

Proceedings of the 3rd IAGC International Conference

Water-Rock Interaction - 18 & Applied Isotope Geochemistry - 15
Cagliari, Italy, 16-21 June 2025

UNICApress/ateneo

edited by
Franco Frau, Richard B. Wanty,
Elisabetta Dore, Dario Fancello



RESOCONTI /14

The third IAGC International Conference, held in Cagliari (Sardinia, Italy) in June 16-21, 2025, was widely attended by researchers from around the world. This resulted in the present volume of proceedings containing as many as 308 abstracts, both short and extended, distributed among 22 sessions in addition to the plenary sessions. The subjects covered in the abstracts span numerous topics in geochemistry, from low to high temperature, from frozen to hydrothermal systems, and natural and manmade environments.

The conference was hosted by the Department of Chemical and Geological Sciences at the University of Cagliari (UNICA).

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Cagliari
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2025

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Indice

25 PREFACE

27 PLenary SESSIONS

Application of environmental isotopes in mining environments

Aravena, R.

Trace metal at the crossroad between metabolic diversity and the evolution of biogeochemistry

Giovannelli, D.

Isotopes at the interface between the mantle and the crust

Pinti, D.L.

Geological storage of carbon dioxide through carbon mineralization

Snæbjörnsdóttir, S.Ó., Marieni, C., Sigfússon, B., Kapatza, A., and Aradóttir, E.S.

Superhot geothermal resources - the next generation of geothermal energy

Stefánsson, A., Scott, S.W., and Driesner, T.

51 SESSION 1. GEOTHERMAL SYSTEMS AND VOLCANISM: FROM HAZARD ASSESSMENT TO GEOTHERMAL RESOURCES

Hydrothermal systems of lithospheric plates margins

Auzina, L.I., Yoshe, A.K., and Didenkov, Yu.N.

Laboratory earthquakes under hydrothermal conditions in Neapolitan Yellow Tuff (Campi Flegrei, Italy)

D'Ippolito, G., Tesei, T., Gomila, R., Piochi, M., and Di Toro, G.

Compositional reconstruction of geothermal waters of İstanbul (Türkiye) by numerical geochemical modelling

Ozcan, D., Beren, M., and Hosgormez, H.

Geological model of supercritical geothermal energy in subduction zone as terrestrial energy system

Tsuchiya, N.

UAV-based volcanic morphometry of monogenetic volcanoes: Insights from Inner Mongolia, China

Wang, L., Zhao, Y., and Li, N.

Sources of lithium, rubidium, and cesium in geothermal waters of the Yangbajain-Gulu Rift Valley: Evidence from geochemical and water-rock interactions

Duan, J., Kong, Y., Zhang, W., and Liu, M.

Estimation of reservoir temperatures in the geothermal field of the Central Baikal Rift Zone (Russia)

Zippa, E.V.

65 SESSION 2. VOLATILE FLUXES AND GEOCHEMICAL TRACERS AT VOLCANIC, GEOTHERMAL AND TECTONICALLY ACTIVE REGIONS

Soil gas CO₂ flux in the Theistareykir geothermal field, NE Iceland

Aðalsteinsdóttir, S.M., Clark, D.E., Óladóttir, A.A., Óskarsson, F., and Sigurðardóttir, Á.K.

Chlorine isotope ($\delta^{37}\text{Cl}$) systematics in hydrothermal fluids and volcanic gases across diverse tectonic settings

Aðalsteinsdóttir, S.M., Stefánsson, A., Barnes, J.D., and Mandon, C.L.

The shape of compositional anomalies caused by magma degassing events and implications for the current unrest at Campi Flegrei

Chiodini, G.

Deep geogenic degassing along an active fault system in the Osmaniye Province of Turkey

D'Alessandro, W., Yüce, G., Italiano, F., Fu, C.C., Li Vigni, L., Elmacı, H., İçhedef, M., Kürkcüoğlu, B., Kahraman, B., Demirtaş, A., and Lin, L.H.

Tectonic degassing from South-Eastern Europe: Preliminary results from Albania and Kosovo

Li Vigni, L., Calabrese, S., Ionescu, A., Abdullahi, S., Pilana, E., Hajra, A., and D'Alessandro, W.

Magmatic volatiles in the Yellowstone Plateau volcanic field: The knowns, the unknowns, and the uncertainties

Hurwitz, S., and Lowenstern, J.B.

Carbonyl Sulfide (COS) and other sulphur-bearing trace compounds in volcanic and geothermal discharges: New geoindicators for better characterization of fluid source(s)

Lelli, M., Bini, G., Caliro, S., Chiodini, G., Dallara, E., and Marini, L.

Fluid sources and reservoir processes in the Krafla-Námafjall geothermal system, Iceland from $\delta^{18}\text{O}$, $\delta^2\text{H}$, $^{87}\text{Sr}/^{86}\text{Sr}$ and noble gas isotopes on well fluid samples

Mattioli, J., Pinti, D.L., Berlo, K., van Hinsberg, V., Sigurðardóttir, A.K., Alfreðsson, H.A., and Gautason, B.

Noble gas isotopes and fractionation processes illustrate deep groundwater flow and radiogenic volatile scavenging in a low-temperature continental geothermal system

Newman, C.P., Hunt, A.G., Seltzer, A.M., Pepin, J.D., and Robertson, A.J.

Geochemistry of light hydrocarbons and redox conditions in hydrothermal systems: New insights from fumarolic gases of Vulcano Island, southern Italy

Ricci, A., Fiebig, J., Tassi, F., Hofmann, S., Capeccchiacci F., and Vaselli, O.

Temporal evolution of noble gases in volcanic fumaroles at Vulcano Island (southern Italy): Preliminary insights from a year-long geochemical monitoring

Ricci, A., Romano, P., La Pica, L., and Federico, C.

Diffuse soil CO_2 flux variation at the western base of La Fossa cone of Vulcano (Aeolian Islands, Italy)

Tarchini, L., Ranaldi, M., and Carapezza, M.L.

Geochemical estimation of the total natural CO_2 output from the City of Rome

Tarchini, L., Carapezza, M.L., and Ranaldi, M.

Deep CO_2 transported by Apennine rivers: Fluxes quantification and implications for the development of a geochemical monitoring network of seismicity

Tieri, M., Cardellini, C., Chiodini, G., Caliro, S., Frondini, F., Cinti, D., Barberio, D., Di Renzo, D., Santi, A., Cuoco, E., Rufino, F., and Caracausi, A.

Exceptionally low mercury emissions from volcanic and geothermal activity in Iceland

Edwards, B.A., Outridge P.M., and Wang, F.

103 SESSION 3. CARBON CAPTURE AND STORAGE AND HYDROGEN FOR ENERGY TRANSITION

Carbon mineralization from mafic, ultramafic rocks and alkaline industrial waste products

Bénézech, P., Saldi, G., Marieni, C., Barré, H., Blotvogel, S., Patapy, C., and Castillo A.

Mining and industrial waste: A mechanochemical approach to CO_2 mitigation

Cau, C., Mameli, P., Murgia, F., Garroni, S., and Mulas, G.

Interaction between marly-limestone and H_2S -saline solution: Application to underground hydrogen storage

Ceballos, E., Cama, J., and Soler, J.M.

A geochemical assessment of Carbon Capture and Mineralization for the Olkaria IV Geothermal Plant, Kenya

Barlow, C.S.J., Clark, D.E., Kleine-Marshall, B.I., Davíðsdóttir, B., and Stefansson, A.

Geological CO_2 storage in Switzerland: Insights from numerical simulations

Gunatilake, T., Zappone, A., Zhang, Y., Zbinden, D., Mazzotti, M., and Wiemer, S.

Abiotic mineral-fluid-gas reactivity in underground H_2 storage: A kinetic rate law for reductive pyrite dissolution from 60-150 °C and up to 150 bar H_2

Hintzen, R., van Winden, J., Hellmann, R., and Truche, L.

Climate change: Direct CO_2 capture to limit global warming to 1.5 °C

Kharaka, Y. K.

Reactive transport modelling of CO_2 storage and the fate of calcite in clastic reservoirs, seals and baffles

Kirste, D.M., Dawson, G.K.W., Pearce, J.K., and Golding, S.D.

Geochemical modeling of CO_2 storage in the Lyons Formation: Are equilibrium assumptions sufficient?

Littlefield, A.A., and Navarre-Sitchler, A.K.

Bridging numerical predictions and experimental realities: CO_2 mineralization in basaltic rocks

Masoudi, M., Nooraiepour, M., and Hellevang, H.

Salt precipitation dynamics in saline aquifers during geological CO_2 storage: Role of continuous brine access and its implications for injectivity and containment integrity

Nooraiepour, M., Masoudi, M., and Hellevang, H.

Natural hydrogen exploration in Italy: Geologic suitability, prospects, and current challenges

Ogunyele, A.C., Aldega, L., Billi, A., Botteghi, S., Caracusi, A., Carminati, E., Lelli, M., Schirripa Spagnolo, G., Smeraglia, L., Correale, A., and Boschi, C.

Carbon storage through mineral carbonation: Potential in the Iblean Plateau, Sicily (Italy)
 Castellari, I., Ganci, F., Baneschi, I., Dini, A., Marieni, C., Rielli, A., Snaebjornsdottir, S., Sigfússon, B., Trumpp, E., and Boschi, C.
CO₂ storage in serpentinised peridotites: Complete serpentine carbonation and metal mobilisation during the formation of magnesite deposits in the Ligurian Ophiolites
 Rielli, A., Baneschi, I., Dini, A., and Boschi, C.
Modelling and laboratory studies of fluid-solid interaction during H₂ injection
 Vujević, I., Truche, L., Magnin, V., Jelavić, S., Grekov, D., and de Rango, P.
Enhancing mineral carbonation through molecular simulations on mineral surfaces
 White, J.J., Mei, Y., Xing, Y., and Liu, W.
What controls mineral sequestration in basaltic terrains?
 Wolff-Boenisch, D., and Vialle, S.
Laboratory experiments and geochemical models for CO₂ mineralization in basalts
 Yakisik, O., Orlando, A., Borrini, D., Gherardi, F., Ruggieri, G., and Toscani, G.

147 SESSION 4. GEOTHERMAL AND SUSTAINABLE ENERGY

Circulation dynamics, recharge altitudes, and geochemical evolution of South Korean deep thermal groundwater: An integrated approach using environmental tracers and hydrochemical variables
 Choi, J., Lee, J.-H., Seo, H., Ahn, H.T., and Yun, S.-T.
Isotope tracers for the investigation of the water recharge at Le Biancane, Larderello geothermal system (Tuscany, Italy)
 Dallara, E., Fulignati, P., Gioncada, A., and Lelli, M.
Numerical modeling of acid fracturing in carbonate geothermal reservoir: A case study of the Well D22 in Xiong'an, Hebei Province, China
 Feng, B., Cui, Z.P., Wang, D., and Cui, R.
Insights from helium and heat flow in geothermal areas: The role of dedicated databases
 Bellani, S., Magro, G., and Gherardi, F.
Water chemistry and fracture mineralogy to investigate water-rock interactions in enhanced geothermal systems
 Kirshen, A.B., Swager, K., and Navarre-Sitchler, A.
Genesis of travertine in high-temperature geothermal system in Tibetan Plateau
 Li, Y.M., Pang, Z.H., Li, B., Gao, B.B., Huang, T.M., and Zhao, Y.J.
Feasibility study on efficient reinjection of exogenous and homologous water into carbonate geothermal reservoirs
 Li, Y.M., Pang, Z.H., Li, B., Gao, B.B., and Huang, T.M.
Characteristics and formation mechanism of medium-temperature geothermal water in Lantian, Ningdu, Jiangxi province, China
 Liu, J., Qin, Q., Chen, G., and Shi, X.
Solubility of anhydrite and calcite in supercritical water from 380 °C to 625 °C and 220 bar to 270 bar
 Rendel, P.M., Mountain, B.W., Sajkowski, L., and Kamiya, A.
Design and development of modular nanoparticle-based tracers for geothermal reservoir exploration
 Spitzmüller, L., Berson, J., Schimmel, T., Kohl, T., and Nitschke, F.
Increasing the efficiency of geothermal power plants by coupling with artificial intelligence
 Trumpp, M., Ystroem, L.H., Eichinger, F., Amtmann, F., Winter, D., Koschikowski, J., Nitschke, F., and Kohl, T.
Experimental and modeling study on the multiphase reactive transport under supercritical geothermal conditions
 Xu, T.F., Zhong, C.H., Feng, G.H., Yuan, Y.L., and Gong, Y.
The evolution law of permeability in rough fractures under stress: Insights into the sustainable development of geothermal energy
 Yuan, Y.L., Zhong, C.H., Zhang, X.L., and Xu, T.F.
Hydrogeochemical processes in the high-temperature geothermal system of Rehai, Tengchong, China
 Yue, G., Gherardi, F., and Zhang, W.
Experimental study on the effect of quartz dissolution/precipitation on granite fracture permeability under supercritical geothermal conditions
 Zhong, C.H., Xu, T.F., Yuan, Y.L., and Feng, G.H.

177 SESSION 5. ISOTOPIC TOOLS AND APPLICATIONS FOR SUSTAINABLE WATER MANAGEMENT,
MINING-RELATED SETTINGS, ENVIRONMENTAL SCIENCES, AND THE ENERGY TRANSITION

Comparative hydrogeochemical and isotopic insights into lithium enrichment in hyperarid salar systems of northern Chile

Álvarez-Amado, F., Tardani, D., Poblete-Gonzalez, C., Matte-Estrada, D., Poncell, B., and Godfey, L.

Integrating limnological and isotopic analyses to design geothermal heat pump systems at flooded open pit mines: The case of two former asbestos mines in Quebec, Canada

Bordeleau, G., Goldoni De Souza, M., Raymond, J., and Comeau, F.X.

The isotope composition of clay (Pb, Sr, Nd) as a proxy for provenance study

Harlavan, Y., Morag, N., Ryb, U., and Berlin, O.

In-situ trace element and sulfur isotopes of pyrite constrain molybdenum enrichment and ore genesis in a hydrothermal vein system

Hu, X.K.

Tracing heavy metal contamination in drainage water of abandoned mine sites with Rare Earth Element and Antimony isotope fractionation

Kraemer, D., Kaufmann, A., Viehmann, S., Hering, S., and Weyer, S.

In situ $\delta^{34}\text{S}$ and $\delta^{33}\text{S}$ isotope analyses by UV-fs-MC-ICP-MS

Lazarov, M., and Horn, I.

Isotope compositions of CBM production waters in Russia as a result of long-term interaction in the water-rock-methane-coal system

Lepokurova, O.E., and Domrocheva, E.V.

Sulfur isotopes as a new indicator for the maturity degrees of submarine hydrothermal systems

Meng, X., Li, X., Holzheid, A., Zoheir, B., and Jin, X.

Metal content and Pb, Zn isotopic signatures across different types of dust originating from E-waste processing: Impact of decomposition methods

Martinková, E., Šebek, O., Andronikov, A., Štěpánová, M., Čuřík, J., Veselovský, F., and Čvančarová, Z.

Isotopic fractionation of O_2 during enzymatic and photochemical O_2 consumption: Mechanistic insights and relevance for field studies

Pati, S.G., de Carvalho, C.F.M., Brunner, L.M., and Lehmann, M.F.

Development and application of isotope techniques for efficient water resources management in mining areas: Results from an IAEA Coordinated Research Project (F33026)

Sacchi, E., Cardona Benavides, A., Chajduk, E., De Carvalho Filho, C.A., Dong, Y., Ghaffar, A., Gurmessa, S.K., Hendry, M.J., Huneau, F., Jiménez Oyola, S.T., Mhizha, A., Oyarzún Lucero, R.A., Panasiuk, M., Qurtobi, M., Rai, S.P., Ramaroson Eprasolofonirina, V., Samaniego, J., Vitvar, T., and Saravana Kumar, U.D.

