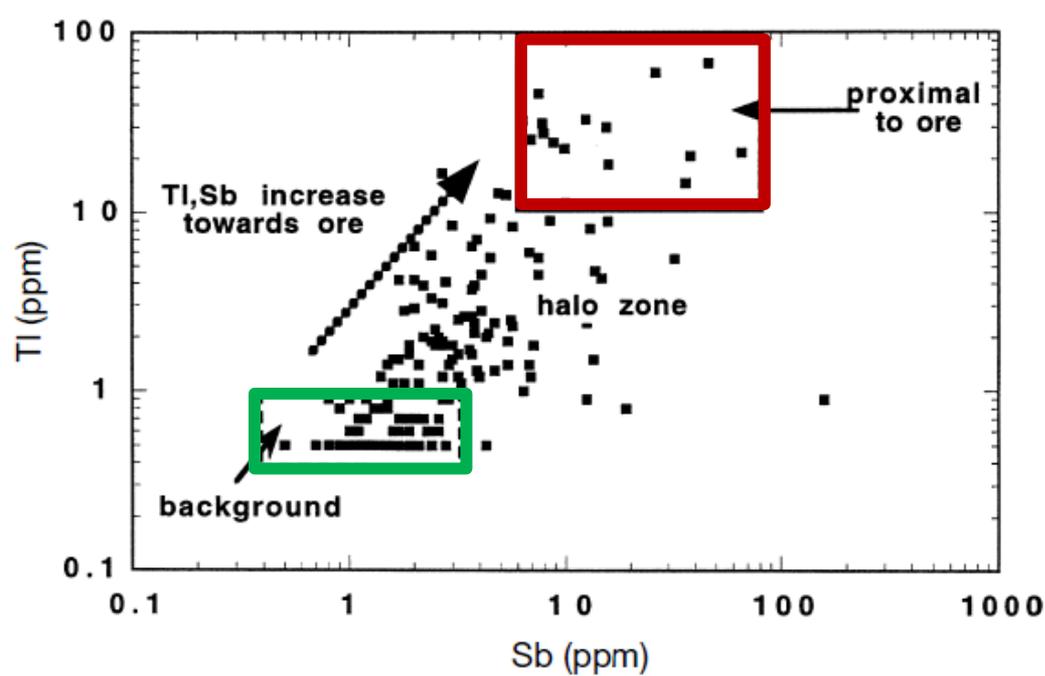


FIG. 1. Plot of ionic radius vs. ionic charge (after Jochum et al., 1993). Siderophile/chalcophile–lithophile element groups which have constant ratios form subparallel arrays. Incompatibility increases with increasing radius for a given charge and vice versa.

# Affinité Tl-Sb et gisements zincifères



Large et al., 2001

# Des traceurs de l'altération par l'eau de mer

**Eau de mer**

Sb = 0.2 ppb

Tl = 0.015 ppb

Jochum et Verma, 1996

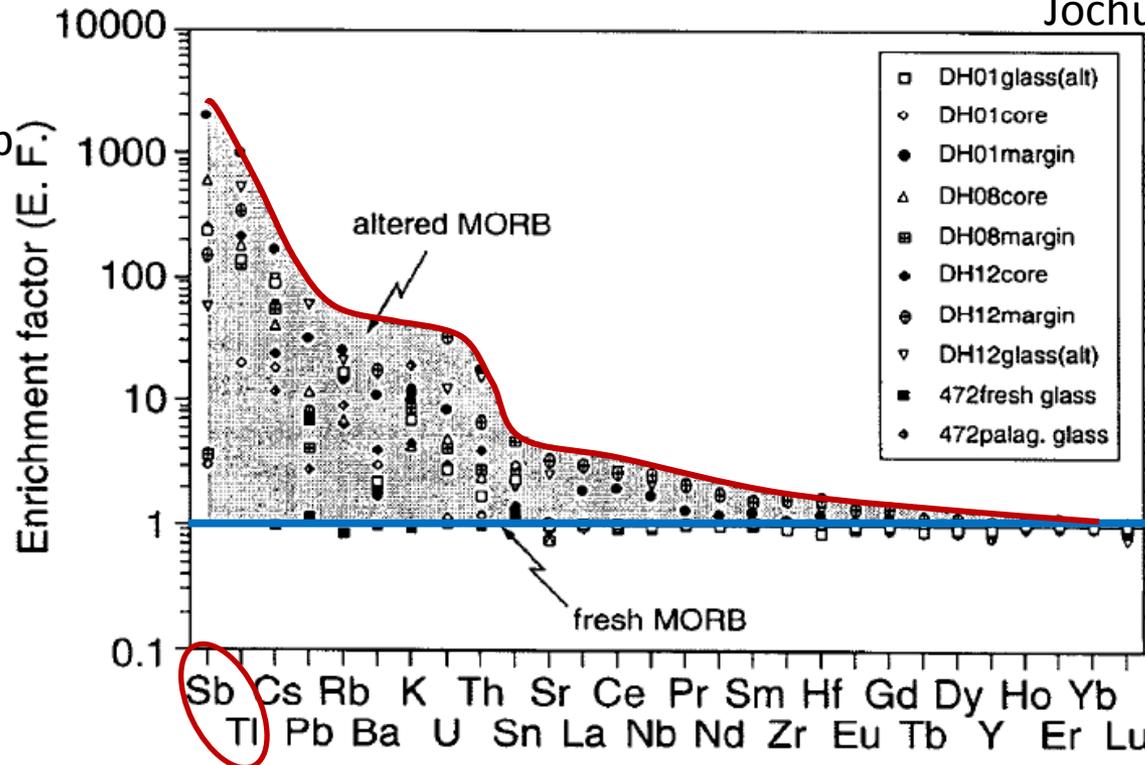


Fig. 5. Enrichment factors E.F. (= element concentrations in an altered sample compared with the 'fresh' equivalent; Fig. 4) of altered MORB samples arranged approximately according to the decreasing E.F. values of extremely altered samples. Antimony, Tl, Cs, Pb, and Rb are most easily modified by water-rock interaction and are therefore the best indicators for seawater alteration.

