



Laboratory of excellence
RESSOURCES21

Strategic metals in the 21st Century

Annual report
2018



ANR-10-LABX-21-01

www.ressources21.univ-lorraine.fr



Contents

The Director's message	4
Focus on research and approaches	5
Board members	8
Quick facts	9
Research highlights	
Integrated project on Nickel	12
Agromining - special focus on Nickel	20
Integrated project on REEs	26
Environment and mining - special focus on REEs	32
Ore genesis	38
Geometallurgy	44
Modelling	50
Education and diffusion	
Graduating students	56
Thematic scientific school	66
Training course in New Caledonia	68
International collaborations	71
Publications	80

The Director's message

RESSOURCES21 is an excellence laboratory centre (LabEx from the National Programme of Investments for the Future) in the field of Geosciences, located in Lorraine (France). It has been operated since 2011 by the OSU (Observatory in Science of the Universe-CNRS-INSU) so-called OTELO, which federates the Geosciences laboratories.

According to the Shanghai evaluation, the University of Lorraine now ranks in the 24th position in the mining sector, the second one at the European scale, and it is the only French University recognised in this field. This great result is related to the LabEx activity.

The present report, available from the website, provides:

- data on the LabEx's activity in 2018,
- a compilation of highlights obtained since 2014, with abstracts of the most representative scientific contributions sorted by research areas (2014-2018),
- a list of LabEx scientific papers published in 2018.

2018 has marked the occasion of enhanced brainstorming sessions on the scientific and societal challenges for the next decade. The LabEx RESSOURCES21 definitively follows Europe's orientation for a more sustainable circular economy and the overall goals defined by the Paris agreement to combat climate change and to accelerate and intensify scientific research, so as to formulate the best choices needed for a low carbon future and a more sustainable world.

Two main international collaborations have been enhanced through two International laboratories (Laboratoire International Associé): the LIA "Ecoland" with Sun Yat Sen University in China, and the LIA "SUCRE" with the University of Queensland, currently being implemented.

Dr Michel Cathelineau and Dr Frédéric Villiéras

The Université de Lorraine now ranks in the 24th position in the mining sector by Shanghai (ARWU*)


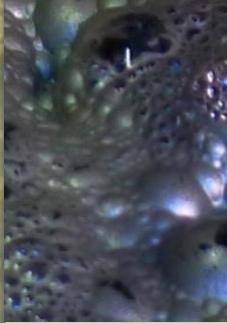
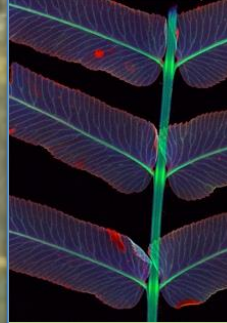





Dr Michel Cathelineau
Scientific Director
of LabEx RESSOURCES21

*<http://www.shanghairanking.com/ShanghaiRanking-Subject-Rankings/mining-mineral-engineering.html>

** <http://ressources21.univ-lorraine.fr/>
This report is available as a downloadable pdf file from this website.

The main goal of RESSOURCES21 is to produce high quality research on cutting-edge issues in the field of the geochemical cycle of metals, ore genesis, exploration techniques, processing including hydrometallurgy and mine environment evaluation

Geology Ore genesis Exploration	Ore processing Separation Geometallurgy	Agromining	Ecotoxicology Environment Remediation	Territorial Integration	Recycling
					
GeoRessources CRPG	GeoRessources Steval	LSE Coll LRGP	LSE LIEC	GeoRessources	GeoRessources (Steval, Hydroval)

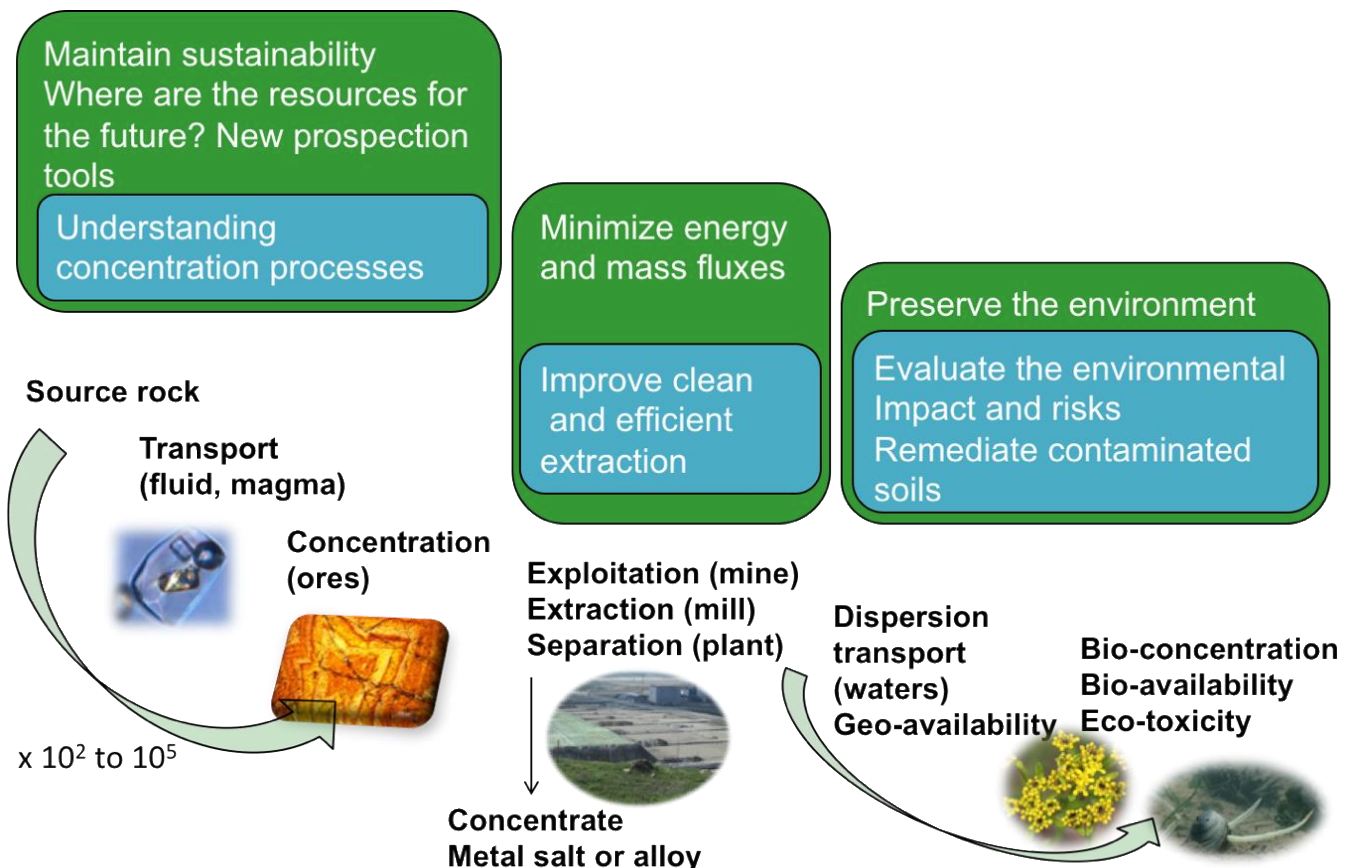
Main topics and related laboratories

- the development of all in situ techniques, necessary to the full geochemical (isotopes, geochronology) and mineralogical characterisation of ores and gangue minerals in order to develop conceptual and numerical models of ore genesis
- the processing of unconventional ores, especially fine grained ores, the search for covalorisation conditions
- agromining, e.g. farming hyperaccumulator plants to decontaminate land or harvest metal resources non accessible by conventional mining techniques
- to understand the modes of dissemination and bio-accumulation of metals in the trophic chain
- develop better knowledge of the integration of raw material circular economy within specific areas, understand people's perception of the new challenges to address for a more sustainable mining industry.



We’re focusing research on three complementary aspects of metal cycles:

1. understanding the natural and anthropogenic cycles of strategic metals and the processes of concentration (ore deposits) or dispersion in the environment;
2. developing innovative tools for better ore processing and better metal extraction;
3. evaluating the environmental effects these metals have once they have been scattered throughout the ecosystem.



To reach its goals, Labex RESSOURCES21 developed several complementary strengthening tasks or tools:

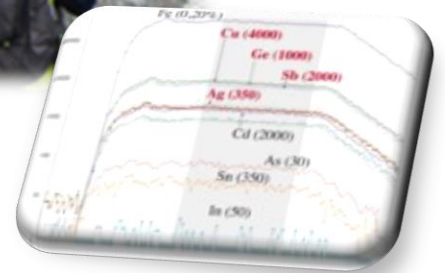
New analytical tools for the determination, distribution and concentration of trace elements within rocks and minerals, as well as for dating geological events,

3D-modelling of ore geometries, of metal transport at complementary scales, in order to understand the distribution of metals and how ore deposits form over space and time,

A hydrometallurgical platform complementing separation/flotation devices of the STEVAL platform,

New devices for **in situ analysis of rocks, minerals and plants** (spectroscopic tools),

Inventing and perfecting biogeochemical environmental sensors to monitor the spread of hazardous elements, with the aim of being able to predict pollution.



Executive board



Research area supervisors



Quick facts

LabEx RESSOURCES21 activity since 2012

Research



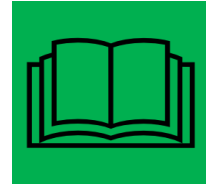
87 research projects
2 major programmes

Education



22 PhD-graduate
28 Post-graduate
124 Masters

Production



157 publications
with Labex signature

International networking



3 privileged countries for
international collaborations:
Australia, China and Canada

People



74 academic
staff members
1 scientific chair
3 senior researchers



14 international visitors
3 long stays abroad
6 co-supervised PhDs

Conferences and workshops



4 workshops
1 major conference
1 Thematic school

Funding

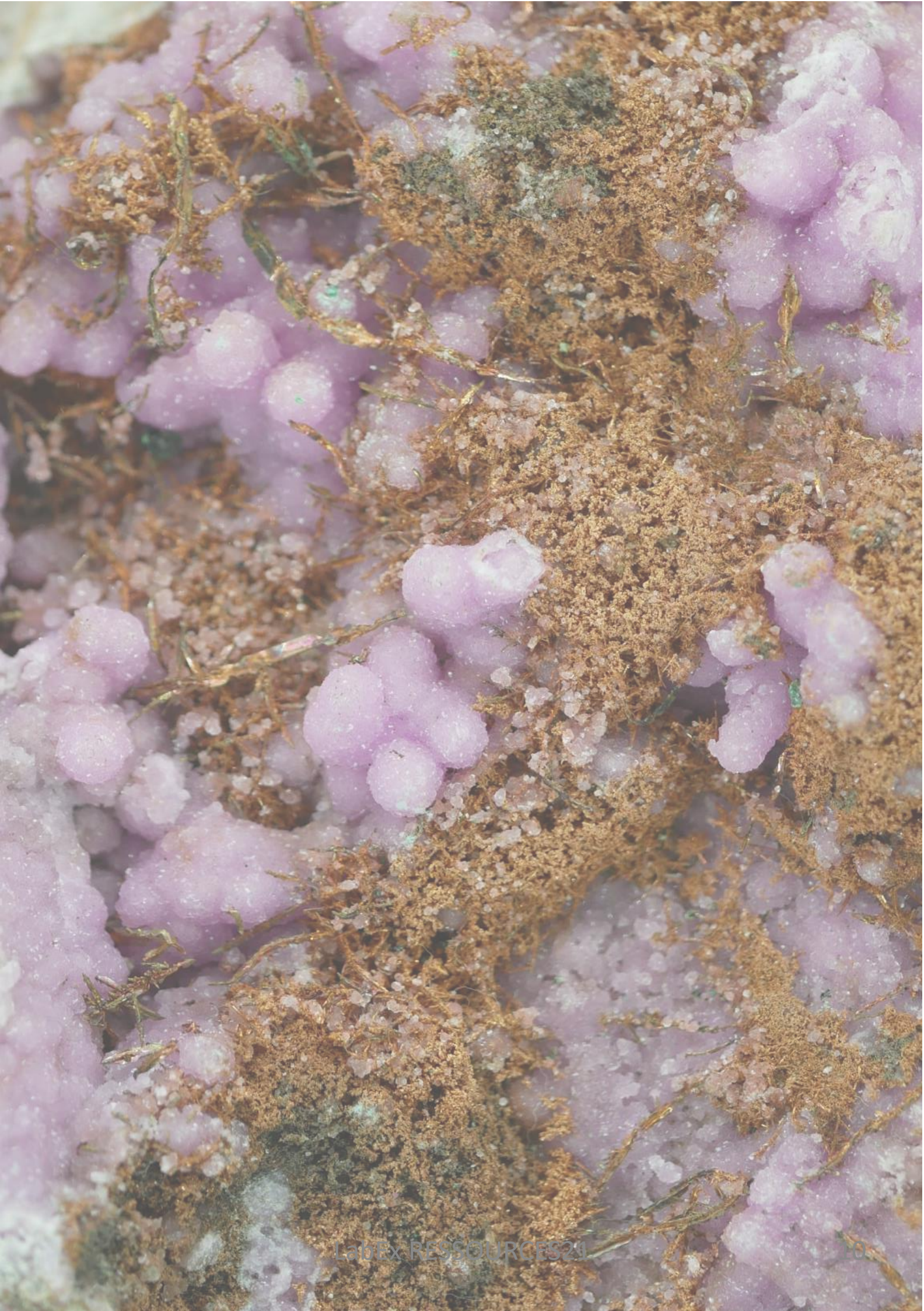


9 M euros
for 9 years

Shanghai ranking ARWU (mining)



24
UL, second European
and unique French
University





Research Highlights

Integrated projects on Nickel

Sc

Co

Ni


Integrated projects on supergene Nickel

The programme on the nickel geochemical cycle covers almost all aspects of research from exploration and metallogenesis to soil remediation, including nickel agromining, nickel laterite ore processing and ecotoxicology.

The studies aimed to contribute to a better understanding of the behaviour of the Ni-Co-(Sc) system and the lithospheric and biogeo-chemical cycles of these metals. The project considered the processes of transport and entrapment of these metals into primary deposits (laterites and saprolites) and developed new concepts for the extraction of secondary reserves (soils and technosoils). The stakes and innovative aspects of the project consist of the followings:

- **Testing and assessing a new concept of ore genesis** to explain metal enrichment in saprolites and laterites, taking both the low-temperature 'hydrothermal' history linked to early deformational stages and the supergene processes into account. Reactive geochemical transport modelling was carried out to understand the development of a nickel laterite profile in New Caledonia over the last few million years. It reveals the main factors controlling the trace element mobility in ultramafic environments. Long-term 1-D simulations (10 Ma) clearly demonstrate that Ni enrichment and thickening of iron-rich zone were governed by the vertical progression of the pH front (Myagkiy et al., 2017) while 2-D modelling reveals the Ni transfer from oxide zones and its subsequent redistribution and concentration in saprolite (Myagkiy et al., 2018).
- **Scandium** is a metal found in most geological formations but it has no specific ore. Because Sc is relatively non-mobile under supergene conditions, it is enriched with residual soils. Preliminary studies conducted in New Caledonia point to the preferential accumulation of scandium within laterites. The objective here is to better understand the mechanisms of multi-metal incorporation, especially Sc, in goethite/hematite (e.g., Al, Cr, Co, Ni, Zn, Sc), through the development of *in situ* quantitative methods for the analysis of trace elements (Teitler et al, 2018, Ulrich et al., 2018).
- **Pre-concentration of valuable elements** (e.g., Ni and REE) from fine-grained low-grade ores and waste products: in order to enhance ore grades, new approaches including separation of gangue minerals have been tested (Farrokhpay and Filippov, 2016, 2017).
- **Ni agromining**, in strong collaboration with the University of Queensland (UQ, Australia): understanding the functioning of hyperaccumulators and identifying the most suitable species for Ni phytoextraction or phytoremediation are key steps for the optimisation of agronomical efficiency and value (see specific section on "agromining").
- **A better understanding of metal transfers from soil ecosystems to the hydrosphere** and evaluation of the toxicity when transferred towards aquatic environments; the case study is the Ohrid Lake in Albania near old Ni and Cr mines. The metal accumulation is higher in primary producers (Myriophyllum and biofilms) than in gastropods indicating a trophic dilution and no metal transfer to higher levels of food webs. This work combining complementary lines of evidence confirms that chemical analyses should always be associated to the assessment of biological effects.

Multistage crack seal vein and hydrothermal Ni enrichment in serpentinized ultramafic rocks (Koniambo massif, New Caledonia)

Michel Cathelineau¹  · Andrey Myagkiy¹ · Benoit Quesnel² · Marie-Christine Boiron¹ · Pierre Gautier² · Philippe Boulvais² · Marc Ulrich³ · Laurent Truche¹ · Fabrice Golfier¹ · Maxime Drouillet⁴

Abstract Sets of fractures and breccia sealed by Ni-rich silicates and quartz occur within saprock of the New Caledonian regolith developed over ultramafic rocks. The crystallization sequence in fractures is as follows: (1) serpentine stage: lizardite > polygonal serpentine > white lizardite; (2) Ni stage: Ni-Mg kerolite followed by red-brown microcrystalline quartz; and (3) supergene stages. The red-brown microcrystalline quartz corresponds to the very last stage of the Ni sequence and is inferred to have precipitated within the 50–95 °C temperature range. It constitutes also the main cement of breccia that has all the typical features of hydraulic fracturing. The whole sequence is therefore interpreted as the result of hydrothermal fluid circulation under medium to low temperature and fluctuating fluid pressure. Although frequently described as the result of a single downward redistribution of Ni and Mg leached in the upper part of the regolith under

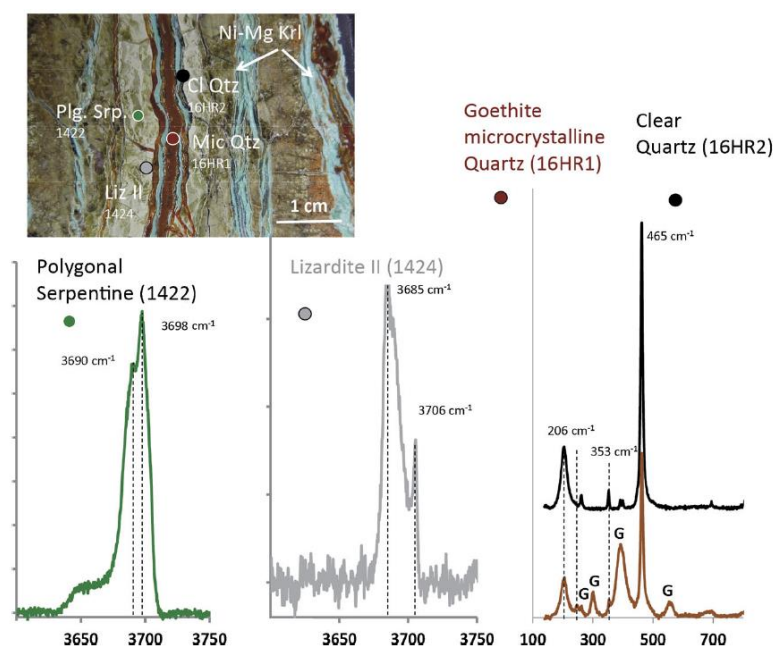


Fig. 6 Succession of lizardite (talc)–polygonal serpentine–Mg–Ni kerolite–hematite microcrystalline quartz and clear quartz fillings along subparallel fissures (elder pit, KON-207-H), with representative Raman spectra of the different silicates. Same abbreviations as in Fig. 4; *Mic Qtz* goethite microcrystalline quartz



Petrology and geochemistry of scandium in New Caledonian Ni-Co laterites

Y. Teitler^{a,*}, M. Cathelineau^a, M. Ulrich^b, J.P. Ambrosi^c, M. Munoz^d, B. Sevin^e^a Laboratoire GéoRessources, rue Jacques Callot, BP 70239, 54506 Vandœuvre-lès-Nancy Cedex, France^b EOST, 1 rue Blessig, 67084 Strasbourg Cedex, France^c CEREGE, Aix-Marseille Université, CNRS, IRD, Cdf, CEREGE, BP 80, 13545 Aix en Provence, France^d Geosciences Montpellier, CNRS UMR5243, Université de Montpellier, Place E. Bataillon, 34095 Montpellier, France^e Service de la Géologie de Nouvelle-Calédonie, Direction de l'Industrie, des Mines et de l'Énergie, 1er rue Unger, BP M2, 98849 Nouméa Cedex, New Caledonia

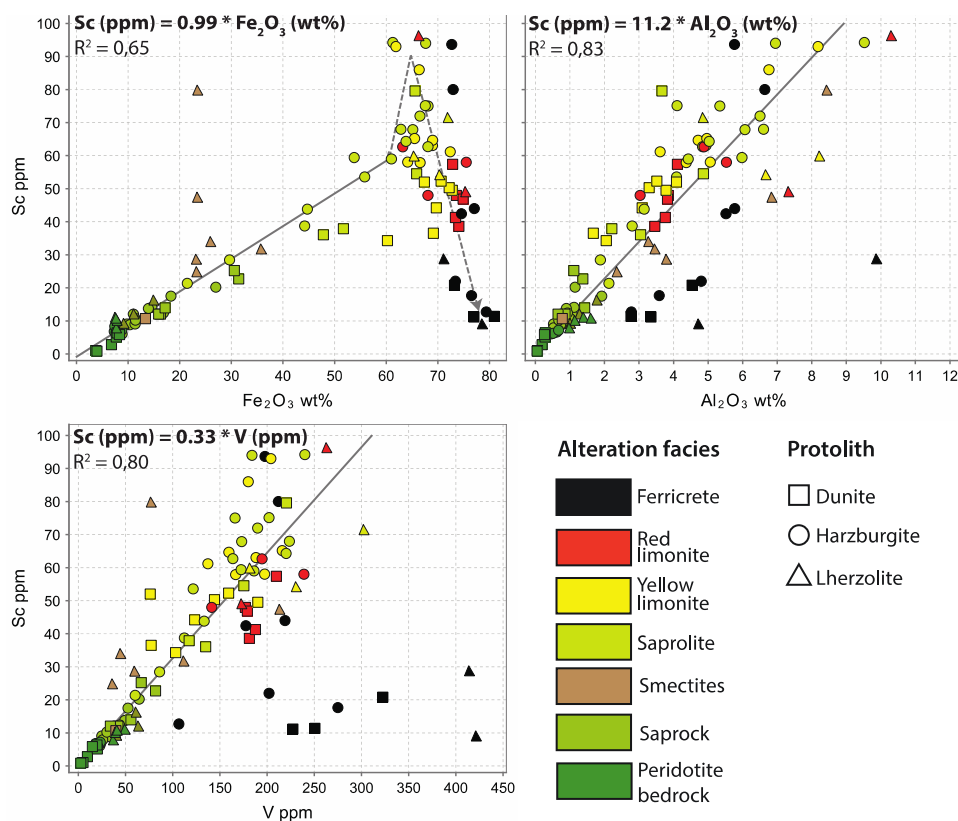
ARTICLE INFO

Keywords:

Scandium
Laterite
Ni-laterite
Goethite
New Caledonia

ABSTRACT

The growing demand for scandium (Sc), essential for several modern industrial applications, drives the mining industry to develop alternative Sc sources. In such context, significant Sc concentrations (~100 ppm) were recently reported in several Ni-Co lateritic oxide ores developed after mafic-ultramafic rocks. This contribution examines the distribution of Sc in Ni-Co laterites from New Caledonia, the sixth largest Ni producer worldwide. Representative lateritic profiles were selected based on the protolith type and include dunite, harzburgite and lherzolite protoliths, wherein the Sc content, determined by the relative proportion of olivine and pyroxene, ranges from < 5 ppm in dunite to > 10 ppm in lherzolite. In Ni-Co laterites, dissolution and leaching of primary Mg-rich silicates leads to the residual enrichment of iron as ferric oxides/oxyhydroxides in the upper horizons. Downward remobilization and trapping of Ni and Co lead to their local enrichment to economic concentrations, with maximum grades reached in the saprock/saprolite and in the transition horizons, respectively. In contrast, maximum Sc enrichment occurs in the yellow limonite horizon, where Sc-bearing goethite contains about ten times the Sc content of the parent rock. Consequently, harzburgite- and lherzolite-derived yellow limonites yield maximum Sc concentrations up to 100 ppm, together with moderate Ni and Co concentrations. There, Sc is potentially a valuable by-product that could be successfully co-extracted along with Ni and Co through hydrometallurgical processing. In addition to peridotite-hosted laterites, hornblende-rich amphibolites yield elevated Sc up to 130 ppm. The saprolitization of amphibolites leads to the formation of a goethite-gibbsite-kaolinite mixture with Sc concentrations > 200 ppm. There, goethite is the main Sc carrier with up to 800 ppm Sc. Therefore, despite their relatively limited volumes, amphibolite-derived saprolites may also represent attractive targets for Sc in New Caledonia. It is proposed that three main factors control the distribution and intensity of Sc enrichment in laterites derived from mafic and ultramafic rocks: (i) the initial Sc content of the parent rock, (ii) the development of goethite-dominated, yellow limonite after long-lived tropical weathering, and (iii) the local remobilization of Sc from the uppermost horizons through dissolution/recrystallization of goethite and partial replacement of goethite by hematite, thus leading to downward Sc concentration in the yellow limonite.



Revealing the conditions of Ni mineralization in the laterite profiles of New Caledonia: Insights from reactive geochemical transport modelling

Andrey Myagkiy^{a,*}, Laurent Truche^{a,b}, Michel Cathelineau^a, Fabrice Golfier^a

^a GeoRessources Lab., UMR 7359 of CNRS, CREGU, University of Lorraine, F-54518 Vandoeuvre-Lès-Nancy Cedex, France

^b ISTerre, UMR 5275 of CNRS, University of Grenoble Alpes, Grenoble Cedex 9 F-38041, France

ABSTRACT

New Caledonia is one of the world's largest nickel laterite deposits that form from intense chemical and mechanical weathering of a peridotite bedrock. As a result of such a weathering process a subsequent downward migration of Si, Mg and Ni takes place, which eventually leads to redistribution of the elements in depth and over time depending on their mobility. Being released from ultramafic parent rock to groundwater, the mobility of nickel is to a great extent controlled by sorption, substitution and dissolution/precipitation processes. Therefore, the final profile of nickel enrichment is the result of the superposition of these possible fates of nickel. The way how Ni is redistributed in between them represents and defines its mineralization in laterite. Knowledge of these processes along with factors, controlling them appears to be a key to detailed understanding of laterite formation. In this study a numerical model, which solves the reaction-transport differential equations, is used to simulate the formation of laterite profile from ultramafic bedrock with particular emphasis on modelled Ni enrichment curve, its comparison with in situ observations, and detailed understanding of trace elements mobility. Since nickel deposits in New Caledonia is characterized by oxide and hydrous Mg silicate ores, three different concurrent fates of Ni deposition in a profile were taken into account in the modelling: i) Ni in a goethite crystal lattice, ii) Ni sorbed on weak and strong goethite sorption sites, and iii) Ni precipitated with silicates (garnierite). Simulations were performed using PHREEQC associated with *lnl.dat* thermodynamic database that has been edited in order to account garnierite minerals used in the calculations. The work outline is represented by: i) long term (10 Ma) simulation of nickel laterite formation and evolution, ii) analysis of mobility of the elements and understanding its controlling factors, iii) comparison of modelled and in situ Ni enrichment profile and analysis of nickel distribution in between different retention processes, iv) modelling and in depth understanding of these retention processes. The modelling reveals that the vertical progression of the pH front controls thickening of iron-rich zone, explains the vertical mobility of the elements and governs the Ni enrichment. Adsorption itself plays an important role in lateritization process retarding Ni mobility, but i) becomes significant in a narrow range of pH (slightly alkaline) due to competition of Mg and Ni for sorption sites and ii) does not explain such a high nickel content in limonite nowadays, suggesting that Ni is held in goethite mostly by stronger ties i.e. substituted for Fe in the crystal lattice of iron oxide. 1-D modelling appears to be a powerful tool in understanding the general behavior of trace elements upon the formation of laterite and at the same time reveals that locally Ni mineralizations should be explained by more complex processes, such as lateral transfers, convective flows and preferential pathways.

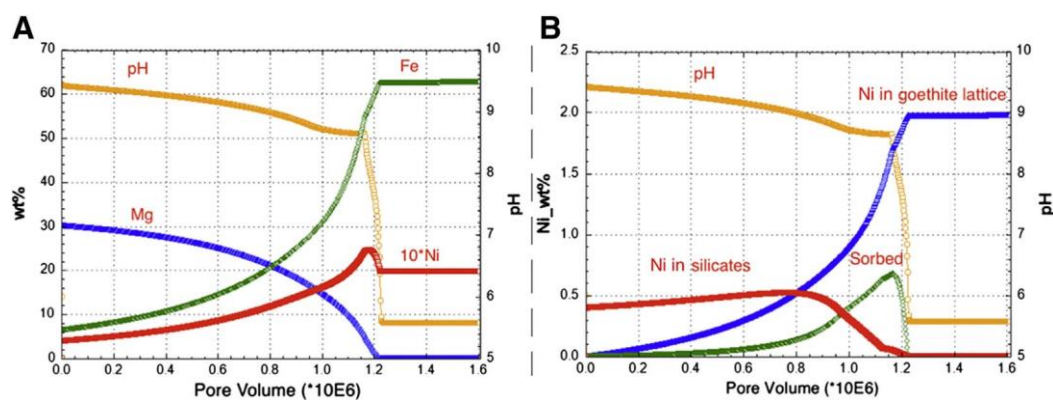


Fig. 7. Panel A represents the mobility of the elements in a 1-D reactive transport modelling through one cell; supergene enrichment of Ni and its retention by three different mechanisms: i) Sorption on goethite surface, ii) Retention in goethite structure, and iii) Precipitation with Ni-silicates. Panel B shows the split (redistribution) of Ni between different retention mechanisms upon the formation of laterite. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)



Characterization of Weda Bay nickel laterite ore from Indonesia

Saeed Farrokhpay^{a,*}, Michel Cathelineau^a, Simon B. Blancher^b, Odile Laugier^b, Lev Filippov^a

^a Université de Lorraine, CNRS, CREGU, GeoResources Laboratory, UMR 7359 CNRS, 2 rue du Doyen Marcel Roubault, TSA 70605, 54518 Vandoeuvre-lès-Nancy, France

^b ERAMET RESEARCH, 1 Avenue Albert Einstein, 78190 Trappes, France



ARTICLE INFO

Keywords:

Weda Bay
Nickel laterite
Serpentine
Saprolite
Raman spectroscopy
QEMSCAN mapping

ABSTRACT

The association of fine grained Mg–Ni silicates with oxy-hydroxides in laterites and saprolites represents challenges for ore processing, in particular, in nickel enrichment. The Weda Bay nickel deposit in Indonesia is a typical example of these complex ores, where clays such as nontronites develop on polyphase serpentinite as protolith. Thus, ores at Weda Bay have a very fine textured and complex mineralogy, which requires a comprehensive mineralogical identification through the use of a series of different types of analytical approaches (i.e. macroscopic and microscopic methods including SEM equipped with energy dispersive X-ray spectrometry (EDS), Raman spectroscopy, Infrared and X-ray fluorescence spectroscopy, and QEMSCAN® mapping). Nickel rich saprolites were found to be principally composed of several types of Mg–Ni serpentines, quartz, clays (nontronite in particular) and little amounts of iron hydroxides. Besides, some parts of the deposit were characterized by the development of nontronites at the interface between the saprolite and the limonite zone. Above this zone, the limonite zone is dominated by iron hydroxides as expected, which replace all earlier silicates including serpentine, and contains a significant amount of nickel. The representative composite ore sample contains several nickel bearers with variable nickel grade of 2 to 3%. Exceptionally richer phases such as polygonal Fe (Ni)-rich serpentine were also found with nickel grade of 5 to 10%. Serpentine types as well as other newly formed silicates such as Fe-Mg-(Ni) smectites, are intimately mixed, preventing any mineral separation. Therefore, the only phases which can be separated are quartz and magnetite. This complicates the upgrading of nickel in Weda Bay laterite ore.

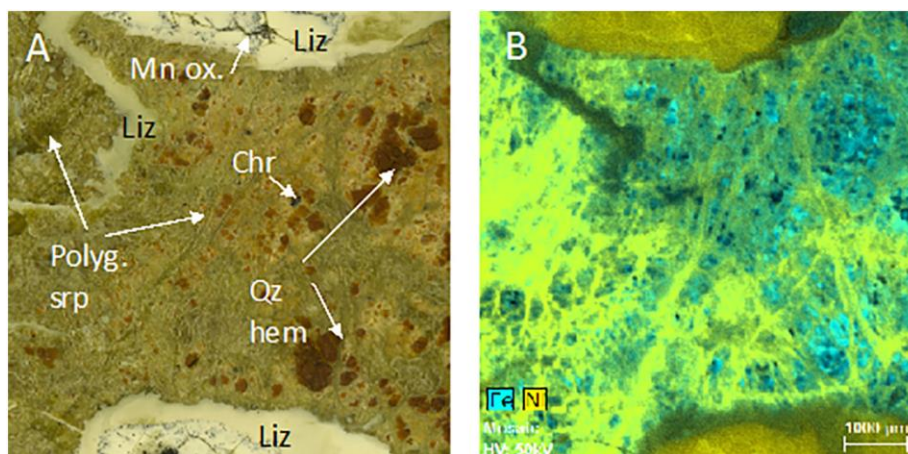


Fig. 5. X-ray microfluorescence maps obtained on the same sample than that presented in Fig. 3.

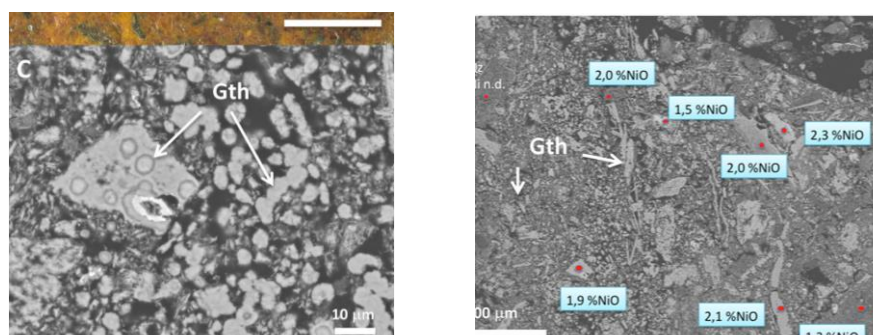


Fig. 8. Main features of the fine grained part of the representative ore sample dominated by earthy saprolite:



Aggregation of nickel laterite ore particles using polyacrylamide homo and copolymers with different charge densities

Saeed Farrokhpay^{a,*}, Lev Filippov^{a,b}

^a Université de Lorraine, GeoRessources Laboratory, CNRS, UMR 7359, 2 rue du Doyen Marcel Roubault, 54518 Vandoeuvre-lès-Nancy, France

^b National University of Science and Technology MISIS, Leninskiy prospekt 4, 119049, Moscow, Russia

ARTICLE INFO

Article history:

Received 23 November 2016

Received in revised form 2 May 2017

Accepted 11 May 2017

Available online 13 May 2017

Keywords:

Nickel laterite

Aggregation

Polyacrylamide

Flocculation

Settling rate

Floc size

ABSTRACT

In this work, the effect of polyacrylamide mono and copolymers with different charge densities on the aggregation of nickel laterite ore particles was studied. The methodology involved settling tests, characterisation of the flocs using microscope, and evaluation of the flocs stability. The flocs resulted from the nonionic polyacrylamide were found to be bigger and more stable, than the high charged or low charged ionic copolymers. The settling of particles was also faster when nonionic polyacrylamide was used. On the contrary, the flocs resulted from the high charged density copolymer were small, with very slow settling rate. The size of the flocs obtained experimentally was in a good agreement with those calculated theoretically using Stokes' law.

© 2017 Elsevier B.V. All rights reserved.

