



Lunar Resources

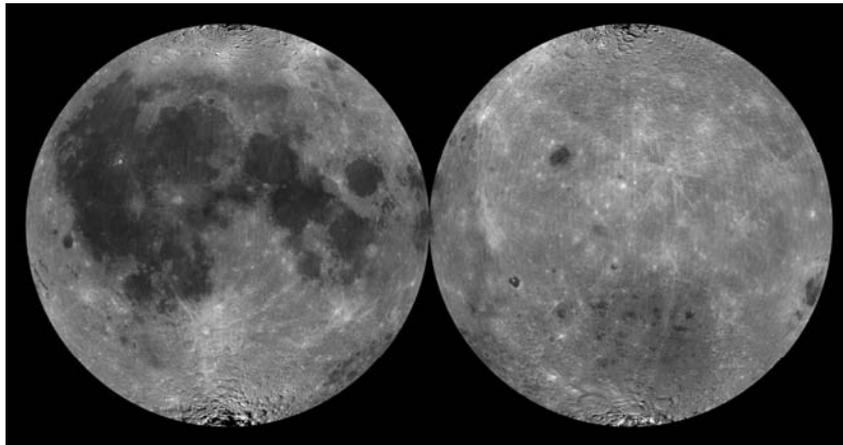
Dr. Jennifer Edmunson

October 5, 2010

**Workshop for the Lunar Applications of Mining and
Mineral Beneficiation**

Outline

- Lunar resources
- Locations
 - Highlands
 - Mare
 - Poles / polar cold traps



- Sunlight
 - Solar power
- Solar wind
 - H, ^3He
- Water / ice
 - Source of the water
- Rock Types
 - Highlands
 - Mare
 - Recently identified concentrates
- Regolith
- Conclusions

Regolith
Conclusions

Water
Rock Types

Sunlight
Solar Wind

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Location

Regolith
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Water
Rock Types

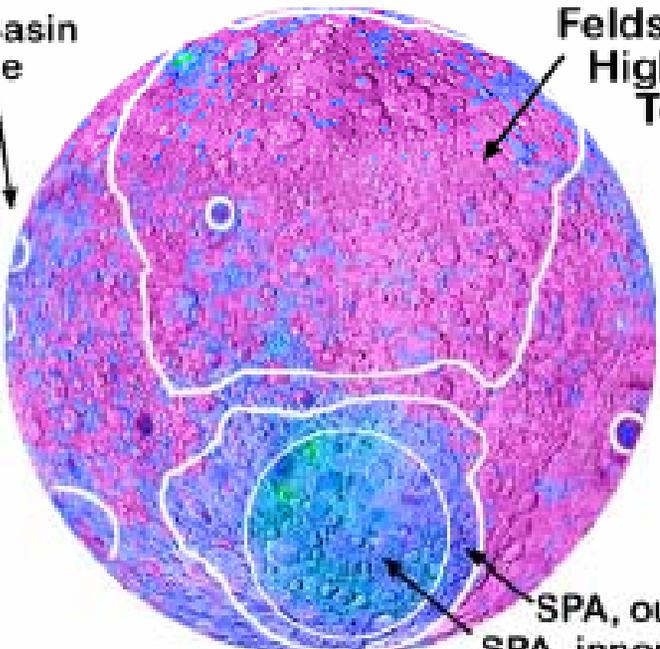
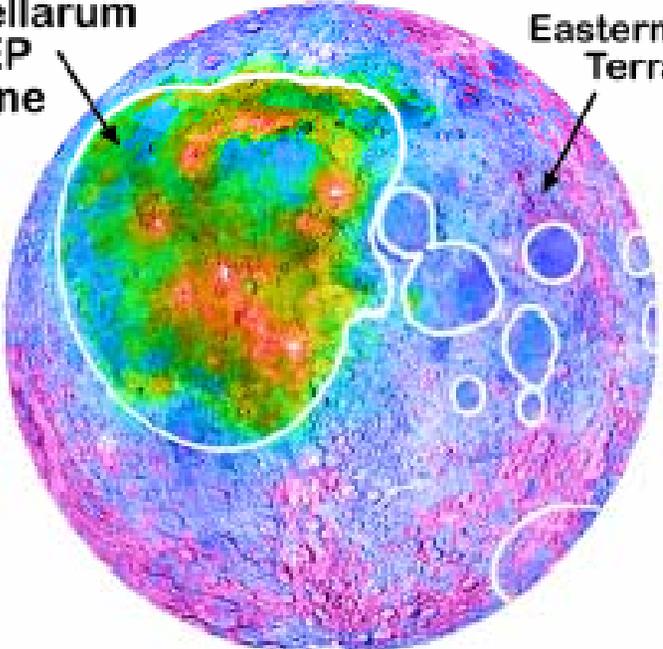
Sunlight
Solar Wind

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Procellarum
KREEP
Terrane

Eastern Basin
Terrane

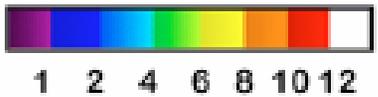
Feldspathic
Highlands
Terrane



Near Side

Far Side

Th, ppm



Gillis et al. (2000), Jolliff et al. (2000)



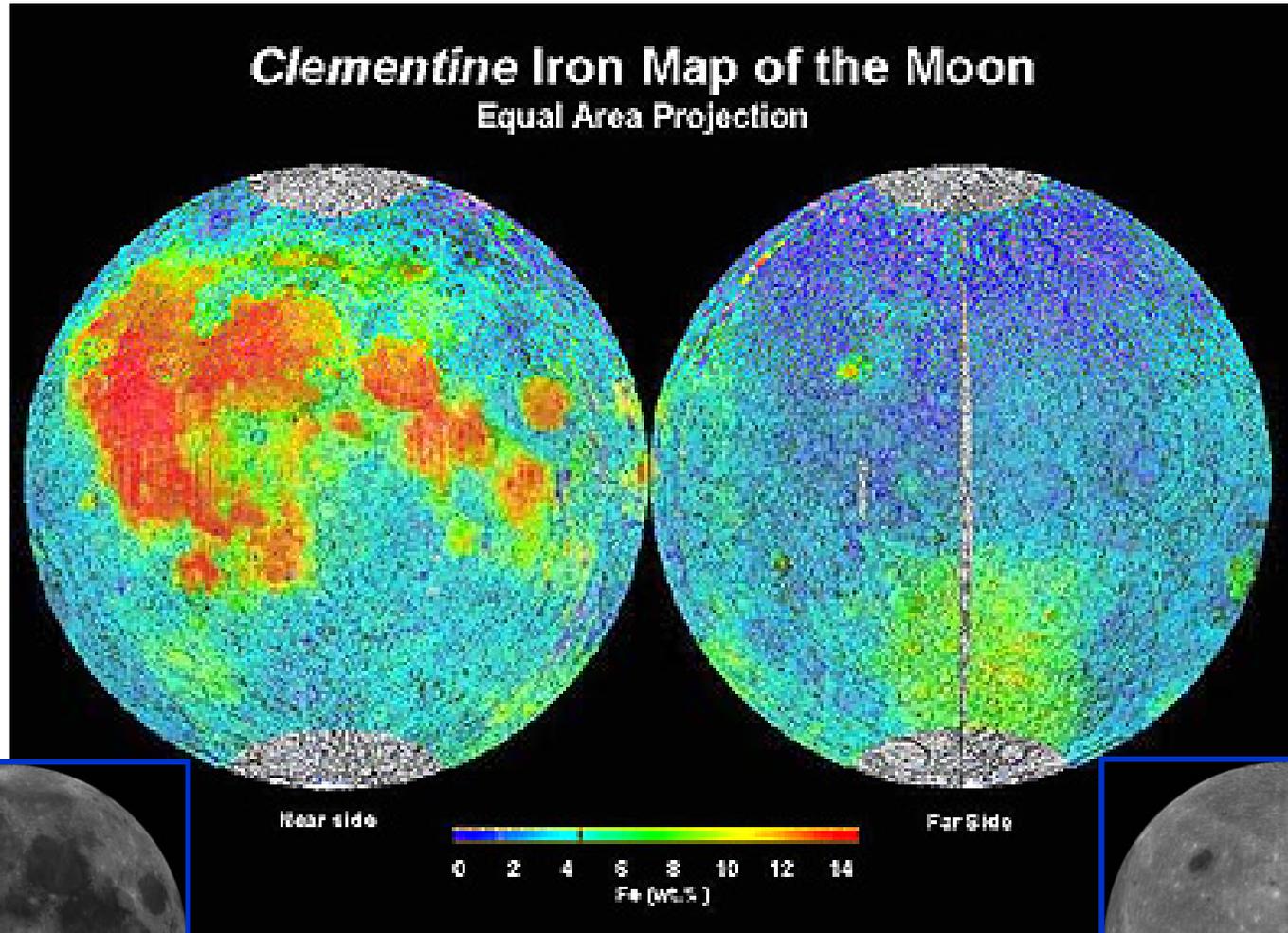
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Location

