U.S. Spacesuit Knowledge Capture (KC) Series Synopsis

Topic: Conduct of Geologic Field Work During Planetary Exploration: Why Geology Matters

This event was recorded March 15, 2010 at NASA Johnson Space Center.

Presenter: Dean Eppler, Ph.D.

Synopsis: The science of field geology is the investigative process of determining the distribution of rock units and structures on a planet's surface, and it is the first-order data set that informs all subsequent studies of a planet, such as geochemistry, geochronology, geophysics, or remote sensing. For future missions to the Moon and Mars, the surface systems deployed must support the conduct of field geology if these endeavors are to be scientifically useful. This lecture discussed what field geology is all about—why it is important, how it is done, how conducting field geology informs many other sciences, and how it affects the design of surface systems and the implementation of operations in the future.

Biography: Dean Eppler earned a bachelor of science in geology from St. Lawrence University in 1974, a master of science in geology from the University of New Mexico in 1976, and a doctor of philosophy (Ph.D.) in geology from Arizona State University in 1984. From 1986 to 2009, he was a Senior Scientist with Science Applications International Corporation, which included 20 years of support to NASA at the Johnson Space Center (JSC). During that time, he was a Lead Suit Test Subject for advanced planetary spacesuit development and geologic field testing from 1996 to 2005; the International Space Station (ISS) Payloads Office Program Lead on development of a high-quality research window on the ISS from 1994 to 2005; the Program Originator and Lead Scientist on the ISS Window Observational Research Facility (WORF) from 1998 to 2003; and the Lead for Science Operations and Logistics Concept Development for Advanced Planetary Exploration Programs, including 2 years in the lunar surface systems for Constellation. In 2009, he transitioned to NASA and works in the Astromaterials Research and Exploration Science (ARES) Directorate, doing science operations development for lunar missions, including working up science operations concepts for Desert Research and Technology Studies (RATS) and developing and implementing the geologic training curriculum for the 2009 Astronaut Class. During his career, Dean has published more than 30 scientific publications and has been awarded the Army Commendation Medal, the Antarctic Service Medal, and the NASA Exceptional Public Service Medal.

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Conduct of Geologic Field Work During Planetary Exploration: Why Geology Matters

Dean Eppler
NASA-JSC
Astromaterials Research and Exploration Sciences Directorate

This talk will cover a three topics:

- Define, describe and explain the actual nature of geologic field work as it is done terrestrially
- Look at an example of geologic field work to understand how and why this activity is done
- Consider the implications of geologic operations on surface hardware development

Apollo 17 Crewmember Dr. Harrison Schmitt, Station 6-Split Rock

- Field work is the basic method of obtaining geologic data, and will continue to be so as manned missions move out into the solar system
- It is an area of science that is critically different from the basic concept of a scientist in a white coat in a lab setting, particularly in light of conducting lunar surface operations
- Because this kind of scientific activity is so different from activities conducted in a laboratory setting, we cannot apply the same kind of deterministic planning for lunar surface EVAs that we do, for instance, for an ISS construction EVA

Cavernous weathering, Victoria Valley, Antarctica

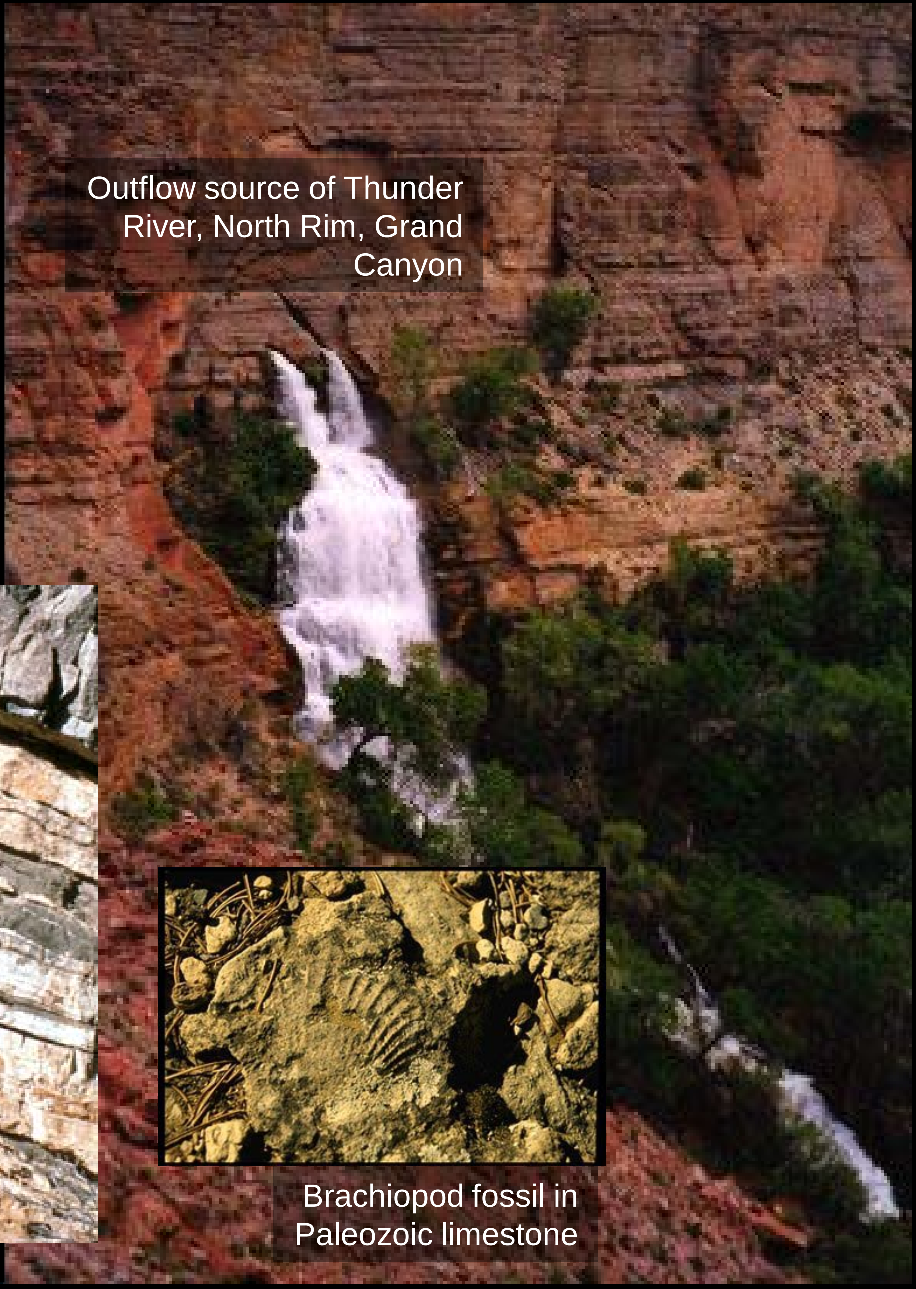
First, some misconceptions we have to deal with up front:

- Collecting samples is doing geology
- Sample analysis is the most important part of doing geology
- Geologists go in the field to make quantitative measurements on rocks
- There is a quantifiable, spatially-regular “model” applied to doing geologic field work
- When a geologist goes into the field, they know exactly where to go and what they are going to find
- Chemical composition data is the most important piece of information in the conduct of geologic investigations
- Remote sensing data will define the geology of the Moon unambiguously, making geologic field work unnecessary

Each of these statements is wrong

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

Brachiopod fossil in Paleozoic limestone

Folding in metamorphosed sediments

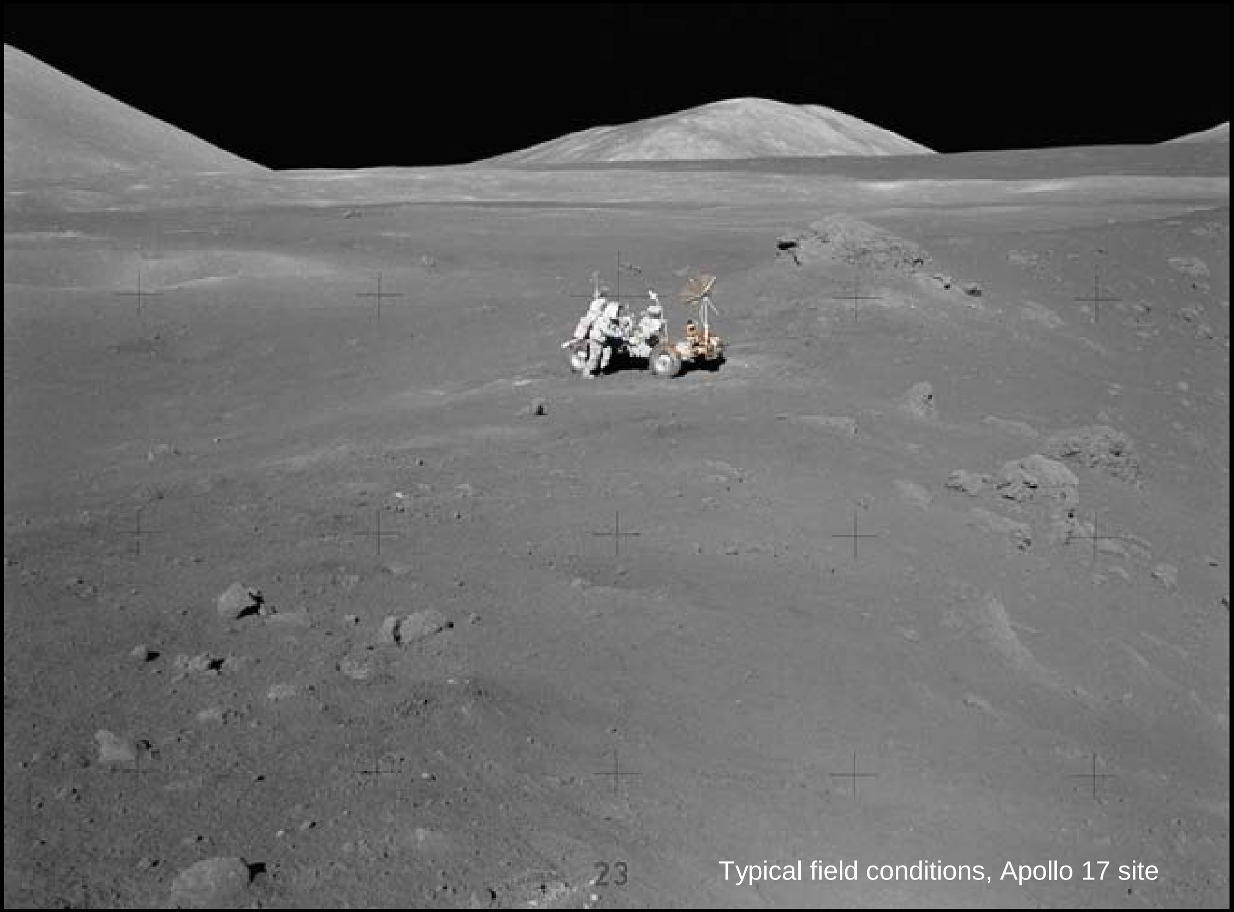
Field work remains the primary source of geologic data because the rocks, in the field, are the primary data set we work with…and while geologists would love to have this kind of exposure everywhere to develop their understanding of geologic history and processes…

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

…no matter what planet you go to...