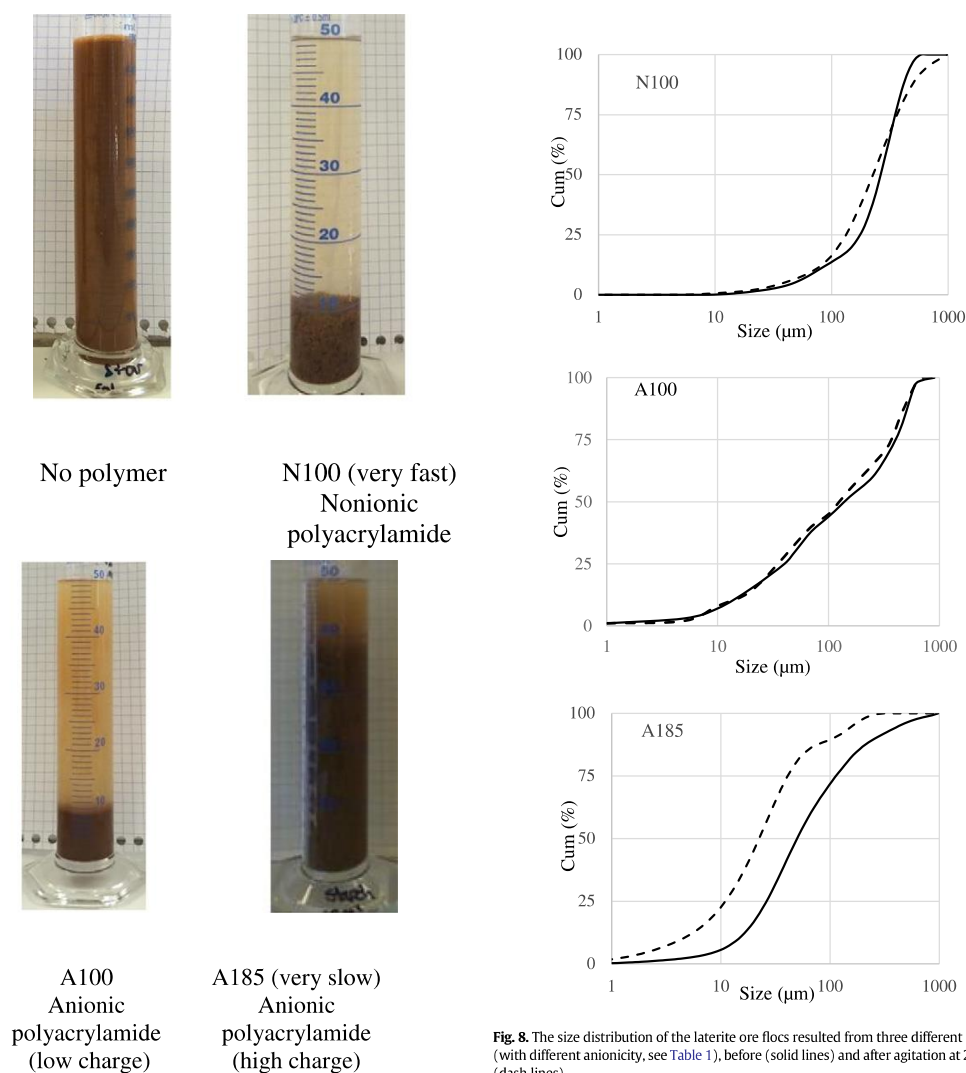
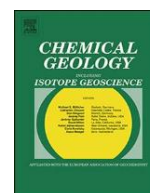


Fig. 8. The size distribution of the laterite ore flocs resulted from three different polymers (with different anionicity, see Table 1), before (solid lines) and after agitation at 2000 rpm (dash lines).



The influence of organic complexation on Ni isotopic fractionation and Ni recycling in the upper soil layers

I.O. Zelano^{a,b,*}, C. Cloquet^a, F. Frayssé^b, S. Dong^a, N. Janot^b, G. Echevarria^c, E. Montargès-Pelletier^b

^a CRPG, UMR 7358, CNRS-Université de Lorraine, 15, rue Notre-Dame-des-Pauvres, BP20, 54501, Vandœuvre-lès-Nancy, France

^b LIEC, UMR 7360, CNRS-Université de Lorraine, 15, Avenue du Charmois, 54500, Vandœuvre-lès-Nancy, France

^c LSE, UMR 1120 INRA Université de Lorraine, 2 avenue de la Forêt de Haye, 54500 Vandœuvre-lès-Nancy, France



ARTICLE INFO

Editor: G. Jerome

Keywords:

Ni
Isotopic fractionation
Complexation
Organic matter
Hyperaccumulating plants

ABSTRACT

The quantification of Ni isotopic fractionation induced by Ni binding to organic acids is a preliminary step to better constrain the mechanisms determining Ni isotopic fingerprint observed in surface soils, waters and plants, as well as the contribution of metal recycling during plant litter degradation. In this study, Ni isotopic fraction induced by reaction with small organic acids, e.g. citric and oxalic acids, and with soil purified humic acids (PHA) was investigated at different Ni-L ratio and pH conditions. The Donnan Membrane Technique was used to separate Ni bound to organic ligands from the free metal. Obtained results highlighted that Ni binding with carboxylic groups produces, in the adopted experimental conditions, a $\Delta^{60}\text{Ni}_{\text{bond-free}} < 0.2\%$. This value is not high enough to justify neither metal fractionation previously observed between soil and hyperaccumulators, nor the fractionation between different plant parts, e.g. roots and leaves. In parallel, leaf degradation experiments of two hyperaccumulating plants, where Ni is mainly present as Ni-citrate, were performed to simulate litter decomposition and to highlight the contribution of plants on Ni isotopic composition in surface soils and waters. In the case of the hyperaccumulator *Alyssum murale*, the degradation process did not induce any observable fractionation. On the contrary, during *Rinorea bengalensis* degradation experiment, a fractionation between Ni leached out in the first 10 days and between 10 and 30 days was observed ($\Delta^{60}\text{Ni}_{10-30\text{day}} = 0.20 \pm 0.05\%$). The observed fractionation evidenced a heterogeneous distribution of Ni within the leaves, and/or distinct chemical bonding to the leaf cells, and finally suggested the influence of the chemical bonding on Ni isotopic signature. Although a precise quantification of plant contribution on Ni isotopic signature in surface soils and waters is still not reached, our results produced important progress to elucidate the role of organic matter in regulating Ni isotopic fingerprint in surface layers.

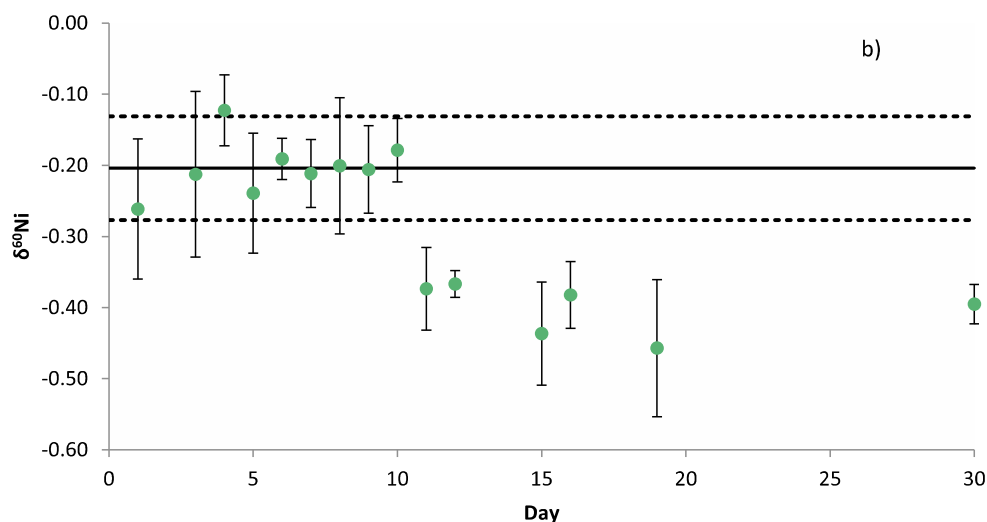


Fig. 3. *Rinorea bengalensis* leaves leaching experiments in presence of NaN_3 . a) Ni concentration ($\mu\text{mol L}^{-1}$) in the leached solution as a function of time. b) $\delta^{60}\text{Ni}$ value in the leached solution. The continuous and dot black lines indicate the average isotopic composition of leaves before leaching and the corresponding standard deviation.



Agromining - special focus on Nickel

- **Ni fractionation:** the fractionation of nickel and its isotopes between soil and plants was studied on cases illustrating the functioning of metal hyperaccumulating plants (Estrade et al., 2015, Deng et al., 2016; 2017; Nkrumah et al, 2016, van der Ent et al. 2017, 2018, Zelano et al., 2018).
- **Ni hyperaccumulators:** thanks to botanic surveys and further plant domestication (Bani et al., 2013), hyperaccumulators could be grown under field conditions to produce biomass on Ni-bearing soils and to extract metals (Ni) from contaminated soils (Bani et al., 2015) and from industrial waste (Rue, 2017). Understanding the functioning of hyperaccumulators and identifying the most suitable species for Ni phytoextraction or phytoremediation are key steps for the optimisation of agronomical efficiency and value and defining strategies for the development and implementation of materials for the construction of technosoils.
- **Biomass processing** towards a commercial end-product (metal salt) was demonstrated as being feasible and patented (Zhang et al., 2014, Vaughan et al., 2017, Simmonot et al., 2018). Works were carried out in close collaboration with the University of Queensland (UQ, Australia, van der Ent et al., 2018) and Sun Yat-sen University (SYSU, China) with an extension to the REE biogeochemical cycle.



Characterisation and hydrometallurgical processing of nickel from tropical agromined bio-ore



James Vaughan^{a,*}, Justin Riggio^b, Jeff Chen^a, Hong Peng^a, Hugh H. Harris^c, Antony van der Ent^{d,e}

^a The University of Queensland, School of Chemical Engineering, Australia

^b McGill University, Department of Materials Engineering, Canada

^c Department of Chemistry, The University of Adelaide, South Australia, Australia

^d Centre for Mined Land Rehabilitation, Sustainable Minerals Institute, The University of Queensland, Australia

^e Université de Lorraine – INRA, Laboratoire Sols et Environnement, UMR 1120, France

ABSTRACT

Hyperaccumulator plants (“metal crops”) can be used for selective extraction of Ni from low-grade resources, thereby producing a high-grade “bio-ore”. This so-called agromining (or phytomining) technology involves farming select metal crops on ultramafic soils, mineral wastes, or overburden that are sub-economic Ni resources for conventional extractive technology. Key to profiting from agromining is the efficient recovery of Ni and by-products from the bio-ore, either directly from freshly harvested biomass or from the ash after incineration. Bio-ore of wild grown specimens of the Ni hyperaccumulator plants *Rinorea bengalensis* and *Phyllanthus securinegoides* were collected in Malaysia. After incineration, the ash composites contained 5.5 and 12.7 wt% Ni for *Rinorea* and *Phyllanthus* respectively, along with substantial amounts of Ca, K, C, Mg, P, Na, S and Cl. Other minor impurities included Si, Fe, Al, Mn and Zn. The solids were characterised in detail by SEM-EDS, XRD and XANES. The effect of solution chemistry on the leaching behaviour of the bio-ore (dried biomass and ash) was also assessed. A hydrometallurgical process for recovering Ni from the bio-ore was then demonstrated. The process involves the bio-ore (ash) being water-washed, yielding >90% recovery of K to solution. After water washing, >95% Ni recovery was achieved by H₂SO₄ leaching at 60 °C, although long residence times and high acid concentrations were required. Ni(OH)₂ was then precipitated from solution using the K₂CO₃ rich wash-water. The bio-ore generated precipitant was compared with NaOH and MgO used industrially.

© 2017 Elsevier B.V. All rights reserved.

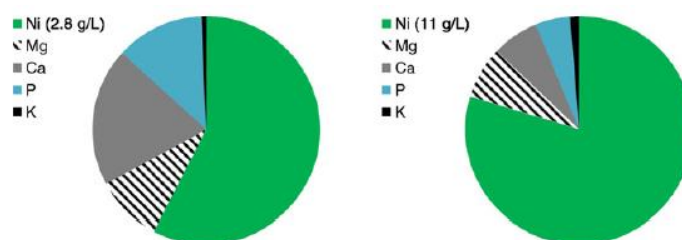


Fig. 7. Major components (except S) of the final leach solution Stage 2 leach (1 M H₂SO₄). *Rinorea* left, *Phyllanthus* right.

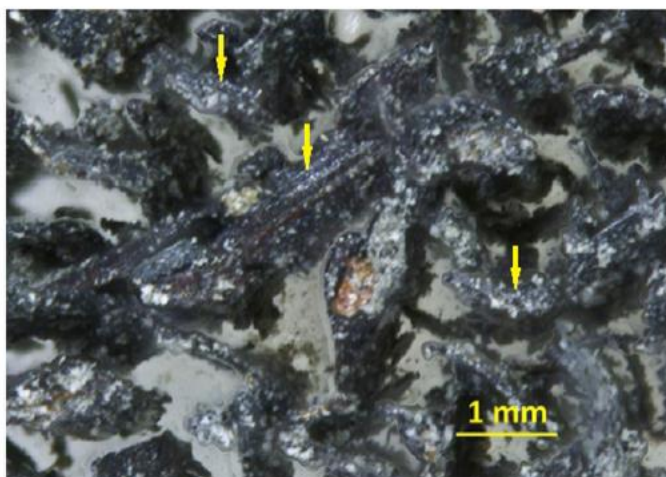


Fig. 5. Optical microscope image of *Phyllanthus* ash. Yellow arrows highlight areas more concentrated in reduced nickel on the surface of the ash that appear as fine light grey particles which are relatively evenly distributed.



Weathering and vegetation controls on nickel isotope fractionation in surface ultramafic environments (Albania)



Nicolas Estrade^{a,*}, Christophe Cloquet^a, Guillaume Echevarria^b, Thibault Sterckeman^b, Tenghaobo Deng^{b,c}, YeTao Tang^c, Jean-Louis Morel^b

^a CRPG, UMR 7358 CNRS/Université de Lorraine, 15 rue Notre-Dame-des-Pauvres, BP 20, 54501 Vandoeuvre-lès-Nancy, France

^b Laboratoire Sols et Environnement, INRA-Université de Lorraine, 2 avenue de la Forêt de Haye, TSA 40602, F-54518 Vandoeuvre-lès-Nancy Cédex, France

^c School of Environmental Science and Engineering, Sun Yat-sen University, Guangzhou 510275, PR China

ABSTRACT

The dissolved nickel (Ni) isotopic composition of rivers and oceans presents an apparent paradox. Even though rivers represent a major source of Ni in the oceans, seawater is more enriched in the heavier isotopes than river-water. Additional sources or processes must therefore be invoked to account for the isotopic budget of dissolved Ni in seawater. Weathering of continental rocks is thought to play a major role in determining the magnitude and sign of isotopic fractionation of metals between a rock and the dissolved product. We present a study of Ni isotopes in the rock–soil–plant systems of several ultramafic environments. The results reveal key insights into the magnitude and the control of isotopic fractionation during the weathering of continental ultramafic rocks. This study introduces new constraints on the influence of vegetation during the weathering process, which should be taken into account in interpretations of the variability of Ni isotopes in rivers.

The study area is located in a temperate climate zone within the ophiolitic belt area of Albania. The serpentinized peridotites sampled present a narrow range of heavy Ni isotopic compositions ($\delta^{60}\text{Ni} = 0.25 \pm 0.16\text{‰}$, $2\text{SD } n = 2$). At two locations, horizons within two soil profiles affected by different degrees of weathering all presented light isotopic compositions compared to the parent rock ($\Delta^{60}\text{Ni}_{\text{soil-rock}}$ up to -0.63‰). This suggests that the soil pool takes up the light isotopes, while the heavier isotopes remain in the dissolved phase. By combining elemental and mineralogical analyses with the isotope compositions determined for the soils, the extent of fractionation was found to be controlled by the secondary minerals formed in the soil.

The types of vegetation growing on ultramafic-derived soils are highly adapted and include both Ni-hyperaccumulating species, which can accumulate several percent per weight of Ni, and non-accumulating species. Whole-plant isotopic compositions were found to be isotopically heavier than the soil ($\Delta^{60}\text{Ni}_{\text{whole plant-soil}}$ up to 0.40‰). Fractions of Ni extracted by DTPA (diethylenetriaminepentaacetic acid) presented isotopically heavy compositions compared to the soil ($\Delta^{60}\text{Ni}_{\text{DTPA-soil}}$ up to 0.89‰), supporting the hypothesis that the dissolved Ni fraction controlled by weathering has a heavy isotope signature. The non-hyperaccumulators ($n = 2$) were inclined to take up and translocate light Ni isotopes with a large degree of fractionation ($\Delta^{60}\text{Ni}_{\text{leaves-roots}}$ up to -0.60‰). For Ni-hyperaccumulators ($n = 7$), significant isotopic fractionation was observed in the plants in their early growth stages, while no fractionation occurred during later growth stages, when plants are fully loaded with Ni. This suggests that (i) the high-efficiency translocation process involved in hyperaccumulators does not fractionate Ni isotopes, and (ii) the root uptake process mainly controls the isotopic composition of the plant. In ultramafic contexts, vegetation composed of hyperaccumulators can significantly influence isotopic compositions through its remobilization in the upper soil horizon, thereby influencing the isotopic balance of Ni exported to rivers.

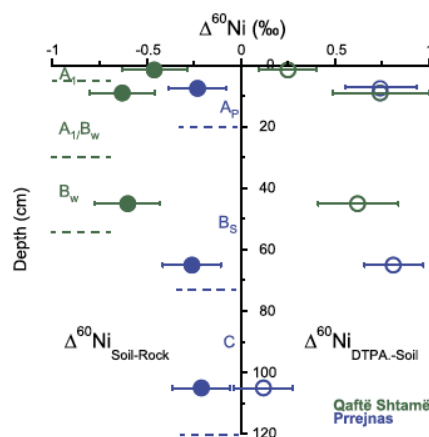


Fig. 3. $\Delta^{60}\text{Ni}$ (‰) as a function of depth (cm) for the soil profiles at Qaftë Shtamë (green) and Prrejas (blue). The isotopic fractionation between the soil and the rock is negative and is plotted on the left-hand side. The isotopic fractionation between the Ni-available fraction extracted using DTPA and the soil is positive and is plotted on the right-hand side. Horizon depth and names are reported using corresponding colors. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Improving the Agronomy of *Alyssum murale* for Extensive Phytomining: A Five-Year Field Study

AIDA BANI^{1,2}, GUILLAUME ECHEVARRIA^{2,3}, SULEJMAN SULÇE¹, and JEAN LOUIS MOREL^{2,3}

¹Agro-Environmental Department, Faculty of Agronomy and Environment, Agricultural University of Tirana, Koder-Kamez, Albania

²Université de Lorraine, Laboratoire Sols et Environnement, Vandœuvre-lès-Nancy, France

³INRA, Laboratoire Sols et Environnement, Vandœuvre-lès-Nancy, France

Large ultramafic areas exist in Albania, which could be suitable for phytomining with native *Alyssum murale*. We undertook a five-year field experiment on an ultramafic Vertisol, aimed at optimizing a low-cost Ni-phytoextraction crop of *A. murale* which is adapted to the Balkans. The following aspects were studied on 18-m² plots in natural conditions: the effect of (i) plant phenology and element distribution, (ii) plant nutrition and fertilization, (iii) plant cover and weed control and (iv), planting technique (natural cover vs. sown crop). The optimal harvest time was set at the mid-flowering stage when Ni concentration and biomass yield were highest. The application of N, P, and K fertilizers, and especially a split 100-kg ha⁻¹ N application, increased the density of *A. murale* against all other species. It significantly increased shoot yield, without reducing Ni concentration. In natural stands, the control of graminaceous weeds required the use of an anti-monocots herbicide. However, after the optimization of fertilization and harvest time, weed control procured little benefit. Finally, cropping sown *A. murale* was more efficient than enhancing native stands and gave higher biomass and phytoextraction yields; biomass yields progressively improved from 0.3 to 9.0 t ha⁻¹ and phytoextracted Ni increased from 1.7 to 105 kg ha⁻¹.

Keywords: hyperaccumulator, nickel, phytoextraction, ultramafic soil

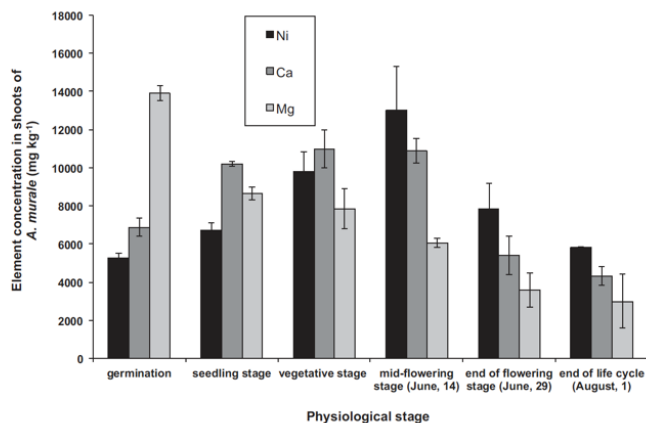


Fig. 5. Ni, Ca, Mg concentrations in shoots of *A. murale* according to the observed phenological stage in 2007 in the experimental phytomining site of Pojskë. Results are given as mean value \pm standard deviation ($n = 3$).

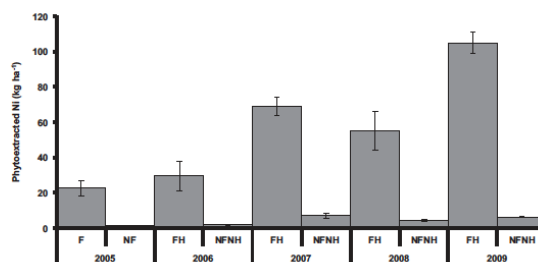


Fig. 6. Phytoextracted nickel by *A. murale* (kg ha⁻¹) during the 5-year phytomining field experiment. F: fertilization alone treatment; FH: fertilization+herbicide; NF or NFNH: no fertilization+no herbicide treatment. Results are given as mean value \pm standard deviation ($n = 3$).

Agromining: Farming for Metals in the Future?

Antony van der Ent,^{*,†,○} Alan J. M. Baker,^{†,+,○} Roger D. Reeves,[‡] Rufus L. Chaney,[§] Christopher W. N. Anderson,^{||} John A. Meech,^{⊥,@} Peter D. Erskine,[†] Marie-Odile Simonnot,[#] James Vaughan,[∇] Jean Louis Morel,[○] Guillaume Echevarria,[○] Bruno Fogliani,[◆] Qiu Rongliang,[¶] and David R. Mulligan[†]



Figure 1. Phytomining/agromining operations with harvesting of biomass and processing of bio-ore. The top four panels show the parallel strategies of phytomining and agromining on degraded/mined land or on low productive agricultural land, respectively. The lower four panels show harvesting of biomass and production of Ni (intermediate) products. Photo credits: EcoRCE/IAC/G Losfeld, A Baker, Société le Nickel, R. Chaney, A. Bani, J. Vaughan.



Phytomining technology employs hyperaccumulator plants to take up metal in harvestable plant biomass. Harvesting, drying and incineration of the biomass generates a high-grade bio-ore. We propose that “agromining” (a variant of phytomining) could provide local communities with an alternative type of agriculture on degraded lands; farming not for food crops, but for metals such as nickel (Ni). However, two decades after its inception and numerous successful experiments, commercial phytomining has not yet become a reality. To build the case for the minerals industry, a large-scale demonstration is needed to identify operational risks and provide “real-life” evidence for profitability.

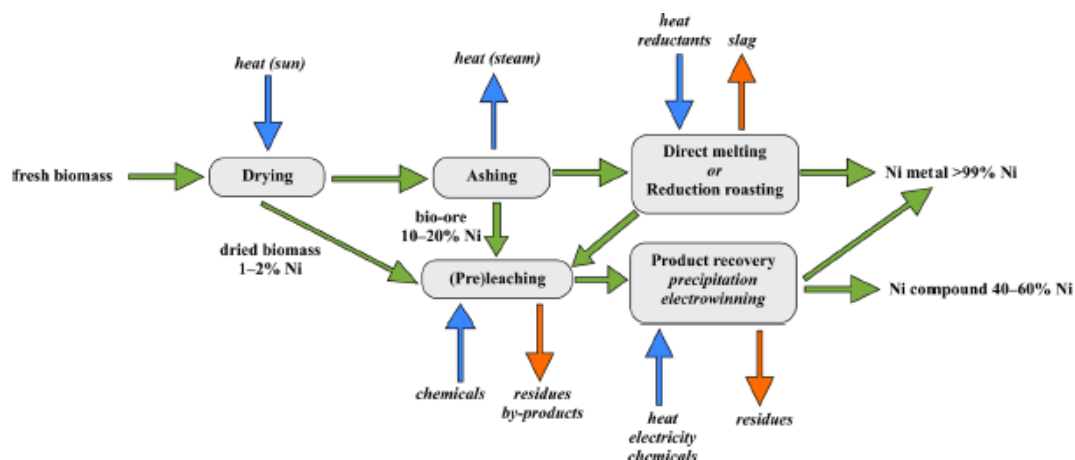


Figure 2. Flow sheet of bio-ore processing options as discussed in the text. Major inputs, intermediate products and wastes are indicated. Approximate Ni concentrations of the biomass, bio-ore and products are also indicated.

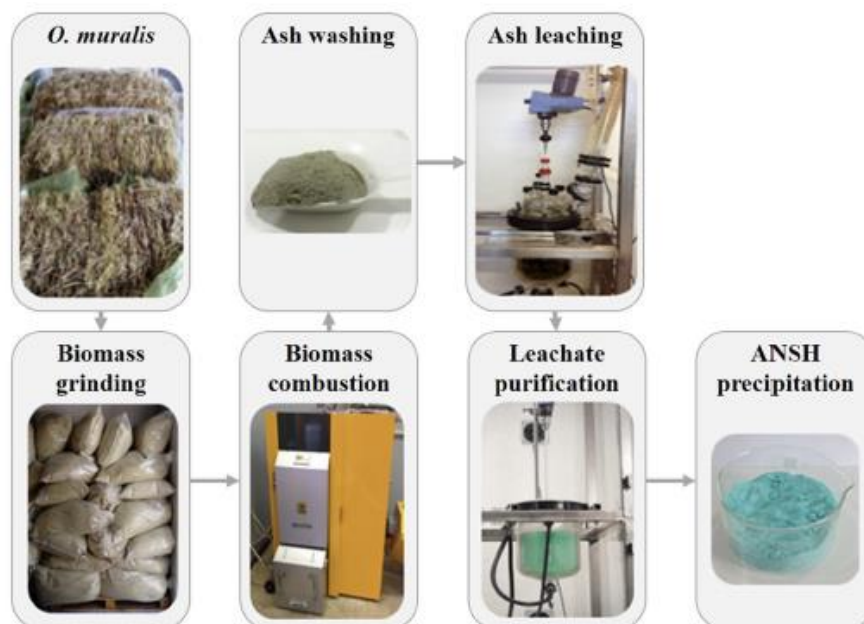
Developing Sustainable Agromining Systems in Agricultural Ultramafic Soils for Nickel Recovery

Petra Susan Kidd^{1*}, Aida Bani^{2,3}, Emile Benizri⁴, Cristina Gonnelli⁵, Claire Hazotte⁶, Johannes Kisser⁷, Maria Konstantinou⁸, Tom Kuppens⁹, Dimitris Kyrkas¹⁰, Baptiste Laubie⁶, Robert Malina⁹, Jean-Louis Morel⁴, Hakan Olcay⁹, Tania Pardo¹, Marie-Noëlle Pons⁶, Angeles Prieto-Fernández¹, Markus Puschenreiter¹¹, Celestino Quintela-Sabaris⁴, Charlene Riddard¹¹, Beatriz Rodríguez-Garrido¹, Theresa Rosenkranz¹¹, Piotr Rozpądek¹², Ramez Saad⁴, Federico Selvi¹³, Marie-Odile Simonnot⁶, Alice Tognacchini^{7,11}, Katarzyna Turnau¹⁴, Rafal Wazny¹², Nele Witters⁹ and Guillaume Echevarria⁴

¹ Instituto de Investigaciones Agrobiológicas de Galicia, Consejo Superior de Investigaciones Científicas (CSIC), Santiago de Compostela, Spain, ² Environment Department, Faculty of Agronomy and Environment, Agricultural University of Tirana, Kodër-Kamëz, Tirana, Albania, ³ Agro-Environmental and Economic Management Center, Tirana, Albania, ⁴ Université de Lorraine, INRA, Laboratoire Soils et Environnement, Nancy, France, ⁵ Department of Biology, University of Florence, Firenze, Italy, ⁶ Université de Lorraine, Centre National de la Recherche Scientifique, Laboratoire Réactions et Génie des Procédés, Nancy, France, ⁷ Alchemia-nova GmbH, Vienna, Austria, ⁸ Department of Landscape Architecture, Eastern Macedonia and Thrace Institute of Technology, Drama, Greece, ⁹ UHasselt—Hasselt University, Environmental Economics Research Group, Centre for Environmental Sciences, Diepenbeek, Belgium, ¹⁰ Department of Agricultural Technology, Technological Educational Institute of Epirus, Arta, Greece, ¹¹ Department of Forest and Soil Sciences, Institute of Soil Research, University of Natural Resources and Life Sciences, Vienna, Austria, ¹² Małopolska Centre of Biotechnology, Jagiellonian University, Kraków, Poland, ¹³ Department of Agrifood Production and Environmental Sciences, Laboratories of Botany, Firenze, Italy, ¹⁴ Institute of Environmental Sciences, Jagiellonian University, Kraków, Poland

Ultramafic soils are typically enriched in nickel (Ni), chromium (Cr), and cobalt (Co) and deficient in essential nutrients, making them unattractive for traditional agriculture. Implementing agromining systems in ultramafic agricultural soils represent an ecological option for the sustainable management and re-valorisation of these low-productivity landscapes. These novel agroecosystems cultivate Ni-hyperaccumulating plants which are able to bioaccumulate this metal in their aerial plant parts; harvested biomass can be incinerated to produce Ni-enriched ash or "bio-ore" from which Ni metal, Ni cocatalysts or pure Ni salts can be recovered. Nickel hyperaccumulation has been documented in ~450 species, and in temperate latitudes these mainly belong to the family Brassicaceae and particularly to the genus *Odontarrhena* (syn. *Alyssum pro parte*). Agromining allows for sustainable metal recovery without causing the environmental impacts associated with conventional mining activities, and at the same time, can improve soil fertility and quality and provide essential ecosystem services. Parallel reductions in Ni phytotoxicity over time would also permit cultivation of conventional agricultural crops. Field studies in Europe have been restricted to Mediterranean areas and these only evaluated the Ni-hyperaccumulator *Odontarrhena muralis* s.l. Two recent EU projects (Agronickel and LIFE-Agromine) have established a network of agromining field sites in ultramafic regions with different edapho-climatic characteristics across Albania, Austria, Greece and Spain. Soil and crop management practices are being developed so as to

optimize the Ni agromining process; field studies are evaluating the potential benefits of fertilization regimes, crop selection and cropping patterns, and bioaugmentation with plant-associated microorganisms. Hydrometallurgical processes are being up-scaled to produce nickel compounds and energy from hyperaccumulator biomass. Exploratory techno-economic assessment of Ni metal recovery by pyrometallurgical conversion of *O. muralis* s.l. shows promising results under the condition that heat released during incineration can be valorized in the vicinity of the processing facility.



| Process description for the preparation of ANSH from *Odontarrhena muralis* s.l. at the pilot scale.

Integrated projects on REEs

Nd
Dy

La

Gd

REE geochemical cycle programme

The objective of the overall REE project is to:

- develop a complementary series of cross-functional multidisciplinary projects which encompass the cycle of rare earths in and on the surface of the lithosphere,
- solve scientifically important problems and of strong interest to the industrial world, yet unresolved still,
- bring a community working on "rare earth elements" at the Université de Lorraine, which could be fully recognised within a few years, to the foreground.

This justifies the cross-functional general plan based on:

- the study of two main workshop sites, characterised by two types of mineralisation (felsic magmas and carbonatites), two stages contrasted in the mining operation (pre- and post-exploitation stages) under two climates (arctic and humid-warm sub-tropical),
- several experimental (mineral solubility), analytical or methodological (thermodynamics, speciation, isotopy) works carried out as complementary approaches.

REE at magmatic stage

- A large exploration area where the expectation from the metallogenic point of view concerns the understanding of the magmatic processes at the origin of REE abnormal concentration within a variety of intrusion types (carbonatites, alkaline intrusions, felsic pegmatitic dykes): the Grenville province in Québec where orogenic root is exposed as bedrock shows numerous REE (\pm Nb-Ta) occurrences, associated with pegmatitic granite dykes ("PGD") and syenitic/carbonatitic intrusions. A multimethod approach (field geology, petro-geochemistry, geochronology and isotopy) allows to characterise PGDs and discuss their petrogenesis during the geodynamic evolution of the Canadian orogeny (Turlin et al., 2018). This work benefits from a consortium of collaborations from the Ministère des Ressources Naturelles of Québec and the DIVEX and IRME network.
- From the magmatic / concentration point of view, another workshop dedicated to the carbonatites is the unique worldwide occurrence of active carbonatitic volcano: the Ol Doinyo Lengai in Tanzania. The study of this complete magmatic edifice and magmatic chambers is of utmost interest for the understanding of older carbonatitic intrusions and the REE concentration processes in such magmas. Based on noble gas geochemistry, studies have shown that the Oldoinyo Lengai carbonatites and silicate magmas were generated by the melting of a metasomatised subcontinental lithospheric mantle (Mollex et al., 2018). Thus, carbonatites are the main exploited concentration worldwide: Bayan Obo (China), Mount Weld (Australia)...



