CONSOREM 10 ans

Signature géochimique des rhyolites et fertilité en minéralisations volcanogènes

(Les centres felsiques de l'Abitibi)

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LAMEQ - CERM - CONSOREM

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Rhyolite Geochemical Signatures and Association with Volcanogenic Massive Sulfide Deposits: Examples from the Abitibi Belt, Canada

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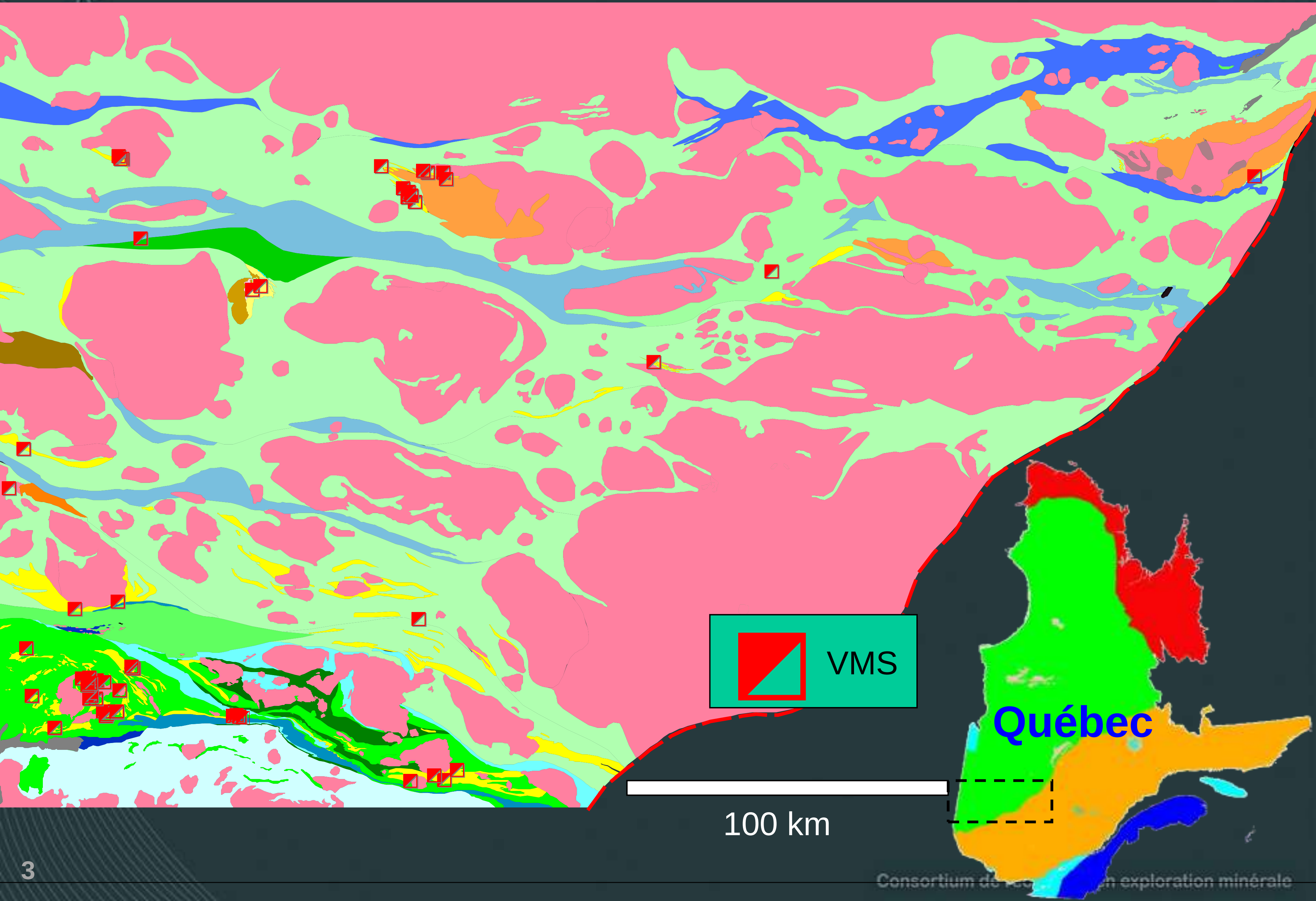
Abstract

The relationship between rhyolite geochemistry and volcanogenic massive sulfide (VMS) mineralization has been proposed as an exploration tool to discriminate prospective felsic volcanic centers. The most widely used classification discriminates between four types of rhyolite: FI, FII, FIIIa, and FIIIb. The FI rhyolites are calc-alkaline, with strongly fractionated REE patterns and strongly negative Ta and Nb anomalies. They are usually considered barren, unless associated with FII or FIII felsic volcanic rocks. The FII rhyolites are calc-alkaline to transitional with moderately fractionated REE patterns and moderate Ta and Nb anomalies. They range from barren to having a high potential to host VMS mineralization. The FIIIa and FIIIb rhyolites are tholeiitic and show weakly fractionated REE patterns and weak to absent Nb and Ta anomalies. They have the highest potential to host VMS mineralization. The FIIIb rhyolites are high-temperature rhyolites with flat REE patterns and no Ta or Nb anomalies.

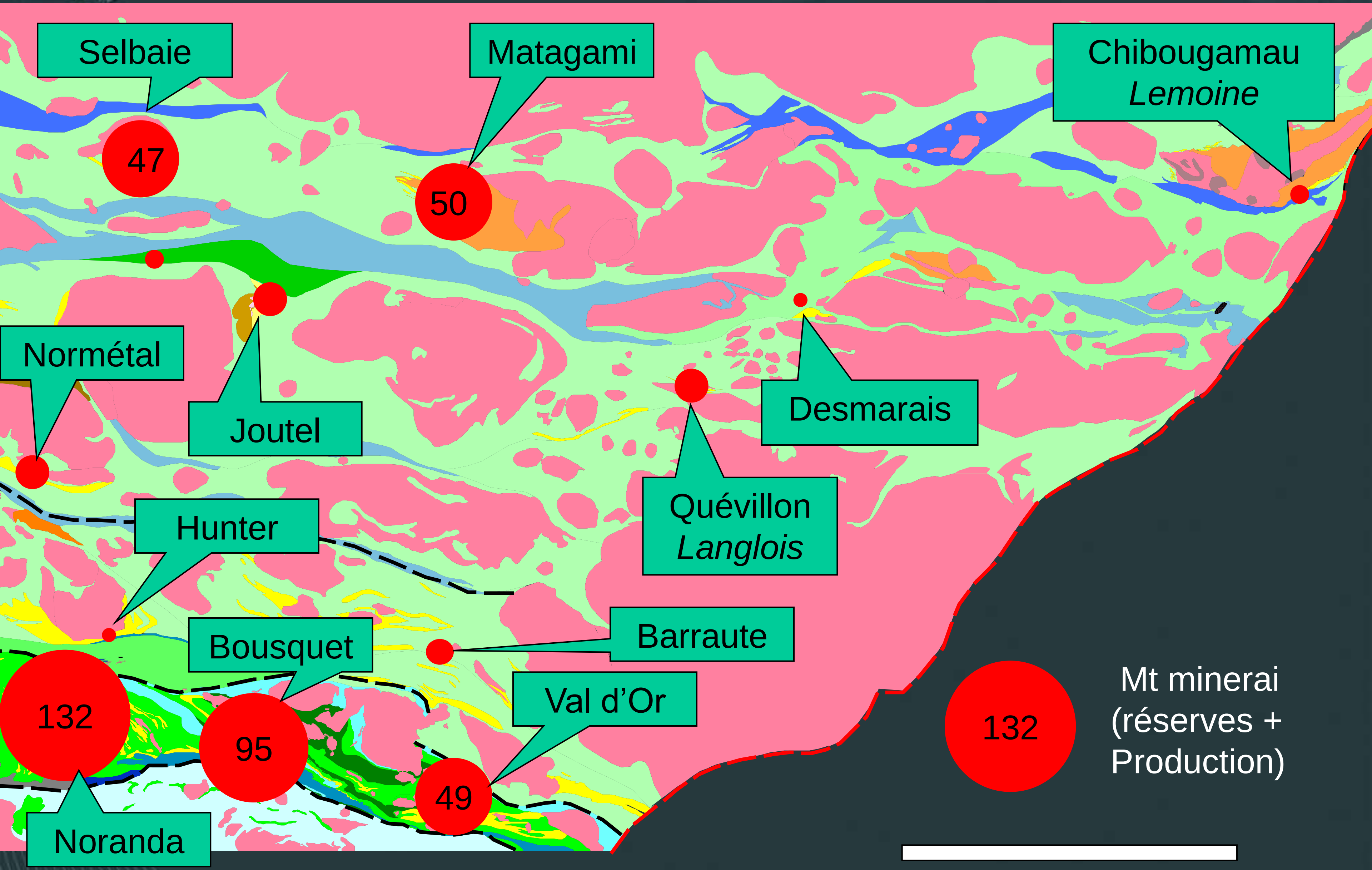
The Abitibi greenstone belt, especially in Quebec, is well known for its abundant and diverse VMS deposits. Representative samples of VMS-associated rhyolites within and outside of mining districts, including the classic Noranda VMS district, were analyzed for major and trace elements to validate their proposed favorability for hosting VMS deposits. Results indicate that all of the rhyolite types are prospective, but mineralization may differ from the classic Noranda-type VMS deposit. The FI-type rhyolites appear to be particularly associated with gold-rich VMS deposits, such as the world-class Laronde deposit, and are more prospective for Cu-Au replacement and vein-type deposits. The FII-type rhyolites account for about 70 percent of rhyolites in the Abitibi belt. Although considered less prospective, some districts dominated by FII rhyolites, such as Val-d'Or and Selbaie, have collectively produced in excess of 100 million metric tons (Mt) of ore. Deposits in these districts mainly consist of sulfide veins and disseminated ore with low Cu and Zn grades and are associated with abundant and highly vesicular volcaniclastic rocks that display a compositional continuum from andesite to rhyolite. Other weakly mineralized FII districts (e.g., Hunter mine, Gemini-Turgeon) are characterized instead by bimodal flow-dome sequences. The FIIIa-type rhyolites occur mainly in the Noranda district and form flow-dome complexes in bimodal sequences with associated Noranda-type VMS mineralization. In small felsic centers (Joutel, Normétal, Chibougamau, Quévillon) that show a volcanic evolution from FIIIa to FII to FI affinities, VMS deposits are directly associated with FIIIa rhyolites, thus demonstrating the usefulness of rhyolite geochemistry for exploration in these areas. The FIIIb rhyolites are rare in the Abitibi belt, with most occurring in the Matagami district where they are associated with Zn-Cu VMS deposits. Based on this analysis, we suggest that a combination of rhyolite geochemistry, volcanic facies, and style of the mineralization may be more meaningfully applied in exploration than rhyolite type alone, particularly in the case of FI and FII rhyolites.

Econ. Geol, vol. 103, p. 1531-1562120

Abitibi: distribution des gisements VMS



Tonnage (production + reserves) pour les camps VMS (Mt)



Lien entre chimie des rhyolites et potentiel VMS

A l'attention des rédacteurs financiers:

Mines d'Or Virginia - La technologie MegaTEM permet l'identification de deux nouvelles zones minéralisées

MONTREAL, le 8 sept. /CNW Telbec/ - Mines d'Or Virginia ("Virginia") annonce que le partenariat Virginia-Noranda-Novicourt a identifié deux nouvelles zones minéralisées anomales en Zn-Cu-Pb-Ag grâce à la technologie MegaTEM.

Nouveaux environnements VMS favorables

La première zone minéralisée correspond à une séquence volcanique de laves andésitiques, de coulées rhyolitiques et de tuffs où le contact rhyolite/basalte est très altéré en chlorite-séricite sur une épaisseur d'environ 40 mètres. La zone de contact enrichie en sulfures et caractérisée par une zone de stringers de chalcopyrite-sphalérite a rapporté une intersection anomale de 0,47 % Zn, 0,06 % Cu, 0,08 % Pb et 30,5 g/t Ag sur 38,9 mètres (incluant : 0,68 % Zn, 0,19 % Cu, 0,23 % Pb, 208,3 g/t Ag sur 3,3 mètres.

Une large anomalie pulse EM de type "offhole" indique l'extension de la zone minéralisée en profondeur et latéralement. La modélisation de l'anomalie géophysique suggère un contact subvertical correspondant au contact basalte/rhyolite. Un forage additionnel est prévu sous peu afin de tester ce contact.

L'intérêt de cette nouvelle zone minéralisée réside dans le fait qu'elle se situe au sein d'une séquence de basalte (andésite), de coulées felsiques et de tuffs ayant le même âge que la séquence volcanique de Kidd Creek (2714 Ma). De plus, la majorité des roches rhyolitiques en présence sont de type "favorable" i.e. à fort contenu en silice et à faible ratio Zr/Y.

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OBJECTIFS

- Redéfinir les caractéristiques lithogéochimiques des environnements volcaniques dits favorables.
- Valider l'approche par les terres rares et déterminer quels sont les éléments (analyses) essentiels à l'identification de ces environnements.
- Identifier de nouveaux secteurs favorables, négligés par les travaux d'exploration antérieurs.

États des connaissances

- Lesher et 1986: 4 Gr Rhyolites FI, FII, FIII(a,b)
  FIII + fertile pour VMS

Trace-element geochemistry of ore-associated and barren, felsic metavolcanic rocks in the Superior Province, Canada

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E69

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Revision accepted August 9, 1985

- Barrie et al. 1993: 5 Gr Rhyolites
  GrI, GrII et GrIII + fertiles pour VMS

Geochemistry of Volcanic Rocks Associated with Cu-Zn and Ni-Cu Deposits in the Abitibi Subprovince

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John N. Ludden,
Terrestrial Magmatism Research Group, Département de Géologie, Université de Montréal, Montréal, Québec, Canada H3C 3J7

and Tony H. Green
Falconbridge Ltd., P.O. Box 398, Windsor, Nova Scotia, Canada B0N 2T0

CONSOREM 10 ans

Lesher et al. 1986

FIII a: n = 23 (camp de Noranda)
FIII b: n = 25 (15 Kamiskotia, 6 Kidd Creek, 2 Noranda)
FII: n = 5 (Misema)
FI: n = 8 (divers)
Total n = 61

Pour l'Abitibi

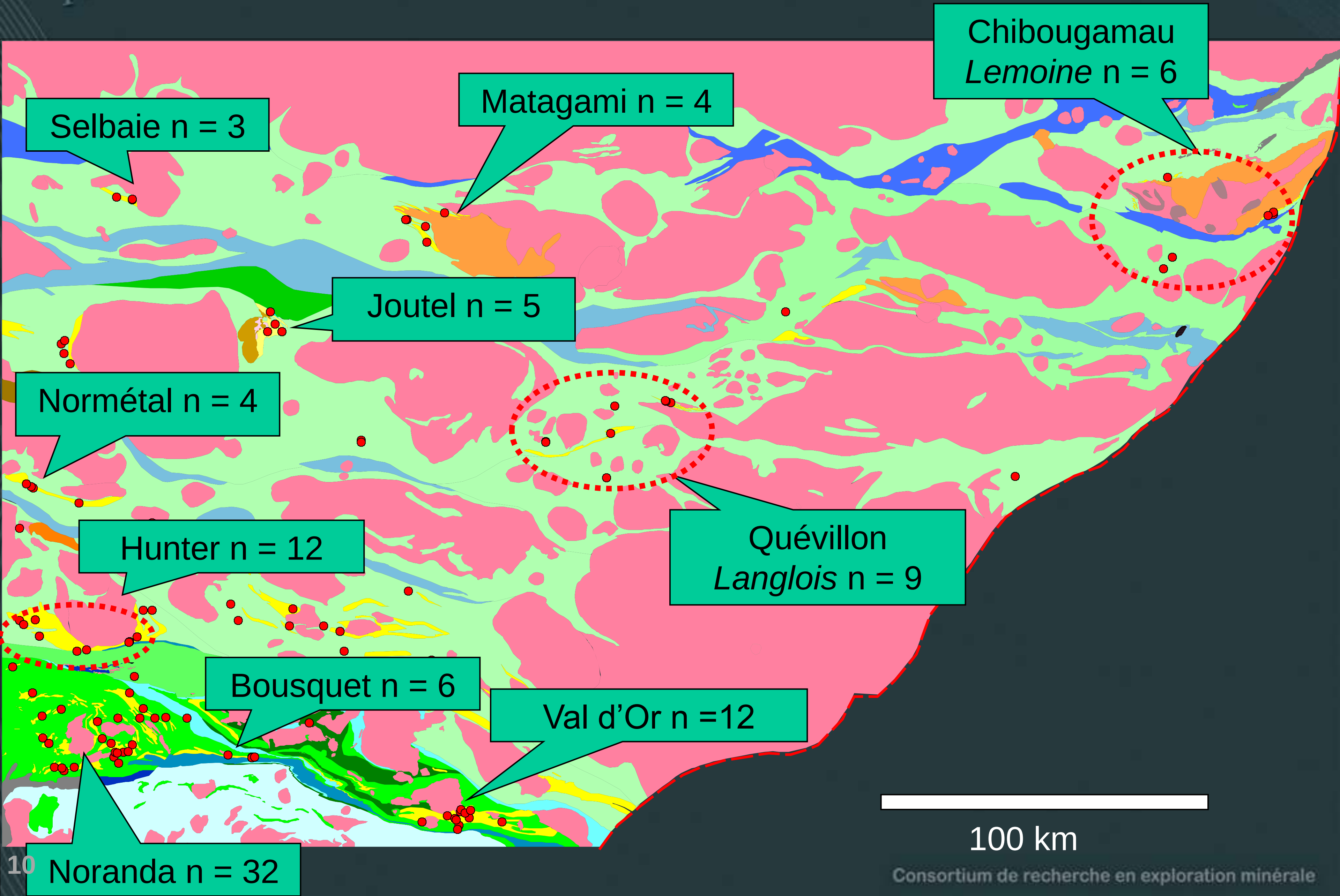
Barrie et al. 1993

Gr I: n = 7 (Kamiskotia)
Gr II: n = 5 (Noranda)
Gr III: n = 5 (Selbaie)
Gr IV n = 8 (groupe Upper Skead)
Gr V n = 6 (groupe Timiskaming)
Total: n = 31

