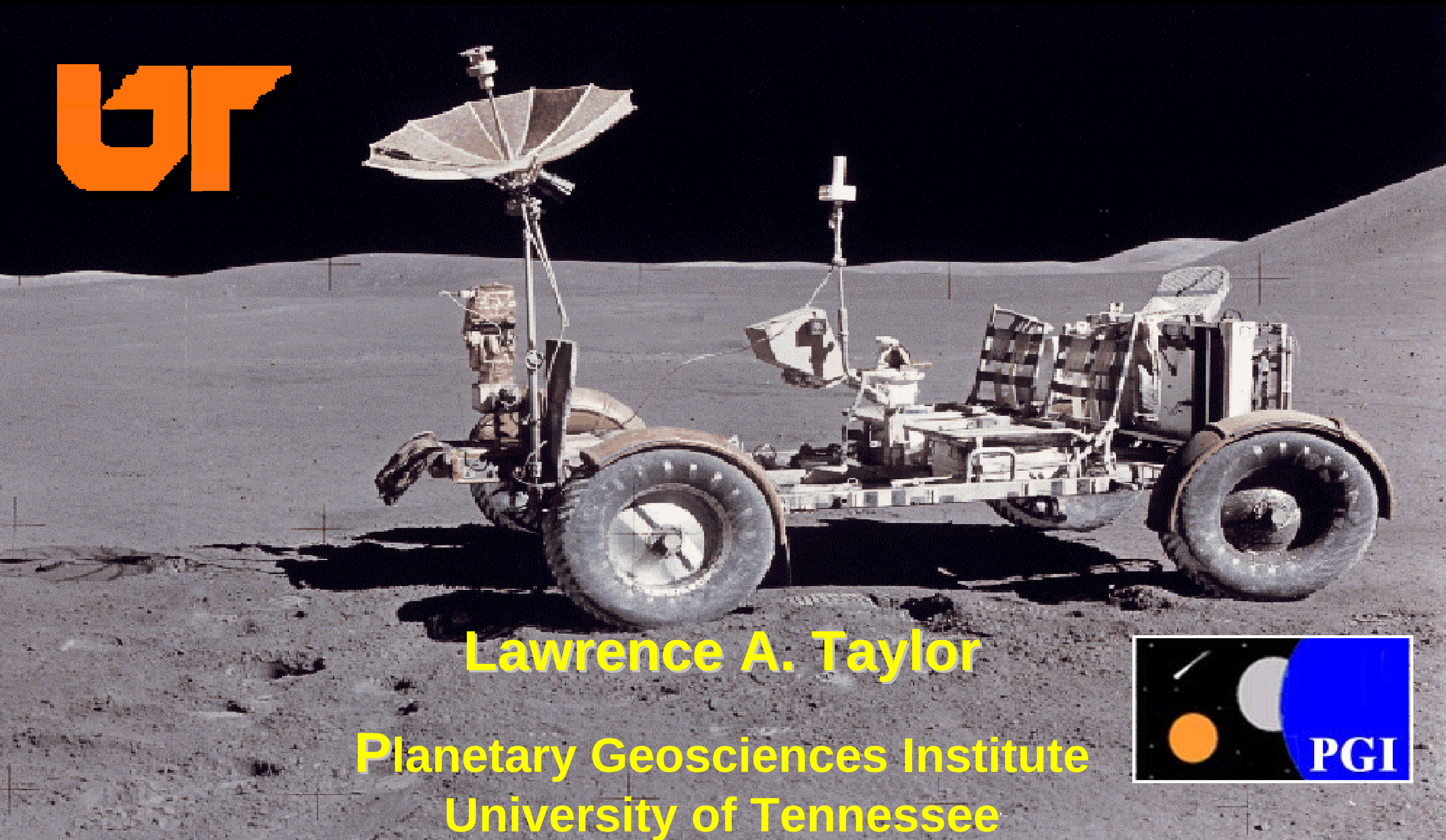
Lunar Soil for a Myriad of Purposes and Products: Science, Engineering, and Applications



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University of Tennessee

Objectives

- NEW LUNAR SAMPLES
- UNIQUE PROPERTIES OF LUNAR SOIL
- NEW LUNAR MINERALS
- UNIQUE ABILITIES OF MICROWAVE RADIATION
- MICROWAVE PROCESSING OF LUNAR SOIL
- PRODUCTS FOR “THE BUSH LUNAR BASE”

Newly Recovered Planetary Materials

- **Meteorites from Antarctica**

  Japan and USA

- **Meteorites from Hot Deserts**

  French Entrepreneurs in the Sahara

  Russian Entrepreneurs in Oman

- **Meteorites as samples of :**

  The Moon

  as well as Mars & Asteroidal Matter

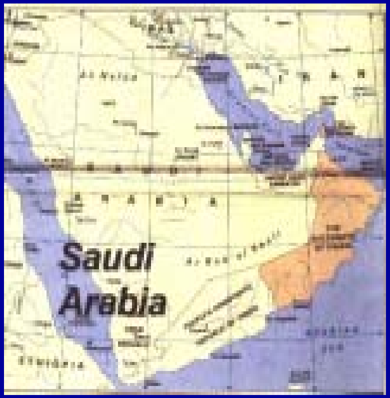
SEARCHING FOR METEORITES IN THE OMAN DESERT

When viewed with binoculars, the Black Spot in the sand is:

a) a 'coke can' [alcohol is verboten!];

b) evidence that a camel has stopped there recently; or

c) a dark-colored rock [fusion crust on a meteorite].



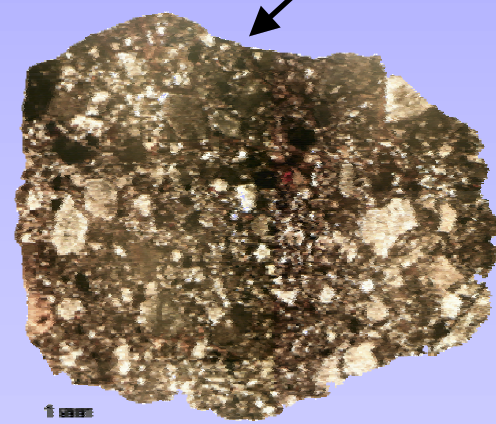
Lunar Meteorites from Oman

Dhofar 287
(Basalt + Breccia)

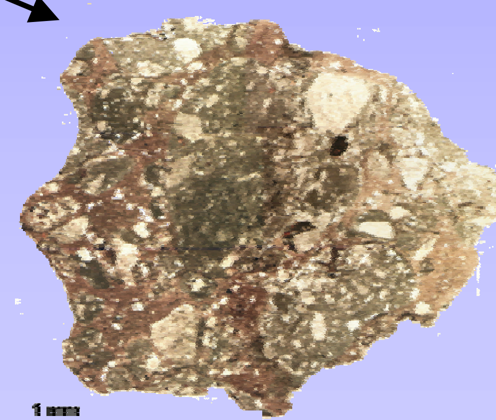
Dhofar 025 (Impact-Melt Breccia)

