



# Progress at the USGS toward Quantitative Resource Assessments of Lunar Resources

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# Outline

- Past publications
- Some definitions
- Progress on each of the parts of a quantitative assessment

# Feasibility Studies

2017 USGS Open File Report concluded that it was feasible to apply USGS mineral assessment methods to asteroids with modest adjustments

2023 USGS Circular showed that USGS methods could be extended to energy, mineral, and water resources on the Moon



## Feasibility Study for the Quantitative Assessment of Mineral Resources in Asteroids

By Laszlo Keszthelyi, Justin Hagerty, Amanda Bowers, Karl Ellefsen, Ian Ridley, Trude King, David Trilling, Nicholas Moskovitz, and Will Grundy

Open-File Report 2017-1041

## Assessment of Lunar Resource Exploration in 2022

Laszlo P. Keszthelyi, Joshua A. Cohan, Kristen A. Bennett, Lillian R. Ostrach, Lisa R. Gaddis, Travis S. J. Gabriel, and Justin Hagerty



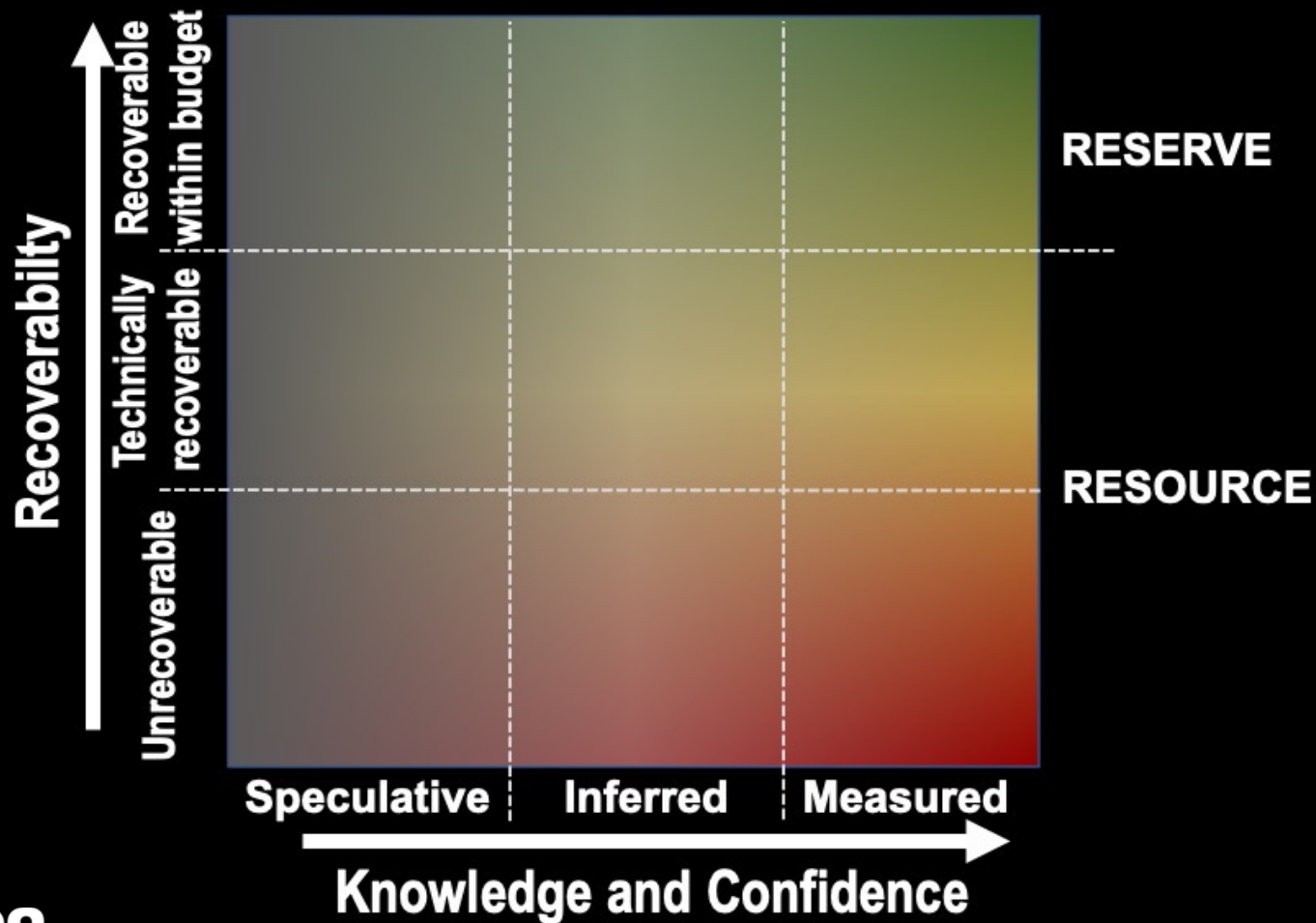
Circular 1507

U.S. Department of the Interior  
U.S. Geological Survey

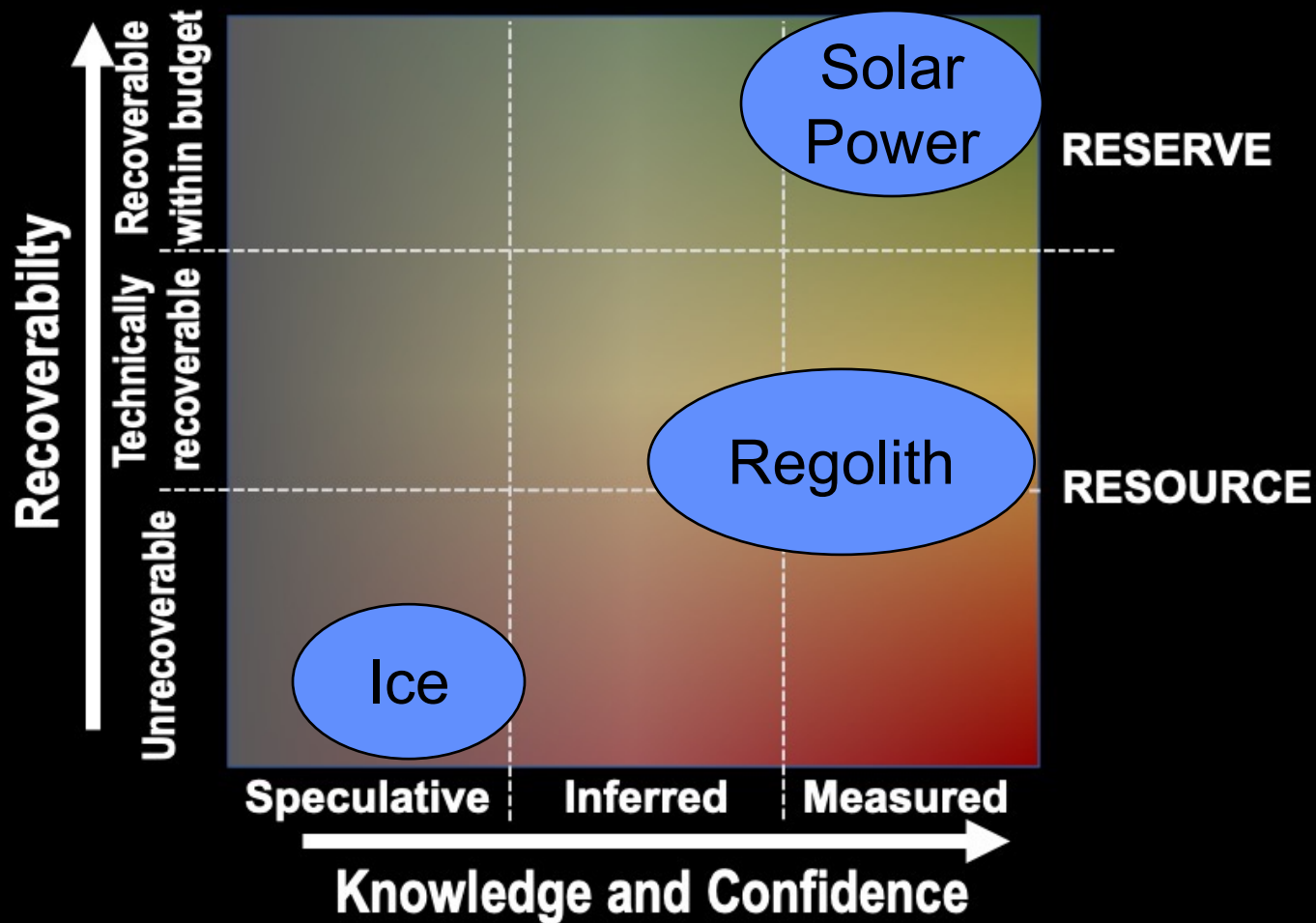
# Some Definitions (in a lunar context)

