Lunar Outpost Site Selection

Enabling Exploration: The Lunar Outpost and Beyond

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Considerations

Objective: Establishment of outpost site for long-term occupation.

"…sustained human presence on the Moon…"

Environmental considerations (lighting, thermal) may be paramount.

Resource potential may be important.

Scientific objectives not likely to be a driver.

International cooperation, commercial ventures, ….

Different from Apollo and Mars robotic missions.

Raison d'etre for lunar outpost must be established.

It defines what characteristics are important.

Apollo Site Selection

Environment

- Define surface characteristics
- Assess hazard potential
- Topography of landing site and effects on LM landing radar performance

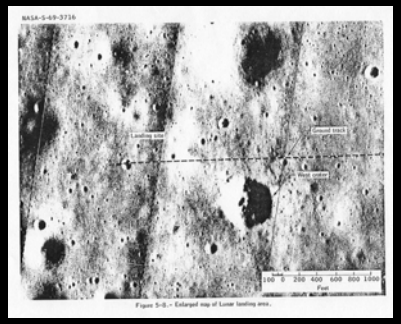
Safety

- Free return trajectory – landing site ±5° latitude
- Navigation: emerge from eastern limb, acquire signal, calculate position
  - Required location uncertainty of ground reference points <1500' (450 m)
  - Large uncertainties near limb – landing site ±40° longitude (later ±45° longitude)
- Landing zone: 185 miles (300 km) x 1500 miles (2400 km)
- Lighting for lunar landing and surface temperature and lighting at KSC for launch

Primary and two backups to deal with launch delays

Science secondary early on.

- 1962 Iowa summer study
- 1965 Woods Hole study
- Falmouth conference on lunar exploration
- Continuous study and modification
- Became a greater consideration in later missions




"DESTINATION
MOON"
COLOR BY
TECHNICOLOR


NEVER
BEFORE
HAS ANY
WOMAN...


HERGE
THE ADVENTURES OF
TINTIN
EXPLORERS
ON THE MOON


...SENT
HER MAN
ON
SUCH AN
EXPLOIT!

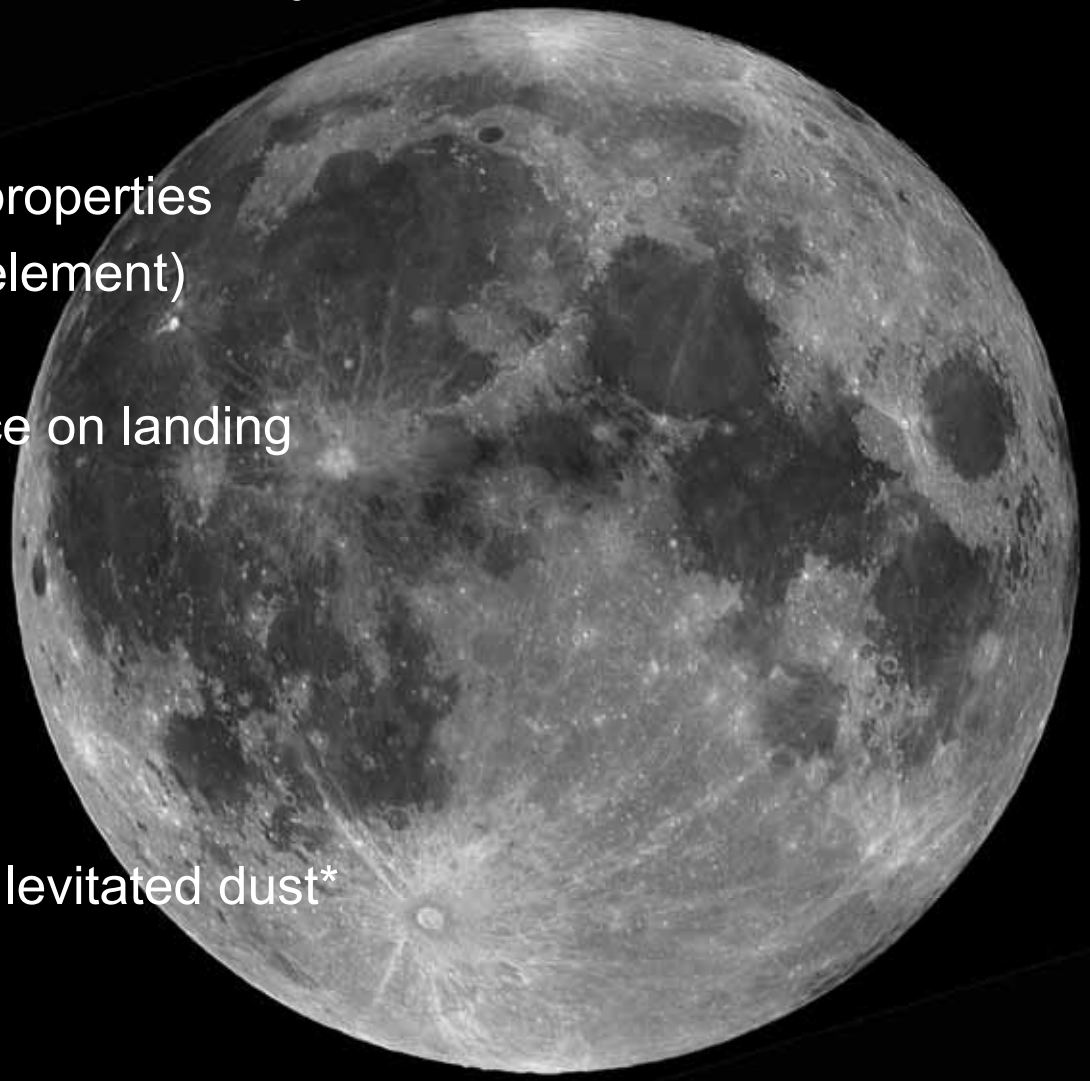
Environment

	Non Polar	**Polar**
Temperature	-150°C to +100°C	-50°C ± 10°C
Sunlight	~354 hours ± 90° Incidence Angle	~ 530 to 708 hours ± 1.7° Incidence Angle
Darkness	~354 hours	0 to 148 hours (discontinuous)
H Content (avg.)	10-90 ppm	>150 ppm
Resource Potential	Solar wind gases Bound oxygen	Solar wind gases Bound oxygen Shadowed volatiles
Direct Earth Communications	Continuous on near side	Discontinuous but predictable (~ ½ time in Earth view)

The Moon is not JSC-1

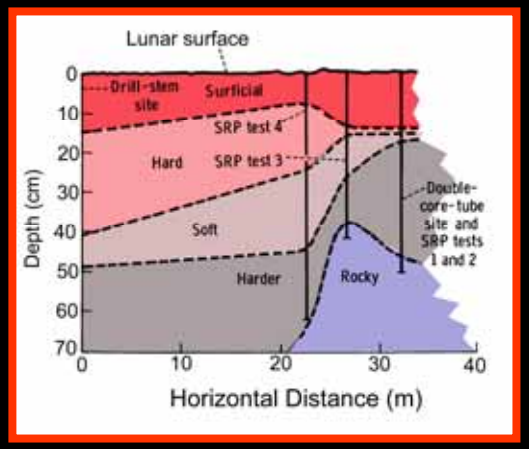
The Moon is not Terra Incognita

Spatially Independent

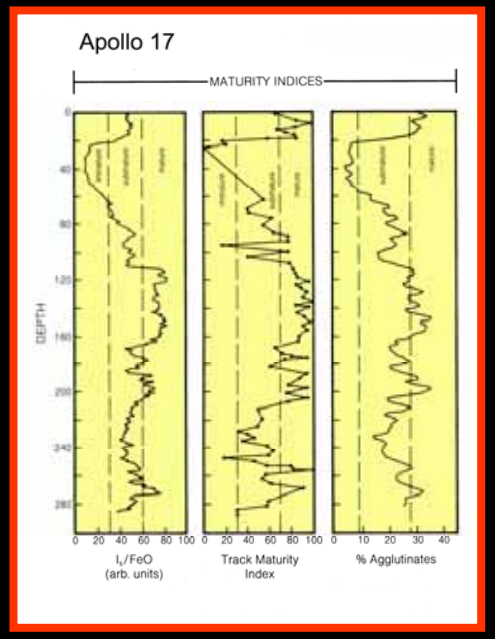


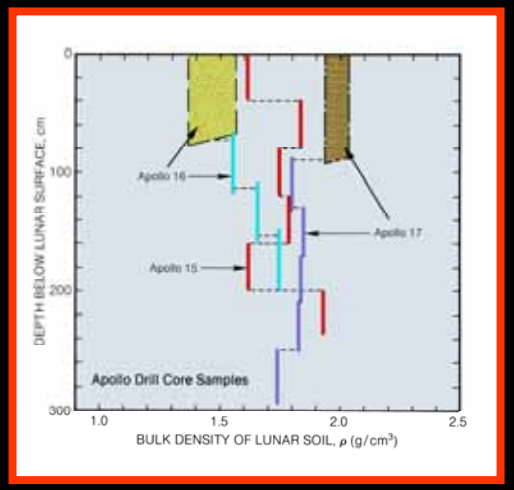
Regolith physical properties
Chemistry (major element)
Dust
Surface disturbance on landing
Rock frequency
Radiation
Micrometeoroids
Magnetic field***
Atmosphere**
Surface charging / levitated dust*

