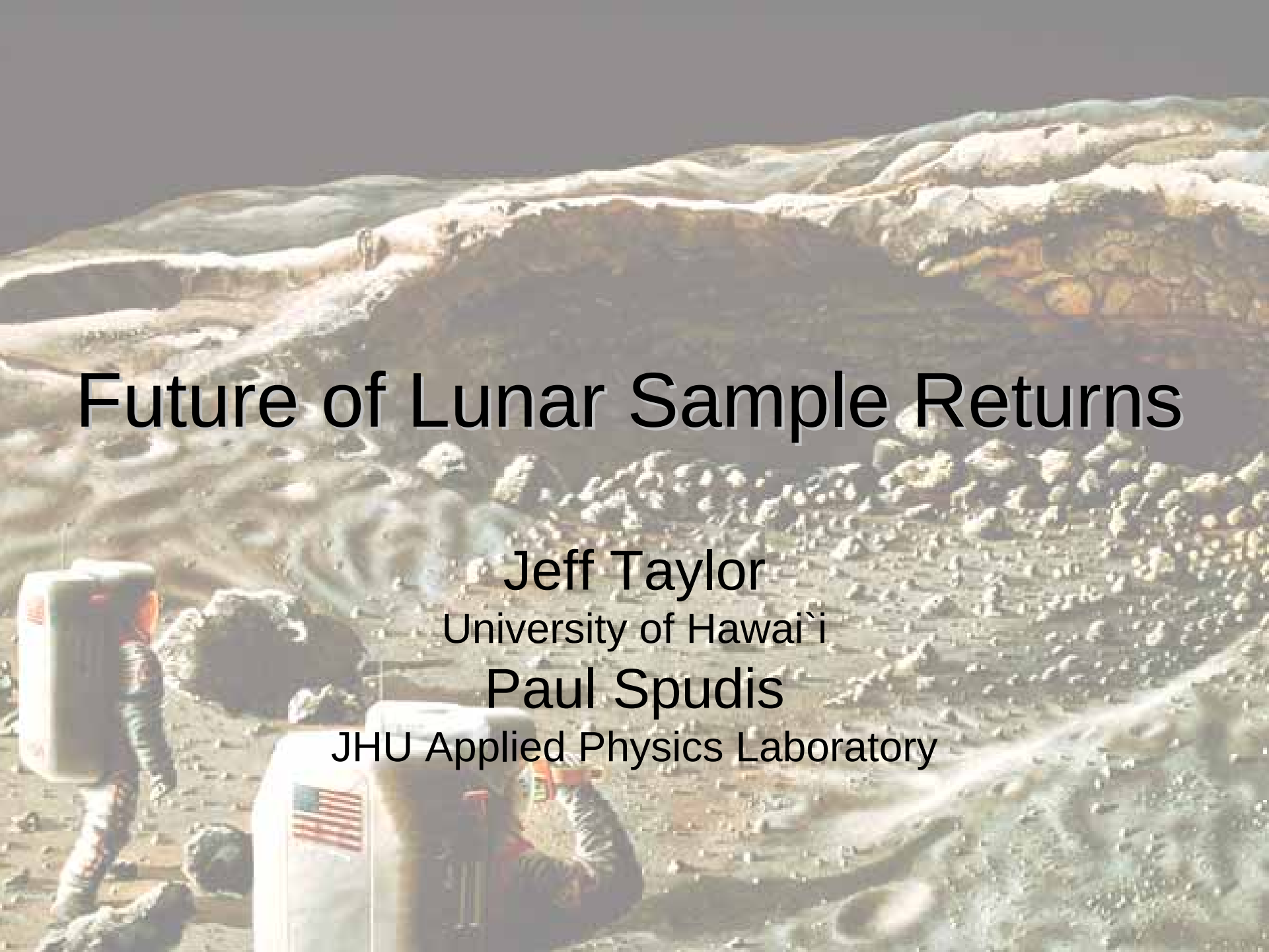

Future of Lunar Sample Returns

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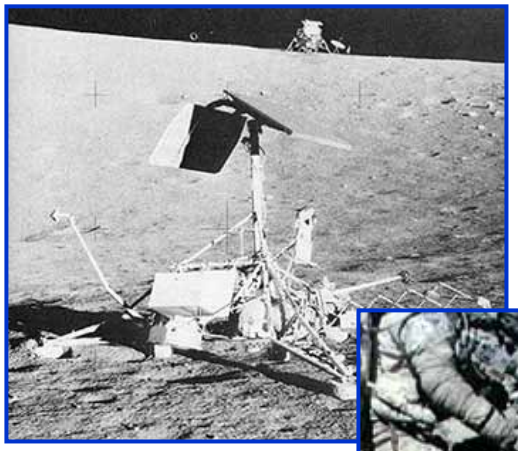
Future of Lunar Sample Returns