Verre volcanique Sb = 0.01 – 0.05 ppm



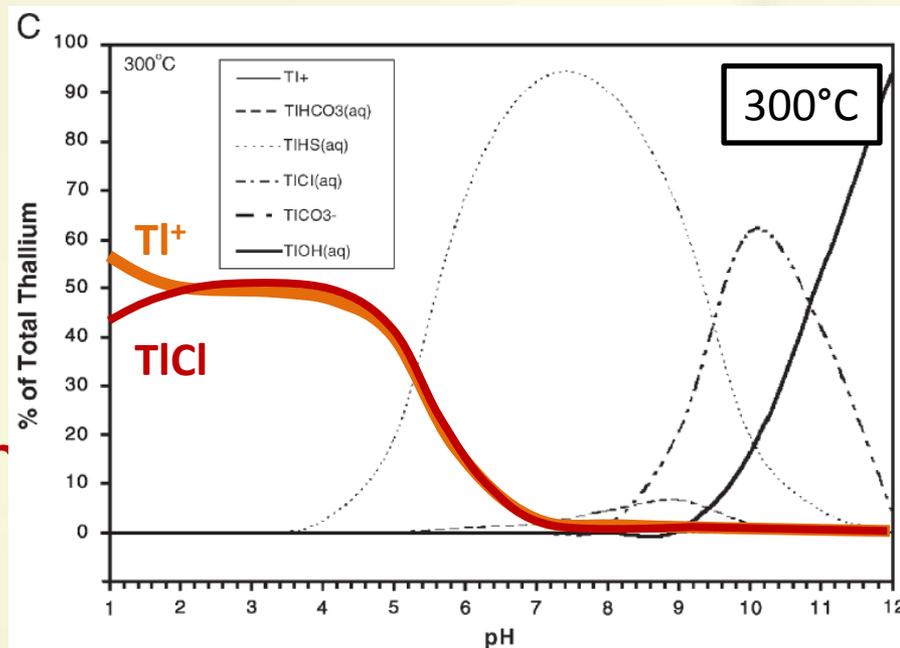
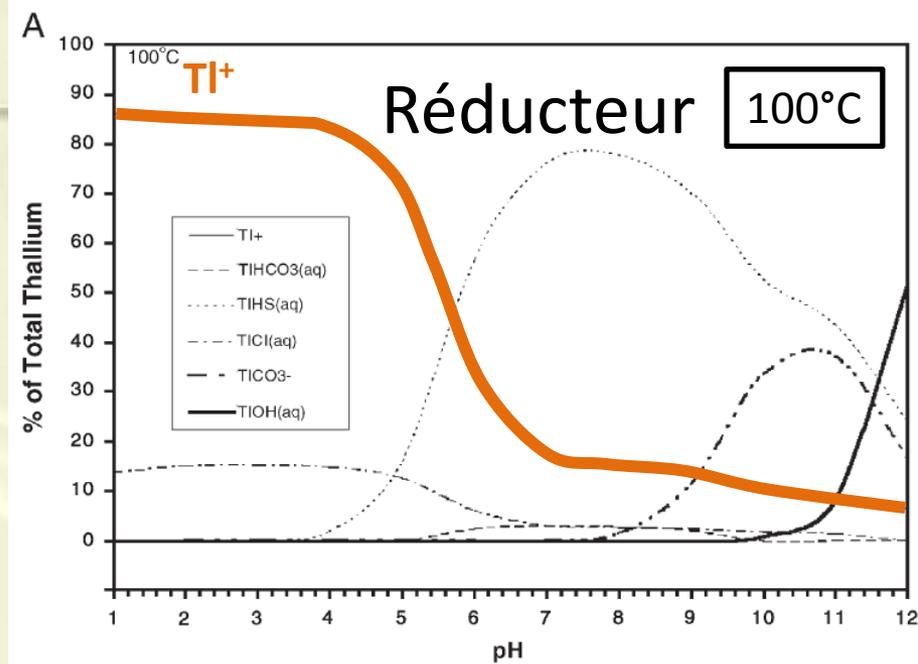
Équivalent altéré Sb = 40 ppm

