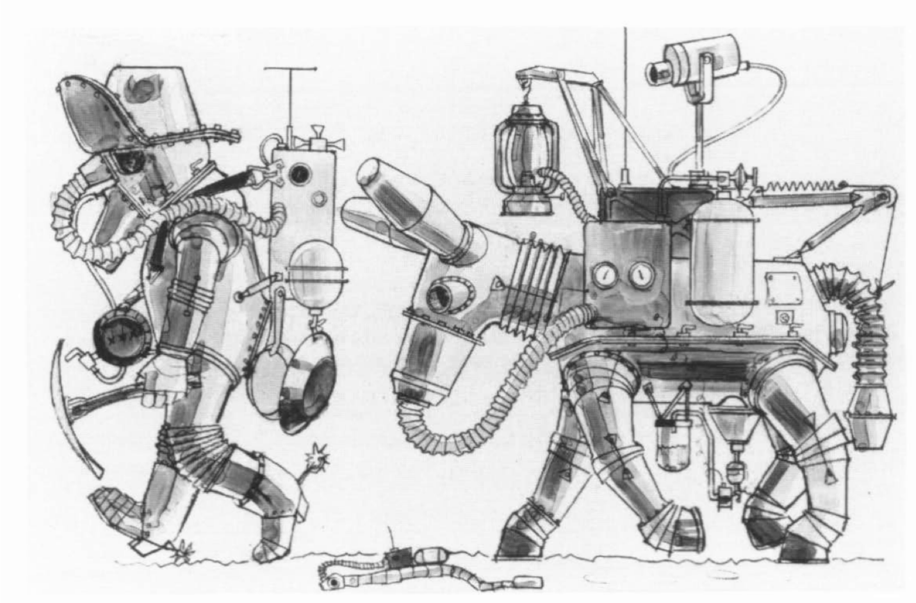

SPACE RESOURCES
ROUNDTABLE
LEAG
LUNAR EXPLORATION ANALYSIS GROUP
Summary of Prospecting
Technologies
Christopher Dreyer
June 15, 2018
Copyright © 2018 Colorado School of Mines
All Rights Reserved

Mineral Prospecting

The search for an economically exploitable mineral resource.

