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Analysis of lunar highland regolith samples from Apollo 16 drive core 64001/2 and lunar regolith simulants – an expanding comparative database

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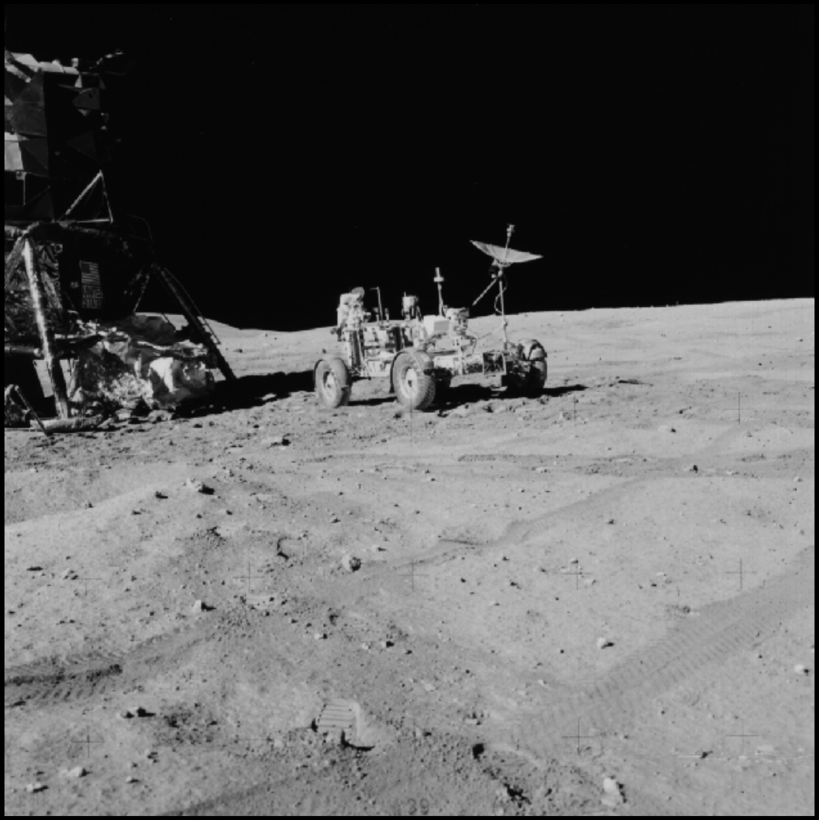
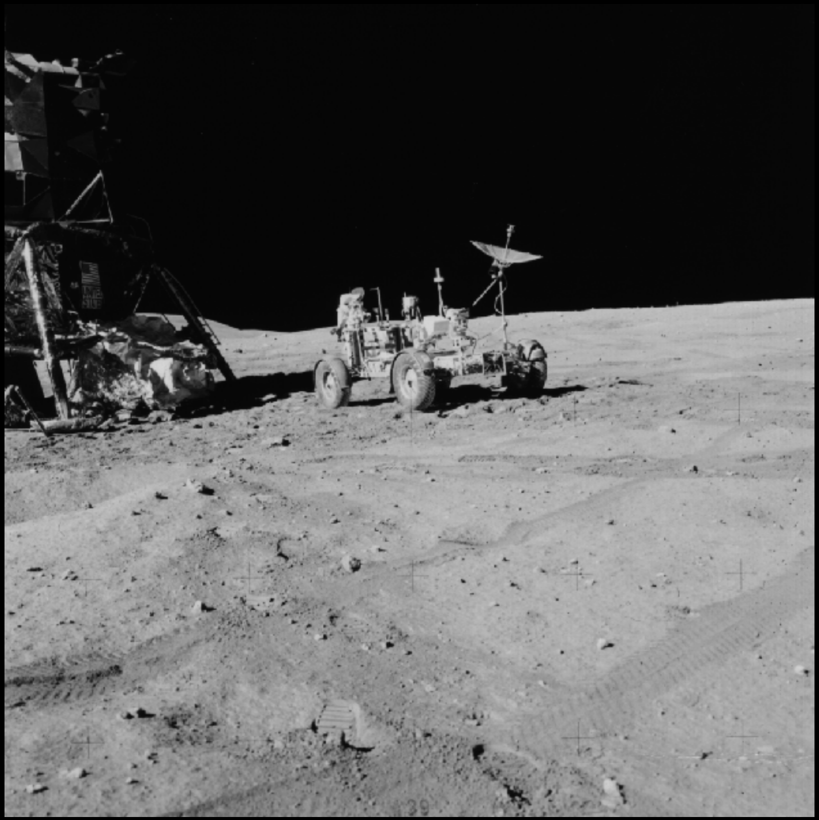
Outline

- Background of the lunar regolith simulant effort
- Apollo site and sample selection
- Results of QEMSCAN® modal analysis of lunar material
  - change in major mineral modal% with size fraction
  - comparison of major/trace minerals in sieved vs. thin section samples



Outline, cont.

