EXPLORATION SPACE SUIT ARCHITECTURE AND CRITICAL SCIENCE OPERATIONS FOR MARS

Presented to the Workshop on Planetary Protection Knowledge Gaps for Human Extraterrestrial Missions

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Questions Addressed

- What is geology?
- How do you do field geology?
- Why is it a critical science operation?
- Why can't robots just do the geology?
- What does a planetary walking suit look like?
- Can suited astronauts do geology?
- From where and how much does the suit leak?

What Geology Isn't

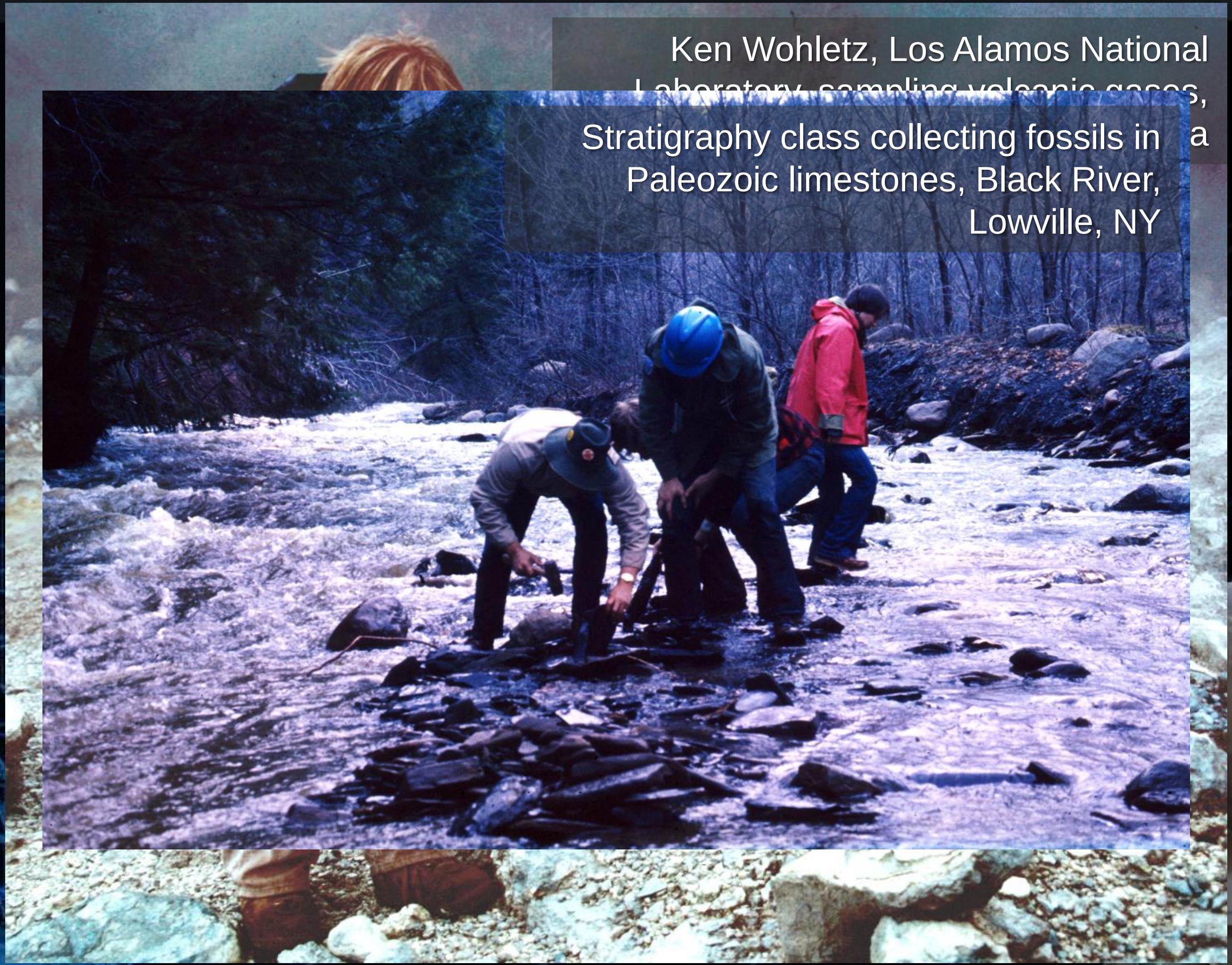
- First, some misconceptions we have to deal with up front:
  - Collecting samples is doing field geology
  - Sample analysis is the most important part of doing geology
  - Geologists go in the field solely to make quantitative measurements on rocks
  - Field geologists work on measurement precision scales of millimeters or less
  - 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 planetary surfaces unambiguously, making geologic field work unnecessary

Each of these statements is wrong

Sample Collection

- An important of doing field geology, but it augments the understanding achieved by field observations.
- Without that field context, you cannot interpret geochemical or geophysical data.
- 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

