



# Assessing Lunar Rare Earth Element Resources

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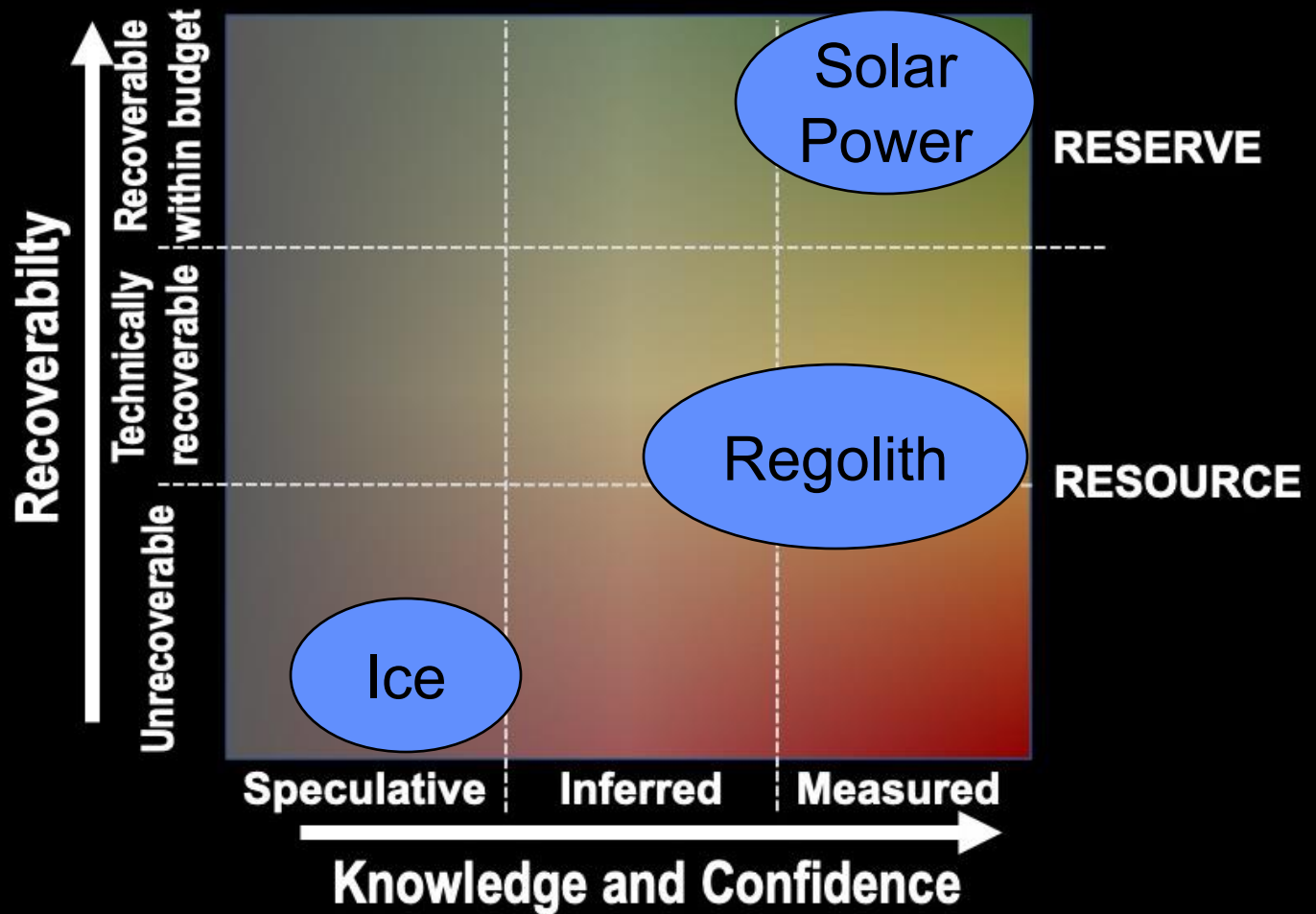
# Outline