Regolith Breccia

Dhofar 301

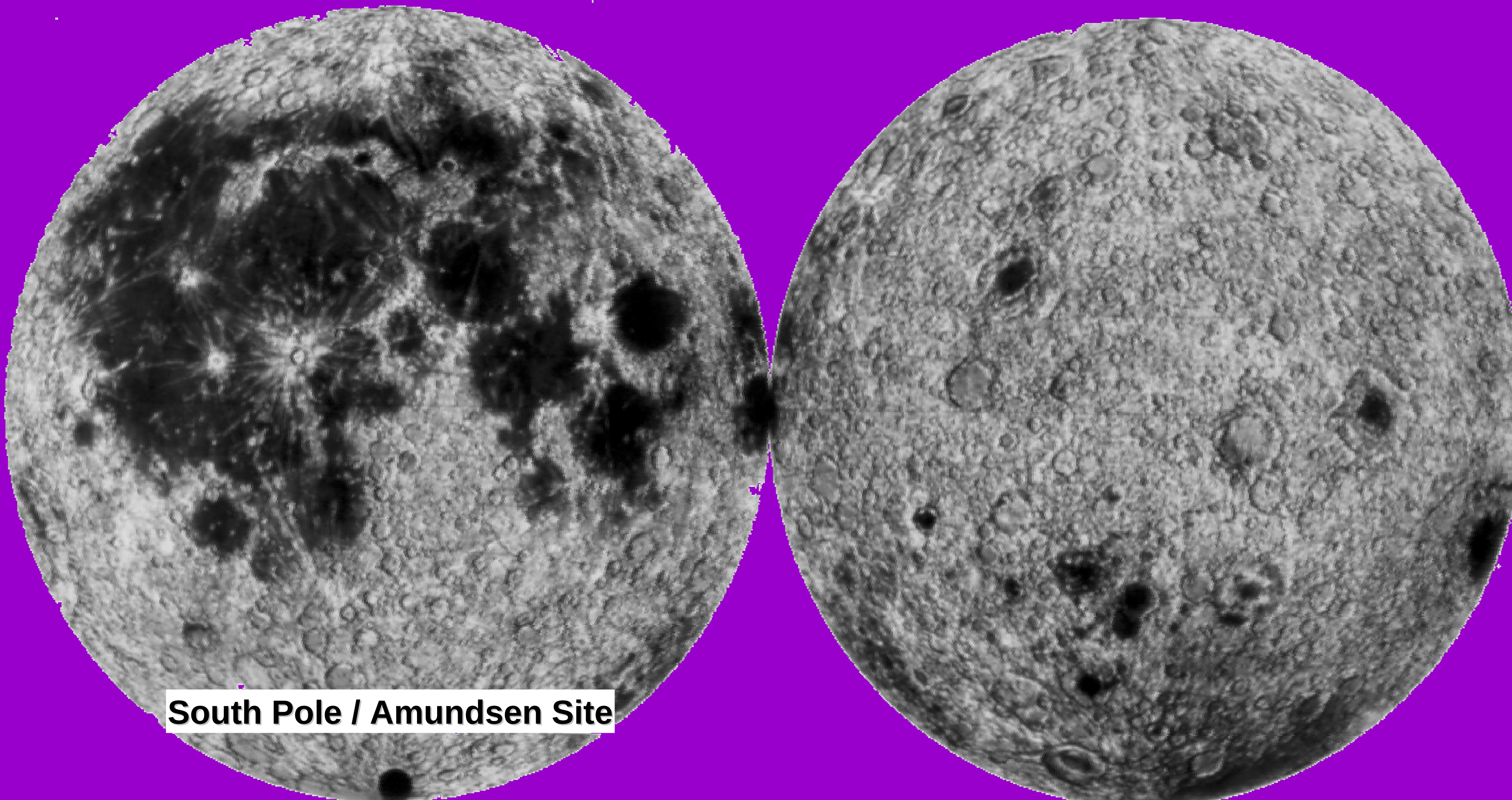


Dhofar 302

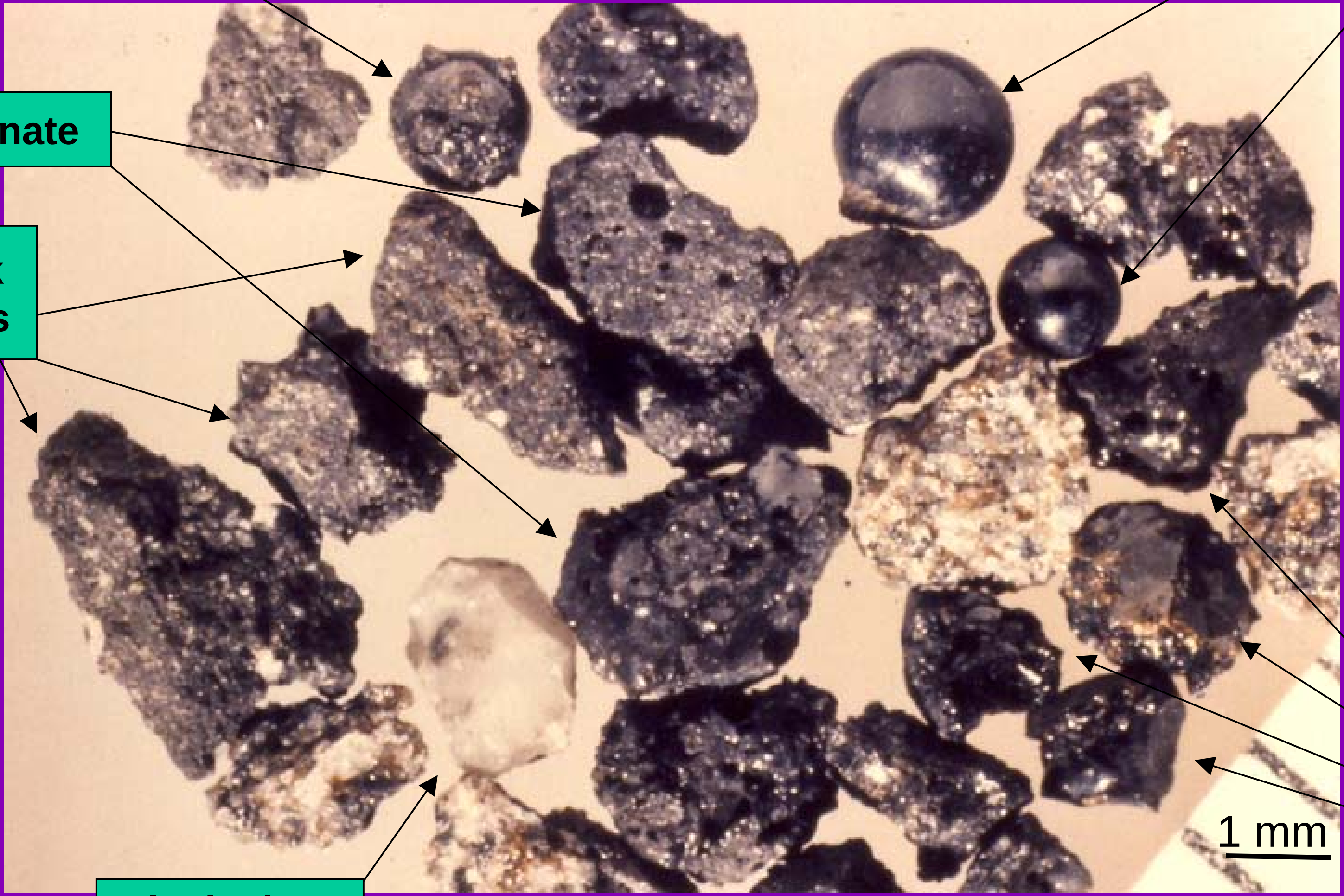


Dhofar 303

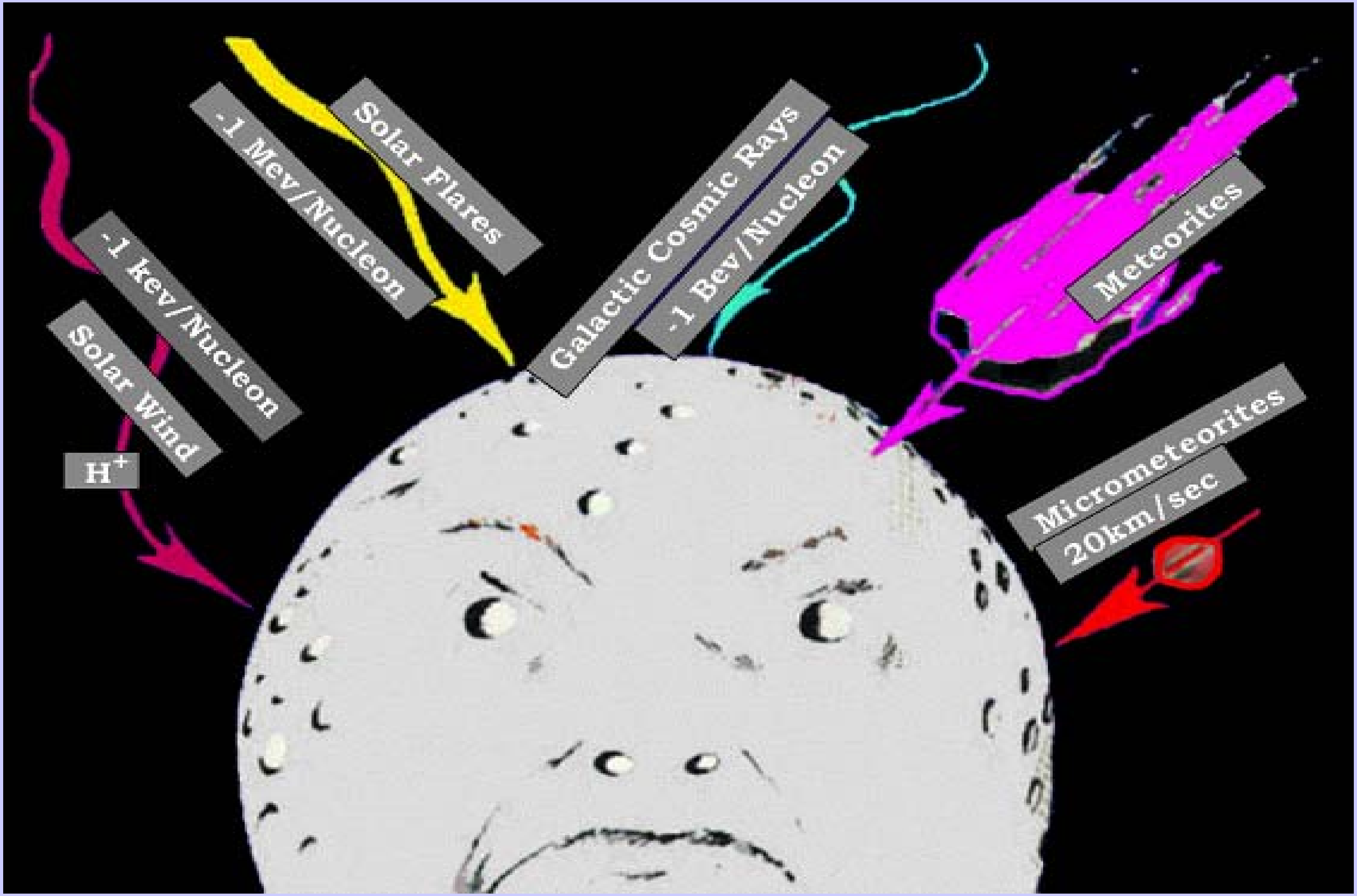
New Lunar Rocks and Minerals: Farside Samples of the Moon