- 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

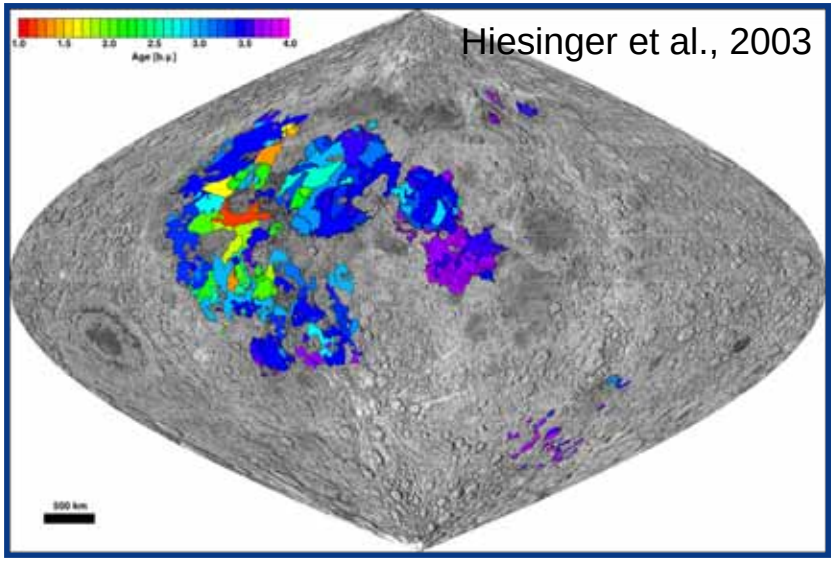
Reconnaissance and Field Study

- 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

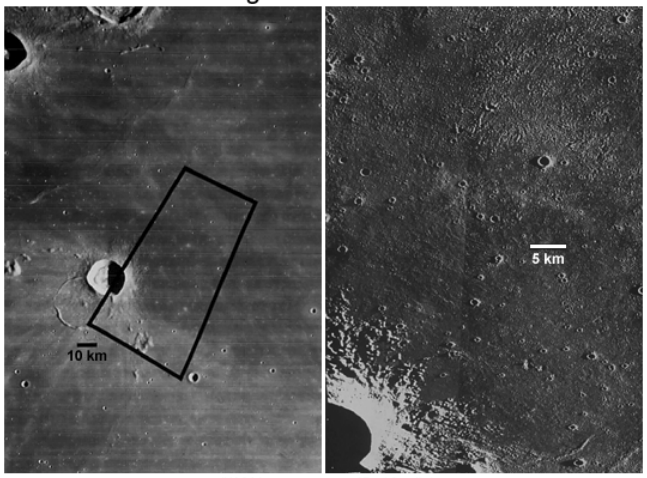
Geological Context: Youngest Maria

- **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



Lichtenberg Crater on the Moon

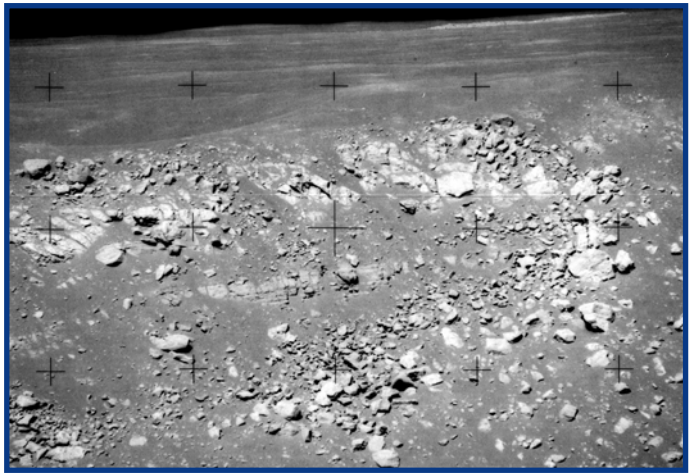


(NASA images courtesy of Paul Spudis.)

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

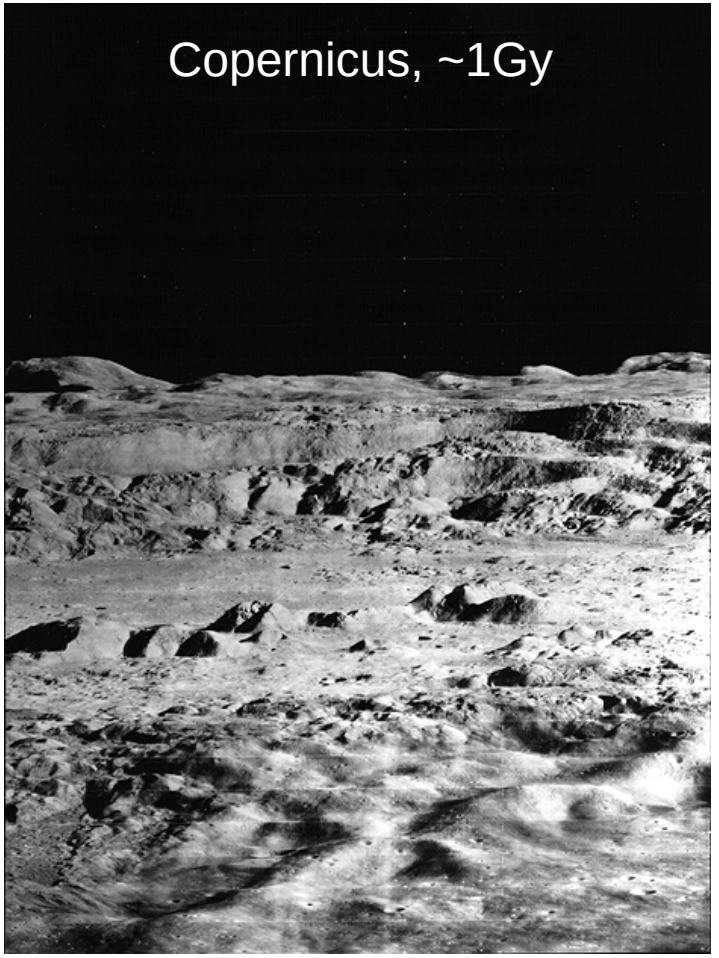
Field work essential; for some problems, long traverse distances