Common Rock Types

anorthosite



basalt



norite



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Location

Common Components

Regolith
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Anorthite



Ilmenite



Olivine



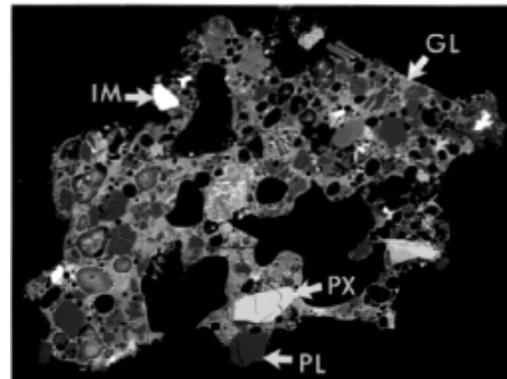
Water
Rock Types

Pyroxene

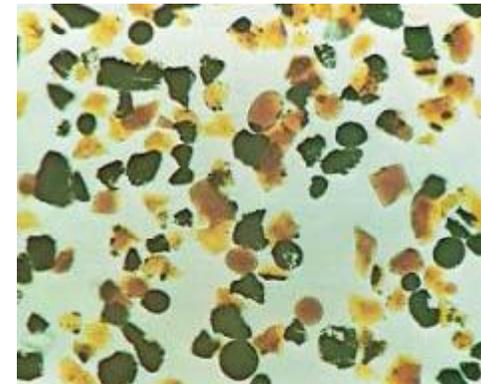


CPX

Agglutinate



Volcanic Glass Beads



Sunlight
Solar Wind

OPX



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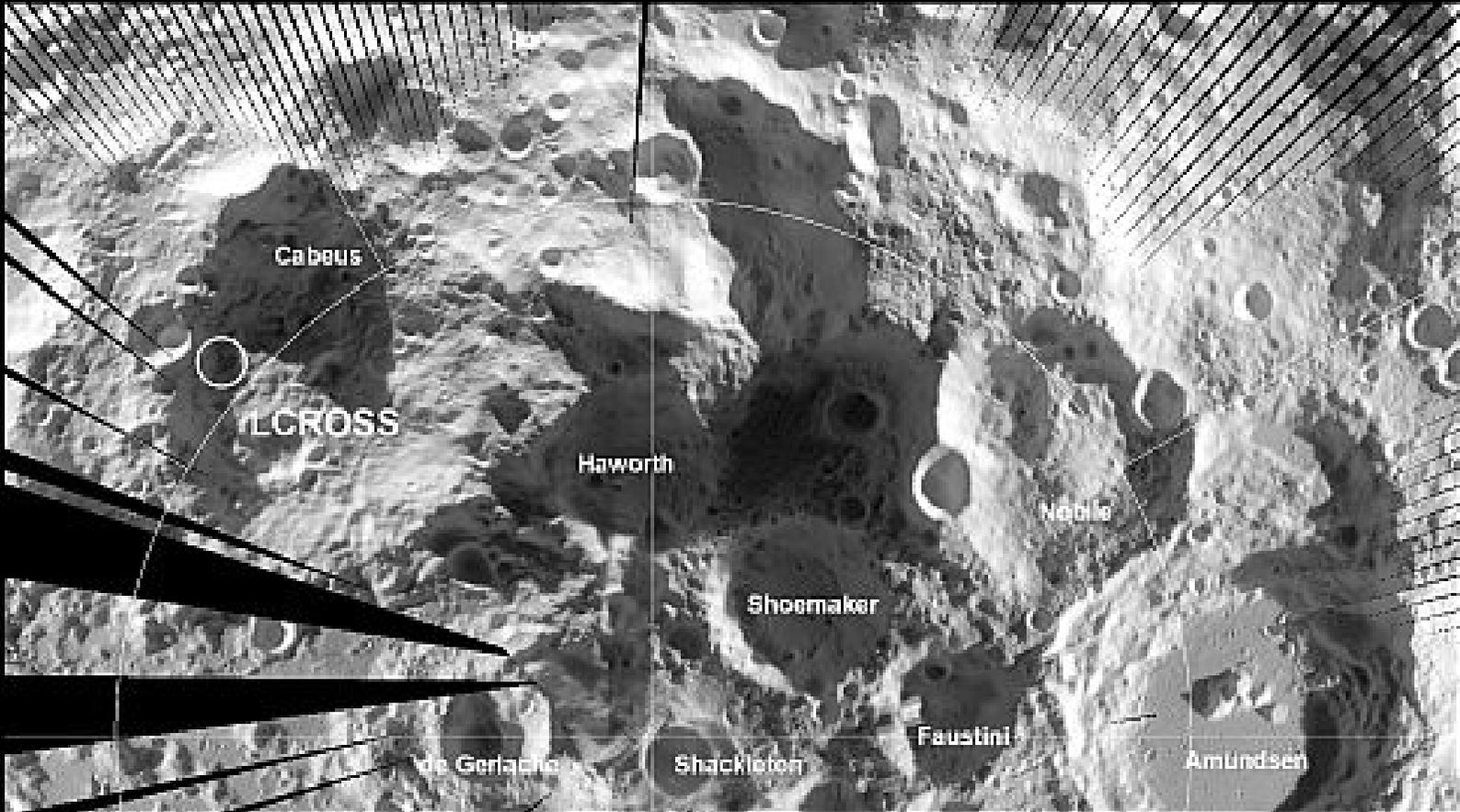
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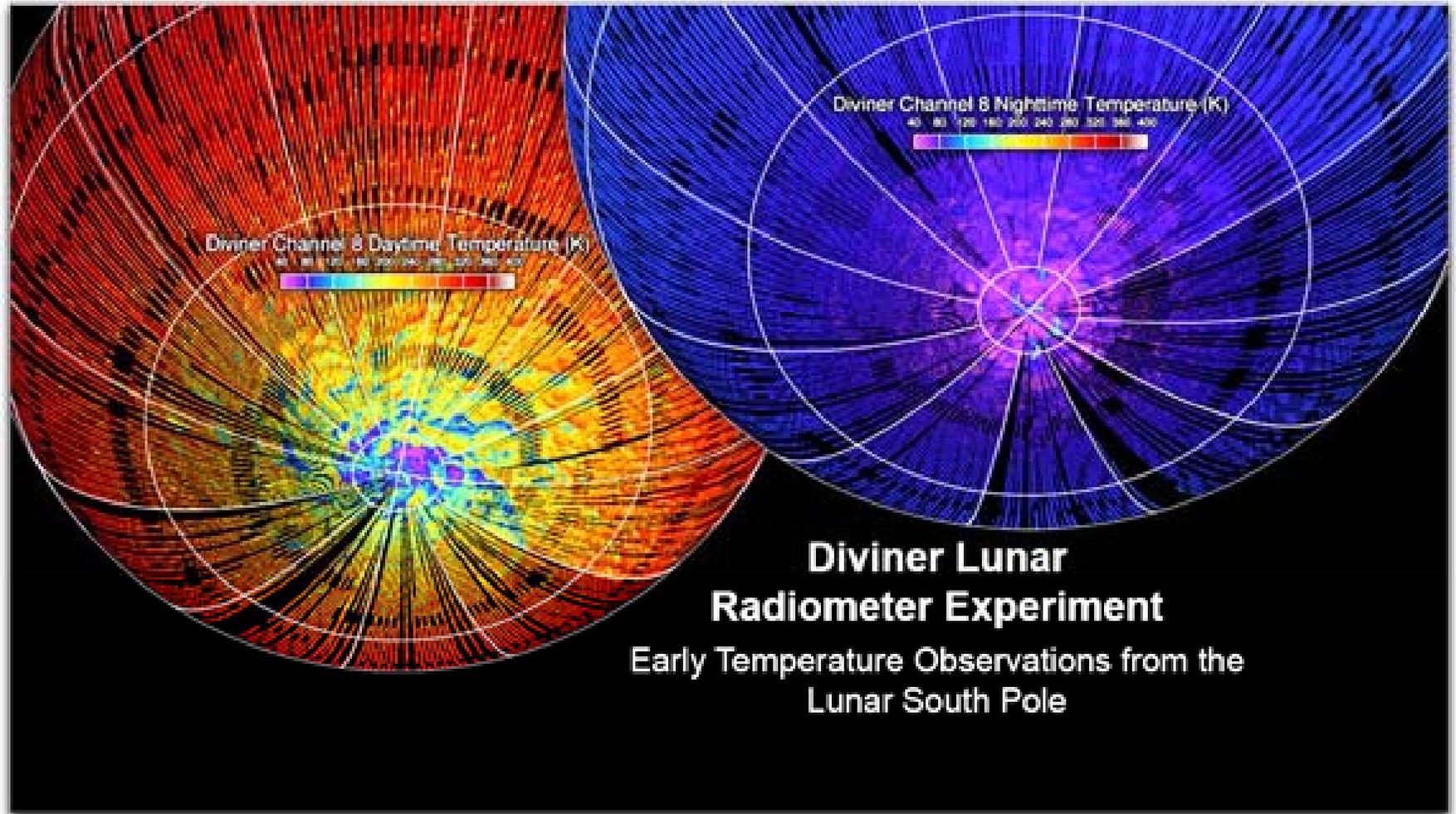
Introduction
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Diviner Channel 8 Brightness Temperature Map (K)