- Some terminology
- Some lunar geology
- Lunar REE as a resource and reserve

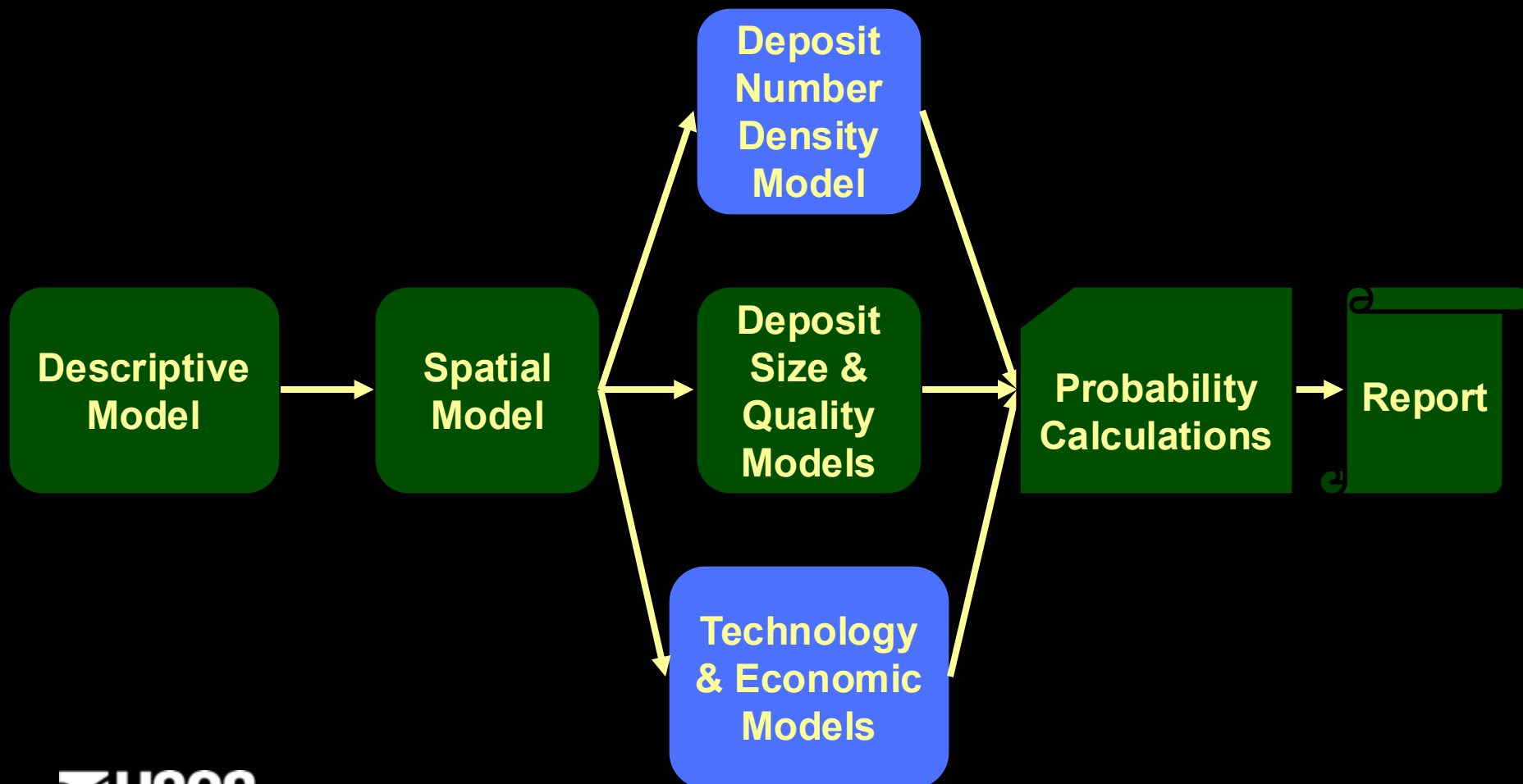
# Some (Lunar) Terminology

- **Resource**: something on the Moon that can be converted into a *commodity*.
- **Commodity**: something that can be used (or, eventually, sold).
- **Deposit**: a concentration of a resource.
- **Reserve**: a resource that can be converted into a commodity within your budgets (cost, mass, power, volume, schedule, risk, etc.).