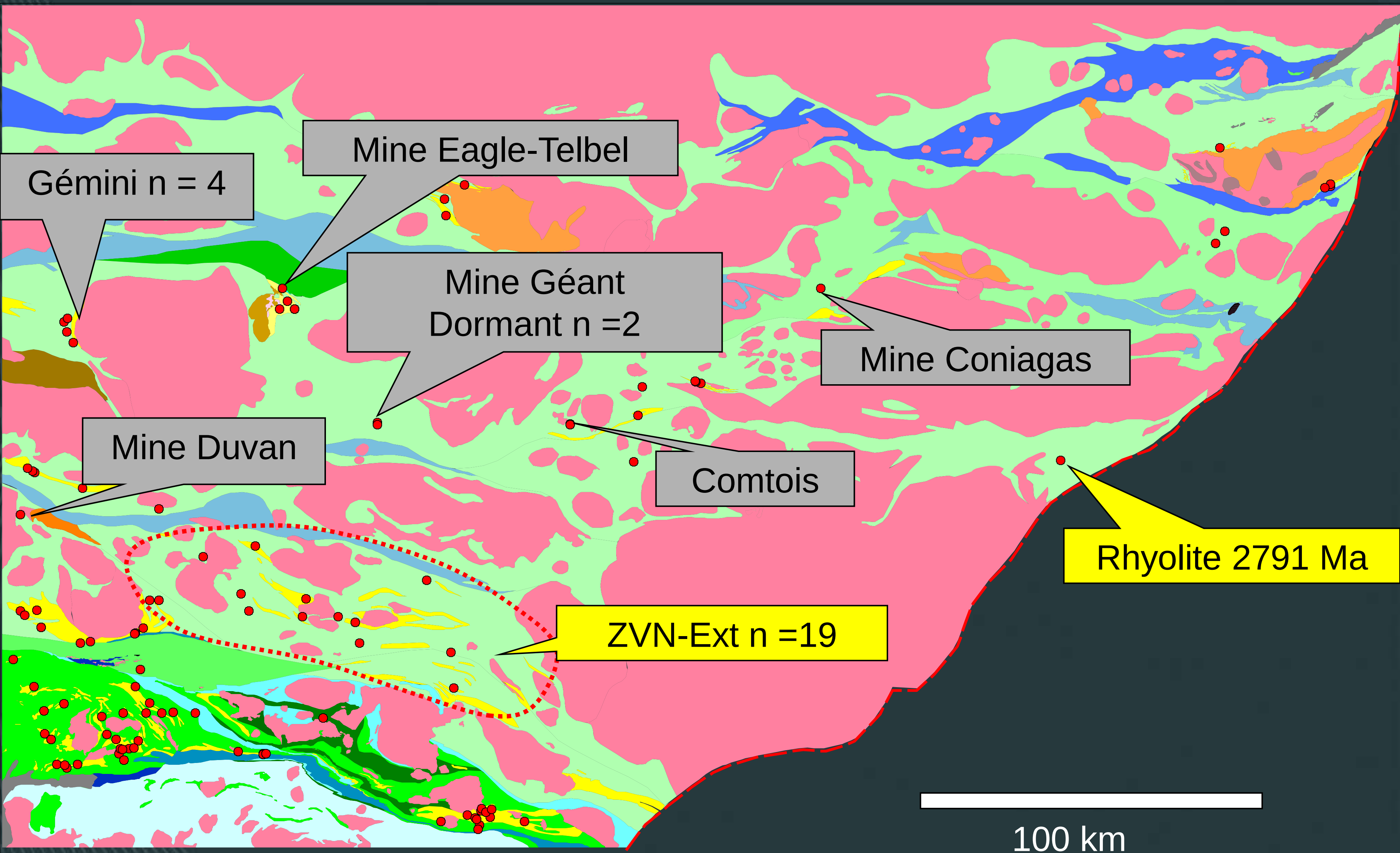
On a refait un échantillonnage…



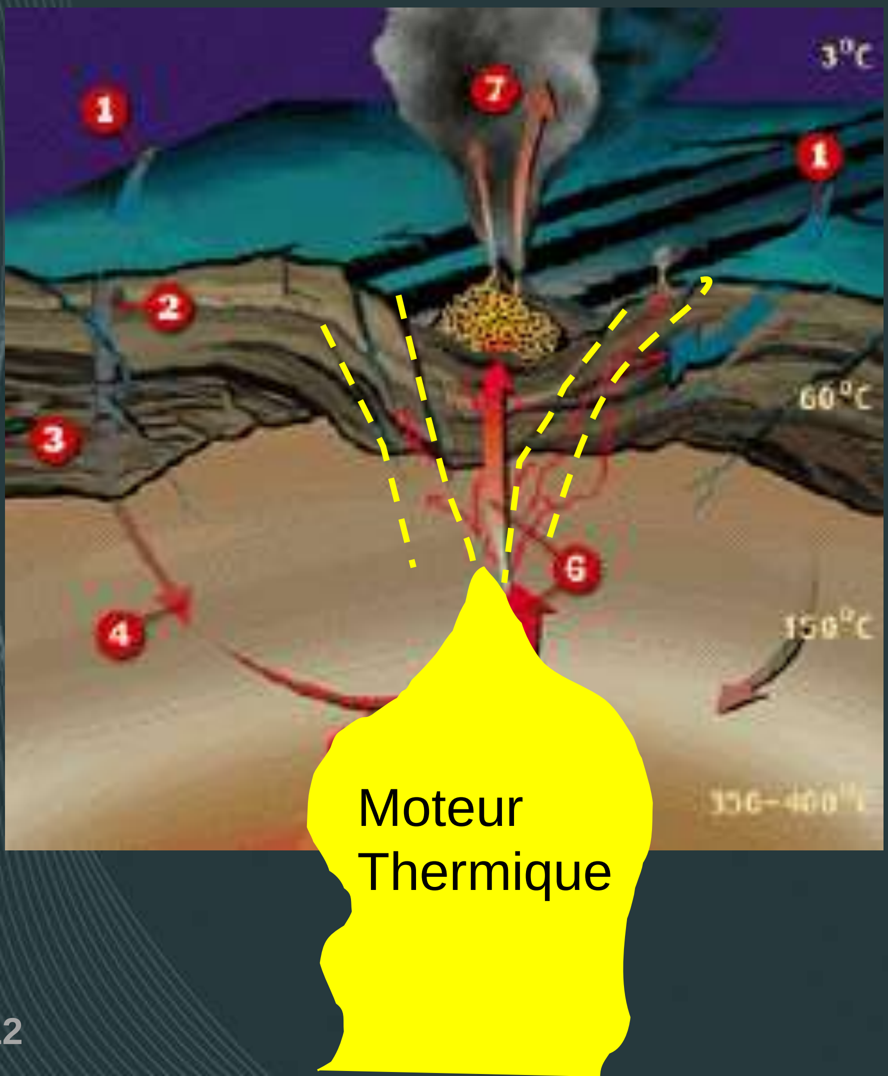

Localisation des échantillons selon les camps miniers VMS



Localisation des échantillons selon minéralisations volcanogènes et particularités

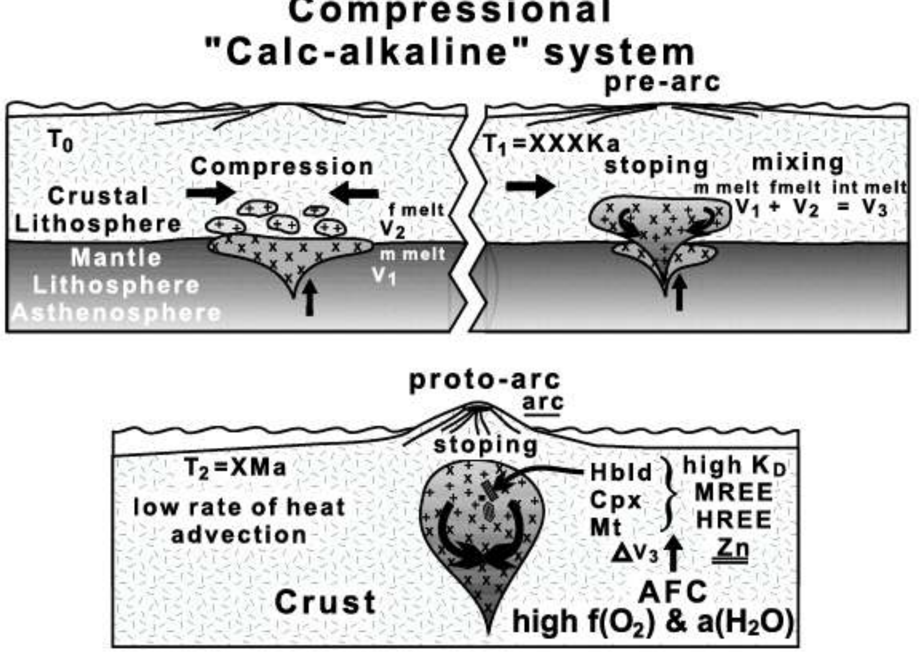


Lien entre la chimie du volcanisme felsique et la fertilité en VMS

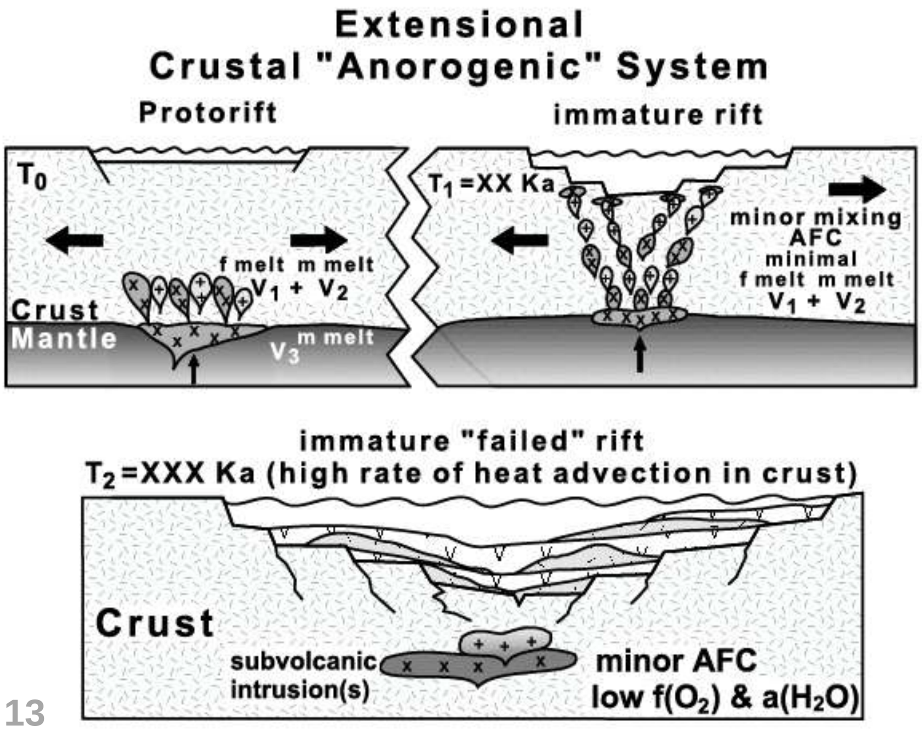


- Fluide: eau de mer
- Roche source

- Perméabilité structurale
- Flux thermique



Contexte d'arc
Régime neutre
Favorable: Cu-Au porphyric
Séquence fractionnée continue
Transfert lent magma
Magma riche en H_2O



Contexte de rift
Régime en extension
Favorable aux VMS
Séquence bimodale
Transfert rapide magma
Magma pauvre en H_2O

Lentz, 1998

Nouveau papier 2004

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TRACE ELEMENT GEOCHEMISTRY AND PETROGENESIS OF FELSIC VOLCANIC ROCKS ASSOCIATED WITH VOLCANOGENIC MASSIVE Cu-Zn-Pb SULFIDE DEPOSITS

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Hart et al. 2004

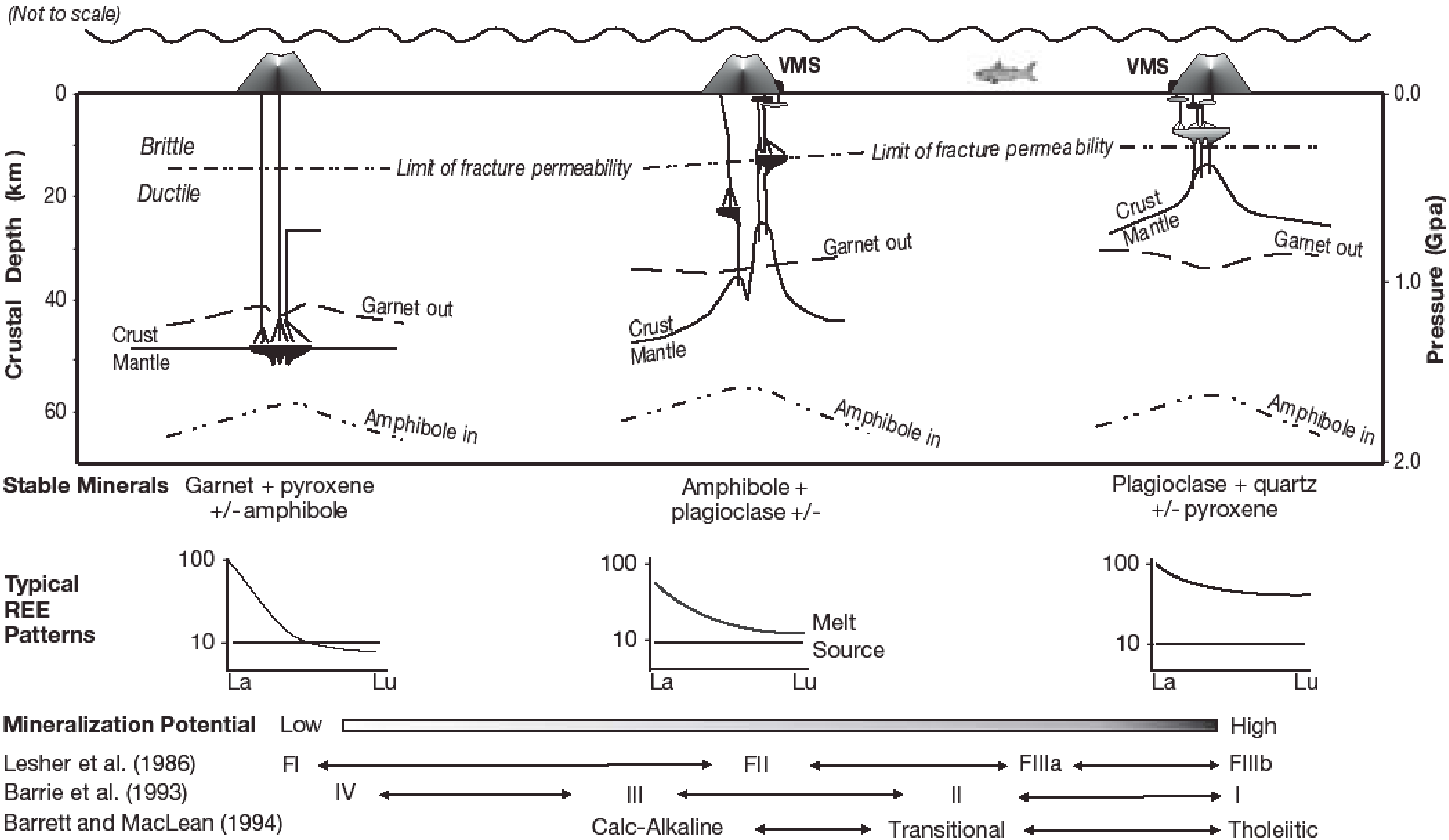

FIG. 3. Conceptual petrogenetic model for the formation of FII and FIII-IV felsic volcanic rocks by partial melting at progressively shallower crustal depths in a rift environment. Combined high heat flow and an extensional-rift environment allow low-pressure, higher temperature crustal melting within the zone of brittle fracture permeability and promote convective seawater fluid flow. The complex arrangement of magma chambers depicted for FII felsic volcanic centers corresponds to the fact that FII felsic volcanic rocks forming below the maximum depth of convective fluid flow are barren, whereas those forming above this depth may be mineralized.

