Conduct of Geologic Field Work During Planetary Exploration: Implications for Human and Robotic Activities

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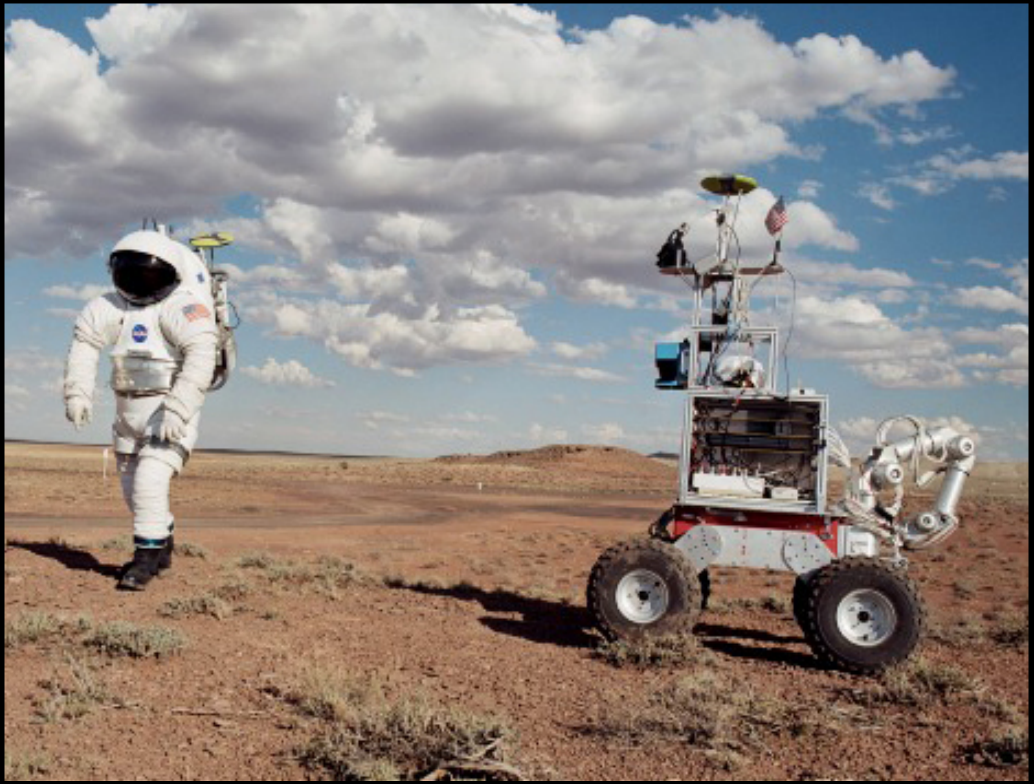
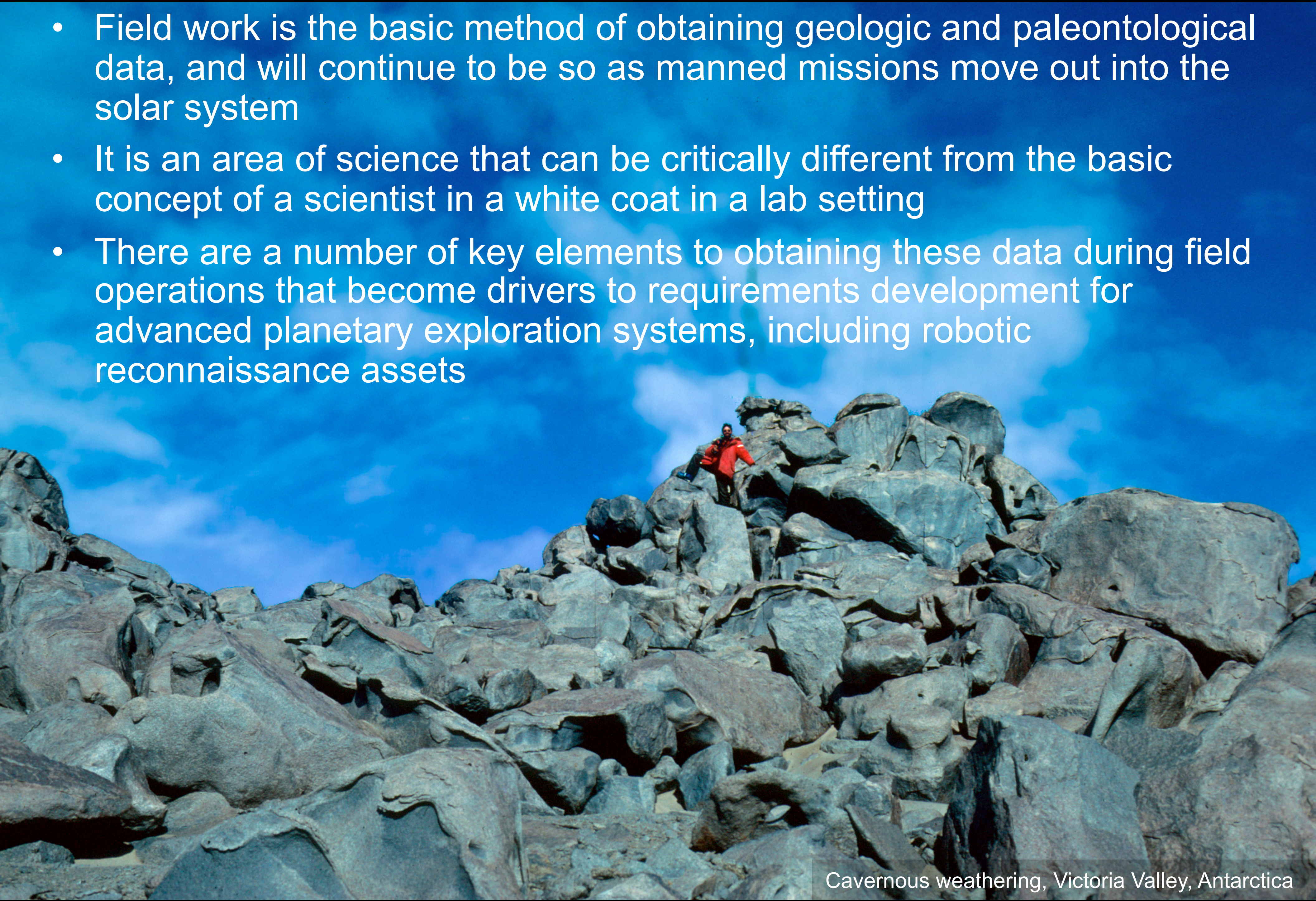
- This talk will cover a two topics:
  - Define, describe and explain the nature of geologic field work as it is done terrestrially
  - Suggested design requirements for a Constellation robotic reconnaissance rover derived from the Apollo experience



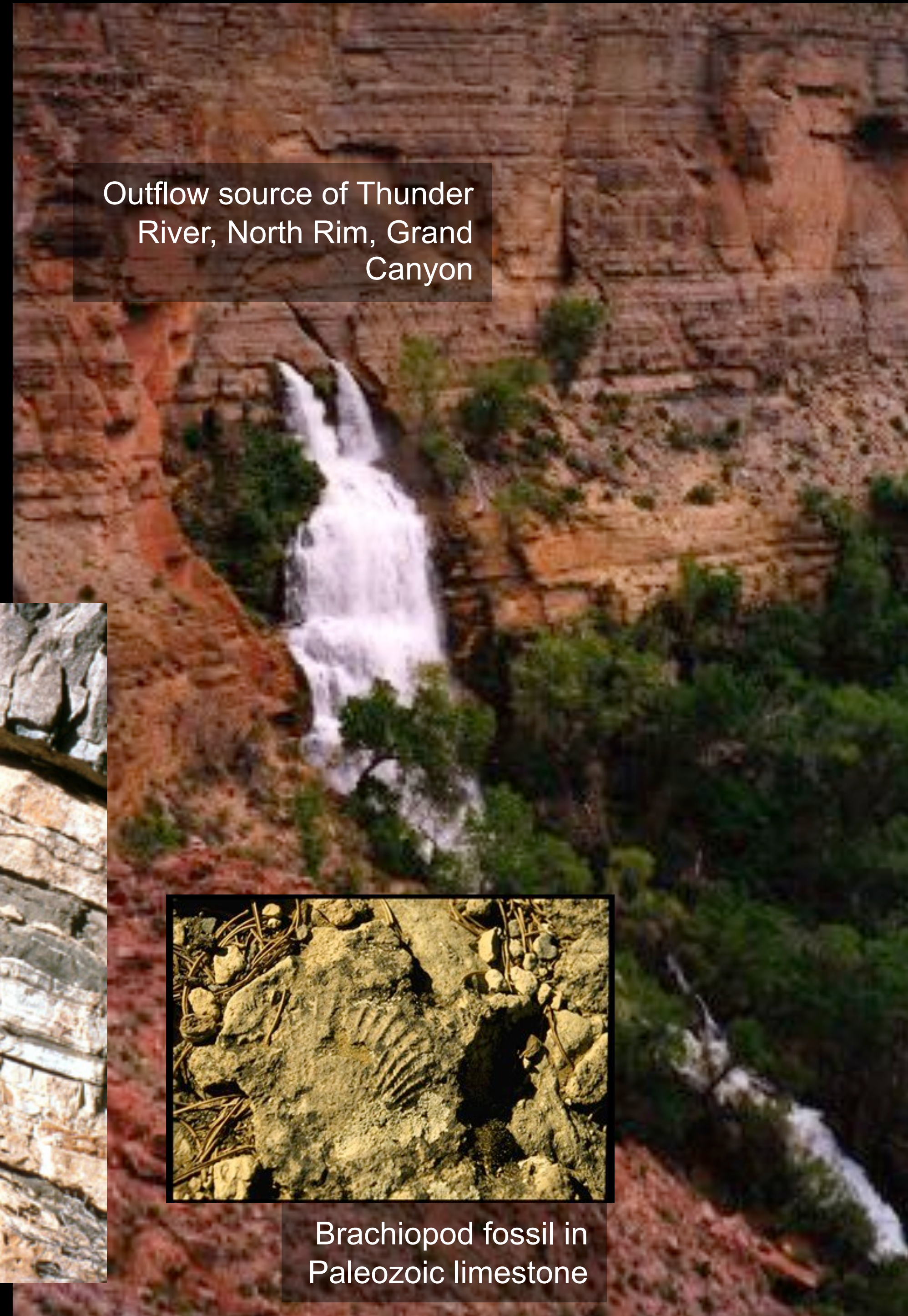
- Field work is the basic method of obtaining geologic and paleontological data, and will continue to be so as manned missions move out into the solar system
- It is an area of science that can be critically different from the basic concept of a scientist in a white coat in a lab setting
- There are a number of key elements to obtaining these data during field operations that become drivers to requirements development for advanced planetary exploration systems, including robotic reconnaissance assets