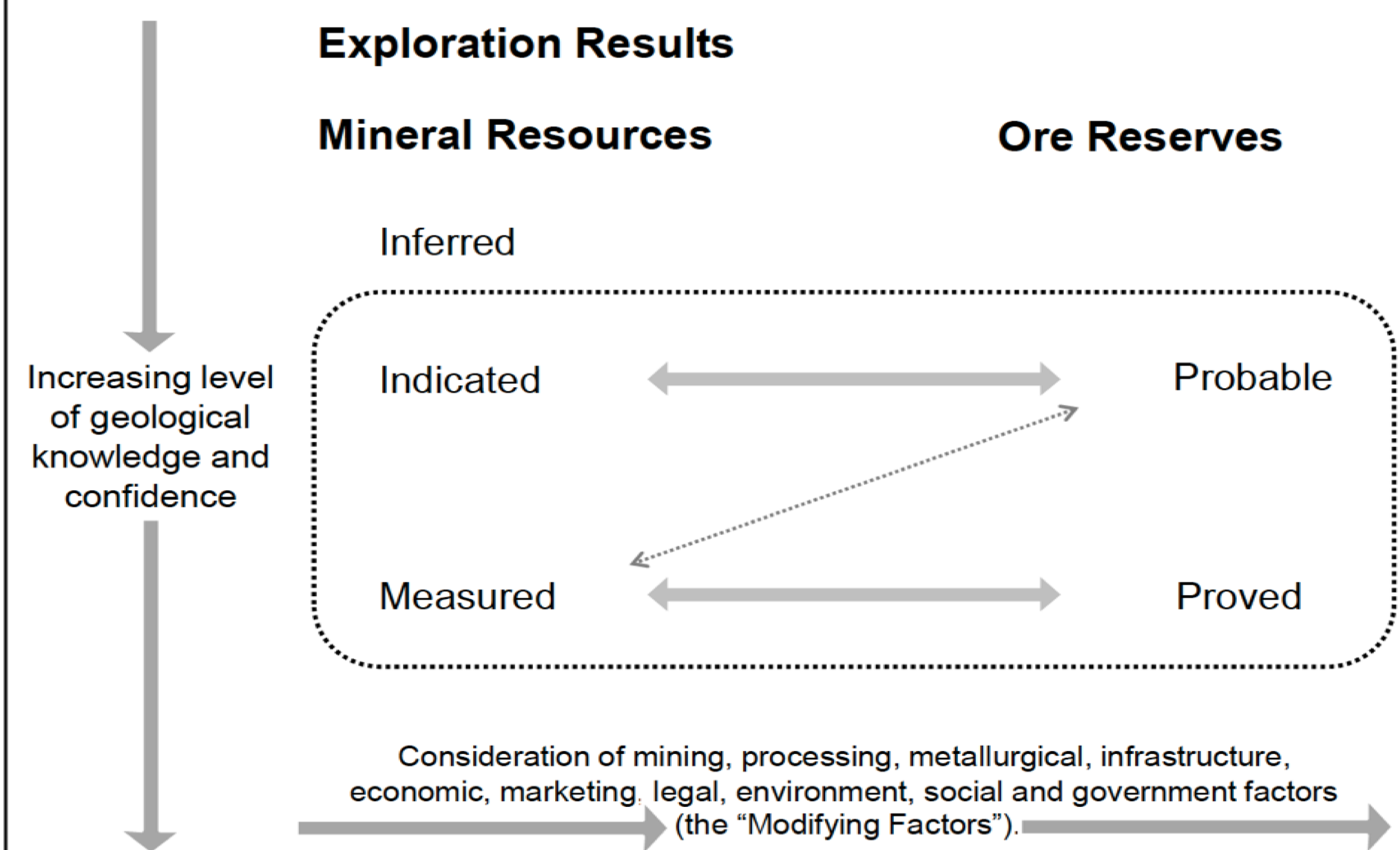


Credit: NASA SP509 Vol 1: Scenarios

- Mineral Resource

  Concentration of solid material in such form, grade, and quantity that there are reasonable prospects for eventual economic extraction.

Adapted from JORC, 2012. Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves (The JORC Code) [online]. http://www.jorc.org