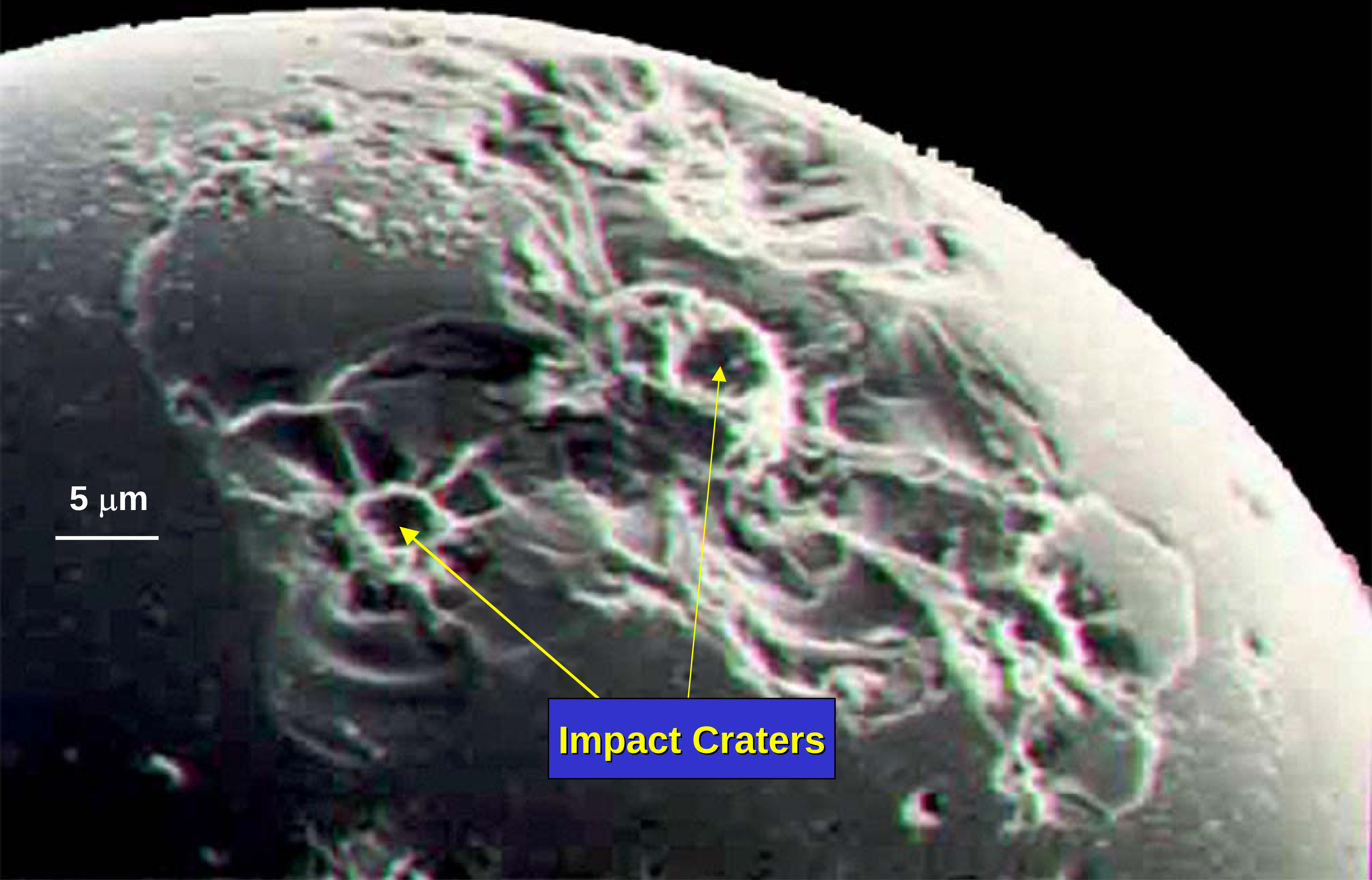
Lunar Mare Soil



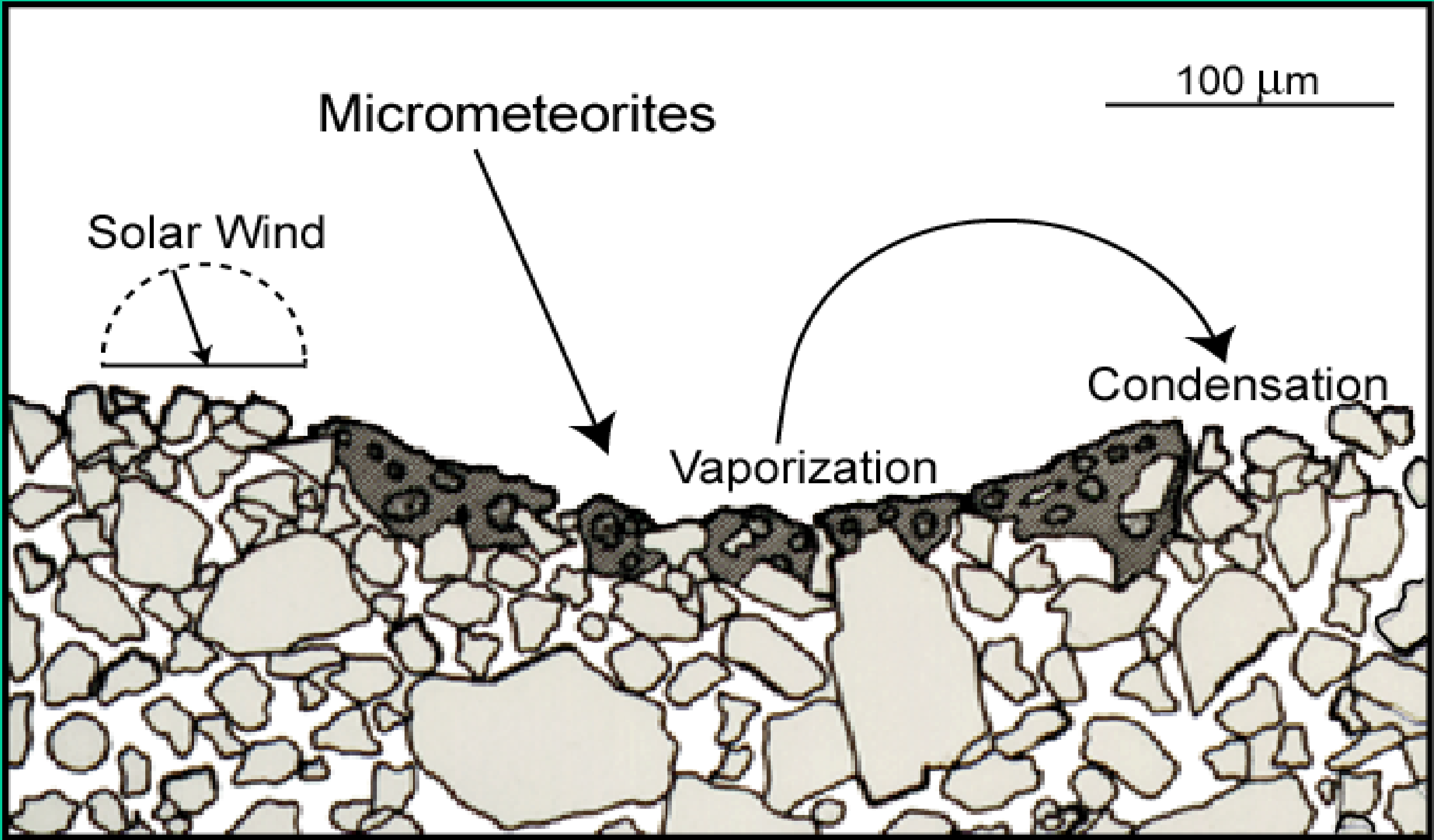
Our Unhappy Moon



Micrometeorite Impacts on Lunar Glass Bead



Lunar Soil Formation



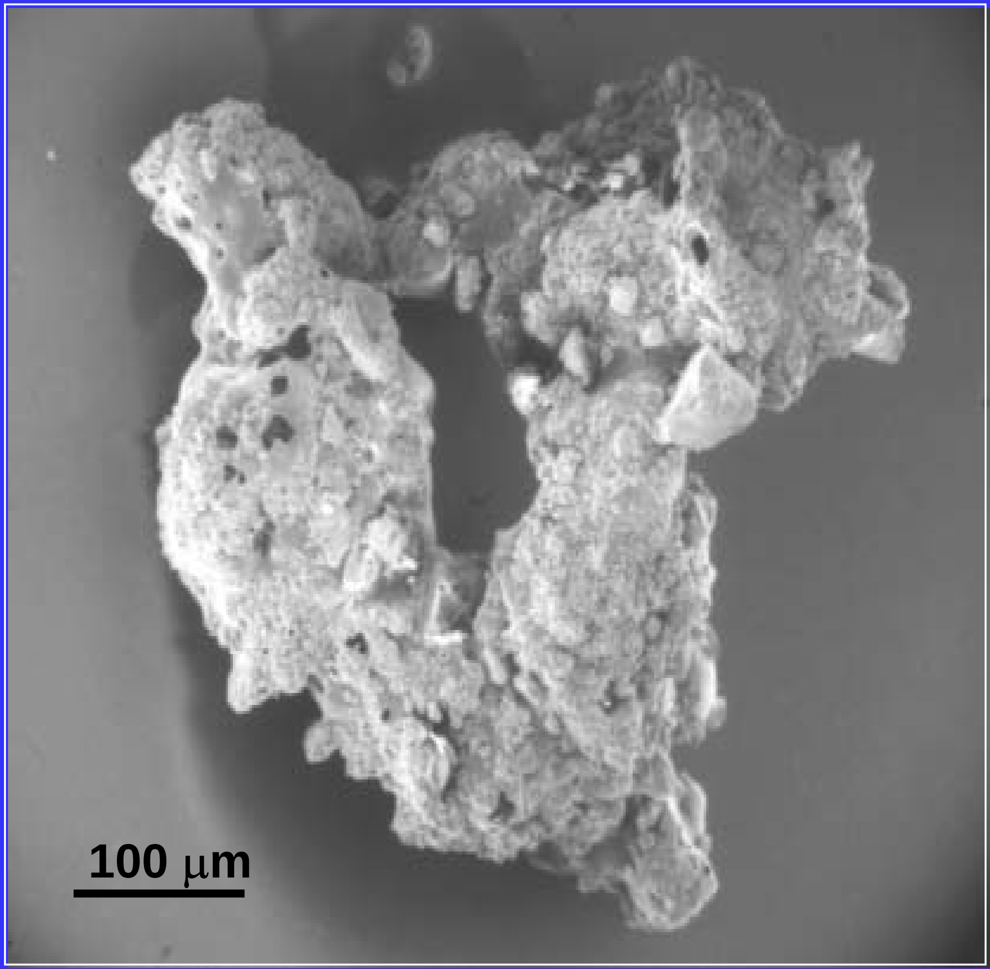
Comminution, Agglutination, & Vapor Deposition

The only Weathering and Erosional agent on the Moon is Meteorite and Micrometeorite Impact.

BASIC PROCESSES IN LUNAR SOIL FORMATION

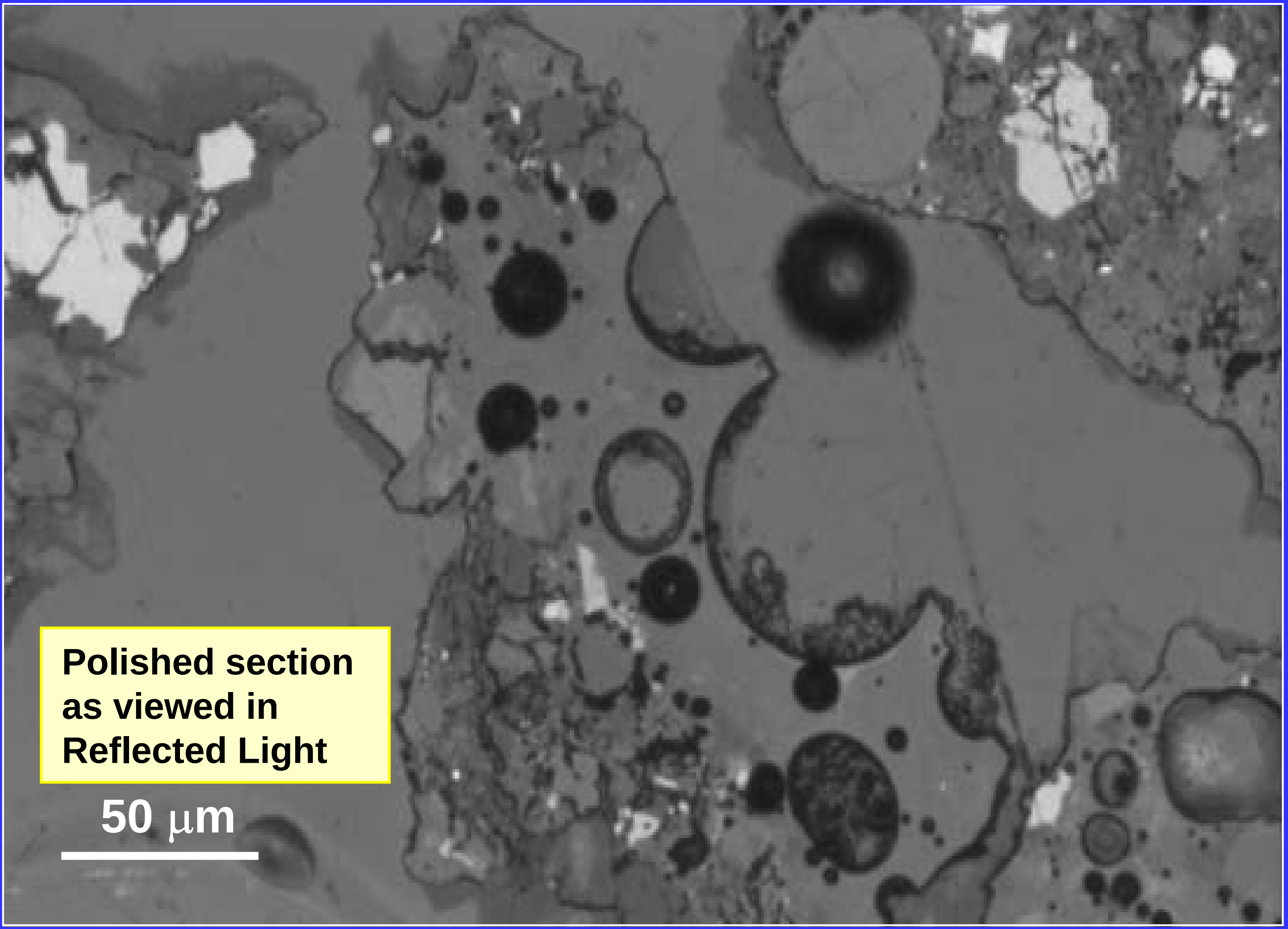
- ***COMMINUTION:*** **breaking of rocks, minerals, and glasses into smaller particles;**
- ***AGGLUTINATION:*** **welding of rock, mineral, and glass fragments together by micrometeorite-produced, impact-generated melt (quenched to glass);**
- ***SOLAR-WIND SPALLATION AND PARTICLE IMPLANTATI ON*:** **Erosion and vaporization caused by sputtering from impacting high-energy particles;**
- ***IMPACT-MELT VAPORIZATION AND DEPOSITION:*** **Vaporization of volatile components in the micrometeorite-produced, impact- generated melt.**

