Future of Lunar Sample Returns

Jeff Taylor
University of Hawai`i

Paul Spudis
JHU Applied Physics Laboratory
Future of Lunar Sample Returns

• Must have well defined goals
  – For lunar studies in general
  – For the specific sample-return mission

• Samples Must Have Geologic Context
  – Global/regional data
  – Appropriate choice of landing (field) site
  – Appropriate level of field work (robotic or human)
  – Appropriate use of *in situ* analysis to provide geologic context and to choose samples
Types of Sample-Return Missions

• Robotic
  – Bulk regolith
  – Sieved samples to optimize size of fragments
  – Simple, limited range rover
  – Telerobotic field geologist

• Human
  – Can do all of the above
  – Can return to specific field sites
Important Questions to Ponder

• How much ambiguity are we willing to accept when we address scientific goals of a mission?
• How much field work is necessary to address a specific problem?
• No sample return: When is robotic field work and in situ analysis enough to address problems?
• Obviously, the answers affect the cost of a mission—but not necessarily its cost effectiveness
Reconnaissance and Field Study

• Reconnaissance:
  – Broad characterization of geologic features
  – Often asks specific questions (ages of flows in maria)
  – Can be done with robotics or humans
  – Sampling does not require great sophistication, e.g.,
    • Sieve regolith to obtain 1 kg of 2–20 mm fragments
  – Geologic context provided by regional data
Reconnaissance and Field Study

• Field Study:
  – Goal is to understand geologic processes and units at all levels of detail
  – Long-duration, iterative (return to same site)
  – Absolutely requires human observational ability, intelligence, and experience
  – Observations can be enhanced by remote sensing
  – Sampling done by humans (shovels, hammers), but can be aided by robotic tools (drills)
  – Can be done directly by humans, possibly telerobotically
Geological Context: Youngest Maria

- **Mission goal:** Determine age of youngest lava flows to calibrate cratering flux
- **Regional Context:** Crater counts using images
- **Site:** Any site with apparent age < 2 Gy
- **Samples:** Grab sample, sieved to appropriate size range
- **No field work needed**

**Ambiguity:** almost none
Geological Context: Youngest Maria+

- **Mission goal:** Determine age of youngest lava flows to calibrate cratering flux, *and* understand volcanic flow processes and stratigraphy
- **Regional context:** Crater counts using images, remote sensing chemistry
- **Site:** Apparent age < 2 Gy
- **Samples:** Pieces of specific regions within a flow and representative samples of a sequence of flows

Field work essential; for some problems, long traverse distances
Geological Context: Impact Melt Sheet

- **Mission goal:** Determine age of a young, large impact crater
- **Regional Context:** Crater counts using images, rays
- **Site:** Melt sheet of any Copernican impact crater
- **Samples:** Grab sample, sieved to appropriate size range
- **No field work needed**

Ambiguity: almost none
Geological Context: Impact Melt Sheet+

- **Mission goal**: Determine age of a young, large impact crater and understand vertical and lateral variations in its properties
- **Context**: Crater counts using images, remote sensing chemistry
- **Site**: Apparent age < 2 Gy
- **Samples**: Surface rocks with a range of properties (e.g., clast content), samples of large boulders ejected from craters

Field work essential; long traverse distances
Geological Context: Plutonic Rocks

- Mission goal: Identify and characterize main rocks composing central peak of a large crater
- Regional Context: Imaging, remote sensing
- Site: Near base of central peaks, or on a peak
- Samples: Grab sample, sieved to appropriate size range
- No field work needed

Ambiguity: Relation of lithologies to each other; unsampled rock types
Geological Context: Plutonic Rocks+

- **Mission goal**: Identify and characterize main rocks composing central peak of a large crater, and understand their relationship to each other (e.g., one differentiated intrusion? Multiple intrusions?)
- **Regional Context**: Imaging, remote sensing
- **Site**: On central peaks and their slopes, more than one site.
- **Samples**: Carefully chosen samples from outcrops and large boulders

Field work essential; long traverse distances; mobility from peak to peak
South Pole – Aiken Basin

• Potential mission goals:
  – Test cataclysm idea by dating SPA and superimposed basins
  – Determine compositions of impacting bodies
  – Decipher composition of mid- to lower crust (maybe mantle)
  – Unravel basaltic history