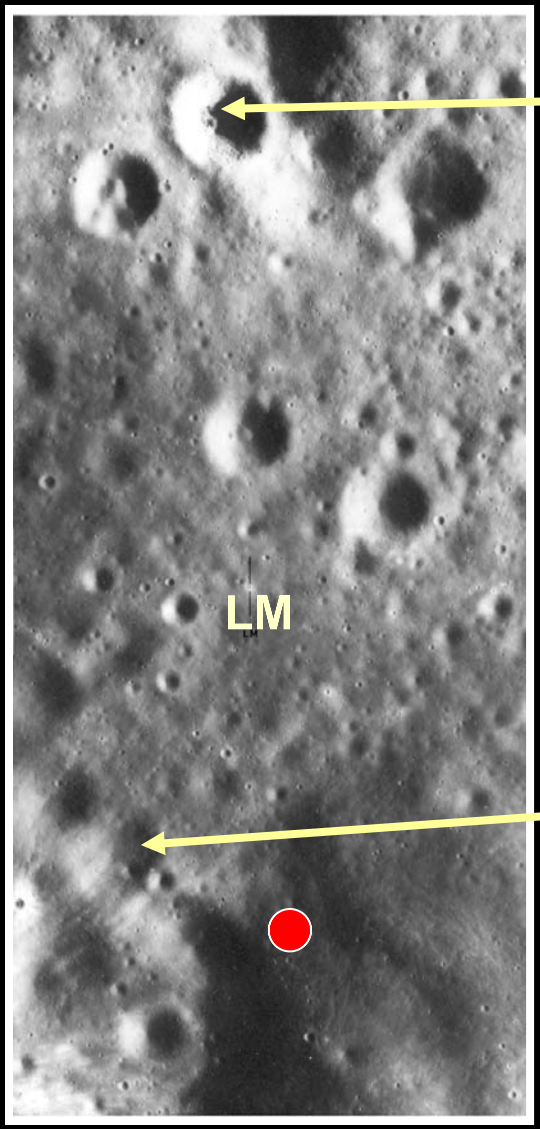
- Results of analysis of simulants vs. Apollo samples
- Future, ongoing, and parallel work

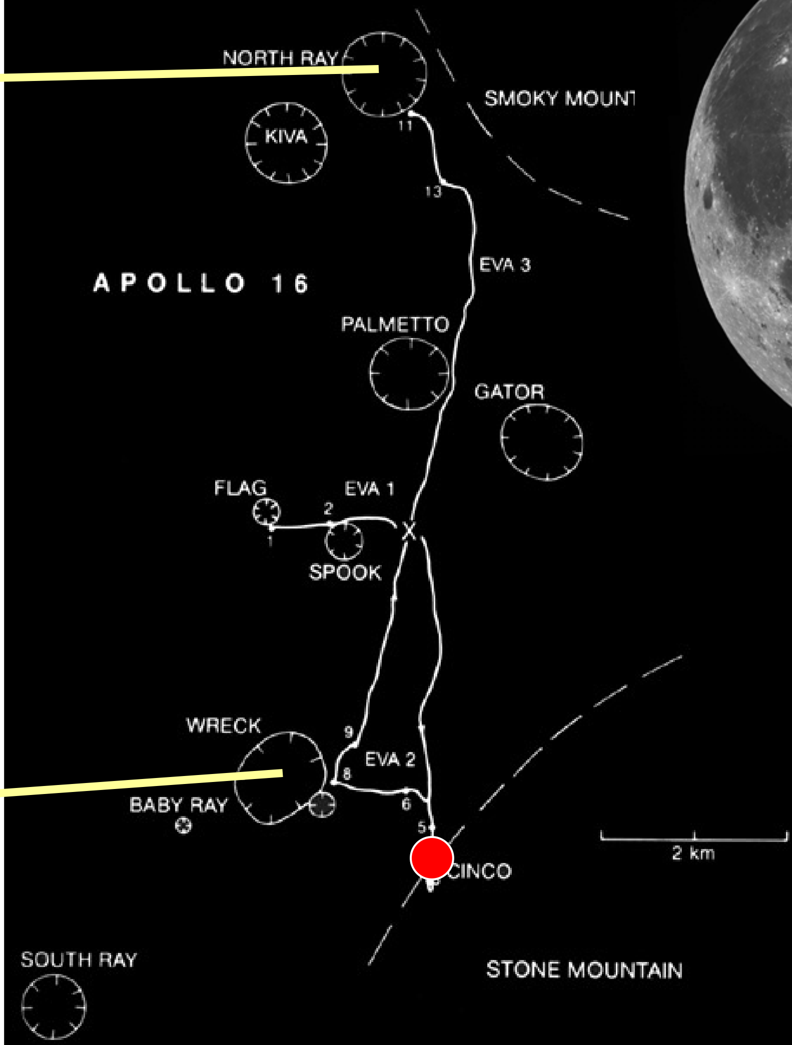


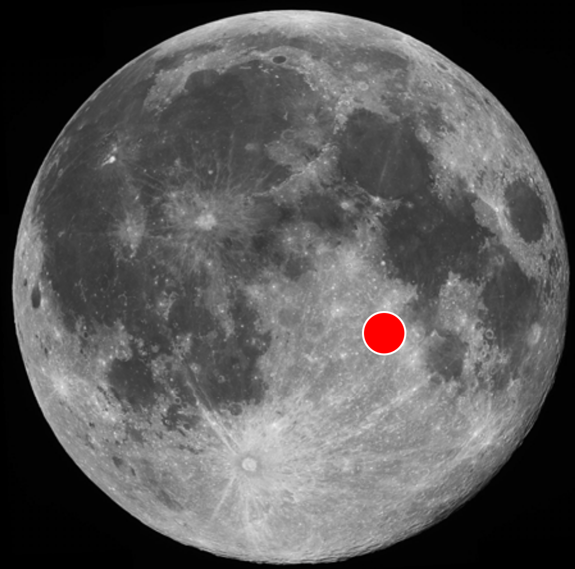
In support of a future lunar outpost...

