U-Th-Pb Geochronology by LA-MC-ICPMS at the Arizona LaserChron Center

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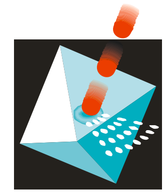


Introduction

U-Th-Pb geochronology has become a fundamental tool in Earth Science research, with applications that cover the span of structural geology, tectonics, stratigraphy, paleontology, petrology, and geochemistry. Although many U-Th-Pb analytical techniques and applications are well established, emerging technologies are revolutionizing the way geochronologic information can be acquired and applied. Some of the most exciting advances in the field are being driven by laser-ablation multicollector ICP mass spectrometers, which allow for rapid determination of U-Th-Pb ages with micron-scale spatial resolution.

The Arizona LaserChron Center currently utilizes a Multicollector Inductively Coupled Plasma Mass Spectrometer (GVI Isoprobe) coupled to a 193 nm Excimer laser ablation system (New Wave Instruments). Geochronologic applications of the laser-ICPMS have been particularly successful because the instruments:

- Can determine U-Th-Pb ages efficiently (~40 analyses/hour)
- Generates U-Th-Pb ages with a precision and accuracy of 1- 2% (2-sigma), which is appropriate for most problems in Earth Science.
- Offers the potential for development of new U-Th-Pb geochronological techniques and applications
- Is highly amenable to multi-user operation
- Provides an excellent tool for training students and faculty in the generation and interpretation of geochronologic information.

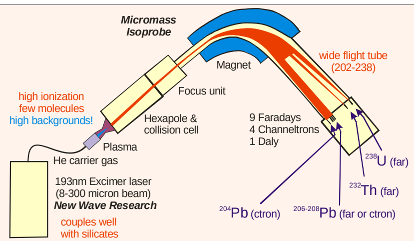
The primary goals of the ALC are to (1) help the NSF-supported Earth Science community generate the highest-quality U-Th-Pb geochronologic information possible through LA-MC-ICPMS, and (2) develop new techniques and applications that are optimized by LA-MC-ICPMS.

Recent publications describing ALC analytical methods include:

Gehrels, G.E., Valencia, V., Pullen, A., 2006, Detrital zircon geochronology by Laser-Ablation Multicollector ICPMS at the Arizona LaserChron Center: Paleontology Society Papers, v. 11, 10 p.

Gehrels, G.E., Valencia, V., Ruiz, J., 2008, Enhanced precision, accuracy, efficiency, and spatial resolution of U-Pb ages by laser ablation–multicollector–inductively coupled plasma–mass spectrometry: Geochemistry, Geophysics, Geosystems, v. 9, Q03017, doi:10.1029/2007GC001805.

Johnston, S., Gehrels, G., Valencia, V., Ruiz, J., in review, Small-volume U-Pb geochronology by LA-MC-ICPMS: Chemical Geology.

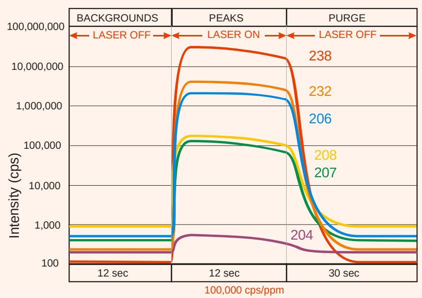


Instrument used for U-Th-Pb analyses, showing strengths (in red) and challenges (in light blue). To right are laser pits ranging from 10 to 75 microns in diameter (20 microns depth).

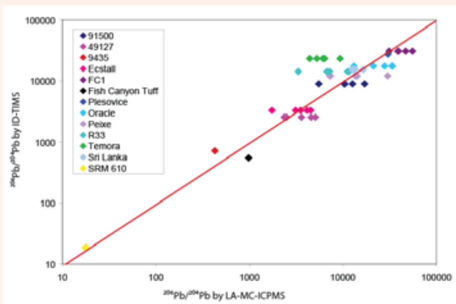
Analytical Methods

Analyses are conducted in static mode, with ^{238}U and ^{232}Th in faraday collectors, ^{204}Pb in a channeltron, and $^{206-208}Pb$ in either faraday collectors (with 10^{12} ohm resistor for ^{207}Pb) or channeltrons. Each analysis takes ~60 seconds, with 12 seconds on backgrounds (on peaks with no laser firing), 12 seconds on peaks with laser firing, and 30 seconds of purge between samples. Beam size is selected according to the size and complexity of crystals, with typical beam sizes of 10-35 microns.

