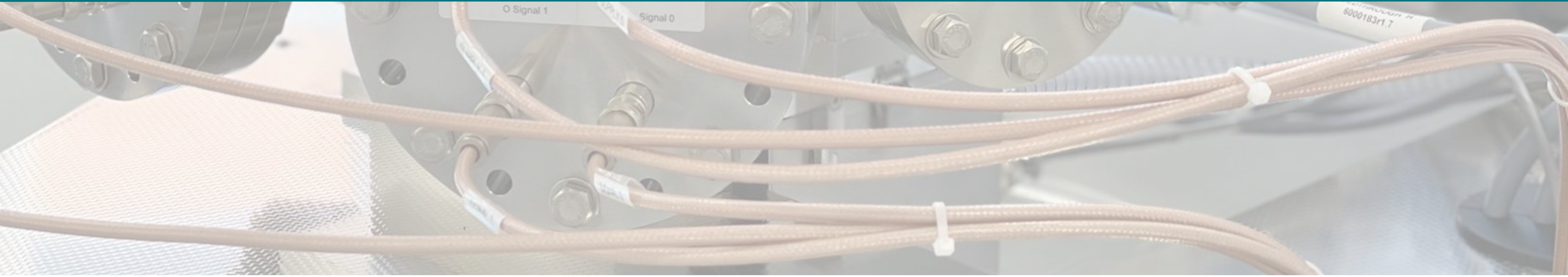
Fe, Zn and Mg stable isotope records of early differentiation and core formation of the ureilite parent body

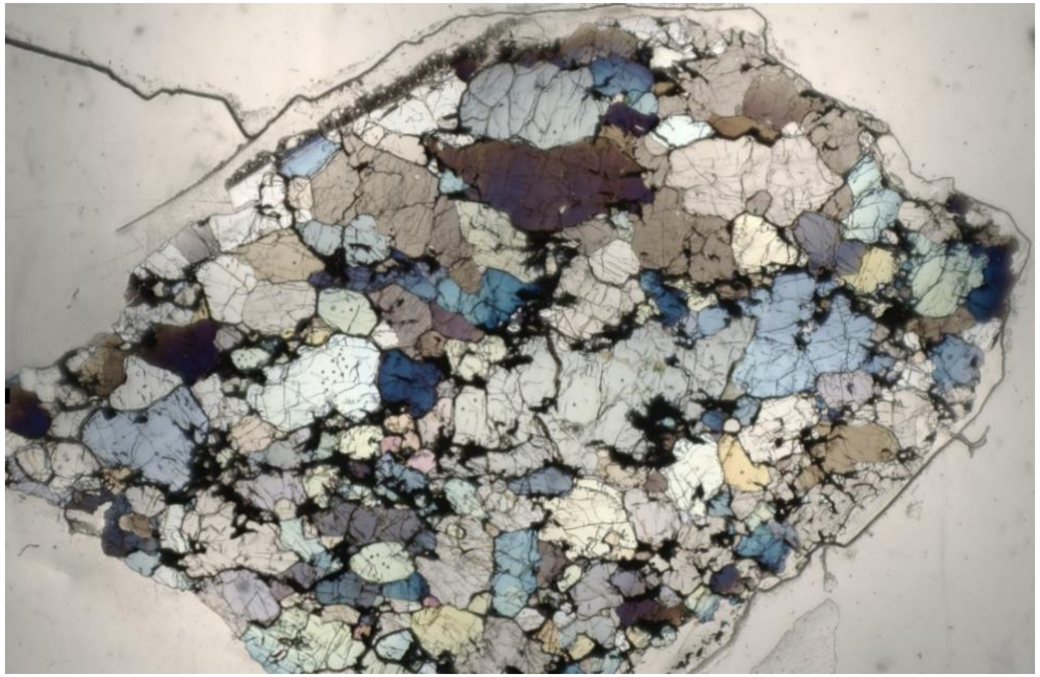
Stepan M. Chernonozhkin, Steven Goderis, Genevieve Hublet, Stefan Weyer, Ingo Horn, Lidia Pittarello, Philippe Claeys, Vinciane Debaille and Frank Vanhaecke

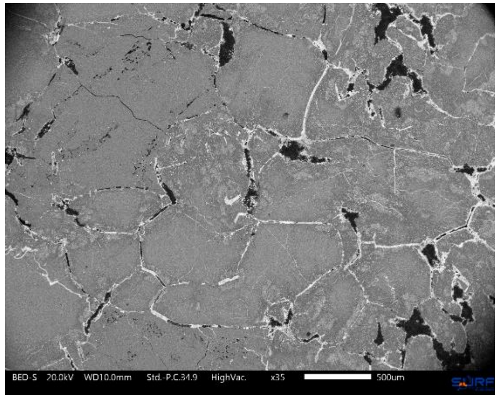
MONTAN UNIVERSITÄT LEOBEN
GHENT UNIVERSITY
VUB VRIJE UNIVERSITEIT BRUSSEL
ULB UNIVERSITÉ LIBRE DE BRUXELLES
Leibniz Universität Hannover
naturhistorisches museum wien nhm

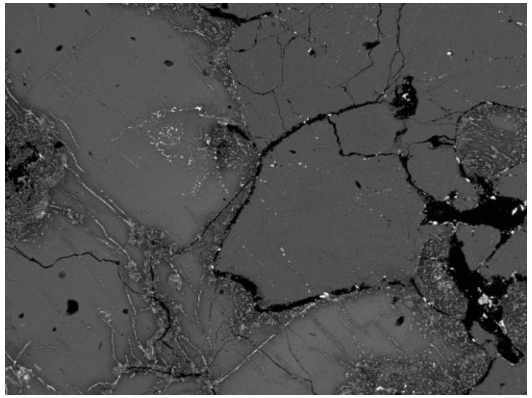


GOLDSCHMIDT LYON 2023 9-14 JULY

WHY UREILITES?