Using $\delta^{18}\text{O}$ and $\delta^2\text{H}$ to refine the conceptual groundwater circulation model at the former Balangero asbestos mine (Northern Italy)

Sacchi, E., Fornelli Genot, S., and Soldi, G.L.

Hydrogeochemical, isotope and geophysical studies applied in lithium resource research (Hungary)

Szűcs, T., Gál, N., Vári, Z., Szűcs, A., Bauer, M., Csató, I., and Falus, Gy.

Unconventional lithium mineralization: Unconventional surficial media geochemistry?

Voinot, A., Mloszewski, A., Moore, L., Rossiter, S., Lintell, M., and Day, S.

Lead (Pb) isotope geochemistry of global phosphate rocks: Implications for environmental tracing

Wang, Z., Hill, R., Williams, G., Dwyer, G.S., Hu, J., Schnug, E., Bol, R., Sun, Y., Coleman, D.S., Liu, X.M., Sandstrom, M.R., and Vengosh, A.

Assessing the impact of oil and gas wastewater on freshwater mussels: Geochemical and ecotoxicological insights

Warner, N.R.

The origin of Lithium at the Salar de Uyuni: A multi-isotope and elemental approach

Williams, G.D.Z., Hall, G.A., Hill, R.C., Petrović, M., Louvat, P., Berail, S., Barre, J., Millot, R., Warner, N.R., Baker, P., and Vengosh, A.

211 SESSION 6. ADVANCEMENTS IN GROUNDWATER AGE DATING

³⁹Ar analysis in rocks for surface exposure dating and for studying underground production

Cymanek, L., Neumann, F.P., Arck, Y., Hieronimus, E.G.E., Junkermann, A., Meienburg, F.N., Wachs, D., Gardner, W.P., Schaefer, J.M., Ritterbusch, F., Oberthaler, M., and Aeschbach, W.

Inter-comparison between ⁸¹Kr and ¹⁴C dating of groundwater

Li, H., Jiang, W., Yang, G., and Lu, Z.

Water rock interaction and mixing of deep thermal groundwater revealed by ⁸¹Kr, ¹⁸O and ⁸⁷Sr-isotopes in the Austrian Alpine Foreland Basin

Kralik, M., and Heidinger, M.

A user-friendly software for unified Bayesian Inference of Transit Time Distributions and its application to groundwater

Negele, S.H., Noll, J., Meienburg, F.N., Scott, S.M., Neuner, L.J., and Aeschbach, W.

Tracing water budget changes using dynamic groundwater residence times in the Upper Colorado River Basin

Newman, C.P., and Palko, K.M.

Integrating U-Th/⁴He and ¹⁴C dating to constrain geothermal fluid residence time in a volcanic arc setting

Poblete-Gonzalez, C., Tardani, D., Saldias, C., Álvarez-Amado, F., and Pinti, D.L.

Practical applications of the combined use of ⁸⁵Kr and ³H/³He dating for hydrological studies

Purtschert, R., and Sültenfuss, J.

Groundwater age dating using basinal Helium diffusion profile

Soud, F.A., Mutairi, S., Hillegonds, D., Kazak, E., Shouakar-Stash, O., Cheng, A., and Ballentine, C.

High Argon-39 concentrations in groundwater of a mountain hillslope in the East River Watershed, Colorado, USA

West, C.E., Thiros, N.E., McGillen, H., Urbach, K.L., Wachs, D., Neumann, F.P., Oberthaler, M., Aeschbach, W., and Gardner, W.P.

227 SESSION 7. STABLE ISOTOPES IN FOOD AND CONTAMINATION TRACKING

Source apportionment of polycyclic aromatic compounds in the Athabasca River with dual compound-specific isotopes ($\delta^{13}\text{C}$ and $\delta^2\text{H}$)

Alam, Md-S., Ahad, J.M.E., and Cooke, C.A.

*Multi-isotopic provenancing of irrigated agricultural products: A case study of *Vitis vinifera* to examine the impact of farm practices on food isotope signatures*

Bunney, E., Welty, N., Petrie, P., Pritchard, J., and McNerney, F.A.

Compound specific isotope analysis (CSIA) of contaminants of emerging concern (CECs) in water treatment systems: Methodological advances and field applications

Caballero-Alcazar, N., Nascimento, R.C., and Torrentó, C.

Referencing strategies for position-specific isotope analysis of sulfa-methoxazole by ESI-Orbitrap

Canavan, A., Precht, L., and Elsner, M.

Unlocking stable isotopes for PFAs compounds: A new CSIA method

Di Marcantonio, E., Shouakar-Stash, O., Marchesi, M., and Dallai, L.

Decoding siderite: Insights into sample processing for clumped isotope analysis

Fosu, B.R., and Josué, J.J.

Dual C-Cl isotope analysis allowed identification of different tri-chloromethane transformation reactions during alkaline persulfate activation under different simulated field conditions

Gil-Villalba, S., Rosell, M., Torrentó, C., Vinyes-Nadal, M., Soler, A., and Palau, J.

Metals in honey: A biomonitoring tool for environmental contamination across the United States

Godebo, T.R., Stoner, H., Kodsup, P., and Jeuland, M.

Strontium isotope ratio (⁸⁷Sr/⁸⁶Sr) as a marker for the geotracerability of the Falanghina del Sannio (South of Italy) white wine

Mercurio, M., Tranfa, P., Izzo, F., Cappelletti, P., Di Renzo, V., Grifa, C., Guarino, C., Mercurio, V., Zuzolo, D., D'Antonio, M., and Langella, A.

Compound Specific Isotopes Analysis (CSIA) to assess degradation of MTBE and ETBE at contaminated gasoline station sites

Di Marcantonio, E., Marchesi, M., Villalba, G.S., and Dallai, L.

Preliminary study on multi-isotopic analysis for the geographical authentication of almonds

Nicotra, S.B., Rovira, M., Romero, A., Soler, A., Padró, A., Pena, L.D., Guardiola, F., Tres, A., Vichi, S., and Rosell, M.

Toward greater transparency: Stable isotopes and explainable Machine Learning solutions for food traceability

Ogrinc, N., Drole, J., and Eftimov, T.

Preliminary results of an automated flow-injection method for analysis of $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ of benzoic acid by Orbitrap-IRMS

Pati, S.G., Groß, M., and Göldner, V.

Position-specific isotope analysis of serine using ESI-Orbitrap

Precht, L., Seidel, M., Eisenreich, W., and Elsner, M.

Characterization of a monochlorobenzene-contaminated site using multi-element compound-specific isotope analysis (CSIA), molecular biological techniques (MBTs), and numerical modeling

Marchesi, M., Pietrini, I., Antelmi, M., Alberti, L., Stella, T., Franzetti, A., Antonelli, D., de Ferra, F., Aravena, R., and Shouakar-Stash, O.

Puzzle game of isotope effects: Fingerprint and reconstruct the fates of organic molecules

Wang, C.

Authenticating the origin of maple syrups in Quebec, Canada: A new tool based on the study of strontium isotopes

Saar de Almeida, B., Widory, D., Stevenson, R., Sadiki, M., and Lagac, L.

255 SESSION 8. ISOTOPES IN WATER RESOURCES, HYDROTHERMAL SYSTEMS,
AND ENVIRONMENTAL PROCESSES

Isotopic composition ($\delta^{18}\text{O}$, $\delta^2\text{H}$, $^3\text{He}/^4\text{He}$, $\delta^{13}\text{C}$, $^{87}\text{Sr}/^{86}\text{Sr}$) of groundwaters, surface waters, ground ice and travertines of the Oka Plateau, Eastern Sayan Ridge (Russia)

Alexeev, S.V., Alexeeva, L.P., Svetlakov, A.A., Pellinen, V.A., Orgil'yanov, A.I., Badminov, P.S., and Gutareva, O.S.

Genesis of the salt component of thermomineral waters of intermountain basins and mountain-folded regions

Baranovskaya, E.I., Kharitonova, N.A., and Chelnokov, G.A.

Hydrogeochemistry of natural mineral waters in the Issyk-Kul Basin (Tien Shan Region)

Baranovskaya, E.I., Kharitonova, N.A., and Chelnokov, G.A.

New concept for identifying a typical expected isotopic range of denitrification for nitrate-impacted groundwaters

Boumaiza, L., Stotler, R. L., Mayer, B., Matiatos, I., Sacchi, E., Otero, N., Johannesson, K. H., Huneau, F., Chesnaux, R., Blarasin, M., Re, V., and Knöller, K.

A new approach for studies of atmospheric deposition: Boron and strontium isotopic fingerprints in rain-water from urban, industrial, rural, and volcanic areas of Sicily, Italy

Brugnone, F., Salvadori, M., Pennisi, M., Brusca, L., D'Alessandro, W., Parello, F., and Calabrese, S.

Feasibility of using agro-industrial by-products to induce denitrification in the Campo de Cartagena Aquifer (Murcia, Spain)

Escalona-Orellana, H., Margalef-Martí, R., Luque, J.M., Jiménez-Guñe, J.H., Soler, A., Otero, N., Robles-Arenas, V.M., Morales, S., Manzano, M., Ros, N., Gros, M., and Mas-Pla, J.

Isotopic composition ($\delta^{18}\text{O}$ and $\delta^2\text{H}$) of mobile and bound water within mud volcanoes in the southern part of the West-Kuban trough

Kharitonova, N.A., Kazak, E.S., Chelnokov, G.A., and Lavrushin, V.Yu.

Determination of ^{18}O and ^2H in rain, surface, and groundwaters in Baja California

Kretzchmar, T.G., Espinosa, A.K., Cavazos, T., Pacheco, M., and Andrade, L.

Characteristics of boron isotopes and their indicative significance in groundwater arsenic mobilization from an alluvial basin

Lei, C., Guo, H., Ming, X., Xing, S., Liu, Y., and Jiang, X.

The contribution of microbial cycling to the enrichment of dissolved phosphate in floodplain aquifers

Li, Y., Guo, H., Oelmann, Y., and Neidhardt, H.

Isotopic indicators and chemical properties of glacial lakes at Adygene glacier complex, Northern Tien Shan
Lyamina, L.A., Erokhin, S.A., Omorova, G.K., Ermakov, A.V., Orolbaeva, L.E., Kapakly, V.S., and Filimonova, E.A.

Evaluating biostimulation efficiency in a constructed wetland to treat nitrate pollution with isotopic tools
Margalef-Marti, R., Escalona-Orellana, H., Barbieri, M., Causapé, J., Otero, N., and Soler, A.

Clumped isotopes of abiotic methane to investigate origins and formation temperatures in serpentinized peridotites of the Ronda Peridotite Massifs, Southern Spain

Ojeda, L., Etiope, G., Jiménez-Gavilán, P., Martono, I.M., Röckmann, T., Popa, M.E., Sivan, M., Castro-Gámez, A.F., Benavente, J., and Vadillo, I.

Cross-correlation analysis of water stable isotope time series in a river-dominated alluvial aquifer (Zagreb aquifer, Croatia)

Parlov, J., and Kovač, Z.

Application of Ca and Sr isotopes to understanding water-rock interactions and pore fluid stability in an Archean age pluton

Schulz, M.P., Frape, S.K., Yakymchuk, C., Stotler, R.L., Makahnouk, W.R.M., and Eichinger, F.

297 SESSION 9. ISOTOPES IN THE CRITICAL ZONE AND THE GEOCHEMISTRY OF AIR

CONTAMINANTS: SOURCES AND PROCESSES

Quantifying denudation and uplift in the Albanides using cosmogenic nuclides: Insights from in situ ^{10}Be and meteoric $^{10}\text{Be}/^9\text{Be}$

Bazzucchi, C., Wittmann, H., Crosetto, S., Ballato, P., Faccenna, C., and Rossetti, F.

Variable coalbed methane provenance in underground mine workings: Gas and water isotopic study

Bezyk, Y., Szurgacz, D., Górka, M., Strapoć, D., Wachniew, P., Nęcki, J., Modelska, M., van der Veen, C., and Röckmann, T.

New metal isotope proxy for tracing continental weathering

Chen, J.B., Zheng, W., Yuan, W., Cai, H.M., and Gao, X.

Main sources and mechanisms controlling chlorine and bromine isotopic ratios in saline lakes: A case study from Transbaikalia

Drebot, V., Borzenko, S., Shouakar-Stash, O., and Stotler, R.

Carbon isotope fractionation during CO_2 invasion and its impact on DIC and organic matter carbon isotope composition

Gavrieli, I., Younkin, A.D., Fontana, C.G., McGlynn, S.E., Hurley, S.J., and Wing, B.A.

Iron isotopes in anoxic basement fluids, Forsmark area, Sweden

Krall, L. M., and Mercier, L. A.

Isotope exchange in mineral-fluid systems at near chemical equilibrium conditions

Mavromatis, V., Harrison, A.L., van Zuilen, K., and Schott, J.

Chemical and C and N stable isotope compositions of three species of epiphytic Tillandsia in a Caribbean coastal zone: Air pollution sources and biomonitoring implications

Morera-Gómez, Y., Armas-Camejo, A., Santamaría, J.M., Alonso-Hernández, C.M., Lasheras, E., Widory, D., and Elustondo, D.

Contribution of Radium isotopes to the alkaline-earth cations cycle in soils

Rihs, S., Lascar, E., Chabaux, F., Pourcelot, L., Calmon, P., Redon, P.O., Galy, C., and Turpault, M.P.

Identifying sources of Br and processes affecting Br concentrations in Shield environments

Schulz, M.P., Visram, A.K., Frape, S.K., Stotler, R.L., Makahnouk, W.R.M., Blomqvist, R., and Ruskeeniemä, T.

Amorphous silica vs short-range ordered hydroxyaluminosilicate formation – Reaction kinetics, transition stage and Si isotope fractionation

Stamm, F.M., Baldermann, A., Frick, D.A., Frings, P.J., Pettau, M., Wilkening, H.M.R., Marko, A., von Blanckenburg, F., Schott, J., and Dietzel, M.

Isotope tracing of lithium contamination and its environmental impact

Vigier, N., Araùjo, D.F., Poet, M., Jouini, A., Payant, L., Montanes, M., De Tourdonnet, C., Uher, E., Counillon, L., Grouhel-Pellouin, A., and Metian, M.

Jury is still out on the origin of S-MIF in urban atmospheric sulfate aerosols

Dasari, S., and Widory, D.

325 SESSION 10. NANOPARTICLES AS DRIVERS OF BIOGEOCHEMICAL BEHAVIOR

Transformation of ferrihydrite to hematite/goethite in salt solutions: Implications for the rare detection of goethite on Mars

Fukaya, S., Fukushi, K., and Takahashi, Y.

U(VI) partitioning on monohydrocalcite by adsorption and coprecipitation during transformation under high pH conditions: Implications for U(VI) accumulation in alkaline lakes

Morita, Y., Fukushi, K., An, D., Gankhurel, B., Davaadorj, D., and Takahashi, Y.

Sulfidation of iron oxides enhances carbon fixation by sulfur-reducing bacteria in hydrothermal environments

Liu, J., Liu, B., Deng, Y., Chen, J., and Ding, Y.

Elucidating the structure of labile Fe(III) using X-ray spectroscopy – A key reactive intermediate to iron oxide phase transitions in aqueous solution

Rosso, K.M., Li, X., Latta, D., Colina-Ruiz, R., Zhang, X., and Sokaras, D.

The influences of Fe(II) supply rates and extracellular polymeric substances on ferrihydrite nanoparticle biotransformation

Sheng, A., Ding, Y., Deng, Y., Li, X., Rosso, K.M., and Liu, J.

*Biorecovery of gold nanoparticles from industrial wastewaters by *Shewanella oneidensis**

Xie, J., Coker, V.S., Byrd, N., Haigh, S.J., Bueno, A., Sankar, M., and Lloyd, J.R.