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

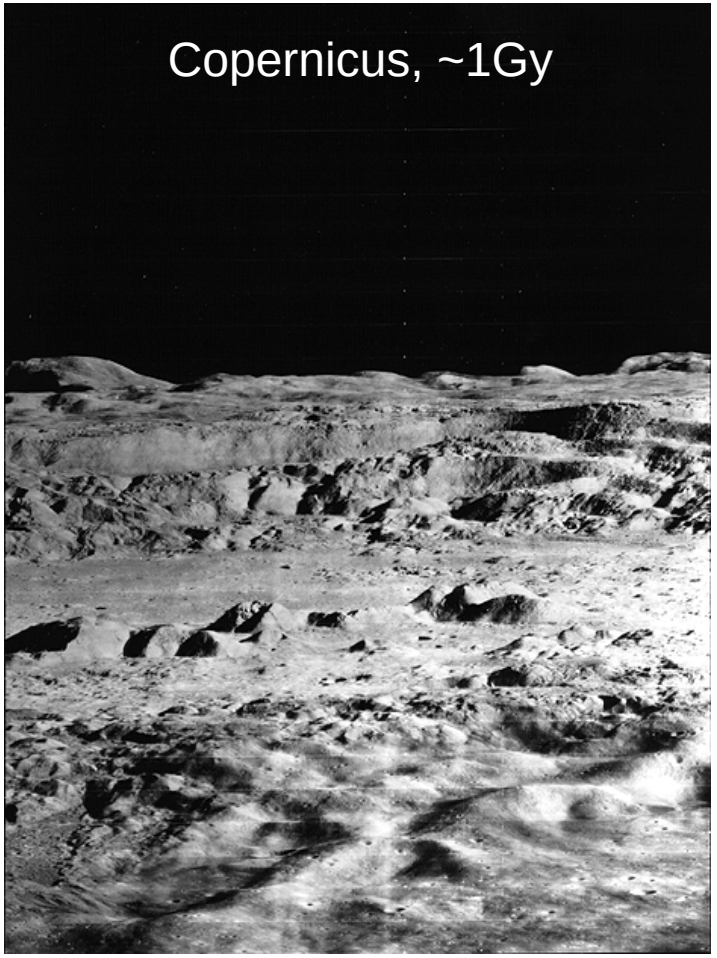
Ambiguity: almost none



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

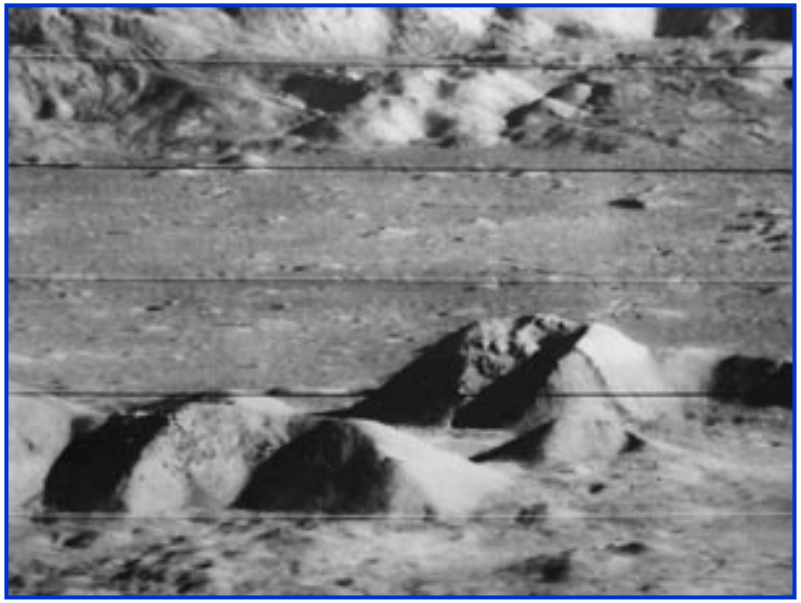
Field work essential; long traverse distances