Concepts pétrogénétiques

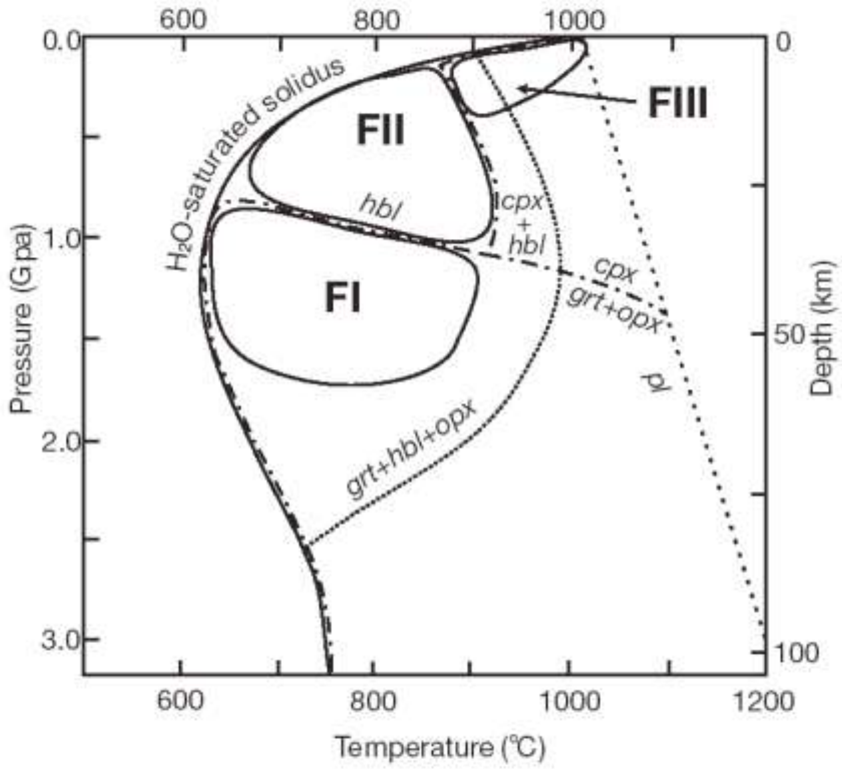

FIG. 1. Approximate fields for FI, FII, and FIII felsic volcanic rocks based on phase relationships from melting experiments using dry basalt, basalt-H_2O, and amphibolite. Compiled from Wyllie and Wolf (1993), Rapp (1995), and Wolf and Wyllie (1995). Stable minerals with high partition coefficients for HREE and HFSE are displayed with the abbreviations: cpx = clinopyroxene, grt = garnet, hbl = hornblende, opx = orthopyroxene.

Hart et al. 2004

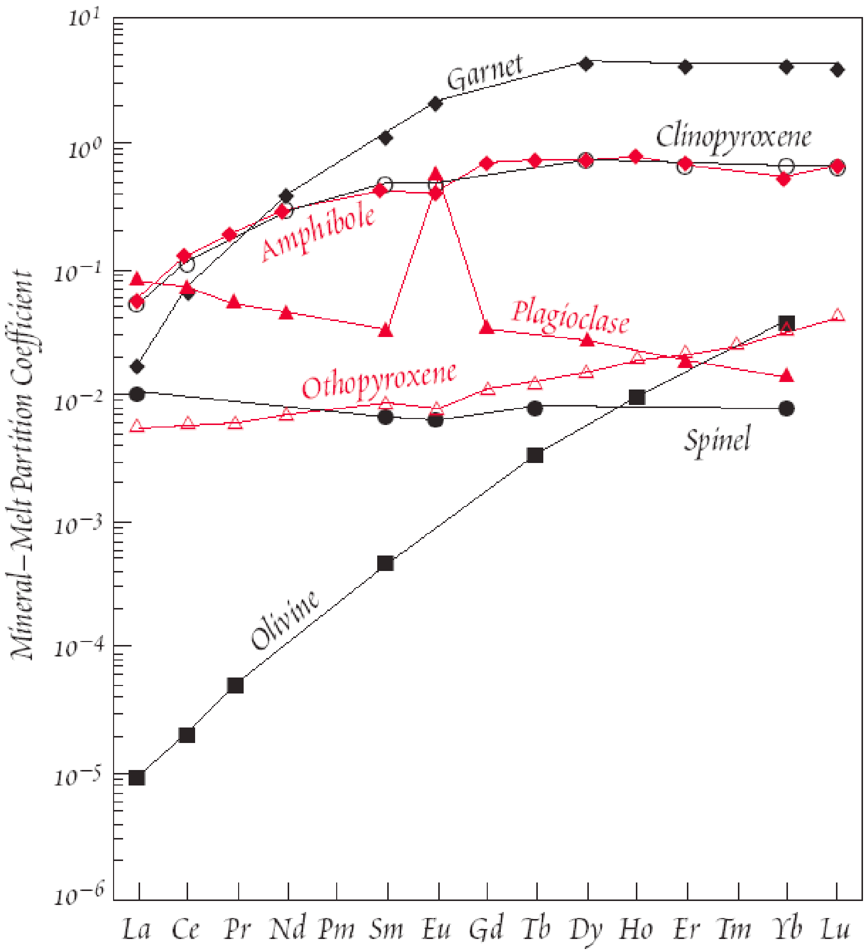

Figure 7.15. Rare earth mineral–melt partition coefficients for mafic magmas. Data from Table 7.5.

White, 2001

TABLE 1. Geochemical Classification, Petrogenetic Models, and Tectonic Environments Proposed for the Formation of FI, FII, FIII, and FIV Felsic Volcanic Rocks (from Lesher et al., 1986, and this study)

	FI	FII	FIIIa	FIIIb
Lithology	Dacite-rhyolite	Dacite-rhyolite	Rhyodacite-high silica rhyolite	Rhyodacite-high silica rhyolite
SiO_2 (wt %)	64–72	64–81	67–78	67–84
TiO_2 (wt %)	0.16–0.65	0.16–0.89	0.21–0.99	0.09–0.73
Y (ppm)	6–31	11–73	25–96	72–238
Zr/Y	8.8–31	3.2–12.12	3.9–7.7	1.7–6.2
Yb ppm)	0.43–3.8	1.3–7.9	3.4–9.3	5–32
$[La/Yb]_{cn}$	5.8–34	1.7–8.8	1.5–3.5	1.1–4.9
Eu/Eu*	0.87–1.5	0.35–0.91	0.37–0.94	0.20–0.61
Affinity	"Alkaline–calc-alkaline"	"Calc-alkaline"	"Tholeiitic"	"Tholeiitic"
Petrogenetic mode[ls]	Low-degree partial melting of mafic source at high			; Lesher

Shallow (<10 km)

Notes: Chrondrite ... rite-normalized Sm and Tb

FI

calco-alc

Spectres fractionn

Anomalie fortes en

Considér stériles à

FII

calco-alca transition

Spectres fractionné

Anomalies Ta et Nb.

Considéré relativement peu fertiles.

FIIIa

Tholéiiti

Spectre fraction

Anomal nulles e

Considé plus fert

FIIIb

Tholéiitiques

Spectres ETR est plat

Anomalies en Ta et Nb sont absentes.

Unique à l'archéen

Considérées très fertiles

Comment les classifier: plage de valeurs

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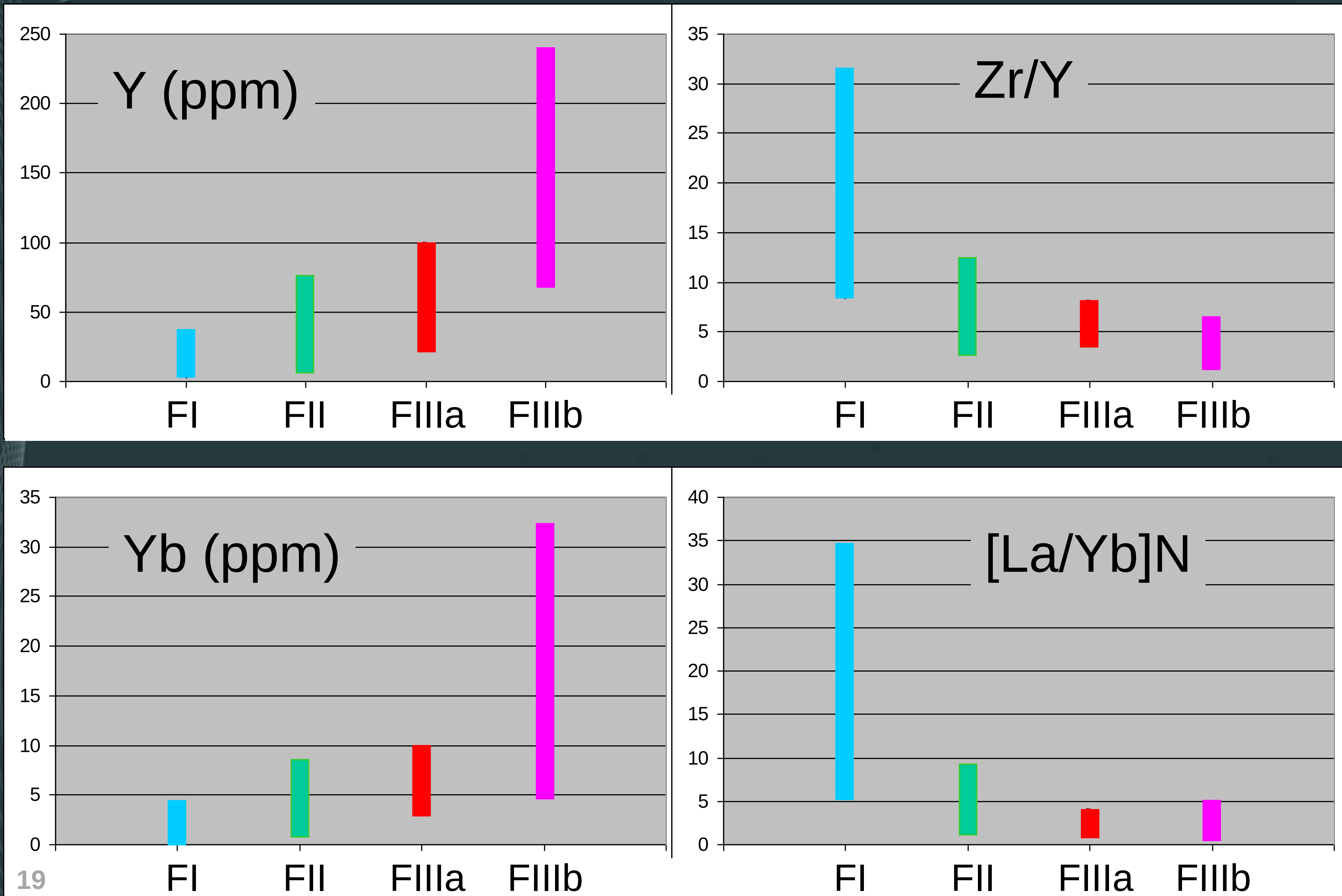
Eu/Eu*	0.87–1.5	0.35–0.91	0.37–0.94	0.20–0.61
Affinity	"Alkaline–calc-alkaline"	"Calc-alkaline"	"Tholeiitic"	"Tholeiitic"
Petrogenetic models	Low-degree partial melting of mafic source at high pressure with minimal fractionation, do not appear ...	Fractional crystallization of intermediate magma (Campbell et al., 1981, 1982; Lesher et al., 1986); high-degree partial ... partial melting related to metasomatism of mantle wedge over subducted slab, fractional crystallization of resulting mafic magma (Barrett and MacLean, 1999); high-temperature partial melting of crustal material with magma compositions controlled by differences in composition of crust (Lentz, 1998)	Low-pressure partial melting of tholeiitic basalt with no residual amphibole (Hart, 1984) or garnet (Campbell et al., 1981, 1982; Lesher et al., 1986; Barrie et al., 1993) in a subvolcanic magma chamber; low-pressure plagioclase-dominated fractional crystallization of ... Contamination of tholeiitic magma by hydrous mafic crust during fractional crystallization; high-pressure crystallization of clinopyroxene (Barrie et al., 1993); high-temperature partial melting of crustal material with magma compositions controlled by differences in composition of crust (Lentz, 1998)	Partial melting of granulite lower crust with fractionation producing higher silica contents; extreme fractional crystallization of tholeiitic mafic liquid resulting in liquid immiscibility with possible wall-rock contamination (Thurston and Fryer, 1983); high-temperature partial melting of crustal material with magma compositions controlled by differences in composition of crust (Lentz, 1998)
Tectonic environment	Arc-related suites derived from metasomatized wedge with variable crustal contamination (Barrie et al., 1993)	Continental arc (Barrie et al., 1993); rifted mature arc/continental back arc floored by oceanic crust (Barrett and MacLean, 1999); extensional environments (e.g., intra-continental, intraoceanic intra-arc, intra-arc, and back-arc rift; Lentz, 1998)	Rifted island arc (Barrie et al., 1993); rifted continental margin (Barrett and MacLean, 1999); extensional environments (e.g., intracontinental, intraoceanic intra-arc, intra-arc, and back-arc rift; Lentz, 1998)	Oceanic rift (Hart, 1984; Barrie et al., 1993)
Examples		Sturgeon Lake, Kuroko, Rio Tinto, Bathurst, Myra Falls, Mt. Windsor, Tulsequah Chief, Mt. Chalmers, Thalanga, Mt. Read, Boliden, Selbaie, Salt Creek, Murgul, Benambra	Noranda, Jerome, United Verde, Teutonic Bore, Parys Mountain, Ambler, Avoca, Woodlawn, Buchans, Prieska, Fox Lake, Manitouwadge, Hood River, Sulphur Springs, Scuddles, Berslagen, Winston Lake	Kidd Creek, Kamiskotia, Eskay Creek, Neves Corvo, Shasta, Crandon, Mattagami Lake, Mons Cupri, South Bay
Source depth (this study)	Deep (>30 km)	Intermediate (> 10 but < 15 km) for mineralized FII	Shallow (< 10 km)	Shallow (< 10 km)