337 SESSION 11. UNVEILING GEOSPHERE-BIOSPHERE INTERACTIONS IN SPACE AND TIME

Linking hydrothermal fluid geochemistry and microbial community patterns in Nisyros Island, Greece

Amico, F., Angelatou, V., Vimercati, L., Safitri, B., Fazi, S., Tassi, F., Vaselli, O., and Vougioukalakis, G.

Redox characters of subpermafrost groundwaters in deep crystalline rocks (west margin of the Greenland ice sheet)

Auqué, L., Gimeno, M., Claesson Liljedahl, L., Bomberg, M., Kalinowski, B., Tullborg, E-L., and Hobbs, M.

Electron shuttling of dissolved organic matter in high arsenic groundwater

Guo, H.M., Feng, X.J., and Li, Y.

*Root-mineral interactions and Sb uptake by *Dittrichia viscosa**

Medas, D., Dore, E., Fancello, D., Biddau, R., Musu, E., and Podda, F.

Karst geographies. Permeable metamorphoses of the landscape

Murru, M.

The tale of H₂ and hydrocarbons genesis from mid-ocean ridge to deep subduction settings recorded by the Monte Maggiore peridotite, Alpine Corsica (France)

Olivieri, O.S., Vitale Brovarone, A., Ressico, F., Fiebig, J., and Pastore, Z.

Energetic convergence nodes in high-altitude Andean hydrothermal systems: Microbial metabolic adaptation in extreme environments

Paquis, P., Pardo-Esté, C., Tapia, J., Florez, J., Pérez, V., Molina, V., Cornejo-D'Ottone, M., Pérez, P., Jeffrey, W.H., Calabrese, S., Quatrini, P., Tassi, F., and Hengst, M.B.

Imbalances in dissolved elemental export fluxes disclose “hidden” Critical Zone compartments

Uhlig, D., Sohr, J., and von Blanckenburg, F.

357 SESSION 12. GEOCHEMISTRY AND BIOMINERALIZATION ON EARTH AND PLANETARY BODIES IN THE SOLAR SYSTEM: OBSERVATIONS, EXPERIMENTAL STUDIES, MODELLING AND PERSPECTIVES

EXCITE²: A European network providing transnational access to state-of-the-art imaging facilities

Chogani, A., Plümper, O., ter Maat, G., Wessels, R., Amiri, H., and the EXCITE team

Microbial-mediated coprecipitation of Zn, Fe, and Mn in secondary minerals within a mine tailings drainage (Rio Roia Cani, Sardinia, Italy)

Guerrieri, S., Borrelli, M., Medas, D., De Giudici G.B., Sedda, L., Musu, E., and Perri, E.

Determining ⁸⁷Sr/⁸⁶Sr ratio in organic biominerals for environmental issues: Preliminary results on Staghorn and Jackstone calculi

Izzo, F., D'Antonio, M., Langella, A., Muslim, M., Pappalardo, L., and Mercurio, M.

Layered growth histories of polymetallic nodules from the Eastern and Western Clarion-Clipperton Zone as recorders of paleoenvironment: Insights from geochemical stratigraphy

Li, J., Wang, H., Yang, K., Zhu, Z., and Li, X.

Small- and Ultrasmall-Angle Neutron Scattering as a tool for characterization of geological structures and biomineralization processes

Littrell, K.C.

Biomineralization in extreme mining wastes and application of advanced techniques

Ambu, C., Birarda, G., Onnis, P., Sedda, L., Medas, D., Dore, E., Musu, E., Podda, F., and De Giudici, G.

Modelling of volatile volcanic outgassing and chemical speciation to investigate rocky planets atmospheres

Ortenzi, G.

Icy worlds habitability and the objectives of MAJIS, the imaging spectrometer on board the ESA JUICE mission to the Jupiter system

Piccioni, G., Poulet, F., Langevin, Y., and the MAJIS team

PETRAS summer school and research campaign: The island of Vulcano as analog for planetary exploration

Pisello, A., Ortenzi, G., Baqué, M., Poggiali, G., Urso, A.R.G., Boerner, J., Dodiya, J., Porreca, M., Irmisch, P., Riedel, C., Unnithan, V., Cassaro, A., Bohnhardt, T., Gwinner, A.K., Kraft, T., and Sohl, F.

What role does silica play in the dawn of life on planet Earth?

Román-Moreno, F.I., Reolid-Pérez, J., and Estrada-González, G.R.J.

Effect of the organic mineral on Mg/Fe fractionation during aqueous alteration of meteoritic material

Yoshihara, K., and Isobe, H.

Biogeosignatures of life-supporting gradients within the ocean habitats of icy moons: Perspectives from Planet Earth

Yücel, M., Alimli, N., Demir, N.Y., Cura, H., and Tüzün, S.

379 SESSION 13. INTEGRATING GEOCHEMICAL TOOLS FOR SUSTAINABLE GROUNDWATER MANAGEMENT: A MULTIDISCIPLINARY APPROACH

A parsimonious method to model the intrusion depth of environmental tracers in groundwater

Gerber, C., Suckow, A., and Mallants, D.

Groundwater-rock interactions and mixing in karst aquifers controlled by deep-seated faults: Hydrogeochemical and multi-isotopic insights from the Pontina Plain (Central Italy)

Gori, F., Barberio, M.D., Barbieri, M., Boschetti, T., Cardello, G.L., and Petitta, M.

Fate of nitrate in the unsaturated zone: Evidence from the Arborea Plain (Sardinia, Italy)

Lobina, F., Coppola, A., Vacca, A., Arras, C., Biddau, R., Porru, M.C., Podda, F., and Da Pelo, S.

Assessing groundwater-surface water interactions in an anthropized alluvial aquifer: A geochemical and isotopic study

Mahamat, H., Cognard-Plancq, A.L., Gibert, E., Barthelemy, N., and Savoye, S.

Integrating hydrogeochemistry and isotope hydrology for sustainable management of drinking water springs: The case of Capannori (Tuscany, Central Italy)

Natali, S., Raco, B., Stasi, G., Bucci, G. L., and Zanchetta, G.

Multi-isotopic characterization to trace nitrate sources: Results at country scale

Otero, N., Navarro-Ciurana, D., Culi, L., Soler, A., Pena, L.D., García-Solsona, E., García-Gscheidle, A., and Yuste, A.

Investigating hyporheic zone dynamics in the lower Flumendosa River valley (SE Sardinia, Italy) for groundwater resource management

Piscetda, F.A., Wanty, R., Arras, C., Porru, M.C., Podda, F., Musu, E., Biddau, R., Vacca, S., and Da Pelo, S.

Applying groundwater dating and isotopic analysis to a saline-intruded coastal aquifer

Porru, M.C., Manning, A., Arras, C., Lobina, F., Piscetda, F.A., and Da Pelo, S.

Geogenic and anthropogenic processes define the groundwater quality in a landfill site with a complex hydrogeological setting

Cisternino, A., Casentini, B., Amalfitano, S., Melita, M., and Preziosi, E.

Coupling environmental isotopes and organic pollutants to investigate the impact of wastewater treatment plants on groundwater

Tomei, A., Re, V., Raco, B., Ticciati, N., and Battaglini, R.

401 SESSION 14. HYDROGEOCHEMISTRY AND WATER QUALITY

Waters and ground ice geochemistry of the Oka Plateau, Eastern Sayan (Russia)

Alexeev, S.V., Alexeeva, L.P., Svetlakov, A.A., and Pellinen, V.A.

Travertine deposits of Greece: Mineralogical, chemical and isotopic characterization

Schifano, V., Li Vigni, L., Randazzo, L., Brusca, L., Bellomo, S., Calabrese, S., and D'Alessandro, W.

Geochemical and microbiological investigations of waters in the metropolitan area of the Palermo Plain and Oreto river (Sicily, Italy)

Bonafede, R., Li Vigni, L., Brugnone, F., Tripodi, F., Pedone, B., D'Alessandro, W., Brusca, L., Bellomo, S., Maida, C., Andolina, G., Tricoli, M.R., Aiello, P., Giudice, V., Balduccio, M., Spataro, S., Marino, G., and Calabrese, S.

Evaluation of recharge sources and nitrates origin in a karst spring: A case study from the F.na Nurighe spring (NW Sardinia, Italy)

Arras, C., Calia, M., Biddau, R., and Da Pelo, S.

Beyond CSIA: The role of environmental isotopes in contaminated site assessment - insights from Italian case studies

Caschetto, M., Oldani, E., Gil Villarba, S., Marchesi, M., and Alberti, L.

Hydrochemical characteristic of groundwater in Mahong Region, Jiangxi Province, China

Chen, G., Sun, Z., Liu, J., Huang, G., Yu, S., and Bai, X.

Study on the evolution and recharge capacity of carbonate geothermal system in the Taiyuan Basin, China

Chen, Z., Ma, T., Chen, L., and Zhang, L.

How paleoclimate-driven depositional evolution shaped high iodine aquifers in alluvial-lacustrine plains

Deng, Y.M., Xu, Z.L., Xue, J.K., Du, Y., and Wang, Y.X.

Geogenic phosphorus enrichment in groundwater due to anaerobic methane oxidation-coupled Fe(III) oxide reduction

Du, Y., Xiong, Y., Deng, Y., and Wang, Y.

Geochemical features and mineral-forming ability of the water of Lake Taloe (Republic of Khakassia, Russia)

Dutova, E.M., Khrushcheva, M.O., Tishin, P.A., Arkhipov, A.I., Nikitenkov, A.N., and Chernyshov, A.I.

Characterizing emerging contaminant dynamics in an induced denitrification experiment using groundwater and soils from the Campo de Cartagena aquifer (Murcia, Spain)

Ros-Berja, N., Escalona-Orellana, H., Gros, M., Margalef-Martí, R., Luque, J.A., Jiménez-Guñe, J.H., Soler, A., Otero, N., Robles-Arenas, V.M., Morales, S., Manzano, M., and Mas-Pla, J.

Methane cycling and its roles in arsenic mobility in the Hetao Basin, China

Feng, S., Guo, H., Li, Y., Liu, Y., and Hu, X.

Investigating river water variations using compositional methods in a low-impacted catchment (Serchio River Basin, Northern Tuscany, Italy)

Ferrari, M., Gozzi, C., Bucciatti, A., Venturi, S., Tassi, F., and Vaselli, O.

Comparative speciation of germanium in two Czech reservoirs and Southern Ocean waters: Insights into geochemical behavior across contrasting aquatic systems

Matoušek, T., Prokopová, M., Pivokonský, M., Laglera, L., and Filella, M.

Groundwater uranium mobilization linked to nitrate contamination in the Songnen Basin, China

Gao, Z., and Guo, H.

Unravelling cation exchange processes in a Mediterranean detrital coastal aquifer (Costa del Sol area, South Spain): A preliminary hydrogeochemical modelling prior to managed aquifer recharge

García-Cuadra, M.R., Barberá, J.A., and Andreo, B.

What if the data represent proportions? Decoding river hydrogeochemistry with compositional methods: The project of the Ombrone Grossetano River Basin (Italy)

Gozzi, C., Bucciatti, A., Giannetti, F., and Venturi, S.

Hydrogeochemical evolution of the Valle de Guadalupe aquifer, Baja California, Mexico

Kretzschmar, T.G.

The formation and mechanisms of high iodine groundwater in China

Li, J., Xie, X., and Wang, Y.

Constraints on vertical variability of geogenic ammonium in multi-layered aquifer systems

Liu, W., Du, Y., Qiu, W., Deng, Y., and Wang, Y.

Water quality assessment and recharge processes at the Estero del Cobre watershed (Central Chile): A hydrogeochemical and isotopic approach

Macchioli Grande, M., Taucare, M., Casado, I., Mohor, A., and Daniele, L.

A province-wide assessment of redox controls on the quality of groundwater in Alberta, Canada
Mayer, B., Humez, P., Plata, I., Date, A., Nightingale, M., McClain, C.N., and Liggett, J.E.

The effects of severe drought events on coastal lagoons hydrochemistry
Menció, A., Mateos, M., Gonzalvo-Henry, G., Madaula, E., Roqué, C., Meredith, W., Amore, V., Quintana, X.D., and Casamitjana, X.

Using natural springs to analyze groundwater recharge events under severe climatic conditions
Jiménez-Llobet, M., and Menció, A.

Contribution of microbial metabolism to geogenic phosphorus enrichment in groundwater: Insights from metagenomic sequencing and organic molecular characterization
Ning, J., Du, Y., Wang, J., Liu, W., Deng, Y., Gan, Y., and Wang, Y.

Groundwater-rock interactions and hydrogeochemical related processes in the Espera Endorheic Complex (Cádiz-Sevilla, Spain): Implications for the proper wetlands management
Palomino Gómez, A., Mudarra Martínez, M., Gil Márquez, J.M., and Andreo Navarro, B.

Calibration of models for remote sensing estimation of chlorophyll concentrations with limited in situ measurements
Peterson, J.G., Wanty, R.B., Bearup, L.A., and Navarre-Sitchler, A.

Cave formation in micaschists: The role of acid rock drainage
Roqué, C.

Tidal influence on uranium dynamics in an estuary impacted by acid mine drainage
Sánchez-López, L., Romero-Matos, J., and Pérez-López, R.

Mechanism on DOM driven heavy seasonal fluctuation of metals content: Insight from Guanshan Watershed (Danjiangkou, Central China)
Shang, R.H., Ma, T., Chen, L.Z., Zhou, G.Y., Liu, W.H., Chen, Y., and Chen, Z.Q.

Source-oriented health risk assessment of groundwater nitrate by using EMMTE coupled with HHRA model
Shi, H., Du, Y., Xiong, Y., Deng, Y., and Li, Q.

Influence of rock-water interactions on groundwater chemistry in hard-rock aquifers: A case study from the Palakkad District, Kerala, Southern India
Thanooja, P.V., Arun, P.R., Muhamed Bin Rahman, K., Silpa, A.s., Manu, E., and Naveena, K.

Water quality and strontium isotope analysis of shallow groundwater near the Salar de Uyuni, Bolivia
Wudke, H., Williams, G.D.Z., and Vengosh, A.

471 SESSION 15. LATEST ADVANCEMENTS IN CRITICAL ZONE SCIENCE AND REACTIVE TRANSPORT

Modeling of radium mobility in a temperate forested catchment under present and future climate
Beaulieu, E., Rihs, S., Saoudi, L., Heyser, C., Di Chiara, R., and Pierret, M.-C.

Micro-continuum reactive transport modeling for water-rock interactions
Deng, H., Zhang, Q., and Poonoosamy, J.

Geochemical modeling tools for simulating water-rock interactions for the critical zone processes, critical minerals formation and extraction, and carbon sequestration
Gong, L., Zhu, C., Tu, K., Hageboeck, R., Ji, X.Y., and Pamidighantam, S.

Impacts of climate variables on basalt weathering rates and CO₂ removal
Harrison, A.L., Brazier, J.-M., Hakimi, M., Mavromatis, V., and Godelitsas, A.

Geochemistry and mass transport N₂-bearing groundwater within Khodja Obi Garm thermal field, Pamir-Alay region, Tajikistan
Kharitonova, N.A., Lukanov, D.D., Aseeva A.V., Baranovskaya, E.I., and Salikhov, F.S.

Sr transport in an unsaturated alluvium: Dependence of water content
Maillet, J., Savoye, S., and Latrille, C.

Changing Arctic Critical Zone: Tracing permafrost thaw
Opfergelt, S., Roux, P., du Bois d'Aische, E., Henrion, M., Osy, C., Thomas, M., and Villani, M.

From marine- to land-terminating glaciers in Greenland fjords: Influence on dissolved P in this aquatic critical zone
Strepenne, V., Bonneville, S., Mattielli, N., IMAQA team, Roevros, N., Delille, B., Leseurre, C., and Opfergelt, S.

