THE ROLE OF LUNAR SIMULANTS VERSUS APOLLO SAMPLES IN ISRU ACTIVITIES

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The Greatest Deterrent to the Production of Suitable Lunar Regolith Simulants?

Literally DOZENS of Lunar Simulants Exist!

a General Lack of Knowledge of Lunar Sample Chemical and Physical Characteristics!!

TWO PRIMARY TYPES of TERRAIN on the MOON:

1) the heavily cratered and very old **highlands**, and
2) the relatively smooth and younger **maria.**

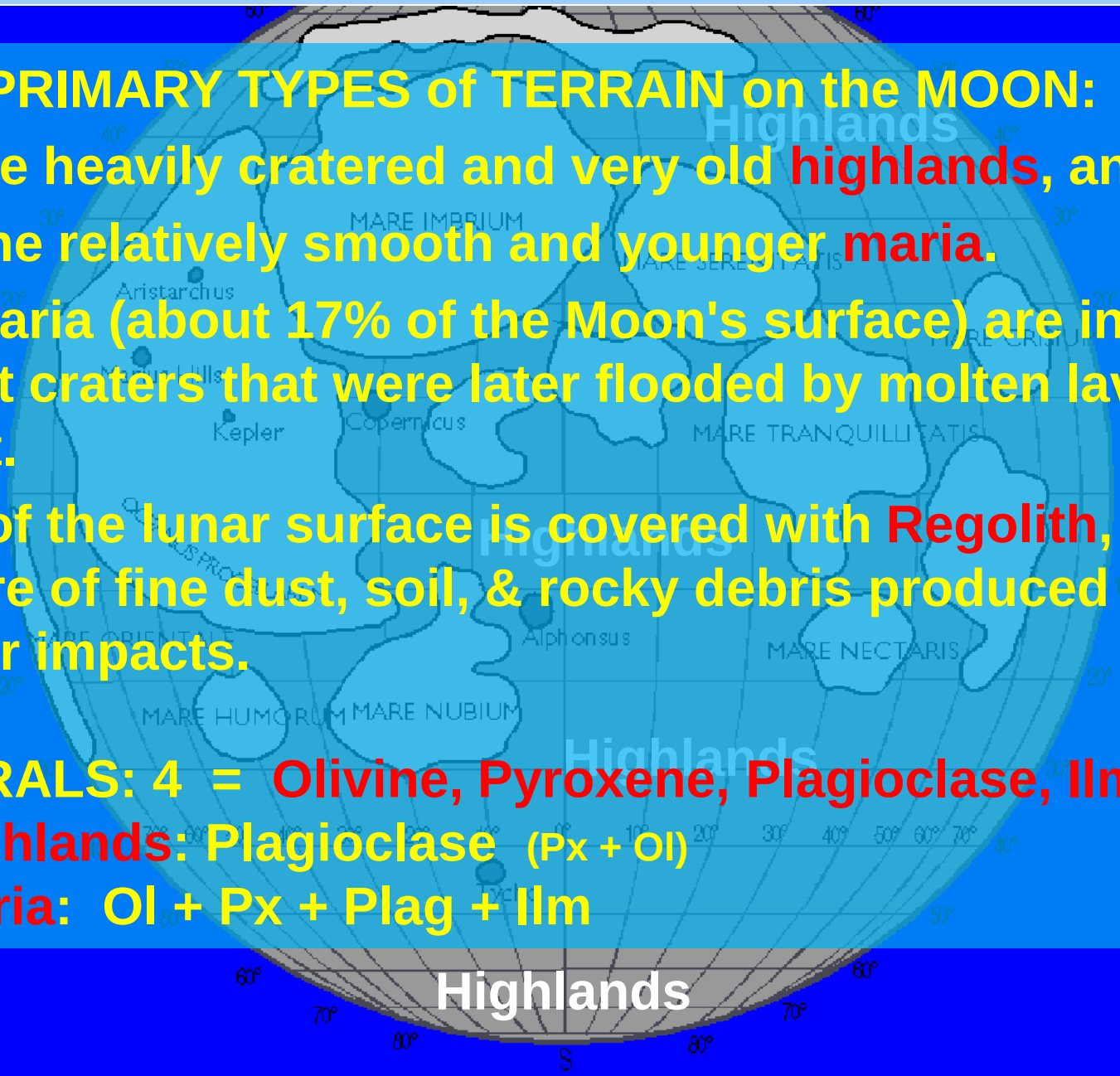
The maria (about 17% of the Moon's surface) are in huge impact craters that were later flooded by molten lava = Basalt.

Most of the lunar surface is covered with **Regolith**, a mixture of fine dust, soil, & rocky debris produced by meteor impacts.

MINERALS: 4 = **Olivine, Pyroxene, Plagioclase, Ilmenite**

Highlands: Plagioclase (Px + Ol)

Maria: Ol + Px + Plag + Ilm



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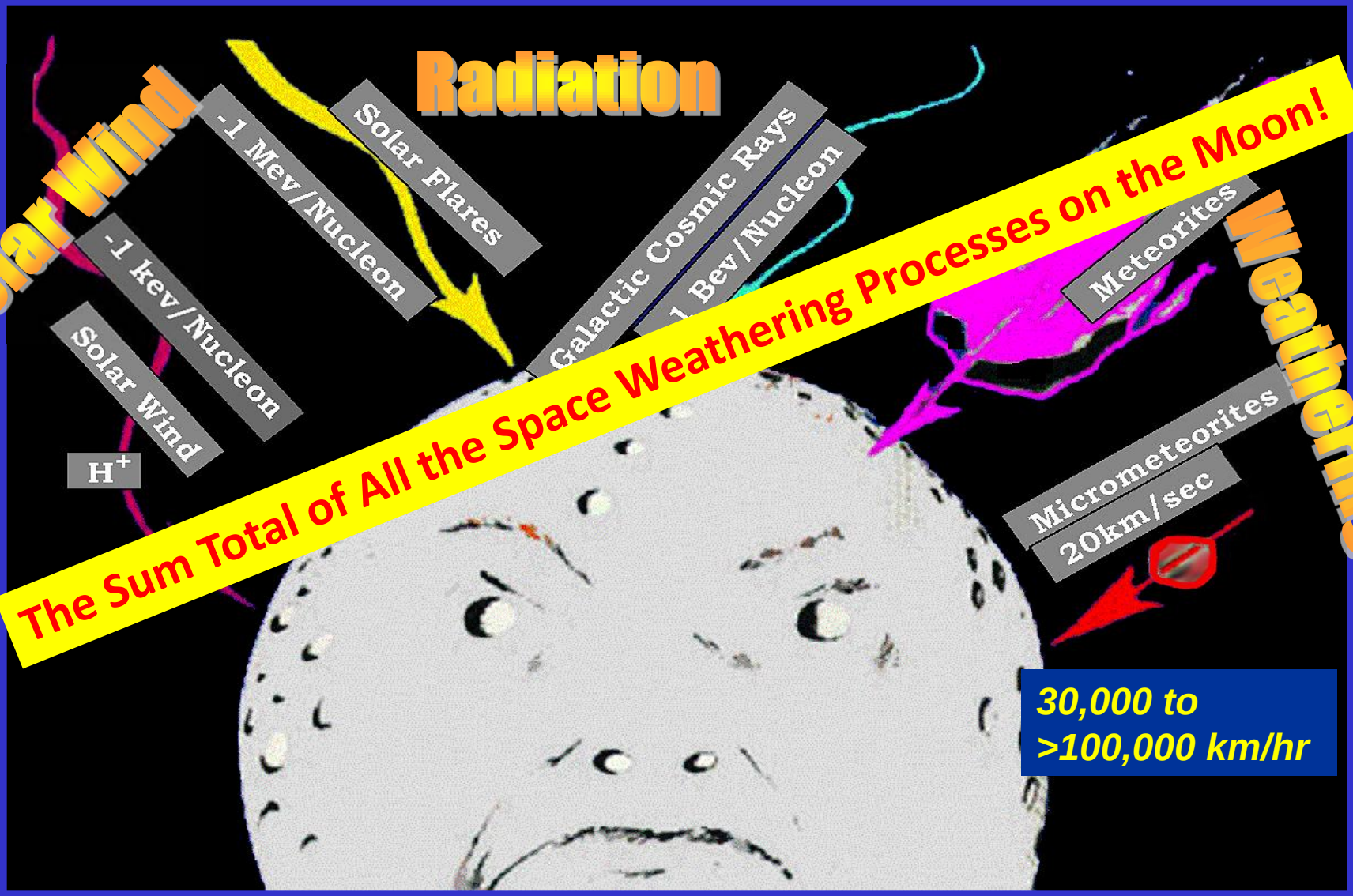
Our Unhappy Moon



The Sum Total of All the Space Weathering Processes on the Moon!

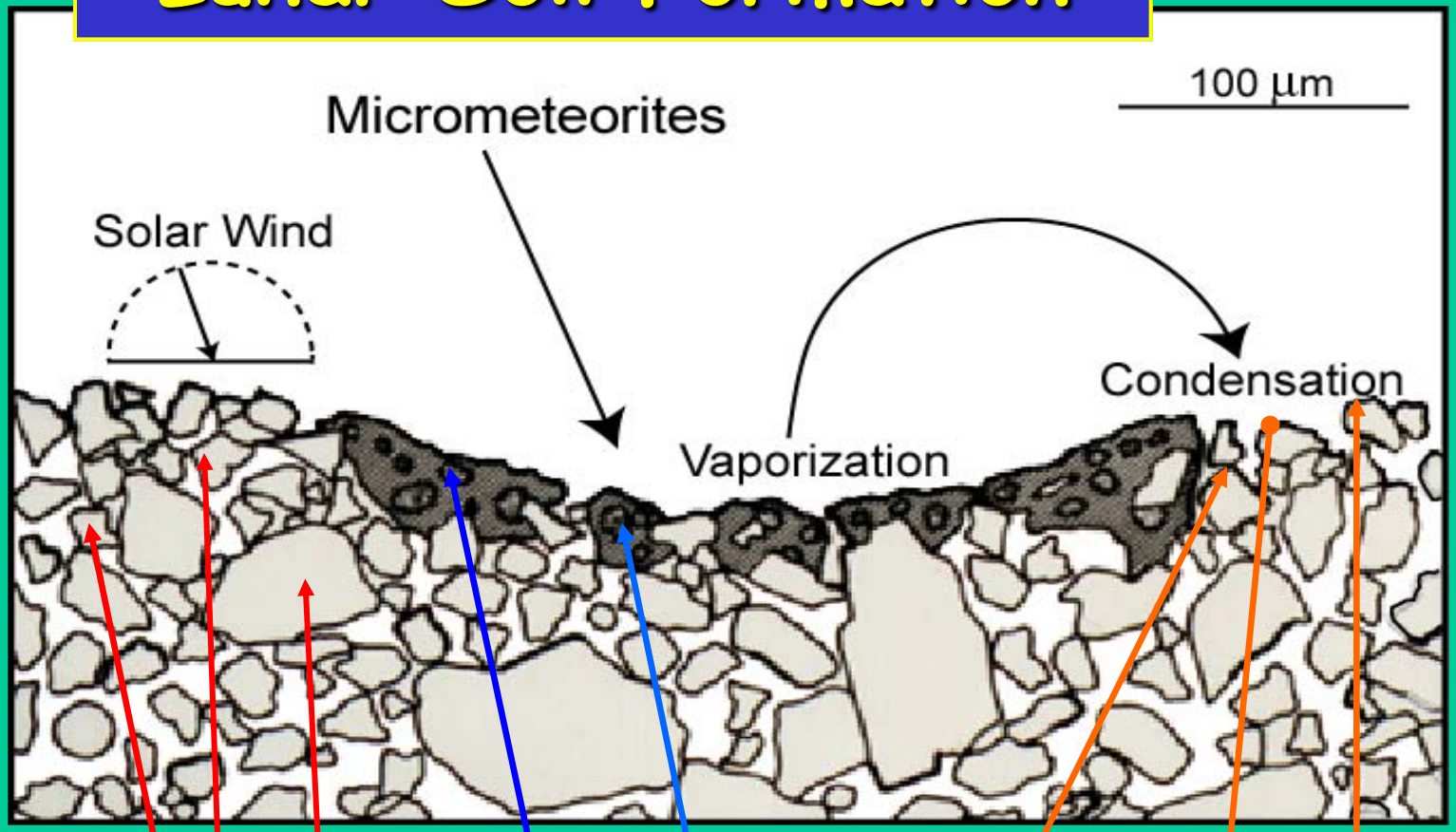
Concentrations of Solar-Wind Volatile Species in Lunar Regolith Samples, in ppm

	H	He	C	N	Ne	Ar
Apollo 11	20-100	20-84	96-216	45-110	2-11	1.3-12
Apollo 12	2-106	14-68	23-170	46-140	1.2-6	0.5-4.6
Apollo 14	67-105	5-16	42-225	25-130	0.14-1.6	0.4-2.2
Apollo 15	13-125	5-19	21-186	33-135	0.6-108	0.5-2.7
Apollo 16	4-146	3-36	31-280	4-209	0.4-1.2	0.6-3
Apollo 17	1-206	13-41	4-200	7-94	1.2-2.7	0.6-2.6

100 parts per million = 0.01 wt%

Haskin and Warren, 1991

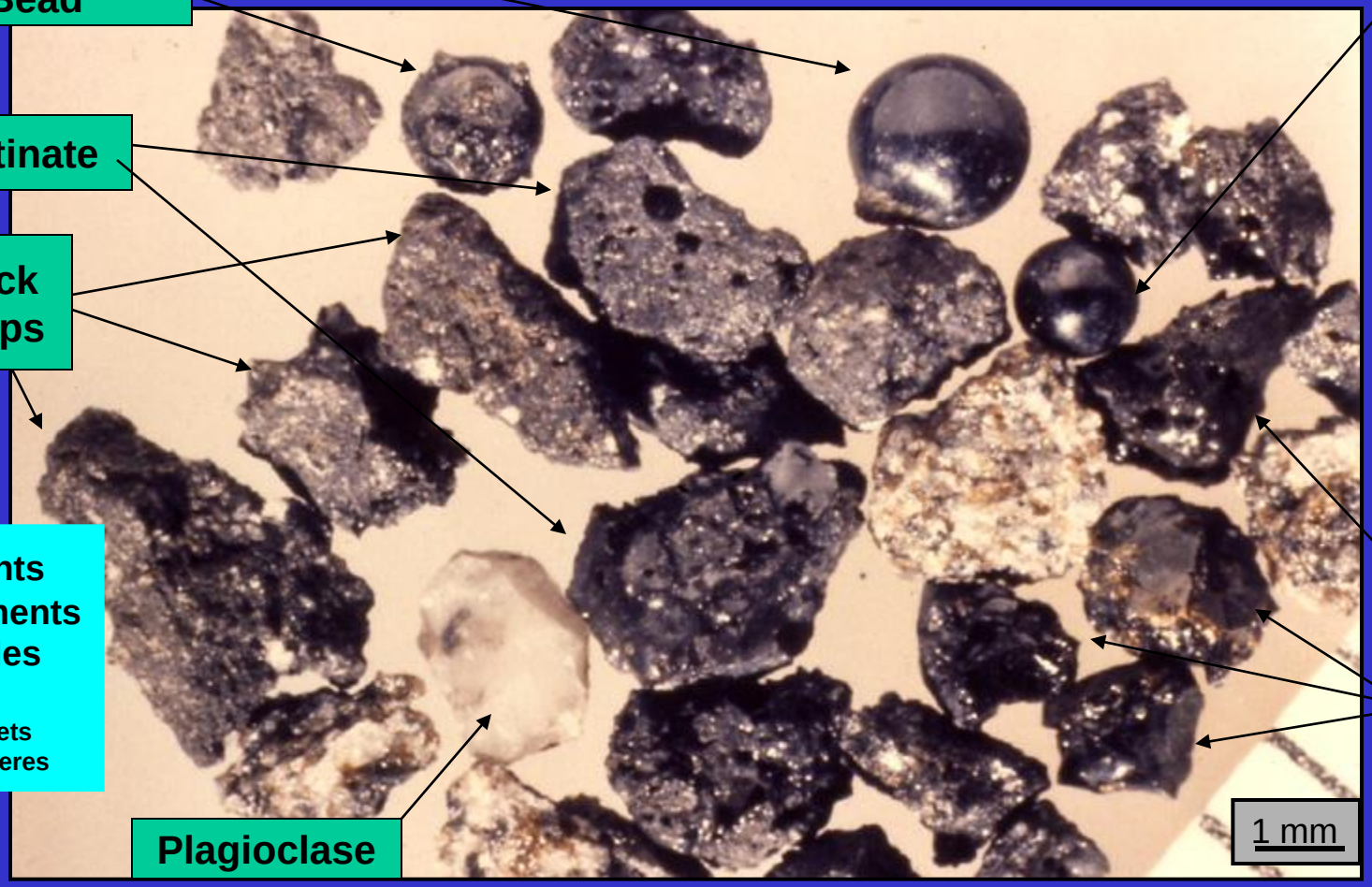
Lunar Soil Formation



Comminution, Agglutination, & Vapor Deposition

The major Weathering and Erosional agent on the Moon is
Meteorite / Micrometeorite Impacts

