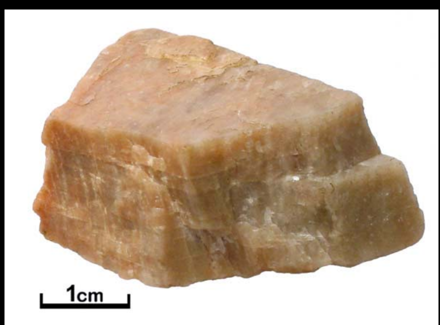
UV-V-NIR Reflectance Spectroscopy

Methods and Results

A. Nathues

Minerals

- Naturally-occurring inorganic substances with a definite and predictable chemical composition and physical properties
- Major groups:
  - Silicates
  - Carbonates



Rocks

- Naturally-occurring aggregates showing similar composition and texture; composed of minerals or their fragments (+ organics on Earth)

- Groups:
  - igneous rocks (e.g. basalt)
  - sedimentary rocks (e.g. sandstone)
  - metamorphic rocks (e.g. gneiss)

Regolith

- Fragmental incoherent rocky debris that covers the most areas of atmosphere-less bodies like for example the Moon and asteroids

Spectra of Rock Forming Minerals

- Absorption features that occur in reflectance spectra are a sensitive indicator of mineralogy and chemical composition for a wide variety of materials
- The investigation of the mineralogy and chemical composition of surfaces delivers insights into the origin and evolution of planetary bodies
  - e.g. Pyroxene mineralogy and chemistry are important for determining the petrogenesis
  - e.g. Iron content crucial for the degree of body differentiation

Lab Spectra and Remote Sensing

- Lab spectra of well–characterized minerals and mineral mixtures are the basis for the analysis of ground and space based spectra since only laboratory measurements allow to investigate homogeneous samples in which all parameters can be controlled
- Tasks
  1. Characterization of individual phases (minerals, ices, glasses)
     - mineralogy
     - chemistry
     - particle size
  2. Characterization of rocks and mineral mixtures
     - mineralogy
     - chemistry
     - particle sizes
     - packing
  3. Characterization of effects caused by the physical environment
     - temperature
     - viewing geometry
     - maturation processes (Space Weathering)

Spectra of Rock Forming Minerals

1) Silicates
   - Olivine: strong absorption at ~ 1 µm due to three overlapping bands
   - Pyroxene:
     - Opx displays strong absorptions around 0.9 µm and 1.9 µm
     - Cpx displays strong absorptions around 0.9 µm and sometimes around 2.2 µm
   - Feldspars: often faint absorption bands
     - Plagioclase for example displays absorption around 1.3 µm
   - Phyllosilicates: partly very sharp and narrow absorptions!
2) Carbonates
   - show a number of narrow, sharp absorption features for wavelengths > 1.6 µm
3) Oxides
   - e.g. spinel (lunar rocks) display strong absorptions near 2 µm
   - iron oxides show strong absorptions in UV
4) Sulfides and Sulfur are less important and barely investigated
5) Hydrates (H_2O) and hydroxides (OH^-)
   - bands located often > 3 µm
6) Metals
   - no absorption features, but reddish spectra, identification via suppressed absorption bands

Most Relevant Minerals for Remote Sensing

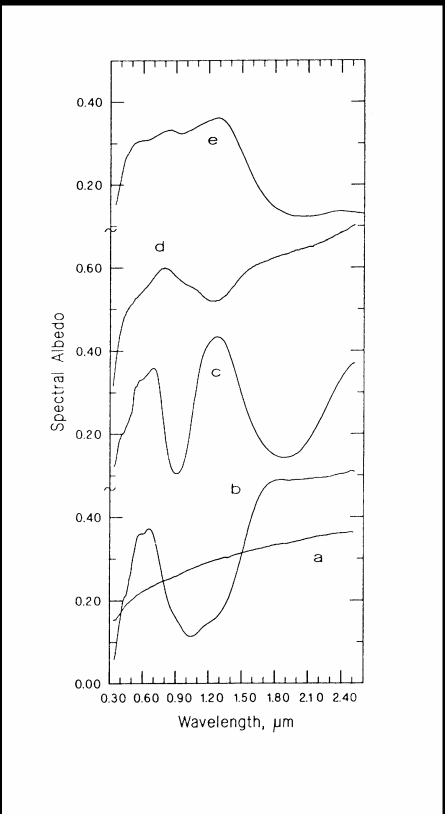
a) Ni-Fe metal

b) Olivine

c) Pyroxene, here Orthopyroxene (offset)