# A Few Examples

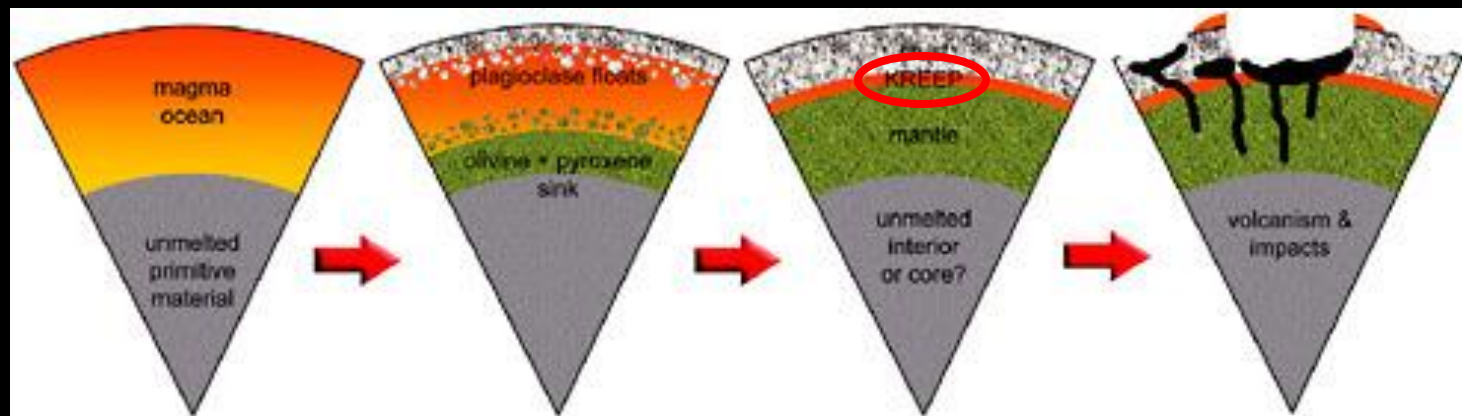


# USGS Assessment Methodology



# Descriptive Model

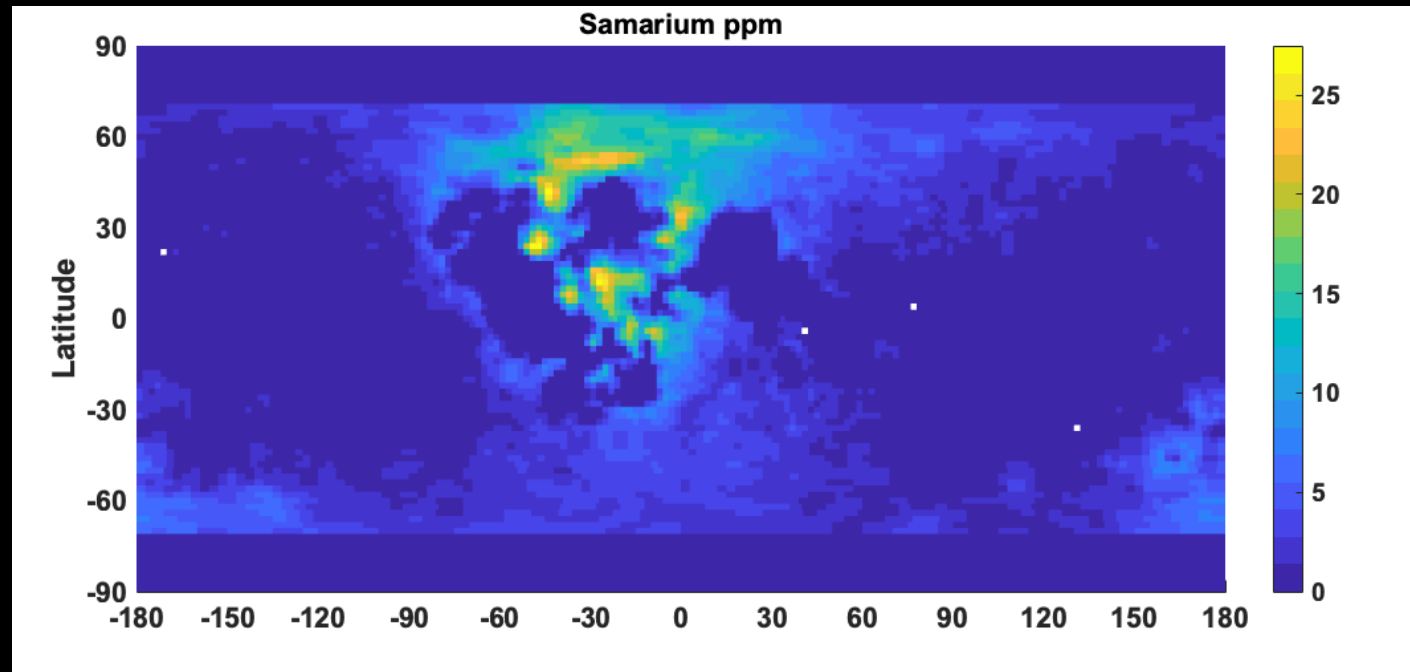
- **Lunar REE are associated with KREEP**
  - Rocks relatively rich in K, REE, and P
  - KREEP is the last dregs of the freezing magma ocean