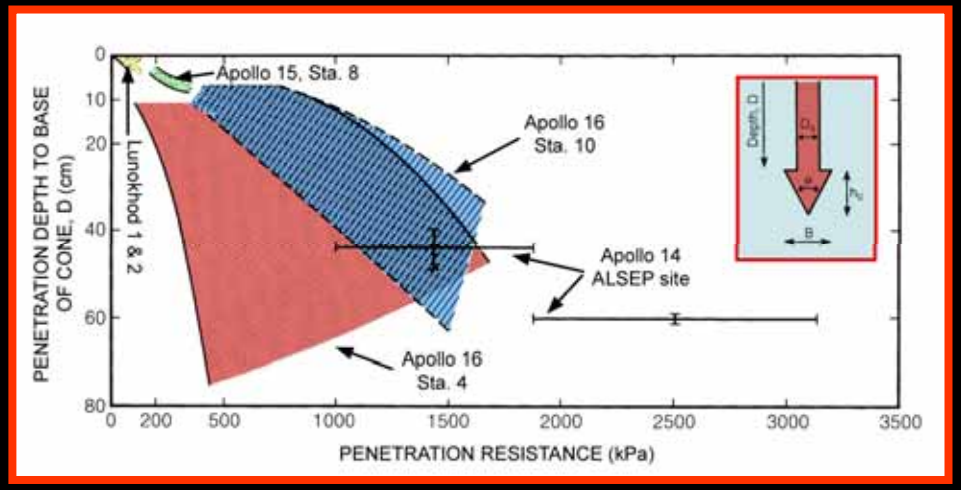
Regolith Physical Properties

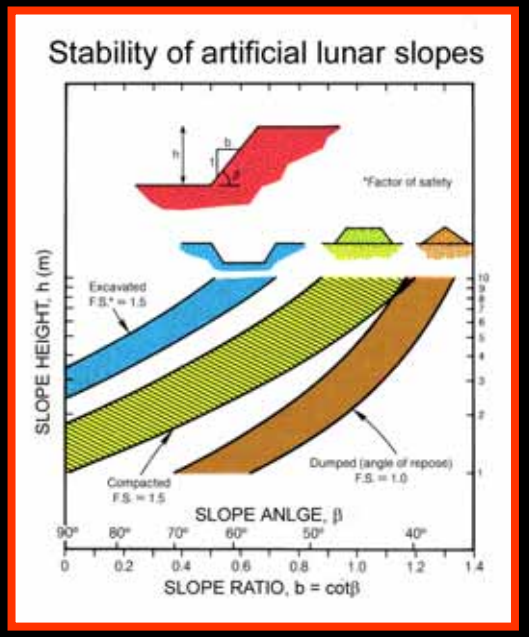


Apollo 16: Station 10 ALSEP

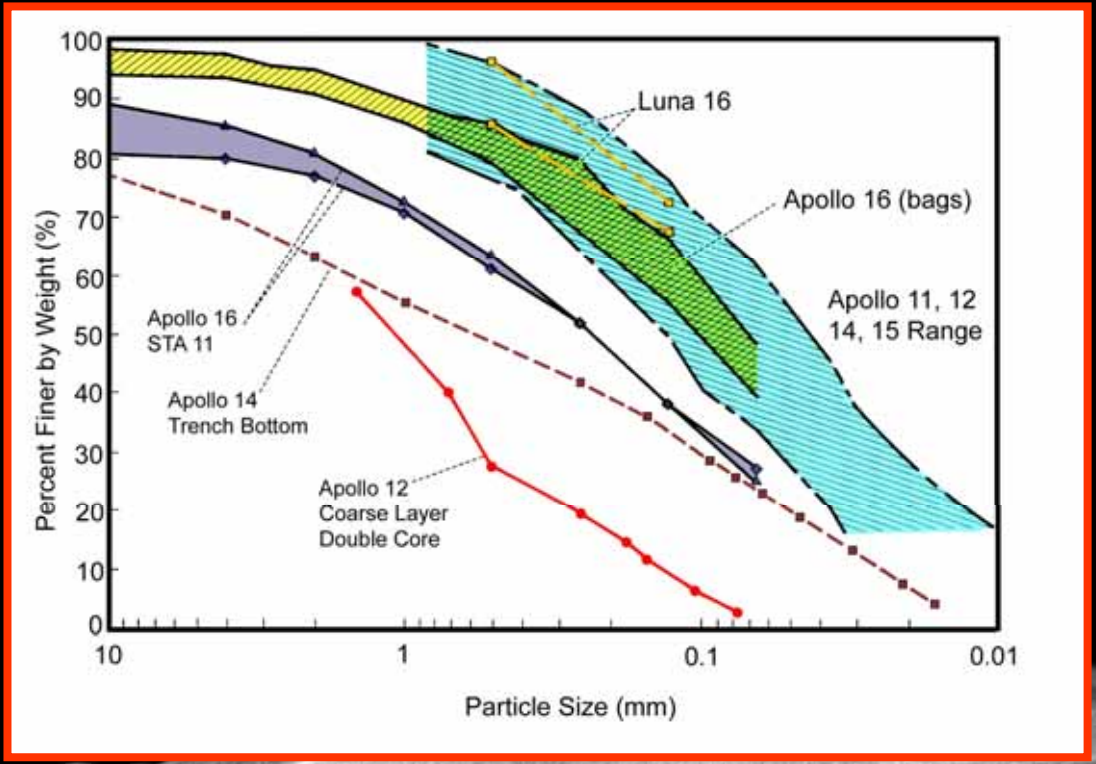




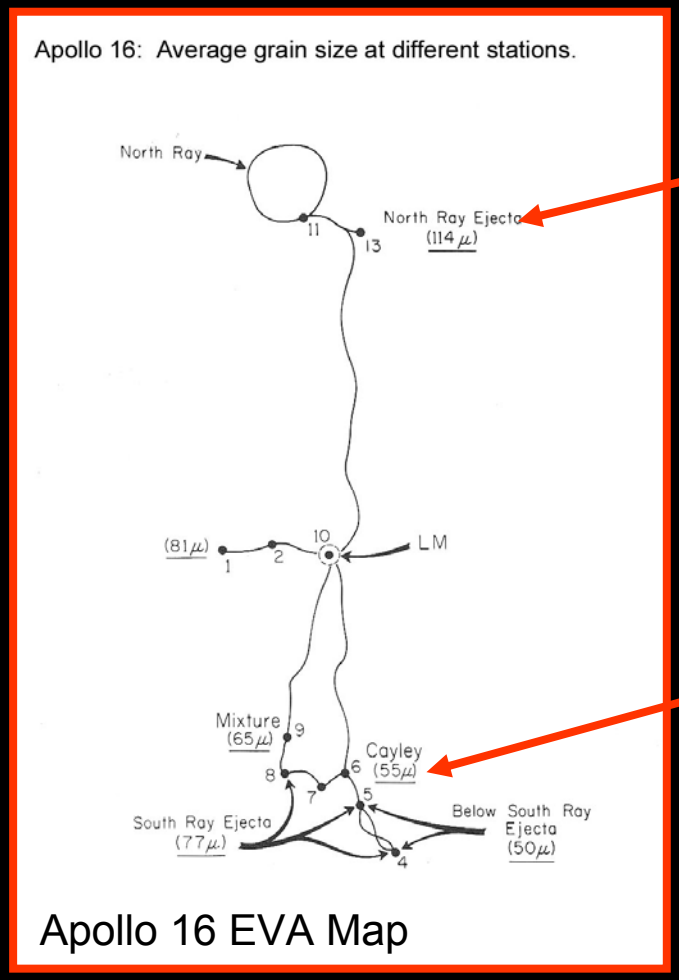


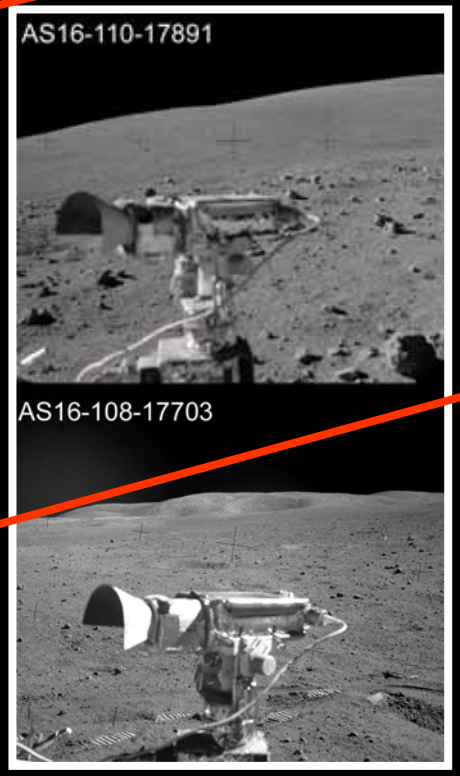


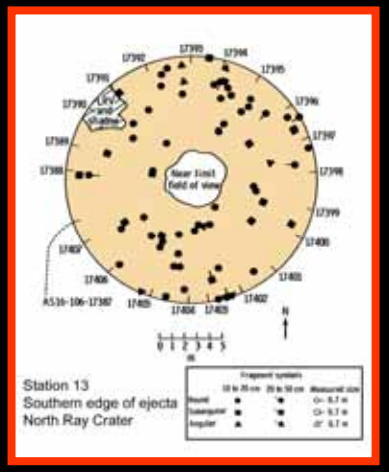
Regolith Particle Size-Frequency Distribution