# Solubilité du Tl

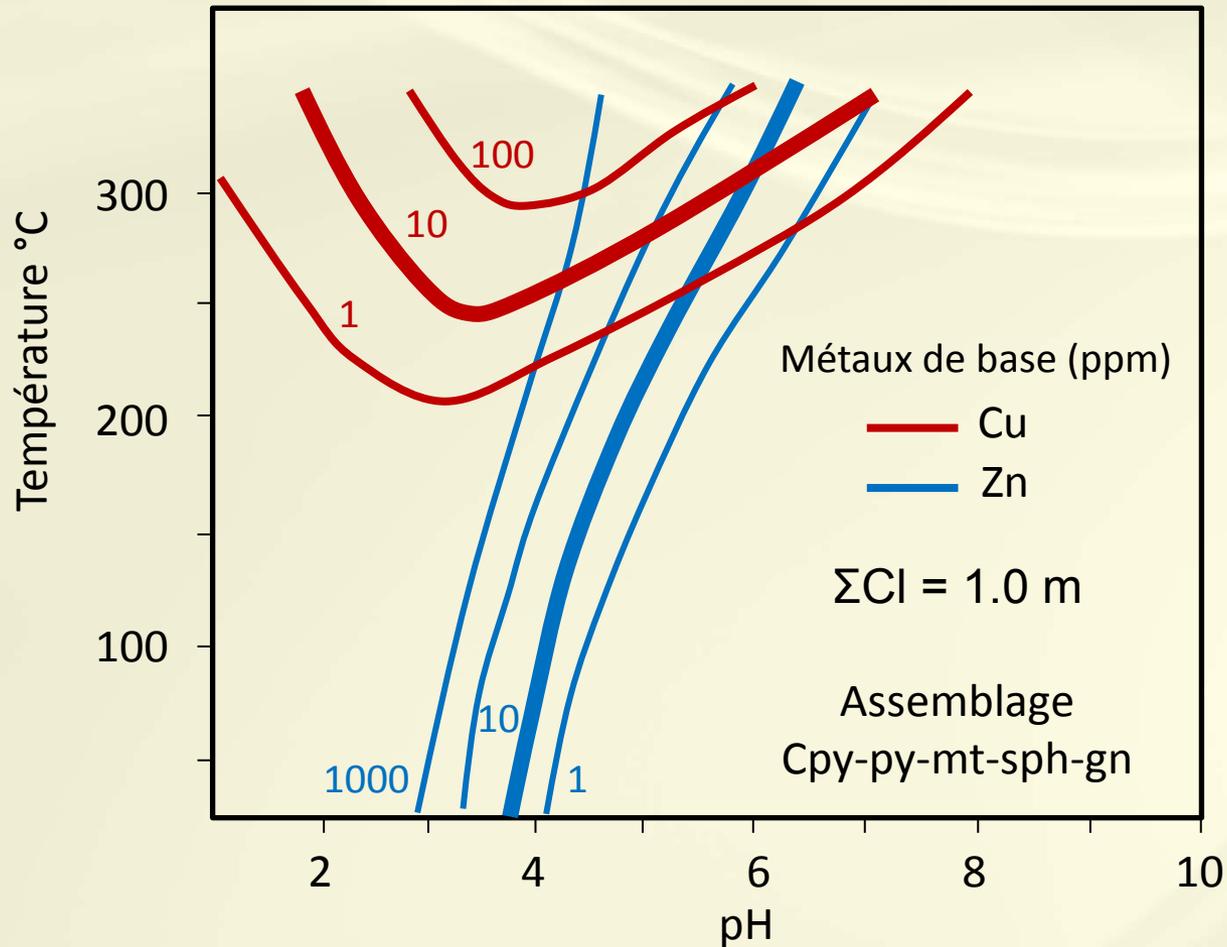
- Lessivage roche >250°C
- Précipitation par neutralisation des fluides (mélange avec eau de mer)

Conditions identiques au transport et à la précipitation du zinc!

Xiong, 2007



# Importance de la température: Solubilité des métaux

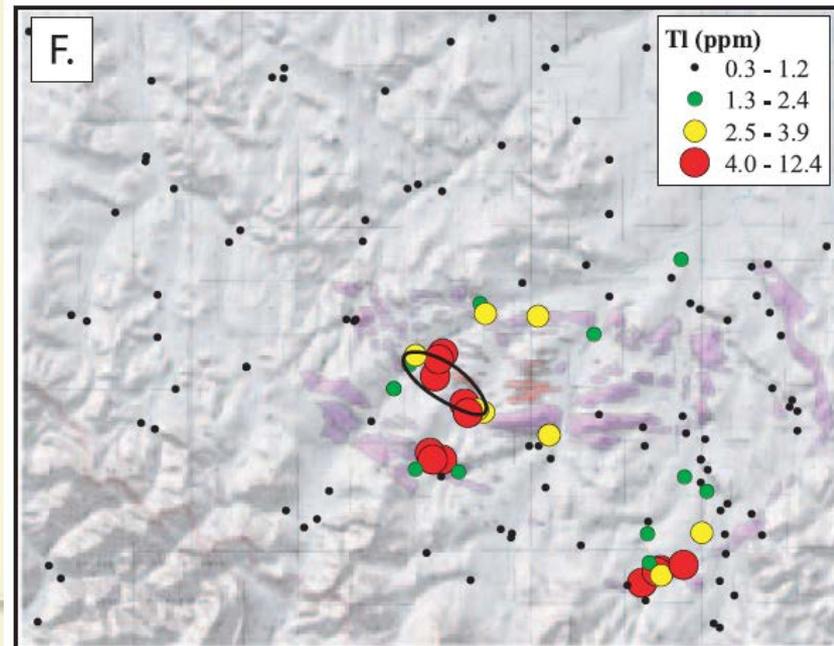


Lydon, 1988  
dans Franklin et al. 2005

# Tl: un champion sous-estimé!

- **VMS** (Murao et Itoh, 1992; Large et al. 2001)
- **SEDEX** (Slack et al. 2004; Graham et al. 2009)
- **Épithermal** (Celenk et al. 1987)
- **Carlin** (Ikramuddin et al. 1983, 1986)
  
- Bonne dispersion dans l'environnement secondaire!