Location

Diviner measures T of the top 1mm of the surface



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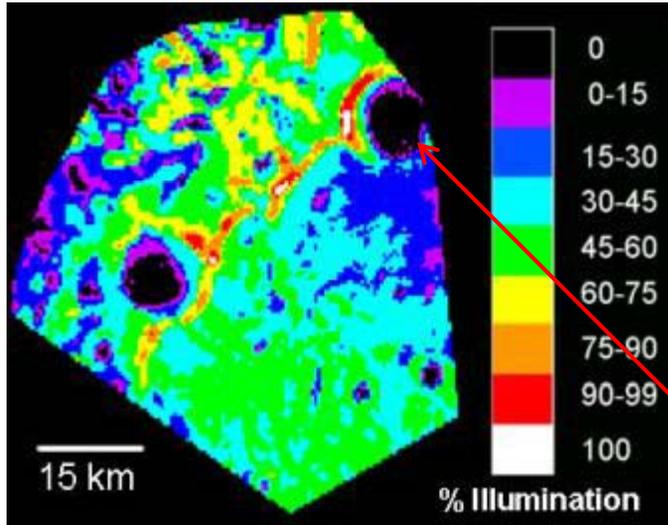
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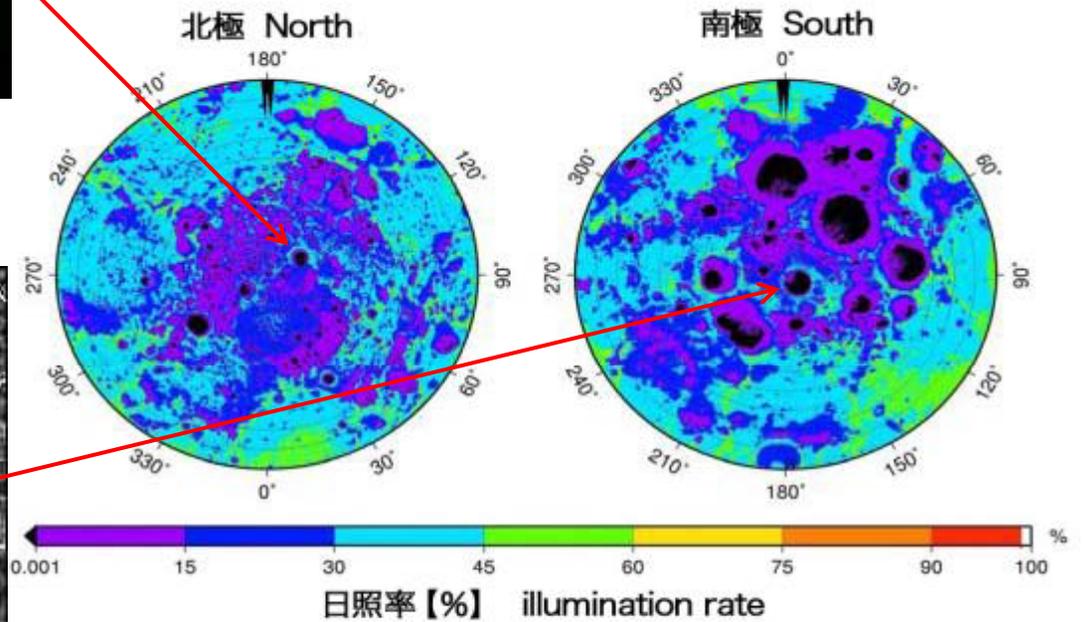
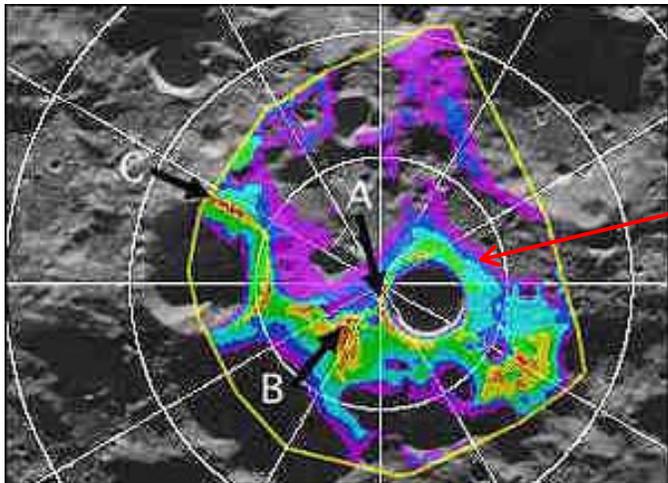
Regions of permanent sunlight and shadow at the poles

Temperatures in craters ~40K

Water
Rock Types

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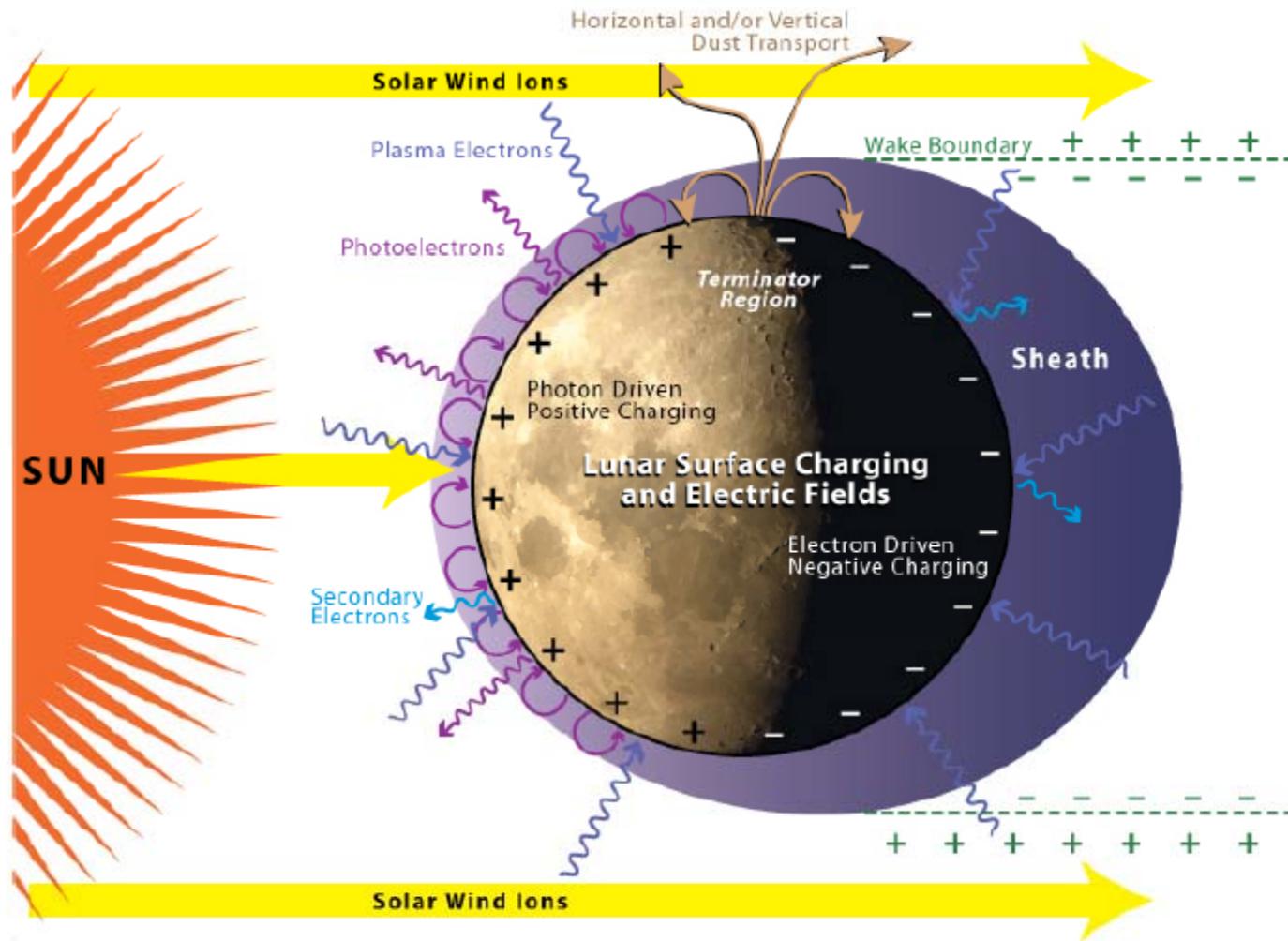
Solar Wind

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Stubbs, 2007

Solar Wind

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➤ Hydrogen

- Implanted on surface
- Reducing environment
- Source of OH/H₂O on the surface(?)

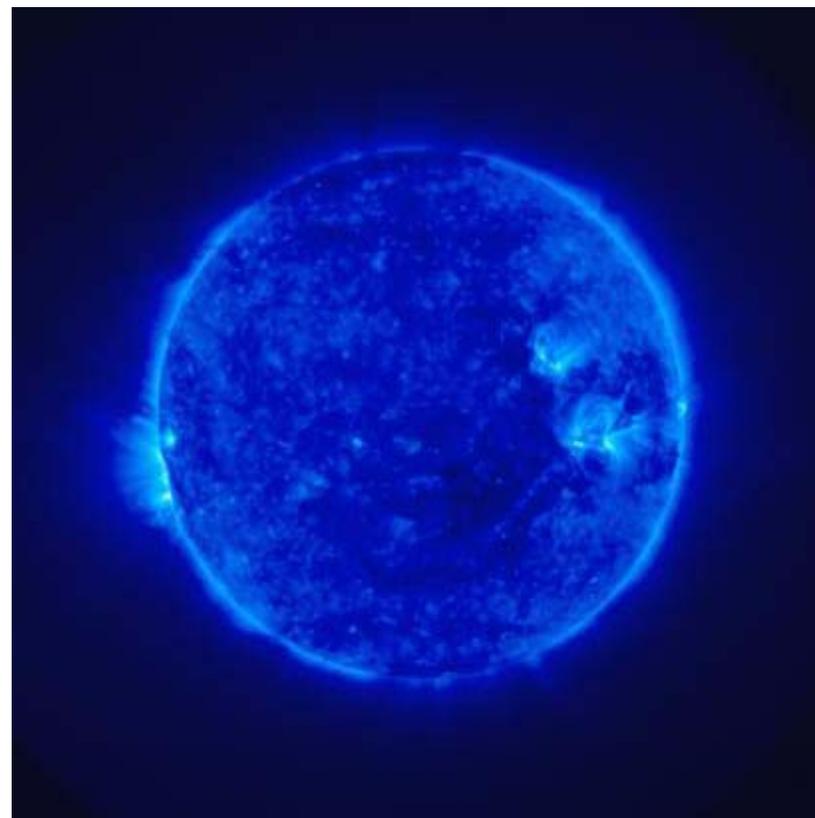
Water
Rock Types

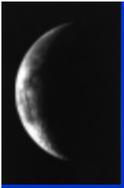
➤ Helium-3

- Source of electricity
- Estimates vary based on exposure to solar wind particles
- Greatest concentration likely found in the mineral ilmenite

