Lunar Dust: Characterization and Mitigation

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Outline

- Definitions
- Framework for Lunar Exploration
- Regolith Management Strategy
- Dust Management Project
  - Technology Development
  - Engineering Design Environments
    - Lunar Regolith / Simulant Dependencies
    - Apollo Engineering Forensics
- Summary
- Acknowledgments

Useful Definitions

- ***Regolith***: General term for the mantle of loose, incoherent, or unconsolidated rock material, of whatever origin, size or character, that nearly everywhere forms the surface of rocky planetary bodies
  - Definition adapted from the Glossary of Geology, 1972
  - Most lunar regolith is formed by hypervelocity impacts
  - Lunar regolith is spatially very heterogeneous in composition and particle size distribution compared to terrestrial regolith
- ***Lunar Regolith Simulant***: Synthetic analogue that approximates, to a known extent, one or more regolith properties at a particular lunar location or region
- ***Dust***: An informal term - regulatory definitions for “dust” related health concerns set for particle sizes smaller than 10µm & 2.5µm
- ***Lunar Dust***: Particles from the Moon $\leq$ 20µm in size
  - Convention informally adopted at a NESC Lunar Dust Workshop at Ames Research Center, Jan 2007
  - The departure from American regulatory definitions in part reflects the lower surface gravity of the Moon.
- ***Lunar Dust Simulant***: A regolith simulant where virtually all particles are less than 20µm in size

coutrtesy: C. McLemore, NASA_MSFC

SOIL (including dust) IS UBIQUITOUS ON THE MOON

Courtesy of J. Lindsay, LPI

Global Framework for Lunar Exploration

To Achieve

Successful & Safe Extended Missions & Outpost

Requires

Knowledge of Lunar Environment

Involves

- Understanding Properties & Processes
  - **Regolith Soil and Dust,** plasma, radiation, meteorites, vacuum, gravity, thermal, etc.
- Measurements on & near the Moon
- Evaluation of Returned Samples

Enables

Risk Mitigation

Through

- Earth-based Testing, Verification & Validation
  - Simulation of environment (**Regolith Soil and Dust**, plasma, radiation, vacuum, thermal, etc.)
- Lunar-based testing

For

- **Humans**
- **Hardware**
- **Instruments**

coutrtesy: C. McLemore, NASA_MSFC

Lunar Regolith Management Technology and Capability Needs

- Apollo experience and lessons learned applied to development of a Regolith Management Strategy
- Lunar Regolith Posed Many Operational Challenges*
  - Surface obscuration during lunar module descent
  - Dust Coating and Contamination
    - Anthropogenic sources
    - Surface Systems Effects
      - Lunar Rover
        - Thermal control
      - EVA Suits and Mechanisms
        - Abrasion and wear
        - Seals
  - Crew efficiency
    - Maintenance and cleaning
  - Human Exposure
    - Inhalation and irritation

* From Gaier, J.R., NASA T/M-2005-213610-REV1, and Wagner, S.A., NASA/TP-2006-231053

Lunar Regolith Management Technology and Capability Needs

- Site Preparation – Roads, landing site, construction materials, radiation shielding
  - In-situ microwave sintering
  - Waste recycling
  - Temporary mats
  - Fixative or adhesive
  - Vibration
- Hard and soft goods surface coatings
  - Coatings that attract and/or repel dust
  - Abrasion resistant coatings
  - Strippable coatings
  - Easy don and doff over-garments
- Compressed gas extraction
  - Storage
  - Re-use
  - Cleaning systems
- Automated cleaning systems
  - Electrostatic
  - Magnetic
  - Vacuum
  - HEPA filtration
  - Self cleaning connectors
- Manual cleaning systems
  - Non-abrasive brushes
  - Magnetic / electrostatic wand
- Crew and equipment translation systems
  - Pressurized articulating jet ways
  - Vacuum transfer

Addressed by ETDP Dust Project

Addressed by other ETDP Projects

Exploration Technology Development Program
Dust Project - Technical Content Summary

Dust Mitigation Technology Development

- Mechanical Components and Seals
  - Dust Tolerant Bearings, Gimbal/Drive Mechanisms
- Materials and Coatings
  - Abrasion resistant materials, surface coatings
- Dust Mitigation for Habitat/Airlock Applications
  - CO_2 shower
  - SPARCLE
    - Space Plasma Alleviated Regolith Concentrations in Lunar Environment
  - Industry Solicitation
- Dust Mitigation for Surface System Applications
  - Electrostatic curtain
  - Protection of Thermal Control Surfaces
  - Self Cleaning Solar Arrays