d) Plagioclas (offset)

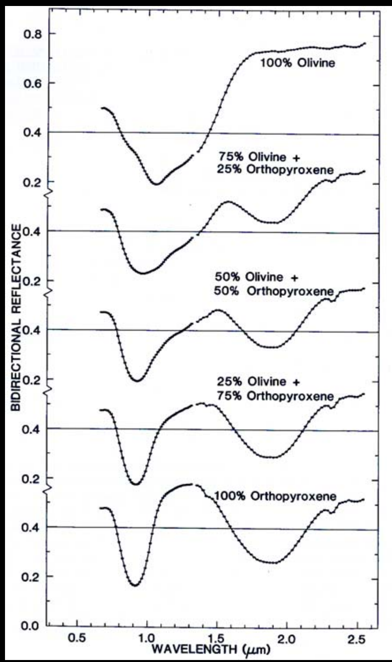
e) Spinel (offset)



Mineral Mixtures

- Almost all by remote sensing investigated solid surfaces consist of polymict rocks / mineral mixtures and show a wide range of grain sizes
- It's often not possible to uniquely define the contributions of each parameter without independent constraints ➔ ground reference sample helpful for remote sensing

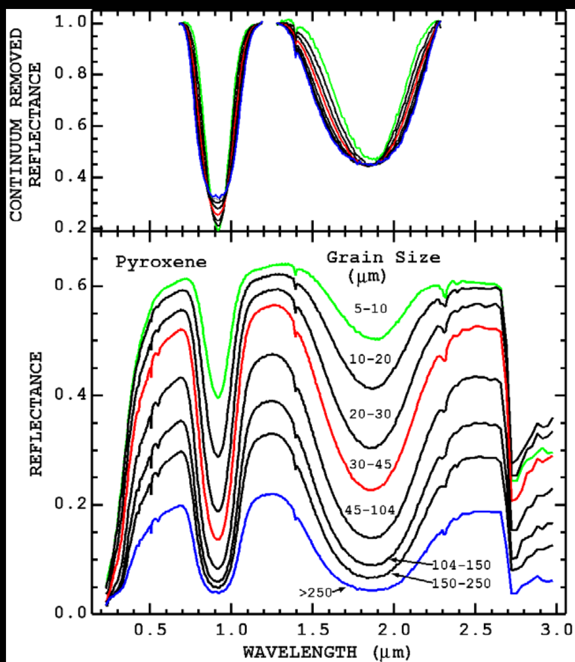
Most regoliths need nonlinear mixing models for composition determination, purely empirical and more quantitative methods including "Gaussian fitting" have been developed



Physical Effects (1)
Grain Size and Albedo

- Particle size and albedo
  - The albedo of weakly absorbing minerals increases with decreasing particle size
  - The albedo of very strongly absorbing minerals decreases with decreasing particle size
- Particle size and contrast
  - Absorption band contrast varies with particle size but does not affect positions of absorption features