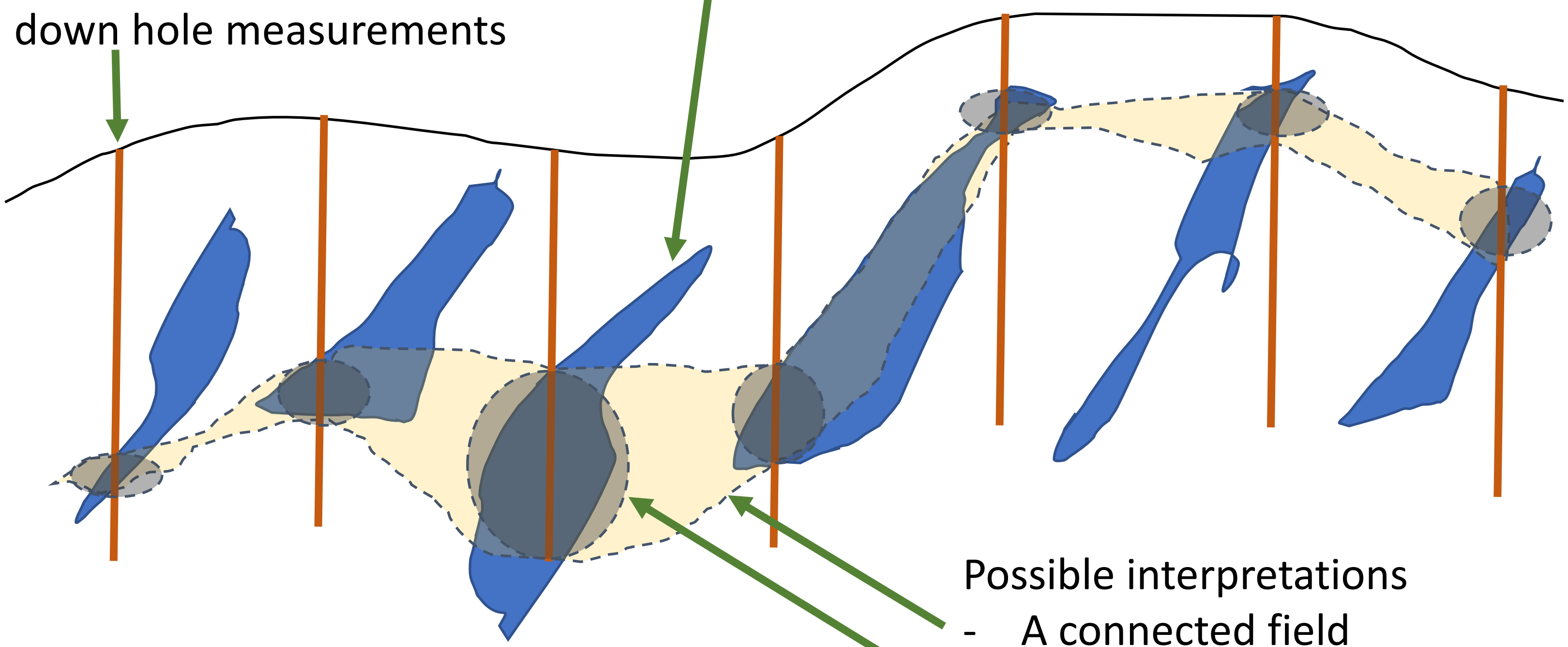


JORC, 2012. Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves (The JORC Code) [online]. http://www.jorc.org

Prospecting Choices Affect Outcome

A resource deposit

Location of a subsurface sampling method, such as borehole cores or in situ down hole measurements

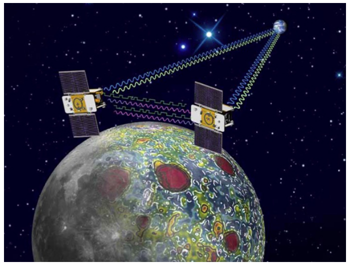
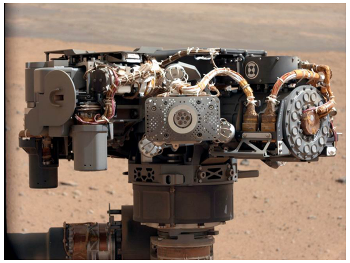


Possible interpretations
- A connected field
- Isolated deposits

Both interpretations are wrong

Prospecting Technologies



A platform
- Spacecraft • Rover • Lander

Instruments
- Remote Sensing
- In Situ Instrument

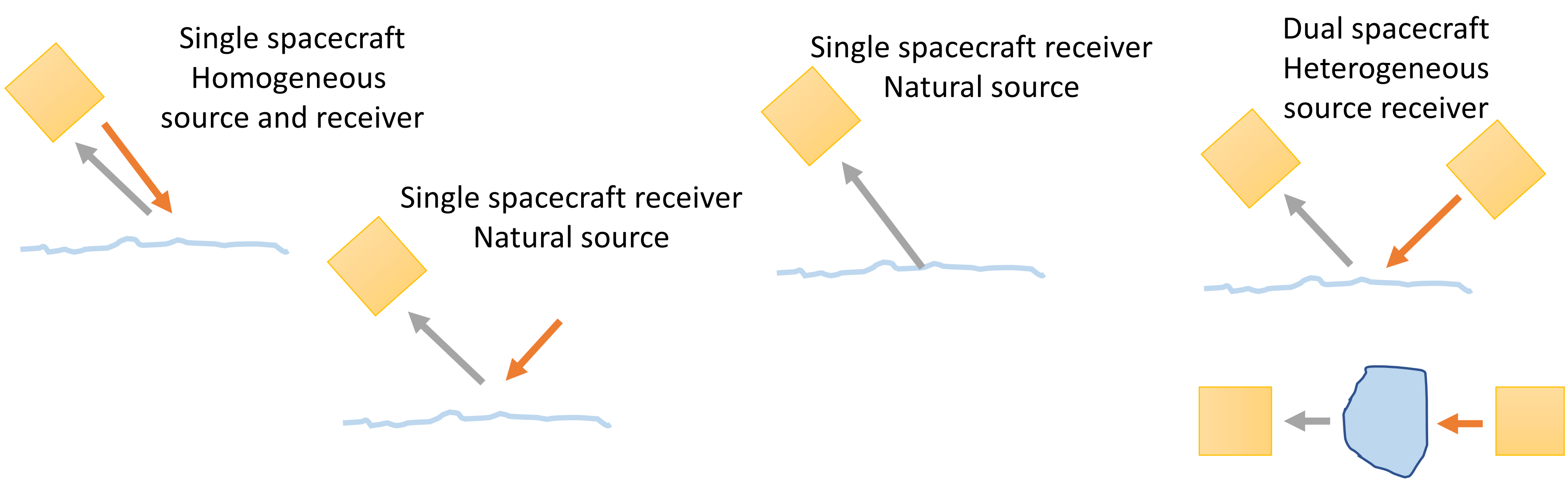
Surface or Sample Access
- Orbit • Spacecraft Attitude
- Drill • Boreholes • Scoops

