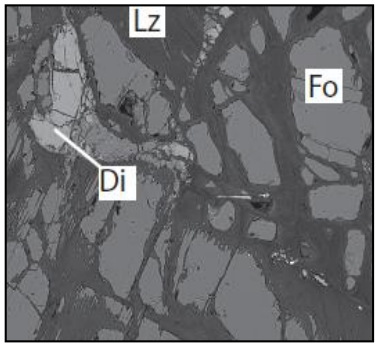
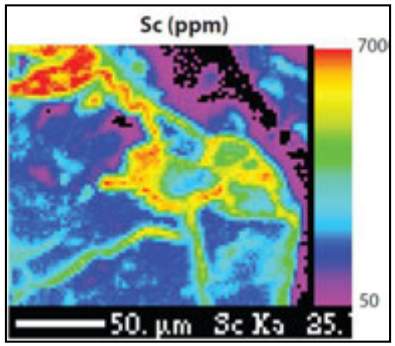
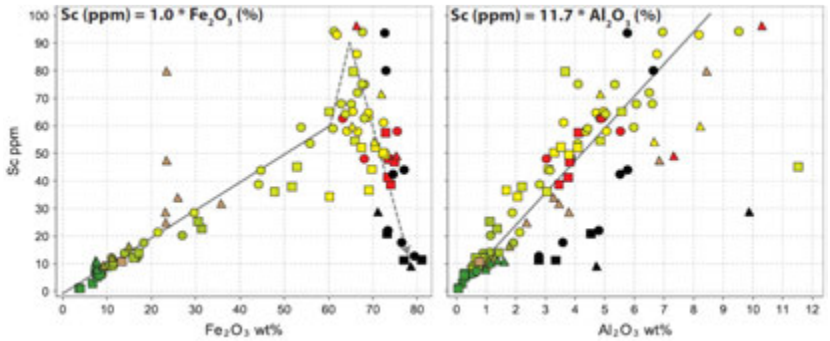
Géochimie et minéralogie du scandium dans les latérites



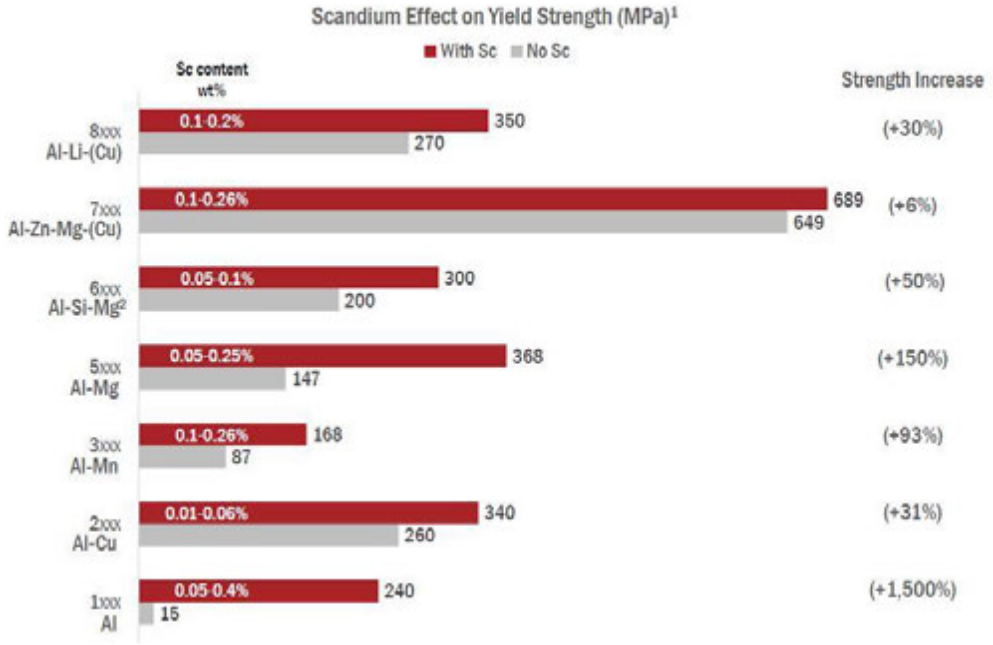


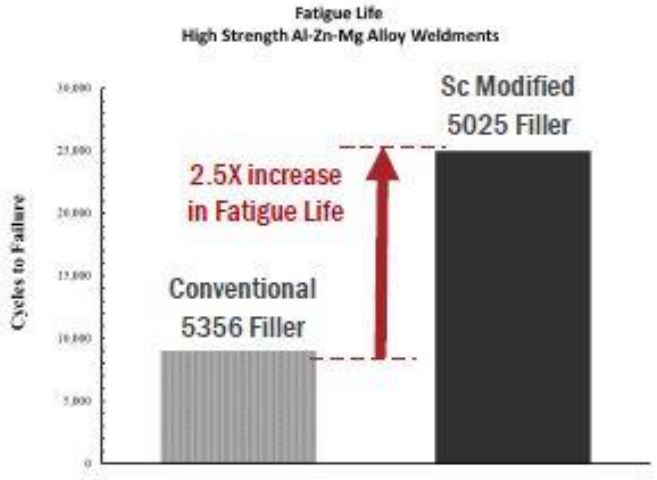


➢ Industrie moderne et applications du Sc

- **Alliages Al-Sc (< 1wt% Sc)**

Industrie aéronautique, équipements haut de gamme. Améliore considérablement la résistance au stress, température, corrosion.





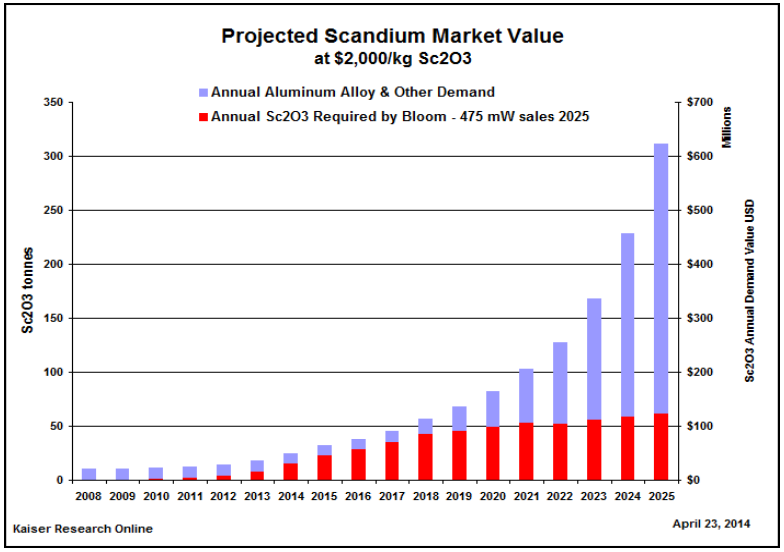
- **Remplace l'Yttrium dans les SOFCs**

« solid oxide fuel cells »

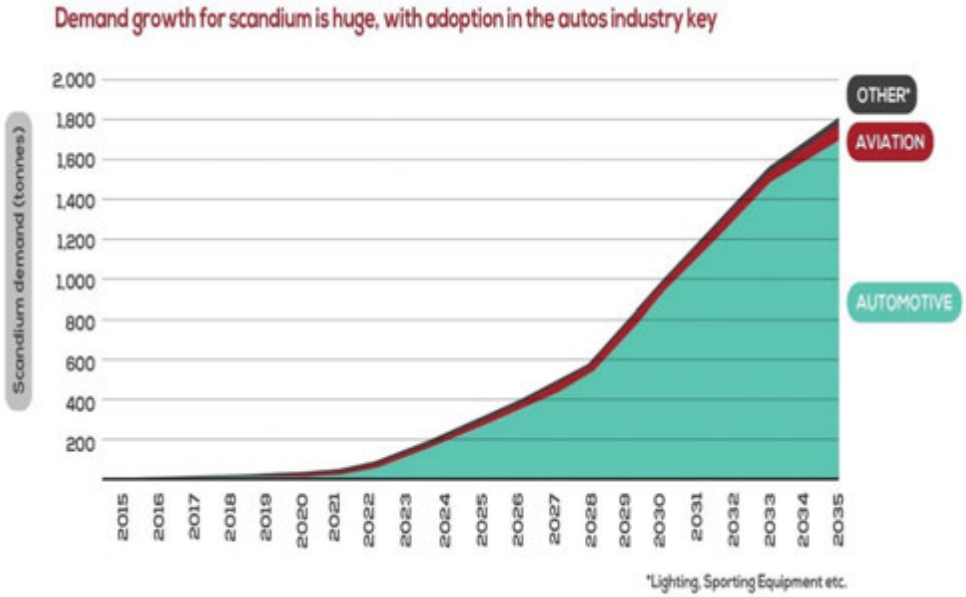
- **Éclairages haute-température** (stades…)

“Game changer” pour l’industrie ?

- Pas (encore) de mines, pas de marché, sous-produit de U, W (Chine)
- Potentiel pour fort accroissement de la demande



- ➢ Si 1% des alliages Al utilise Sc (à 0.2% Sc) => nécessiterait, selon usage actuel, 167 t/an Sc2O3, juste pour les marchés US et européens.
- ➢ Si 10% par an d’augmentation de l’utilisation de Al pour véhicules, dont 1% alliages Al-Sc (1.5 kg Sc2O3 par voiture), nécessitera 433 t/an Sc2O3 en 2025.



- Plusieurs projets miniers en développement (Australie) : Latérites sur roches mafiques - ultramafiques

Prix du Scandium

- Pas de marché officiel du Sc, négociation entre parties privées
- 10/15 tonnes par an

Salient Statistics—United States:	**2013**	**2014**	**2015**	**2016**	**2017[e]**
Price, yearend, dollars:					
Compounds, per gram:					
Acetate, 99.9% purity, 5-gram sample size[2]	51.90	43.00	43.00	44.00	44.00
Chloride, 99.9% purity, 5-gram sample size[2]	148.00	123.00	123.00	126.00	124.00
Fluoride, 99.9% purity, 1-to-5-gram sample size	[2]253.00	[2]263.00	[2]263.00	[3]270.00	277.00
Iodide, 99.999% purity, 5-gram sample size[2]	228.00	187.00	187.00	149.00	183.00
Oxide, 99.99% purity, 5-kilogram lot size[4]	5.00	5.00	5.10	4.60	4.60
Metal:					
Scandium, distilled dendritic, per gram, 2-gram sample size[2]	213.00	221.00	221.00	228.00	226.00
Scandium, ingot, per gram, 5-gram sample size[2]	175.00	134.00	134.00	107.00	132.00
Scandium-aluminum alloy, per kilogram, metric-ton lot size[4]	155.00	386.00	220.00	340.00	350.00
Net import reliance[5] as a percentage of apparent consumption	100	100	100	100	100

Recycling: None.

Source : USGS

⇒ **Sc2O3 (99,99%) = 4 600 000 $/tonne = 317x Ni stock price (14 500 $ tonne)**

Prix du Scandium

Source	Time	HEAVY RARE EARTH METALS		Last Price	% Week	% Year	31.Dec.2017	Units
mineralprices.com	31 Dec 2017	Europium Oxide ≥ 99.99%	0.0	150.00	0.0%	0.0%	150.00	US$/kg
mineralprices.com	31 Dec 2017	Gadolinium metal 99.9%	0.0	55.00	0.0%	0.0%	55.00	US$/kg
mineralprices.com	31 Dec 2017	Gadolinium Oxide ≥ 99.5%	0.0	32.00	0.0%	0.0%	32.00	US$/kg
mineralprices.com	31 Dec 2017	Terbium metal ≥ 99.9%	0.0	550.00	0.0%	0.0%	550.00	US$/kg
mineralprices.com	31 Dec 2017	Terbium Oxide ≥ 99.5%	0.0	400.00	0.0%	0.0%	400.00	US$/kg
mineralprices.com	31 Dec 2017	Dysprosium metal ≥ 99%	0.0	350.00	0.0%	0.0%	350.00	US$/kg
mineralprices.com	31 Dec 2017	Dysprosium Oxide ≥ 99.5%	0.0	230.00	0.0%	0.0%	230.00	US$/kg
mineralprices.com	31 Dec 2017	Erbium metal ≥ 99.9%	0.0	95.00	0.0%	0.0%	95.00	US$/kg
mineralprices.com	31 Dec 2017	Erbium Oxide ≥ 99.5%	0.0	34.00	0.0%	0.0%	34.00	US$/kg
mineralprices.com	31 Dec 2017	Yttrium metal ≥ 99.9%	0.0	35.00	0.0%	0.0%	35.00	US$/kg
mineralprices.com	31 Dec 2017	Yttrium Oxide ≥ 99.99%	0.0	6.00	0.0%	0.0%	6.00	US$/kg
mineralprices.com	31 Dec 2017	Scandium metal 99.9%	0.0	15,000.00	0.0%	0.0%	15,000.00	US$/kg
mineralprices.com	31 Dec 2017	Scandium Oxide ≥ 99.95%	0.0	4,200.00	0.0%	0.0%	4,200.00	US$/kg
mineralprices.com	31 Dec 2017	Mischmetal ≥ 99%	0.0	6.00	0.0%	0.0%	6.00	US$/kg

Source : Mineralprices.com

Un approvisionnement long-terme à prix abordables (1500-2000$/kg) sera nécessaire à une large adoption des alliages Al-Sc par l'industrie automobile dans le futur.

