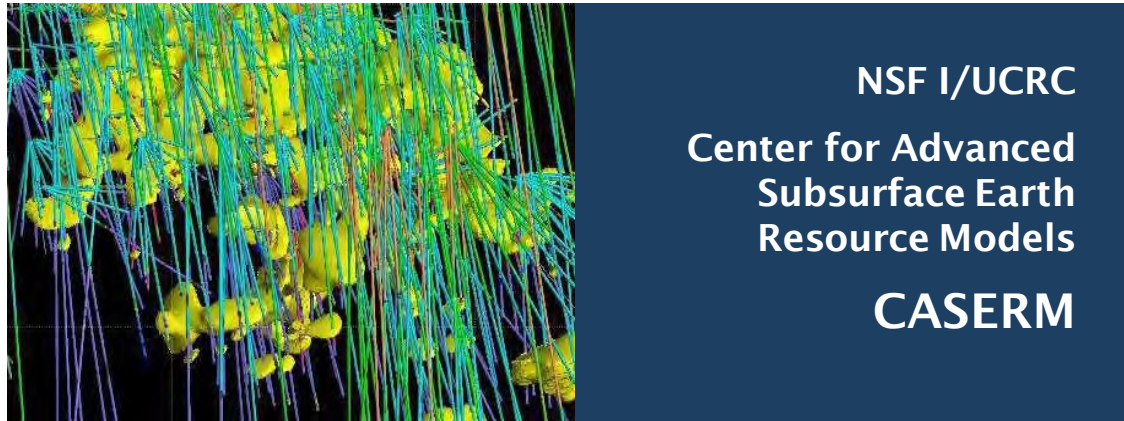


I/UCRC: Industry/University Cooperative Research Center



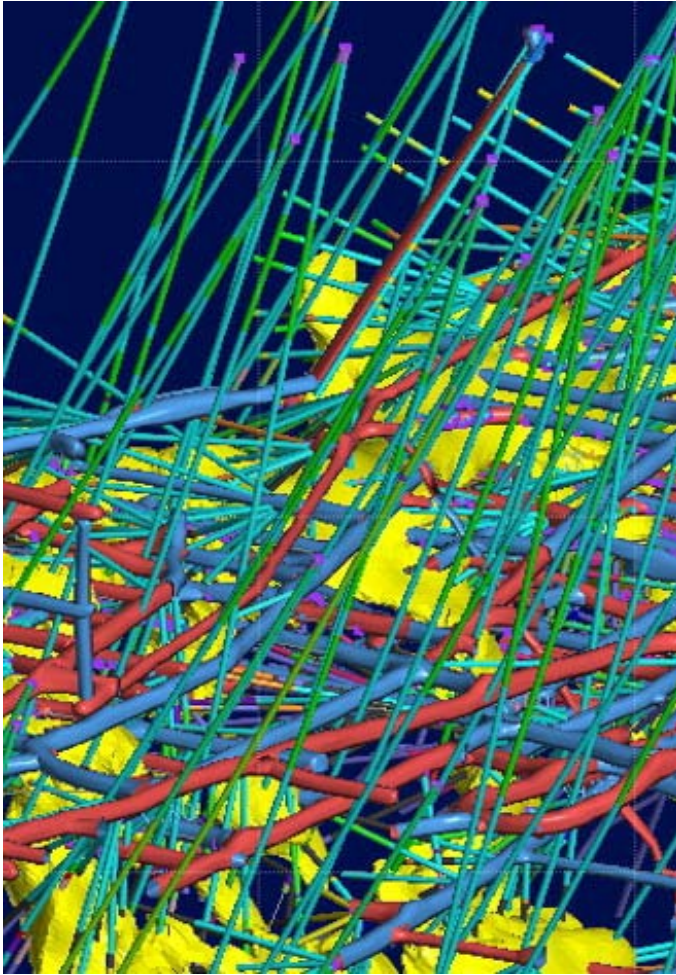
Subsurface Data and Machine Learning

Committee on Earth Resources
Board on Earth Sciences and Resources, NAS

June 6, 2019



What is CASERM?



The CASERM is a collaboration among industry, government agencies, and universities with the purpose of:

- transforming the way geoscience data is used in the mineral resource industries, beginning with locating, developing, and mining subsurface resources and continuing through mine closure and environmental remediation;
- disseminating this knowledge to Center members; and
- addressing the critical industry need for trained and prepared employees by educating future researchers, engineers, and scientists.