Cavernous weathering, Victoria Valley, Antarctica

Geologic field work can be loosely defined as the body of work necessary to:

- Determine the spatial distribution, age and attitude of the rock types within an area
- Document those structures that have deformed or cut those units
- Determine the processes that led to the emplacement of these rocks, and have subsequently modified them



Outflow source of Thunder River, North Rim, Grand Canyon

Folding in metamorphosed sediments

Brachiopod fossil in Paleozoic limestone

Field work remains the primary source of geologic data because the rocks, in the field, are the primary data set we work with…and while geologists would love to have this kind of exposure everywhere to develop their understanding of geologic history and processes…

Grand Canyon of the Colorado, in the vicinity of Lava Falls

…there are always less data (i.e., fewer rocks showing) than we would like to have for complete understanding.

Typical field conditions, southern Adirondack Mountains, NY

Sharp (1988) noted that learning to arrive at workable, testable conclusions, often in the face of insufficient data, is part of doing geologic field work.

Field work is also critical because models always have less fidelity and complexity than the real world…

Laboratory scale modeling of strike slip faulting

…and the rocks in the field remain the true test of any laboratory model.

Strike slip faulting,
Anatolian Fault, northern Turkey

“Nature is a perverse ego-humbler, and she exercises that trait freely in field geology. She delights in throwing spitball curves that send the overconfident neophyte, and often the hardened, experienced field mapper, back to the dugout, muttering to themselves.” Robert P. Sharp, 1988

Exploratory trenching along the San Andreas Fault, California

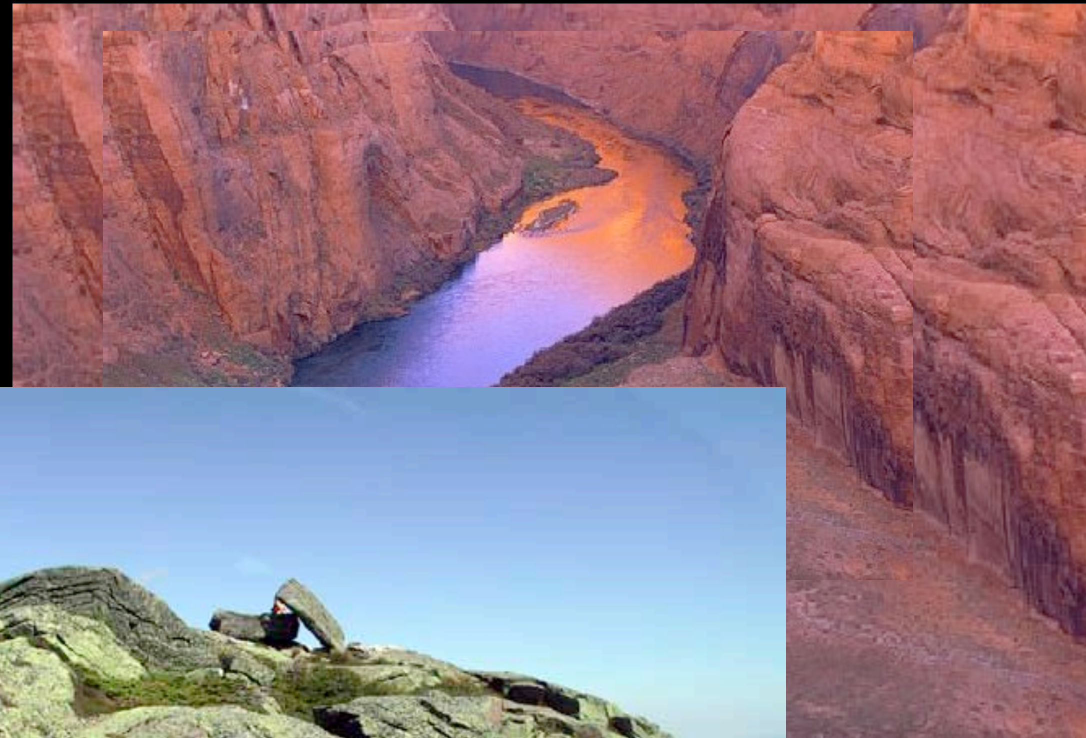
Geologists collect a variety of data in the field, but it starts with:

- the spatial distribution and geometric attitude of the rocks in the field

Entrance to the Inner Canyon of the Colorado, Grand Canyon, AZ

Geologists collect a variety of data in the field, but it starts with:

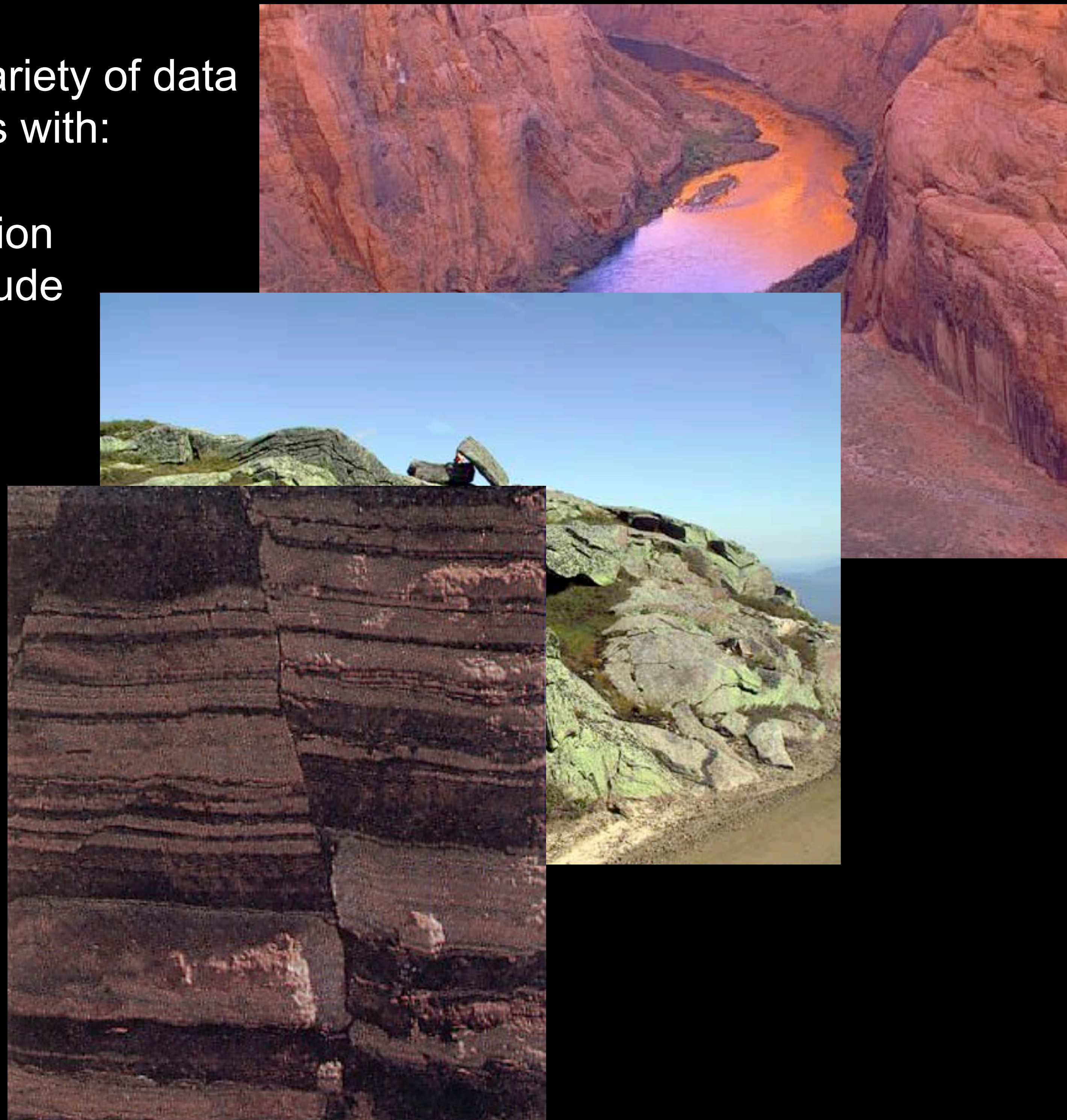
- the spatial distribution and geometric attitude of the rocks in the field
- the structures and the forces that deform them