Unusual LREE-rich, peraluminous, monazite- or allanite-bearing pegmatitic granite in the central Grenville Province, Québec

François Turlin^{a,*}, Anne-Sylvie André-Mayer^a, Abdelali Moukhsil^b, Olivier Vanderhaeghe^c, Félix Gervais^d, Fabien Solgadi^e, Pierre-Arthur Groulier^f, Marc Poujol^g

^a GeoRessources lab., UMR 7359, Université de Lorraine, CNRS, CREGU, Faculté des Sciences et Technologies, Vandœuvre-lès-Nancy F-54506, France

^b Ministère de l'Énergie et des Ressources naturelles, Direction du Bureau de la connaissance géoscientifique du Québec, 5700, 4^e Avenue Ouest, Québec, Québec G1H 6R1, Canada

^c Géosciences Environnement Toulouse, GET, Université de Toulouse, CNRS, IRD, UPS, CNES, Toulouse, France

^d Département des génies civil, géologiques et des mines, Ecole Polytechnique de Montréal, Canada

^e Ministère de l'Énergie et des Ressources naturelles, Direction du Bureau de la connaissance géoscientifique du Québec, 400, boulevard Lamaque, Val-d'Or, Québec J9P 3L4, Canada

^f Earth Sciences Department, Memorial University, St. John's NL A1B 3X5, Canada

^g Géosciences Rennes, UMR 6118, OSUR, Université de Rennes 1, 35042 Rennes Cedex, France

ARTICLE INFO

Article history:

Received 23 January 2017

Received in revised form 19 April 2017

Accepted 24 April 2017

Available online 27 April 2017

Keywords:

Grenville Province

Peraluminous

Pegmatitic granite

LREE

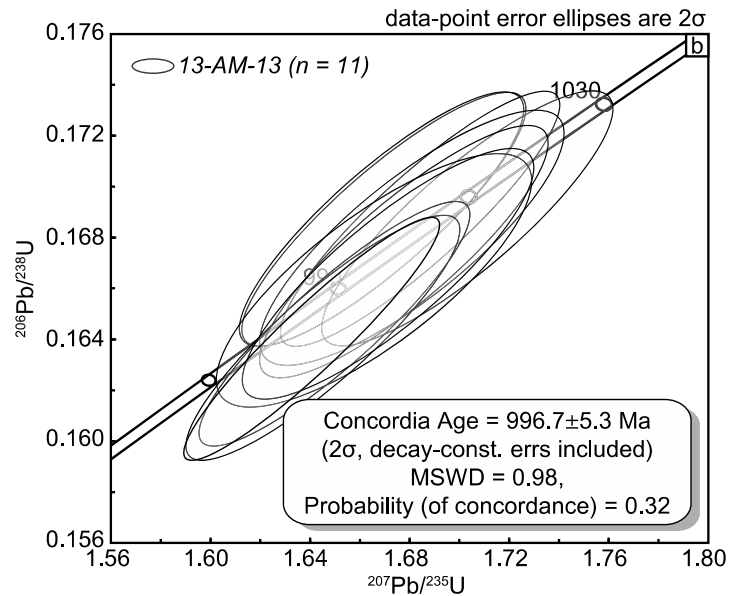
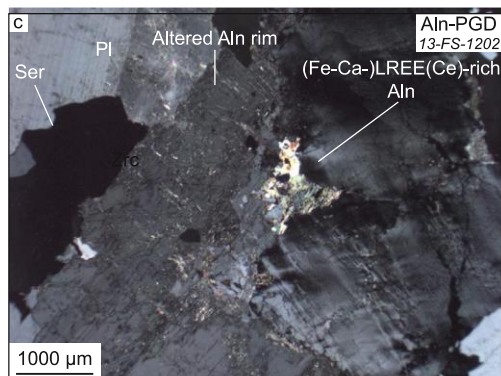
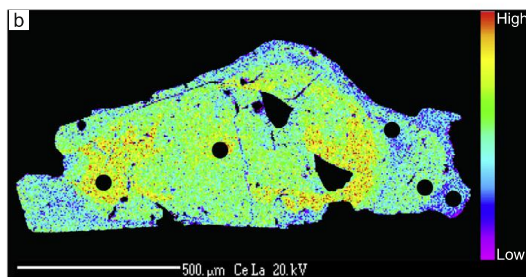
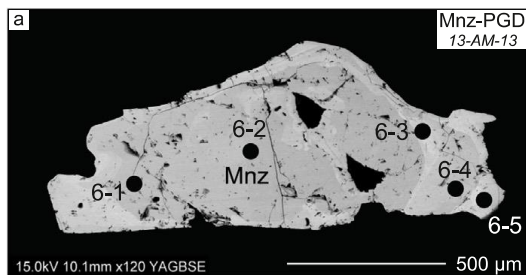
Whole-rock geochemistry

Allanite/monazite

ABSTRACT

This contribution presents an original study combining detailed mapping, petrography, whole-rock geochemistry and geochronological constraints on the recently identified LREE (Light Rare Earth Elements) occurrences associated with pegmatitic granite dykes (PGD) from the central Grenville (Lac Okaopéo region). These PGD intrude paragneisses or meta-igneous complexes with a REE mineralization hosted either in monazite-(Ce) or in allanite-(Ce) respectively. The investigated samples display peraluminous signatures and are dominated by a quartz + K-feldspar + plagioclase + biotite + monazite/allanite assemblage. Field relationships and the magmatic textures of the dykes combined with U-Pb dating of magmatic monazite grains at 1005.4 ± 4.4 Ma and 996.7 ± 5.3 Ma (concordant igneous ages) imply that the LREE-rich PGD were emplaced in a post-tectonic setting. Allanite-(Ce)- and monazite-(Ce)-bearing PGD have Σ REE contents up to 9242 ppm and 7048 ppm, respectively. The allanite-rich assemblage is consistent with the petrographic assemblage of LREE-enriched PGD identified in the southwestern Grenville Province and elsewhere in the world, but this study constitutes the first evidence for a sole presence of monazite as LREE-bearing phase in strongly peraluminous PGD from the Grenville Province.

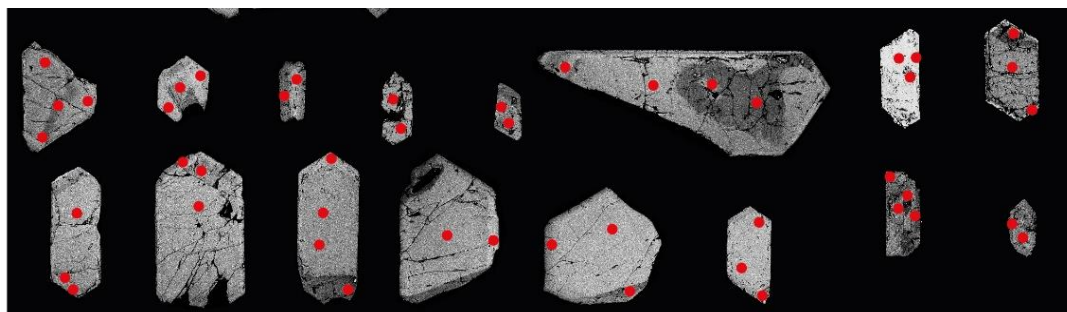
© 2017 Elsevier B.V. All rights reserved.



Petrogenesis of LREE-rich pegmatitic granite dykes in the central Grenville Province by partial melting of Paleoproterozoic-Archean metasedimentary rocks: evidence from zircon U-Pb-Hf-O isotope and trace element analyses

François Turlin ^{a, b} ✉, Olivier Vanderhaeghe ^c, Félix Gervais ^d, Anne-Sylvie André-Mayer ^a, Abdelali Moukhsil ^e, Armin Zeh ^f, Fabien Solgadi ^g, I.P.T.N. ^h

The Allochthonous Belt of the central Grenville Province in Quebec (Canada) hosts LREE-rich pegmatitic granite dykes (PGDs) intrusive into orthogneisses and migmatitic paragneisses. Zircon crystals from a monazite-bearing PGD and two allanite-bearing PGDs of the Lac Okaopéo region were investigated. Concordia U-Pb ages of 1004.2 ± 2.1 Ma, 1001.9 ± 3.9 Ma and 1004.2 ± 2.3 Ma, respectively, indicate that emplacement of the dykes occurred during the early-Rigolet orogenic phase. Trace element contents (U, Yb, Y) of zircon grains, their subchondritic $\varepsilon_{\text{Hf}}(1003 \text{ Ma})$ values from -4.7 to -11.8, Hf model ages from 2.05 to 2.44 Ga, and predominant supra-mantle $\delta^{18}\text{O}_{\text{V-SMOW}}$ values (>5.3 ‰) indicate that the dykes were formed by partial melting of Paleoproterozoic-Archean metasedimentary rocks equivalent to those exposed in the Parautochthonous Belt (Knob Lake Group paragneisses), and located beneath the thickened Allochthonous Belt. This implies that the Parautochthonous Belt is present beneath the Allochthonous Belt hosting the LREE-rich PGDs and that it was affected by horizontal ductile flow towards the north for at least 80 km where it is currently exhumed along the Grenville Front.



● U-Pb LA-ICP-SF-MS analysis



Tracing helium isotope compositions from mantle source to fumaroles at Oldoinyo Lengai volcano, Tanzania

Gaëlle Mollex^{a,*}, Evelyn Füre^a, Pete Burnard^a, Laurent Zimmermann^a, Gilles Chazot^b, Emmanuel O. Kazimoto^c, Bernard Marty^a, Lydéric France^a

^a CRPG, UMR 7358, CNRS, Université de Lorraine, 15 rue Notre Dame des Pauvres, 54501 Vandœuvre-lès-Nancy, France

^b Université de Brest, CNRS, UMR 6538 Domaines Océaniques, Institut Universitaire Européen de la Mer, Place Copernic, 29280 Plouzané, France

^c Department of Geology, University of Dar es Salaam, P. O. Box 35052, Dar es Salaam, Tanzania

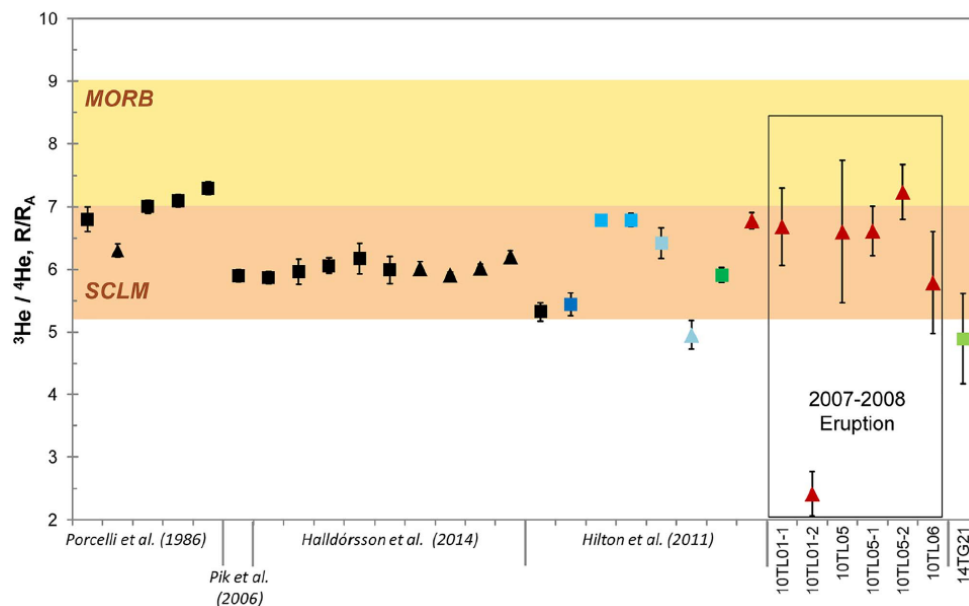
ARTICLE INFO

Keywords:

Carbonatite
Neon
2007–2008 eruption
SCLM
Cognate xenoliths
Helium
Neon
Argon

ABSTRACT

Oldoinyo Lengai is the only volcano on Earth currently erupting natrocarbonatites, of which the source and genesis remain controversial. Cognate xenoliths and fumaroles were sampled at the summit of Oldoinyo Lengai, and deep crustal xenoliths from Olatwa maar, in 2010 and 2014, after the 2007–2008 sub-Plinian eruption. The summit cognate xenoliths provide direct information on the isotopic composition of the mid-crustal magma chamber that was active during the 2007–2008 explosive eruption. Cognate xenolith-hosted pyroxenes from Oldoinyo Lengai have an average $^3\text{He}/^4\text{He} = 6.58 \pm 0.46 R_A$, similar to values from nearby silicate volcanoes ($4.95\text{--}7.30 R_A$), and reflecting a sub-continental lithospheric mantle (SCLM) signature. This similarity implies that Oldoinyo Lengai carbonatites form from a similar mantle reservoir as the nearby silicate volcanoes. We identify SCLM, metasomatized by fluids/melts derived from the depleted convective mantle, as the common source of magmas in the Arusha volcanic province. Fumarole measurements highlight that fumarolic $^3\text{He}/^4\text{He}$ values have been relatively constant since at least 1988, indicating that dramatic changes to the crater region morphology during the 2007–2008 eruption did not affect the architecture of the hydrothermal system, which is probably connected to the crustal magma chamber(s). Moreover, the similarity between $^3\text{He}/^4\text{He}$ values from the mid-crustal magma chamber ($6.58 \pm 0.46 R_A$) and fumaroles ($7.31 \pm 0.24 R_A$) of Oldoinyo Lengai attests that helium is not subjected to atmospheric contamination or crustal assimilation during transport to the surface.





Rare earths (La, Ce, Nd) and rare metals (Sn, Nb, W) as by-products of kaolin production – Part 3: Processing of fines using gravity and flotation



L.O. Filippov*, Q. Dehaine, I.V. Filippova

GeoResources, Université de Lorraine, CNRS, UMR 7359, 2 rue du Doyen Marcel Roubault, TSA 70605, F54518 Vandœuvre-lès-Nancy, France

ARTICLE INFO

Article history:

Received 19 March 2016
Revised 1 June 2016
Accepted 7 June 2016
Available online 25 June 2016

Keywords:

Light rare-earths
Low grade ore
Flotation
Clay coating
Falcon concentrator

ABSTRACT

This is the last in a series of papers addressing the by-product potential of Light Rare-Earth Elements (LREE, La, Ce, Nd) and rare-metals (Sn, Nb, W) within the St Austell kaolin deposits (UK). Previous results have shown that heavy minerals are pre-concentrated in the micaceous residue which displays relatively high LREE content (around 170 ppm) hosted by monazite. A combined gravity/flotation concentration flowsheet, starting with classification of the residue into 3 size fractions (+150 μm , 150–53 μm and –53 μm) was developed. This study presents the results of the clay-rich –53 μm size fraction beneficiation by flotation using sodium oleate and hydroxamate as collectors and compares them to results obtained with a Falcon Ultra-Fine (UF) concentrator. The effect of dispersant addition during de-sliming operations on flotation efficiency was also investigated. The LREE grade in the floated product obtained with sodium oleate increased from 3370 ppm to 5350 ppm and recovery from 30% to 80% with dispersant which is attributed to clay coating. Saturation tests performed on the Falcon UF show a positive effect of desliming on separation performance which produces higher LREE grades and recoveries. Comparison of flotation performance and Falcon UF concentration of monazite to previous results obtained with the Falcon Semi-Batch (SB) gravity concentrator on the un-screened raw residue clearly shows that flotation of the fine residue is more efficient than the Falcon UF and Falcon SB. Indeed the Falcon UF produced high recoveries (87–95%) but with almost no enrichment (1.3–1.4 ratios) whereas the Falcon SB concentration of un-screened residue produced higher grades (up to 0.6% LREE) but with low recoveries (17–22%). This study has shown that LREE can be recovered with simple two-stage operations, suggesting that the micaceous residue stream (and the associated tailings dams) could be considered as a potential resource for these metals.

© 2016 Elsevier Ltd. All rights reserved.

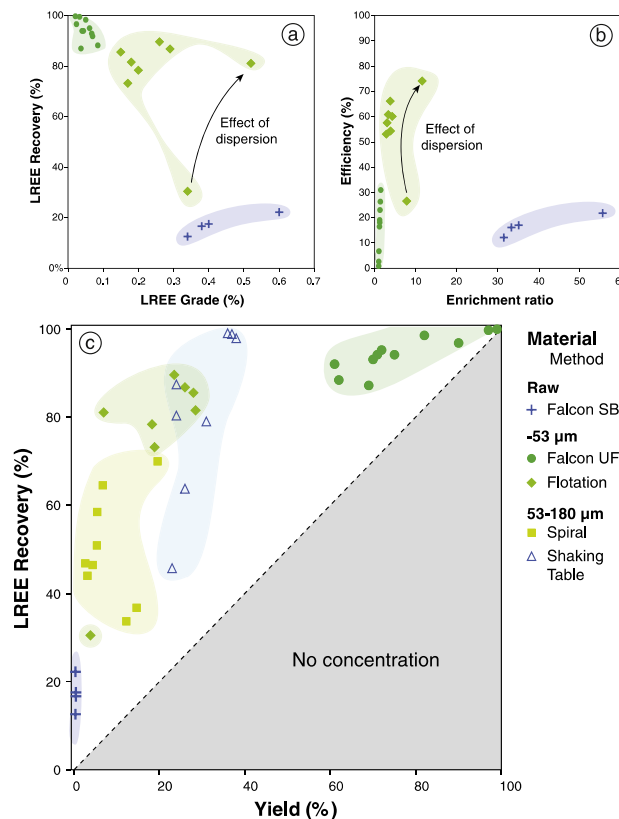
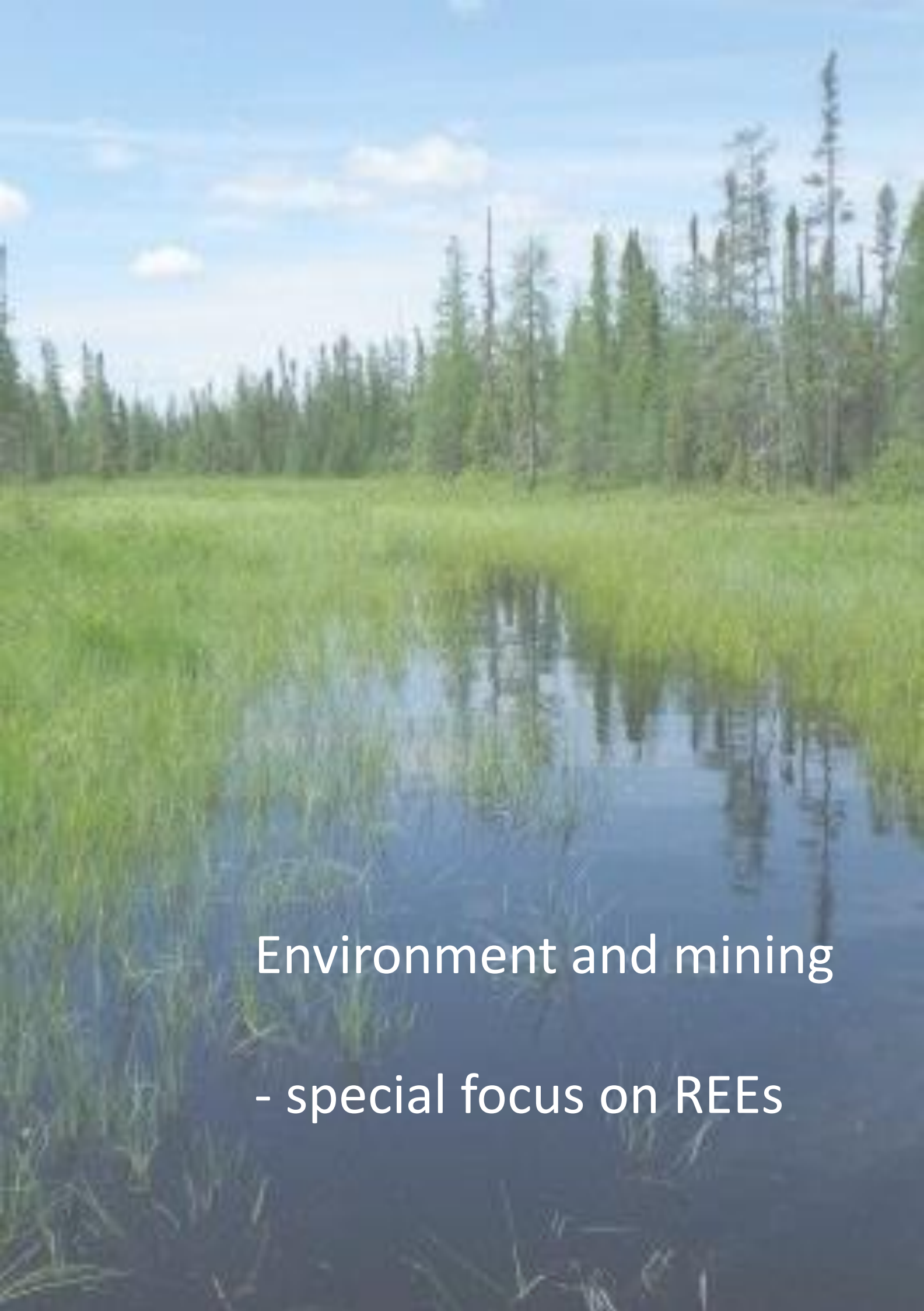


Fig. 11. Comparison of the performance of the different beneficiation methods tested in this study. (a) LREE grade vs. recovery curve for beneficiation of the –53 μm residue. (b) Comparison of the efficiency of flotation and Falcon concentration. (c) Summary of the overall performance of all the methods investigated for the recovery of metals from the micaceous residue using data from Dehaine and Filippov (2015) and Dehaine et al. (2016a).



Environment and mining
- special focus on REEs

REE geochemical cycle: a study case

Southern China (Guangdong and Jiangxi provinces) is the second mining area in the world for REE exploitation. It was chosen because several areas degraded by mining industry need significant post-exploitation restoration, occurring under a warm and humid tropical climate. There, the restoration of soils and control of the fate of REEs by plants is of primary importance. A large area of surficial exploitation by ionic exchange using ammonium sulphate resulted in several square kilometres of mine soils composed of mineral residues resulting from leaching. The main objective there is to develop a quick and sustainable re-vegetation approach to reduce erosion and further leaching from residual REEs to water bodies. This was made possible thanks to the establishment of the LIA ECOLAND in 2015, between the LSE (UL and INRA) and the LEPCRT (SYSU, Guangzhou), after more than one decade of fruitful collaboration (Tang et al., 2018). Three main strategies are promoted for REE mining sites: i) soil construction using amendments, ii) phytostabilisation of soils (using hemp, ramie or kenaf), ii) agromining of REE using various plants (for instance *Phytolacca Americana*, *Dicranopteris linearis*), and iii) understanding of the REE geochemistry. Ecotoxicological studies of REE-rich magmatic rocks in **Québec (Grenville province)** show that the potential release of REEs into the environment in mining areas could occur after REE extraction. The only potential toxic effects that could be related to REE contents could occur in the ostracod and luminotox tests. Our study reveals that the physicochemical properties of sediments are a key factor controlling both REE availability and potential toxicity. It is a starting point to understand potential future pollution in mining areas.

REE surficial cycle and toxicology: Although used extensively in various application fields, knowledge of REE toxicity in cells and molecular mechanisms underlying REE tolerance is still partly lacking (Gonzalez et al., 2016). To investigate cellular targets and tolerance mechanisms towards REE, high-throughput methods were carried out and the implication of identified genes and functions were confirmed by complementary studies of biochemistry, microscopy, physiology and molecular biology (Wehrmann et al., 2017). This approach was performed on three well-known bacterial, fungal and plant model organisms. Genome-wide phenotyping of a mutant collection for both *Escherichia coli* and *Saccharomyces cerevisiae* was carried out as well as identification of genes and functions that take part in the REE toxicity response in these organisms. As exemplified for yeast, several functions involved in REE toxicity mitigation emerged, primarily acidification and retrograde transport. Lipidomic, ionomic and proteomic analyses were conducted and revealed the central role of sphingolipids in REE tolerance, emphasising the role of the plasma membrane as a hotspot for REE toxicity (Grosjean et al. 2018). In conclusion, these pioneer studies using model organisms are an excellent first basis for the assessment of REE toxicity towards eukaryotes and bacteria. The specific responses which were pointed out will lead to a better understanding of REE transfer from contaminated substrates to living organisms and should allow the identification of biomarkers of REE exposure.

Gadolinium (Gd) is related to an organic part to form gadolinium contrast agents (Gd-CAs) used worldwide in medicine during magnetic resonance imaging (MRI). The number of gadolinium anomalies reported in the rivers of several European and US countries increased over the last 20 years. These compounds prevent the release of free Gd in rivers but little is known concerning their bioavailability for aquatic organisms. The field study conducted in the north-east of France demonstrated the presence of anthropogenic Gd in the environment originating from the release of Gd-CAs from 14 wastewater treatment plants after hospital waste treatment (Gd-based MRI contrast agents). For the first time, these results clearly showed that Gd can bioaccumulate in bivalve tissues even when it is only present as Gd-CAs (Perrat et al., 2017)

Search for new and innovative bio-sensors: Because of their low bioavailability, rare earth elements (REEs) have long been considered to be biologically inert. In recent years, however, the identification of REEs as essential metals for the activity and expression of the XoxF family of methanol dehydrogenase in methylotrophic bacteria attracted tremendous interest among various biological fields. The first works revealed that PedH from *P. putida* KT2440 actually uses REE as a cofactor (Wehrmann et al., 2017). Reporter assays demonstrated that PedH not only has a catalytic function but is also involved in the transcriptional regulation of *pedE* and *pedH*, most likely acting as a sensory module: they thus demonstrated that REE-utilising bacteria are not limited to the methano- and methylotrophs.



Assessment of baseline ecotoxicity of sediments from a prospective mining area enriched in light rare earth elements



A. Romero-Freire^{a,*}, L. Minguez^{a,1}, M. Pelletier^b, A. Cayer^b, C. Caillet^c, S. Devin^a, E.M. Gross^a, F. Guérol^a, S. Pain-Devin^a, D.A.L. Vignati^{a,2}, L. Giamberini^{a,2}

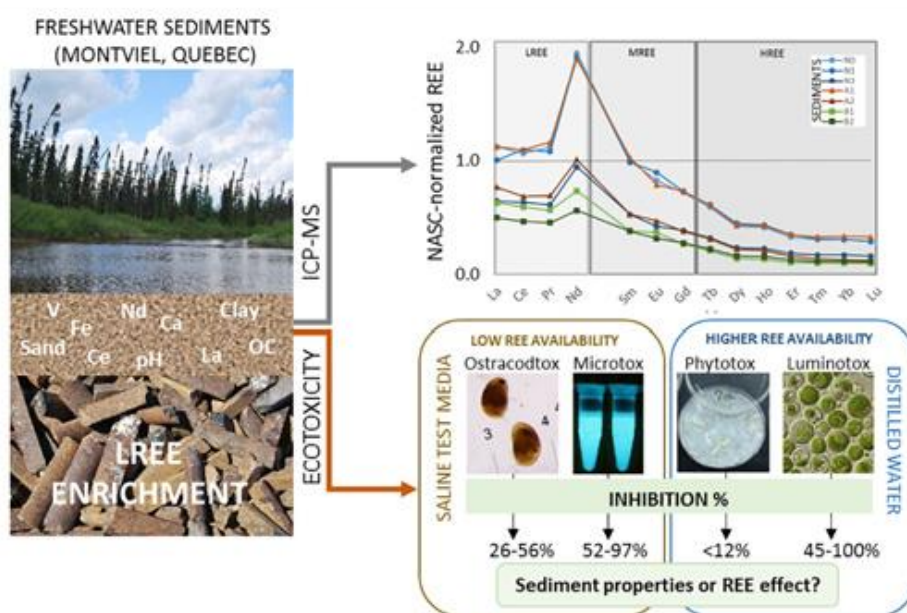
^a LIEC, CNRS, UMR 7360, Université de Lorraine, Campus Bridoux, Bâtiment IBISE, 8 rue du Général Delestraint, 57070 Metz, France

^b Ressources Géoméga, 75 Boulevard de Mortagne, Boucherville J4B 6Y4, Québec, Canada

^c LIEC, CNRS, UMR 7360, Université de Lorraine, 15 Avenue du Charmois, 54500 Vandœuvre-lès-Nancy, France

ABSTRACT

Rare earth elements (REEs) disperse from indigenous rocks to the environment, thus making sediments one of the major sinks and sources of metal pollution. The emerging use of REEs and the subsequent opening of new mining areas may contribute to their release into surrounding ecosystems. For this reason, this study was performed in a natural area with geological material abundant in ferrocarnatites and light REE. The aim of this work was to assess the natural REE availability and (eco)toxicity in freshwater sediments. Sediments showed high REE concentrations in samples with fine grain size fractions, and low in organic-rich sediments. The enrichment in LREE was mostly from rocks and the obtained enrichment factors (EF) confirmed that the sediments are not anthropogenically polluted. To assess REE availability and ecotoxicity, four toxicity tests were performed. REEs measured as the dissolved concentration in the test media were very low compared to the potentially available total REE in sediments and showed positive or negative correlations with fine or coarse grain sizes, respectively, and positive correlations with the content in Mg, Fe and Al. In tests performed in media supplemented with salts, the availability of REEs decreased considerably. Only some toxic effects could be linked to the REE contents in the ostracodtox and luminotox tests. However, measurement of toxicity could be influenced by the sediment properties and lead to a potential overestimation of ecotoxicity if only REE are regarded. Our study reveals that the physicochemical properties of sediments are a key factor controlling both REE availability and toxicity, whereas the determination of REE effects from toxicity tests using liquid media with salt addition will decrease



PEST-ORCHESTRA, a tool for optimising advanced ion-binding model parameters: derivation of NICA-Donnan model parameters for humic substances reactivity

Noémie Janot,^{A,B} José Paulo Pinheiro,^{A,B} Wander Gustavo Botero,^C Johannes C. L. Meeussen^D and Jan E. Groenenberg^{A,B,E,F}

^ACNRS, LIEC, UMR7360, 15 Avenue du Charmois, Vandoeuvre-lès-Nancy F-54501, France.

^BUniversité de Lorraine, LIEC, UMR7360, 15 Avenue du Charmois, Vandoeuvre-lès-Nancy, F-54501, France.

^CFederal University of Alagoas (UFAL), Campus Arapiraca, 57309-005-, Arapiraca, AL, Brazil.

^DNRG Consultancy & Services, PO Box 25, 1755 ZG Petten, The Netherlands.

^EWageningen University, section soil quality, PO Box 47, 6700 AA Wageningen, The Netherlands.

^FCorresponding author. Email: bertjan.groenenberg@wur.nl

Environmental context. The environmental behaviour of trace metals in soils and waters largely depends on the chemical form (speciation) of the metals. Speciation software programs combining models for the binding of metals to soil and sediment constituents are powerful tools in environmental risk assessment. This paper describes a new combination of speciation software with a fitting program to optimise geochemical model parameters that describes proton and metal binding to humic substances.

Abstract. Here we describe the coupling of the chemical speciation software *ORCHESTRA* with the parameter estimation software *PEST*. This combination enables the computation of optimised model parameters from experimental data for the ion binding models implemented in *ORCHESTRA*. For testing this flexible tool, the NICA-Donnan model parameters for proton-, Cd- and Zn-binding to Laurentian fulvic acid were optimised. The extensive description of the method implementation and the examples provided facilitate the use of this tool by students and researchers. Three procedures were compared which derive the proton binding parameters, differing in the way they constrain the model parameters and in the implementation of the electrostatic Donnan model. Although the different procedures resulted in significantly different sets of model parameters, the experimental data fit obtained was of similar quality. The choice of the relation between the Donnan volume and the ionic strength appears to have a strong influence on the derived set of optimal model parameters, especially on the values of the protonation constants, as well as on the Donnan potential and Donnan volume. Optimised results are discussed in terms of their physico-chemical plausibility. Coherent sets of NICA-Donnan parameters were derived for Cd and Zn binding to Laurentian fulvic acid.

Received 19 February 2016, accepted 28 July 2016, published online 5 September 2016

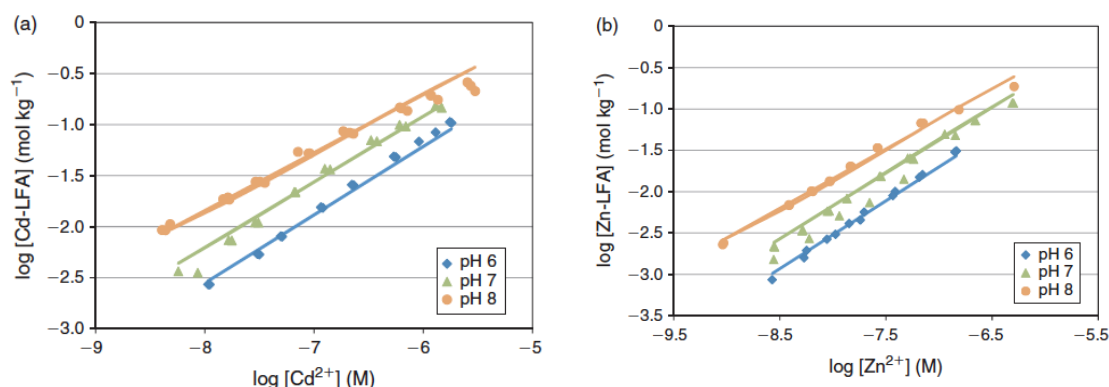
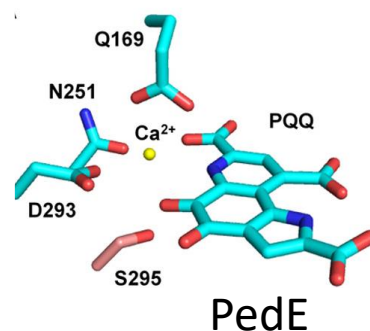


Fig. 3. Cd (a) and Zn (b) binding to Laurentian fulvic acid at 0.01 M NaNO₃. Symbols are experimental data and lines are fit results.

Functional Role of Lanthanides in Enzymatic Activity and Transcriptional Regulation of Pyrroloquinoline Quinone-Dependent Alcohol Dehydrogenases in *Pseudomonas putida* KT2440



Matthias Wehrmann,^a Patrick Billard,^{b,c} Audrey Martin-Meriadec,^{b,c} Asfaw Zegeye,^{b,c} Janosch Klebensberger^a

University of Stuttgart, Institute of Technical Biochemistry, Stuttgart, Germany^a; Université de Lorraine, LIEC UMR7360, Faculté des Sciences et Technologies, Vandoeuvre-lès-Nancy, France^b; CNRS, LIEC UMR7360, Faculté des Sciences et Technologies, Vandoeuvre-lès-Nancy, France^c

ABSTRACT The oxidation of alcohols and aldehydes is crucial for detoxification and efficient catabolism of various volatile organic compounds (VOCs). Thus, many Gram-negative bacteria have evolved periplasmic oxidation systems based on pyrroloquinoline quinone-dependent alcohol dehydrogenases (PQQ-ADHs) that are often functionally redundant. Here we report the first description and characterization of a lanthanide-dependent PQQ-ADH (PedH) in a nonmethylotrophic bacterium based on the use of purified enzymes from the soil-dwelling model organism *Pseudomonas putida* KT2440. PedH (PP_2679) exhibits enzyme activity on a range of substrates similar to that of its Ca²⁺-dependent counterpart PedE (PP_2674), including linear and aromatic primary and secondary alcohols, as well as aldehydes, but only in the presence of lanthanide ions, including La³⁺, Ce³⁺, Pr³⁺, Sm³⁺, or Nd³⁺. Reporter assays revealed that PedH not only has a catalytic function but is also involved in the transcriptional regulation of *pedE* and *pedH*, most likely acting as a sensory module. Notably, the underlying regulatory network is responsive to as little as 1 to 10 nM lanthanum, a concentration assumed to be of ecological relevance. The present study further demonstrates that the PQQ-dependent oxidation system is crucial for efficient growth with a variety of volatile alcohols. From these results, we conclude that functional redundancy and inverse regulation of PedE and PedH represent an adaptive strategy of *P. putida* KT2440 to optimize growth with volatile alcohols in response to the availability of different lanthanides.

IMPORTANCE Because of their low bioavailability, lanthanides have long been considered biologically inert. In recent years, however, the identification of lanthanides as a cofactor in methylotrophic bacteria has attracted tremendous interest among various biological fields. The present study reveals that one of the two PQQ-ADHs produced by the model organism *P. putida* KT2440 also utilizes lanthanides as a cofactor, thus expanding the scope of lanthanide-employing bacteria beyond the methylotrophs. Similar to the system described in methylotrophic bacteria, a complex regulatory network is involved in lanthanide-responsive switching between the two PQQ-ADHs encoded by *P. putida* KT2440. We further show that the functional production of at least one of the enzymes is crucial for efficient growth with several volatile alcohols. Overall, our study provides a novel understanding of the redundancy of PQQ-ADHs observed in many organisms and further highlights the importance of lanthanides for bacterial metabolism, particularly in soil environments.

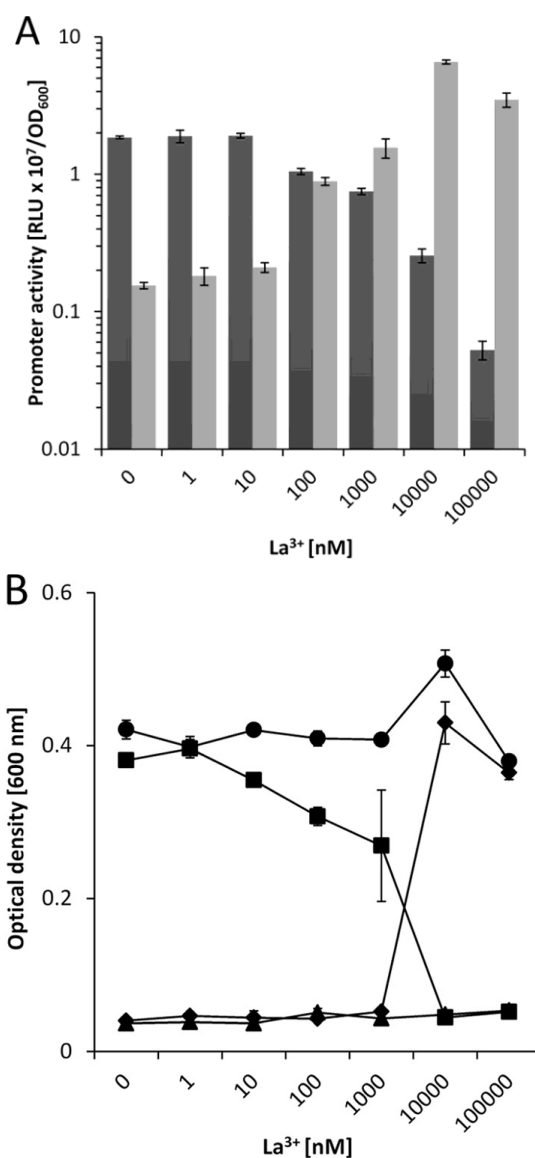


FIG 5 (A) Activities of the *pedE* (dark gray bars) and *pedH* (light gray bars) promoters in strain KT2440* during incubation in liquid M9 medium supplemented with 1 mM 2-phenylethanol in the presence of various concentrations of La³⁺. Promoter activities are in relative light units (RLU × 10⁷) normalized to the OD₆₀₀. (B) The growth of KT2440* (black circles), a $\Delta pedE$ strain (black diamonds), a $\Delta pedH$ strain (black squares), and a $\Delta pedE \Delta pedH$ strain (black triangles) in liquid M9 medium with 5 mM 2-phenylethanol in the presence of different concentrations of La³⁺ was determined as the OD₆₀₀ after incubation at 30°C for 24 h. Data are presented as mean values of biological triplicates, and error bars represent the corresponding standard deviations.