- This work is part of a larger effort to compile an internally consistent database on lunar regolith (Apollo samples) and lunar regolith simulants.
  - Characterize existing lunar regolith and simulants in terms of
    - Particle type
    - Particle size distribution
    - Particle shape distribution
    - Bulk density
    - Other compositional characteristics
  - Evaluate regolith simulants (Figure of Merit) by above properties by comparison to lunar regolith (Apollo sample)

Apollo 16 site







Station 4:
64001/64002

Station 4 samples

geochemical data from Korotev (1982) and Korotev et al. (1984)

<u>64002</u>
(Houck, 1982)

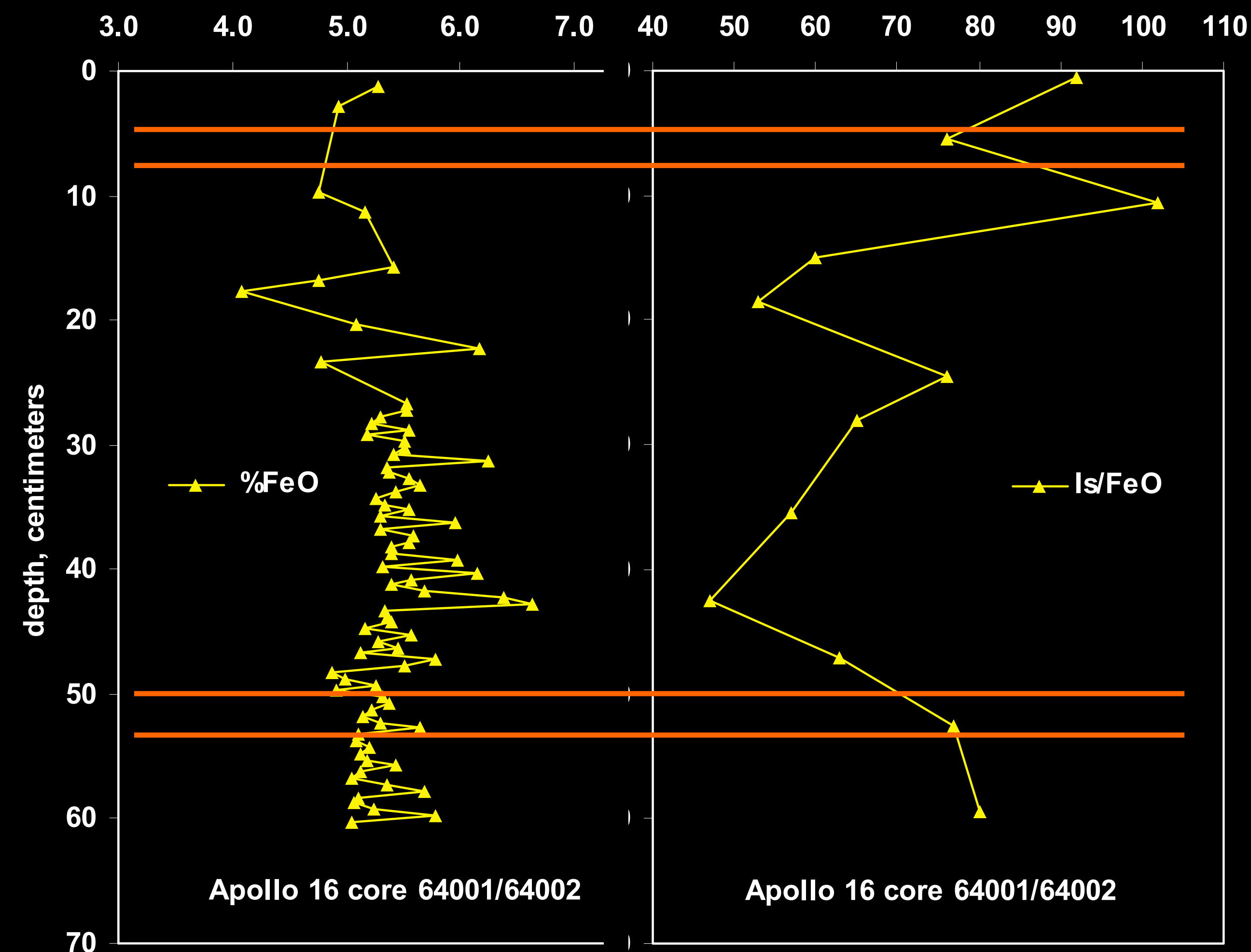
One thin-section
64002,6019*:* 5.0 – 8.0 cm