  - Brought to the surface by impacts and volcanism



# Spatial Model

## ■ Global Maps

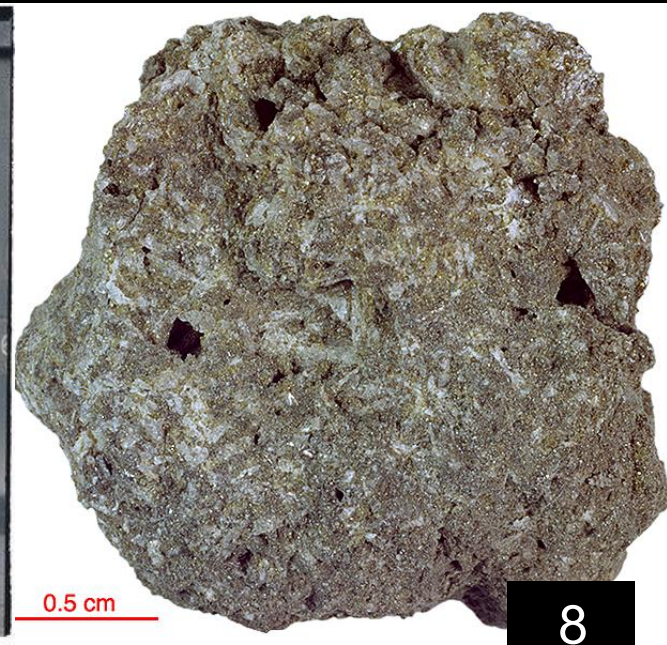
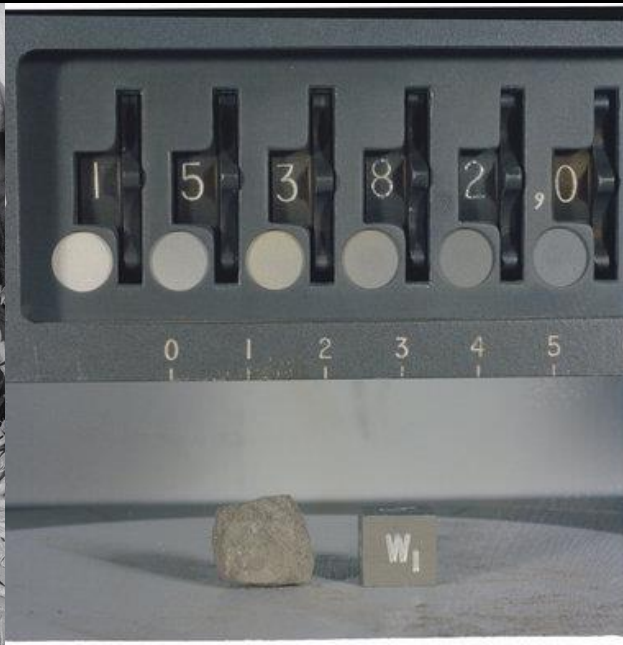
- From orbital neutron spectrometers
- Does not resolve individual deposits, but shows KREEP-rich rocks form a ring around the Imbrium basin