Global Deletome Profile of *Saccharomyces cerevisiae* Exposed to the Technology-Critical Element Yttrium

Nicolas Grosjean^{1,2}, Elisabeth M. Gross², Marie Le Jean^{2†} and Damien Blaudez^{1††}

¹ Université de Lorraine, CNRS, LIEC, Nancy, France, ² Université de Lorraine, CNRS, LIEC, Metz, France

The emergence of the technology-critical-element yttrium as a contaminant in the environment raises concern regarding its toxicological impact on living organisms. The molecular mechanisms underlying yttrium toxicity must be delineated. We considered the genomic phenotyping of a mutant collection of *Saccharomyces cerevisiae* to be of particular interest to decipher key cellular pathways involved either in yttrium toxicity or detoxification mechanisms. Among the 4733 mutants exposed to yttrium, 333 exhibited modified growth, of which 56 were sensitive and 277 were resistant. Several functions involved in yttrium toxicity mitigation emerged, primarily vacuolar acidification and retrograde transport. Conversely, functional categories overrepresented in the yttrium toxicity response included cytoskeleton organization and endocytosis, protein transport and vesicle trafficking, lipid metabolism, as well as signaling pathways. Comparison with similar studies carried out using other metals and stressors showed a response pattern similar to nickel stress. One third of the identified mutants highlighted peculiar cellular effects triggered by yttrium, specifically those affecting the pheromone-dependent signaling pathway or sphingolipid metabolic processes. Taken together, these data emphasize the role of the plasma membrane as a hotspot for yttrium toxicity. The up-to-now lack of data concerning yttrium toxicity at the cellular and molecular levels makes this pioneer study using the model *S. cerevisiae* an excellent first basis for the assessment of yttrium toxicity toward eukaryotes.

Keywords: genome-wide screening, *Saccharomyces cerevisiae*, technology critical element, yeast mutants, yttrium toxicity

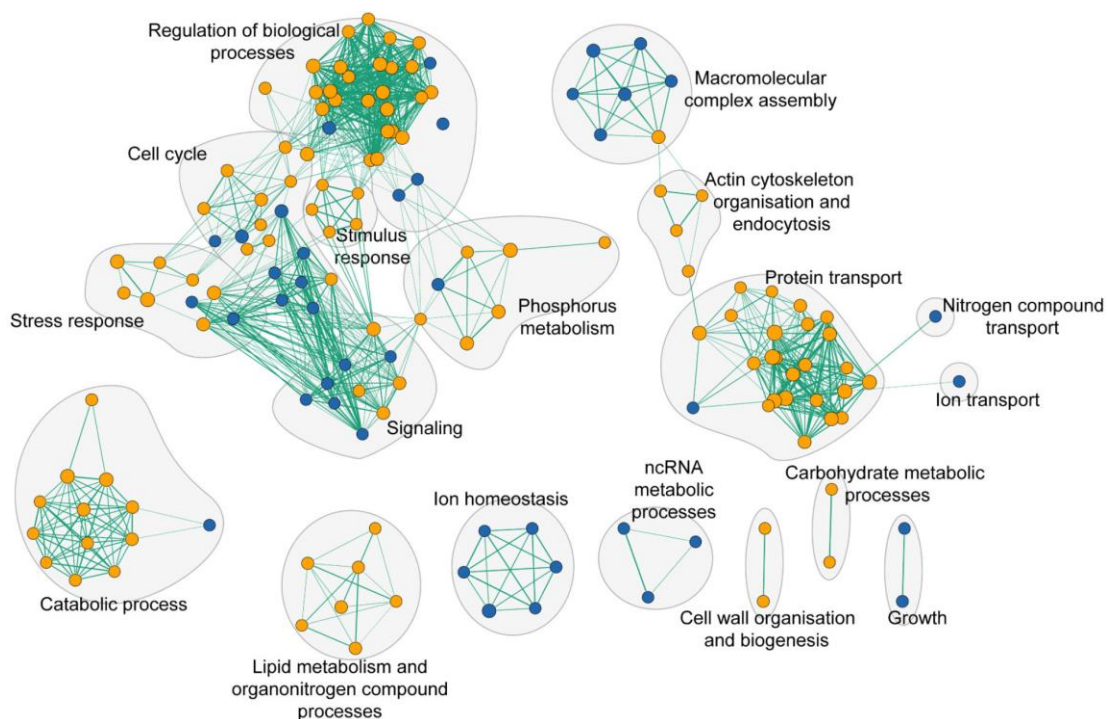
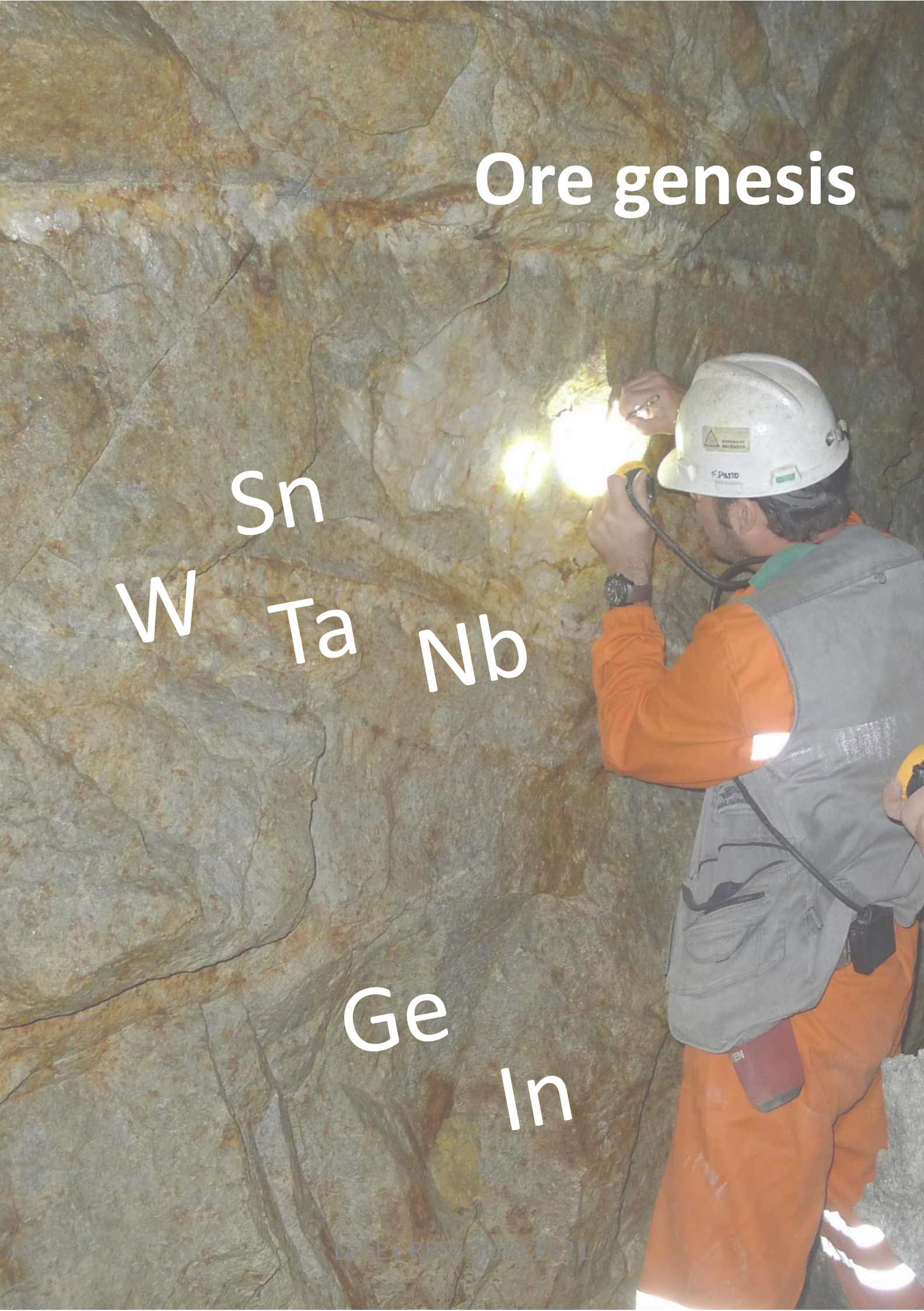


FIGURE 5 | Functional enrichment analysis network of functions that when deleted render cells either sensitive (blue nodes) or resistant (orange nodes) to yttrium. Green lines represent gene overlap between two functions, with the edge width being proportional to the number of shared genes. The enrichment map was built using GSEA and visualized by the enrichment map plugin in Cytoscape.

Ore genesis

W Sn
Ta Nb

Ge
In



Several projects focus on a series of strategic elements (W-Sn-Nb-Ta; Ge-In) :

Tungsten (W) –(Nb-Ta-Sn) hydrothermal ore deposits in the Variscan orogeny (co-funded by Labex R21 and ERAMIN “New ores” programme)

W ores from French Massif Central are related to three major geodynamic events (Harlaux et al., 2017a): from Visean-Namurian times (333-327 Ma) to Stephanian-Permian (298-274 Ma). Thanks to *in situ* LA-ICPMS methodological developments on fluid inclusions and minerals (Harlaux et al., 2015b ; 2018), sources of metals have been identified in rare metal granites, through *in situ* analysis of trace elements in wolframite. Fluids responsible for ore deposition belong to the magmatic-hydrothermal transition and are enriched in Sn, W, Nb (10^2 - 10^3 ppm) (Harlaux et al., 2017b). Eleonora Carocci's PhD thesis is devoted to the study of W enrichment processes with a special focus on the main W deposit in Panasqueira. It is shown that Sn-W-Nb-Ta are introduced very early on in the system during the tourmaline-rutile stage which is prior to wolframite. Rutile minerals thus appear as excellent pathfinders.

Germanium and related elements in sulphide minerals: crystal chemistry, incorporation and isotope fractionation (co-funded by Labex R21 and the Lorraine region)

Germanium occurs as traces in sulphides in minor amounts, from various types of ore deposits. The most significant Ge enrichments occur in low-T deposits (MVT, SedEx). Trace element signatures in sphalerite indicate a first order relation of Ge contents with temperature. Along with Ga and Sb, Germanium is associated with low-T, sediment- and carbonate-hosted deposits, while Indium is markedly incorporated in high-T, magmatic-related deposits (Belissant et al. 2014). Synchrotron-based XAFS spectroscopy show that Ge^{4+} occurs in tetrahedral coordination and that Ge is chiefly incorporated through coupled substitutions like $3\text{Zn}^{2+} \leftrightarrow \text{Ge}^{4+} + 2(\text{Cu},\text{Ag})^+$ and $3\text{Fe}^{3+} \leftrightarrow 2\text{Ge}^{4+} + \text{Cu}^+$ respectively in sphalerite and chalcopyrite (Belissant et al., 2016). The positive correlation between $\delta^{74}\text{Ge}$ and Ge content observed in sphalerite from the Saint-Salvy deposit could indicate that the Ge partition coefficient, $K_{\text{Ge}} = [\text{Ge}]_{\text{ZnS}} / [\text{Ge}]_{\text{sol}}$, increases with temperature.

LA-ICP-MS analyses of minor and trace elements and bulk Ge isotopes in zoned Ge-rich sphalerites from the Noailhac – Saint-Salvy deposit (France): Insights into incorporation mechanisms and ore deposition processes

Rémi Beïssont ^{a,b,□}, Marie-Christine Boiron ^a, Béatrice Luais ^b, Michel Cathelineau ^a

^aGeoRessources, Université de Lorraine, CNRS, UMR 7359, Boulevard des Aiguillettes, B.P. 70239, F-54506 Vandœuvre-lès-Nancy, France

^bCentre de Recherches Pétrographiques et Géochimiques (CRPG), Université de Lorraine, CNRS, UMR 7358, 15 Rue Notre Dame des Pauvres, B.P. 20, F-54501 Vandœuvre-lès-Nancy Cedex, France

Received 18 June 2013; accepted in revised form 30 October 2013; available online 17 November 2013

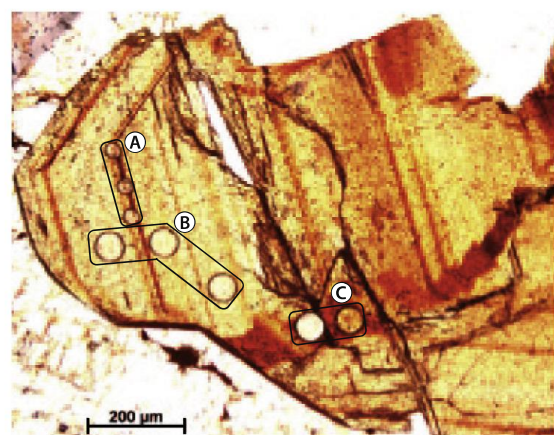
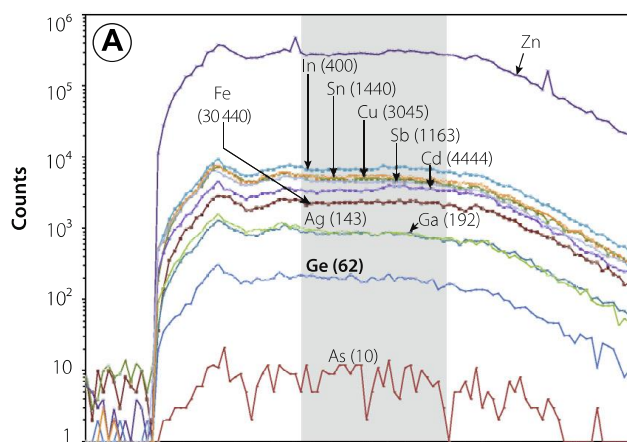
Abstract

The increasing worldwide demand in germanium (Ge) is driving renewed research for understanding its geological cycle and the factors controlling its concentration in minerals. The advent of accurate, high-resolution trace element analysis by LA-ICP-MS, as well as the advances in MC-ICP-MS technique for Ge isotopes in sulphides, has enhanced studies in this field. Ge isobaric interferences, standard calibration and data interpretation remain outstanding issues needing to be addressed for more precise and comprehensive LA-ICP-MS analyses.

An integrated mineralogical and geochemical study was carried out on typical sphalerite (ZnS) samples from the main Ge deposit in western Europe: the vein-type Zn–Ge–Ag–(Pb–Cd) deposit of Noailhac – Saint-Salvy (Tarn, France). In situ coupled measurements of trace elements and S isotopes were performed using LA-ICP-MS and SIMS, respectively, together with bulk Ge isotopes by MC-ICP-MS. Principal component analyses revealed element clusters antithetically distributed within distinct zoning types in sphalerite: sector zonings are enriched in Cu, Ge, Ga, Sb and As, whereas rhythmic bandings (dark brown bands primarily) are enriched in Fe, Cd, In and Sn. This typical distribution points to crystallographic controls on trace element uptake during sphalerite growth, occurring with concomitant microscale variations in fluid compositions at the fluid–crystal interface. Regardless of the zoning type, in all spots, Cu contents approach the sum of tri- and tetravalent cations (Ge, Ga, In, etc.) so that Cu could provide charge-balance for the entire set of coupled substitution mechanisms responsible for the incorporation of the whole range of trace elements in this sphalerite. Strong binary correlations suggest direct substitutions as $Zn^{2+} M (Fe^{2+}, Cd^{2+})$ and coupled substitutions as $2Zn^{2+} M Cu^{+} + Sb^{3+}$, $3Zn^{2+} M Ge^{4+} + 2Ag^{+}$, and $3Zn^{2+} M In^{3+} + Sn^{3+} + h$ (vacancy) despite no clear evidence for the presence of Sn^{4+} .

$\delta^{74}Ge_{NIST3120a}$ in bulk sphalerite varies from $-2.07 \pm 0.37\%$ to $+0.91 \pm 0.16\%$ (2 σ SD) and positively correlates with bulk Ge content. This indicates considerable Ge isotopic fractionation within sphalerite during low-T hydrothermal deposition and zoning processes, associated with possible microscale open system fluid mixing. The trace element features in sphalerite from Saint-Salvy compared with those of other deposits confirm their use as discriminators among genetic types of ores (e.g., high In contents for magmatic-related deposits, and Ge for low-temperature deposits).

© 2013 Elsevier Ltd. All rights reserved.





First evidence of the trisulfur radical ion S_3^- and other sulfur polymers in natural fluid inclusions



Guillaume Barré^{a,*}, Laurent Truche^{a,b}, Elena F. Bazarkina^{a,c,d}, Raymond Michels^a, Jean Dubessy^a

^a Université de Lorraine, CNRS, GeoRessources, UMR 7359, BP 70239, F-54506 Vandoeuvre-lès-Nancy, France

^b Université Grenoble Alpes, CNRS, ISTERre, UMR 5275, BP 53, 38041 Grenoble, France

^c Institute of Geology of Ore Deposits, Mineralogy, Petrography and Geochemistry, Russian Academy of Sciences, IGEM RAS, Staromonety per. 35, 119017 Moscow, Russia

^d Inst. Néel, UPR 2940 CNRS, Univ. Grenoble Alpes, F-38000 Grenoble, France

ARTICLE INFO

Keywords:

S_3^-
Fluid inclusion
Raman spectroscopy
Sulfur speciation
Thermochemical Sulfate Reduction

ABSTRACT

Sulfur plays a key role in numerous processes occurring in the Earth's crust. However, its speciation in deep and hot geological fluids remains poorly constrained. Here, we used quantitative in-situ Raman spectroscopy on natural fluid inclusions from deep sedimentary environments where thermochemical sulfate reduction (TSR) occurred to determine the sulfur speciation at temperatures representative of their entrapment conditions (100–300 °C). Results unambiguously demonstrate the presence of the trisulfur ion S_3^- and other polymeric S species ($S_n^{2-} \pm S_n^0$) at temperature (T) > 100 °C, whereas only sulfide and sulfate were detected at 25 °C. From 200 to 300 °C, sulfate and sulfide, the two dominant S species, contribute to $41 \pm 9\%$ and $59 \pm 9\%$ of the mean total dissolved S concentration ($[S_{tot}] = 0.25 \text{ mol/kg}_{H_2O} = 0.8 \text{ wt}\%$), respectively. The S_3^- concentration accounts for 0.2 to 3% of S_{tot} in this T range, with a maximum recorded concentration of $2.9 \times 10^{-2} \text{ mol/kg}_{H_2O}$ (2780 ppm) at 300 °C. This observation implies that the TSR process occurs under physico-chemical conditions that enhanced the stability of S_3^- and other polymeric S species. This conclusion has important consequences for the genesis of base metal sulfide deposits and sour gas fields where reduced sulfur originates from TSR.

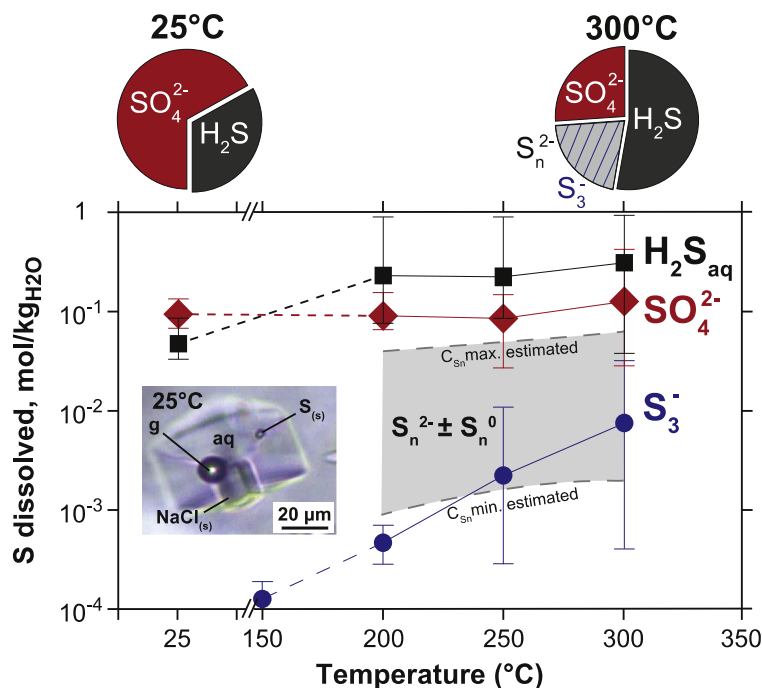


Fig. 7. Temperature evolution of sulfur speciation in natural fluid inclusions from the Carnian evaporites formation (French Alps). At high temperature, trisulfur radical ion S_3^- (blue circles) and $S_n^{2-} \pm S_n^0$ (estimated in grey shaded area) attain significant concentrations. During cooling, their concentrations drop and only sulfates and sulfides are detected at 25 °C. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

40 Ma years of hydrothermal W mineralization during the Variscan orogenic evolution of the French Massif Central revealed by U-Pb dating of wolframite

Matthieu Harlaux^{1,2} · Rolf L. Romer³ · Julien Mercadier¹ · Christophe Morlot¹ · Christian Marignac¹ · Michel Cuney¹

Received: 4 November 2016 / Accepted: 20 February 2017
© Springer-Verlag Berlin Heidelberg 2017

Abstract We present U-Pb thermal ionization mass spectrometer (TIMS) ages of wolframite from several granite-related hydrothermal W±Sn deposits in the French Massif Central (FMC) located in the internal zone of the Variscan belt. The studied wolframite samples are characterized by variable U and Pb contents (typically <10 ppm) and show significant variations in their radiogenic Pb isotopic compositions. The obtained U-Pb ages define three distinct geochronological groups related to three contrasting geodynamic settings: (i) Visean to Namurian mineralization (333–327 Ma) coeval with syn-orogenic compression and emplacement of large peraluminous leucogranites (ca. 335–325 Ma), (ii) Namurian to Westphalian mineralization (317–315 Ma) synchronous with the onset of late-orogenic extension and emplacement of syn-tectonic granites (ca. 315–310 Ma) and (iii) Stephanian to Permian mineralization (298–274 Ma) formed during post-orogenic extension contemporaneous with the Permian volcanism in the entire Variscan belt. The youngest ages (276–274 Ma) likely reflect the reopening of the U-Pb isotopic system after wolframite crystallization and may correspond to late hydrothermal alteration (e.g. ferberitization). Our results demonstrate that W(±Sn) mineralization in the FMC formed during at least three distinct hydrothermal events in different tectono-metamorphic settings over a time range of 40 Ma.

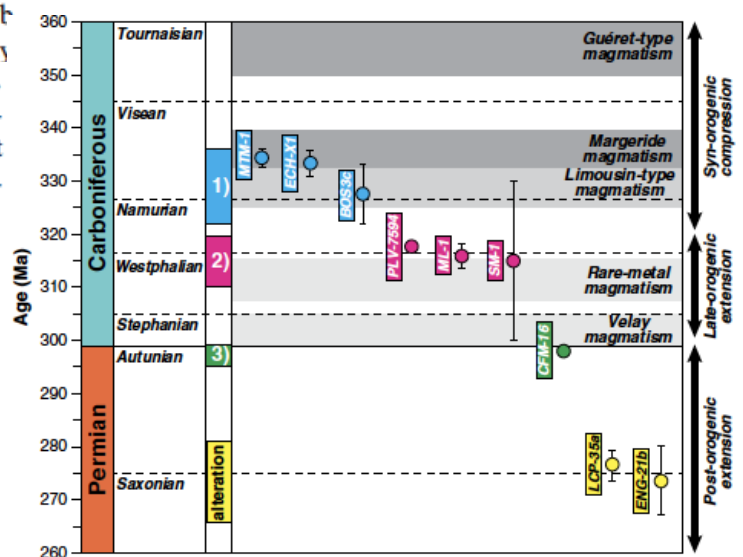
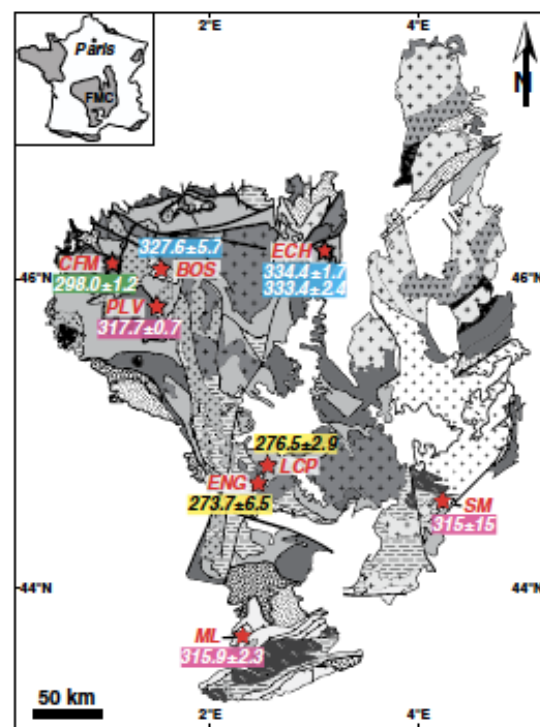





Fig. 10 Synthesis of the U-Pb ages of wolframite obtained in this study and comparison with the ages of the main tectono-metamorphic and magmatic episodes in the French Massif Central (Faure et al. 2009 and references therein). Subdivisions for the Carboniferous and Permian time-scales are from McCann (2008)

Article

Rutile from Panasqueira (Central Portugal): An Excellent Pathfinder for Wolframite Deposition

Eleonora Carocci ¹, Christian Marignac ^{2,*} , Michel Cathelineau ^{1,*} , Laurent Truche ³,
Andrei Lecomte ¹ and Filipe Pinto ^{4,5} 

¹ GeoRessources, Université de Lorraine, CREGU, rue Jacques Callot, F-54506 Vandoeuvre-lès-Nancy, France; eleonora.carocci@univ-lorraine.fr (E.C.); andrei.lecomte@univ-lorraine.fr (A.L.)

² GeoRessources, Université de Lorraine, Ecole Nationale Supérieure des Mines de Nancy, Parc de Saurupt, F-54042 Nancy, France

³ ISTERRE, Université de Grenoble-Alpes, F-38041 Grenoble, France; laurent.truche@univ-grenoble-alpes.fr

⁴ Beralt Tin and Wolfram Portugal, 6225-051 Barroca Grande, Portugal; filipe.pinto@beraltportugal.pt

⁵ Instituto de Ciências da Terra, Rua Campo Alegre 687, 4169-007 Porto, Portugal

* Correspondence: christian.marignac@univ-lorraine.fr (C.M.); michel.cathelineau@univ-lorraine.fr (M.C.); Tel.: +33-679-213-617 (C.M.); +33-372-745-543 (M.C.)

Received: 31 October 2018; Accepted: 18 December 2018; Published: 24 December 2018



Abstract: Abundant W-rich rutile in the tourmalinized wall-rocks from the Panasqueira W-deposit appears to be a marker of the onset of the main wolframite depositing event. Rutile displays spectacular zoning, both sector (SZ) and oscillatory (OZ). An extensive set of compositional data obtained on crystals, beforehand studied using back-scattered electron images and X-ray maps, was used to address (i) the effects of SZ on differential trapping of minor elements, and (ii) the significance of the OZ in deciphering fluid sources and fluid circulation dynamics. Particular attention was paid to Sn, W (Nb, Ta) concentrations in rutile as pathfinders of the W deposition. Concerning the sector zoning, W is more incorporated than (Nb, Ta) onto more efficient faces, whereas Sn contents are nearly not impacted. The net effect of the sector zoning is thus a progressive increase of the relative weight of Sn from pyramid to prism faces, in combination with a less significant increase in the relative weight of Nb + Ta. The oscillatory zoning concerns most minor elements: W, Nb (Ta), Fe, V, Cr and Sn. In the frequent doublets, the clear bands are in general enriched in W relatively to the dark ones, whereas the inverse is true for Nb and Ta. The doublets may be viewed as the result of the successive influx of (i) a W-rich, Nb + Ta poor fluid, abruptly replaced by (or mixed to) (ii) a Nb + Ta-rich and W-poor fluid. The Nb + Ta-rich fluid could be in turn related to a rare-metal granite layer observed atop of the Panasqueira granite.

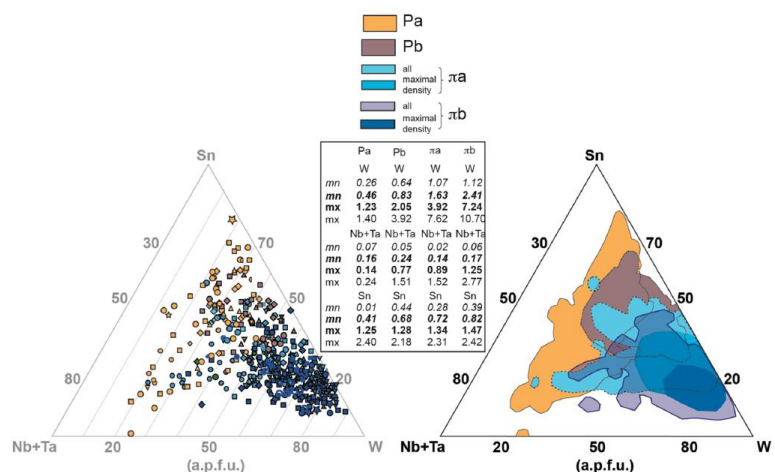
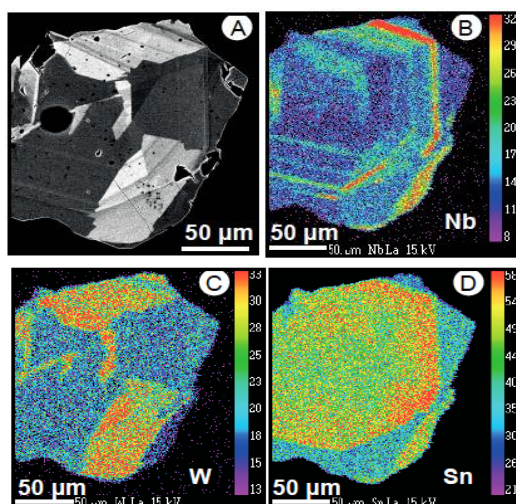


Figure 7. Demonstration of the sector zoning compositional effects in the W–Sn–(Nb + Ta) triangular diagram. Insert: minimal and maximal values (wt %) for W, Nb + Ta and W according to the type of faces. Both absolute (italics) and average (bold) values are given. Not the regular changes from the less to the more efficient faces.

Geometallurgy



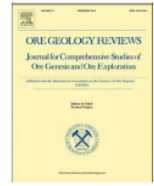
A geometallurgical approach including all operations of extractive metallurgy processes, i.e. from mineral processing to pyrometallurgy to hydrometallurgy, is being developed through the STEVAL facility that has recently implemented a hydrometallurgical laboratory (HYDROVAL).

Rare earth elements (see section on REEs above)

A new technology for fine particle recovery from the micaceous residues of an European kaolin processing plant was developed at lab scale and tested at pilot scale. The rare-earth concentrate obtained displayed a 62% rate of recovery. These results were obtained thanks to new intensive gravity and flotation devices. A geometallurgical model was also developed to optimise the exploitation model of the deposits by maximising the main concentrate and the quality of the by-product.

Advanced modelling of collector mineral interaction

Advanced mineral processing approaches were developed to create new chemical formulations for fine particles flotation based on the original collector blend and advanced modelling (DFT) of the mineral surface hydration and collector adsorption. Thus, the spontaneous formation of an adsorption layer can be predicted and optimised by modelling the molecule features and the molecule-molecule interactions. The results obtained were applied to develop an efficient flow sheet for the recovery of tungsten from a European complex skarn ore (Tabuaço, Portugal).



Rare-metal granites as a potential source of critical metals: A geometallurgical case study

Quentin Dehaine^{a,b,*}, Lev O. Filippov^{a,c}, Hylke J. Glass^b, Gavyn Rollinson^b

^a GeoResources, Université de Lorraine, CNRS, UMR 7359, 2 rue du Doyen Marcel Roubault, TSA 70605, F54518, Vandœuvre-lès-Nancy, France

^b University of Exeter, Camborne School of Mines, Penryn, Cornwall, TR10 9FE, United Kingdom

^c National University of science and technology MISIS, 119049 Moscow, Russia



ARTICLE INFO

Keywords:

Kaolin residue
Light Rare Earths
Critical metals
Rare-metal granites
Geometallurgy
QEMSCAN®

ABSTRACT

Because of their low grades in critical metals such as Light Rare Earth Elements (LREE) or Sn, rare-metal granites are not considered as economic for metal recovery but, when altered, they are often exploited for their industrial minerals. The St Austell rare-metal granite is well known for its world-class kaolin deposits which formed as a result of the extensive weathering and alteration of the underlying granite. The St Austell granite body is composed of several granite components, each having its own accessory minerals assemblage. As a result of the kaolinisation process, some metal-bearing accessory minerals of the granite, such as monazite (LREE) or cassiterite (Sn), are partially liberated from the gangue which allow their pre-concentration in the micaceous residue which is considered as a potential source for critical metals recovery. Similarities with other similar rare-metal granites suggest that topaz granite is the most prospective for disseminated magmatic Sn-Nb-Ta-REE mineralization. However, comparison of the potentiality of 3 granite types *i.e.*, biotite, topaz and tourmaline granites suggest that biotite granites is actually the most prospective due to higher degree of kaolinisation of the biotite granite which favour pre-concentration of its accessory mineral in the micaceous residue. In order to develop a geometallurgical framework for extraction of kaolin and metals from the selected granite component, a field sampling campaign is performed. Core samples are processed in the laboratory using a characterisation program that mimics the full-scale kaolin refining route. Two main products are recovered through this program, *viz.* MR180 (−180 + 53 μm) and P5 (−5 μm), which correspond to a fine micaceous residue and a fine kaolin product respectively. These products are both analysed routinely for major and minor trace elements by XRF and yields are recorded to indicate process performance. A selected number of MR180 samples are also being characterised in terms of particle size by laser light scattering, geochemistry by ICP-MS, and mineralogy by QEMSCAN®. Comparison of characterisation results of MR180 samples and corresponding industrial residue samples shows a good correlation, suggesting that sample analyses are representative for the in-situ deposit and the processing behaviour. Monazite is found to be either fully liberated or fully locked from one sample to the other. Next, pilot-scale gravity concentration tests are performed on micaceous residue samples. Characterisation of the processing products shows that monazite lost in the tailings is mostly locked within tourmaline or mica and is fine grained. Then, predictive regression models for spiral separation performance in terms of recovery, product grade and enrichment as a function of the feed grade are developed for MR180 LREE grade data. Finally, kaolin resources can be classified using quantitative indicators such as yield of the P5 product and the iron oxides content which provides insight into the kaolin quality in terms of whiteness. This geometallurgical classification can be used to delineate zones of interest within the deposit. Although kaolin quality and recovery primarily inform extraction planning, zones which are also of interest for metal recovery can be identified. The proposed model predicts whether the expected LREE grade and recovery satisfy the by-product requirements.