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



Copernicus Central Peaks

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

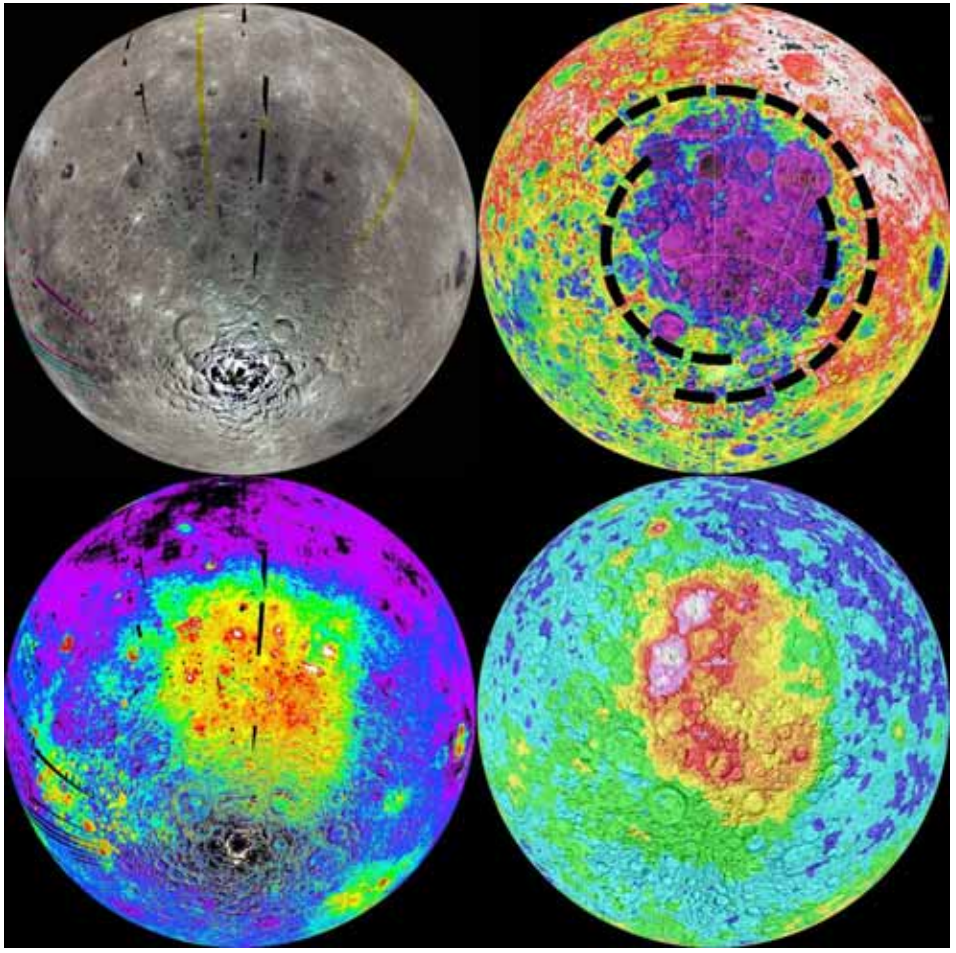
Copernicus Central Peaks

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

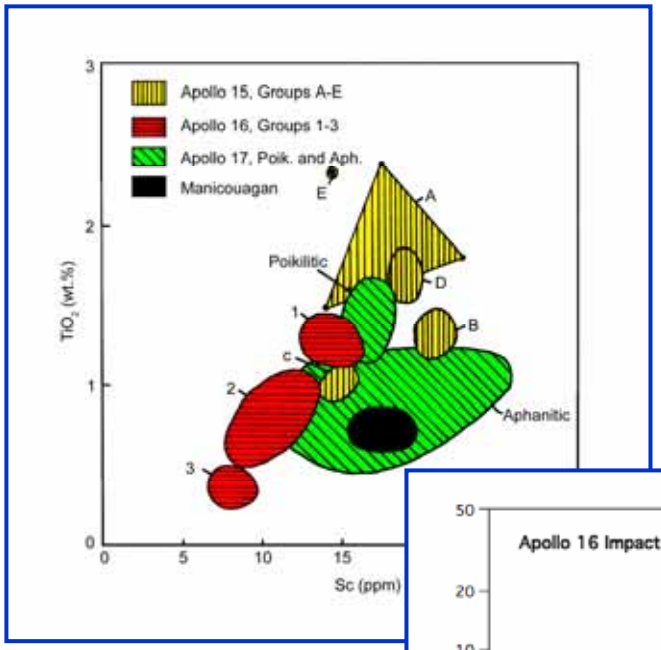
South Pole – Aiken Basin

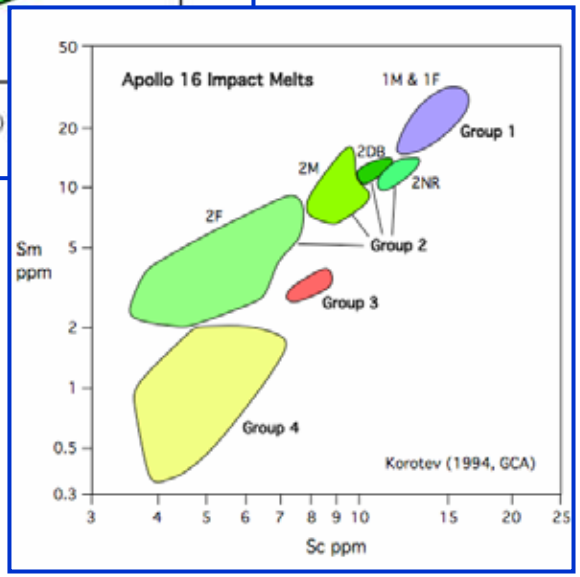


- To test the cataclysm idea, do we need to know we dated SPA?
- Do we need to know we dated any other specific impact basins?
- Depends on:
  - Problem being addressed
  - Level of ambiguity we are ready to accept