Mastering reactive flow through fracture networks in the deep subsurface: A multiscale grand challenge for clean energy

Rosso, K.M., Burghardt, J., Detwiler, R., Fenter, P., Hammond, G., Hopp, C., Johnson, T.C., Karra, S., Lichtner, P., Mills, R., Murdoch, L., Navarre-Sitchler, A., Pyrak-Nolte, L., Qomi, M., Tartakovsky, A., and Zhu, W.

Modeling of a core infiltration experiment (fractured crystalline rock from ONKALO): Fracture vs. matrix reactivity

Soler, J.M., Cama, J., Silva, O., and Lamminmäki, T.

Fluorescence imaging of calcite dissolution in a microfluidic device

Swager, K.C., and Navarre-Sitchler, A.

501 SESSION 16. GEOCHEMICAL BASELINE IN MINE ABANDONED AREAS

Mineralogical and geochemical characterization of smelting slags from the Iberian Pyrite Belt

Amaya Yaeggy, G.A., Ruiz Cánovas, C., Pérez López, R., Nieto, J.M., and Macías, F.

New insights on the impact of the Rodalquilar tailing dump (Cabo de Gata-Níjar Natural Park, SE Spain) on groundwater

Buera-Cuerva, J., Mudarra, M.M., and Andreo, N.B.

Encapsulation of sulfide mine wastes as a tool to mitigate acid mine drainage (AMD) processes

Castellanos Vásquez, M., Cánovas, C.R., Nieto, J.M., and Macías Suarez, F.

Abandoned mines in Sardinia (IT): The Heavy Metals soils background values project

Dessi, R., Alfano, F., Chessa, P., Corda, V., De Giudici, G.B., Demurtas, M., Massidda, S., Ortu, S., Olla, P., Pili, V., Testa, M., and Uras, G.

Environmental concerns and future perspectives related to the legacy of metal(loid) contamination in the vicinity of a dismissed Pb-Zn mining area (Raibl, NE Italy)

Floreani, F., Pavoni, E., Marussi, G., Lenaz, D., and Covelli, S.

Reusing degraded land while protecting the environment: The role of risk assessment in the Montevecchio Ponente mining area (Sardinia, Italy)

Vecchio, A., Guerra, M., Andrisani, M.G., Mariani, E., Dessi, R., De Giudici, G.B., Murgia, A., and Olla, P.

Selective recovery of Zn-Cu-REE from Acid Mine Drainage using active treatment

León, R., Romero-Matos, J., Cánovas, C.R., Macías, F., Szlachta, M., and Nieto, J.M.

Distinguishing natural from mining-related sources of stream metal loading with a new approach employing streambank wells

Manning, A.H., Runkel, R.L., Morrison, J.M., Warix, S.R., Wanty, R.B., and Walton-Day, K.

Integrated approach (CoDA and machine learning) for determining geochemical baseline values in soils from decommissioned mining areas

Meloni, F., Gozzi, C., Nisi, B., Cabassi, J., Rappuoli, D., and Vaselli, O.

From stratigraphy to isotopes: A comprehensive approach to distinguish landfill impacts from geochemical baselines in groundwater

Natali, S., Raco, B., Battaglini, R., Da Prato, S., Catania, M., Giorgi, C., and Ticcianti, N.

Effects of groundwater and tailings interaction on the mobility of Thallium and other potentially toxic elements in a decommissioned Pb-Zn mining site (Raibl mine, north-eastern Italian Alps)

Pavoni, E., Floreani, F., Pisoni, C., Marussi, G., Oberti di Valnera, S., Mauri, M., Lenaz, D., and Covelli, S.

Metal and metalloid concentrations in water, sediments and plants in the Carnon and Tregeseal rivers and the Trevaunance Stream, Cornwall, UK

Ramos, V., Kender, S., Ullmann, C.V., and Compton-Jones, C.

Uranium and thorium in acid mine drainage: Origin and mobility in the Odiel River (SW, Spain)

Romero-Matos, J., Sánchez-López, L., Cánovas, C.R., Macías, F., Nieto, J.M., and Pérez-López, R.

Determining premining water quality in streams draining mineralized watersheds: An overview of the Proximal Analog Approach

Runkel, R.L., Verplanck, P.L., and Walton-Day, K.

Abandoned mines in Sardinia (IT): The GW background values project in Iglesias-Fluminese, SW Sardinia, Italy

Testa, M., Dessi, R., Alfano, F., Corda, V., De Giudici, G.B., Demurtas, M., Massidda, S., Ortu, S., Chessa, P., Olla, P., Pili, V., and Uras, G.

Environmental profile of arsenic in soils and derivation of reference values in light of the EU proposal for a Soil Monitoring and Resilience Directive

Pirani, G., Vecchio, A., Onorati, F., Paina A., Tornambè, A., Silvestri, F., and Andrisani, M.G.

Gamma radiation and soil concentrations of U, As, Cu, and Mo during the mine life cycle and reclamation of breccia-pipe U deposits, Arizona, USA

Walton-Day, K., Bern, C.R., and Qi, S.L.

Metal loading dynamics in the hyporheic zone as a result of Acid Mine Drainage

Winkler, A., Swift Bird, K., Navarre-Sitchler, A., and Wanty, R.

547 SESSION 17. THERMODYNAMICS AND KINETICS OF GEOCHEMICAL REACTIONS

A kinetic model of silica precipitation

Lassin, A., Dixit, C., and André, L.

Advanced argillic alteration at Cave di Caolino, Lipari, Aeolian Islands (Italy): Implications for the exploitation of geothermal resources

Apollaro, C., Bloise, A., Fuoco, I., De Rosa, R., Viccaro, M., La Russa, M. F., Belmonte, D., Guido, A., Iezzi, G., Marini, L., and Vespasiano, G.

Reaction path modelling as a tool to estimate the climate change effects at basin-scale

Apollaro, C., Fuoco, I., Vespasiano, G., De Rosa, R., La Russa, M.F., Ricca, M., Pantuso, A., Belmonte, D., and Bloise, A.

Silver: The magic “bullet” for chalcopyrite dissolution

Etschmann, B., Verdugo, L., Kalintsev, A., Olamide Abdus-Salam, M., Ram, R., and Brugger, J.B.

The GRAAL2 glass alteration model: Assessing the impact of environmental ions on gel composition and passivation performance

Frugier, P., Delcroix, M., and Noiriel, C.

Identification of colloidal species based on uranium (VI) in silicate solutions: Structure, formation and stability domain in environmental conditions

Kraemer, C., Rébiscoul, D., and Szenknect, S.

Thermodynamic models of fluid and mineral evolution in the mines in Jáchymov: From extremely acidic to neutral conditions

Majzlan, J., Plášil, J., Dachs, E., and Benisek, A.

Trace metal incorporation in ACC derived carbonate minerals

Mavromatis, V., Harrison, A.L., Brazier, J.-M., and Schott, J.

Mineralogy, chemistry and kinetic modeling of KEU (Kraftanlagen Energie und Umwelttechnik): A new material from tannery waste

Montegrossi, G., Meloni, F., Vaselli, O., and Panarese, M.

Understanding the natural basalt carbonation formation: The case study of Sverrefjellet Volcano (Svalbard, Norway)

Pierozzi, A., Faulkner, N., Di Benedetto, F., Montegrossi, G., Meloni, F., Kele, S., Rinyu, L., and Rodriguez Blanco, J.D.

Sorption of uranium and thorium onto secondary iron minerals and clay minerals: Influence of algal biomass and humic acids

Sekudewicz, I., Rohovec, J., Matoušková, Š., Kornaus, K., Szczerba, M., Działak, P., Gąsiorowski, M., and Borkowski, A.

Reading the topography of mineral surfaces to better quantify the kinetics of (bio)geochemical reactions

Wild, B., Stigliano, L., Heuret, A., Bas-Lorillot, J., Pusztai, Á., Knauss, K.G., and Daval, D.

The role of boron in controlling the pH of lithium brines

Williams, G.D.Z., and Vengosh, A.

What happens geochemically when you inject H₂ into a limestone?

Wolff-Boenisch, D., and Vialle, S.

577 SESSION 18. URBAN GEOCHEMISTRY

Molecular characteristics and plastic additives in dissolved organic matter derived from polystyrene microplastics: Implications for urban biogeochemical cycles

Cao, Y., Liu, Y., He, W., Hur, J., and Guo, H.

Reconstructing metal (Pb, Zn, Cu and Sn) enrichments in the Upper Rhine hydrosystem from geochemical analysis of overbank fine sediments

Chabaux, F., Euzen, C., Schmitt, L., Badariotti, D., Eyrolle, F., Rixhon, G., Preusser, F., and Schmitt, A.-D.

Gadolinium on the move: Improving detection in water and understanding human uptake

Coyte, R.M., Ezz al Dine, A., Kanaththage, M.I., Rubasinghege, G., and Frey, B.

Source apportionment in urban aquifers. SOUPY code, an update of MIX code

Schmidlin, D., Domènech, C., Thaysen, E., Otero, N., Pérez, S., Santana, S., Palau, J., Soler, A., Rosell, M., and Vazquez-Suñé, E.

Geochemical evolution of stream waters through a rural to urban transect (Greve River, Tuscany, Italy), with a focus on extreme dry periods and human impacts

Ferrari, M., Biagi, R., Venturi, S., Gozzi, C., Tassi, F., and Frezzi, F.

Lead, arsenic, cadmium, and uranium contamination in soils of southern Louisiana, USA

Godebo, T.R., Nyachoti, S., and Kodesup, P.

Quantified effects of multiple parameters on inputs and potential sources of microplastics from a typical river flowing into the sea

Liu, Y., You, J., Breider, F., Guo, H., Tao, S., and Liu, W.

Microbial impact of groundwater chemistry of ATES wells at coastal area of Osaka Bay, Japan

Masuda, H., Cui, L., Mihara, S., Nakaya, S., Toya, N., Nakaso, Y., and Nakao, M.

Changes in the physical speciation of lead (Pb) and other toxic metals in urban soils during soil weathering linked to increases in potential bioaccessibility

Nwoko, C.E., Singer, D.M., Tessin, A.C., Stoltz, B., and Corty, P.

595 SESSION 19. SECONDARY MINERALS OF AS, SB, AND BI, AND THEIR ROLE IN SEQUESTRATION AND RELEASE OF THESE ELEMENTS IN THE ENVIRONMENT

The fate of arsenic in the Carletti Spring System (Viterbo, Italy): A XAS speciation study

Montegrossi, G., Venturi, S., Baroni, T., Casentini, B., Fazi, S., Costagliola, P., Rimondi, V., Piacentini, A., Mazzoni, C., d'Acapito, F., and Di Benedetto, F.

Synchrotron-based X-ray spectroscopy study of thallium partitioning and retention in metal-sulfide deposits

Dorđević, T., Voegelin, A., and Gomez-Gonzalez, M.A.

Molecular transformation of dissolved organic matter in high arsenic groundwater during electron shuttle

Feng, X., Su, Z., and Guo, H.

Understanding the detrital fraction in the riverine transport of antimony and bismuth

Filella, M., and Majzlan, J.

Microbial-mediated arsenic-rich iron oxy/hydroxysulphate (schwertmannite) in an acid mine drainage system

Guerrieri, S., Borrelli, M., Medas, D., De Giudici, G.B., Onnis, P., and Perri, E.

Antimony isotopic fractionation in natural tropical river waters

Kaufmann, A.B., Hohl, S.V., Kraemer, D., Weyer, S., and Viehmann, S.

Fate of Sb and Bi in the oxidation zone of REE-U-Au quartz veins at Prakovce-Zimná Voda (Slovakia)

Majzlan, J., Ondrejka, M., Ferenc, Š., Števkó, M., and Mikuš, T.

Evaluating water-tailing interaction processes and geochemical monitoring in the historic Sb-Mine of Le Cetine di Cotorniano (Tuscany, Italy)

Meloni, F., Montegrossi, G., Cabassi, J., Nisi, B., Bianchi, F., Mirri, S., and Vaselli, O.

Arsenic mobilization in abandoned Au-mine tailings and removal using passive treatment systems

Ptacek, C.J., Angai, J., Bain, J., Hilger, D.M., Pakostova, E., Verbuyst, B., Wang, A.O., and Blowes, D.W.

Secondary precipitation of As- and Sb-bearing minerals in karst groundwater from the Xikuangshan Sb mine area, China

Qiao, W., Gao, Z., and Guo, H.

Microbial transformation of natural organic matter modulates As(V) reduction in electron shuttling systems

Su, Z., Guo, H., and Gao, Z.

617 SESSION 20. WATER-ROCK INTERACTIONS: CRITICAL FACTORS IN ORE-FORMING PROCESSES

Ore genesis in a greisen system from northern Sardinia, Italy

Attardi, A., Cossu, D., Deidda, M., Majka, J., and Naitza, S.

Effects of magmatic-hydrothermal F-rich fluids on REE mobility and Mo-W mineralization in the Ochtiná-Rochovce granite, Western Carpathians (Slovakia)

Bévan, M., Ondrejka, M., and Uher, P.

C and H isotopes of organic compounds reveal water-rock interactions accumulating critical minerals

Cesar, J.C., Ardakani, O.H., and Ahad, J.M.E.

Mechanism of formation, mineralogy and geochemistry of the ooidal ironstone of Djebel Had, Northeast Algeria

Diab, H.

Formation of the groundwater chemical composition in the coal-bearing regions of Kuzbass (Russia)

Domrocheva, E.V., and Drebot, V.V.

Contrasting episyenite formation in Cretaceous volcanic arc granitoid: An example from the Hakata-jima Island, southwest Japan

Fukui, T., Shimooka, K., Takahashi, T., and Saito, S.

On the importance of using metal isotope hydrogeochemistry to fingerprint critical metals

Mathur, R., Newman, C.P., Morgan, M., Holley, E., Messler, C., and Munk, L.A.

Role of ultramafic rocks weathering in the formation of Critical Raw Material (CRM) placers in rivers of the Emilia Romagna Region (Italy)

Rotta, D., Bonadiman, C., Bianchini, G., Cipriani, A., Tagliacollo, L., Tassinari, R., and Viola, I.

Exploring pelitic formations as a potential source of lithium-rich waters in the Northern Apennines (Italy)

Salvadori, M., Pennisi, M., D'Orazio, M., Kloppmann, W., Desaulty, A.M., Perret, S., and Dini, A.

Rare Earth Elements remobilisation and reconcentration in hydrothermal systems of Fluminèse-Arburèse districts (Sardinia, Italy)

Sedda, L., Attardi, A., Casu, M., De Giudici, G., Fancello, D., Melis, M.T., Onnis, P., Scano I., and Naitza, S.

Possible fluids responsible for mineralization in ophiolite-related Volcanogenic Massive Sulfide (VMS) deposits in the Modena province, Northern Apennine, Italy

Tagliacollo, L., Bonadiman, C., Bianchini, G., Viola, I., Rotta, D., and Tassinari, R.

Ultra-acidic and hyper-alkaline waters of the Kuril-Kamchatka region. Formation and related issues

Taran, Y.A., and Kalacheva, E.G.

Formation of the Mount Weld rare earth element deposit, Western Australia: A carbonatite-derived laterite

Verplanck, P.L., Thompson, J.M., Mercer, C.M., Bhat, G., Lowers, H.A., and Boehlke, A.R.

Metasedimentary basement from Elatsite porphyry-copper deposit: Petrographic and geochemical features

Vladinova, Tz., Georgieva, H., Nanov, Z., and Nedialkov, R.

Mineral chemistry features of pyroxenes from the skarn alteration associated with the Elatsite porphyry-copper deposit, Bulgaria

Georgieva, H., Vladinova, Tz., Milenkov, G., and Nedialkov, R.