# Deposit Quality and Quantity Models

- **Most direct: Apollo Samples**
  - Small fragments of KREEP-rich rocks scattered across the Moon by impacts
  - Apollo 14 had the most KREEP-rich rocks

AS15-90-12233



# Apollo Sample Analysis

<https://www.lpi.usra.edu/lunar/samples/atlas/compendium/15382.pdf>



Figure 2: Photomicrograph of thin section of 15382 showing bent plagioclase crystals intergrown with pyroxene. NASA # S79-27741. Field of view is 2.7 mm. Photo is "off-color" because of fading of print.

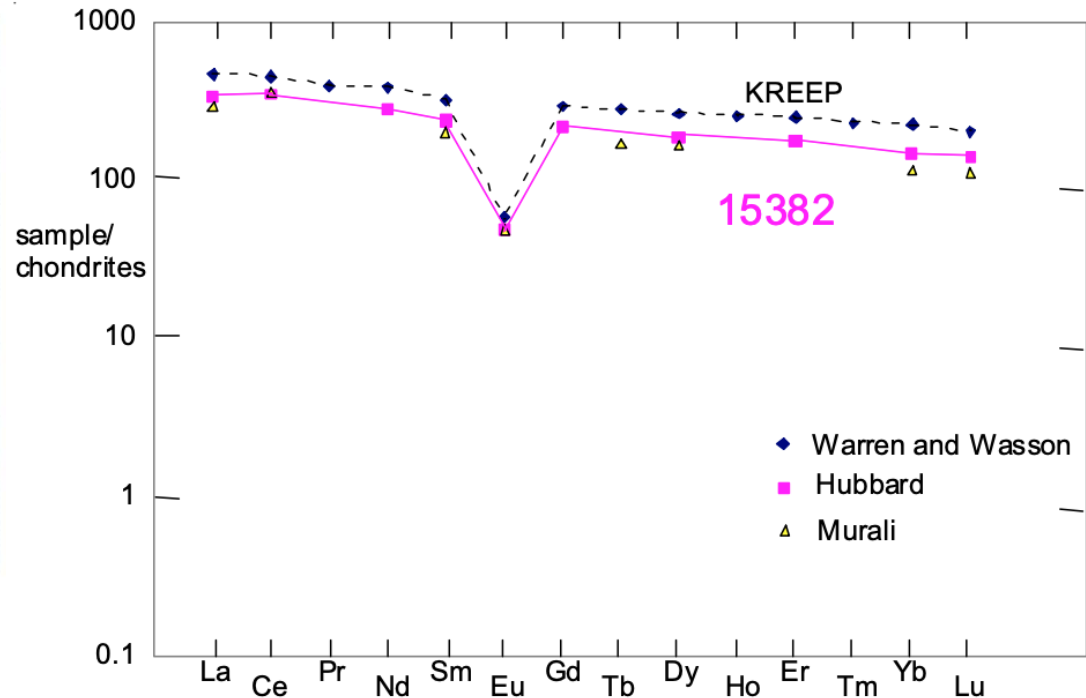
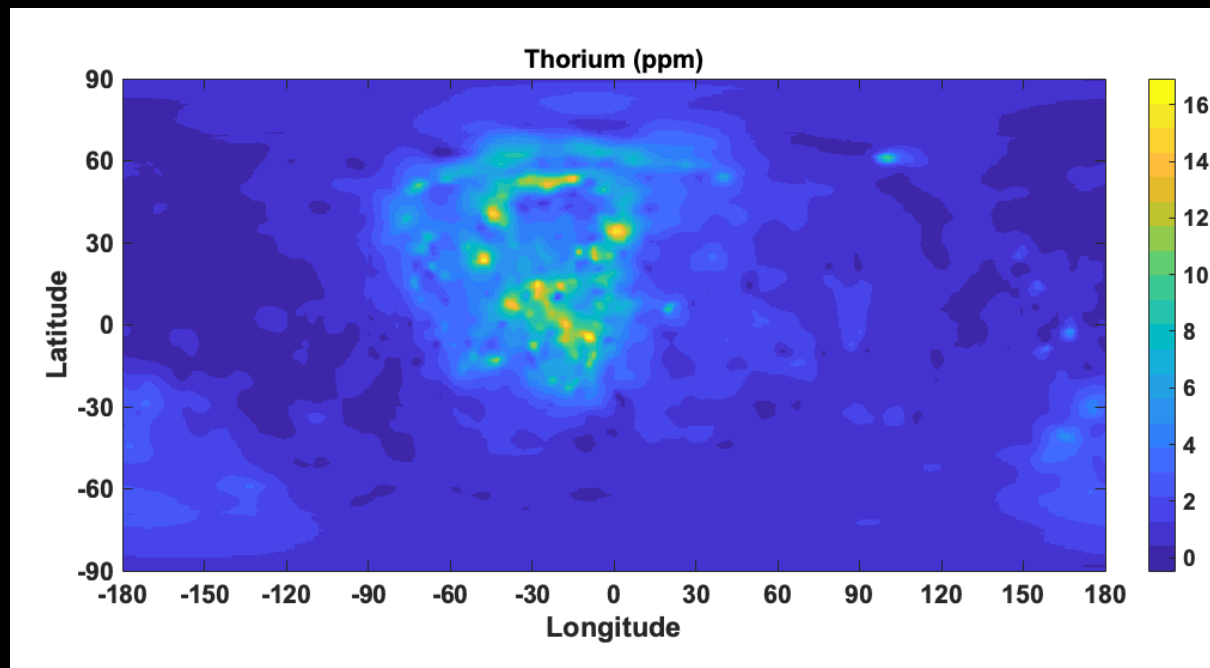


Figure 4: Normalized rare-earth-element diagram for 15382. Data from Hubbard et al. (1973) and Murali et al. (1977). "KREEP" pattern shown for comparison (see text).