Typical field conditions, Apollo 17 site

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

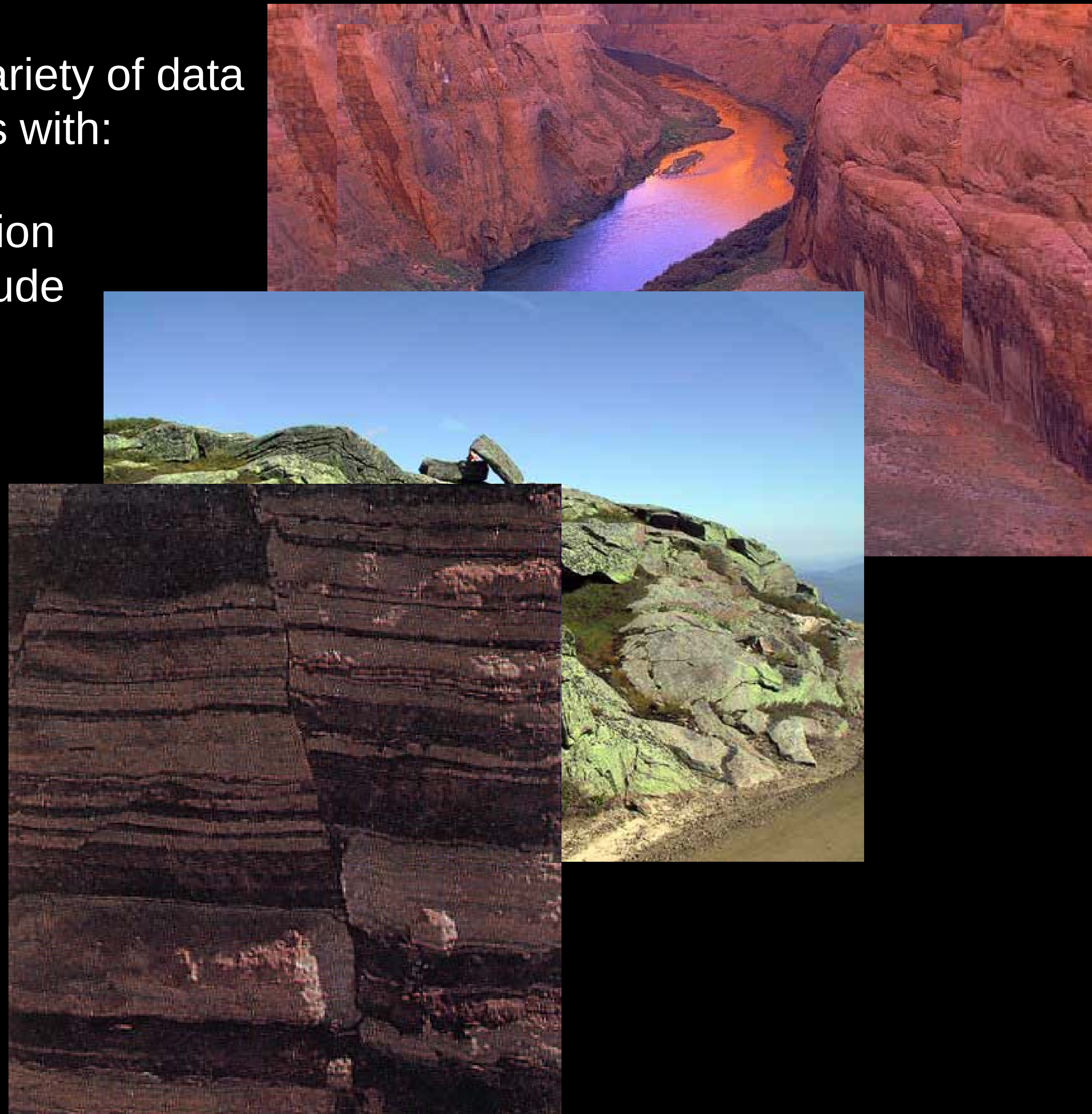
Geologists collect a variety of data in the field, but it starts with:

- 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

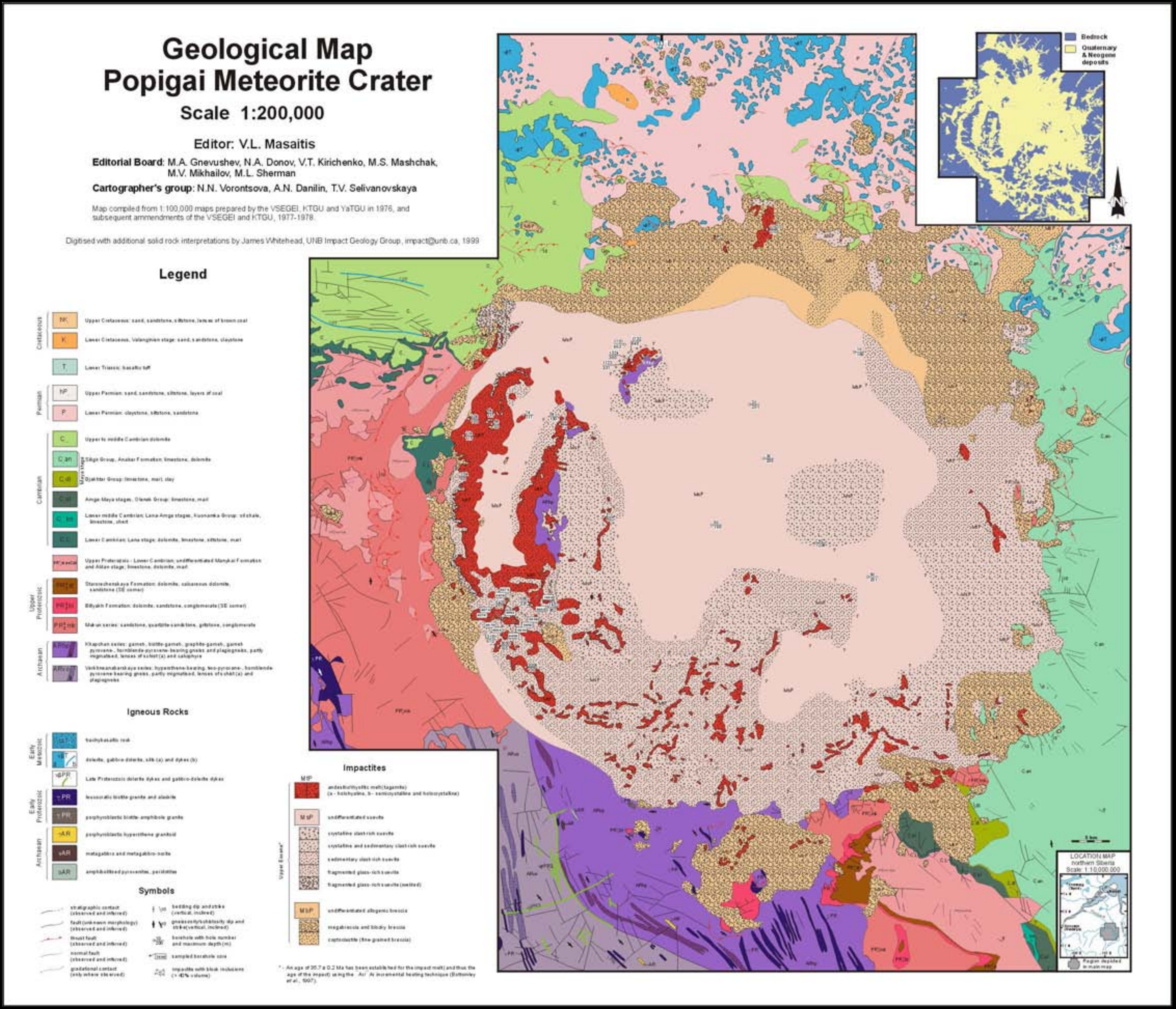
Geologists collect a variety of data in the field, but it starts with:

- 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

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



OK, so how do you do this?