Eight sieved samples
64002,262: 5.0 – 5.5 cm

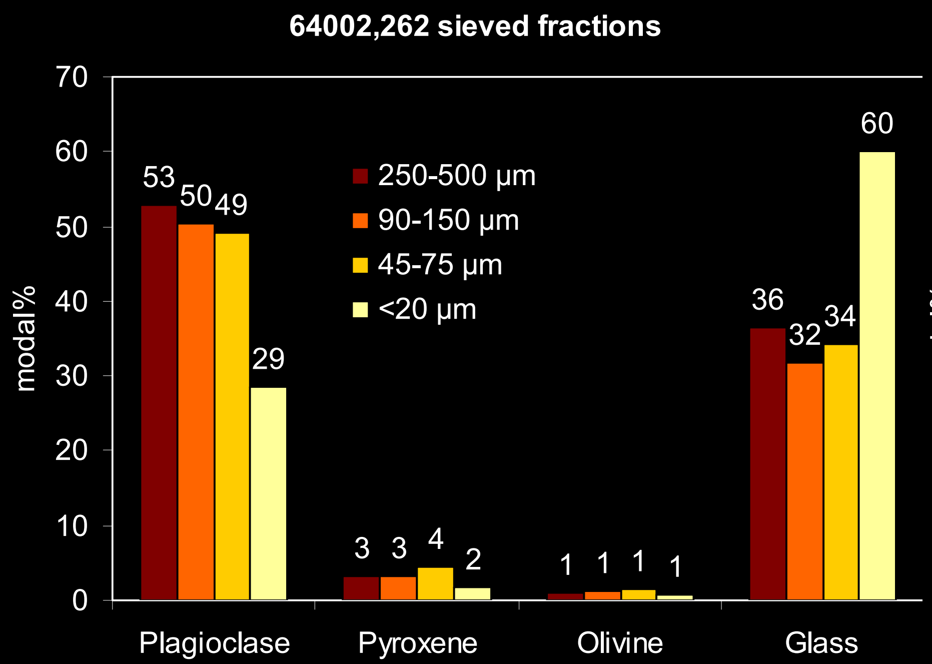
<u>64001</u>
(Basu & McKay, 1984)

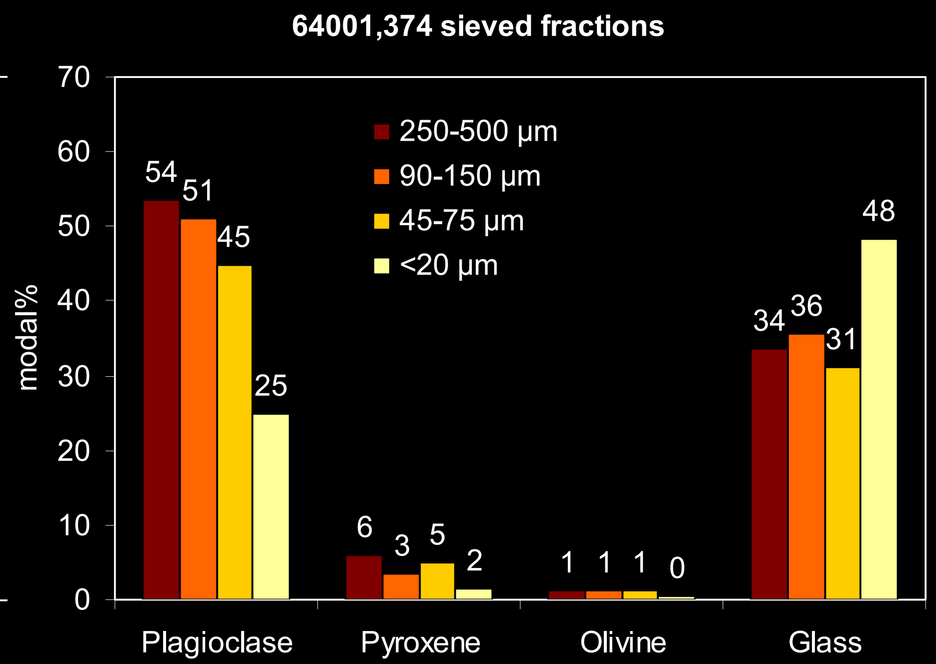
One thin-section
64001,6031: 50.0 – 53.1 cm

Eight sieved samples
64001,374*:* 52.0 – 52.5 cm



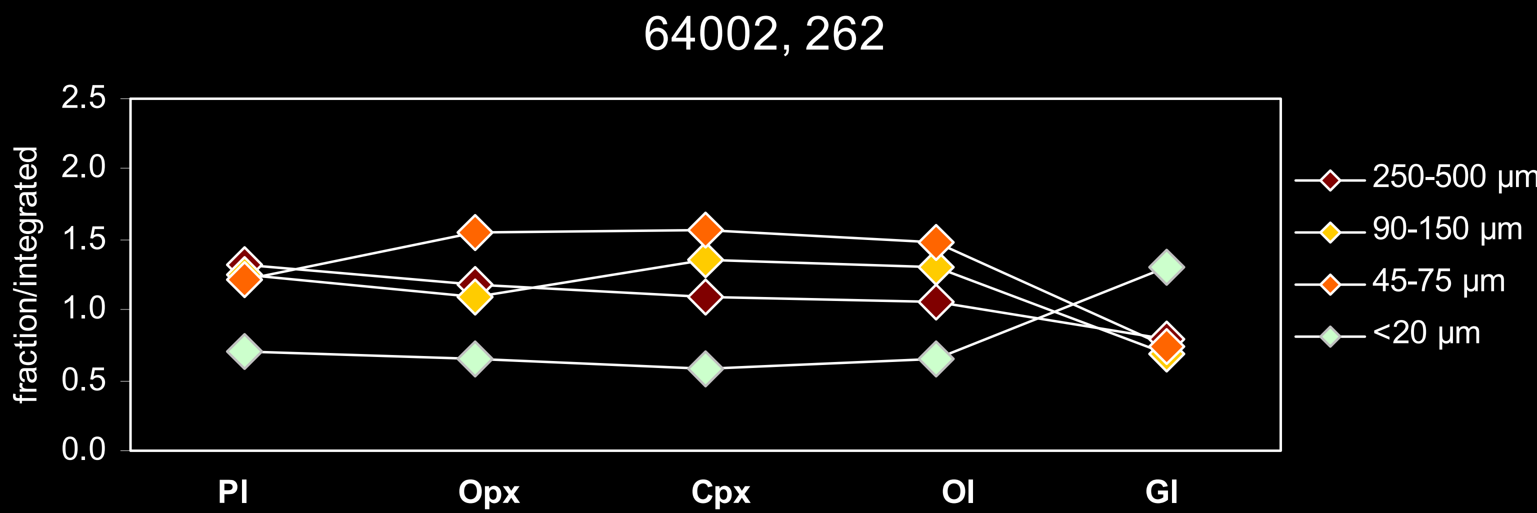
Modal analysis of sieved grain mounts





As size decreases, glass modal% increases at the expense of mineral modal%.