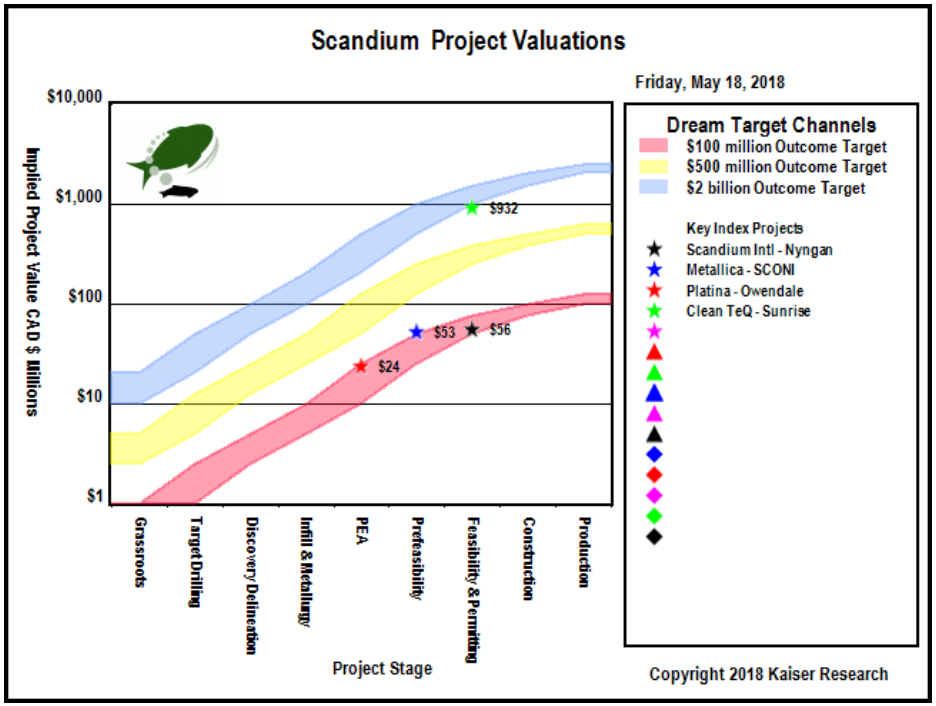
Projets Sc australiens

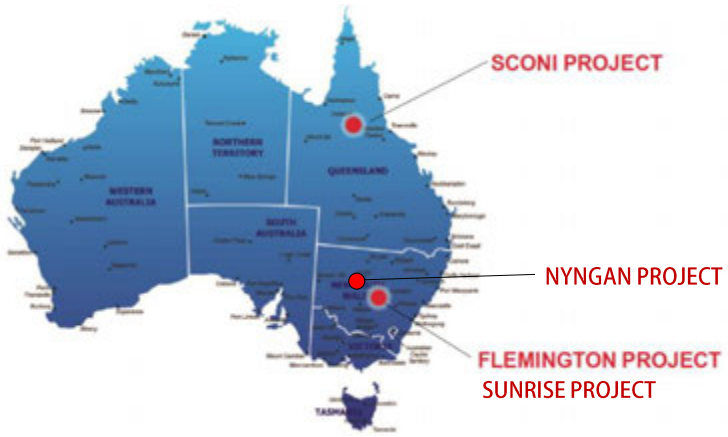
- **Laterites sur clinopyroxénite**

Teneurs en Sc jusqu'à 500-600 ppm

- **Ni-Co latérites sur péridotite**

Sc jusqu'à~100 ppm, sous-produit de Ni-Co





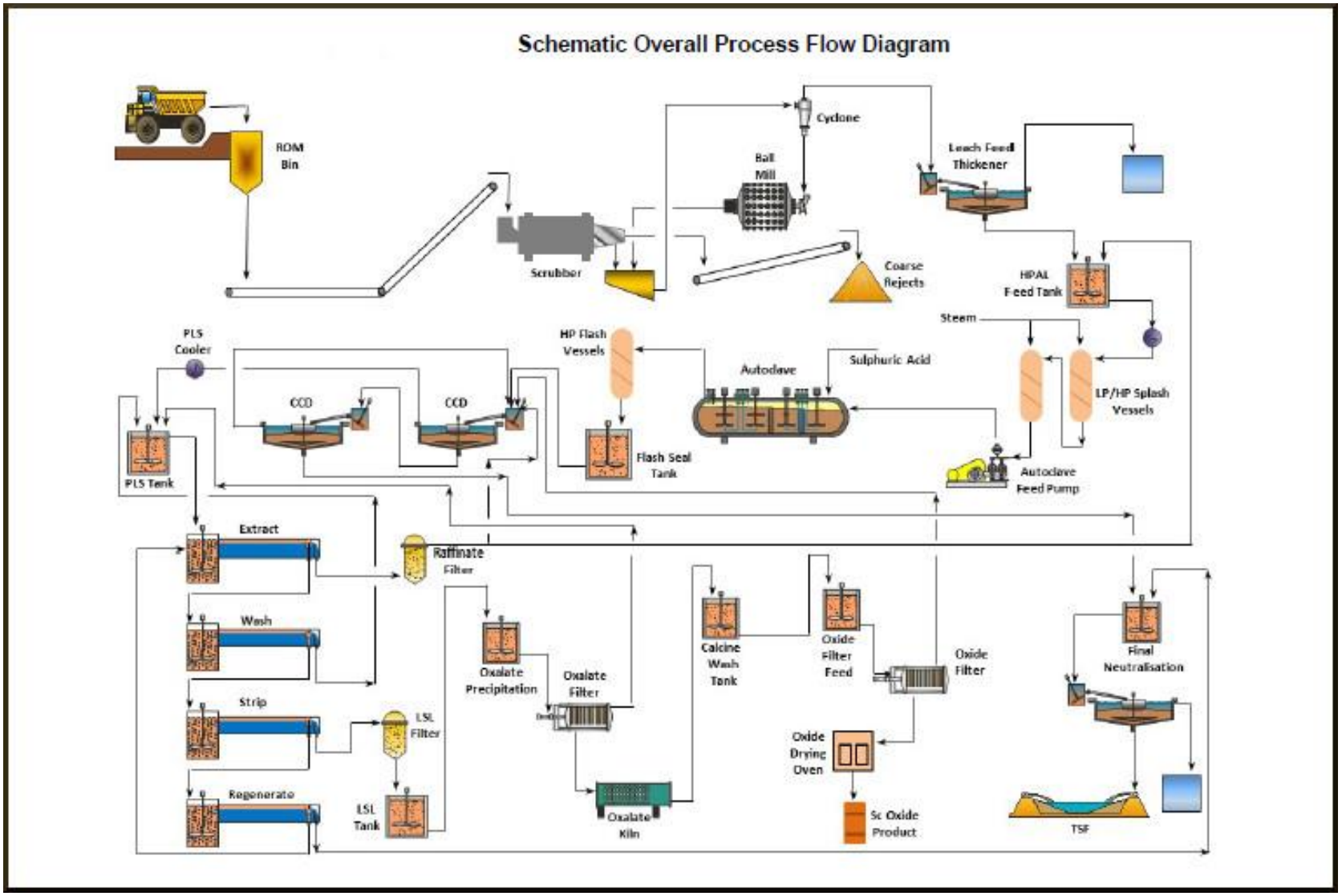
Sc enrichi dans Fe oxydes-oxyhydroxydes (car principalement immobile), co-extractible par procédés hydrométallurgiques.

⇒ 100 ppm Sc ~ 1 wt% Ni

Projet	Sunrise (ex Syerston)	Flemington	Nyngan	SCONI
Companie	Clean TeQ	Australian Mines	Scandium Int. Mining Corp.	Australian Mines
Ressource Sc	11,8Mt @ 419ppm (> 300ppm) 1,0Mt @ 670ppm (>600ppm)	3,1Mt @ 434ppm (>300ppm)	16,9Mt @ 235ppm (>100ppm) 1,44Mt @ 409ppm (>155 ppm)	12Mt @ 162 ppm (>100 ppm)
Planification	Étude de faisabilité en cours (prévu Juin 2018)	Pré-faisabilité en cours (mai 2018)	Production horizon 2020	Étude de faisabilité en cours

Nyngan

Accords commerciaux prévoyant de forunir, au plus tard à partir de décembre 2020, 225 tonnes/an d'alliages Al-Sc (pendant durée minimum 3 ans)

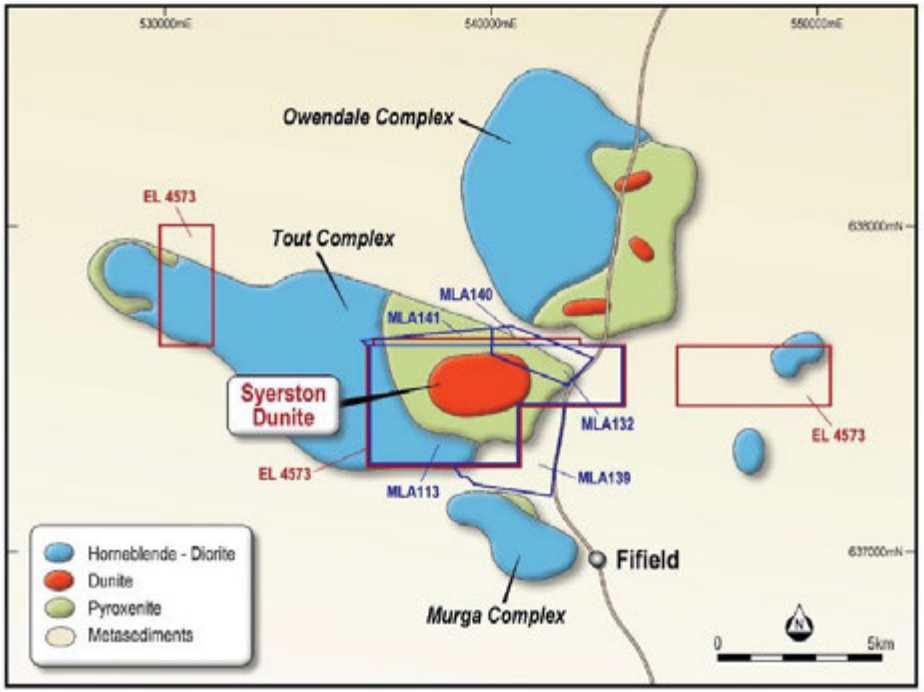


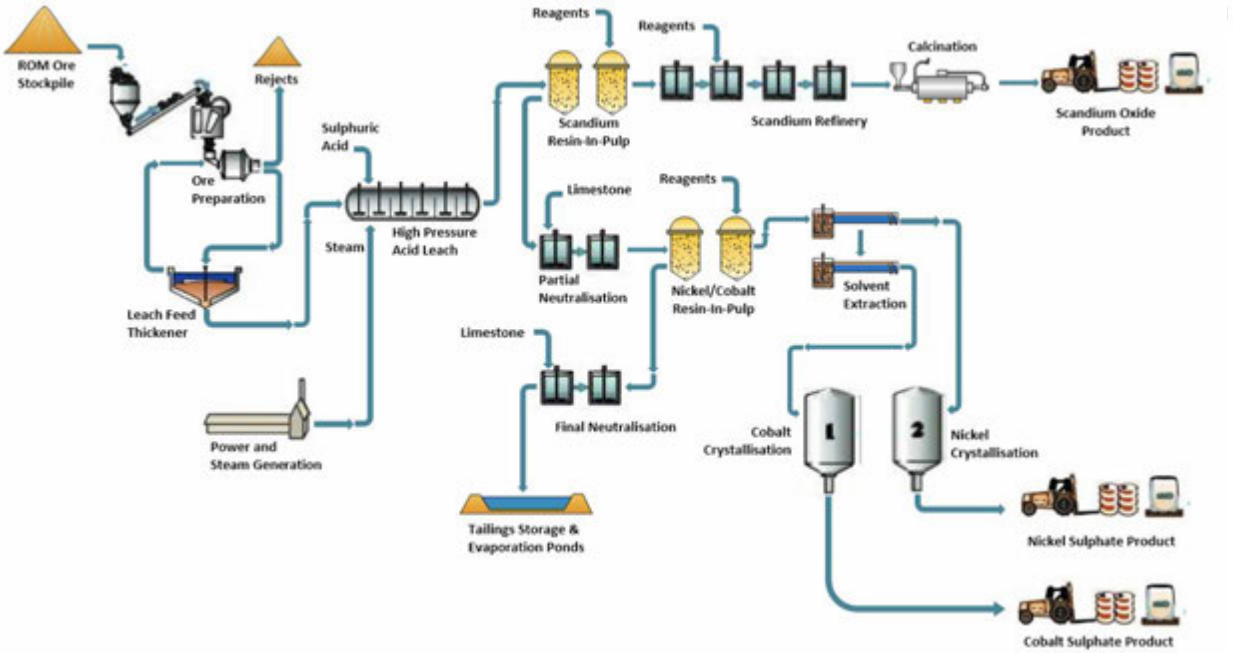
SUNRISE (SYERSTON)

Contrat avec Airbus?

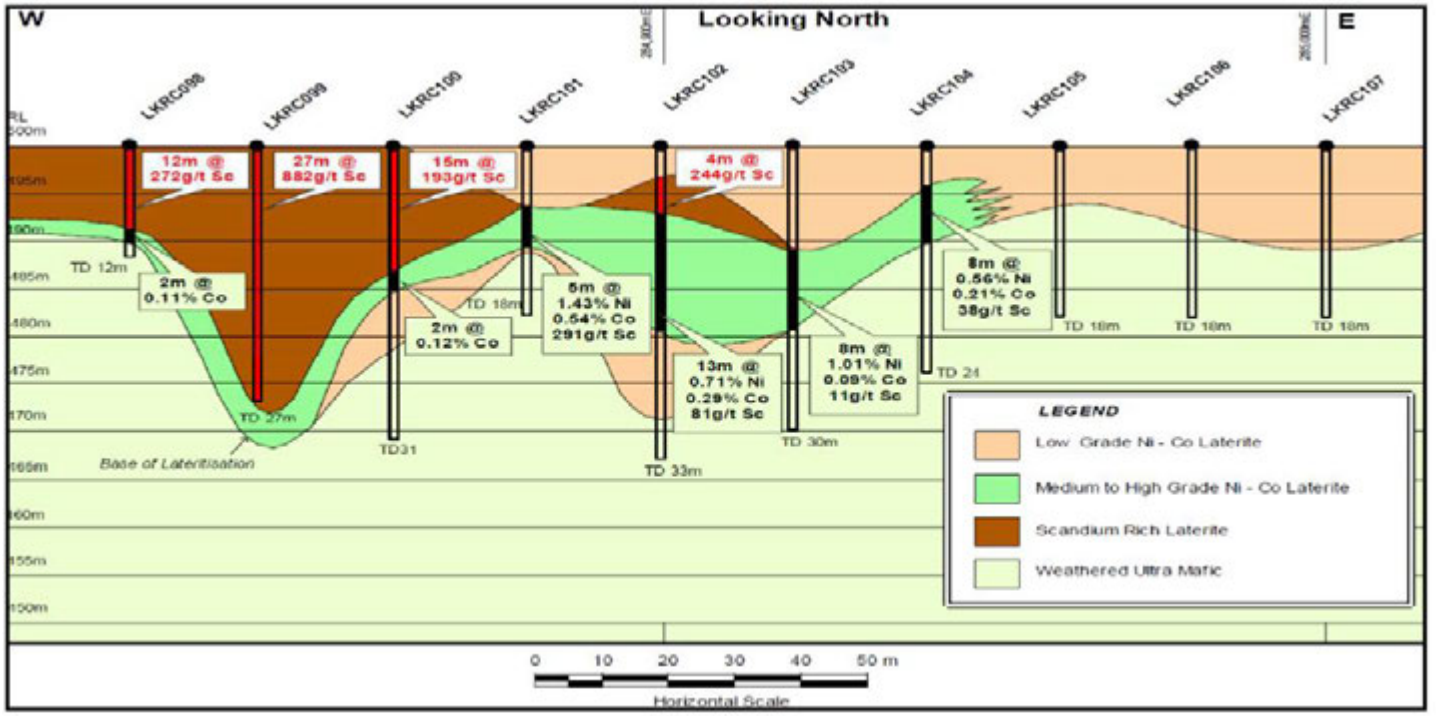
En cours de discussion/négociation avec nombreux partenaires industriels :

- Industriels automobiles
- Industriels tubes cathodiques
- “Trading houses” en Asie, Europe, et Amérique du Nord



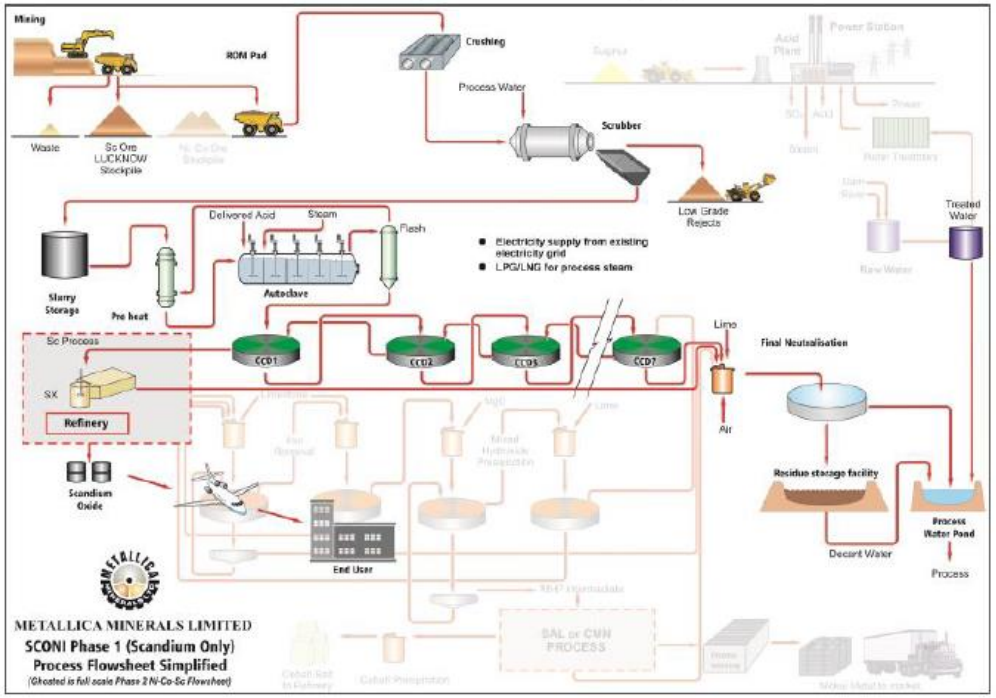


SCONI



Accord avec SK Innovation (Corée du Sud) pour Nickel + Cobalt + Scandium

Récupération de 85% jusqu'à 97%
Pureté 99, 99 %



Ardea Resources Limited

ASX & Media Release
14 December 2017

ASX Symbol
ARL

Ardea Resources Limited
Suite 2, 45 Ord St
West Perth WA 6005

PO Box 1433
West Perth WA 6872

Telephone
+61 8 6244 5136

Email
ardea@ardearesources.com.au

Website
www.ardearesources.com.au

Directors
Katina Law
Chair
Matt Painter
Managing Director
Ian Buchhorn
Technical Executive Director

Issued Capital
Shares
83,364,801

Extensive scandium complements the cobalt-nickel deposits of Goongarrie South

Completion of resampling of historic pulps confirms scandium throughout the focus area of initial mining at the KNP Cobalt Zone

- Scandium mineralisation is extensive at Goongarrie South, usually sitting above or coincident with the cobalt and nickel mineralisation.
- Intercepts proximal the Goongarrie South deposit area include:
  - GSDD0004, **8.6 m at 147.7 g/t scandium** from 12 m
  - GSRC0334, **35 m at 96.1 g/t scandium** from 19 m[1]
  - GSRC0524, 18 m at 62.5 g/t scandium from 18 m
  - GSRC0571, **14 m at 105.3 g/t scandium** from 15 m
  - GSRC0688, **22 m at 67.2 g/t scandium** from surface
  - GSRC1035, 16 m at 77.6 g/t scandium from 4 m
  - GSRC1036, **8 m at 127.5 g/t scandium** from 20 m
- The two main bodies of scandium mineralisation have been extended:
  - The Pamela Jean / Patricia Anne measures over **3 km strike length.**
  - The Elsie Tynan line in the west is now over **2.5 km strike length**.
- Extraction of **scandium oxide** as a by-product of **cobalt sulphate** and **nickel sulphate** production is entirely compatible with the KNP Cobalt Zone flowsheet for grades in excess of 40 g/t.