Lunar Mare Soil

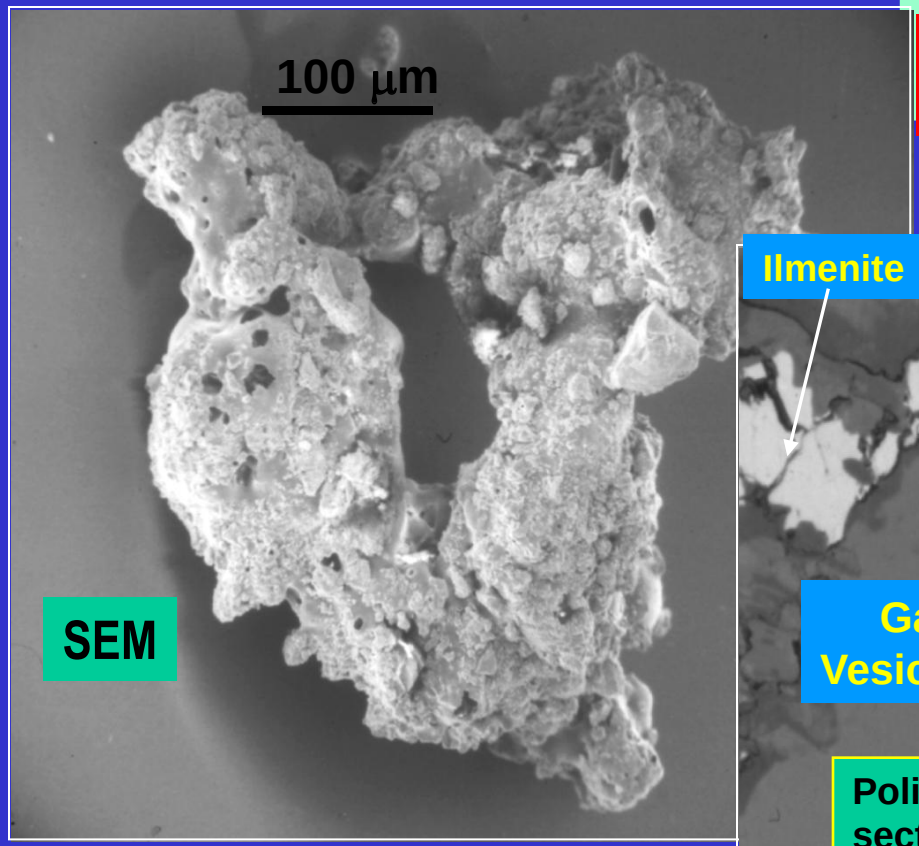


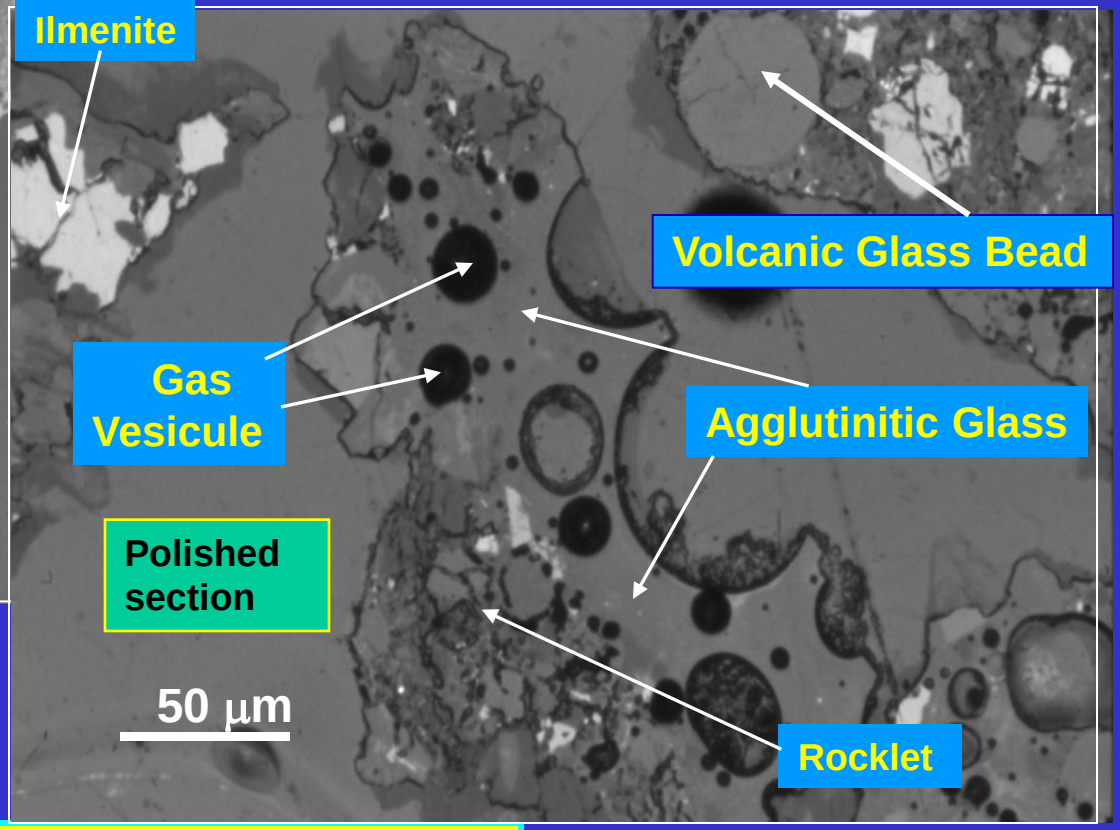
- Rock Fragments
- Mineral Fragments
- Glassy Particles

Agglutinates
Impact-Glass Droplets
Volcanic Glass Spheres

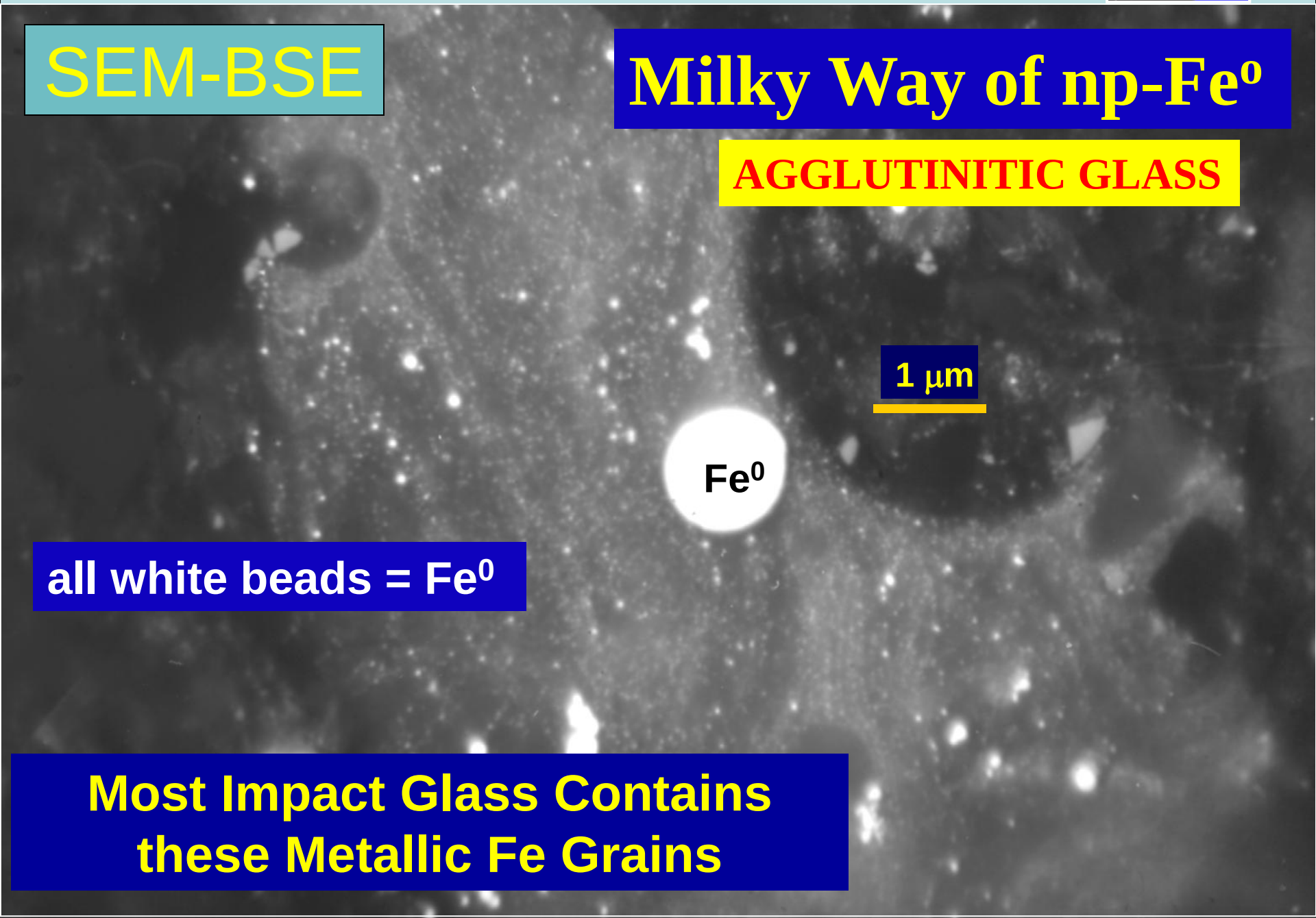
Regolith: broken up rock material; **'Soil':** <1 cm portion of the Regolith
Dust: < 20 μm portion of the Soil

Agglutinates





Pieces of minerals, rocklets, and glass welded together by shock-melt glass


SEM-BSE
Milky Way of np-Fe^0
AGGLUTINITIC GLASS
1 μm
Fe^0
all white beads = Fe^0
Most Impact Glass Contains these Metallic Fe Grains

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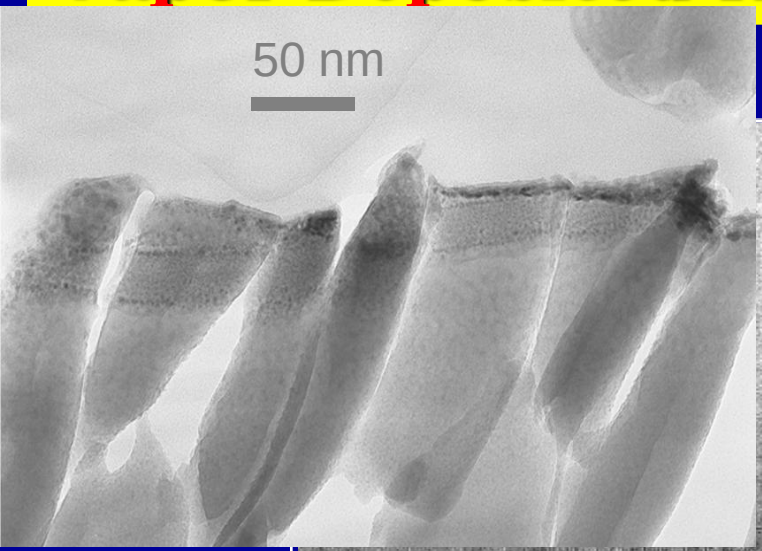
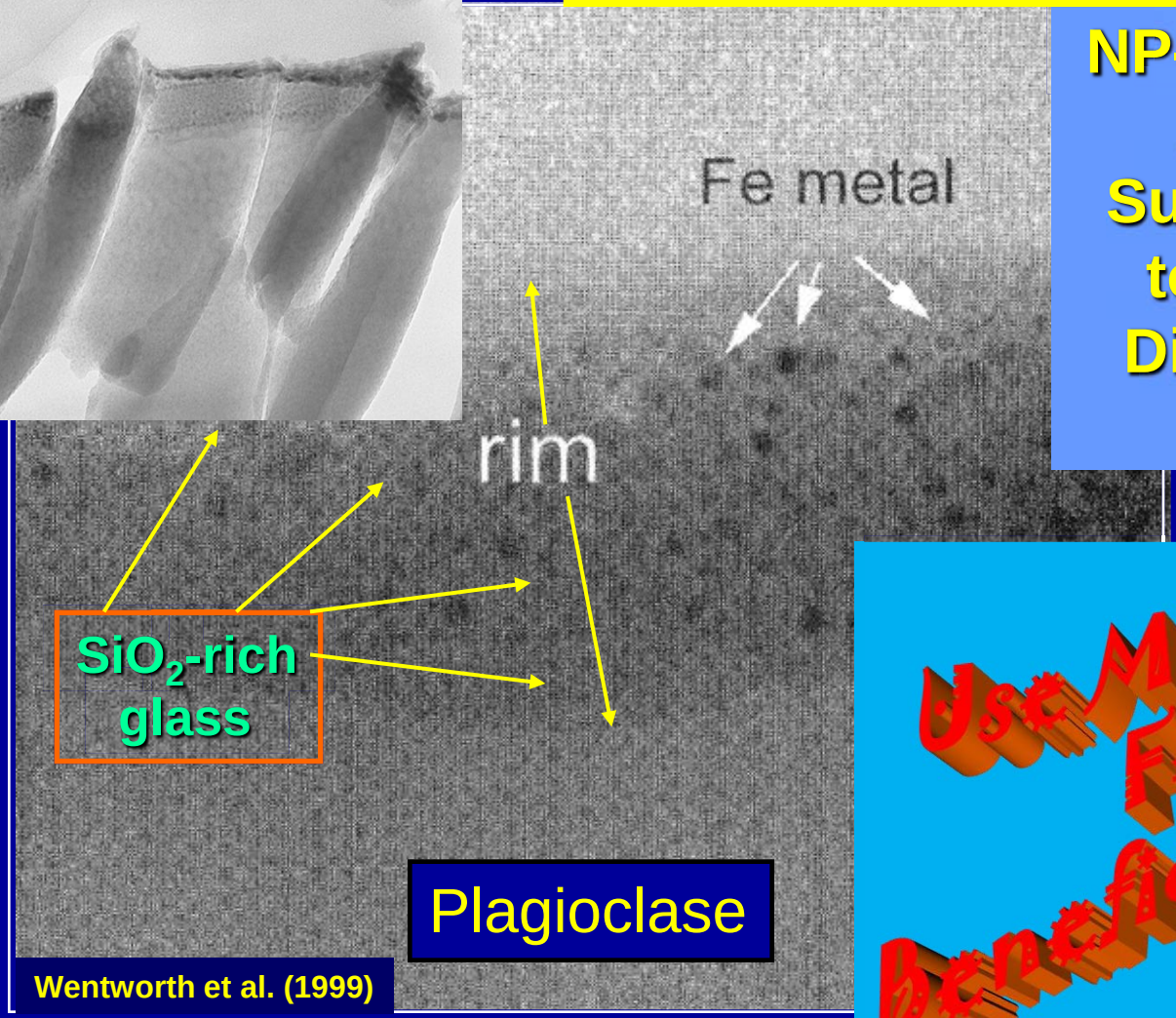
Vapor-Deposited Nanophase Fe° on Plagioclase



TEM: (all black spots = np-Fe)



Wentworth et al. (1999)

NP-Fe^0 Imparts Magnetic Susceptability to Normally Diamagnetic Feldspar

Use Magnets For Beneficiation!!