Exploration Technology Development Program
Dust Project Technical Content Summary

- Engineering Design Environments
  - Simulant Characterization, Definition, and Requirements
    - Proves regolith characterization methodology
    - Establishes dust simulant figures of merit (FOMs) - FOM tool development
    - Characterizes current simulants to assess applicability for technology development, integration, and testing (procedures/protocols)
    - Simulant Requirements Document and Characterization Datasheets
  - Regolith Characterization
    - Addresses knowledge gaps and guides simulant definition and FOMs
  - Environment Characterization
    - Analytically assesses lunar surface environment and applies to engineering design and technology development, integration, and testing
  - Forensic Engineering Investigations

Specific Framework for Lunar Regolith

Role of Regolith

It Touches Everything

3 Aspects – (1) Understand It, (2) Manage It, (3) Utilize It

Interrelationships & Connectivity

Science
(Properties & Processes)

Engineering
(Design, Test & Operations)

Knowledge

Environment Simulation

Resource Utilization

Regolith Simulants
(ESMD/SMD)

Dust Simulants

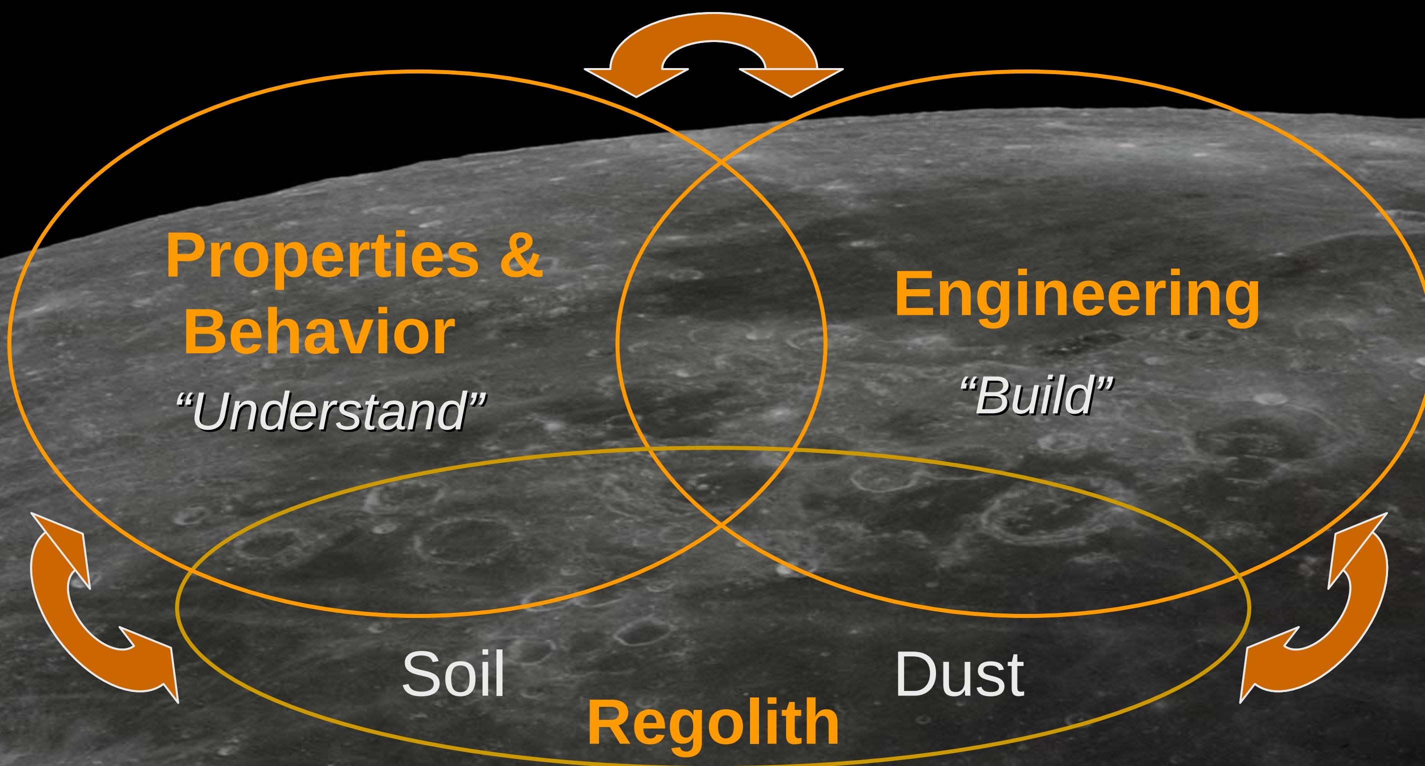
Bulk Simulants

Earth Based Environmental Testing

Human Health
HW/System Development &Verification

coutrtesy: C. McLemore, NASA_MSFC

Lunar Regolith/Simulant Dependencies



Simulants:

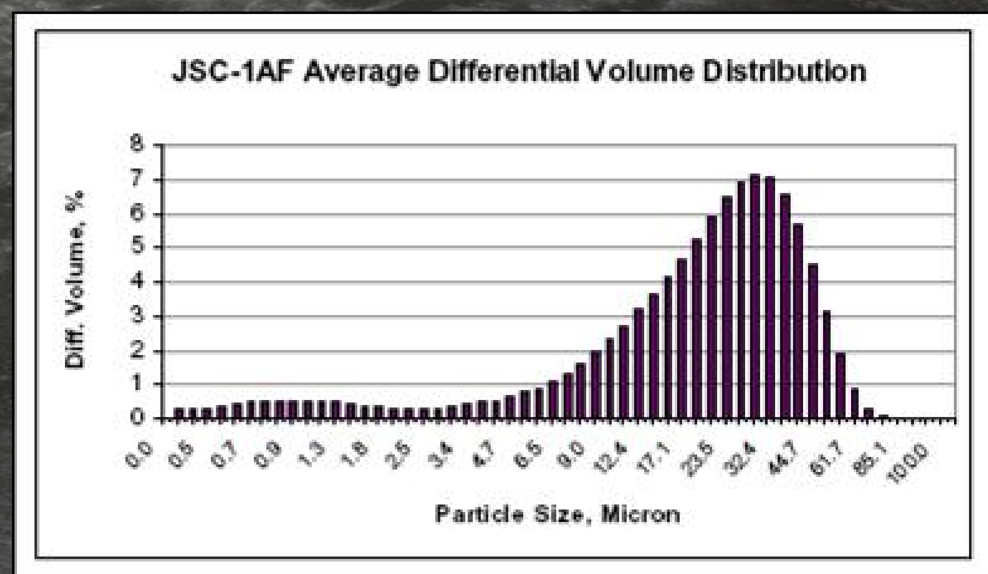
"Tools for Risk Reduction and Technology Advancements"

coutrtesy: C. McLemore, NASA_MSFC

Simulant and Regolith Characterization

- Physical Properties to be Assessed
  - Particle size and shape
  - Adhesion, Hardness, Abrasivity
  - Surface Energy, Chemistry and Reactivity
  - Dielectric function and Conductance
  - Charge capacity and electrostatics
  - Magnetic Susceptibility
  - Tribocharging

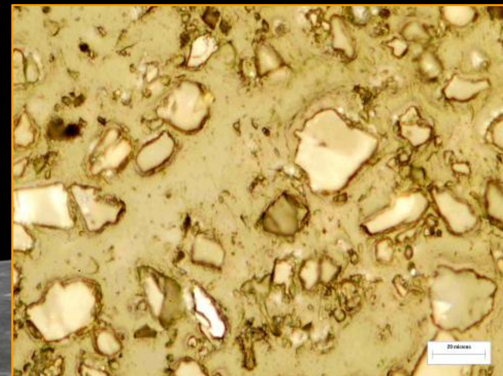
Simulant Fidelity - for example: JSC-1af significantly under-represents the fine and ultrafine fraction of lunar regolith*



*Greenberg, NASA/TM -2007-214956

Apollo Engineering Forensics Investigation

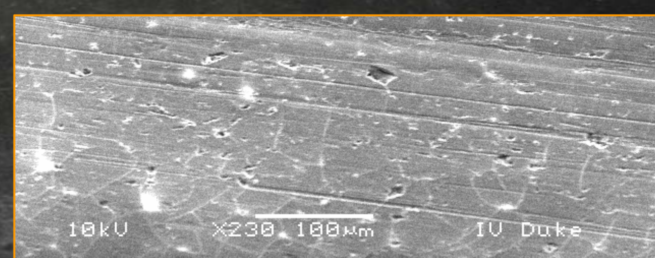
- **Objective:** To obtain useful data on the effects of lunar dust exposure on Apollo equipment and space suits.
  - *Results will be used to guide dust mitigation technology development and to help develop models for the effects of dust exposure on materials and systems*
- **Approach:**
  - Examination of spacesuits at the Smithsonian Institution by XRF and tape peels to reveal trapped dust
  - Inspection of LiOH cartridge filters
  - Disassembly and Inspection of IVA/EVA glove seal bearings and races
  - Chemical analysis of polymer degradation in suit materials
  - Direct SEM imaging of exposed surfaces of an EVA glove
  - SEM analysis of dust samples vacuumed from suits upon return to Earth