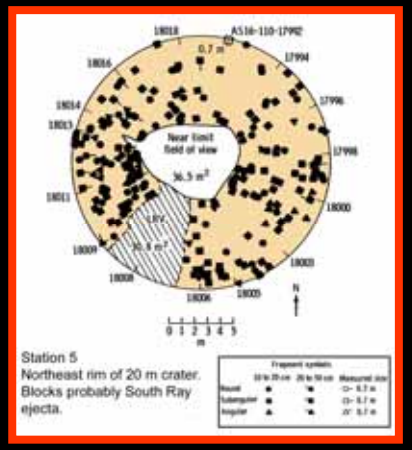
Apollo 16 Regolith Grain Size vs. Rock Frequency







Average grain size 114 μm



Average grain size 55 μm

Agglutinates

Individual particles – aggregates of smaller particles (mineral grain, glass, rocks, older agglutinates) bonded together by vesicular flow banded glass in varying proportions. 30-80% glass

Melting and remixed during micrometeoroid bombardment

Small agglutinates (e.g., <45 microns) are fragments of originally larger (90-150 micron) bodies

Irregular shape, branching or dendritic morphology

Usually <1 mm

25-30% volume average; 5-65% range, up to 60% volume in mature soil

Vesicles (holes): liberated solar wind gases and generated H_2O ($FeO + 2H = Fe + H_2O$)

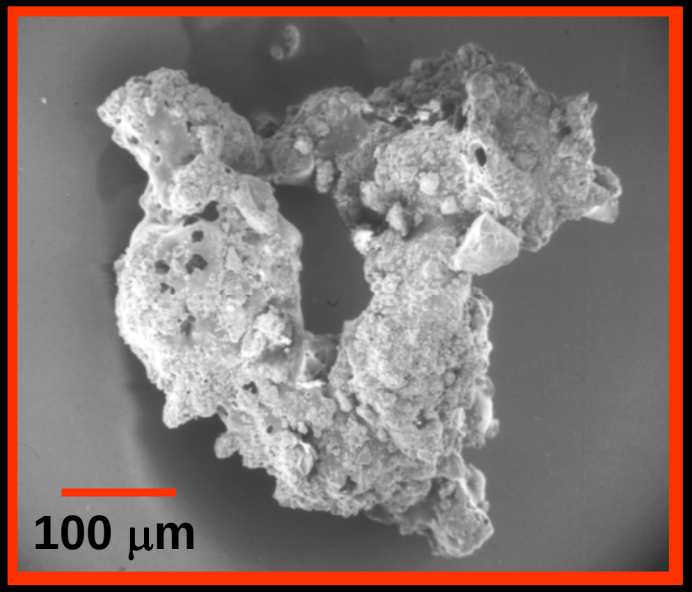
Contain minute droplets of near pure Fe metal (very fine grained single domain Fe^0, 30-100Å mounds and trains of metal Fe, attached to grains

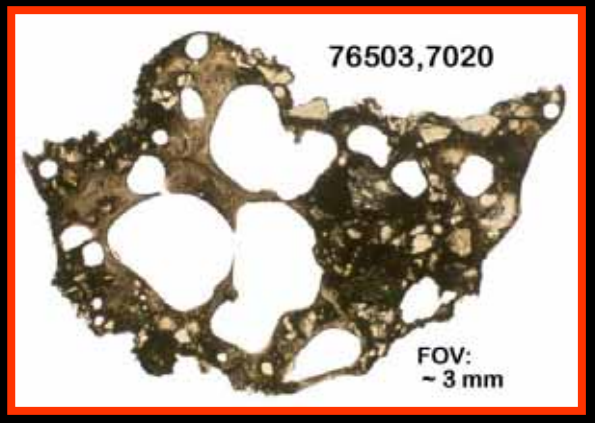
Glass composition mimics <10 micron size-fraction of the regolith

Contain solar wind gases (e.g., He, H) in higher concentration than other particles

Mare: composition mimics regolith plus a feldspathic component

Composition generally matches the composition of <10 micron fraction better than the <1 mm fraction





Chemistry

	SiO_2	TiO_2	Al_2O_3	FeO	MgO	CaO	Na_2O
A11 Mare Basalt	40.46	10.41	10.08	19.22	7.01	11.54	0.38
A11 Soil and Regolith Breccia	41.99	7.94	12.58	16.40	7.93	11.74	0.47
A12 Mare Basalt	44.88	3.62	8.93	20.48	10.64	9.81	0.25
A12 Soil and Regolith Breccia	46.21	2.61	12.13	17.19	10.42	9.85	0.41
A17 Mare Basalt	39.03	11.94	9.00	18.82	8.54	10.82	0.39
A17 Soil and Regolith Breccia	44.47	2.84	18.93	10.29	9.95	12.29	0.43
Anorthosite	45.57	0.08	33.4	1.00	1.21	19.1	0.40

Apollo LM Descent

Apollo 11
- Dust: 73-33 m (240-110')
- 75% Obscuration at Touchdown
- Material moved along surface – deflected by rocks

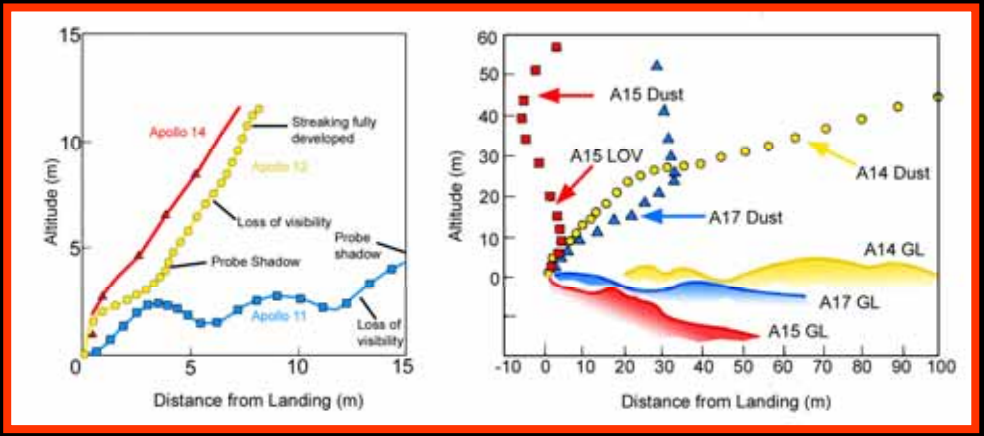
Apollo 12
- Dust: 53 m (175')
- Obscuration 12 m (40')
- Surface altered below 9-12 m altitude

Apollo 14
- Dust: 33 m (110')
- Erosion of 10 cm 1 m SE of nozzle

Apollo 15
- Dust: 45 m (150')
- Obscuration 18 m (60')

Apollo 16
- Dust: 25 m (80')
- Block and small crater visible to surface

Apollo 17
- Dust: 20 m (65')
- No obscuration
- Evidence of plume interaction with surface across 50 m

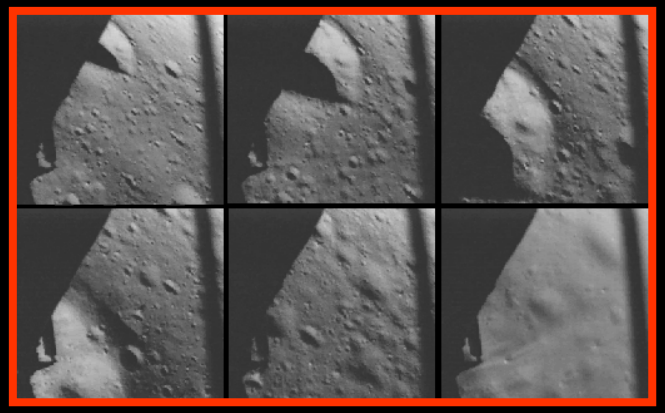


The amount of material disturbed by the LM descent engine is a strong function of the approach trajectory and speed. Oblique trajectory causes the least disturbance of the surface. Vertical descent (A15) caused the most disturbance.