- **Resource**: something on the Moon that can be converted into a *commodity*.
- **Commodity**: something that can be used to further space exploration.
- **Deposit**: a concentration of a resource; called a *continuous deposit* if widely distributed.
- **Reserve**: a resource that can be converted into a commodity within your budgets (cost, mass, power, volume, schedule, risk, etc.).

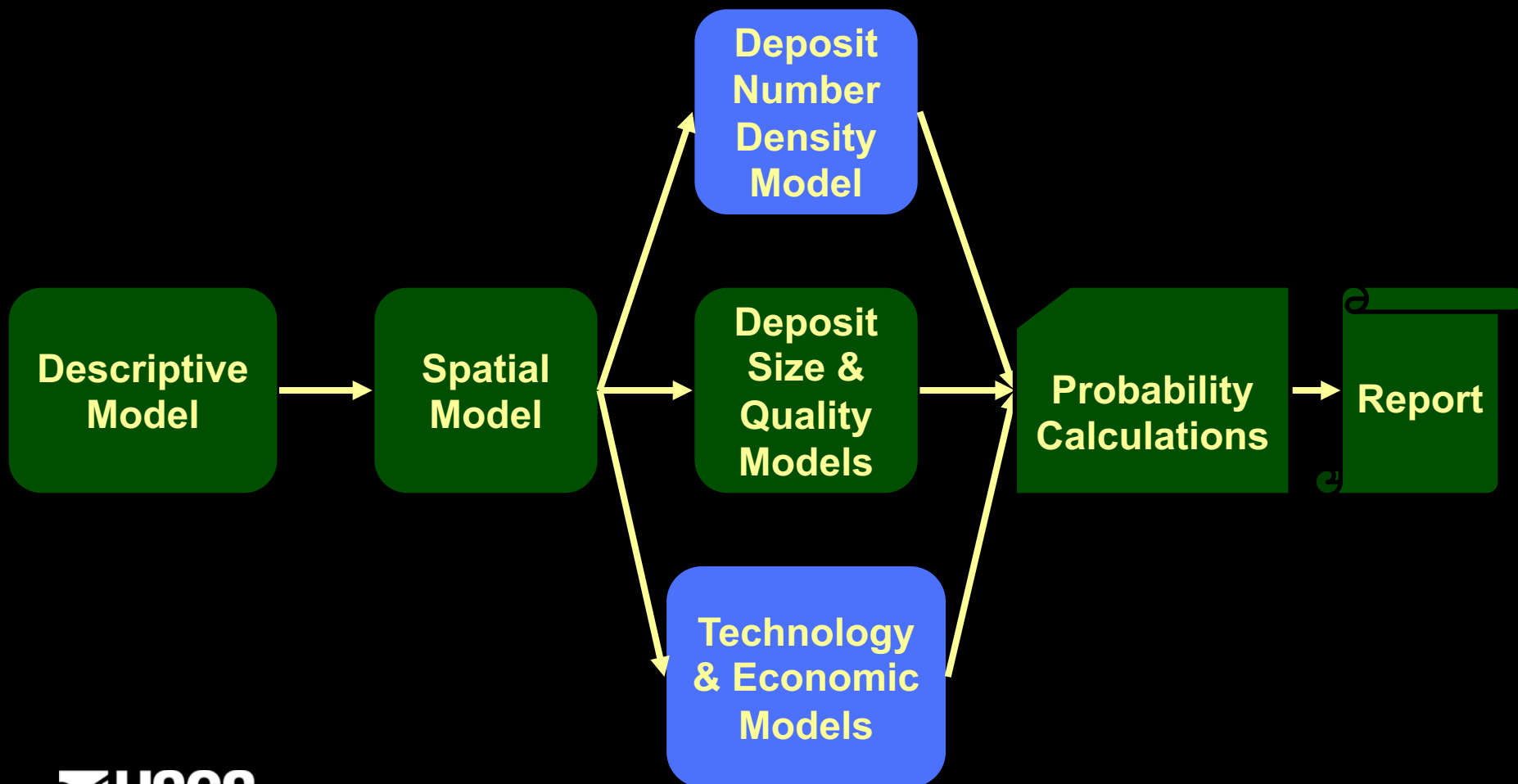
# Suggested Classification (2023)