JORC Category	Cutoff	Tonnage	Grades						Contained metal					
		Mt	Ni (%)	Co (%)	Mn (%)	Sc (g/t)	Pt (g/t)	Pd (g/t)	Ni (t)	Co (t)	Mn (t)	Sc (t)	Pt (oz)	Pd (oz)
Black Range cobalt-nickel deposit														
Indicated	0.5% Ni	9.33	0.67	0.09	0.49	33.8	0.09	0.13	62,400	8,200	46,000	310	27,600	39,000
Inferred	0.5% Ni	9.89	0.69	0.10	0.61	33.0	0.09	0.13	68,300	9,600	60,000	320	28,600	39,500
Total	**0.5% Ni**	**19.22**	**0.68**	**0.09**	0.55	33.4	0.09	0.13	**130,700**	**17,800**	106,000	630	56,200	78,500
Black Range scandium deposit														
Inferred	50g/t Sc	**8.70**	0.39	0.05		**65.6**	0.20	0.20	33,700	4,000	-	**570**	56,500	56,200
Black Range PGM deposit														
Inferred	0.25g/t Pt	**6.55**	0.23	0.02		39.3	**0.33**	**0.21**	14,900	1,300	-	250	**70,300**	**44,000**

PHILIPPINES

April 28, 2016

Press Release

Sumitomo Metal Mining Co., Ltd.

Establishment of Scandium Recovery Business

Sumitomo Metal Mining Co., Ltd. (SMM) has taken a decision to establish operations for recovery of scandium, a rare earth element, at its nickel plant and has concluded a long-term sales agreement of scandium oxide with a major US-based fuel cell manufacturer.

SMM constructed a pilot plant at its subsidiary Coral Bay Nickel Corporation (Palawan Island, the Philippines) in 2013, and has developed technology for commercial-scale scandium recovery from the nickel and cobalt mixed sulfides manufacturing process. The successful test result has lead SMM to decide to construct a plant for the recovery of an intermediate product for scandium oxide at its subsidiary Taganito HPAL Nickel Corporation (THPAL, Mindanao Island, the Philippines). Processing of this intermediate product into the final product (scandium oxide) shall be performed at SMM's Harima Refinery.

TURQUIE

ALTA 2018

DEVELOPMENT OF AN HPAL NICKEL PROJECT AND POTENTIAL SCANDIUM RECOVERY

By

Mete Yeşil, A. Safder İplikçioğlu and Emre Ege

Egemad, Turkey

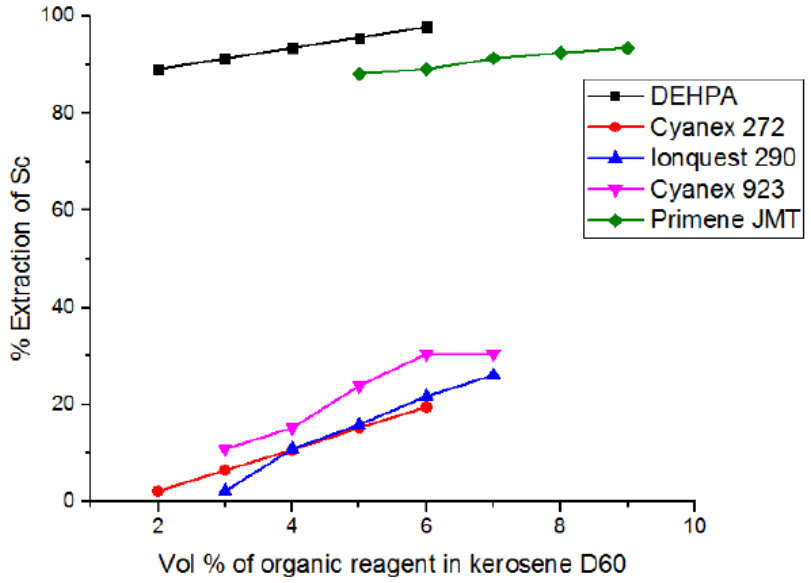
Presenter and Corresponding Author

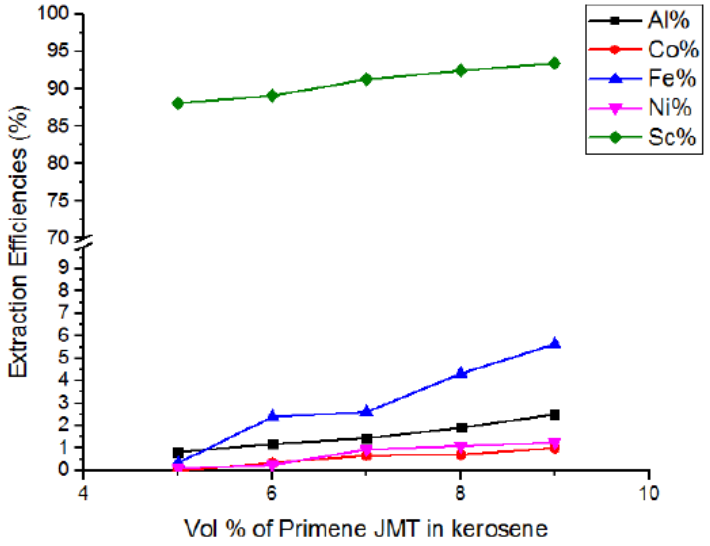
Emre Ege

Solvent extraction behaviour of scandium from lateritic nickel-cobalt ores using different organic reagents

Article *in* Physicochemical Problems of Mineral Processing · October 2017

DOI: 10.5277/ppmp1855





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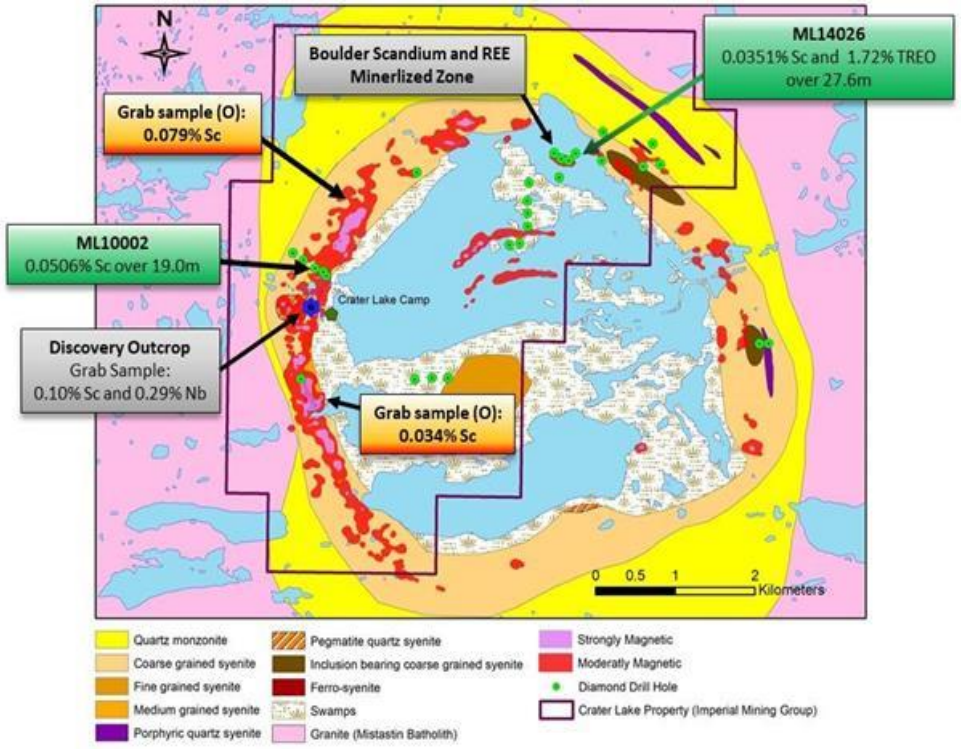

USA

Table 14.11.3: SRK Mineral Resource Statement for Elk Creek Nb_2O_5%, Effective Date February 20, 2015

Classification	Cut-off (Nb_2O_5%)	Tonnage (000's Tonnes)	Grade (Nb_2O_5%)	Contained Nb_2O_5 (000's kg)	Grade (TiO_2%)	Contained TiO_2 (000's kg)	Grade (Sc g/t)	Contained Sc (000's kg)
Indicated	0.3	80,500	0.71	572,000	2.68	2,160,000	72	5,800
Inferred	0.3	99,600	0.56	558,000	2.31	2,300,000	63	6,300

(19) **United States**
(12) **Patent Application Publication**
Duyvesteyn
(10) **Pub. No.: US 2016/0289795 A1**
(43) **Pub. Date: Oct. 6, 2016**

(54) **SYSTEMS AND PROCESSES FOR RECOVERING SCANDIUM VALUES FROM LATERITE ORES**

(71) Applicant: **Scandium International Mining Corporation**, Sparks, NV (US)

(72) Inventor: **Willem P.C. Duyvesteyn**, Sparks, NV (US)

(73) Assignee: **Scandium International Mining Corporation**, Sparks, NV (US)

(21) Appl. No.: **15/040,116**

(22) Filed: **Feb. 10, 2016**

Related U.S. Application Data

(60) Provisional application No. 62/114,429, filed on Feb. 10, 2015.

Publication Classification

(51) **Int. Cl.**

C22B 59/00	(2006.01)
C22B 1/24	(2006.01)
C22B 3/22	(2006.01)
C22B 3/08	(2006.01)

(52) **U.S. Cl.**
CPC ***C22B 59/00*** (2013.01); ***C22B 3/08*** (2013.01); ***C22B 1/24*** (2013.01); ***C22B 3/22*** (2013.01)

(57) **ABSTRACT**

A method is provided for extracting scandium values from a scandium bearing laterite ore. The method includes providing a portion of a scandium bearing laterite ore having an average particle size of no more than 200 mesh, leaching the ore to produce a leachate, and recovering scandium values from the leachate.

Patents Assigned to Clean Teq Pty Ltd.

A Process, Method and Plant for Recovering Scandium

Publication number: 20150307966

Abstract: The present invention relates to a process, method and plant for recovering scandium and ions containing scandium using an ion exchange resin from a feed stream. The feed stream may be, but is by no means limited to, a leach liquor or leach pulp.

Type: Application

Filed: December 10, 2013

Publication date: October 29, 2015

Applicant: Clean TeQ Pty Ltd

Inventors: Peter Voight, Nikolai Zontov, John Carr

(12) **United States Patent**
Mihaylov et al.

(10) **Patent No.: US 9,677,155 B2**
(45) **Date of Patent: Jun. 13, 2017**

(54) **METHOD FOR RECOVERING SCANDIUM FROM INTERMEDIATE PRODUCTS FORMED IN THE HYDROMETALLURGICAL PROCESSING OF LATERITE ORES**

(71) Applicant: **VALE S.A.**, Rio de Janeiro (BR)

(72) Inventors: **Indje Mihaylov**, Mississauga (CA); **Ryan Peterson**, Mississauga (CA); **Avinash Singhal**, Mississauga (CA); **Christopher Massey**, Mississauga (CA)

(73) Assignee: **VALE S.A.**, Rio de Janeiro (BR)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 391 days.

(21) Appl. No.: **14/257,647**

(22) Filed: **Apr. 21, 2014**

(56) **References Cited**

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2012/0207656	A1 *	8/2012	Duyvesteyn	C22B 1/04 423/21.1

FOREIGN PATENT DOCUMENTS

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OTHER PUBLICATIONS

European Search Report dated Sep. 3, 2014 issued in European Patent Application No. EP14165405.
Weiwei Wang et al., "Metallurgical processes for scandium recovery from various resources: A review,"Hydrometallurgy 108 (2011) 100-108.

* cited by examiner

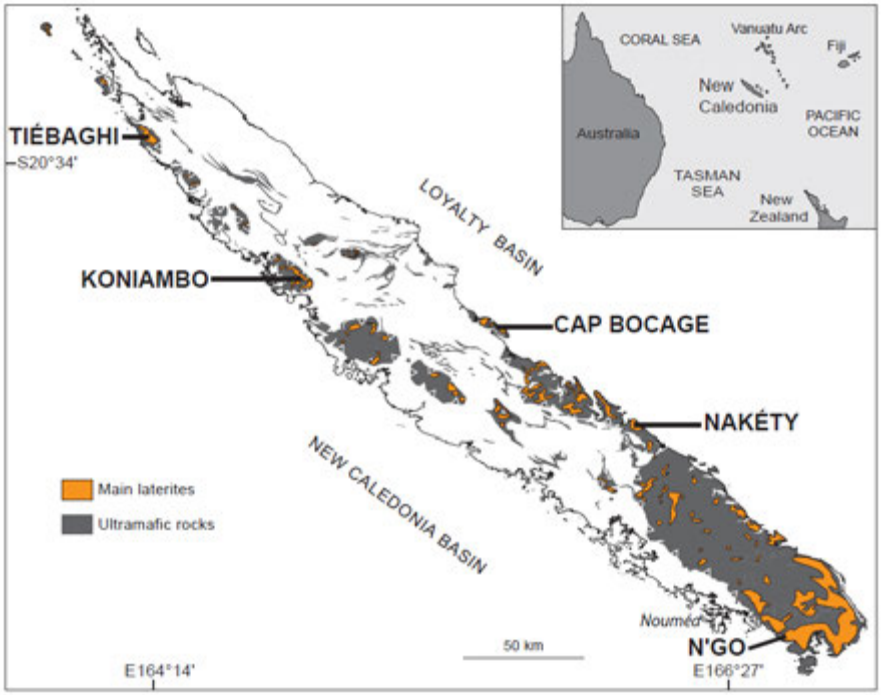
Minerai processé 5 Mt/an
@60 ppm Sc
$\Rightarrow$ 300 t/an Sc = 450 t/an Sc2O3
Si 1500 $/kg => 675 M$/an

Latérites scandifères en Nouvelle-Calédonie ?

- **Ni-Co latérites sur péridotite ?**
  - Potentiel pour co-valorisation de Sc ?

- **Latérites sur roches intrusives ?**
  - Existence de dykes de pyroxénite / amphibolite recoupant la péridotite

  - Proximal aux gisements Ni-Co: Sur-enrichissement en Sc ?
  - Distal aux gisements Ni-Co : Ressource Sc primaire ?