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Lunar Soil

Microwave Heating of Lunar Soil

NanoPhase Fe^0 in Silicate Glass

so small as to be below the effective "skin depth" of microwave penetration; makes for

GREAT MICROWAVE COUPLING!

Lunar soil in your kitchen microwave oven will melt [~1200 ^{0}C], BEFORE your tea-water boils [100 ^{0}C]!!

(Taylor and Meek, 2005, Jour. Aerspace Engr.)

UNIQUE LUNAR SOIL PROPERTIES

Reduced Nature: Fe^0; no Fe^{3+}; ilmenite beneficiation?

All Lunar Rocks contain metallic Fe as a normal phase

Glass and Agglutinates: Not just glass, texture

Lunar Dust: PSD, morphology, 70-90% glass

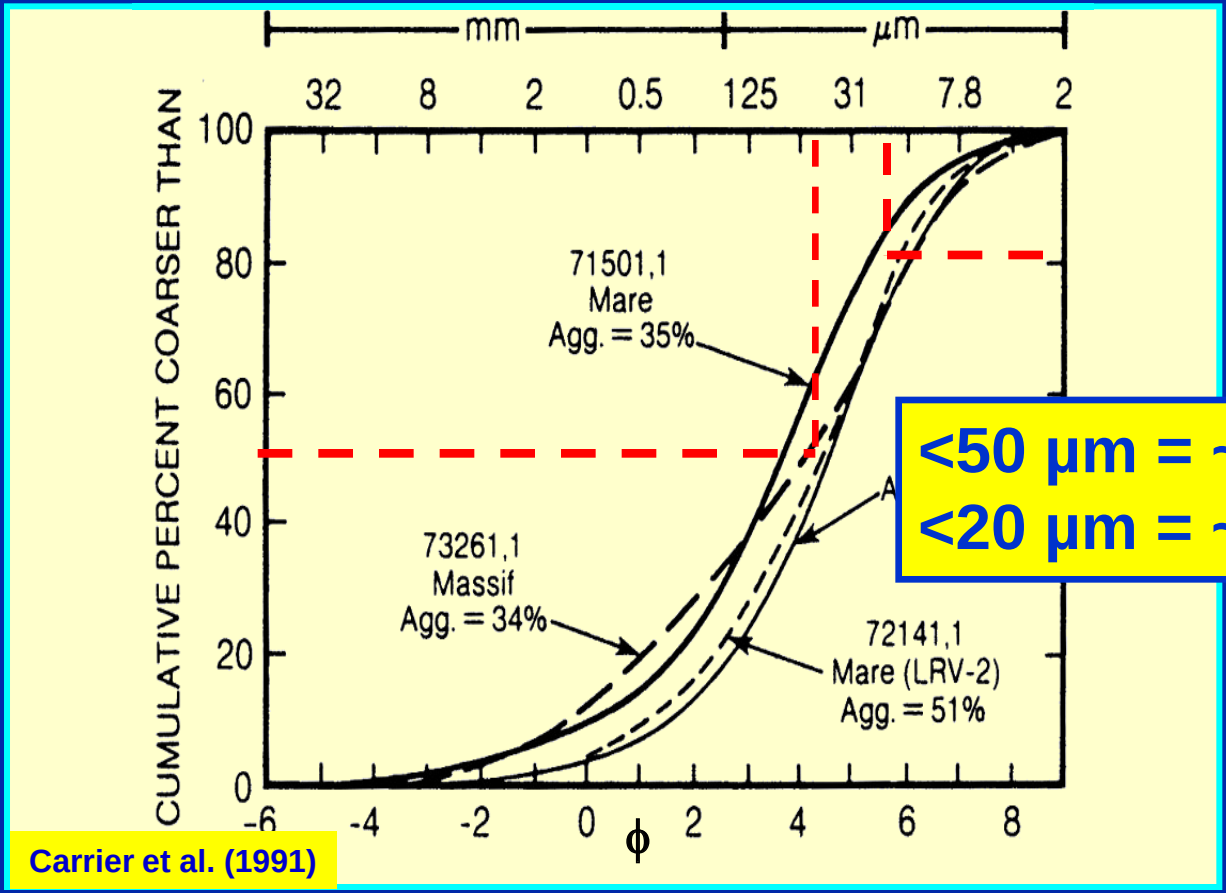
Nanophase Fe: proper size distribution; no magnetite

Magnetic Properties: not from Fe^{3+} phases

No Hydrated Alteration: clays, goethite

REVIEW

Mare Soil Particle Size Distribution



Carrier et al. (1991)

<50 μm = ~50 wt%
<20 μm = ~20 wt%

Approximately 50 wt% of Lunar Soil is < 50 μm ;

DUST = <20 μm = ~20 wt% = >50% Impact Glass

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Wet Versus Dry

~450 mg
<1 mm lunar soil
DRY Sieved to <45 µm

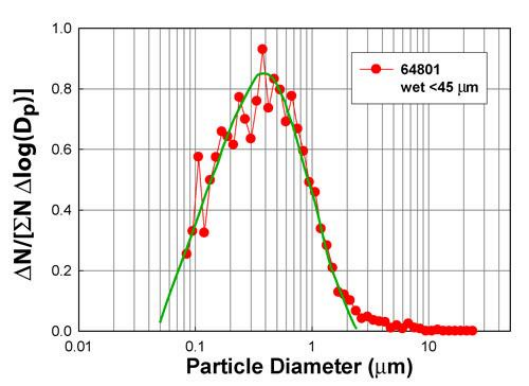
WET Sieved

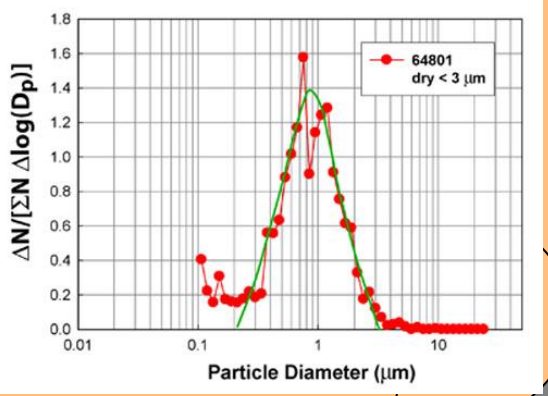
<3 µm
~30 mg

64501 - 71

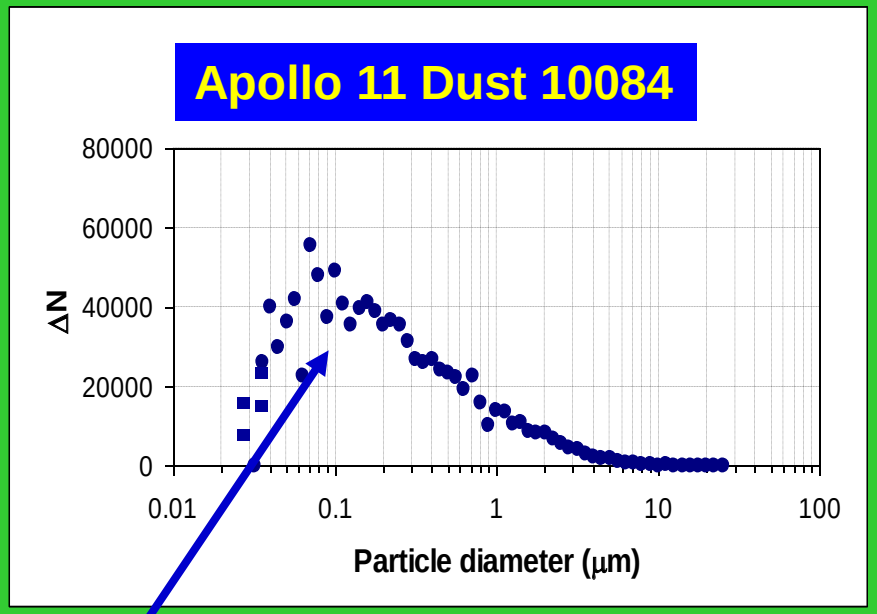
DRY Sieved

<3 µm
<10 mg





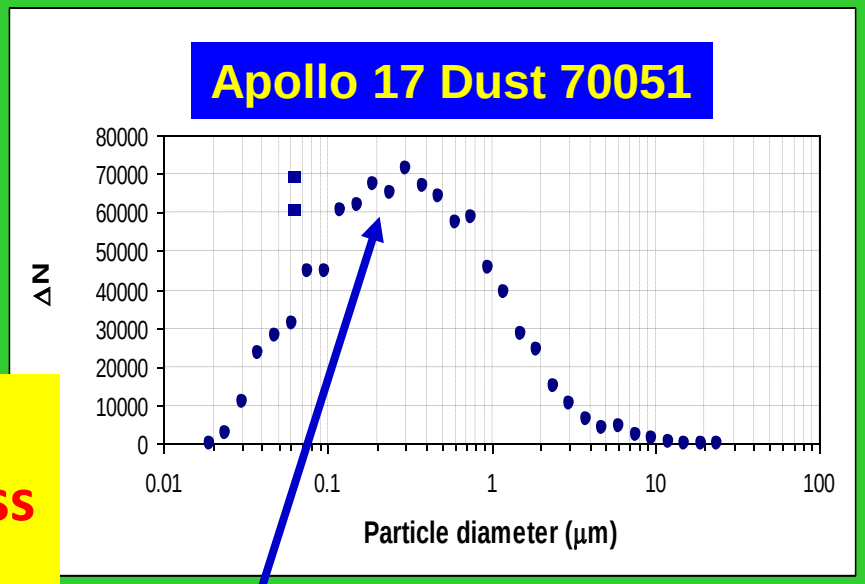
PSD OF LUNAR MARE DUST



Max Particles ~ 100 nm

PSD by SEM

Park et al. (2008)



Max Particles ~ 200 nm

Particle Size with the Largest Number of Grains / Mass is at 100-300 nm

LUNAR DUST

SO! Rather than Work with MSFC,

GRC Makes Their OWN DUST SIMULANTS!

Dirty Apollo 17 Aatronauts

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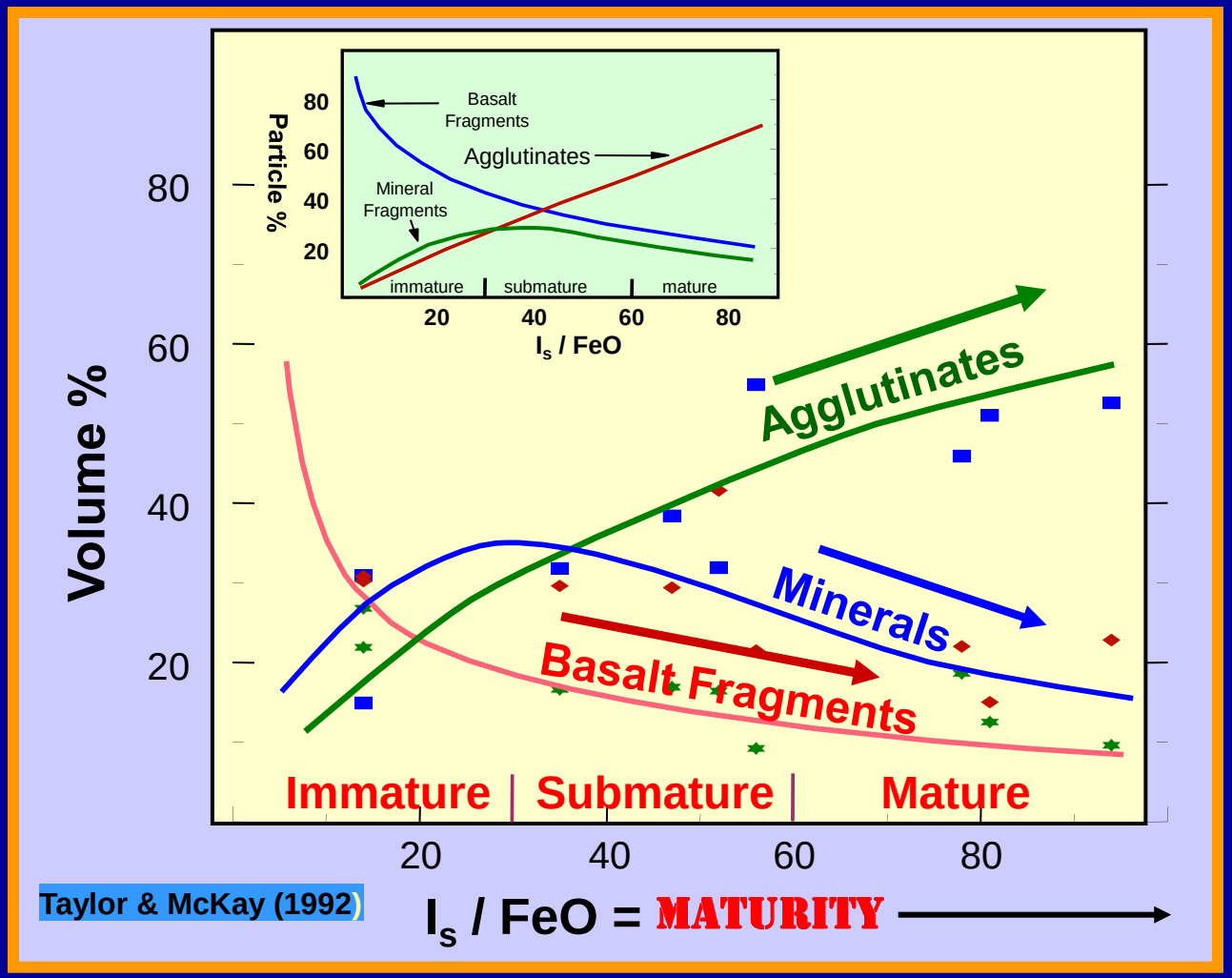
Soil Maturation of a Mare Soil



Taylor & McKay (1992)

Immature Soil is Better for Mineral Beneficiation Than Mature Soil!

