FAILURE AND FRAGMENTATION OF METEORITE AND BASALT: UNDERSTANDING LUNAR REGOLITH GENERATION

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1 Extreme Behavior of Planetary Materials

Understanding the behavior of planetary materials in extreme environments is central in interpreting planetary impacts [1] and collisions between asteroids [2]. Planetary materials are comprised of mineral and metal grains and amorphous clasts, each with varying properties, shapes and sizes. During impact events, the bodies will experience a range of deformation rates (units: s^{-1}) and stress states (e.g., compression, tension, shear). Failure during impact occurs predominantly in compression. The complex loading history and the mineral phases dictate the degree of intergranular (along grain boundaries) fracture versus transgranular (through grains) fracture.

The coalescence of fractures results in a wide range of fragment sizes, and these fragment size distributions can offer insight into important physical processes. For example, the size-frequency distribution of larger fragments (boulders) on Eros [3] has been used to constrain its collisional history. For smaller fragments, interests exist in understanding regolith generation and in excavation and processing [1,4]; important areas in the development of lunar colonies.

Scope: In this study, we investigate compressive failure and fragmentation of meteorite and basalt for loading rates of $10^{-3}s^{-1}$ and $10^{+3}s^{-1}$. Fragment size and shape distributions are linked to the microstructure and mass-size distributions are compared with lunar regolith samples from Apollo 17 [5].

2 Materials: Meteorite, Basalt and Lunar Regolith

Fig 2. **Basalt (Coverall Stone, WA):** Comprised of 55% plagioclase, 25% olivine, and 20% clinopyroxene.

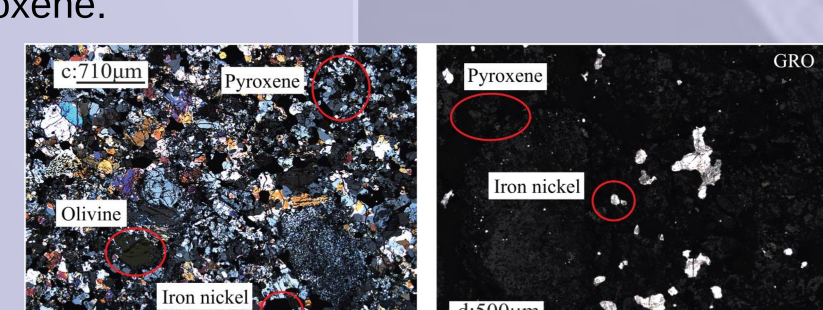


Fig 3. **Meteorite** (GRO 85209): L6 chondrite consisting primarily of olivine (25% Fa), low-Ca pyroxene (21% Fs), and iron nickel [6];

Apollo 17 sample 78481, 27: Surface sample (<1 cm depth) from a trench at Station 8 at the base of Sculptured Hills. GRO has an Is/FeO of 82 and is mature.

3 Experimental Setup

Uniaxial compression experiments were performed at strain rates of 10^{-3} s^{-1} (MTS machine) and $10^{+3}s^{-1}$ (Kolsky bar- schematic in Fig 4). Fragments were collected after experiments and image analysis techniques were used to covert the images to black and white and fragment sizes were determined (Fig 5).

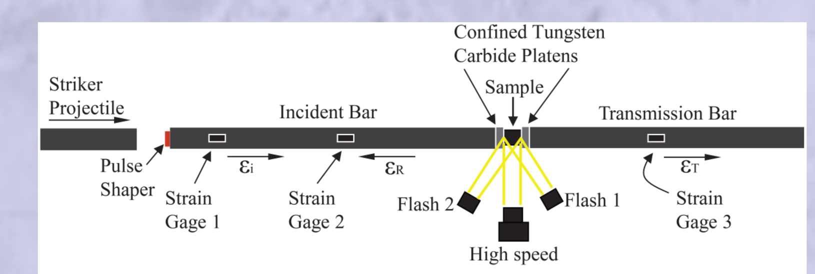


Fig 4. Kolsky bar schematic. The striker impacts right bar and generates a stress wave. This wave loads the sample until failure and its magnitude is recorded.