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

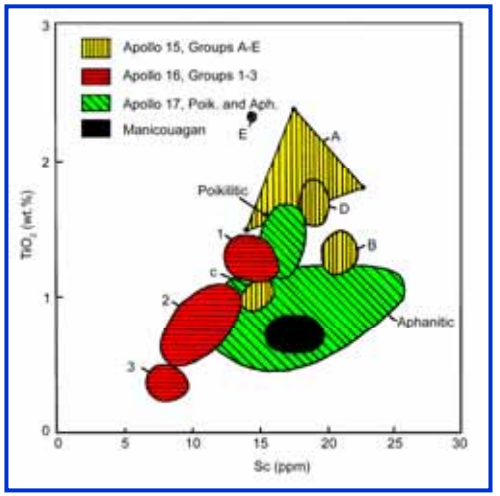


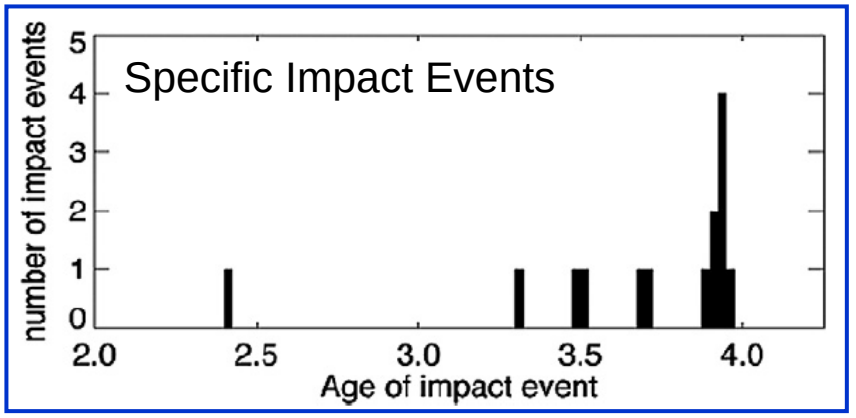


The Statistical Approach

- **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.

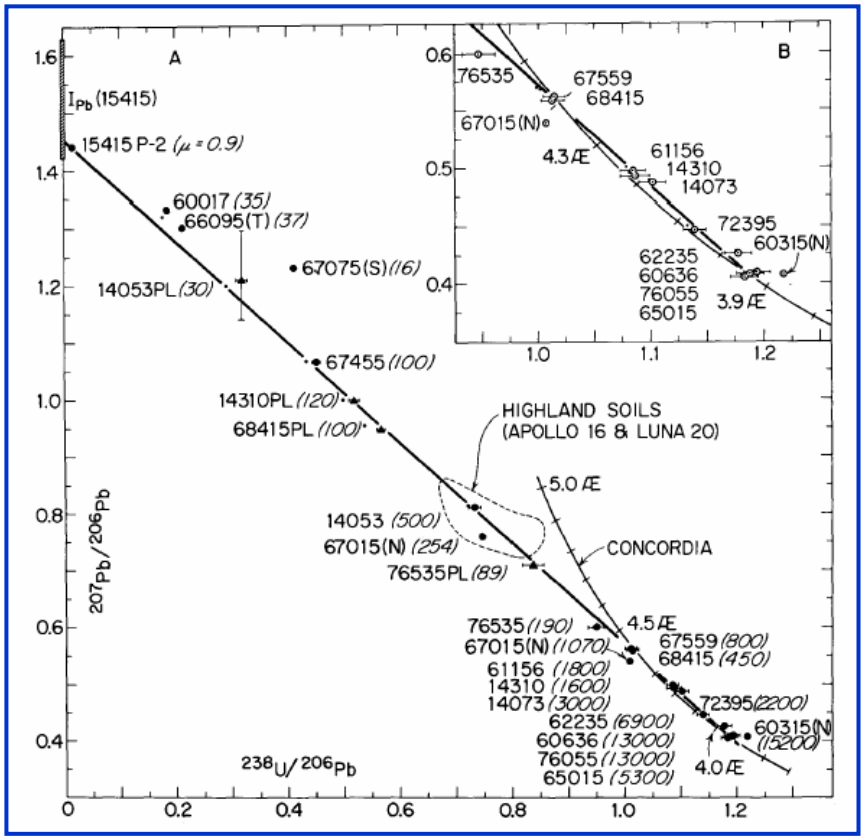




Chapman et al. (2007)