Industry/University Cooperative Research Center

- NSF provides organizational expertise and funding for center development and operation over three 5-year phases
- Each center is usually comprised of two or more university sites with industry and other fee-paying members
- Membership fees support center research activities:
 - Members prioritize the research agenda and direct the progress of research
 - 90% of membership fees are directed toward research (indirect costs are <10%)
 - Members get access to graduates and institutional expertise
 - Members get royalty free license to new discoveries

Opportunity Space for CASERM

Low Global Success Rate of Greenfields Exploration

Target Size	Average Number of Annual Discoveries	Average Number of Annual Exploration Programs	Probability of Greenfield Discovery
Irrespective of size	23.37	2669	0.9 %
Major	7.79	2669	0.3 %
World-class	1.74	2669	0.07 %

Guj and Bartrop (2009)

Prolonged Project Development Time

- Average development time for greenfield Cu projects (1950-2013) was 18.4 years, and
- 1995-2004 Au projects took an average of 9 years from discovery to onset of mining (Jennings and Schodde, 2016).

Discovery Costs Increasing

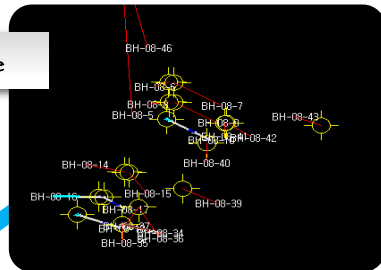
- In 2014, global exploration expenditures were ~10.7 billion US\$ (Monecke, pers. comm.)
- Over the past decade, the average cost per discovery have increased 3-fold from \$86m to \$238m in constant 2016 dollars (Schodde, 2017).

Opportunity Space for CASERM

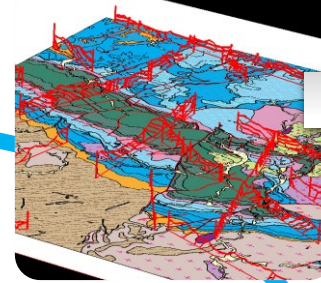
Data Integration, Scaling, and Inversion

Dissimilar geoscience data types, spatial resolutions, and distributions

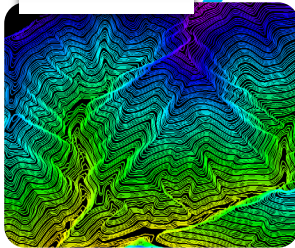
Borehole



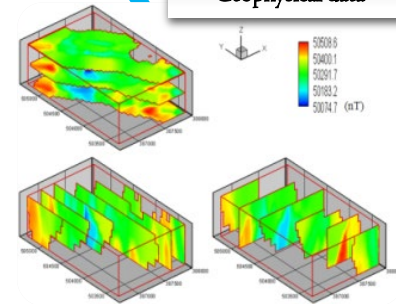
Geological data



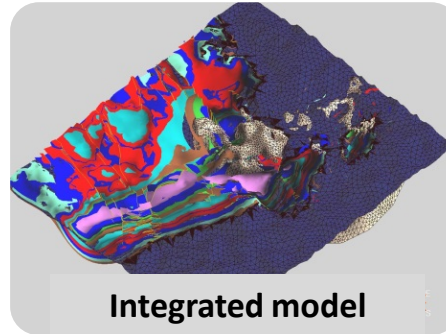
Terrain



Geophysical data



Integrated model



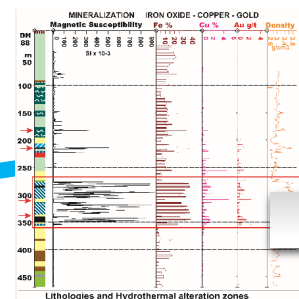
Ore body section



(Park, 2015)