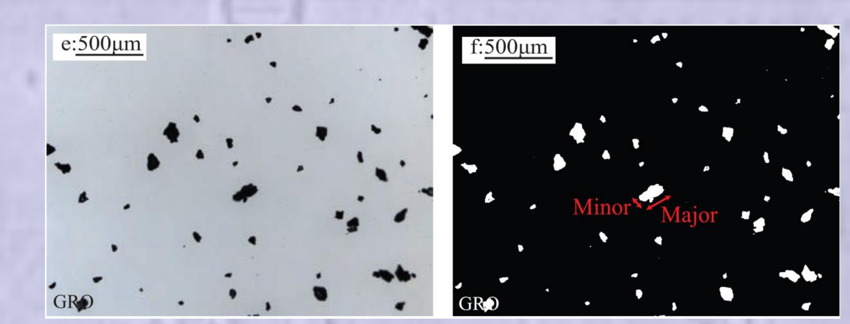
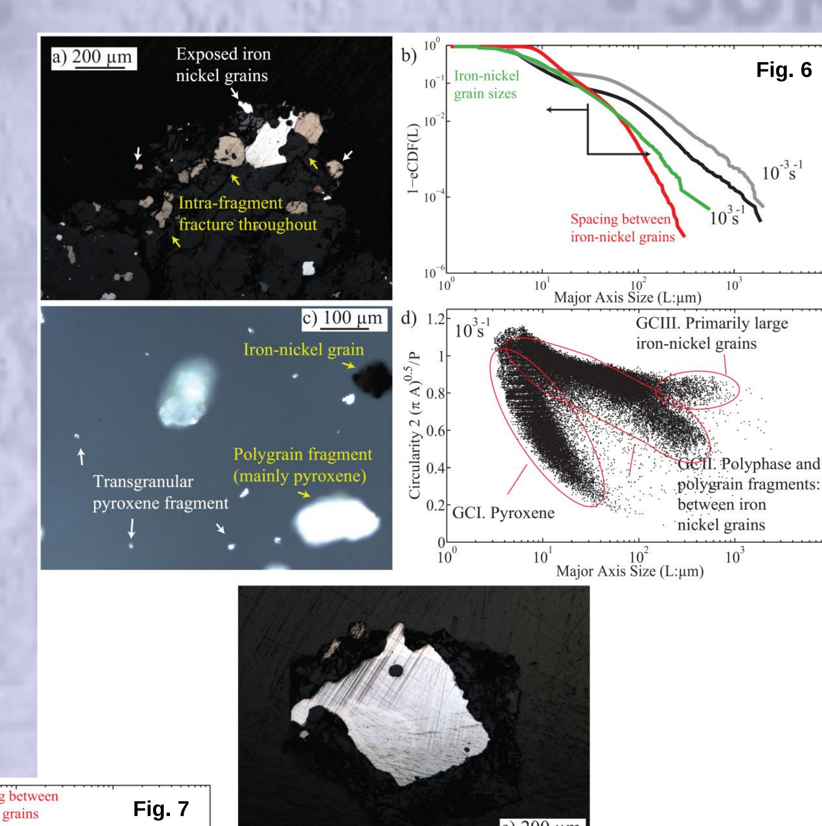
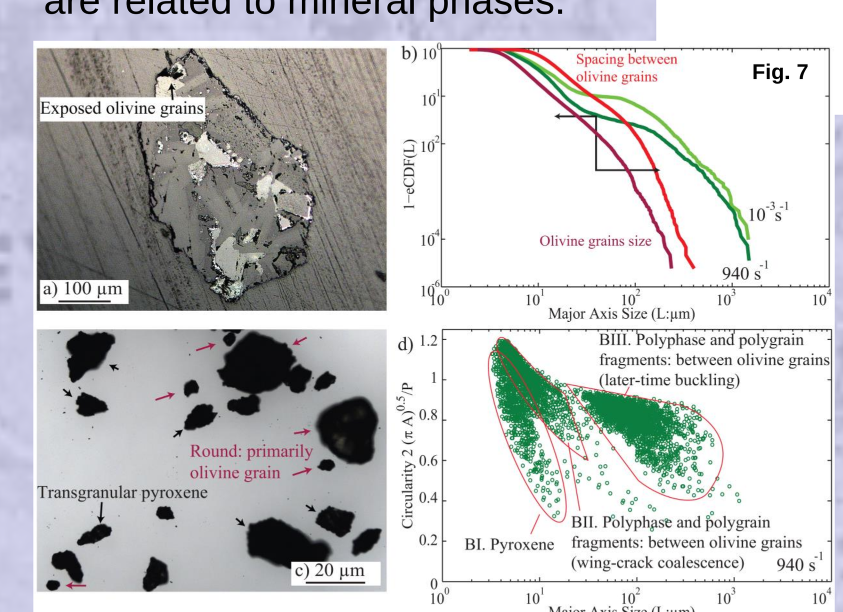


Fig 5. (a) Image of GRO fragments and (b) converted black and white image with "sizes" defined.

4 Fragmentation Results

Figs 6 and 7. (a) features inside of fragments illustrating the dominant actors (GRO: iron-nickel grains, basalt olivine grains); (b) cumulative distributions of fragment sizes and spacing between dominant actors; (c,e) optical images of fragments; and (d) circularity vs. size with three regimes labelled. Note that some of these regimes correspond to the spacing between the dominant actors, while others are related to mineral phases.