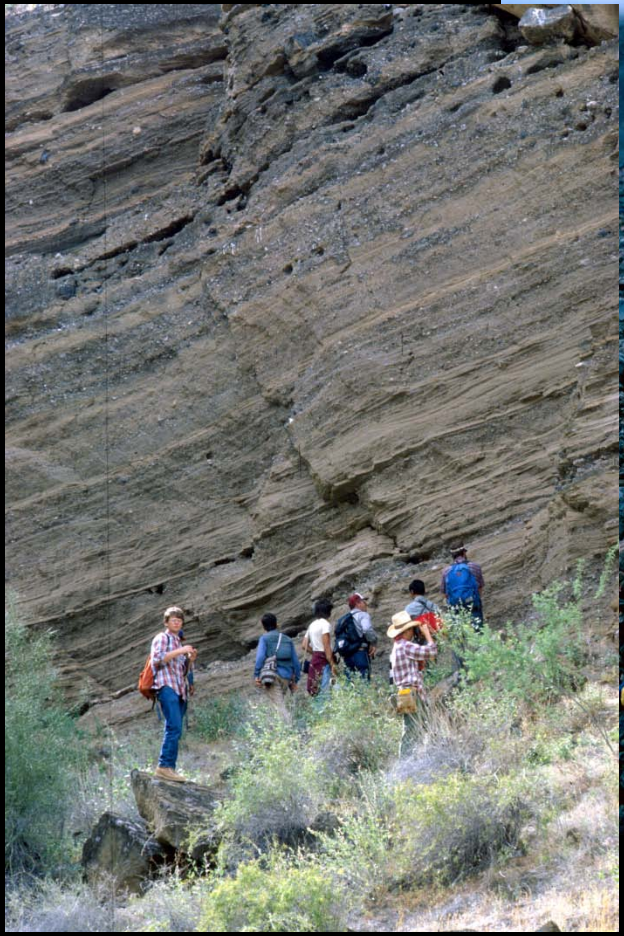
First, you have to get into the terrain, and know where we are on a geographically-based data base. You can not do geology solely from the inside of a pickup truck (or a pressurized rover).

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

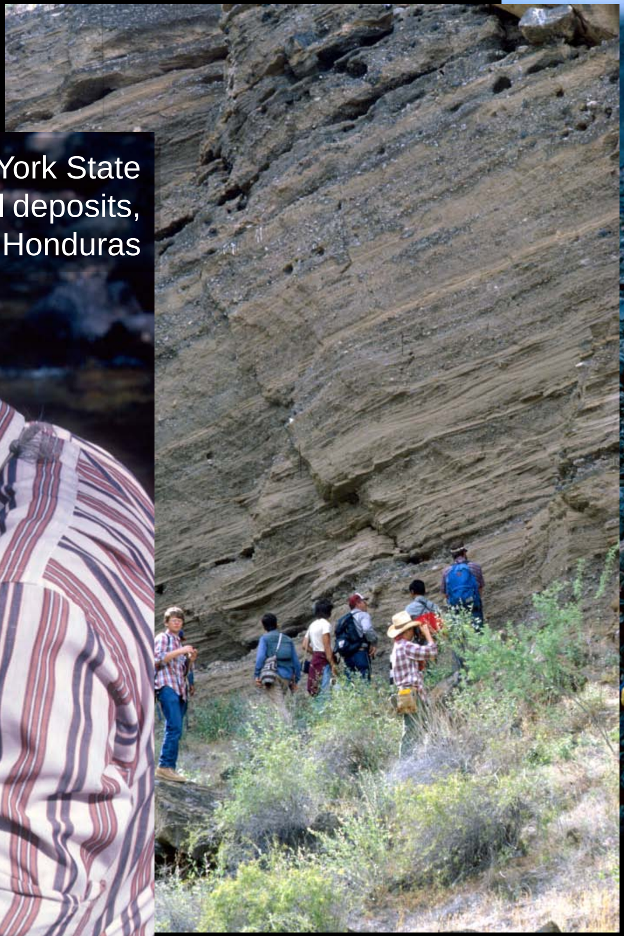
Second, you have to get up close and personal to the rocks, to get the micro-scale as well as the macro-scale picture.

Geologists have to deal with substantive variations in scale in the field, ranging from looking at mineral grains <0.1 mm in size to rock units and structures that may be hundreds to thousands of meters in size, sometimes in the same outcrop.



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

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



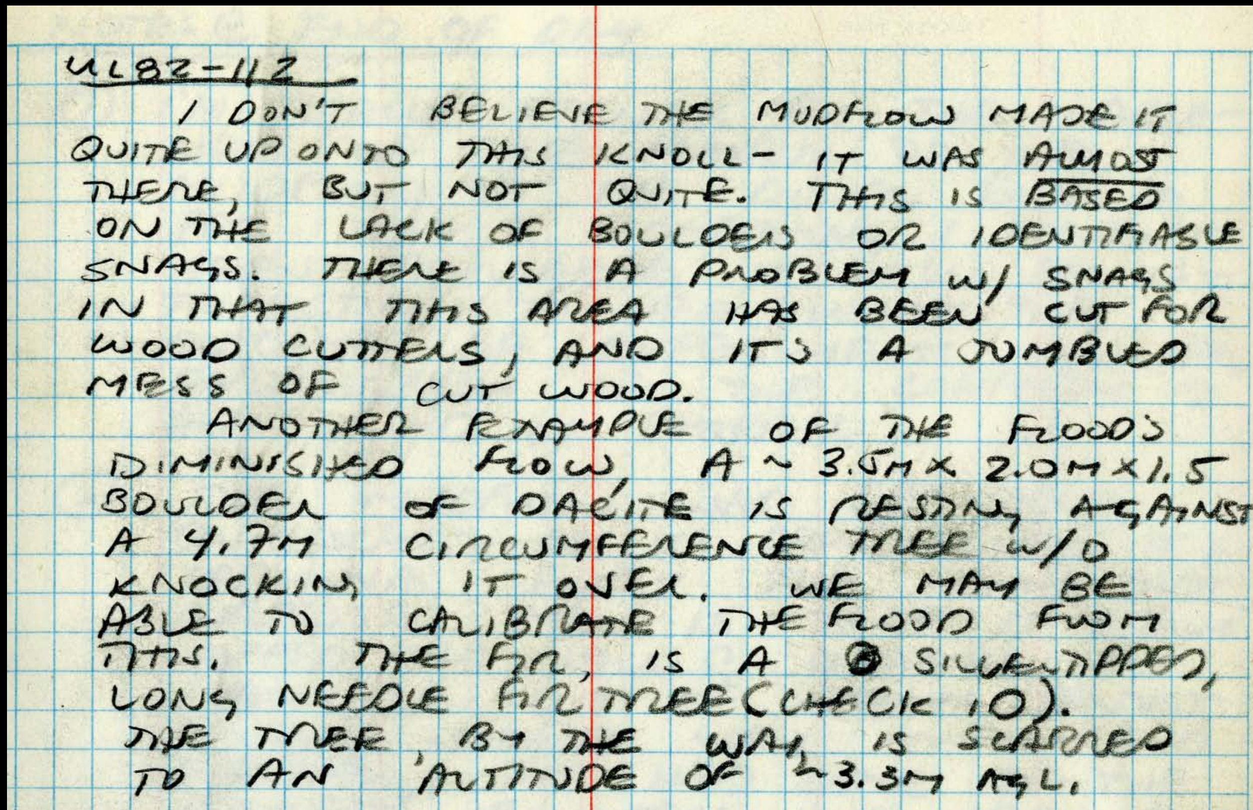
This includes having the capability to look at rocks at a resolution above that of normal human vision

Third, you have to be able to observe and describe, in detail, what you are seeing in the outcrop, and you have to be able to record that data in some fashion.

Note taking is absolutely critical in geology; field notes are the primary data set, along with the notations on maps and air photos. I still have all the field notebooks from my entire career, and they are locked up in a fireproof box so they are never lost.

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

Along with the map data, the descriptions and speculations in notebook entries like this are the input data for field geology, and all subsequent conclusions derive from them.


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 x 2.0M x 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 ID). THE TREE, BY THE WAY, IS SCARRED TO AN ALTITUDE OF ~3.3M AGL.

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

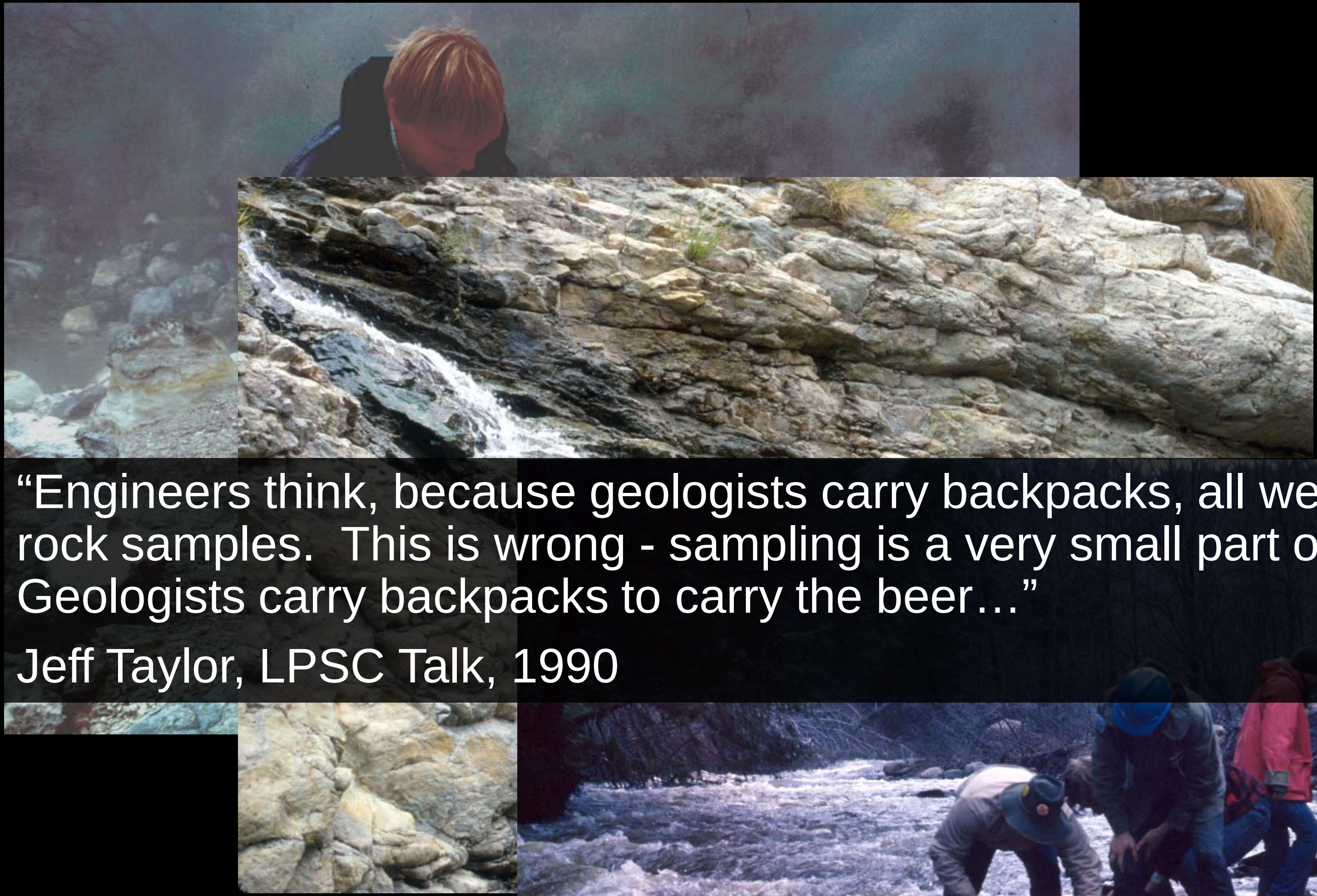
This is the science of doing geology, not the chemical or physical analyses that take place months later in the lab; without this description and context, all you're doing is walking around in the woods collecting rocks…