Very large data sets allow application of machine learning methodologies

Geochem, assays, logs



Opportunity Space for CASERM

Workforce Crisis in the Extractive Industries

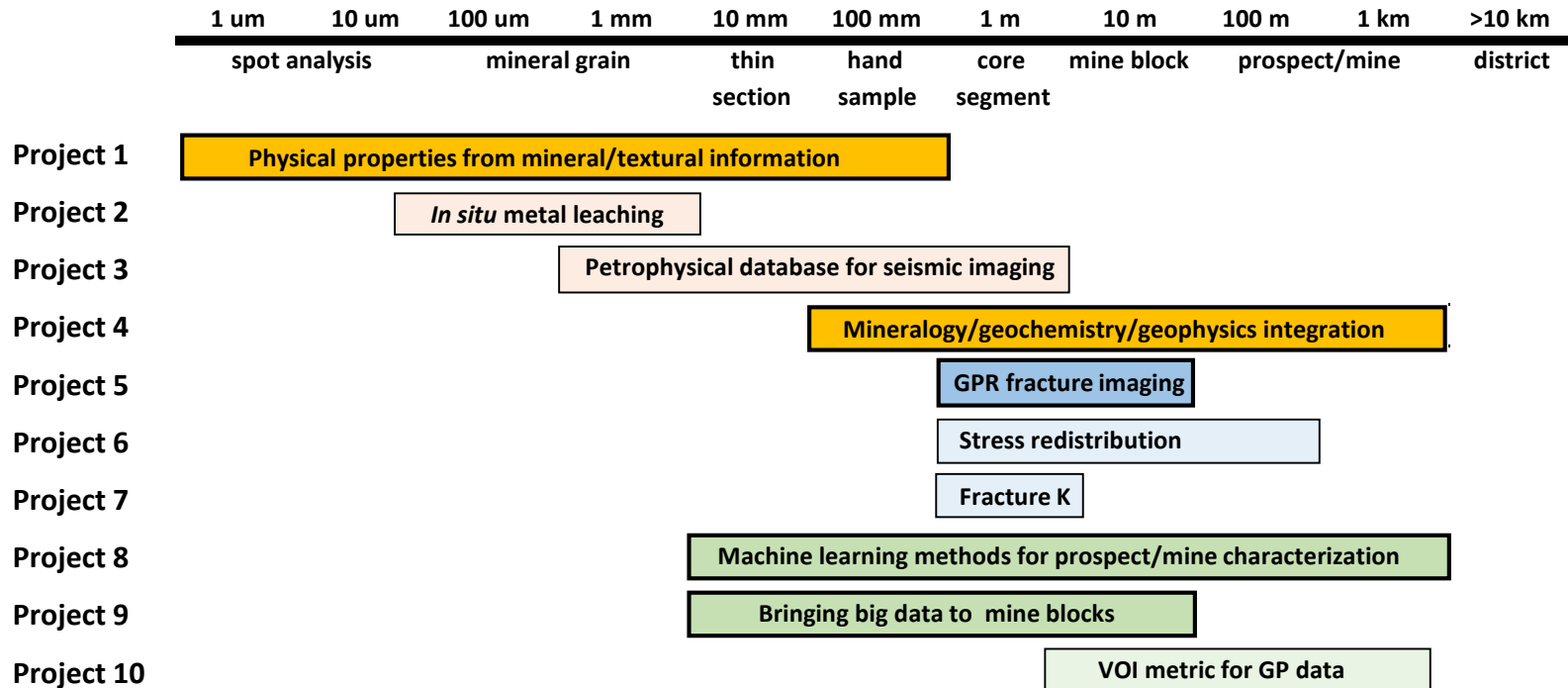
- Demand - 11,000-13,000 jobs/year for next 20 years based on retirements and increased demand for resources – vastly exceeds supply (Brandon 2012).
- Current workforce is 7 years older than US workforce average, with 50% of current workforce being retired by 2029 (NRC, 2013).
- Academic institutions aren't providing needed trained professionals:
 - 25-year trends in Mining Engineering (NRC, 2013)
 - Loss of 50% of mining faculty
 - Accredited mining engineering programs have decreased from 25 to 14
 - Only 1/3 of needed mining engineers graduate/year
 - 150 graduate students in economic geology in 2006 with <40 graduating/year (half the number required) (Hitzman, 2009)

Economic Geoscience Research Funding Limits Graduate Programs

- Support for economic geology research and academic programs is limited.
- Most research is company-sponsored, highly applied, limited in time and scope, over-headed.
- Dedicated federal funding not available.