Mare-Soil Agglutinate

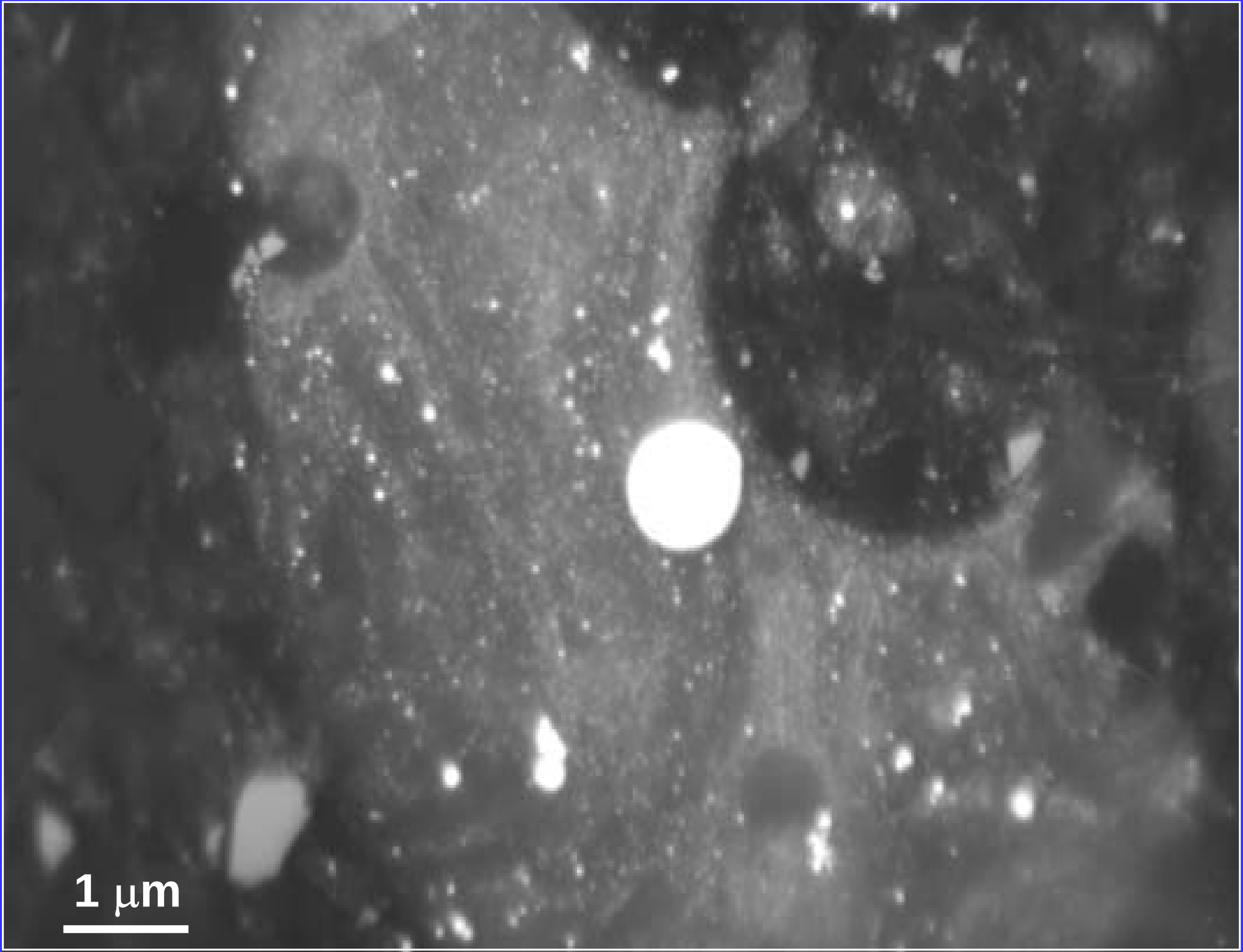


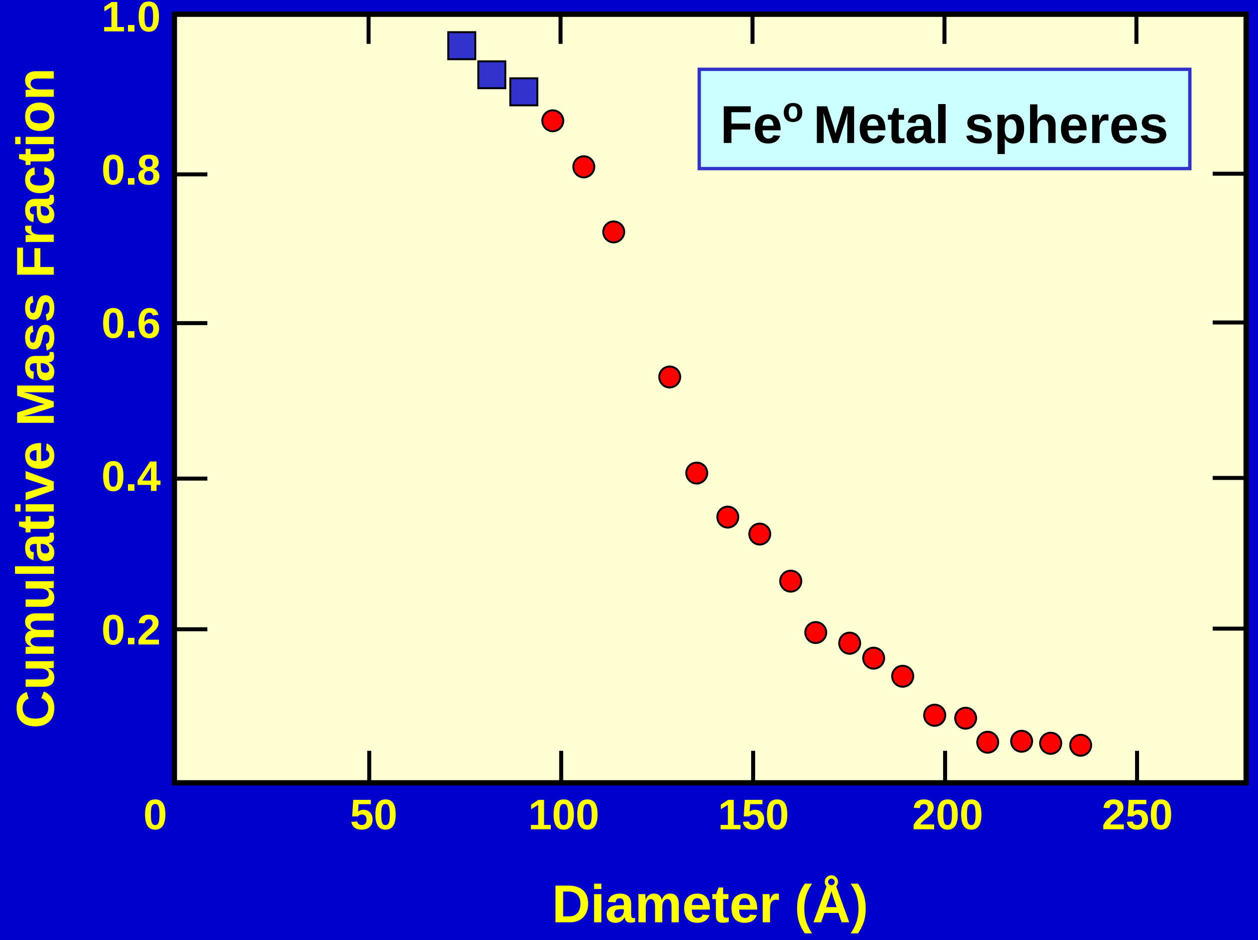
Pieces of minerals, rocklets, and glass cemented together by shock-melt glass

Mare-Soil Agglutinates



SEM BSE-Image of Mare Agglutinitic Glass





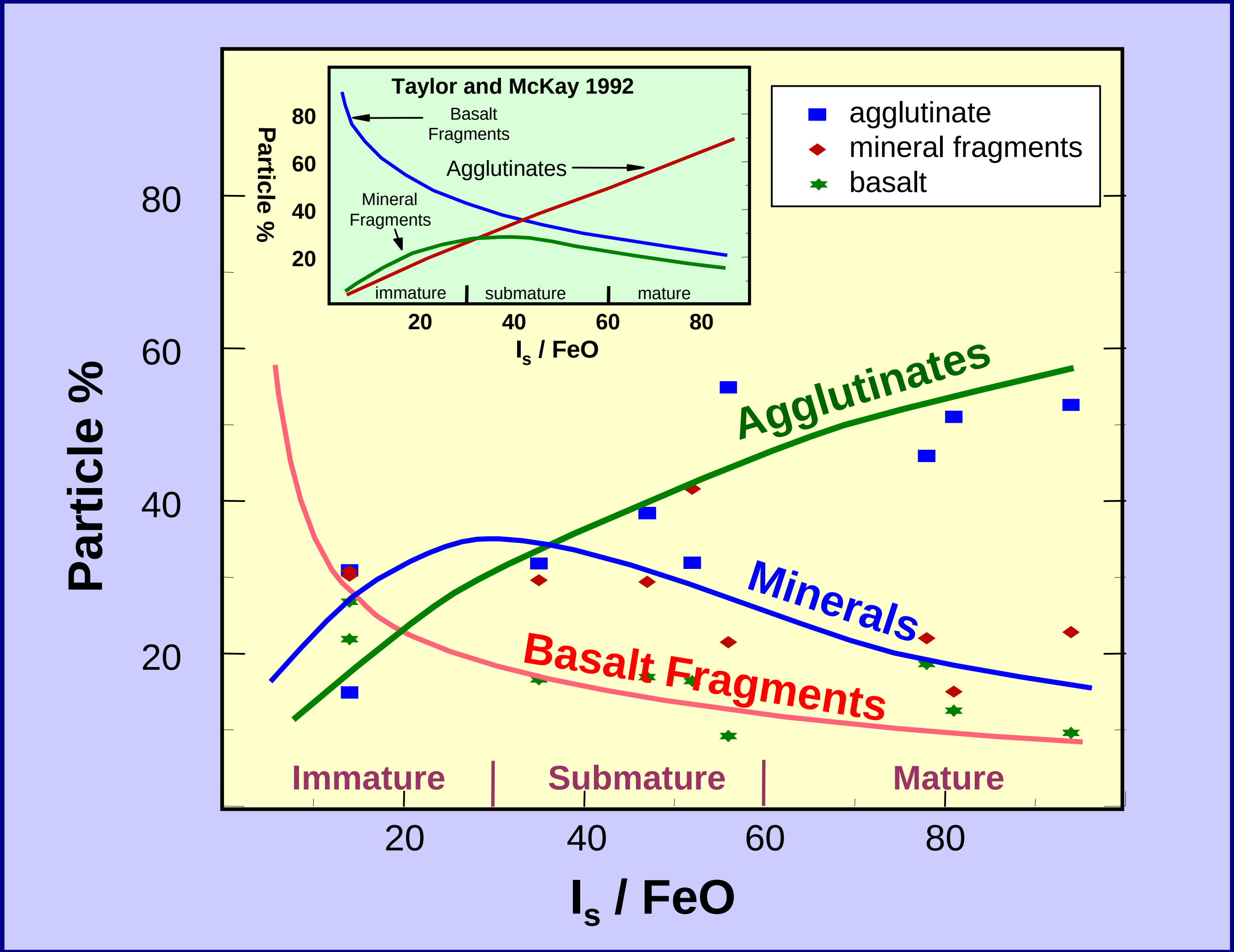
TEM-measured Size Distribution of Fe Metal Spheres in Agglutinitic Glass of Apollo 11 Soil 10084

FERROMAGNETIC RESONANCE (FMR):

- **Measurement of Single-Domain, Nanophase Fe^0 (I_S)**
- **Normalized I_S for Iron Content: I_S / FeO**
- **I_S / FeO = amount of total iron that is present as Fe^o**
- **I_S / FeO is a Function of Agglutinate Abundance**
- **Agglutinate Abundance is a Function of Maturity**

I_s / FeO = Soil Maturity

Mare Soil Maturation



What are the differences between Lunar Soils and the Rocks from which they were derived ??

Major Difference = ~ 10 X more native Fe^{o} in the soil

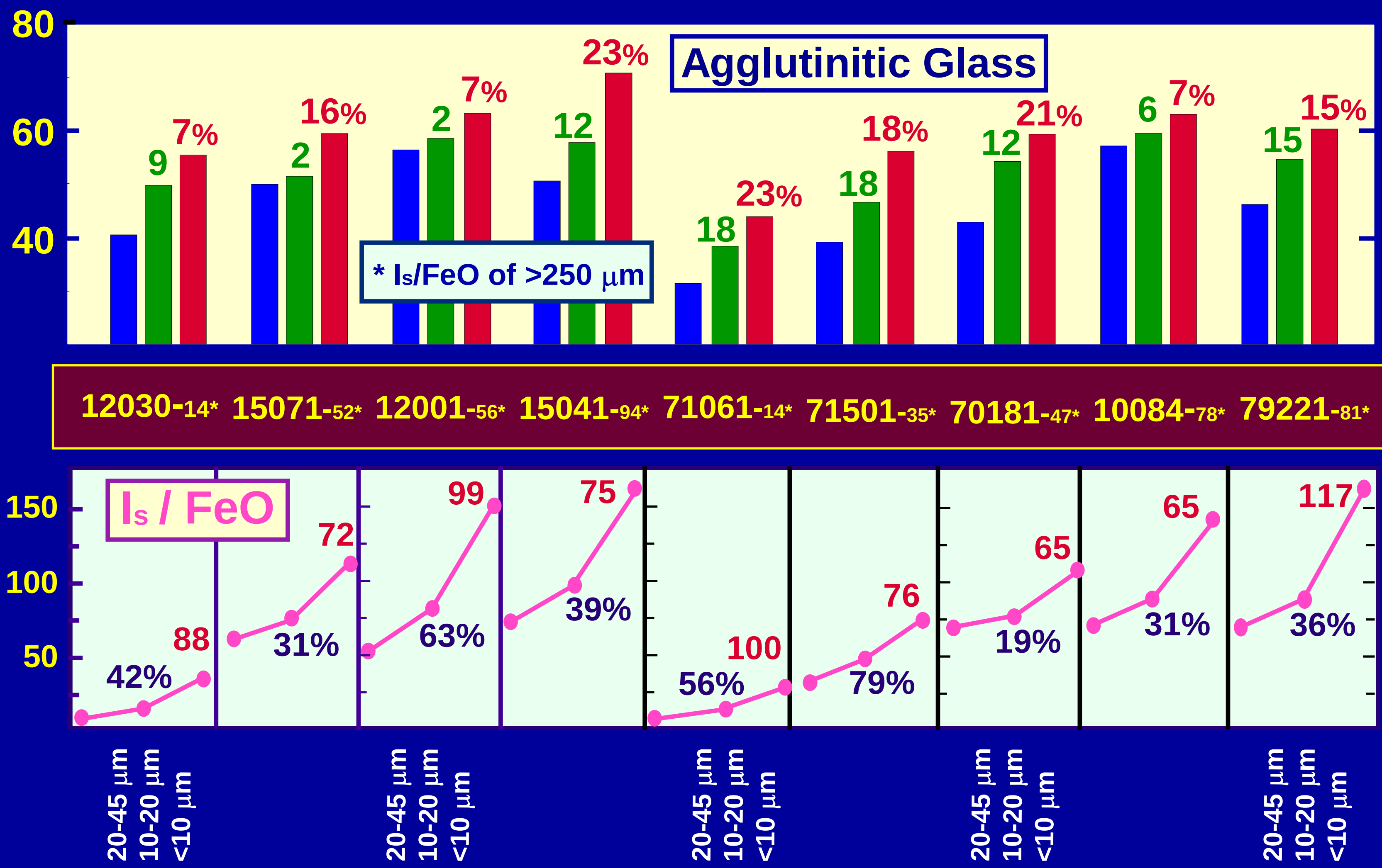
FORMATION OF NANOPHASE Fe^{0} in AGGLUTINITIC GLASS:

Auto-Reduction Reaction in Impact-Soil Melt

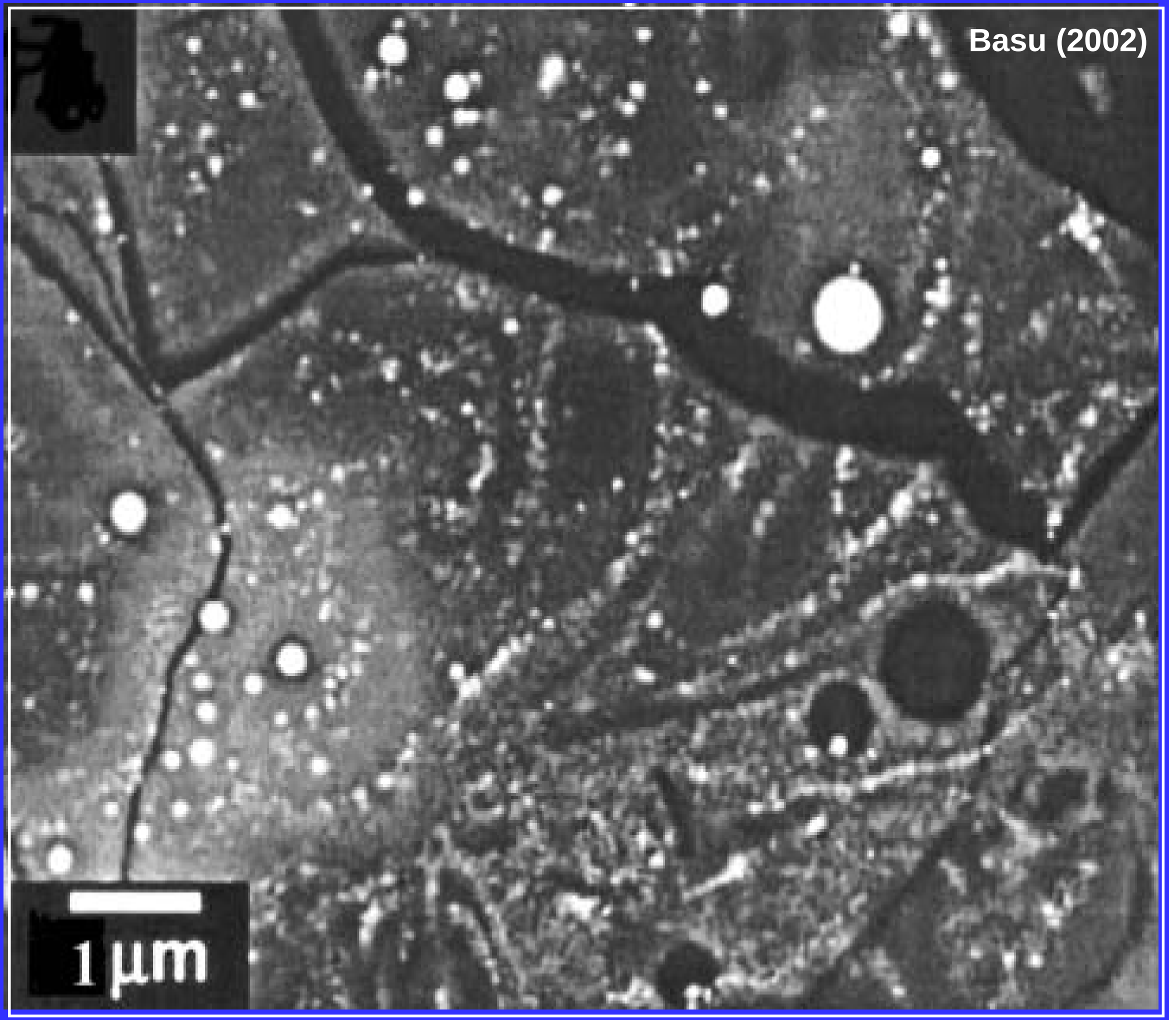
$$\text{“}FeO_{melt}\text{”} + H_2 = Fe^{0} + H_2O\uparrow$$

Solar-Wind Implanted H^{+} in Lunar Soil
Causes Reduction of Fe^{2+} to Fe^{o}
in Micrometeorite-Produced Impact Melt

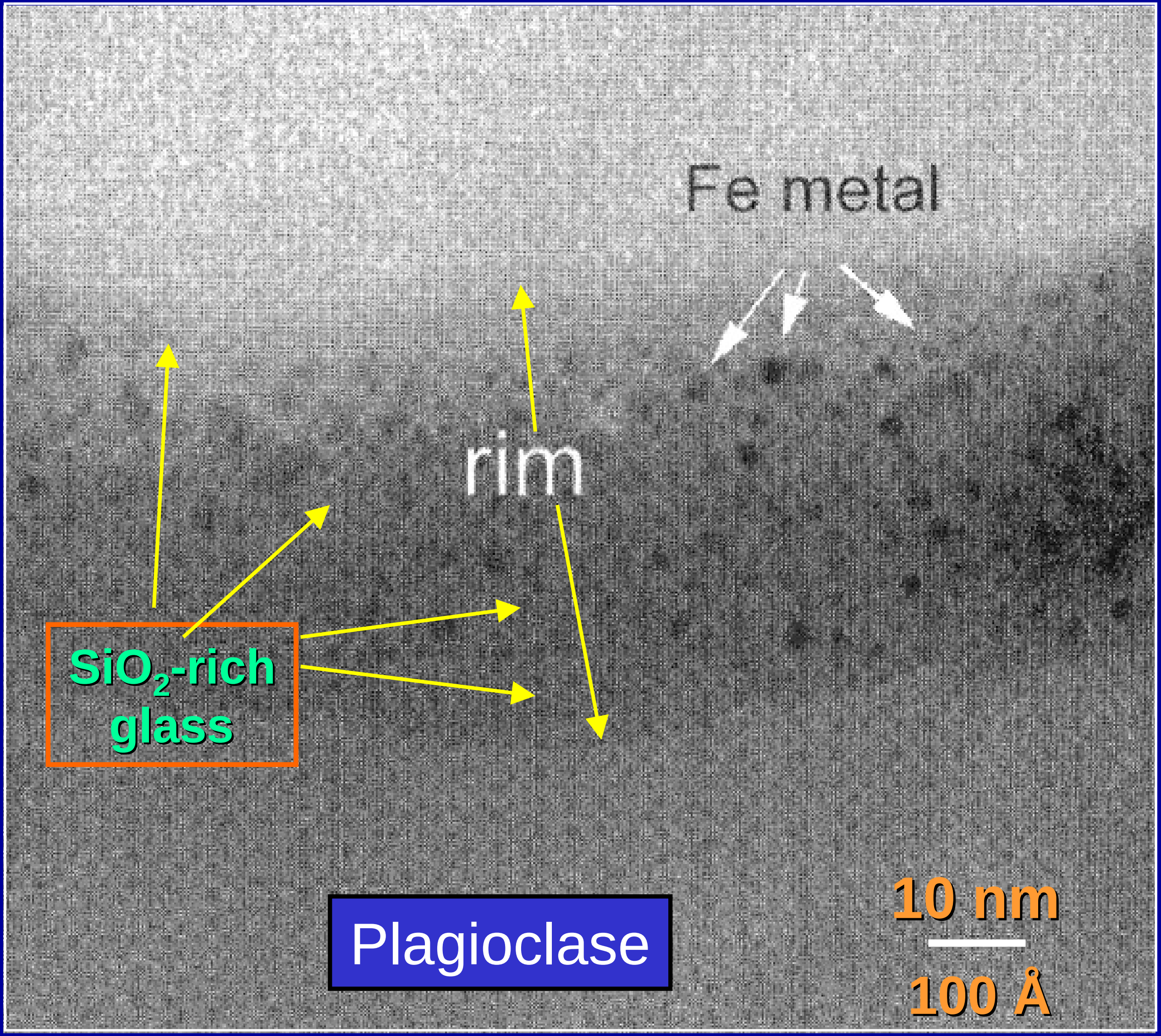
Is/FeO Values Versus Agglutinitic Glass Contents

