The bombardment history of 4 Vesta as told by sample geochronology

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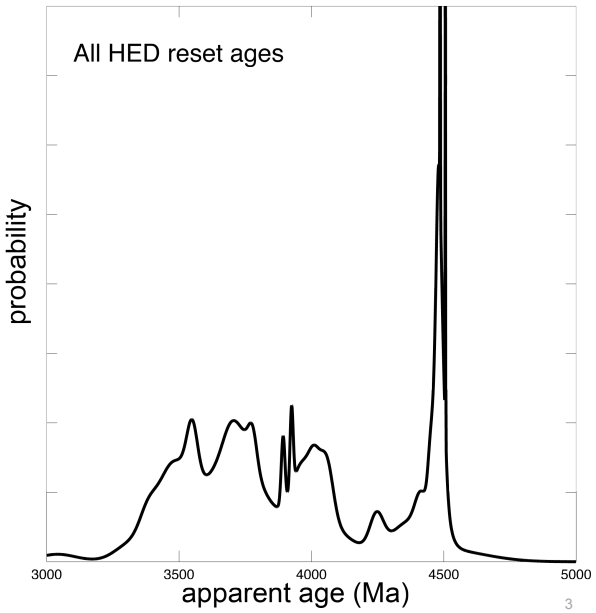
The 4 Vesta rock record

- HEDs = Howardites, Eucrites, Diogenites, largest achondrite group, spectrally linked to Vesta
- The HED parent body globally differentiated and fully crystallized around 4.56 Ga (Lugmair and Shukolyukov, 1998)
  - Eucrites – basaltic crust
  - Diogenites – cumulate mantle
- Dawn shows that Vesta is extensively cratered and covered with a well-developed regolith spectrally similar to howardites
  - Howardites - polymict regolith breccias
- Regolith brecciation and heating by impacts should be reflected in HED disturbance ages

Disturbance ages in HEDs

- Age distribution of all HED impact-reset rocks (Bogard and Garrison (1993, 2003)
  - a short, intense spike at 4.48 Ga,
  - followed by a period of relative quiescence, then
  - ramping up between about 4.0 and 3.5 Ga

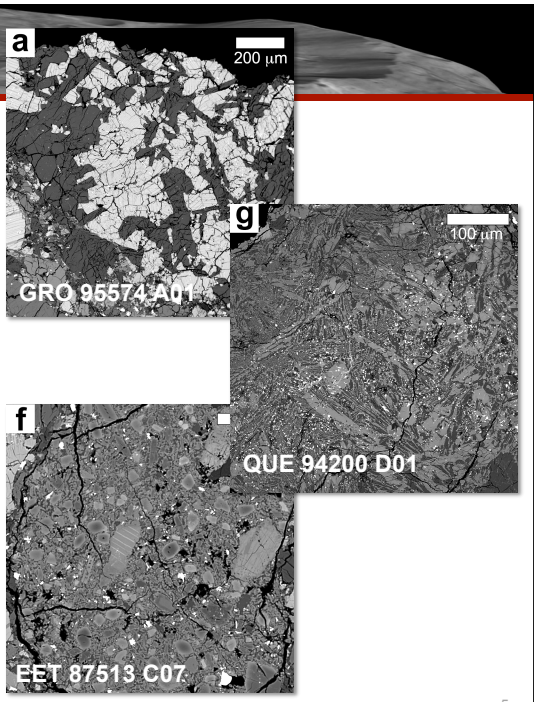


Impact-melt clasts in howardites

- Most dated rocks and clasts are eucrites - heated and degassed without fundamentally changing their character
- Impact-melt clasts are less common, smaller, but possibly more likely to have been fully degassed, and largely unstudied
- Characterized texture, bulk composition, mineralogy, and ^{40}Ar-^{39}Ar ages of 37 individual clasts within howardites EET 87513, QUE 94200, GRO 95574 and QUE 97001 in 100-µm thick, polished sections