Current Technical Scope

Scales of Investigations



Optimizing integration of mineralogy, petrophysics, geochemistry, & geophysics data



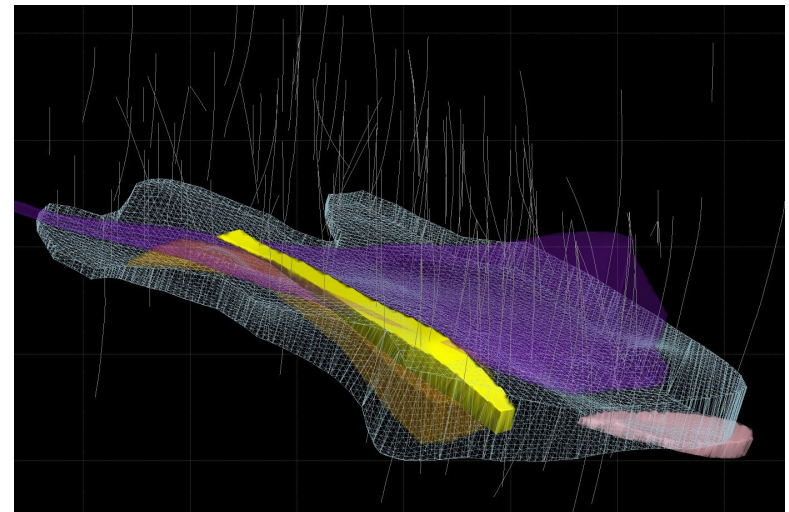
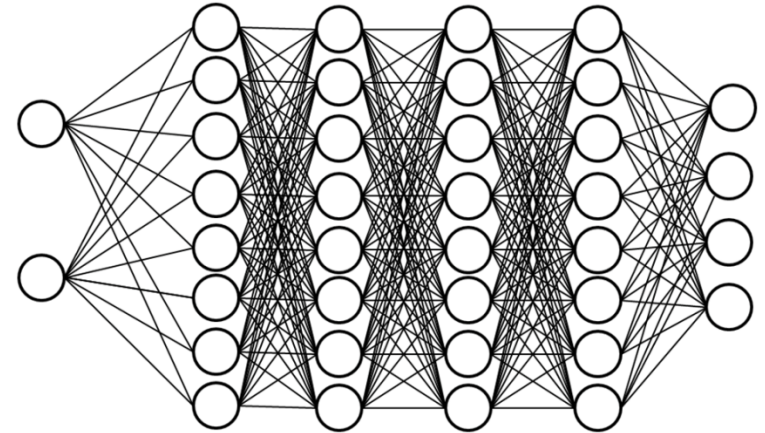
Enhancing understanding of fractured rock environments



Developing innovative methods for using large data sets in exploration and mining

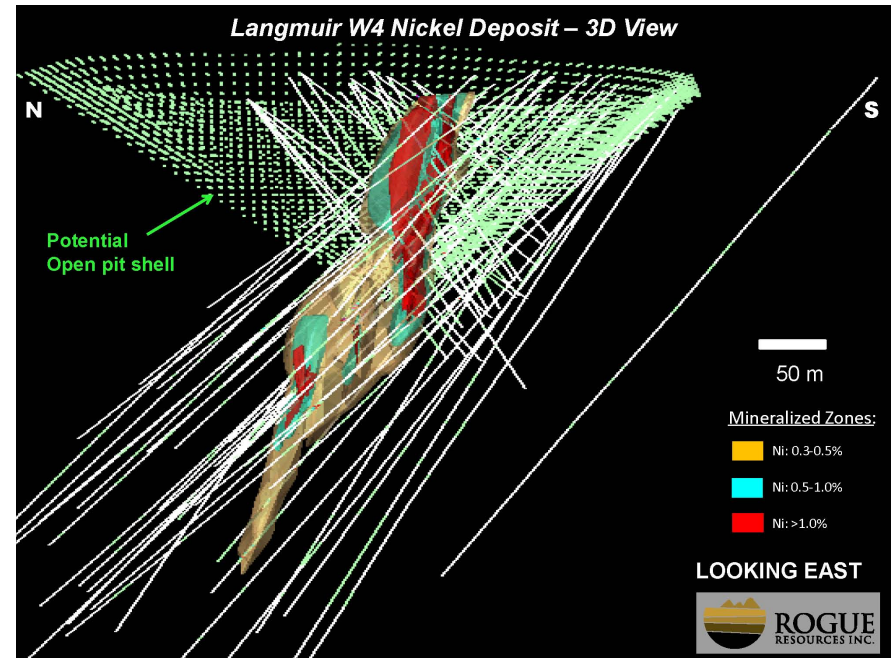
Machine Learning in Resource Modeling and Mine Planning