# A Few Example Resources



# Basic Methodology



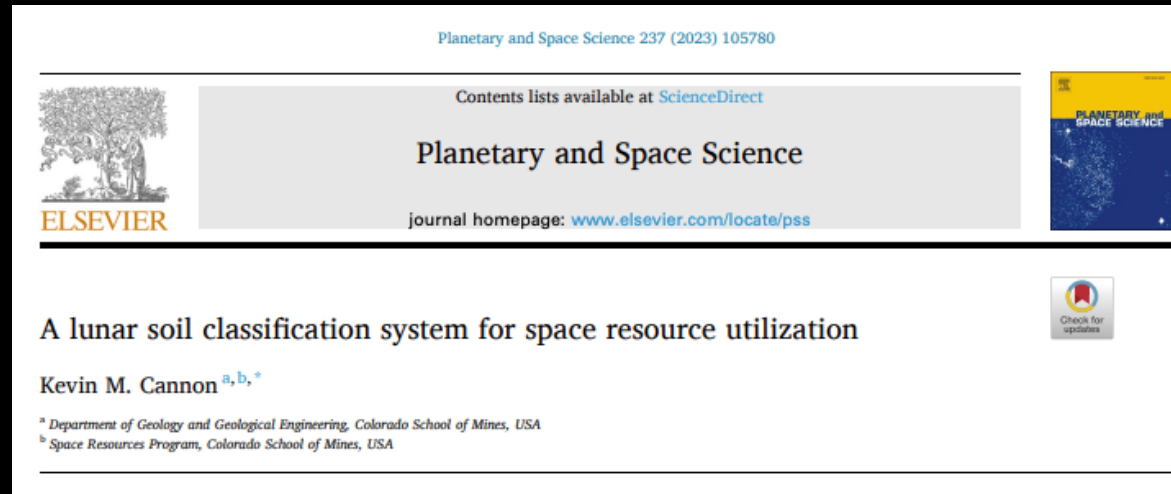
# Descriptive Model

- **Systematic description of deposits and their genesis**
  - Essential to avoid statistical mess by mixing data from different types of deposits of the same resource
  - Should be systematic, allowing comparison between types of deposits and resources
  - Solar: pretty trivial
  - Regolith: possible with current understanding
  - Ice: insufficient scientific understanding (need VIPER)

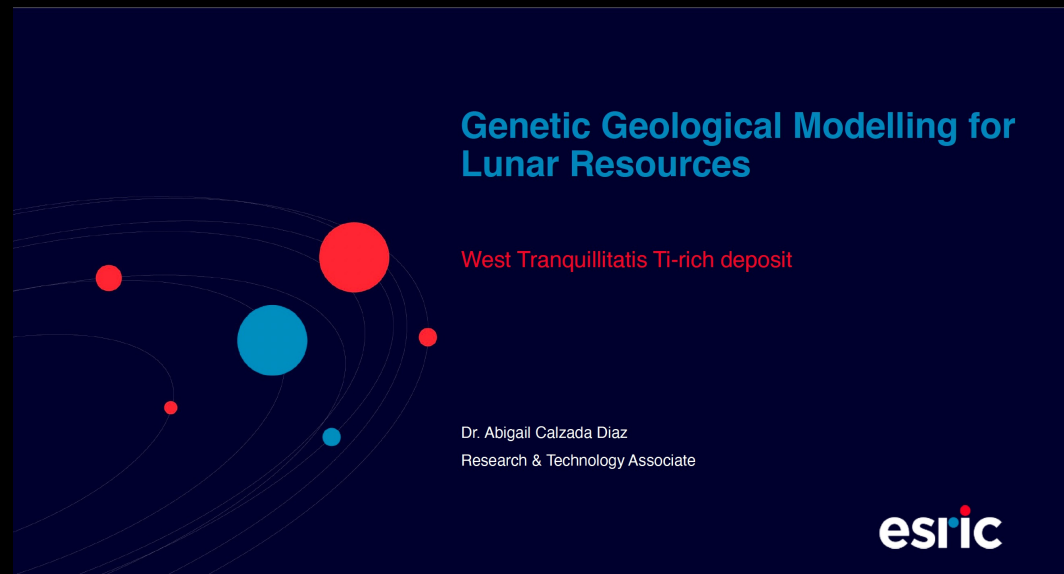


# Descriptive Regolith Models are Being Published!

- Cannon (2023)