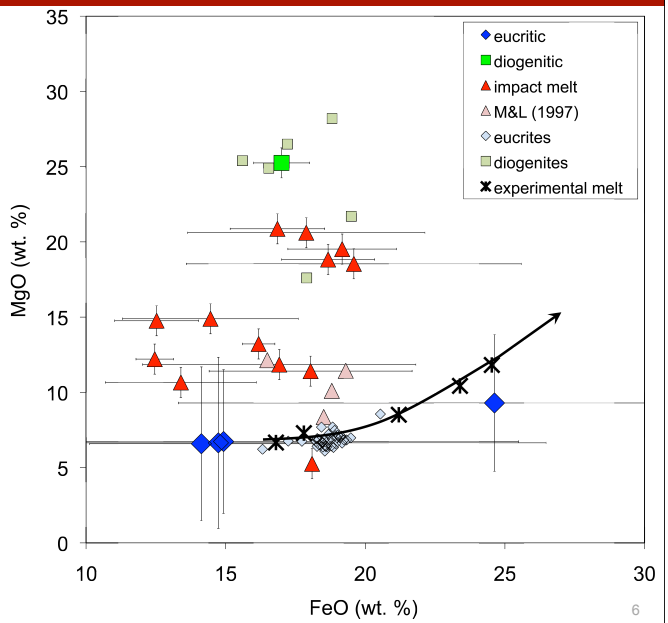
Clast textures

- A01, eucritic clast with a classic basaltic texture consisting of blocky feldspar (gray) and pyroxene (white)
- D01, acicular pyroxene and plagioclase in an impact-melt clast
- C07, also a microporphyritic impact-melt clast, but with a higher proportion of relic clasts



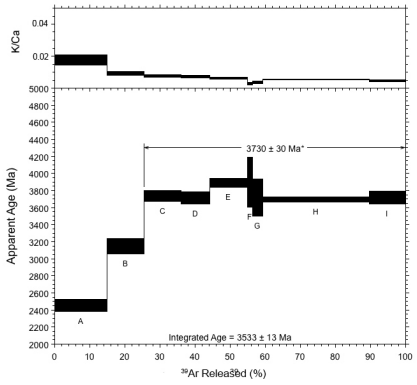
Clast compositions

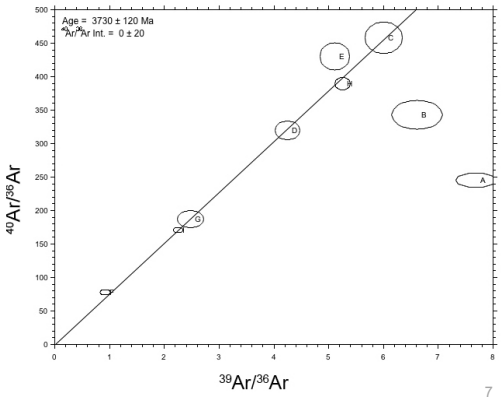
- Impact-melt clasts have a composition intermediate between eucrites and diogenites
- Clasts are not a previously-unknown evolved basaltic product (sorry Duck)



^{40}Ar-^{39}Ar data

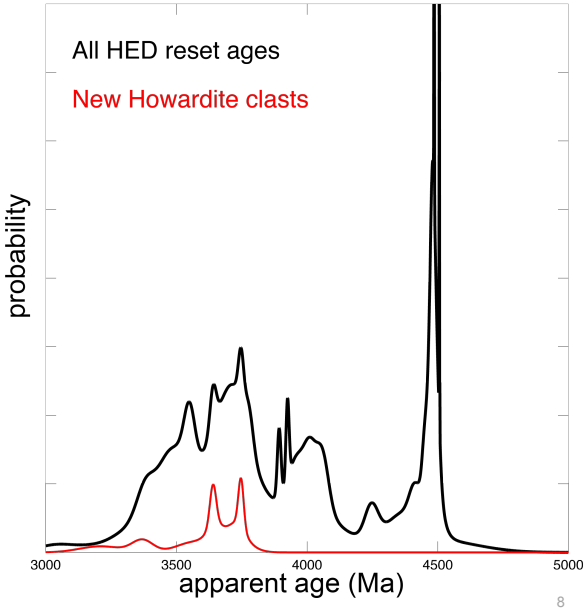
- Not all clasts produced good Ar-Ar data (not enough heating steps, discordant “plateaus”, etc.)
- Data examined using plateau plots, isochrons, and inverse isochrons, most conservative interpretations chosen