Optical Micrograph of lunar dust vacuumed from Apollo suit

Initial visit to Smithsonian to evaluate condition of artifacts, such as the Apollo 17 suit shown above

Electron micrographs showing damage to the outer layer of Alan Bean's Apollo 12 suit

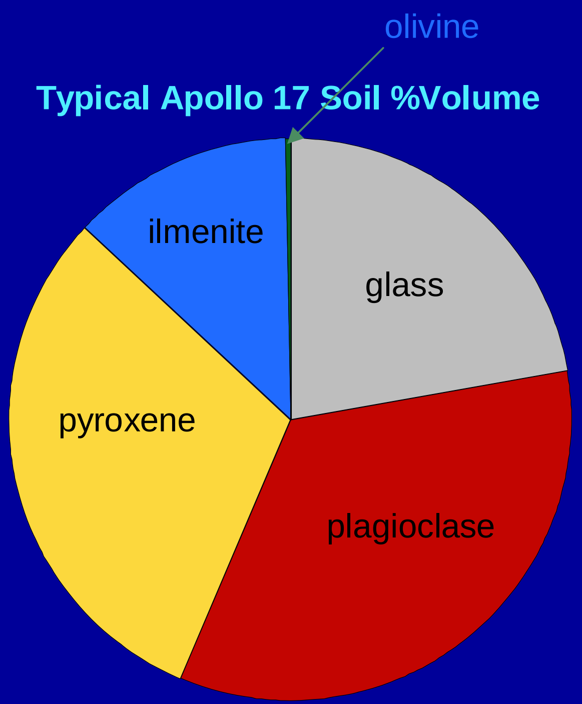


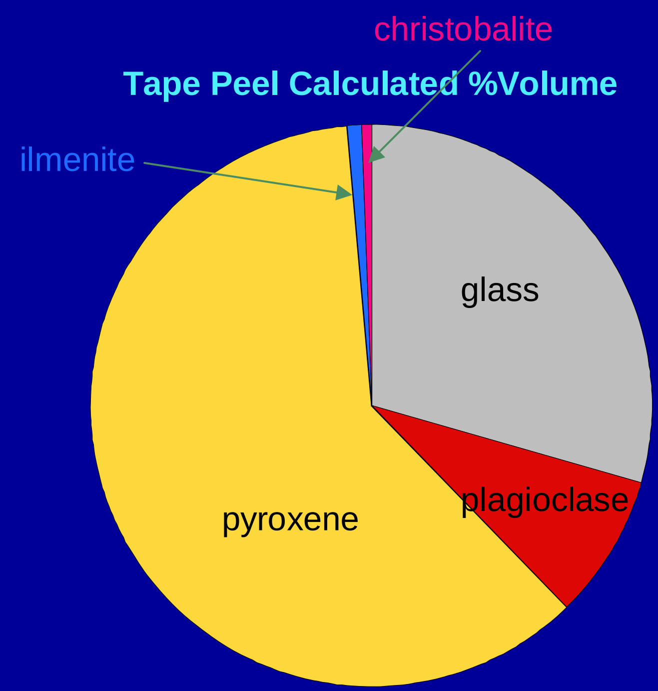
SEM image of inner bearing race from Apollo 12 IVA glove (not lunar exposed control case)

Coutesy: J. Feighery, NASA-JSC

Apollo Engineering Forensics Investigation

Mineralogy of Suit Tape Peel Samples





Breakdown by percent volume of lunar grain types for grain sizes between 20-90 microns from Apollo 17 (Mare soils 72501,76501, and 78221)*.