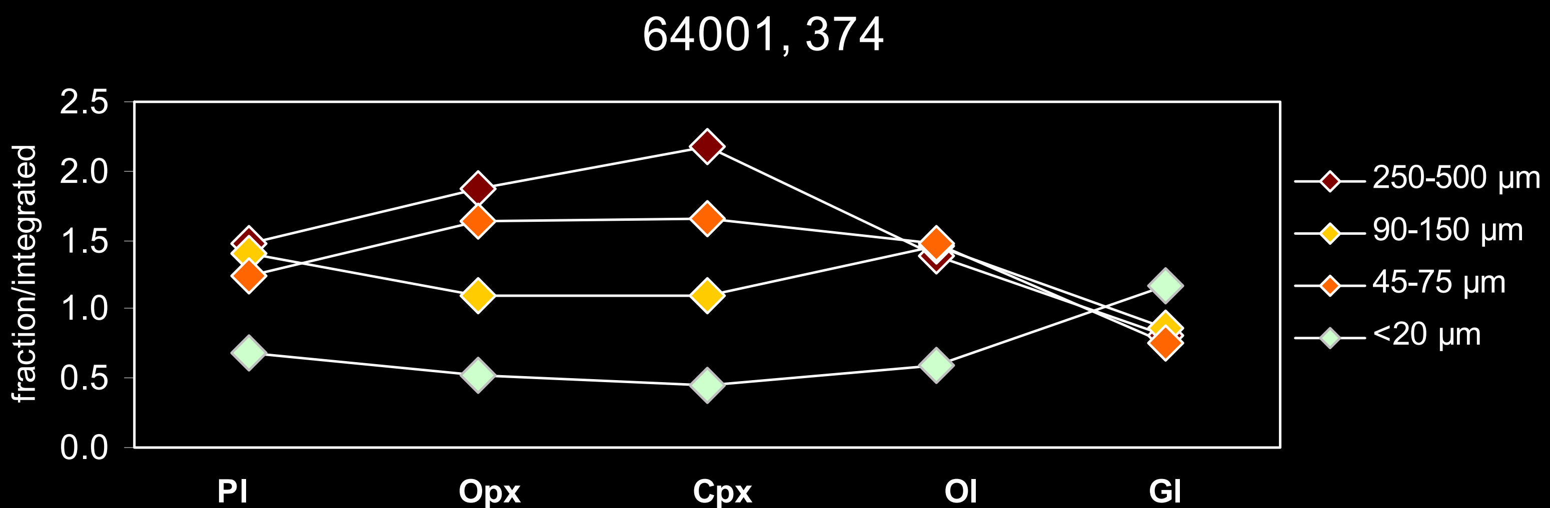
Change in modal% by size fraction: 64002,262



<u><20 µm fraction</u>: All minerals are depleted relative to bulk sample: 29-43%. Glass is enriched relative to bulk sample: 30%.

<u>All fractions</u>: Plagioclase is increasingly depleted as grain size decreases. The 250-500 µm fraction is less enriched in other minerals than in the 64001 sample.

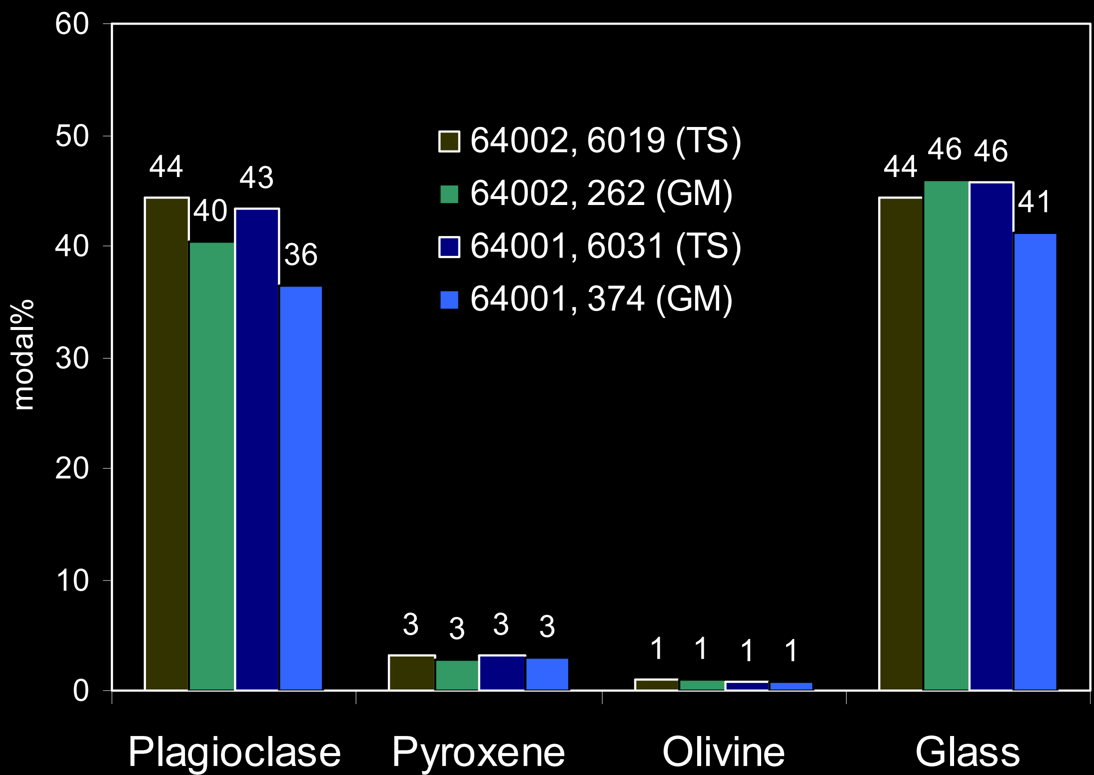
Change in modal% by size fraction: 64001,374