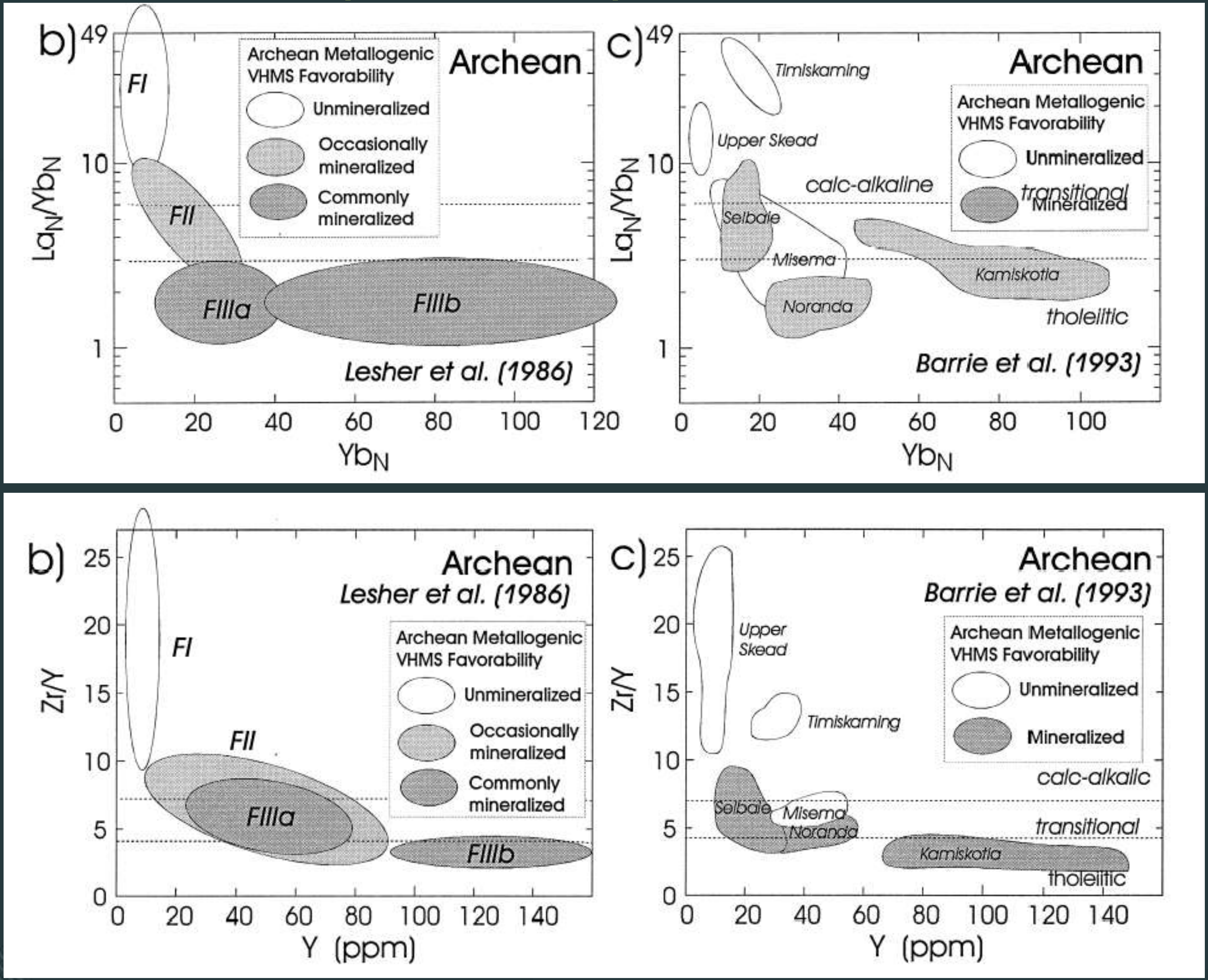
Notes: Chrondrite-normalizing values from Nakamura (1977); Eu* calculated by linear interpolation between chondrite-normalized Sm and Tb

CONSOREM 10 ans

Plage des valeurs discriminates *(Hart et al. 2004)*



Champs définis pour classification



Lentz, 1998

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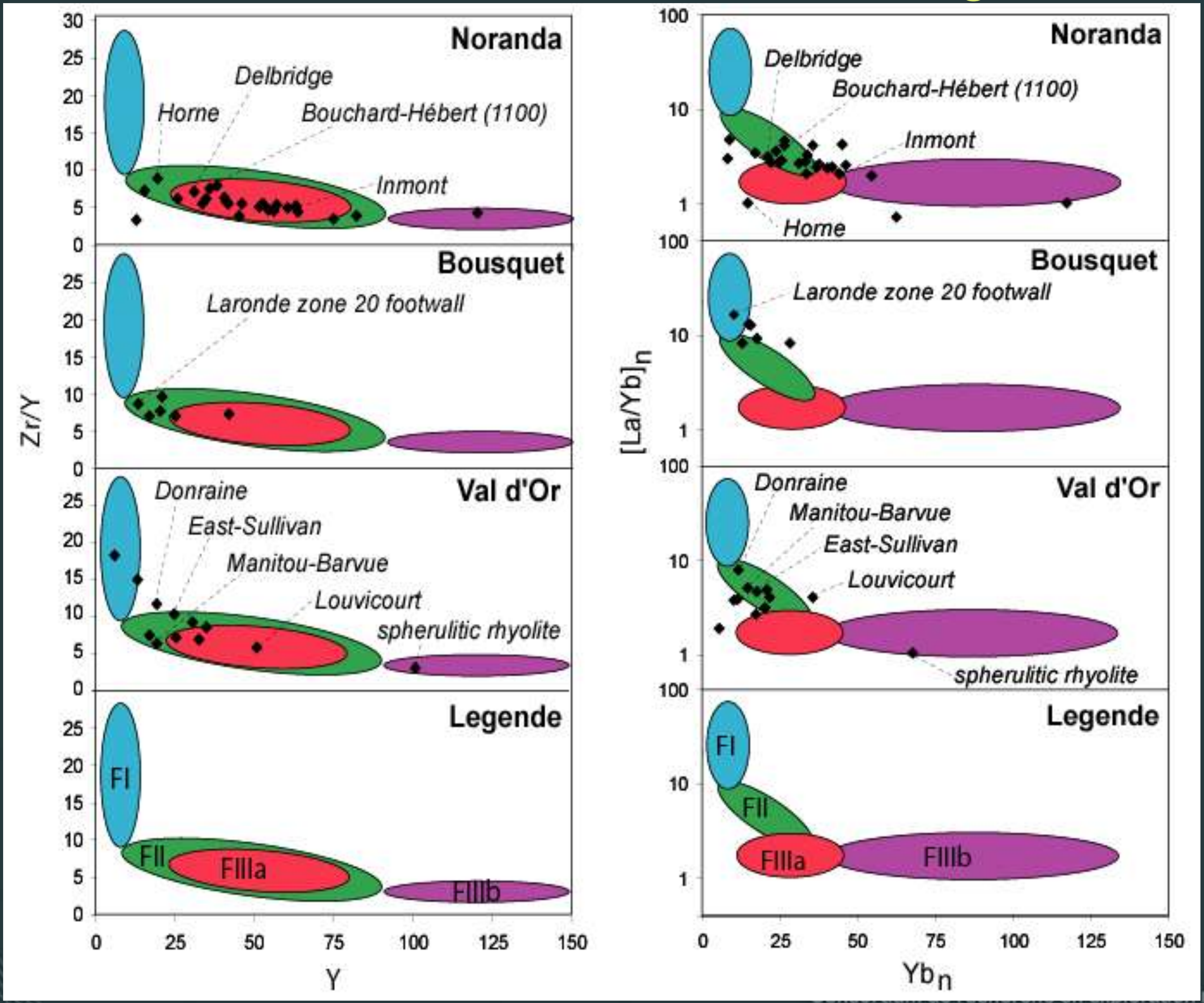
Discordance entre les deux diagrammes



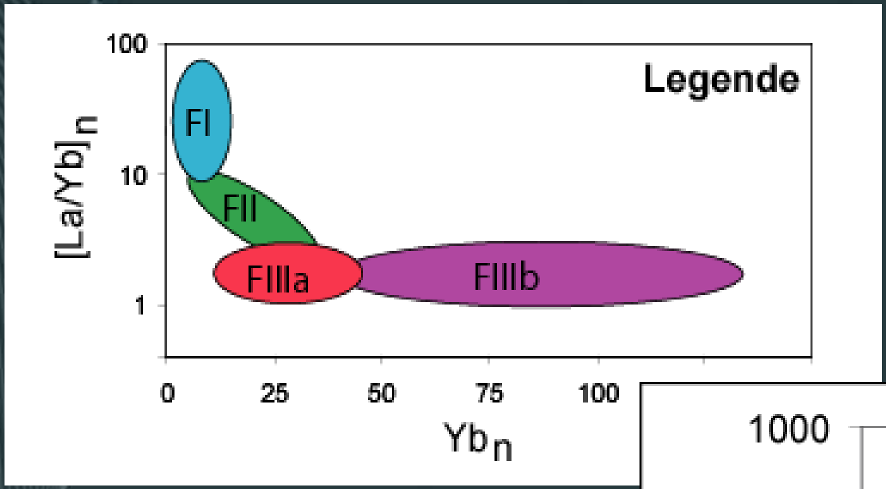
CONSORem 10 ans

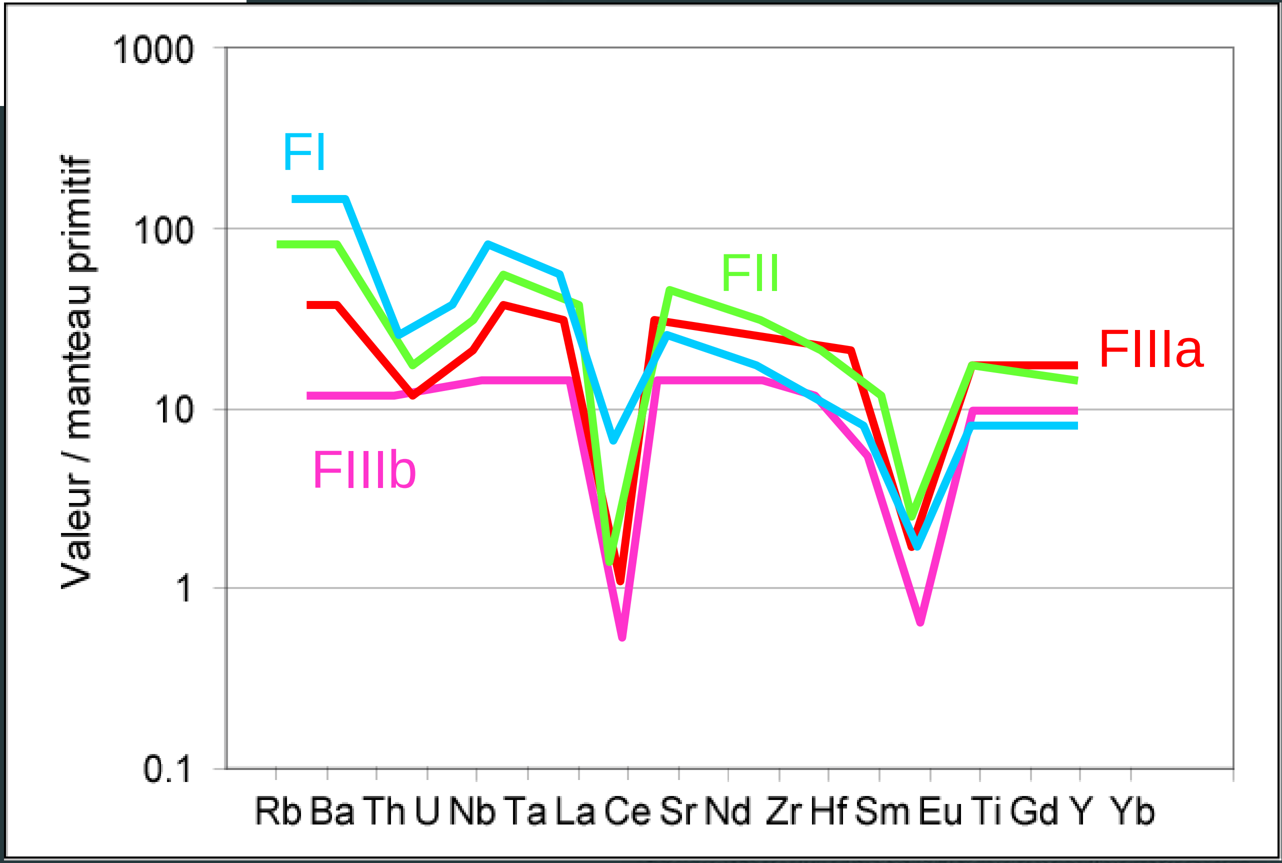
Compilation Groupes: Zr-Y vs La - Yb

Camps miniers	Gr idem
1. Bousquet	4 / 6
2. Chibougamau	6 / 6
3. Hunter Mine	8 / 12
4. Joutel	3 / 5
5. Matagami	4 / 4
6. Noranda	15 / 26
7. Normétal	3 / 4
8. Quévillon	4 / 7
9. Selbaie	0 / 3
10. Turgeon-Gémini	4 / 4
11. Val d'Or	7 / 13
12. Lasarre-Senneterre	8 / 14
13. Autre	2 / 8