Graham et al. 2009

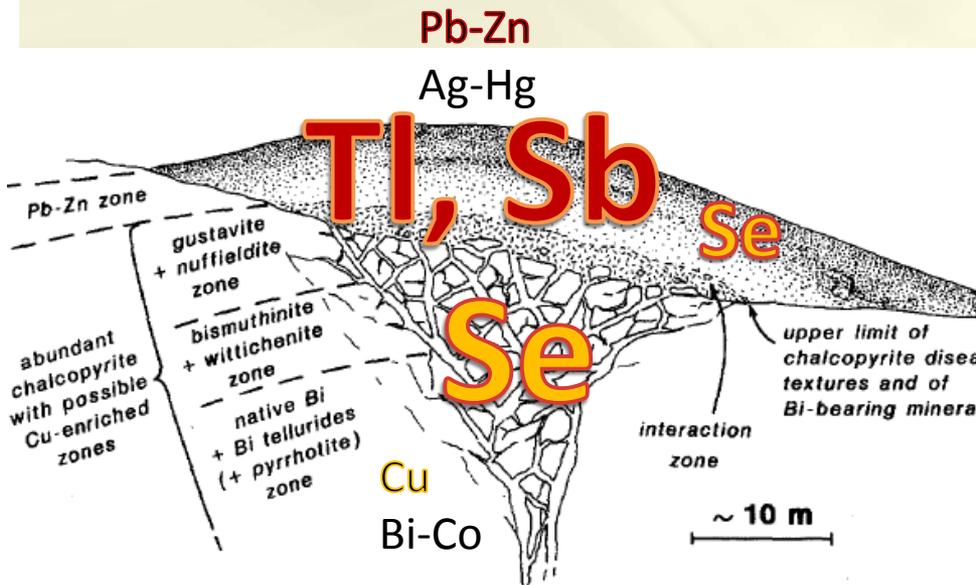
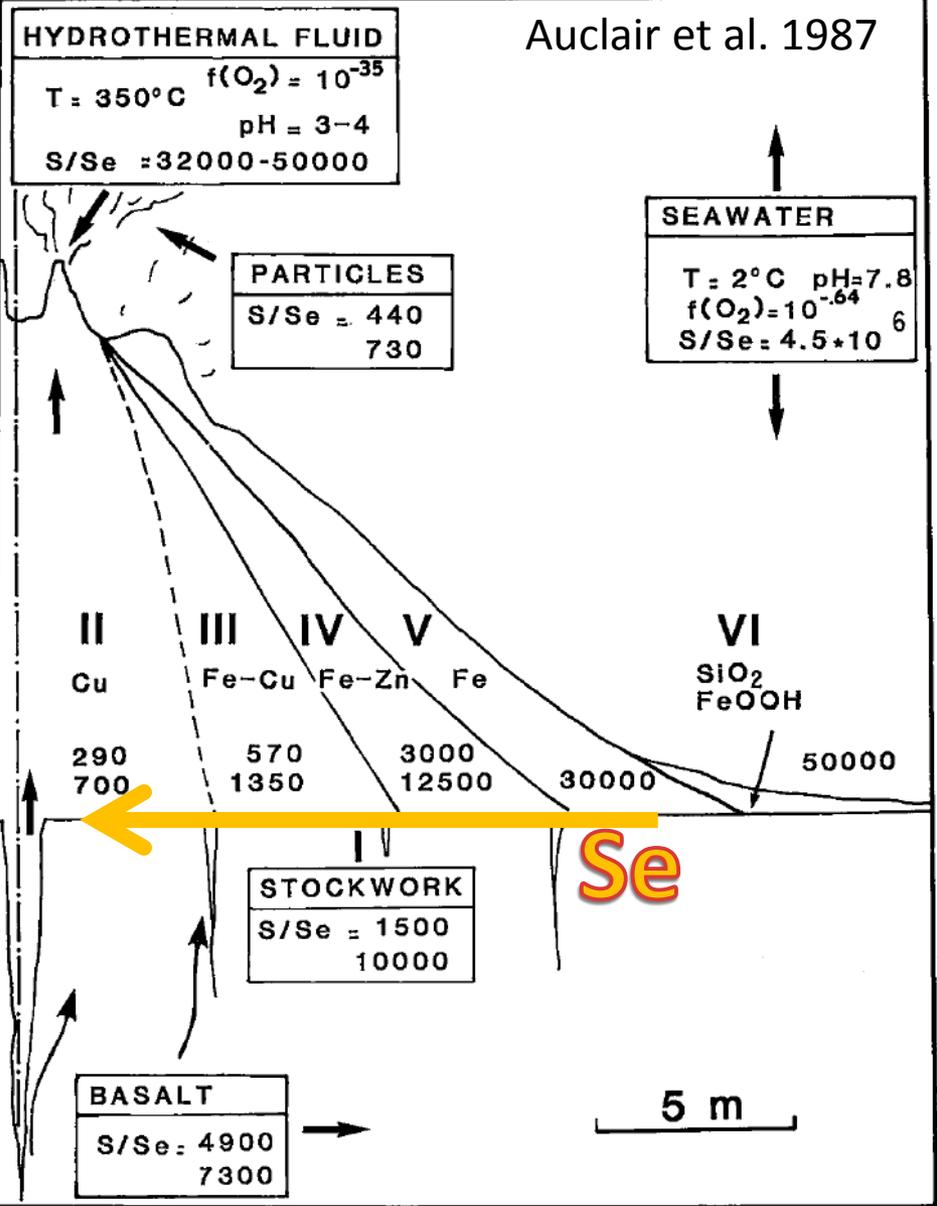