<u><20 µm fraction</u>: All minerals are depleted relative to bulk sample: 32-56%. Glass is enriched relative to bulk sample: 17%.

<u>All fractions</u>: Plagioclase, pyroxenes, and olivine are increasingly depleted as grain size decreases.

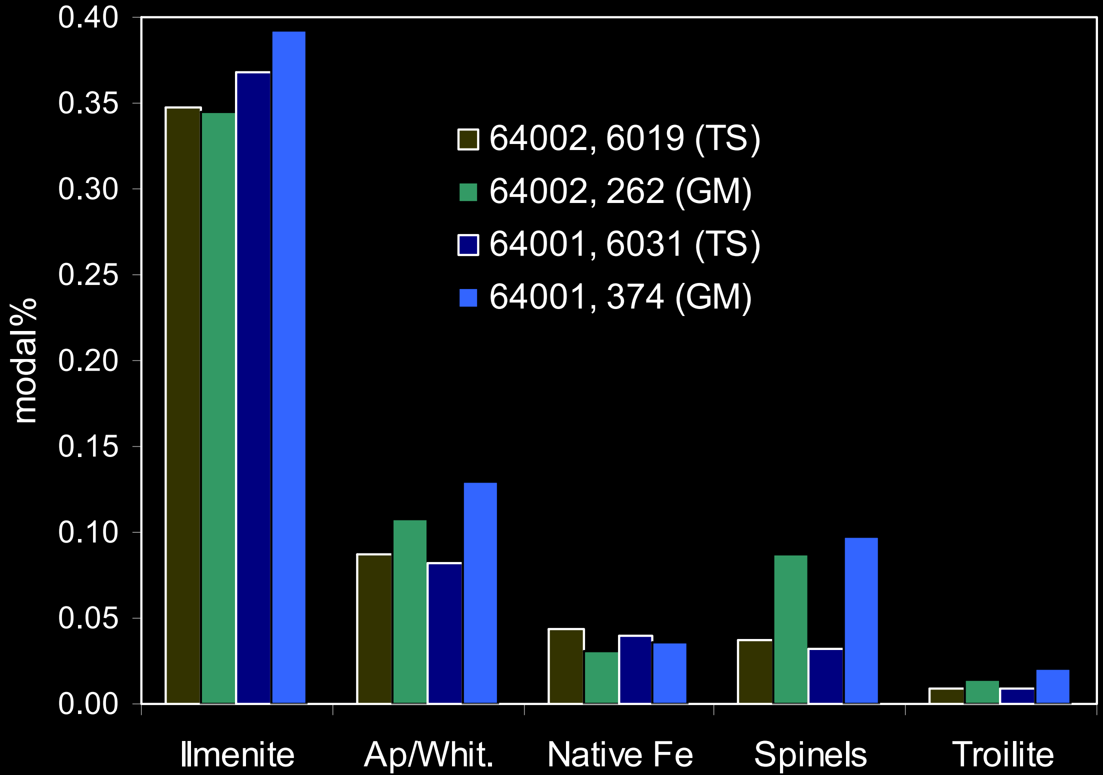
Modal analysis: thin sections versus integrated bulk grain mounts



- Minerals report as higher in thin section than in corresponding integrated grain mounts.
  - Edge effects/mixed phases in thin sections report as minerals?
  - Real effect from missing fractions in grain mounts?
  - Sampling error from sieving?

Glass shows less regular pattern.

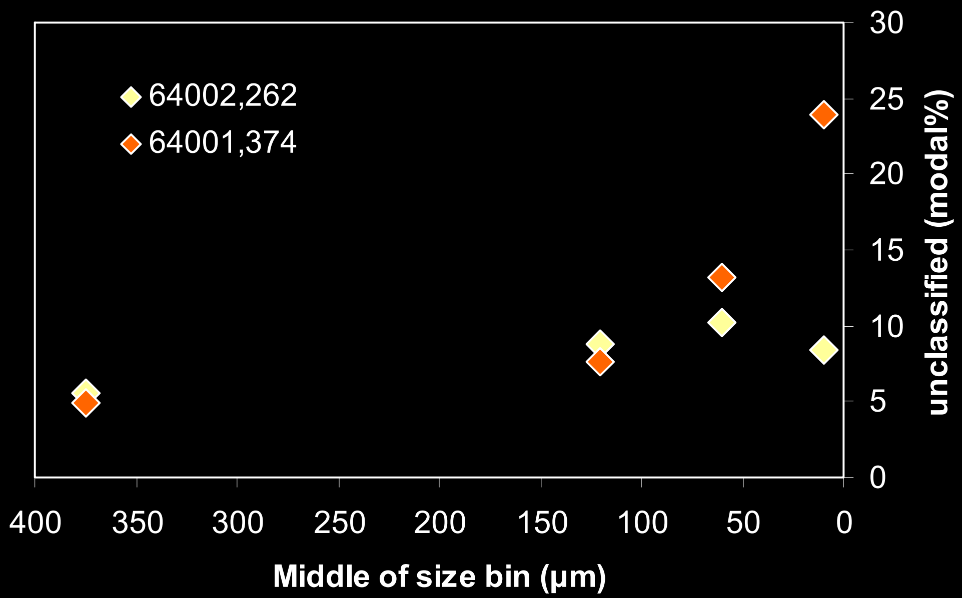
Modal analysis: thin sections versus integrated bulk grain mounts