Sites étudiés

- 5 massifs miniers traduisant la diversité des protolithes et des types d'altération

Protolithes

Péridotites
- Dunite
- Harzburgite
- Lherzolite

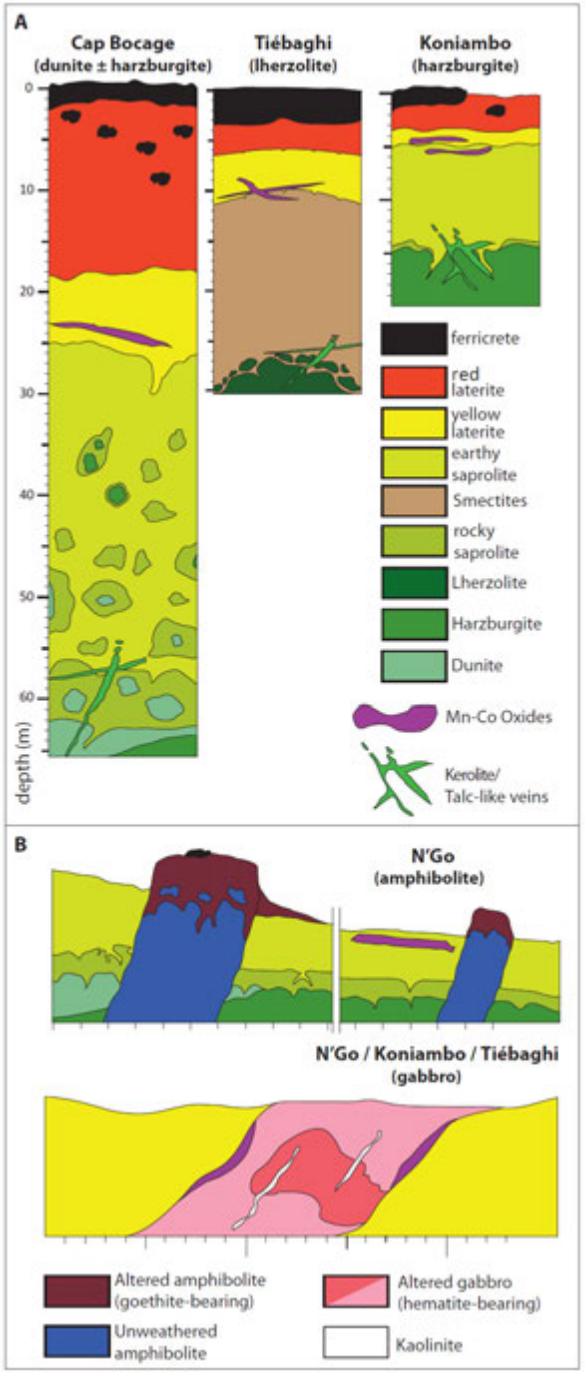
Roches intrusives
- Gabbro
- Pyroxénite
- Amphibolite

Types d'altération

Échantillonnage (protolithe => cuirasse) de:

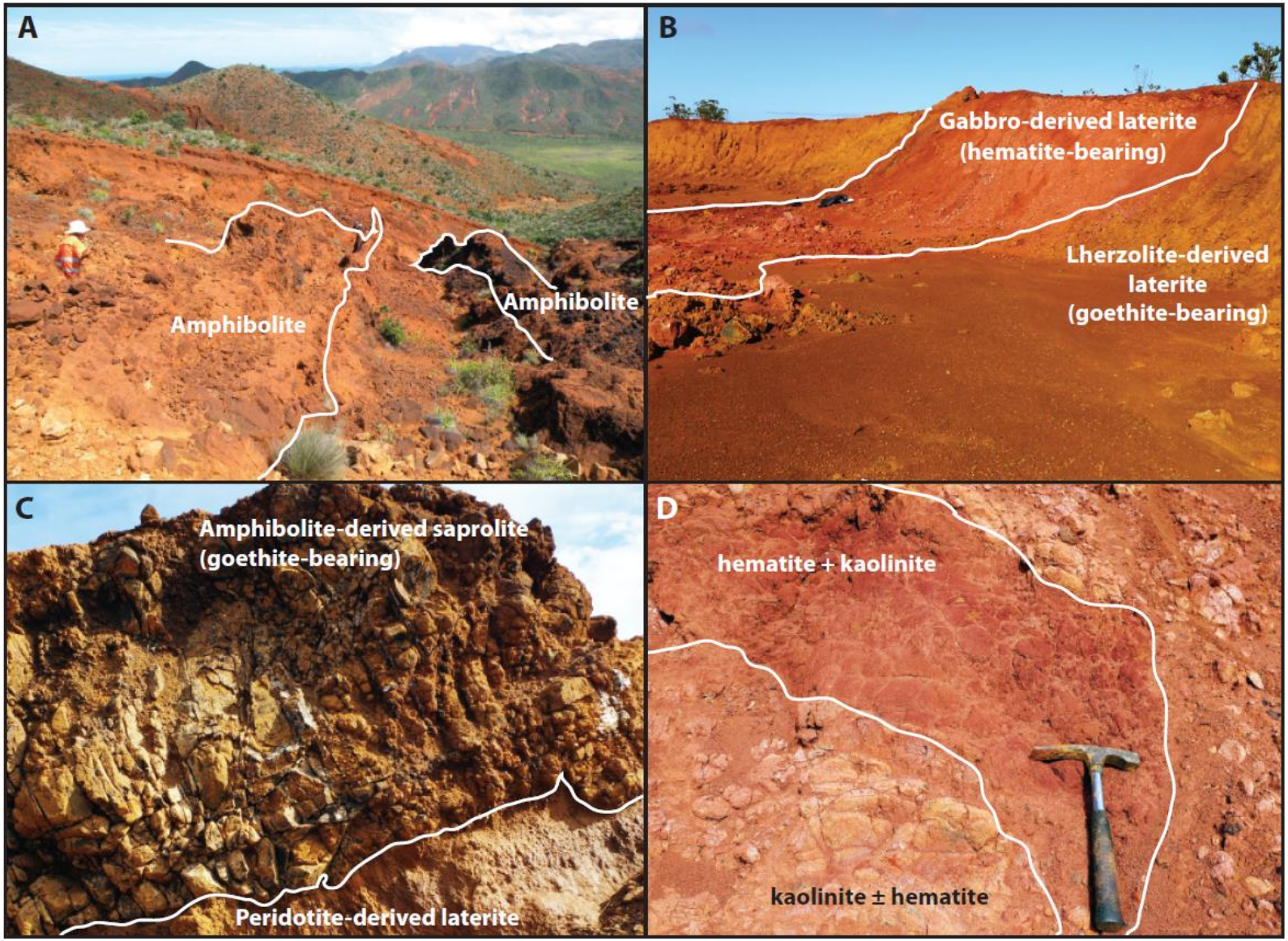
- Ni-laterites type oxyde, de plateau et de bassin
- Ni latérites smectitiques (atypiques)

- Fe-Al-latérites sur roches intrusives
- ***Pyroxénites et amphibolites: altérites à goethite***
- ***Gabbros : altérites à hématite***



Amphibolites/ Pyroxénites

Gabbros

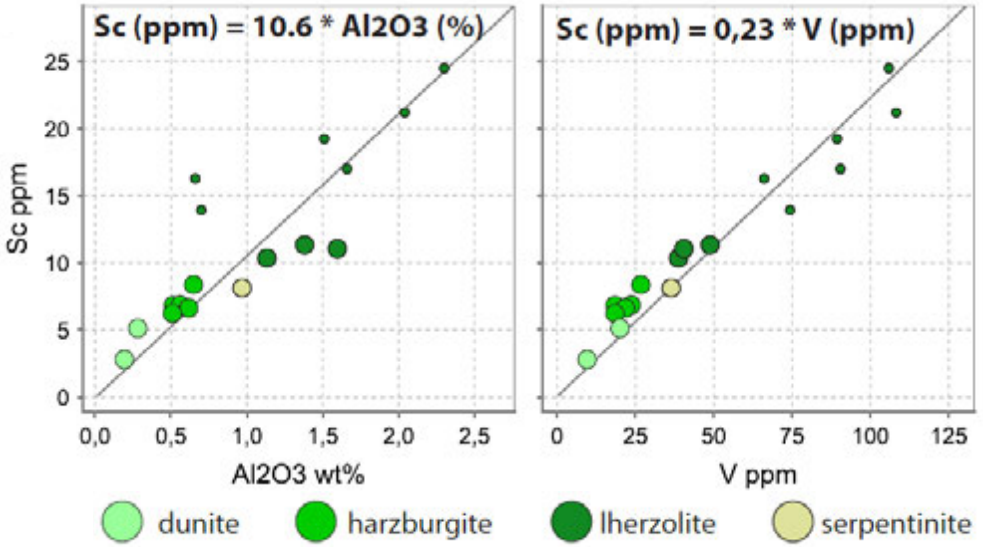


Fertilité des protolithes

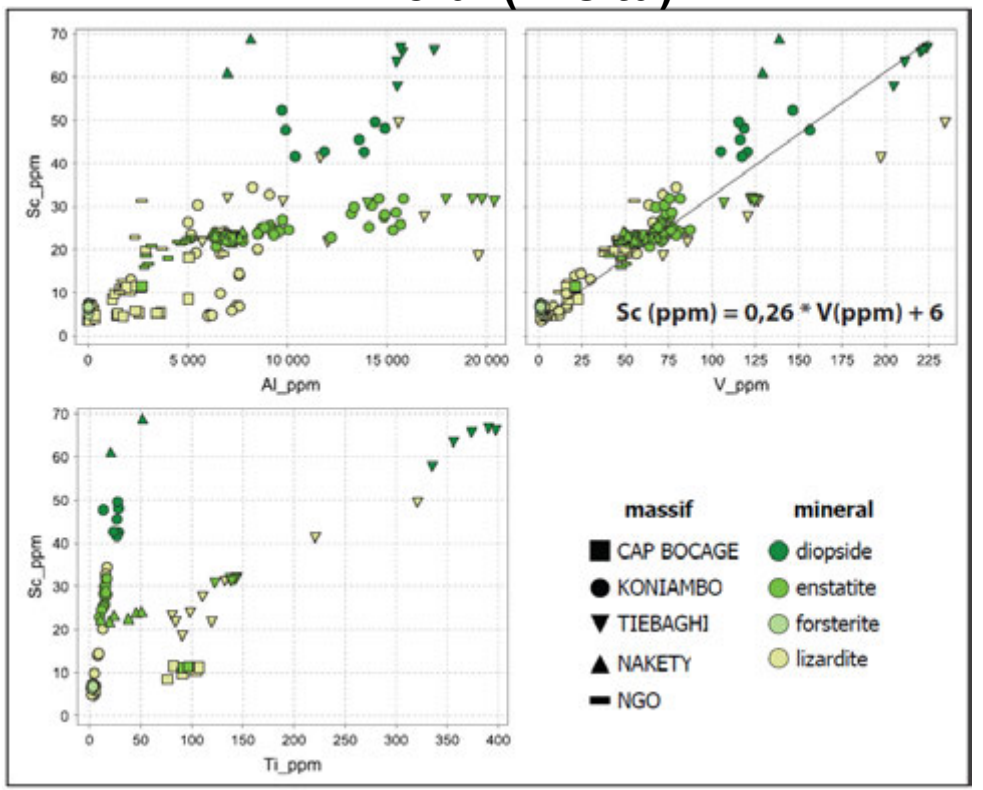
Péridotites

- Dunite < Harzburgite < lherzolite
- Max. ~10 ppm (25 ppm?)
- Olivine < orthoPx < ClinoPx
- Variations 2nd ordre à l'échelle régionale, controllées par variations des orthoPx
- Corrélation Al-V-Sc (= proxies)
- Possible corrélation Ti-Sc mais spécifique à chaque massif ?

Roche totale



Minéral (in situ)

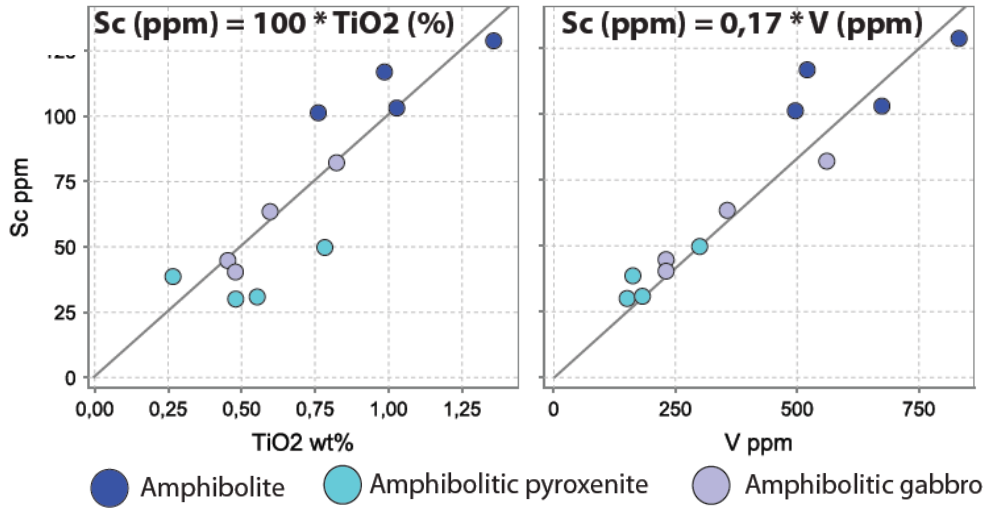


Fertilité des protolithes

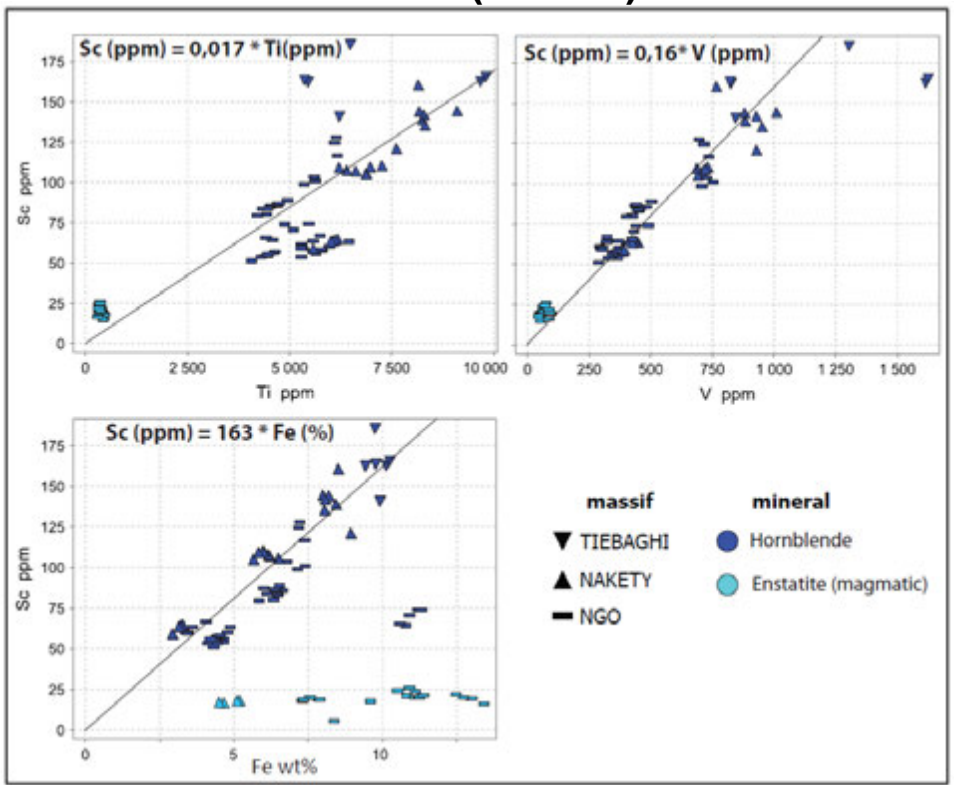
Intrusifs

- Gabbro ~ Pyroxénite < Amphibolite
- Max. ~130 ppm
- Plagios < orthoPx << Hornblende
- Variations 1nd ordre à l'échelle de l'affleurement (filon-spécifique)
- Corrélation Ti-V-Sc (= proxies)

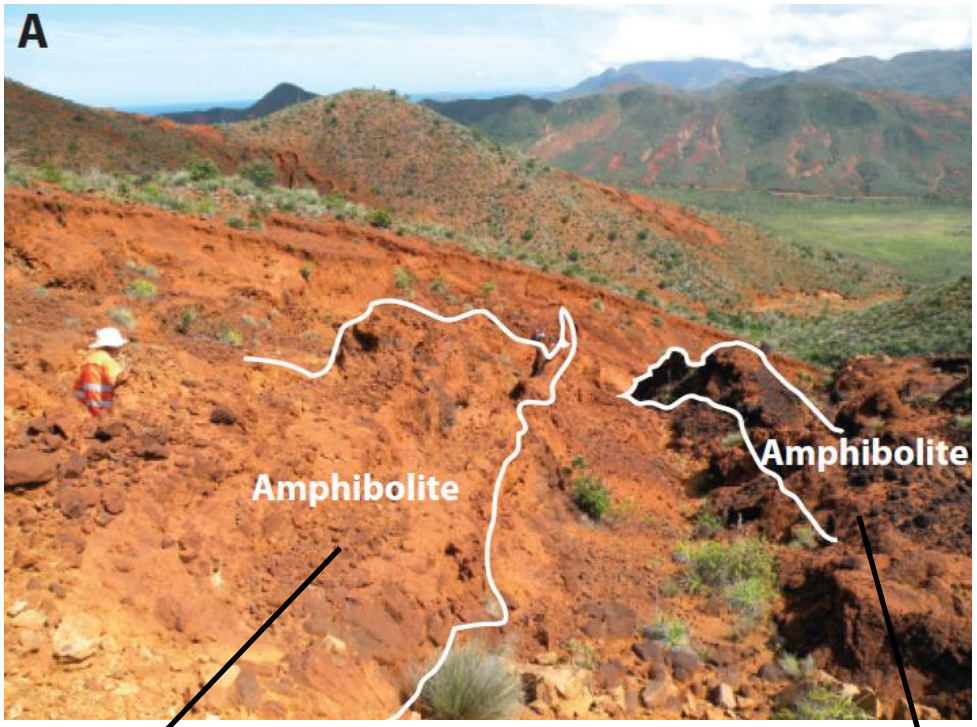
Roche totale



Minéral (in situ)