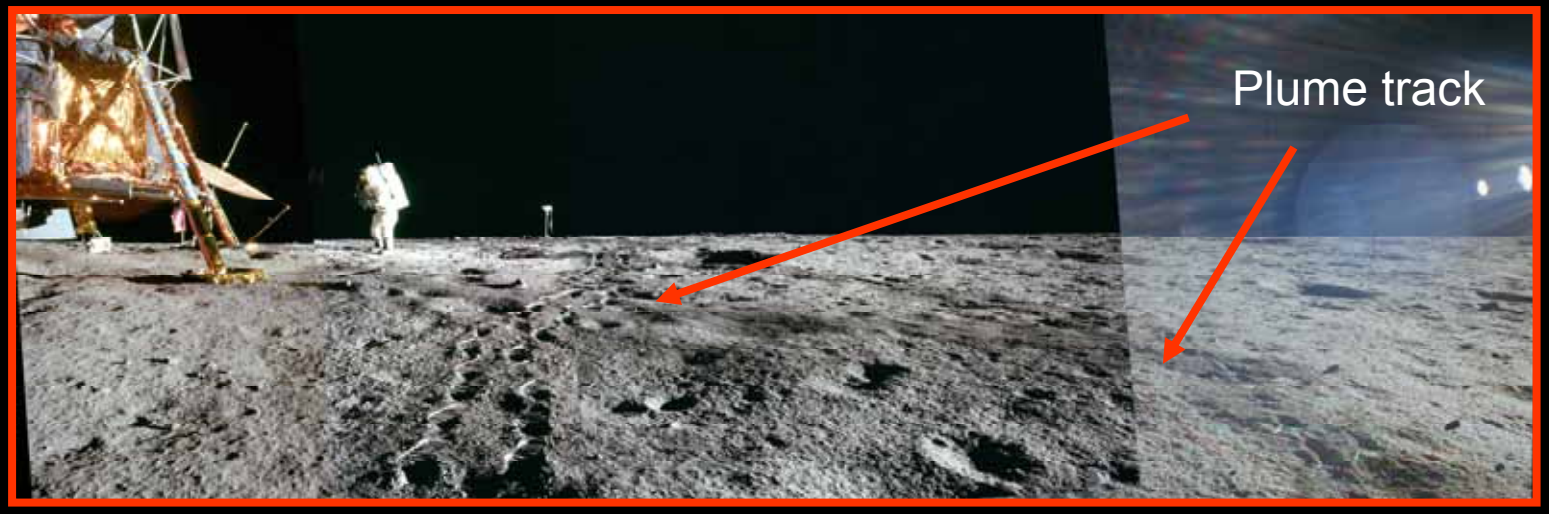
AS11-40-5920

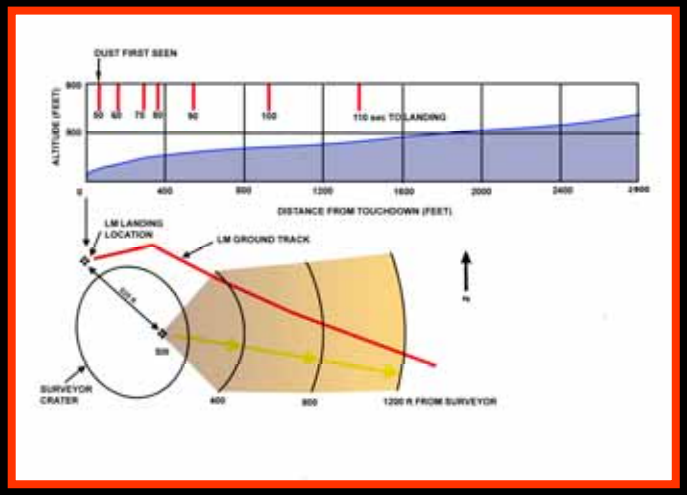
AS12-47-6906

AS14-66-9261



Apollo 12 LM Descent





LM descent engine scoured the surface during the final phases on landing.

Material was blown onto the Surveyor spacecraft.

Dust

Dust readily kicked up by walking and the LRV and adheres to everything.

Some portions of the rover became coated with dust. Coating depended upon the material.

Suits were easily coated with dust
Bearing surfaces on gloves / helmets scratched

Coating on Surveyor was thin, but hard to rub off

Dust

Dust: <50 μm size fraction

consists largely of impact produced glass

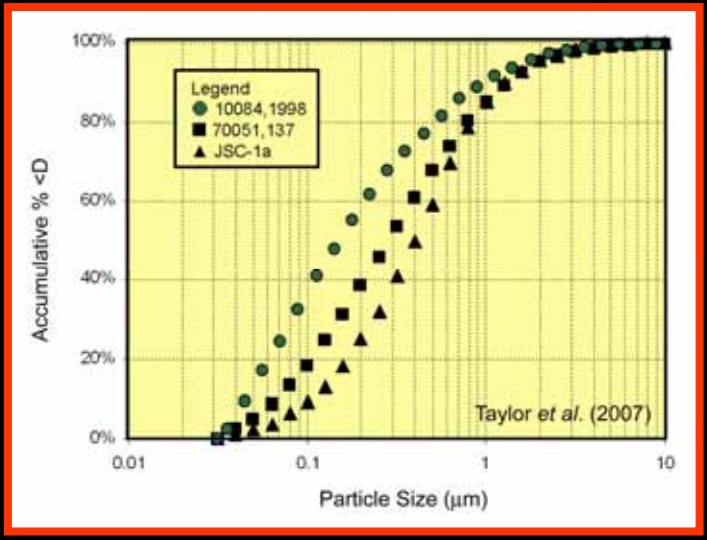
complicated shapes, jagged edges, large surface area

<20 micron size fraction: 20 wt % of soil

Different composition from bulk regolith.

Impact generated glass and nano-phase Fe increase with decreasing grain size.

~80 wt. % at sizes <10 micron



Taylor et al. (2007) and Liu et al. (2007) data on size-frequency distribution of dust-sized material (20 microns-20 nm).

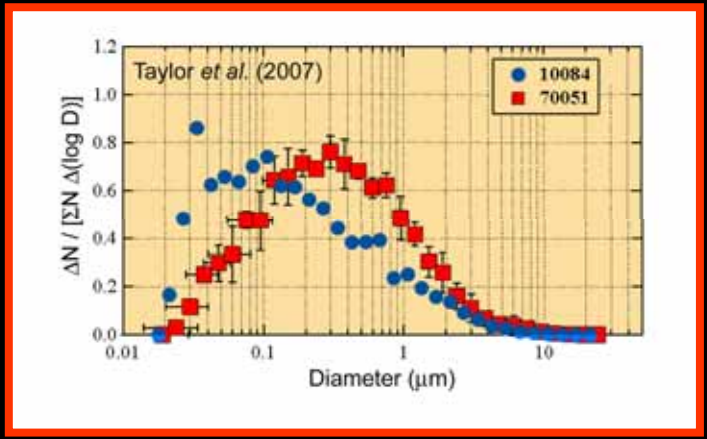
Two samples 10084-70051 both display peaks at 100-200 nm

>95% are <2 micron

A11-10084: 50% of particles are <0.1 micron

A11-10084: >40% ultrafine (<100 nm) particles

A17-70051: 50% of particles are <0.3 micron



Levitated Dust

Surveyor Observations

- Glow observed after sunset on horizon at Surveyors 5, 6, 7, and maybe 1
- Extends about 6° across horizon ±3° from point of sunset
- No polarization anomaly detected
- Horizon in glow matches illuminated horizon

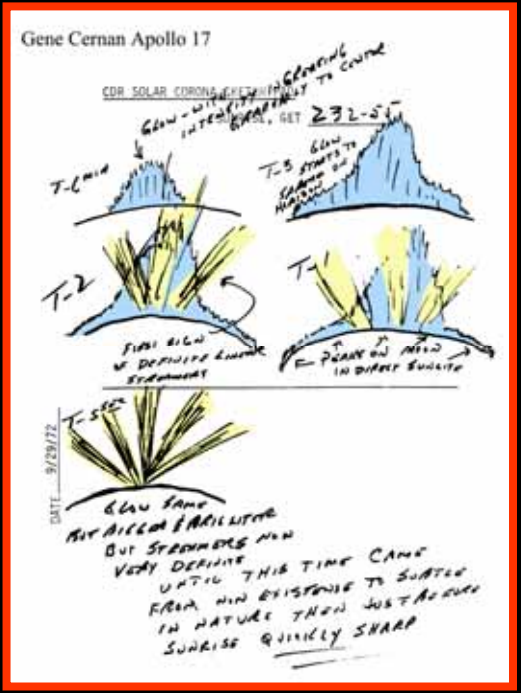
Model

- Visible sunlight forward scattered by electrically charged dust grains ~ 5-6 micron radius electrostatically levitated above partially illuminated rocks or surface irregularities (Rennilson and Criswell 1974)
- Strength of local electrostatic field 600 V cm^{-1}

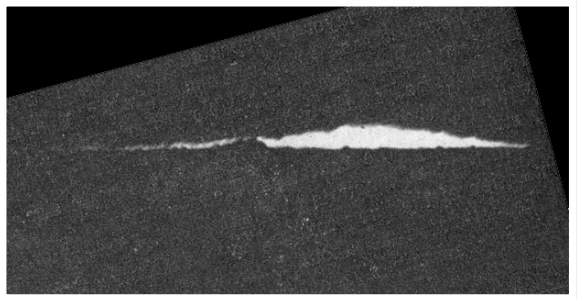
- Source region 10-30 cm high and deep (along line of sight)
- Source region is meters to km west of Surveyor