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

Sample collection *is* important, but it augments the understanding achieved by field observations, and without that field context, you cannot interpret geochemical or geophysical data.

Bob Fakudiny sampling geothermal waters,
Platanares geothermal area, Copan, Honduras

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

Example Field Investigation

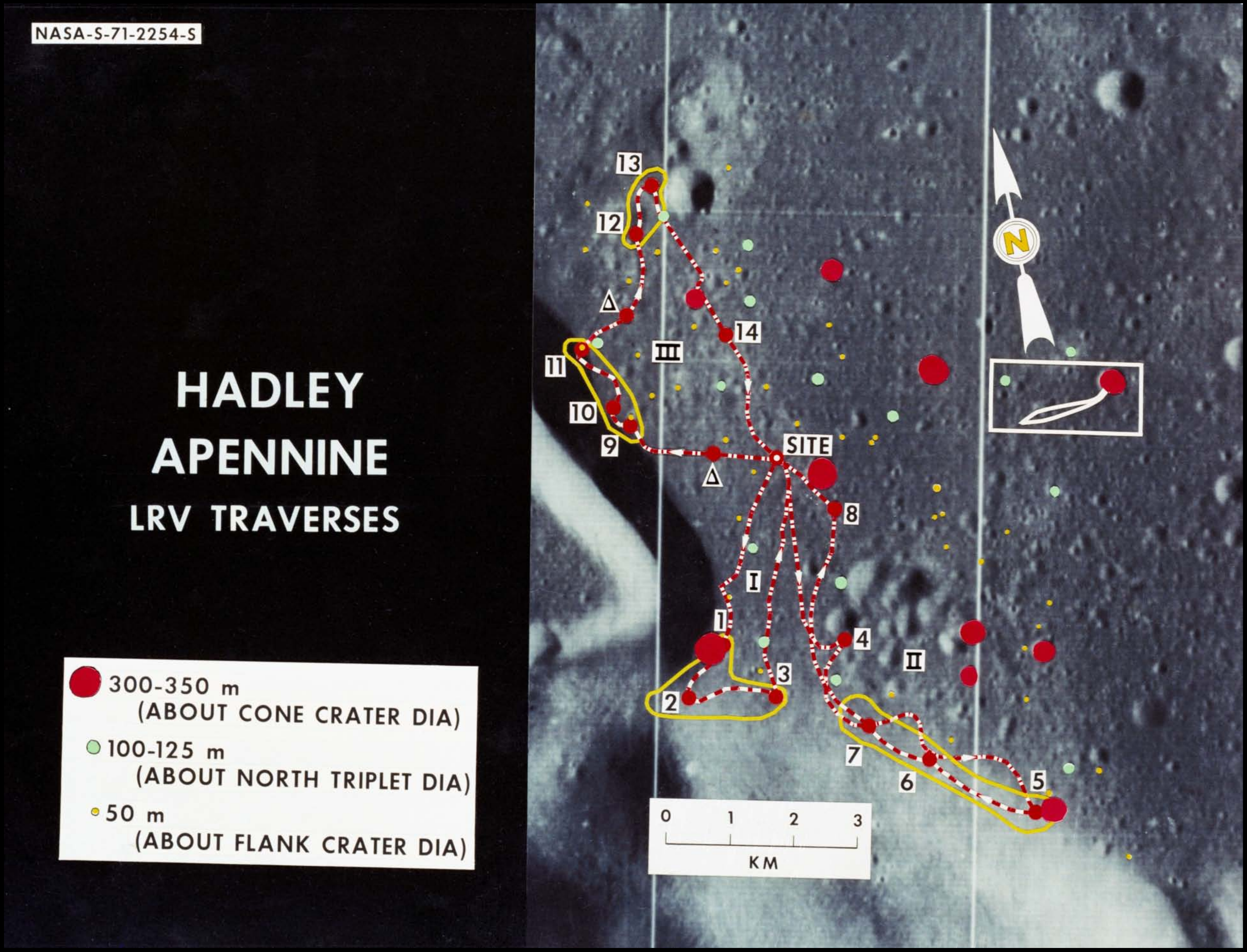
Hadley Rille Geology

One of the critical science questions that Apollo missions tackled is the general nature of the lunar maria, as well as the variety of straight and sinuous valleys that cut them

The Apollo 15 landing site put the crew within access (using the LRV) of the edge of a prominent sinuous rille in Mare Imbrium, and visiting the rille was a high priority science target

In the course of planning the mission, the crew underwent extensive geologic training in areas that provided a roughly 1:1 topographic analog to the Hadley Rille site

Hadley Rille Geology - Pre-mission Traverse Plan



Geologic Training for Apollo 15

Apollo 15 CDR and LMP, geologic training field trip, Rio Grande River Gorge, Taos, NM

- This is a location in the Rio Grande Valley in northern New Mexico where the Rio Grande has eroded into a series of basaltic lava flows that were erupted ≈3 million years ago
  - Both the canyon, and the Sangre de Christo range in the distance, have essentially the same scale and geometry of Hadley Rille at the Apollo 15 site
- This was one of an extensive series of training trips the Apollo 15 crew went on to develop their observational skills for the lunar surface traverses to follow

Geologic Training for Apollo 15

- **General Scientific Training (includes all science training prior to mission selection and mission specific training for Apollo 15): ≈375 hours**
- **Apollo 15 Specific Science Training (AS-16 & -17 had similar training)**
  - General science lectures - 80 hours
  - PI briefings - 20 hours
  - Orbital geology training - 80 hours
  - Lunar sample training - 12 hours
  - Geologic field training trips - ≈470 hours
    - Orocopia Mts, CA ≈20 hours
    - Mojave Desert, CA ≈10 hours
    - Meteor Crater, AZ ≈16 hours
    - San Francisco Volcanic Field ≈20 hours
    - Suffield, Alberta, Canada ≈4 hours
    - San Juan Mountains, CO ≈20 hours
    - Buell Park, AZ ≈16 hours
    - Ely, MN ≈12 hours
    - Merriam Crater, AZ ≈16 hours
    - San Gabriel Mountains, CA ≈16 hours
    - Hawaiian volcanoes ≈40 hours
    - Kilbourne Hole, NM ≈8 hours
    - Ubehebe Craters, CA ≈24 hours
    - Taos, NM ≈20 hours
    - Coso Hills, CA ≈20 hours
    - Nevada Test Site, NV ≈16 hours

- **Total training hours: ≈1037 hours for Apollo 15 science operations**

Geologic Training for Apollo 15:
Geologic Field Trip “Traffic Model”