Variations 1er ordre à l'échelle de l'affleurement: exemple PB5 (N'Go)



Roche totale (saine) = 101 ppm
Contient >90 vol% hornblende
Hornblende ~110 ppm Sc

Roche totale (saine) = 30 ppm
Contient 40-50 vol% hornblende
Hornblende ~60 ppm Sc

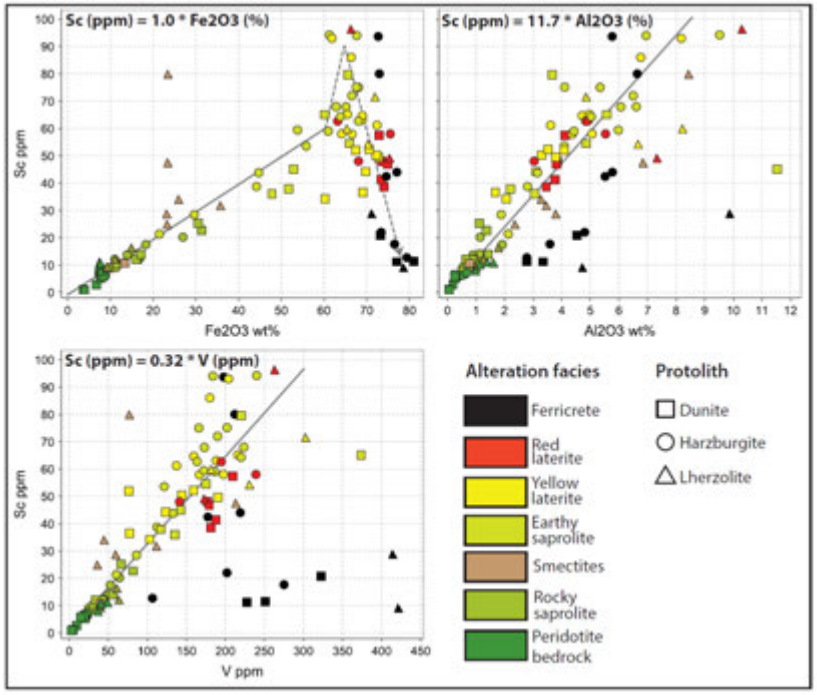
Distribution du Sc : Latérite sur péridotite

- Sc max. dans horizon de latérite jaune
- Max. 10x Sc protolithe

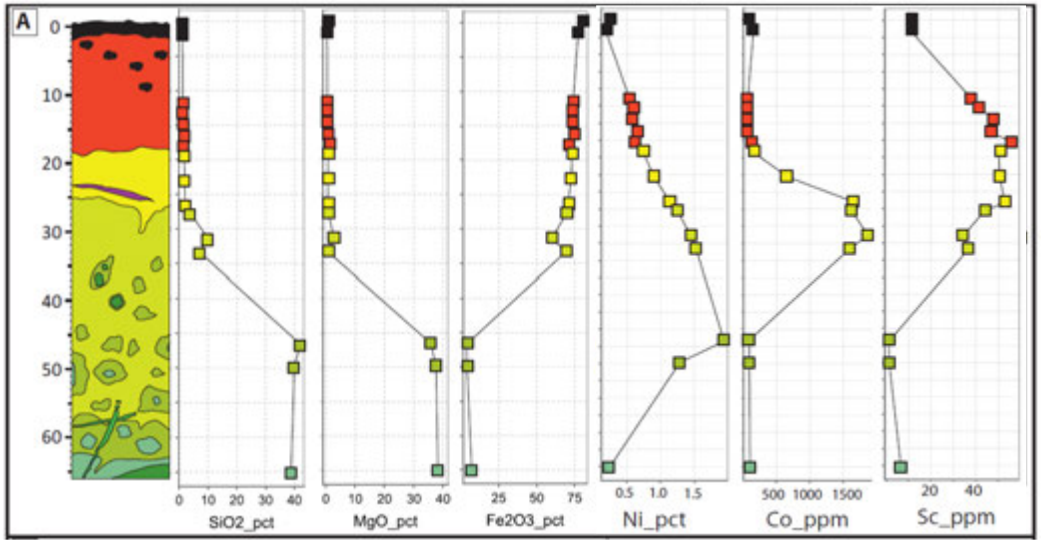
⇒ 60 à 100 ppm

- Corrélation Fe-Sc si Fe2O3 < 60%
- Meilleure correlation avec Al, V

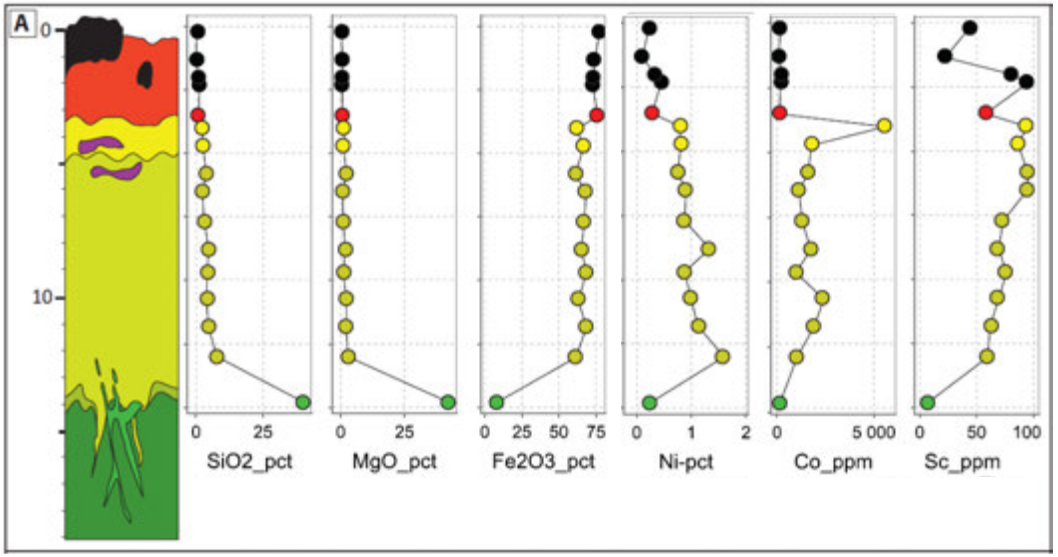
⇒ Enrichiss. résiduel + remobilisation (maturation + hématit. des goethites)



Dunite



Harzburgite



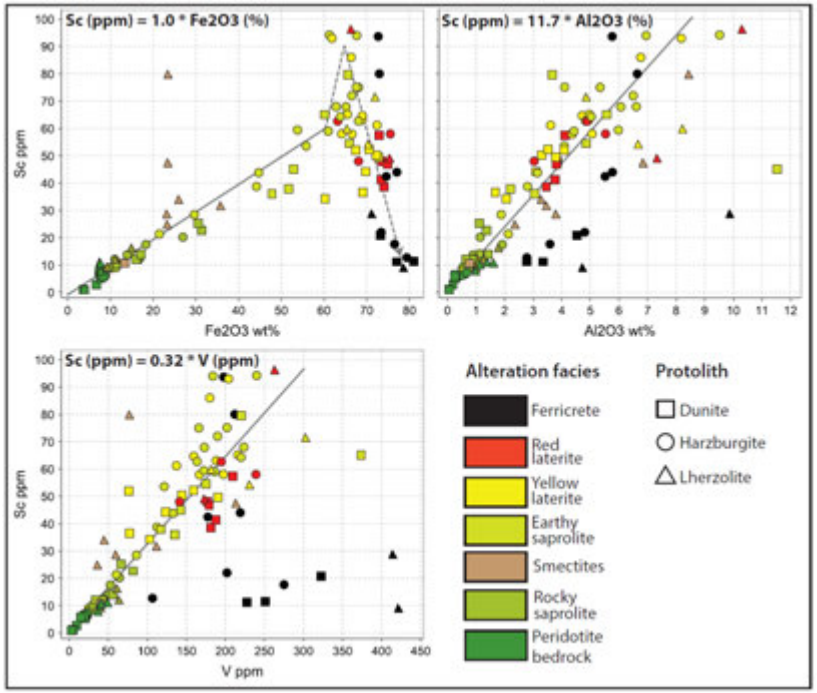
Distribution du Sc : Latérite sur péridotite

- Sc max. dans horizon de latérite jaune
- Max. 10x Sc protolithe

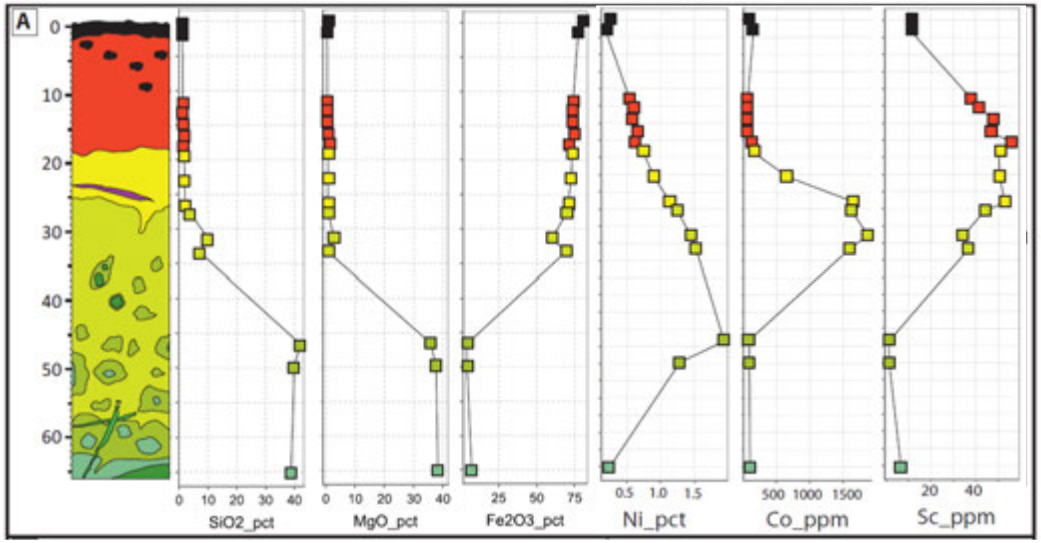
⇒ 60 à 100 ppm

- Corrélation Fe-Sc si Fe2O3 < 60%
- Meilleure correlation avec Al, V

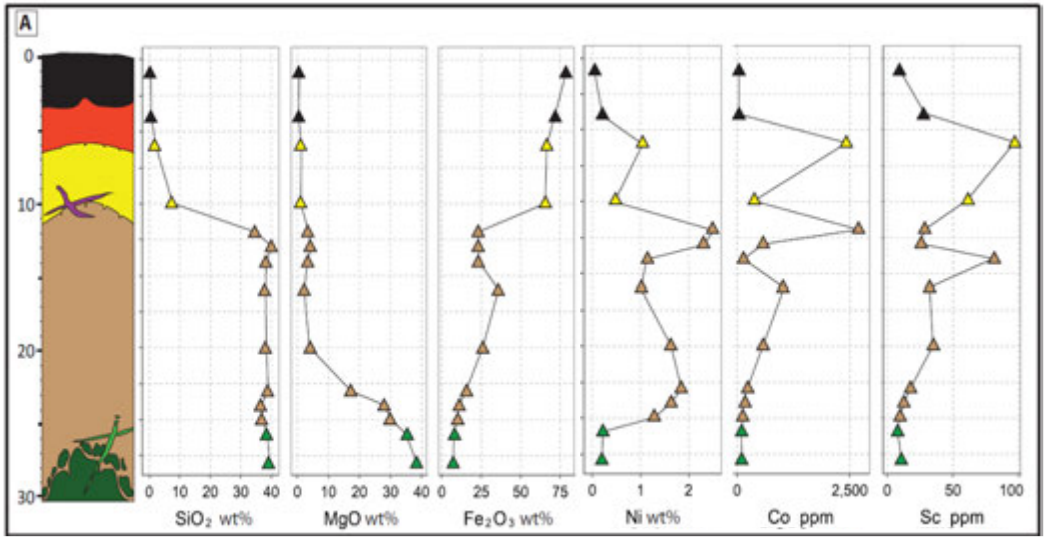
⇒ Enrichiss. résiduel + remobilisation (maturation + hématit. des goethites)



Dunite



Lherzolite

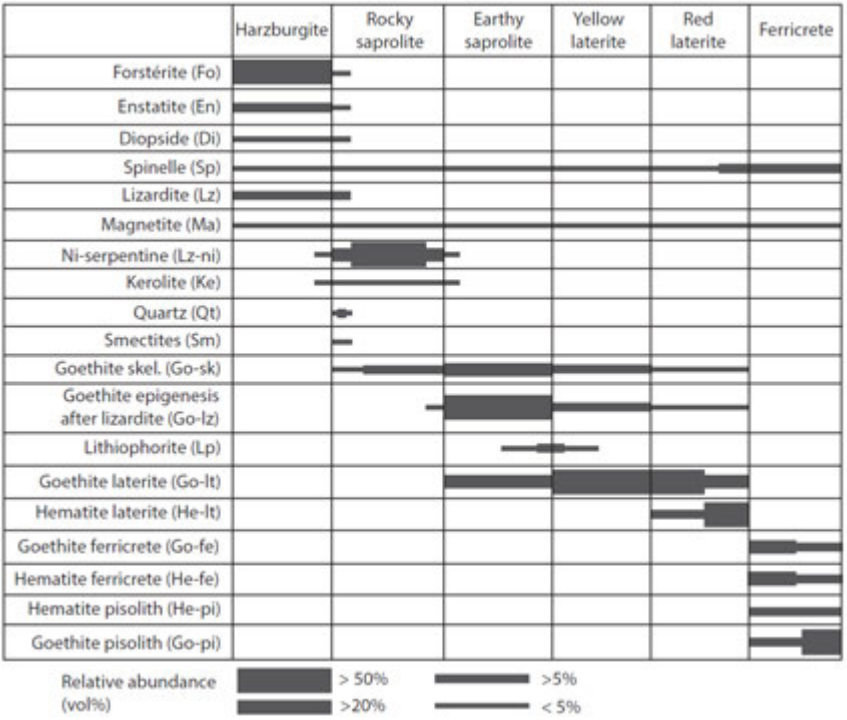


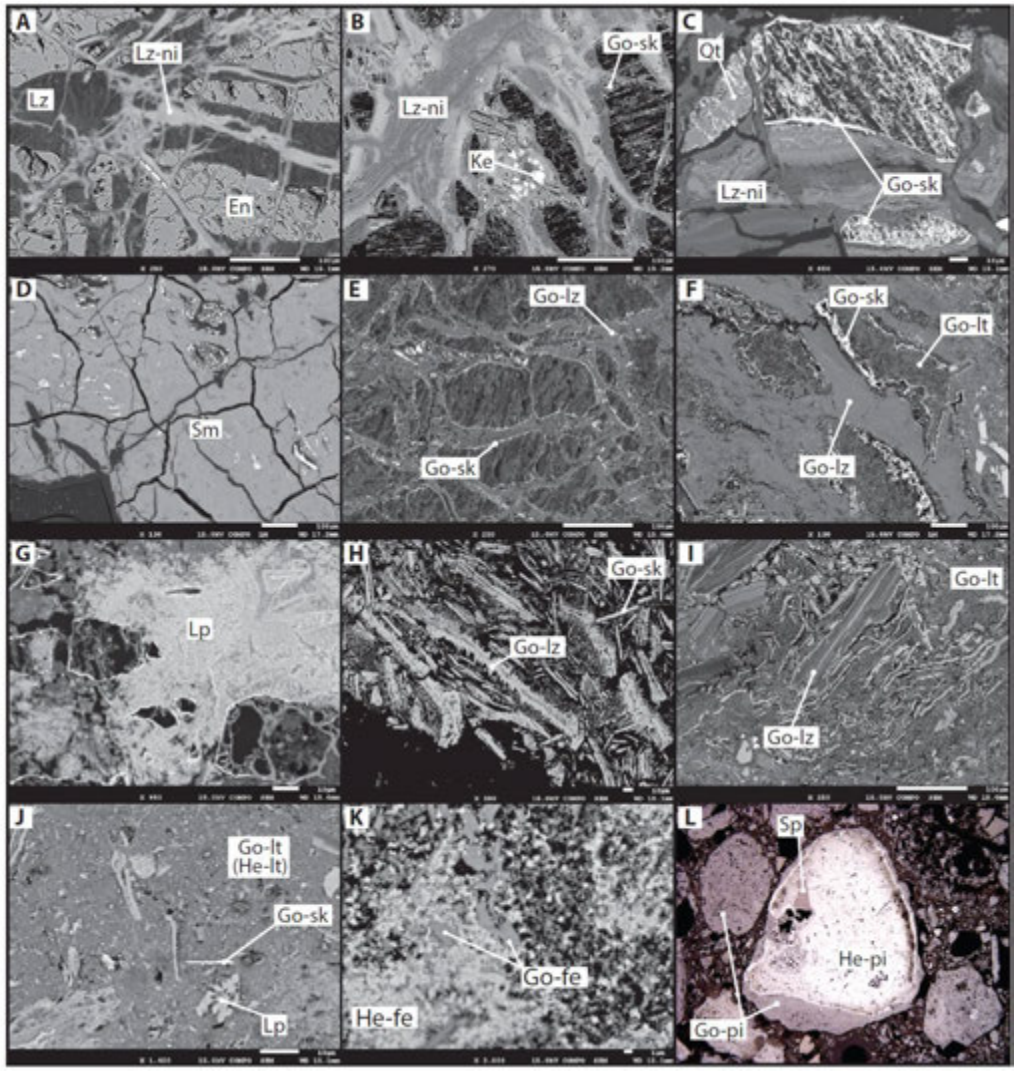
Évolution texturale des goethites et hématites