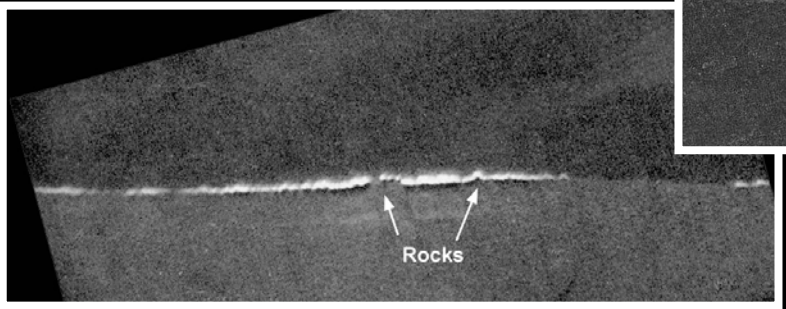
But

- Rocks not coated with dust
- Laser reflectors continue to operate 35 years later



Orbital observations





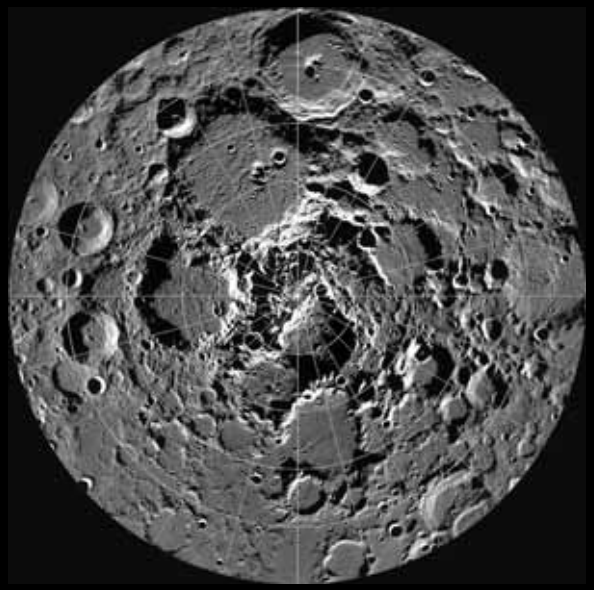
Surveyor observations

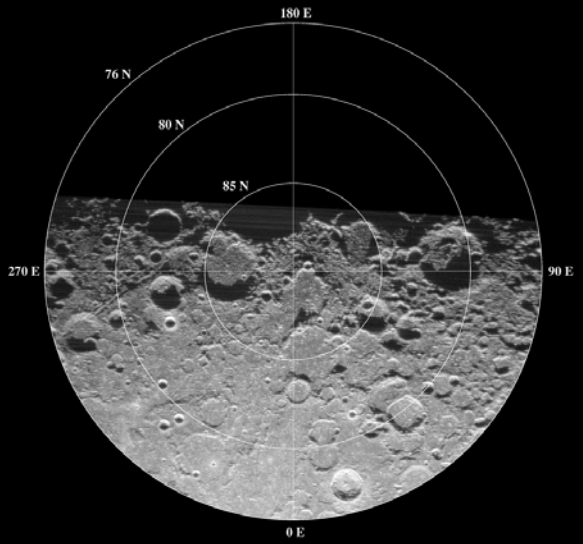
Spatially Dependent

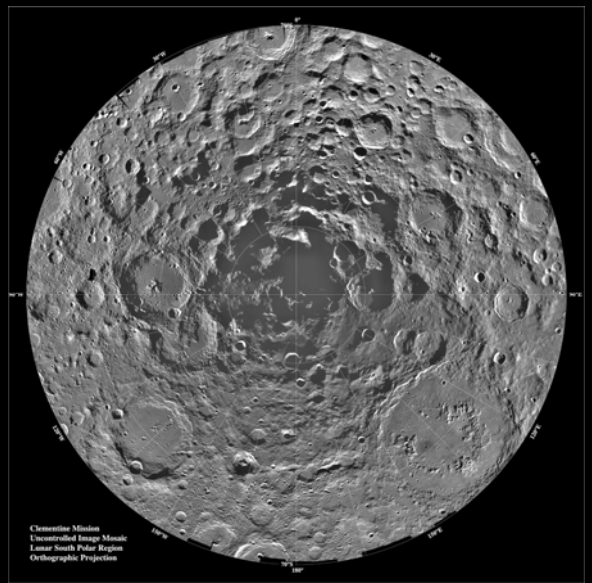
- Lighting
- Thermal
- Topography
- Communication / Earth View
- Resources
- Science
- Commerce
- Flight
  - Precision landing
  - Delta V budget
  - Approach over shadowed terrain

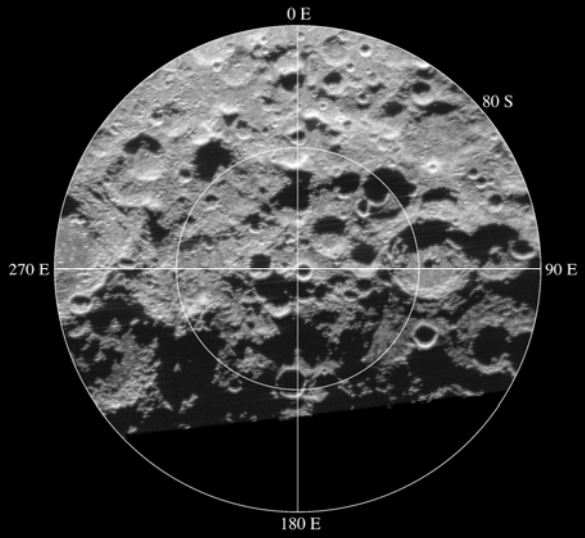
These are the site discriminators.

Poles




180 E
76 N
80 N
85 N
270 E
90 E
0 E


Clementine Mission
Uncontrolled Image Mosaic
Lunar South Polar Region
Orthographic Projection


0 E
80 S
270 E
90 E
180 E

Surface Lighting

Mission	EVA 1	Local Time	EVA 2	Local Time	EVA 3	Local Time
Apollo 11	14.0°-15.4°	6.93-7.03				
Apollo 12	7.5°-9.5°	6.50-6.63	15.8°-17.8°	7.05-7.19		
Apollo 14	13.0°-15.5°	6.87-7.03	22.0°-24.3°	7.47-7.62		
Apollo 15	19.6°-22.9°	7.31-7.51	31.0°-34.7°	8.07-8.31	41.7°-44.3°	8.78-8.95
Apollo 16	22.2°-25.7°	7.48-7.71	34.1°-37.9°	8.27-8.53	45.8°-48.7°	9.05-9.25
Apollo 17	15.3°-19.0°	7.02-7.27	27.3°-31.2°	7.82-8.08	39.0°-42.6°	8.60-8.84

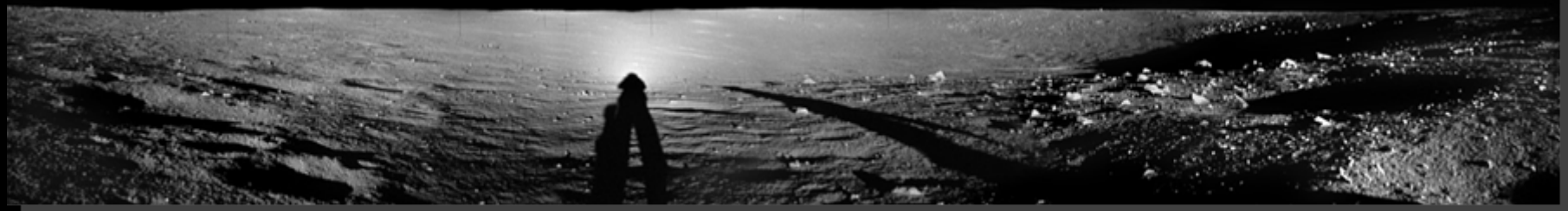
Time: Decimal hours with 6.00 as sunrise / 12.00 as noon.
Illumination: degrees above horizon
Apollo 12 EVA 1 had the lowest illumination angle
Apollo 16 EVA 3 had the highest illumination angle