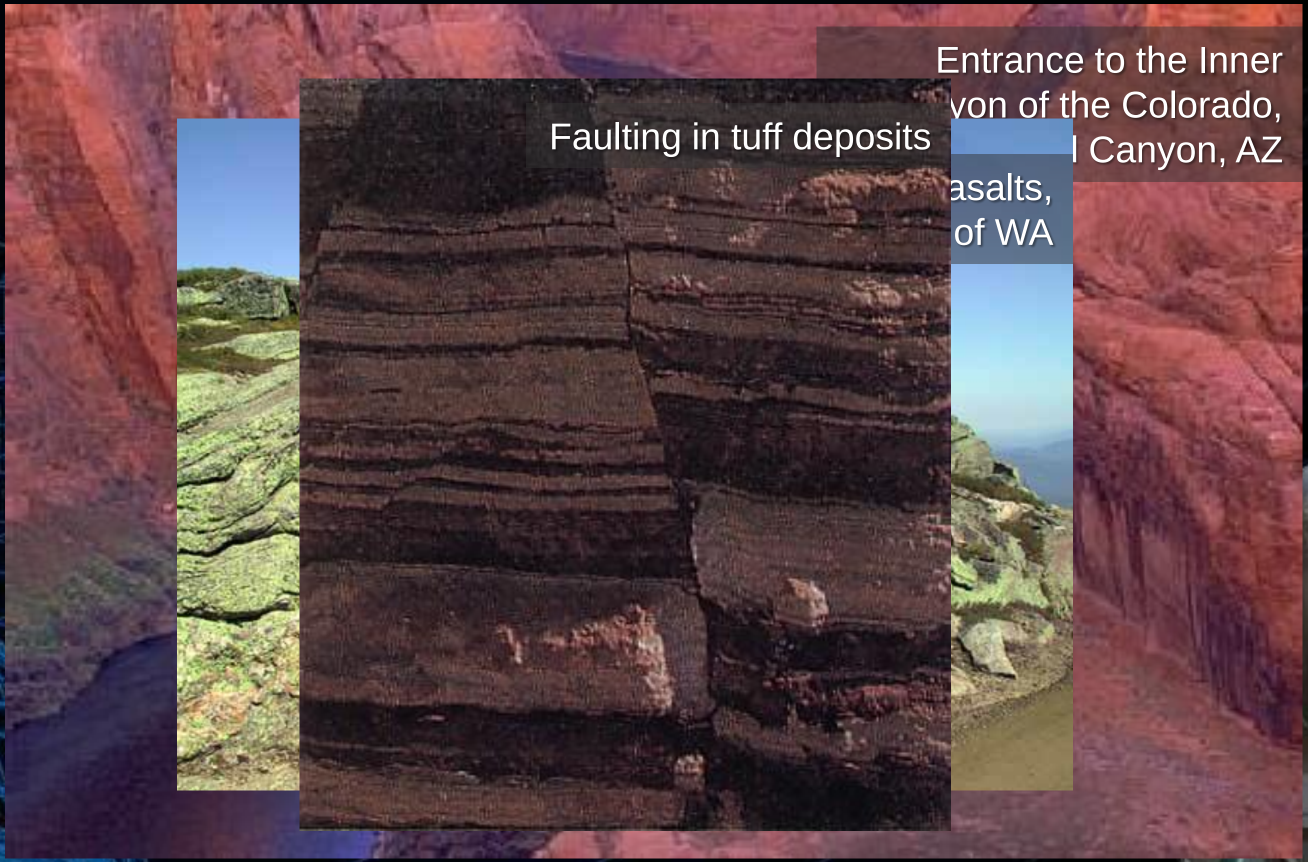


What Geology Is

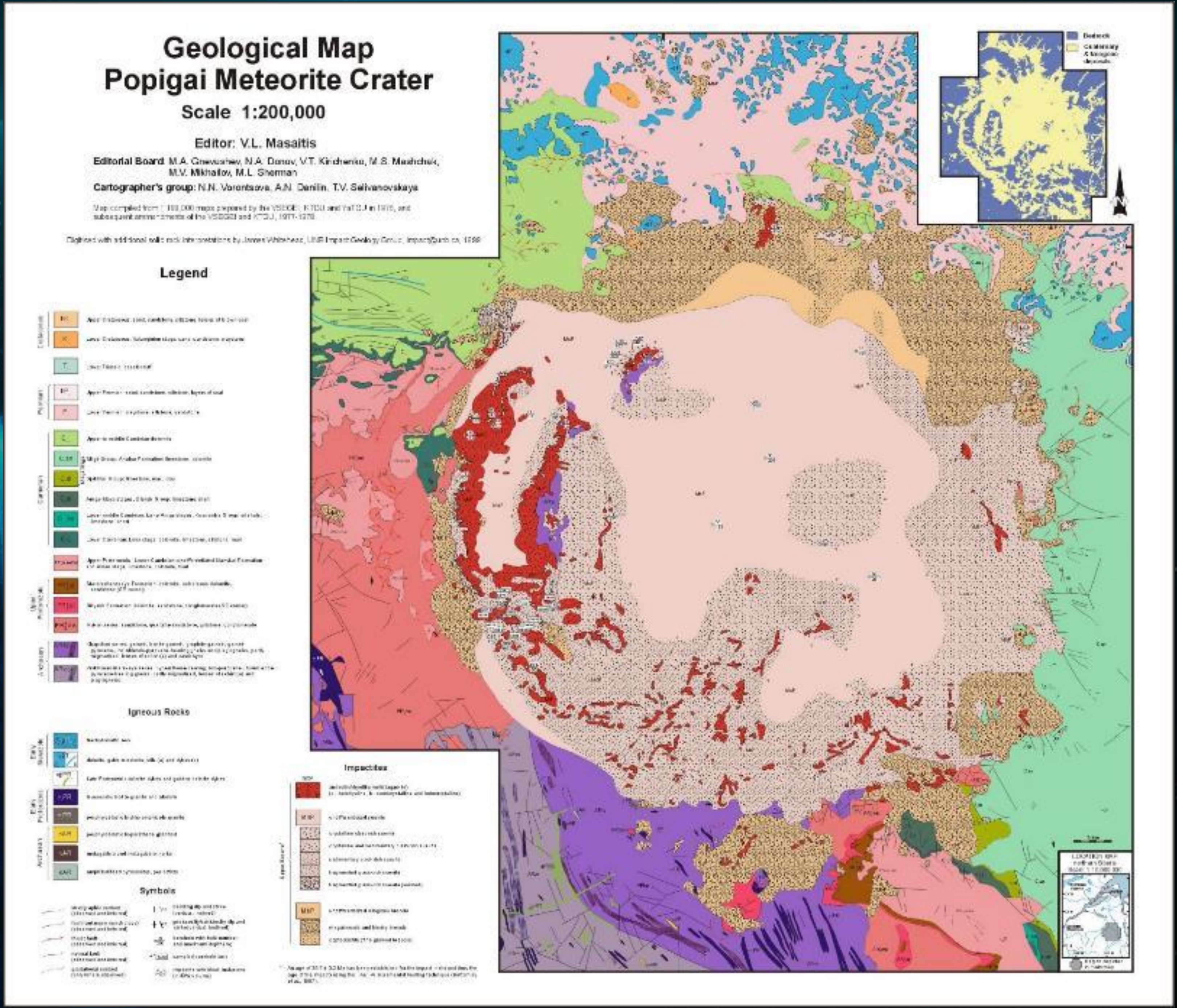
- Geologic field work can be loosely defined as the body of work necessary to:
  - Determine the spatial distribution, age and attitude of the rock types within an area
  - Document those structures that have deformed or cut those units
  - Determine the processes that led to the emplacement of these rocks, and have subsequently modified them