GEOLOGIST

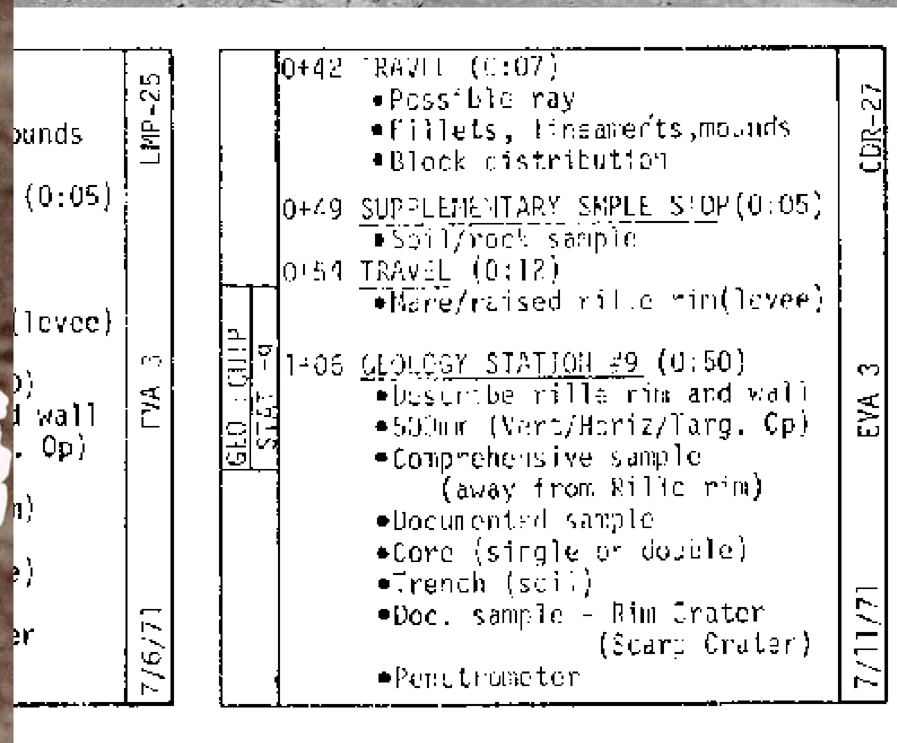
APOLLO GEOLOGIC TRAINING
TRIP PARTICIPATION

APOLLO 15																													
5/70 - Orocopia Mts		X														X													
6/70 - Mojave Desert											X						X												
6/70 - Flagstaff						X					X							X											
7/70 - Flagstaff		X	X	X			X												X										
7/70 - Medicine Hat						X																							
7/70 - Medicine Hat	X					X																							
8/70 - San Juan Mts	X	X					X				X																		
9/70 - Buell Park	X	X	X				X	X			X																		
10/70 - N. Minnesota	X	X			X															X									
11/70 - Flagstaff	X	X	X	X	X																								
11/70 - San Gabriel Mts.	X	X		X	X				X																				
12/70 - Hawaii	X	X	X	X	X			X	X			X	X	X							X	X							
1/71 - Kilbourne Hole	X		X	X				X							X								X						
2/71 - Ubehebe Craters	X			X		X			X	X					X									X	X				
3/71 - Taos	X	X	X		X		X			X		X																	
4/71 - Coso Hills	X	X	X	X	X		X	X	X	X		X	X	X															
5/71 - Nevada Test Site	X	X	X	X	X	X	X	X	X																	X	X		
6/71 - Flagstaff	X									X																		X	X
Number of Trips	**13**	**11**	**8**	**8**	**7**	**5**	**5**	**5**	**5**	**4**	**4**	**3**	**2**	**2**	**2**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Apollo 15 Geology at Station 9: Hadley Rille, Far Wall

Apollo 15 CDR training for surface geologic traverses

Surface procedure cuff checklist for activities at Station 9, Hadley Rille edge



...ounds
(0:05)
(levee)
...)
...d wall
... Op)
...n)
...e)
...er
LMP-25
EVA 3
7/6/71

0+42 TRAVEL (0:07)
•Possible ray
•Fillets, lineaments, mounds
•Block distribution

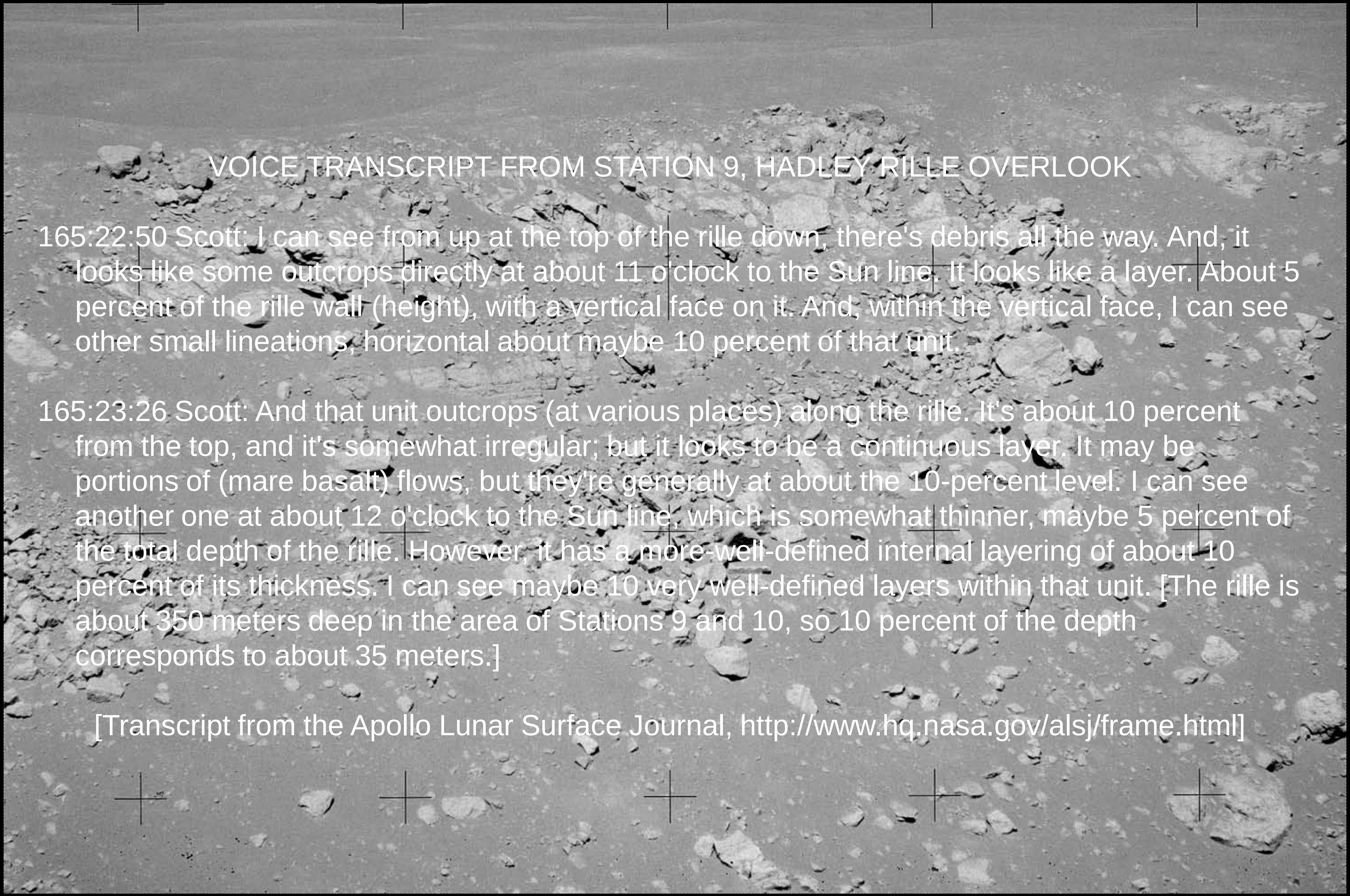
0+49 SUPPLEMENTARY SMPLE STOP (0:05)
•Soil/rock sample

0+54 TRAVEL (0:12)
•Mare/raised rille rim (levee)

1+06 GEOLOGY STATION #9 (0:50)
•Describe rille rim and wall
•500mm (Vert/Horiz/Targ. Op)
•Comprehensive sample
(away from Rille rim)
•Documented sample
•Core (single or double)
•Trench (soil)
•Doc. sample - Rim Crater
(Scarp Crater)
•Penetrometer

GEO EQUIP
STAT 9
CDR-27
EVA 3
7/11/71

Apollo 15 Geology at Station 9: Hadley Rille, Far Wall



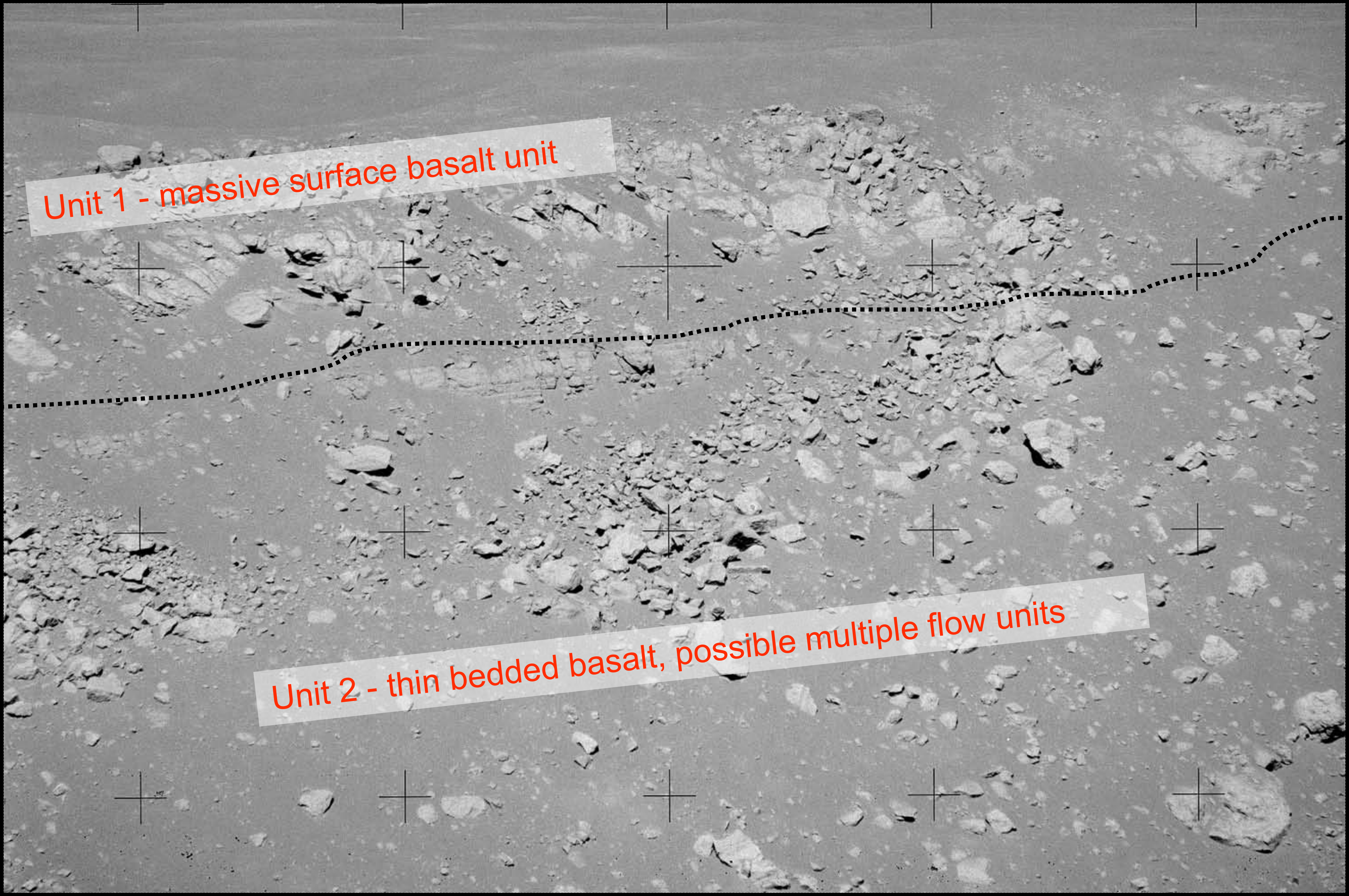
VOICE TRANSCRIPT FROM STATION 9, HADLEY RILLE OVERLOOK

165:22:50 Scott: I can see from up at the top of the rille down, there's debris all the way. And, it looks like some outcrops directly at about 11 o'clock to the Sun line. It looks like a layer. About 5 percent of the rille wall (height), with a vertical face on it. And, within the vertical face, I can see other small lineations, horizontal about maybe 10 percent of that unit.