Précoce

- Goethite squelettique : Go-sk
- Goethite épigénétique : Go-lz
- Goethite matrice latéritique : Go-lt
- Hématite latéritique : He-lt
- Goethite cuirasse : Go-fe
- Hématite cuirasse He-fe
- Hématite pisolithes He-pi
- Goethite pisolithes Go-pi

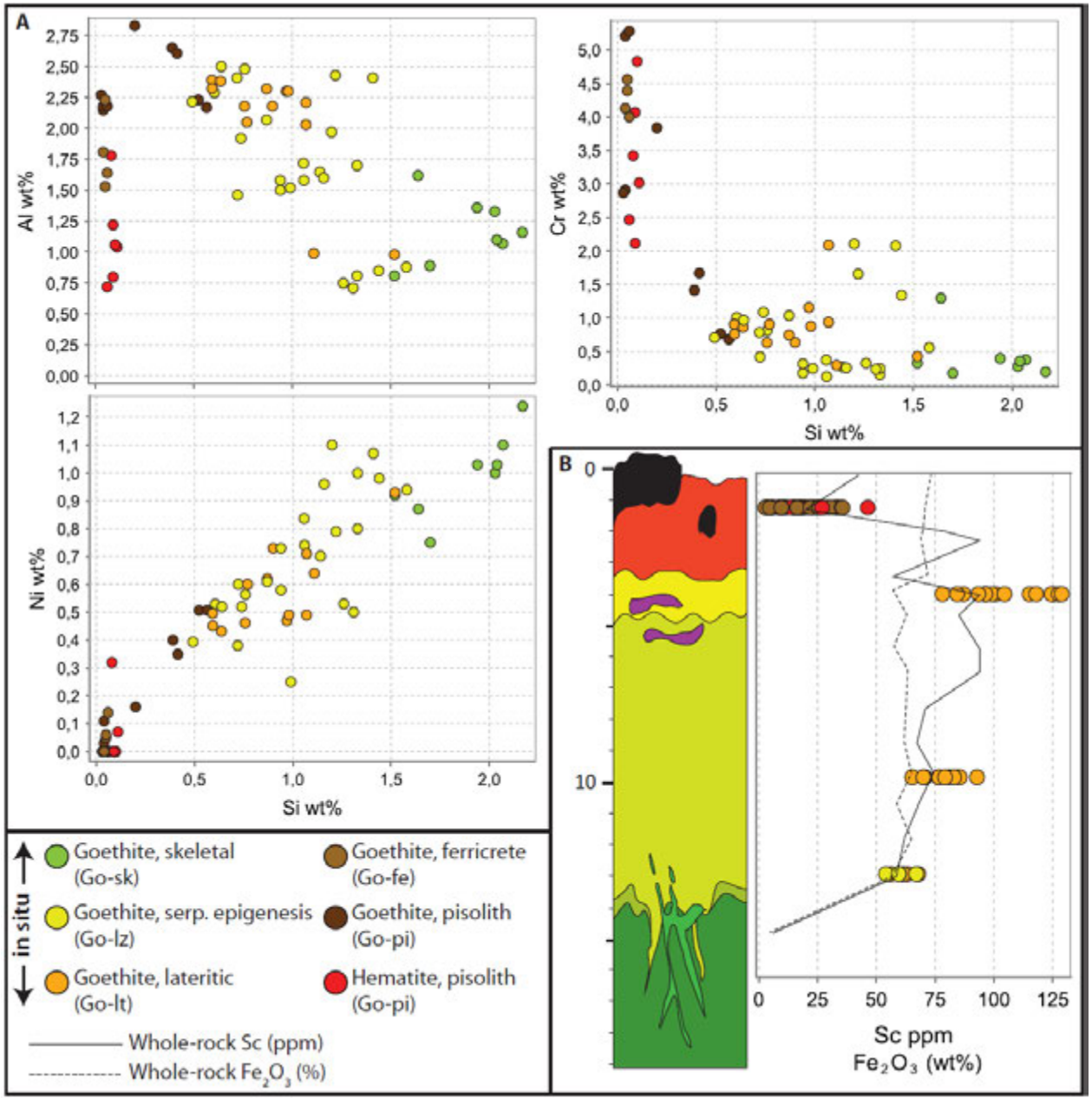
Tardif





Évolution chimique des goethites et hématites (profil OPB7, Koniambo)

Microsonde
1-3 µm
> 50-100 ppm



LA-ICP-MS
60 µm
>1-2 ppm

Distribution du Sc : Latérite sur amphibolite *(altérites à goethite)*

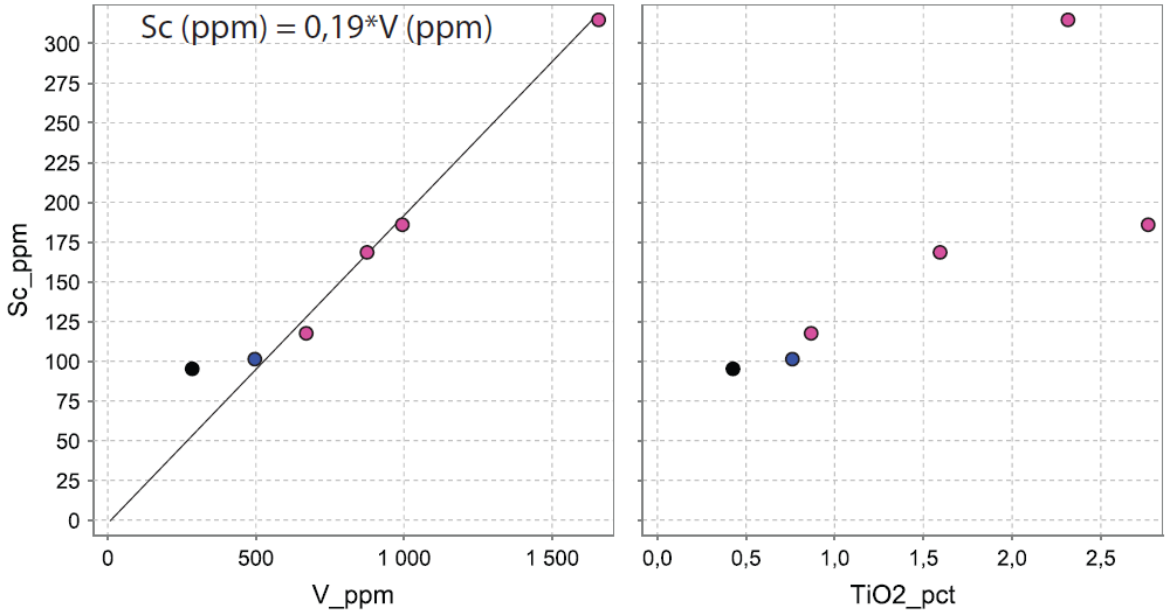
- Sc max. 2-3x Sc protolithe

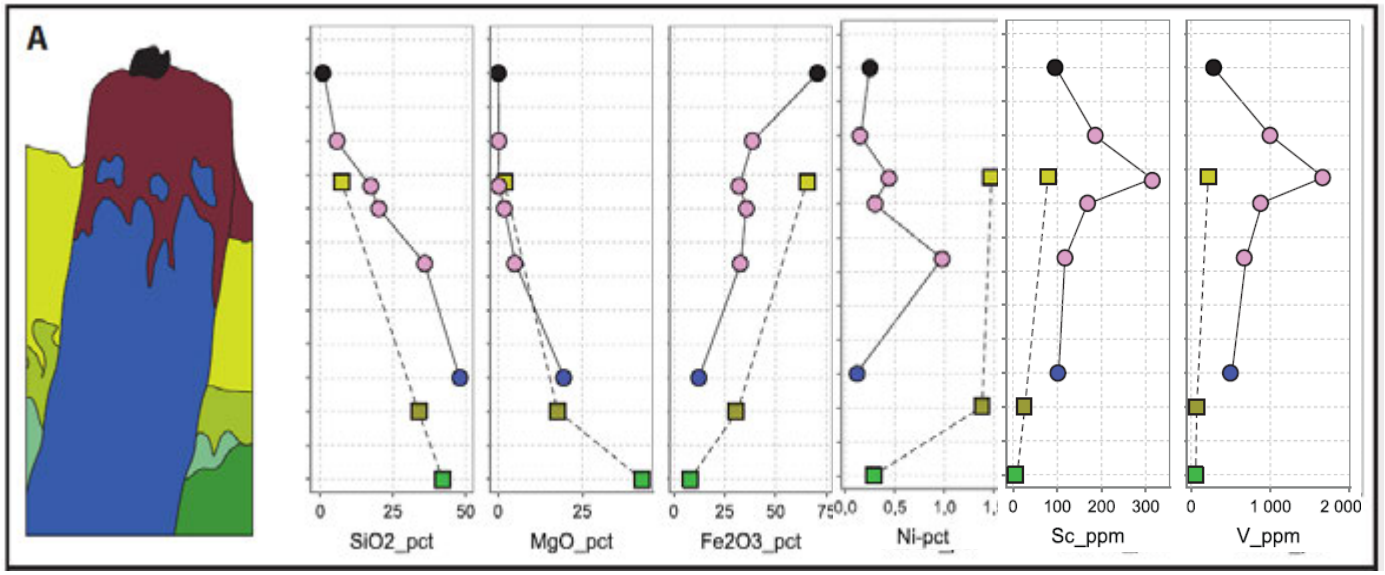
⇒ Jusqu'à 200-300 ppm
Mais faibles volumes, Ni peu élevé

- Corrélation Sc-V(-Ti)

Mais ~profil-spécifique

⇒ Enrichiss. résiduel + remobilisation

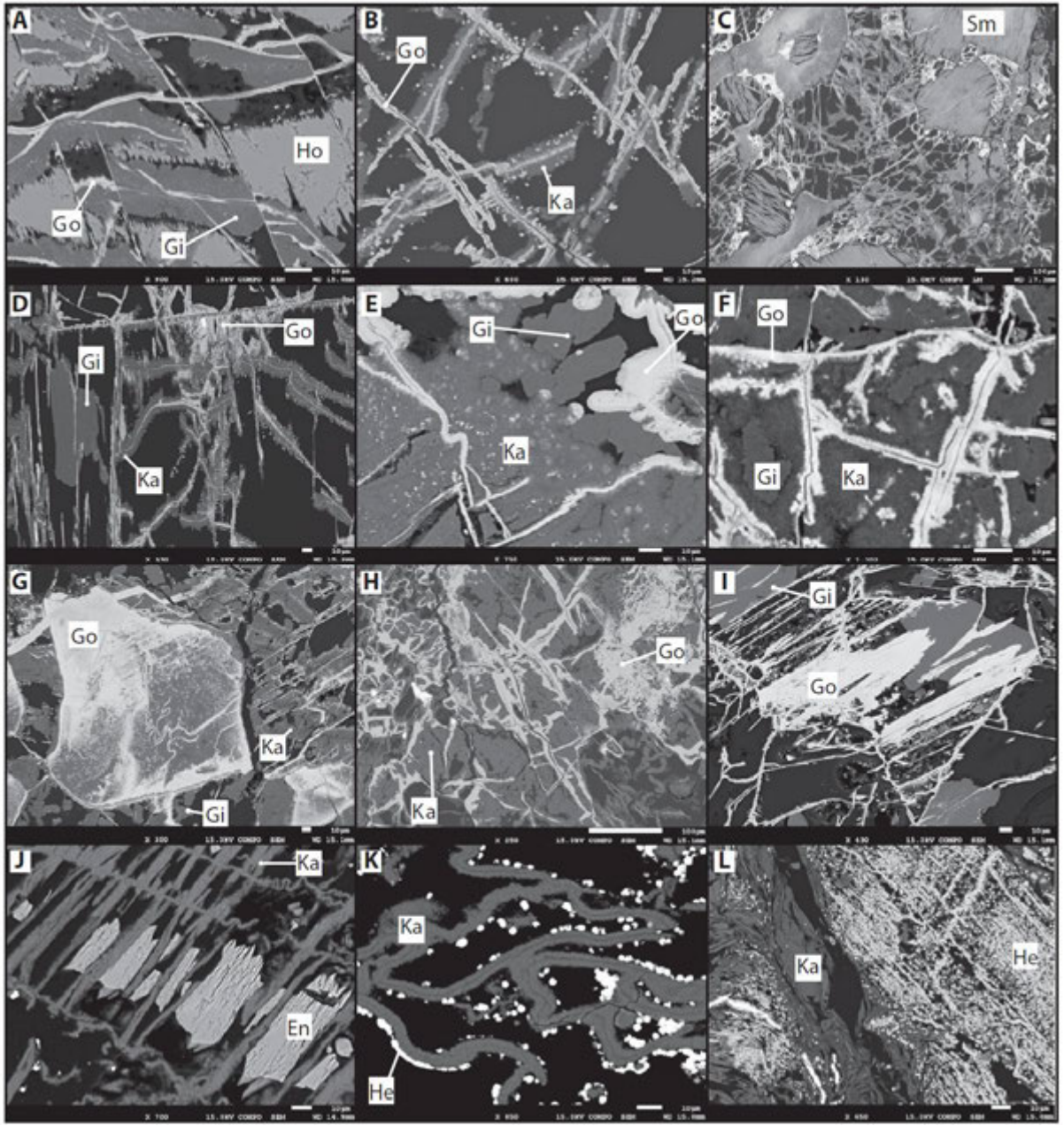




Amphibolite? (ferricrete)
Amphibolite (saprolite)
Amphibolite (bedrock)