Geology Is…

- 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
  - Geologists collect a variety of data in the field, but it starts with
    - The structures and the forces that deform them
    - The structures and forces that break them

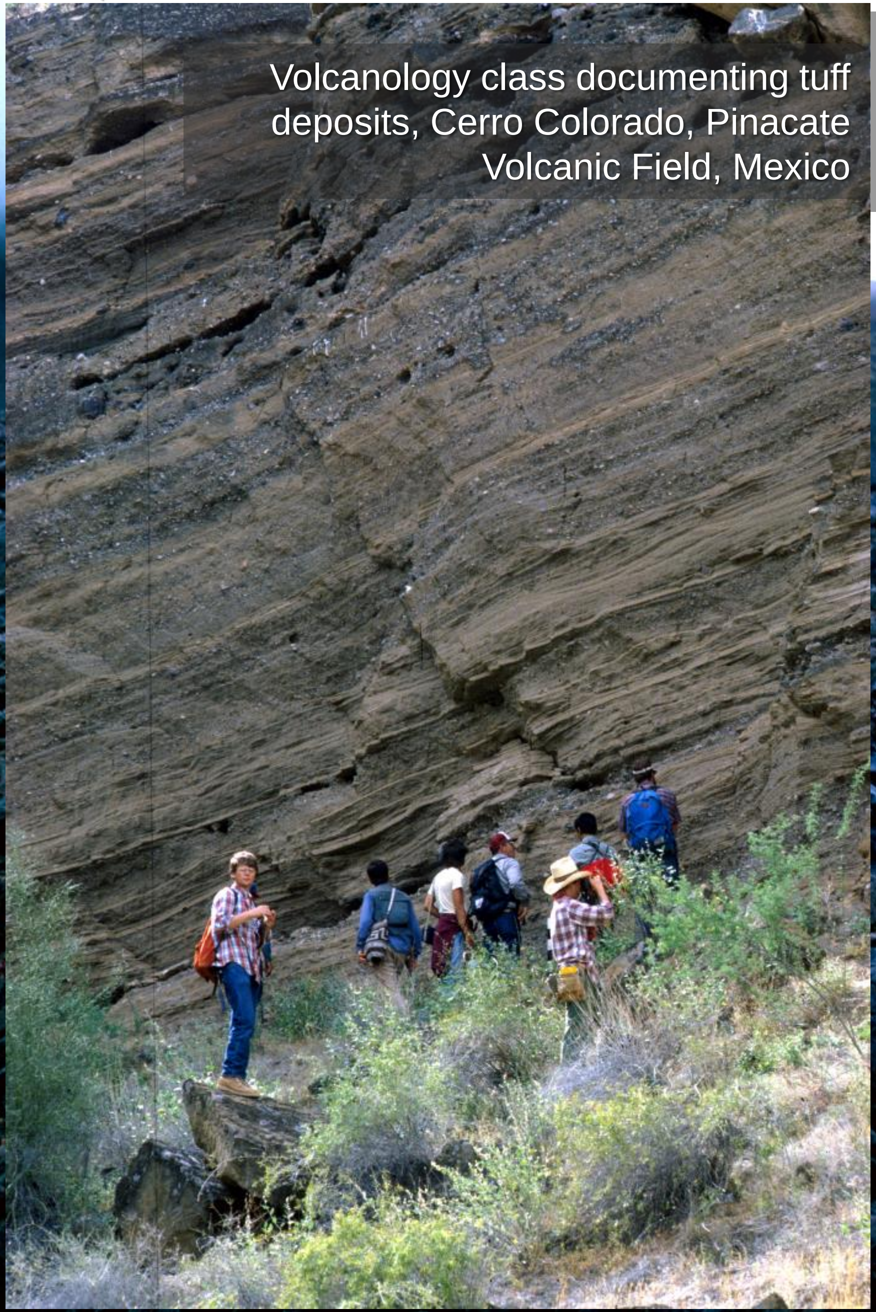


This allows development of a geologic map, which is the first order output from geologic field studies and the basic tool for understanding geologic problems.