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."*

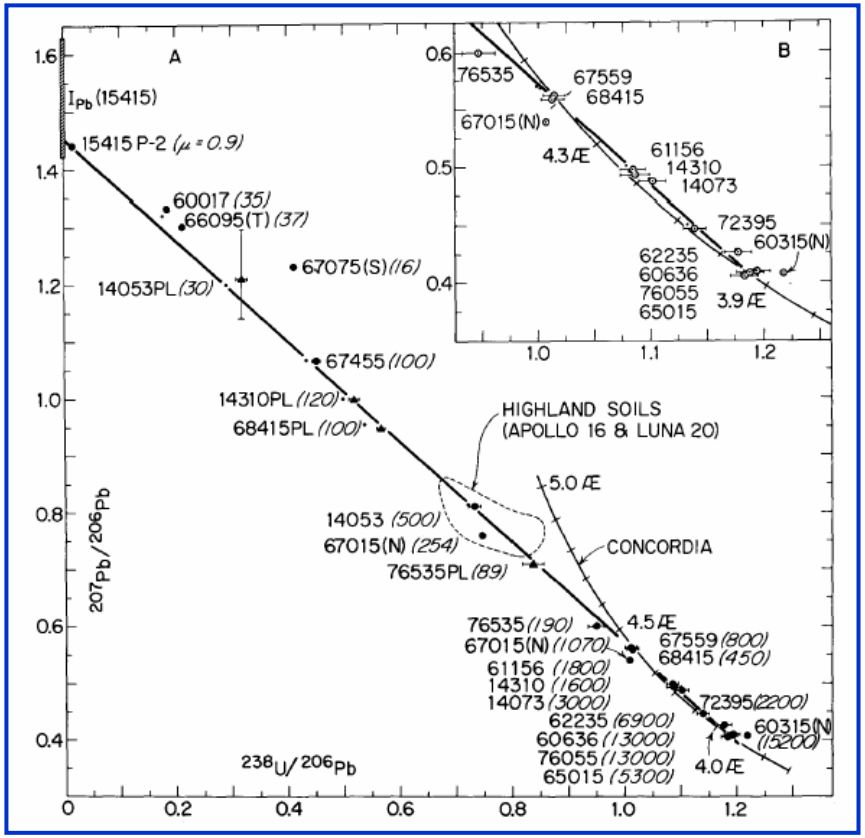


Tera et al., 1974, *EPSL*

U-Pb Characteristics

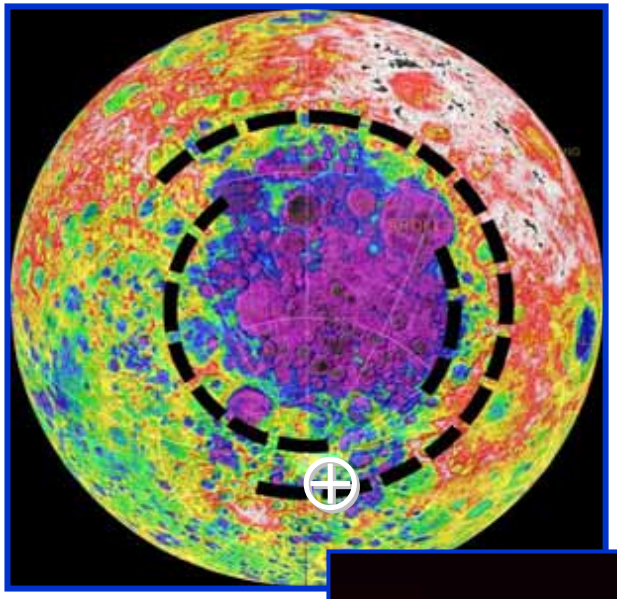
- Problem: redistribution by the Imbrium event might dominate this system
- Solution: collect rocks far from Imbrium and do the same experiment
- SPA is far from Imbrium