# Higher Concentration Deposits?

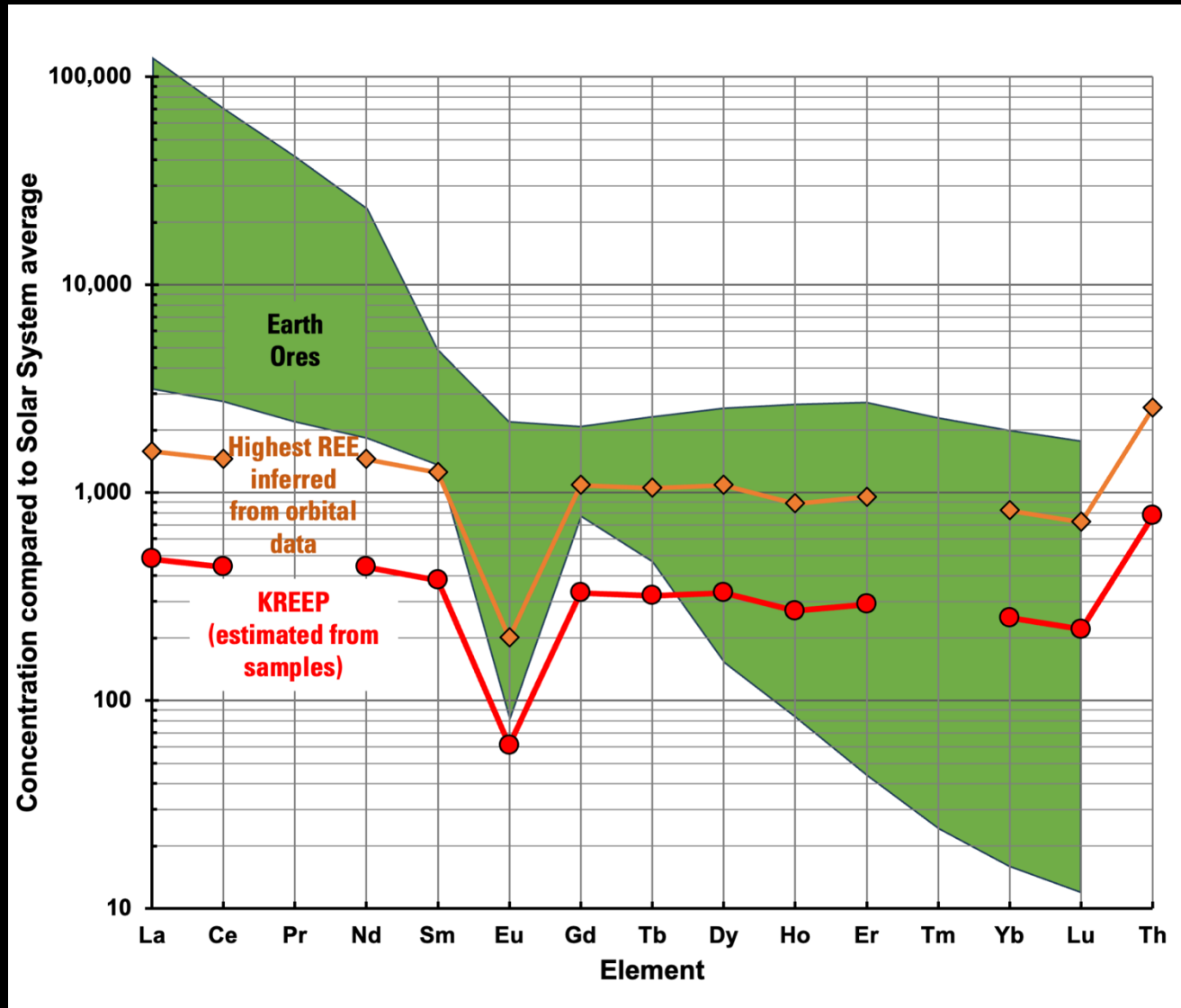
- Infer from orbital thorium measurements
  - Th easier to map from orbit because it is radioactive
  - Modeling of Th in geologic features suggests some rocks are more REE-rich than the Apollo samples
  - Supported by KREEP-rich lunar meteorite clasts



# Potential Reserves?

- **Local lunar REE concentrations may be comparable to REE ores on Earth**
- **To be economic, (a) mining the Moon needs to be similar in cost to mining on Earth or (b) REE prices need to rise significantly**
- **A combination may be plausible over 30 years (the timeframe often used by USGS assessments)**

# Potential Reserves?



# Summary

- **Lunar REE resources are comparable to Earth**
- **Deposit-scale exploration still needed**
  - CLPS-21, flying in 2028, includes the Lunar-VISE package to explore KREEP-rich volcanic domes
- **Technical and economic challenges exist**
  - Need to transport 100s tons (refined) or 1000s of tons (partially beneficiated) from the Moon to Earth
  - Need to develop beneficiation technology, perhaps to concentrate phosphates with possible O<sub>2</sub> reduction?

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