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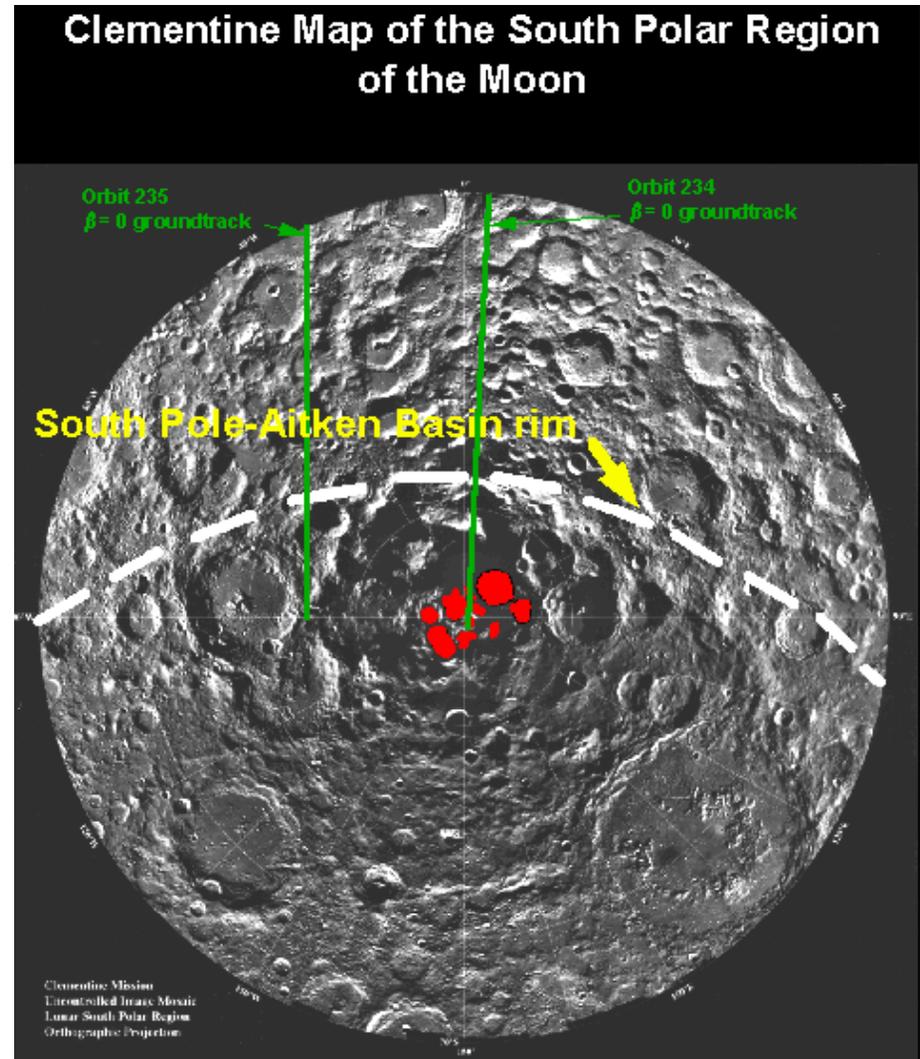
Magnitude and polarization of radar signals indicated volatile ices (Bistatic Radar Experiment)

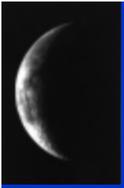
Water
Rock Types

First detection of possible water ice (or surface roughness – doubt caused by similar results for other areas by the Arecibo Telescope)

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Water

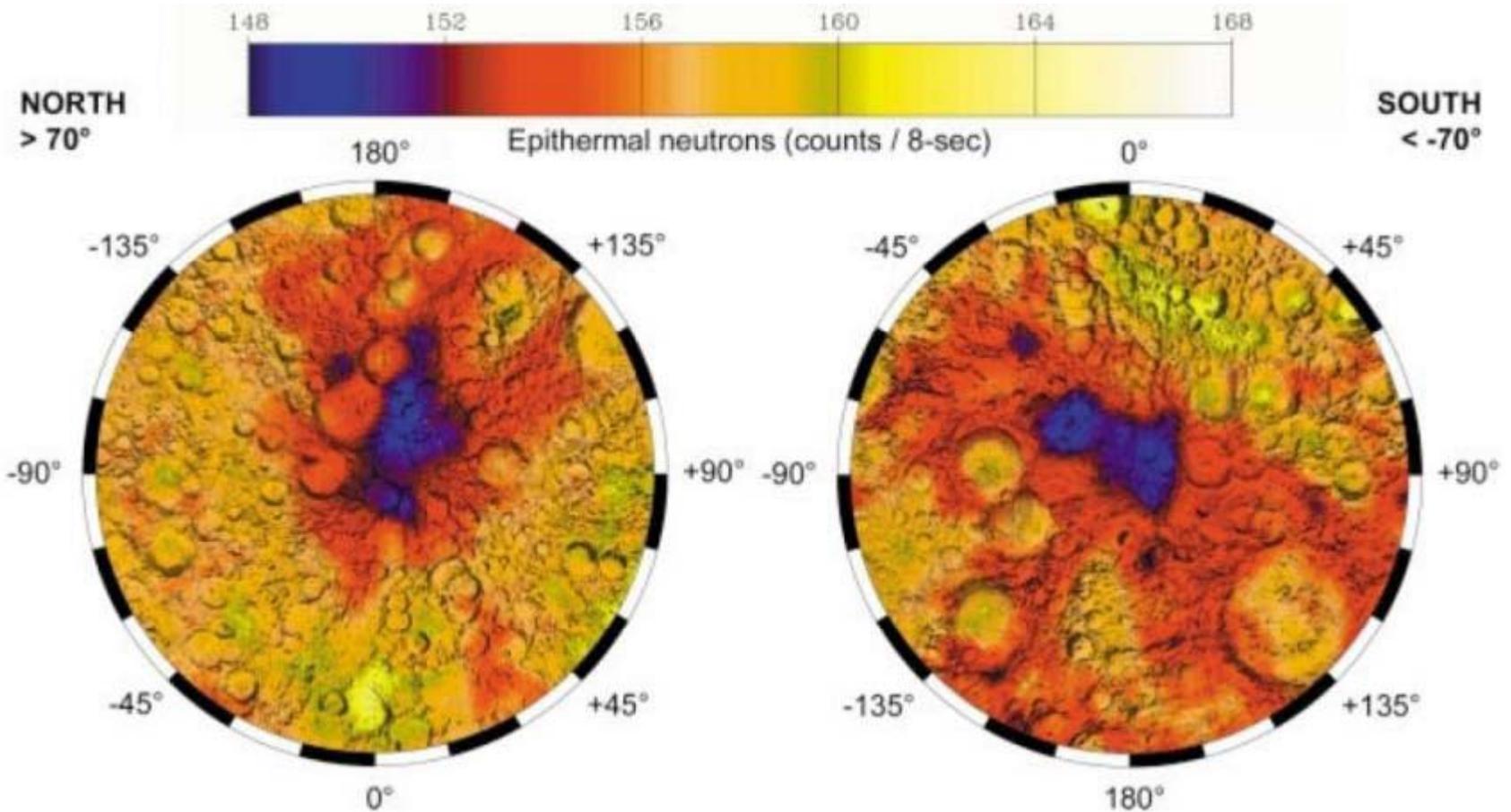
Lunar Prospector Epithermal Neutrons (Poles)

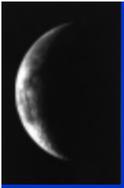
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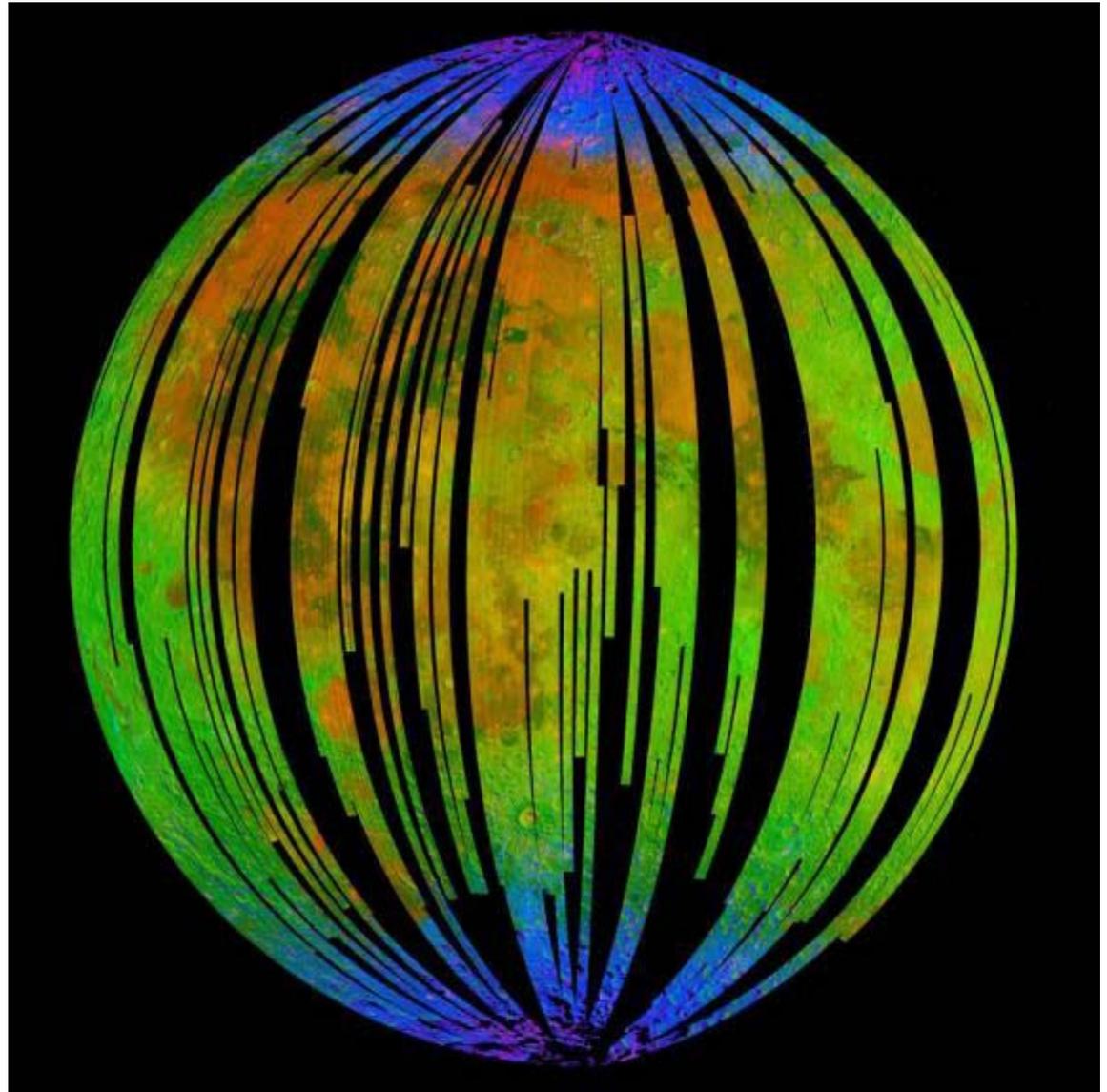
Chandrayaan-1