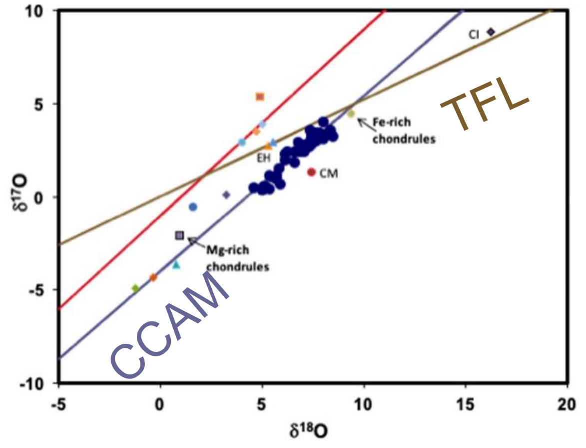


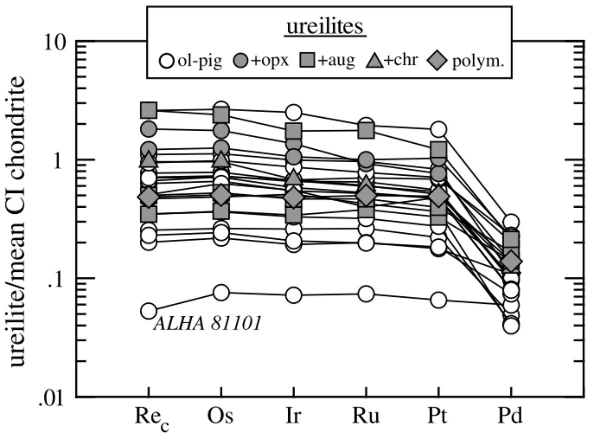


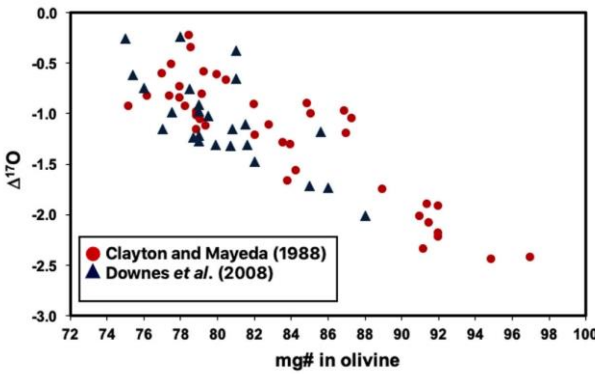
- Ureilites are achondrite meteorites
- Ultramafic olivine-pyroxen rocks
- Interstitial carbon, Fe-Ni metal, sulfides
- Olivine in contact with C is zoned
- Metal blebs in olivine rims

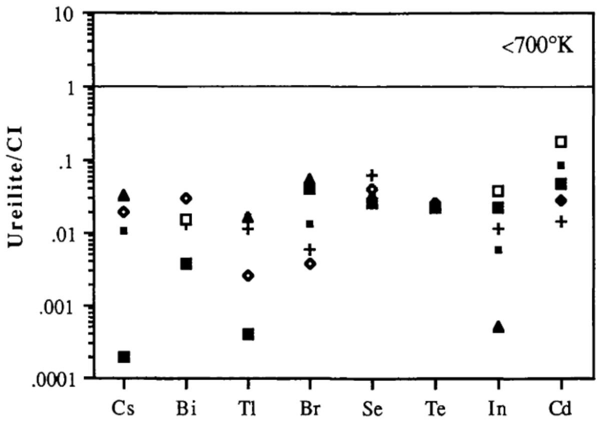
MONTAN UNIVERSITÄT LEOBEN
GOLDSCHMIDT LYON 2023 9-14 JULY

WHY UREILITES?









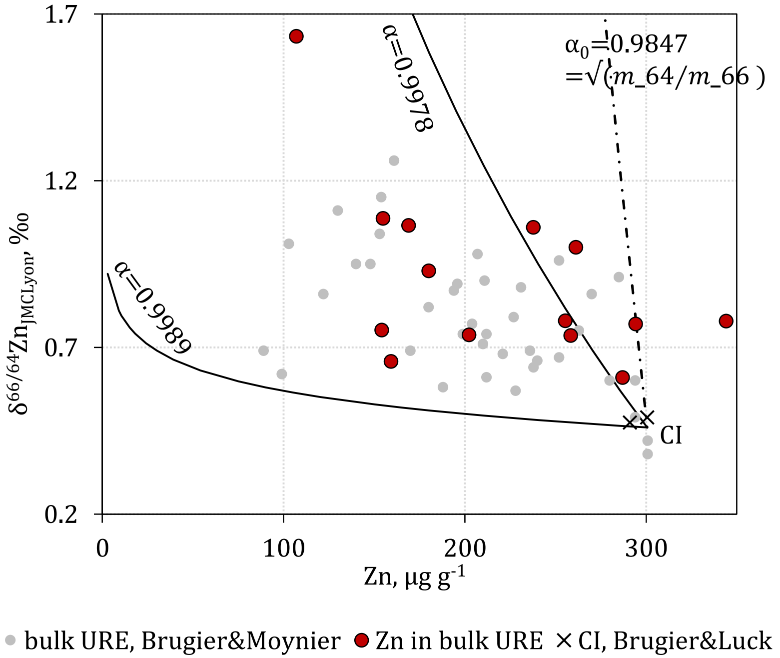
- ▶ The Fo# is ~74 to 97 among ureilites
- ▶ Oxygen isotopes fall close to the CCAM line
- ▶ Oxygen isotopes correlate with Fo#
- ▶ Extraction of PGE with a S-bearing metallic melt
- ▶ Lithophile elements suggest a ~25% removal of silicate partial melt
- ▶ Depleted in volatile elements