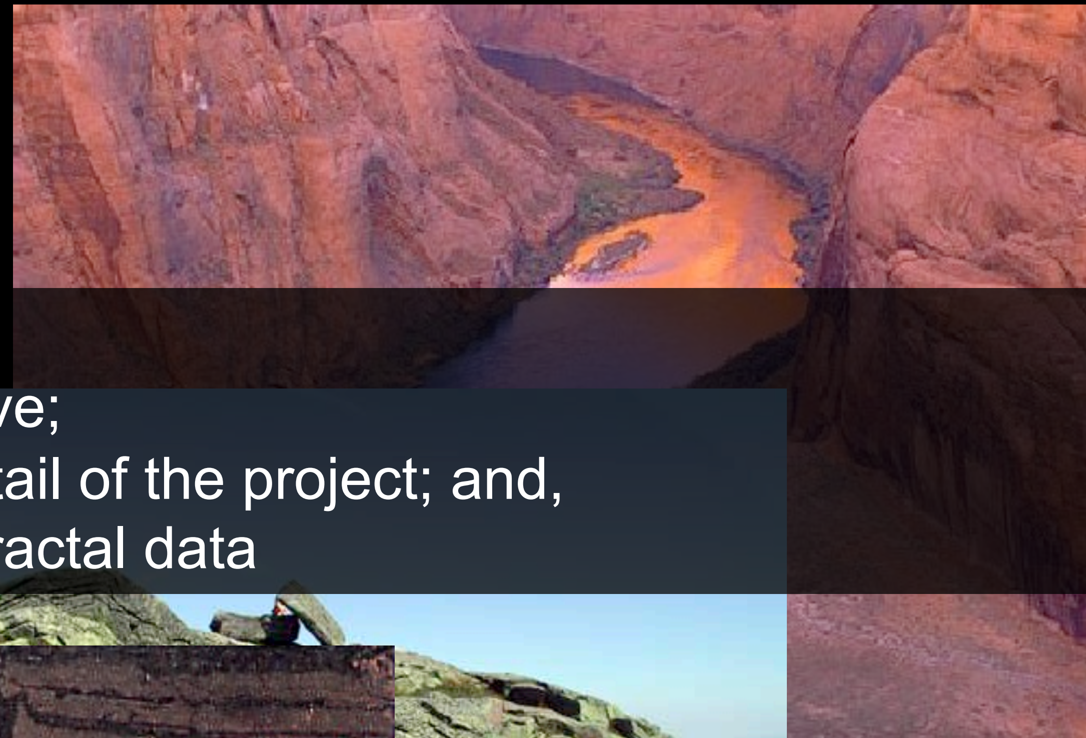
Folding in Miocene basalts, coast of WA

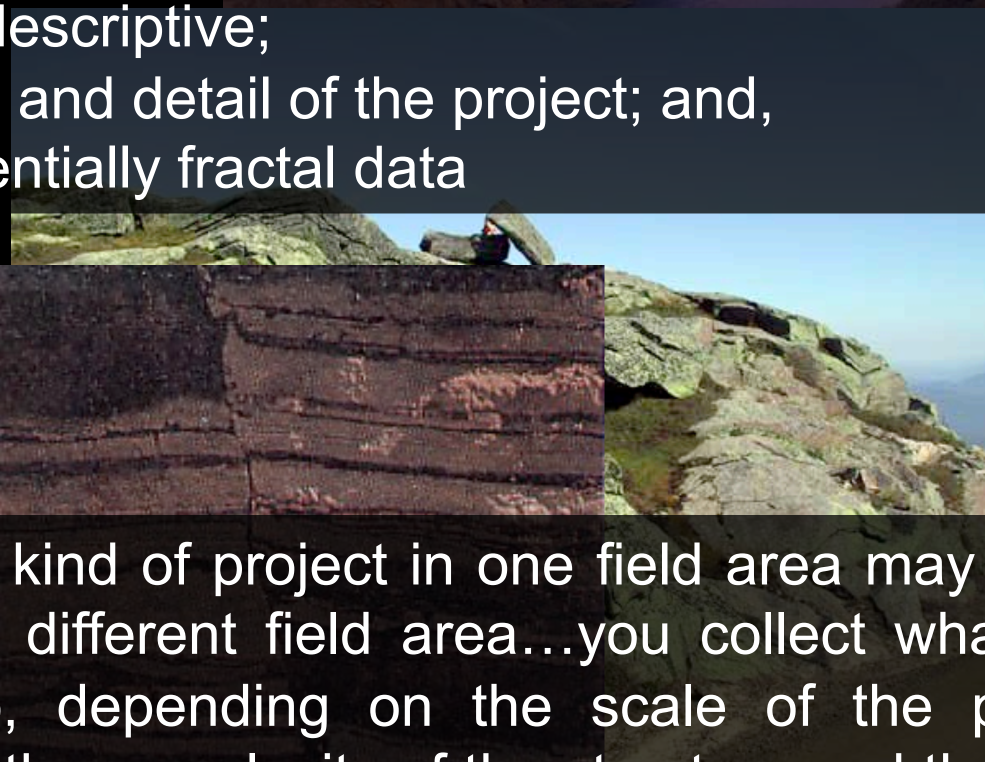
Geologists collect a variety of data in the field, but it starts with:

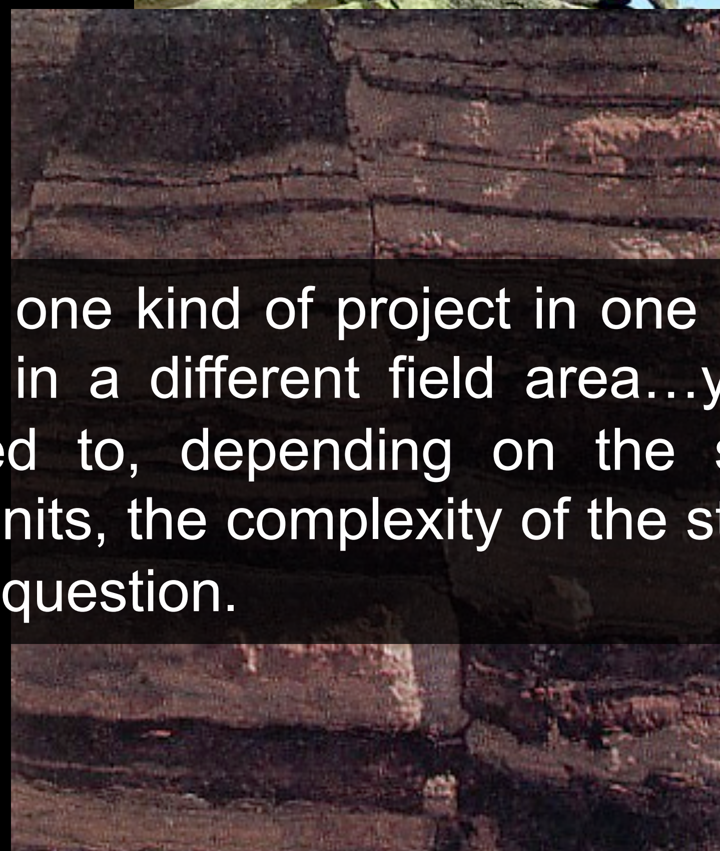
- the spatial distribution and geometric attitude of the rocks in the field
- the structures and the forces that deform them
- the structures and forces that break them