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

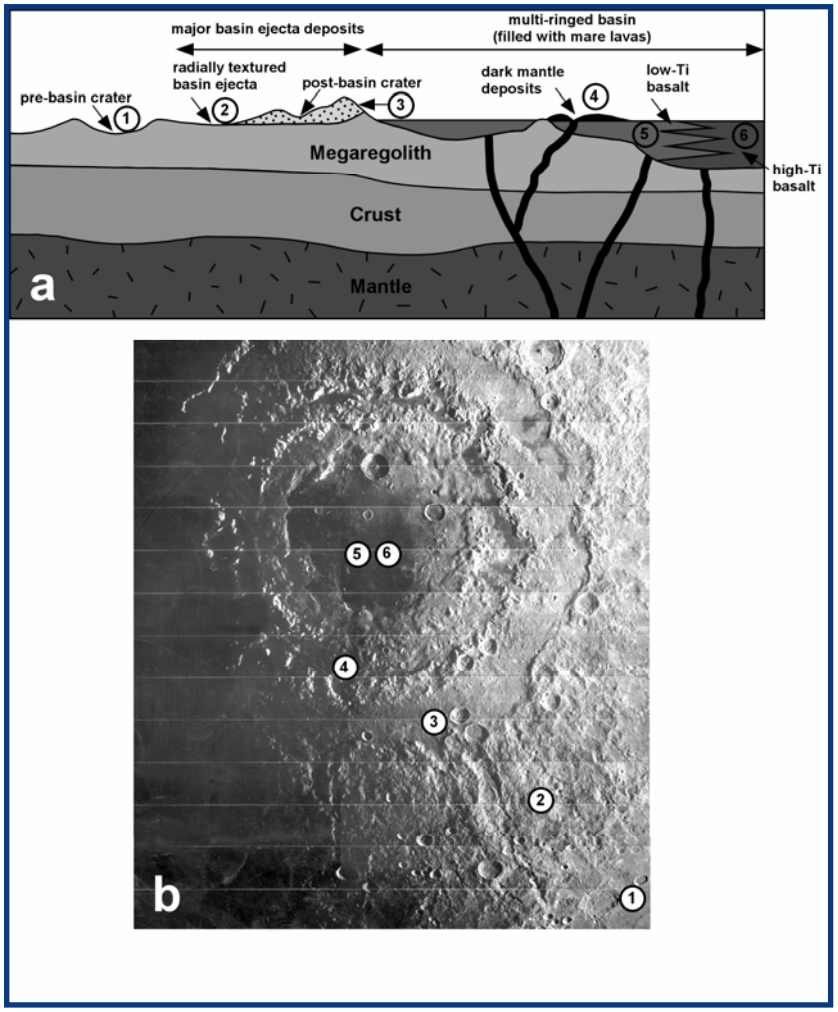


Lowering Ambiguity with Field Study

- **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

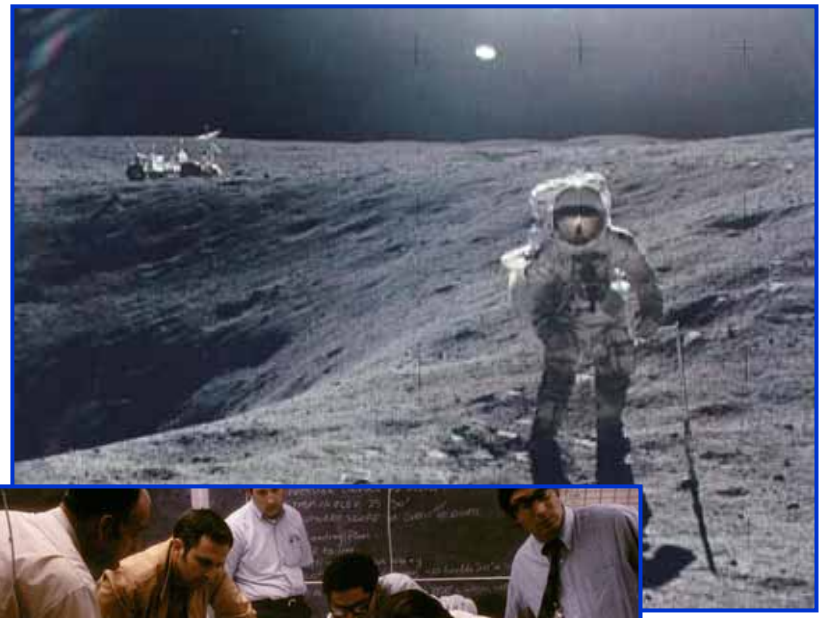
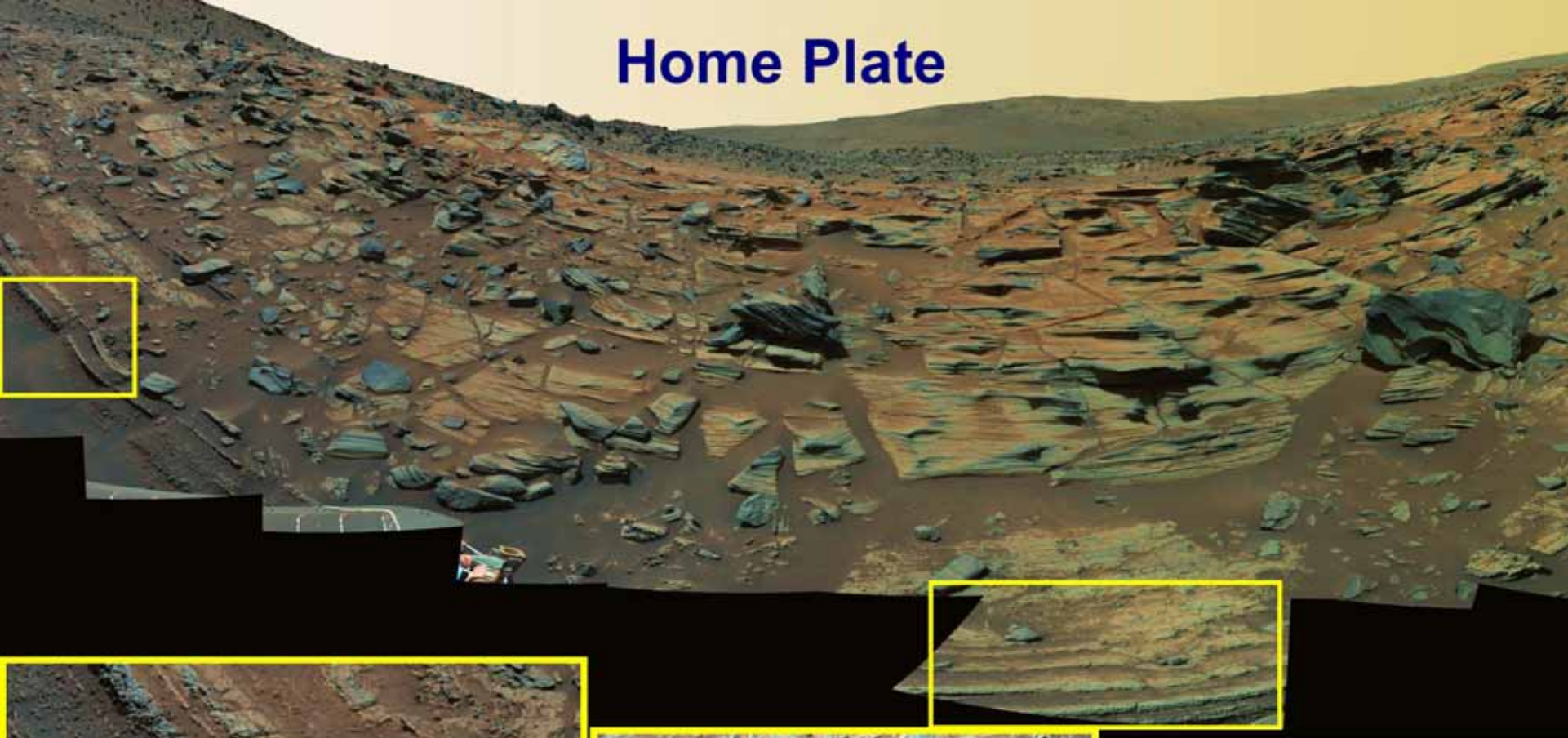


