Martian meteorite chronology: Progress and challenges (A very brief history)

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Challenges in martian meteorite geochronology

- Relatively rare
  - Currently >160 (including pairing groups; see [https://imca.cc/mars/martian-meteorites-list.htm](https://imca.cc/mars/martian-meteorites-list.htm))
- Majority are fine-grained basalts
- All have been shocked (up to 10s GPa)
  - Effects include maskelynite, planar deformation features, melt veins, melt pockets

Photomicrographs showing maskelynite (diaplectic glass of feldspar composition) in ALH 77005.

Courtesy Erin Walton

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Chassigny, France (Oct. 3, 1815)

Shergotty, India (Aug. 25, 1865)
- ALH77005, Y793605, EETA79001

Nakhla, Egypt (June 28, 1911)
- Lafayette, Governador Valadares

All oddballs (“SNCs”) until:
- McSween & Stolper (1980)
- Bogard & Johnson (1983)
Chen and Wasserburg (1986)

**In Zagami, Shergotty, and EETA79001 (shergottites)**

Despite ~200 Ma $^{238}\text{U}/^{206}\text{Pb}$ ages, concluded that timing = resetting by impact (forming maskelynite)
Jones (1986)

- Considered different scenarios based on Rb-Sr, Sm-Nd and U-Th-Pb systems
  - Mineral disequilibria/compositional zoning

- Concluded that shergottites are ~200 Ma, and nakhlites and chassignites ~1300 Ma

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Borg et al. (1997)

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Zagami, Shergotty, EETA79001, QUE 94201 (shergottites)
Revisiting U-Pb: Borg et al. (2005)

► Combined U-Pb, Rb-Sr, and Sm-Nd of Zagami
  – On same WR, mineral and leachate fractions
  – Rb-Sr: 166 ± 6 Ma
  – Sm-Nd: 166 ± 12 Ma
  – $^{238}$U-$^{206}$Pb: 156 ± 6 Ma (cf. 230 Ma)
  – Presence of a high $^{207}$Pb/$^{206}$Pb contaminant that disturbs the U-Pb system
    • Terrestrial
    • Martian
Revisiting U-Pb: Bouvier et al. (2005)

Fig. 1. $^{206}$Pb/$^{238}$Pb vs. $^{204}$Pb/$^{206}$Pb for whole-rocks and mineral separates from this study and from Chen and Wasserburg [6]. LA: Los Angeles; Zag: Zagami; Sh: Shergotty; EETA: EETA79001. Black symbols: this study; grey symbols: Chen and Wasserburg [6]. Bull’s-eye symbols: maskelynite; crosses: pyroxene.

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U-Pb baddeleyite: Zhou et al. (2013)

Zagami (shergottite)
Table 3  
Summary of geochronological studies of Zagami (ages in Ma).

<table>
<thead>
<tr>
<th>Ar-Ar</th>
<th>Rb-Sr</th>
<th>Sm-Nd</th>
<th>Lu-Hf</th>
<th>U-Th-Pb</th>
<th>Pb-Pb</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>209 ± 2(^a)</td>
<td></td>
<td></td>
<td></td>
<td>156 ± 6(^g)</td>
<td>4048 ± 17</td>
<td>Bogard and Park (2007)</td>
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<tr>
<td>223 ± 6(^d)</td>
<td>180 ± 4</td>
<td>180 ± 37</td>
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<td>Shih et al. (1982)</td>
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<td>186 ± 5(^e)</td>
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<td>Nyquist et al. (1995)</td>
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<td></td>
<td>183 ± 6(^f)</td>
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<td>Borg et al. (2005)</td>
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<td></td>
<td>166 ± 6</td>
<td>166 ± 12</td>
<td>185 ± 36</td>
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<td>Bouvier et al. (2005)</td>
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<td></td>
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<td>155 ± 9</td>
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<td>Chen and Wasserburg (1986)</td>
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<td></td>
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<td></td>
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<td>230 ± 5(^f)</td>
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<td>This study</td>
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<td>229 ± 8(^g)</td>
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<td></td>
<td>183 ± 7(^h)</td>
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<td>153 ± 81(^i)</td>
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</tbody>
</table>

\(^a\) \(^{40}\)Ar-\(^{39}\)Ar age with no correction for cosmogenic \(^{36}\)Ar.
\(^b\) \(^{40}\)Ar-\(^{39}\)Ar age corrected for cosmogenic \(^{39}\)Ar.
\(^c\) For fine-grained portion of Zagami.
\(^d\) For coarse-grained portion of Zagami.
\(^e\) \(^{238}\)U-\(^{206}\)Pb age obtained from the purest mineral fractions.
\(^f\) \(^{238}\)U-\(^{206}\)Pb age.
\(^g\) \(^{235}\)Th-\(^{208}\)Pb age.
\(^h\) \(^{238}\)U-\(^{206}\)Pb age from baddeleyite, corrected for nonradiogenic Pb using the \(^{207}\)Pb correction method (see text).
\(^i\) \(^{238}\)U-\(^{206}\)Pb age from phosphates, corrected for nonradiogenic Pb using the \(^{207}\)Pb correction method (see text).
U-Pb baddeleyite: Moser et al. (2013)

The “Pb paradox” resolved…see also: Bellucci et al. (2016)
Martian Meteorites - summary

- **Shergottites (~82%)**: 165-700 Ma ages
- **Nakhlites & Chassignites (~14%)**: 1300 Ma ages
- **Augite-rich shergottites (~2%); 2400 Ma age**
- **NWA 7034 (~1%)**: 1500 Ma age, clasts >4300 Ma
- **ALH 84001 (~1%)**: 4100 Ma age

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After Borg et al. (1997)

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After Borg et al. (1997)
Constraints on the Timing of Planetary Differentiation

Rb-Sr whole rock mixing diagram

Martian mantle today and at ~4.5 Ga

Evolved component today

Evolved component at ~4.5 Ga

Courtesy Lars Borg
Shergottite radiogenic isotopes and REE

Depleted
La/Yb ~ 0.1

~ Range of Earth basalts!

“Enriched”
La/Yb ~ 1

This holds for nearly all shergottites!

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After McCoy et al. (2011)
Shergottites: Implications

Old shergottites (~340 Ma)
- NWA1195
- NWA1460
- DaG
- Dho SaU Y98

Old shergottites (>474 Ma)
- NWA1460

Young shergottites (~175 Ma)
- EET B
- EET A
- LA NWA856
- Shergotty Zagami

Intermediate Source

Enriched Mantle (contains trapped liquid)

Magma ocean model. After Symes et al. (2008)
Invaluable information, BUT:

- Bias in sampling
- Gaps in chronology
- Not linked to specific units on Mars (having crater retention ages)

Udry et al. (2020)
Reference list


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