Faulting in tuff deposits





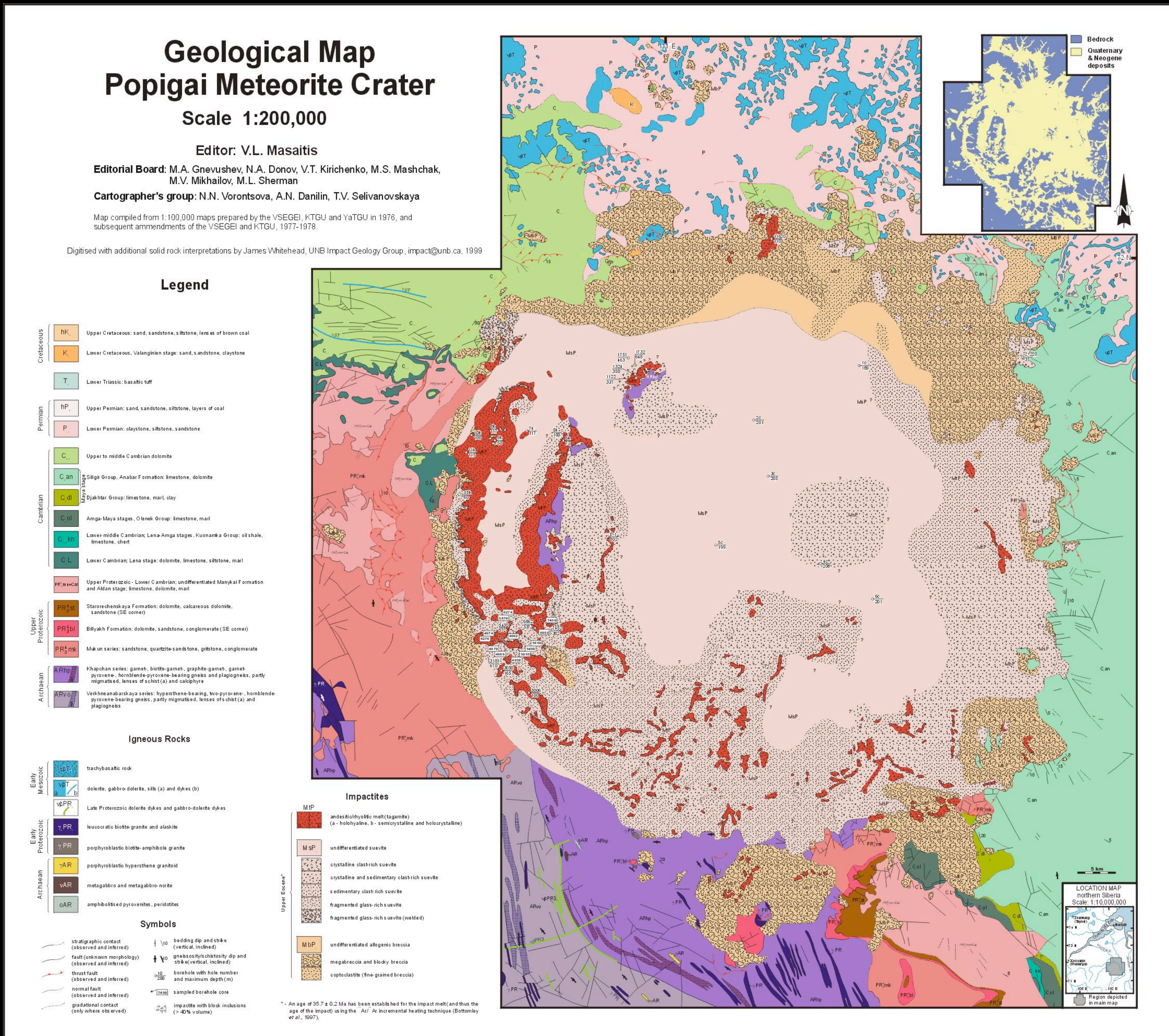


Note that these data are

1) largely qualitative and descriptive;
2) dependent on the scale and detail of the project; and,
3) irregularly spaced, essentially fractal data

What is “standard” for one kind of project in one field area may be useless for a different project in a different field area…you collect what data you need, when you need to, depending on the scale of the project, the variability of the rock units, the complexity of the structure and the objectives of a particular science question.

This allows development of a geologic map, which is the first order output from geologic field work and the basic tool for understanding geologic relationships.



What capabilities do our systems need to conduct this kind of science?

First, we need to be able to move through the terrain, and understand where we are on a geographically-based data base

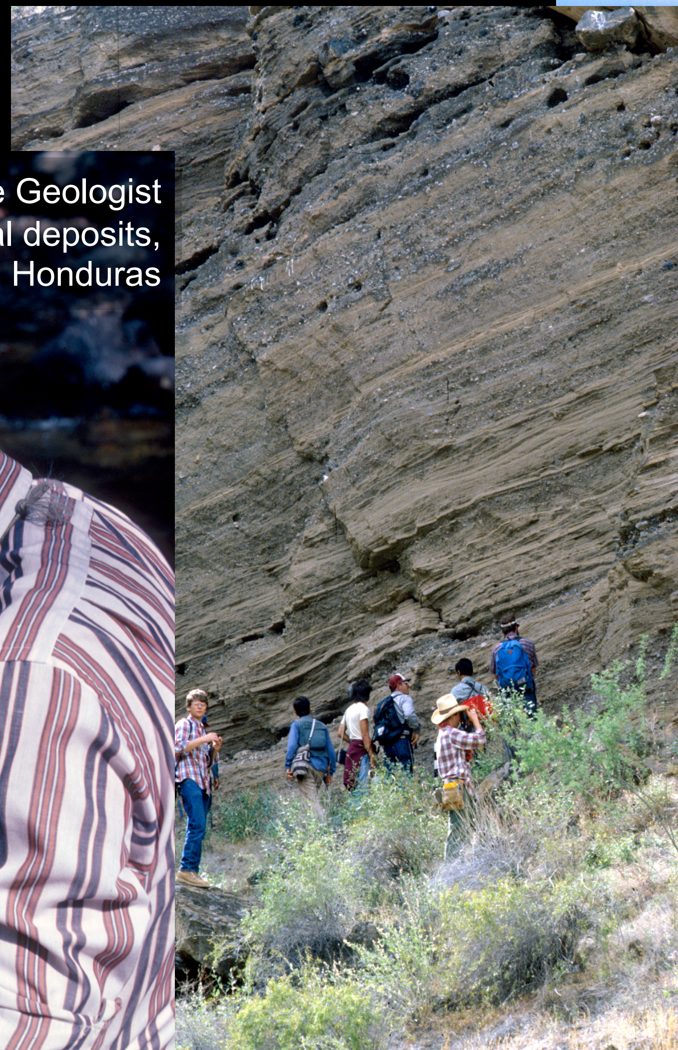
Gordon Ozinski mapping impact melt rocks, Haughton Crater, Devon Island, Canada

Mike Malin, Mars Observer Camera PI and founder of Malin Space Science Systems, reconnoitering lahar deposits from the May 1915 eruptions, Lassen Peak, CA

Second, we need to be able to get up close and personal to the rocks, to get the micro-scale as well as the macro-scale picture

Volcanology class documenting tuff deposits, Cerro Colorado, Pinacate Volcanic Field, Mexico

Bob Fakudiny, New York State Geologist (retired), examining geothermal deposits, Azacualpa, Honduras



This includes having the capability to look at rocks at a resolution above that of normal human vision