# Pourquoi est-ce que ça fonctionne?

- **Se**
  - Non métal, chalcophile, remplace le S
  - **Se/S**
    - Fractionnement lié à la température
    - Fractionnement contrôlé par le pH et le niveau d'oxydation du fluide
    - Fractionnement durant mélange avec l'eau de mer
  - Moins volatil que Sb-Tl
    - Utilisation sur les sulfures massifs seulement

**Eau de mer**  
Se = 0.17 ppb

Auclair et al. 1987



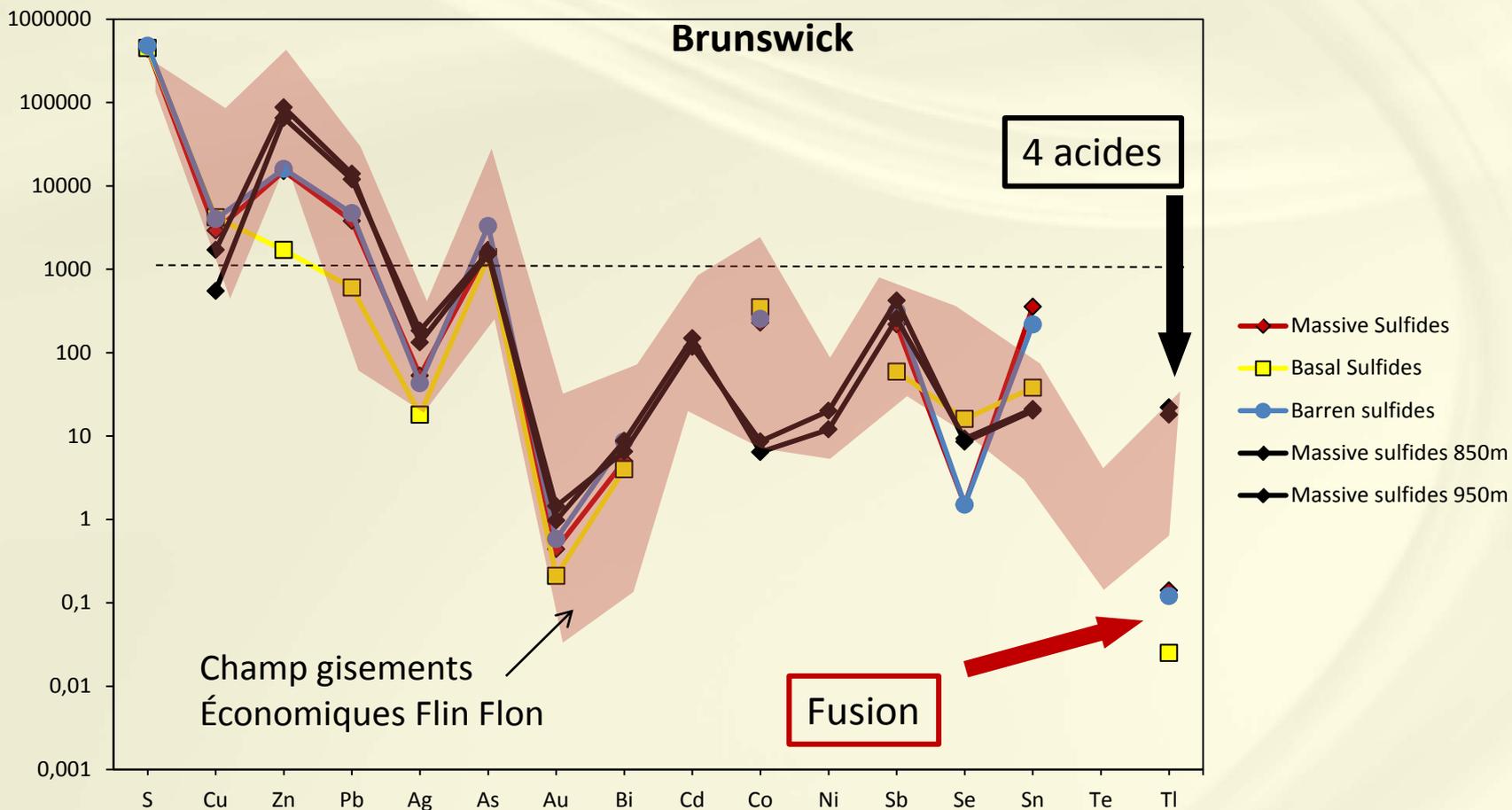
Marcoux et al. 1996

FIG. 4. Variation of S/Se ratio in present-day hydrothermal edifice, as proposed by Hekinian & Fouquet (1985). I Stockwork mineralization, II sulfides formed at high temperature during localized event of chimney formation, III high-temperature Fe-Cu-rich sulfides, IV intermediate-temperature Fe-Zn sulfides, V low-temperature porous Fe sulfides, and VI oxidized formation of primary sulfide phases and silica deposits.