A concept of operations
- How the technologies work together

Space Resources Roundtable

Instruments

- Interaction of energy with a material
  - Light • Radio waves • particles • mechanical
- Signal - a detected form of energy
  - Light • Radio waves • particles • mechanical
  - Intensity of detected energy • Spatial distribution • Frequency change



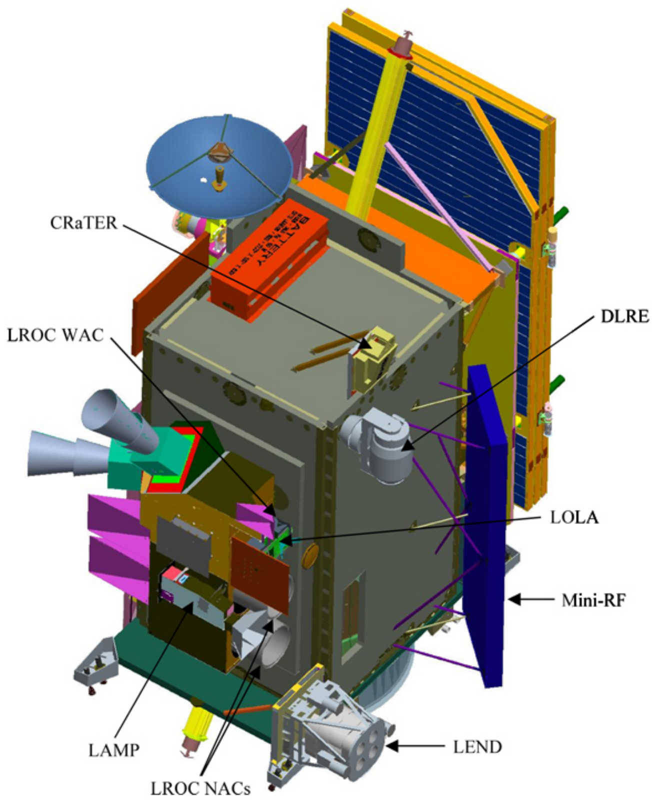
Space Resources Roundtable

Notable Lunar PSR Instruments and Missions

Instrument	Mission
Radar	Clementine, Chandrayaan-1, Lunar Reconnaissance Orbiter
Thermal imaging	Clementine, Lunar Reconnaissance Orbiter
Visible imaging	Clementine, Lunar Reconnaissance Orbiter
Altimeter	Clementine, Chandrayaan-1, Lunar Reconnaissance Orbiter
Neutron Spectrometer	Lunar Prospector, Lunar Reconnaissance Orbiter
Impactor	LCROSS, Chandrayaan-1
Infrared Spectroscopy	Chandrayaan-1