Goodrich 1992, Rankenburg *et al.* 2008, Barrat *et al.* 2016, Ray *et al.* 2020

GOLDSCHMIDT LYON 2023 9-14 JULY

WINDOW INTO A PLANETESIMAL FORMING PROCESS

- Accretion of **inhomogeneous PB** from MgO-rich and FeO-rich chondrules
- Ureilites formed as **ultramafic mantle restites**
- The parent body **did not reach the magma ocean** stage
- Episode of **reduction**
- Episode of **loss of volatiles** (during the catastrophic break up or in a diffusion limited regime?)



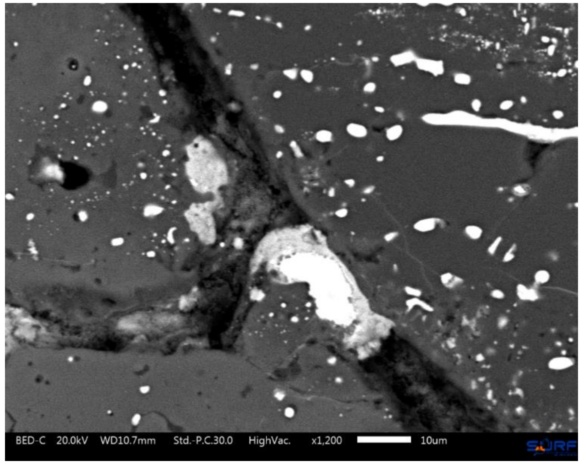
Brugier *et al.* 2019, Moynier *et al.* 2010, Luck *et al.* 2005

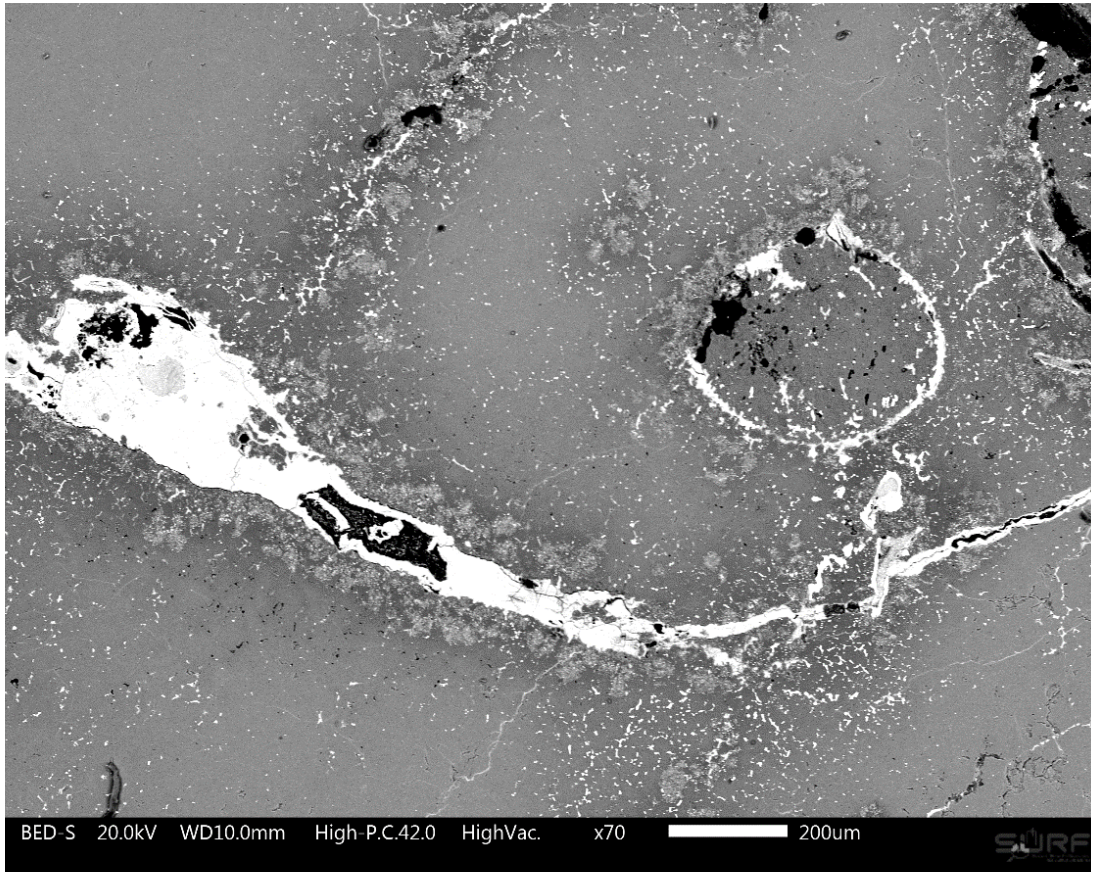
MONTANUNIVERSITÄT LEOBEN

GOLDSCHMIDT® LYON 2023 9-14 JULY

SEPARATION OF METAL AND SILICATE MINERALS

- Crushing to 150 – 250 µm
- Handmagnet
- Franz isodynamic separation
- Handpicking