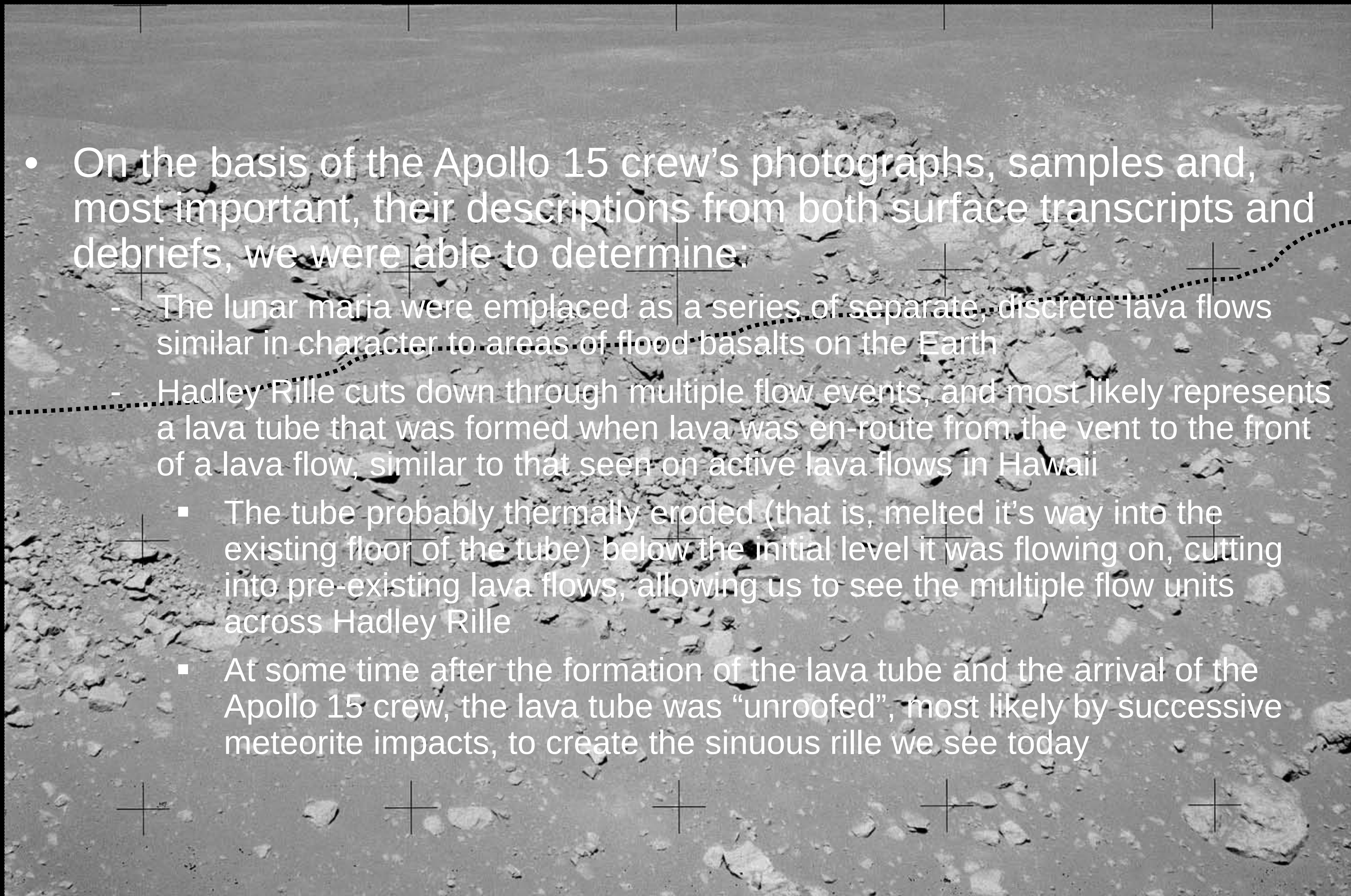
165:23:26 Scott: And that unit outcrops (at various places) along the rille. It's about 10 percent from the top, and it's somewhat irregular; but it looks to be a continuous layer. It may be portions of (mare basalt) flows, but they're generally at about the 10-percent level. I can see another one at about 12 o'clock to the Sun line, which is somewhat thinner, maybe 5 percent of the total depth of the rille. However, it has a more-well-defined internal layering of about 10 percent of its thickness. I can see maybe 10 very well-defined layers within that unit. [The rille is about 350 meters deep in the area of Stations 9 and 10, so 10 percent of the depth corresponds to about 35 meters.]

[Transcript from the Apollo Lunar Surface Journal, http://www.hq.nasa.gov/alsj/frame.html]

Apollo 15 Geology at Station 9: Hadley Rille, Far Wall



Apollo 15 Geology at Station 9: Hadley Rille, Far Wall



- On the basis of the Apollo 15 crew's photographs, samples and, most important, their descriptions from both surface transcripts and debriefs, we were able to determine:
  - The lunar maria were emplaced as a series of separate, discrete lava flows similar in character to areas of flood basalts on the Earth
  - Hadley Rille cuts down through multiple flow events, and most likely represents a lava tube that was formed when lava was en-route from the vent to the front of a lava flow, similar to that seen on active lava flows in Hawaii
    - The tube probably thermally eroded (that is, melted it's way into the existing floor of the tube) below the initial level it was flowing on, cutting into pre-existing lava flows, allowing us to see the multiple flow units across Hadley Rille
    - At some time after the formation of the lava tube and the arrival of the Apollo 15 crew, the lava tube was "unroofed", most likely by successive meteorite impacts, to create the sinuous rille we see today

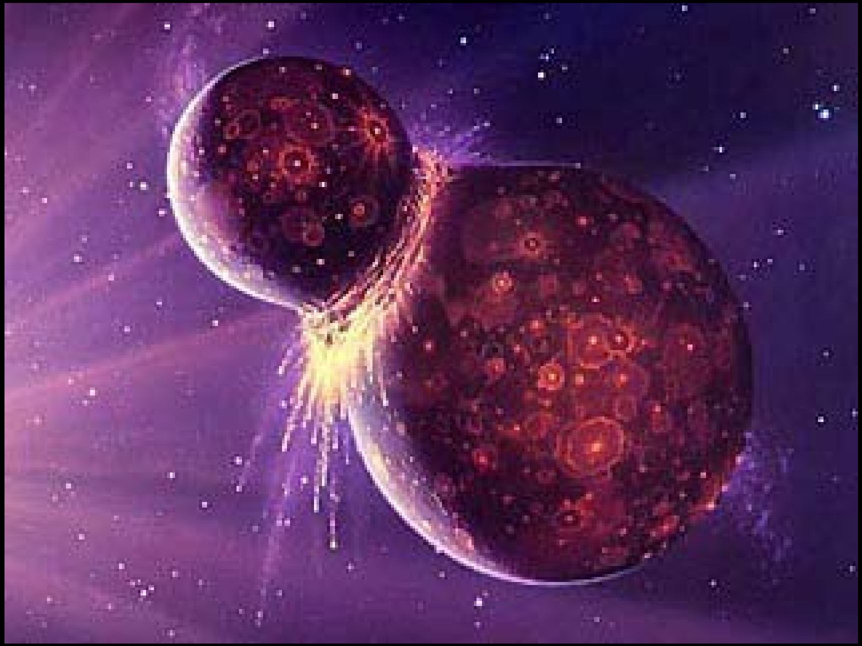
OK, so why should you care?

The Legacy from Apollo's Geologic Investigation of the Moon

The Moon from ISS, Expedition 4

- The Apollo Program landed six missions on the lunar surface
  - All the landing sites were on the front side, largely in the equatorial region
- Everything we knew about the Moon prior to Apollo is pretty much what you see in this picture: an indistinct globe with a largely light colored surface, with patches of darker material and lots of holes in the ground

The Legacy from Apollo's Geologic Investigation of the Moon



Proposed first step in creation of the Earth-Moon system

The Moon is not simply a dust ball collected up from the remnants of solar system formation; it is a geologically complex body that has had a long and complicated history associated with the formation and the first 2 billion years of the solar system

Further, we had the realization that the Earth went through the same history, which was unimaginably more violent than we had ever considered prior to Apollo

The Legacy from Apollo's Geologic Investigation of the Moon


Earthrise, Apollo 10

Prior to Apollo, most scientists thought the Moon had a composition similar to a large meteorite, and that it was a simple body composed of accumulated debris that was swirling around at the beginning of the Solar System…it was not assumed to have any geologic processes, although there was much controversy about whether lunar craters were formed by volcanic or impact processes. In short, the assumption was that this body was accumulated under generally quiescent processes about 4.5 billion years ago, after which nothing happened except the occasional explosion on it's surface.

Apollo showed us that the formation of the Moon and, by inference, the Earth, was extremely violent, involving the creation of huge impact basins (1000s of km across), the melting of the *entire planet* (!) to a depth of several hundred kilometers, and the eruption of significant volumes of lava.