Samples are measured with an ablation rate that is sufficient to measure 204 reliably, as this is essential for an accurate common Pb correction. Because we generally have ~200 cps of background in the 204 mass position, this requires an ablation rate that generates at least ~200 cps of sample ^{204}Pb. This yields the signal intensities shown below.



A comparison of the 206/204 in zircon crystals by ID-TIMS and by LA-MC-ICPMS (figure below) demonstrates that we can successfully measure 206/204, and accordingly correct for common Pb accurately.



Data Quality

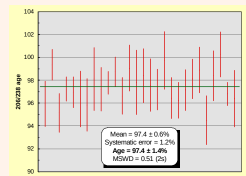
Precision

Analytical uncertainties include the following, which are propagated separately and then added quadrically:

Measurement errors = uncertainties that apply to only a single analysis. These are generally 1-2% (2-sigma) and include errors from 206/238, 206/207 206/204.

Systematic errors = uncertainties that apply to a set of analyses rather than a single analysis. These combine to 1-2% for most samples and include:

- error in the fractionation factor of 206/238 and 206/207
- age of the calibration standard
- composition of initial Pb
- decay constants for ^{238}U and ^{235}U.

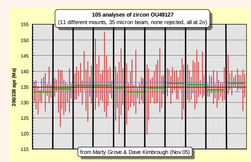


Age determination of zircons from a granite:

- Uncertainty of individual analyses = 1-2% (2σ)
- Low MSWD shows that scatter is consistent with error.
- Weighted mean error = 0.6%.
- Systematic error = 1.2%.
- Total error in age = 1.4%

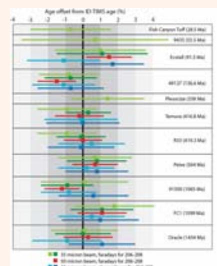
Reproducibility

Reproducibility has been determined through analysis of secondary standards during 11 different sessions.



- Red bars show uncertainty of individual analyses.
- Green lines show mean of analyses from each session.
- Blue lines show 1% error.

This shows that reproducibility is better than 1%.



Accuracy

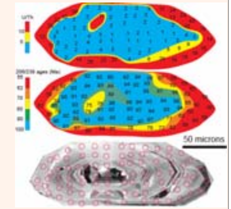
Accuracy is constrained by analysis of zircons that have been calibrated by ID-TIMS.

This age-offset diagram shows that sets of analyses (using both faradays and channeltrons) are accurate to within 1% (2-sigma) of the known (ID-TIMS) age. This is about the same as SIMS.

Applications

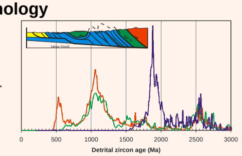
Igneous geochronology (age mapping)

U-Pb ages for simple zircon crystals are determined with a 25-35 micron beam. Complex zircons can be mapped using a 10 micron beam, as shown to right.



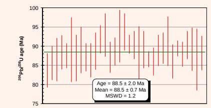
Detrital mineral geochronology

LA-MC-ICPMS is ideal for detrital mineral studies because the rapid throughout allows generation of large number of analyses rapidly (~700 per 24 hour session).



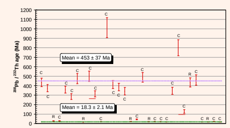
Cooling ages of titanite and apatite

U-Pb ages of titanite and apatite are readily determined by LA-MC-ICPMS. Reliable measurement of ^{204}Pb is critical.



Monazite geochronology

U-Pb and Th-Pb ages can be determined for monazite crystals and >10 micron size monazite inclusions in garnet. Ages of monazite inclusions in garnets from the Greater Himalayan Sequence are shown.



The future…

A Nu Plasma MC-ICPMS, dedicated to geochronologic and geochemical research in the ALC, will arrive September 2008. This instrument has a newly designed collector block that allows for analysis of U-Th-Pb and Hf-Lu-Yb isotopes during the same acquisition, from the same laser pit. The collector configuration and acquisition sequence are as follows:

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	IC1	IC2	IC3	IC4
30 sec			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
12 sec	[illegible]	[illegible]											[illegible]	[illegible]	[illegible]	[illegible]
12 sec	238U	232Th											208Pb	207Pb	206Pb	204Pb
30 sec (?)			180Hf	179Hf	178Hf	177Hf	176Hf 176Lu 176Yb	175Lu	174Hf 174Yb	173Yb	172Yb	171Yb				

Acknowledgments

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