An overview of thermodynamics, kinetics, and modeling of water-rock interactions in ore-forming and critical mineral extraction processes

Zhu, C.

Water-rock interaction in the hydrothermal field of the Central Baikal Rift Zone (Russia)

Zipa, E.V.

657 SESSION 21. A JOURNEY INTO HOT FLUID-ROCK INTERACTIONS:

FLUID INCLUSION STUDIES ACROSS THE LITHOSPHERE

Optimization of lithium release during crustal melting and implications for hard-rock lithium ore formation

Bartoli, O., Carvalho, B.B., Tacchetto, T., Petrelli, M., Richard, W., and Wälle, M.

Fluid-rock interactions in deep lithosphere at nano-, micro- and macroscale: Complex geochemical, inclusion and modeling approach from the Pannonian Basin

Berkési, M.

Geochemistry and petrogenesis of igneous rocks from the Yap forearc in the western Pacific: Implications for forearc magmatism

Chen, L., Tang, L., and Zhang, J.

Fluid-melt immiscibility during lower crustal melting recorded in the orthogneiss of Punta de li Tulchi, Sardinia (Italy)

Ferrero, S., Cruciani, G., Franceschelli, M., Fancello, D., and Gresky, K.

Halogen behaviors of subducted oceanic crust: Constraints from the New Caledonian metamorphic mélange

Li, Y.C., Xiong, Q., Chen, C.F., Dai, H.K., He, T., Wang, W., Su, Y.P., and Zheng, J.P.

Porosity-induced chemical compaction and fluid segregation: An experimental and modeling approach

Nakamura, M., Fujita, W., and Uesugi, K.

Greenhouse gas release by chemical and mechanical alteration of exposed rocks: Insights from metapelites

Roig González, C.I., Olivieri, O.S., and Brovarone, A.V.

Hydrothermobarometry and oxybarometry for granites using melt inclusions and host zircons

Saito, S., Kawashima, T., and Fukuyama, M.

Study on the melt inclusions in zircon of the Cretaceous Habu granitoid pluton, San-yo Belt, southwest Japan: Constraint on crystallization pressure of granitoid pluton

Kumagai, S., and Saito, S.

Novel agents of upper crustal fluid-rock interaction

Steele-MacInnis, M.

Formation of gaseous molecular water in coesite: From OH⁻ to H₂O cluster

Yan, W., Yang, Y., Zhang, L., Li, X., Sun, W., and Liu, X.

Serpentinization versus carbonation: Insights from products of interaction between peridotite and CO₂-rich fluids

Zheng, H.D., Xiong, Q., Dai, H.K., Zhou, X., Wang, L., and Zheng, J.P.

681 SESSION 22. SOURCE, FATE, TRANSPORT AND FRACTIONATION OF RARE EARTH ELEMENTS IN THE ENVIRONMENT: CHALLENGES AND FUTURE PERSPECTIVES

A multivariate approach to understanding soil properties through Rare Earth Element profile

Barbera, M., Malegori, C., Gariglio, S., Oliveri, P., Saiano, F., and Piazzese, D.

Mapping soil legacy data: Unexpensive insights into Rare Earth Elements

Belvisi, G., Scalenghe, R., and Saiano, F.

Estimation of the association constants of Rare Earth Elements in aqueous solutions in STP conditions from their electronegativities and polarizabilities and check of the model on thermal waters from Sahara

Bourrié, G., and Nezli, I.E.

Northern Flinders Ranges, South Australia: A natural laboratory for REE (bio)geochemistry

Brugger, J., Sanyal, S., Paton, L., Clases, D., Etschmann, B., Lausberg, E., and Kalintsev, A.

Rare-earth and ultra-trace elements concentrations in rainwater from rural, urban, industrial, and volcanic areas of Sicily, Italy

Brugnone, F., Brusca, L., Dominech, S., D'Alessandro, W., Parello, F., and Calabrese, S. *Bioaccumulation patterns of Rare Earth Elements in plant matrices: Insights from volcanic and anthropic environments*

Brusca, L., Paquis, P., Saiano, F., D'Alessandro, W., and Calabrese, S.

Precipitation of rare-earth-element (REE)-oxalates from acid mine water (AMW): A sustainable strategy for the recovery of REEs
 Crespo, O., Gibert, O., Cama, J., Cortina, J., and Hermassi, M.

Specific strategies for ensuring data quality in the quantitative determination of REE in sediments
 Fabietti, Y., Barbera, M., Saiano, F., Sarà, G., and Piazzese, D.

The importance of studying the Rare Earth Elements over time in hyperacid crater lakes: Tracers of fluid-mineral dynamics
 Inguaggiato, C., Pappaterra, S., and Rouwet, D.

Geochemical characterization of the Cenomanian-Campanian Red Sandstone Group of SW Tanzania: Implications for provenance, climate and paleo-redox conditions
 Kasanzu, C.H.

Rare Earth Elements as tracers in alkaline Lake Dujiali, central Qinghai-Tibet Plateau: Implications for the origin of hydromagnesite deposits
 Lin, Y., Zheng, M., Ye, C., and Power, I.M.

Rare earth elements in acid uranium mine drainage and sediments in southern China
 Liu, H.Y., Dong, S., Guo, H.M., Sun, Z.X., and Zhou, Z.K.

The characteristics of metal elements in mussel from Wocan-1 hydrothermal vent of Northwest Indian Ocean
 Liu, J.Q., Wan, H.X., Han, X.Q., and Fan, W.J.

Controls on Rare Earth Elements (REEs) in thermal waters along Italy: Evidence of distribution and correlation patterns
 Paquis, P., Randazzo, A., Calabrese, S., Procesi, M., Pecoraino, G., and Brusca, L.

Searching for unconventional critical raw minerals resources: The co-occurrence of rare-earth elements and radionuclides in phosphate rocks and phosphogypsum byproducts
 Vengosh, A., Hill, R.C., Wang, Z., and Nativ, P.

Behaviour of zirconium and hafnium in natural systems: Fundamental and applied implications
 Zuddas, P., Saiano, F., Inguaggiato, C., Censi, V., Caracausi, A., Sposito, F., and Barbera, M.

Session 22

Source, fate, transport and fractionation of Rare Earth Elements
in the environment: Challenges and future perspectives

A multivariate approach to understanding soil properties through Rare Earth Element profile

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ABSTRACT

This work aims to propose a method capable of identifying similar or dissimilar REE distributions without prior information (by applying suitable mathematical pretreatments), ensuring objectivity and addressing the issue of high variable correlation. One of the main challenges lies in comparing distributions, which becomes even more complex with large numbers of samples. In this context, the implementation of chemometric tools offers valuable methods for simplifying complex datasets across various fields of application. In literature, chemometrics, particularly through Principal Component Analysis (PCA), has already been proven to be beneficial on REE analysis. However, although these studies effectively apply PCA as a tool, none of them have proposed a method to compare REE distributions a priori, either from raw or normalized data. In addition, the main challenge in describing REE patterns lies in the high correlation among variables, which is directly addressed in this work using appropriate preprocessing strategies. Specifically, the "sum 100" pretreatment was applied. This method normalizes each variable by dividing it by the sum of all variables and multiplying the result by 100, thus emphasizing relative differences over absolute intensities while minimizing the global intensity effect. Following pretreatment, PCA was employed to create REE chemometric maps, enabling straightforward evaluation of similarities and differences across geographical regions. The combined use of the "sum 100" pretreatment and PCA facilitated the characterization of REE profiles in soils, improving interpretability and extracting chemical information embedded in concentration profiles. Results reveal that loading plots of PC1, PC2, and PC3 distinguish between light and heavy REE while highlighting anomalies of specific elements and REE groups. Data compression allows visualization of REE behaviour using an RGB colour scale (PC1= red channel; PC2= green channel; PC3= blue channel) directly on a geographical map. Remarkably, similarities in agrochemical conditions were observed among soils belonging to the same lithological family, correlating with similar REE distribution patterns. This underscores the relationship between REE distributions and soil characteristics, supporting traceability studies and environmental monitoring. Significantly, the methodology demonstrated consistency when applied to both raw and normalized datasets. For the first time, this study shows that similarities

and differences in REE distributions can be identified directly from raw concentration data. The use of raw data is crucial for environmental assessments, offering new insights into spatial-temporal evolution.

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Mapping soil legacy data: Unexpensive insights into Rare Earth Elements

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ABSTRACT

Can we envision our lives without smartphones or computers? Yet these technologies – along with numerous applications in renewable energy, power generation systems, and magnetic resonance imaging – rely heavily on Rare Earth Elements (REE), seventeen elements in the Periodic Table include fifteen lanthanides (La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu), as well as Sc and Y. Although REE deposits are distributed worldwide, there is currently a global shortage due to the decreasing number of economically viable deposits. Furthermore, as our high-tech, gadget-dependent world continues to grow, so does our reliance on REE, yet their supply remains uncertain. Understanding these elements' spatial distribution is critical for identifying potential alternative sources.

Geostatistics, a branch of statistics that focuses on analyzing and modeling spatially distributed data, coupled with the plethora of free and open-source GIS software, can help us understand the spatial variability of the REE and estimate them in unmeasured locations. Soil surveys are known to be expensive and time-consuming. Analyzing the already available georeferenced soil data makes it possible to efficiently plan the next surveys and correlate together other available GIS data, in raster or vector form. Every day the amount of data from satellites or from past soil surveys, the so-called “legacy data”, became accessible to everyone with an internet connection, making possible a multitude of analyses.

A recent study investigated the spatial distribution of soil REE in Sicily, the largest island in the Mediterranean Basin. We compiled a comprehensive dataset of soil properties, focusing particularly on exchangeable magnesium in the topsoil, alongside the Corine Land Cover 2018 dataset. This work aims to demonstrate the potential of GIS tools in enhancing our understanding of REE distribution and their spatial and economic implications.

Estimation of the association constants of Rare Earth Elements in aqueous solutions in STP conditions from their electronegativities and polarizabilities and check of the model on thermal waters from Sahara

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ABSTRACT

Rare Earth Elements (REE) associate with ligands in aqueous solutions. A model correlating association constants with electronegativities and polarizabilities of REE is proposed. Variation of coordination number from light REE (LREE) to heavy REE (HREE) is taken into account.

The model applies to elements for which 4f shell is neither zero (lanthanum) nor complete (lutetium), i.e. from Z = 58 (cerium) to Z = 70 (ytterbium). Association constants of REE with inorganic anions were critically evaluated. Elements were divided into two subsets: the first subset was used to compute double linear regressions of association constants with electronegativities and polarizabilities; the second subset was used to fit electronegativities and polarizabilities on the basis of linear regressions obtained on the first subset.

Association constants (log K) were then estimated to ± 0.03 to 0.1 logarithmic unit. Sulfate association constants decrease while phosphate association constants increase from LREE to HREE. Chloride and nitrate association constants are independent on the atomic weight of REE. Association constants with hydroxide, fluoride and carbonate slightly increase from LREE to HREE. The ratio sulfate/phosphate may thus fractionate REE in waters, soils and sediments.

The set of estimated association constants was incorporated in databases for Phreeqc. It includes association constants predicted for promethium.

The model is used to improve the speciation of REE in geothermal waters from Sahara.

REFERENCES

- Nezli, I.E., Kechiched, R., Mongelli, G., Abdelali, A., Nezli, A.R., Kouider, M.H., and Benhamida, S.A., 2024. REE and Y distribution and speciation in fossil water: the northwestern African Continental Intercalaire aquifer, Algerian Sahara. *Chemical Geology*, 645, 121894.

Northern Flinders Ranges, South Australia: A natural laboratory for REE (bio)geochemistry

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ABSTRACT

Due to the rapidly increasing demand for a diversified REE supply, spending for REE exploration is increasing. REE occur together with U in many deposits. Hence opportunities for mining REE come with significant risks, many associated with our limited understanding of the biogeochemical behaviour of critical minerals and U in the Critical Zone.

Australia hosts world-class resources of both REE and U, mostly associated with Mesoproterozoic magmatic provinces. These rocks have been subjected to extensive weathering over 10's of millions of years, and now reside in arid and semi-arid climate.

Here we demonstrate that the Arkaroola Wilderness Sanctuary, located in the Northern Flinders Ranges in South Australia, provides a unique "natural laboratory" to study the cycling of REE and U in natural and anthropogenic settings. Geologically, Arkaroola covers large parts of the Mount Painter Inlier, a basement unit rich in U-Th-K-REE-rich Mesoproterozoic granites. The radiogenic heat generated by these rocks has driven long-term hydrothermal circulation in the province, resulting in the formation of numerous U-REE-Cu deposits. Radiogenic heat still drives a geothermal system, expressed as the Paralana Hot Springs (~60 °C), the only permanent surface water in the region. Unlike conventional, transient mining sites, Arkaroola Wilderness Sanctuary offers a controlled environment that supports long-term multidisciplinary research.

Arkaroola protects historic mines like Number 6, that provided Radium following the discovery of the element by Marie and Pierre Curie in 1898. The historic tailings, left mostly untouched since the late 1930's, contain high amounts of residual U (100's to 1000's of ppm, depending on mining period) associated with REE and Cu. The primary mineralogical hosts of uranium (torbernite) and rare earth elements (monazite-(Ce)) are phosphate minerals, which are typically considered to limit REE and U mobility in groundwater. Microbial communities in the U-rich tailings are dominated by Actinobacteria, indicating that they have adapted to extreme conditions of

radioactivity and metal toxicity within this harsh semi-arid environment (Sanyal et al., 2024). In in-vivo experiments, the microbes cultured from these biomes were able to detoxify uranyl-rich growth medium via precipitation of an insoluble uranyl phosphate nano-mineral, chernikovite $(\text{H}_3\text{O})_2(\text{UO}_2)_2(\text{PO}_4)_2 \cdot 6\text{H}_2\text{O}$.

Single-particle ICP-MS analysis revealed substantial concentrations of polymetallic nanoparticles enriched in both U and REE in the mine waste. Microbial diversity is highest near the surface, which is interpreted to promote the dissolution of phosphate minerals and their transformation of liberated metals into nanoparticles. These results underscore the potential of microbial consortia in extracting metals from stable minerals and transforming them into environmentally mobile colloidal forms. The transformation of coarse minerals into colloids suggest that sporadic high rainfall events, that typify semi-arid climates, could release significant amounts of REE+U from the tailings. In terms of geochemical exploration and formation of secondary REE deposits within the regolith, these results indicate that colloids are potentially an important transport mechanism for REE+U.

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REFERENCES

- Sanyal, S.K., Etschmann, B., Hore, S.B., Shuster, J., and Brugger, J., 2024. Microbial adaptations and biogeochemical cycling of uranium in polymetallic tailings. *Journal of Hazardous Materials*, 465, 133334.

Rare-earth and ultra-trace elements concentrations in rainwater from rural, urban, industrial, and volcanic areas of Sicily, Italy

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ABSTRACT

Although there are only a few studies on the concentration of rare-earth elements (REE) in rainwater, their significant environmental impact has been recognized. Shale-normalized REE patterns are used to identify the sources of these elements in rainwater. Different geological environments produce unique REE patterns.

In this study, REE concentrations were measured, together with other ultra-trace elements (V, Ge, Zr, Nb, Te, Hf, and Th), in 97 rainwater samples collected from March to November 2021, and from November 2022 to January 2023, at 15 sites across Sicily, representing various contexts: rural (Nebrodi mountains), urban (Palermo and Catania), industrial (Milazzo and Priolo Gargallo), and volcanic (Mt. Etna). Rainwater samples were collected using bulk collectors and underwent a pre-concentration procedure, following the methodology outlined by Arslan et al. (2018) and re-elaborated by Dominech et al. (2024), prior to analytical determination with ICP-MS.

