In-situ U-Pb dating of extraterrestrial materials using SHRIMP

Kentaro Terada
(Hiroshima University)

2010/3/11

Outline of my talk

1. Scientific background and Motivation
   - Recent chronological views
   - Advantage of in-situ U-Pb dating

2. Some applications to extraterrestrial materials
   Success and/or unsuccess

Evolution of planetesimal

For complete understanding of planet-forming, it is essential to constrain on the timescale for the evolution of planetary bodies.
Evolution of planetesimals

Accretion and fragmentation

- Sequential collisions between planetesimals obscured and destroyed much of the primitive features of the first generation planetary bodies.

Small clasts and/or cosmic dust potentially provide us a new insight into the evolution. And in-situ absolute dating is required to decipher.

Advantages of U-Pb dating

- Comparable half-lives to the evolution of Solar System
  - $^{200}Pb$/$^{200}U$: 1.37x10^4 year
  - $^{238}Pb$/$^{238}U$: 4.5x10^9 year
- Decay constants are well determined
  - Less ambiguity for age determination
- U-host phase have high closure temperatures
  - Zircon (ZrSiO₄): ~900°C
  - Apatite (Ca₅(PO₄)₂(F, OH, Cl)): ~600°C
  - Resists to secondary alteration like impact events
- Two decay series of which parents & daughters are same
  - Both the formation and alteration ages can be determined, even if alteration occurred.

Commonly used radiometric ages

Long-lived nuclides

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Absolute age T (year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{235}U$ → $^{207}Pb$</td>
<td>4.47x10^8</td>
</tr>
<tr>
<td>$^{238}U$ → $^{206}Pb$</td>
<td>4.47x10^9</td>
</tr>
<tr>
<td>$^{232}Th$ → $^{208}Pb$</td>
<td>1.40x10^10</td>
</tr>
<tr>
<td>$^{238}U$ → $^{209}Th$</td>
<td>1.5x10^11</td>
</tr>
<tr>
<td>$^{235}U$ → $^{227}Th$</td>
<td>1.6x10^11</td>
</tr>
</tbody>
</table>

Short-lived nuclides

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Relative age</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{40}K$ → $^{40}Ar$</td>
<td>1.25x10^9</td>
</tr>
<tr>
<td>$^{90}Sr$ → $^{90}Y$</td>
<td>4.88x10^9</td>
</tr>
<tr>
<td>$^{147}Sm$ → $^{147}Nd$</td>
<td>1.06x10^7</td>
</tr>
<tr>
<td>$^{176}Lu$ → $^{176}Hf$</td>
<td>3.57x10^6</td>
</tr>
<tr>
<td>$^{182}Hf$ → $^{182}W$</td>
<td>9.87x10^3</td>
</tr>
<tr>
<td>$^{187}Re$ → $^{187}Os$</td>
<td>4.2x10^3</td>
</tr>
</tbody>
</table>

$\beta$ decay systems are difficult for current SIMS (by magnet)

Total Pb/U Isochron methods

Concordia case

Linear regression gives A formation age

Discordia case

Planar regression gives formation age and alteration age

Outline of my talk

1. Scientific background and Motivation
   - Recent new findings
   - Advantage of in-situ U-Pb dating

2. Some applications to extraterrestrial materials
   - Success and/or unsuccess

(1) Lunar Basaltic meteorites

Chronological studies on basaltic meteorites have been difficult because there are polymict breccia composed of highland and mare origins

Highlands

Lunar meteorite

3.2±0.2 Ga

Mare

4.4 Ga & 4.0 Ga

Highland-U-Pb, Takahashi 1991)

References

Polnau et al. 2000

Arai et al. 2000

Arai et al. 1993
(1) Lunar Basaltic meteorites
Chronological studies on basaltic meteorites have been difficult because these are polymict breccias composed of highland and mare origins

Highlands

Mare

SHRIMP ages (2σ)
3.53±0.17 Ga (Terada et al. Nature 2007)
3.40±0.17 Ga & 0.06±0.20 Ga (Terada et al. 2005)
3.53±0.11 Ga (EET87)
3.57±0.10 Ga & 0.10±0.13 Ga (EET36)

Average is 3.53 ± 0.06 Ga
⇒ support hypothesis of "launch-pair origins"

(2) Ancient lunar magmatism
Kalahari 009 (nonomict breccia)

4.35 ± 0.15 Ga
(Terada et al. Nature 2007)

Lu/Hf age 4.2 ±0.35 Ga (Shih et al. 2007)
Lu/Hf age 4.3±0.05 Ga (Sakul et al. 2006)
Sm/Nd age 4.30±0.05 Ga (Shih et al. 2008)

5 μm spot analysis

(3) Granitic clasts in LL chondrite

Pb isotopes in the Solar system?

Pb age: 4.48 ± 0.12 Ga
Pb model age: 4.53 ± 0.03 Ga

SUMMARY

- We have established in-situ U-Pb dating methods using Hiroshima-
  SHMRM
  - Could be a powerful tool to decipher the unlabeled evolution in the
  early Solar System
- If we choose appropriate samples, we derive the new insights into
  the evolution of the Solar System
- Martian/lunar meteorites, achondritic clast in primitive meteorites
- Impact/volcanic, spherical from lunar origin
- cosmic dust from Antarctic ice field

- For more precise ages, we need the further developments
  - robust estimation of initial lead composition
  - Multi-collector system for SHRIMP
  - Post-ionization after the sputtering