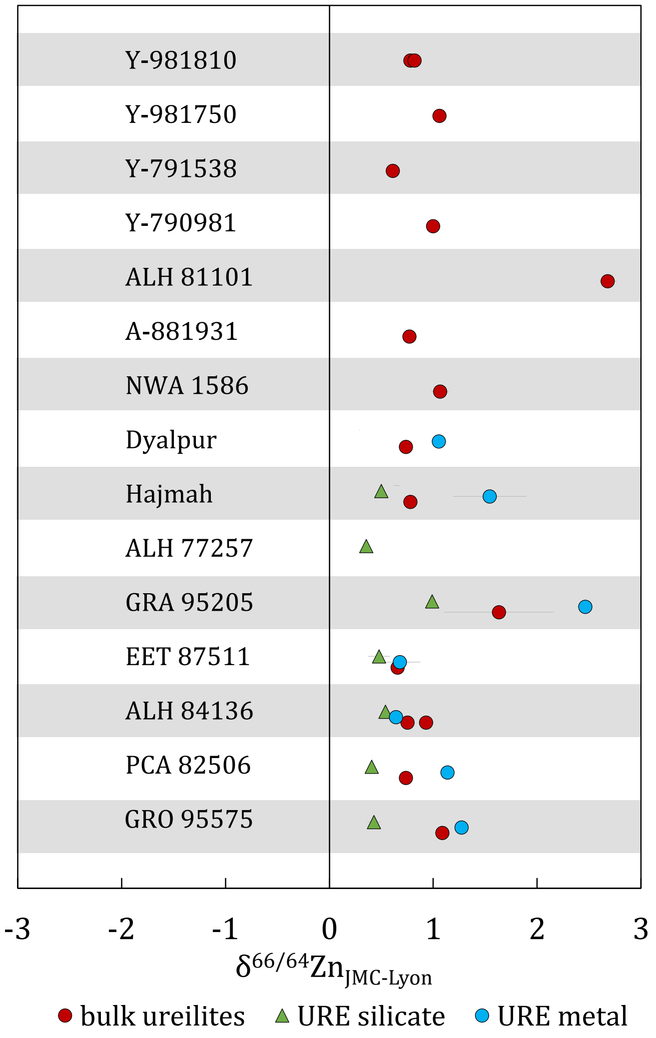
“Silicate fractions” = cores of silicate grains

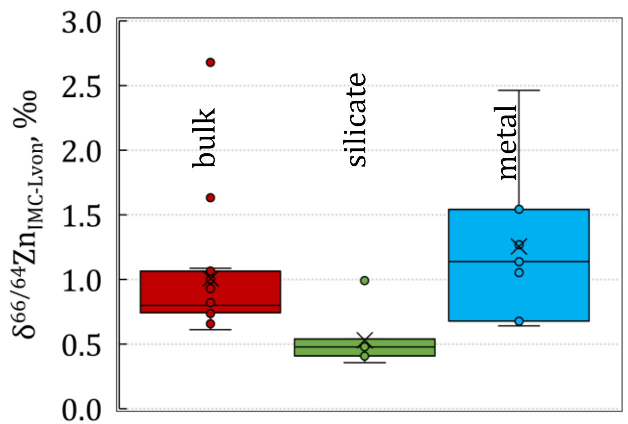
“Metal fractions” = mixture of interstitial metal and sulfide