Trace Minerals:

- Given, the very low amounts of some trace minerals (<0.01 modal%), the consistency is encouraging.
- Some of these are especially important to *In Situ* Resource Utilization (ISRU) on the moon.

Unclassified material in QEMSCAN® modal analysis



The modal% of unclassified material:

- ranges from ~5-24% in any one analysis;
- *tends* to increase as size fraction decreases in grain mounts;
- is higher in integrated grain mounts than in thin sections
  - (is more material *mis*classified due to edge effects and phase mixing?)
  - (is this from another, unknown effect?)

<u>Thin sections</u>
64002,6019: 6.6% unclassified
64001,6031: 6.4% unclassified

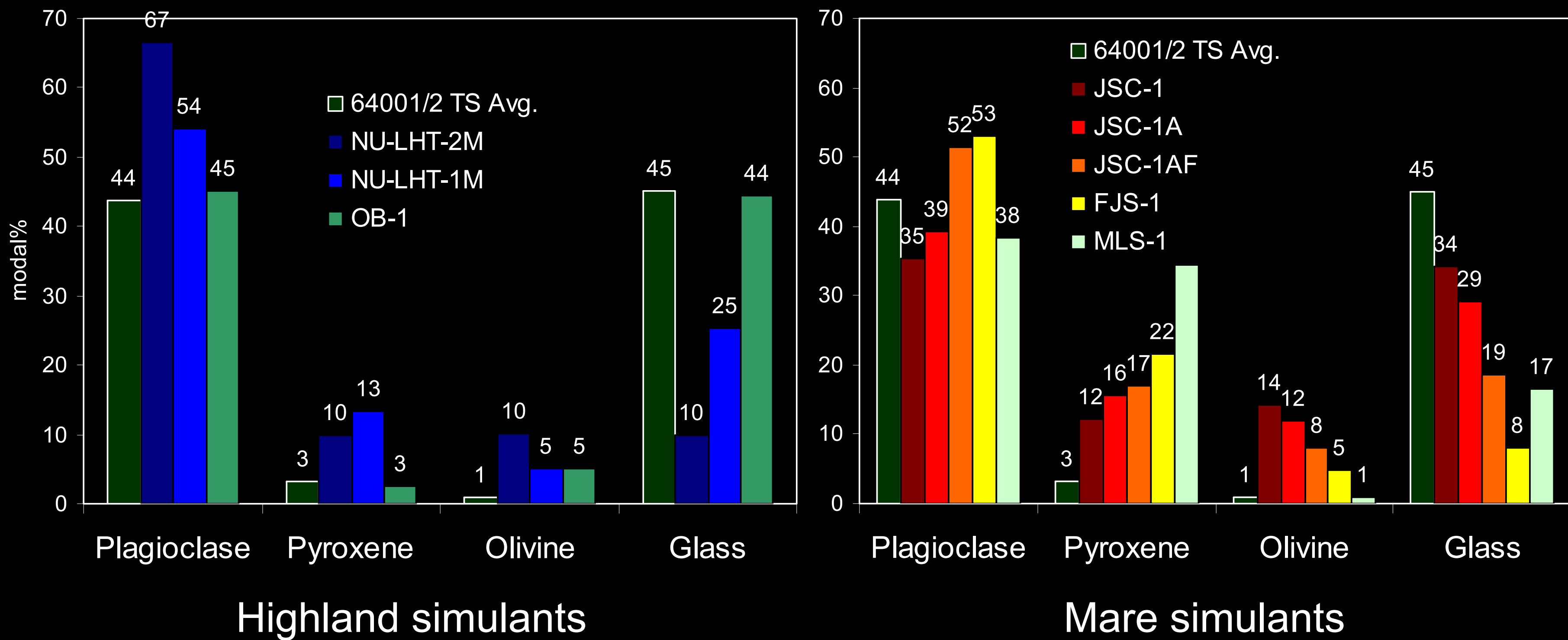
<u>Integrated grain mounts</u>
64002,262: 8.4% unclassified
64001,374: 16.9% unclassified