The concentrations of REE and ultra-trace elements in the rainwater samples varied substantially. For each study area, median values, calculated as the sum of REE and ultra-trace element median concentrations, were: 69.2 ng L⁻¹ for Nebrodi, 142 ng L⁻¹ for Milazzo, 183 ng L⁻¹ for Palermo, 231 ng L⁻¹ for Catania, 257 ng L⁻¹ for Mt. Etna, and 264 ng L⁻¹ for Priolo Gargallo.

Elevated lanthanum (La) concentrations were observed at all sampling sites, with median lanthanum/cerium (La/Ce) ratios reaching as high as 4.6 in the Priolo Gargallo industrial area. The enrichment of La in urban areas is likely attributable to vehicular traffic, specifically from automobile catalysts. In the industrial areas, sources may be linked to traffic emissions and to the combustion of fuel oils from power plants, as indicated by low lanthanum/vanadium (La/V) ratios (0.06 for Priolo Gargallo and 0.02 for Milazzo).

Additionally, small La enrichments, sometimes accompanied by europium (Eu) enrichments, were observed at Nebrodi and Etna, possibly due to crustal sources and volcanic emissions, respectively.

The distinctive signature of the volcanic source was identified through the high concentrations of tellurium (Te – median 8.80 ng L⁻¹) and germanium (Ge – median 5.22 ng L⁻¹) found in rainwater, particularly at locations most affected by the dispersion of volcanic gases and ashes (Mt. Etna). Strong positive correlations were observed between hafnium (Hf), zirconium (Zr), scandium (Sc), and to some extent, niobium (Nb). The highest concentrations of Hf (median 2.90 ng L⁻¹) and Zr (median 169 ng L⁻¹) were detected in two urban areas and two industrial regions, suggesting that anthropogenic sources are likely responsible for the emissions of these elements. Additionally, the highest concentrations of thorium (Th – median 2.04 ng L⁻¹) were recorded in the urban area of Catania and at the rural site of Nebrodi mountains (median 1.41 ng L⁻¹).

This study demonstrates that REE in rainwater, associated with other ultra-trace elements, can be considered good tracers of geochemical processes and can be considered a useful tool for distinguishing between various natural (e.g., volcanic) and anthropogenic sources.

REFERENCES

- Arslan, Z., Oymak, T., and White, J., 2018. Triethylamine-assisted Mg(OH)₂ coprecipitation/preconcentration for determination of trace metals and rare earth elements in seawater by inductively coupled plasma mass spectrometry (ICP-MS). *Analytica Chimica Acta*, 1008, 18–28. <https://doi.org/10.1016/j.aca.2018.01.017>
- Dominech, S., Federico, C., Brusca, L., et al., 2024. Exploring Rare Earth Element behavior in the Mount Etna volcanic aquifers (Sicily). *Environ. Geochem. Health*, 46, 237. <https://doi.org/10.1007/s10653-024-02020-4>

Bioaccumulation patterns of Rare Earth Elements in plant matrices: Insights from volcanic and anthropic environments

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ABSTRACT

Rare Earth Elements (REE) serve as critical geochemical tracers in environmental systems, yet their behaviour in biological matrices remains incompletely characterised. We present a comprehensive analysis of 428 leaves samples collected across diverse environments (primarily volcanic: Etna, Gorely, Masaya, Nyiragongo, Nisyros, Stromboli, plus industrial, urban and rural settings), providing unprecedented insights into REE bioaccumulation patterns. Using high-precision ICP-MS analysis, we systematically quantified the full REE suite across 10 distinct plant genera (*Betula*, *Cistus*, *Erica*, *Pinus*, *Polystichum*, *Populus*, *Rumex*, *Salix*, *Senecio* and *Olea*), enabling robust cross-comparison of uptake mechanisms.

Leaf tissues constituted our primary sampling material, with additional analysis of bark (*Betula* from Etna) and roots/trunk (*Senecio* and *Rumex* from Etna) to assess tissue-specific distribution. Sample preparation involved oven-drying (48 h at 40 °C) and mechanical pulverisation using agate equipment to avoid metal contamination. For selected *Pinus* samples, a washing experiment with ultrapure-water was conducted to differentiate between surface-deposited and biologically-incorporated REE. Analytical quality control included certified reference materials with recoveries typically between 80-120% and analytical precision <5% RSD.

REE concentrations exhibit striking matrix-dependence (Figure 1), with *Rumex* consistently displaying the highest concentrations (up to 91.3 µg/g Ce, 35.2 µg/g Y), followed closely by *Senecio* (up to 93.8 µg/g Ce). In contrast, *Olea* maintains consistently low concentrations (typically 0.01-0.2 µg/g) across all REE, with *Pinus* (n=189) showing intermediate values but the most statistically robust dataset. Chondrite-normalised patterns reveal consistent LREE enrichment relative to HREE across all matrices, with La/Lu ratios typically ranging from 5-20 and a subtle but consistent negative Eu

anomaly ($\text{Eu}/\text{Eu}^* = 0.7\text{-}0.9$). PAAS-normalised patterns display relatively flat signatures ($0.1\text{-}1\times$ PAAS), suggesting compositions broadly comparable to average shale.

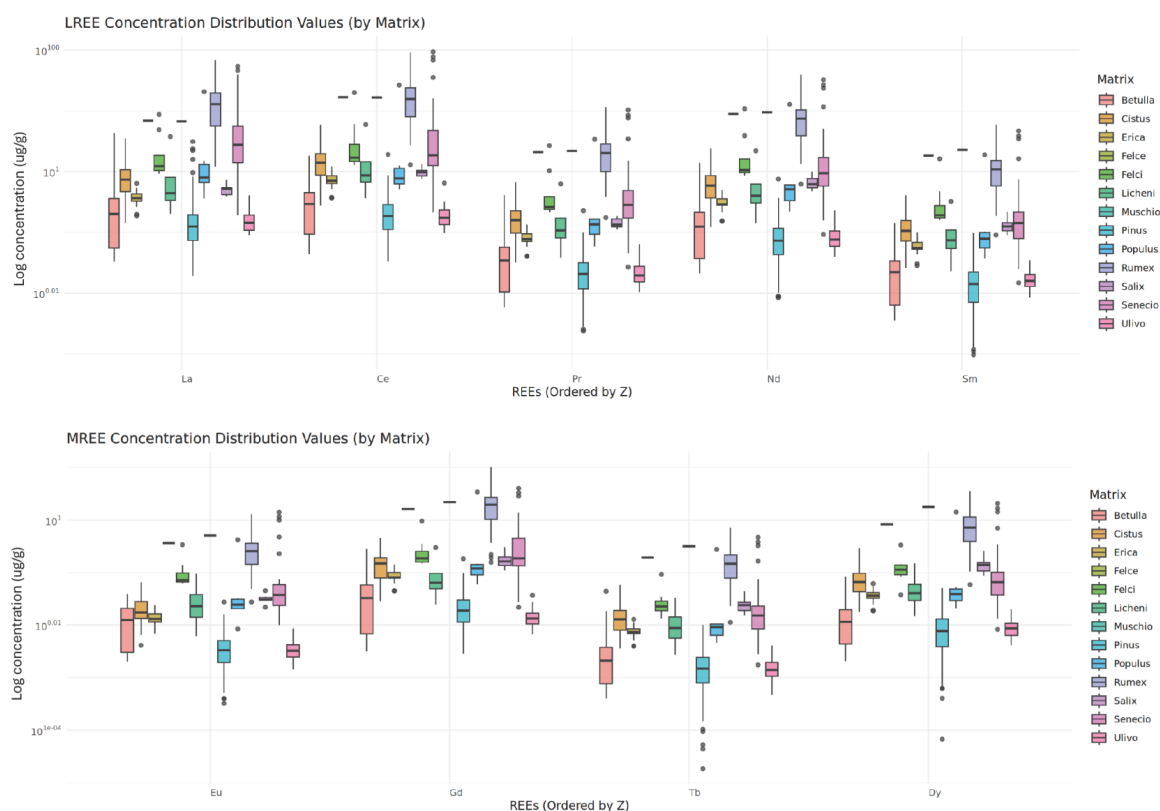


Figure 1: REE distribution across different matrices (mostly plants) shows *Rumex* and *Senecio* consistently accumulating higher concentrations ($10\text{-}100\text{ }\mu\text{g/g}$), while *Betula* and *Populus* display lower values ($0.01\text{-}1\text{ }\mu\text{g/g}$). Clear bioaccumulation differences persist across all REE elements.

The washing experiment on *Pinus* needles (growing years I-III representing increasing needle age) demonstrates that 20-60% of total REE content derives from surface deposition, with this effect progressively diminishing from LREE to HREE. Years II-III showed more consistent patterns (W/nW ratios of 0.57-0.67) compared to year I (more variable ratios). Over 80% of samples across all elements show W/nW ratios <1 , confirming the significance of surface deposition to total plant REE loads.

Distinct trends emerge when comparing element groups: LREE (La-Sm) show highest absolute concentrations (typically $0.1\text{-}10\text{ }\mu\text{g/g}$) and greatest removable fractions during washing; MREE (Eu-Dy) display intermediate pattern with maximum values in *Rumex* ($10.2\text{ }\mu\text{g/g}$ Gd); while HREE (Ho-Lu) exhibit lowest concentrations (typically $0.001\text{-}0.1\text{ }\mu\text{g/g}$) and smallest washing effects. Y behaviour particularly warrants attention, showing concentrations and washing effects more aligned with MREE than with its theoretical HREE counterparts, despite similar ionic radius to Ho.

This comprehensive dataset reveals robust bioaccumulation patterns that transcend geographical and environmental contexts, with matrix type explaining 62% of observed variance whilst geographical location accounts for only 27%. The consistent matrix-dependent concentration hierarchies, coupled with predictable fractionation patterns and distinct surface-vs-internal distribution, provide fundamental insights into REE trends in plant systems. These findings establish crucial baseline parameters for using plants as effective biomonitors of environmental REE signatures, particularly in volcanic environments where these elements may serve as sensitive indicators of volcanic activity impact.

Precipitation of rare-earth-element (REE)-oxalates from acid mine water (AMW): A sustainable strategy for the recovery of REEs

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ABSTRACT

The recovery of rare earth elements (REEs) from acid mine water (AMW) is a sustainable approach to diversify the REEs supply and to alleviate environmental issues. To recover low REE contents (10-30 g L⁻¹) from AMW two sequential stages are performed: (i) extraction of REEs (via co-precipitation of REEs with Al- and Fe-hydroxy-sulphates or via adsorption of REEs on ion-exchange resins) and (ii) precipitation of REE-oxalates in the sulphuric acid solutions used to regenerate the sorbent (e.g. IX resin). Precipitation experiments with oxalic acid solutions and the REE IX-concentrate were performed to determine the optimal conditions to precipitate REE-oxalates by varying three key parameters: dose of oxalic acid, addition method and solution pH.

INTRODUCTION

Rare earth elements (REEs) are crucial raw materials for modern technological devices. Their occurrence and distribution worldwide are important aspects of the global economy and green energy transition. The development of technologies for the extraction, separation and recovery of REEs from secondary sources is a promising alternative to traditional REEs mining.

On the one hand, acid mine waters (AMWs) derived from coal mining (Zhang et al., 2020) and metal sulphide mining have been identified as potentially valuable secondary sources for REEs (Roa et al., 2024), and, on the other hand, REEs recovery from AMWs mitigates the detrimental environmental impacts of AMWs.

REEs recovery from AMWs requires a number of steps to ensure an efficient separation. One approach is the selective precipitation with an appropriate anion together with another approach that includes oxalate, either oxalate or oxalic acid (Dewulf et al., 2022). The latter one is an organic compound considered environmentally friendly, which has a high affinity for REEs, forming REE-oxalates (Wang et al., 2023), which can be readily separated by physical methods. The precipitation of REEs, both light REEs (LREEs; La, Ce, Pr, Nd, Pm, Sm, Eu) and heavy REEs (HREEs; Y, Gd, Tb, Dy,

Ho, Er, Tm, Yb and Lu) is considered the most widely used method in the processing of rich mineral deposits (e.g. primary sources) (Larochelle et al., 2021). However, there are only a few studies that (1) deal with the REE concentrates generated after a selective separation and concentration stage via ion-exchange (e.g., Hermassi et al., 2022), (2) determine the overall process of precipitation/crystallization of REE-oxalates, and that (3) investigate idoneous reactors and the mode of adding reactants (e.g., oxalic acid) as well as the chemical composition and particle size of the REE-oxalates (Meng et al., 2023).

In an attempt to improve the recovery of REEs, this study focuses on the recovery of REEs through precipitation with oxalic acid ($\text{H}_2\text{C}_2\text{O}_4$). We used a synthetic solution similar to a REE ion-exchange concentrate generated after the selective extraction of REEs from the AMW at the mine of Aznalcóllar (Sevilla, SW Spain). We evaluated the effect of the following variables on REE-oxalate precipitation: 1) pH (0.5-3.0 range typically found in AMW), 2) oxalic acid dosage (varying five times the stoichiometric value) and 3) method of adding oxalic acid (rapidly poured or slowly but continuously injected). The precipitates formed were analyzed by X-ray Diffraction (XRD), Energy-dispersive X-ray spectroscopy (EDX) and Scanning Electron Microscope (SEM).

METHODS

A first series of synthetic REE-containing solution was prepared to emulate the chemical composition of the treated AMW from the mine of Aznalcóllar (Sevilla, SW Spain). The REE-containing solutions were prepared by dissolving desired amounts of REE salts in 200 mL of Milli-Q grade water (Merck-Millipore). A different dose of 1M oxalic acid ($\text{H}_2\text{C}_2\text{O}_4$) solution with pH of 1.20 (H_2SO_4) was applied. The four doses were 1, 2, 3 and 5 times the stoichiometric one (i.e., 1 SQ, 2 SQ, 3 SQ and 5 SQ, respectively, where SQ = stoichiometric demand for all REE in the medium). The suspensions were stirred (300 rpm) for 12 h. Different volumes of 96 % w/w H_2SO_4 were then added to obtain seven solutions with different pH to cover a pH range of 0.5-3: 0.50, 0.75, 0.95, 1.20, 1.70, 2.10 and 3.00. Before the experiments, the solutions were filtered using a vacuum system and dried inside a desiccator at room temperature ($T = 22 \pm 2$ °C) for 72 h.

In a second series of experiments, the REE-oxalate precipitation was studied by performing seven experiments with different pH (pH range of 0.5-3.0) using different concentrations of H_2SO_4 and the fast and slow additions of a 2Q dose of $\text{H}_2\text{C}_2\text{O}_4$. The chemical composition of the liquid samples was determined by ICP optical emission spectroscopy (ICP-OES) using an Agilent 5100 apparatus and by ICP mass spectrometry (ICP-MS) using an Agilent 7800 apparatus, with analytical uncertainties of 3%. The retrieved REE-oxalate precipitates were identified with XRD (Bruker® EVA diffractometer). The morphology and the qualitative element composition of the oxalate

precipitates were studied by SEM-EDX using a field emission JEOL JSM-700 IF instrument under a 15-20 kV and an Oxford Instruments X-MAX 30 mm² detector.

RESULTS AND DISCUSSION

DOSE OF OXALIC ACID

The REE content in the precipitates obtained using a 1 SQ dose was lower than the contents obtained with higher SQ doses. Using dosages greater than 2 SQ resulted in a slight improvement on the REE recovery (Fig. 1). Since doses larger than 2Q consume more oxalic acid, a 2 SQ dosage is sufficient. An increase in the dose shortened the precipitation time given that more oxalic acid was available for the same duration.