61 % Groupes définis par Zr-Y et La-Yb

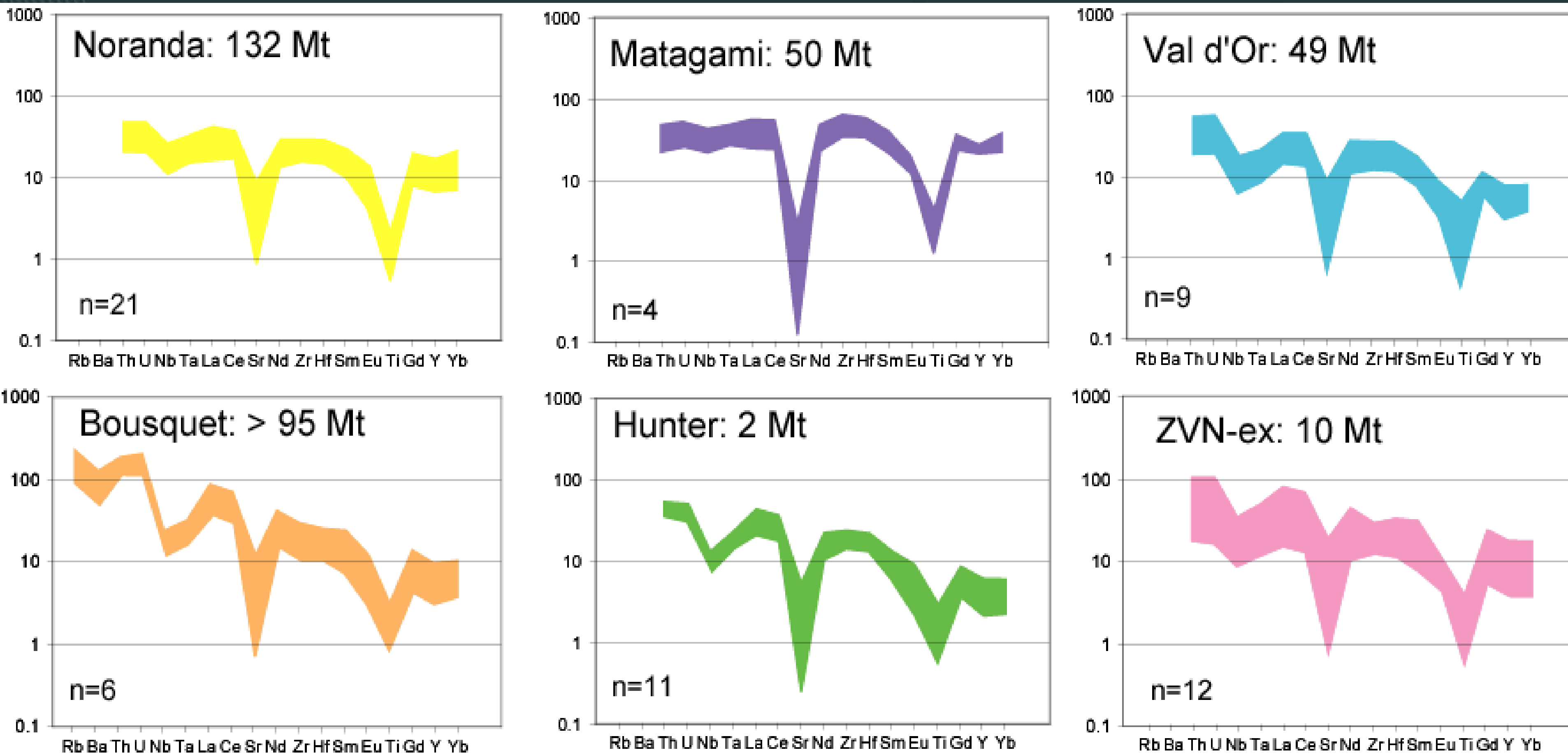
Approche par les Terres Rares





Comparaison

FIIIa FIIIb FII

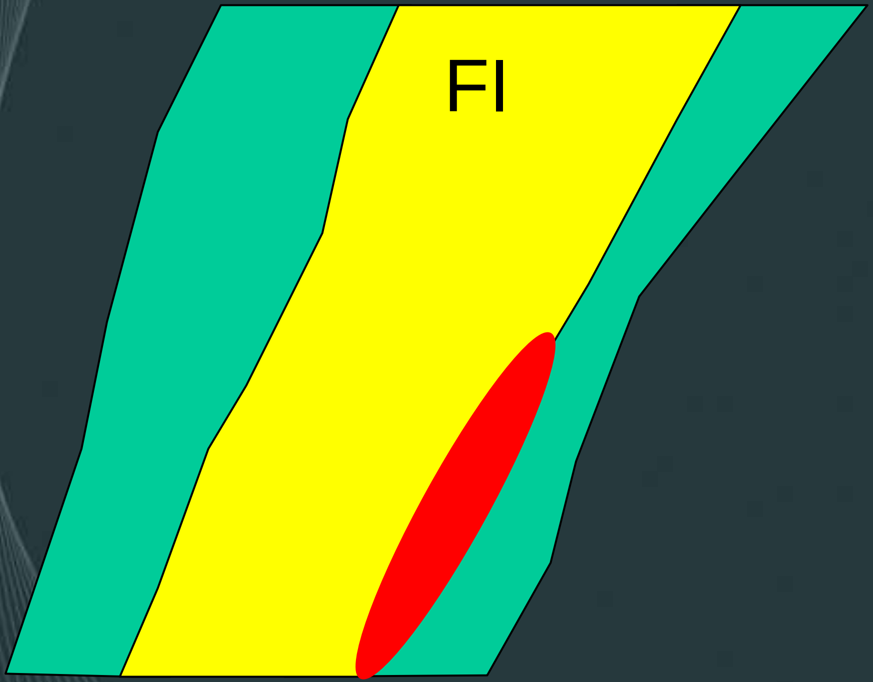


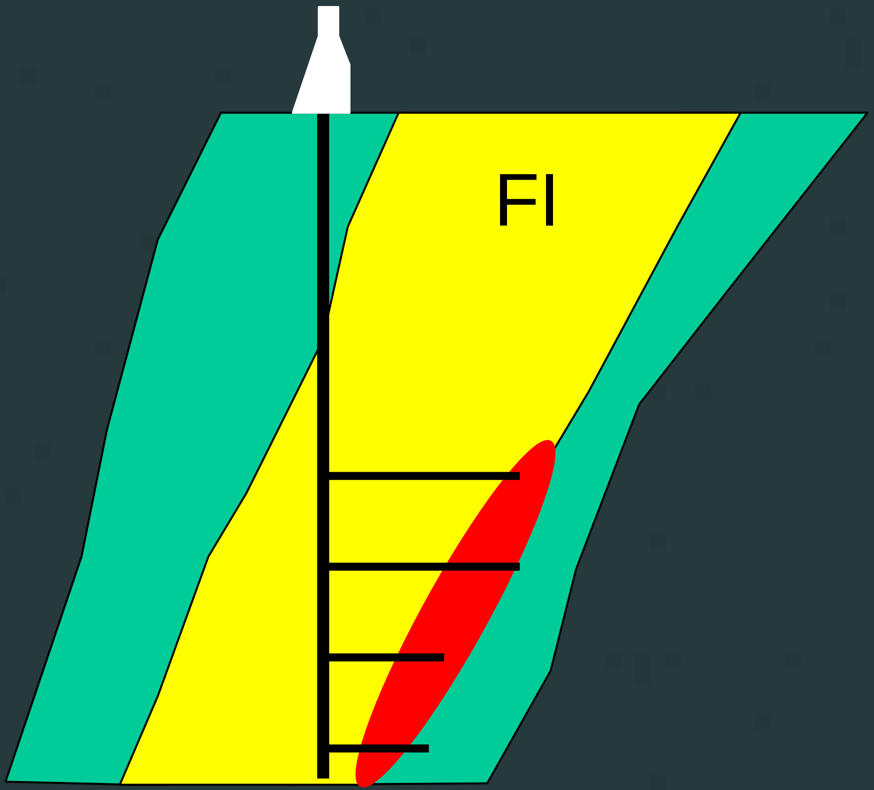
FI FII FII

État des connaissances

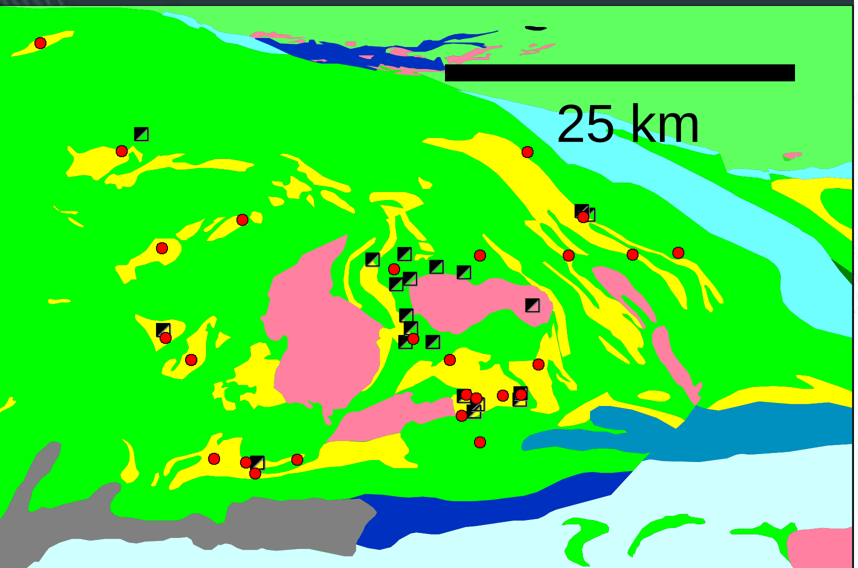
Stérile
FI = Stérile

Fertile
FI = Stérile ?

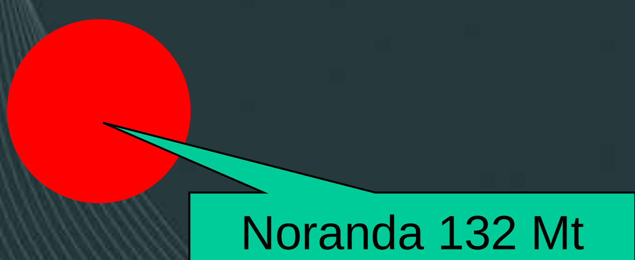


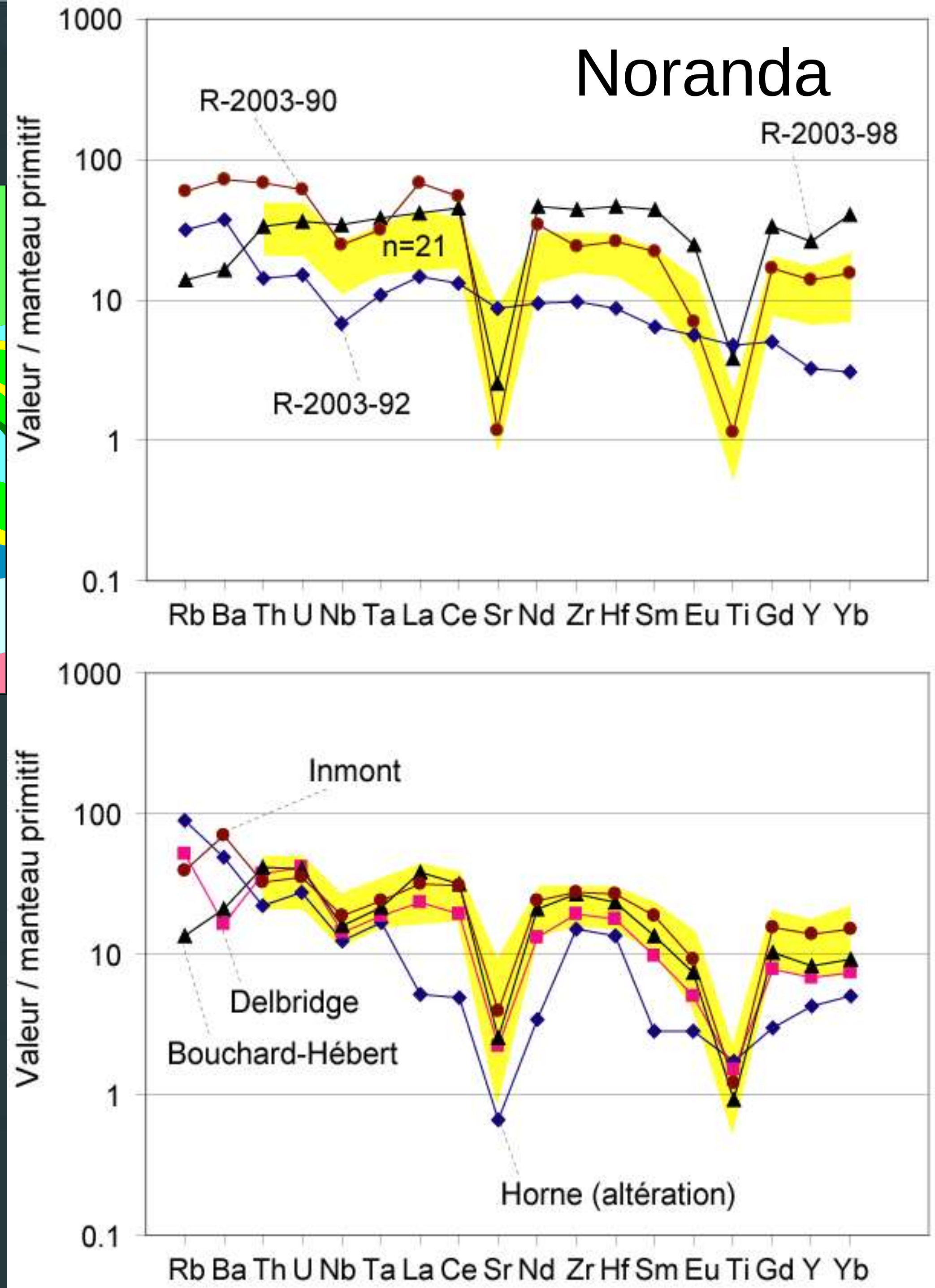


Camp Noranda

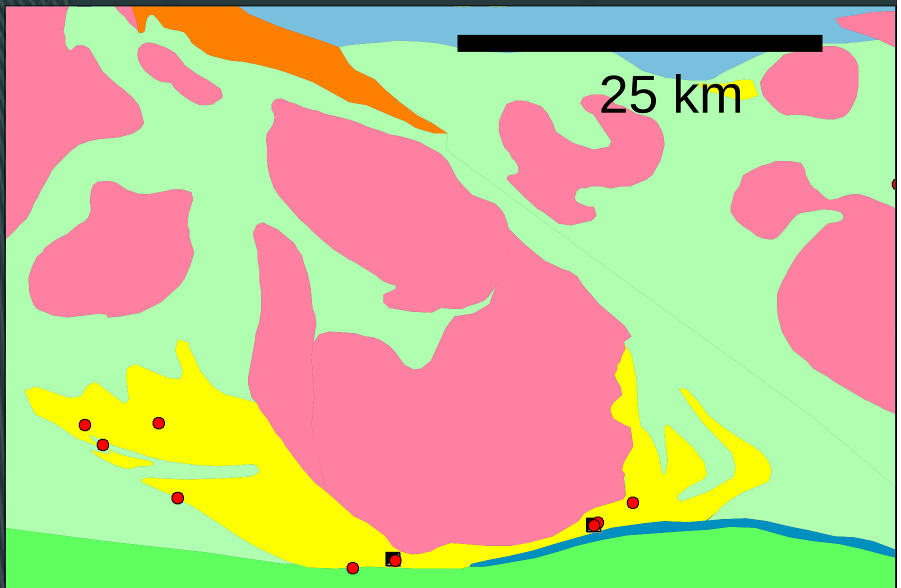


FIIIa: fertile
Homogène sur
Territoire de 2000 km²



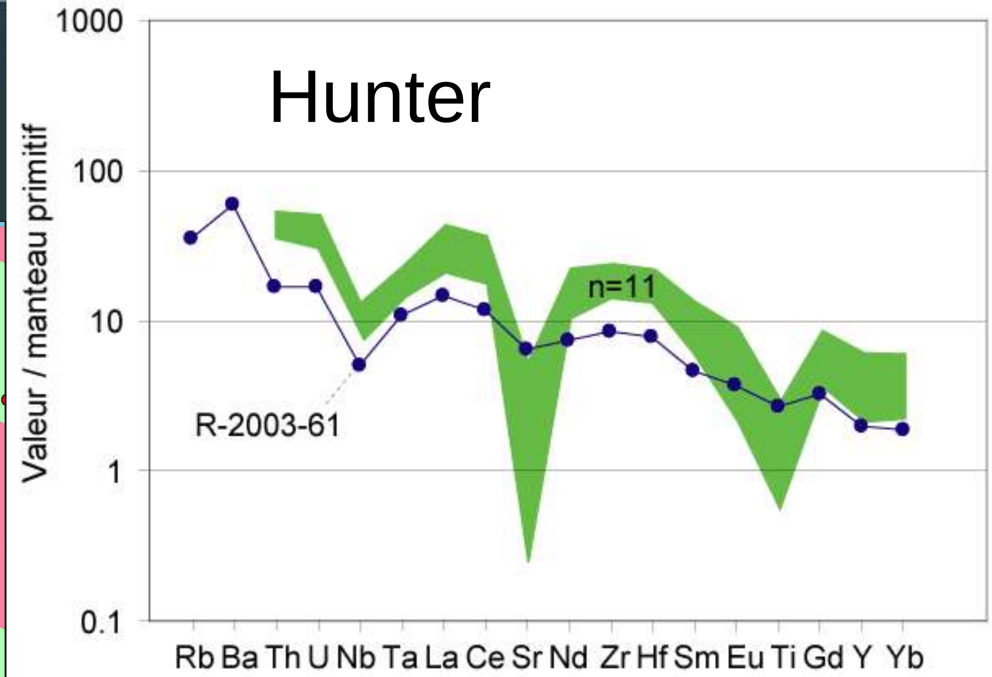


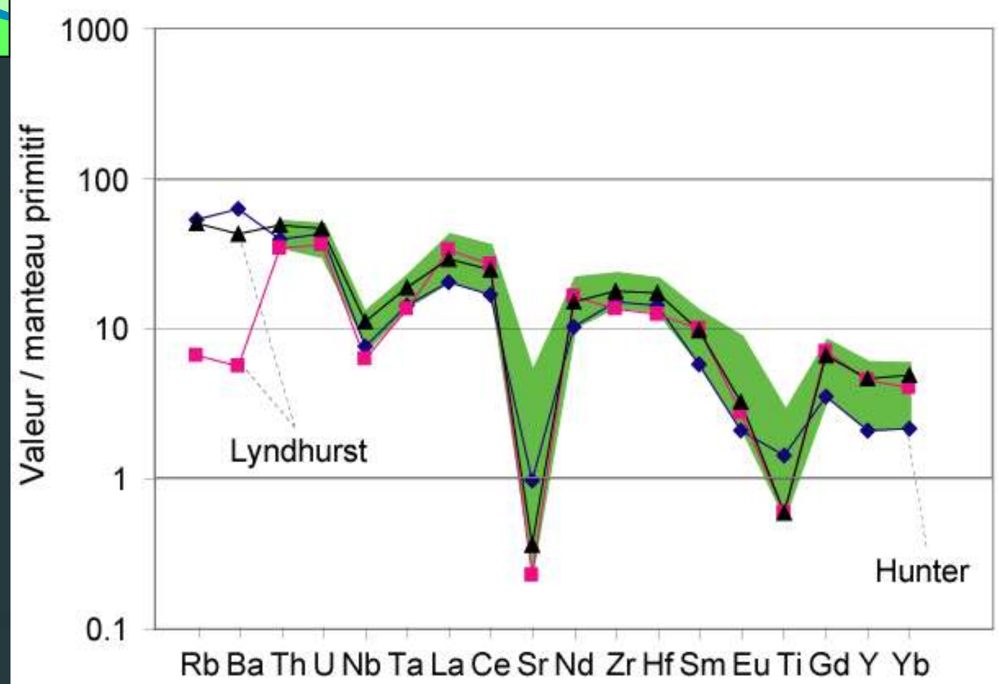
Camp Hunter



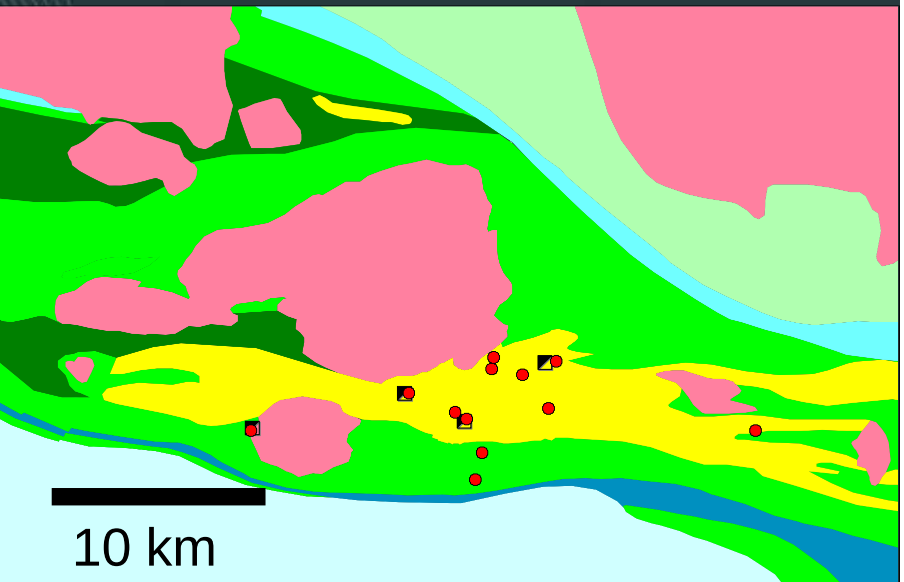
FII: peu fertile
Homogène sur
Territoire de 300 km²

