The Onset of the Cataclysm: In situ dating of a nearside basin impact-melt sheet

or, there and not back again

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A Lunar Cataclysm…?

- Impact-melt samples from Apollo & Luna are 3.85-4.1 Ga, tied to Imbrium, Serenitatis, Crisium, Nectaris, plus other craters?
- May have been caused by destabilization of material in early solar system by dynamic forces such as gas drag and gravitational interactions.
- Coincident with the oldest rocks on the Earth and *later* than the earliest isotopic signs of life on Earth – Earth was already a planet with oceans, plate tectonics, and single celled life.
- **What was happening on the Moon before 3.9 Ga affected the course of life on Earth, the structure of our Solar System, and the dynamics of extrasolar planetary systems**
But wait. What if there was no cataclysm?

- What we thought were Serenitatis impact-melt rocks actually have strong affinity to Imbrium samples, and their origin in the Descartes Fm has been geologically linked to Imbrium. Oops.
- Crisium samples from Luna 20 are small and discordant, no agreement on whether they are impact melt.
- Impact-melt samples from Apollo 16 give ages for Nectaris from 3.85 Ga-4.2 Ga depending on who interprets them – no agreement on what is from Nectaris. Oops.
- Samples thrown from basins don’t come tagged with their origin. Norman (2009) called this ”Pulling the pin” on the start of the Cataclysm!
So, how can we resolve this?

- Date the melt sheet of a well-known, pre-Imbrian basin!
- **South Pole – Aitken Basin** is far from Imbrium, records impact history since its formation (including Apollo, Ingenii, Poincare)
  - New Frontiers class mission – farside, comsat, sample return
- Near side basins generally have mare covering their impact-melt sheets, but impact-melt kipukas may have been identified!
- **Nectaris** is a stratigraphic horizon - the Nectarian Epoch defines the onset of the cataclysm
- **Crisium** is also pre-Imbrian and may also have promising sites
Small plains near inner basin ring massifs and intermassif “draped” deposits mapped as Nectaris basin impact melt sheet remnants (Spudis and Smith 2013)
Crisium in-place impact melt identified

- Low FeO, cracked texture, higher crater density (Spudis & Sliz 2017)
Much of the present debate about the ages of the nearside basins arises because of the difficulty in understanding the relationship of distal samples to their parent basin.

Melt sheets are a fundamentally different geologic setting than the Apollo sites.

Regolith formed on the basin impact-melt substrate, diluting but not destroying native impact-melt rocks.

Geochemical signatures are evident from orbit.

1% of the lunar regolith is rocklets 1-3 cm; need a scoop/sieve strategy (well-developed for MoonRise).
Regolith scoop sampling

Proportion of material from different craters in the upper 1 m at Bhabha site in SPA
# Science Instrument Payload (~30 kg)

<table>
<thead>
<tr>
<th>Mission Element</th>
<th>Objective</th>
<th>Heritage</th>
<th>Mass (kg)</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample collection &amp; delivery mechanism</td>
<td>• Scoop &amp; sieve regolith</td>
<td>Apollo, MoonRise</td>
<td>15</td>
<td></td>
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<tr>
<td></td>
<td>• Present rocks to MIBS and MI for triage</td>
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<td></td>
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<td></td>
<td>• Introduce individual rocks to analysis chamber</td>
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<tr>
<td>LIBS</td>
<td>• Survey landing site materials (active and passive)</td>
<td>ChemCam (MSL), SuperCam (Mars 2020)</td>
<td>10</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>• Characterize and prioritize samples</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Determine K for geochronology</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Mass Spectrometer</td>
<td>• Determine Ar for geochronology</td>
<td>NG/IMS flown on MAVEN, MSL, etc.</td>
<td>5</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>• Measure other volatile compounds and their isotopic composition</td>
<td></td>
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</tr>
<tr>
<td>Microscopic imager</td>
<td>• Workspace documentation</td>
<td>MER MI, MSL MAHLI, MSSS Hawkeye</td>
<td>1 (for 2)</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>• Characterize and prioritize samples</td>
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</tr>
<tr>
<td></td>
<td>• Measurements of LIBS pits for geochronology</td>
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<tr>
<td>Possible: LIDAR</td>
<td>• Descent support</td>
<td></td>
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<tr>
<td></td>
<td>• Workspace definition</td>
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</tbody>
</table>
K-Ar Geochronology using LIBS-MS

- K measured using laser-induced breakdown spectroscopy (e.g. Chemcam), also ablates the rock
- Liberated Ar measured using mass spectrometry (e.g. MAVEN-MS)
- K and Ar related by volume of the ablated pit using optical measurement (e.g. MAHLI)
- All TRL 9 instruments – low risk, known cost
- Instruments do double duty – complete composition, petrology, volatiles
- Conops fits with real mission flight ops
- Precision ±100-150 Myr for a 4 Ga sample
K-Ar Geochronology using LIBS-MS

Results from multiple laboratories yield whole-rock ages within error of accepted ages and precision close to theoretical = TRL 4

Basin in situ dating mission

- Accomplishes solar-system wide science by visiting a stratigraphically important lunar basin
  - In situ geochronology
  - Sample and site characterization
- Accomplishes three of the four major goals of the SPA New Frontiers mission recommended in the Decadal Survey by conducting in situ dating rather than sample return
  - Single lander, no mobility
  - Nearside, subequatorial site
  - Extensively covered by LRO imaging
- Extensive conceptual design work by JPL exists from MoonRise and Lunette robotic lunar lander activities
- Advances NASA investments in development of in situ geochronology measurements and science
Science Goals *from Decadal Survey*

- **Determine the chronology of basin-forming impacts and constrain the period of late heavy bombardment in the inner solar system and thus address fundamental questions of inner solar system impact processes and chronology**
  - Measure the K-Ar age of the Nectaris/Crisium basin impact-melt sheet (10-20 samples) and also KREEPy materials thrown far from the Imbrium basin (2-4 samples)

- **Determine age and compositions of basalts to determine how mantle source regions differ from regions sampled by Apollo and Luna**
  - Measure the age and composition of Mare Nectaris/Mare Crisium basalt (2-4 samples)

- **Characterize a large lunar impact basin through "ground truth" validation of global, regional, and local remotely sensed data of the sampled site**
  - Landing site characterization to correlate with orbital datasets
  - Measure the composition & petrology of samples at a site remote from the Apollo and Luna landing sites to understand their origin
Summary

✦ **Mission Goal:** Determine the age of a nearside basin, defining the epoch of late heavy bombardment throughout the solar system

✦ **Mission Status:** In study for potential Discovery response

✦ **Unique new science:**
  - Constrain the onset of the Cataclysm by determining the age of samples directly sourced from the impact melt sheet of a major lunar basin
  - Identify basin impact-melt samples for detailed follow-on studies using existing (& future, e.g. Chang’E) collections
  - Understand lunar evolution by characterizing new lunar lithologies far from the Apollo and Luna landing sites
  - Ground truth remote sensing measurements from orbital missions (e.g. LRO, Chandrayaan-1, Kaguya)

✦ **Other mission contributions:**
  - First US soft lander on the Moon since 1972
  - Conduct the first use of in situ geochronology, opening the gate to using it as a standard measurement on landed missions
  - Potential to use teleoperation and/or immersive VR environment for planning
Land in predawn. Create LIDAR-based view of the workspace

Scoop and sieve operations to collect rocks from the regolith