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 either a pickup truck or a pressurized rover.
- **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

n Crater, Canada

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

OK, So How Do You Do This?

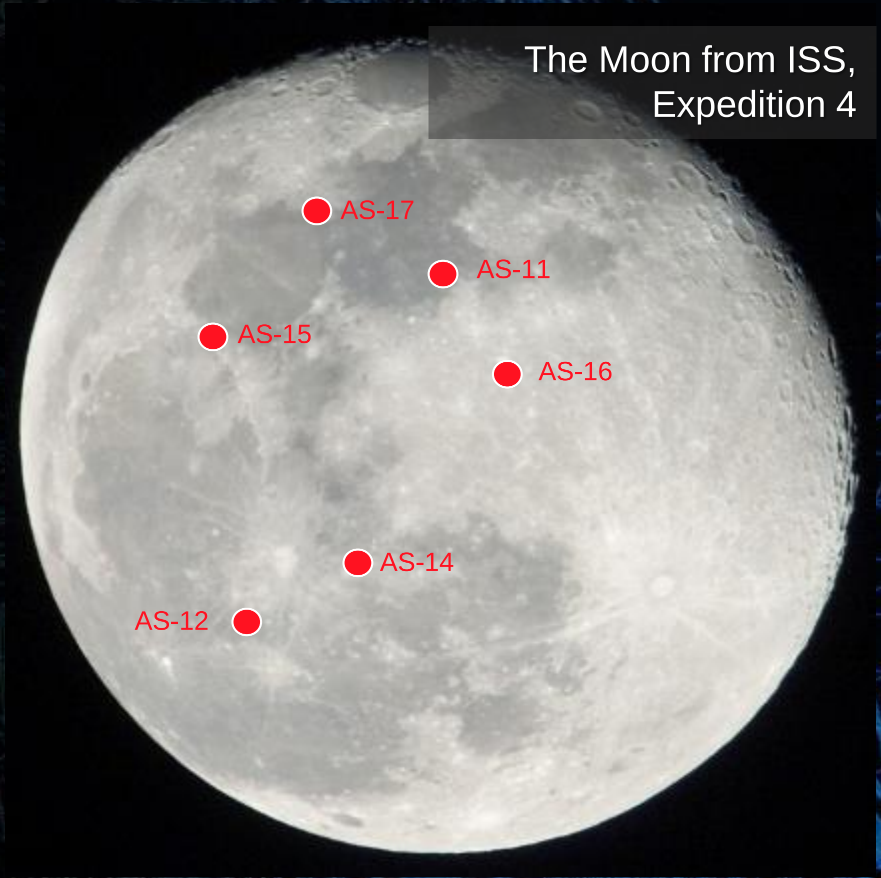
- **Third**, you have to be able to observe and describe, in detail, what you are seeing in the outcrop, and you have to be able to record that data in some fashion.

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

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

Why Geology is a Critical Science Operation

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, interspersed with patches of darker material and lots of holes in the ground

The Legacy from Apollo's Geologic Investigation of the Moon

- Prior to Apollo, most scientists thought that the Moon was a simple body composed of debris that was passively accumulated …it was not assumed to have any geologic processes of note, 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 surface explosion.

- Apollo showed us that the formation of the Moon and, by inference, the Earth, was extremely violent, involving whacking Mars- and Earth-size planets together, the creation of huge impact basins (1000s of km across), the melting of the planet to a depth of several hundred kilometers (!), and the eruption of significant volumes of basaltic 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…the place we first learned that story was on the Moon, with geologic discoveries that came from

Earthrise, Apollo 10

Why Humans?