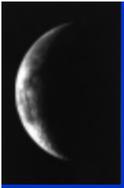
Reflected near
infrared radiation

Purple/blue =
water/hydroxyl
signature

Red = pyroxene

Cover of Science Magazine,
10-23-09





Water

Water Formation on the Lunar Surface (M³)

Regolith
Conclusions

➤ Hypothesized that water forms by the bombardment of the lunar surface by solar wind hydrogen

3μm band depth for Orientale
(lunar **8AM** and **4PM**)
- A surface effect?

Water
Rock Types

➤ The hydrogen bonds with oxygen from lunar surface minerals

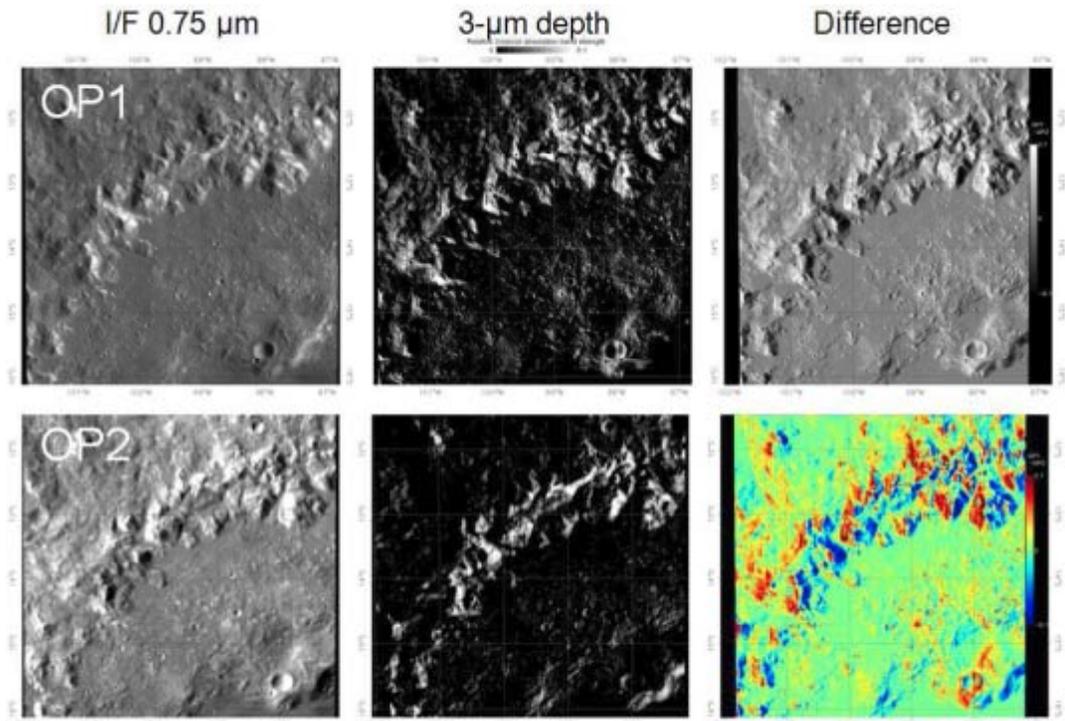
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Solar Wind

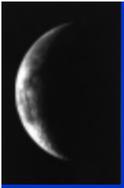
➤ If the OH⁻ remains bound to the surface, it has a chance of bonding with another H

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➤ Subject to photodissociation

H₂O band 3μm,
OH band 2.85μm





Water

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Lunar CRater Observation and Sensing Satellite

Water
Rock Types

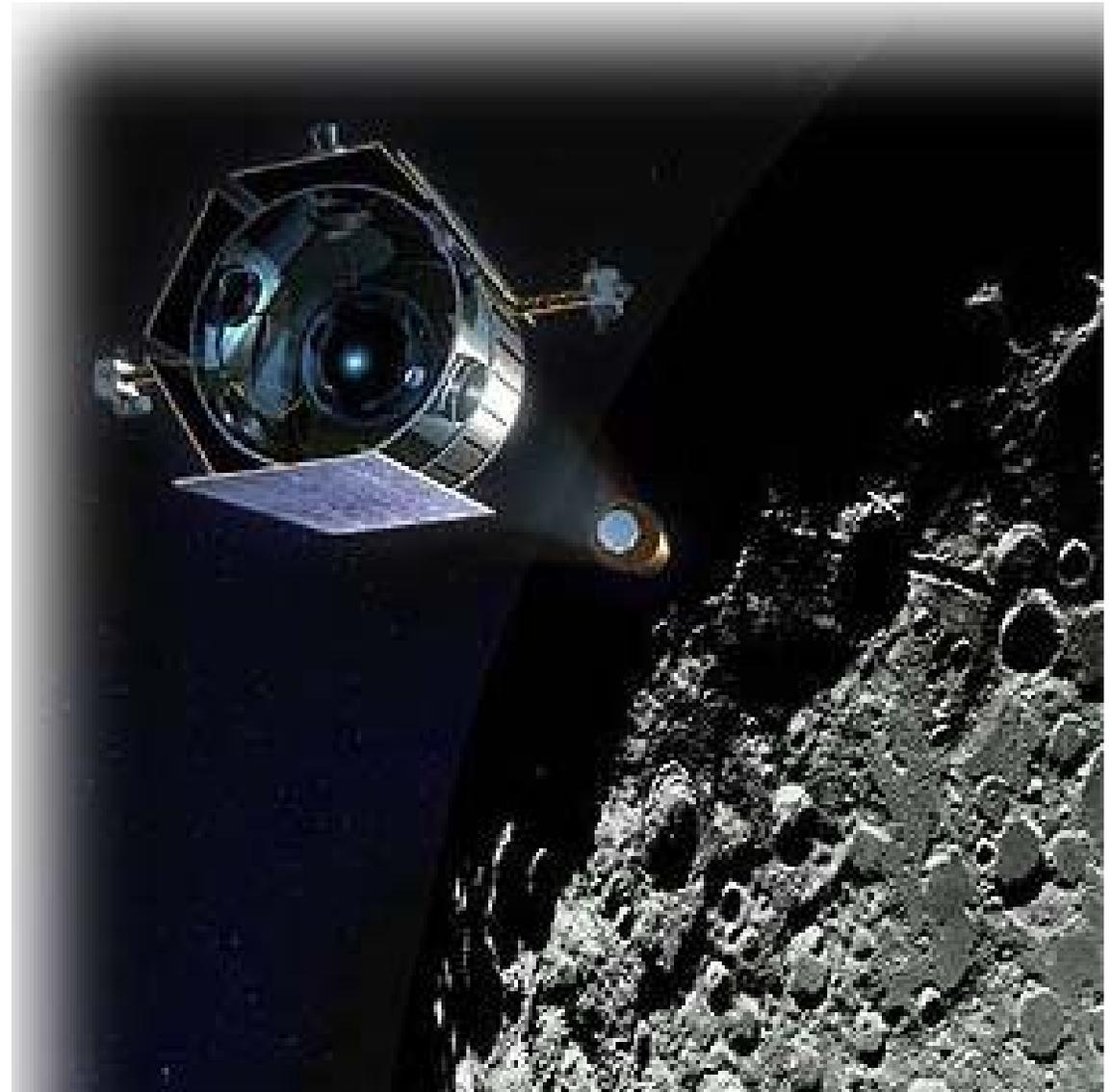
Visible and Infrared
Spectrometers, Cameras,
and a Photometer

Sunlight
Solar Wind

Impacted Cabeus Crater
(south pole)

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Confirmed the presence
of water (~25 gallons
within the plume)!