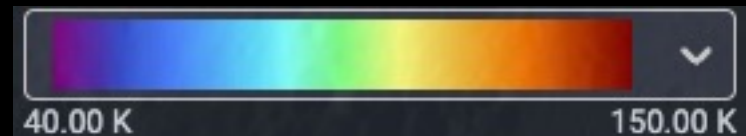
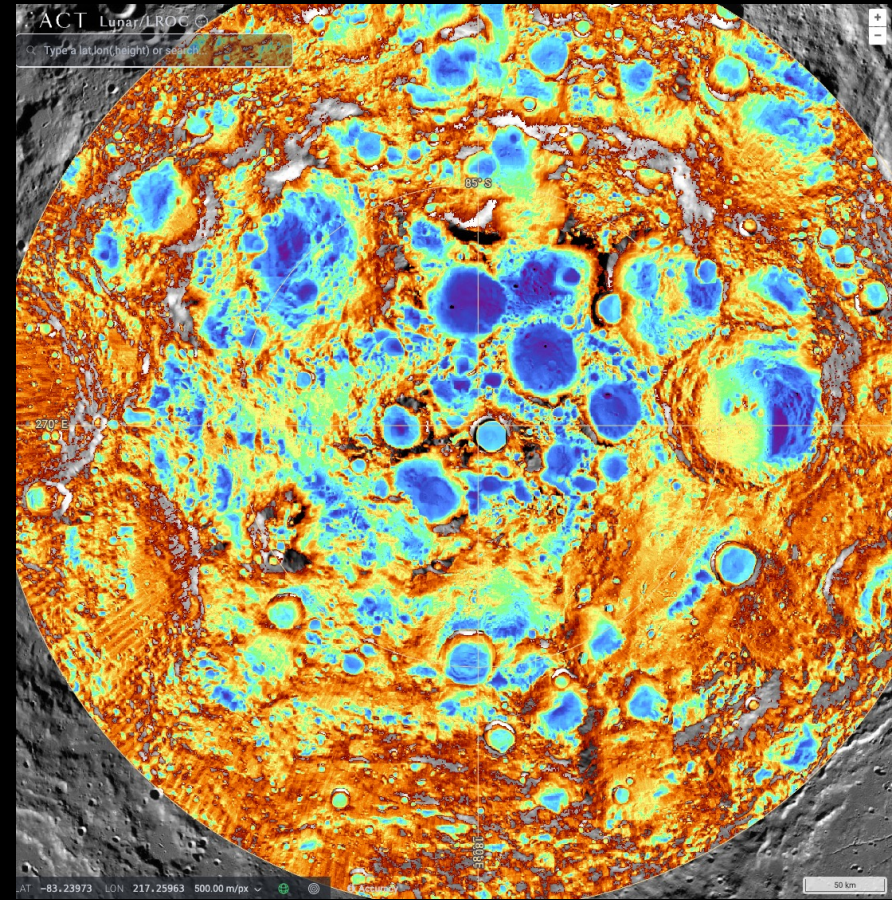
- Calzada-Diaz at 2023