# Limitations d'utilisation

- Spectres développés à Flin Flon semblent bien fonctionner dans d'autres environnements VMS (Kuroko, Brunswick, Hackett-River, moderne...)
- Cependant, ils doivent être adaptés
  - Environnement géodynamique (contexte arc vs dorsale)
  - Bruit de fond régional (influence sédiment...)
  - Limites de détections et méthodes analytiques
  - Niveau de métamorphisme (>schiste vert non testé)

# Importance de la méthode de dissolution



ICP-ES-MS avec digestion 4 acides  
INAA (Au, As, Co, Sb, Se)

ICP-ES-MS avec Fusion Li-metaborate  
INAA (Au, As, Co, Sb, Se)

# Recommandations

- Ajouter les éléments volatils à vos analyses lithogéochimiques!
- Tl: un élément souvent sous-estimé!
  - Élément indicateur (« Pathfinder ») pour de nombreux types de minéralisations
  - Difficile à analyser

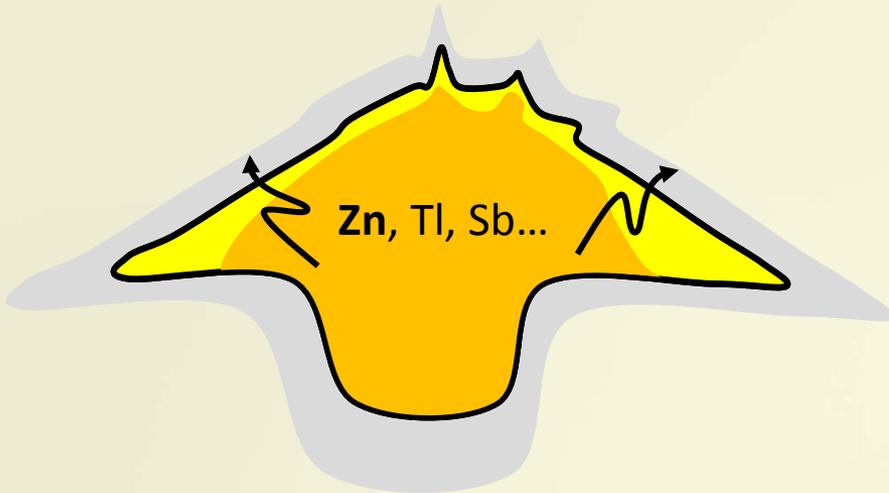
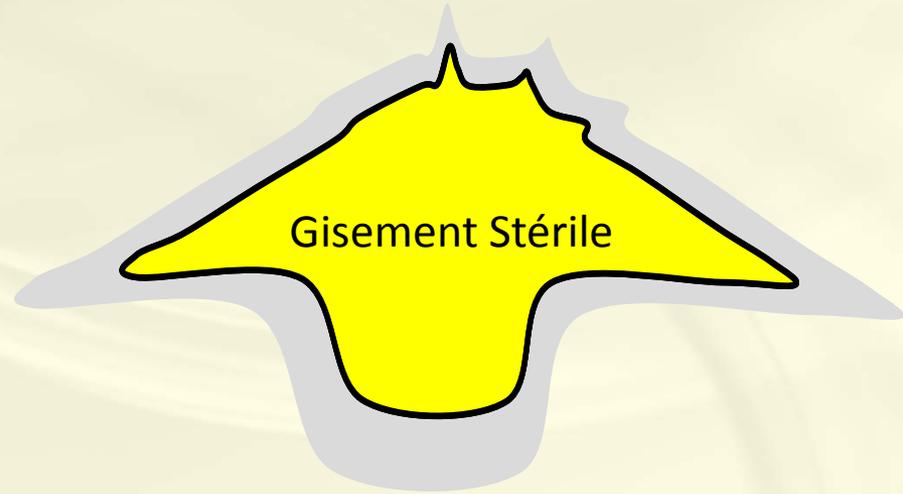
# Recommandation: Méthodologie

- Exemple Flin Flon
- Méthodes d'analyses:
  - ICP-AES (majeurs) – Fusion Li-tétraborate
  - ICP-MS (mineurs et traces) – 4 acides
  - INAA (As, Au, Hg, Se)
  - S et CO<sub>2</sub>

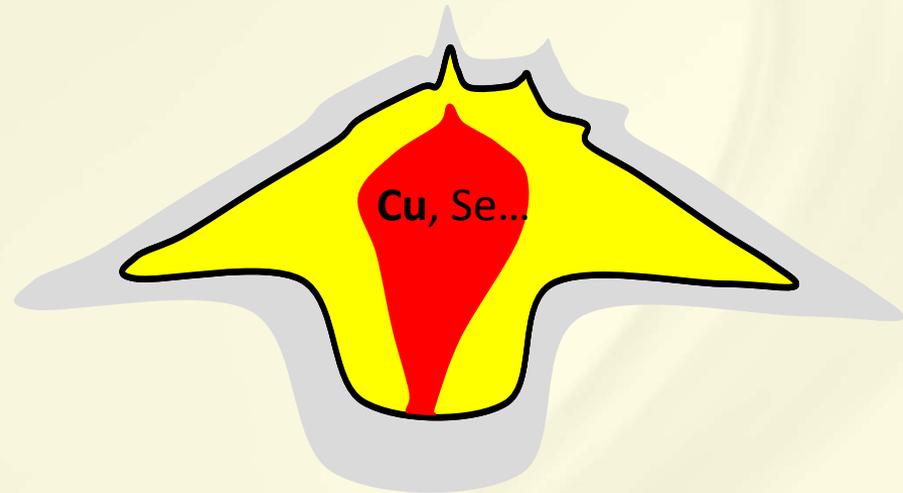
Table 2. Geochemistry methodology, source, and detection limits.