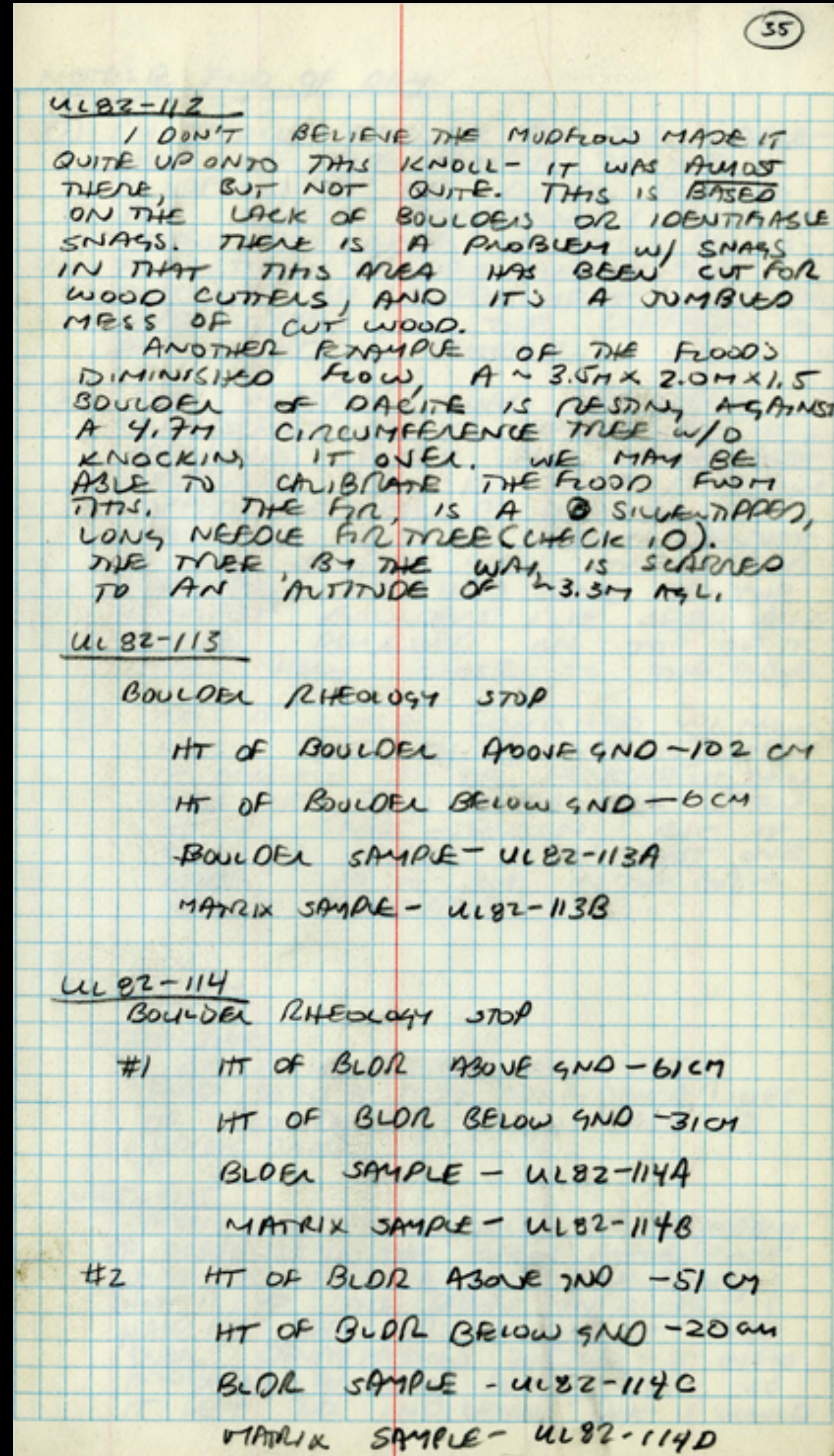
Note taking is critical in geology; field notes are our primary data set, along with the notations on maps and air photos.

Steve Bolivar, Los Alamos National Laboratory, documenting field observations, Sambo Creek hot springs, San Pedro Sula, Honduras

The descriptions and speculations in this passage are the primary data set associated with observing the geology in the field.

This is the science of doing geology, *not* the chemical or physical analyses that take place months later in the lab.

Without this description and context, all you're doing is walking around in the woods collecting rocks…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UL82-112

I DON'T BELIEVE THE MUDFLOW MADE IT QUITE UP ONTO THIS KNOLL – IT WAS ALMOST THERE, BUT NOT QUITE. THIS IS BASED ON THE LACK OF BOULDERS OR IDENTIFIABLE SNAGS. THERE IS A PROBLEM W/ SNAGS IN THAT THIS AREA HAS BEEN CUT FOR WOOD CUTTERS, AND IT'S A JUMBLED MESS OF CUT WOOD.

ANOTHER EXAMPLE OF THE FLOOD'S DIMINISHED FLOW, A ~ 3.5M × 2.0M × 1.5 BOULDER OF DACITE IS RESTING AGAINST A 4.7M CIRCUMFERENCE TREE W/O KNOCKING IT OVER. WE MAY BE ABLE TO CALIBRATE THE FLOOD FROM THIS. THE FIR IS A SILVERTIPPED, LONG NEEDLE FIR TREE (CHECK I.D.). THE TREE, BY THE WAY, IS SCARRED TO AN ALTITUDE OF ~3.3M AGL.

UL82-113

BOULDER RHEOLOGY STOP

HT OF BOULDER ABOVE GND – 102 CM

HT OF BOULDER BELOW GND – 6 CM

BOULDER SAMPLE – UL82-113A

MATRIX SAMPLE – UL82-113B

UL82-114

BOULDER RHEOLOGY STOP

#1 HT OF BLDR ABOVE GND – 61 CM

HT OF BLDR BELOW GND – 31 CM

BLDER SAMPLE – UL82-114A

MATRIX SAMPLE – UL82-114B

#2 HT OF BLDR ABOVE GND – 51 CM

HT OF BLDR BELOW GND – 20 CM

BLDR SAMPLE – UL82-114C

MATRIX SAMPLE – UL82-114D

Notebook page from Eppler's dissertation field work in Lassen Volcanic National Park, CA

142:52:53 Schmitt: Okay, Bob. The blue-gray rocks are breccias. They're multilithic, gray-matrix, matrix-dominated breccias, I guess. There are fragments in them, but it doesn't look like more than about 10 or 15 percent fragments.

[Schmitt - "When I was estimating the percentage of fragments, (the 10 to 15 percent figure) was related only to fragments large enough that they seemed to jump out of the matrix, that were clearly of a larger size than the matrix components. My guess is that the minimum was of the order of a few millimeters in size and that the estimate was really biased toward the larger fragments of centimeter size and more."]

142:53:10 Schmitt: Some of the light-colored fragments seem to have very fine-grained dark halos around them. The zap pits (in the dark matrix) do not have white halos, so I suspect they are not crystalline (rocks). They might be the vitric or glassy breccias. At least, the one big rock we have here.

142:53:43 Parker: Copy that.

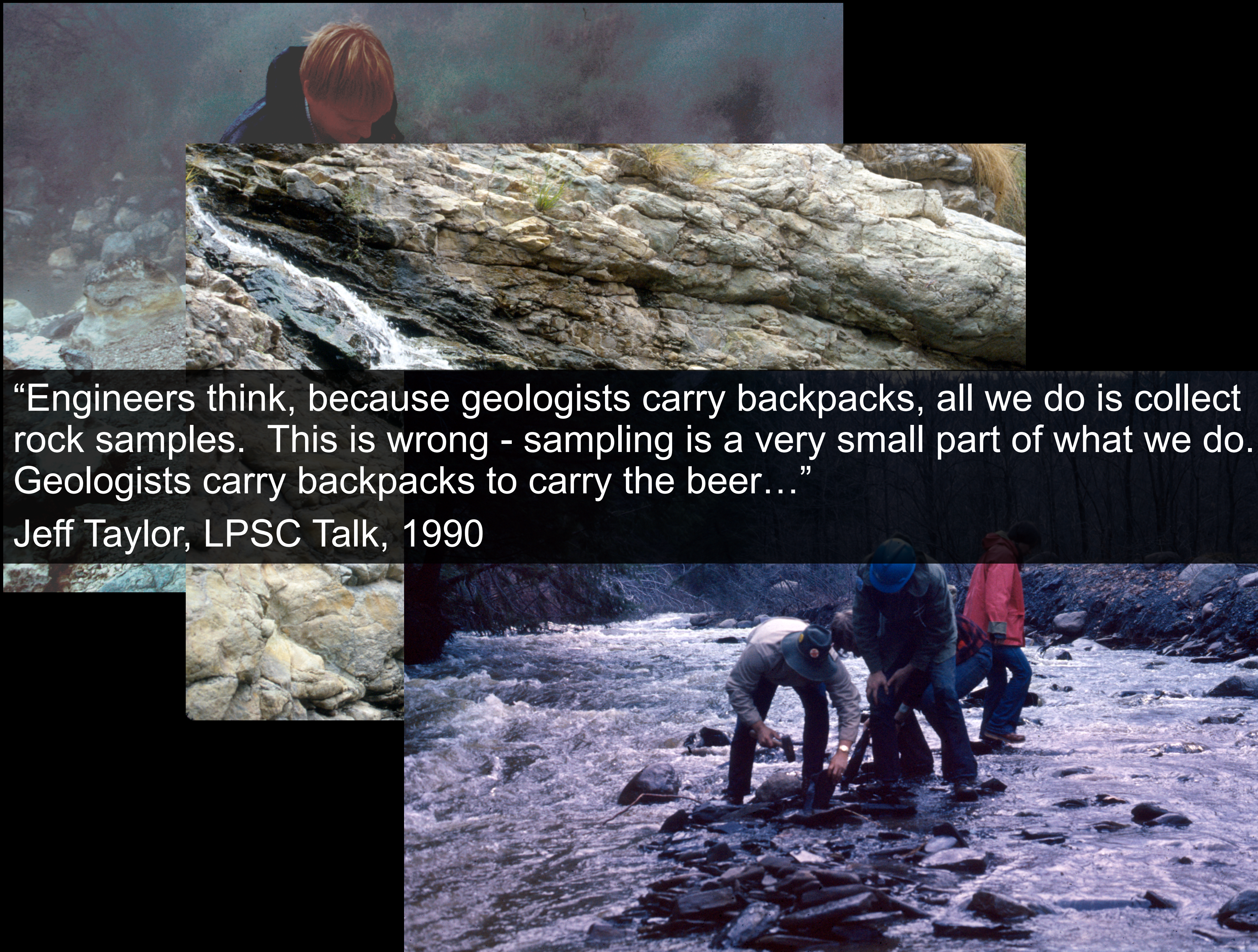
[Schmitt - "When the small impacting particles that form the zap pits hit, if there's crystalline rock - particularly plagioclase - at the impact point, then the halos look white. And in this case I'm saying that, because the halos don't look white, the rocks are not coarsely crystalline on the scale of the zap pit."]