Hunter: 2 Mt





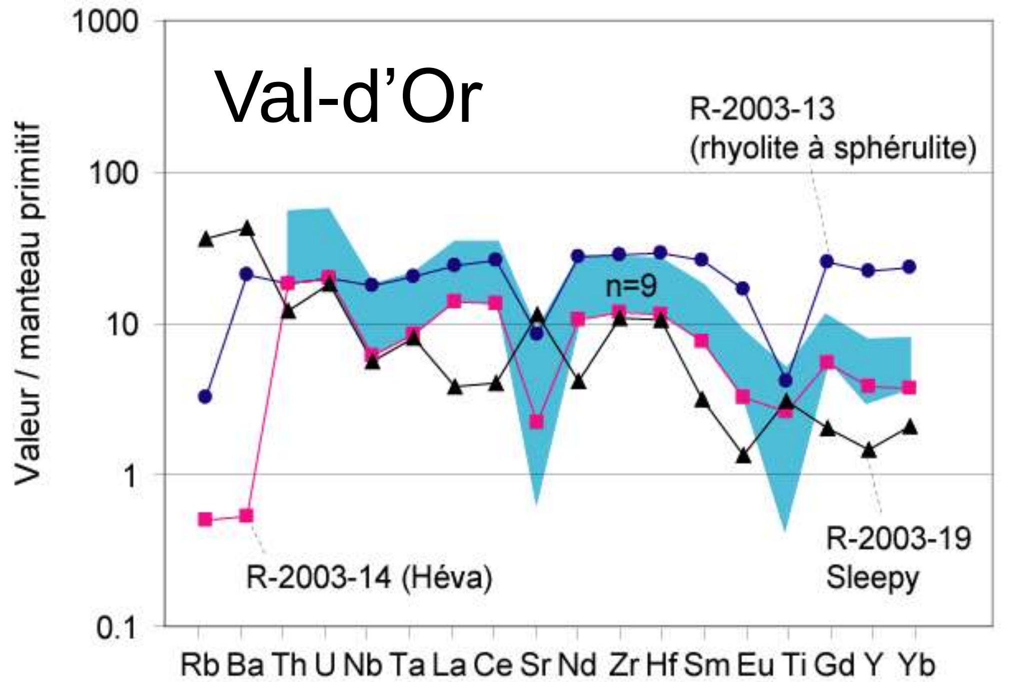
Camp Val d'Or

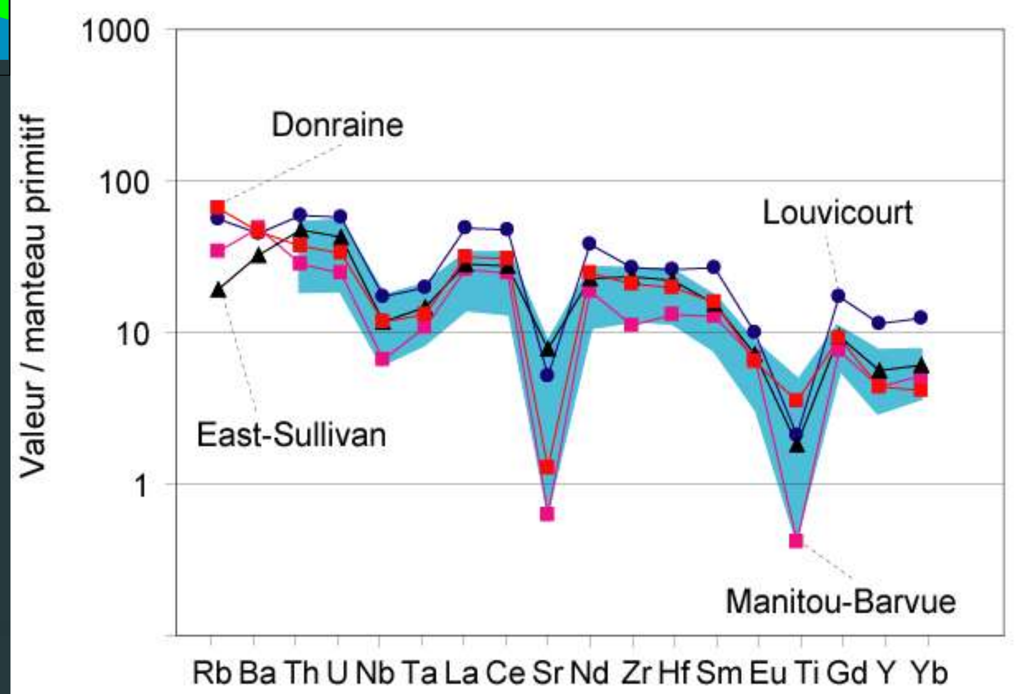


FII: fertile

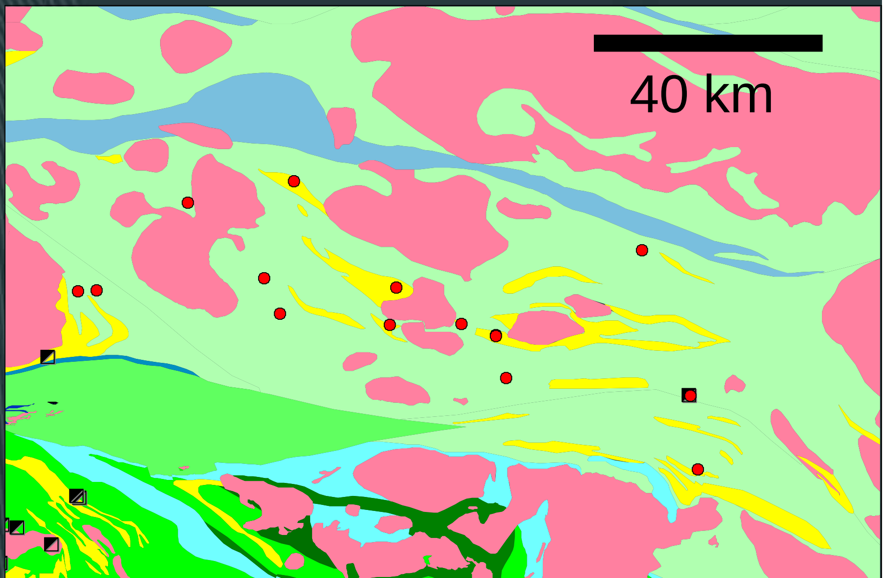
Territoire de 200 km^2

Val d'Or: 49 Mt





ZVN-ext

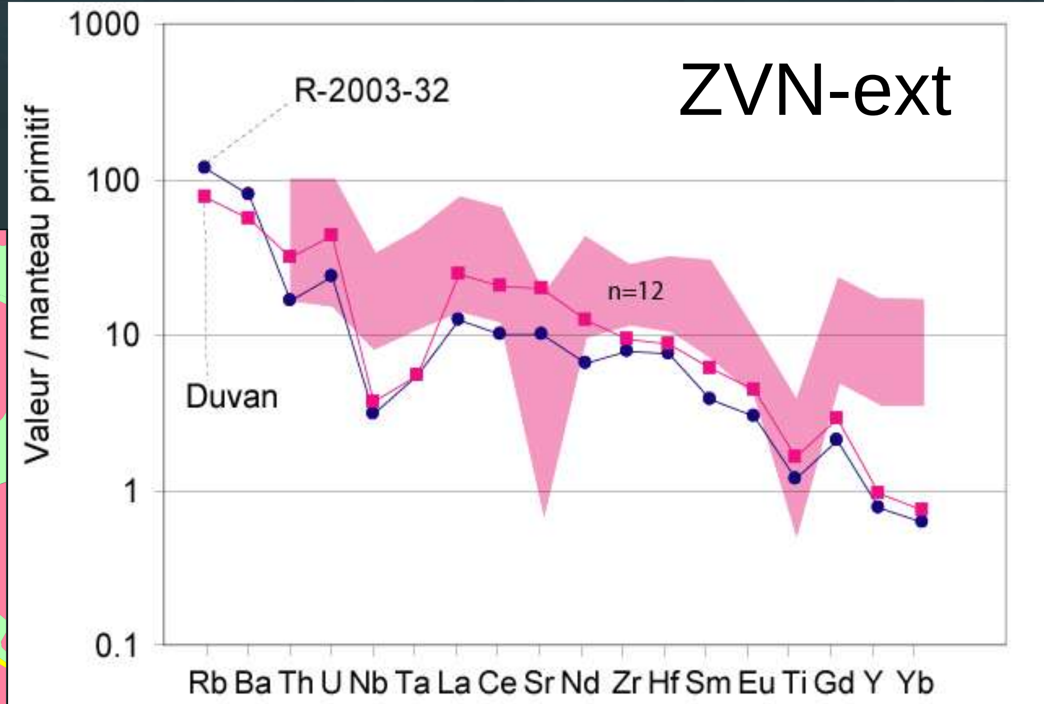


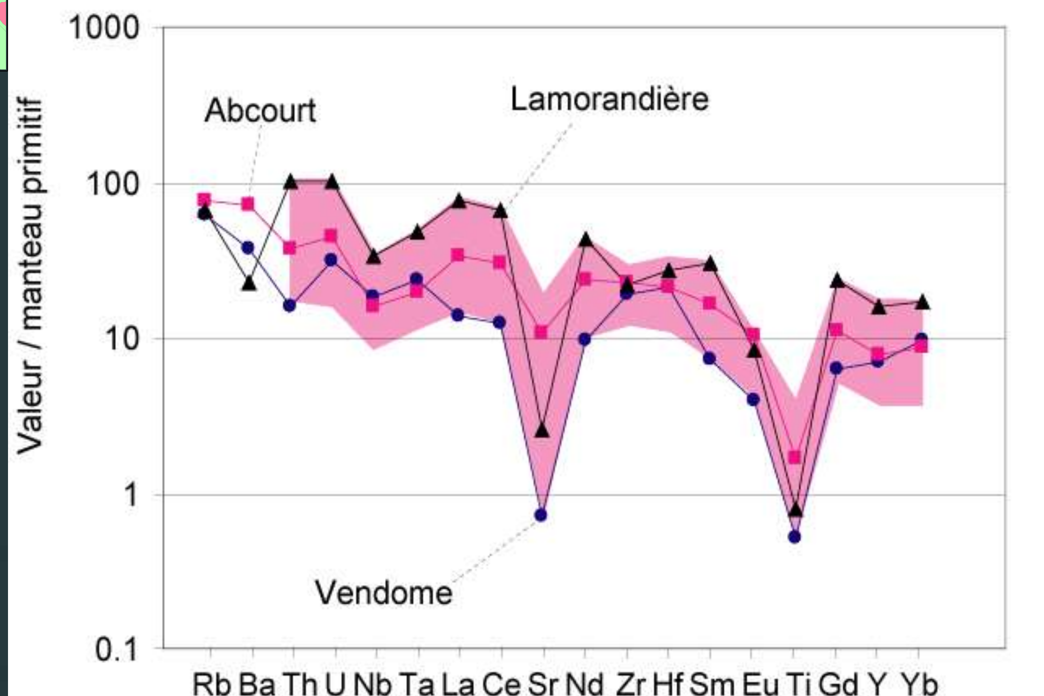
FII: peu fertile

Territoire immense

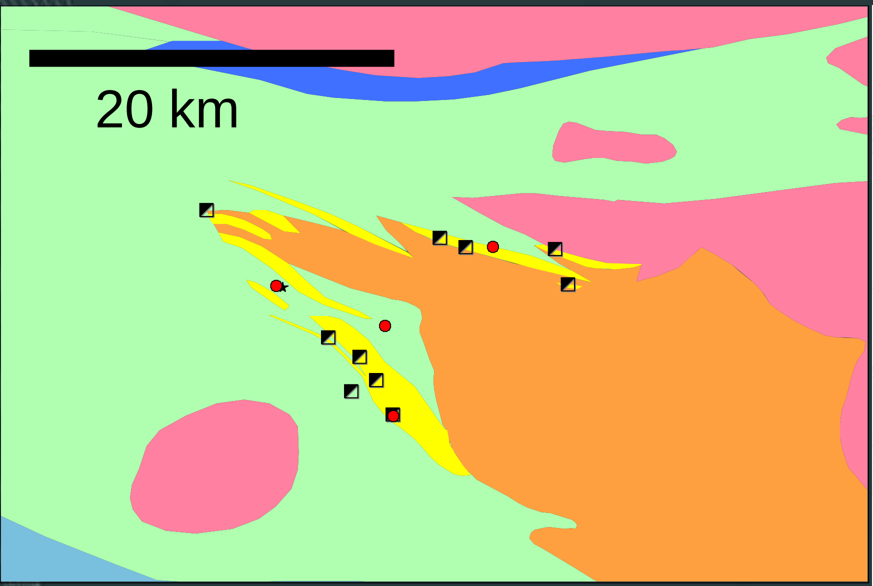
~ 5000 km^2

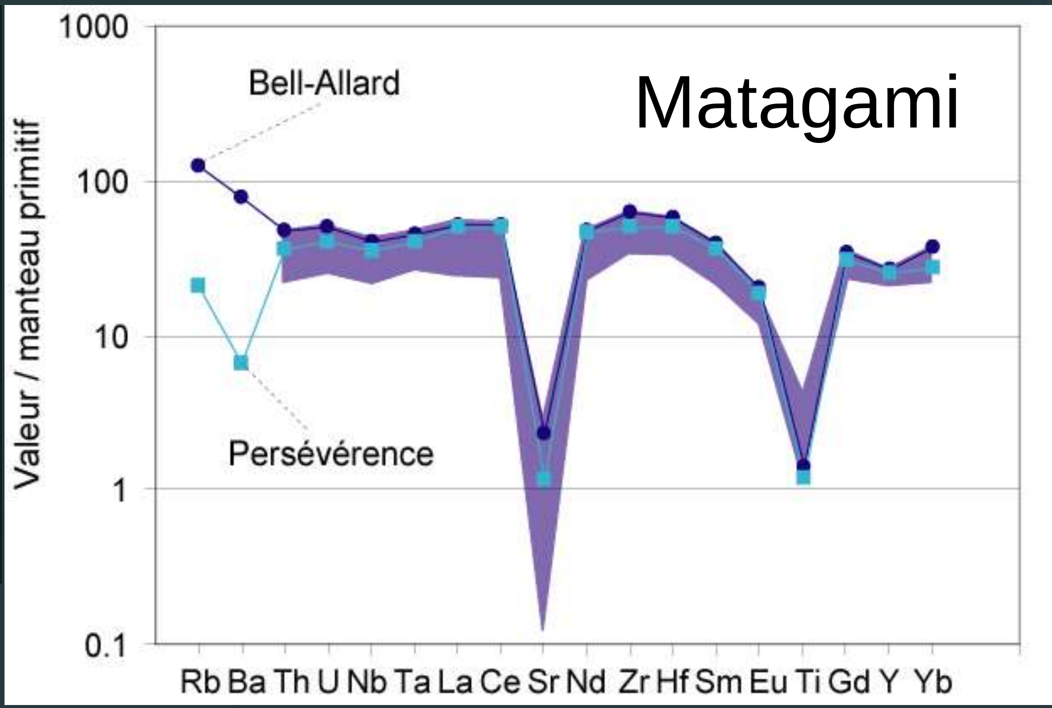
Barraute: 10 Mt





Camp Matagami

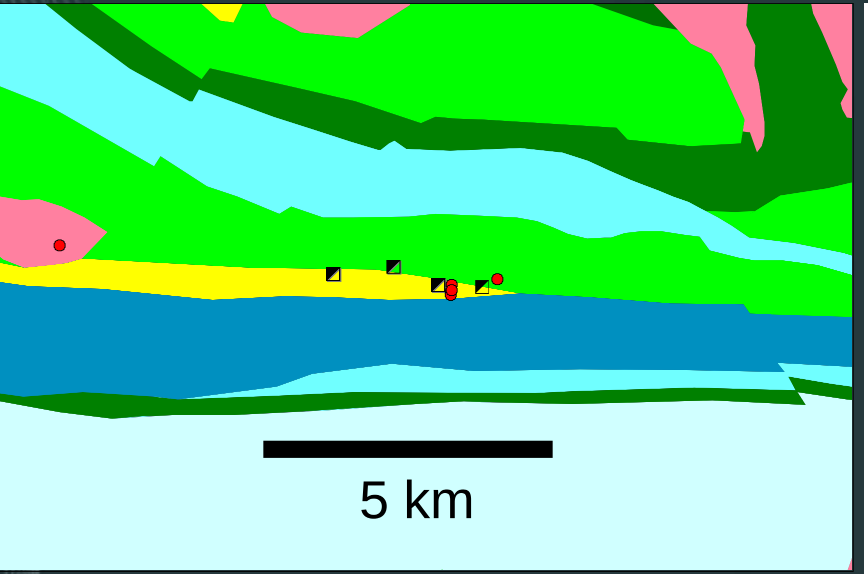


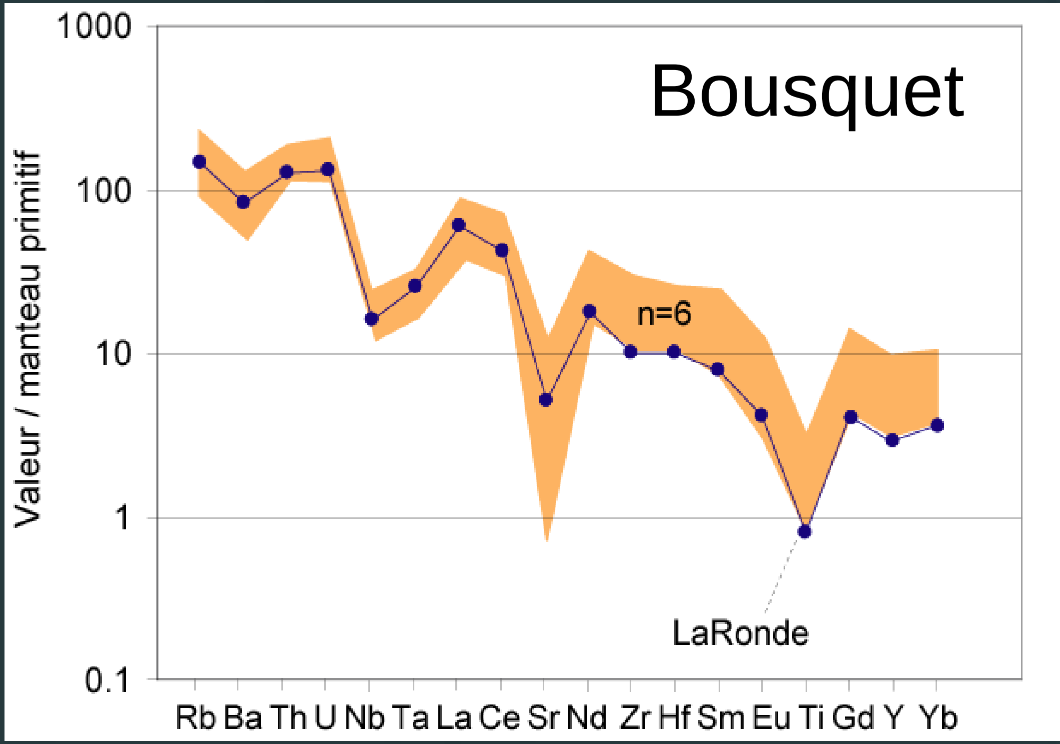


FIIIa: Très fertile
Homogène
Territoire de 100 km^2

Matagami 50 Mt

Camp Bousquet

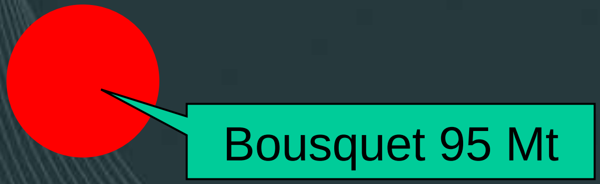




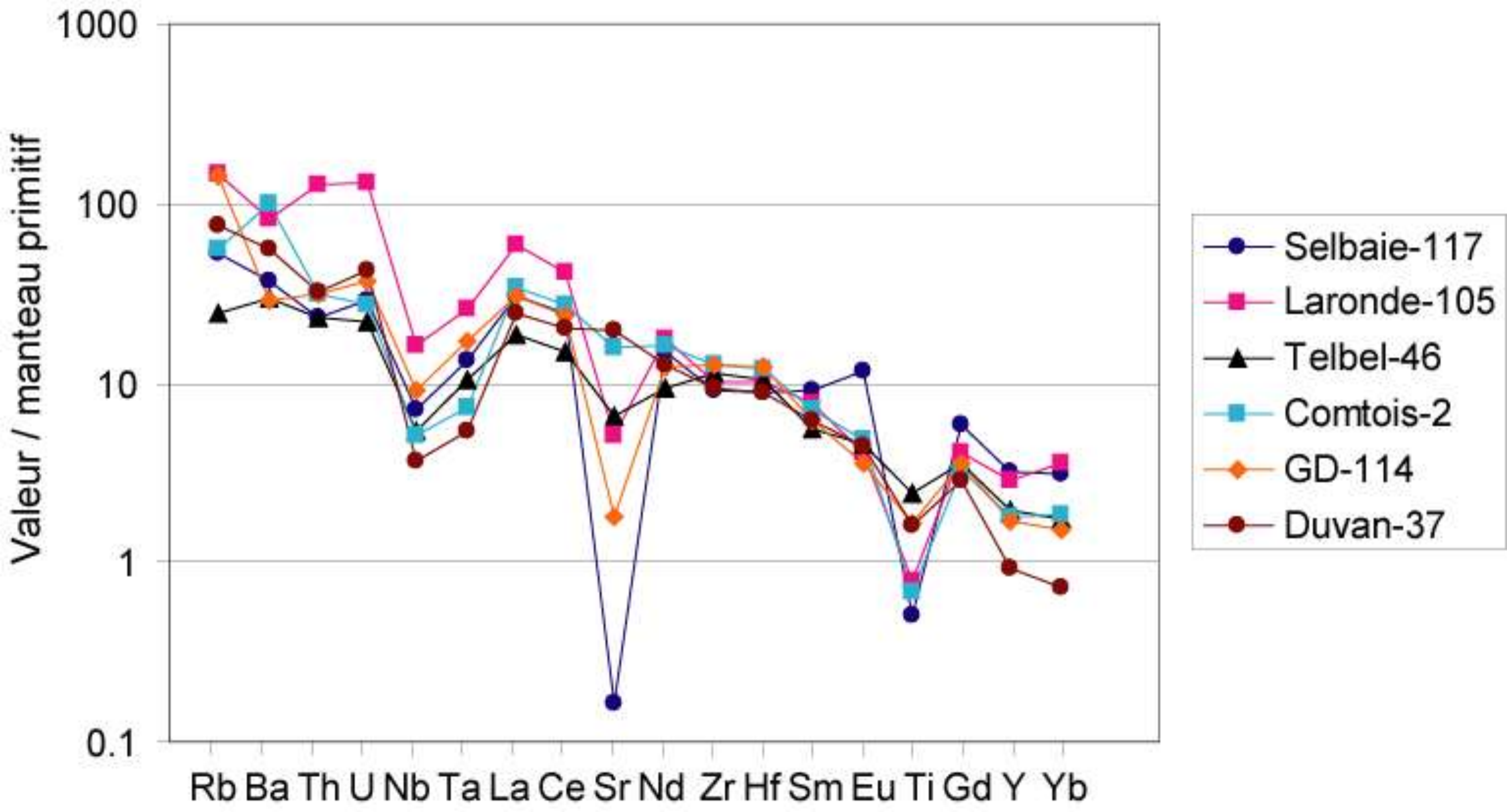
FI: Très fertile

Territoire minuscule

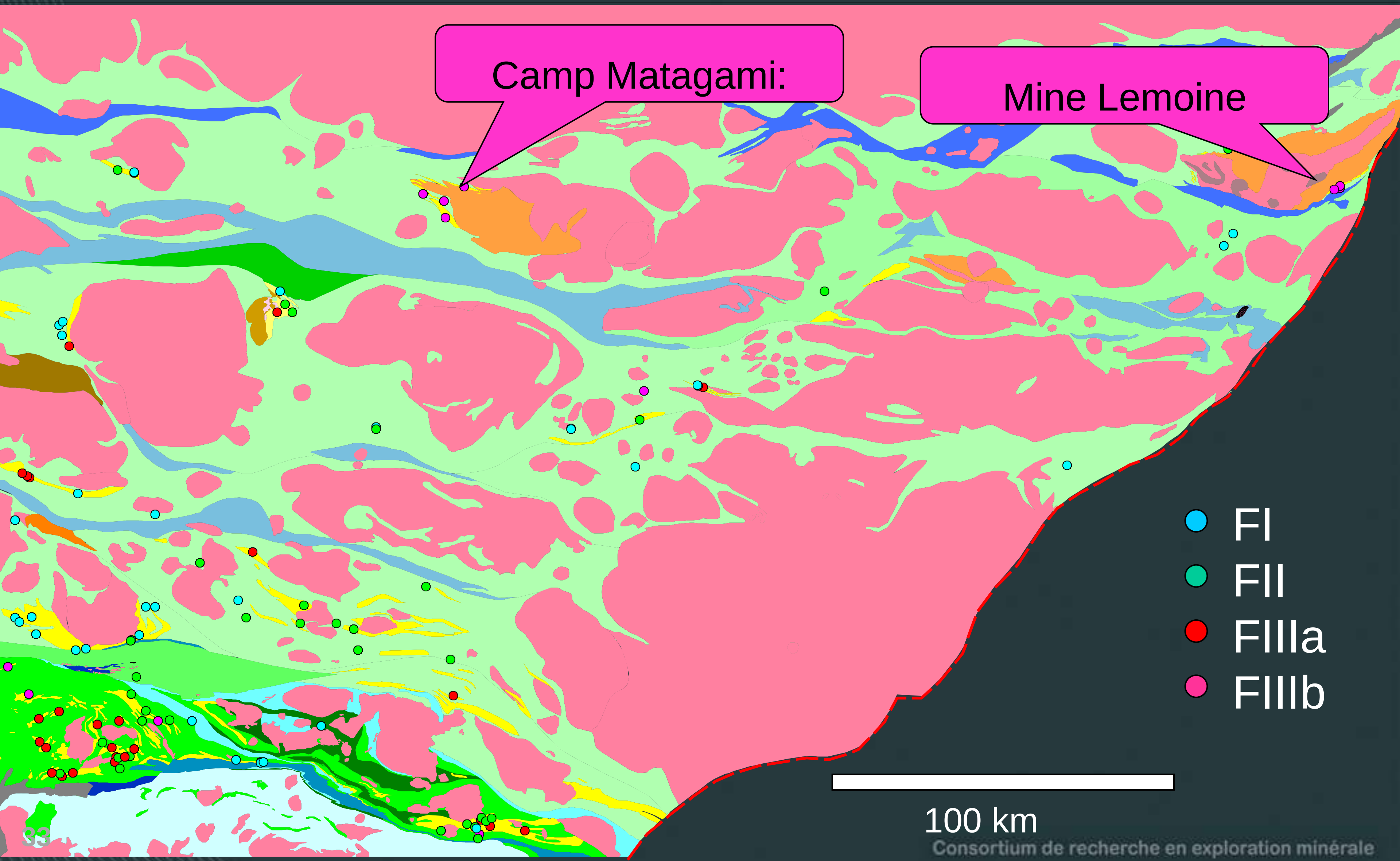
~ 20 km^2



Voilà les FI minéralisées

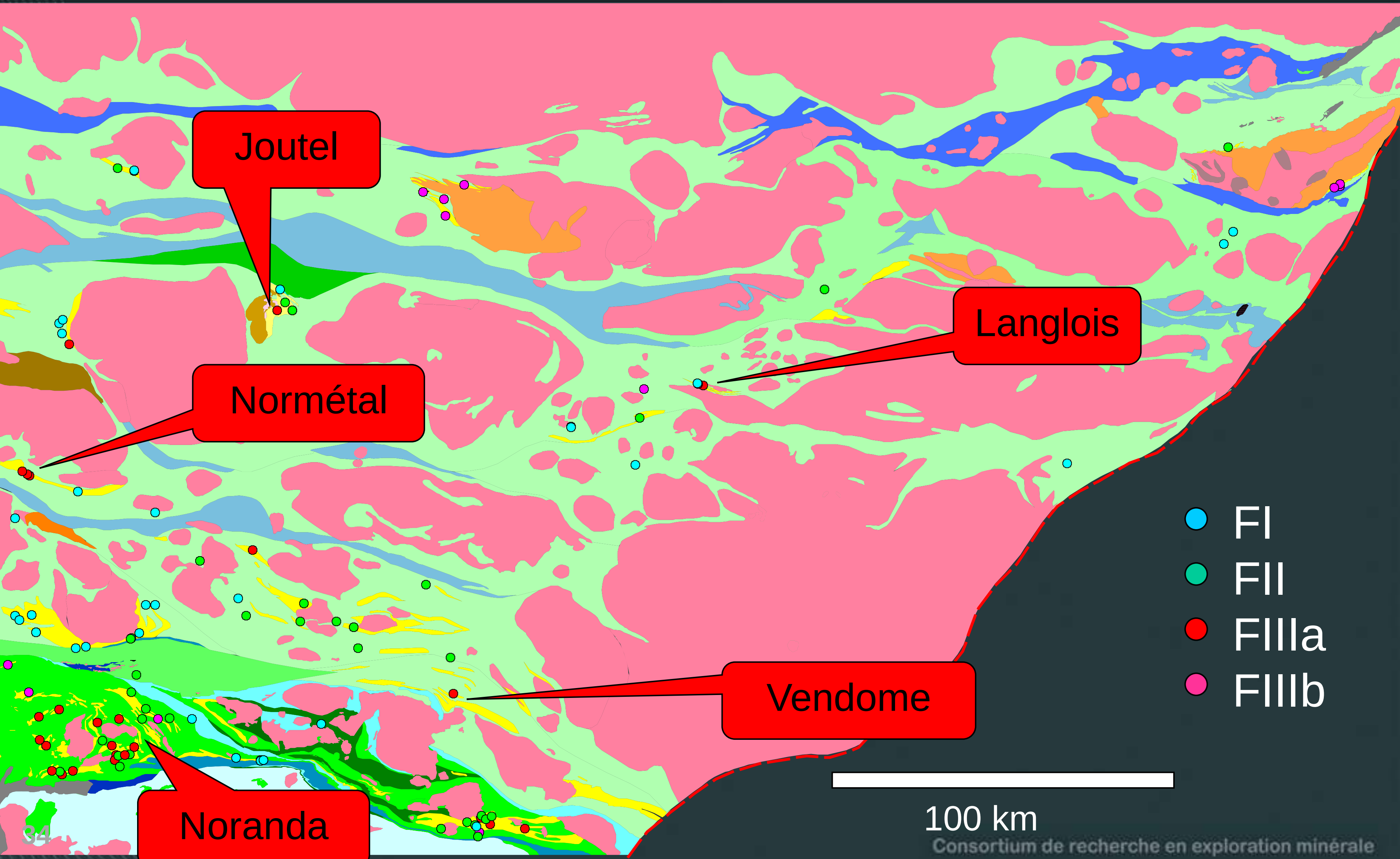


FIIIb: Camps et mines

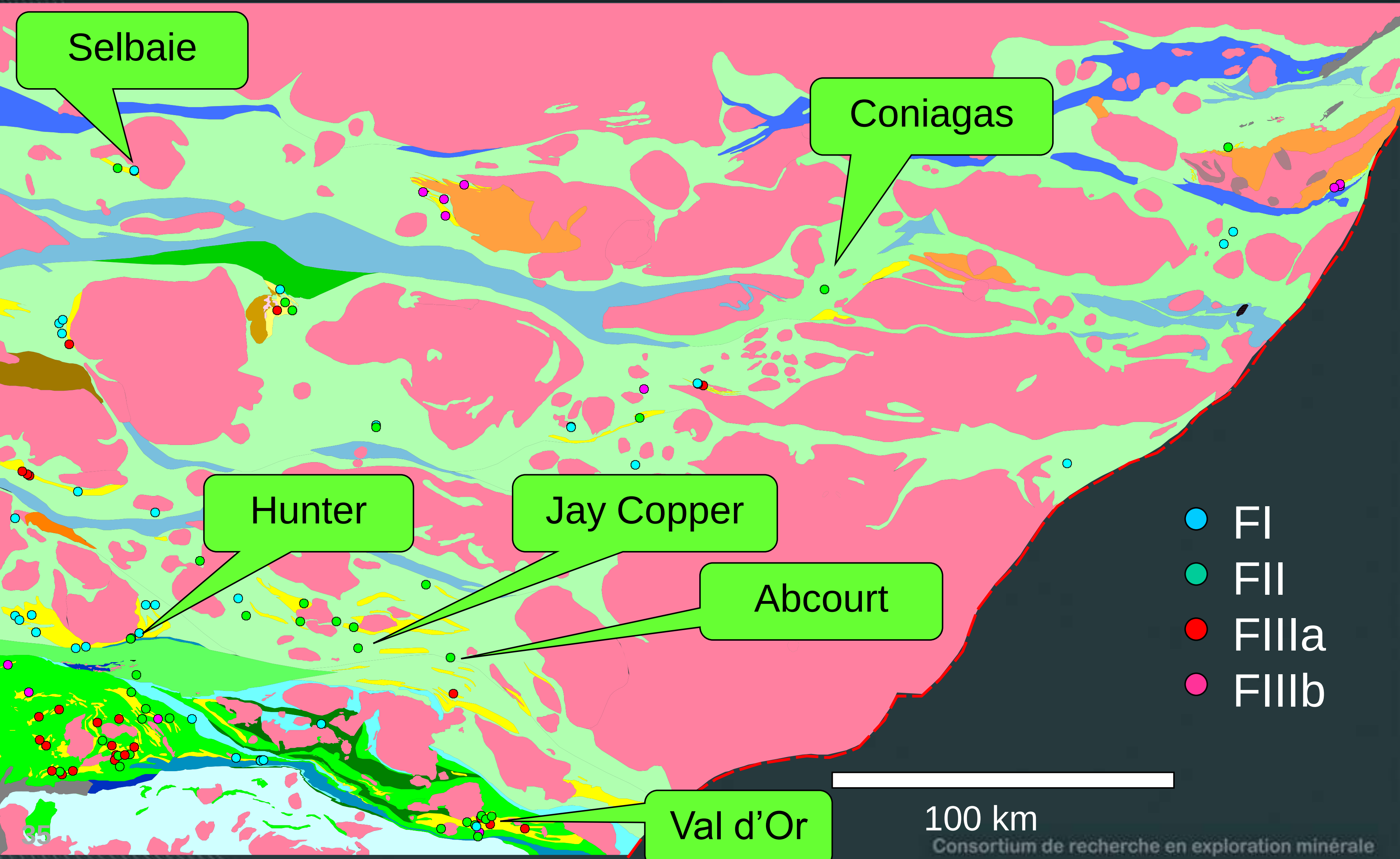


CONSOREM 10 ans

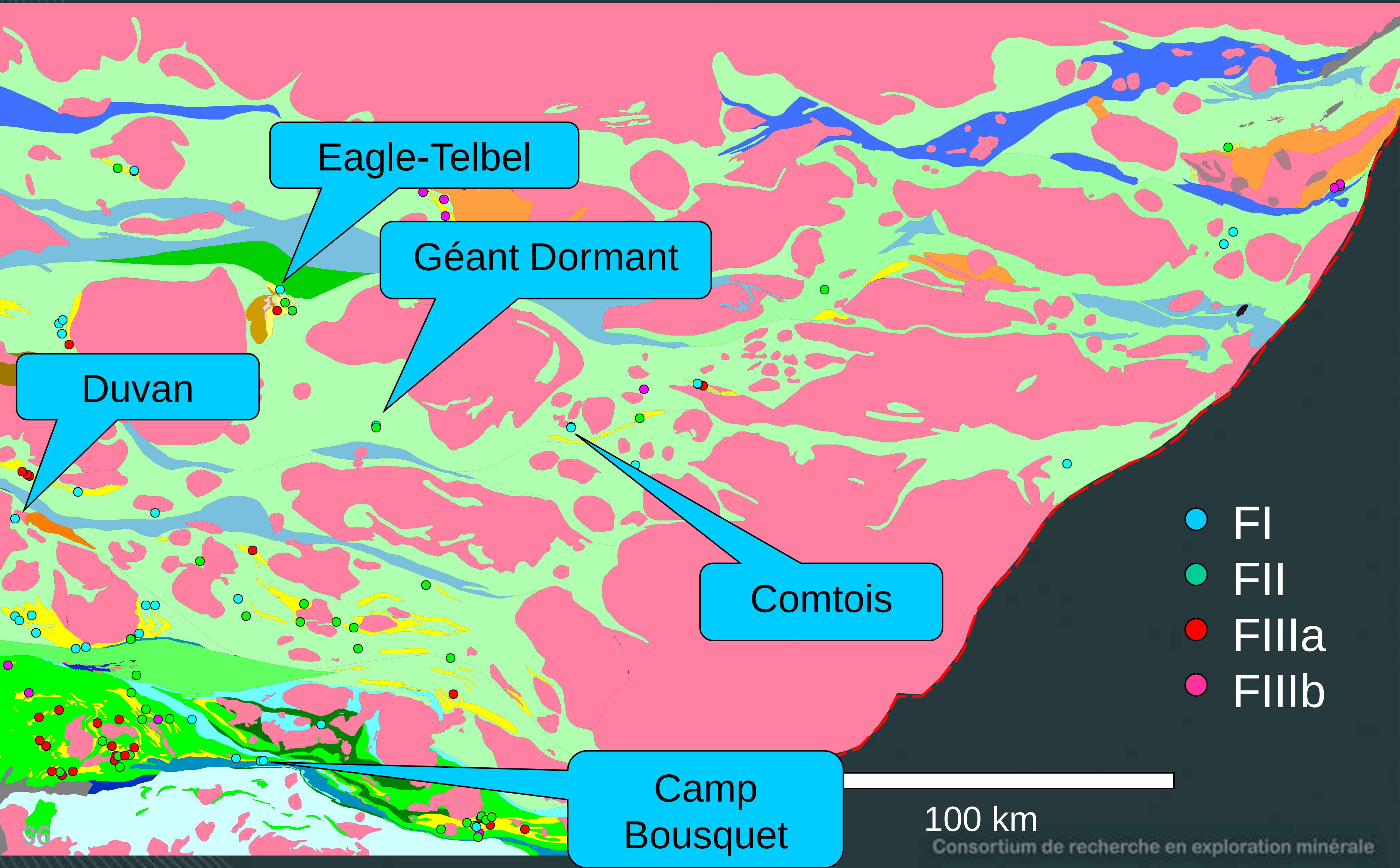
FIIIa: Camps et mines



FII: Camps et mines



FI: Classification



Le problème des FII