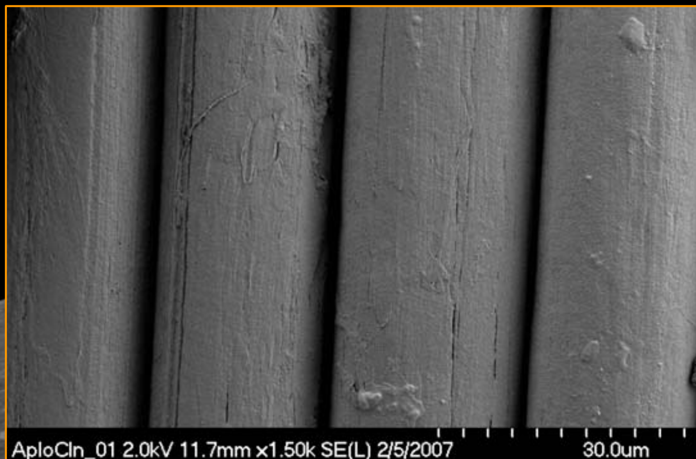
Breakdown by percent volume for each lunar grain type calculated from the tape peels for sizes greater than 2 microns**

*Papike et. al. 1982

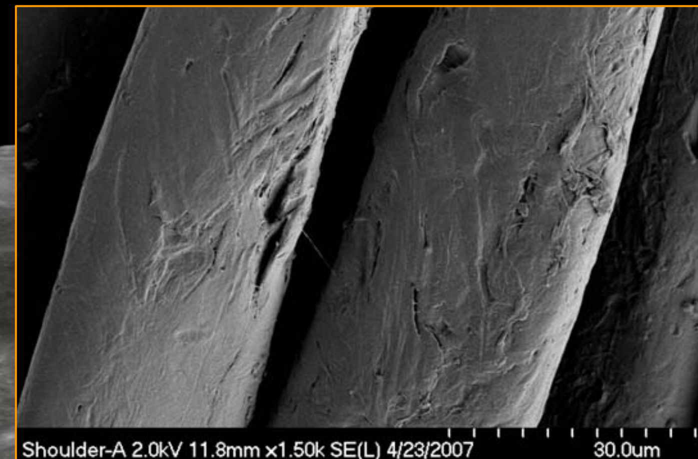
**J. Anneliese Lawrence, Marshall University John F. Lindsay, Lunar and Planetary Institute Sarah K. Noble, NASA-JSC

Apollo Engineering Forensics Investigation

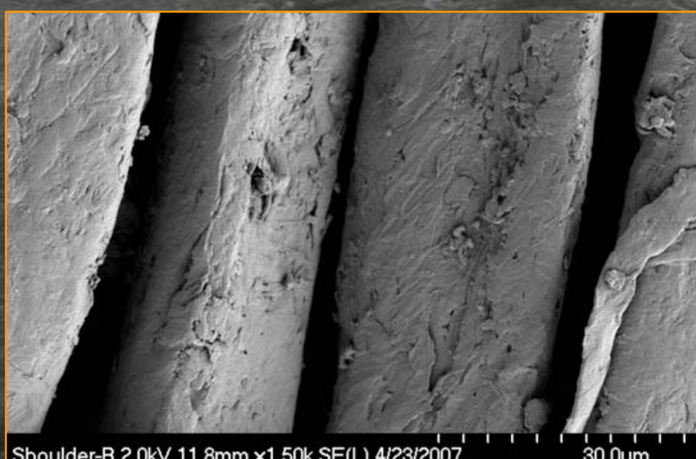
Progression of damage seen in samples with different degrees of exposure