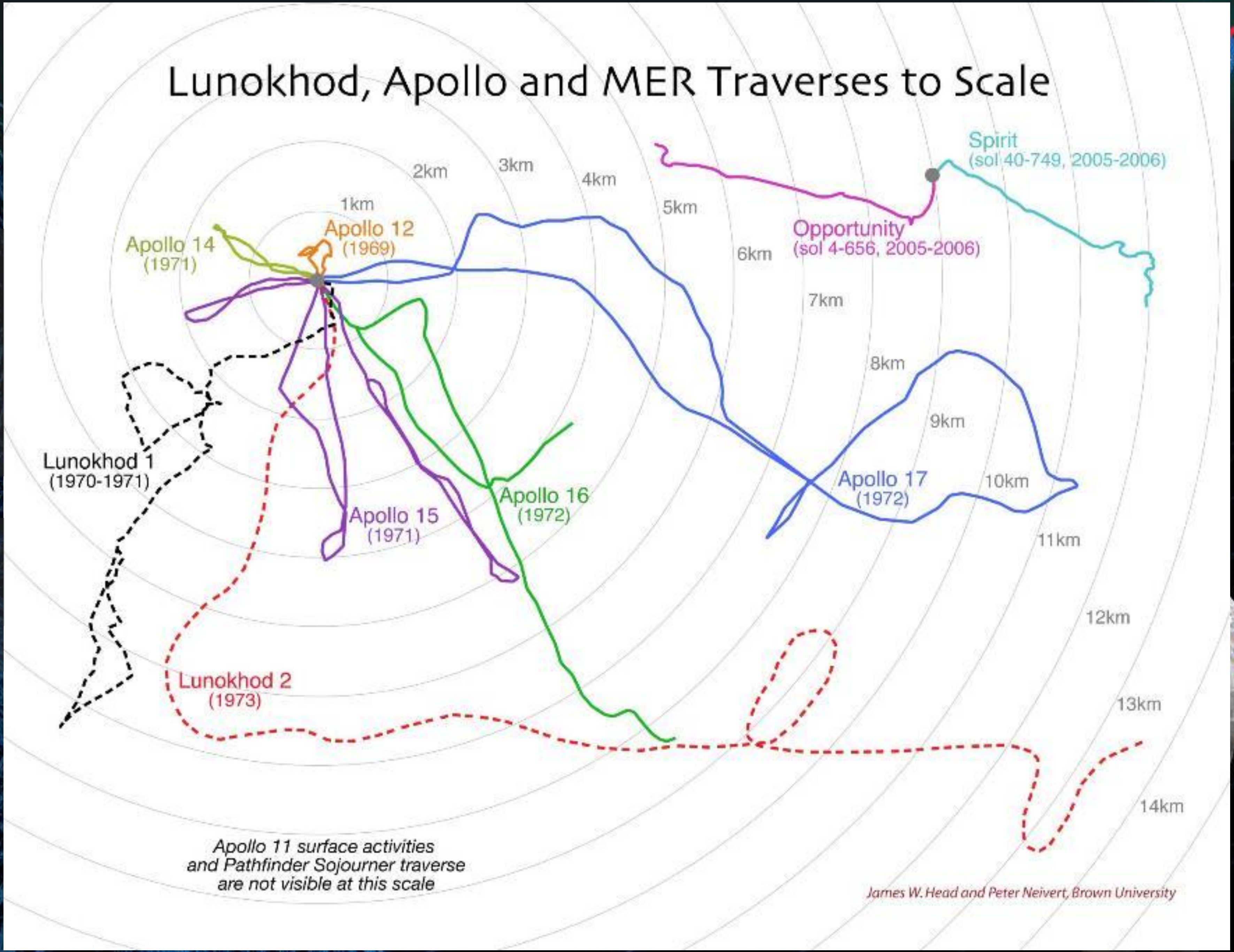
To compare statistics:

At the end of 3,042 days on Mars, the Opportunity Rover had driven:

21.4 miles

At the end of 3 days on the Moon, the Apollo 17 crew had driven:

21.6 miles



Basics: Why Do You Need an EVA Suit?

Space Suits Provide 3 Basic Functions For EVA Astronauts:

1 **First, in conjunction with a portable life support system, the space suit maintains the physiological well-being of the astronaut**

- Supplying oxygen for pressurization, breathing, and ventilation
- Provide carbon dioxide and metabolic heat removal

2 **Secondly, the space suit incorporates various mobility joint systems to enable the astronaut to perform EVA tasks in the pressurized condition**

- Includes both dual-axis and single axis joints and bearings

3 **Finally, the space suit provides protection against the hazards of the particular EVA environment**

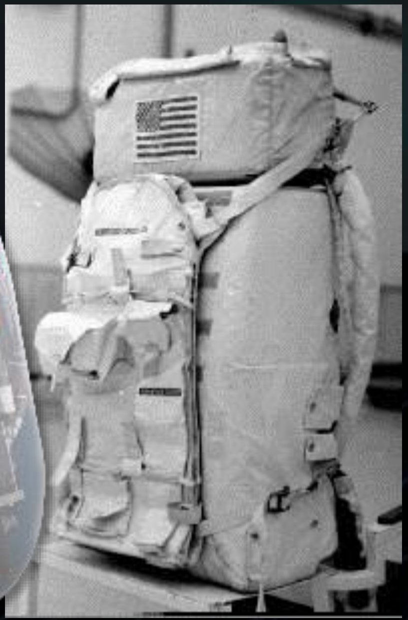
- Thermal extremes
- Meteoroid and orbital debris
- Radiation conditions
- Abrasion and sharp edges
- Sand, dust, and rocks

In essence, the space suit is a small spacecraft in itself

What Does a Planetary Walking Suit Look Like?

- A space suit consists of two main components: a pressure garment that covers your body and a life support system that can be worn on your back

- Pressure garments are what we typically think of as a “space suit”, while the PLSS is that ill-defined box nobody pays much attention to…except, of course, if you’ re in the pressure garment…



What Does a Planetary Walking Suit Look Like?

- Rear-entry
- Helmet angled and shaped for wide field view, including downward visibility
- Hard or soft torso, briefs and hip
- Waist bearing and flexion/extension joints
- Hip mobility joint system with 2 or more bearings and features for adduction/abduction
- Softgood arms and knees
- Walking boots with an ankle flexion/extension joint and ankle bearing
- Environmental protection garment that addresses dust,
  - Durability with UV radiation exposure, thermal protection in a
  - Low atmospheric pressure,
  - Durability with exposure to products of chemical reactions
- Could include a suitport interface plate (SIP)

What Does a Planetary Walking Suit Look Like?

Can Suited Astronauts Do Geology?