# Spatial Model

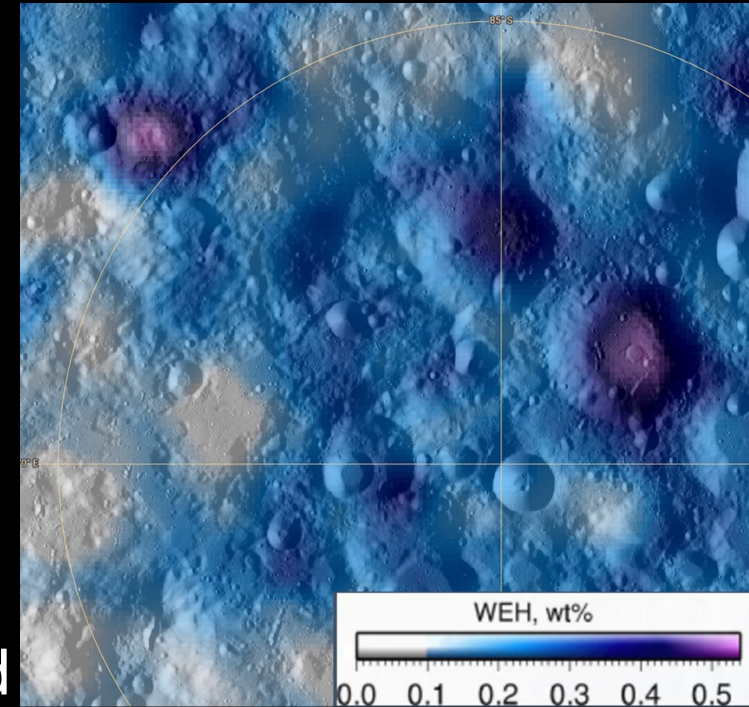
- **Delineates where deposits are possible**
  - Traditionally a large region (state or country)
- **Prospectivity maps are a step beyond**
  - Map of probability
  - Not currently possible for the Moon, but VIPER hopes to create some

Average Summer Temperature [Williams, J.-P., et al. (2019). J. Geophysical Research, 124, 2505–2521. <https://doi.org/10.1029/2019JE006028>]



# Deposit Density Model

- How many deposits per square km, with uncertainties
- Needed for discrete hidden deposits
  - Not for continuous deposits like regolith
  - Not for deposits readily mapped
  - Decimeter MicroPSRs?

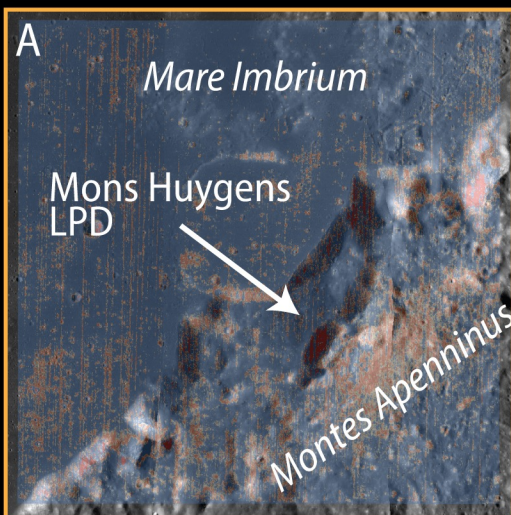


Water Equivalent Hydrogen (WEH) Sanin et. al., *Icarus*, 283, (2017), 20–30, doi:10.1016/j.icarus.2016.06.002

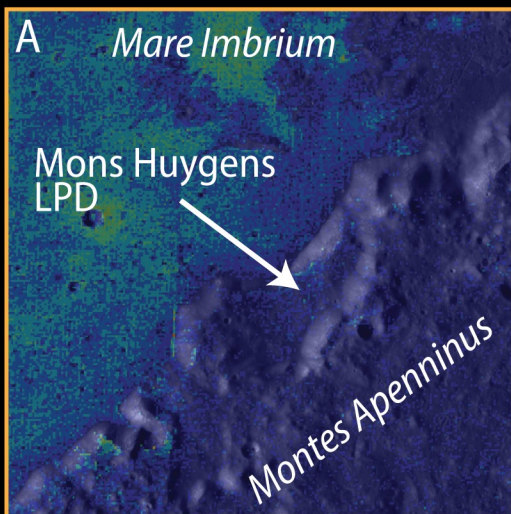
# Deposit Quality and Quantity Models

- **Probability distribution for deposit characteristics that affect recoverability**
  - For terrestrial minerals = grade and tonnage
  - Have enough data to start calculating for regolith
    - Global remote sensing
    - Some samples and geophysics
    - Few drill cores and trenches
  - What parameters matter?
    - Grain size
    - Mineralogy
    - Details process dependent!



