Lunar Resources

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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, $^3$He
- Water / ice
  - Source of the water
- Rock Types
  - Highlands
  - Mare
  - Recently identified concentrates
- Regolith
- Conclusions
Location

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

Introduction
Locations

Regolith
Conclusions

Water
Rock Types

Sunlight
Solar Wind

Clementine Iron Map of the Moon
Equal Area Projection

Near side
Far side

0 2 4 6 8 10 12 14 Fe (wt.%)
Location

Common Rock Types

- **anorthosite**
- **basalt**
- **norite**
Location

Common Components

- Anorthite
- Ilmenite
- Olivine

- Pyroxene
- Agglutinate
- Volcanic Glass Beads

Regolith Conclusions

Water Rock Types

Sunlight Solar Wind

Introduction Locations
Diviner measures T of the top 1mm of the surface
Sunlight

Regions of permanent sunlight and shadow at the poles

Temperatures in craters ~40K
Solar Wind

Introduction

Locations

Sunlight

Solar Wind

Water

Rock Types

Regolith

Conclusions

Stubbs, 2007
Solar Wind

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

- Helium-3
  - Source of electricity
  - Estimates vary based on exposure to solar wind particles
  - Greatest concentration likely found in the mineral ilmenite
Magnitude and polarization of radar signals indicated volatile ices (Bistatic Radar Experiment)

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

Lunar Prospector Epithermal Neutrons (Poles)
Chandrayaan-1
Reflected near infrared radiation
Purple/blue = water/ hydroxyl signature
Red = pyroxene

Cover of Science Magazine, 10-23-09
Hypothesized that water forms by the bombardment of the lunar surface by solar wind hydrogen

- The hydrogen bonds with oxygen from lunar surface minerals
- If the OH⁻ remains bound to the surface, it has a chance of bonding with another H
- Subject to photodissociation

H₂O band 3µm, OH band 2.85µm

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

Lunar CRater Observation and Sensing Satellite

Visible and Infrared Spectrometers, Cameras, and a Photometer

Impacted Cabeus Crater (south pole)

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

- NIR detected dust, vapor, and ice, SO$_2$, H$_2$O, CH$_3$OH, CH$_4$, CO$_2$, H$_2$CO, C$_2$H$_2$
- UV detected OH, obtained grain size measurements due to reddening or bluing of spectra, also NH+NH$_2$, CN, CH, HCO, H$_2$S, CS, CO
- Data reduction is “a work in progress”

UV spectra also shows “prompt dissociation of H$_2$O”
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 Retention in PSRs

- Annual temperature is ~60-70K at 75cm depth, indicates residence time of water is >1Ga in permanently shadowed regions.
- 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.
- Different methods of water collection proposed, none definitive.
  - Hydrothermal
  - Random Walk
  - Cometary Source

Modeled from Diviner data by Elphic et al.
Rock Types

Common Rock Types

- **anorthosite**
- **basalt**
- **norite**
Areas of pure anorthite located in crater peaks (called “PANs” for purest anorthosite)

Multiband imager (spectral resolution of 20m)

Small craters <30km
Rock Types

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)”

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

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

- Regolith is what we measure with remote sensing satellites
  - X-ray fluorescence, optical and infrared spectra, and gamma ray techniques penetrate no more than 20µm, 1m, and 10-20cm, respectively. (Radar can penetrate ~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!
Regolith

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

- 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