Element	Method.Lab	Detection Limit
SiO <sub>2</sub>	ICP. GSC	0.5 (%)
TiO <sub>2</sub>	ICP. GSC	0.02
Al <sub>2</sub> O <sub>3</sub>	ICP. GSC	0.2
Fe <sub>T</sub>	ICP. GSC	0.04
MgO	ICP. GSC	0.04
CaO	ICP. GSC	0.01
Na <sub>2</sub> O	ICP. GSC	0.03
K <sub>2</sub> O	ICP. GSC	0.05
Cu	ICP. GSC	0.001
Zn	ICP. GSC	0.001
Pb	ICP. GSC	0.001
Mn	ICP. GSC	0.001
CO <sub>2,T</sub>	chemistry.GSC	0.1
P <sub>2</sub> O <sub>5</sub>	ICP. GSC	0.01
S <sub>T</sub>	chemistry.GSC	0.02
Total	calculated	-
LOI	chemistry.GSC	-
Ag (ppm)	ICP. GSC	0.5 (ppm)
As	INAA. Act labs	0.5
Au (ppb)	INAA. Act labs	5 ppb
Ba (ppm)	ICP. GSC	20
Bi	ICP. GSC	0.2
Cd	ICP. GSC	0.2
Co	ICP. GSC	5
Cr	ICP. GSC	10
Cs	ICP. GSC	0.02
Ga	ICP. GSC	0.1
Hf	ICP. GSC	0.05
Hg	INAA. Act labs	1
In	ICP. GSC	0.05
Mo	ICP. GSC	0.2
Nb	ICP. GSC	0.05
Ni	ICP. GSC	10
Rb	ICP. GSC	0.05
Sb	ICP. GSC	1
Sc	ICP. GSC	0.5
Se	INAA. Act labs	3
Sn	ICP. GSC	0.5
Sr	ICP. GSC	10
Ta	ICP. GSC	0.05
Te	ICP. GSC	0.2
Th	ICP. GSC	0.02
Tl	ICP. GSC	0.02
U	ICP. GSC	0.02
V	ICP. GSC	5
Y	ICP. GSC	0.1
Zr	ICP. GSC	0.5
La (ppm)	ICP. GSC	0.1
Ce	ICP. GSC	0.1
Pr	ICP. GSC	0.02
Nd	ICP. GSC	0.1
Sm	ICP. GSC	0.02
Eu	ICP. GSC	0.02
Gd	ICP. GSC	0.02
Tb	ICP. GSC	0.02
Dy	ICP. GSC	0.02
Ho	ICP. GSC	0.02
Er	ICP. GSC	0.02
Tm	ICP. GSC	0.02
Yb	ICP. GSC	0.02
Lu	ICP. GSC	0.02
REE <sub>T</sub>	calculated	-