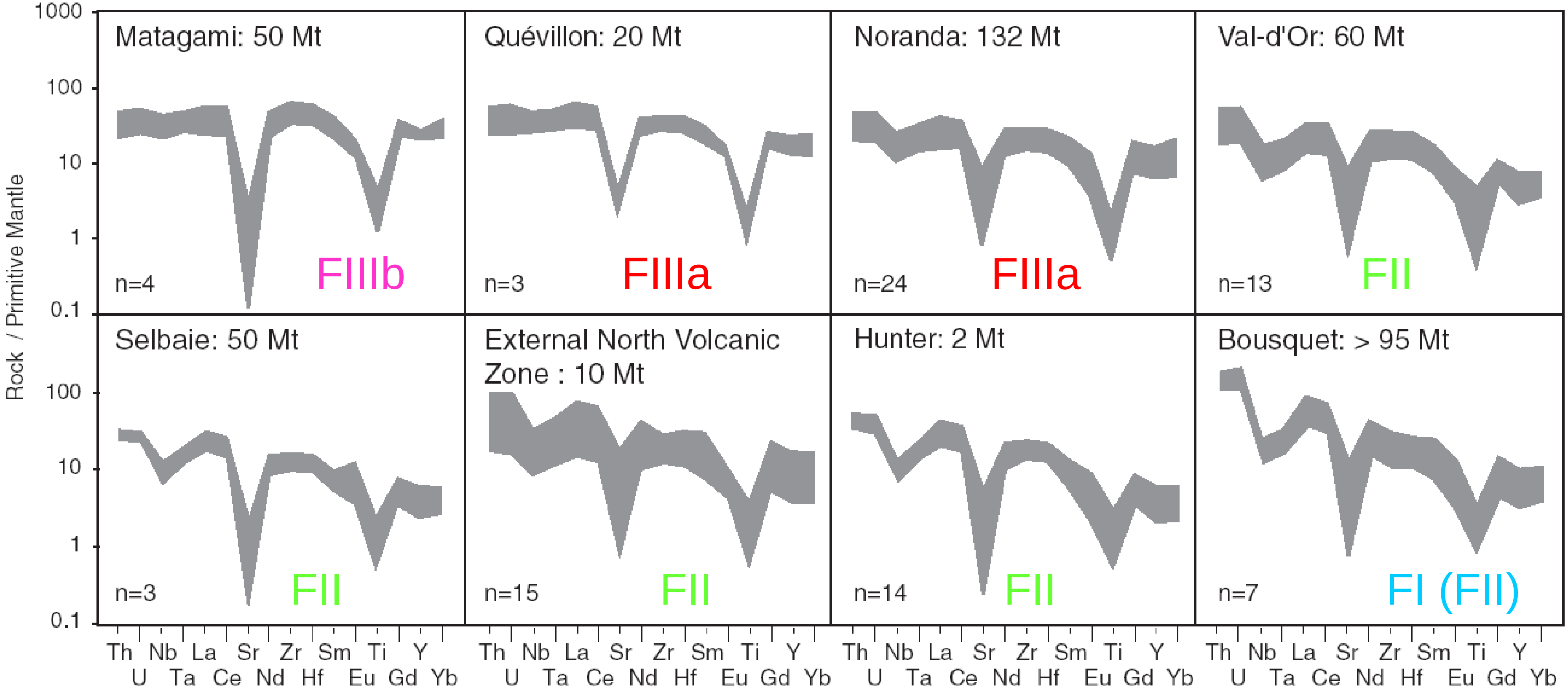


FIG. 11. Summary multielement plots normalized to primitive mantle (Sun and McDonough, 1989) for felsic volcanic rocks from mining districts, showing ore tonnages (production and reserve) in millions of metric tons (Mt).

Gaboury et Pearson, 2008

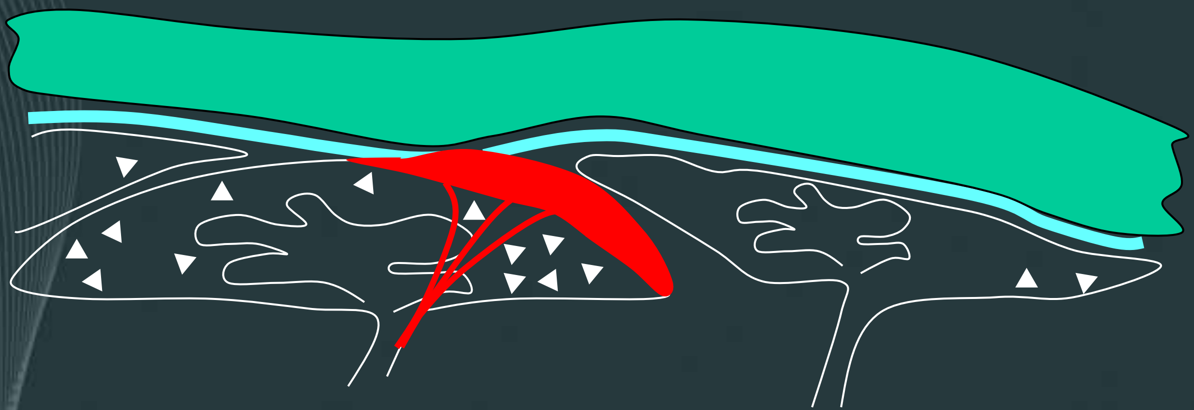
CONSOREM 10 ans

TABLE 3. Style of Volcanism and Mineralization Associated with Different Rhyolite Types

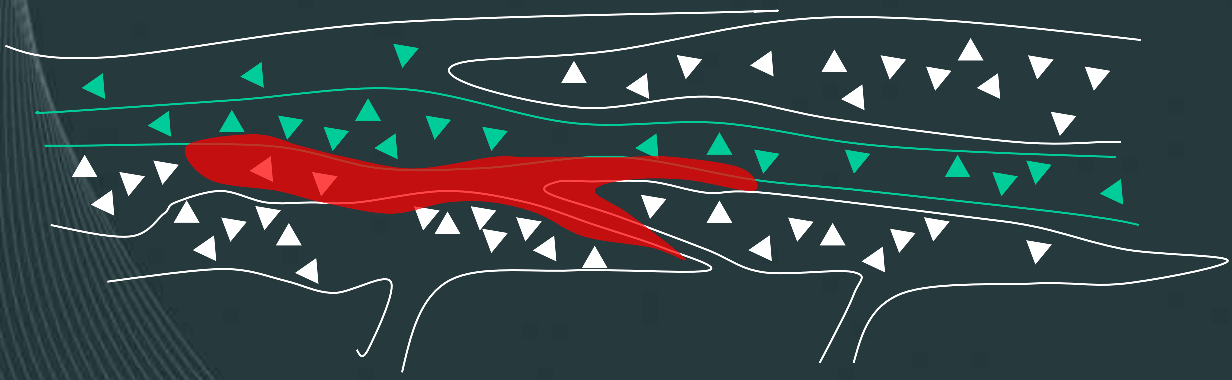
Group	Volcanism style	Mineralization style
FIII	Bimodal Low volatile content Domes and flows Low vesicularity index Few volcaniclastic rocks Exhalite-chert: common	Exhalative stratiform lenses High grade, low tonnage Cu-Zn ± Ag ± Au Discrete alteration pipe and Cu-rich stringer zone Examples: Quémont, Mattagami Lake, Ansil
FII	Similar to FIII-type	Similar to "FIII-type" Examples: Lyndhurst, Hunter mine, Gemini
	Similar to FI-type	Similar to "FI-type" Examples: Selbaie, Manitou-Barvue
FI	Continuum basalt to rhyolite Abundance of volcaniclastic rocks High vesicularity Exhalite-chert: absent	Atypical Cu-Au veins, disseminations and replacement of permeable volcaniclastic rocks Diffuse alteration Examples: Laronde, Bousquet 1 and 2, Comtois

