

## **Tracing differentiation processes through siderophile elements, from meteorites to giant ore deposits (DESIRED)**

### **Context**

The DESIRED project investigates how moderately to highly siderophile elements—including Au, PGE (Os, Ir, Ru, Rh, Pt, Pd), Re, and companion metals such as Cr, Co, Ni, Mo, and W—are distributed in both terrestrial and extraterrestrial materials. These metals preferentially partition into metallic phases during planetary differentiation and therefore became sequestered into Earth's core early in its history. Their pronounced depletion in the crust and mantle relative to solar abundances explains their status as precious metals and their tendency to form economically significant deposits only when specific geodynamic or surface processes concentrate them, often through the erosion of (ultra)mafic rocks that sample chemically distinct mantle reservoirs.

Understanding siderophile element behaviour provides a window into the earliest stages of Earth's accretion. Distinct suites of elements with particular metal affinities have proven especially useful for reconstructing the isotopic composition of the planet's building material through time. A key concept here is the **late veneer**, a final influx of meteoritic matter that arrived after core–mantle differentiation and enriched Earth's silicate reservoirs in highly siderophile elements (HSE). By determining the relative contributions and isotopic fingerprints of late-veneer versus pre-late veneer material, it becomes possible to identify the abundances and type of meteoritic inputs, refine models of planetary growth, and reconcile diverging isotopic observations—such as those suggesting either volatile-rich or extremely dry accreting components. These insights may be helpful to explain the formation of giant PGE-rich deposits and other Earth's defining features, such as liquid water, volatile budgets, a protective magnetic field, mantle convection, and the evolution of life.

### **Objectives**

- **Origin of precious-metal deposits in the Kaapvaal Craton**  
Analyse ~3.5–2.0 Ga mafic magmatic rocks and associated shales to determine how Au and PGE were transferred from mantle reservoirs into the crust. The Kaapvaal Craton hosts globally unparalleled mineral endowments: the Witwatersrand Basin has produced roughly one-third of all gold ever mined, and the nearby Bushveld Complex is the dominant source of global PGE. Despite this extraordinary concentration of precious metals, no unified genetic model exists. This objective aims to test whether these deposits reflect isotopic signatures characteristic of late-veneer additions or earlier, pre-late veneer mantle heterogeneities possibly tied to incomplete early core formation or later additions of undifferentiated extraterrestrial material.
- **Meteorite constraints on pre-late veneer and late-veneer isotopic signatures**  
Characterize selected meteorites—especially enstatite meteorites and carbonaceous chondrites—to determine what each isotopic proxy (Cr, Ni, Mo, Ru, Os, W) records. Concentration data, isotopic ranges, and experimentally determined high-pressure, high-temperature partition coefficients are used to discriminate between materials incorporated early in Earth's accretion and those added in the late veneer. Existing work suggests that early accreting matter was dominantly enstatite-like, whereas late-accreting matter may

resemble CI carbonaceous chondrites. This implies a late veneer sourced from further out in the Solar System and potentially smaller in mass than previously estimated.

- **Preservation of extraterrestrial signals in Belgian Phanerozoic limestones**  
Apply the isotopic tools developed in the first two objectives to Phanerozoic limestone successions showing chromium enrichments and indications of extraterrestrial inputs, such as cosmic dust. This objective tests whether isotopic signatures of meteorite bombardments can survive diagenesis and long-term geological processes, thereby allowing reconstruction of ancient fluxes of extraterrestrial material and improving interpretation of sedimentary archives.
- **Expansion and curation of the Antarctic meteorite collection at RBINS**  
Enhance the size, quality, and scientific utility of the RBINS Antarctic meteorite repository through targeted collection missions (BELARE 2022–2023; 2024–2025 and beyond). The expanded collection—already exceeding 1,450 specimens—provides sufficiently large samples for high-precision isotopic analyses required for Objective 2. Improved curation protocols further support long-term accessibility and reliability of these key extraterrestrial samples.

## Conclusions

During the project period, substantial progress was achieved across all major research axes, beginning with extensive work on the Kaapvaal Craton, where electron microprobe and LA-ICP-MS analyses of silicates, sulphides, oxides, and phosphates revealed significant mineralogical diversity and clear evidence of post-crystallization alteration, emphasizing the potential impact of metamorphic processes on siderophile element distributions and isotopic systems. The completed digestion and chromatographic separation of eight Kaapvaal samples were validated against previously reported datasets and reveal HSE variability driven primarily by petrology, likely dominated by small-scale heterogeneity. The newly established microdistillation-TIMS method for Os isotope measurements, obtaining DROSS standard values consistent with published data (differences  $<0.007$  in  $^{187}\text{Os}/^{188}\text{Os}$ ). Because such analyses are extremely time-consuming, further study is ongoing. The paper related to the characterization of in situ HSE distribution in unequilibrated ordinary chondrites analysed via LA-ICP-MS is currently in preparation. Parallel efforts at VUB advanced the study of meteorite-derived signatures in terrestrial impact structures, including collaborative Ru and Cr isotope measurements. The Antarctic meteorite program also advanced significantly, with the RBINS collection now surpassing 1,450 specimens following the 2022–2023 recovery mission and the 2024–2025 field season, which yielded 110 new fragments from the Belgica Mountains. Curation, classification, and micro-CT imaging are ongoing, contributing essential data for the digitalization of the collection and future virtual exhibits, alongside publications stemming from earlier cosmic-particle analyses. Work on fossil micrometeorites from Belgian limestone deposits likewise delivered major results, with 130 kg of carbonate rock processed to recover more than 2000 micrometeorites, including rare, well-preserved silicate-bearing types, now representing one of the world's largest such collections. Comprehensive mineralogical and isotopic characterization (SEM, XRF, EMPA, LA-ICP-MS, O and Fe isotopes) enabled the reconstruction of a pronounced micrometeorite flux peak preceding the Hangenberg Event, and culminated in a publication in *Geochimica et Cosmochimica Acta* (Krämer Ruggiu et al., 2025), with a second paper on the extraction technique in preparation.

Finally, community engagement was strengthened through the organization of the 86th Annual Meeting of the Meteoritical Society (27 July-2 August 2024) by the ULB-VUB team, which included a dedicated workshop on meteorite curation at RBINS, further enhancing international collaboration and visibility.

**Keywords**

Siderophile elements; planetary differentiation; precious metals; Kaapvaal Craton; platinum-group elements (PGE); isotopic geochemistry; osmium isotopes; meteorites; Antarctic meteorite curation; micrometeorites; Devonian-Carboniferous boundary; Hangenberg Event; ore genesis; mantle processes; LA-ICP-MS; TIMS; digital collections.