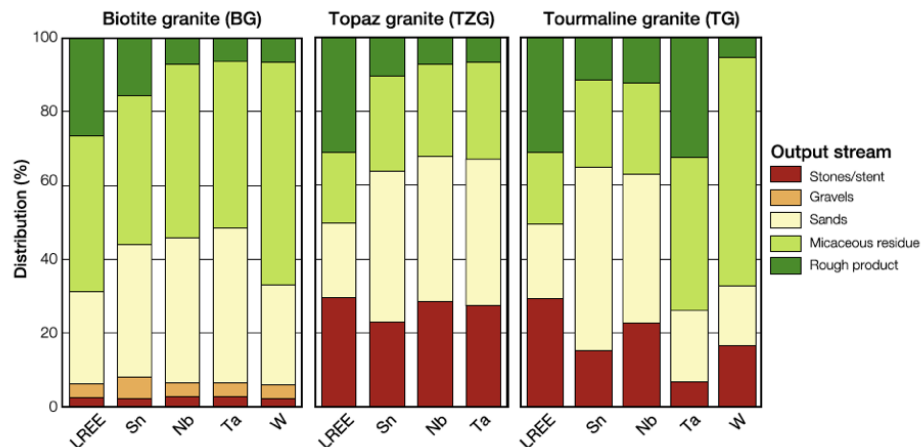


Fig. 6. Metallurgical balances showing the distribution of the LREE (La, Ce, Nd) and rare metals (Sn, Nb, Ta, W) within the output streams of kaolin refining process for biotite, topaz and tourmaline granites.



New reagent formulations for selective flotation of scheelite from a skarn ore with complex calcium minerals gangue



L.O. Filippov^{a,*}, Y. Foucaud^a, I.V. Filippova^a, M. Badawi^b

^a Université de Lorraine, Laboratoire GeoRessources, UMR 7359 UL-CNRS-CREGU, ENSG, 2 rue du Doyen Marcel Roubault BP10162, 54505 Vandoeuvre-les-Nancy, France

^b Université de Lorraine, Laboratoire de Chimie et Physique – Approche Multi-Echelle des Milieux Complexes (LCP-A2MC, EA4632), Institut Jean Barriol FR2843 CNRS, Rue Victor Demange, 57500 Saint-Avold, France

ARTICLE INFO

Keywords:

Scheelite
Fluorite
Flotation
Collectors blend
Adsorption
DFT modeling

ABSTRACT

The approach using synergistic effects of the blend of carboxylic collectors was applied to process the Tabuaco tungsten skarn ores (Portugal) by flotation. However, a very complex mineral composition with high amounts of the fluorite (> 10%) and apatite (3–5%), as well as the presence of more than 40% of vesuvianite, a silicate of calcium, implied that such separation is highly challenging. In this work, the influence of sodium silicate and sodium carbonate on the selective flotation of scheelite has been investigated. A study of depressants dosage allowed to reach a selective flotation of scheelite from calcium minerals at 1125 g/t, except from fluorite. The use of sodium carbonate with sodium silicate showed synergistic effects, increasing the WO₃ grade from 6.6% to 11.2% without impacting the recovery. Collector formulations were created in the laboratory by mixing the commercial fatty acids, in which oleic and linoleic acid predominated, in various proportions with rosin acids while the ratio between oleic and linoleic acids was kept constant. The tungsten recovery increased significantly, up to 98%, with the amount of rosin acids in the mixture while the concentrate grade decreased from 16% WO₃ grade to 10.5% WO₃ grade impacting the selective flotation of scheelite from an ore with 0.9% WO₃ grade. The optimal ratio of fatty and rosin acids was then experimentally set to 5/1-6/1. An unprecedented increase of the flotation selectivity between scheelite and fluorite was obtained when the saturated acids were introduced in the formulation. The concentrate grade reached 27% WO₃ grade for the same ratio between anionic reagents. Thus, the new reagent formulation allowed to obtain a tungsten concentrate after only one cleaner stage without additional use of thermal treatment or activating heavy metals salts or specific depressants.

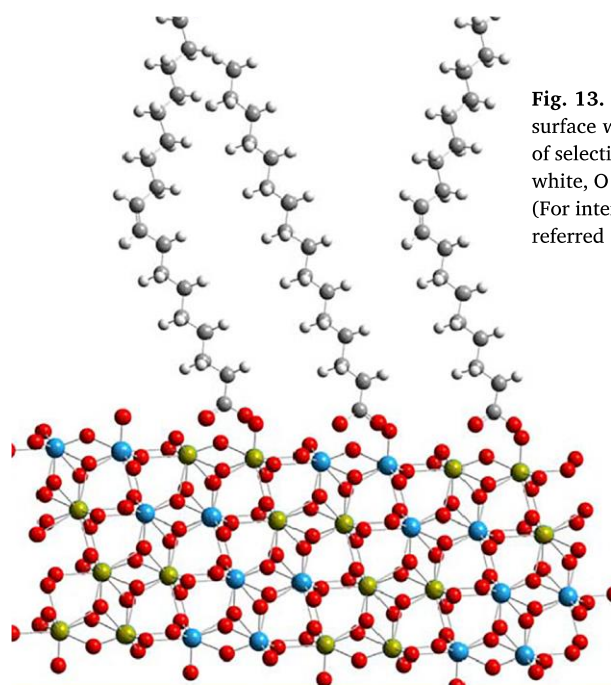


Fig. 13. Suggestion of organization of the adsorption layer on (1 1 2) scheelite surface when palmitate is introduced. It could explain the observed differences of selectivity between scheelite and fluorite. C atoms are in grey, H atoms are in white, O atoms are in red, Ca atoms are in yellow and W atoms are in dark blue. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)



Salt effect on gas dispersion in flotation column – Bubble size as a function of turbulent intensity



L.O. Filippov^{a,b,*}, Z. Javor^a, P. Piriou^a, I.V. Filippova^{a,b}

^a Université de Lorraine, CNRS, GeoRessources Laboratory, 2 rue du Doyen Marcel Roubault, BP10162, F-54505 Vandoeuvre-les-Nancy, France

^b National University of Science and Technology MISIS, Leninsky pr., 4, 119049 Moscow, Russia

ARTICLE INFO

Keywords:

Flotation column
Bubble coalescence
Brine
Chloride salts
Structure of air-liquid interface
Ion partition

ABSTRACT

The present work investigates the role of chloride salts on bubble coalescence properties by average bubble diameter measurement. The tested chloride salts (NaCl, MgCl₂ and CaCl₂) were dissolved in fresh running water and used as feeding of a three-meter high pilot flotation column. The column was operated in close circuit while the superficial gas rate (J_g) was varied. Gas holdup in the collection zone of the column was measured using pressure sensors. Drift flux model is employed to obtain the mean bubble diameter between two pressure-tapping points. The change of cations of chloride salts has an indisputable effect on bubble coalescence; hence the bubble size in the column varies as a function of chloride salt type. The hydrodynamics factors on bubble coalescence and difference in inhibition behavior of monovalent (NaCl) and divalent cations (CaCl₂ and MgCl₂) based on the partition of the different hydrated ions at the gas-liquid interface were highlighted. The characterisation of the liquid phase used for flotation separation should not only focus on the concentration of salts but also on the ion-water, ion-ion and water-water properties as a function of hydrodynamic condition.

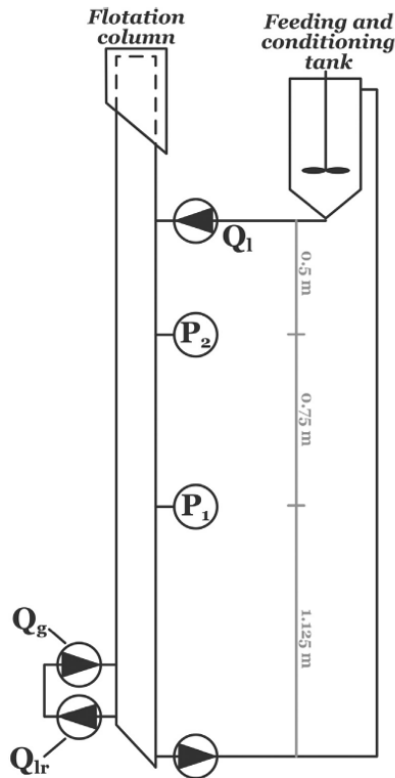


Fig. 3. Schematic of the experimental set-up.

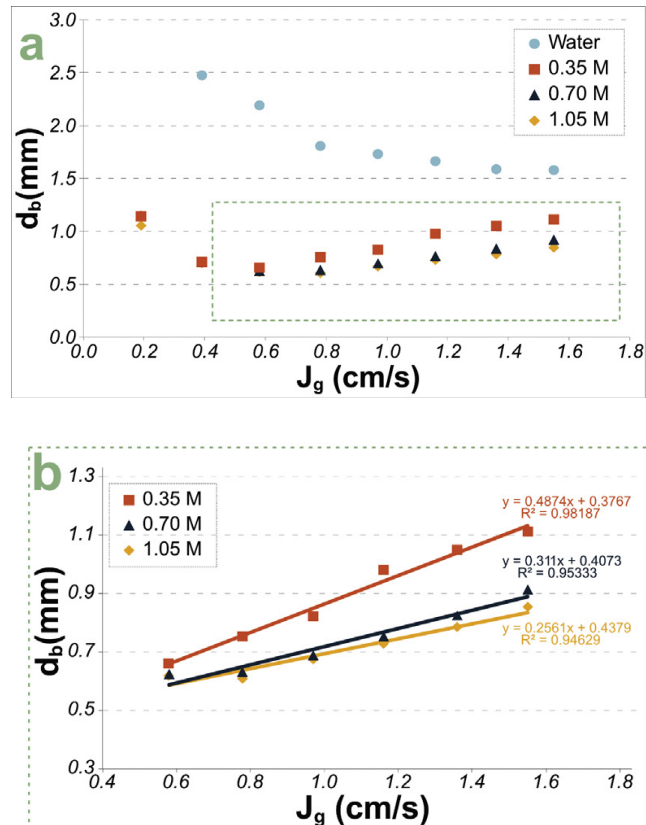


Fig. 6. Average bubble size as a function of increasing J_g in NaCl solutions.



A multi-analytical approach to the study of uranium-ore agglomerate structure and porosity during heap leaching



Emerence Hoummady^{a,*}, Fabrice Golfier^a, Michel Cathelineau^a, Laurent Truche^{a,b},
Nicolas Durupt^c, Jean-Jacques Blanvillain^c, Jeremy Neto^c, Eric Lefevre^a

^a Université de Lorraine, CNRS, CREGU, GeoRessources lab., 54518 Vandoeuvre-lès-Nancy Cedex, France

^b ISTERre, UMR 5275 Université Grenoble Alpes, CNRS, 1381 rue de la Piscine, BP 53, F-38041 Grenoble Cedex 09, France

^c AREVA Mines, SEPA, 2 route de Lavaugrasse, 87250 Bessines-sur-Gartempe, France

ARTICLE INFO

ABSTRACT

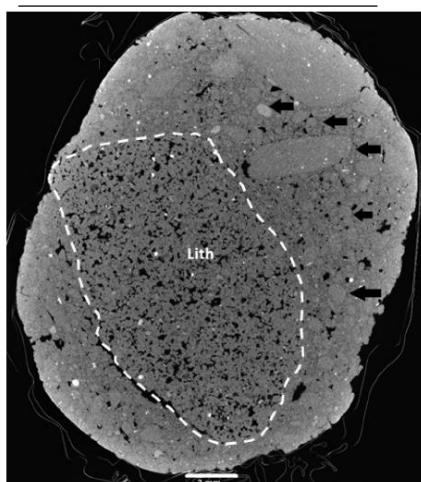


Fig. 1. X-ray tomography analysis of an acid bound agglomerate (diameter of 20 mm) before leaching. Notes: The black arrows indicate some egg-shaped structures within the agglomerate. Porosity is represented in black. White dotted lines show a fragment of sandstone (Lith) which is more porous than the edge of the agglomerate.

Agglomeration is commonly used for processing clay-rich ores in order to prevent undesirable effects, especially the risks of plugging or preferential channelling within the heap leaching piles. As the mechanical and chemical stability of the agglomerates is of crucial importance for the behaviour of the pile, a detailed characterization of the structure and porosity of agglomerates seems necessary. In the present study, uranium-bearing clay rich ore was agglomerated and agglomerates were studied before as well as after 10 days of leaching. A multi-analytical approach (by X-ray tomography, SEM, XRD and MIP analyses) was used for the study of the mineralogy, porosity distribution and textures of the agglomerates. X-ray tomography and SEM images showed that agglomerates were the result of coalescence and layering of micro-agglomerates where each one in turn was composed of a nucleus embedded within phyllosilicates and an aluminous silicate matrix. MIP analyses highlighted that unleached agglomerates had a low connected porosity (between 3 and 7%). During the 24 first hours of process, the connected porosity increased by a factor 2 because of the leaching of the aluminous silicate matrix and about 60% of the uranium was recovered. During the next 9 days, the formation of a secondary aluminous silicate matrix derived from the dissolution of illites resulted in the plugging of mesopores and therefore led to a decrease of porosity and uranium extraction extent.

Cross section

3D Volume

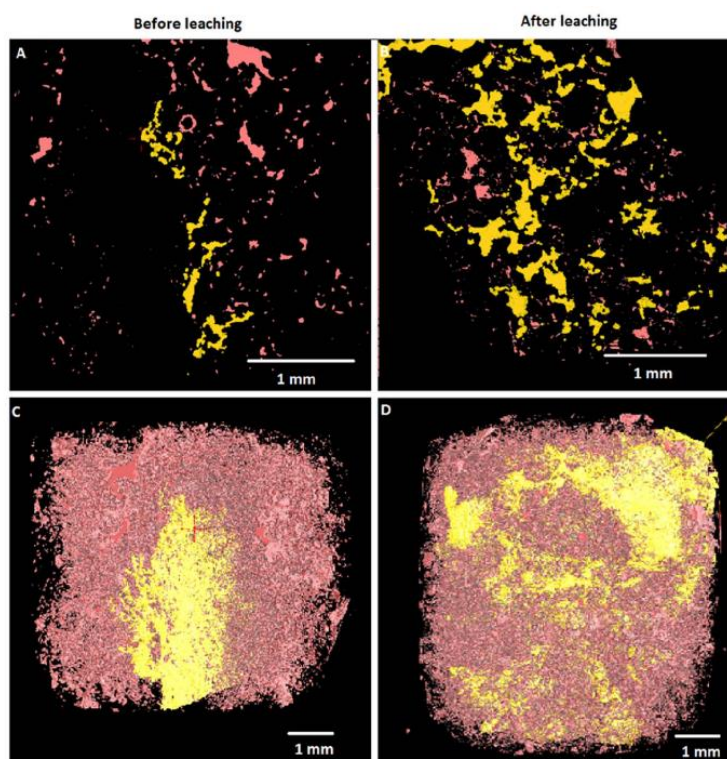


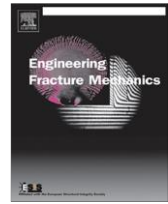
Fig. 10. Pore network within an agglomerate before (A and C) and after 10 days of leaching (B and D). Notes: Pores in red correspond to the total porosity and pores in yellow correspond to connected pores. Connected porosity clearly increases during leaching. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Modelling

Developing numerical tools and new modelling strategies for a better assessment of mineral resources is one of the main axes of research of the Labex. Over the last decade, with the support of Labex, significant advances in these fields have been achieved, including:

- (i) the improved modelling of 3D geological objects (faults and sedimentary channels) with a better integration of all subsurface observations (petrophysics and geophysics) (e.g., Rongier et al., 2014; Collon et al., 2015; Laurent, 2016; Laurent et al., 2016; Grose et al., 2017) and a better constrained uncertainty (Lallier et al., 2015; Julio et al., 2015)
- (ii) the development and numerical assessment of various modelling/theoretical approaches (direct coupling and upscaling or hybrid modelling strategies) for a better description of these coupled thermo-hydro-chemico-mechanical processes (e.g., Sevostianov and Giraud, 2013; Chen et al., 2015; Faivre et al., 2016; Myagkiy et al., 2017).

During Maxime Faivre's PhD works (2012-2015), the development of hydraulic breccias in ore deposits was modelled. Ore deposit may result from fluid-overpressure events in some formations due to hydraulic fractures or breccias. In these works, an original numerical approach based on the extended finite element method (XFEM) was proposed to model fracture dynamics and flow calculation (Faivre et al., 2016; Paul et al., 2018).



2D coupled HM-XFEM modeling with cohesive zone model and applications to fluid-driven fracture network



M. Faivre ^{a,*}, B. Paul ^{a,b,c}, F. Golfier ^a, R. Giot ^a, P. Massin ^b, D. Colombo ^c

^a Université de Lorraine, ENSG, CNRS, CREGU, GeoResources Laboratory, F-54501 Vandoeuvre-Lès-Nancy, France

^b IMSIA, UMR EDF-CNRS-CEA-ENSTA ParisTech, Université Paris Saclay, France

^c IFP Energies Nouvelles, 92852 Rueil-Malmaison Cedex, France

A B S T R A C T

The present work focuses on a new numerical model for the fully coupled hydro-mechanical analysis of groundwater flows through poroelastic saturated media. In particular, the presence and eventual propagation of fluid-driven fractures is accounted for within a non-regularized cohesive zone model. In this paper, the fracture propagation is considered as a reactivation process: the fracture already exists and evolves (*i.e.* opens or closes) on a pre-defined path initially constrained. The Talon–Curnier constitutive law is considered for the fracture interfaces and its expression has been adapted to the hydro-mechanical coupling related to the fracture evolution. The fluid pressure inside the fracture is governed by the lubrication equation. The momentum-stress balance equations involving fluid flow and deformation of the solid porous matrix are derived within the framework of the generalized Biot theory. The extended finite element method (XFEM) is preferred to a standard finite element spatial discretization in order to easily handle the presence and evolution of discontinuities in the porous medium. A set of four Lagrange multipliers is introduced to prevent spurious oscillations of the numerical solution at the interface. Comparisons between numerical results and theoretical solution assess the validity of the model presented in this paper. In addition, the hydro-mechanical interactions between neighboring fractures and the effects of the permeability of the porous medium are investigated. We also demonstrate the capability of our model to handle non-planar fracture paths.

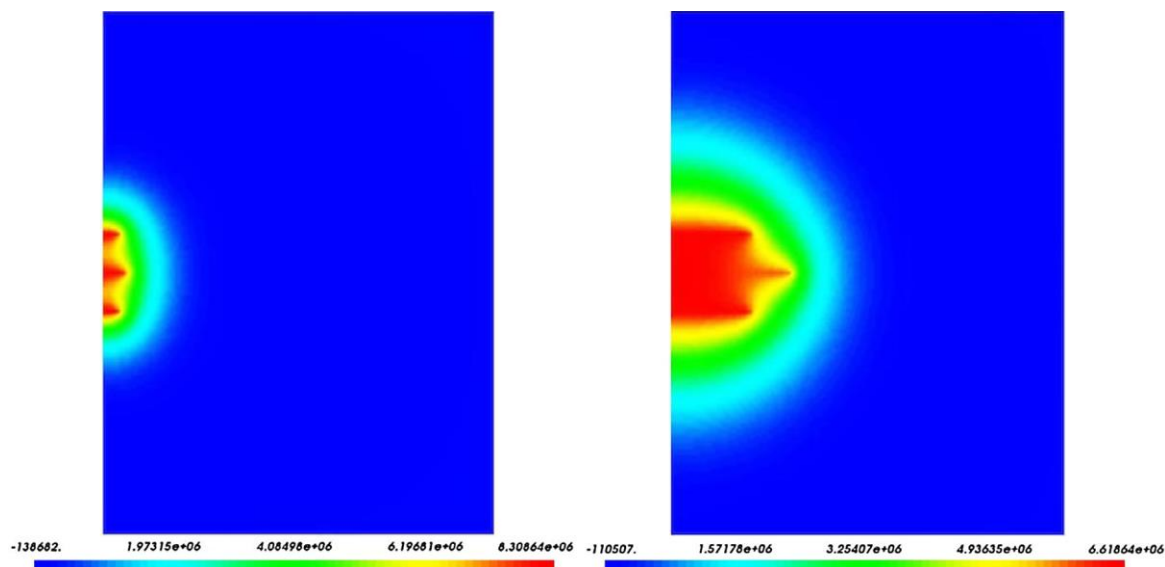


Fig. 25. Scalar maps for the pore pressure at $t_1 = 18$ s (left) and $t_2 = 80$ s (right).

3D coupled HM–XFEM modeling with cohesive zone model and applications to non planar hydraulic fracture propagation and multiple hydraulic fractures interference

B. Paul^{a,b,c,*}, M. Faivre^b, P. Massin^a, R. Giot^b, D. Colombo^c, F. Golfier^b, A. Martin^a

^a *IMSIA, UMR EDF-CNRS-CEA-ENSTA ParisTech, Universit Paris-Saclay, 7 boulevard Gaspard Monge, 91120 Palaiseau, France*

^b *Université de Lorraine, ENSG; CNRS; CREGU; GeoRessources Laboratory, F-54501 Vandoeuvre-Lès-Nancy, France*

^c *IFP Energies Nouvelles, 92852 Rueil-Malmaison Cedex, France*

Abstract

A 3D fully coupled hydromechanical model for the simulation of fluid-driven fracture propagation through poroelastic saturated media is presented and compared to several analytical or numerical benchmarks. The hydromechanical coupling in the porous matrix is derived within the framework of the generalized Biot theory and the fluid flow in the fractures satisfies the lubrication equation. The presence and propagation of fluid-driven fractures is handled with the extended finite element method and the propagation of the fluid-driven fractures is governed by a mixed linear cohesive law relying on a stable mortar formalism. A comparison between numerical results and a semi-analytical solution for plane fluid-driven fractures in porous media assess the validity of the proposed model. Then, a procedure for the propagation of fluid-driven fractures on non predefined paths is detailed. In particular, the fracture reorientation angle is computed exclusively from cohesive quantities. Various numerical experiments are performed to study the interferences between neighboring fluid-driven fractures as well as the reorientation of fluid-driven fractures under complex stress conditions. Finally, the model is extended to discontinuity junctions and an application to arrays of vertical fractures initiated from horizontal wells is presented.

© 2018 Elsevier B.V. All rights reserved.

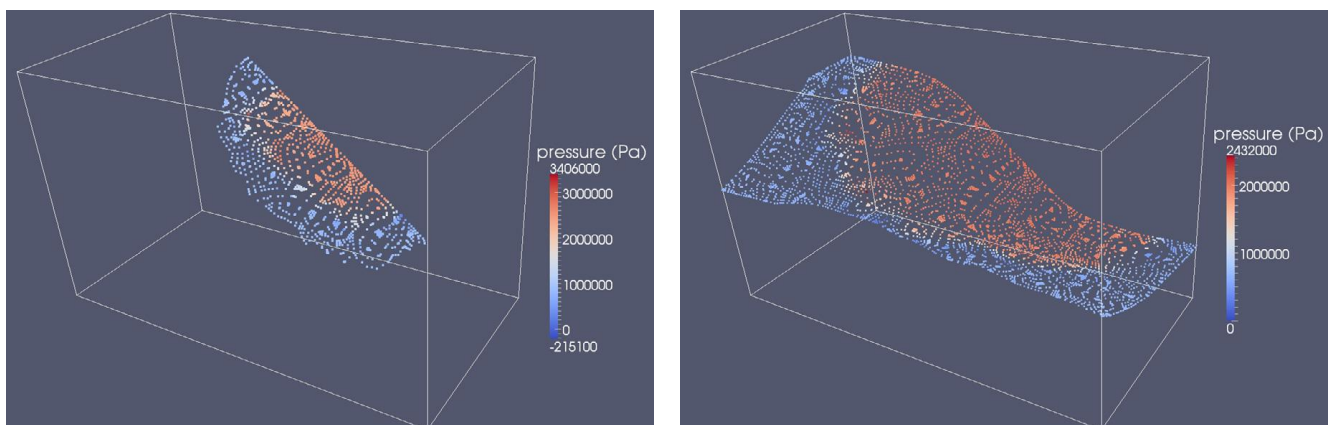
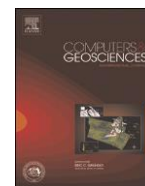


Fig. 19. Points of the initial crack surface and pore pressure at $t = 2.5$ s (left) and points of the final crack surface and pore pressure at $t = 17$ s (right) for the 3D fluid-driven fracture reorientation test. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)



3D geomodelling combining implicit surfaces and Voronoi-based remeshing: A case study in the Lorraine Coal Basin (France)

Pauline Collon ^{a,*}, Wendy Steckiewicz-Laurent ^{a,b}, Jeanne Pellerin ^a, Gautier Laurent ^{a,1},
Guillaume Caumon ^a, Guillaume Reichart ^{a,b}, Laurent Vaute ^b

^a GeoRessources UMR7359, Université de Lorraine, CNRS, CREGU, ENSG, 2 rue du doyen Marcel Roubault, TSA 70605, 54518 Vandœuvre-lès-Nancy Cedex, France

^b BRGM, 1 avenue du Parc de Brabois, 54500 Vandoeuvre-lès-Nancy, France

ARTICLE INFO

Article history:

Received 12 August 2014

Received in revised form

15 October 2014

Accepted 15 January 2015

Available online 16 January 2015

Keywords:

Geomodelling

3D surface-based model

Implicit modelling

Surface remeshing

Post-mining

Geothermics

ABSTRACT

In this paper we demonstrate how recent geomodelling techniques can be combined and used to build a 3D geological model on a real case study: the former coal mine of Merlebach (France), that is targeted to be exploited for low-temperature geothermal energy production. From geological maps, cross-sections, borehole and mine exploitation data, we build a 3D model in which are identified the rocks and infrastructures having significantly different permeabilities. First, a structural model of the main geological interfaces in our area of interest (2 horizons and 13 faults) is built with classical geomodelling techniques. Then, we propose to model by surfaces the 71 irregularly stacked, very close and very thin, sub-vertical coal beds. To ease their construction, we use an implicit method which represents 3D surfaces as isovalues of a scalar field defined in a 3D tetrahedral grid of the area. The corresponding triangulated surfaces are remeshed with a recently proposed method based on Voronoi diagrams so that the exploited parts of the coal beds, now filled by sand, can be computed. The 3D surface-based geological model, in which infrastructures can be inserted as piecewise lines, can be volumetrically meshed. It is available for download as supplemental material, as well as a volumetric grid.

© 2015 Elsevier Ltd. All rights reserved.

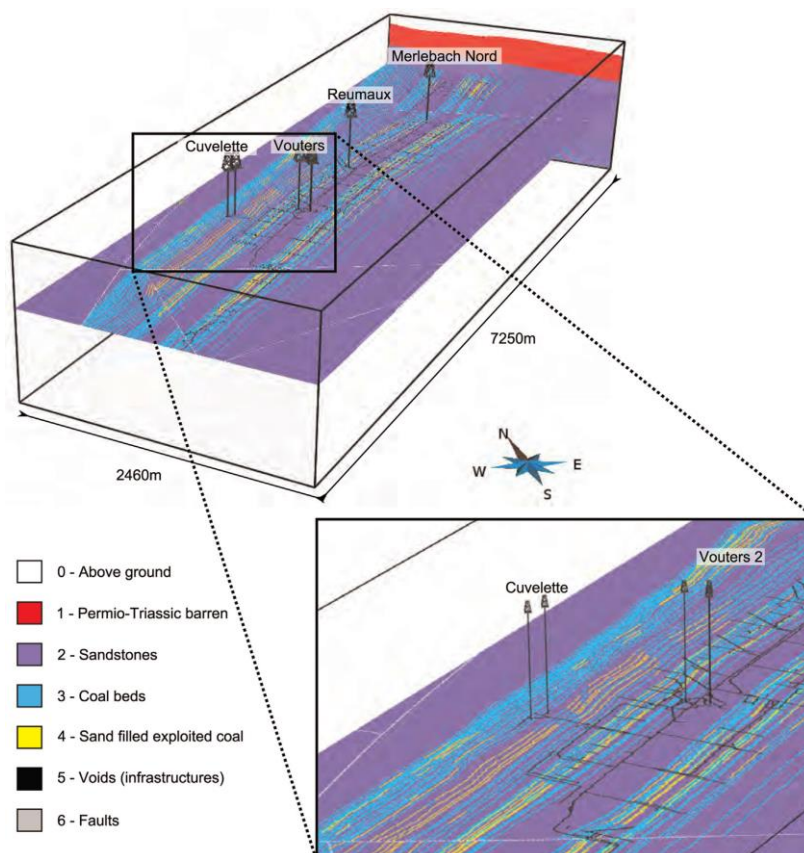
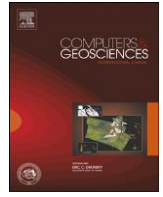


Fig. 14. Slices in the 3D regular Cartesian volumetric grid of the Vouters 2 mining area. The grid contains about 125 million cubic cells of 6 m side.



Automatic surface remeshing of 3D structural models at specified resolution: A method based on Voronoi diagrams



Jeanne Pellerin ^{a,c,b,*}, Bruno Lévy ^b, Guillaume Caumon ^a, Arnaud Botella ^{a,c,b}

^a Géoressources (UMR 7359), Université de Lorraine-ENSG/CNRS/CREGU, Vandoeuvre-lès-Nancy F-54500, France

^b Inria - Project Alice, Villers-lès-Nancy F-54600, France

^c ASGA, Vandoeuvre-lès-Nancy F-54500, France

ARTICLE INFO

Article history:

Received 12 April 2013

Received in revised form

12 September 2013

Accepted 15 September 2013

Available online 23 September 2013

Keywords:

Remeshing

Structural model

Non-manifold

Restricted Voronoi diagram

ABSTRACT

We propose a method to remesh the surfaces of 3D sealed geological structural models for subsequent volumetric meshing. The input of the method is a set of triangulated surfaces that are in contact along given lines and at given points. The output is a set of surfaces meshed with triangles as equilateral as possible. The method relies on a global Centroidal Voronoi optimization to place the vertices of the final surfaces combined with combinatorial considerations to either recover or simplify the surfaces, lines and points of the input model. When the final resolution is sufficient, the input contact lines and points are also contact lines and points of the final model. However, when dealing with models with complex contacts, resolution may be insufficient and instead of a refinement strategy that may lead to too many points, we propose to locally merge some features of the input model. This ability to simplify the input model is particularly interesting when the model is to be volumetrically meshed. The method is demonstrated on twelve structural models, including seven models built with an implicit modeling method, and one folded layer model affected by a discrete fracture network.

© 2013 Elsevier Ltd. All rights reserved.

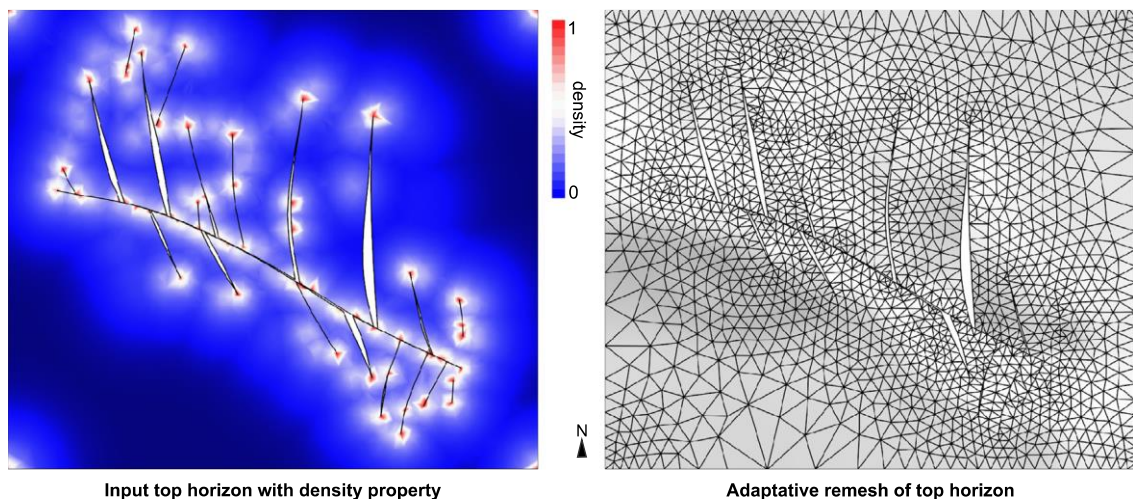


Fig. 21. Adaptive remeshing of top horizon in Clyde model. A density property computed from the distance to the triple points of the model $\rho(y) = (1 - d(y)/d_{max})^4$ was used to obtain an adaptive remesh of the Clyde model with 10,000 seeds. Unlike uniform remeshing, the result depends on the input mesh quality because density is interpolated on it.



Training and diffusion

Graduating students (PhD)



Pablo-Eliécer Mejía-Herrera

Supervisor: Jean-Jacques Royer

Awarded: 16-12-2014

Thesis title: Ore-deposits modeling and improving their understanding with structural restoration

Partial funding by Labex

The objective of this Ph.D. thesis is to apply 3D and 4D modelling methods to reconstruct the architecture and deformations over time of geological entities in a defined region. Structural restoration modelling is used here to estimate geological, physical and structural attributes for understanding the origin of ore-deposits, and for identifying potential mineralized areas. We focused this thesis on 3D and 4D modelling on real case studies with different geological contexts (e.g. uplifting, fault activity and shortening), demonstrating the advantages and drawbacks on their use for similar situations. This thesis is organized into three parts: (i) the application of structural modelling in the mining district of the Copper Belt of Legnica-Głogów (south-west Poland). A surface-restoration approach was applied to estimate favourable conditions for hydraulic fracturing during an inversion, occurred in the northern part of Europe at Late Cretaceous–Early Paleocene. In our hypothesis, hydraulic fracturing developed at that time played an important role in the distribution of copper content observed in present days in the mining district. (ii) The curvature calculated on triangulated surfaces that represent the stratigraphic horizons in the Fore-Sudetic region (Poland), are used to highlight the fault systems in the basement as well as their activity. High curvature values reveal the fault activity which is associated with the copper mineralization process in the region. (iii) Mechanical restoration of the Mount Pleasant, Western Australia, simulates an Archean shortening event which occurred in the area linked to the gold mineralization process. The mechanical restoration was used to estimate the strain field in the region at the time of shortening. This deformation field was used to estimate the damage parameters of the rock mass. They show new potential gold areas located in off-fault gold systems. In conclusion, it is shown that 3D modelling and structural restoration could be used to identify potential favourable zones for the presence of mineralization, and seem promising as a tool for the exploration of ore-deposits and mineral resources.



Jennifer Andreï

Supervisor: François Guérol et de Sandrine Pain

Awarded: 18-12-2015

Thesis title: (Sub)individual and functional effects of nanoparticles on freshwater Crustaceans Gammaridae

Products incorporating nanoparticles are now ubiquitous in our everyday life. For example, sunscreens, fuel additives or food packaging materials contain nanoparticles which could be released in the aquatic environment during the entire life cycle of the nanoproduct, from its production to its use and aging. Therefore an increase of nanoparticle emissions in the aquatic ecosystems needs to be considered and raises the question about their potential effects on living organisms. The collaborative program ANR P2N – MESONNET (2011- 2015) was focused on the evaluation of the nanoparticle fate (transfer and transformation in media and living organisms) and on their ecotoxicity. The present work took part in this assessment by studying the effects of nanoparticles of silver, titanium and carbon (nanotube) on the Crustaceans Amphipod Gammarus sp.. The experimental approach was designed to assess, in laboratory conditions, the effect of nanoparticles on the gammarids, focusing on biomarker measurements at the (sub)individual level (cellular, physiological, behavioral) and on some parameters related to their functional roles. Experiments were designed as close as possible to natural conditions using environmentally realistic contamination scenario: exposure in a complex media (natural water from river) to low nanoparticle concentrations and with food. In this context, the effects of nAg were investigated in three gammarids species and results revealed a higher sensibility of *G. roeseli*, for which exposure induced a decrease of the locomotor activity and of the production of fine particles of organic matter (FPOM). At the physiological level, an increase of the oxygen consumption was observed in gammarids exposed to nAg, despite a stability observed for the studied markers of energetic metabolism. The oxygen consumption was correlated with the silver concentration measured in the organisms, and also with the tested nanoparticle sizes. The influence of the nanoparticle forms (nAg: plate triangular and spherical; nTiO₂: cubic and rod-shaped) and of the organic matter (CNT) was studied in mesocosms by focusing mainly on cellular indicators (energetic storage, antioxidant response, damage...) and individual ones (osmoregulation, ventilation and locomotion). The obtained results suggest form-dependent effects of nanoparticles. This work shows the interest of a coupled approach using ecological and ecotoxicological endpoints to better understand the effects of nanoparticles on freshwater ecosystems

Maxime Faivre -

Supervisor: Fabrice Golfier , Richard Giot.

