Advanced U-Th-Pb Geochronology

with CAMECA Ultra High Sensitivity SIMS

Over the past decades, hundreds of scientific papers on U-Th-Pb geochronology have been published based on data obtained with CAMECA ultra high sensitivity (UHS) SIMS (IMS 1270, IMS 1280 and IMS 13000-HR^3 models).

Along with **KLEORA**, a specialized platform fully optimized for U-Th-Pb geochronology, the **IMS 1300-HR^3** large geometry ion microprobe offers a unique combination of High Reproducibility at High spatial Resolution and High mass Resolution.

Thanks to proven instrumental advantages and dedicated geochronology data reduction software, our Large Geometry SIMS provide benchmark performance for precise age determination of zircon and other U rich minerals.

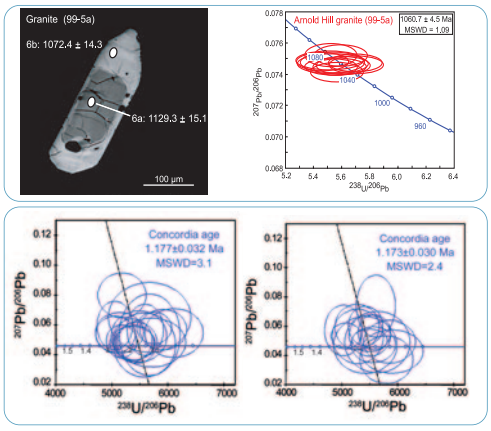
Superior SIMS analytical capabilities:

- **In situ analysis with excellent sensitivity, and now greatly improved spatial resolution**
- **Superior analytical performance: isotopic ratio precision down to permil level**
- **Versatility: spot analysis, ion imaging, depth profiling**
- **Ease-of-use and high throughput**

Zircon

From old to (very) young zircon dating with excellent precision

Accurate zircon geochronology with good spatial resolution requires advanced instrumentation capable of dating small minerals within their petrographic context and/or domains in single crystals. Our UHS SIMS perform in situ dating of zircon with excellent precision thanks to:



- **High mass resolution** for peak separation between Pb isotopes and interferin molecular ions.
- **Optimized transmission** for analyses of low radiogenic Pb content even in very young zircons (e.g. in a zircon ca. 1 Ma, [Pb] is < 30 ppb for [U] ~ 20-50 ppm).
- **Oxygen flooding - uniquely available on CAMECA IMS -** provides improved sensitivity (~2x Pb signal increase) and highly reproducible analytical conditions.
- **State-of-the-art detection system** with low background levels (detector signal/noise is a critical parameter for achieving high precision).

Top: *First U-Pb direct dating of iron oxide-copper-gold (IOCG) mineralization. Hydrothermal zircon crystals from IOCG-type ore deposits (Lyon Mountain, US). Data from P.M. Valley et al., Geology 37 (2009), p.223.*

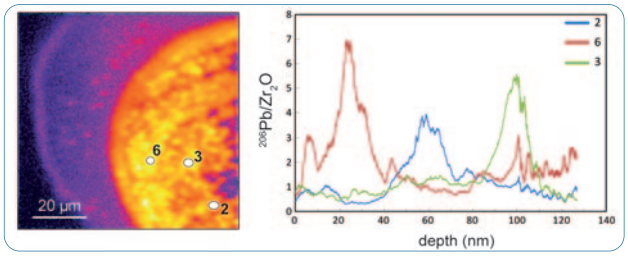
Bottom: *Lower-intercept age (Th corrected data) for young Quaternary zircon (Chinkuashi dacite, Taiwan). Data from Y. Gao et al., Earth Science Frontiers 17 (2010), p.146*

In-depth ion imaging: an innovative method for resolving dates within the most complex samples

The superior imaging capabilities of the CAMECA UHS SIMS allow characterization of problematic zircons that cannot be dated using conventional spot analysis conditions.

A new method of in-depth ion imaging, combining scanning ion imaging (SII) and depth-profiling, is used to investigate the length scale of Pb-enriched domains in zircon. SII reveals a heterogeneous pattern of radiogenic Pb distribution, but the lateral resolution is limited to 1-2 µm. The combination of ion imaging and depth profiling ensures unequaled spatial resolution (three orders of magnitude better than SII alone).

Furthermore, the optimized transmission of the UHS SIMS provides excellent sensitivity for investigating Pb spatial distribution in zircon.



Zircon crystals from Southern India, region affected by Ultra High Temperature (UHT) metamorphism at ca. 570 Ma. ^{206}Pb ion image with reconstructed depth profiles from selected areas. In-depth ion imaging shows the presence of nm-scale domains of isolated radiogenic Pb whose formation is assigned to annealing processes during the UHT event. Data from M. J. Whitehouse et al., Contrib Mineral Petrol 168 (2014), p.1042