Grain size needs to be considered



Physical Effects (2)
Temperature

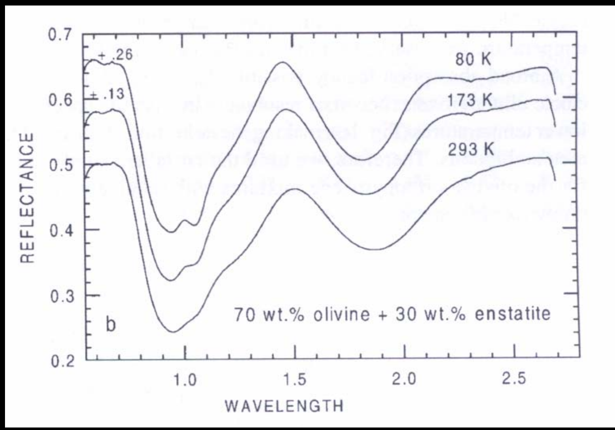
- Lowering of sample temperature can lead to:

1) Slight negative shifts of absorption band positions

2) Splitting of absorption bands

→

For detailed investigations: T difference between observed surface and lab sample to be considered



Physical Effects (3)
Maturation – Space Weathering

Solar and cosmic radiation + micrometeoritic bombardment

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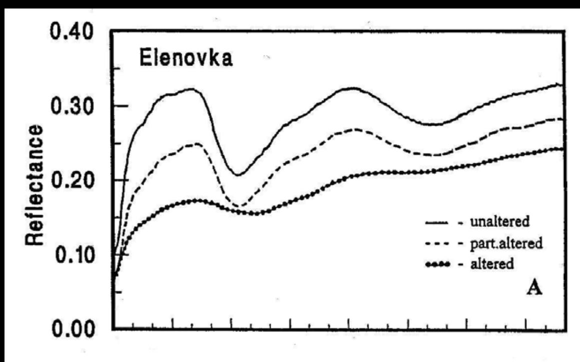
- Lowering of albedo
- Reddening of spectral slopes
- Weakening of absorption bands



Physical Effects (4)
Geometry Effects

- Phase angle increase leads to:

  1) phase reddening, i.e. the steepness of the spectral slope outside of absorption features increases

  2) Absorption band depth increase

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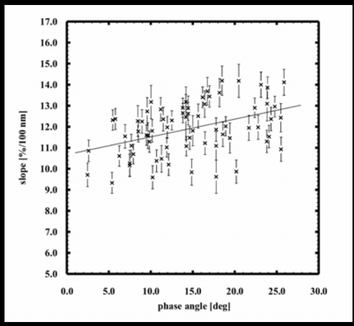
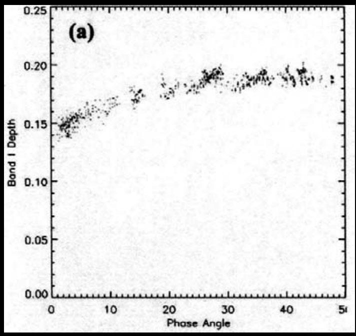
Photometric correction necessary





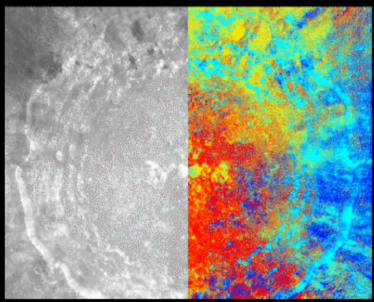
Color Photometry + Spectroscopy

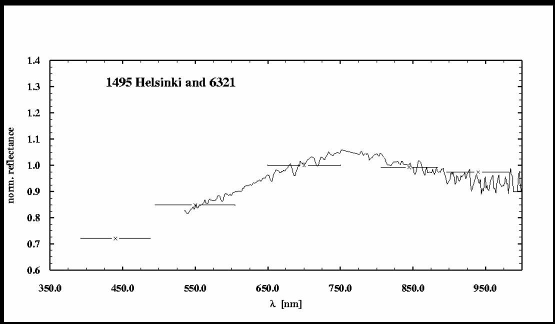
- Color photometry (filter):
  Advantages:
  – Large surface area coverable in one exposure
  – Morphological information

  Disadvantages:
  – Often low spectral resolution ➔ raw mineralogical analysis
  – Colors not measured simultaneously ➔ further tricky corrections needed

- Spectroscopy:
  Advantage:
  – High Spectral resolution and simultaneous measurements ➔ best possible composition analysis