Awarded: 06-07-2016

Thesis title: Modeling of the hydro-geomechanical behavior of a fault

This work, addresses the issue of groundwater flow in the fractured porous media submitted to local or regional stress-state variations. Due to the increasing pore fluid pressure, the length and aperture distribution of the fractures are modified resulting in the formation of preferential flow channels within the geological formation. The numerical approach proposed is a fully coupled hydro-poro-mechanical model in saturated conditions involving single-phase flow both in fractures and in the porous matrix. The extended finite element method (XFEM) is employed for modelling fracture dynamics and flow calculation for fracture which do not lie on the mesh but cross through the elements. In this study : (i) we consider the pressure build up generated by fluid flow inside and through the fracture,(ii) the fracture dynamics by using a cohesive zone model (CZM) on pre-existing propagation path and (iii) fluid exchanges may occur in between fractures and porous medium. The last specification of the HM-XFEM model is taken into account through the introduction of a Lagrange multiplier field along the fracture path. These fields are the result of the dualised condition of pressure continuity between the pore pressure and the fluid pressure inside the fracture. As a function of the Lagrange multiplier value, both permeable and impervious fractures can be considered. The cohesive law employed is a non-regularized-type cohesive law to ensure propagation and eventually closure of the fracture. Validation of the model has been conducted by means of the well-known KGD fracture model when different propagation regimes are considered. We applied the HM-XFEM model to the case of multi-stage fracture network stimulated by the injection of incompressible fluid at constant rate. Fractures are not connected to each other and evolve on pre-existing propagation paths. We aim at appreciating the influence of the fluid viscosity, the injection rate and spacing between each fracture, on the fracture propagation. A peculiar attention is paid to the stress-shadowing effect (i.e. interaction between fractures).



Matthieu Harlaux

Supervisor: Michel Cuney

Awarded: 01-12-2016

Thesis title: Tungsten and rare-metal (Nb, Ta, Sn) hydrothermal metallogenic systems in the late-variscan orogenic context : example of the French Massif Central

The French Massif Central (FMC), located in the internal part of the European Variscan belt, is the host for a significant economic potential in W (>45 kt WO₃), mainly as disseminated mineralization in specialized granites or associated with peri-granitic quartz-wolframite±cassiterite hydrothermal vein systems. The aim of this thesis is (i) to characterize the fluids and metals sources involved in the genesis of W mineralization and (ii) to date these metallogenic events in the framework of the orogenic evolution of the Variscan belt, especially in link with the late-Carboniferous metamorphic and magmatic events. This work is based on the study of several W±Sn hydrothermal deposits in the FMC using a multidisciplinary approach combining petrography and detailed mineralogy, mineral and isotope geochemistry, whole-rock geochemistry of granites and metamorphic rocks, geochronology and fluid inclusions study. U-Pb dating of wolframite show that the W mineralization formed during several distinct hydrothermal events in a period of at least 40 Ma, corresponding to three major geodynamic episodes affecting the Variscan belt: (i) Viséan-Namurian (333-327 Ma) mineralization coeval with the syn-orogenic compression and the emplacement of peraluminous leucogranitic complexes at 335-325 Ma; (ii) Namurian-Westphalian (315-310 Ma) mineralization associated with a complicated setting characterized by coeval compressive and extensive conditions in the internal zones of the Variscan belt, typical of the late-Carboniferous; (iii) Stephanian-Permian (298-274 Ma) mineralization emplaced in post-collisional context. In situ analysis of minor and trace elements in wolframite showed the existence of different types of regional geochemical signatures, which share several similarities with those from rare-metal-rich evolved granites. The detailed study of the Puy-les-Vignes deposit, an exceptional case of hydrothermal W mineralization associated with a breccia pipe, allowed to demonstrate the superposition of a Nb-Ta stage on the primary W paragenesis, which is interpreted as the contribution of a magmatic fluid derived from a rare-metal granitic cupola. This result appears similar with those already obtained in the Echassières W deposit, where the La Bosse quartz-wolframite stockwork is cut by the Beauvoir rare-metal granite. Similarly, rare-metal aplites and pegmatites overprinting W±Sn mineralization have been shown in the Puy-les-Vignes and St-Mélany deposit. LA-ICPMS analysis of fluid inclusions from the Beauvoir granite and the La Bosse stockwork allowed to characterize the chemical composition of the primary fluids exsolved during the magmatic-hydrothermal transition and to show their very high concentrations (10²-10³ ppm) in rare-metals (Sn, W, Nb), and the higher hydrothermal mobility of Nb compared to Ta. Mineralogical and geochemical analyses of minerals markers of fluid circulations, such as tourmaline and titanium oxides, bring new evidences of the important role played by the early regional metamorphic fluids in the emplacement of W-Sn mineralization. Finally, this thesis gives new methodological developments for the multi-element analysis of fluid inclusions and wolframite by LA-ICPMS.



Rémi Belissont

Supervisor: Michel Cathelineau, Marie-Christine Boiron, Béatrice Luais

Awarded: 15-03-2016

Thesis title: Germanium and related elements in sulphide minerals : crystal chemistry, incorporation and isotope fractionation

Germanium is a critical metalloid in many high-tech industries, especially for the energy transition and the communication sector. Being distinctly siderophile, lithophile, chalcophile and organophile, Ge can be a particularly useful geochemical tracer. This thesis aims at understanding the Ge geochemistry and the factors controlling its concentration in Ge-bearing minerals and ore deposits. Three contrasted Ge-bearing deposits were studied, the Saint-Salvy Zn vein-type deposit, French Massif Central, the Barrigão Cu vein-type deposit, Iberian pyrite belt, Portugal, and the Kipushi Zn-Cu carbonate-hosted deposit, Central African copper-belt, D.R. Congo. The most important Ge-bearing minerals are sphalerite (up to 2580 ppm Ge), chalcopyrite (up to 5750 ppm Ge), and renierite (5.0-9.1 wt.% Ge). The results show a first order relation between the Ge content and the deposition temperature. Synchrotron-based XANES spectroscopy showed that Ge⁴⁺ occur in tetrahedral sites in the studied sulphides. Element correlations suggest that Ge is chiefly incorporated in sphalerite and chalcopyrite through coupled substitutions, e.g., 3Zn²⁺ ↔ Ge⁴⁺ + 2(Cu,Ag)⁺ and 3Fe³⁺ ↔ 2Ge⁴⁺ + Cu⁺, respectively, or via the creation of lattice vacancies, e.g., 2Zn²⁺ ↔ Ge⁴⁺ + ?. The positive δ⁷⁴Ge-Ge content correlation observed in

sphalerite from Saint-Salvy could indicate that Ge partition coefficient (K_{dGe}) increases with temperature. Ge isotopes in sulphides yield $\delta^{74}Ge$ values spanning from -5.72‰ to $+3.67\text{‰}$. The light $\delta^{74}Ge$ compositions of Saint-Salvy and Barrigão ores appear to be related to variations in low to moderate fluid temperatures during Ge uptake in open system (e.g., fluid cooling), while the trend towards heavy $\delta^{74}Ge$ compositions observed at Kipushi likely translates a Rayleigh fractionation effect during ore formation in closed system, associated with significant fluid modification.



François Turlin

Supervisor: Anne-Sylvie André-Mayer, Olivier Vanderhaeghe

Awarded: 15-12-2017

Thesis title: Light rare-earth elements enriched pegmatitic granite as tracers of crustal growth and differentiation processes: example of the Proterozoic Grenville Province, Quebec

The Rare Earth Elements (REE) are of great economic interest and first order geological tracers. However, their metallogenic cycle remains poorly defined. The Grenville Province exposes its orogenic root and shows numerous REE occurrences that are especially associated with pegmatitic granite dykes (“PGD”) in the central Grenville. Two hypotheses can account for the genesis of these PGD, whether (i) the partial melting of the orogenic root composed of reworked Archean and/or Proterozoic pre-existing continental crust, or (ii) the extreme differentiation of mantle melts produced during post-orogenic extension. A multi-method approach (field geology, petrogeochemistry, geochronology and isotopy) allow to characterize the PGD and discuss their petrogenesis during the geodynamic evolution of the province. They intruded at ca. 1005-1000 Ma (U-Pb on monazite and zircon) metaplutons (mineralization hosted in allanite) or metasedimentary sequences (mineralization hosted in monazite) from the mid-pressure allochthonous crustal segment. U-Pb dating on monazite and apatite from a single leucosome of these migmatitic paragneisses evidence for a peak of metamorphism at ca. 1080-1050 Ma that was followed by a slow cooling at a rate of 2 to 6°C/Ma, first under suprasolidus conditions until the close to wet-solidus intrusion of PGD, and then under subsolidus conditions down to the 450-500°C isotherm dated at ca. 970-950 Ma. The intrusion of the PGD is coeval with the initiation as early as ca. 1005 Ma of the protracted (> 20 Ma) partial melting of underlying parautochthonous paragneisses. The peraluminous character of the PGD, the investigation of pristine magmatic zircon of the PGD (U-Pb-Hf-O isotopes and trace elements), and the petrogeochemical investigations of parautochthonous Paleoproterozoic-Archean metapelites that derive from the Laurentian margin’s erosion, points to the derivation of the PGD from their partial melting. To the contrary, one PGD derived from the reworking of allochthonous plutonic units is poorly mineralized in REE, and confirms that REE from the central Grenville occurrences are issued from crustal rocks of the Superior Craton



Gaëlle Mollex

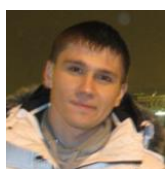
Supervisor: Bernard Marty, Lydéric France

Awarded: 12-07-2017

Thesis title: Architecture of the plumbing of the Oldoinyo Lengai carbonatitic volcano : New constraints on the source, hydrothermal transfer, and magmatic differentiation in the active chamber

The uniqueness of Oldoinyo Lengai to emit natrocarbonatite lavas makes this volcano a natural laboratory to study the genesis of these magmas. New helium isotopic data permit to assert that the signature of the fumaroles has been constant since 1988 despite the radical morphological change of the summit crater after the last sub-Plinian eruption in 2007-2008. The alternation of the effusive and explosive eruptions does not cause major modifications in the hydrothermal system architecture, which is inferred to be deeply rooted. Cognate xenoliths that were emitted during the eruption in 2007-2008 represent a unique opportunity to document the igneous processes occurring within the active magma chamber. The comparison between the noble gas (helium) isotopic compositions of the active magma chamber and those of the other silicate volcanoes of the Arusha region indicates that both types of magmatism have similar sources, identified as being a typical sub-continental lithospheric mantle, which was previously metasomatized by asthenospheric fluids. Moreover, these isotopic signatures confirm that no crustal contamination has occurred during the magma ascent from the mantle to the surface. Detailed petrographic descriptions coupled to a thermo-barometric approach, and to the determination of volatile solubility models for a phonolite composition, allow us to identify the melt evolution at magma chamber conditions and the storage parameters. These results indicate that the magma injected in 2007 has a phonolitic

composition and contains a high amount of volatiles (3.2 wt.% H₂O and 1.4 wt.% CO₂) as well as a temperature around 1060° C. This magma subsequently evolved in the crustal magma chamber located at 11.5 ± 3.5 km depth until reaching a nephelinite composition and a temperature of 880°C. During the differentiation in the magma chamber, the silicate magma is enriched in calcium, sodium, magnesium and iron, whereas the content of silicate, potassium and aluminium decreases. Our results support previous studies related to this eruption, and are similar to the historical products emitted during the whole volcano history, permitting the suggestion that no major modification in the plumbing system has occurred during the Oldoinyo Lengai evolution. The trace elements (REE, LILE and HFSE) measured in the minerals and melt inclusions reveal a concentration reaching 100 to 1000 times the primitive mantle composition. A preliminary experimental study based on the recharge melt composition (phonolite) and identified magma chamber conditions (P, T) permits to reproduce the immiscibility between silicate and carbonatite liquids, key processes at the origin of the Oldoinyo Lengai carbonatites. The continuation of this experimental study will lead to a better comprehension of the carbonatite genesis, thus improving our understanding of the processes that are responsible for the enrichment in trace elements



Andrey Myagkiy

Supervisor: F. Golfier-L. Truche

Awarded: 08/12/2017

Thesis title: Mineralization of Nickel in saprolitic ore of New Caledonia: Dynamics of metal transfer and modeling of coupled geochemical and hydrodynamic processes

New Caledonia hosts significant lateritic nickel reserves, and presently became the fifth largest Ni producer in the world. These deposits are generally thought to be closely associated with the intense chemical and mechanical weathering of peridotite bedrock that is a principal source of nickel. Thus, the main ore genesis model for Ni ores in New Caledonia is based on a single per descensum model where most elements (Mg, Ni, and Si) are leached from the surface, particularly, during lateritic soil development. Nickel is then concentrated either in the fine-grained laterite where goethite is the main Ni bearer, the so-called 'lateritic ore', or below the laterites, in the saprolite level, where nickel occurs as goethite and several types of Mg-Ni silicates, in particular kerolite. Recent mineralogical and structural observations together with mining data have revealed a lot of different types of heterogeneities associated with the distribution and mineralogy of Ni bearing minerals. Therefore, in depth investigations of Ni mobility, its retardation processes along with its governing chemical and hydrodynamic parameters are of big importance for understanding and subsequent prediction of Ni distribution in profiles of New Caledonia. The concept is based on the development of i) a powerful 1D model with particular emphasis on Ni geochemical behaviour during ophiolite weathering, its comparison with in situ observations, and detailed understanding of trace elements mobility, and ii) 2D hydro-geochemical model coupled with complex hydrodynamics, that would additionally provide new insight into the structural control on Ni redistribution and mineralization. While the 1D simulations provide a remarkable result for understanding the chemical features that drive Ni retention processes in a profile, 2D model appears to be a powerful tool for understanding how local Ni-enrichments may form. The results of this model show the reactivation of Ni from upper horizons and its concentration in neo-formed silicates in bottom of the saprolite. The reactivated Ni comes mostly from the saprolite horizon due to the redissolution of previously formed Ni-bearing silicates and still persisting in this olivine zone. Modelling has revealed minor contribution of the laterite horizon (Ni-oxi-hydroxides) into the Ni remobilization. The lateral infiltration of water with remobilized Ni from areas such as topographic highs to downstream slope areas leads to the formation of richest deposits in this lower part of profile. The manner of redistribution is fully governed by the topographic slopes, orientation and position of the fractures. Presented models appear to be of importance in attempt of explanation of Ni mineralization processes, revealing the main keys to understanding the control of trace elements mobility in ultramafic environment. The latter gives new insights into the Ni distribution in present day profiles and, therefore, may greatly help in mineral prospecting and forecasting the distribution of future resources



Emilie Perrat

Supervisor: Carole Cossu-Leguille, Marc Parant, Christophe Rosin

Awarded: 12-12-2017

Thesis title: Environmental impacts of Gadolinium-based contrast agents : local situation, cellular and in vivo approaches

The increasing use of Gadolinium-based Contrast Agents (Gd-CA) for Magnetic Resonance Imaging (MRI) results in their rejection in Waste Water Treatment Plants (WWTPs). Due to the lack of specific recycling process in European WWTPs, these pharmaceutical produces enter the aquatic environment from river to tap water. The effects of Gd-CA in aquatic media have been not studied yet. The lack of knowledge about these effects highlighted the need to study their environmental impacts on aquatic organisms. In this context, we decided to measure anthropogenic concentrations of Gd in the aquatic environment in the Lorraine region (France) closed to WWTPs outputs and catchment areas used for drinking water. Our measurements underlined the presence of anthropogenic Gd on all the collected samples at concentrations ranging from few ng/L to several dozen of µg/L. In this research we focused on the effects of the most frequently used Gd-CA, the gadoteric acid (Gd-DOTA - Dotarem®) which is also the most stable one. Several representative species of aquatic environment were selected for ecotoxicological assays: i.e. unicellular green microalgae (*Chlorella vulgaris* and *Pseudokirchneriella subcapitata*), microcrustacean (*Daphnia magna*) and aquatic vertebrate (*Danio rerio*). Assays were conducted in laboratory under controlled conditions as well as in situ. Gd-DOTA accumulation was measured in the tissues of the different organisms. Environmental realistic concentrations of Gd-CA were used to assess their effects at the individual level by means of growth, reproduction and mortality measurements. The Gd-DOTA accumulation was also measured in bivalves' tissues (*Corbicula fluminea* and *Dresseina rostriformis bugensis*) and compared to Gd ones in situ in these organisms. Physiological responses were assessed based on a battery of 11 complementary biomarkers measured in the digestive gland and in the gills of both bivalve species. At cellular level, the effects of Gd-DOTA were studied in vitro on *D. rerio* fibroblasts (ZF4 – ATCC-2050). Indirect ecotoxicological effects of Gd-CA and of Gd-DOTA especially have been highlighted at all biological levels. Accumulation of Gd-DOTA was observed in bivalves only, but defense systems were mobilized in all organisms to limit toxicity. Our results demonstrated that following both research on ecotoxicological effects of the Gd-CA and evolution of their concentrations in aquatic ecosystem are necessary to assess more precisely their environmental risk and to propose solutions for their environmental management.



Séverine Lopez

Supervisor: Emile Benizri, JL Morel

Awarded: 26-11-2018

Thesis title: Determinism of rhizosphere bacterial diversity for Ni hyperaccumulators

Knowledge of the microbial diversity in ultramafic areas is essential to establish the ecological functioning of these environments, which display high level of Ni and are characterized by the presence of particular plants, e.g. Ni hyperaccumulators. The rhizosphere of these plants promotes a high proportion of Ni resistant bacteria that can act on plant nutrition and soil physicochemical properties. The first challenge of this thesis was to understand the bacterial rhizosphere diversity of Ni hyperaccumulators. The second was to test the interest of PGPR (Plant Growth Promoting Rhizobacteria) strains in order to improve agromining based on rhizobacteria and Ni hyperaccumulators interactions. The approach was based on two-contrasted climatic areas prospection and on high-throughput sequencing analyzes. Tests on culture of hyperaccumulator plants inoculated were also conducted. The results show that the determinism of this bacterial diversity is variable according to the spatial scale. On a global scale, the vegetation type, indirectly influenced by the climate, is the major factor structuring bacterial communities. The direct influence of the climate (temperature and humidity) on bacterial diversity is significant but lower. At the scale of a climatic region, the physico-chemistry of ultramafic soils structures and determines the rhizosphere bacterial community diversity. Finally, the inoculation of highly Ni bioaccumulative PGPR strains modifies the Ni dynamic in the soil, demonstrating that there is a competition for this metal between the inoculated bacteria and the hyperaccumulator plant. In conclusion, the rhizosphere bacterial community diversity is dependent on the considered spatial scale. Furthermore, these results emphasize how the choice of the PGPR strain to inoculate is important in order to improve Ni agromining.

Year	Name	Country	Host University	University prior to PhD	Supervisors	Laboratory	Title of the project	Nowadays occupations after RESSOURCES21
2012-2015	Rémi BELISSONT	France	University of Lorraine	UL (ENSG)	Dr M. Cathelineau, Dr MC Boiron & Dr B Luais	GeoRessources	Germanium and related elements in sulphide minerals: crystal chemistry, incorporation and isotope fractionation	Research and development engineer ARCELORMITTAL Lorraine FRANCE
2012-2016	Maxime FAIVRE	France	University of Lorraine	UL (ENSG)	Dr F Golfier & Dr R Giot	GeoRessources	Hydro-geomechanical modeling of fault networks impacted by stress-state changes	Postdoc at the University of Minnesota Twin cities USA
2012-2015	Jennifer ANDREI	France	University of Lorraine	BORDEAUX University	Dr S Pain Devin & Pr Fs Guerold	LIEC	(Sub)individual and functional effects of nanoparticles on freshwater Crustaceans Gammaridae	Teacher in private school préparating for medicine studies Bordeaux FRANCE
2013-2016	Matthieu HARLAUX	France	University of Lorraine	UL (ENSG)	Dr M Cuney & Pr C Marignac	GeoRessources	Late orogenic tungsten mineralization and associated rare metals in the West European Variscan belt: example of the French Massif Central deposits	2 years Postdoc fellow at the Geneve University - SWITZERLAND
2013-2017	Gaëlle MOLLEX	France	University of Lorraine	Université Blaise Pascal Clermont-Ferrand	Dr L. France, Pr B. Marty	CRPG	Genesis, evolution and alteration of carbonatite magmas	Preparing French national university concourses
2013-2014	Damien PARRELLO	France	University of Lorraine	Institut des BIOTECH PARIS	Dr C. Mustin	LIEC	Using genetically modified bacteria, identification of biotic and abiotic parameters controlling Ni mobility	Postdoc at the University of Dakota USA
2013-2017	Emilie PERRAT	France	University of Lorraine	ANGERS University	Dr M. Parant, Dr Cossu-Leguille, C. Rosin	LIEC	Environmental impacts of Gadolinium-based contrast agents: local situation, cellular and in vivo approaches	Looking for a position
2011-2014	Pablo MEJIA-HERRERA	Colombia	University of Lorraine	UL (ENSG) and formation in Mexico	Dr JJ Royer	GeoRessources	Ore-deposits modeling and improving their understanding with structural restoration	Senior Consultant at MIRA Geoscience in Vancouver, British Columbia, CANADA
2014-2017	François TURLIN	France	University of Lorraine	UL	Pr A-S André-Mayer, Pr O. Vanderhaeghe	GeoRessources	Light rare-earth elements enriched pegmatitic granite as tracers of crustal growth and differentiation processes: example of the Porterosic Grenville Province, Quebec	Université du Québec à Montréal (UQAM), CANADA
2014-2017	Andrei MYAGKYI	Russia	University of Lorraine	UL (ENSG) and formation in Russia	Dr F. Golfier, L. Truche	GeoRessources	Mineralization of Nickel in saprolitic ore of New Caledonia: Dynamics of metal transfer and modeling of coupled geochemical and hydrodynamic processes	Postdoc at the University of GRENOBLE, FRANCE
2015-2018	Séverine LOPEZ	France	University of Lorraine		Pr E. Benziri, Pr JL Morel	LSE	Determinism of rhizosphere bacterial diversity for Ni hyperaccumulators	-



Current RESSOURCES21 PhD students

Year	Name	Country	Host University	University of origin	Supervisors	Laboratory	Title of the project
2018-2021	Bastien JAILLY	France	UL	UL (ENSG)	Pr Marie-Odile, SIMONNOT & Dr Batiste LAUBIE	LRGP	Rare earth Agromine
2017-2020	Romane TISSERAND	France	UL	UL (ENSG)	Pr Guillaume Echevarria, Dr Antony VAN DER ENT & Pr Peter ERSKINE	LSE	The Ni biogeochemical cycle in a tropical agromine metal crop system
2017-2020	Ottone SCAMMACCA	France	UL	AgroParisTech	Dr Yann GUNZBURGER & Dr RASTOOL MEHDIZADEH	GeoResources	Project risks in mining operations. Evaluation and commensuration of technical and societal risks, with application to open pit mines during the development and exploitation phases, especially under tropical climate
2017-2020	Hu RUOYU	China	UL	University of Bordeaux	Dr Corinne LEYVAL	LIEC	Mobility and transfer of rare earth elements from soil to plants by arbuscular mycorrhizal fungi" supervisors
2016-2019	Chang LIU	China	UL	Sun Yat-Sen University, Canton, Chine	Pr Jean-Louis MOREL & Pr Geoffroy SERE	LSE	REE hyperaccumulators (Dicranopteris dichotoma): their behavior and potential for soil revegetation and REE recovery
2016-2019	Meina GUO	China	UL	Sun Yat-Sen University, Canton, Chine	Pr Jean-Louis MOREL & Pr Geoffroy SERE	LSE	Pedogenetic processes controlling crust formation on mine soils : role on water flow and pollutant infiltration
2016-2019	Yann FOUCAUD	France	UL	UL (ENSG)	Pr Lev FILIPPOV	GeoResources	Synergistic effects of reagents with different molecular structures in the flotation of W-ores with low separation contrast
2016-2019	Eleonora CAROCCI	Italy	UL	Perugia University, Italy	Pr Laurent TRUCHE, Dr Michel CATHÉLINEAU and Pr Christian Marignac	GeoResources	Transport and deposition of W (Sn, Nb (Ta) ores from in magmatic-metamorphic fluids around plutons
2016-2019	Nina BOTHAMY	France	UL	Claude Bernard University, Lyon 1	Pr Albert GALY	CRPG	New biogeochemical tracers: REE stable isotopes (NTB-REE)
2016-2019	Nicolas GROSJEAN	France	UL	UL (ENSG)	Dr Damien BLAUDEZ	GeoResources	Study of gene response to REE in model organisms

Current occupation of former RESSOURCES21 Postdoctoral fellows

Year	Name	Origin	Supervisors	Laboratory	Title of the project	Nowadays occupations after RESSOURCES21
2012-2013	Asfaw ZEGEYE	Ethiopia	Dr Christian Mustin	LIEC	Bio-Reduction of Metal-substituted Iron Oxides: A Mechanism for Metal Remobilization	CNRS Researcher at LIEC, Lorraine, FRANCE
2012-2013	Marc ULRICH	France	Dr Michel Cathelineau	GeoResources	Geochemistry and Mineralogy of Scandium in Laterites	Lecturer at Strasbourg University, FRANCE
2012-2013	Nicolas ESTRADE	France	Dr Christophe Cloquet & Dr Thibault Sterckeman	CRPG	Optimizing nickel phytomining: use of isotope fractionation to better understand soil to hyperaccumulating plant transfers	Postdoc University of British Columbia, CANADA
2012-2014	Véronica GONZALES ANDRES	Spain	Pr Laure Giamberini & Dr Corinne Leyval	LIEC	Transfer and dissemination of REE in the ecosphere : mechanisms, ecotoxicological impact and et remediation strategies	Researcher at LEITAT Technological Center, Barcelona, SPAIN
2013-2014	Jennifer MABRY	USA	Dr Christian France Lanord & Pr Bernard Marty	CRPG	Noble gas analysis	Senior Lab. Tech. International Atomic Energy Agency Vienne, AUSTRIA
2014-2015	Antony Van Der ENT	Australia	Pr Jean Louis Morel & Pr Guillaume Echevarria	LSE	Agromining of Ni in tropical Ni mine environments	ARC Postdoc Research Fellow at The University of Queensland Brisbane, AUSTRALIA
2015	Ritech MISHRA	India	Dr Marc Chaussidon	CRPG	Developing high precision, isotope measurement with ion probe IMS 1270 et ims 1280HR2	NASA Johnson space centre, Houston, USA
2015	Afifé EL KORH	Switzerland	Dr Etienne Deloule, Dr Marie-Christine Boiron, Dr Béatrice Luais	CRPG	Mobility of metallic trace elements in the Limousin ophiolite massifs : implication for fluid-rock interactions signatures and concentration processes	Lecturer at Fribourg University, SWITZERLAND
2014-2017	Thomas BOULESTEIX	France	Dr Christian France-Lanord, Dr Michel Cathelineau & Mr Pacal Robert	CRPG/ GeoResources	A K-Ar laboratory for dating clays	Postdoc-UNAM MEXICO
2016-2017	Laetitia. MINGUEZ	France	Pr Laure Giamberini & Pr François Guérolde	LIEC	An integrated approach to the ecotoxicity assessment of nickel and other metals in aquatic organisms: A case study at Lake Ohrid (Albania)	CNRS Researcher at LIEC, Lorraine, FRANCE
2016-2017	Rémi BELISSONT	France	Dr Marie-Christine & Dr Béatrice Luais	GeoResources	Experimental study of Ge isotopic fractionation in sphalerite	Research and development engineer ARCELORMITTAL Lorraine, FRANCE
2016-2017	Ana ROMEIRO FREIRE	Spain	Dr Davide VIGNATI	LIEC	Predicting and understanding Rare Earth Element (REE) effects at the sediment-water interface	Postdoc at IIM, Madrid, SPAIN
2017-2018	Charlotte BERTHELOT	France	Dr Patrick BILLARD	LIEC	Use of Bacterial biosensor to access the bioavailability of Rare earth elements in environmental samples	Engineer at CTIFL Paris, FRANCE
2015-2018	Gauthier LAURENT	France	Dr Guillaume CAUMON	GeoResources	Modelling reactive transport as well as mass and heat transfer in the case of complex structural contexts	Lecturer at University of Orleans, FRANCE

Current RESSOURCES21 Postdoctoral fellows					
Year	Name	Origin	Supervisors	Laboratory	Title of the project
2016-2019	Dr Yoram TEITER,	France	Dr Michel CATHÉLINEAU	GeoResources	<ul style="list-style-type: none"> • Scandium in New Caledonian laterites (CNRT project). • Conception of a Database on New Caledonia
2018-2019	Dr Ruben ROSENKRAN	Germany	Dr Raphaël PIK	CRPG	Thermochronology and erosion history :a methodological approach
2018-2019	Dr Sushenta KUMAR	Iran	Pr Alexandre CHAGNES	GeoResources	HydroVAL platform: valuation of metals contained in polymetallic residues
2018-2019	Dr Alba OTERO-FARINA, Dr Kahina MEHNNAOUI	Spain	Pr Laure GIAMBERINI, DR Bert-Jan GROENENBERG, & Dr Davide VIGNATI,	LIEC	Ecotree: REE Speciation in ecosystems
2018-2019	Dr Cécile BAUDOIN	France	Dr Lydéric FRANCE	CRPG	Genesis and evolution of the main rare earth deposits: carbonatites



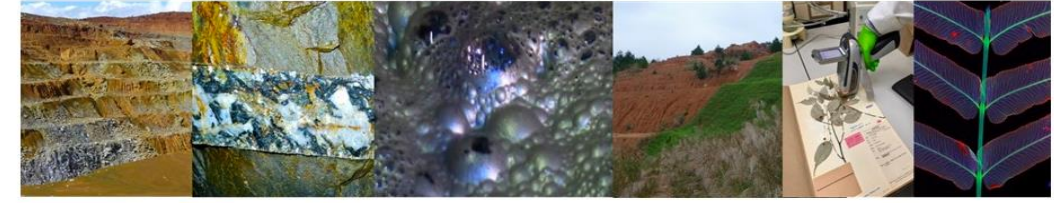
Y. Teitler sampling laterites in New Caledonia



Thematic school and workshops

CNRS Thematic School

Geochemical Cycle of Metals



Lecture in lecture theatre 8 at the Faculty of Science

The CNRS school devoted to mineral resources and the geochemical cycle of metals took place in Nancy from 2 to 4 of October 2018. It gathered 135 people, researchers and PhD students from various French universities as well as geologists from the industry. The lectures given by renown researchers concentrated on geological characterisation of ore deposits of strategic metals, innovative and eco-responsible development and recycling, agromining, metal behaviour in nature and their ecotoxicological consequences and the societal acceptability of mining.



Visit of the LA-ICP-MS laboratory at GeoRessources

Two round-table discussions were dedicated to: i) the evolution of careers related to metallic resources over the next 20 years and ii) experiences related to the exploitation of mines and their acceptance by the populations from within the industry. Laboratory visits were organised on the third day.

Geology and Ni-ore genesis in New Caledonia

A seminar for mine geologists from all mining companies working in New Caledonia



SEMINAIRE GEOLOGIE-METALLOGENIE DU NI EN NOUVELLE-CALEDONIE



SEMINAIRE 28 & 29 mai 2018
Liste des interventions

N°	INTERVENANTS	EXPOSE
1	France BAILLY	Présentation CNRT et Objectifs du séminaire
1 bis	Michel CATHELINEAU	
2	Mohamed KADAR	Principaux challenges pour la mine d'aujourd'hui en NC
3	Pierre MAURIZOT	Histoire précoce de l'ophiolite, géologie et pétrographie des roches ultrabasiques: implications sur les gisements ?
4	Michel CATHELINEAU	Processus de latéritisation, introduction aux latérites nickélicifères
5	Pierre MAURIZOT	Minerais silicatés et oxidés en NC : modèle(s) génétique(s) à grande échelle
6	Brice SEVIN	Codifications minières : comment adopter une nomenclature identique d'un site à l'autre
7	Michel CATHELINEAU	Chronologie des minéralisations silicatées sur discontinuités : un pré-enrichissement nécessaire ?
8	Michel CATHELINEAU	Formation de la saprolite : données géochimiques et modélisation thermodynamique
9	Brice SEVIN	Contrôle par les phénomènes gravitaires des gisements de Ni ; modèle structural pièges primaires et secondaires
10	Michel CATHELINEAU	Modélisation 3D des anomalies de teneurs et couplage 2D-transport réactif
11	Farid JUILLOT	Rôle de la maturation sur la cristallinité des goethites et implications sur les teneurs en Ni dans les horizons latéritiques
12	Farid JUILLOT	Évolution des teneurs et de la spéciation du Mn et Co dans les profils d'altération
13	Yoram TEITLER	Synthèse sur la distribution et le comportement du Sc, relation avec Ni et Co. Potentiel et outils d'exploration



SEMINAIRE
GEOLOGIE-METALLOGENIE DU NICKEL
EN NOUVELLE-CALÉDONIE

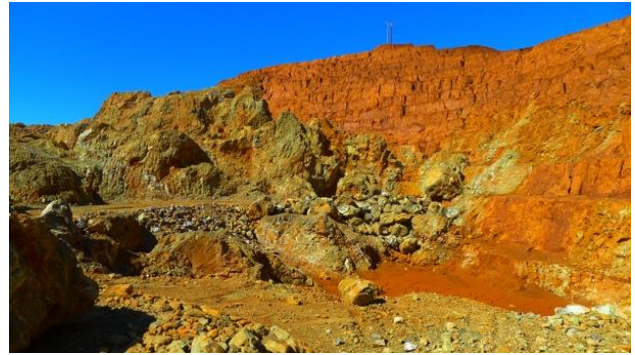
CNRT
NICKEL
& SON ENVIRONNEMENT

Du 28 au 30 mai 2018 à 10h-15h30 | Site Poro / CFTMC



2 jours de séminaire théorique

1 jour de séminaire terrain



The seminar on Nickel ore genesis in New Caledonia provided the first occasion to gather geologists from all New Caledonia mining companies together and was a unique moment of discussion on genetic models of Ni-Co-Sc enrichment processes. Specifically, field works were an occasion to share identification keys of representative minerals from the serpentine and talc-like groups and their time and genetic relationships with Ni ore formation.





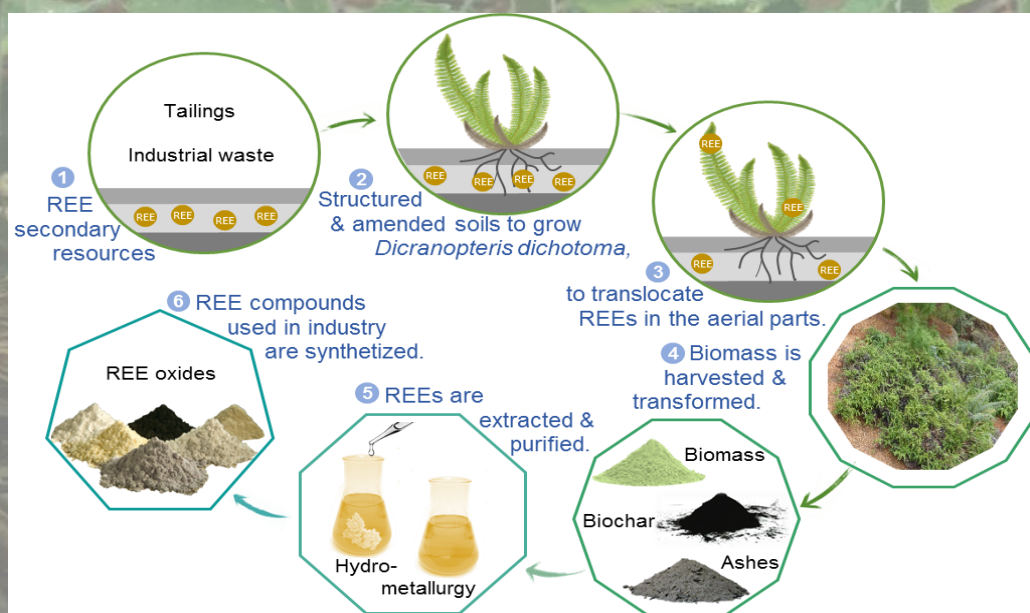


International collaborations

**International cooperation on mine sites and agromining
The International Laboratory - LIA ECOLAND –
between the Université de Lorraine, INRA and Sun Yat-sen
University (China)**



The **LIA ECOLAND** ("Ecosystem Services Provided by Contaminated Soils") created in 2015 by the LSE (UL-INRA) and the LEPCRT (SYSU) studies the dynamics of pollutants in soils and the potential of large contaminated areas to generate a wide range of ecosystem services. The strategies are: i) the production of healthy food on contaminated soils based on genetic resources and the modification of soil properties; ii) the production of biomass for industrial or food use on degraded and contaminated soils (e.g. mining sites); and iii) the recycling by agromining of metals present in contaminated soils.