Apollo 17 transcript from the Apollo Lunar Surface Journal (http://www.hq.nasa.gov/alsj/a17/a17.html) recorded in 1972 and annotated in 1995 by Lunar Module Pilot Harrison Schmitt

Sample collection *is* of critical importance, but it augments the understanding achieved by field observations…

Ken Wohletz, Los Alamos National Laboratory, sampling volcanic gases, Miravalles geothermal area, Costa Rica

Simply sampling local rocks without the geologic context is not sufficient.



"Engineers think, because geologists carry backpacks, all we do is collect rock samples. This is wrong - sampling is a very small part of what we do. Geologists carry backpacks to carry the beer…"

Jeff Taylor, LPSC Talk, 1990

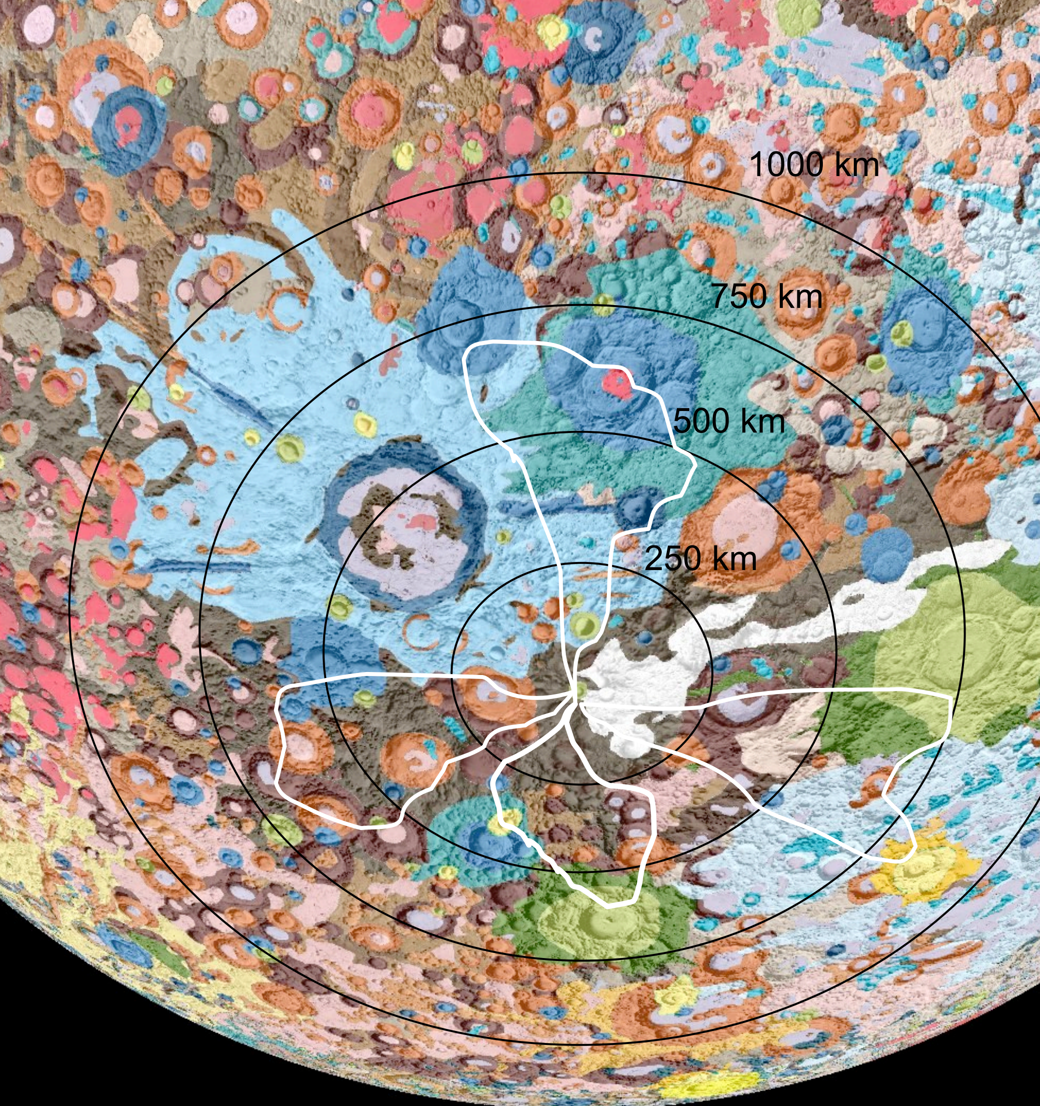
Implications for Human-Robotic Interaction

Human-robotic partnerships must be based on the concept that the robot is there to augment the human's unique capabilities at observation, integration and formulating hypotheses.

My experience, both as a field geologist and as a suit subject, has led me to believe that the best use of robotic assets will be conducting reconnaissance of traverses paths for crewed roves, looking both for scientific "sweet spots" and determining surface trafficability.

Mike Malin, Mars Observer Camera PI and founder of Malin Space Science Systems, reconnoitering lahar deposits from the May 1915 eruptions, Lassen Peak, CA

Gordon Ozinski mapping impact melt rocks, Haughton Crater, Devon Island, Canada



EXAMPLE REGIONAL SCALE GEOLOGICAL STUDIES INVOLVING LONG-DISTANCE ROVING*

- Sample early crustal rocks to understand the development of the magma ocean, formation of the crust and mantle, timing of anorthosite formation and other large intrusive magmatic events, size and composition of the lunar core
- Measure bulk chemical composition of the Moon to constrain the processes by which elements were partitioned in the Earth-Moon system at the time of formation
- Use the Moon's craters as a natural laboratory to study the large impact process, including the origin and mechanism of central peaks and basin ring development, excavation dynamics and dimensions, and the mechanics of ejecta emplacement

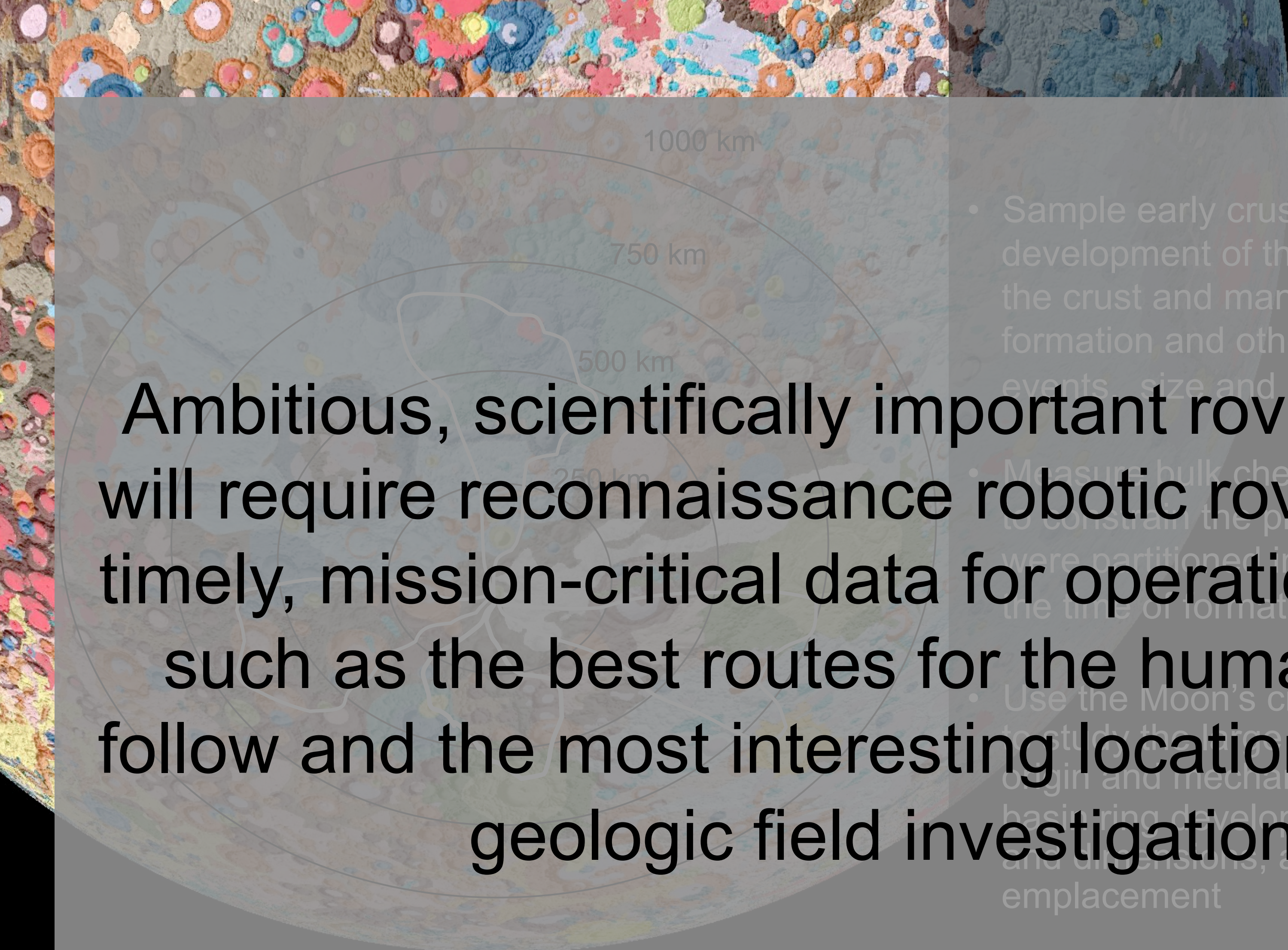
FOR EACH GEOLOGIC UNIT:

- Determine and map the lateral extent of major lithologies and landforms
- Define and sample ejecta blankets from major pre-imbrian impacts
- Map the major structures associated with various size impact craters
- Collect samples that will date major geologic events, including impacts and magmatic events

CAPABILITIES REQUIRED:

- Pressurized rove capability with a minimum radius of ≈1000 km
- A campaign of multiple long roves
- 100s to 1000s of EVA crew days

*LEAG SASS_SAT Report, 2005



Ambitious, scientifically important roves like these will require reconnaissance robotic rovers to collect timely, mission-critical data for operations planning, such as the best routes for the human crews to follow and the most interesting locations to conduct geologic field investigations.

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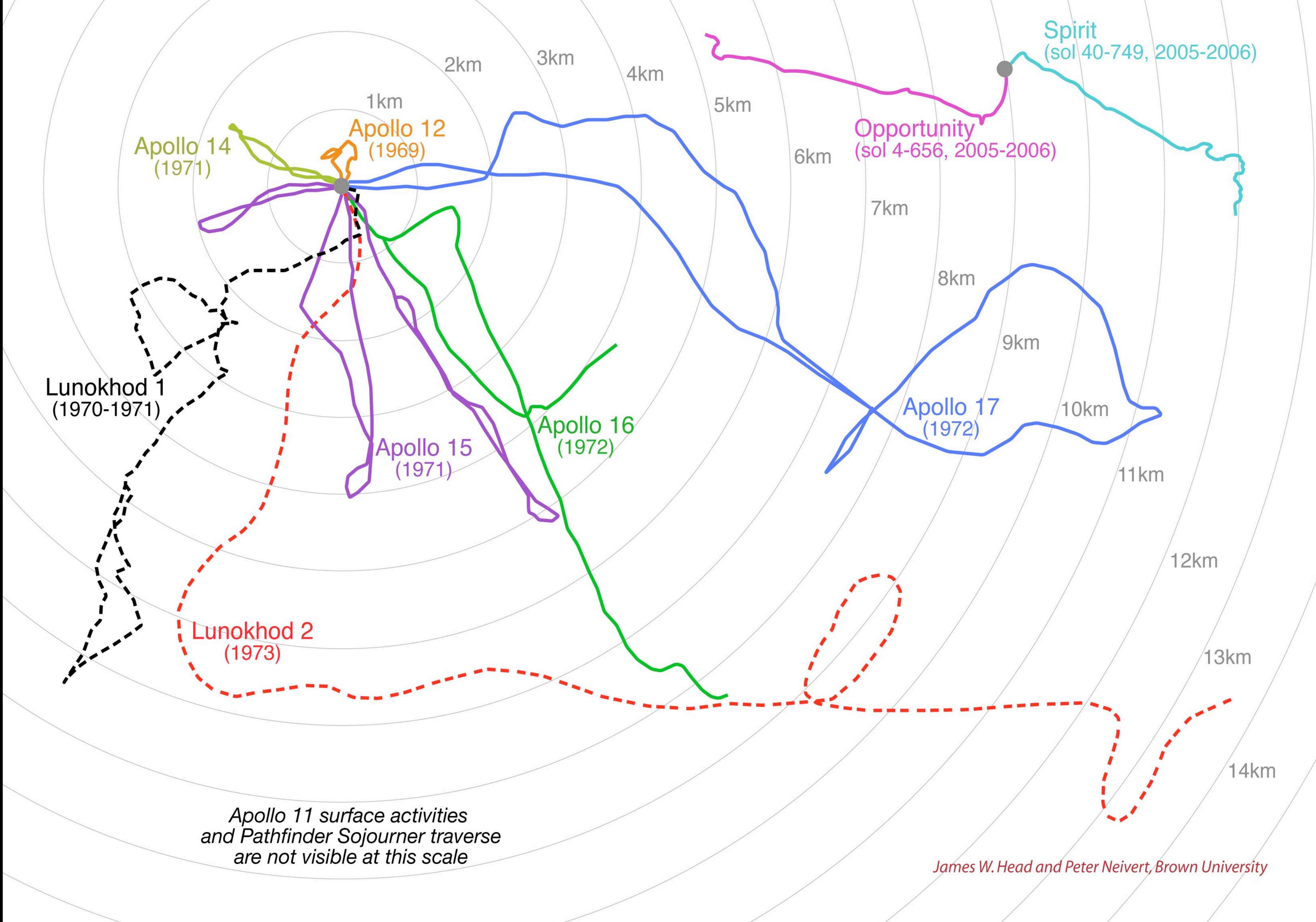
Lunokhod, Apollo and MER Traverses to Scale