Photo by John A. Wood

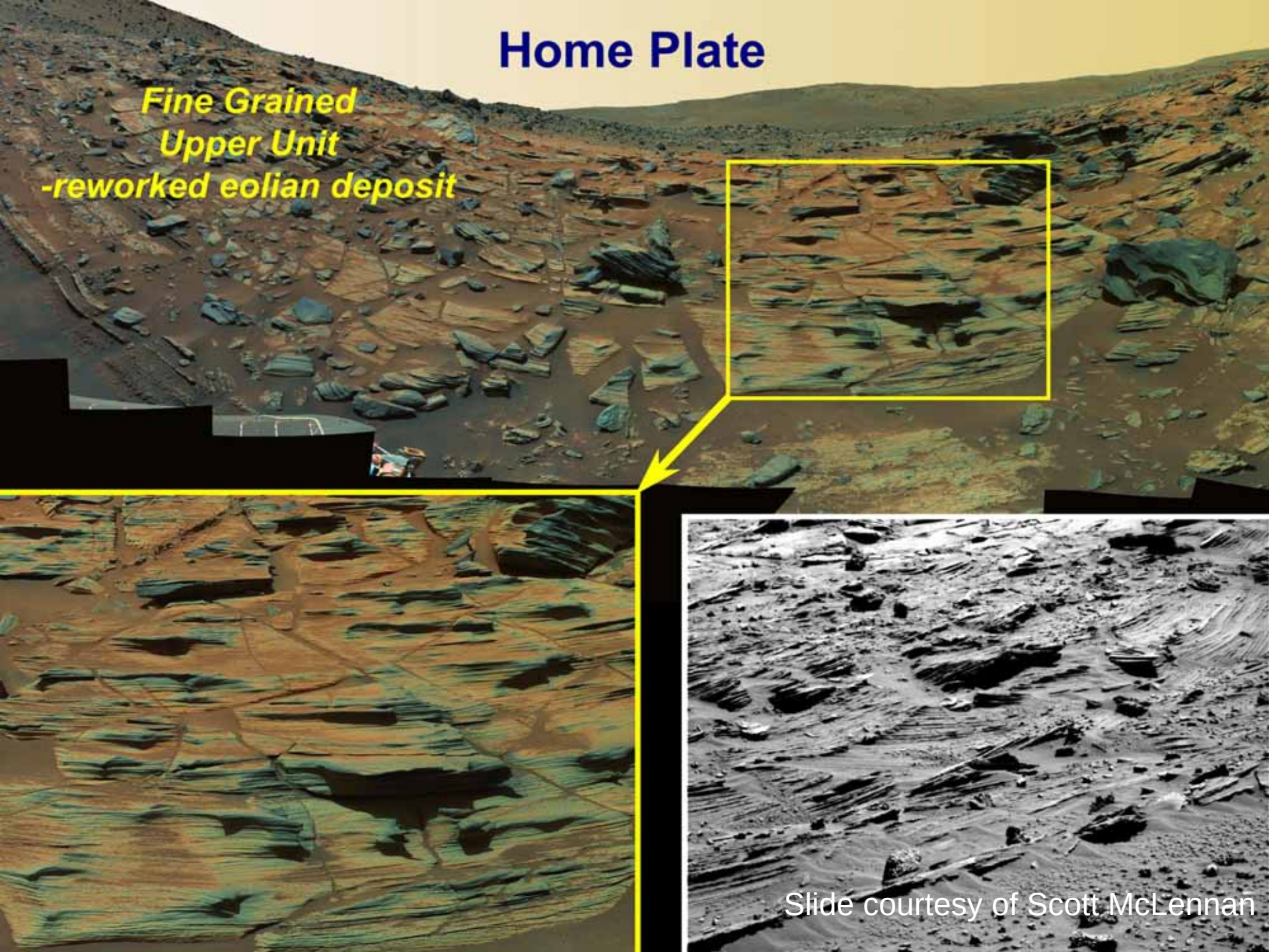
Home Plate



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?)