Suits will 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.

Suited Subjects Performing Geology Tasks

Suited Subjects Performed Traverses Over Rough Terrain

Suited Subjects "Searched for Life" Using Lab-on-a-Chip Development (LOCAD) Hardware

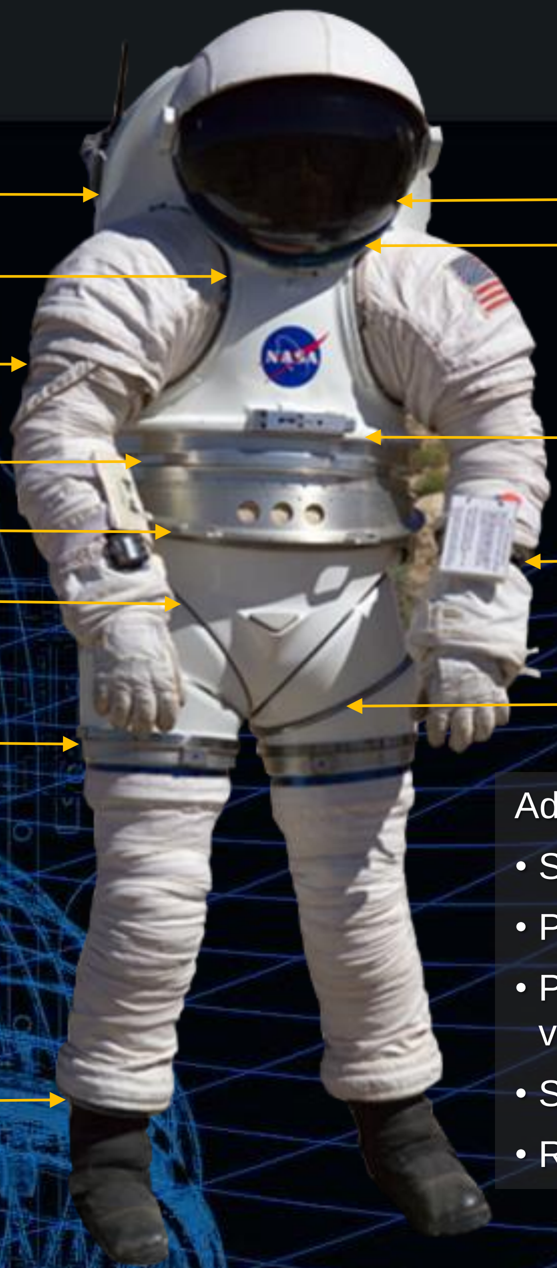
Subjects Performed Traverses Incorporating Various Styles of Rover Vehicles


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
4

Places Pressure Garments Can Leak

- Bearings
  - lip seals
- Hardgoods to hardgoods interfaces
  - o-rings, gaskets, lip seals
  - Sizing elements, joint assemblies to torso or brief, disconnects (e.g. helmet, hatch, gloves)
- Softgoods to hardgoods interfaces
  - o-rings, compression features, compression
  - Ex: lower arm softgoods to suit-side wrist disconnect
- The Mark III has 50 potential leakage path areas

Places Pressure Garments Can Leak



Additional suit leakage paths include:

- Sizing ring interfaces
- PLSS cooling loops (water)
- PLSS ventilation loop (swing bed vents water, CO2, +)
- Suit purge valve (off-nominal)
- Relief valves (off-nominal

How Much Do Space Suits Leak?

- ISS Suit leakage specification:
  - 99.3 sccm O2 (ground test)/35 sccm O2 (EVA cnditions)
    - 104.1 sccm air (ground test)
    - For a 4.3 psi suit
- Leakage is based on seal run length.
- Exploration suits have approximately twice the seal run length due to the rear-entry hatch, additional mobility features, and higher operating pressures for some portion of the EVA.
- The goal is to minimize leakage to minimize PLSS size; however, there is a practicable limit.
  - Suits will leak.
  - Leakage will likely increase over useful life.

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BACK-UP

Human Exploration of Mars, with Robots

- Humans, in space suits, out on planetary surfaces, will be a critical component in any future planetary surface exploration mission set
  - Humans can move faster, see more, and handle the unexpected better than robotic explorers
- Robotic explorers will also be a critical component of planetary surface exploration
  - Robots are more precise, better able to handle repetitive tasks and, for planetary protection considerations, cleaner than humans
- These systems provide both conundrums and solutions for planetary protection problems associated with human planetary exploration

Space Suit Design Requirements and Considerations

- All space suit systems (i.e., pressure garment and life support system) have a relatively simple set of physiological/mechanical constraints they operate with:
  - Humans have to breathe O2 constantly at a partial pressure of ≈3 psi
  - Humans generate, and must get rid of excess heat
  - Humans generate, and must get rid of CO2 and other trace gasses
  - Humans shed skin cells, hair, viruses, microbes and other unmentionables which become suspended in the internal suit environment
  - Humans live in a pressurized environment which must remain fairly stable across their entire body surface
  - Human joints and appendages have specific kinetics and ranges of motion
  - Pressurized volumes created out of soft goods, when pressurized, will tend to assume a particular shape and volume and will be hard to move out of those stable shapes
  - Metal parts do not change shape when pressurized, but they weigh considerably more than soft goods, and the join between metal and soft good becomes a potential leak path
  - All pressure systems leak, at some rate which can be defined in the design requirements but not reduced to zero
  - Complex mechanical devices in constant use require maintenance, and will eventually break and need repair
- A space suit, in addition to satisfying all these constraints, has to allow the crewmember to do their primary job while being worn, or what’s the point…