Training

The cooperation is based on intensive exchanges of masters, doctorates, post-docs and scientists. Currently, three co-supervised PhD theses are in preparation, two Chinese students (LSE-LEPCRT) and one French student (LRGP-LEPCRT) receiving technical and scientific support from LabEx R21. A Chinese teacher is a professor at the Université de Lorraine (Professor@Lorraine position) and a French professor is associate professor at SYSU. Since the creation of the LIA (December 2015), scientific production has already achieved 16 publications (e.g. ES&T, Plant&Soil).



International workshops

are organised in France and in China alternately. In 2018, the general topic was "The circular economy by recycling of secondary resources". A delegation of 25 French scientists (UL, INRA and CNRS) took part in it. The LIA is a bridge for other scientific groups (e.g. LRGP, LIEC) to initiate new collaborations and expand the cooperation scope between the two institutions.



Collaborations between the Université de Lorraine and the University of Queensland (Australia)



From 2011 to 2018, collaborative research in **agromining**, including common fieldwork, PhDs (2 of which started in 2015, 1 in 2017 and 3 in 2018), synchrotron experiments in Australia and Europe and various conferences were achieved by the research group including Guillaume Echevarria (LSE, UL), Jean-Louis Morel (LSE, UL), Marie-Odile Simonnot (LRGP, UL), Emmanuelle Montargès-Pelletier (LIEC, UL), Antony van der Ent and Peter Erskine (CMLR, SMI, UQ) and James Vaughan (School of Chemical Engineering, UQ). The role of LabEx RESSOURCES21 in supporting their joint research has always been recognised as constant and very effective.



During Guillaume Echevarria's residency visit in the SMI (from 18 June to 18 August 2018), common fieldwork with SMI team was carried out in Northern Queensland and New Caledonia.

The International Laboratory “SUCRE” “Sourcing Unconventional Critical Resource Elements” is under construction between the Université de Lorraine and the University of Queensland (Australia)



The laboratory has been initiated in 2017 within the frame of the already on-going and successful collaboration between the Université de Lorraine’s LSE (*Laboratoire Sols et Environnement*) and LRGP (*Laboratoire Réactions et Génie des Procédés*), and the University of Queensland’s CMLR (Centre for Mined Land Rehabilitation) laboratories.

Signature of the initiation of the International Laboratory
at the SMI, University of Queensland, Brisbane, 6 June 2018

Now, in 2019 and 2020, the collaboration is extending to 2 other research fields:

- **hydrometallurgy**, with a co-supervised PhD starting in 2019 between the School of Chemical Engineering at the University of Queensland and the hydrometallurgy group of GeoRessources lab at the University of Lorraine, under the supervision of James Vaughan from the University of Queensland and Alexandre Chagnes from the Université de Lorraine;
- and the initiation of projects in **social responsibility concerning mining** between the CSRM, SMI, University of Queensland and Yann Gunzburger’s group from GeoRessources Lab at the Université de Lorraine, on mining and communities.



In August 2018, Julien Merlin and Agnès Samper from LabEx R21 joined a workshop and training programme organised for a delegation of the Nigerien government on post-mining planning, communities and environmental issues, at the CSRM Centre for Social Responsibility in Mining, SMI, University of Queensland.

REE project on the Grenville province (Québec)

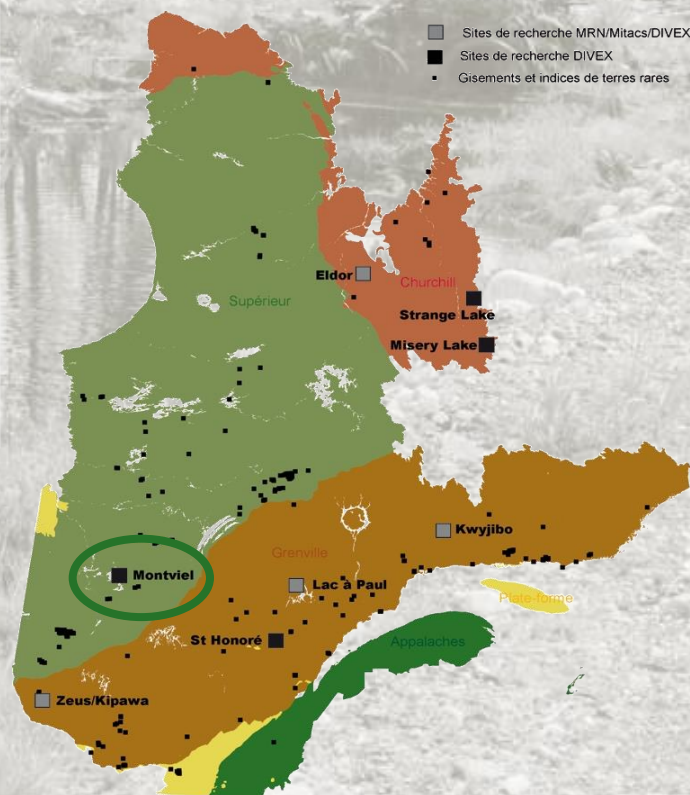
A joint LabEx project including RESSOURCES21 researchers (A-S André and L. Giamberini) within the framework of a consortium agreement **DIVEX Québec - IRME (UQAT Polytechnique) - Ministère des Ressources Naturelles du Québec**




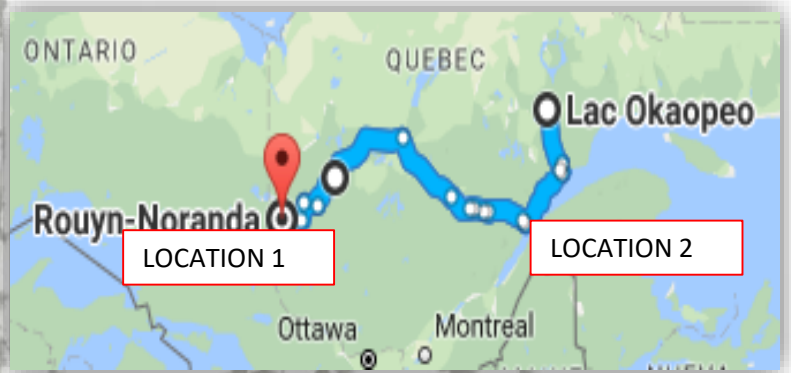
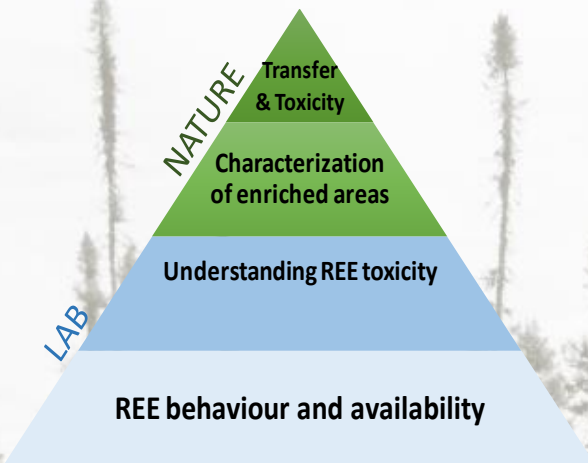
From exploration...

DIVEX is a research group made up of university and government researchers from seven Québec universities (INRS-ETE, Laval, Polytechnique, McGill, UQAC, UQAM, and UQAT). Created in 2002, the DIVEX Innovation Network is entirely financed by the Québec Research Fund - Nature and Technologies (FRQ-NT). In mid-2014, the network launched a research programme on REE occurrences in Québec (<http://divex.ca/>).

The RESSOURCES21 LabEx is an official scientific partner of this programme: a co-supervised PhD project on REE occurrences in the Grenville Paleoproterozoic province began in September 2015 and was defended in December 2018 (F. TURLIN). This collaboration has recently been extended to the environment spectra through discussions and interactions with the MEDDLCC (Ministère du Développement durable et de la Lutte contre le changement climatique) currently involved in designing a research programme on the environmental consequences of REE, from exploration and mining.



 **éoMégA** **Montviel site, a natural case study REE - rich in Neoarctic conditions**



The release of REEs from enriched rock materials and the evaluation of their toxicity for the aquatic ecosystem was studied on two sites

Location 1: Montviel, an area enriched in LREE-Nb,
Location 2: REE-rich pegmatitic granites, Lac Okaopéo region (François Turlin's thesis).

... to environmental pre-mining study



Institut de Recherche en Mines et Environnement (IRME)

The Institute for Research on Mines and the Environment (IRME) was created in 2013 by the Université du Québec en Abitibi-Témiscamingue (UQAT) and the Polytechnique Montréal. As an equivalent of a LabEx structure in France, which is unique in Québec, this joint research programme was created in association with several industrial mining partners. Focusing on the environment and management of mining wastes, the IRME aims to develop environmental solutions for the entire life cycle of mines.



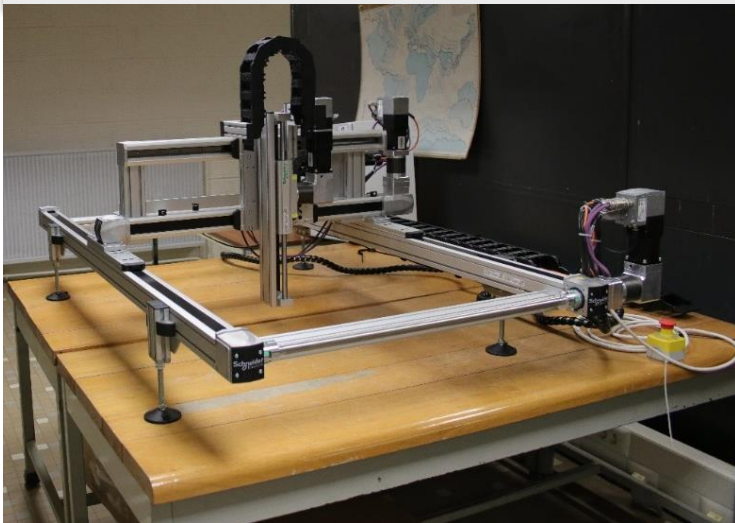
Following the reception of the IRME director (Bruno Bussière) in November 2013 and scientific discussions held in the Québec Mine (November 2013 and 2014) and PDAC meetings (March 2013 and 2014), an international convention between the UQAT and the Université de Lorraine was signed in December 2014. This agreement covers both research and teaching aspects in the geosciences domain, with an emphasis put on subjects related to the mining cycle. Mukendi Kongolo, who is currently participating in a long term exchange at the UQAT, and Laure Giamberini, who was invited to give a presentation on ecotoxicology issues at Québec Mine 2014, both benefited from this rising partnership.

Training the current and next generations of geologists

How to face the increasing demand of in situ portable devices in mining exploration?

Eurocore training

Get new skills on spectro-scopical field devices and data management!



An ongoing challenge...

The use of portable field devices in mining exploration is challenging as it increases the accuracy of ore targeting while reducing:

- *analytical costs.*
- *bias on drilling decision* due to a lack of geochemical information.
- *the duration required for exploration.*

Their handling requires specific skills geologists should be taught.

...addressed by formation

The EuroCore training aims at improving the use of innovative *in situ* tools for mining exploration:

- *acquisition of large in situ geochemical datasets on core samples and database management.*
- *development of educational online training on innovative core logging.*
- *training of geologists on the field.*



Fraunhofer



POLITÉCNICA
"Engineering the future"

**TAL
TECH**

<http://eurocore.eitrawmaterials.univ-lorraine.fr>

<https://eurocore.rocks/#/>



This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation



RawMaterials
ACADEMY



TRAVELEX, A tale of humans and metals

Minerals have got talent: from underground to home!



TravelEx is a European project funded by the EIT RAW MATERIALS, the European Institute of Innovation and Technology on raw materials.

Designed as a travelling exhibition, TravelEx provides easily accessible general information to society at large, especially to children aged 8-12 and 14-17, on metallic raw materials and their importance in human societies.

The 200-m² large exhibition will be available for rent in European museums all throughout the project, i.e. for a period of about 4 to 6 month per country, for an overall time length of 5 years.



The exhibition combines interactive participatory activities, with multimedia technology and hand-on approaches.

The exhibition has been designed on three main themes representing the three main ages of the Earth with regards to the evolution of human civilisations and their relationships to metals.

An European team made up of scientists in geosciences, curators, architects and designers from the Czech Republic, Estonia, Finland, France and Portugal has been working together to create this exciting exhibition since February 2018. They meet in different European locations regularly to gather information and get inspiration from the science museums and mines they get to visit.





Publications 2018

In blue: publication corresponding to a programme funded by Labex, in part at least, and with reference to the Labex ANR RESSOURCES21 funding in the acknowledgements section.

In green: work within the field of Labex, some of which benefited from the Otelos platforms (some of the platforms were co-funded by Labex RESSOURCES21).

In black: within the general theme of Labex RESSOURCES21 but with other funding.

Geological processes and ore deposits, exploration, exploitation



- Baudouin, C., Parat, F., & Michel, T. (2018). CO₂-rich phonolitic melt and carbonatite immiscibility in early stage of rifting: Melt inclusions from Hanang volcano (Tanzania). *Journal of Volcanology and Geothermal Research*, 358, 261–272.
- Bonnetti C., Liu X., Mercadier J., Cuney M., Deloule E., Villeneuve J., Liu W. (2018) The genesis of granite-related hydrothermal uranium deposits in the Xiazhuang and Zhuguang ore fields, North Guangdong Province, SE China: Insights from mineralogical, trace elements and U-Pb isotopes signatures of the U mineralisation, *Ore Geology Reviews*, 92, 588–612, <https://doi.org/10.1016/j.oregeorev.2017.12.010>
- Burg, J. P., & Bouilhol, P. (2018). Timeline of the South-Tibet–Himalayan belt: the geochronological record of subduction, collision, and underthrusting from zircon and monazite U-Pb ages. *Canadian Journal of Earth Sciences*. DOI: 10.1139/cjes-2018-0174
- Camprubí A., González-Partida E., Richard A., Boiron M.-C., González-Ruiz L. E., Aguilar-Ramírez C. F., Fuentes-Guzmán E., González-Ruiz D., Legoux C. (2018) MVT-Like Fluorite Deposits and Oligocene Magmatic-Hydrothermal Fluorite–Be–U–Mo–P–V Overprints in Northern Coahuila, Mexico, *Minerals*, 9, 58, doi:10.3390/min9010058
- Carocci E., Marignac C., Cathelineau M., Truche L., Lecomte A., Pinto F. (2018) Rutile from Panasqueira (Central Portugal): An Excellent Pathfinder for Wolframite Deposition, *Minerals*, 9, 9, doi:10.3390/min9010009
- Chopard A., Marion P., Royer J.-J., Taza R., Bouzahzah H., Benzaazoua M. (2018) Automated sulfides quantification by multispectral optical microscopy, *Minerals Engineering*, 131, 38–50, <https://doi.org/10.1016/j.mineng.2018.11.005>
- Corre B., Boulvais P., Boiron M.-C., Lagabrielle Y., Marasi L., Clerc C. (2018) Fluid circulations in response to mantle exhumation at the passive margin setting in the north Pyrenean zone, France, *Mineralogy and petrology*, 112 (5), 647–670, <https://doi.org/10.1007/s00710-018-0559-x>
- Dyja-Person V., Tarantola A., Richard A., Hibsich C., Siebenaller L., Boiron M.-C., Cathelineau M., Boulvais P. (2018) Metamorphic brines and no surficial fluids trapped in the detachment footwall of a Metamorphic Core Complex (Nevado-Filábride units, Betics, Spain), *Tectonophysics*, 727, 56–72, <https://doi.org/10.1016/j.tecto.2018.02.001>
- Fabre C., Devismes D., Moncayo S., F. Pelascini, Trichard F., Lecomte A., Bousquet B., Cauzid J., Motto-Ros V. (2018) Elemental imaging by laser-induced breakdown spectroscopy for the geological characterization of minerals, *Journal of Analytical Atomic Spectroscopy*, <https://doi.org/10.1039/c8ja00048d>
- Fosso Tchunte, P.M., Tchameni, R., André-Mayer, A.-S., Dakoure, H.S., Turlin, F., Poujol, M., Nomo, E.N., Saha Fouotsa, A.N., Rouer, O., 2018. Evidence for Nb-Ta Occurrences in the Syn-Tectonic Pan-African Mayo Salah Leucogranite (Northern Cameroon): Constraints from Nb-Ta Oxide Mineralogy, Geochemistry and U-Pb LA-ICP-MS Geochronology on Columbite and Monazite. *Minerals* 8, 188. <https://doi.org/10.3390/min8050188>
- Fournier, J., Régnier, E., Faure, F., Le Goff, X., Brau, H. P., Brackx, E., et al. (2018). Modeling of dissolution kinetics of rare earth crystals in a borosilicate glass melt. *Journal of Non-Crystalline Solids*, 481, 248–253.
- Füri, E., Deloule, E., & Dalou, C. (2018). Nitrogen abundance and isotope analysis of silicate glasses by secondary ionization mass spectrometry. *Chemical Geology*, 493, 327–337.
- Giuliani, G., & Fallick, A. E. (2018). Isotope signatures of gem minerals. *Wooshin Gemological Institute of Korea*, 5, 2–9.
- Giuliani, G., Dubessy, J., Ohnenstetter, D., Banks, D., Branquet, Y., Feneyrol, J., et al. (2018). The role of evaporites in the formation of gems during metamorphism of carbonate platforms: a review. *Mineralium Deposita*, 53, 1–20.
- Giuliani, G., Dubessy, J., Pignatelli, I., & Schwarz, D. (2018). Fluid inclusions study of trapiche and non-trapiche rubies from the Mong Hsu deposit, Myanmar. *The Canadian Mineralogist*, 56, 1–13.
- Giuliani, G., Fallick, A. E., Boyce, A., Pardieu, V., & Pham, V. L. (2018). Origine géographique des spinelles chromifères et vanadifères associés aux marbres d'Asie et d'Afrique de l'Est. *Revue de l'Association Française de Gemmologie*, (203), 17–25.
- Giuliani, G., Groat, L. A., & Marshall, D. D. (2018). Emerald deposits in the 21st century. *Incolor*, (40).
- Grand'Homme, A., Janots, E., Seydoux-Guillaume, A.M., Guillaume, D., Magnin, V., Hövelmann, J., Höschen, C., Boiron, M.C., 2018. Mass transport and fractionation during monazite alteration by anisotropic replacement. *Chemical Geology* 484, 51–68. <https://doi.org/10.1016/j.chemgeo.2017.10.008>
- Grare A., Lacombe O., Mercadier J., Benedicto A., Guilcher M., Trave A., Ledru P., Robbins J. (2018) Fault Zone Evolution and Development of a Structural and Hydrological Barrier: The Quartz Breccia in the Kiggavik Area (Nunavut, Canada) and Its Control on Uranium Mineralization, *Minerals*, 8(8), 319, <https://doi.org/10.3390/min8080319>

- Greaney, A. T., Rudnick, R. L., Gaschnig, R. M., Whalen, J. B., Luais, B., & Clemens, J. D. (2018). Geochemistry of molybdenum in the continental crust. *Geochimica et Cosmochimica Acta*, 238, 36–54.
- Grose L., Ailleres L., Laurent G., Armit R., Jessell M. (2018) Inversion of geological knowledge for fold geometry, *Journal of Structural Geology*, 119, 1–14, <https://doi.org/10.1016/j.jsg.2018.11.010>
- Gu, X., Ingrin, J., Deloule, E., France, L., & Xia, Q. (2018). Metasomatism in the sub-continental lithospheric mantle beneath the south French Massif Central: Constraints from trace elements, Li and H in peridotite minerals. *Chemical Geology*, 478, 2–17.
- Guezenc J., Payré V., Fabre C., Syvilay D., Cousin A., Gallet-Budynek A., Bousquet B. (2018) Variable selection in laser-induced breakdown spectroscopy assisted by multivariate analysis: An alternative to multi-peak fitting, *Spectrochimica Acta Part B*, 152, 6–13, <https://doi.org/10.1016/j.sab.2018.12.001>
- Harlaux, M., Mercadier, J., Marignac, C., Peiffert, C., Cloquet, C., Cuney, M., 2018a. Tracing metal sources in peribatholithic hydrothermal W deposits based on the chemical composition of wolframite: The example of the Variscan French Massif Central. *Chemical Geology* 479, 58–85. <https://doi.org/10.1016/j.chemgeo.2017.12.029>
- Harlaux, M., Romer, R.L., Mercadier, J., Morlot, C., Marignac, C., Cuney, M., 2018b. 40 Ma of hydrothermal W mineralization during the Variscan orogenic evolution of the French Massif Central revealed by U-Pb dating of wolframite. *Mineralium Deposita* 53, 21–51. <https://doi.org/10.1007/s00126-017-0721-0>
- Hauquin T., Gunzburger Y., Deck O. (2018) Predicting pillar burst by an explicit modelling of kinetic energy, *International Journal of Rock Mechanics and Mining Sciences*, 107, 159–171, <https://doi.org/10.1016/j.ijrmms.2018.05.004>
- Holycross, M. E., Watson, E. B., Richter, F. M., & Villeneuve, J. (2018). Diffusive fractionation of Li isotopes in wet, highly silicic melts. *Geochemical Perspectives Letters*, 6, 39–42.
- Hulsbosch N., Boiron M.C., Thomas R., Van Daele J., Dewaele S., Muchez P. (2018) Evaluation of the petrogenetic significance of melt inclusions in pegmatitic schorl-dravite from graphic tourmaline-quartz assemblages: Application of LA-ICP-QMS analyses and volume ratio calculations, *Geochimica, Cosmochimica Acta*, 244, 308–335, <https://doi.org/10.1016/j.gca.2018.10.023>
- Hybler J., Klementova M., Jarosova M., Pignatelli I., Mosser-Ruck R., Durovic S. (2018) Polytype identification in trioctahedral 1:1 layer silicates using electron diffraction with application to a cronstedtite that was synthesized from metallic iron-clay interactions, *Clays and Clay Minerals*, 4, 209–232, DOI: 10.1346/CCMN.2018.064106
- Iwatsuki Y., Nakajima K., Yamano H., Otsuki A., Murakami S. (2018) Variation and changes in land-use intensities behind nickel mining: coupling operational and satellite data, *Resources Conservation and Recycling*, 134, 361–366, <https://doi.org/10.1016/j.resconrec.2018.02.028>
- Jacob, J. B., Martelat, J. E., Goncalves, P., Giuliani, G., Devidal, J. L., Feneyrol, J., et al. (2018). New P-T-X conditions for the formation of gem tsavorite garnet in the Voi area (southwestern Kenya). *Lithos*, 320–321, 250–264.
- Legros H., Marignac C., Tabary T., Mercadier J., Richard A., Cuney M., Wang R.-C., Charles N., Lespinasse M.-Y. (2018) The ore-forming magmatic-hydrothermal system of the Piaotang W-Sn deposit (Jiangxi, China) as seen from Li-mica geochemistry, *American Mineralogist*, 103, 39–54, <http://dx.doi.org/10.2138/am-2018-6196>
- Legros H., Richard A., Tarantola A., Kouzmanov K., Mercadier J., Vennemann T., Marignac C., Cuney M., Wang R.-C. Charles N., Bailly L., Lespinasse M.-Y., 2018 ou 2019, Multiple fluids involved in granite-related W-Sn deposits from the world-class Jiangxi province (China), *Chemical Geology*, <https://doi.org/10.1016/j.chemgeo.2018.11.021>
- Lerat J. G., Sterpenich J., Mosser-Ruck R., Lorgeoux C., Bihannic I., Fialips C. I., Schovsbo N. H., Pironon J., Gaucher E. C. (2018) Metals and radionuclides (MaR) in the Alum Shale of Denmark: Identification of MaR-bearing phases for the better management of hydraulic fracturing waters, *Journal of Natural Gas Science and Engineering*, 53, 139–152, <https://doi.org/10.1016/j.jngse.2018.02.015>
- Levresse G., Tritlla J., Rosique A.R., Cardellach E., Rollion-Bard C., Pironon J., Sandoval S. J. (2018) "Hydrocarbons in silica: PVTX properties of fluids and the genesis of diamond quartz from Caravia-Berbes Fluorite district (Asturias, Spain)", *Marine and Petroleum Geology* , 102, janv-15, <https://doi.org/10.1016/j.marpetgeo.2018.11.039>
- Liu-Zeng, J., Zhang, J., McPhillips, D., Reiners, P., Wang, W., Pik, R., et al. (2018). Multiple episodes of fast exhumation since Cretaceous in southeast Tibet, revealed by low-temperature thermochronology. *Earth and Planetary Science Letters*, 490, 62–76.
- Martz, P., Mercadier, J., Cathelineau, M., Boiron, M.-C., Quirt, D., Doney, A., Gerbeaud, O., De Wally, E., Ledru, P., 2018. Formation of U-rich mineralizing fluids through basinal brine migration within basement-hosted shear zones: A large-scale study of the fluid chemistry around the unconformity-related Cigar Lake U deposit (Saskatchewan, Canada). *Chemical Geology*. <https://doi.org/10.1016/j.chemgeo.2018.05.042>
- Mollex, G., Furi, E., Burnard, P., Zimmermann, L., Chazot, G., Kazimoto, E.O., Marty, B., France, L., 2018. Tracing helium isotope compositions from mantle source to fumaroles at Oldoinyo Lengai volcano, Tanzania. *Chemical Geology* 480, 66–74. <https://doi.org/10.1016/j.chemgeo.2017.08.015>
- Montel, J. M., Razafimahatratra, D., de Perseval, P., Poitrasson, F., Moine, B., Seydoux-Guillaume, A. M., et al. (2018). The giant monazite crystals from Manangotry (Madagascar). *Chemical Geology*, 484, 36–50.
- Parra-Avila L. A., Belousova E., Fiorentini M.L., Eglinger A., Block S., Miller J. (2018) Zircon Hf and O-isotope constraints on the evolution of the Paleoproterozoic Baoulé-Mossi domain of the southern West African Craton, *Precambrian Research*, 306, 174–188, <https://doi.org/10.1016/j.precamres.2017.12.044>
- Payré V., Fabre C., V. Sautter, A. Cousin, N. Mangold, L. Le Deit, O. Forni, W. Goetz, R. C. Wiens, O. Gasnault, P.-Y. Meslin, (2018) Copper enrichments in the Kimberley formation in Gale crater, Mars: Evidence for a Cu deposit at the source Icarus, 321, 736–751, <https://doi.org/10.1016/j.icarus.2018.12.015>
- Pham V.L., Giuliani, G., Fallick, A. E., Boyce, A., & Pardieu, V. (2018). Trace elements and oxygen isotopes of gem spinels in marble from the Luc Yen – An Phu areas, Yen Bai province, North Vietnam. *Vietnam Journal of Earth Sciences*, 40(2), 166–179.

- Pochon A., Gloaguen E., Branquet Y., Poujol M., Ruffet G., Boiron M.C., Boulvais P., Gumiaux C., Cagnard F., Gouazou F., Gapais D. (2018) Variscan Sb-Au mineralization in Central Brittany (France): A new metallogenic model derived from the Le Semnon district, *Ore Geology Reviews*, 97, 109-142, <https://doi.org/10.1016/j.oregeorev.2018.04.016>
- Richard A., Banks D.A., Hendriksson N., Lahaye Y. (2018) Lithium isotopes in fluid inclusions as tracers of crustal fluids: An exploratory study, *Journal of Geochemical Exploration*, 184, 158-166, <http://dx.doi.org/10.1016/j.gexplo.2017.10.017>
- Richard, A., Morlot, C., Créon, L., Beaudoin, N., Balistky, V.S., Pentelel, S., Dyja-Person, V., Giuliani, G., Pignatelli, I., Legros, H., Sterpenich, J., Pironon, J., 2018. Advances in 3D imaging and volumetric reconstruction of fluid and melt inclusions by high resolution X-ray computed tomography. *Chemical Geology*. <https://doi.org/10.1016/j.chemgeo.2018.06.012>
- Royer J.J. (2018) "Are world Uranium resources log-normally distributed? ", IAEA - International Atomic Energy agency - Tecdoc 1861
- Royer J.J., Cuney M. (2018) Statistical distribution of the uranium resources in the variscan hydrothermal uranium deposits of Western Europe ,IAEA - International Atomic Energy agency - Tecdoc 1861
- Turlin, F., Deruy, C., Eglinger, A., Vanderhaeghe, O., André-Mayer, A.-S., Poujol, M., Moukhsil, A., Solgadi, F., 2018. A 70 Ma record of suprasolidus conditions in the large, hot, long-duration Grenville Orogen. *Terra Nova* 30, 233–243. <https://doi.org/10.1111/ter.12330>
- Van Daele, J., Hulsbosch, N., Dewaele, S., Boiron, M.-C., Piessens, K., Boyce, A., Muchez, P., 2018. Mixing of magmatic-hydrothermal and metamorphic fluids and the origin of peribatholithic Sn vein-type deposits in Rwanda. *Ore Geology Reviews* 101, 481–501. <https://doi.org/10.1016/i.oregeorev.2018.07.020>
- Vignerresse J.-L., Truche L., Richard A. (2018) How do metals escape from magmas to form porphyry-type ore deposits?, *Ore Geology Reviews*, 105, <https://doi.org/10.1016/j.oregeorev.2018.12.016>
- Voudouris P., Mavrogonatos C., Rieck B., Kolitsch U., Spry P. G., Scheffer C., Tarantola A., Vanderhaeghe O., Galanos E., Melfos V., Zaimis S., Soukis K., Photiades A. (2018) The Gersdorffite-Bismuthinite-Native Gold Association and the Skarn-Porphyry Mineralization in the Kamariza Mining District, Lavrion, Greece, *Minerals*, 8, 531, doi:10.3390/min8110531
- Voudouris P., Melfos V., Mavrogonatos C., Tarantola A., Götze J., Alfieris D., Maneta V., Psimis I. (2018) Amethyst Occurrences in Tertiary Volcanic Rocks of Greece: Mineralogical, Fluid Inclusion and Oxygen Isotope Constraints on Their Genesis, *Minerals*, 8, 324, doi:10.3390/min8080324
- Zelenski, M., Kamenetsky, V. S., Mavrogenes, J. A., Gurenko, A. A., & Danyushevsky, L. V. (2018). Silicate-sulfide liquid immiscibility in modern arc basalt (Tolbachik volcano, Kamchatka): Part I. Occurrence and compositions of sulfide melts. *Chemical Geology*, 478, 102–111.
- Zhu Z., Wang R., Marignac C., Cuney M., Mercadier J., Che X., Lespinasse M.-Y. (2018) A new style of rare metal granite with Nb-rich mica: The Early Cretaceous Huangshan rare-metal granite suite, northeast Jiangxi Province, southeast China, *American Mineralogist*, 103, 1530-1544, <http://doi.org/10.2138/am-2018-6511>

Ore processes



- Chagnes A., Cote G. (2018) Chemical Degradation of a Mixture of tri-n-Octylamine and 1-Tridecanol in the Presence of Chromium(VI) in Acidic Sulfate Media, *Metals*, 8, 57-67, [10.3390/met8010057](https://doi.org/10.3390/met8010057)
- Farrokhpay S. (2018) Significance of rheology characterisation in mineral flotation process performance, *Journal of Physics Conference Series*, 121, 100-106, [doi:10.1088/1742-6596/1045/1/012010](https://doi.org/10.1088/1742-6596/1045/1/012010)
- Farrokhpay S., Fornasiero D., Filippov L. (2018) Upgrading nickel in laterite ores by flotation, *Minerals Engineering*, 121(1), 100-106, <https://doi.org/10.1016/j.mineng.2018.02.021>
- Farrokhpay S., Ndlovu B., Bradshaw D. (2018) Behavior of talc and mica in copper ore flotation, *Applied Clay Science*, 160, 270-275, <https://doi.org/10.1016/j.clay.2018.02.011>
- Filippov L.O., Foucaud Y., Filippova I.V., Badawi M. (2018) New reagent formulations for selective flotation of scheelite from a skarn ore with complex calcium minerals gangue, *Minerals Engineering*, 123, 85-94, <https://doi.org/10.1016/j.mineng.2018.05.001>
- Filippov, L.O., Javor, Z., Piriou, P., Filippova, I.V., 2018. Salt effect on gas dispersion in flotation column – Bubble size as a function of turbulent intensity. *Minerals Engineering* 127, 6–14. <https://doi.org/10.1016/j.mineng.2018.07.017>
- Filippova I.V., Filippov L.O., Lafhaj Z., Barrès O., Fornasiero D (2018) Effect of calcium minerals reactivity on fatty acids adsorption and flotation, *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 545, 157-166, <https://doi.org/10.1016/j.colsurfa.2018.02.059>
- Flamme B., Haddad M., Phansavath P., Ratovelomanana-Vidal V., Chagnes A. (2018) Anodic stability of new sulfone-based electrolytes for lithium-ion batteries, *ChemElectroChem*, <https://doi.org/10.1002/celc.201701343>
- Foucaud Y., Badawi M., Filippov L.O., Filippova I.V., Lebègue S. (2018) Surface Properties of Fluorite in Presence of Water: An Atomistic Investigation, *The Journal of Physical Chemistry B*, 122, 6829-6836, <https://doi.org/10.1021/acs.jpcc.8b02717>
- Foucaud Y., Lebègue S., Filippov L.O., Filippova I.V. and Badawi M (2018) Molecular insight into fatty acid adsorption on bare and hydrated (111) Fluorite Surface, *The Journal of Physical Chemistry B*, 122-51, 2403-2410, DOI: 10.1021/acs.jpcc.8b08969

- Hoummady, E., Golfier, F., Cathelineau, M., Truche, L., Durupt, N., Blanvillain, J.-J., Neto, J., Lefevre, E., 2018a. A study of uranium-ore agglomeration parameters and their implications during heap leaching. *Minerals Engineering* 127, 22–31. <https://doi.org/10.1016/j.mineng.2018.07.012>
- Hoummady, E., Golfier, F., Cathelineau, M., Truche, L., Durupt, N., Blanvillain, J.J., Neto, J. and Lefevre, E. 2018b, An integrated multi-scale approach to heap leaching of uranium-ore agglomerates, *Hydrometallurgy*, 178:274-282.
- Hubau A., Minier M., Chagnes A., Jouliau C., Perez C., Guezennec A.G. (2018) Continuous production of a biogenic ferric iron lixiviant for the bioleaching of printed circuit boards (PCBs), *Hydrometallurgy*, 180, 180-191, <https://doi.org/10.1016/j.hydromet.2018.07.001>
- Kanari N., Menad N.E., Ostrosi E., Shallari S., Diot F., Allain E. and Yvon J. (2018) Thermal behavior of hydrated iron sulfate in various atmospheres, *Metals*, 8, 1084, [doi:10.3390/met8121084](https://doi.org/10.3390/met8121084)
- Li C, Runge K., Shi F, Farrokhpay S. (2018) Effect of flotation conditions on froth rheology, *Powder Technology*, 340, 537-542, <https://doi.org/10.1016/j.powtec.2018.09.050>
- Omelchuk K., Chagnes A. (2018) New cationic exchangers for the recovery of cobalt(II), nickel(II) and manganese(II) from acidic chloride solutions: Modelling of extraction curves, *Hydrometallurgy*, 180, 96-103, <https://doi.org/10.1016/j.hydromet.2018.07.003>
- Otsuki A., Dodbiba G., Fujita T. (2018) Two-liquid flotation for separating mixtures of ultra-fine rare earth fluorescent powders for material recycling - a review, *Colloids and Interfaces*, 2, 2-7, [doi:10.3390/colloids2010007](https://doi.org/10.3390/colloids2010007)
- Otsuki A., Miller T. (2018) Experimental investigation on safer frother option for coal flotation, *Current Works in Mineral Processing*, 1, 13-20,
- Otsuki A., Robinson D.J. (2018) Sulphidization to improve the nickel oxide recovery by froth flotation, *MAYFEB, Journal of Chemistry and Chemical Engineering*, 1, 1-10, ISSN 2560-693X
- Otsuki A., Zhao Y. (2018) UV-Vis. study of mixed collector adsorption on pyrite to enhance refractory gold ore beneficiation by flotation, *Current Works in Mineral Processing*, 1, 13-20
- Simon B., Bouyer C., De Sio S., Berthon C., Boubals N., Miserque F., Brackx E., Raymond N., Chagnes A., Berthon L. (2018) Characterization of palladium species after g-irradiation of a TBP-alkane-Pd(NO₃)₂ system, *RSC Advances*, 8, 21513-21527, DOI: 10.1039/c8ra02695e
- Tran C., Flamme B., Chagnes A., Haddad M., Phansavath P., Ratovelomanana-Vidal V (2018) A Practical Access to Functionalized Alkyl Sulfonates, *Synlett*, 29,, DOI: 10.1055/s-0036-1591588
- Veloso C.H., Filippov L.O., Filippova I.V., Ouvrard S., Araujo A.C. (2018) Investigation of the interaction mechanism of depressants in the reverse cationic flotation of complex iron ores, *Minerals Engineering*, 125, 133-139, <https://doi.org/10.1016/j.mineng.2018.05.031>