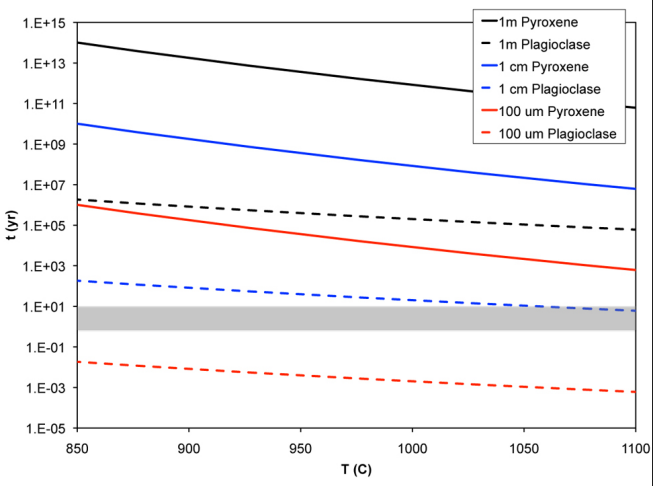
Clast ages

- New impact-melt ages (11) predominantly 3.6-3.8 Ga
- Fall well within the age distribution of all HED impact-reset rocks



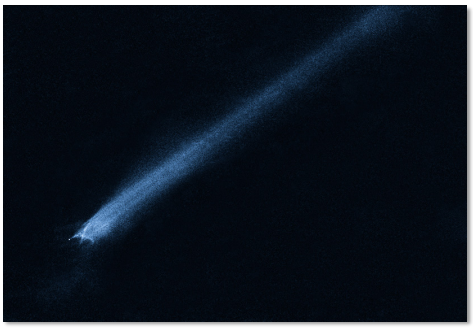
Resetting material on Vesta

- Significant diffusion in 100-10,000 y (cooling of an impact blanket) takes >800°C
- Typical impact *v* between objects in the main belt (5 km/s) imparts too little energy to raise T more than a few hundred °C



Diffusion coefficients in plagioclase and pyroxene (Cassata et al. 2008, 2010; Weirich et al. 2012)

Melting material on Vesta



- Melting material requires even more energy = higher relative *v*
- Main belt velocity distribution unlikely to explain so much melt from so many different impact events spaced so closely in time
- Howardite impact-melt clasts, and therefore probably most of the Vesta impacts in this period, must be the result of highly velocitous impacts
  - Excited main belt (E-Belt) (Bottke et al. 2010)?
  - Cometary flux of the Nice model (Gomes et al. 2005)?

Conclusions

- Impact-melt clasts in howardites are rare but present – formed by that impact-mixing of other 4 Vesta regolith
  - Textures demonstrate they were melted and recrystallized
  - Compositions demonstrate they are a mixture of eucrites and diogenites
- Impact-melt clast ages range between 3.5 and 4.0 Ga
  - Coincident with most Ar-reset ages of eucrites and eucritic clasts
- Forming impact melt on the surface of Vesta well after solar system accretion demands IOUVs (impacts of unusual velocity)
- **Vestal Cataclysm = A period of bombardment beginning around 4.0 (and extending to 3.5 Ga) caused by a distinct, high velocity population of impactors**
- Demonstrates the power of synergy between samples, sample ages, and dynamical models (thanks NLSI/SSERVI!)