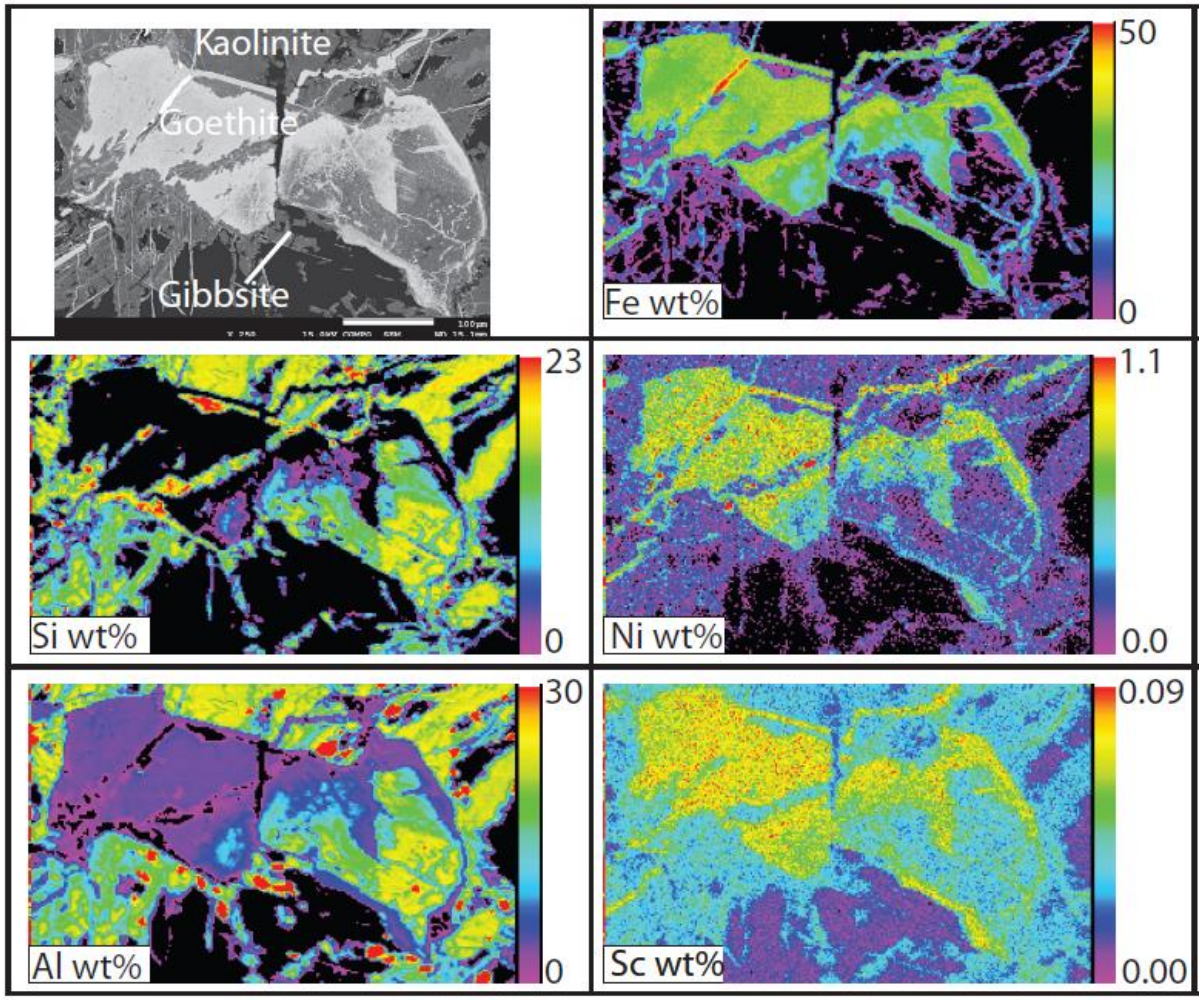
Harzburgite (earthy sap.)
Harzburgite (rocky sap.)
Harzburgite (bedrock)

Minéralogie des saprolites sur amphibolites

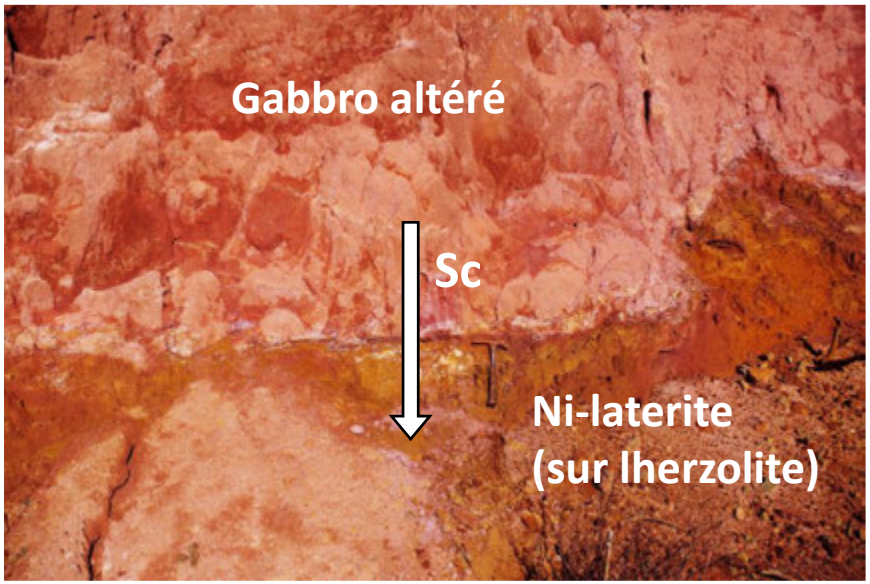


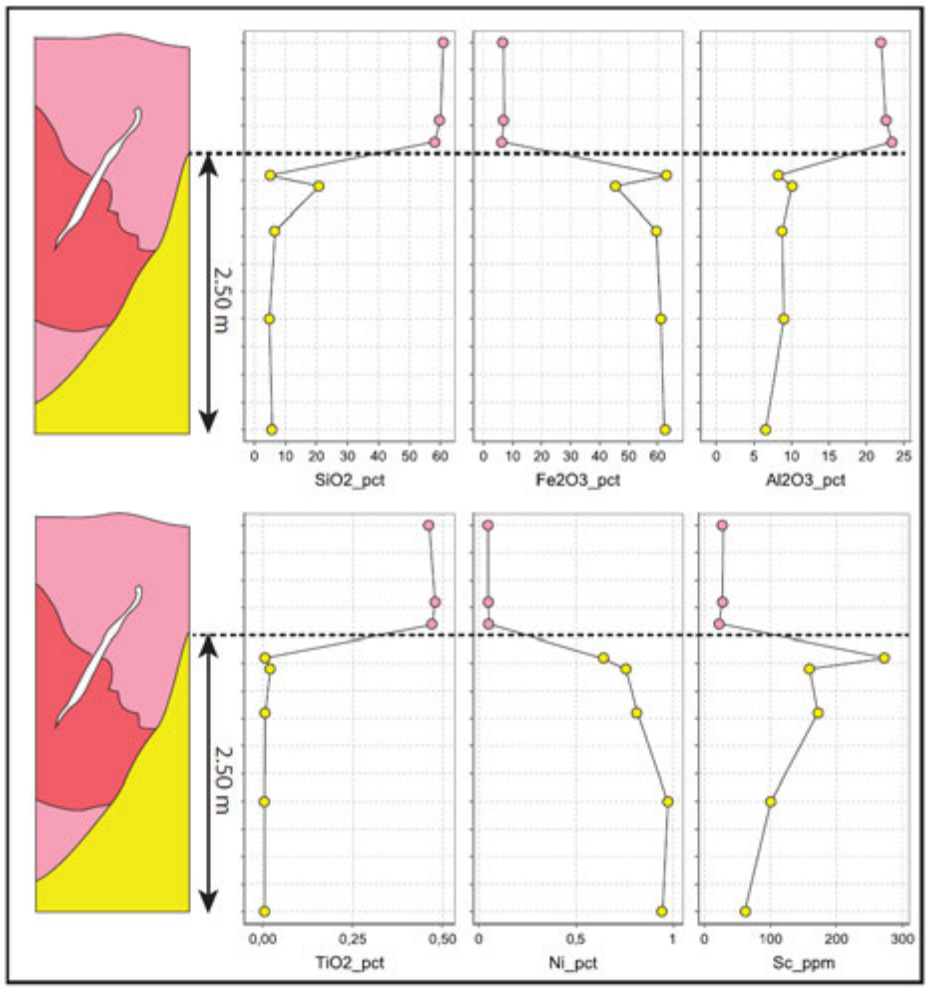
Latérite sur amphibolite : localisation du Sc

- **Sc (~700 ppm) – Ni (~0.7%) co-localisés dans Al-goethite**
- **Séparation des phases minérales envisageable ?**



Distribution du Sc : Latérite sur gabbro *(altérites à hématite)*



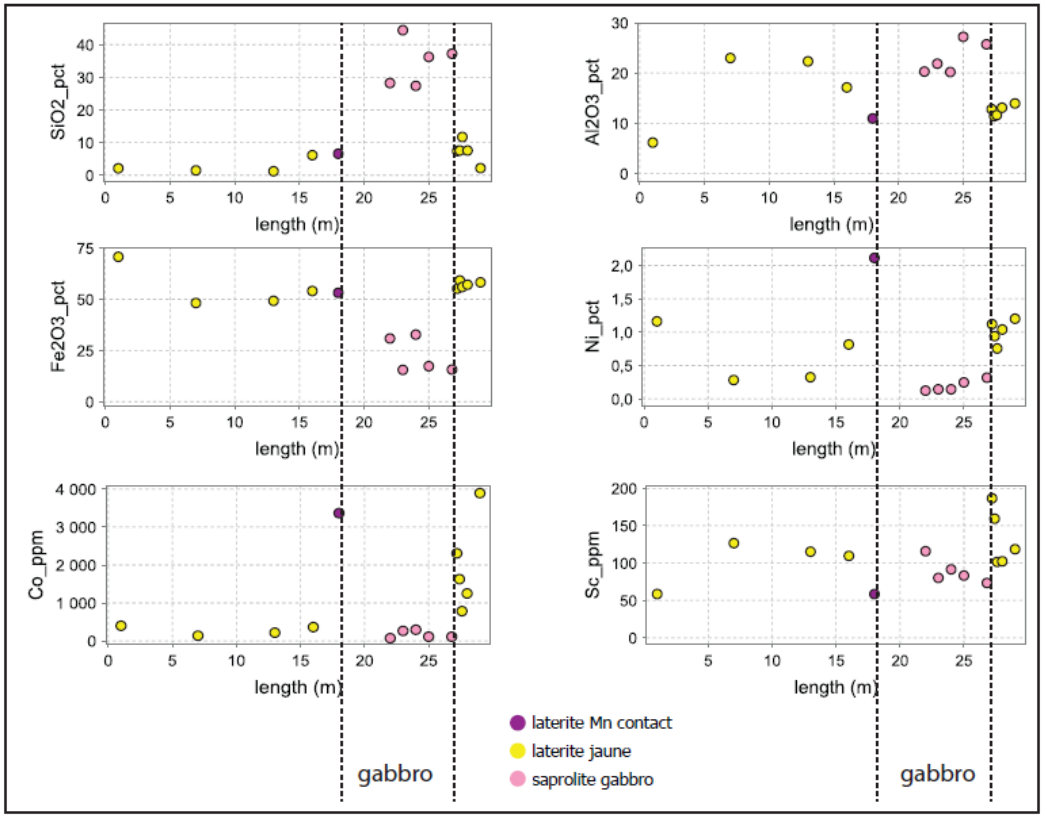


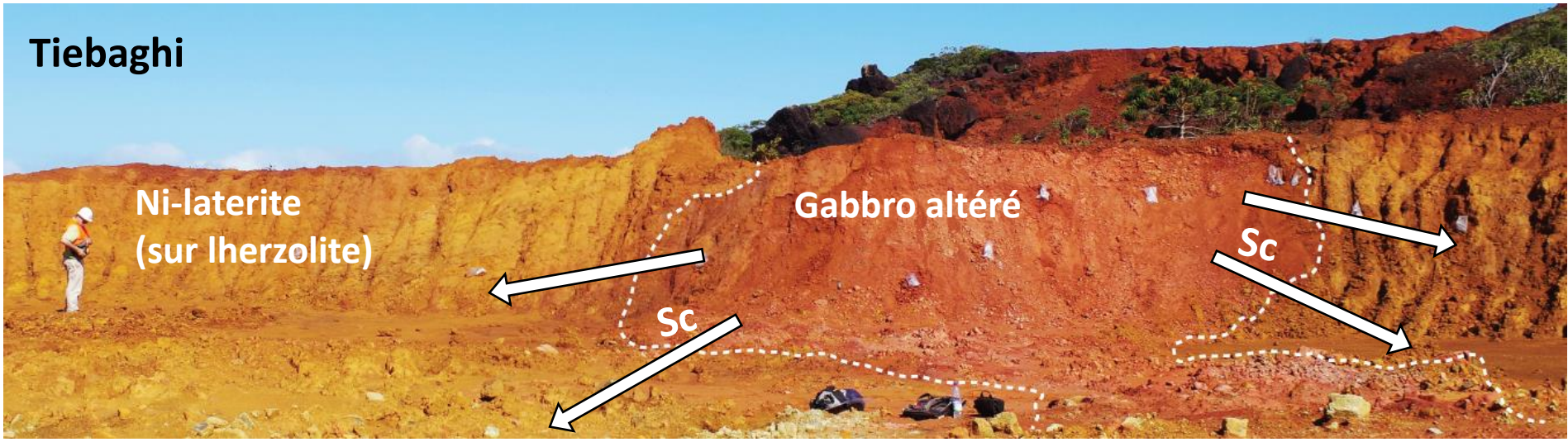
- Expulsion du Sc contenu dans le gabbro

⇒ Sur-enrichissement dans laterite sous-jacente 150-200 ppm (sur 2-3m)

- Intérêt pour co-valorisation des latérites recoupées par les gabbros ?

Distribution du Sc : Latérite sur gabbro *(altérites à hématite)*





Distribution du Sc et processus d'enrichissement

- **Contrôles majeurs sur les enrichissements en Sc**

1) Fertilité du protolithe
2) Latéritisation goethitique
3) Sur-enrichissement par remobilisation (maturation et hématitisation des goethite)

- **Co-valorisation Ni-Co-Sc dans les latérites développées sur péridotites ?**

- Potentiel pour co-valorisation si recoupement suffisant des zones d'enrichissement.
- Nécéssite traitement hydrométallurgique. Al et V = proxies pour Sc

- **Ressources primaires dans latérites développées sur amphibolites ?**

- Teneurs max. ~250-300 ppm. Potentiel pour >500 ppm ? car protolithe similaire à ceux des gisements australiens

- Faibles volumes, mais sous-exploré jusqu'à présent. V (et Ti) = proxy pour Sc.

- **Sur-enrichissement en Sc dans Ni-Co-laterites intrudés par des gabbros ?**

- Significatif (jusqu'à ~200 ppm) mais faibles volumes concernés ?
- Également sous-exploré. Occurrences plus importantes que les amphibolites.
- Pas de proxies géochimiques pertinents

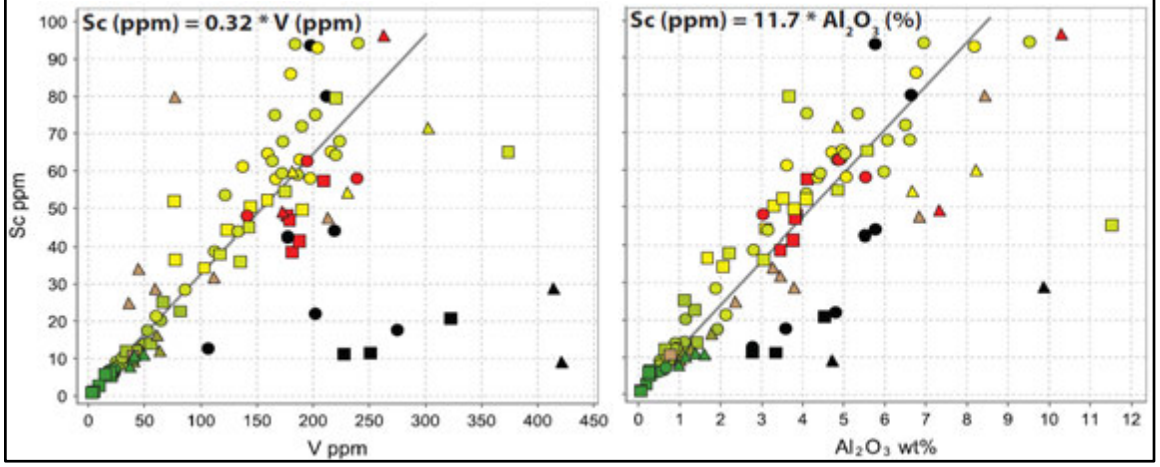
Outils d'exploration du Sc

- **Proxies géochimiques (pas d'analyse directe Sc)**

Sur péridotites Al et V = proxies pour Sc

Sur intrusifs V (et Ti) ~proxies pour Sc

Dataset 2016-2017 (péridotites)