Agromining and Phytoremediation



- Bani, A., Pavlova, D., Benizri, E., Shallari, S., Miho, L., Meco, M., Shahu, E., Reeves, R., Echevarria, G., 2018. The relationship between Ni hyperaccumulator *Alyssum murale* and the parasitic plant *Orobanche nowackiana* from serpentines in Albania. *Ecological Research*. Accepted 28 february 2018. doi.org/10.1007/s11284-018-1593-1
- Bartoli, F., Royer, M., Coinchelin, D., Le Thiec, D., Rose, C., Robin, C., Echevarria, G. 2018. Multiscale and age-dependent leaf nickel in the Ni-hyperaccumulator *Leptoplax emarginata*. *Ecological Research*. Accepted 22 december 2017. doi.org/10.1007/s11284-018-1594-0
- Bechet, B., Joimel, S., Jean-Soro, Hursthouse, A., Agboola, A., Leitão, T. E., Costa, H., do Rosário Cameira, M., Le Guern, C., Schwartz, C., Lebeau, T. (2018). Spatial variability of trace elements in allotment gardens of four European cities: assessments at city, garden, and plot scale. *Journal of Soils and Sediments*, 18 (2), 391-406. , DOI : 10.1007/s11368-016-1515-1
- Benizri, É., Kidd, P. S. (2018). The Role of the Rhizosphere and Microbes Associated with Hyperaccumulator Plants in Metal Accumulation. In: *Agromining: Farming for Metals* (p. 157-188). *Mineral Resource Reviews* (Chapter 9). , DOI : 10.1007/978-3-319-61899-9_9
- Bouman, R., van Welzen, P., Sumail, S., Echevarria, G., Erskine, P.D., van der Ent, A., 2018. *Phyllanthus rufuschaneyi*: a new nickel hyperaccumulator from Sabah (Borneo Island) with potential for tropical agromining. *Botanical Studies* 59. <https://doi.org/10.1186/s40529-018-0225-y>
- Bouzouidja, R., Rousseau, G., Galzin, Claverie, R., Lacroix, D., Séré, G. (2018). Green roof ageing or Isolatic Technosol's pedogenesis?. *Journal of Soils and Sediments*, 18 (2), 418-425. , DOI : 10.1007/s11368-016-1513-3
- Cecchi, L., Colzi, I., Coppi, A., Echevarria, G., Pazzaragli, L., Bani, A., Gonnelli C., Selvi, F., 2018. The genus *Odontarrhena* (Brassicaceae) in Albania: Taxonomy and Nickel accumulation in a critical group of metallophytes from a major serpentine hot-spot. *Phytotaxa* 351(1), 1–28.
- Chour, Z., Laubie, B., Morel, J.-L., Tang, Y., Qiu, R., Simonnot, M.-O., Muhr, L. (2018). Recovery of rare earth elements from *Dicranopteris dichotoma* by an enhanced ion exchange leaching process. *Chemical Engineering and Processing*, 130, 208-213. , DOI : 10.1016/j.cep.2018.06.007
- Deng, T.-H.-B., van der Ent, A., Tang, Y.-T., Sterckeman, T., Echevarria, G., Morel, J.-L., Qiu, R.-L., 2018. Nickel hyperaccumulation mechanisms: a review on the current state of knowledge. *Plant and Soil* 423, 1–11. <https://doi.org/10.1007/s11104-017-3539-8>
- Ding, K., Wu, Q. (, Wei, H., Yang, W., Séré, G., Wang, Echevarria, G., Tang, Tao, Morel, J.-L., Qiu (2018). Ecosystem services provided by heavy metal-contaminated soils in China. *Journal of Soils and Sediments*, 18 (2), 380-390. , DOI : 10.1007/s11368-016-1547-6
- Dinh, N., van der Ent, A., Mulligan, D.R., Nguyen, A.V., 2018. Zinc and lead accumulation characteristics and in vivo distribution of Zn 2+ in the hyperaccumulator *Noccaea caerulescens* elucidated with fluorescent probes and laser confocal microscopy. *Environmental and Experimental Botany* 147, 1–12. <https://doi.org/10.1016/j.enxpb.2017.10.008>
- Echevarria, G., Baker, A.J.M., Boyd, R., van der Ent, A., Mizuno, T., Rajakaruna, N., Sakaguchi, S., Bani, A. 2018. A global forum on ultramafic ecosystems: from ultramafic ecology to rehabilitation of degraded environments. *Ecological Research* 33(3), 516–521. Accepted 30 march 2018. doi.org/10.1007/s11284-018-1611-3
- Guilpain, M., Laubie, B., Zhang, X., Morel, J.L., Simonnot, M.-O., 2018. Speciation of nickel extracted from hyperaccumulator plants by water leaching. *Hydrometallurgy* 180, 192–200. <https://doi.org/10.1016/j.hydromet.2018.07.024>
- Hedde, M., Nahmani, J., Séré, G., Auclair, A., Cortet, J. (2018). Early colonisation of constructed technosols by macro-invertebrates . *Journal of Soils and Sediments* . , DOI : 10.1007/s11368-018-2142-9
- Huot, H., Cortet, J., Watteau, F., Milano, V., Nahmani, J., Sirguy, C., Schwartz, C., Morel, J.-L. (2018). Diversity and activity of soil fauna in an industrial settling pond managed by natural attenuation. *Applied Soil Ecology*, 132, 34-44. , DOI : 10.1016/j.apsoil.2018.08.020
- Jacobs, A., De Brabandere, Drouet, Sterckeman, T., Noret (2018). Phytoextraction of Cd and Zn with *Noccaea caerulescens* for urban soil remediation: influence of nitrogen fertilization and planting density. *Ecological Engineering*, 116, 178-187. , DOI : 10.1016/j.ecoleng.2018.03.007
- Jaffré, T., Reeves, R. D., Baker, A. J. M., Schat, H., van der Ent, A. (2018). The discovery of nickel hyperaccumulation in the New Caledonian tree *Pycnanthus acuminata* 40 years on: an introduction to a Virtual Issue. *New Phytologist*, 218 (2), 397-400. , DOI : 10.1111/nph.15105
- Jangorzo, N. S., Watteau, F., Schwartz, C. (2018). Ranking of wetting–drying, plant, and fauna factors involved in the structure dynamics of a young constructed Technosol. *Journal of Soils and Sediments*, 18 (9), 2995-3004. , DOI : 10.1007/s11368-018-1968-5
- Joimel, S., Capiiaux, H., Schwartz, C., Hedde, M., Lebeau, T., Le Guern, C., Nahmani, J., Pernin, C., Salmon, S., Santorufo, L., Béchet, B., Cortet, J. (2018). Effect of Geogenic Lead on Fungal and Collembolan Communities in Garden Topsoil. *Pedosphere*, 28 (2), 215-226. , DOI : 10.1016/S1002-0160(18)60022-0
- Kanso, A., Azouy, S., Benizri, E., Kobaissi, A., Echevarria, G., Sirguy, C., 2018. Improvement of Ni phytoextraction by *Alyssum murale* and its rhizosphere microbial activities by applying nitrogen fertilizer. *Ecological Research*. <https://doi.org/10.1007/s11284-018-1630-0>

- Kidd, P.S., Bani, A., Benizri, E., Gonnelli, C., Hazotte, C., Kisser, J., Konstantinou, M., Kuppens, T., Kyrkas, D., Laubie, B., Malina, R., Morel, J.L., Olcay, H., Pardo, T., Pons, M.N., Prieto-Fernández, Á., Puschenreiter, M., Quintela-Sabaris, C., Ridard, C., Rodríguez-Garrido, B., Rosenkranz, T., Rozpádek, P., Saad, R.F., Selvi, F., Simonnot, M.O., Tognacchini, A., Turnau, K., Ważny R., Witters, N., Echevarria, G. 2018. Developing sustainable agromining systems in agricultural ultramafic soils for nickel recovery. *Frontiers in Plant Science*, Accepted 17 may 2018.
- Li, J.-T., Gurajala, H. K., Wu, L.-H., van der Ent, A., Qiu, R.-L., Baker, A. J. M., Tang, Y.T., Yang, XE., Shu, WS (2018). Hyperaccumulator Plants from China: A Synthesis of the Current State of Knowledge. *Environmental Science and Technology*, 52 (21), 11980-11994. , DOI : 10.1021/acs.est.8b01060
- Navarrete Gutiérrez, D.M., Pons, M.-N., Cuevas Sánchez, J.A., Echevarria, G., 2018. Is metal hyperaccumulation occurring in ultramafic vegetation of central and southern Mexico? *Ecological Research*. <https://doi.org/10.1007/s11284-018-1574-4>
- Nkrumah, P.N., Echevarria, G., Erskine, P.D., van der Ent, A., 2018. Contrasting nickel and zinc hyperaccumulation in subspecies of *Dichapetalum gelonioides* from Southeast Asia. *Scientific Reports* 8. <https://doi.org/10.1038/s41598-018-26859-7>
- Nkrumah, P.N., Erskine, P.D., Echevarria, G., van der Ent, A. 2018. Nickel hyperaccumulation in *Antidesma montis-silam*: from herbarium discovery to collection in the native habitat. *Ecological Research*. Accepted 17 november 2017. doi.org/10.1007/s11284-017-1542-4
- Osmani, M., Bani, A., Gjoka, F., Pavlola, D., Naqellari, P., Shahu, E., Duka, I., Echevarria, G. (2018). The natural plant colonization of ultramafic post-mining area of Përrenjas, Albania. *Periodico di Mineralogia*, 87, 135-146. , DOI : 10.2451/2018PM729
- Pardo, T., Rodríguez-Garrido, B., Saad, R.F., Soto-Vázquez, J.L., Loureiro-Viñas, M., Prieto-Fernández, A., Echevarria, G., Benizri, E., Kidd, P.S. 2018. Assessing the agromining potential of Mediterranean nickel-hyperaccumulating plant species at field-scale in ultramafic soils under humid-temperate climate. *The Science of the Total Environment*, 630, 275–286.
- Paul, A., Erskine, P. van der Ent, A. (2018). Metallophytes on Zn-Pb mineralised soils and mining wastes in Broken Hill, NSW, Australia. *Australian Journal of Botany*, 66 (2), 124-133. , DOI : 10.1071/BT17143
- Quintela-Sabaris, C., L'Huillier, L., Mouchon, L.-C., Montargès-Pelletier, E., Echevarria, G. (2018). Chemicomineralogical changes of ultramafic topsoil during stockpiling: implications for post-mining restoration. *Ecological Research*, 33 (4), 767-775. , DOI : 10.1007/s11284-018-1609-x
- Reeves, R.D., Baker, A.J.M., Jaffré, T., Erskine, P., Echevarria, G., van der Ent, A. 2018. A global database for plants that hyperaccumulate metal and metalloid trace elements. *New Phytologist*. 218 (2), 407-411.
- Saad, A., Kobaissi, A., Machinet, G., Villemin, G., Echevarria, G., Benizri, E. 2018. Crop rotation associating a legume and the nickel hyperaccumulator *Alyssum murale* improves the structure and biofunctioning of an ultramafic soil. *Ecological Research*. En ligne depuis le 11 novembre 2017. doi.org/10.1007/s11284-017-1526-4
- Saad, R. F., Kobaissi, A., Goux, X., Calusinska, Echevarria, G., Kidd, P., Benizri, E. (2018). Soil microbial and Ni-agronomic responses to *Alyssum murale* interplanted with a legume. *Applied Soil Ecology*, 132, 60-73. , DOI : 10.1016/j.apsoil.2018.08.019
- Saad, R.F., Kobaissi, A., Amiaud, B., Ruelle, J., Benizri, E., 2018a. Changes in physicochemical characteristics of a serpentine soil and in root architecture of a hyperaccumulating plant cropped with a legume. *Journal of Soils and Sediments* 18, 1994–2007. <https://doi.org/10.1007/s11368-017-1903-1>
- Saad, R.F., Kobaissi, A., Echevarria, G., Kidd, P., Calusinska, M., Goux, X., Benizri, E., 2018b. Influence of new agromining cropping systems on soil bacterial diversity and the physico-chemical characteristics of an ultramafic soil. *Science of The Total Environment* 645, 380–392. <https://doi.org/10.1016/j.scitotenv.2018.07.106>
- Salihaj, M., Bani, A., Shahu, E., Benizri, E., Echevarria, G. 2018. Metal accumulation by the ultramafic flora of Kosovo. *Ecological Research*.
- Schneider, A., Lin, Z., Sterckeman, T., Nguyen, C. (2018). Comparison between numeric and approximate analytic solutions for the prediction of soil metal uptake by roots. Example of cadmium. *Science of the Total Environment*, 619-620, 1194-1205. , DOI : 10.1016/j.scitotenv.2017.11.069
- Sirguey, C., Seznec, G., Mahevas, Echevarria, G., Gonneau, C., Sterckeman, T. (2018). Soil trace metal content does not affect the distribution of the hyperaccumulator *Noccaea caerulescens* in the Vosges Mountains (France). *Plant and Soil*, 430 (1-2), 245-262. , DOI : 10.1007/s11104-018-3731-5
- Sterckeman, T., Gossiaux, L., Guimont, S., Sirguey, C., Lin, Z. (2018). Cadmium mass balance in French soils under annual crops: Scenarios for the next century. *Science of the Total Environment*, 639, 1440-1452. , DOI : 10.1016/j.scitotenv.2018.05.225
- Tashakor, M., Modabberi, S., van der Ent, A., Echevarria, G. (2018). Impacts of ultramafic outcrops in Peninsular Malaysia and Sabah on soil and water quality. *Environmental Monitoring and Assessment*, 190 (6), 1-19. , DOI : 10.1007/s10661-018-6668-5
- van der Ent, A., Edraki, M (2018). Environmental geochemistry of the abandoned Mamut Copper Mine (Sabah) Malaysia. *Environmental Geochemistry and Health*, 40 (1), 189-207. , DOI : 10.1007/s10653-016-9892-3
- van der Ent, A., Cardace, D., Tibbett, M., Echevarria, G., 2018a. Ecological implications of pedogenesis and geochemistry of ultramafic soils in Kinabalu Park (Malaysia). *CATENA* 160, 154–169. <https://doi.org/10.1016/j.catena.2017.08.015>
- van der Ent, A., Mak, R., de Jonge, M.D., Harris, H.H., 2018b. Simultaneous hyperaccumulation of nickel and cobalt in the tree *Glochidion cf. sericeum* (Phyllanthaceae): elemental distribution and chemical speciation. *Scientific Reports* 8. <https://doi.org/10.1038/s41598-018-26891-7>
- van der Ent, A., Mulligan, Repin, R., Erskine (2018). Foliar elemental profiles in the ultramafic flora of Kinabalu Park (Sabah, Malaysia). *Ecological Research*, 33 (3), 659-674. , DOI : 10.1007/s11284-018-1563-7
- van der Ent, A., Przybyłowicz, W.J., de Jonge, M.D., Harris, H.H., Ryan, C.G., Tylko, G., Paterson, D.J., Barnabas, A.D., Kopittke, P.M., Mesjasz-Przybyłowicz, J., 2018c. X-ray elemental mapping techniques for elucidating the ecophysiology of hyperaccumulator plants. *New Phytologist* 218, 432–452. doi.org/10.1111/nph.14810
- van Oort, F. (Auteur de correspondance), Foy, E., Labanowski, J., Leguedois, S., Jongmans, T. (2018). Soil Processes, Pedofeatures and Microscale Metal Distributions: Relevant Study of Contaminant-Dynamics Calls for Pedology-Based Soil-Depth Sampling Strategies. *Soil Systems*, 2 (1), 17. , DOI : 10.3390/soilsystems2010017

- Vidal-Beaudet, L., Rokia, S., Nehls, T., Schwartz, C. (2018). Aggregation and availability of phosphorus in a Technosol constructed from urban wastes. *Journal of Soils and Sediments*, 18 (2), 456-466. , DOI : 10.1007/s11368-016-1469-3
- Villenave, C., Séré, G., Schwartz, C., Watteau, F., Jimenez, A., Cortet, J. (2018). Rapid Changes in Soil Nematodes in the First Years after Technosol Construction for the Remediation of an Industrial Wasteland. *Eurasian Soil Science*, 51 (10), 1266-1273. , DOI : 10.1134/S1064229318100149
- Vincent, Q., Auclerc, A., Beguiristain, T., Leyval, C (2018). Assessment of derelict soil quality: Abiotic, biotic and functional approaches. *Science of the Total Environment*, 613-614, 990-1002. , DOI : 10.1016/j.scitotenv.2017.09.118
- Yilmaz, D., Cannavo, P. (Auteur de correspondance), Séré, G., Vidal-Beaudet, L., Legret, M., Damas, O., Peyneau (2018). Physical properties of structural soils containing waste materials to achieve urban greening. *Journal of Soils and Sediments*, 18 (2), 442-455. , DOI : 10.1007/s11368-016-1524-0
- Yuan, M., Liu, C., Liu, WS., Guo, MN., Morel, J.-L., Huot, H., Yu, HJ., Tang, Y.-T., Qiu, RL (2018). Accumulation and fractionation of rare earth elements (REEs) in the naturally grown *Phytolacca americana* L. in southern China. *International Journal of Phytoremediation*, 20 (5), 415-423. , DOI : 10.1080/15226514.2017.1365336
- Zelano, I.O., Cloquet, C., Fraysse, F., Dong, S., Janot, N., Echevarria, G., Montargès-Pelletier, E. 2018. The influence of organic complexation on Ni isotopic fractionation and Ni recycling in the upper soil layers. *Chemical Geology* 483, 47-55.

Metals and environment



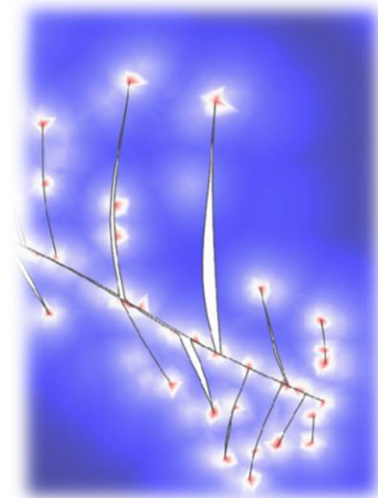
- Aharchaou I., Py J.-S., Cambier S., Loizeau J.-L., Cornelis G., Rousselle P., Battaglia E., Vignati D.-A.-L. (2018) Chromium Hazard and Risk Assessment: New Insights from a Detailed Speciation Study in a Standard Test Medium. *ENVIRONMENTAL TOXICOLOGY AND CHEMISTRY* 37 983-992 - DOI : 10.1002/etc.4044
- Arce-Funck, J., Crenier, C., Danger, M., Billoir, E., Usseglio-Polatera, P., Felten, V., 2018. High stoichiometric food quality increases moulting organism vulnerability to pollutant impacts: An experimental test with *Gammarus fossarum* (Crustacea: Amphipoda). *Science of The Total Environment* 645, 1484–1495. <https://doi.org/10.1016/j.scitotenv.2018.07.227>
- Berthelot C, Blaudez D, Beguiristain T, Chalot M, Leyval C, 2018, Co-inoculation of *Lolium perenne* with *Funneliformis mosseae* and the dark septate endophyte *Cadophora* sp. in a trace element-polluted soil. *Mycorrhiza*, 28, 301-314, DOI: 10.1007/s00572-018-0826-z
- Bosia, C., Chabaux, F., Pelt, E., Coge, A., Stille, P., Deloule, E., et al. (2018). U-series disequilibria in minerals from Gandak River sediments (Himalaya). *Chemical Geology*, 477(22-34).
- Burke, A., Present, T. M., Paris, G., Rae, E. C. M., Sandilands, B. H., et al. (2018). Sulfur isotopes in rivers: Insights into global weathering budgets, pyrite oxidation, and the modern sulfur cycle. *Earth and Planetary Science Letters*, 496, 168–177.
- Dellinger, M., West, A. J., Paris, G., Adkins, J. F., Pogge von Strandmann, P. A. E., Ullmann, C. V., et al. (2018). The Li isotope composition of marine biogenic carbonates: Patterns and mechanisms. *Geochimica et Cosmochimica Acta*, 236, 315–335.
- Devoille L., Revel M., Batana C., Feltn N., Giamberini L., Chatel A., Mouneyrac C. (2018) Combined Influence of Oxygenation and Salinity on Aggregation Kinetics of the Silver Reference Nanomaterial NM-300K. *ENVIRONMENTAL TOXICOLOGY AND CHEMISTRY* 37 1007-1013 - DOI : 10.1002/etc.4052
- Durand A., Maillard F., Alvarez-Lopez V., Guinard S., Bertheau C., Valot B., Blaudez D., Chalot M. (2018) Bacterial diversity associated with poplar trees grown on a Hg-contaminated site: Community characterization and isolation of Hg-resistant plant growth-promoting bacteria. *SCIENCE OF THE TOTAL ENVIRONMENT* 622 1165-1177 - DOI : 10.1016/j.scitotenv.2017.12.069
- Duval J.-F.-L., Town R.-M., van Leeuwen H.-P. (2018) Lability of Nanoparticulate Metal Complexes at a Macroscopic Metal Responsive (Bio)interface: Expression and Asymptotic Scaling Laws. *JOURNAL OF PHYSICAL CHEMISTRY C* 122 6052-6065 - DOI : 10.1021/acs.jpcc.7b11982
- Duval J.-F.-L., Town R.-M., van Leeuwen H.-P. (2018) Poisson-Boltzmann Electrostatics and Ionic Partition Equilibration of Charged Nanoparticles in Aqueous Media. *JOURNAL OF PHYSICAL CHEMISTRY C* 122 17328-17337 - DOI : 10.1021/acs.jpcc.8b05168
- Etique M., Romaine A., Bihannic I., Gley R., Carteret C., Abdelmoula M., Ruby C., Jeannin M., Sabot R., Refait P., Jorand F.-P.-A. (2018) Abiotically or microbially mediated transformations of magnetite by sulphide species: The unforeseen role of nitrate-reducing bacteria. *CORROSION SCIENCE* 142 31-44 - DOI : 10.1016/j.corsci.2018.06.032
- Fan, H., Wen, H., Xiao, C., Zhou, T., Cloquet, C., & Zhu, X. (2018). Zinc geochemical cycling in a phosphorus-rich ocean during the early Ediacaran. *Journal of Geochemical Research: Oceans*, 123,, 5248–5260.
- Grosjean N., Gross EM, Le Jean M, Blaudez D. 2018. Global deletome profile of *Saccharomyces cerevisiae* exposed to the technology-critical element yttrium. *Front. Microbiol.* | doi: 10.3389/fmicb.2018.02005
- Gross E.-M., Nuttens A., Paroshin D., Hussner A. (2018) Sensitive response of sediment-grown *Myriophyllum spicatum* L. to arsenic pollution under different CO₂ availability. *HYDROBIOLOGIA* 812 177-191 - DOI : 10.1007/s10750-016-2956-7
- Guinoiseau, D., Louvat, P., Paris, G., Chen, J. B., Chetelat, B., Rocher, V., et al. (2018). Are boron isotopes a reliable tracer of anthropogenic inputs to rivers over time? *Science of the Total Environment*, 626, 1057–1068.
- Jean J., Sirot V., Hulin M., Le Calvez E., Zinck J., Noel L., Vasseur P., Nessler F., Gorecki S., Guerin T., Riviere G. (2018) Dietary exposure to cadmium and health risk assessment in children - Results of the French infant total diet study. *FOOD AND CHEMICAL TOXICOLOGY* 115 358-364 - DOI : 10.1016/j.fct.2018.03.031
- Koehlé-Divo, V., Cossu-Leguille, C., Pain-Devin, S., Simonin, C., Bertrand, C., Sohm, B., Mouneyrac, C., Devin, S., Giambérini, L., 2018. Genotoxicity and physiological effects of CeO₂ NPs on a freshwater bivalve (*Corbicula fluminea*). *Aquatic Toxicology* 198, 141–148. <https://doi.org/10.1016/j.aquatox.2018.02.020>
- Lemmel F., Maunoury-Danger F., Fanesi A., Leyval C., Cébron A. (2018) Soil Properties and Multi-Pollution Affect Taxonomic and Functional Bacterial Diversity in a Range of French Soils Displaying an Anthropisation Gradient. *MICROBIAL ECOLOGY* 1-21- DOI : 10.1007/s00248-018-1297-7
- Mariet, A. L., Monna, F., Gimbert, F., Bégeot, C., Cloquet, C., Belle, S., et al. (2018). Tracking past mining activity using trace metals, lead isotopes and compositional data analysis of a sediment core from Longemer Lake, Vosges Mountains, France. *Journal of Paleolimnology*, 1-14
- Maunoury-Danger F., Felten V., Bojic C., Fraysse F., Ponce M.-C., Dedourge-Geffard O., Geffard A., Guerold F., Danger M. (2018) Metal release from contaminated leaf litter and leachate toxicity for the freshwater crustacean *Gammarus fossarum*. *Environmental Science And*

- Mehennaoui K, Cambier S, Serchi T, Ziebel J, Lentzen E, Valle N, Guerold F, Thomann JS, Giamberini L, Gutleb AC 2018. Do the pristine physico-chemical properties of silver and gold nanoparticles influence uptake and molecular effects on *Gammarus fossarum* (Crustacea Amphipoda)? *Science of the Total Environment* In press doi.org/10.1016/j.scitotenv.2018.06.208
- Monteiro ASC, Goveia D, Rotureau E, Rosa AH, Masini JC, Pinheiro JP. 2018. Dynamic Speciation Of Trace Metals In Aquatic Environment Using Anodic Stripping Chronopotentiometry. *Quimica Nova* 41 (7) :796-809 DOI: 10.21577/0100-4042.20170242
- Mougin C., Gouy V., Bretagnolle V., Berthou J., Andrieux P., Ansart P., Benoit M., Coeurdassier M., Comte I., Dages C., Denaix L., Dousset S., Ducreux L., Gaba S., Gilbert D., Imfeld G., Liger L., Molenat J., Payraudeau S., Samouelian A., Schott C., Tallec G., Vivien E., Voltz M. (2018) RECOTOX a French initiative in ecotoxicology-toxicology to monitor understand and mitigate the ecotoxicological impacts of pollutants in socioagroecosystems. *ENVIRONMENTAL SCIENCE AND POLLUTION RESEARCH* 25 33882-33894 - DOI : 10.1007/s11356-018-2716-5
- O'Hare M.-T., Aguiar F.-C., Asaeda T., Bakker E.-S., Chambers P.-A., Clayton J.-S., Elger A., Ferreira T.-M., Gross E.-M., Gunn I.-D.-M., Gurnell A.-M., Hellsten S., Hofstra D.-E., Li W., Mohr S., Puijalón S., Szoszkiewicz K., Willby N.-J., Wood K.-A. (2018) Plants in aquatic ecosystems: current trends and future directions. *HYDROBIOLOGIA* 812 1-11 - DOI : 10.1007/s10750-017-3190-7
- Pagnout C., Present R.-M., Billard P., Rotureau E., Duval J.-F.-L (2018) What do luminescent bacterial metal-sensors probe? Insights from confrontation between experiments and flux-based theory. *SENSORS AND ACTUATORS B-CHEMICAL* 270 482-491 - DOI : 10.1016/j.snb.2018.05.033
- Parant M., Perrat E., Wagner P., Rosin C., Py J.-S., Cossu-Leguille C. (2018) Variations of anthropogenic gadolinium in rivers close to waste water treatment plant discharges. *ENVIRONMENTAL SCIENCE AND POLLUTION RESEARCH* 25 36207-36222 - DOI : 10.1007/s11356-018-3489-6
- Potet M, Giambérini L, Pain-Devin S, Catteau A, Pauly D, Devin S 2018. Impact of multiple stressors on biomarker responses in sympatric dreissenid populations. *Aquatic Toxicology* 203 (2018) 140–149
- Potet, M., Giambérini, L., Pain-Devin, S., Louis, F., Bertrand, C., Devin, S., 2018. Differential tolerance to nickel between *Dreissena polymorpha* and *Dreissena rostriformis bugensis* populations. *Scientific Reports* 8. <https://doi.org/10.1038/s41598-018-19228-x>
- Romero-Freire A, Minguez, L, Pelletier M, Cayer A, Caillet C, Devin S, Gross EM, Guerold F, Pain-Devin S, Vignati DAL, Giamberini L. 2018. Assessment of baseline ecotoxicity of sediments from a prospective mining area enriched in light rare earth elements. *SCIENCE OF THE TOTAL ENVIRONMENT*. 612 : 831-839
- Tapia, J., Davenport, J., Townley, B., Dorador, C., Schneider, B., Tolorza, V., et al. (2018). Sources, enrichment, and redistribution of As, Cd, Cu, Li, Mo, and Sb in the Northern Atacama Region, Chile: Implications for arid watersheds affected by mining. *Journal of Geochemical Exploration*, 185, 33–51.
- Torres, M. A., Paris, G., Adkins, J. F., & Fischer, W. W. (2018). Riverine evidence for isotopic mass balance in the Earth's early sulfur cycle. *Nature Geoscience*, 11(9).
- Town R.-M., Duval J.-F.-L., van Leeuwen H.-P. (2018) The Intrinsic Stability of Metal Ion Complexes with Nanoparticulate Fulvic Acids. *ENVIRONMENTAL SCIENCE & TECHNOLOGY* 52 11682-11690 - DOI : 10.1021/acs.est.8b02896
- Vincent Q, Auclerc A, Beguiristain T and LEYVAL C, 2018, Assessment of derelict soil quality: abiotic, biotic and functional approaches. *Science of the Total Environment*, 613, 990-1002
- Yang, W. J., Ding, K. B., Zhang, P., Qiu, H., Cloquet, C., Wen, H. J., et al. (2018). Cadmium stable isotope variation in a mountain area impacted by acid mine drainage. *Science of the Total Environment*, 646, 696–703.

Modelling

2018

- Caumon G. (2018) Geological Objects and Physical Parameter Fields in the Subsurface: A Review, *Handbook of Mathematical Geosciences*, 567-588, https://doi.org/10.1007/978-3-319-78999-6_28
- Chauvin B. P., Lovely P. J., Stockmeyer J. M., Plesch A., Caumon G., Shaw J. H. (2018) Validating novel boundary conditions for three-dimensional mechanics-based restoration: An extensional sandbox model example, *AAPG*, 102, 245-266, DOI:10.1306/0504171620817154
- Godefroy G., Caumon G., Ford M., Laurent G., Jackson C; A.-L. (2018) A parametric fault displacement model to introduce kinematic control into modeling faults from sparse data, *Interpretation*, SAGE Publications, 6(2), B1-B13, 10.1190/INT-2017-0059.1
- Hajjar A., Scholtès L., Oltéan C., Buès M. A. (2018) Effects of the geometry of two-dimensional fractures on their hydraulic aperture and on the validity of the local cubic law, *Hydrological Processes*, 1-16, <https://doi.org/10.1002/hyp.13181>
- Paul, B., Faivre, M., Massin, P., Giot, R., Colombo, D., Golfier, F., Martin, A., 2018. 3D coupled HM-XFEM modeling with cohesive zone model and applications to non planar hydraulic fracture propagation and multiple hydraulic fractures interference. *Computer Methods in Applied Mechanics and Engineering*. <https://doi.org/10.1016/j.cma.2018.08.009>



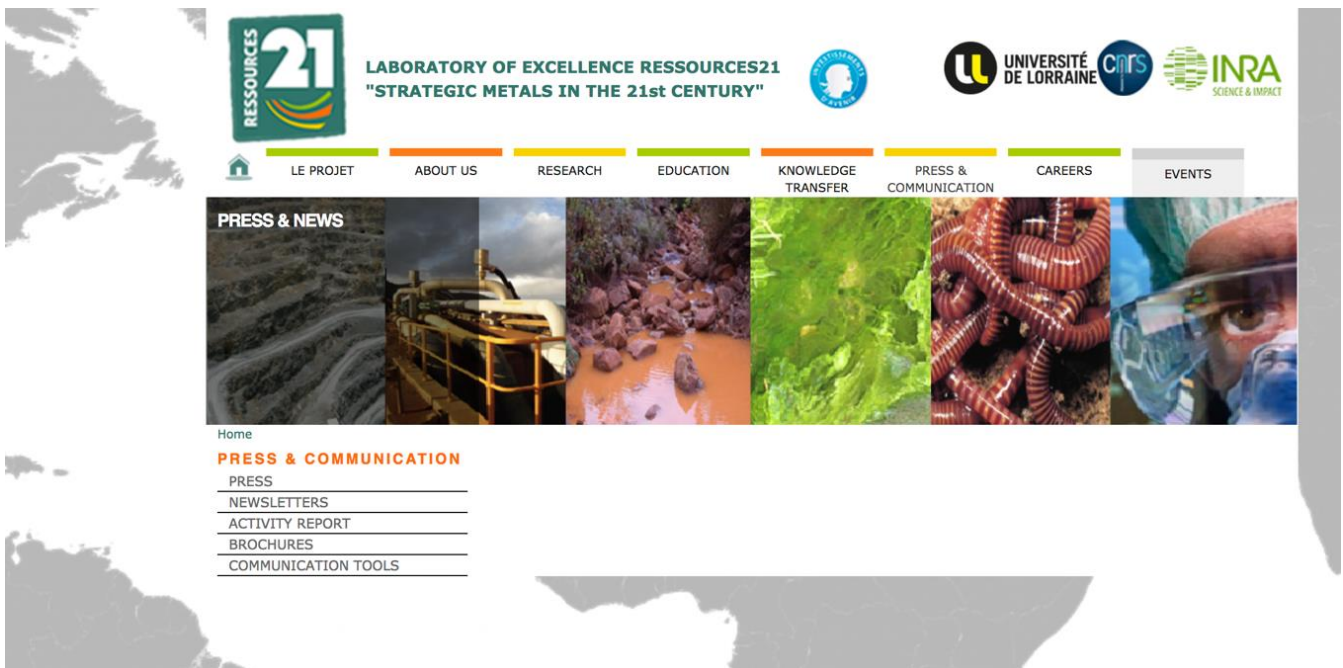
Social sciences

- Chailleux, S., Merlin, J., Gunzburger, Y., 2018. Unconventional oil and gas in France: From popular distrust to politicization of the underground. *The Extractive Industries and Society*. <https://doi.org/10.1016/j.exis.2018.05.007>

Information Resources

All reports and data can be found on the Labex RESSOURCES21 website:

<http://ressources21.univ-lorraine.fr/>



Annual reports



LABORATORY OF EXCELLENCE RESSOURCES21
STRATEGIC METALS IN THE 21ST CENTURY

ANR-10-LABX-21-01
www.ressources21.univ-lorraine.fr



UNIVERSITÉ
DE LORRAINE



LabEx RESSOURCES21