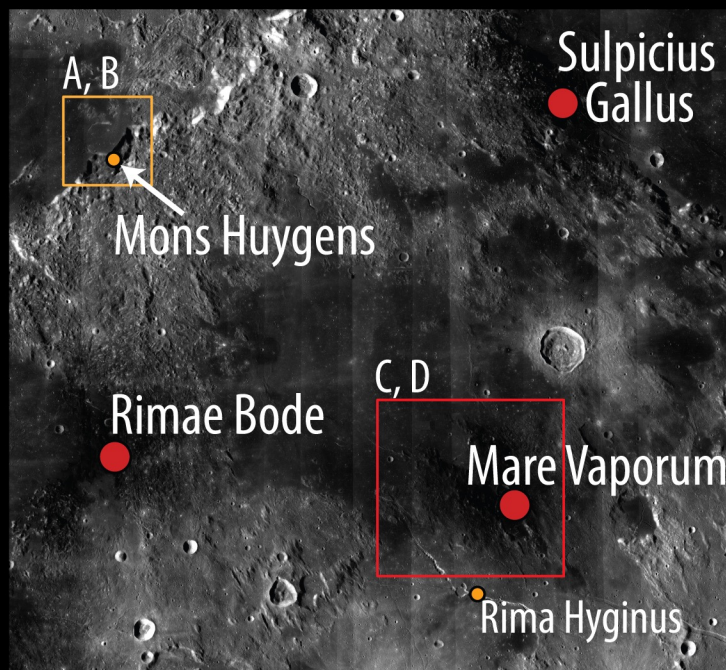


20 km



Ilmenite signal strength

Low High

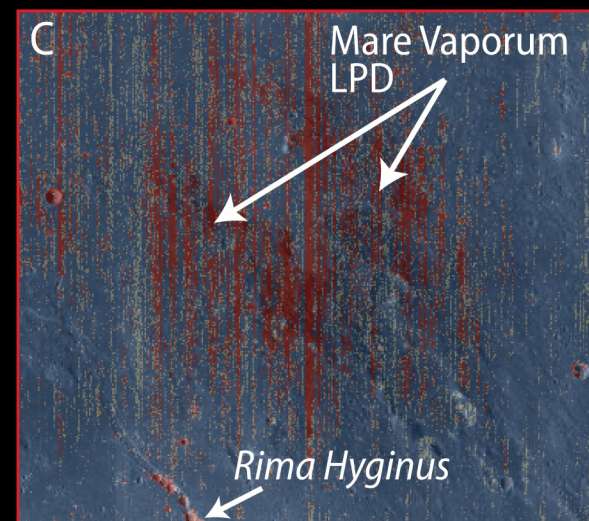


- < 100 sqkm
- 100 - 1000 sqkm
- 1000 < sqkm

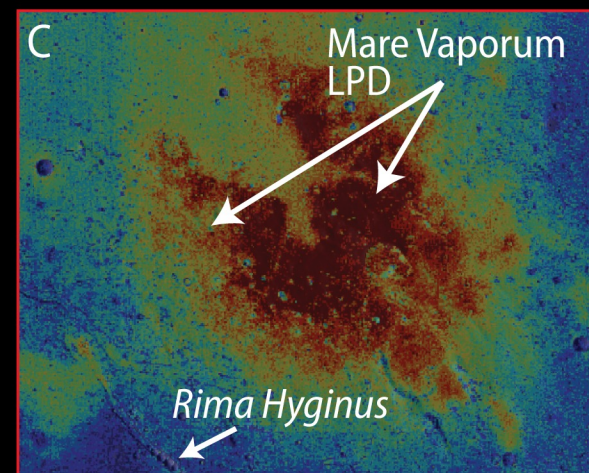
50 km

<2% >10%

TiO<sub>2</sub> concentration



20 km



(TiO<sub>2</sub> from Sato et al., 2017)

# Technology and Economic Models

- **Logical and/or mathematical expressions to describe characteristics that make a resource recoverable within budget(s)**
  - Optional for *resource* assessment, necessary for assessing *reserves*.
  - DARPA/APL LOGIC Consortium has started discussing standards
    - TRL scale could be a key component
    - Should consider “Social License to Operate”
      - Environment, Society, and Governance considerations

# Summary

- **Real progress is being made**
  - USGS is often collaborating, not taking the lead
- **Following a logical progression**
  - Starting with the prerequisites for later steps
  - Focus is on resources for which we have sufficient information and understanding
- **Stay tuned!**
  - More to be submitted this year
  - VIPER will allow major advances