Surface Lighting

AS12-46-6734

A16-117-18825

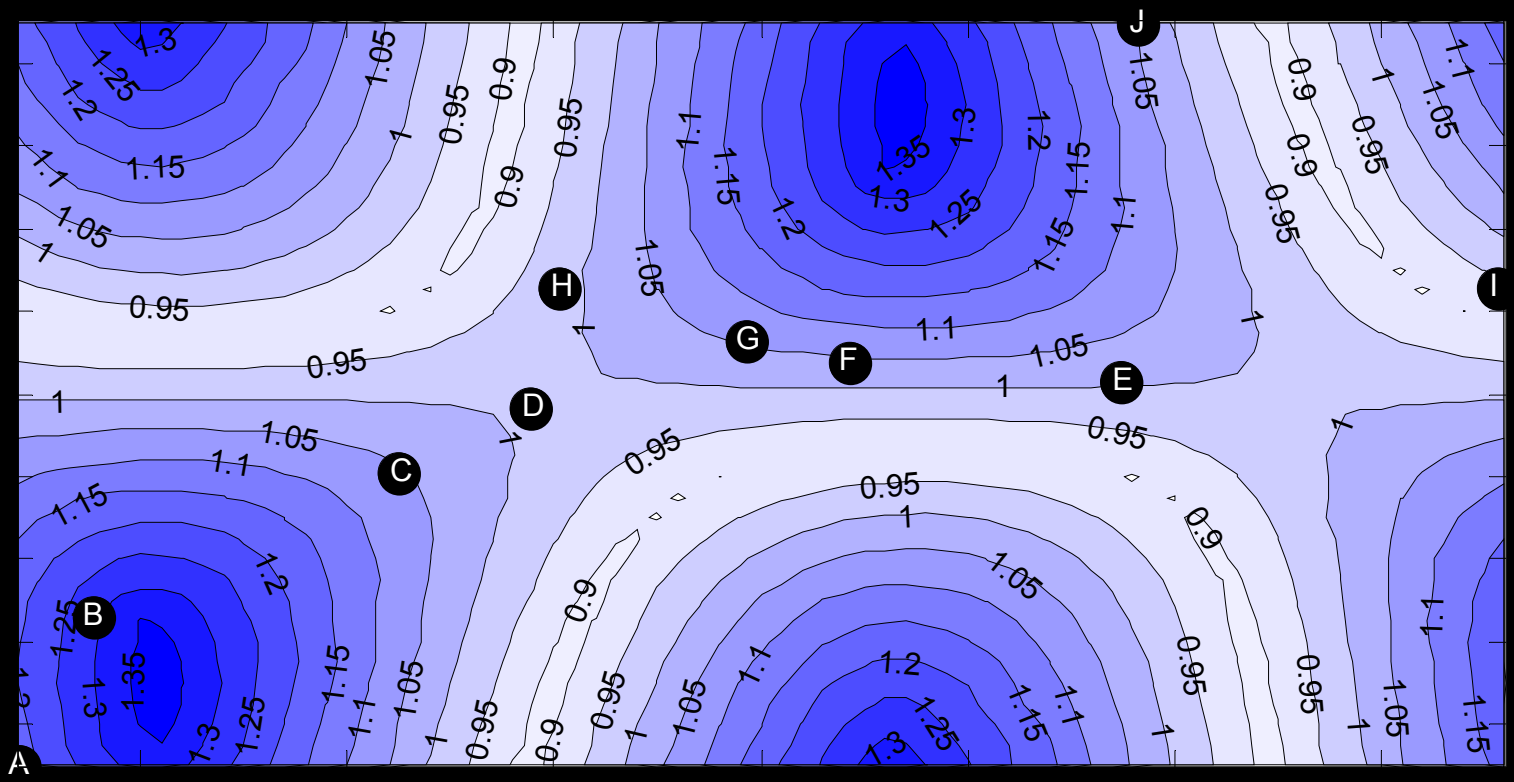
Surface Lighting



LOI ΔV (km/s), No Loiter, CEV WA minimized

Method 1: 2nd LOI burn occurs at Apolune, pure plane change

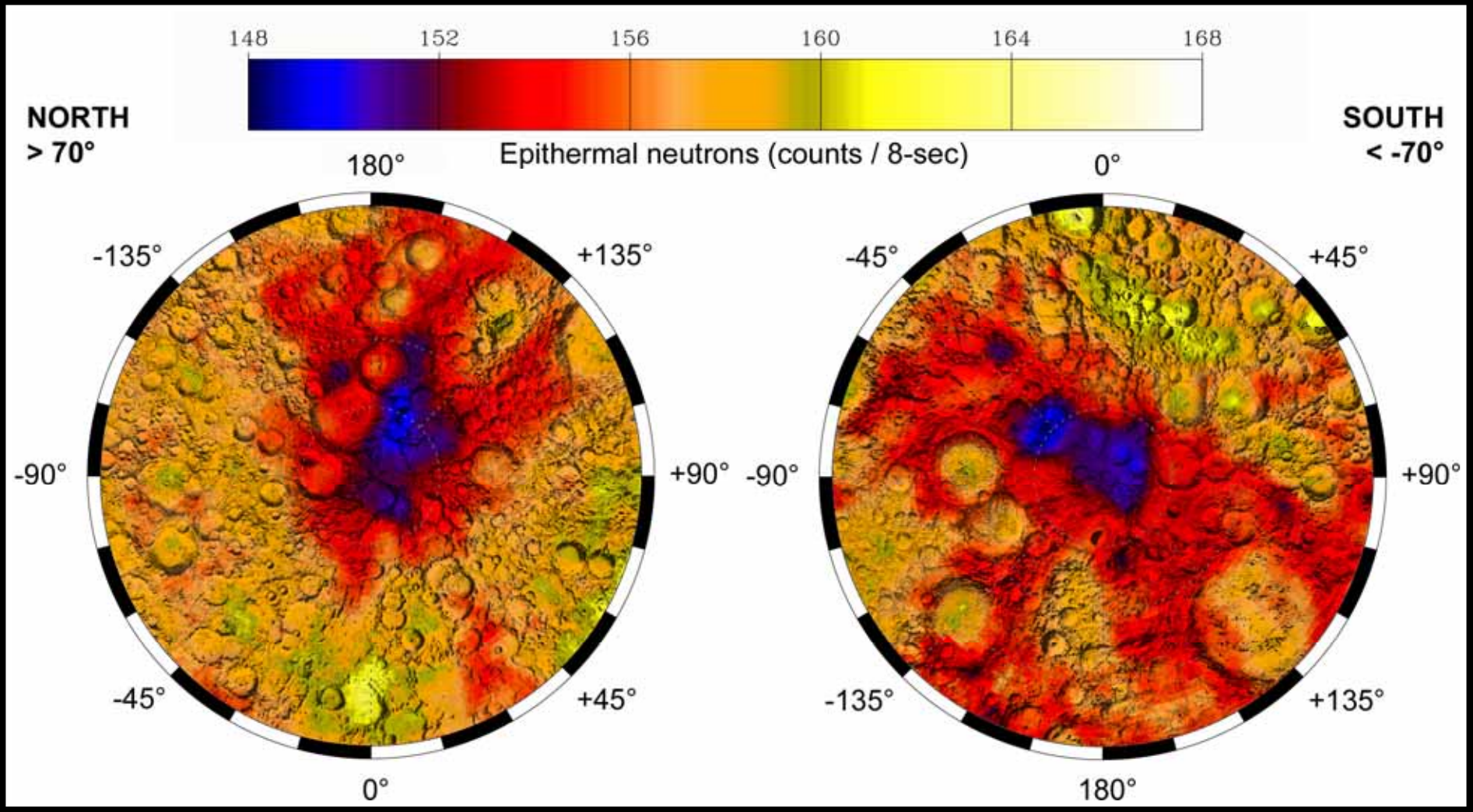
Lunar Arrival 9/18/2024 12:00, 4-day transfer, Nominal mission, Beginning of TLI Window