  Disadvantage:
  – No morphological information





Resources of Spectra

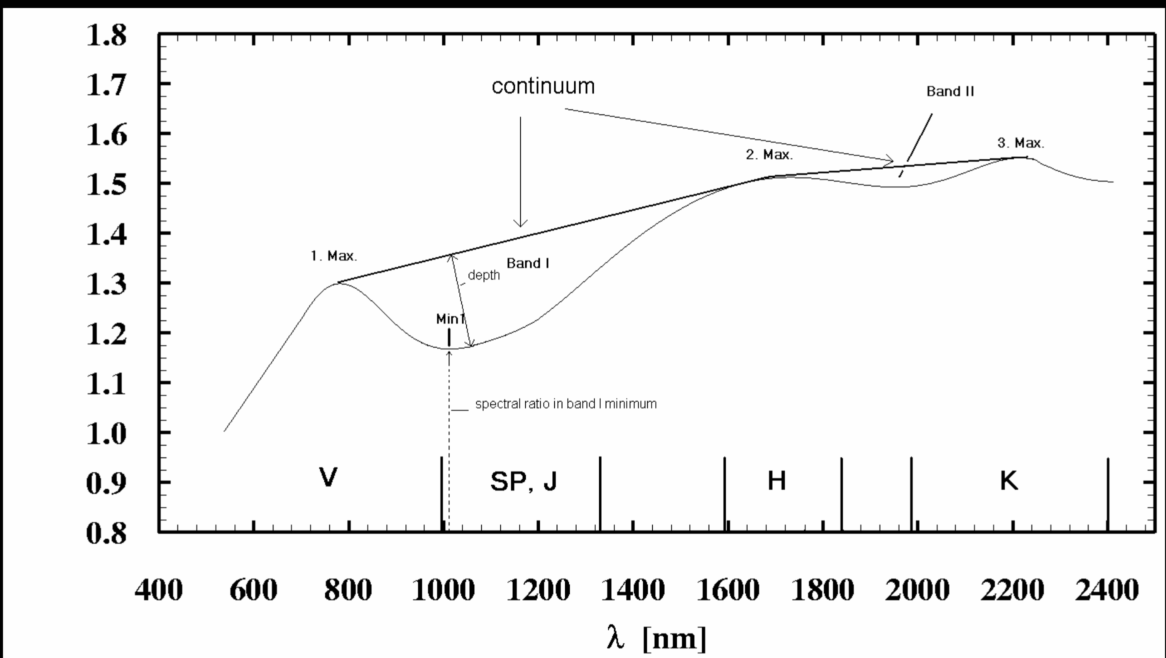
Ground-based Telescopes

- Low costs
- Large number of targets
- Low spatial resolution
- Invisibility of surface areas (e.g. lunar poles and far-side)
- Disturbances by Earth atmosphere (except Hubble)
- Time slots for observations to be watched

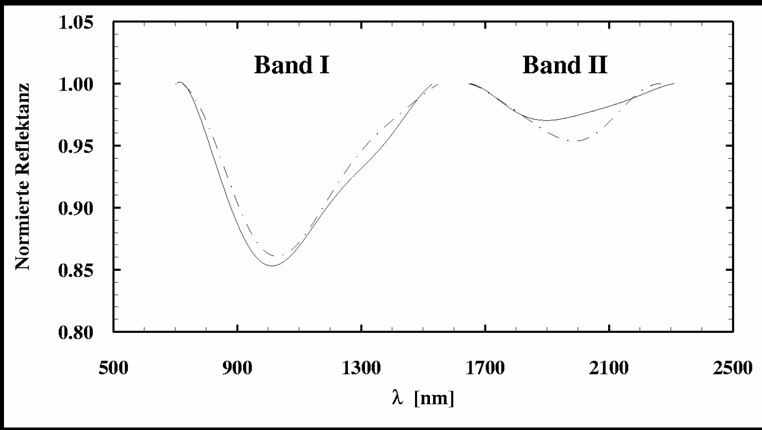
Spacecrafts

- High costs
- Low number of targets
- High spatial resolution
- Visibility of the whole surface
- High risk