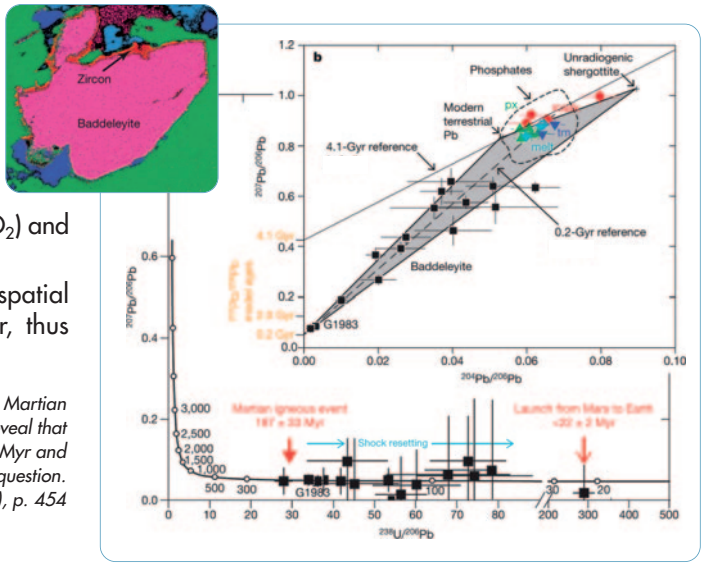
Although zircon is by far the most commonly utilized mineral for U–Th-Pb dating, monazite, apatite, titanite, rutile and baddeleyite are also commonly dated and provide a spectrum of geochronological applications in igneous, metamorphic, hydrothermal, and epithermal systems. The versatility and benchmark analytical performance of our Large Geometry SIMS enable unrivaled dating precision and accuracy at intra-crystalline scale on these most diverse minerals.

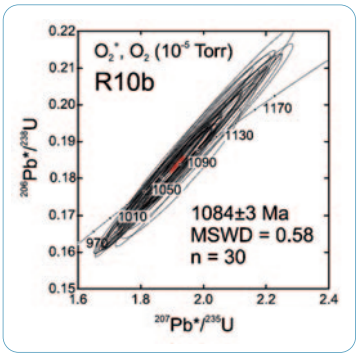
Baddeleyite

Baddeleyite dating is challenging because the grains are small (<20µm) and crystal orientation is known to affect U-Pb isotope ratios. Several instrumental advantages - **unique to CAMECA IMS design** - ensure superior dating precision:

- **Oxygen flooding** greatly enhances the Pb^+ yield (factor of ~7 in ZrO_2) and reduces the crystal orientation dependent Pb/U fractionation.
- **Small spot size combined with ion microscope design** allows spatial selection of ions generated in the center of an analysis crater, thus optimizing the spatial resolution on such small grains.

U-Pb measurements of micro-baddeleyite and host igneous minerals in a Martian meteorite, for which previous interpreted ages were controversial. Results reveal that ZrO_2 grains pre-date the Martian impact event (crystallization age of187 Myr and ejection from Mars < 22 Myr years ago), thus solving the meteorite age question. Data from D.E. Moser et al., Nature 499 (2013), p. 454





Rutile

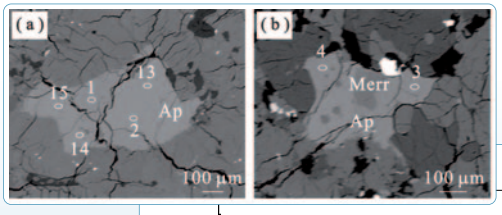
In situ rutile dating is of increasing interest for the geochronology community. Rutile being conductive under ion beam bombardment, a pioneering dating protocol using O_2^+ primary ion beam (in combination with oxygen flooding) has been developed.

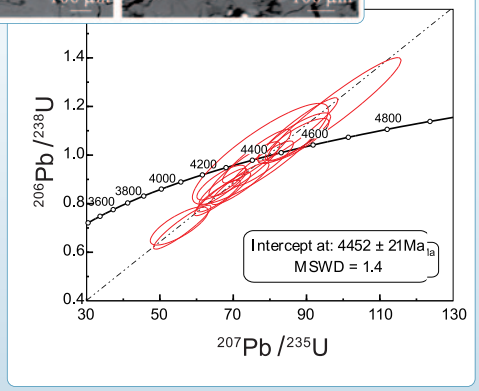
Uniquely available on CAMECA IMS, O_2^+ primary ion conditions present many advantages: ease of operation, higher secondary ion signal (due to the high primary beam intensity) and reduced common Pb contribution (due to the lower impact energy and higher sputter rates).

Apatite

Precise U-Th-Pb dating of apatite from meteorites is challenging due to the very low uranium abundance (<10 ppm). Bulk methods such as ID-TIMS have been used in the past, but in situ dating is preferred in many cases when the apatite must not be destroyed or its textural content is important.

CAMECA UHS SIMS was used to investigate the Chelyabinsk meteorite after the 2013 asteroid impact. 17 apatite spots were analyzed using optimized transmission and high mass resolution conditions (~9000 at 50% peak height) in order to separate $CaPO_3$ as well as the U, Th and Pb isotopes from isobaric interferences. Excellent age precision and accuracy was obtained (4,452±21 Ma).





The asteroid impact near the Russian city of Chelyabinsk in 2013 was the largest airburst on Earth since 1908. Unprecedented measurements were performed in order to characterize the meteorite, including in situ phosphate U-Pb dating. Top: Apatite grains found in Chelyabinsk (section C3-3-2). Ovals indicate analyzed SIMS spots. Bottom: U-Pb Concordia plot for Chelyabinsk apatite grains. The upper intercept age is 4,452±21 Ma, much younger than the majority of other ordinary chondrites phosphate ages. Data from: O. P. Popova et al, Science 342 (2013), p.1069

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