Water

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➤ NIR detected dust, vapor, and ice, SO_2 , H_2O , CH_3OH , CH_4 , CO_2 , H_2CO , C_2H_2

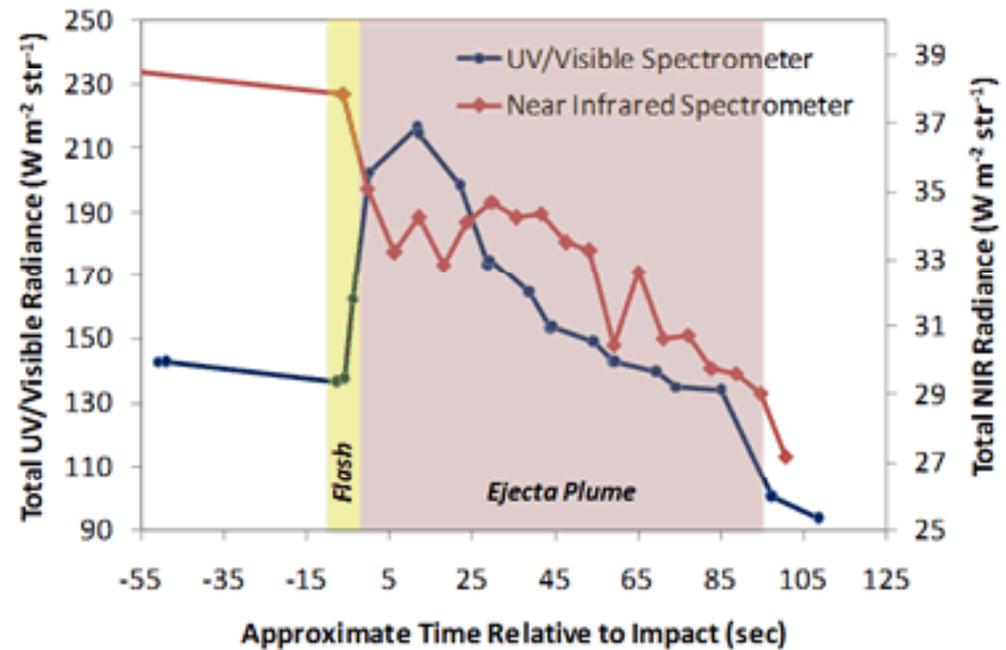
Water
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➤ UV detected OH, obtained grain size measurements due to reddening or bluing of spectra, also $\text{NH}+\text{NH}_2$, CN , CH , HCO , H_2S , CS , CO

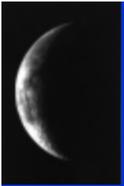
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➤ Data reduction is “a work in progress”



UV spectra also shows “prompt dissociation of H_2O ”



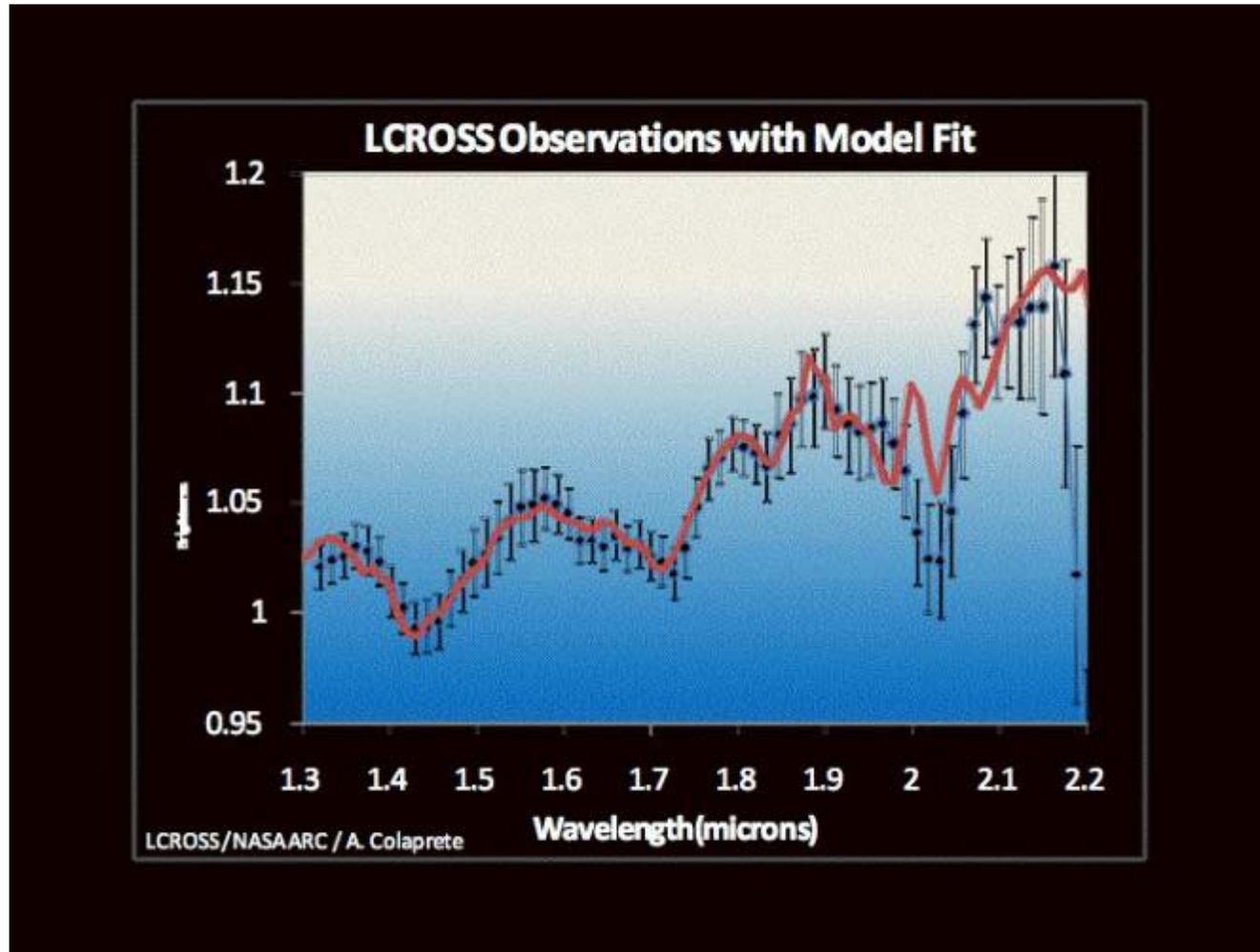
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Model fit includes water and other compounds (hydrocarbons and mercury)

Estimated mercury content based on LCROSS H₂O results:
~6 gallons in plume (after Reed, 1999)



Water

Water Retention in PSRs

Regolith
Conclusions

- Annual temperature is $\sim 60-70\text{K}$ at 75cm depth, indicates residence time of water is $>1\text{Ga}$ in permanently shadowed regions

Water
Rock Types

- Diffusion by regolith gardening would make permafrost disappear in regions except PSRs
- The obliquity of the Moon's orbit had to be less than 4 degrees for volatile emplacement

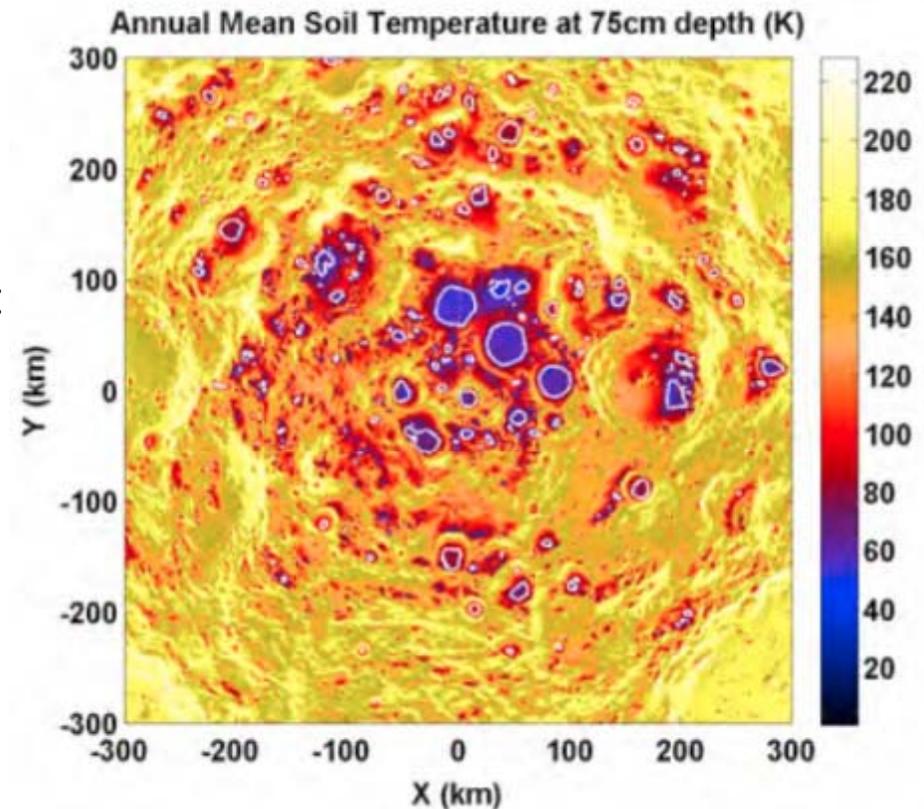
Sunlight
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- Different methods of water collection proposed, none definitive

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- Hydrothermal
- Random Walk
- Cometary Source

Modeled from Diviner data by Elphic et al.