Mineralogical Analysis of Spectra Calibrated Spectrum

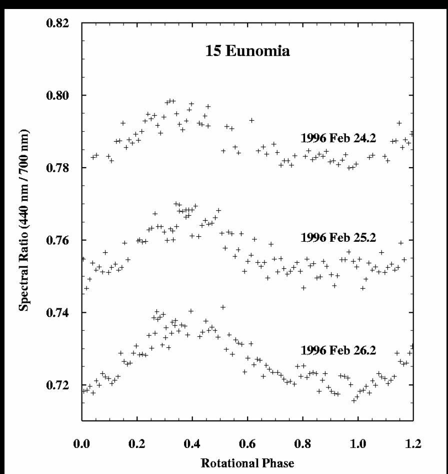


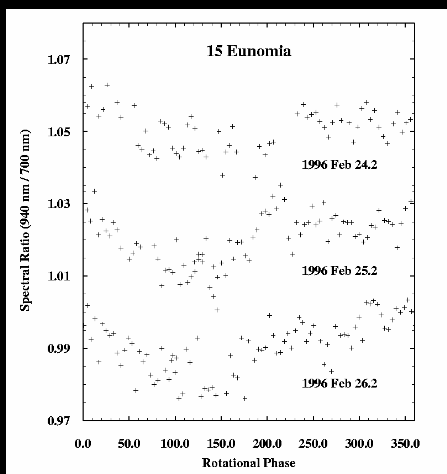
Continuum Corrected Spectrum

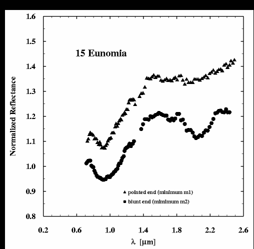


- Band I and Band II depths and minimum positions
  - → Cation content of pyroxene an olivine (olivine: Band I only)
  - Type of Pyroxene
- Band II / Band I area ratio
  - → Olivine-Pyroxene abundance ratio

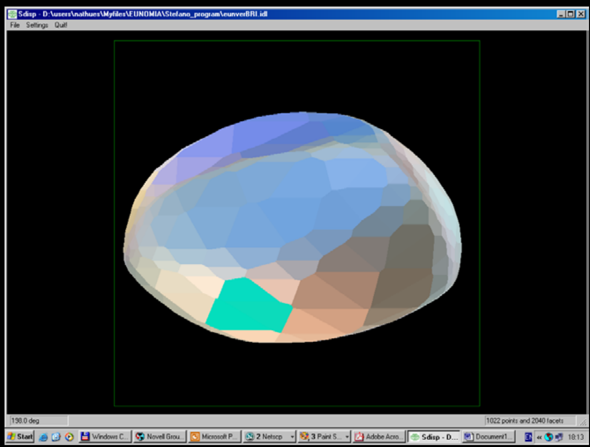
Spectral Variations as Indication for Mineralogical Variations on Asteroid 15 Eunomia (1)