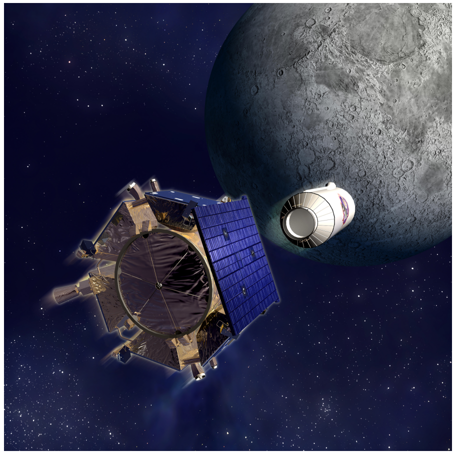
Lunar Reconnaissance Orbiter

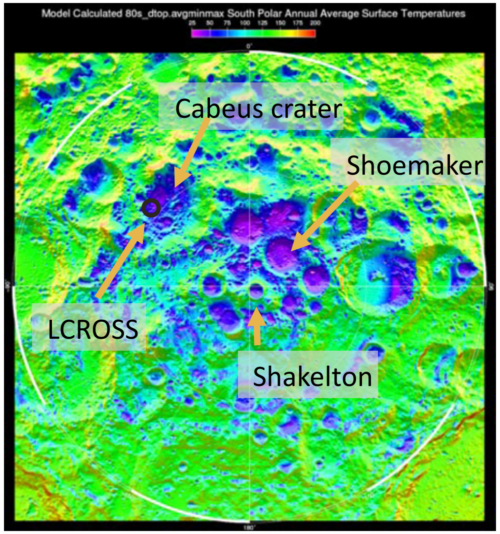
Instrument	Energy/Source/Signal
Cosmic Ray Telescope for the Effects of Radiation (CRaTER)	Natural Cosmic Rays
Diviner Lunar Radiometer (DLRE)	Natural thermal emission
Lyman Alpha Mapping Project (LAMP)	Natural Ultraviolet photons from starlight and H emission
Lunar Exploration Neutron Detector (LEND)	Neutrons formed by cosmic ray impacts
Lunar Orbiter Laser Altimeter (LOLA)	Infrared photons emitted by LRO, reflected photons detected by LRO
Lunar Reconnaissance Orbiter Camera (LROC)	Natural visible light images
Mini-RF	Radar from Arecibo reflected off the surface detected by LRO

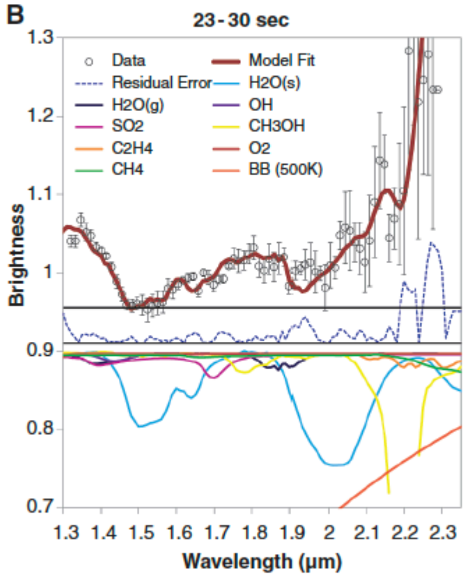


LCROSS

- Crashed a Centaur upper stage into a PSR
- Viewed with following NIR spectrometer







Compound	Concentration (wt%)	Compound	Concentration (wt%)
Water, H_2O	5.5	Magnesium, Mg	0.19
Hydrogen Sulfide, H_2S	0.92	Sulfur Dioxide, SO_2	0.18
Hydrogen, H_2	0.69	Ethylene, C_2H_4	0.17
Carbon Monoxide, CO	0.57	Carbon Dioxide, CO_2	0.12
Calcium, Ca	0.4	Methanol, CH_3OH	0.09
Ammonia, NH_3	0.33	Methane, CH_4	0.04
Mercury, Hg	0.24		

Colaprete et al., "Detection of Water in the LCROSS Ejecta Plume," Science, vol 230, p 463, 2010

Resource Prospector

Mobility

Rover

- Mobility system
- Cameras
- Surface interaction

Prospecting

Neutron Spectrometer System (NSS)

- Water-equivalent hydrogen > 0.5 wt% down to 1 meter depth

NIR Volatiles Spectrometer System (NIRVSS)

- Surface H2O/OH identification
- Near-subsurface sample characterization
- Drill site imaging
- Drill site temperatures