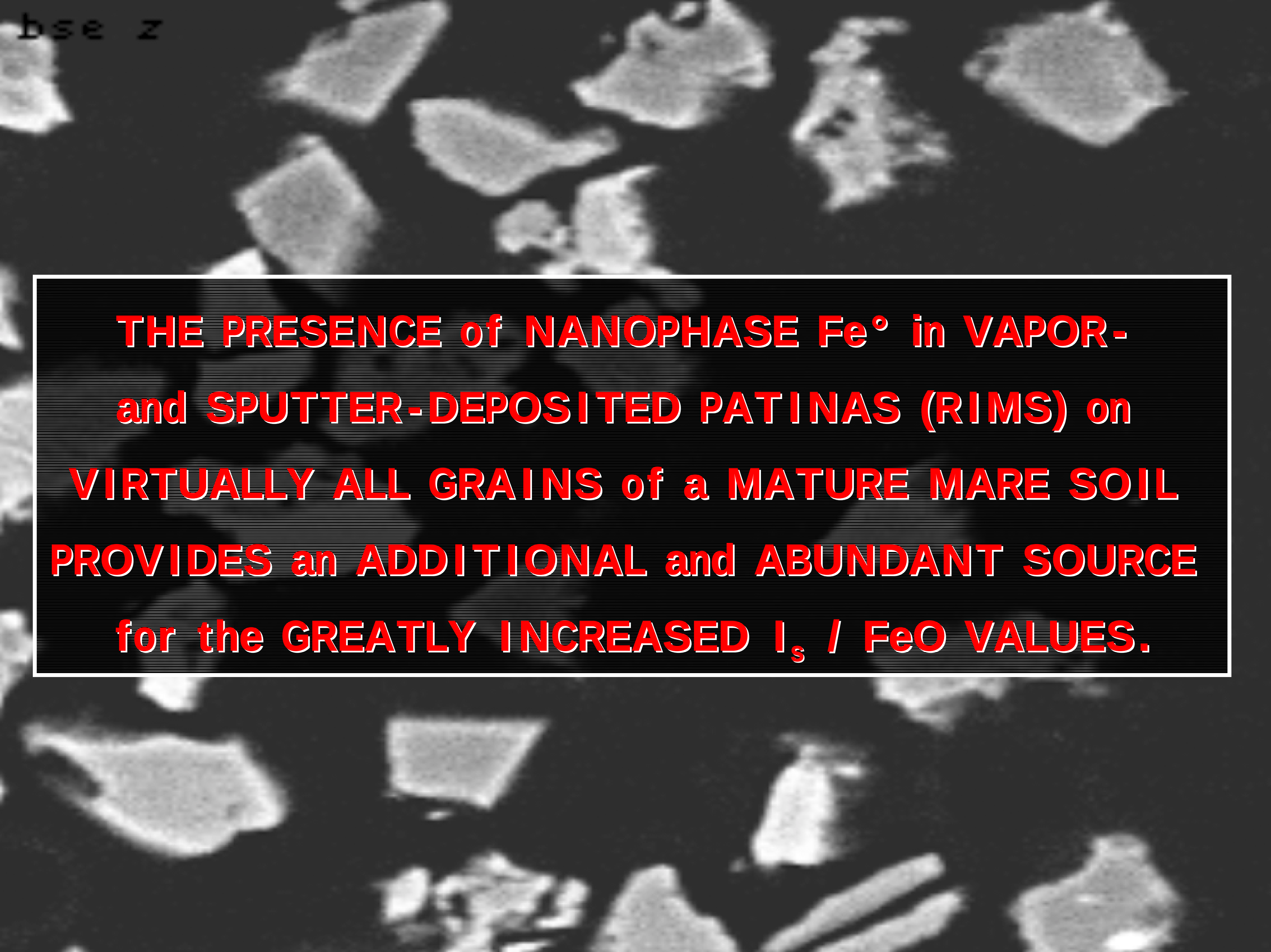


Distribution of Nanophase Fe^0



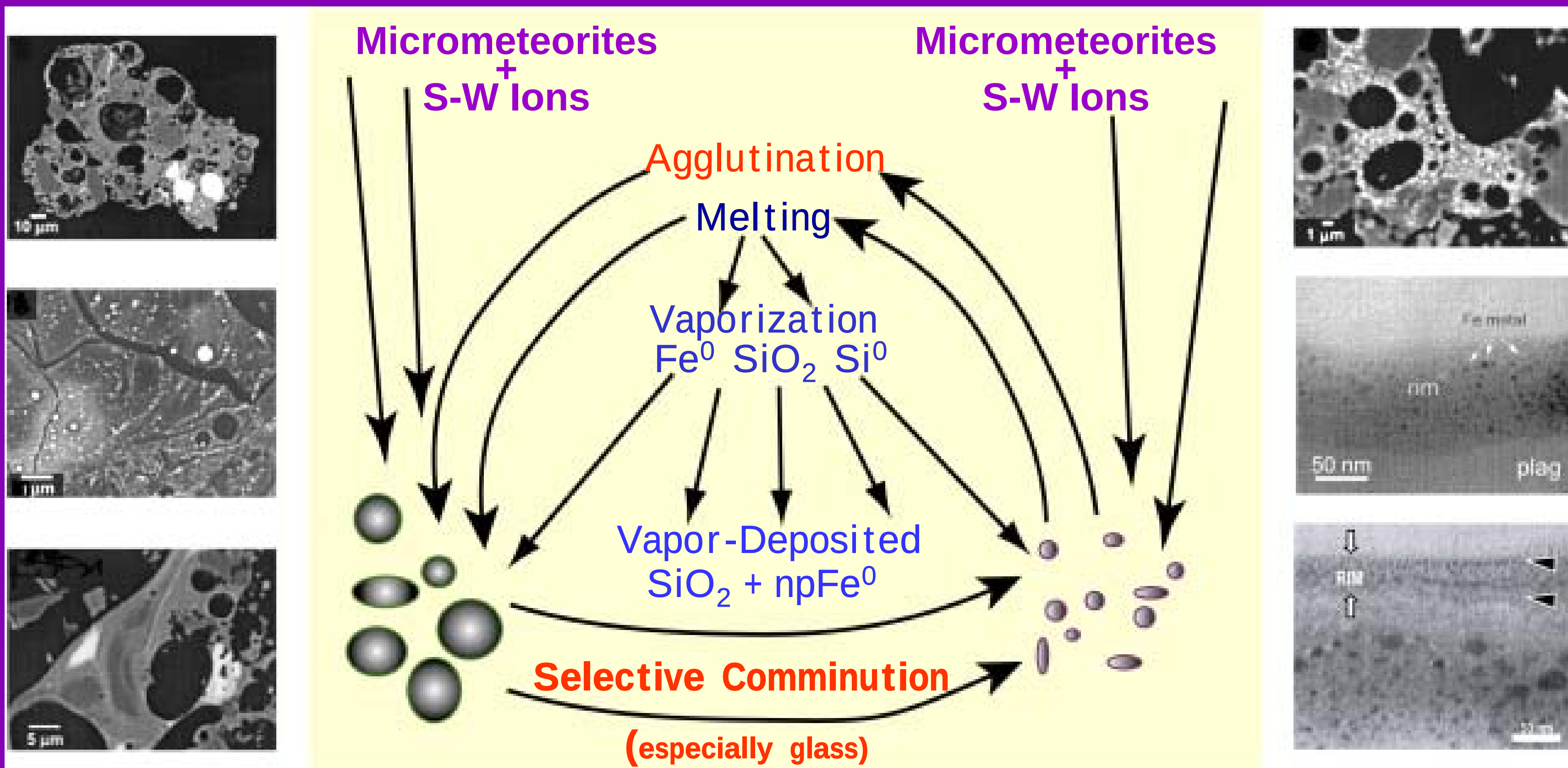
Vapor-Deposited Nanophase Fe° on Plagioclase



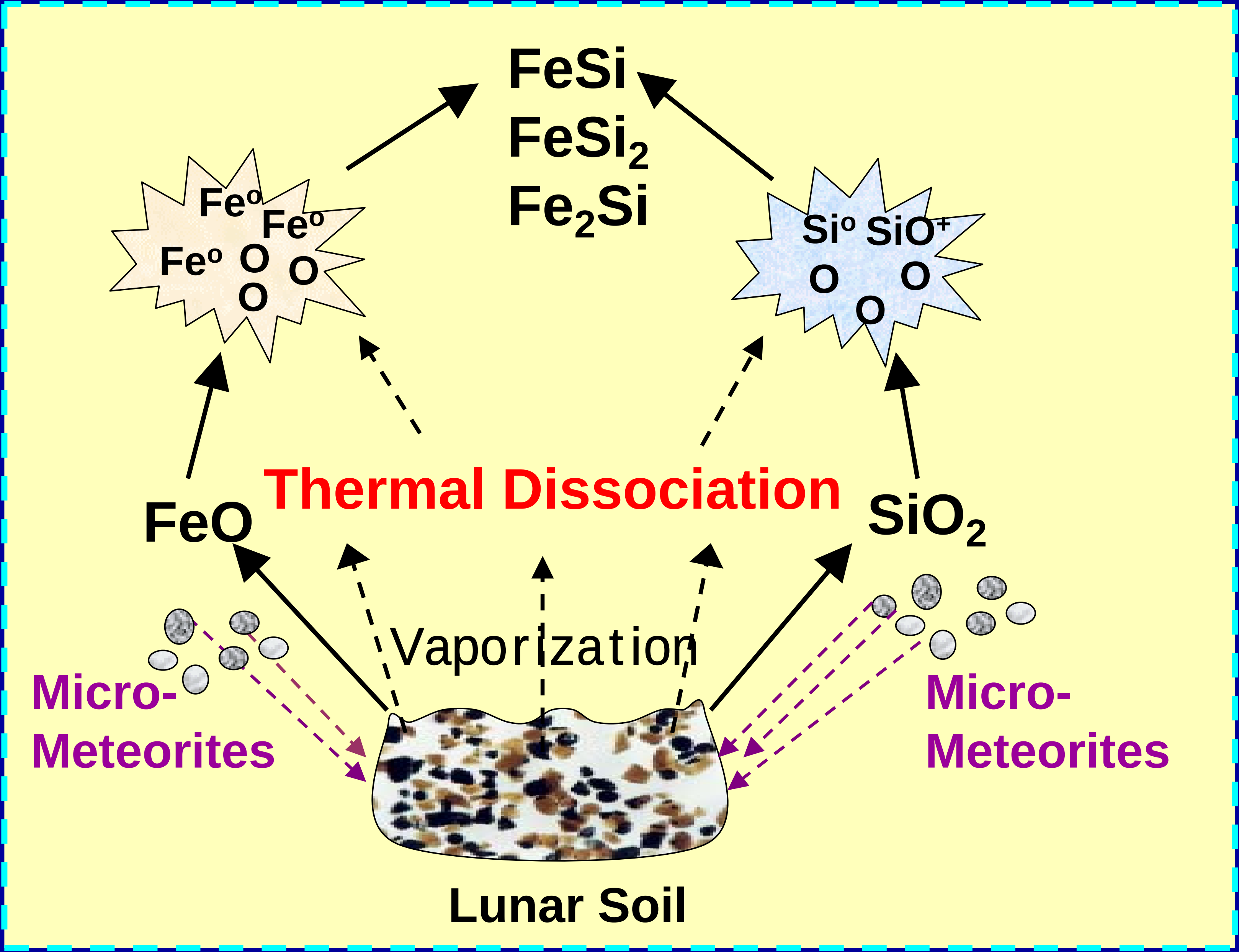


THE PRESENCE of NANOPHASE Fe° in VAPOR- and SPUTTER-DEPOSITED PATINAS (RIMS) on VIRTUALLY ALL GRAINS of a MATURE MARE SOIL PROVIDES an ADDITIONAL and ABUNDANT SOURCE for the GREATLY INCREASED I_s / FeO VALUES.

Lunar Soil Cycle



Course (>100 µm) ← **Grain size** → **Fine (<10µm)**

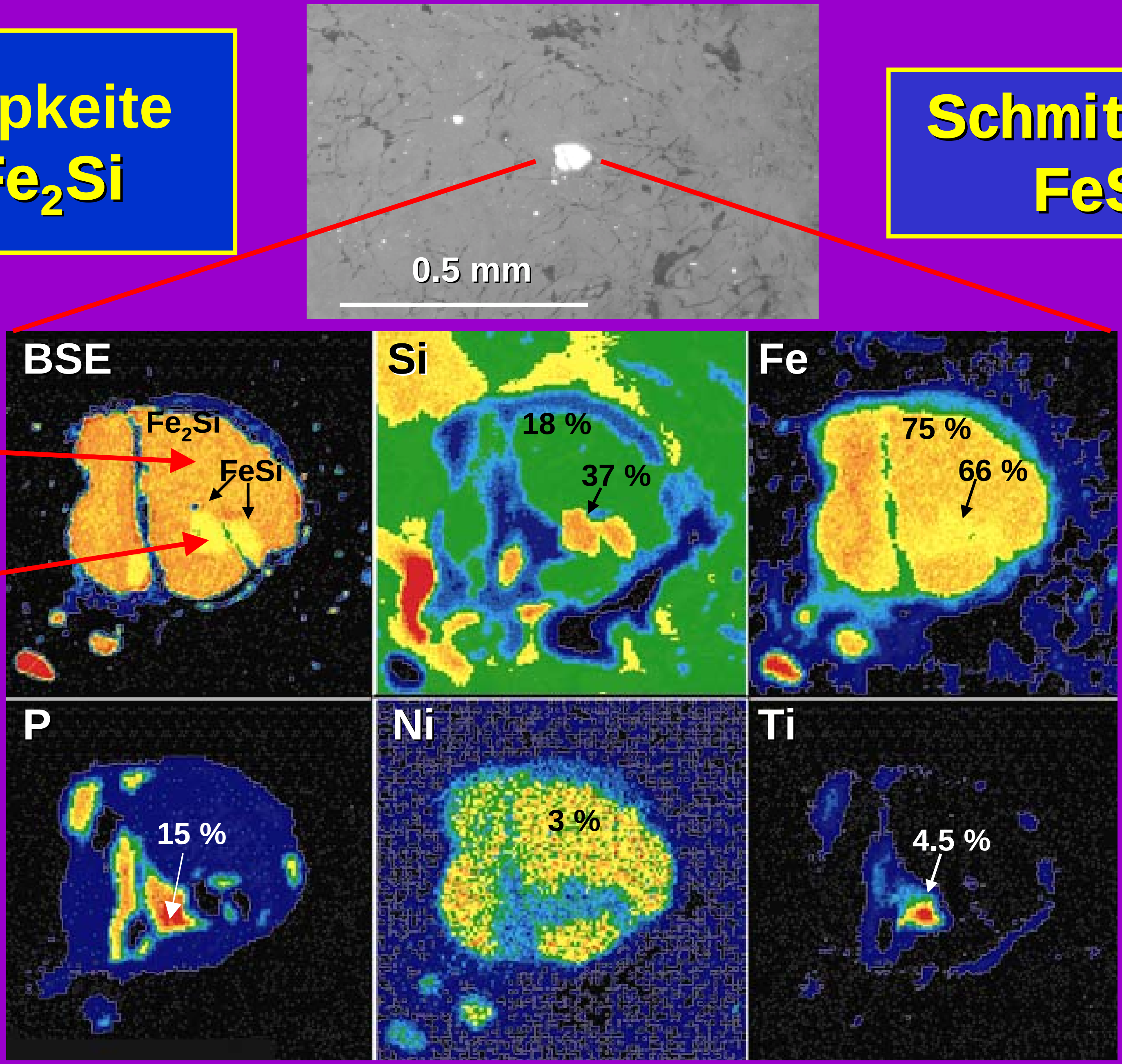


FeSi
$FeSi_2$
Fe_2Si
Fe^o Fe^o Fe^o O O O
Si^o SiO^+ O O O
FeO
Thermal Dissociation
SiO_2
Vaporization
Micro-Meteorites
Micro-Meteorites
Lunar Soil

New Lunar Minerals

Hapkeite
Fe_2Si

Schmittite?
FeSi



Fe_2Si

FeSi

MAGNETIC PROPERTIES OF LUNAR SOILS

- Magnetic Susceptibility of Soil Particles Increases as Grain Size Decreases;
- Effects of Vapor-Deposited Nanophase Fe^{o} are a Direct Function of Surface Area and Most Pronounced in the Finest Grain Sizes;
- Virtually All <10 μm Particles are Easily Attracted by a Simple Hand-held Magnet, Plg, Pyx, Ol, and Agglutinitic Glass alike.

Adverse Lunar Dust Properties must be Addressed before any Commercial Presence on the Moon can be Fully Evaluated.

- ✓ Abrasiveness, with regards to friction-bearing surfaces;
- ✓ Potential for coatings, on seals, gaskets, optical lens, windows, electrical components, et cetera;
- ✓ Potential for settling on all thermal and optical surfaces, such as Solar cells and mirrors; and
- ✓ Physiological effects on humans, especially with respect to the lungs, the lymph system, and potentially the cardiovascular system, in the case of extremely fine particles.

SOLUTION: Magnetic brushes ??

MICROWAVE RADIATION

- There is an entire subculture of people who derive pleasure from putting strange things in microwave ovens
- Things that microwave oven manufacturers would strenuously suggest should not be put there.

