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

Clementine Iron Map of the Moon
Equal Area Projection

Introduction

Regolith

Conclusions

Water

Rock Types

Sunlight

Solar Wind

Locations
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**
- OPX
- CPX
Diviner measures $T$ of the top 1mm of the surface
Sunlight

Regions of permanent sunlight and shadow at the poles

Temperatures in craters ~40K
• **Hydrogen**
  - Implanted on surface
  - Reducing environment
  - Source of OH/H$_2$O 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

**Solar Wind**

- Regolith Conclusions
- Water Rock Types
- Sunlight Solar Wind
- Locations

**Introduction**
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)
Water

Chandrayaan-1
Reflected near infrared radiation

Purple/blue = water/hydroxyl signature
Red = pyroxene

Cover of Science Magazine, 10-23-09
Water Formation on the Lunar Surface (M^3)

- 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

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

H₂O band 3µm, OH band 2.85µm
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”
Water

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
Rock Types

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)
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

“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