EXPOSURE AGE →

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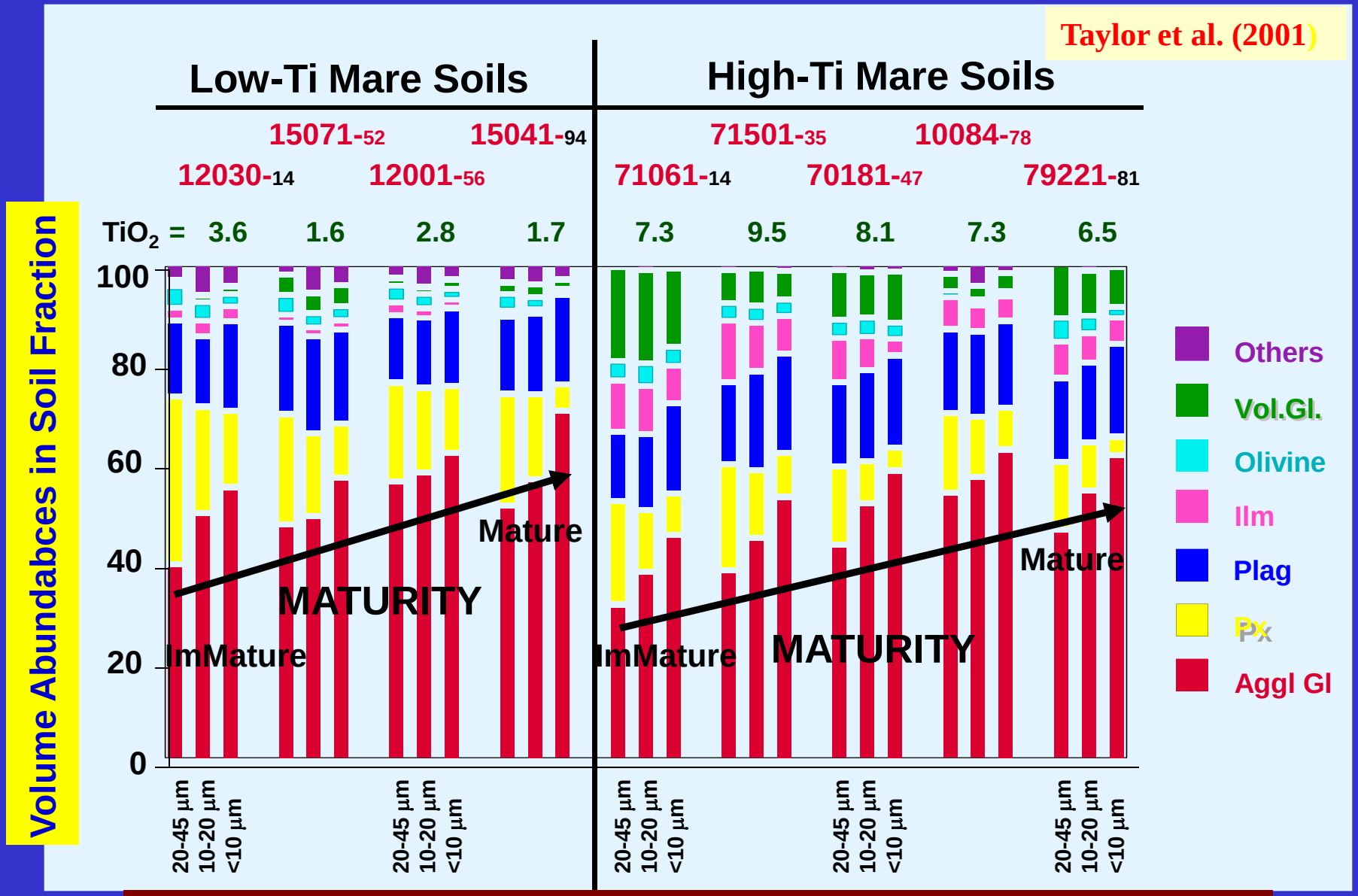
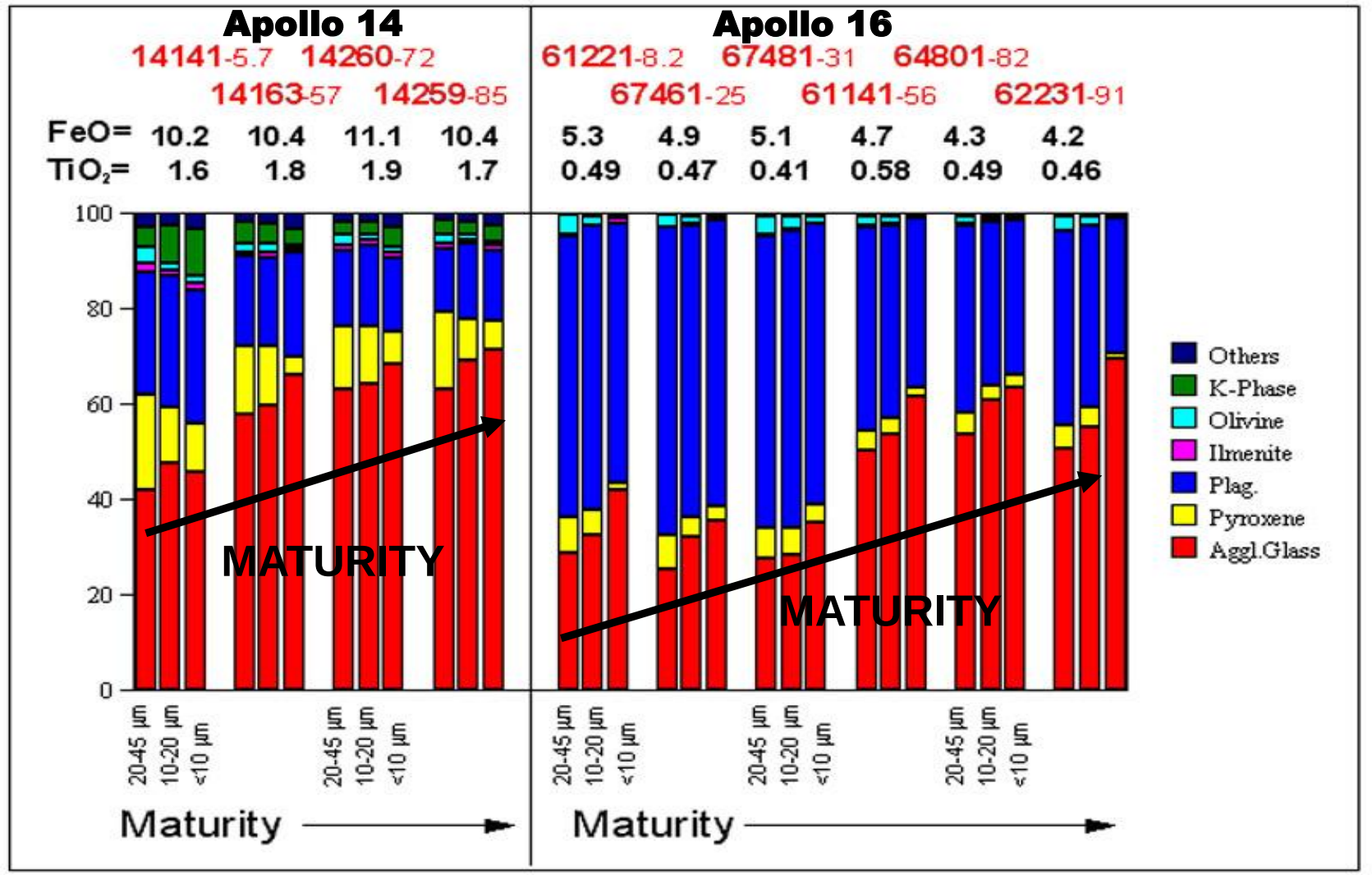


Glass abundances Increase as Grain-Size Decreases

Lunar Highland Soils

Taylor et al. (2010)

Volume Abundabces in Soil Fraction



Glass abundances Increase as Grain-Size Decreases

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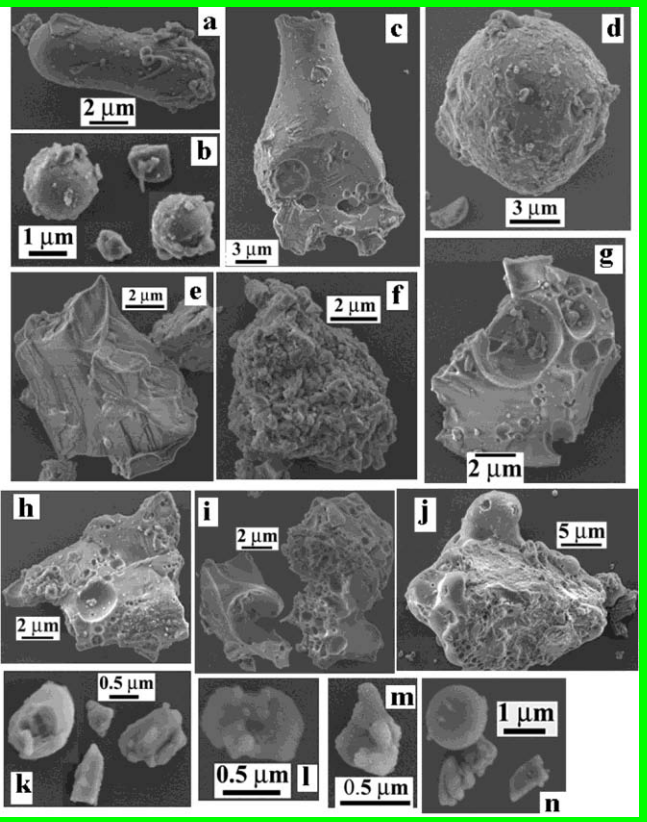
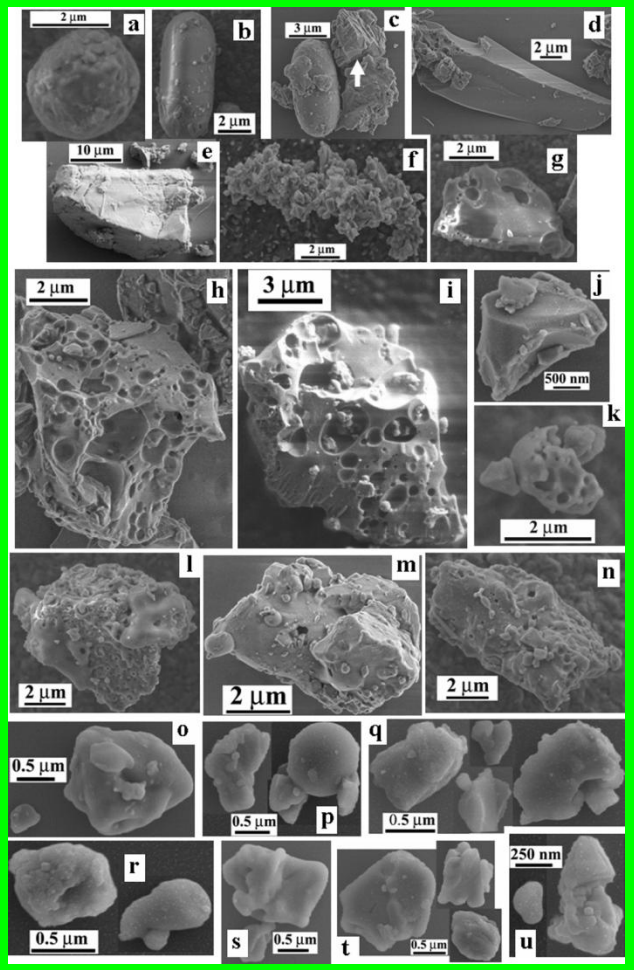
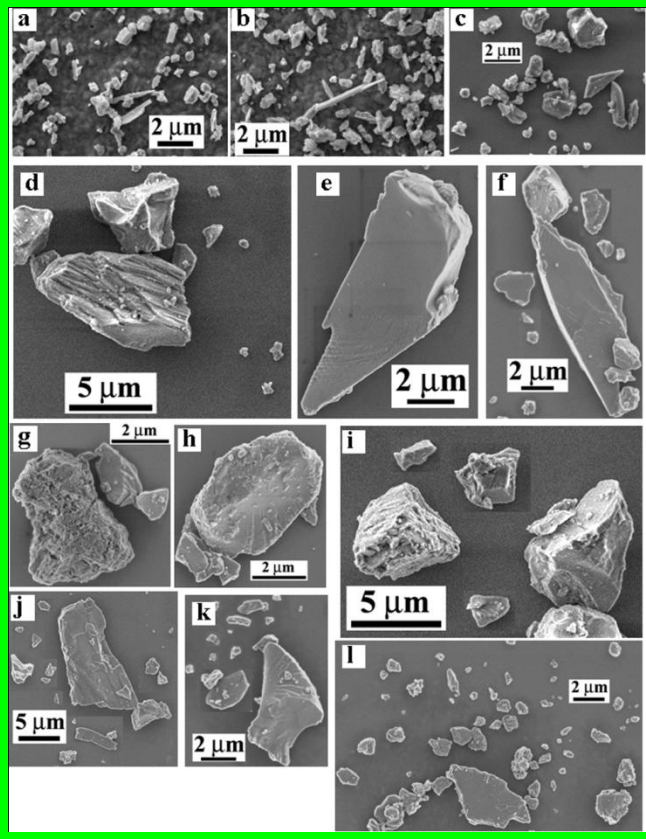
SEM Images