Sampling

Drill

- Subsurface sample acquisition
- Auger for fast subsurface assay
- Sample transfer for detailed subsurface assay

Processing & Analysis

Water Analysis and Volatile Extraction (WAVE):

Oxygen & Volatile Extraction Node (OVEN)

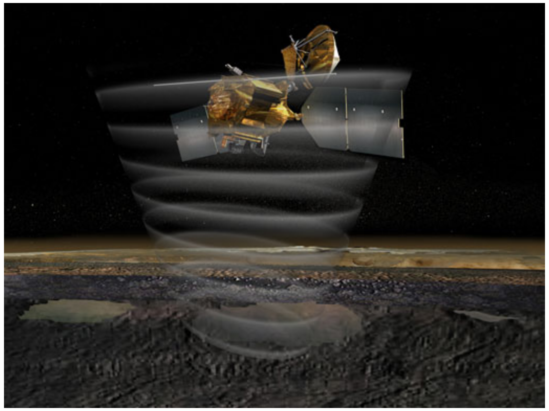
- Volatile Content/Oxygen Extraction by warming
- Total sample mass

Lunar Advanced Volatile Analysis (LAVA)

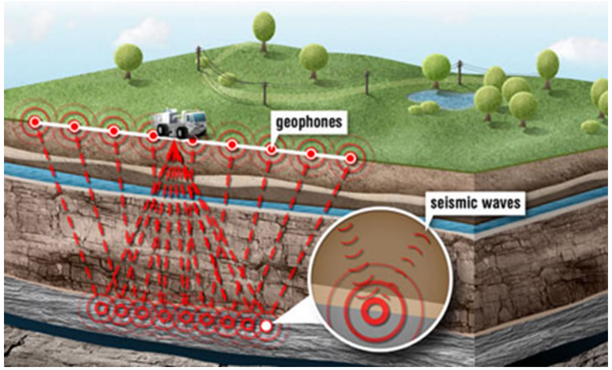
- Analytical volatile identification and quantification in delivered sample with GC/MS
- Measure water content of regolith at 0.5% (weight) or greater
- Characterize volatiles of interest below 70 AMU

Prospecting Needs – Subsurface

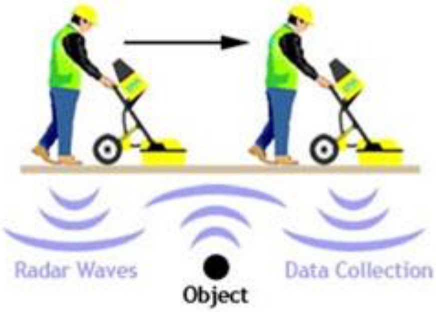
- Sub-surface: Resource variation with depth
  - Drilling
    - Downhole instruments
    - Core analysis
  - Subsurface imaging –
    - Synthetic Aperture Radar (SAR)
    - Ground Penetrating Radar (GPR)
    - Active Seismic Imaging



Shallow Subsurface Radar (SHARAD) NASA/JPL



http://saharawealth.com/drilling/



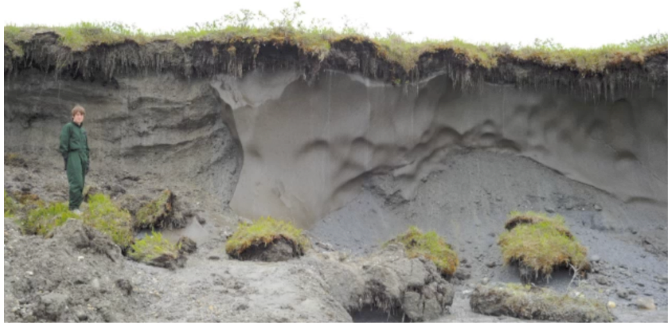
https://www.openpr.com/news/1047329/Ground-Penetrating-Radar-GPR-Market-by-Manufacturers-Countries-Type-and-Application-Forecast-to-2023.html

Prospecting Needs – Spatial resolution and form of ice

- Increase spatial resolution
  - Rover trafficability
  - Volatiles distribution
    - Blocky ice structures vs. Homogeneous
- Form of PSR ice
  - Dirty snow?
  - Pore-filing highly compacted regolith?