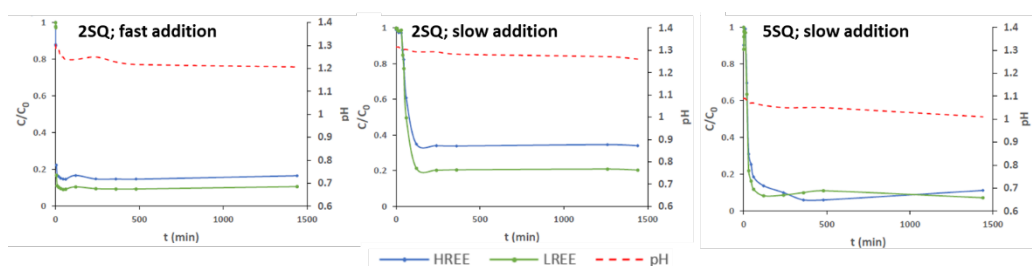


Figure 1: Variation in the normalized concentration of REEs as a function of time in the experiment with solution of pH 1.2 ± 0.1 and addition of oxalic acid: fast addition (2 SQ) and slow addition (2 SQ and 5 SQ).

ADDITION METHOD

The addition method barely influenced the REEs removal (Fig. 1) but affected the precipitation time, which was shorter using fast addition (0.5-3 min for fast addition and 12-39 min for the short addition).

SOLUTION PH

Regardless of the addition method, the REEs recovery was negligible at pH 0.5 and increased from pH 0.75 to pH 3.0 (e.g., using fast addition, the REEs removal was 11-19% for Tm and Y (pH = 0.75), 32-36% for La and Y (pH = 0.95), 77% for Y and La and 96% for Eu and Sm (pH = 1.2), 90-99 % for Y, La, Gd and Sm (pH = 1.7) and up to 95-100 % for Lu, Y, Sm, Gd, Eu and Yb (pH = 2.1 and pH = 3.0)).

OXALATE PRECIPITATES

Within the pH range studied, the REE-oxalate particles are thin and elongated, forming agglomerates of parallelepiped-shaped crystals (Fig. 2). The qualitative EDX composition indicates a substantial content of most REEs in the REE-oxalates precipitated at any pH regardless of the addition method.

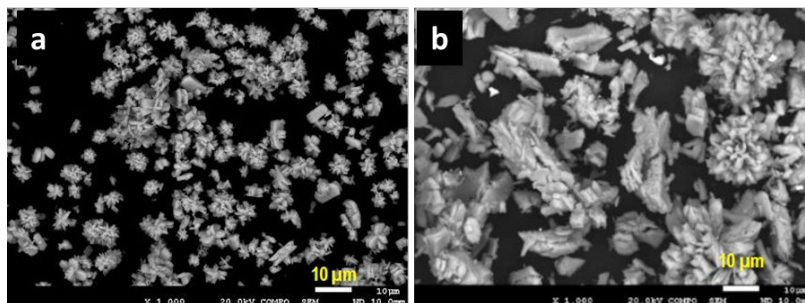


Figure 2: SEM images of the REE-oxalates ($\text{REE}_2(\text{C}_2\text{O}_4)_3 \cdot 10\text{H}_2\text{O}_{(s)}$) that precipitated in the solution with pH of 1.20 using (a) fast and (b) slow addition at 2 SQ dose.

CONCLUSIONS

An optimal REEs recovery is achieved using a 2 SQ dose of oxalic acid at pH of 1.20. REE-oxalates form aggregates of elongated crystals in varying sizes (e.g., slow addition results in larger crystal sizes). In the crystals, the content of most REEs (La, Ce, Nd and Y) ranges within 3 wt% and 10 wt%.

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REFERENCES

- Dewulf, B., Riaño, S., and Binnemans, K., 2022. Separation of heavy rare-earth elements by non-aqueous solvent extraction: Flowsheet development and mixer-settler tests. *Separation and Purification Technology*, 290, 120882.
- Hermassi, M., Granados, M., Valderrama, C., Skoglund, N., Ayora, C., and Cortina, J. L., 2022. Impact of functional group types in ion exchange resins on rare earth element recovery from treated acid mine waters. *Journal of Cleaner Production*, 379, 134742.
- Larochelle, T., Noble, A., Ziemkiewicz, P., Hoffman, D., and Constant, J., 2021. A fundamental economic assessment of recovering rare earth elements and critical minerals from acid mine drainage using a network sourcing strategy. *Minerals*, 11, 1298.
- Meng, X., Zhao, H., Zhao, Y., Shen, L., Gu, G., and Qiu, G., 2023. Heap leaching of ion adsorption rare earth ores and REEs recovery from leachate with lixiviant regeneration. *Science of the Total Environment*, 898, 165417.
- Roa, A., López, J., and Cortina, J. L., 2024. Recovery of rare earth elements from acidic mine waters: A circular treatment scheme utilizing selective precipitation and ion exchange. *Separation and Purification Technology*, 338, 126525.
- Wang, Y., Ziemkiewicz, P., and Noble, A., 2022. A hybrid experimental and theoretical approach to optimize recovery of rare earth elements from acid mine drainage precipitates by oxalic acid precipitation. *Minerals*, 12, 236.
- Zhang, W., Noble, A., Yang, X., and Honaker, R., 2020. A comprehensive review of rare earth elements recovery from coal-related materials. *Minerals*, 10, 451.

Specific strategies for ensuring data quality in the quantitative determination of REE in sediments

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ABSTRACT

Rare Earth Elements (REE) are increasingly studied as biogeochemical tracers due to their distinctive properties and wide applicability across various scientific disciplines. However, their extensive use in recent years in high-tech applications has resulted in significant anthropogenic discharges into the environment, leading to their classification as emerging contaminants (Hanana et al., 2022). In addition to natural processes, human activities have become a major source of REE inputs into marine systems.

Considering the gradual enrichment of REE in natural systems and their potential ecotoxicological risks, studying their interactions at the ecosystem level under natural conditions is essential. The common methods for evaluating fractionation processes from abiotic compartments to biota, and within biota from prey to predator, typically involve the biota-sediment accumulation factor (BSAF) and the bioaccumulation factor (BAF).

Although REE quantification in sediments is critical for assessing fractionation along the trophic chain, the methodologies used lack standardisation, particularly in the choice of mineralisation procedure. Some studies apply total mineralisation, which also determines the fraction of REE associated with silicates, reflecting the lithological background. Other studies focus on pseudo-total mineralisation, which targets REE content in carbonates, sulfates, oxides, and other less stable phases, thereby corresponding to the bioavailable (pseudo-total) fraction. These different approaches yield non-comparable data.

Since REE concentrations in the labile fraction can vary significantly, even when the underlying lithological origin is similar, we argue that studies on REE biogeochemical behaviour should prioritise the labile fraction, which provides a more realistic representation of their availability for bioaccumulation (Zhang and Shan, 2001; Censi et al., 2014). Nonetheless, the analytical validation of REE quantification for the labile fraction is challenging due to the absence of certified reference materials (SRMs) for the pseudo-total fraction and the lack of standardised validation protocols in the literature.

To address these gaps, we validated the analytical process for REE quantification in sediments by assessing accuracy through recovery experiments using certified SRM for the total fraction. Specifically, we estimated the REE concentrations using pseudo-total mineralisation and then calculated the amount of REE to be added to obtain a reference value. We then re-analysed the spiked sample and calculated the recovery. Recovery rates ranged between 84% and 103%, demonstrating that the extraction method effectively quantifies REE concentrations without significant interference. In conclusion, we propose a standardised methodology for validating the labile REE fraction in sediments. This approach ensures data reliability, enhances the comparability of results across studies, and contributes to a broader understanding of REE as biogeochemical tracers.

ACKNOWLEDGEMENTS

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REFERENCES

- Censi, P., Saiano, F., Pisciotta, A., and Tuzzolino, N., 2014. Geochemical behaviour of rare earths in *Vitis vinifera* grafted onto different rootstocks and growing on several soils. *Science of the Total Environment*, 473, 597-608.
- Hanana, H., Gagné, F., Trottier, S., Bouchard, P., Farley, G., Auclair, J., and Gagnon, C., 2022. Assessment of the toxicity of a mixture of five rare earth elements found in aquatic ecosystems in *Hydra vulgaris*. *Ecotoxicology and Environmental Safety*, 241, 113793.
- Zhang, S., and Shan, X.Q., 2001. Speciation of rare earth elements in soil and accumulation by wheat with rare earth fertilizer application. *Environmental Pollution*, 112(3), 395-405.

The importance of studying the Rare Earth Elements over time in hyperacid crater lakes: Tracers of fluid-mineral dynamics

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ABSTRACT

In the last decades, the knowledge about the behavior of Rare Earth Elements (REE) during water-rock interaction in volcanic-hydrothermal systems has increased. New literature has been published on the use of REE to investigate water-rock interaction processes, for example the occurrence of congruent dissolution of primary rocks and precipitation/dissolution processes of secondary minerals in Kawah Ijen (Indonesia), Rincon de la Vieja (Costa Rica) and Poás (Costa Rica) crater lakes (Inguaggiato et al., 2018, 2020; Pappaterra et al., 2023). The precipitation of gypsum was identified in these crater lakes and the REE fractionation due to the gypsum precipitation was investigated using crater lakes as natural laboratory. Light Rare Earth Elements (LREE) are preferentially removed from gypsum with respect to the Heavy Rare Earth Elements (HREE; Inguaggiato et al., 2018, 2020; Pappaterra et al., 2023).

Increasing knowledge about the geochemical behavior of REE in volcanic-hydrothermal systems has sparked interest in exploring the potential applications of REE. It is well known that major elements and physico-chemical parameters are useful to detect volcanic activity changes. What about the sensitivity of REE in hyperacid lakes during volcanic activity changes?

A recent study investigated REE variations over time (2009-2016) in the hyperacid crater lake of Poás (Pappaterra et al., 2022). During this period ~700 phreatic eruptions occurred, and 51 water samples of the crater lake were collected. The variations of REE recognized over time and their comparison with major changes in volcanic activity, as well as major elements and physico-chemical parameters, demonstrated that REE are sensitive to the volcanic activity changes. Specifically, REE concentrations, La/Pr ratios, TDS and temperature increase when the phreatic activity increases, while pH decreases. Additionally, LREE/HREE ratio decreases when the phreatic activity increases. To the author's knowledge, no similar long-term studies on the geochemical behavior of REE, coupled to the most common major elements and physico-chemical parameters, have been conducted during volcanic activity changes in hyperacid crater

lakes. Further long-term studies on REE in hyperacid crater lakes are needed to generalize the usefulness of REE as tracers of volcanic activity changes.

REFERENCES

- Inguaggiato, C., Iñiguez, E., Peiffer, L., et al., 2018. REE fractionation during the gypsum crystallization in hyperacid sulphate-rich brine: the Poás volcano crater lake (Costa Rica) exploited as laboratory. *Gondwana Res.*, 59, 87–96. doi:10.1016/j.gr.2018.02.022
- Inguaggiato, C., Pappaterra, S., Peiffer, L., et al., 2020. Mobility of REE from a Hyperacid Brine to Secondary Minerals Precipitated in a Volcanic Hydrothermal System: Kawah Ijen Crater lake (Java, Indonesia). *Sci. Total Environ.*, 740, 140133–140214. doi:10.1016/j.scitotenv.2020.140133
- Pappaterra, S., Inguaggiato, C., Rouwet, D., et al., 2022. Rare Earth Elements Variations in a Hyperacid Crater Lake and Their Relations with Changes in Phreatic Activity, Physico-Chemical Parameters, and Chemical Composition: The Case of Poás Volcano (Costa Rica). *Front. Earth Sci.*, 9, 716970. doi:10.3389/feart.2021.716970
- Pappaterra, S., Inguaggiato, C., Rouwet, D., et al., 2023. Fluid-mineral dynamics at the Rincón de la Vieja volcano—hydrothermal system (Costa Rica) inferred by the study of major, minor and rare earth elements in the hyperacid crater lake. *Front. Earth Sci.*, 11, 1197568. doi:10.3389/feart.2023.1197568

Geochemical characterization of the Cenomanian – Campanian Red Sandstone Group of SW Tanzania: Implications for provenance, climate and paleo-redox conditions

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ABSTRACT

Trace, major element compositions and rare earth elements (REEs) are presented for the Red Sandstone Group of the Rukwa Basin, SW Tanzania, in order to elucidate source rocks composition, paleo-weathering intensities, climatic variations and paleo-ambient redox conditions. In interpreting the obtained trace element data, it was assumed that elemental ratios such as La/Sc, Th/Sc, Cr/Th, Th/Co, La/Co and REEs in the detrital silicate fraction of the samples behaved as a closed system during weathering, transportation and eventual deposition in the basin. Shales from all the Red Sandstone Group show similar patterns in the primitive mantle normalized diagrams. However, notable depletions characterize the Ba and Sr abundances while Rb and Th contents are significantly elevated relative to adjacent elements. The shales are characterized by enrichments of the LREEs (La/Yb_{CN} range = 8.18 – 27.761; average = 13.699) and flat HREEs (Gb/Yb_{CN} = range 1.115 – 2.958; average = 1.723) coupled with negative Eu anomalies (Eu* average = 0.76). Such features are similar to those of the Post-Archean Australian Shale (PAAS). On the overall, this points to a felsic Upper Crust Continental protolith for the Red Sandstone Group rocks. Furthermore, the trace element ratios of La/Sc, Th/Sc, Y/Ni, Cr/Th and Th/Co indicate a more felsic source than that for the Upper Crust Compositions (UCC) and (PAAS). Discriminant diagrams of Co/Th vs La/Sc and Cr/V vs Y/Ni enabled to make inferences of source rocks to be the meta-anorthosites of the Ubendian and Cratonic granites around and to the NE of the basin. The calculated Chemical Indices of Alteration (CIA) indicate mainly intermediate magnitudes, suggesting sporadic variations of climates. Considerations on Al/Na and CIA values point to prevalent warm-humid climates during deposition of the Red Sandstone Group rocks. On the other hand, V/(V + Ni), V/Cr, Ni/Co and calculated Mn* redox proxy parameters demonstrate an overall well oxygenated/oxic environment when the sediments were deposited in the Rukwa Basin.

Rare Earth Elements as tracers in alkaline Lake Dujiali, central Qinghai-Tibet Plateau: Implications for the origin of hydromagnesite deposits

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ABSTRACT

Rare earth elements (REEs) are useful tracers of geochemical processes in aqueous systems (Johannesson et al., 2004; Censi et al., 2014). This study presents REEs and strontium isotope ($^{87}\text{Sr}/^{86}\text{Sr}$) data for hydromagnesite and surface waters from the alkaline Lake Dujiali, central Qinghai-Tibet Plateau (QTP), China, to explore the origin of hydromagnesite deposits. Hydromagnesite, a magnesium carbonate mineral, forms in alkaline lake environments, but its genesis remains debated. Our results show that lake waters exhibit light REE (LREE) enrichment and Eu anomalies, while recharge waters show a flat REE pattern. REE and Y data suggest fluid-rock interaction and dissolution of ultramafic rocks play a role in hydromagnesite formation. Speciation modeling predicts that the dominant dissolved REEs inorganic species are carbonate complexes $[\text{Ln}(\text{CO}_3)_2^- + \text{LnCO}_3^+]$ in surface waters. The proportion of dissolved REEs present in other inorganic ions such as Ln^{3+} , LnSO_4^+ and LnHCO_3^{2+} are less than 3% in seep water and stream water. The carbonate complexes such as $\text{Ln}(\text{CO}_3)_2^-$ are predicted to dominate all of the REEs in the surface waters. The only exception is La, Ce, Pr and Nd in seep water, La, Ce and Pr in stream water where the carbonate complex LnCO_3^+ is predicted to account for an equal or greater concentration than the corresponding carbonate complex $\text{Ln}(\text{CO}_3)_2^-$. Strontium isotopic compositions suggest that Sr in hydromagnesite is influenced by both Mg-rich hydrothermal fluids and meteoric water (Lin et al., 2019). This study provides new insights into the formation of hydromagnesite and contributes to the understanding of the REE cycle in alkaline lakes.