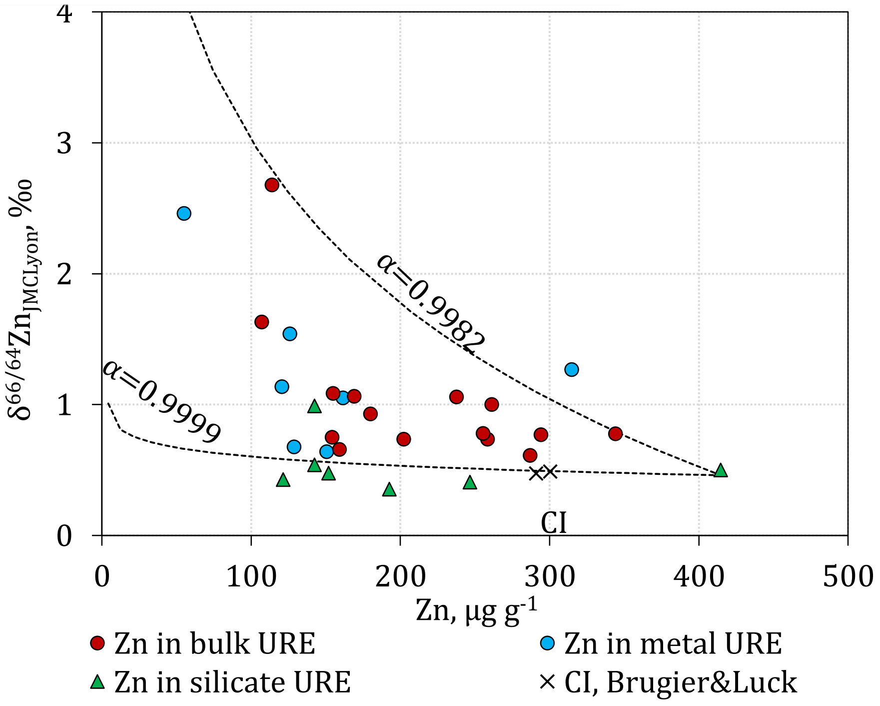
MONTAN UNIVERSITÄT LEOBEN

GOLDSCHMIDT LYON 2023 9-14 JULY

Zn ISOTOPES IN UREILITES AND THEIR COMPONENTS



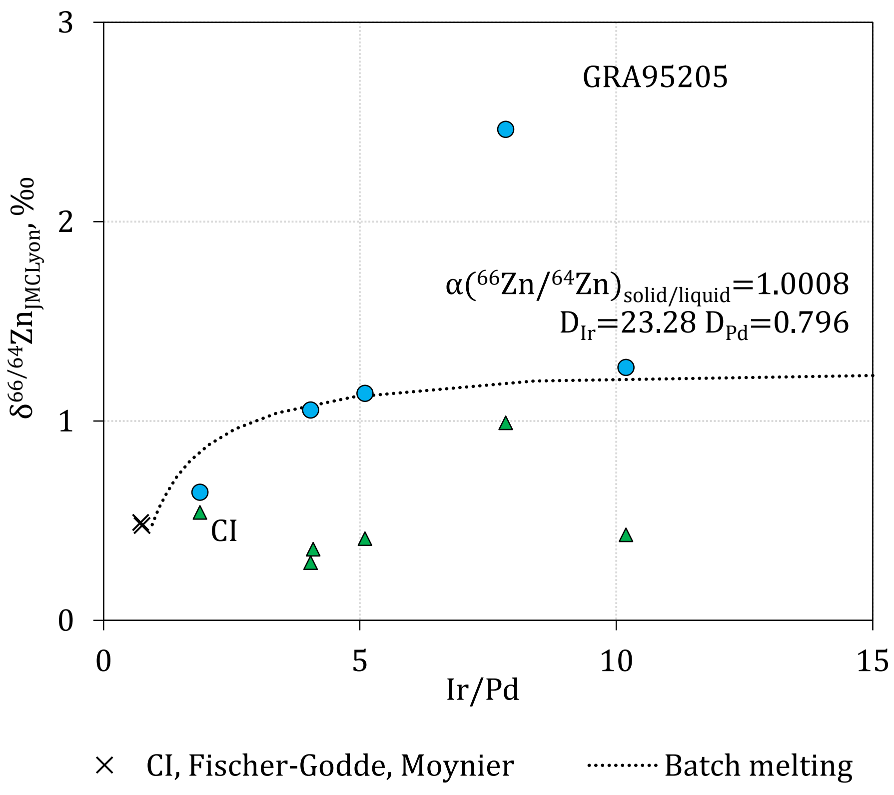




MONTAN UNIVERSITÄT LEOBEN

GOLDSCHMIDT LYON 2023 9-14 JULY

EVAPORATION OR METAL FRACTIONATION?