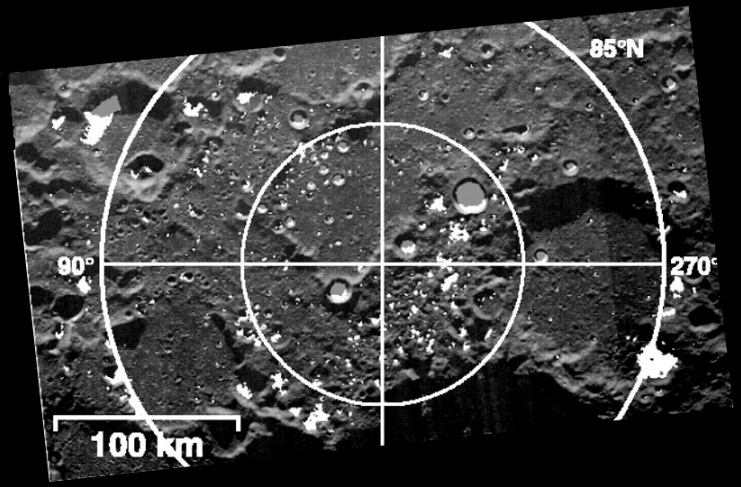
Min = 0.883

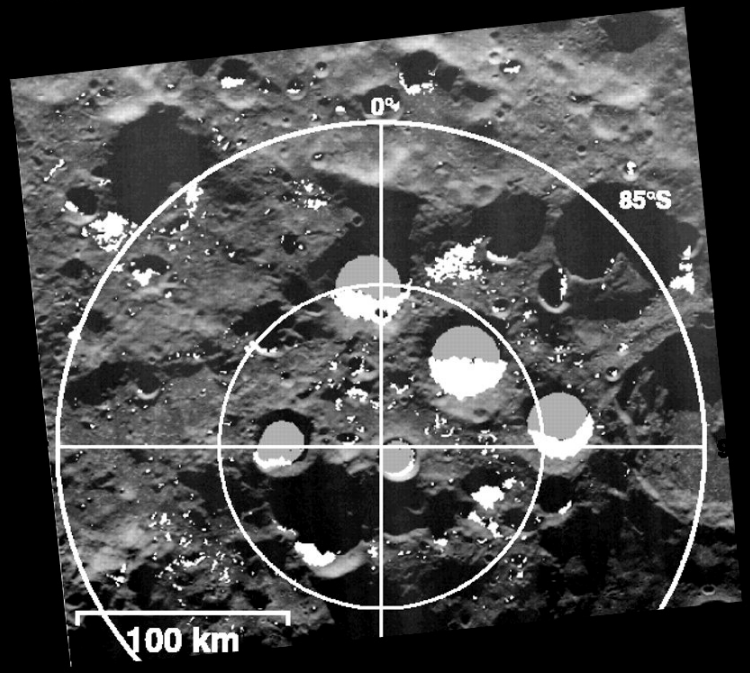
Max = 1.382

Resources - H

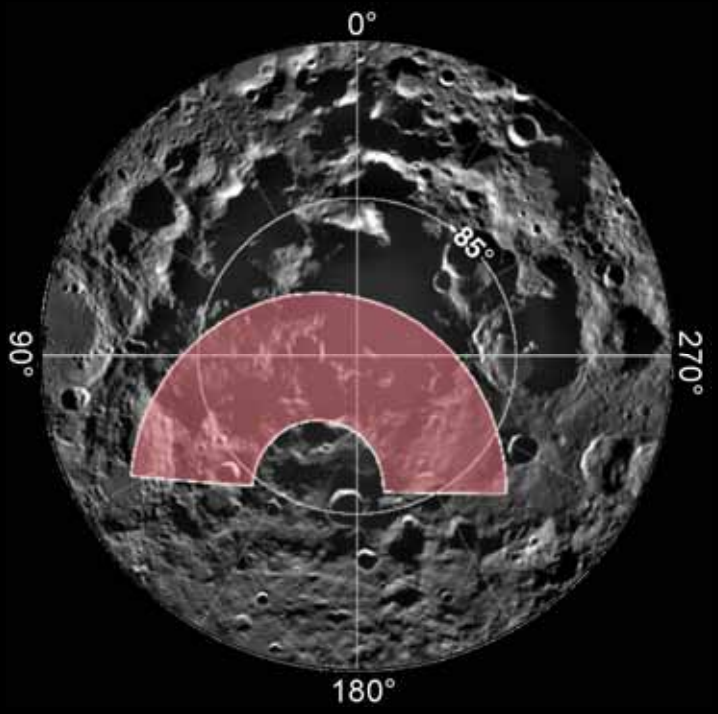

148
152
156
160
164
168
Epithermal neutrons (counts / 8-sec)
NORTH
> 70°
SOUTH
< -70°
180°
-135°
+135°
-90°
+90°
-45°
+45°
0°
0°
-45°
+45°
-90°
+90°
-135°
+135°
180°

Resources - Ice?