10084

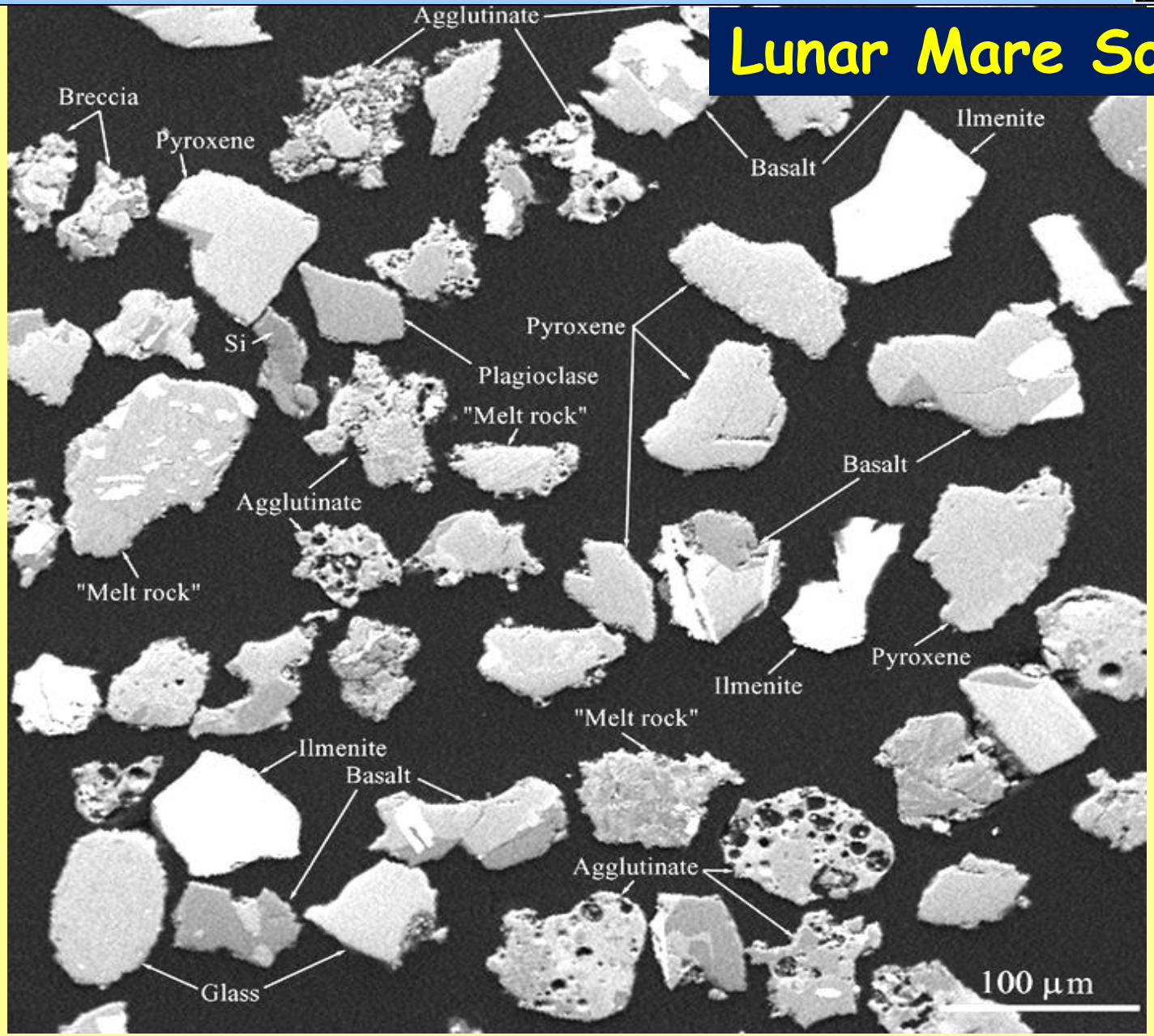
70051



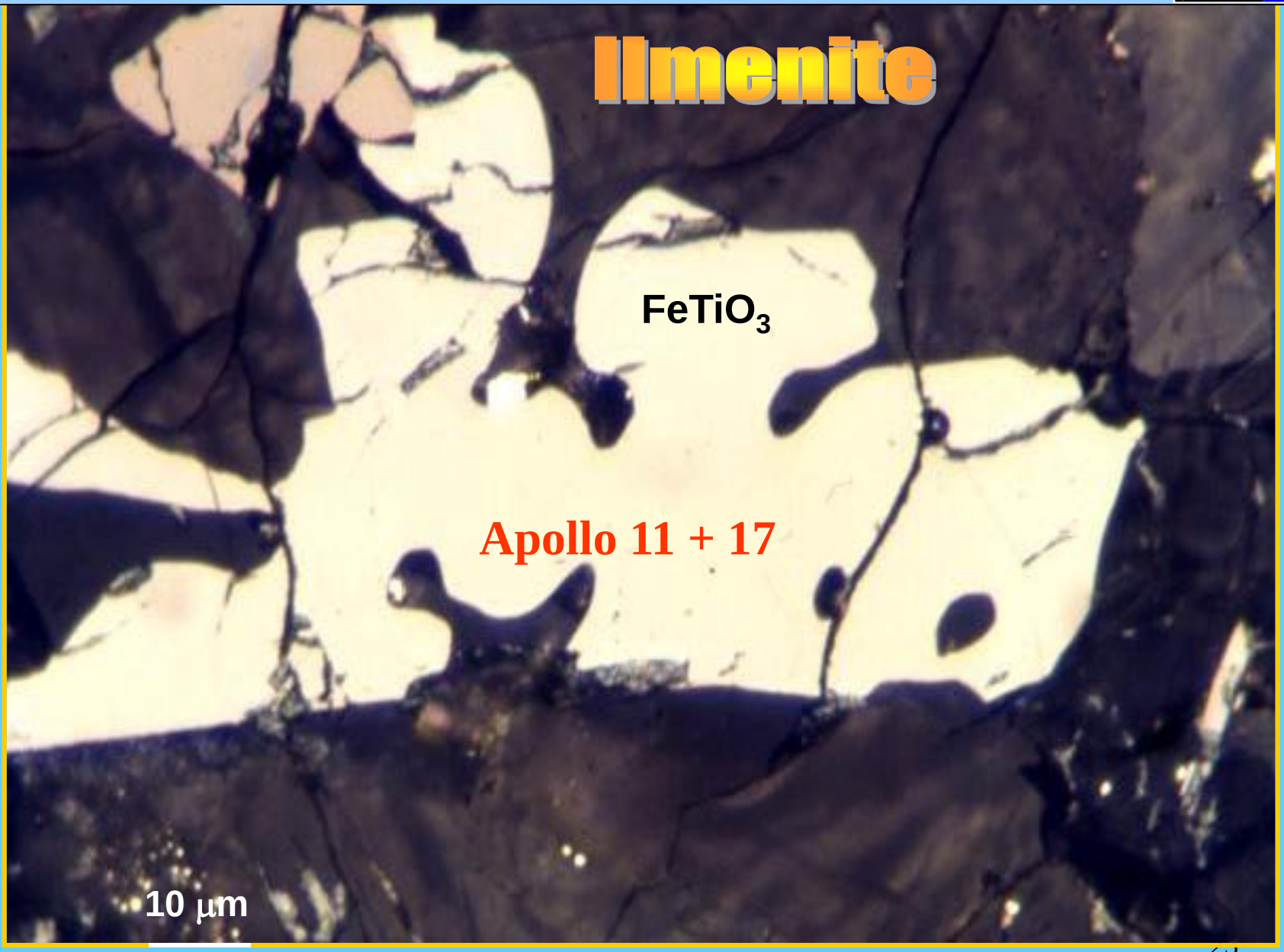


JSC-1Af

Lunar Mare Soil



Ilmenite



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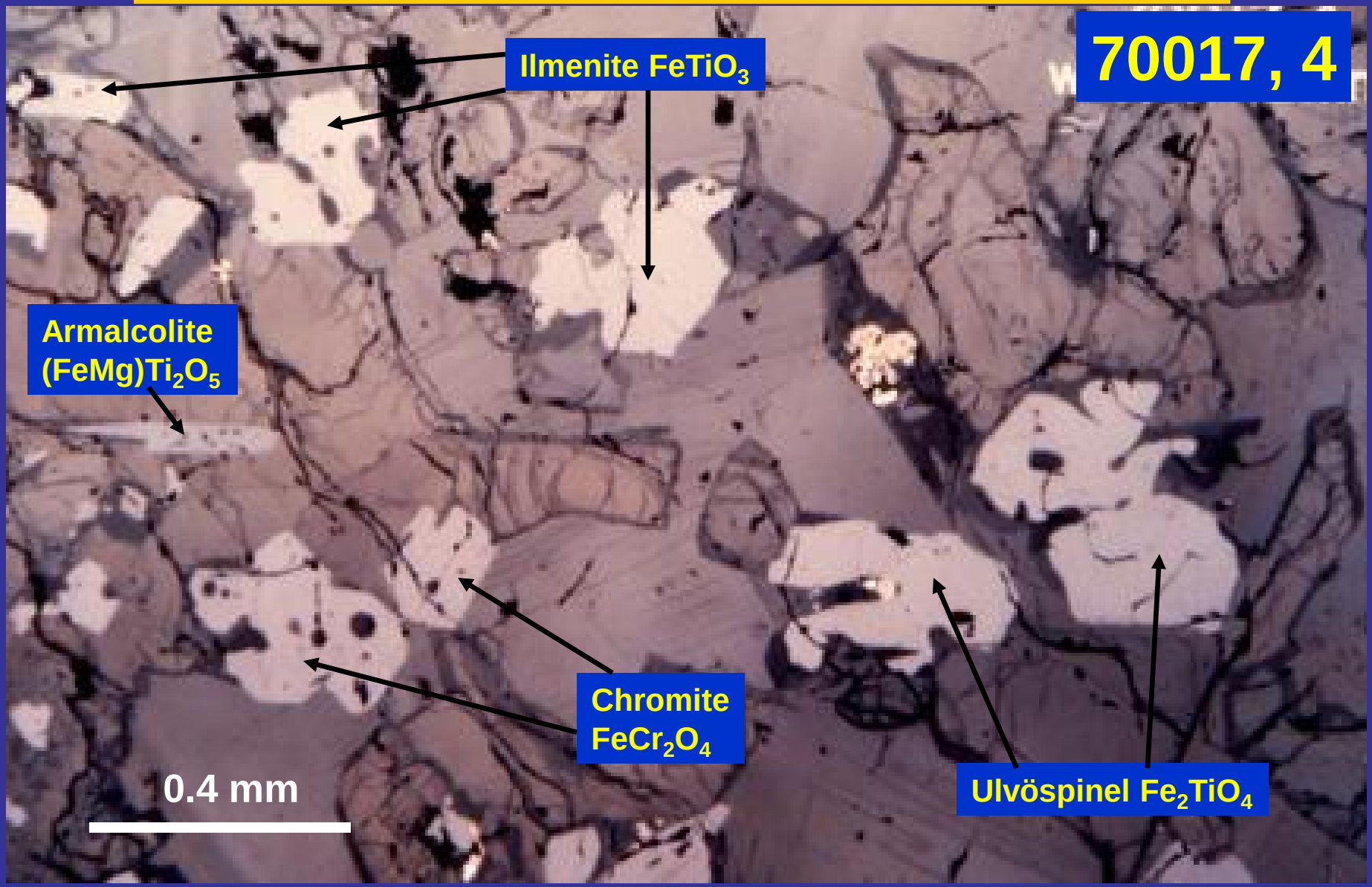
Apollo 17 High-Ti Basalt (reflected light)



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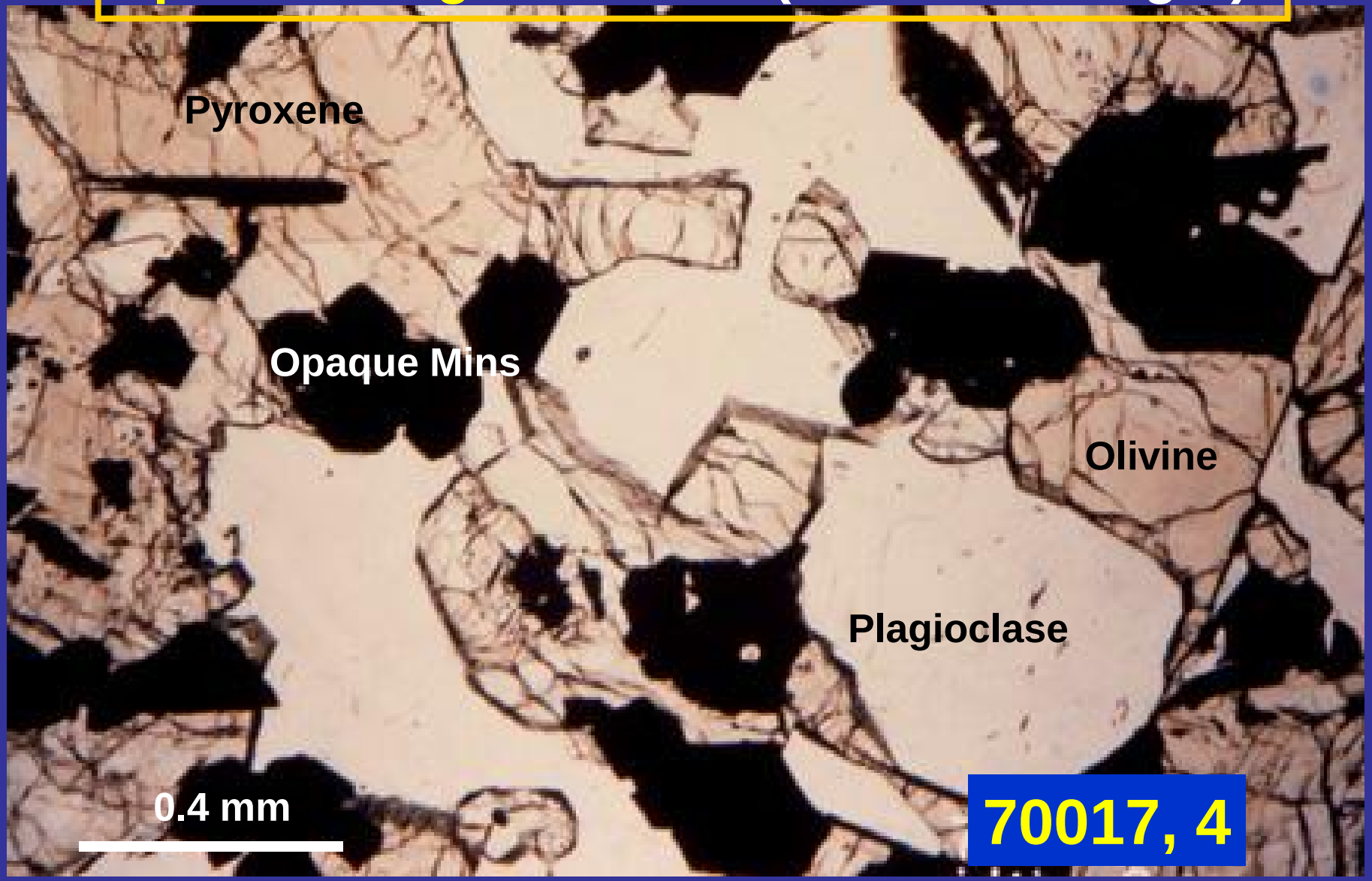
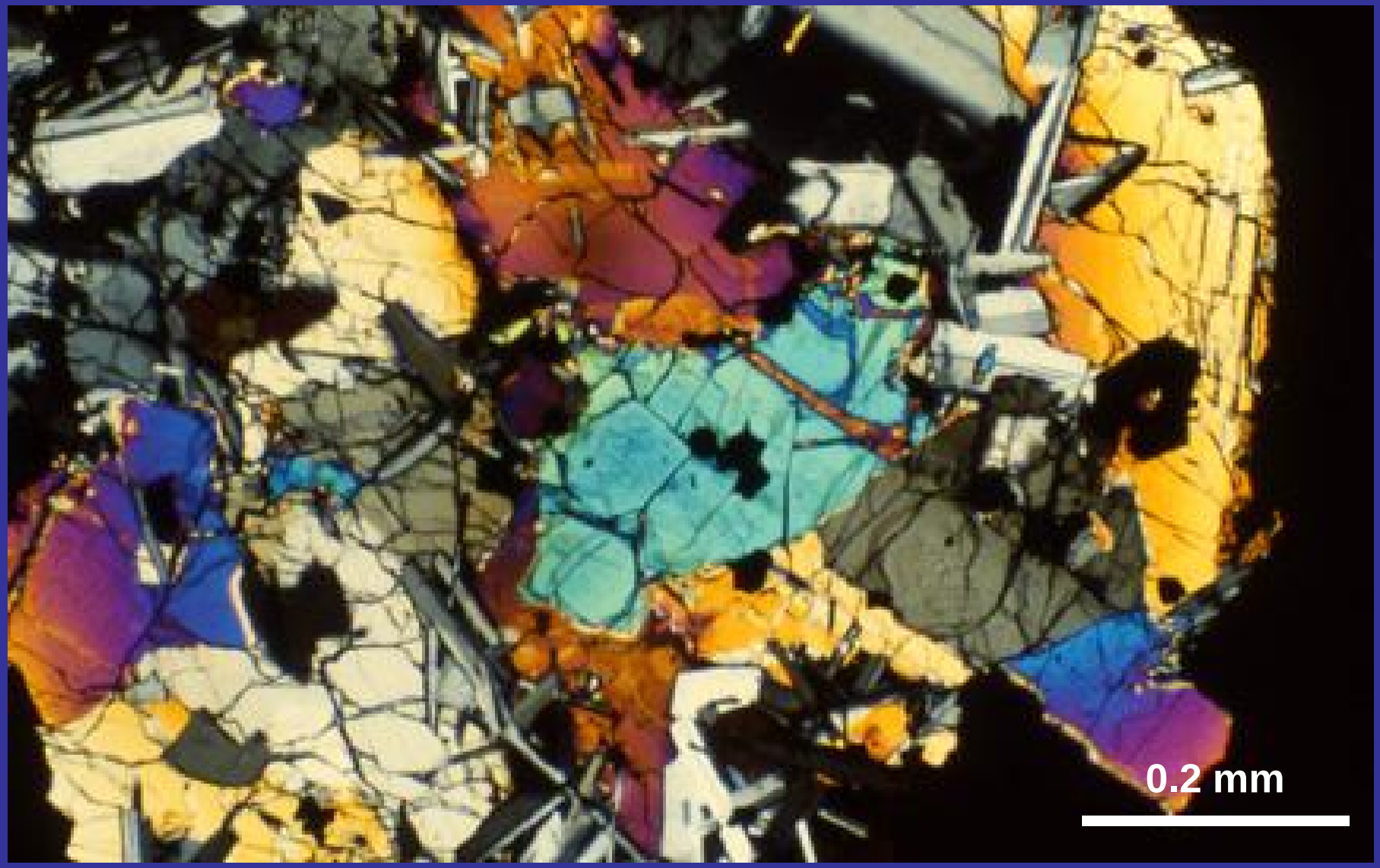
Apollo 17 High-Ti Basalt (transmitted light)