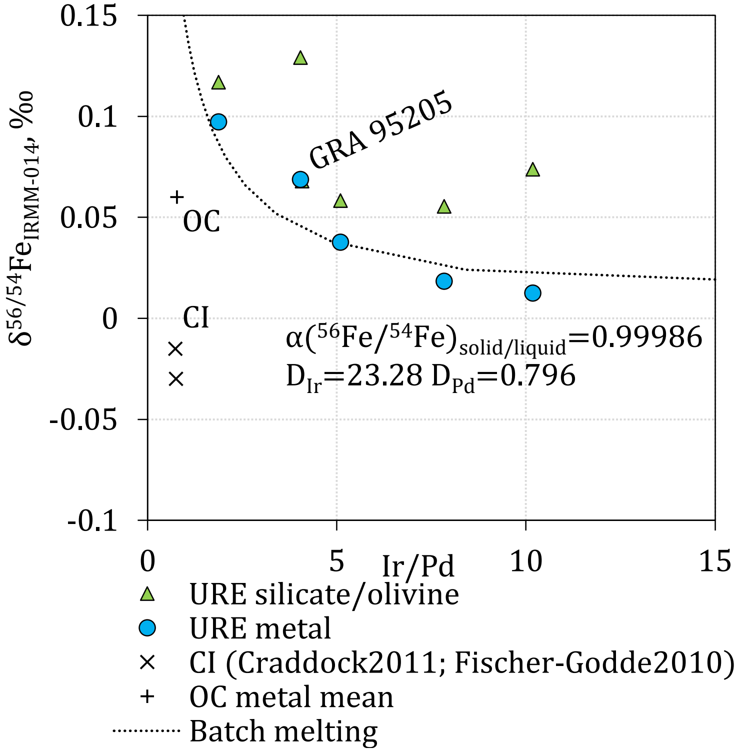


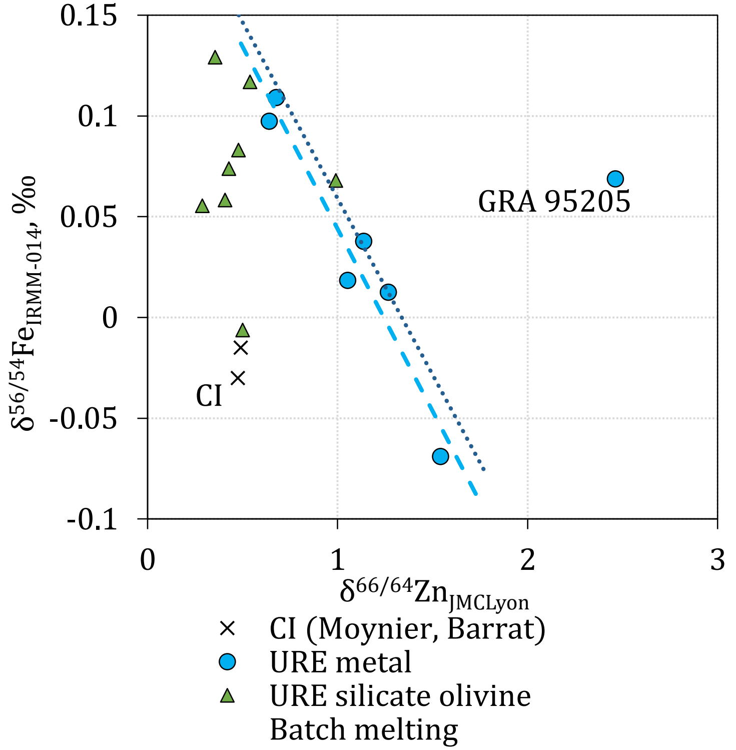
- ► The metal fractions of ureilites fall onto the **batch melting** curve in the $\delta^{66/64}Zn$ – Ir/Pd space
- ► GRA95205 is the only "outlier", but it has likely underwent **localized evaporation event**
- ► CI chondrites can not be the primitive material for the ureilite PB

Brugier *et al.* 2019, Moynier *et al.* 2010, Chabot *et al.* 2003, Warren and Huber 2006, Rankenburg *et al.* 2008, Fischer-Gödde *et al.* 2010, Dhaliwal *et al.* 2017

MONTAN UNIVERSITÄT LEOBEN
GOLDSCHMIDT LYON 2023 9-14 JULY

Fe ISOTOPIC SYSTEMATICS





- The $\delta^{56/54}Fe$ of the metal fractions of ureilites also fall onto the **batch melting curve**
- CI were not the primitive material of the ureilite PB

The early core formation resulted in extraction of heavier Fe isotopes and lighter Zn isotopes with the S-rich metal melts

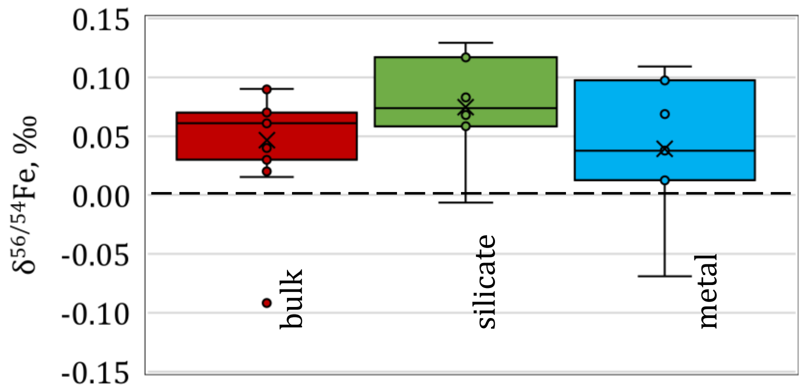
Craddock *et al.* 2011, Chabot *et al.* 2003, Warren and Huber 2006, Rankenburg *et al.* 2008, Fischer-Gödde *et al.* 2010, Dhaliwal *et al.* 2017