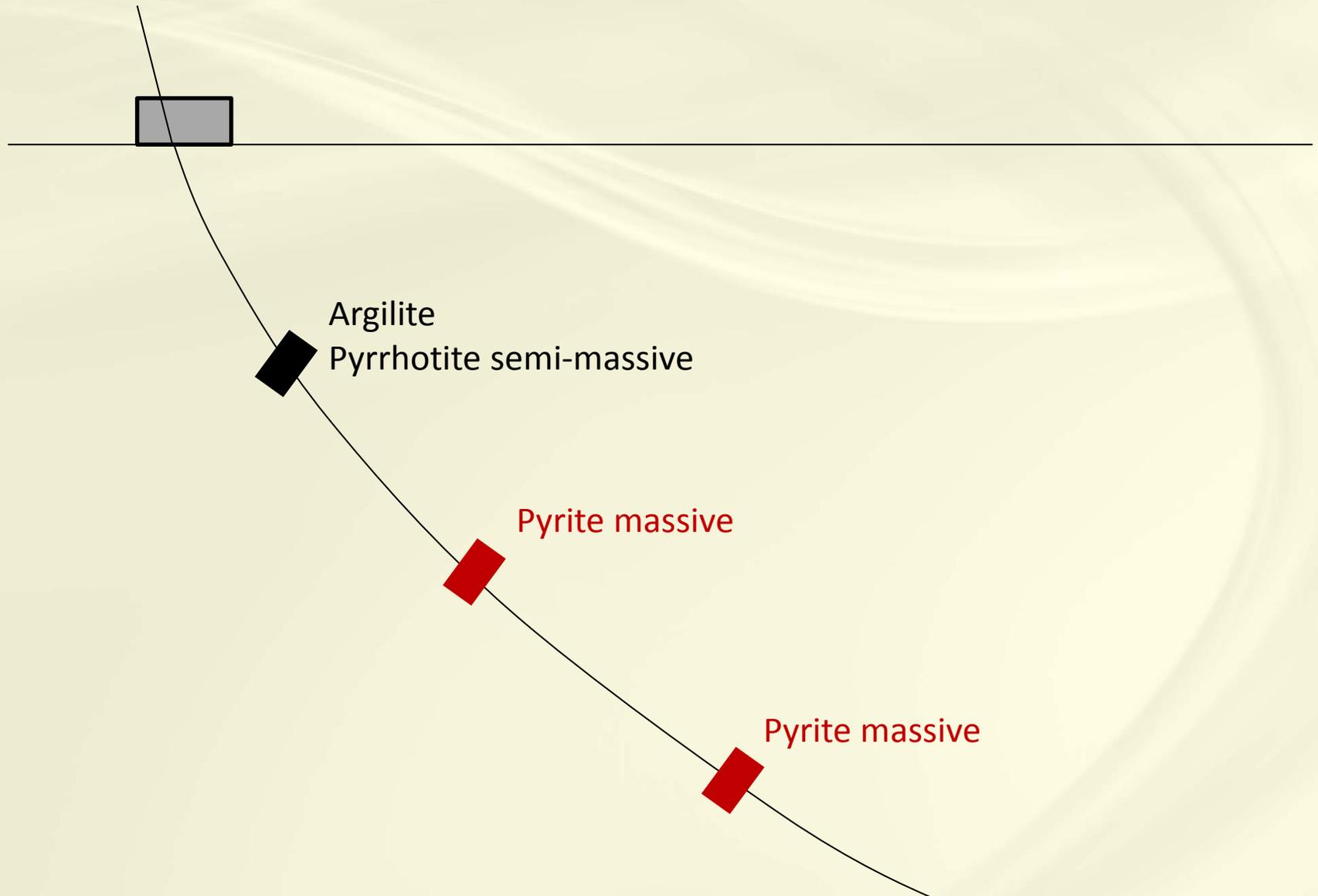
# Bilan empreintes hydrothermales

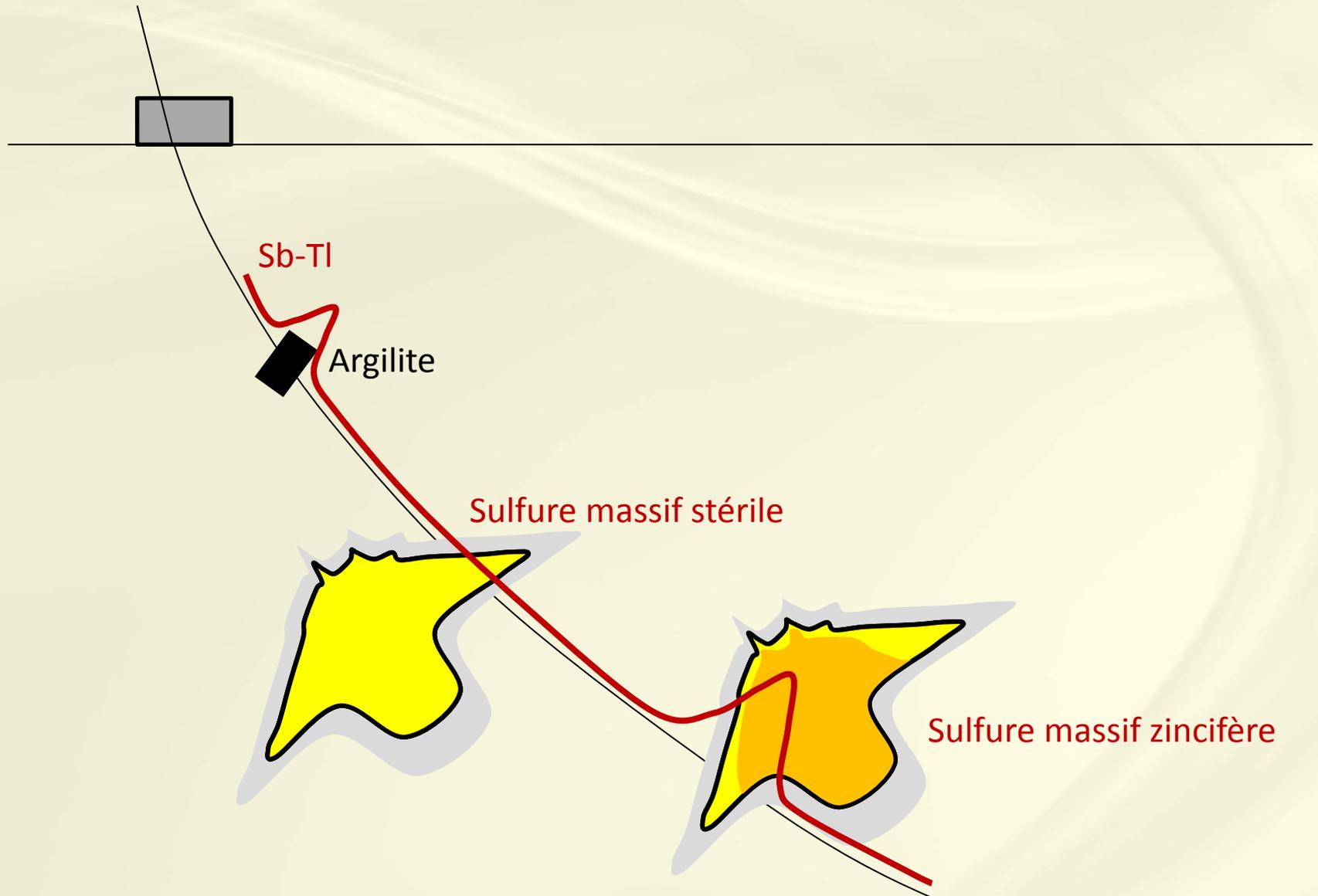


Gisement riche en Zinc



Gisement riche en Cuivre

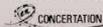




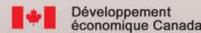
# MERCI!



AGNICO EAGLE



URSTM/UQAT



UQAC

UQÀM