Apollo 15 Mare Basalt



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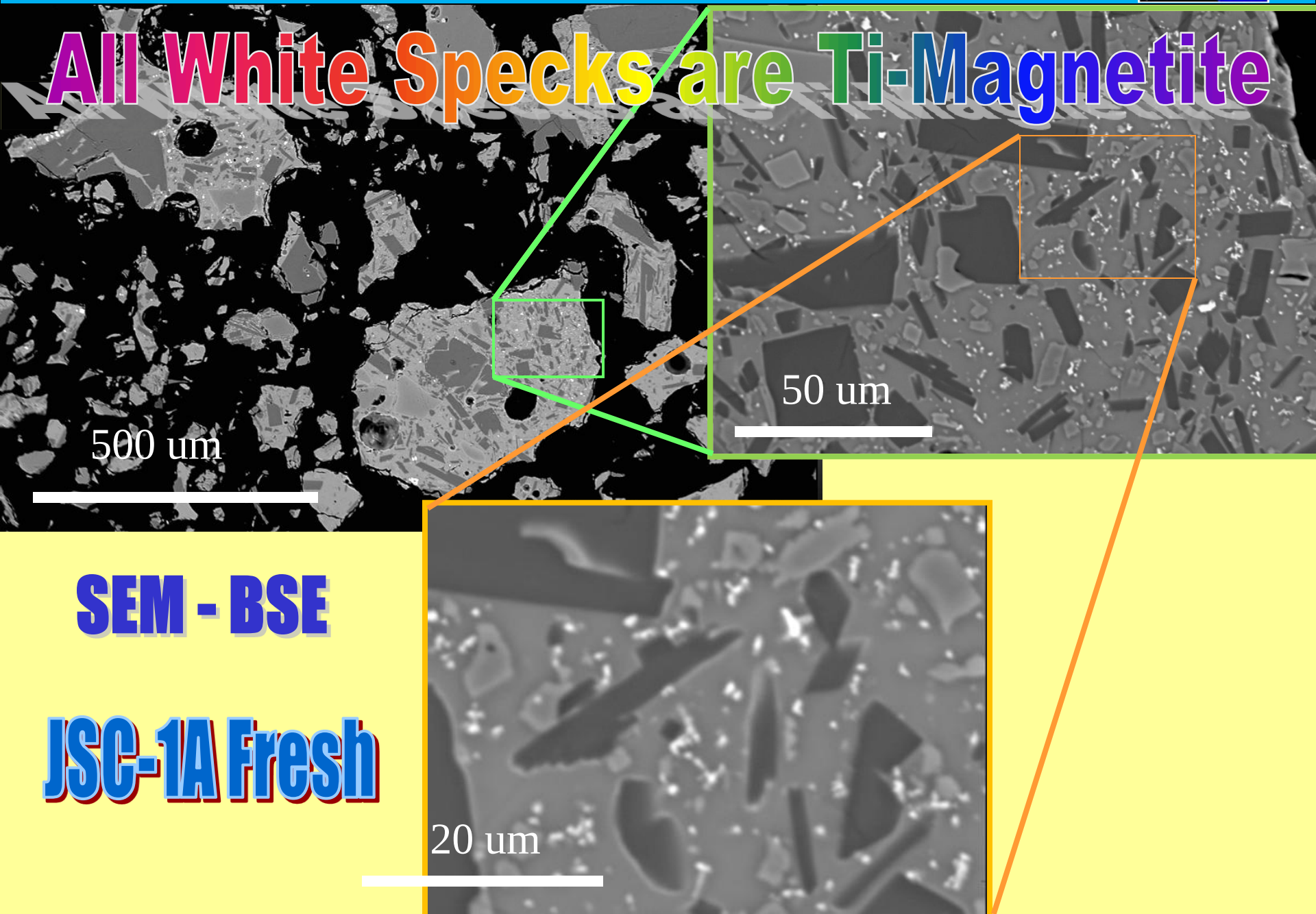
All White Specks are Ti-Magnetite



SEM - BSE

JSC-1A Fresh

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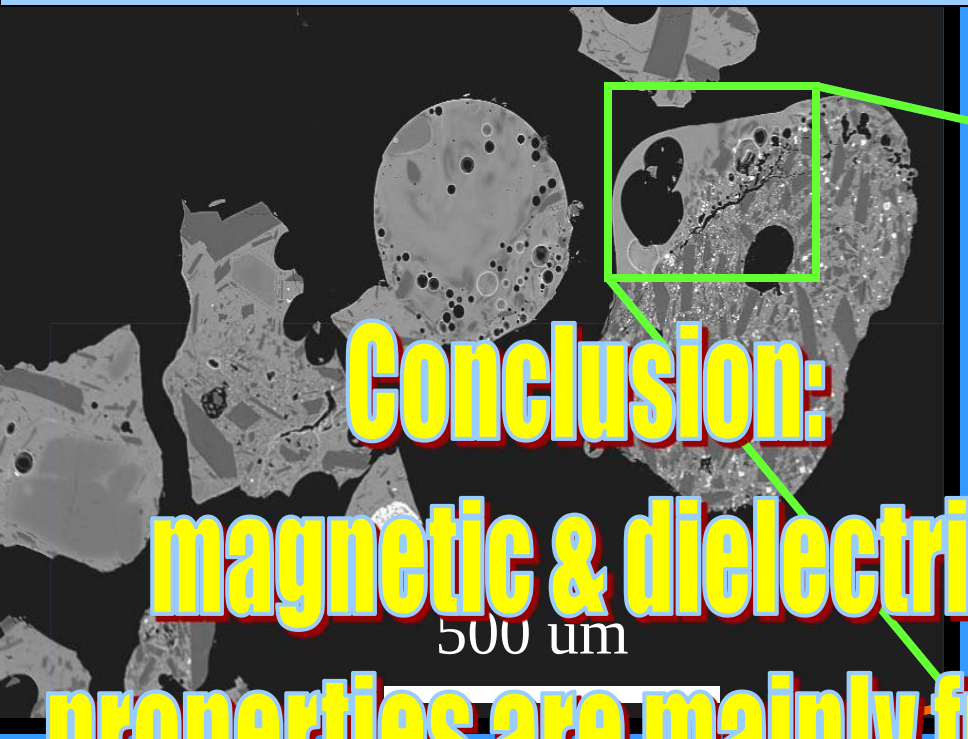
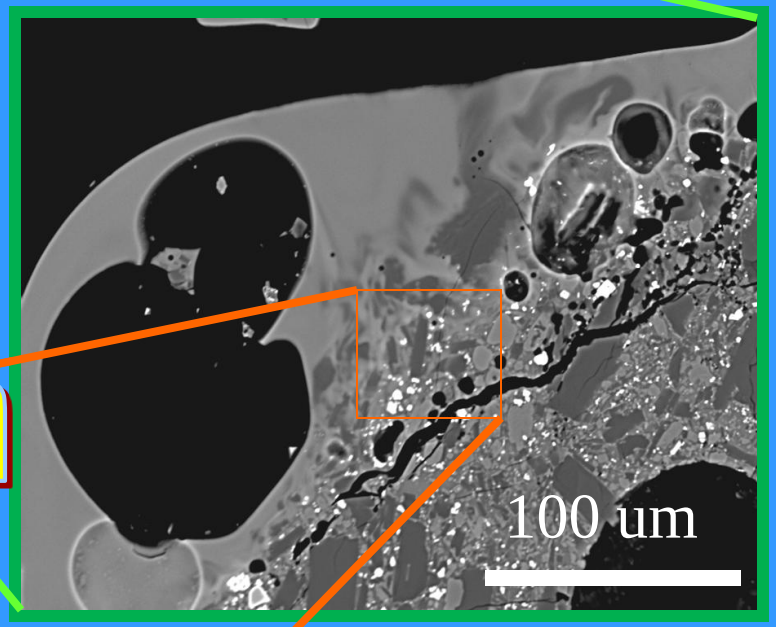
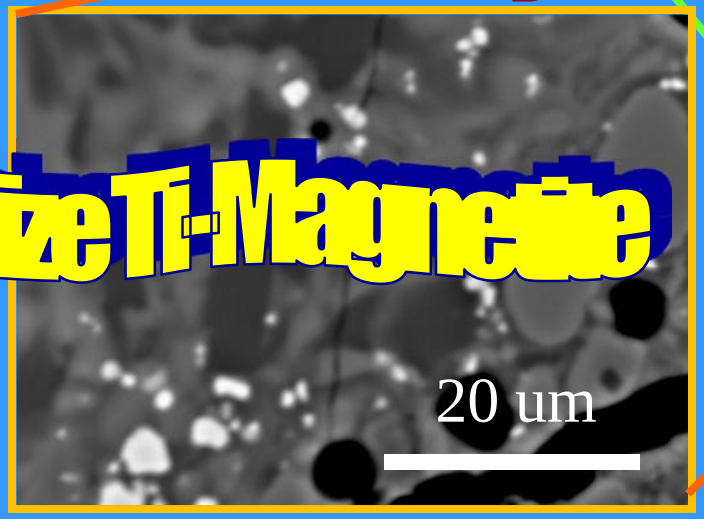
JSC-1A with NP-Fe







Conclusion:

magnetic & dielectric properties are mainly from

Nano-size Ti-Magnetite

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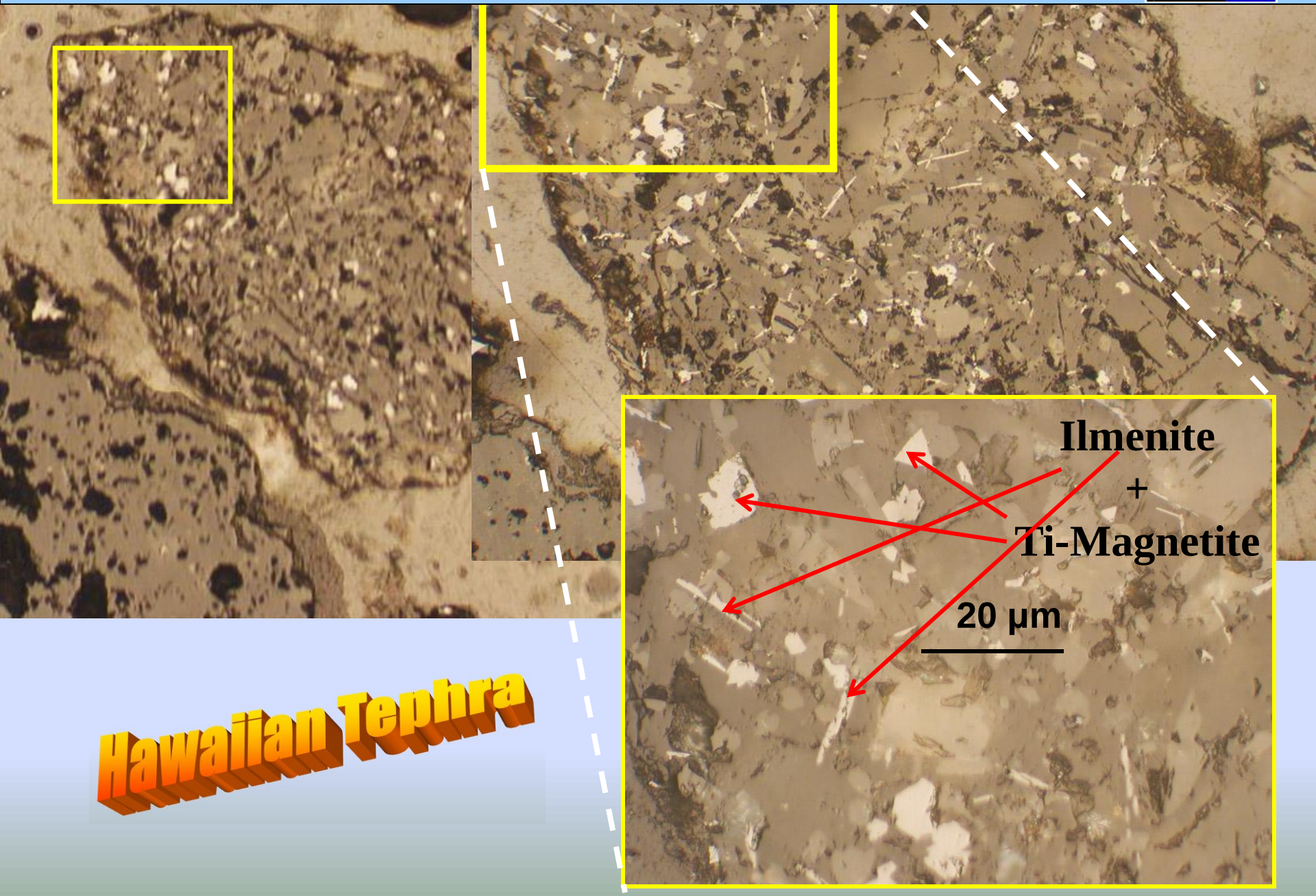


Hawaiian Tephra

White = ilmenite

Production of LLOX by LLH Reduction of Ilmenite

SIMULANT OF CHOICE??

$$FeTiO_3 + H_2 \underset{\Delta}{\rightleftharpoons} Fe + TiO_2 + H_2O \xrightarrow{\text{electrolysis}} H_2 + \tfrac{1}{2} O_2$$

Ilmenite feed — Solid Product — Oxygen Product

JSC-1A, which has 0% ILMENITE

H_2 most easily breaks the bonds between the Fe and the O!

$$Fe\,XYO + H_2 \xrightarrow[\Delta]{} Fe + XY + H_2O$$

American Society of Civil Engineers, pp. 857-866, 1994

JSC-1: A NEW LUNAR SOIL SIMULANT

David S. McKay, James L. Carter, Walter W. Boles,
Carlton C. Allen, and Judith H. Allton

Abstract

A new lunar soil simulant, JSC-1, has been developed and characterized under the auspices of the NASA Johnson Space Center. This simulant was produced in large quantities to satisfy the requirements of a variety of scientific and engineering investigations. JSC-1 is derived from volcanic ash of basaltic composition, which has been ground, sized, and placed into storage. The simulant's chemical composition, mineralogy, particle size distribution, specific gravity, angle of internal friction, and cohesion have been characterized and fall within the ranges of lunar mare soil samples. JSC-1 is available for only the cost of shipping.