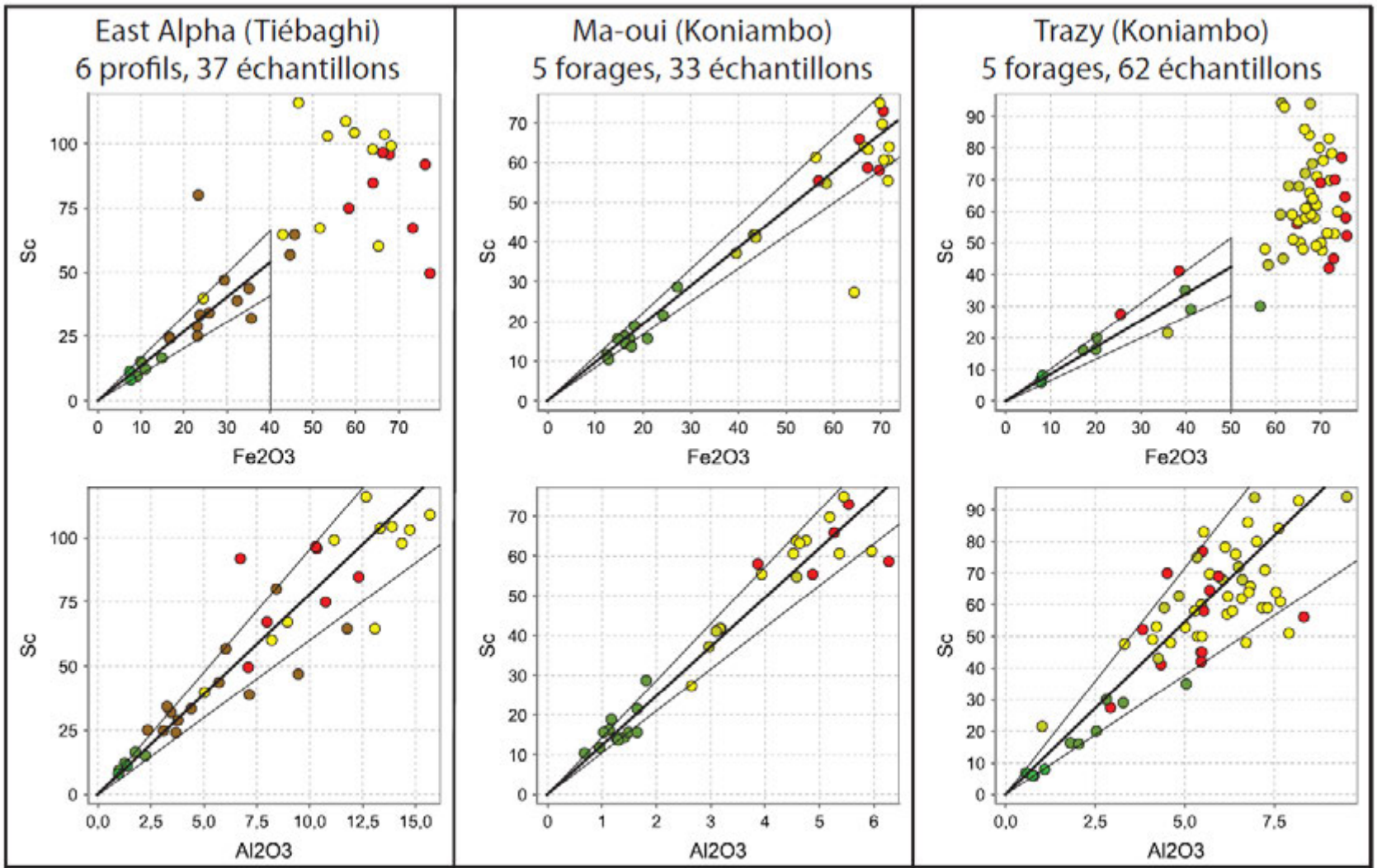
- **Analyses sur Trazy, Ma-Oui (Koniambo) et Alpha Est (Tiébaghi) = 12 forages ou profils**

- **Tester degré de pertinence du proxy Al-Sc à l'échelle du gisement**

- **Modéliser 1er ordre distribution/teneurs en Sc à partir des données Al**

Outils d'exploration du Sc

- **Proxies géochimiques Fe et Al (classiquement inclus dans bases de données)**



East Alpha (Tiébaghi)	Ma-oui (Koniambo)	Trazy (Koniambo)
Sc (ppm) = 1,35*Fe_2O_3 (%) si Fe_2O_3 < 40% ± 23%	Sc (ppm) = 0,96*Fe_2O_3 (%) ± 14%	Sc (ppm) = 0,85*Fe_2O_3 (%) si Fe_2O_3 < 50% ± 21%
Sc (ppm) = 7,75*Al_2O_3 (%) ± 22%	Sc (ppm) = 12,3*Al_2O_3 (%) ± 15%	Sc (ppm) = 11,0*Al_2O_3 (%) ± 31%

Outils d'exploration du Sc

- **Analyse directe Sc**

1) XRF classique sur perles (ex. NILAB)

LoD Scandium = 12 ppm

Interférence du Calcium : calcium > 0,5-3% interfère sur les analyses de Sc
$\Rightarrow$ méthode des ajouts dosés

Précision : la précision des analyses (dispersion à 1 écart type) est de :
16% entre 10 et 15 ppm Sc
13% autour de 20ppm Sc
9% autour de 30ppm Sc
5% autour de 50ppm Sc
2% à partir de 130ppm Sc

1450 cfp prix unitaire

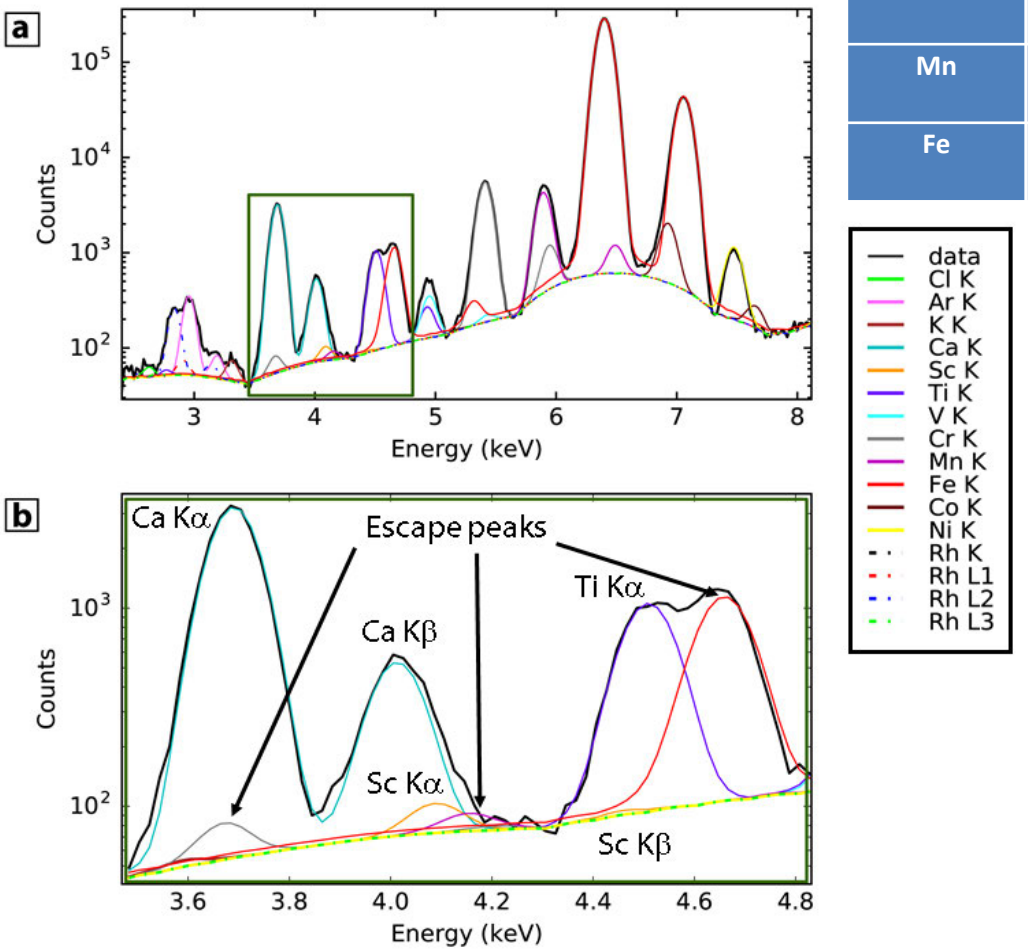
Outils d'exploration du Sc

- **Analyse directe Sc**

2) XRF portable, Quel potentiel ?

Cas d'étude : Niton Gold XL3T

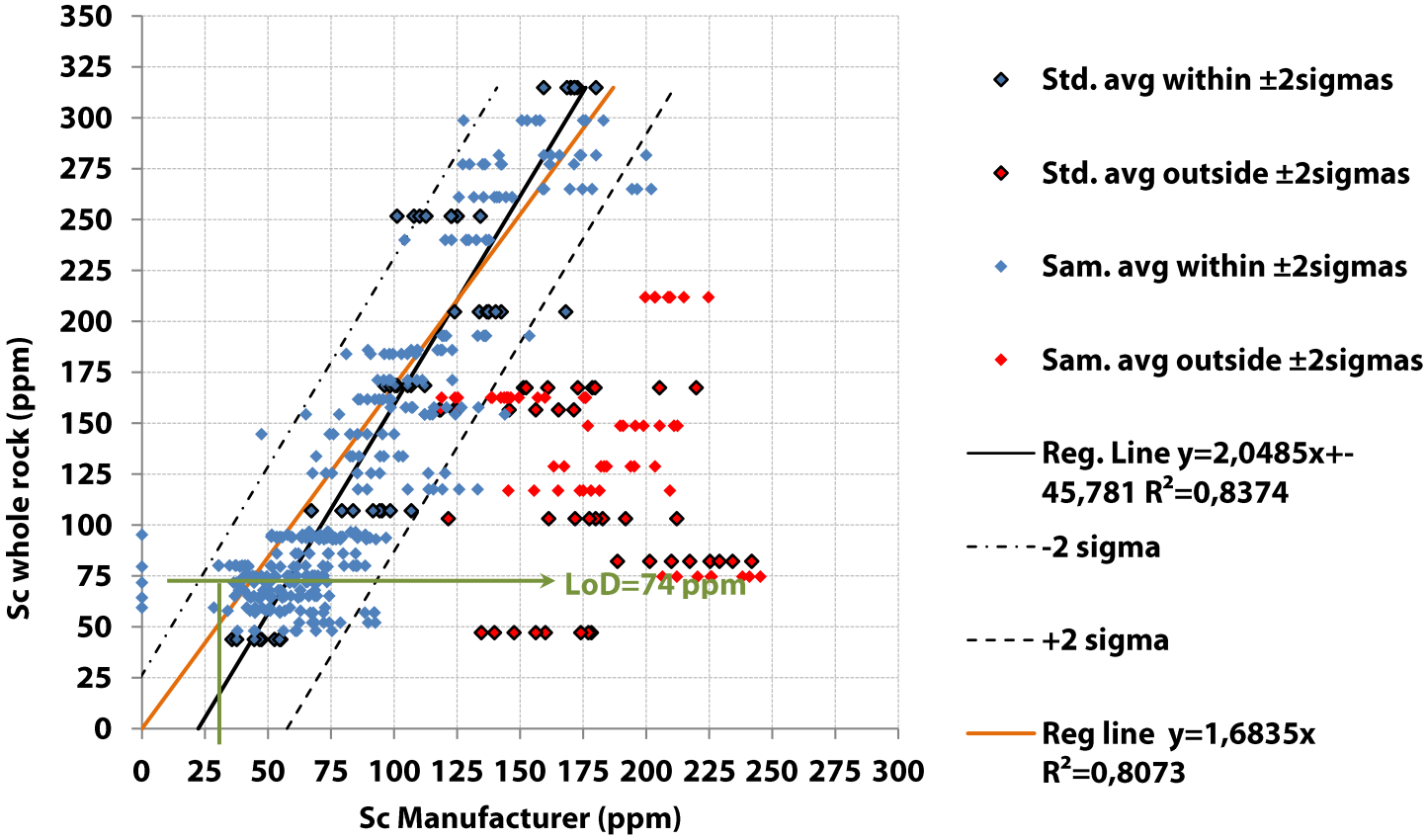
Chemical elements	Region Of Interest (ROI) in keV	Ka (keV)	Kb (keV)	Escape peak (keV)
Ca	3.6 – 3.8	3.692	4.013	-
Sc	3.9 – 4.1	4.091	4.461	-
Ti	4.31 – 4.71	4.511	4.932	-
Mn	-	5.899	6.490	4.159 (relative to Ka) 4.751 (relative to Kb)
Fe	-	6.404	7.058	4.664 (relative to Ka) 5.318 (relative to Kb)



Test de 3 modes d'analyses

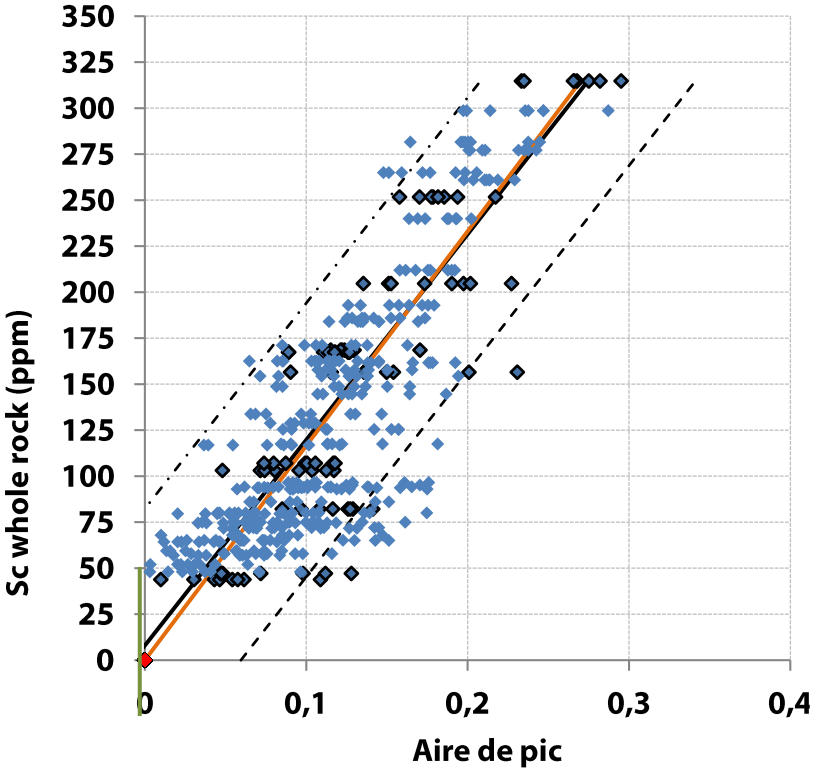
Data processing Sample excitation	"Soil" mode	PyMCA
"Low" filter: voltage of 20 kV and Cu-coated foil	Manufacturer	20 Cu
voltage of 18 kV and Fe-coated foil	-	18 Fe

Mode « Manufacturer »

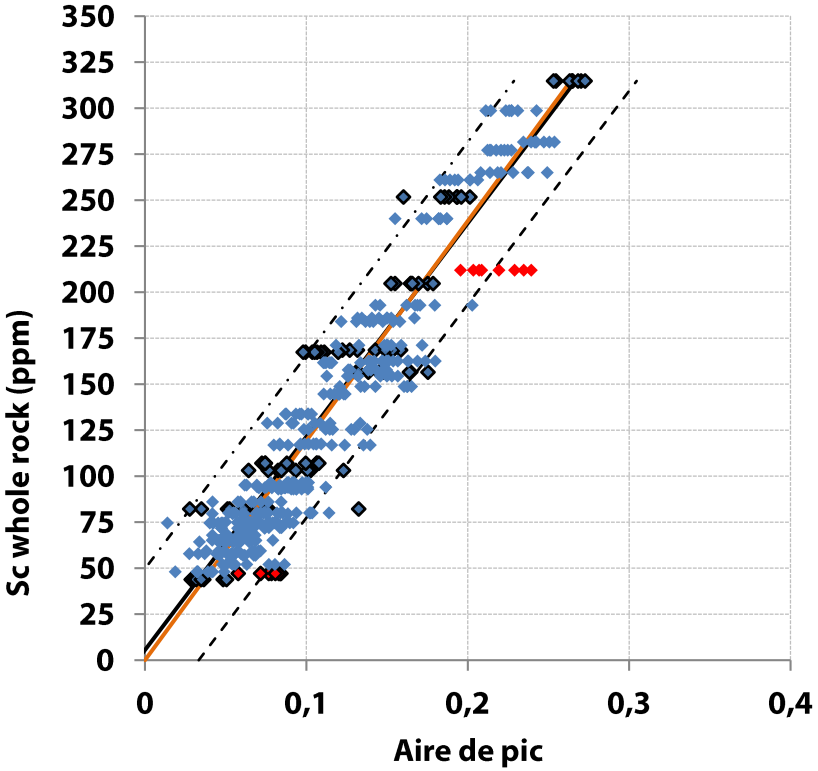


- Sur pastilles (séchage, broyage, pastillage)
- Répétition de la mesure (temps optimal 60 ou 90s)

Mode « 20 Cu »



Mode « 18 Fe »



Analysis methods / Characteristics	Manufacturer	20 Cu	18 Fe
Least Concentrated Sample in Sc by Whole Rock Analysis (ppm)	43.8	43.8	43.8
LoD for Sc (ppm)	74	80	49
LoD for Ca (ppm)	3500	2250	2350
Ca/Sc Limit 1	70	1086*	400
Ca/Sc limit 2	120	-	850

PyMCA logiciel libre de droit

Routine implémentable en automatique