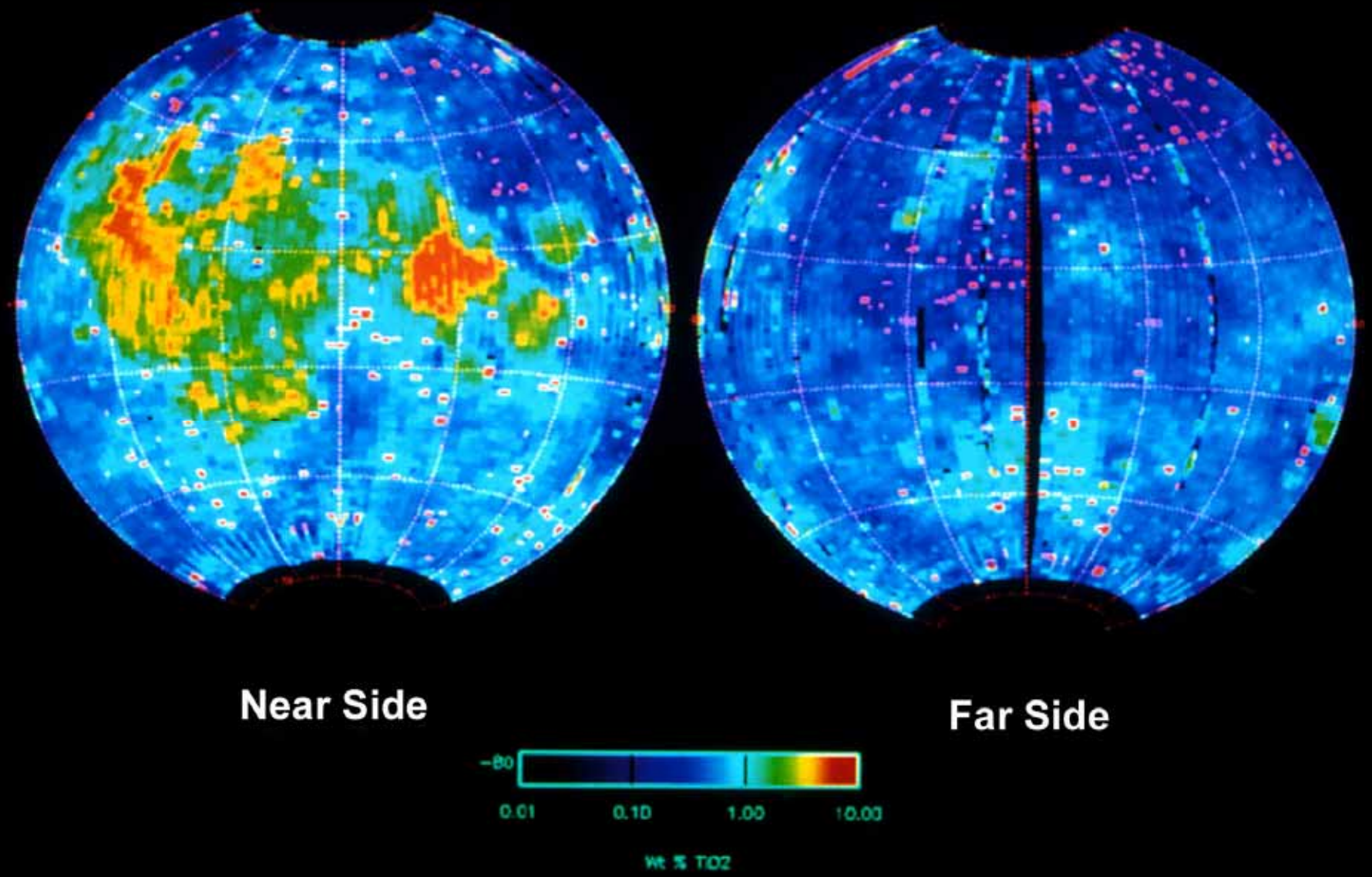


Margot et al. Earth-based radar

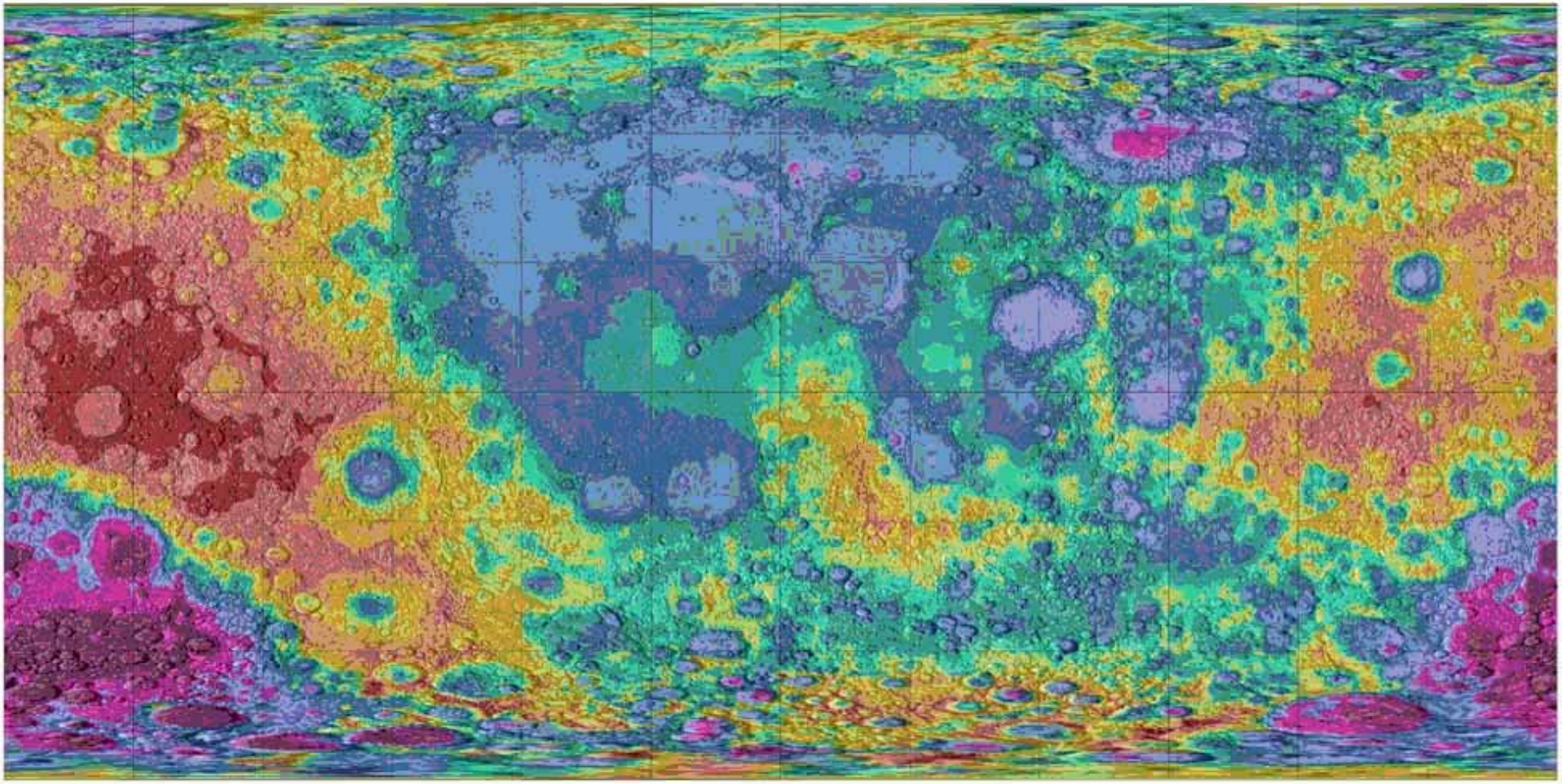


Clementine Bi-Static Experiment

Resources - Ti



Topography



Radii (km)

1,741.7 - 1,745.5	1,738.7 - 1,739.6	1,737.1 - 1,737.6	1,736.1 - 1,736.5	1,734.7 - 1,735.3	1,732.7 - 1,733.6	WORLD30
1,739.7 - 1,741.6	1,737.7 - 1,738.6	1,736.6 - 1,737	1,735.4 - 1,736	1,733.7 - 1,734.6	1,728.2 - 1,732.6	

Science

Science of, from and on the Moon

- NRC Decadal Survey
- LEAG
- NASA Advisory Council

Not a driver, but at present, can not provide constraints.

Commercial

Propellant production

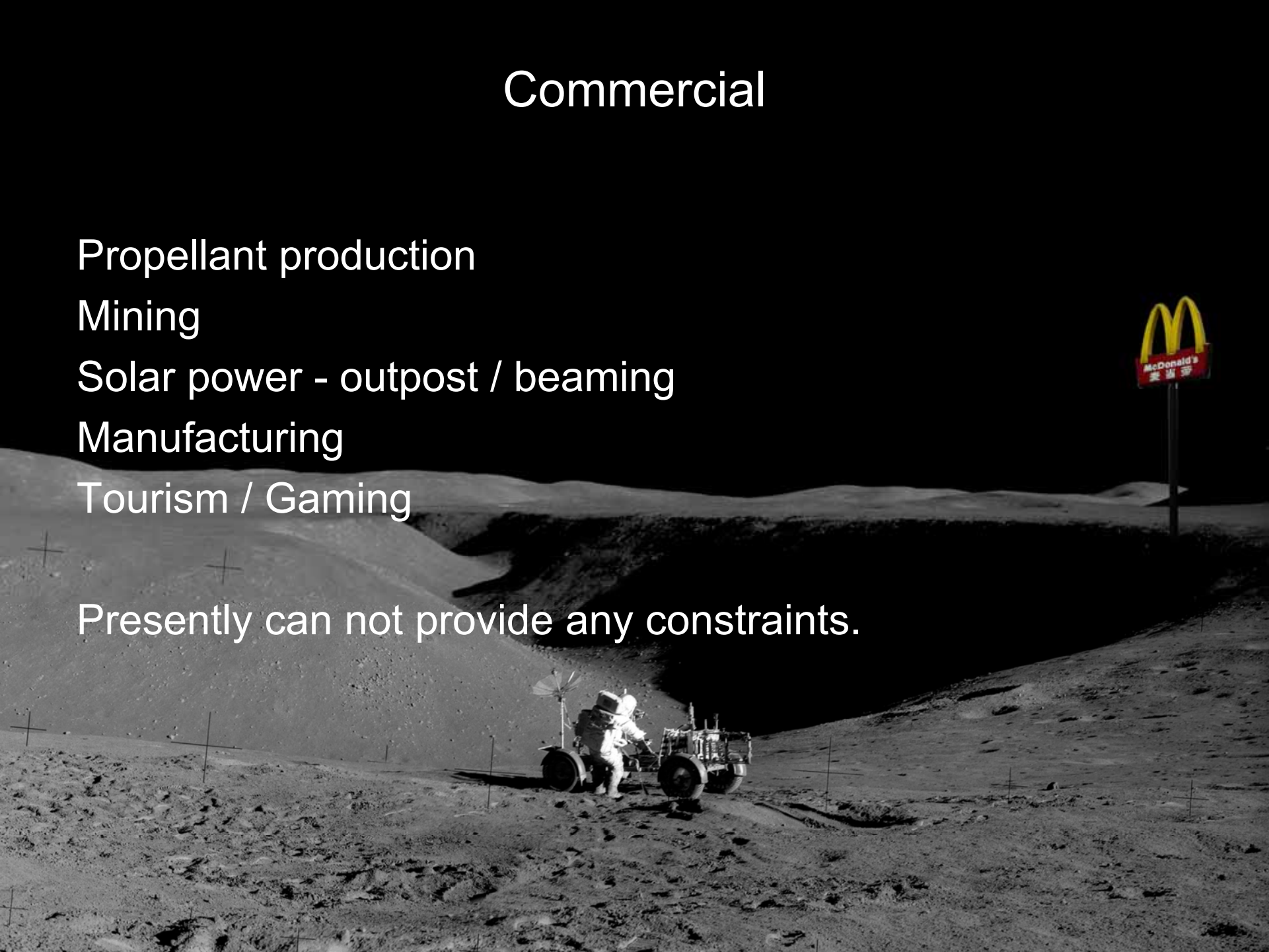
Mining

Solar power - outpost / beaming

Manufacturing

Tourism / Gaming

Presently can not provide any constraints.



What Really Needs to Be Measured at the Moon?

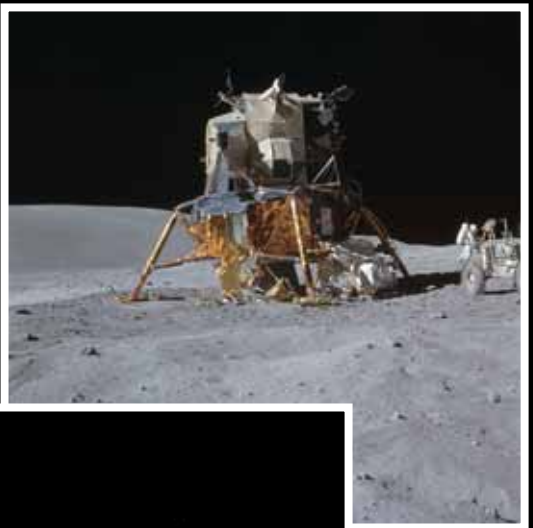
Risk Reduction / Cost Control / Optimization

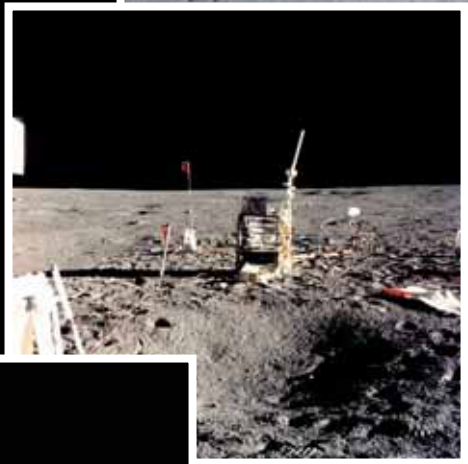
Apollo-like Sortie

- Polar
  - Geodetic control – enabling
  - Topography - enabling
  - High-resolution imaging (hazards) - enhancing
- Non-Polar
  - Nothing – enabling
  - High-resolution imaging (hazards) - enhancing

Outpost – Being There (Just land safely)

- Polar
  - Topography - enabling
  - Geodetic control – enabling
  - Lighting model – enhancing
  - High-resolution imaging - enhancing
- Non-Polar
  - Nothing – enabling
  - High-resolution imaging – enhancing
- Global
  - Dust toxicity – TBD
  - Electrical charging – TBD





What Really Needs to be Measured at the Moon?

Outpost with Resource Utilization

- Resource distribution (ore characterization)
  - H form, concentration, distribution in polar regions (lighted and shadowed)
  - Highlands composition
  - Pyroclastic composition
  - Regolith physical properties
    - Pyroclastic deposits
    - Permanently shadowed

- Polar
  - Topography - enabling
  - Geodetic control – enabling
  - Lighting model – enhancing
  - High-resolution imaging - enhancing
- Non-Polar
  - High-resolution imaging – enhancing
- Global
  - Dust toxicity – TBD
  - Electrical charging – TBD