As we have sent spacecraft throughout the Solar System since Apollo, we have learned that the story of the Moon is the story of the Solar System, but the place we first learned that lesson was on the Moon, with geologic discoveries that came from the Apollo Program.

Implications for Future Planetary Geologic Exploration

Descriptive observations in the field are the critical data set in geologic exploration. Everything else (samples, photographs, encounters with bears) is secondary to having access to the rock, with stereoscopic, color vision, a 360° view of the terrain and the ability to see both near and far…to do geology, you must be in the field, going up hill and down dale, in person. Any robotic assistance for geologic sciences must be based on supporting the human in the field making these primary observations…

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

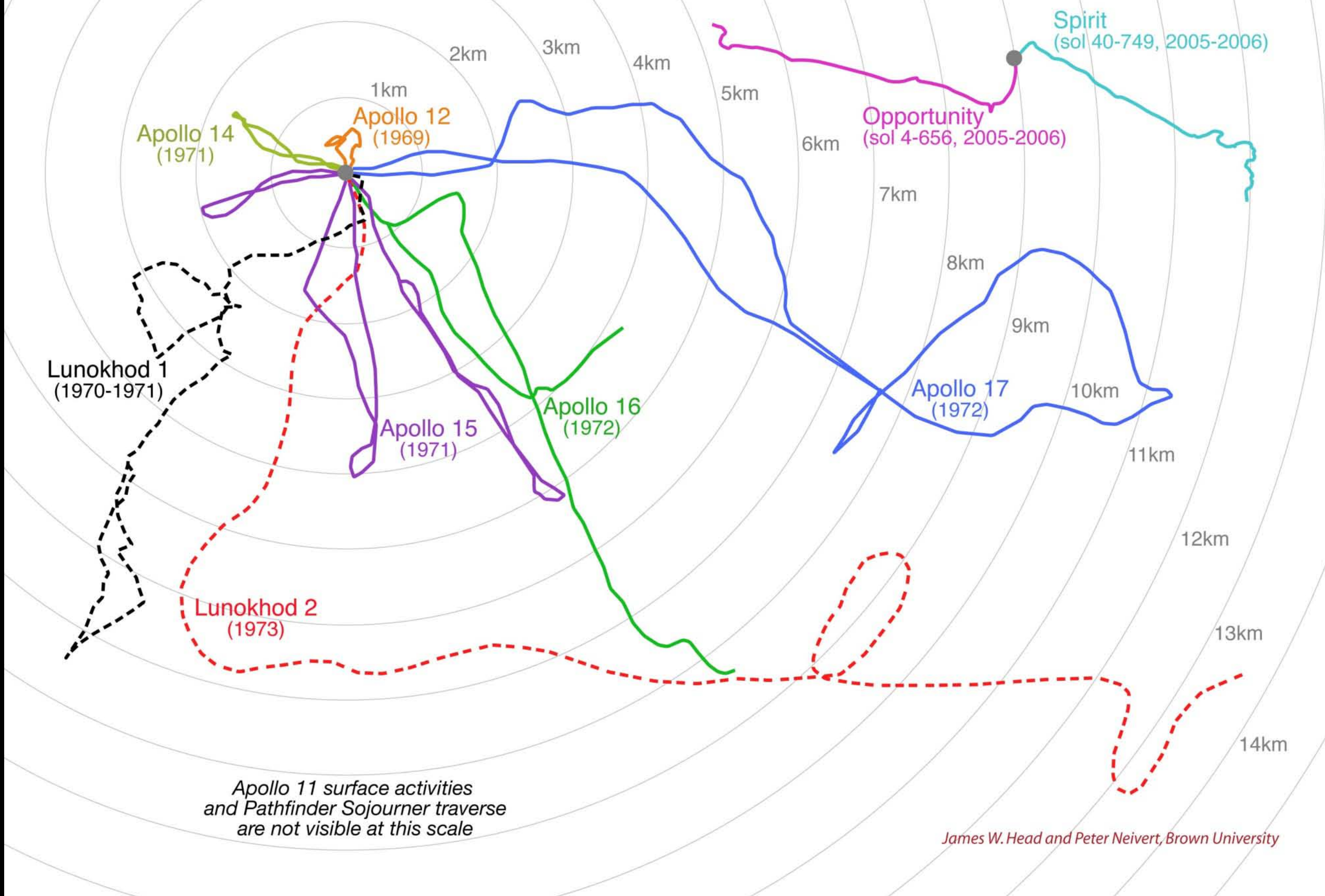
Gordon Ozinski mapping impact melt rocks, Haughton Crater, Devon Island, Canada

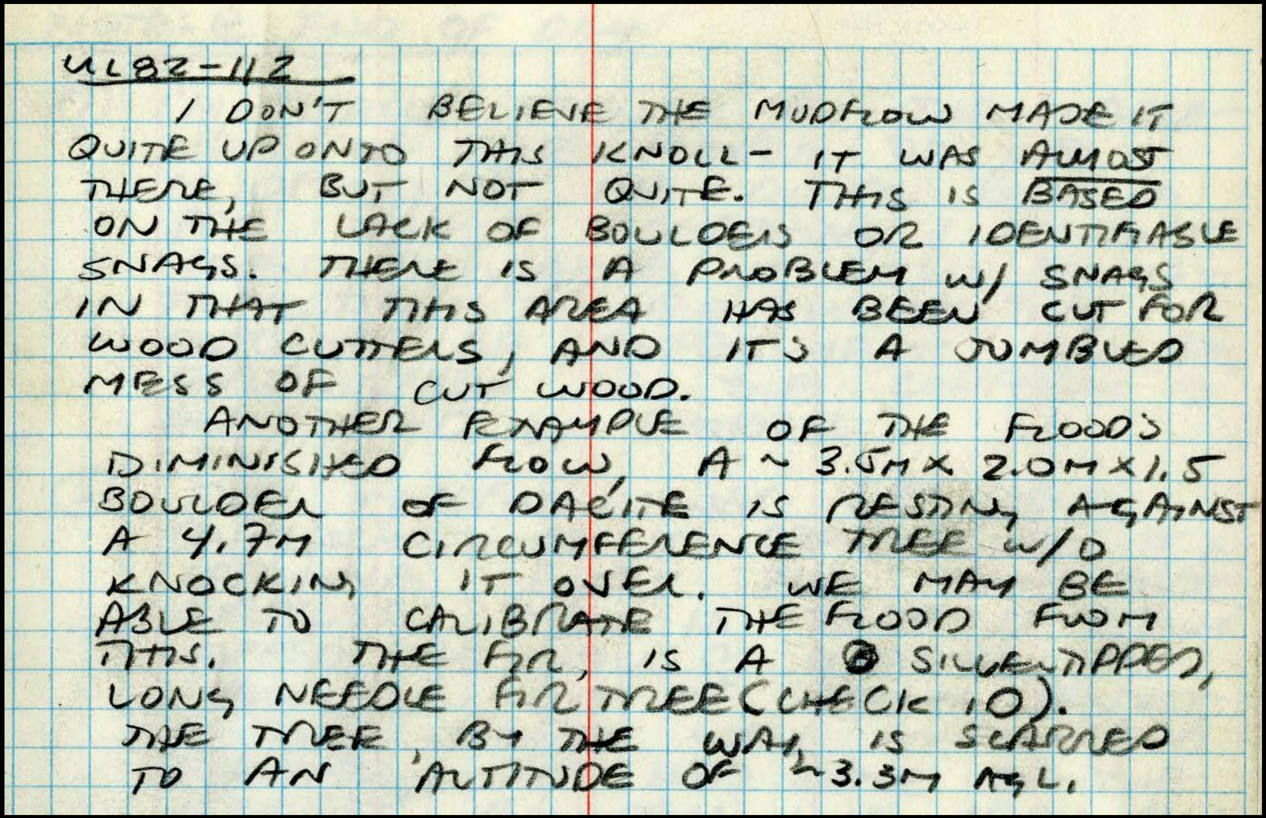
Suits will have to be flexible and rugged enough to bend over, dig holes, walk up hill to the outcrop, bash rocks, collect and stash samples, and look closely at rock specimens.

Robots that support humans in the course of doing field work must be able to go up the hills, over the rocks, everywhere the human goes, at the same speed

JSC Crew & Thermal Systems Division’s robotic tractor assisting in suited field operations, Bar-T-Bar Ranch, Arizona

Lunokhod, Apollo and MER Traverses to Scale





Voice recognition systems must be able to allow crewmembers to record observations like this, without memorized commands or extra equipment that encumbers the crew inside a pressure helmet, and produce electronic transcripts that each crewmember can annotate on days off.

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.