Rock Types

Common Rock Types

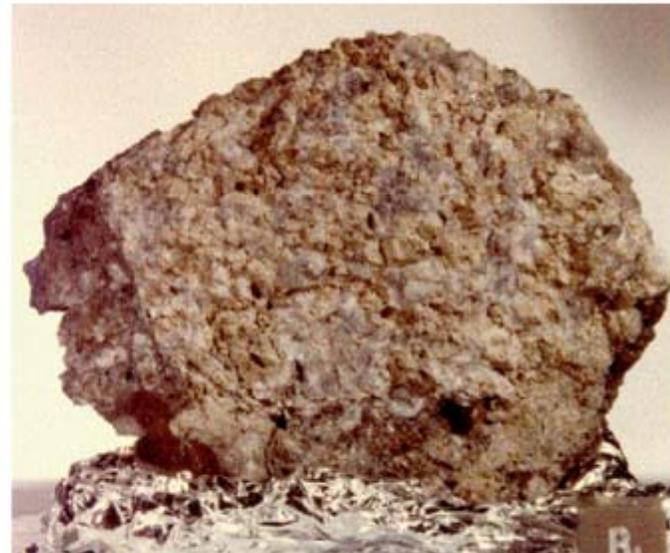
anorthosite



basalt



norite



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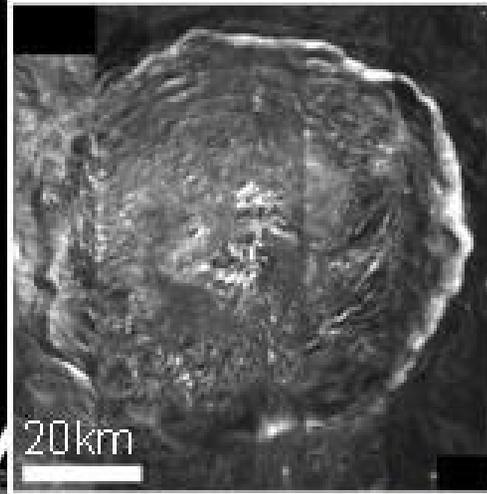
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Jackson



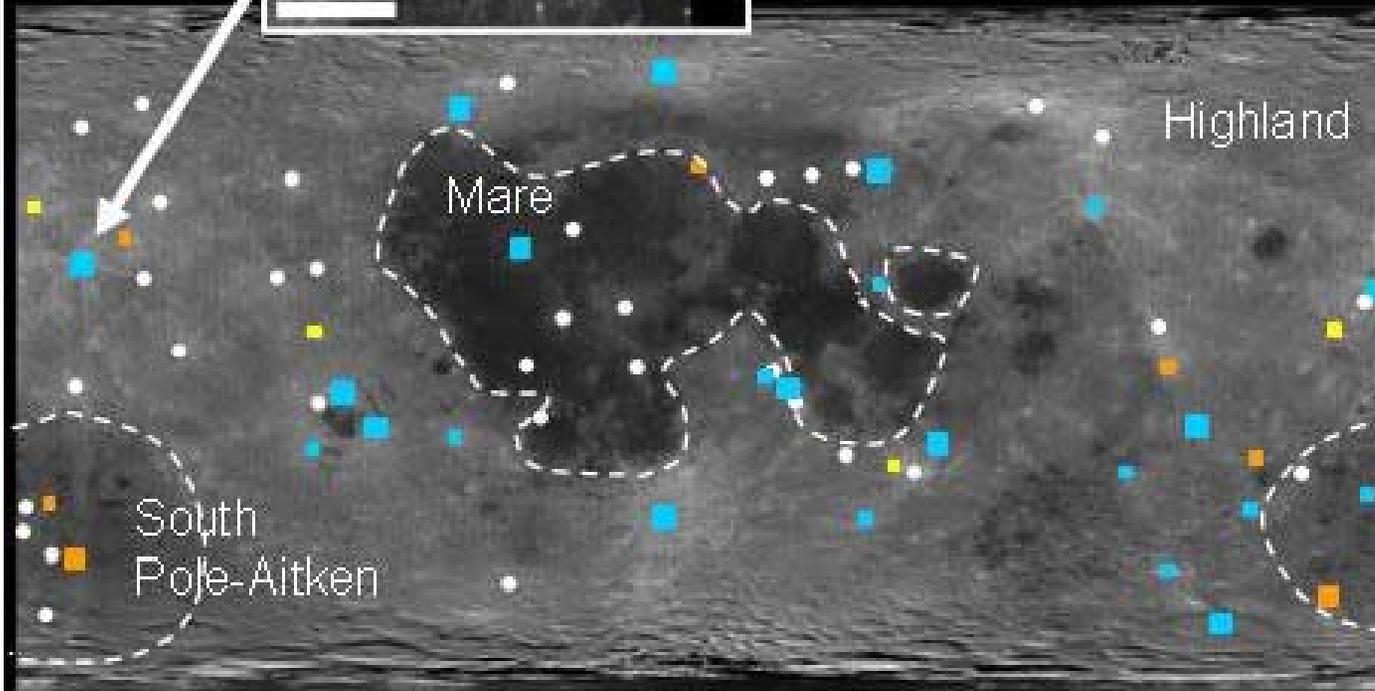
©JAXA/SELENE

- > 98 vol.% pl
- 90-98 vol.% pl
- < 90 vol.% pl
- small craters
- large craters

Areas of pure anorthite located in crater peaks (called "PANs" for purest anorthosite)

Multiband imager (spectral resolution of 20m)

Small craters <30km



Rock Types

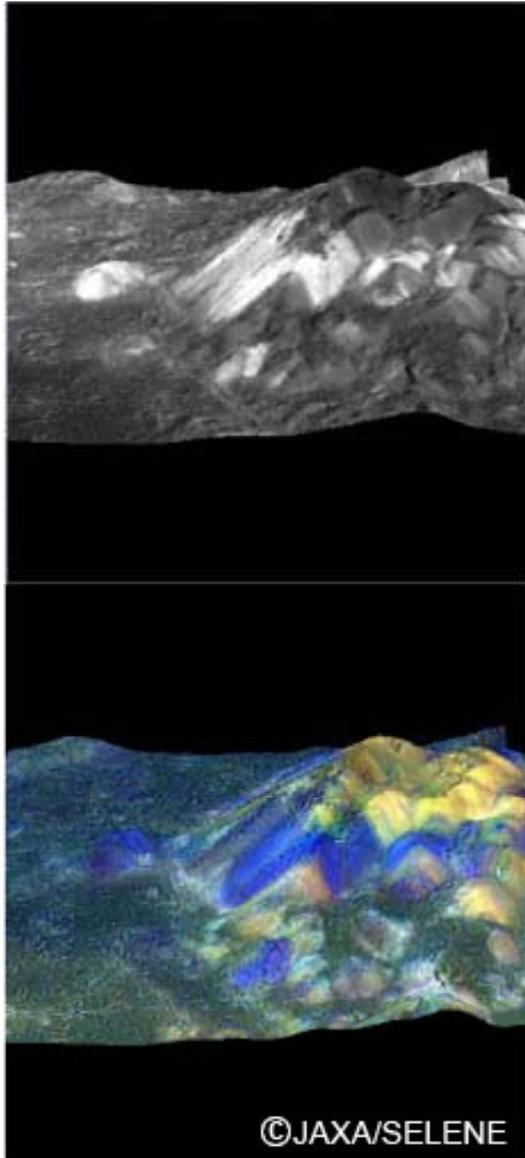


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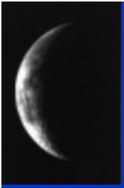
Jackson Crater

“Single-band (750 nm) image and a color image showing rock types (the strengths of absorption bands characteristic of individual minerals are indicated in red: pyroxene, green: olivine, and blue: plagioclase)”

http://www.jaxa.jp/press/2009/09/20090910_kaguya_e.html

Areas of olivine-rich rocks have also been found (Mare Frigoris, Imbrium, and near Mare Humorum)