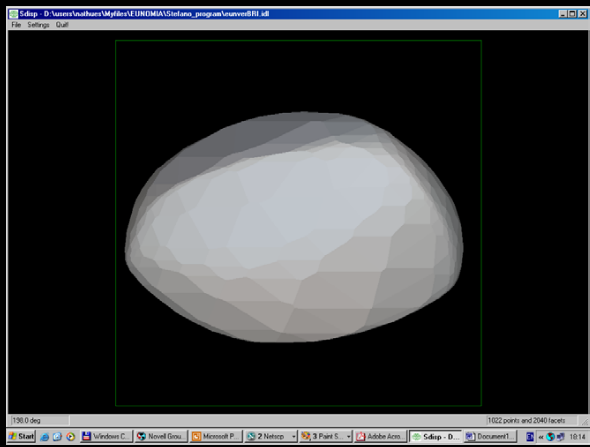




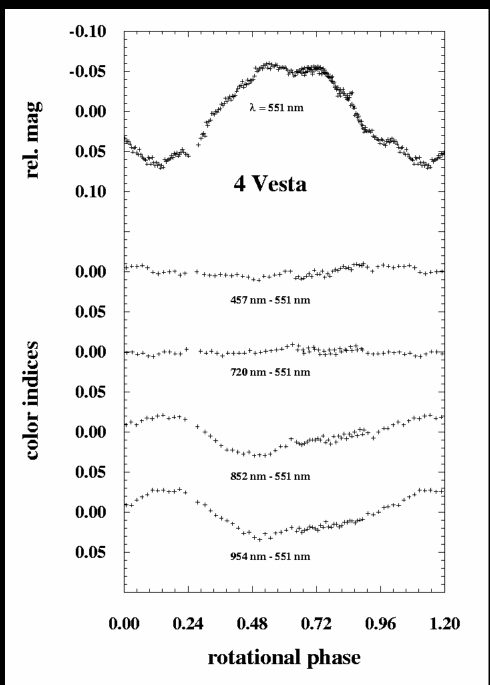


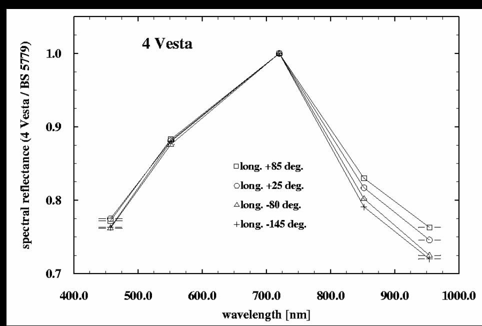
Spectral Variations as Indication for Mineralogical Variations on 15 Eunomia (2)