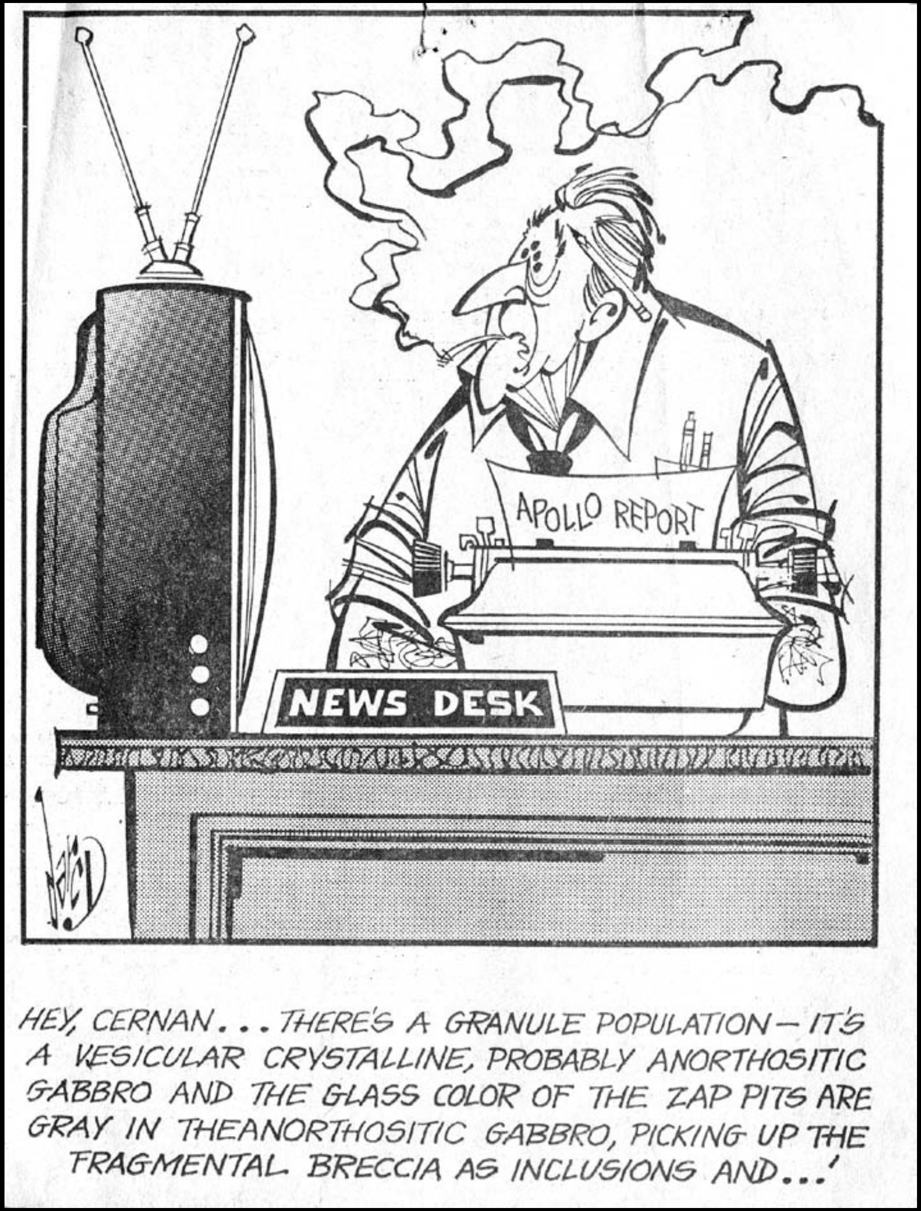
> *[Schmitt - "When I was estimating the percentage of fragments, (the 10 to 15 percent figure) was related only to fragments large enough that they seemed to jump out of the matrix, that were clearly of a larger size than the matrix components. My guess is that the minimum was of the order of a few 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.

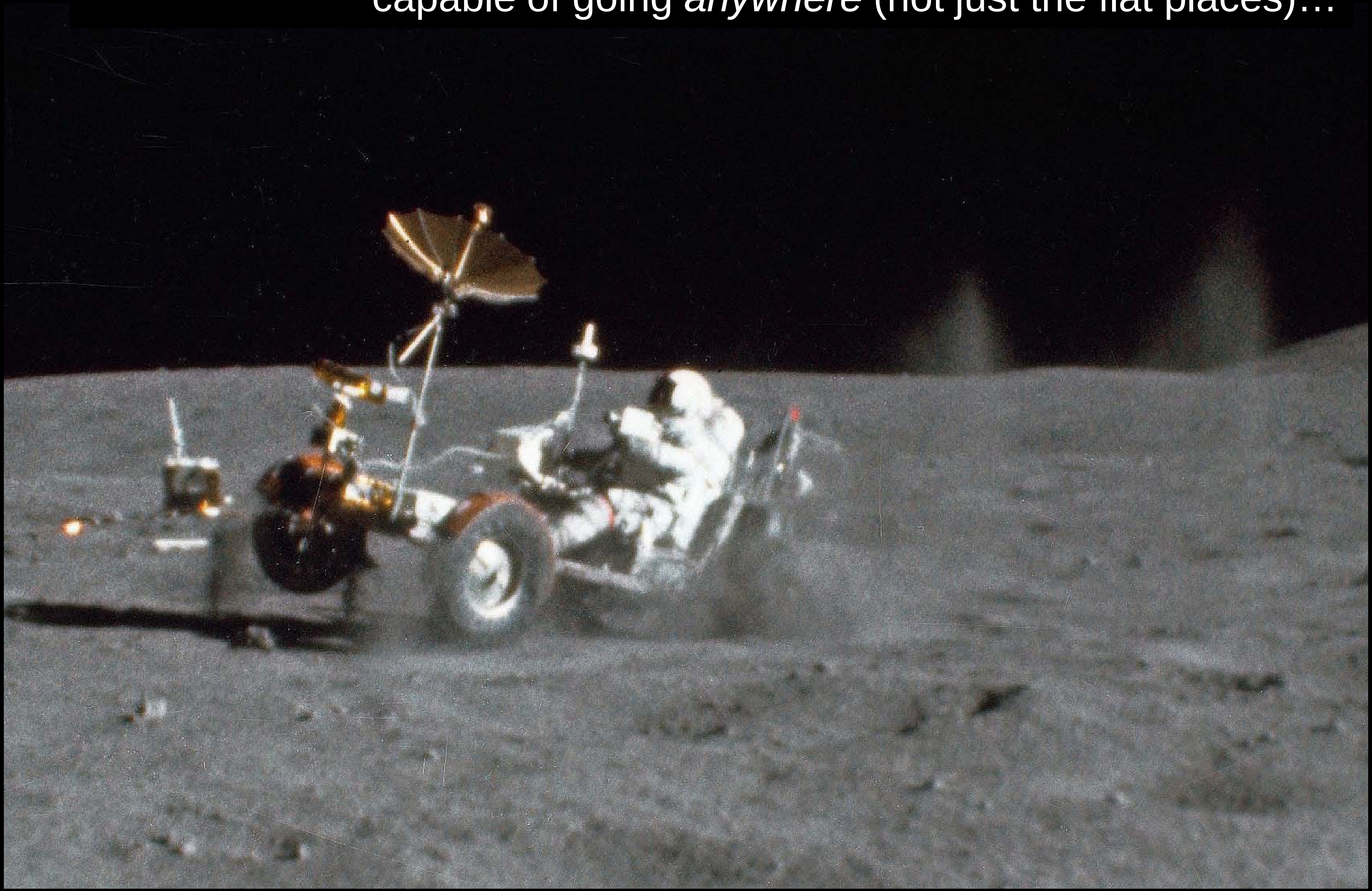
> *[Schmitt - "When the small impacting particles that form the zap pits hit, if there's crystalline rock - particularly plagioclase - at the impact point, then the halos look white. And in this case I'm saying that, because the halos don't look white, the rocks are not coarsely crystalline on the scale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



Of course, you have to be careful who's listening in…

Rovers must be rugged, simple, repairable, easy to operate and capable of going *anywhere* (not just the flat places)…



Apollo 16 Commander John Young putting the Lunar Roving Vehicle through it's paces on the plains at Descartes

CONCLUSIONS

- The primary source of geologic data acquired on the Moon, Mars and other planets will be the collection of geographically-based data on the distribution of rock units and structures, loosely called geologic field work
- Field relations form the basis for interpreting all other data associated with samples and geophysical data
- Understanding field relations is not based on predictable, “regularly scheduled” quantitative measurements
- The distribution of rocks is essentially chaotic, and planning for geologic exploration EVAs has to acknowledge that chaotic nature; we will not be able to choreograph EVAs on the lunar surface like we choreograph a Station construction EVA
- There is no way to create a meaningful “canned” field day…what you do depends entirely on what you find in the field
- The best source for information on how we will do lunar exploration EVAs is the planning and execution data for the Apollo J-mission EVAs

Thanks and Additional Material

This talk benefited greatly from discussions with Paul Spudis, John Gruener, Kent Joosten, and (in times past) Nancy Ann Budden, Steve Hoffman, John Young, Harrison Schmitt and Jay Greene. Any factual or interpretation errors are, however, mine.

There are a lot of sources of historical information about Apollo, not all of which I've read or studied. I list below my favorites, although this is not an exhaustive list. Some of these are out of print, but can be found on Alibris.com or Amazon.com:

- "Apollo, The Race To The Moon," by Charles Murray and Catherine Bly Cox, 1989, Simon & Schuster.
- "Where No Man Has Gone Before: A History of Apollo Lunar Exploration Missions", by William David Compton, NASA SP-4214, 1989.
- "Apollo By The Numbers," by Richard Orloff, NASA SP-2000-4029, 2000, revised 2004.
- "Carrying The Fire: An Astronaut's Journey," by Michael Collins, 1974, Farrar, Straus and Girioux
- "13: The Flight That Failed," by Henry S. F. Cooper, 1973, Dial Press.
- "Apollo On The Moon," by Henry S. F. Cooper, 1969, Dial Press.
- "Moon Rocks," by Henry S. F. Cooper, 1970, Dial Press.
- "A Man On The Moon: The Voyages of the Apollo Astronauts, by Andrew Chaiken, Viking Press
- "The Right Stuff," by Tom Wolfe, 1979, Farrar, Strauss and Giroux
- "U.S. Space Suits," by Kenneth S. Thomas and Harold J. McMahon, 2005, Springer-Praxis.
- "Catalog of Apollo Experiment Operations," by Thomas Sullivan, 1992, NASA RP-1317.
- "Catalog of Apollo Lunar Surface Geologic Sampling Tools and Containers," by Judy Allton, 1989, JSC Publication 23454.
- "The Lunar Sourcebook: A User's Guide To The Moon," by Grant Heiken, David Vanman and Bevan French, 1991, Cambridge University Press.
- "On The Moon: The Apollo Journals," by Grant Heiken and Eric Jones, 2007, Springer-Praxis.
- "The Apollo Lunar Surface Journal," by Eric Jones et. al., http://www.nasa.gov/alsj/frame.html.
- "The Apollo Flight Journal," by David Woods, et. al., http://www.nasa.gov/afj/.

Apollo 13 Rollout

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Earthrise over Mare Smythii, courtesy of the Apollo 8 crew

In Memoriam
Professor R. P. “Bob” Sharp
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