REFERENCES

- Censi, P., Saiano, F., Zuddas, P., Nicosia, A., Mazzola, S., and Raso, M., 2014. Authigenic phase formation and microbial activity control Zr, Hf, and rare earth element distributions in deep-sea brine sediments. *Biogeosciences*, 11(4), 1125-1136.
- Johannesson, K.H., Tang, J., Daniels, J.M., William, J.B., and Burdige, D.J., 2004. Rare earth element concentrations and speciation in organic-rich blackwaters of the Great Dismal Swamp, Virginia, USA. *Chemical Geology*, 209(3-4), 271-294.

- Lin, Y., Zheng, M., Ye, C., and Power, I.M., 2019. Rare earth element and strontium isotope geochemistry in Dujiali Lake, central Qinghai-Tibet Plateau, China: Implications for the origin of hydromagnesite deposits. *Geochemistry*, 79(2), 337-346.

Rare earth elements in acid uranium mine drainage and sediments in southern China

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ABSTRACT

Acid mine drainage (AMD) has attracted worldwide attention due to chemical toxicity and ecological environmental hazard (Akciil and Koldas, 2006; Elghali et al., 2023). This study focused on geochemistry of AMD and sediments in a uranium mine tailings area in southern China. 22 AMD and 31 sediment samples were collected along a flow direction of AMD. Through field and laboratory analyses, the concentrations and fractionations of rare earth elements (REEs) in AMD and sediment and their controlling factors were investigated. Results showed that the pH value of AMD ranged from 3.65 to 6.24 averaging 4.51, and the hydrochemical type was predominated by SO₄-Ca. Total REEs (Σ REEs) concentration ranged between 0.41 and 191 μ g/L averaging 80 μ g/L. The pH value was negatively correlated with Σ REEs concentration, and thus importantly controlled REEs concentrations. Hydrogeochemical calculation using PHREEQC showed that REEs in ADM were mainly in forms of SO₄²⁻ complexes and free ions (>99%). Normalization with upper continental crust (UCC) showed that the AMD was enriched in heavy REEs (HREEs) relative to light REEs (LREEs) with negative Ce anomaly. Σ REEs in sediments ranged from 171 to 1259 μ g/g, and gradually decreased with increasing depth. Shallow sediments had HREEs-enriched patterns, being similar to those of ADM samples. The degree of HREEs enrichment was greater in sediments taken from the tailings pond as compared to sediments from downstream of the tailings pond. However, with an increase in sampling depth, the HREEs enrichment degree of the downstream sediments gradually weakened, and finally sediment UCC-normalized patterns evolved into relatively flat or even LREEs-enriched ones. The results of sediment-sulfuric acid leaching test (1:40) showed that the leaching solution had patterns resembling those of AMD, being enriched in HREEs, indicating that HREEs were preferentially mobilized into solutions than LREEs during the formation of AMD, and shallow sediments readily inherited REEs signatures of AMD. However, REEs fractionations occurred with vertical migration to the deep layers with preferential mobilization of HREEs as compared to LREEs, resulting in an obvious vertical evolution trend in sediment REEs pattern. The results of

this study are of great significance to evolution of uranium mine environment and the prevention and control of soil and water pollution.

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REFERENCES

- Akcil, A., and Koldas, S., 2006. Acid Mine Drainage (AMD): causes, treatment and case studies. *Journal of Cleaner Production*, v.14, pp. 1139-1145.
- Elghali, A., Benzaazoua, M., Taha, Y., et al., 2023. Prediction of acid mine drainage: Where we are. *Earth-Science Reviews*, v.241, 104421.

The characteristics of metal elements in mussel from Wocan-1 hydrothermal vent of Northwest Indian Ocean

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ABSTRACT

The deep-sea mussel, *Bathymodiolus marisindicus*, collected from the Wocan-1 hydrothermal vent of the Northwest Indian Ocean, was chosen to study the characteristics of metal trace elements during their lifetime in vent system. The content of trace and rare earth elements (REEs) in the mussel shell and tissue were determined using LA-ICP-MS and ICP-MS, respectively. Furthermore, the distribution and relationship of metal elements of mussel shell, tissue and sediment, as well as the ecological and chemical characteristics of REEs, were explored. The results show that Fe (284.2 µg/g), Mn (4.2 µg/g) and Zn (12.0 µg/g) are mainly enriched in the mussel shell, while Fe (717.6 µg/g), Cd (15.0 µg/g), Cu (361.9 µg/g), Mn (13.0 µg/g), Pb (19.4 µg/g) and Zn (230.2 µg/g) are mainly enriched in the tissue. The trace elements are more enriched in mussel tissue than shell. The trace and REEs contents of the mussel of Wocan-1 hydrothermal vent are correlated with the elements contents of the sediment of the hydrothermal field. The pattern of REEs of the mussel is more similar to L1, indicating that the mussel grew in the sedimentary period of L1. The total rare earth elements (Σ REEs) of mussel shell and tissue are 0.45 µg/g and 0.33 µg/g, respectively. Both light and heavy rare earth elements (LREEs and HREEs) show fractionation: LREEs (La~Eu) contents are higher (0.27-0.26 µg/g) than those of HREEs (Gd~Lu; 0.18-0.07 µg/g). Therefore, the LREEs were significantly enriched in the mussel shell and tissue, and the mussel shell was more enriched in HREEs than the tissue. The REEs distribution pattern shows positive anomalies for La and Eu, and negative Ce anomalies in mussel tissue; positive anomalies for Gd, Eu, Pr and Ho, and negative anomalies for Sm and Dy in mussel shell. This further indicates that the REEs were selectively enriched for the mussel shell and tissue. The δ Eu and δ Ce of the sediment of the Wocan-1 hydrothermal field were respectively 0~3.00 and 0~1.00 (excluding 1; Qiu et al., 2021), the δ Eu values in the mussel shell and tissue were respectively 3.95 and 4.52, while those of δ Ce were 0.94 and 0.33. The δ Eu values of mussel shell, tissue and sediment were all greater than 1, while the δ Ce values were all less than 1, indicating that the REEs in the mussel of hydrothermal vent were homologous with those in the sediment of the hydrothermal field, and the REEs in mussel were affected by the seawater and hydrothermal fluid. The distribution and enrichment characteristics of trace and rare

earth elements in the mussel of hydrothermal vent were investigated in this paper, which will provide a technical and theoretical basis for further study of hydrothermal geochemical characteristics recorded by organisms of hydrothermal fields.

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REFERENCES

Qiu, Z., Han, X., Li, M., Wang, Y., Chen, X., Fan, W., Zhou, Y., Cui, R., and Wang, L., 2021. The temporal variability of hydrothermal activity of Wocan hydrothermal field, Carlsberg Ridge, northwest Indian Ocean. *Ore Geology Reviews*, 132, 103999.

Controls on Rare Earth Elements (REEs) in thermal waters along Italy: Evidence of distribution and correlation patterns

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ABSTRACT

This study investigates the geochemical characterization of 14 Rare Earth Elements (REEs) across Italy from different low-to-high enthalpy geothermal systems: Friuli Venezia Giulia (FVG), Toscana (TOS), Lipari (LIP), Vulcano (VUL), Pantelleria (PAN), Veneto (VEN), and Trentino (TRE). This study is based on data collected by the IRGIE and EMOTION Projects coordinated by INGV. The research examines key correlations between REEs, speciation patterns, and hydrogeochemical characteristics in waters, categorizing REEs into light (LREEs: La-Nd), middle (MREEs: Sm-Ho), and heavy (HREEs: Er-Lu) groups.

The dataset includes physicochemical parameters, major ions, trace elements from 172 samples across the study regions (FVG=19, TOS=26, TRE=28, VEN=30, VUL=28, LIP=22, PAN=19), and REEs analyses performed on a representative subset of 63 samples (FVG=1, TOS=5, TRE=4, VEN=2, VUL=21, LIP=15, PAN=15). PHREEQC speciation modelling incorporated site-specific data (pH, pe, temperature) to evaluate REEs complexation with key ions including CO_3^{2-} , F^- , SO_4^{2-} , OH^- , and REE^{3+} states.

Hydrogeochemical analysis identified distinct facies: SO_4^{2-} -dominant waters in TOS and VUL reflecting sulfate-bearing lithologies, and HCO_3^- -rich waters in VEN and FVG suggesting carbonate weathering environments. The Langelier Saturation Index indicated supersaturation in PAN and TRE samples, while VEN and FVG showed undersaturation trends. These characteristics reflect diverse geodynamic settings, from active volcanic environments to extensional tectonic regimes.

REEs distribution patterns showed ΣREEs concentrations of 1.21 mg/L distributed as ΣLREEs = 0.92 mg/L (76.2%), ΣMREEs = 0.23 mg/L (18.7%), and ΣHREEs = 0.06 mg/L (5.1%). Light REEs dominated (40-85%) particularly in VUL, TOS, and PAN

regions, while MREEs showed intermediate proportions (10-40%) with notable enrichment in LIP samples. HREEs exhibited the lowest abundances (5-20%), though some FVG and LIP samples showed elevated proportions. Chondrite-normalized patterns revealed LREEs enrichment in TOS and VUL regions, while Post-Archean shale normalization showed subdued patterns. PHREEQC speciation modeling with lanthanide complexes (LnCO_3^+ , LnF_2^+ , $\text{Ln}(\text{CO}_3)_2^-$, LnSO_4^+ , LnOH^{2+} , LnO^+ , LnO_2H , LnO_2^-) demonstrated carbonate and hydroxide complex predominance controlling REEs mobility.

Statistical analyses revealed significant correlations ($p < 0.05$) between REEs and geochemical parameters: LREEs with Mn, Zn, SO_4^{2-} ($R^2 = 0.286-0.639$); MREEs with Ca^{2+} , Ba, NH_4^+ ($R^2 = 0.393-0.905$); and HREEs with Li^+ , Cd, Na^+ . All REEs showed strong correlations with Y ($R^2 > 0.63$) and negative correlations with pH ($R^2 \leq 0.59$). Additional correlations were observed with Al, Be, Co, Cr, Fe, and Ti.

The integration of these analyses reveals systematic REEs patterns influenced by site-specific conditions and water-rock interactions, demonstrating the control of primary lithological sources and secondary environmental processes on REEs mobility in geothermal systems.

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Searching for unconventional critical raw minerals resources: The co-occurrence of rare-earth elements and radionuclides in phosphate rocks and phosphogypsum byproducts

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ABSTRACT

The transition from fossil fuels to green energy requires the acquisition of large quantities of critical raw materials (CRMs). Yet, the traditional mining of CRMs has been limited to specific geological domains that are abundant in only some countries, which creates shortages in supplies and geopolitical constraints for future large-scale production and utilization. In searching for alternative resources of rare earth elements (REEs), previous research has highlighted the occurrence and potential of REEs in phosphate rocks (PRs) (Emsbo et al., 2015; 2016). Here we present a dataset of PRs collected from worldwide major phosphate mines (Wang et al., 2023). We show large variations in REEs abundance, ranging from total REEs concentrations of <300 mg/kg in Precambrian PRs from China, 800 mg/kg in Cretaceous-Paleogene PRs from Northern Africa, and up to 1200 mg/kg in the Permian PRs from Western USA. During the manufacturing process of phosphate fertilizers, REEs become enriched in the phosphogypsum (PG) byproduct, which presents a potential REEs resource given the vast volumes of PG byproduct generate from fertilizers production. However, together with REEs, sedimentary PRs are commonly enriched in uranium and radium nuclides (²²⁶Ra) that are part of the ²³⁸U-decay chain. We show that ²²⁶Ra activities in phosphate rocks vary between 20 -200 Bq/kg in Precambrian PRs from China, 500-1600 Bq/kg in Cretaceous-Paleogene PRs from Northern Africa, and up to 800-1800 Bq/kg in PRs from USA. Investigation of phosphate fertilizers and PGs generated from phosphate rocks reveals chemical fractionation in which U is selectively enriched in the P-fertilizers, while Sr, Ba, and ²²⁶Ra are selectively incorporated into PGs as sulfate salts. Consequently, the radionuclide distributions in P-fertilizers and PGs are generally outside of the ²³⁸U-²²⁶Ra secular equilibrium (i.e., ²²⁶Ra/²³⁸U < 1 in fertilizers) and REE-rich PGs also commonly have elevated radium activities precluding their utilization as a potential REEs viable resource. Yet previous studies have shown that thermal and carbonization methods provide a promising direction towards purification and valorization of PGs (Akfas et al., 2024; Xie et al., 2023). This has been demonstrated for separation of strontium along with REEs from PGs (Kolokolnikov and Kovalev, 2009),

which infer that radium might also exhibit the same trend and separation, potentially generating REEs and Ra-free gypsum as part of the purification process.

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REFERENCES

- Akfas, F., Elghali, A., Aboulaich, A., Munoz, M., Benzaazoua, M., and Bodinier, J. L., 2024. Exploring the potential reuse of phosphogypsum: A waste or a resource?. *Science of the Total Environment*, 908, 168196.
- Emsbo, P., McLaughlin, P. I., Breit, G. N., du Bray, E. A., and Koenig, A. E., 2015. Rare earth elements in sedimentary phosphate deposits: solution to the global REE crisis?. *Gondwana Research*, 27(2), 776-785.
- Emsbo, P., McLaughlin, P. I., du Bray, E. A., Anderson, E. D., Vandenbroucke, T. R., and Zielinski, R. A., 2016. Rare earth elements in sedimentary phosphorite deposits: a global assessment. In: Verplanck, P.L., Hitzman, M.W. (eds.), *Rare Earth and Critical Elements in Ore Deposits*. *Society of Economic Geologists*. <https://doi.org/10.5382/Rev.18.05>
- Kolokolnikov, V. A., and Kovalev, M. I., 2009. Technology for processing technical calcium carbonate obtained from phosphogypsum into pure calcium carbonate and rare-earth element concentrate. *Chemistry for Sustainable Development*, 17(4), 387-393.
- Wang, Z., Hill, R., Williams, G., Dwyer, G. S., Hu, J., Schnug, E., ... and Vengosh, A., 2023. Lead isotopes and rare earth elements geochemistry of global phosphate rocks: Insights into depositional conditions and environmental tracing. *Chemical Geology*, 639, 121715.
- Xie, G., Guan, Q., Zhou, F., Yu, W., Yin, Z., Tang, H., ... and Chi, R. A., 2023. A critical review of the enhanced recovery of rare earth elements from phosphogypsum. *Molecules*, 28(17), 6284.

Behaviour of zirconium and hafnium in natural systems: Fundamental and applied implications

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ABSTRACT

The Zr/Hf ratio is considered constant in meteorites, minerals and rocks while changes by several orders of magnitude in natural aqueous fluids. The difficulty of predicting the behavior in fluids results from lack of reliable thermodynamic constants in aqueous media where Zr and Hf concentrations are in the range of picomol/kg. For this reason, the behavior of these elements has been investigated in a variety of aqueous systems spanning from acidic waters of volcanoes, cold and hot brines to very alkaline natural waters. These 'natural laboratories' made possible the empirical evaluation on the influence of pH, ionic strength, redox conditions, complexing ions and size particles (less than 0.1 micron) of suspended matter. The field systematic-approach reveals that pH and high ionic forces (from 0.7 to 4 mol/kg) do not significantly influence the fluid Zr/Hf ratio while the colloidal fraction is responsible for significant fractionation. We found that the Zr/Hf ratio in dissolved cold waters is mainly related to both solid morphology and electrical properties of the mineral surfaces constituting the colloidal fraction. On the contrary, in thermal fluids fractionation is enhanced by the presence of complexing ions such as Cl, SO₄ and HCO₃. Systematic studies over more than 20 years allowed Professor Paolo Censi to propose the use of Zr/Hf ratio as tracer of rapid magma arrival. By monitoring the Zr/Hf ratio in volcanic fumaroles, he proposed a new geochemical tool to assess the volcanic risk.

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