Used for:
H_2 Reduction of Ilmenite [but no ilm]
Ilmenite mineral beneficiation [no ilm]
Mare soil chem. [it is not typical at all]

Introdu

The Lunar Simulant Working Group at Space 92 identified the need for large
soil. The previous year the report of the Workshop on Production and Uses o
soils with appropriate properties, although difficult to produce in some cases, will be essential to meeting the system requirements for lunar exploration" (McKay and Blacic, 1991). In order to address this need, a new simulant has been developed under the auspices of the NASA Johnson Space Center. JSC-1 is a glass-rich basaltic ash which approximates the chemical composition, mineralogy, particle size distribution, and engineering properties of lunar mare soil.

JSC-1 was produced specifically for large- and medium-scale engineering studies in support of future human activities on the Moon. Such studies include material handling, construction, excavation, and transportation. The simulant is also appropriate for research on dust control, spacesuit durability
quantitie

Take-Away to Engineers: ~~"One Simulant Fits All Needs"~~

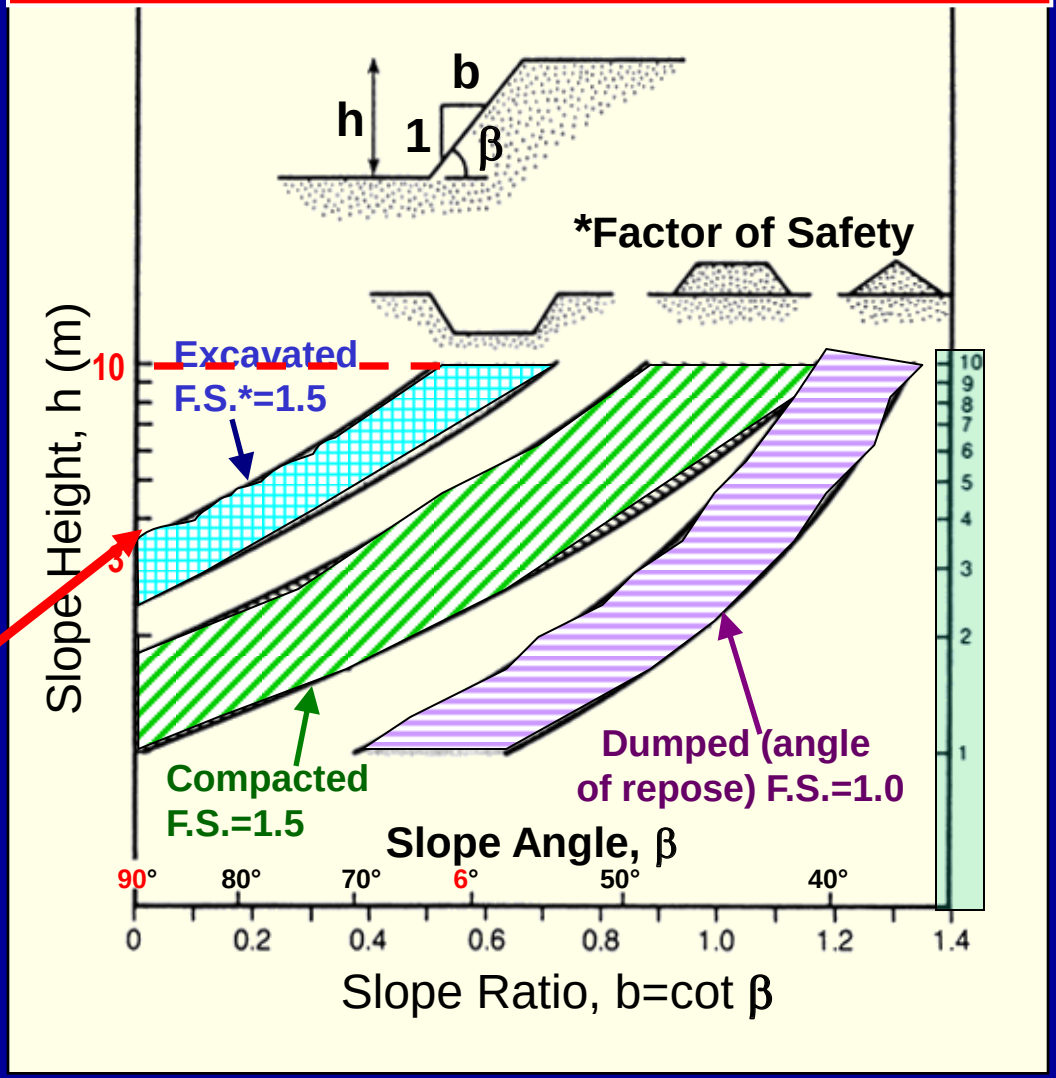
This material complements, but does not replace, lunar simulant MLS-1, produced by the University of Minnesota (Weiblen et al, 1990). MLS-1 is derived from a high-titanium basalt hornfels which approximates the chemical composition of Apollo 11 soil. The starting material is totally

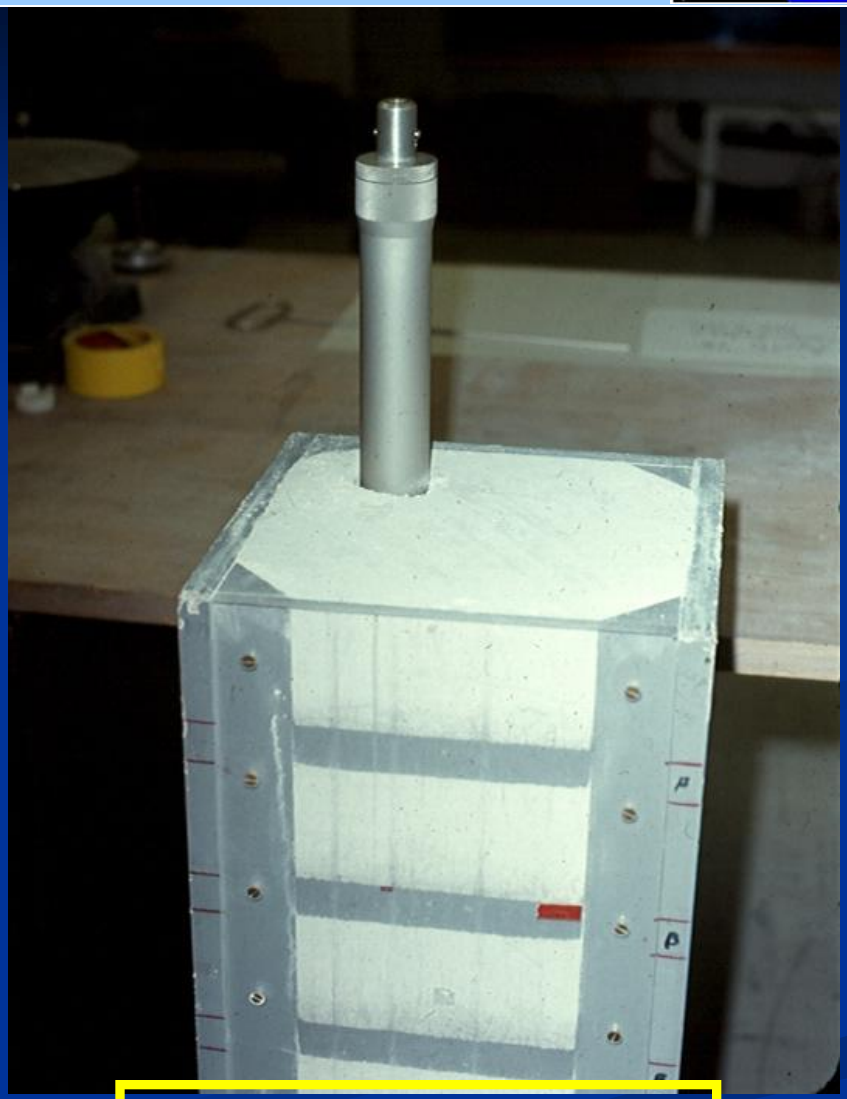
Regolith Simulant Used During Apollo

Calculated stability of artificial slopes constructed in lunar surface material. Data are presented for 3 situations:
(1) an excavation in lunar soil
(2) a compacted pile of excavated lunar soil;
(3) a dumped pile of lunar soil

A vertical cut ***can safely be made in lunar soil to a depth of about*** **3 m**;

Slope Stability (Fig. 9.39; LSB, 1991)





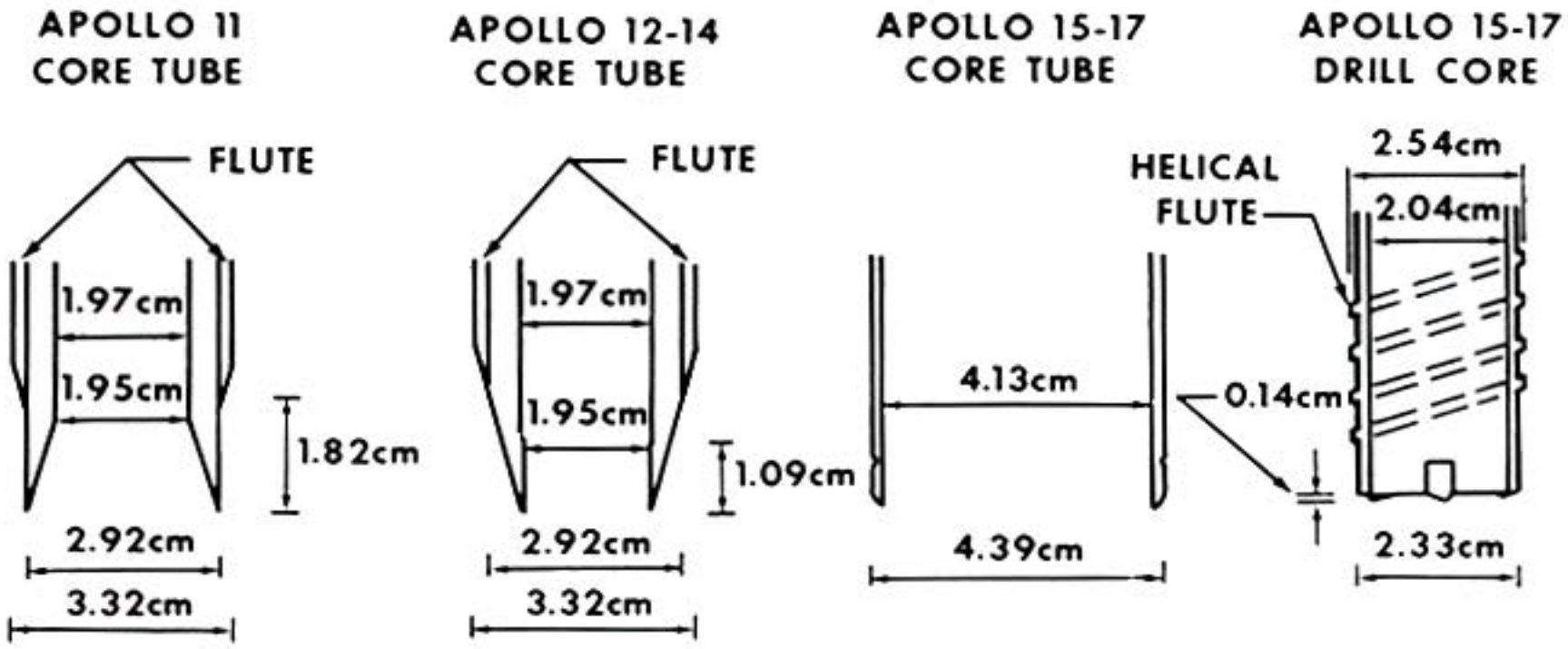
LUNAR SOIL TEST BED

Kaolinite Clay
+
League City Sand

(With C-Black Markers)

Drive-Tube Core Tube
driven into
Lunar soil simulant

Comparison of Apollo Core Bits



APOLLO 15 DRILL BIT
Stem With Helical Fluting for Augering

APOLLO DRILLING PRACTICE

Caltec Prof Don Burnett's
Neutron-Flux Experiment

Lunar Regolith Simulant Situation

- literally Dozens of Lunar Simulants have been Produced;

  Most are being Made by the Actual Users;
- MSFC is NASA's Lunar Simulant Center for the Production & Curation of Regolith Simulants; with ONLY TWO (2) Certified Simulants Produced:
- MSFC was Supposed to be the "Clearing House" for New Simulants;

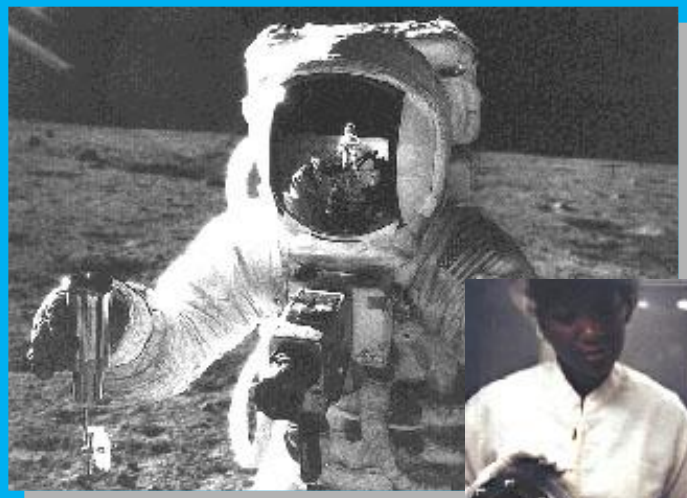
  BUT, They have Little Control on Lunar Simulant Production;
- Most Lunar Simulants Do Not Possess the Correct Properties for Which They were Designed;
- Even Certified Lunar Simulants are being Mis-Used for other Studies than for Which They were Produced;

MSFC MUST TAKE BACK CONTROL OF THE LUNAR SIMULANT FIASCO!!