Rock Types

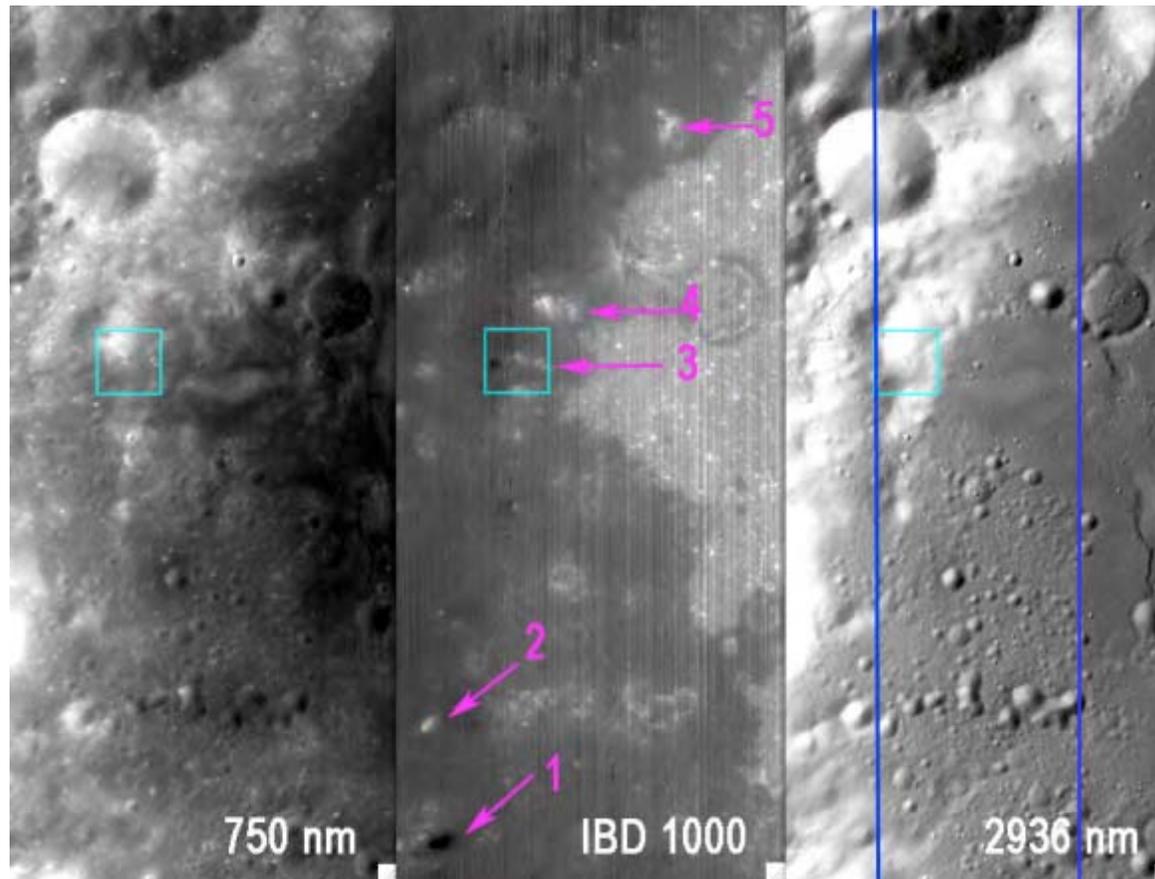


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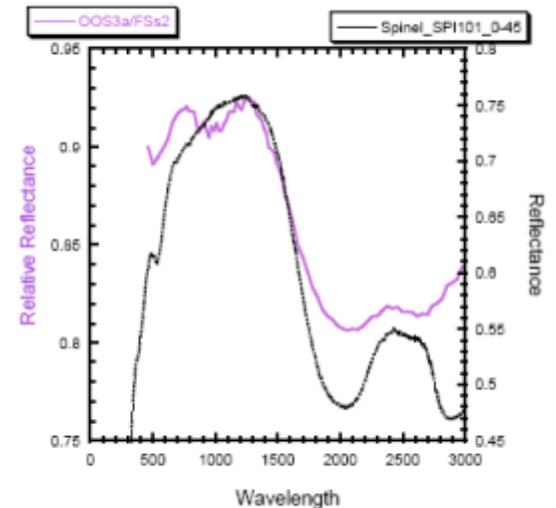
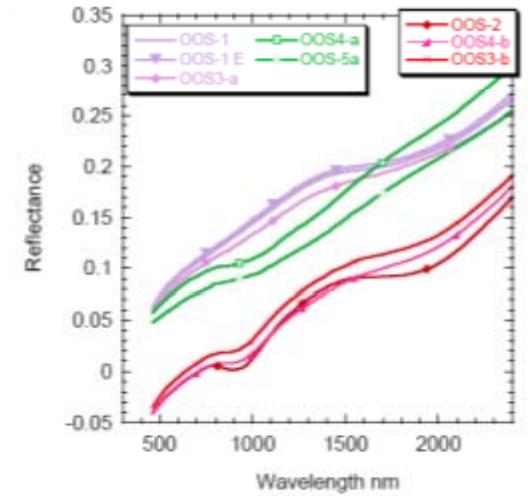
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Five areas in the rim of Mare Moscoviense are rich in olivine (green), pyroxene (red, offset), and spinel (purple)



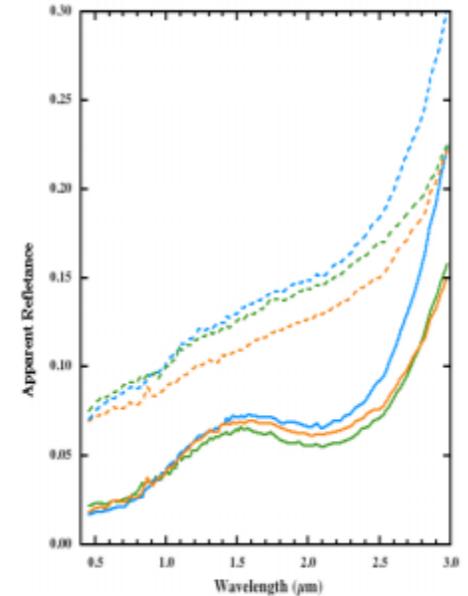
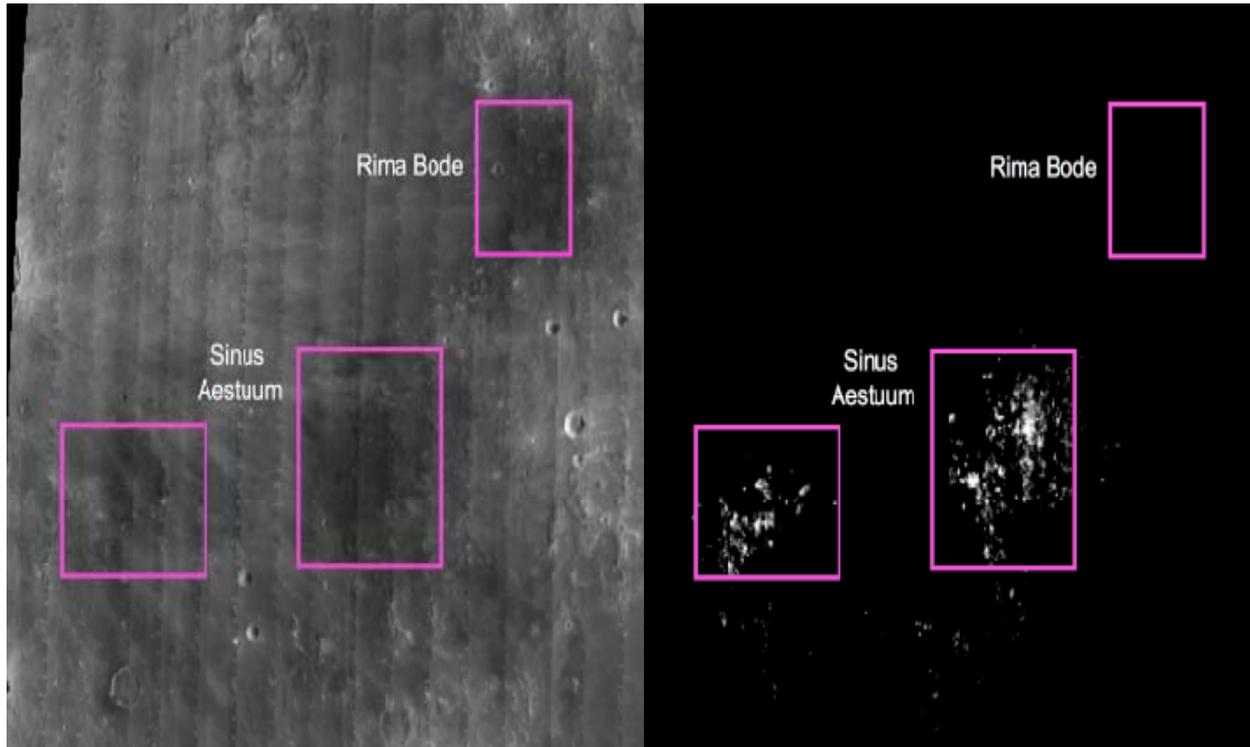
Rock Types

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Chromite deposits, hypothesized to be pyroclastics from a buried vent
Rima Bode also has a dark mantle deposit, but does not have the chromite signature (solid bands, dashed bands are typical regolith)

Regolith

Regolith
Conclusions

- “Regolith” is the term for the layer or mantle of fragmental or unconsolidated rock material, whether residual or transported and of highly varied character, that nearly everywhere forms the surface (Lucey et al., 2006)
- Everything that separates the solid Moon from space
- The CELMS (Chang’e lunar microwave sounder) instrument was used to determine the maximum depth of regolith thickness by changes in temperature (max 20m). Other estimates are between 5 and 12m.

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Regolith

Regolith
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- Regolith is what we measure with remote sensing satellites
 - X-ray fluorescence, optical and infrared spectra, and gamma ray techniques penetrate no more than 20 μ m, 1m, and 10-20cm, respectively. (Radar can penetrate \sim 30m.)
- All lunar materials were returned from the upper 3 meters of the surface
- ALL of our geochemical information was obtained from the lunar regolith!

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Regolith

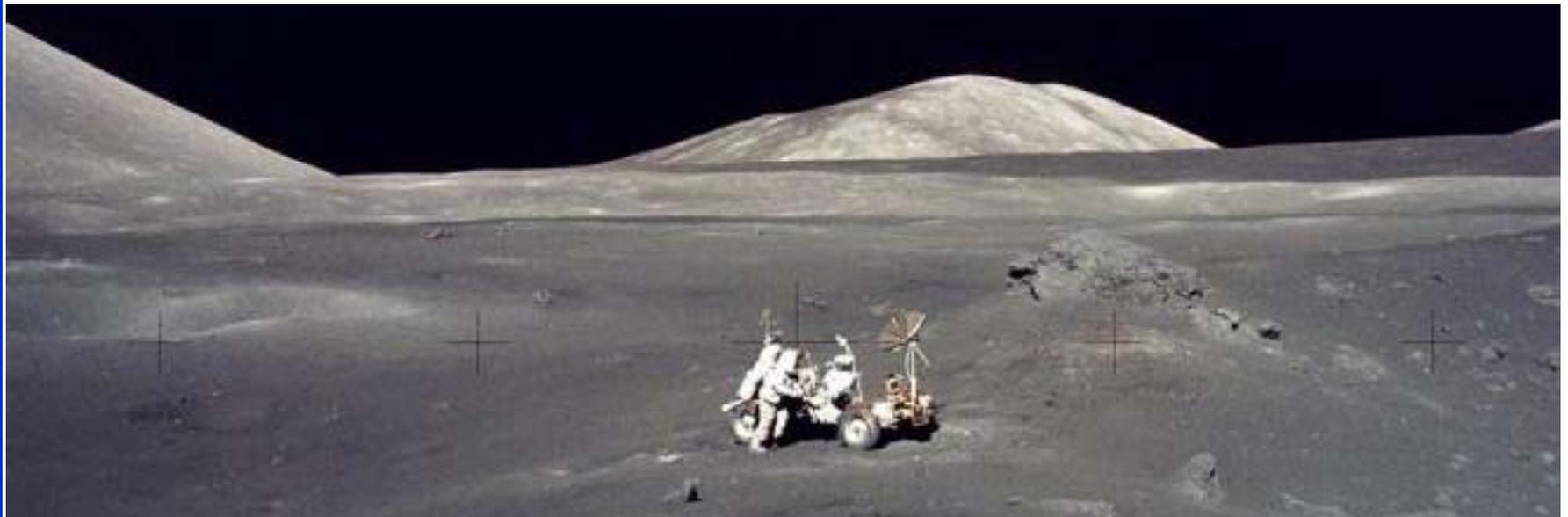
Regolith
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- Can be sintered using microwaves to create roads
- Can provide radiation shielding
- Can be used as a growing medium for plants
- Habitat construction

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- We need to know where we are going to know what technologies we can use
- We also need to develop the technologies now so they can one day be applied to the Moon
- Multiple simulants must be developed to reflect the variability of the lunar surface
- Remote sensing continues to discover new variables in the lunar surface
 - Water/ice deposits
 - Rock types/concentrates