In these figures, dominant microstructural actors (GRO: iron-nickel grains, basalt: olivine grains) are linked to distinct fragmentation regimes.

5 Compressive Brittle Fragmentation

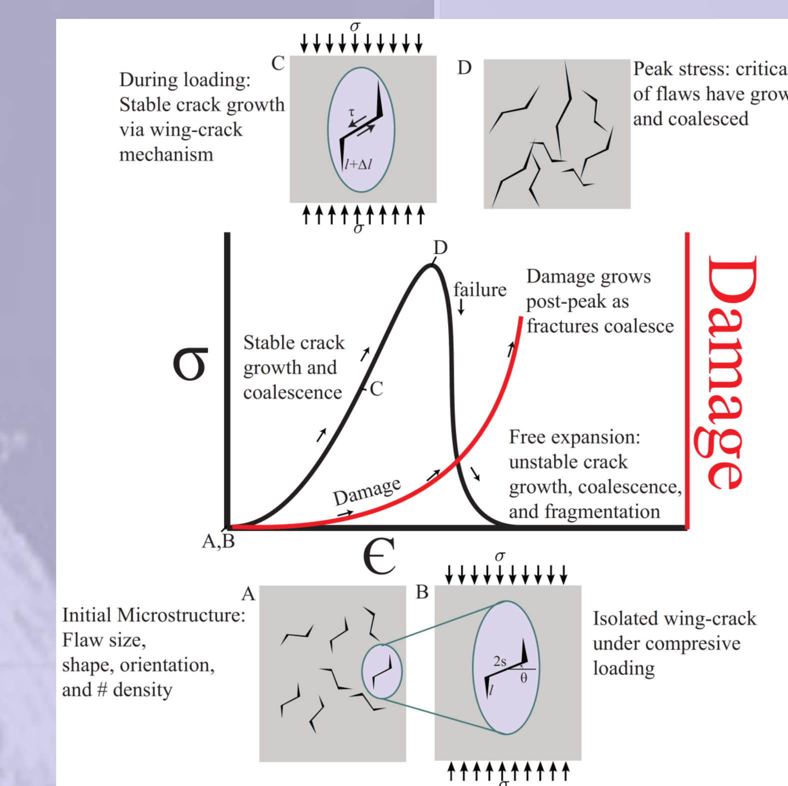


Fig 8. Schematic of compressive stress-strain relationship illustrating crack-growth and coalescence, peak stress, failure, and damage evolution. Fragmentation occurs post-peak stress.

6 Comparison with Lunar Regolith Measurements

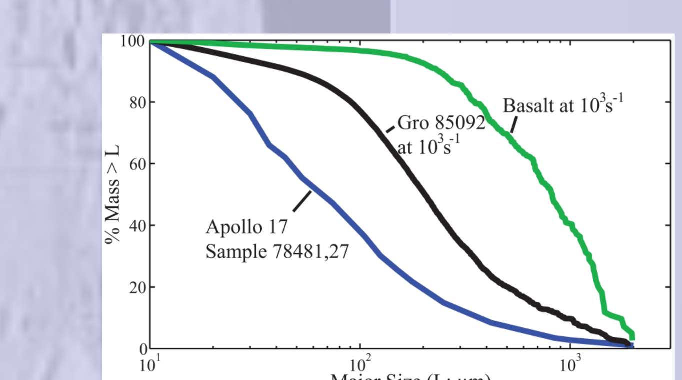


Fig 9. Mass-size distributions of lunar regolith measurements, meteorite and basalt. Results highlight substantially more fragmentation for the meteorite than basalt.

FW: On-going work is needed to bridge lunar regolith measurements with experiments by: 1. computing lunar regolith size distributions using methods outlined here or 2. conducting experiments on pre-fragmented samples to observe further comminution.

7 Concluding Remarks

Understanding the behavior of planetary materials under well-defined stress-states (e.g., compression, tension, shear) and strain rates is central in better interpreting complex impact processes. In this study, dominant microstructural features were linked to compressive failure and fragment mechanisms. These measurements highlight the multi-phase character of the fragmentation of planetary materials, even under simplified conditions

References: [1] Horz F. and Cintala M. (1997), *Meteoritics & Planet. Sci.*, *32*, 179-209. [2] Michel P. et al. (2003), *Nature*, *421*, 608-611. [3] Dombard A. J. et al. (2010), *Icarus*, *210*, 713-721. [4] Landis G. A. (2007), *Acta Astronautica*, *60*, 906–915. [5] Graf J. C. (1993), *NASA Ref. Pub.*, *1265*, 466 pp. [6] Grossman J. N. (1994), *Meteoritics & Planet. Sci.*, *29*, 100-143.