Apollo Lunar Samples

- Lunar Sample Laboratory at NASA JSC in Houston is chief repository for samples from Apollo 11,12,14,15,16,&17
- 382 kg
- 2196 original samples
- Now subdivided into 86,000 samples
- Samples distributed to scientists and educators worldwide
- 80% by weight remains pristine:

OUR NATIONAL TREASURE



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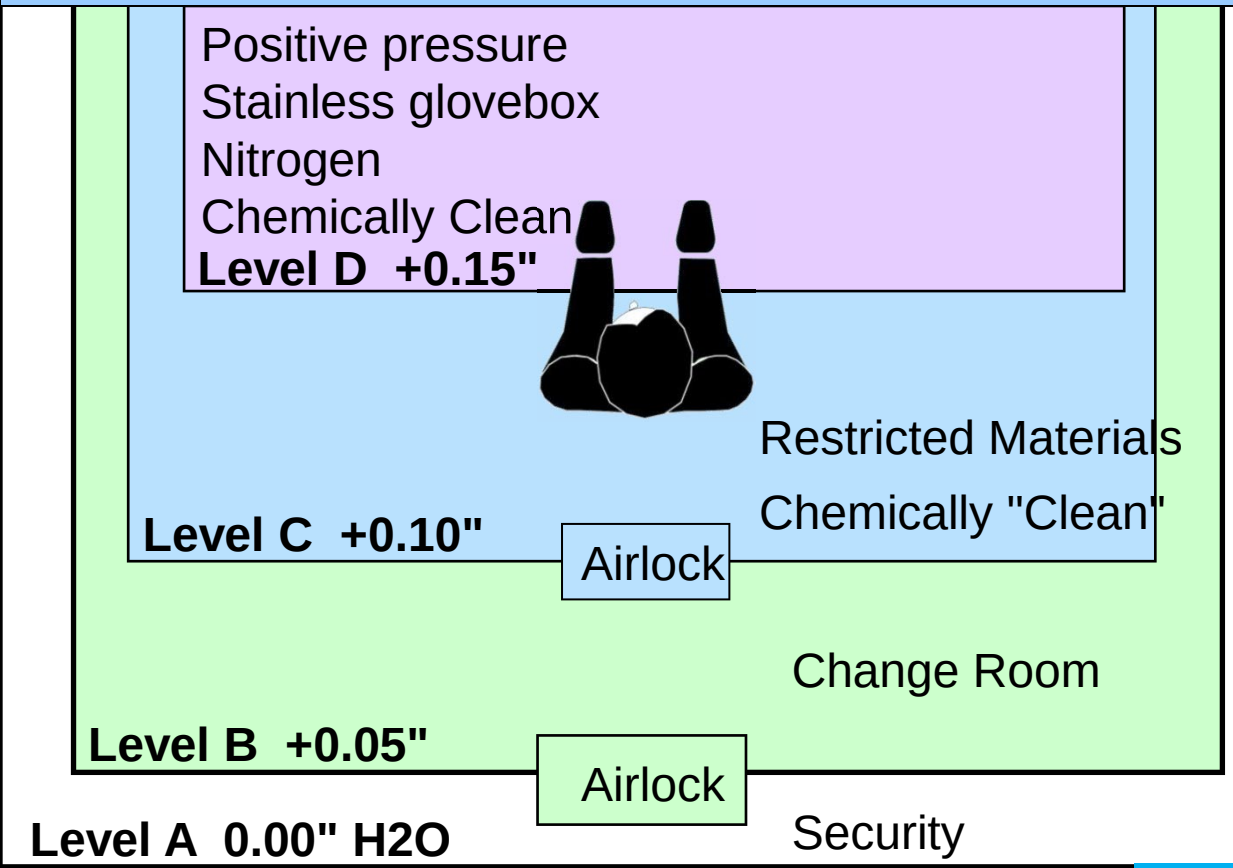

LUNAR SAMPLE CURATION

At

Johnson Space Center

EXAMPLES of LUNAR SOIL ALLOCATIONS

T.D. Lin, Portland Cement

Chris Knudson, Carbotec, Inc.

LAT, Univ. of Tenn., TBI

Lunar Airborn Dust Toxicity Advisory Group, JSC

To Receive Lunar Sample Allocations from CAPTEM,

One Must Prove UNIQUENESS of the Lunar Samples for the Process AND MINITURIZE the Process Involved and Tests to be Made AND Demonstrate Scientific/Engineering Competence.

Very Few ISRU Studies NEED Apollo Rocks / Soils!!
Exceptions: Human factors; Mineral Beneficiation ??

BEWARE!!!! The NEW Moon
A "Watery" Lunar Surface

Three (3) Different Origins for water on the Moon

- Two (2) that are EXogenic (external)
- One (1) that is ENDogenic (internal)

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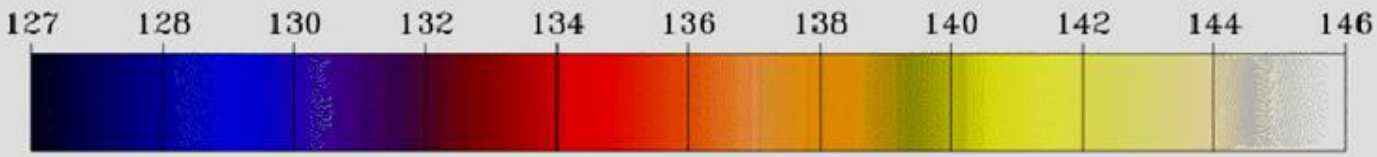
FIRST Evidence for Water on the Moon

Science
9/24/2009

WATER – WATER Everywhere!!

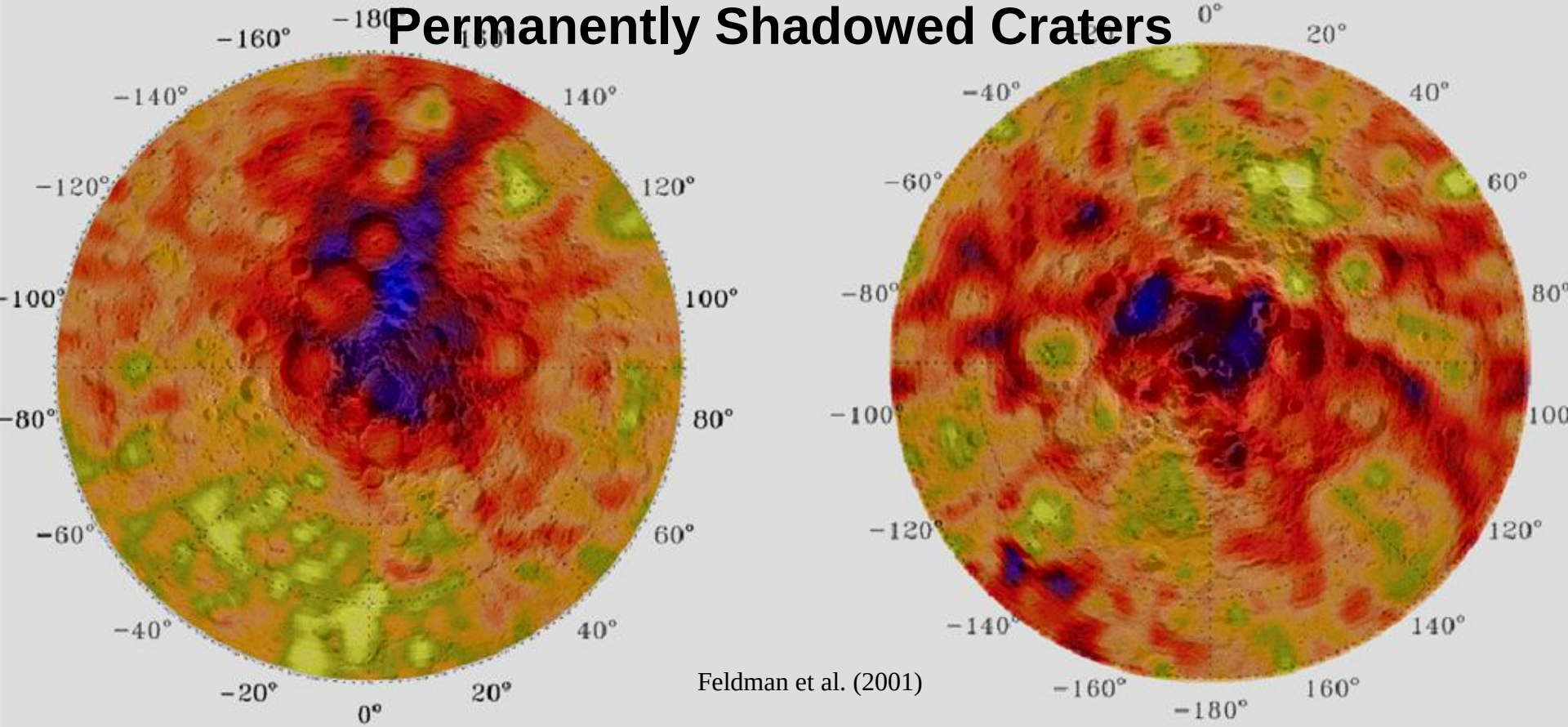
Moon Mineralogy Mapper Chandrayaan-1

Lunar Prospector: **Hydrogen found at lunar poles**



Epiothermal Neutron Flux

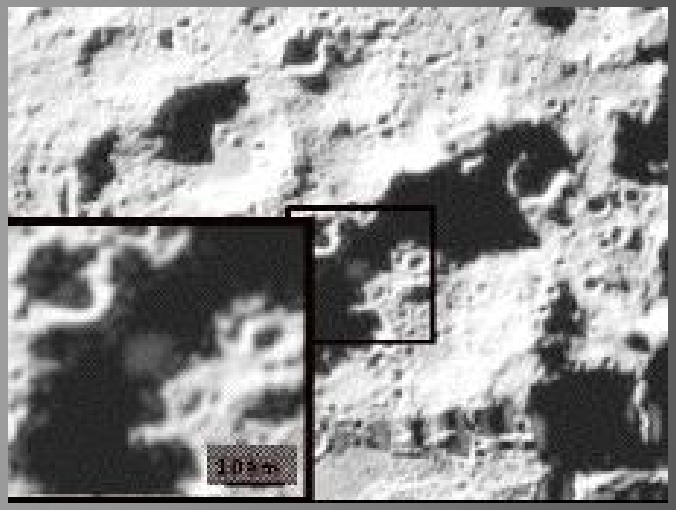
Permanently Shadowed Craters



Feldman et al. (2001)

LCROSS (October,2009)

(Lunar CRater Observation and Sensing Satellite)



Cabeus = PSC

Water – ICE; 100 kg
Organic (ammonia, methane, etc)

More Water

Amount of Surface Dew / Ice

Mini-SAR

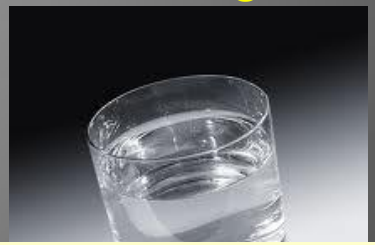
~ 100's of Tonnes

LCROSS

Permanently shadowed crater

M^3

Produced from 1 m^3 Lunar Regolith



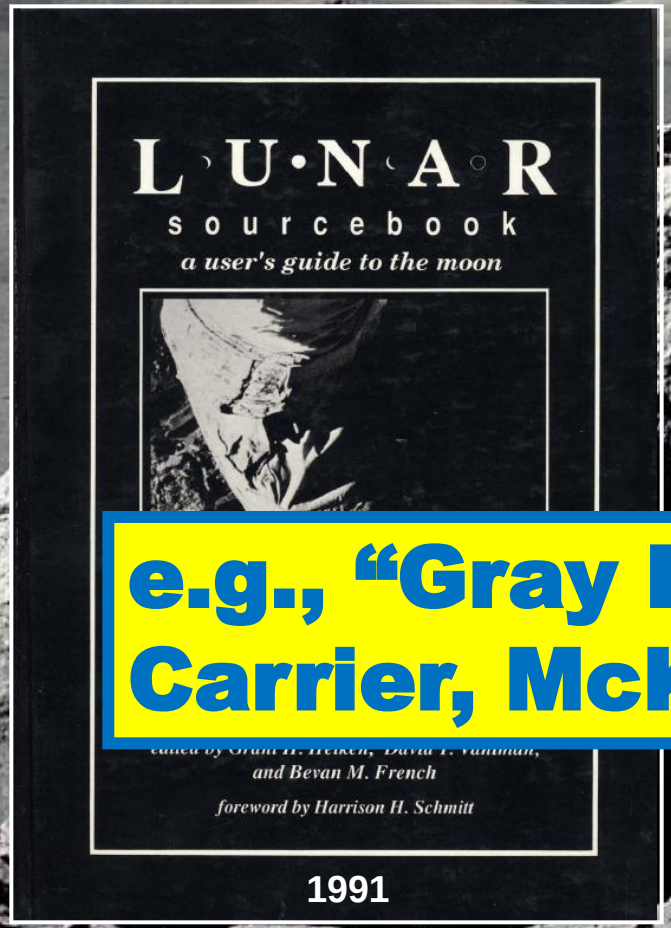
Does This Not Negate the Major Emphasis on Oxygen Production?

Water on the Moon

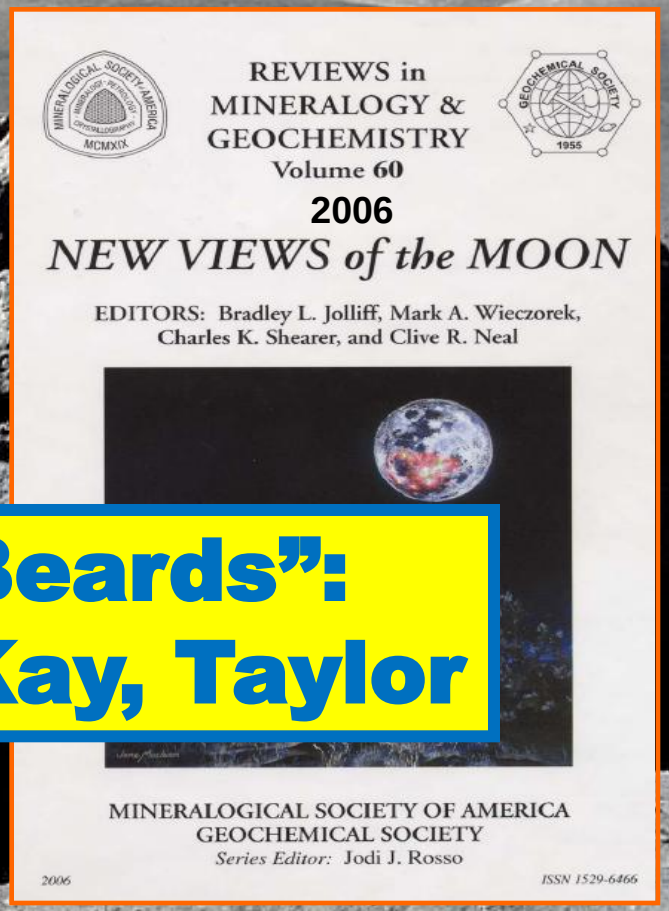
- "It's Not Your Grandpa's Moon";
  Several Sources of Lunar Water;
- Lunar Simulant Situation is Critical;
- MSFC SHOULD Re-Assert its Position as Lunar Simulant Clearing House;
- ONLY a Few ISRU Studies Actually Require Apollo Samples;
- Lunar Regolith EXPERTS MUST be involved with Virtually ALL ISRU Simulant Studies!
- WARNING Labels MUST be Applied on All Simulant Containers!!

Lunar Simulant CHEFS': Needs

"Bibles of the Moon"



1991



2006

e.g., "Gray Beards": Carrier, McKay, Taylor

"PLUS"

Advice of Apollo Lunar Sample Scientists/Engineers

THANKS FOR YOUR ATTENTION