Non-traditional stable isotope variations in the impactites of the Rochechouart impact structure - Tracing impact volatilization, melting, mixing, and hydrothermal overprinting

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Published in:
ICF-CIRIR 2022 conference abstracts

Publication date:
2022

Document Version:
Final published version

NON-TRADITIONAL STABLE ISOTOPE VARIATIONS IN THE IMPACTITES OF THE ROCHECHOUART IMPACT STRUCTURE: TRACING IMPACT VOLATILIZATION, MELTING, MIXING, AND HYDROTHERMAL OVERPRINTING.

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Résumé: Ce travail porte sur l'étude des variations des rapports d'isotopes stables non-traditionnels au sein des impactites de la structure d'impact de Rochechouart (France). Les isotopes stables non-traditionnels comme le germanium, le fer, le zinc ou le cuivre peuvent être utilisés pour mettre en évidence des processus liés à la formation d'une structure d'impact (volatilisation, contamination par le projectile, fusion et mélange des roches cibles, altération hydrothermale). Dix-neuf échantillons issus des forages de la campagne de 2017 ont été analysés pour leur teneur en germanium [Ge] et leur composition isotopique ($\delta^{74/70}$Ge). Les fortes variations isotopiques obtenues (entre ~ 0.1 et 1‰), comparées aux données obtenues pour les roches cibles du socle (granite et gneiss), distinguent deux groupes: (1) les impactoclastites et les suévites, affichant des teneurs en Ge semblables à celles des roches cibles, mais avec des rapports isotopiques plus élevés ; et (2) les roches fondues par impact, présentant des rapports isotopiques semblables ou inférieurs à ceux des roches du socle pour des teneurs en Ge plus importantes. Ces deux groupes pourraient impliquer au moins deux processus différents: (1) la volatilisation induite lors de l'impact et (2) l'altération hydrothermale post-impact. Les analyses en cours des isotopes du fer, du cuivre et du zinc, ainsi que les mesures des teneurs en éléments hautement et moyennement sidérophiles viendront compléter et préciser ces premières constatations.

Introduction: The Rochechouart structure is a deeply eroded impact crater that formed ~ 207 Myr ago and no longer displays any impact-related topography[1]. Its surface is at the level of the crater floor with a diameter of about 20-25 km, based on morphological, geophysical, and structural reconstructions[2,3]. Due to the high erosion rate in the structure, the outcropping crater floor is one of its most pronounced features. Despite this high degree of erosion, the Rochechouart impact structure displays a preserved suite of impactites, with a large proportion of melted material, from ash-like deposits (impactoclastites) to unshocked basement. The melt-bearing lithologies (impactoclastites, suevites, impact melt rocks) contain a strong contribution of meteoritic materials based on the previously determined highly siderophile element (HSE) concentrations[4,5], but may also serve to trace other thermodynamic processes affecting target rocks during impact crater formation (volatilization, melting, mixing). While petrographic and geochemical studies hint towards the occurrence of such processes, non-traditional stable isotope ratios of iron (Fe), zinc (Zn), copper (Cu), and germanium (Ge) represent novel and powerful tools to trace unambiguous evidence of such processes. These isotopic systems have been selected based on their different volatilities and geochemical behaviors[6]. The application of non-traditional stable isotope systems, along with the measurements of HSE and moderately siderophile elements concentrations, may also assist in refining the nature of the projectile, which remains the topic of ongoing debates[3,5].

Methodology: Nineteen samples from 6 drilling sites from across the Rochechouart impact structure (Chassenon, Valette, Puy Chiraux, Montoume, Recoudert, and Rochechouart) have been selected for this study (*Fig. 1*). They are a subset from a total selection of 52 samples, resulting from a sampling campaign held in January 2021 among the drill cores made by the CIRIR in 2017[7] (funded by the Réserve Naturelle Nationale de Rochechouart-Chassenon). These samples represent the first from the Rochechouart impact structure to derive from deep drill cores and not from quarries or exposed outcrops[8]. The samples used

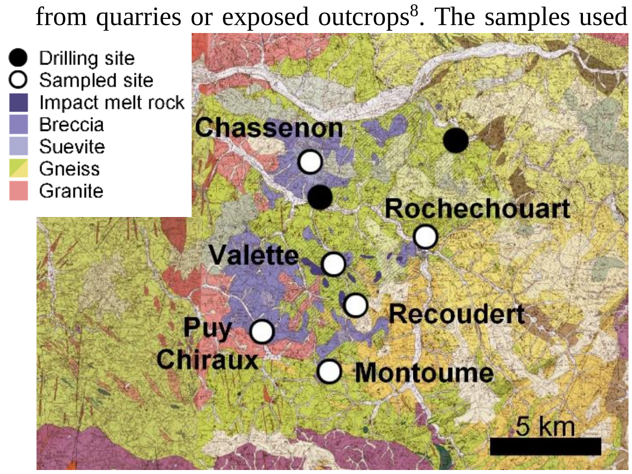

Figure 1: Geological map of the Rochechouart impact structure and location of sampled cores (SC1, SC2, and SC3 in Chassenon, SC7 in Valette, SC11 in Puy Chiraux, SC15 in Rochechouart, SC16 in Montoume, and SC17 in Recoudert).