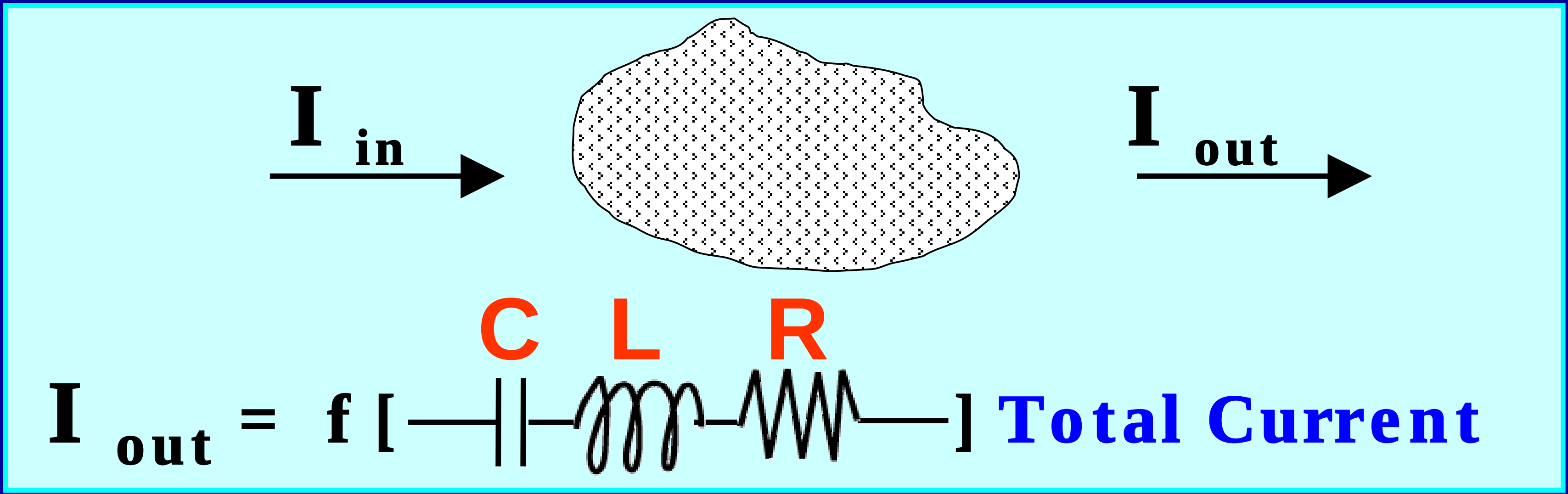
In the hands of these people :

- Table grapes produce glowing plasmas;
- Soap bars mutate into abominable soap monsters;
- Compact discs incandesce;
- Even ‘Wet Poodles’ have been known to “explode.”

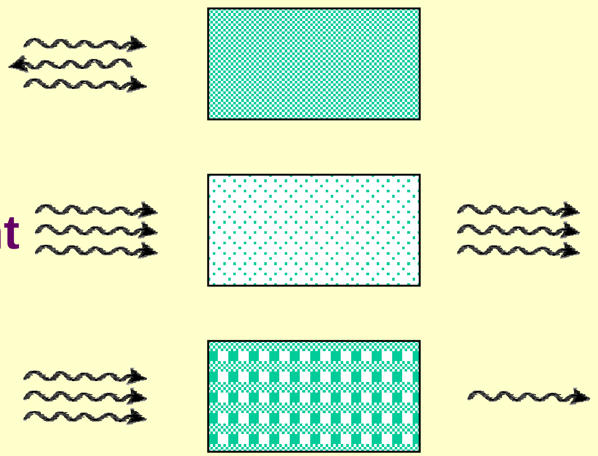
PRINICPLES OF MICROWAVE RADIATION

- Electromagnetic Field Induces Motion in Free & Bound Charges (e.g., Electrons & Ions) and in Dipoles (e.g., Water);
- Induced Motion is Resisted because it Causes a Departure from the Natural Equilibrium of the System;
- This Resistance, due to Frictional, Elastic, and Inertial Forces, leads to the Dissipation of Energy;
- Result: The Electric Field Associated with the Microwave Radiation is Attenuated and Heating of the Material Occurs.

Microwave Principles



Interaction of Materials with Microwaves



Reflectant	Metal	C
Transparent	Glass	L
Absorbent	Water	R

Electromagnetic Field Considerations

- Power Density
- Half-Power Depth
- Heating Rate

Electromagnetic Field Considerations

- **Power Density**
- **Half-Power Depth**
- **Heating Rate**

Power Density

$$P = K f E^2 k' \tan \delta$$

- **P – Power / cc**
- **K – Constant**
- ***f* – Frequency**
- **E – Electric-Field Intensity**
- **k' – Relative Dielectric Constant**
- **tan δ – Material Loss Tangent**

Electromagnetic Field Considerations

- Power Density
- **Half-Power Depth**
- Heating Rate

Half-Power Depth of Penetration

$$D_S = \frac{1}{2\pi\mu c f}$$

$$D_H = \frac{3\lambda o}{8.686\pi(k')^{1/2}\tan\delta}$$

- D_S = Depth of penetration in centimeters
- D_H = Half-Power of penetration in centimeters
- μ = Magnetic permeability
- c = Electrical conductivity
- *f* = Frequency
- λo = Wavelength of incident radiation
- k' = Relative dielectric constant
- $\tan\delta$ = Material loss tangent

Electromagnetic Field Considerations

- Power Density
- Half-Power Depth
- Heating Rate

Heating Rate

$$\Delta T \approx \frac{8x10^{-12} f\, E^2 k' \tan\delta}{\rho Cp}$$

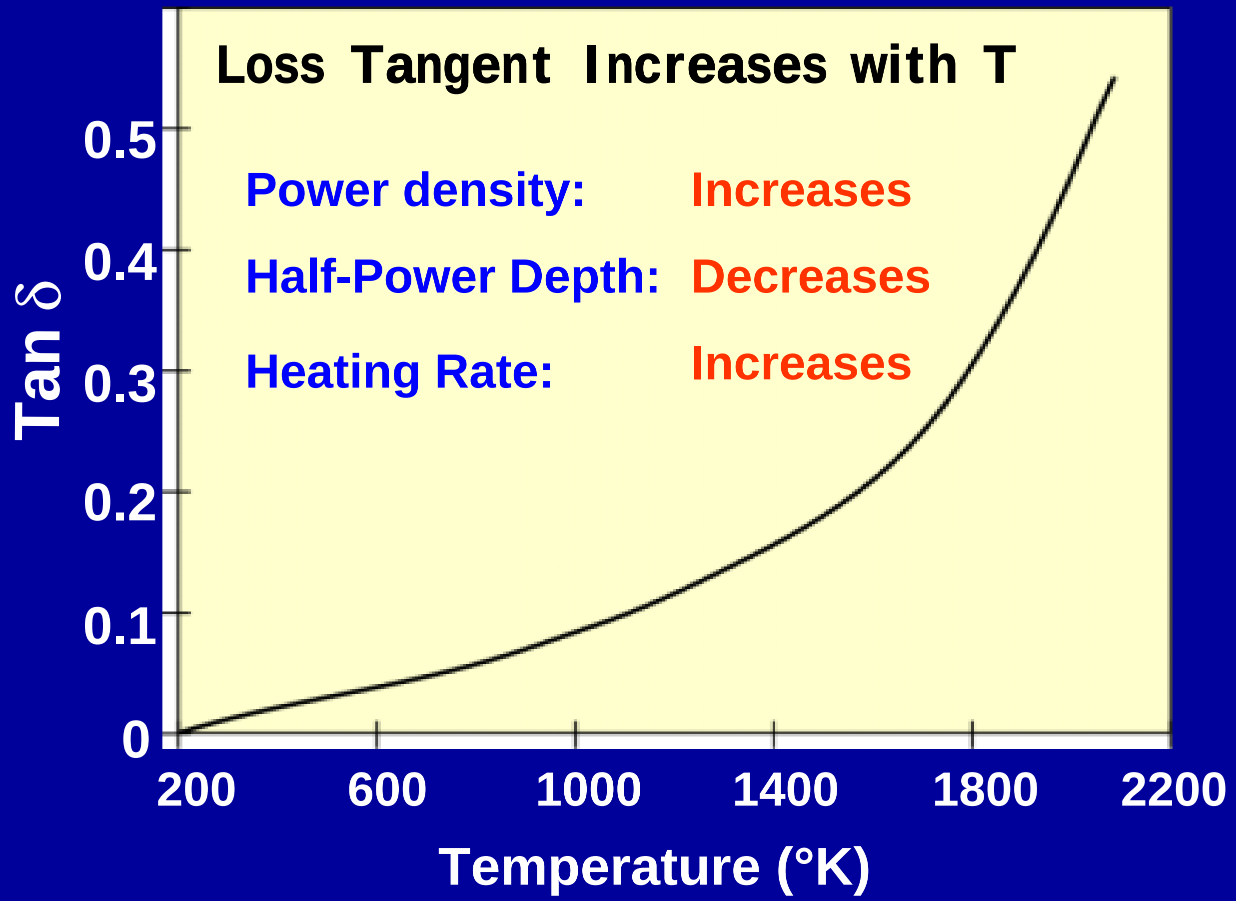
ΔT is a function of local dielectric properties

- ΔT - Temperature change in °C / min
- f - Frequency
- E – Electric-Field Intensity
- k’ - Relative Dielectric Constant
- $\tan\delta$ - Material Loss Tangent
- ρ - Soil Density (g/cm^3)
- Cp - Heat Capacity of Soil (cal/ °C)

MICROWAVE HEATING:

IMPORTANT PARAMETERS FOR MATERIAL RESPONSE

DIELECTRIC CONSTANT, ε_r, AND LOSS TANGENT, TAN δ



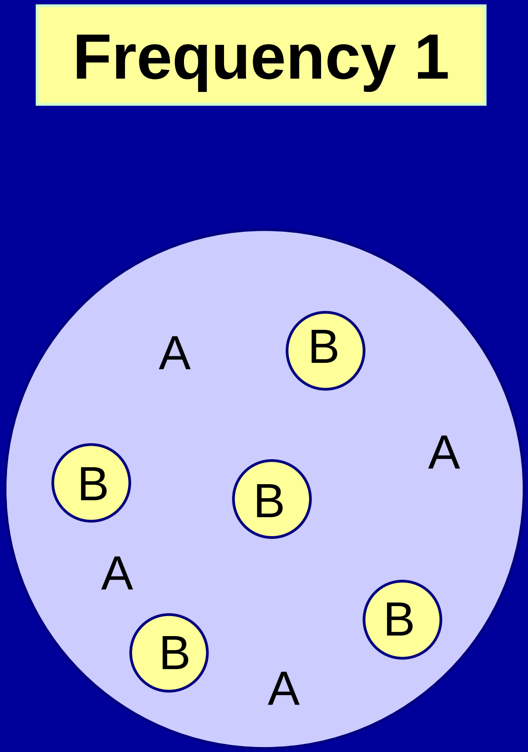
TAN δ = Sum of All Losses from All Mechanisms during Microwave Heating

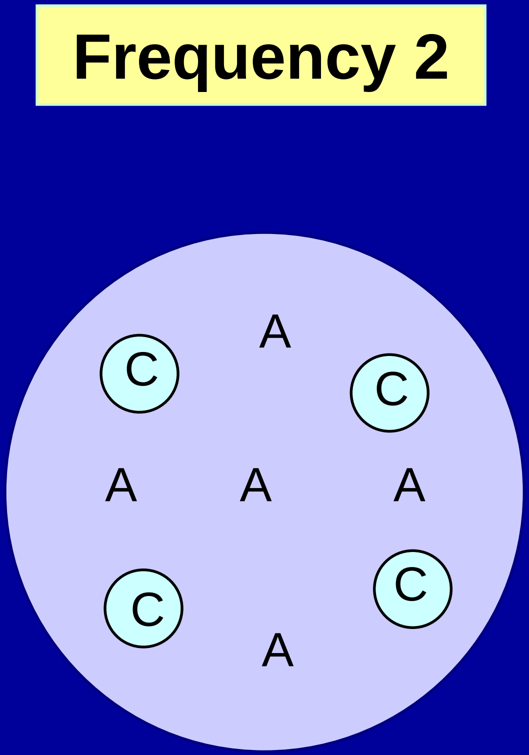
Microwave Heating:
Experimental System Variables