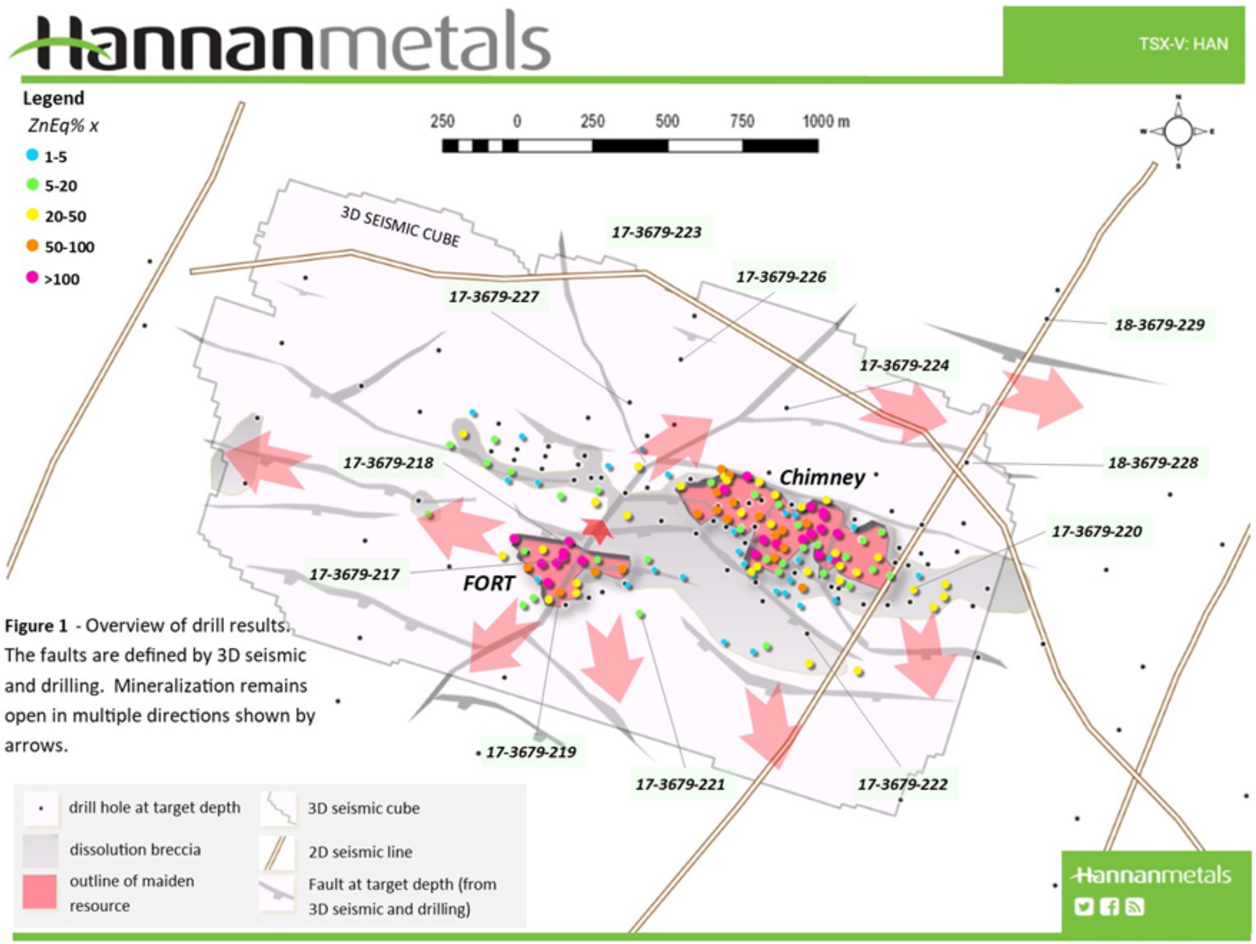
Credit: Off-Road.com

http://etc.usf.edu/clippix/picture/dirty-snow.html



Credit: National Parks Service

Terrestrial Prospecting Example



What measurements are needed to improve the "prospects for eventual economic extraction"?

Brainstorm
- Platform options
- Instrument options
- Concept of operations