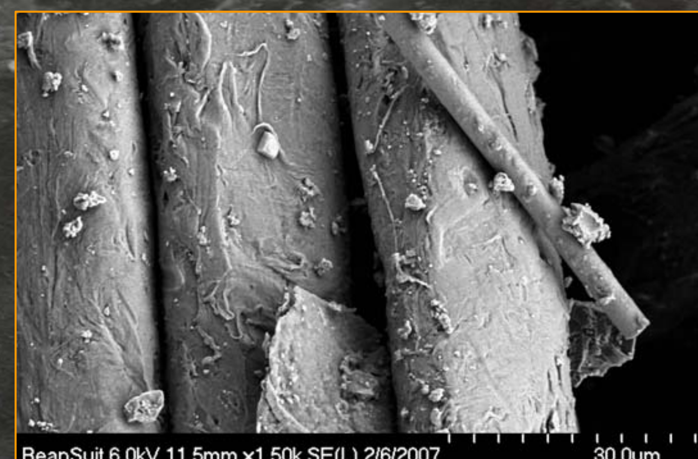
Unused Apollo fabric



Bean's suit—shoulder under flag patch



Bean's suit—shoulder exposed

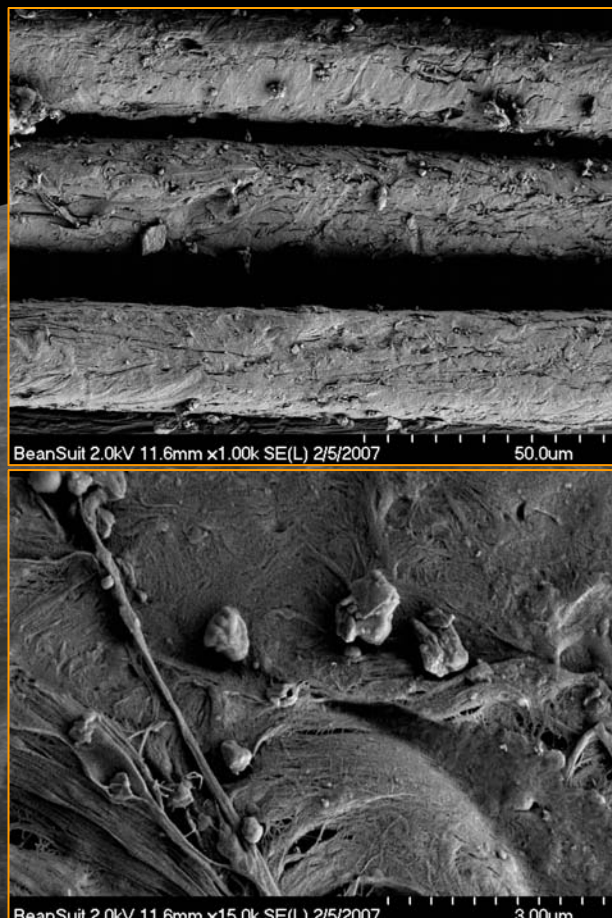


Bean's suit—left knee

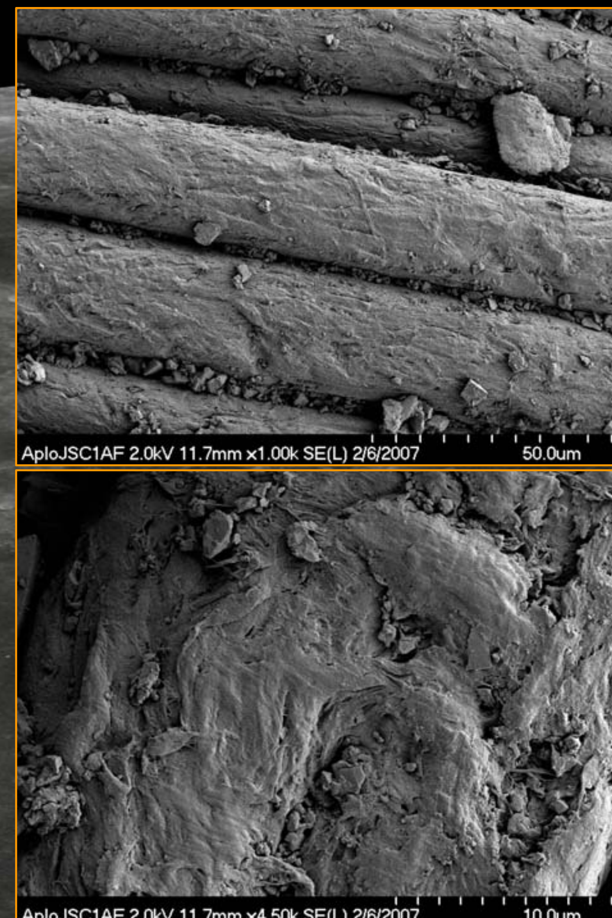
Courtesy: M. A. Meador, NASA-GRC

Apollo Engineering Forensics Investigation

Apollo 12 suit samples show similar damage to that suffered from Apollo Era fabric with ground-in simulant



Apollo 12 suit



Exposed to simulant

Courtesy: M. A. Meador, NASA-GRC

Summary

- Vision for Space Exploration plans to resume human missions to the moon, of extended duration, require a strategic approach to management of lunar regolith
- Layered engineering solutions, based on improved understanding of the integrated lunar environment, can allow safe and sustainable mission operations
- The ETDP Dust Project will provide improved understanding of relevant lunar environment characteristics, and develop mitigation technologies required to address gaps in current capabilities

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