• Complicated set of goals
• Complicated geologic setting

Geological Map of SPA basin. Note superimposed basins
South Pole – Aiken Basin

- To test the cataclysm idea, do we need to know we dated SPA?
- Do we need to know we dated any other specific impact basins?
- Depends on:
  - Problem being addressed
  - Level of ambiguity we are ready to accept
The Statistical Approach

- Analyzing a large number of samples (~cm-sized) allows us to group them by their chemical compositions and see if the clusters have distinctly different ages.
- Each may represent a separate impact event.
- The trick is to know what basin to associate with each melt group.
- Or even if they are melts from basins.
- We are not positive that big basins will have perfectly uniform compositions in their impact melt sheets.
The Statistical Approach

- **Mission**: Test cataclysm hypothesis by measuring compositions and ages of numerous breccias from SPA to establish compositional-age groups
- **Regional Context**: Imaging, remote sensing
- **Site**: Typical floor of basin
- **Samples**: Grab sample, sieved to appropriate size range
- No field work

**Ambiguity**: Do not know with certainty what (if any) basins are being dated. On the other hand, informative about number of datable impacts.

Chapman et al. (2007)
U-Pb Characteristics

- Pb isotopic compositions of lunar highlands rocks:
  - Two intercepts: one at \(~3.9\) Gy and one at \(~4.4\) Gy
  - Young one could represent an extensive metamorphic event
  - Led to redistribution of Pb (volatile element) produced between 4.42 and 3.9 Gy; U and Th (refractory) stay in impact breccias

- Tera et al. (1974): “Highland samples from widely separated areas [of the Moon] bear the imprint of an event or series of events in a narrow time interval which can be identified with a cataclysmic impacting rate of the moon at \(~3.9\) Ga.”

Tera et al., 1974, EPSL
U-Pb Characteristics

- Problem: redistribution by the Imbrium event might dominate this system.
- Solution: collect rocks far from Imbrium and do the same experiment.
- SPA is far from Imbrium.

Ambiguity: Youngest big event might still dominate. Fortunately, there are no nearby huge events like Imbrium.
Lowering Ambiguity with Field Study

- **Mission:** Detailed field studies of SPA to search for and sample its impact melt sheet
- **Regional Context:** Imaging, remote sensing
- **Sites:**
  - Basin floor (including ejecta from craters with a range of sizes)
  - Massifs
- **Samples:** Samples from boulders/outcrops that appear to be composed of impact melt breccias
Geologic Context of the Apollo/Luna Landing Sites

Hiesinger and Head, 2006:

1. similar to Apollo 16 and Luna 20
2. similar to Apollo 14
3. similar to Apollo 15
4. similar to Apollo 17
5. similar to Apollo 12 and Luna 24
6. similar to Apollo 11 and Luna 16

In the case of SPA, sites 5 and 6 do not have extensive mare cover, hence could sample impact melt. Massif sites 3 and 4 could provide possible basin impact melt as they might have at Apollo 15 (3) and 17 (4)

**Ambiguity:** We still may not know that we have the SPA melt, though our chances are enhanced.
How to Do Field Work

• Directly by experienced geologists
  – Centuries of terrestrial experience
  – Apollo missions
• Rovers controlled by experienced geologists
  – MER missions
• Telepresence

Photo by John A. Wood
Home Plate

Coarse Grained Lower Unit - pyroclastic deposit

Slide courtesy of Scott McLennan
Home Plate

Fine Grained Upper Unit
- reworked eolian deposit

Slide courtesy of Scott McLennan
Telepresence: It’s Just Like Being There

• Teleprospector uses telepresence, the sense of being present at a remote site
  – Transports human powers of observation and interpretation to a field site
  – Can have super-human capabilities of vision, strength

• Advantages:
  – Keeps humans out of the hostile space environment (vacuum, radiation)
  – Provides global access from a single site, possibly from Earth
  – Could do the work MER did in a fraction of the time
Sample Returns in our Future

• New Frontiers opportunity
  – One mission
  – Likely in the reconnaissance category (i.e., no rover)

• Human missions
  – Sorties
  – Geology of the outpost area (< 10 km)
  – Excursions from outpost (> 10 km)
  – Use of teleoperation/telepresence (global access)

• Potential for small, inexpensive spacecraft to return small masses of regolith (50 g??)

• Alternative—robotic with sophisticated instruments for in situ analysis (chemistry, mineralogy, age dating?)