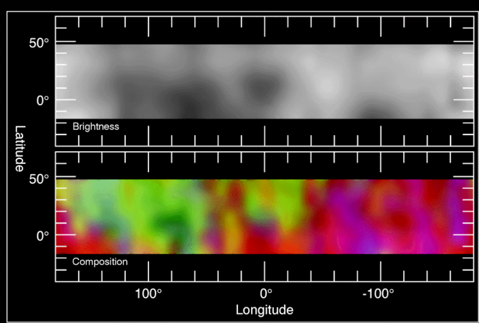




Spectral Variations as Indication for Mineralogical Variations on 4 Vesta

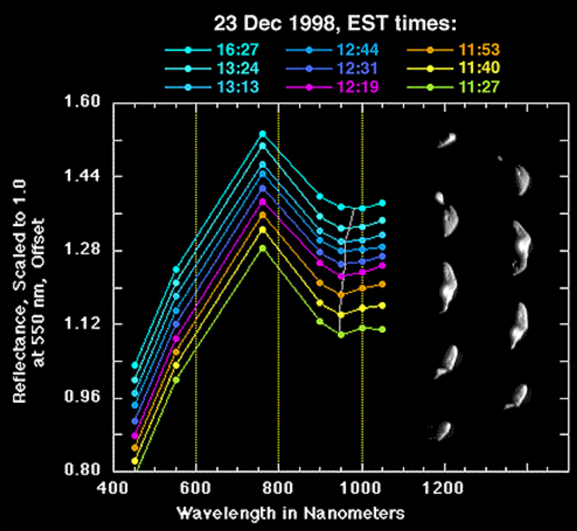


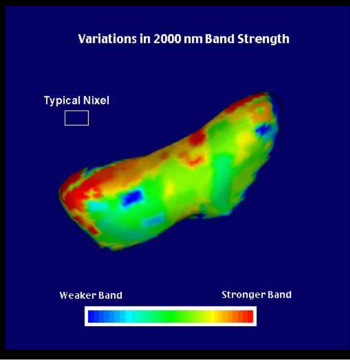


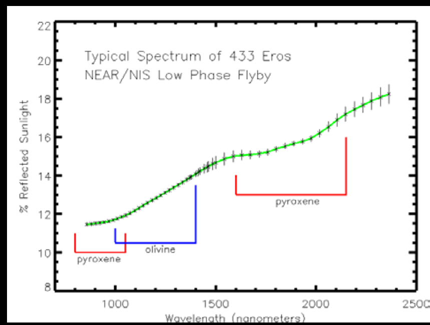


Surface of Asteroid Vesta HST • WFPC2
PRC95-40 • ST ScI OPO • October 9, 1995 •B. Zellner (GA Southern Univ.), NASA

NEAR at 433 Eros







Planned lunar observations with SIR

Maria

- Rock types: basalts
- Major minerals: pyroxene, plagioclase, olivine, and metal oxides
- Spectral characteristics: Strong absorption bands at 1 and 2 µm (mainly due to Ca-rich clinopyroxene)
- Albedo: Low (7% to 10%)

Highlands

- Rock types: impact breccias
- Sub-types and major minerals:
  - **Anorthosites,** mainly Ca-rich plagioclase feldspar, some pyroxene, small amounts of olivine, Fe-metal, …
  - **Magnesium-rich rocks,** less plagioclase and more Mg-rich olivine and pyroxene
  - **KREEP,** mainly pyroxene and plagioclase. Olivine is rare.
- Spectral characteristics: From slight reddish slopes without absorption bands to stronger reddish slopes with clear absorption bands at 1 and 2 µm
- Albedo: High (11% to 18%)

Spectral Mapping (Nadir Pointing)

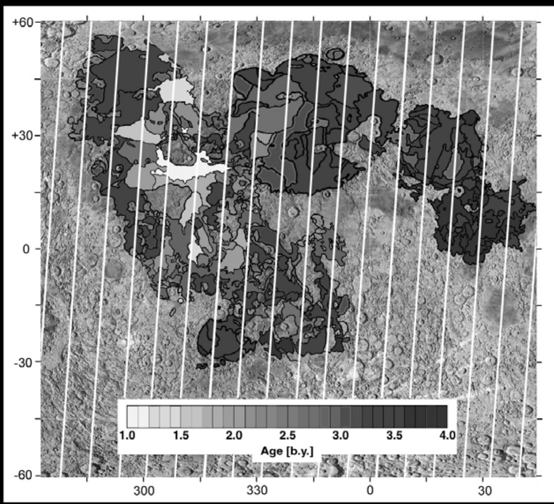


Fig.: Example of nadir projections on a map showing spectral-age units of Hiesinger et al. (*2003*).

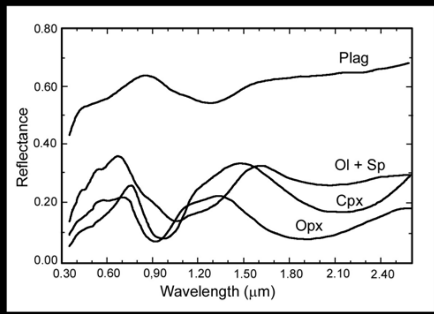


Fig.: Laboratory spectra of lunar minerals (*Pieters, 1993*).

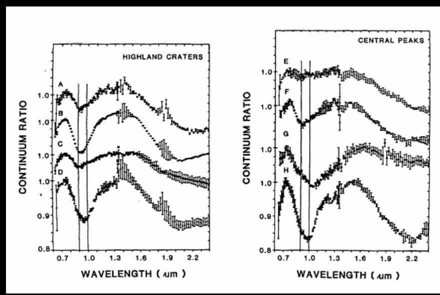


Fig.: Ground-based spectra after continuum removal (*Smrekar and Pieters, 1985*).

Vertical Zonality (Craters and Basins)

The spectral investigation of …

- Ejecta blankets
- Central peaks
- Inner rims resp. rings

will lead to compositional information of the lunar crust

e.g. impact basins probe 20 to 50 km deep levels of the lunar crust