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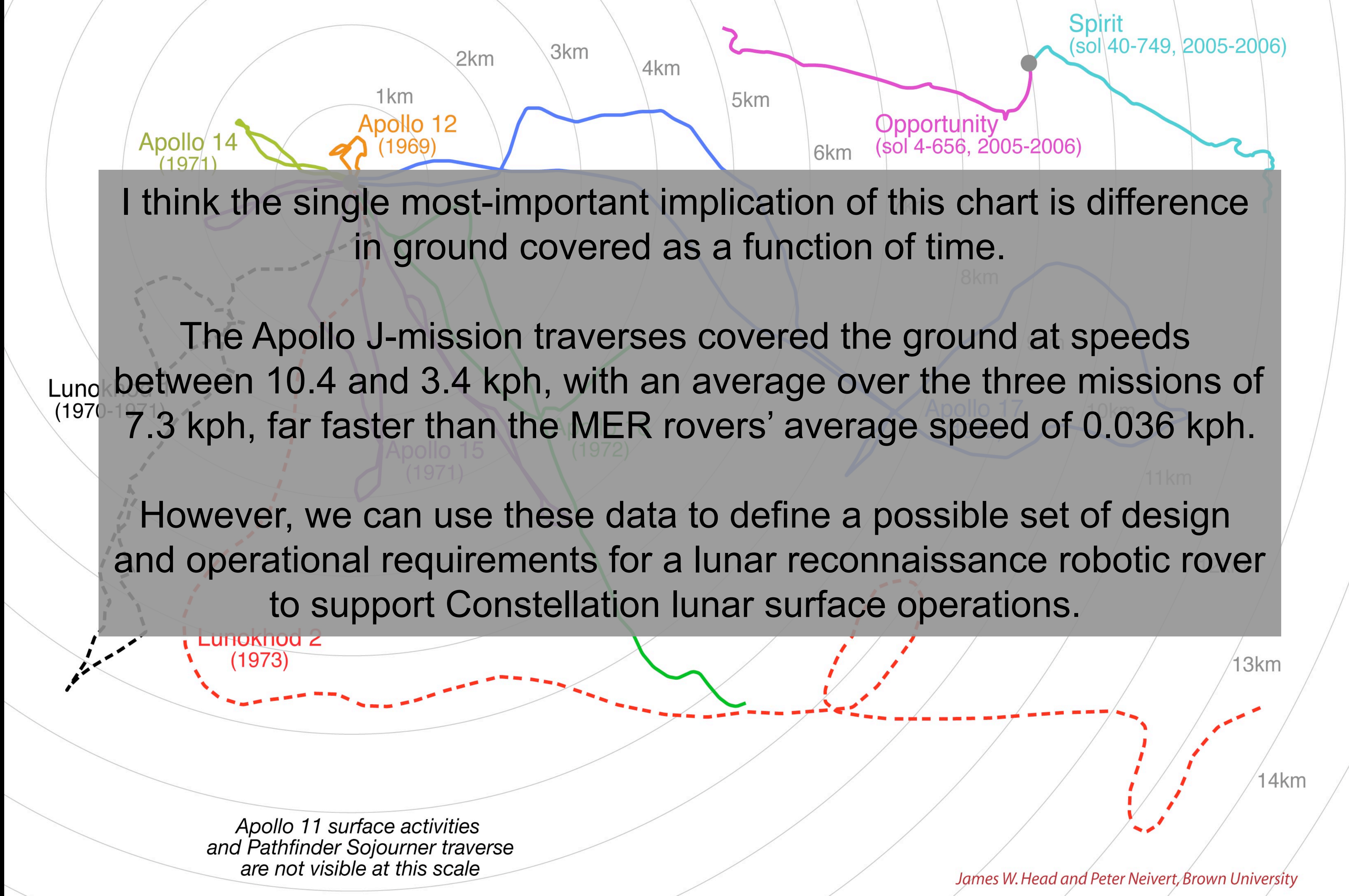
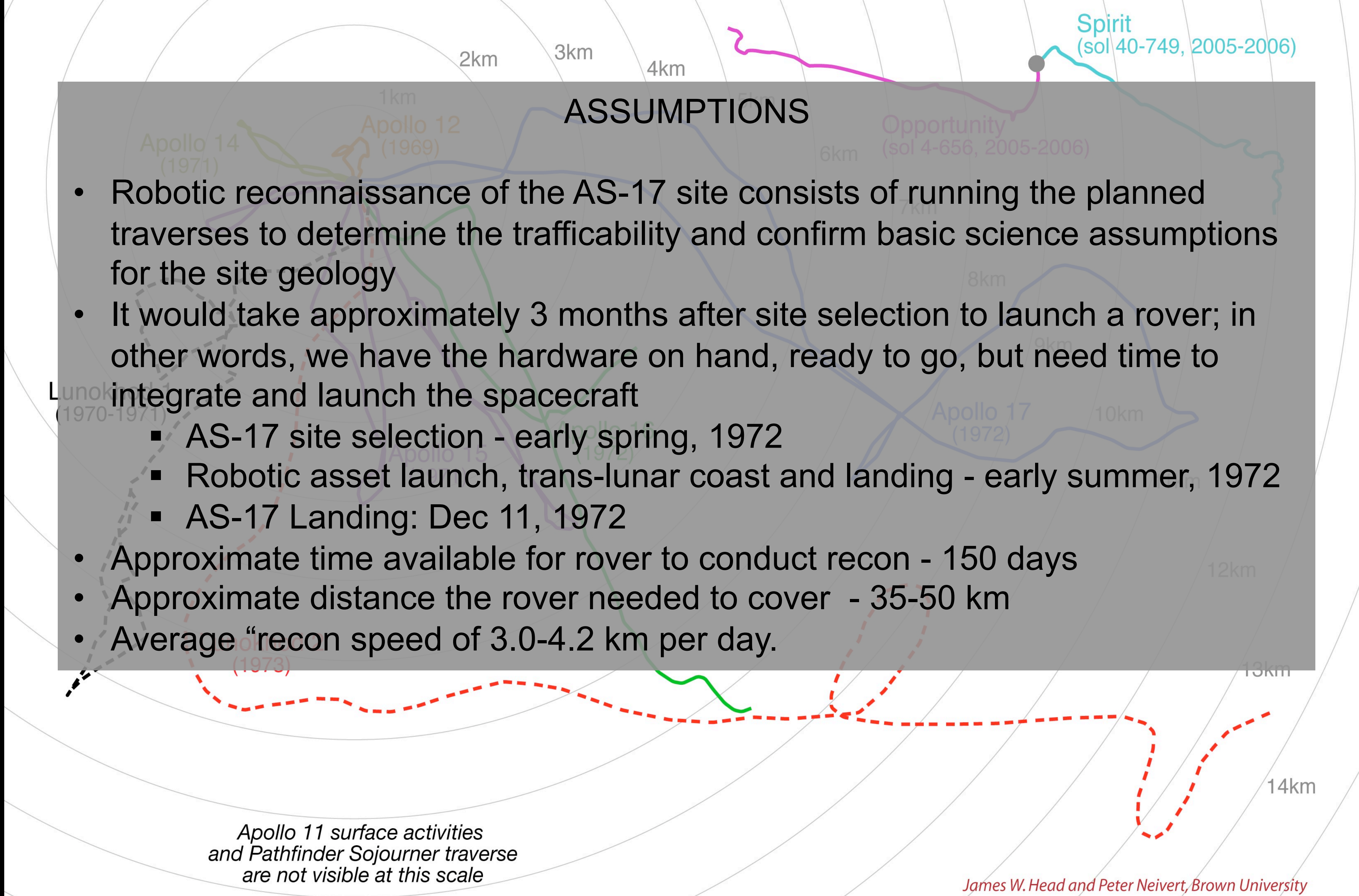


I think the single most-important implication of this chart is difference in ground covered as a function of time.

The Apollo J-mission traverses covered the ground at speeds between 10.4 and 3.4 kph, with an average over the three missions of 7.3 kph, far faster than the MER rovers' average speed of 0.036 kph.

However, we can use these data to define a possible set of design and operational requirements for a lunar reconnaissance robotic rover to support Constellation lunar surface operations.

Lunokhod, Apollo and MER Traverses to Scale



James W. Head and Peter Neivert, Brown University

ASSUMPTIONS

- Robotic reconnaissance of the AS-17 site consists of running the planned traverses to determine the trafficability and confirm basic science assumptions for the site geology
- It would take approximately 3 months after site selection to launch a rover; in other words, we have the hardware on hand, ready to go, but need time to integrate and launch the spacecraft
  - AS-17 site selection - early spring, 1972
  - Robotic asset launch, trans-lunar coast and landing - early summer, 1972
  - AS-17 Landing: Dec 11, 1972
- Approximate time available for rover to conduct recon - 150 days
- Approximate distance the rover needed to cover - 35-50 km
- Average “recon speed of 3.0-4.2 km per day.

IMPLICATIONS

- If we are to use robotic assets to conduct reconnaissance of the lunar surface, I would argue that we need to cover 2.5-5 km per day in order to ensure that robotic reconnaissance is not a bottleneck to efficient surface operations.

- With this kind of capability, we could, for instance, do a reconaissance of the route from Shackleton to Malapert in ≈3-4 months, and do a similar reconnaissance of the route to Schrödinger in 12-15 months

- The assets we would use to do this activity would not be the same assets we use to do primary crew transport (i.e, Chariots or LERs)
  - First, they are two valuable to risk
  - Second, we need to be doing the reconnaissance of these long traverses simultaneously with surface crew activities

- Long range reconnaissance operations would need to be run out of an Earth-based, rather than a Moon-based facility

CONCLUSIONS

- The primary source of geologic and paleontological data acquired on the Moon, Mars and other planets will be the collection of spatially-based data on the distribution of rock units and structures, loosely called geologic field work
- In my opinion, the most important use for robotic assets lies in reconnaissance of the lunar surface to inform operational planning, such as finding safe routes and scientific “sweet spots”
- Robots that conduct reconnaissance field activities must be sufficiently robust to traverse into a wide variety of terrains at speeds of 2.5-5 km per day to define the best routes, and to get as close as possible to the interesting rocks and structures
- The assets we use to conduct robotic reconnaissance operations need to be dedicated robots, such as the Lunakhod or MER, that would be operated out of a terrestrial facility

The grateful assistance, wisdom, patience and tutelage of many individuals must be acknowledged here, including Nancy Ann Budden (USN Postgraduate School), Jon Callendar (UNM), Bob Christiansen (USGS), Mike Clynne (USGS), Chris Culbert (NASA), Pat Dickerson (UT), Bob Dietz (ASU), Wolf Elston (UNM), Duane Eppler (TeleAtlas), Mark Erickson (SLU), Drew Feustel (NASA), Grant Heiken (LANL), Mark Helper (UT), Jose Hurtado (UTEP), Russ Jacoby (SLU), Joe Kosmo (NASA), Dave Krinsley (ASU), Mike Malin (MSSS), John McHone (whereever…), Bill “The Incredible Hulk” Muehlberger (UT), Jim Reilly (NASA), Amy Ross (NASA), Jack Schmitt (UW), Paul Spudis (LPI), Jim Street (SLU), Dave Vaniman (LANL), and Lee Woodward (UNM).

Also, the superb compilation of traverse information on Slide 30 was developed by Jim Head and Peter Nievert of Brown University.

Moonrise over Mare Smythii, courtesy of the Apollo 8 crew