Lunar simulants: Mare and Highlands

NU-LHT-1M lunar highlands simulant

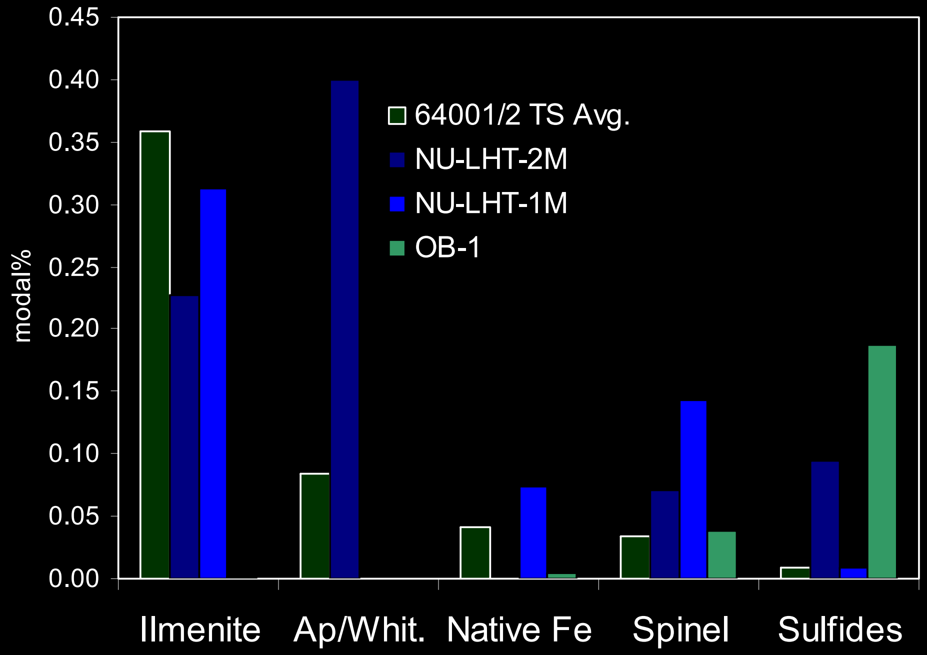
JSC-1A lunar mare simulant

Overview: Major mineral modal comparison between simulants and 64001/64002

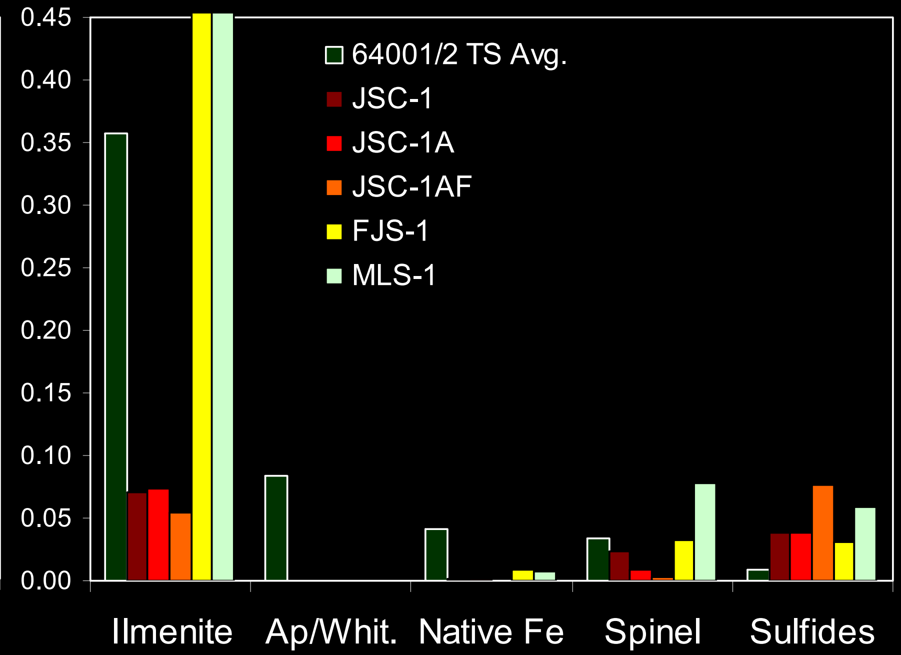


We are incorporating particle type data (e.g., the presence of agglutinates) and phase chemistry into these comparisons.

Overview: Trace mineral modal comparison between simulants and 64001/64002



Highland simulants



Mare simulants

We are incorporating particle type data (e.g., the presence of agglutinates) and phase chemistry into these comparisons.

Further and ongoing work

- Continue to analyze Apollo samples by total phase modal%.
- Incorporate particle type modal analysis by determining which phases are present in lithics, breccias, agglutinates, etc.
- Incorporate phase chemistry.

- Analyze simulants by these same techniques for comparison by Figure of Merit algorithms.

Parallel work

Characterizing particle size and shape distributions and bulk densities of lunar regolith and simulants for comparison by FoM.

References

Basu, A. and Mckay, D.S., “Petrologic Profile of Apollo 16 Regolith at Station 4”, *Proceedings of the 15th Lunar and Planetary Science Conference*, Part 1, *Journal of Geophysical Research*, Vol. 89, Supplement, 1984, pp. C133-C142.

Houck, K.J., “Modal Petrology of Six Soils from Apollo 16 Double Drive Tube 64002”, *Proceedings of the 13th Lunar and Planetary Science Conference*, Part 1, *Journal of Geophysical Research*, Vol. 87, Supplement, 1982b, pp. A210-A220.

Korotev, R.L., “Comparative Geochemistry of Apollo 16 Surface Soils and Samples from Cores 64002 and 60002 through 60007”, *Proceedings of the 13th Lunar and Planetary Science Conference*, Part 1, *Journal of Geophysical Research*, Vol.. 87, Supplement, 1982, pp. A269-A278.

Korotev, R.L., Morris, R.V., and Lauer, H.V., Jr., “Stratigraphy and Geochemistry of the Stone Mountain Core (64001/2)”, *Proceedings of the 15th Lunar and Planetary Science Conference*, Part 1, *Journal of Geophysical Research*, Vol. 89, Supplement, 1984, pp. C143-C160.

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