Gaboury et Pearson, 2008

Implications pour exploration

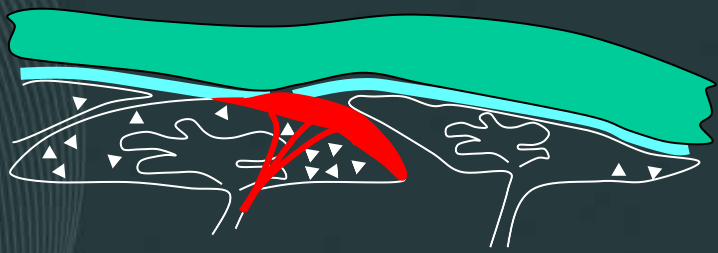


Type Noranda
FIII
Bimodale
Dômes massif
SMV-exhalaison
Chert



Type « Bousquet »
FI - FII
Continuum volcanique
Fragmentaire, vésiculaire
SMV-remplacement
Pas chert

Implications pour exploration FII



FIII

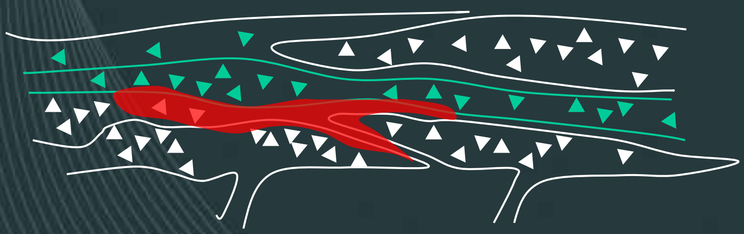
1. Chert, BIF et sédiments
2. Bimodale
3. Pas –peu vésicule et peu de fragment

Hunter
Turgeon
ZVN-ext

FII

Val d’or
Selbaie

1. Pas de chert, pas sédiment
2. Vésiculaire et fragmentaire,
3. séquence de fractionnement continue



FI

Conclusion

- FIIIb: Tholéiitique, unique à l'archéen (Matagami), très fertile (amas massif du type Noranda)
- FIIIa: Tholéiitique, petits centres felsiques du nord et camp de Noranda, très fertile (amas massif du type Noranda)
- FII: Transitionnel à calco-alcalin, "le bruit le fond volcanique": il faut considérer la volcanologie.
- FI: Calco-alcalin, très fertile, minéralisations différentes (aurifère): veine, dissémination, remplacement, etc.