Frequency : 2.45 GHz (λ = 12 cm) Magnetron
60.0 GHz (λ = 0.5 cm) Gyrotron

Power : 700 Watts to 6,000 Watts

Two Phases with Different Microwave Coupling Characteristics





Microwave Heating of Lunar Soil:
System Conditions

<u>NanoPhase Fe^0 in Silicate Glass</u>

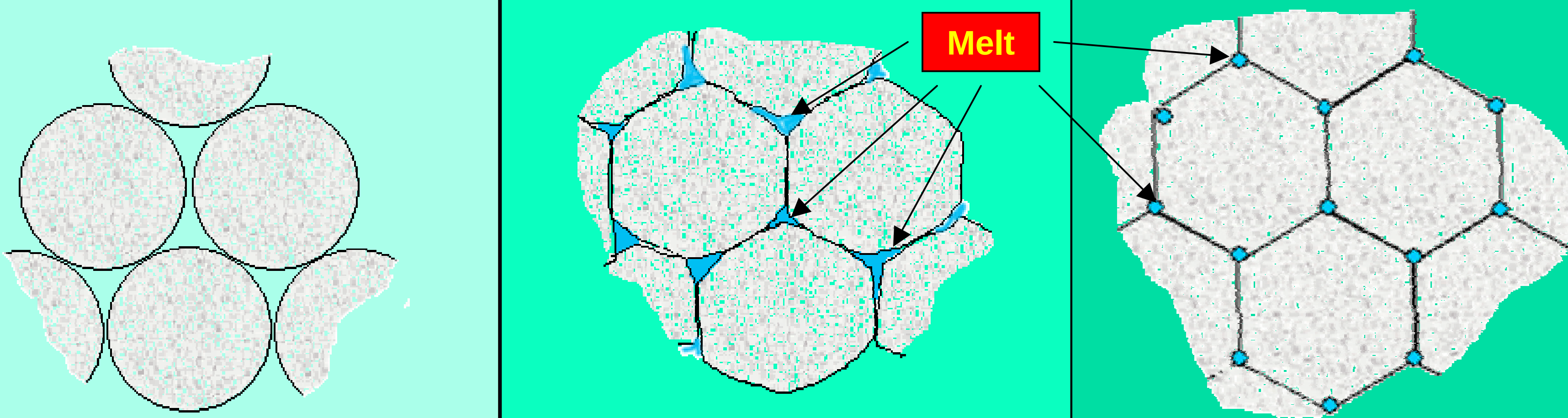
Fe^0 grain size is so small as to be below the effective "skin depth" of microwave penetration;

System is basically one of :

Small <u>conductors</u> of Fe^0 insulated by Intervening <u>dielectric glass</u>

= GREAT MICROWAVE COUPLING!

Sintering Progress of Powder Particles By Microwave Energy

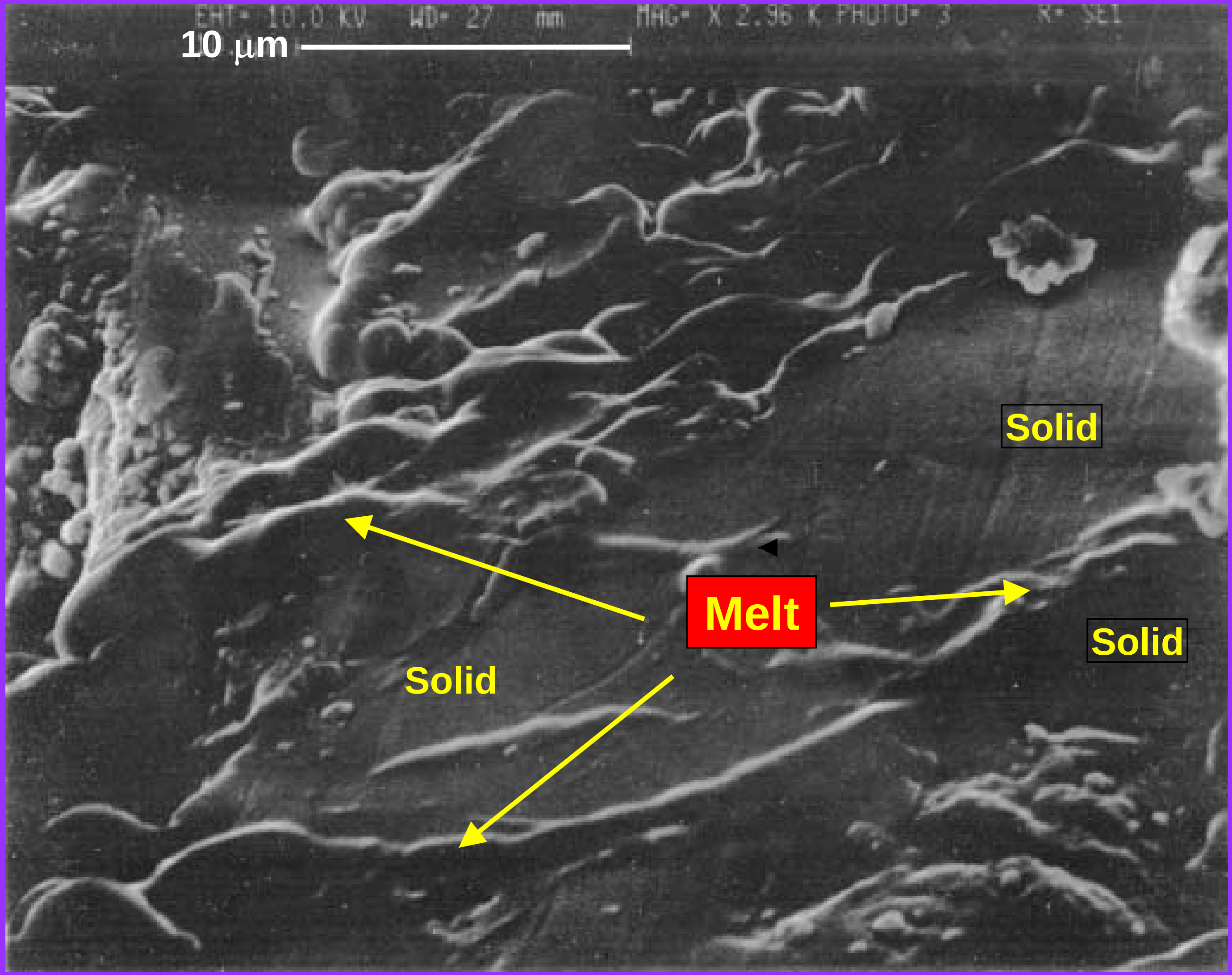


Initial heating of particles

Introduction of liquid phase, plus solid-state diffusion

Combination of Solid-State and Liquid-Phase Sintering

Microwave Melting
Along Grain Boundaries of Mare Soil



BENEFITS OF MICROWAVE OVER CONVENTIONAL HEATING

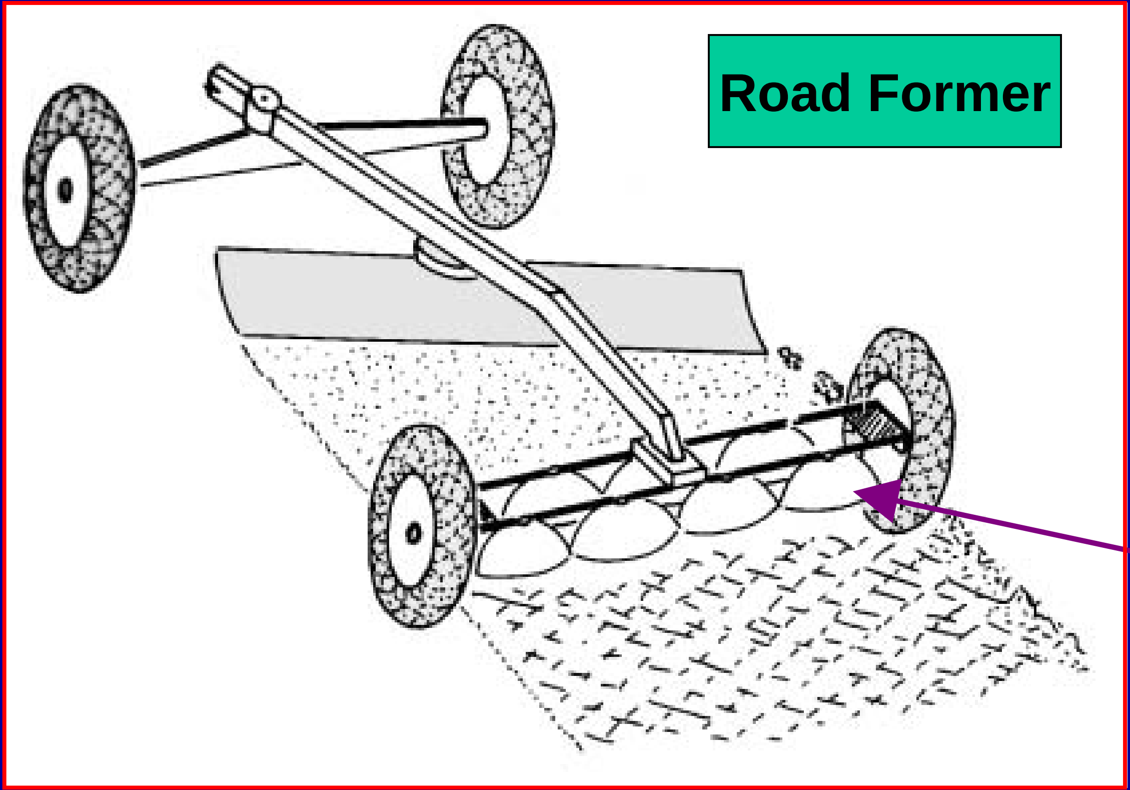
- **RAPID HEATING RATES [>1000 ^{0}C/min]**
- **HIGH TEMPERATURES [2000 ^{0}C]**
- **ENHANCED REACTION RATES [Faster Diffusion Rates]**
- **FASTER SINTERING KINETICS [Shorter Sintering Times]**
- **LOWER SINTERING TEMPERATURE [Energy Savings]**
- **FINE MICROSTRUCTURES [Improved Mechanical Properties]**
- **CONSIDERABLY REDUCED PROCESSING TIME**
- **PROCESS SIMPLICITY**
- **LESS LABOR COSTS**

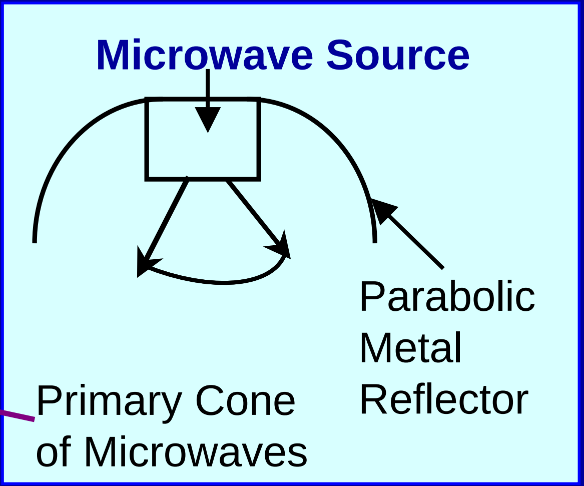
Bottom Line : LOWER ENERGY REQUIREMENTS

LUNAR SOIL PROCESSING & PRODUCTS

SINTERING and MELTING

Creating Smooth-Sintered to Glassy Surfaces on the Moon

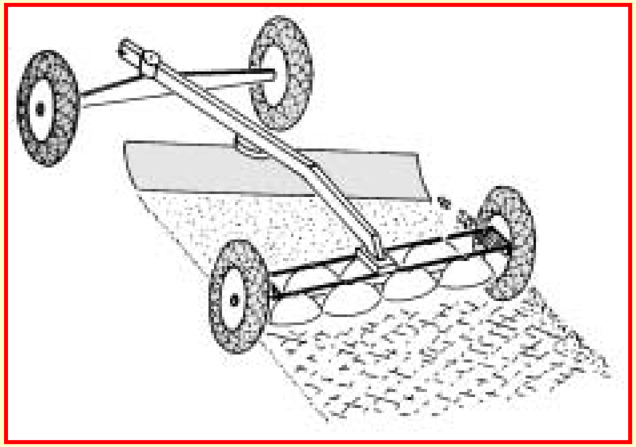




LUNAR SOIL PROCESSING & PRODUCTS

SINTERING and MELTING

- Roads
- Satellite Dishes
- Shielding
- Welding
- Recovery of Volatiles
- Glass Fiber Production
- Solar Cells (Ilmenite)



SUGGESTIONS ??

TM

NASA's Next Moon Mission

2010 Winter

Olympics

At

South Pole

Aitken Basin, Moon