for this study have been selected to exhibit the least surface weathering and to be representative of the variety of lithologies recovered in the cores from the 2017 drilling campaign. The selected samples are from the cores SC1, SC2, SC3, SC7, SC11, SC15, SC16, and SC17. Three samples originate from the basement (1 granite and 2 gneiss), 8 from impact melt rocks, 3 from suevites, 3 from impact breccias, and 2 from impactoclastites intervals.

The total selection of 52 samples have been prepared for various analytical technics: (1) preparation of thin sections for petrographic description, (2) preparation of powders for geochemical and isotopic analyses of the samples. Major and trace elements geochemical analysis have been held on the total of 52 samples (SARM-Nancy). The results and conclusions of the petrographic and geochemical analyses have been described by Déhais et al. (2022, abstract ICF-CIRIR 2022).

The nineteen samples selected for this study have been selected to complement the petrographic and geochemical study. Germanium isotopic composition (CRPG-Nancy), and also HSE and moderately siderophile element concentrations have been measured. The aim is to trace a meteoritic component thanks to Ge isotopic variations and highly/moderately siderophile elements concentrations among the different lithologies selected. Volatilization may also be traced by Ge isotopic variations. Iron, zinc, and copper isotope systematics are also complementing the Ge isotope data to study other syn- and post-impact processes such as melting, mixing of target rocks, and hydrothermal alteration.

Results, discussion and conclusions: The Ge isotope results on the nineteen selected impactites and target lithologies are the first obtained within any impact structure. They display a strong variation in $\delta^{74/70}$Ge of ~ 1‰ (from ~ 0.1 to 1‰). Due to its volatile and chalcophile geochemical behavior, Ge is especially useful to trace the addition of meteoritic contributions to impactites as well as the possible effects of impact volatilization.

The observed Ge isotope compositions, in combination with their Ge concentrations, put forward 2 major groups among the impactite samples, which are distinct from the basement samples (*Fig. 2*). One group exhibits similar Ge concentrations as the basement samples but at higher $\delta^{74/70}$Ge isotopic signatures (mainly impactoclastites and suevites), while the other group displays comparable or lower Ge isotopic signatures relative to the basement samples but at higher Ge elemental concentrations (mostly impact melt rocks). These results imply at least 2 distinct processes that affected the rocks sampled in the Rochechouart drill cores, with heavy $\delta^{74/70}$Ge isotopic signatures possibly indicating impact induced volatilization, while the Group 2 signatures would reflect secondary alteration. Moreover, data for Fe, Cu, Zn isotopes and HSE concentrations are currently collected for the same nineteen samples, in order to constrain the geochemical and isotopic signatures of the various lithologies of the Rochechouart impact structure. Along with geochemical and petrographic parameters, the nature of these syn- and post-impact processes, including melting and mixing of target rocks, volatilization, meteoritic contribution, and hydrothermal alteration, may be traced and refined.

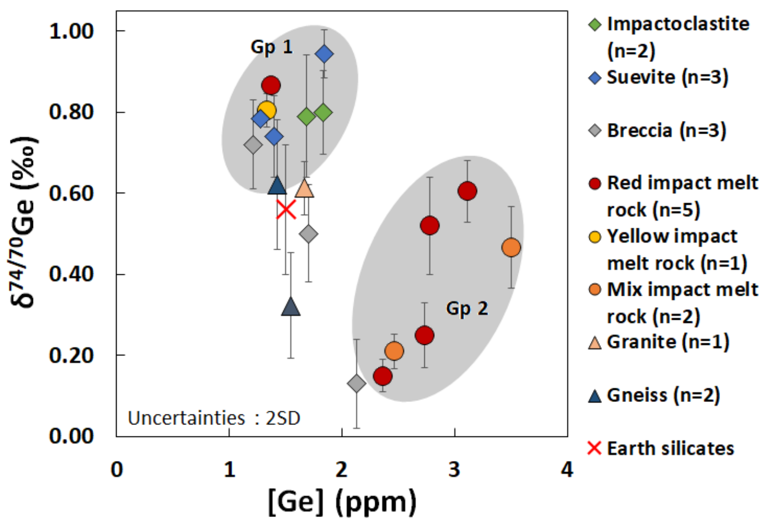

Figure 2: $\delta^{74/70}$Ge versus Ge concentration of the 19 analysed samples. Distinction between 2 major groups and the basement samples. (Silicate Earth mean composition[9])

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Acknowledgements: We thank the Barringer Family Fund for Meteorite Impact Research for funding this project. We appreciated the help of the CIRIR and the National Natural Reserve for providing the samples.