Representative Space Suit System Potential Leakage Path Areas

- Based on modular constructed suit assembly for logistics interchangeability and commonality of components (represented by planetary prototype NASA-JSC MK III advanced technology suit)
- Identified ≈50 separate potential leakage path areas represented by static seals, dynamic seals, and connector hardware pass-thru locations.
    - Does not take into consideration all individual gas bladder pattern heat sealed or adhesively bonded seams or natural permeation characteristics of the bladder material based on wear and abrasion

- The potential suit leakage path areas include:
    - Helmet to neckring
    - Neckring to hard upper torso
    - Rear hatch to hard upper torso
    - Shoulder joints to hard upper torso (2)
    - Shoulder bearings (2)
    - Upper arm bearings (2)
    - Upper arm sizing elements to elbow joints (2)
    - Lower arm sizing elements to elbow joints (2)
    - Wrist disconnects to lower arm sizing elements (2)
    - Glove disconnects w/bearings to wrist disconnects (2)
    - Glove assemblies flange-mounted to glove disconnects (2)
    - Waist ring to hard upper torso
    - Waist Bearing
    - Waist ring rolling convolute joint to brief element
    - Upper hip bearings to brief element (2)
    - Upper hip bearings (2)
    - Mid-hip bearings (2)
    - Lower hip bearings (2)
    - Lower hip bearings to abduction/adduction ring (2)
    - Abduction/adduction ring to upper leg sizing (2)
    - Upper leg sizing elements to knee joints (2)
    - Lower leg sizing elements to knee joints (2)
    - Lower leg sizing elements to ankle bearings (2)
    - Ankle bearings (2)
    - Ankle bearings to boot flange interface (2)
    - Boot flange interface to boots (2)

Given the above information, the robustness of the MK III suit is representative of the fact that after ~950 hrs. of pressurized use over the past 17 years, total leakage rates are on the order of 1,500 – 2000 sccm/min. after normal 40-hr. maintenance periods

Desert RATS

Between 1997 and 2011, the Crew and Thermal Systems Division at JSC, led by Joe Kosmo, Amy Ross and Barb Janoiko, conducted annual forays to Flagstaff, AZ, to test suits, robots, information systems and field tools in preparation for human exploration missions

The purpose of these exercises was extremely varied, but in general considered human-centered, external operations for exploration

- Suits/PLSSs
  - Mobility and dexterity testing of experimental suit systems
  - Carry ergonomics of suit/backpack systems
  - Suited interfaces with surface mobility systems and EVA tools
  - In-suit, "extra-habitat" recharge of life support systems
- Tools
  - Basic geologic exploration and mobility tools
  - Analytical equipment
- Science operations control and planning
- Manned rovers
  - Ergonomics and human factors
  - On-rover recharge of life support systems
- Robotic rovers
  - Human crewmember control of robotic rovers
  - Use of robotic rovers as assistants for human crewmembers
- Information systems
  - Use of helmet and suit mounted information systems
  - Display and use of geographic/topographic information

Eppler's Take-Away History Message

- Mobility is essential for both efficiency and metabolic, as well as mental stress
  - It buys you time on the surface because metabolic rates are considerably lower than walking
  - It buys you easy cargo carrying capability, because there is no easy way, at least that Apollo or Desert RATS has discovered, to manage hardware and sample carry on a long walk in a space suit
  - It buys you crew "attention span" because they are not exhausted from fighting the pressure garment and devote more brain power to making geologic observations
- Walking EVAs are of limited benefit in geologically interesting, but physically challenging terrain
  - It would be an interesting exercise to get a sense of how much better AS-14 science would have been with an LRV
- Continuous, rigorous, regular geologic field training is a must for the crew
  - We are sending crews to the lunar surface to do science – if we're not ready and willing to train them to at least the same level as the Apollo J-mission crews, then send a robot – it's cheaper and less risky
- The science approach must permeate the mission, from T=0 until the samples are back on Earth, and it must be a community effort
  - The quality of science return on Apollo came about because everyone took it seriously and put personal views aside when it came to running the mission

Planetary Protection Strategies for EVA

Planetary Protection Considerations for Advanced Planetary EVA System Design

- Identify potential contaminants and pathways for AEVA systems with respect to forward and backward contamination
- Identify plausible mitigation alternatives and obstacles for pertinent missions
- Identify topics that require further research and technology development and discuss development strategies with uncertain PP requirements
- Identify PP requirements that impose the greatest mission/development cost
- Identify PP requirements/topics that require further definition

Conclusion:
Overall EVA Systems PP Recommendations

- Define specific surface task activities that would require the implementation of appropriate PP measures
- Describe and define the potential physical (chemical or biological) impacts that the identified suit/PLSS vent/leakage constituents would have in regard towards PP “forward” contamination concerns
- Determine what levels of PP back-contamination control are possible or needed for EVA systems; suits, PLSS, airlocks, rovers
- Determine what effect would the natural Martian environment (UV, radiation, thermal, pressure) have towards “natural mitigation” of potential Earth-based contaminants

Planetary Protection Plausible Mitigation Alternatives and Obstacles - Managing Contamination From Humans in Suits, Backwards and Forwards