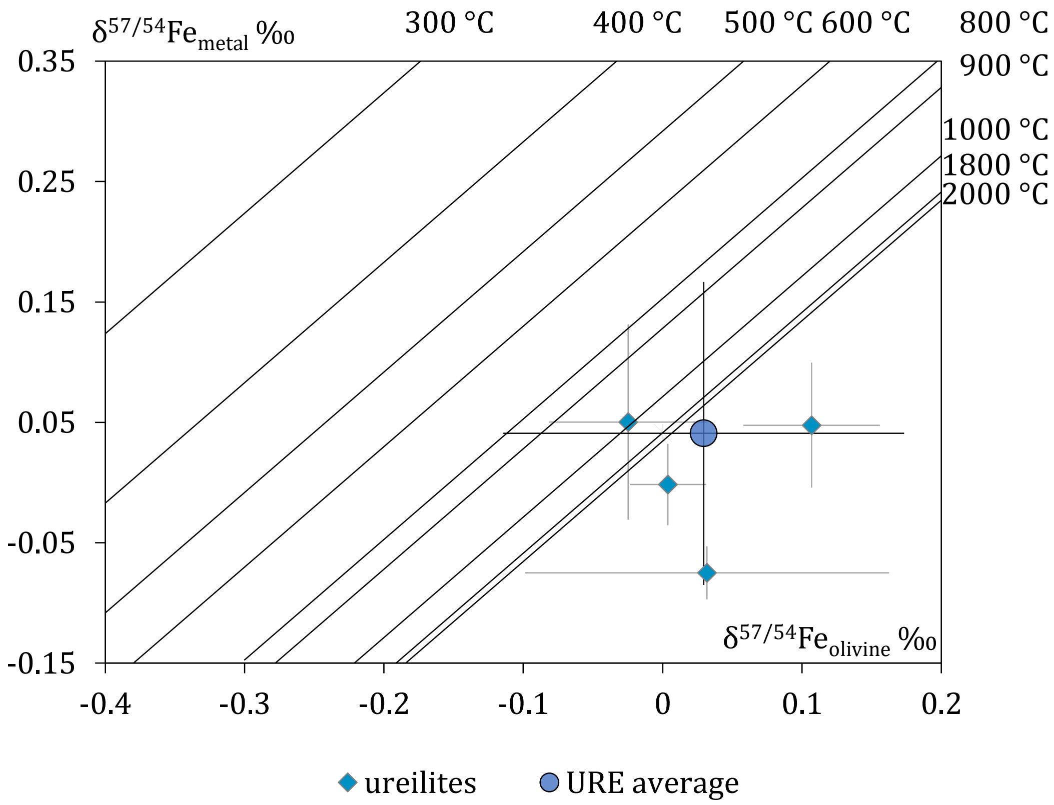
MONTAN UNIVERSITÄT LEOBEN
GOLDSCHMIDT® LYON 2023 9-14 JULY

Fe ISOTOPIC DISEQUILIBRIUM

As a result of heavier Fe isotopes extracted into the core

- Fe in silicate is isotopically heavier than in metal
- Distribution of Fe isotopes in ureilite olivine – metal system plots on unrealistically high isotherms



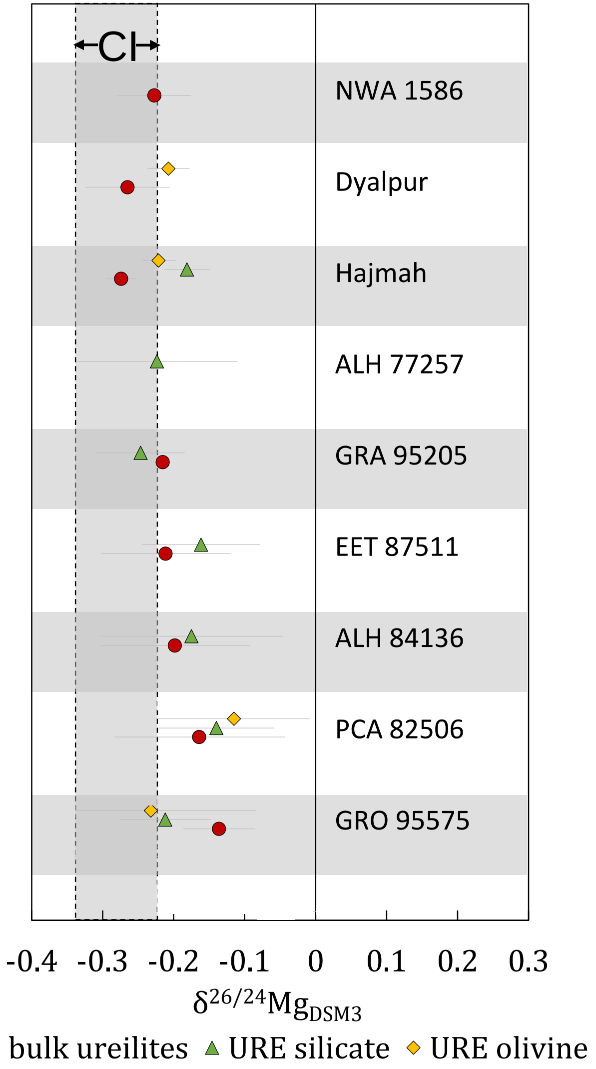


Likely metal silicate assemblage did not equilibrate after the extraction of metal melts

MONTAN UNIVERSITÄT LEOBEN

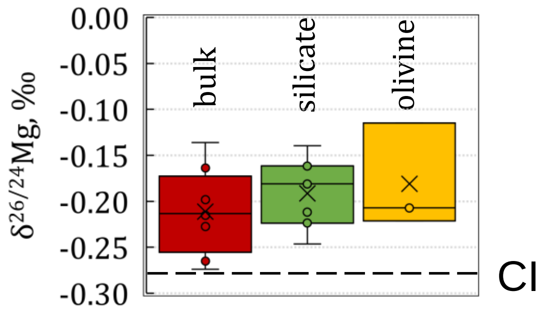
GOLDSCHMIDT LYON 2023 9-14 JULY

Mg ISOTOPIC SYSTEMATICS



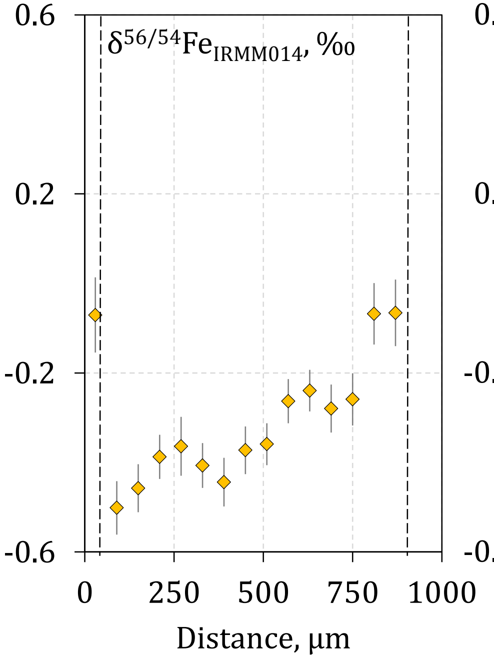
Mg isotopic signatures are heavier than CI (?)

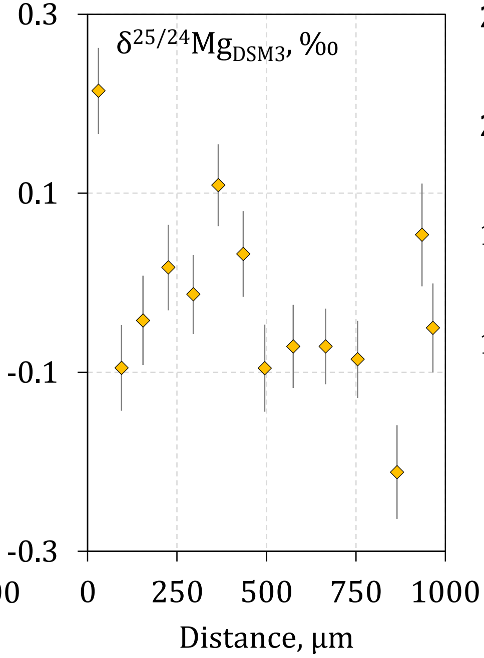
- Fractionation during **magmatic differentiation**
- Partial melting of silicate in the presence of **magnesite**
- **Kinetic isotopic fractionation** during silicate partial melting
- Preferential **evaporation of lighter isotopes** during heating

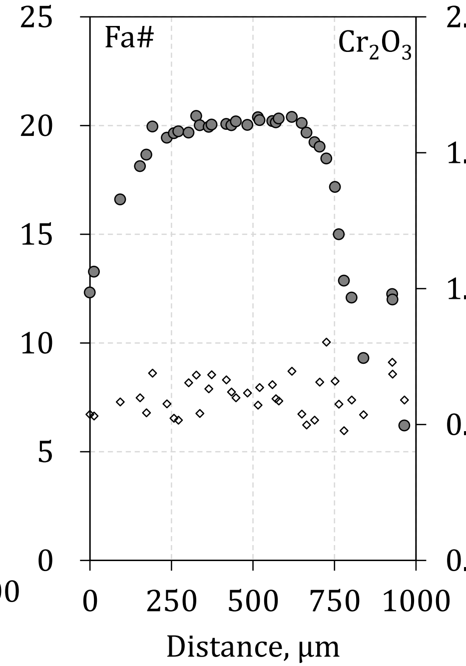


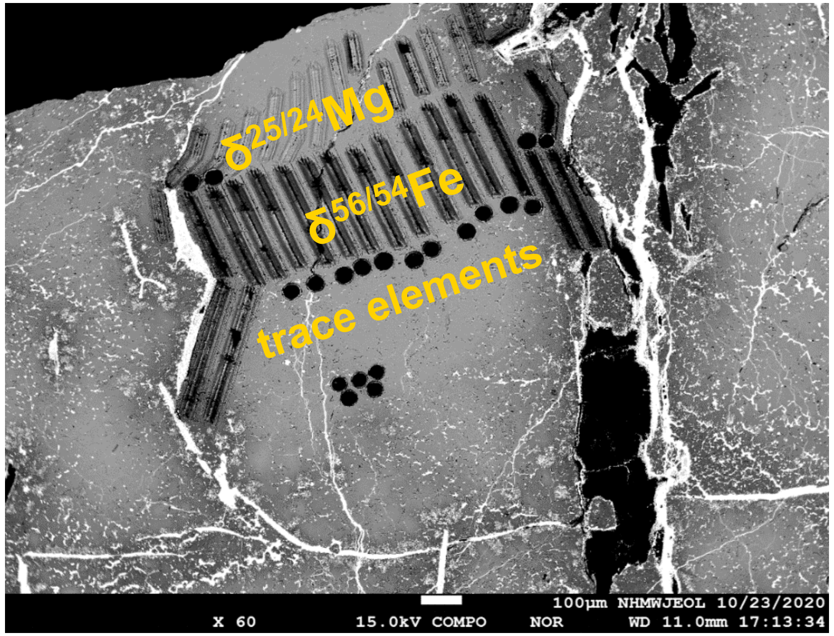
van Kooten *et al.*, 2017

Fe, Mg ISOTOPIC OLIVINE PROFILE (GRA95205)









Zoned olivine which experienced significant reduction by carbon:

- Heavily reduced olivine grains are **not in equilibrium** with the silicate assemblage
- Complex superimposed lateral Fe and Mg isotope ratio profiles
- Cannot be explained solely by **interdiffusion during cooling**
- Diffusive cooling **superimposed by metal-olivine re-equilibration** (redox) reactions

GOLDSCHMIDT LYON 2023 9-14 JULY

CONCLUSIONS

- **Heavier than chondritic Fe, Zn, and Mg** (?) isotopic signatures
- The isotope ratios show **no correlation with proxies of nebular processes**
- Zn and Fe isotopic signatures are controlled by **metal melt fractionation**
  - Heavier Fe and lighter Zn isotopes are **extracted into the core**
- This process left the remaining **metal reservoir in disequilibrium with silicate**
- Metal differentiation is **overprinted by effects of evaporation** (GRA95205)
- **PB scale evaporation** fractionating Fe, Mg and Zn also cannot be dismissed
- The olivine grains, which experienced **reduction**, are significantly affected by **kinetic isotopic fractionation**

MONTAN UNIVERSITÄT LEOBEN

DOI: 10.5281/zenodo.8123825