- Minimize surface contact area of initial human-EVA supported activities:
  - Use robotic precursors (tele-operated or autonomous mode) to scout & survey intended EVA worksite locations and potential science way-point stations prior to human intervention
    - Obstacle – We may be the cost & time overhead associated with robotic vehicle operation; also, there are limitations associated with robotic vehicles as such (lack of real-time decision making, intuition and judgment)
- Identify “safe” and “no-go” zones adjacent to and within x-radius distance of lander/habitat location for method of control for human-EVA supported traffic
  - Obstacle – We may not be able to totally exclude “chance encounter” with “oasis-of-life; also potentially restrictive for critical surface operations (location of ISRU plant or power-plant distribution elements)
- Reduce or eliminate EVA-system element contamination sources
  - Vent gases, leakages, trace chemical contaminants, material abrasion, etc.
    - Obstacle – This may not totally practical; through normal use and wear conditions over time, all potential contamination sources will increase and accumulate; this is also a real restriction on life support technology choices

Planetary Protection Plausible Mitigation Alternatives and Obstacles - Managing Contamination From Humans in Suits, Backwards and Forwards (cont.)

- Screen, identify and catalog all Earth-based "signature" materials associated with EVA-system elements in order to recognize against potential "alien" life-bearing materials:
  - Develop "Contamination Materials Reference Guideline"
    - Obstacle – Time and cost maybe excessively prohibitive; also, we may not fully capture all associated materials and constituents
- To potentially mitigate "backward" PP contamination, quarantine, isolate or discard all EVA surface-exposed hardware items (other than scientific samples) at habitat base-site as a "non-return" to Earth policy:
  - Provide "peel-off layer" over portions of suit to remove/discard prior to airlock entry
  - "Decontaminate" EVA hardware items prior to airlock entry
    - Obstacle – We need to assess logistics and costs associated with "throw-away" versus "re-use" philosophy

PP Requirements Imposing Greatest EVA Mission/Development Costs

- Definition of “design-to” requirements is critical to understanding costs
  - We have a pretty good idea of what we vent, and how much…what we don’t know is what is acceptable and what isn’t…
- The definition of “PP” needs in relation to how it impacts EVA mission & system element development costs should be considered and interpreted as follows:
  - Since EVA operations will have the most direct (wide spread) physical interaction with the Martian surface on a daily/weekly routine basis, “PP” needs should be considered in the following terms to mitigate hardware & operations costs:

"Plausible Protection" Criteria

- Identify, quantify and catalog all potential EVA system contamination sources
- Implement reasonable preventative measures (by combination of design and procedures) to reduce contamination sources that would be technically feasible and non-cost prohibitive
- Screen and manage the contamination stream
- Eliminate any unknown constituents – (Given the intimate human interactions with suit systems and atmosphere, and the complexity and variability of the source of contaminants, this may not be practical at a level that will protect science objectives; it is not an unreasonable suggestion that dominant contaminants in an Earth life signature may be a top priority signature to weed out in a search for Mars life)

Specific Questions Regarding Planetary Protection

- Will interplanetary disposal during transit be allowed, and what conditions will be imposed?
- Will any waste be allowed to be stored or disposed of on/below the surface if adequately contained? If so, what level of containment would be sufficient? What would be the necessary characteristics of the waste? How long will containment need to be assured? What level of certainty is required (e.g., <10-4)? Does the state of the waste need to be rendered so as to preclude serving as a substrate for biological growth (i.e., mineralized)? Will wastes be allowed to remain in the surface habitat after mission completion (or do they need to be contained on the surface or returned home)?
- Will there be constraints as to what will be allowed to be returned to Earth (i.e., potential for back-contamination)? The inside of the returning spacecraft (?) may be contaminated to some degree from EVA interchange. This material will enter the solid, liquid and gas streams through various means. Therefore, how do we return home?
- Determine how internal habitat ALS technologies might affect the potential for planetary surface contamination (e.g., increased bio-loads on suits and equipment, venting gases/liquids/particulates to planetary atmosphere via airlocks) Also – venting as a potential part of the ALS systems – e.g. CO2 (and contaminants) from a regenerable CO2 removal system like CDRA or swing bed, methane from a Sabatier system, “burp” gases from a carbon formation reactor etc. – not directly EVA contaminants, but certainly a factor to be considered in assessing what limits and controls are appropriate for EVA.

Specific Questions Regarding Planetary Protection

- How "clean" do we need to be inside in order to support external PP requirements? Will ALS be involved with cleaning issues, or will someone else be tasked with that? Will ALS need to handle cleaning by-products?
- Are there special measures that should be taken to avoid the propagation of extraterrestrial organisms in ALS systems? For example, if waste is stored "as-is", the waste could serve as a growth medium (if contaminated). The same is true for biological processors for waste, water and air.
- What extent of gas venting (from habitats) will be allowed? What compounds will be allowed/excluded? Will particulate (microbial, organic, inorganic) control be necessary?
- Determine similar restrictions and requirements to be placed on human extravehicular activity (EVA) systems
- Determine restrictions and/or required procedures to be emplaced for human activities and systems for use outside the habitat, particularly with respect to:
  - Subsurface access
  - Use and/or distribution of fluids outside the habitat
  - Planned or unplanned biological experiments or releases
- Determine what types of monitoring systems, procedures and equipment are necessary to assist in PP policy implementation and verification of compliance. This includes issues regarding contamination of the planetary surface, habitat contamination and return of spacecraft and samples to Earth.