- Goal is to develop geologically informed lofting, to radically improve the orebody delineation, reserves and mineability thereby, significantly increase the economic return of discoveries.
- Multidisciplinary research team includes faculty with expertise in geophysics, geology, applied statistics, and computer science



Research Method

- Make full use of multiple data sets associated with Au-Ag deposit* as training sets and validation sets for supervised machine learning (ML)
- Use supervised ML and deep learning algorithms to construct orebody in 3D
- **In progress:** develop data format for ML unsupervised algorithm; 2D and 3D distributions of monetary value of mine blocks

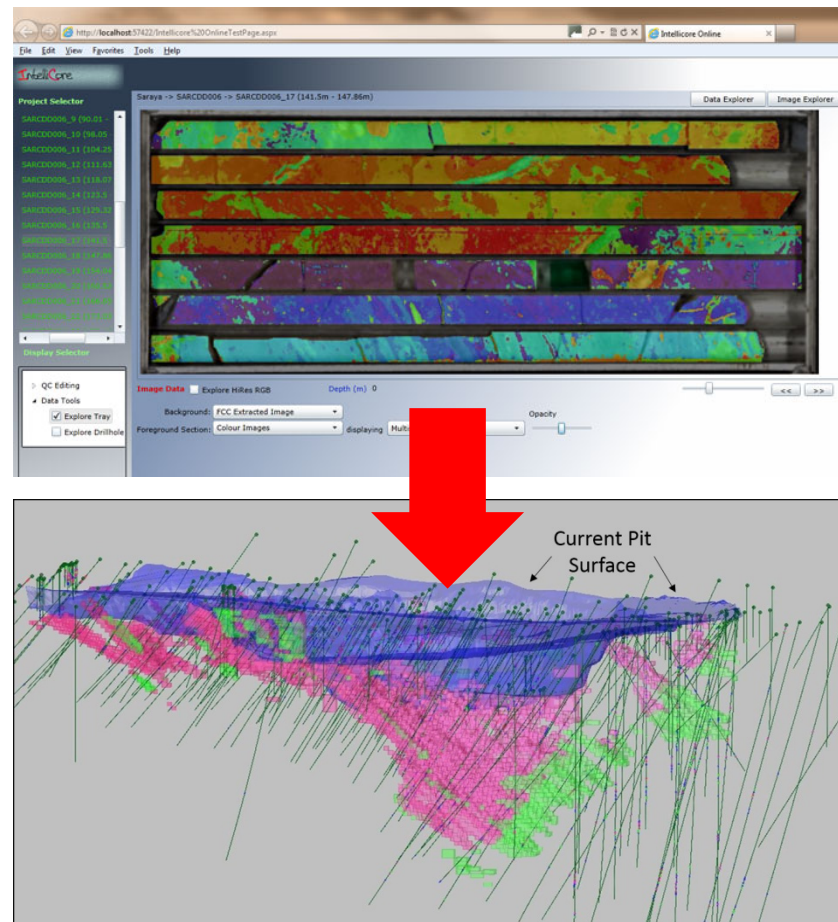


Example: 3D model of White Mountain gold deposit (Eldorado Gold)

**Eskay Creek, Skeena Resources, Center Member*

Increasing the Value of Hyperspectral Data

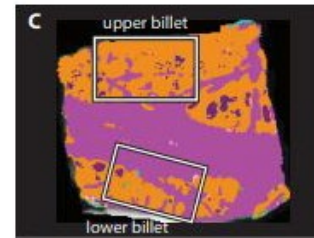
- Goal is to use hyperspectral core scanning data and supervised machine learning to determine quantitative mineralogy of core and predict rock physical and mechanical properties
- Define monetary value of each mine block integrating metal value, energy, and environmental costs
- Multidisciplinary research team includes faculty with expertise in quantitative mineral analysis, geology, applied statistics, and computer science.



Research Method

- Use ML to establish relationships between hyperspectral data and quantitative mineralogy data using training sets.
- Upscale to drill core producing continuous downhole mineral modes.
- Use hyperspectral-derived mineral data to predict rock physical and mechanical properties and to build corresponding 3-D block models.
- **In progress:** training data set prepared, algorithm selection underway.

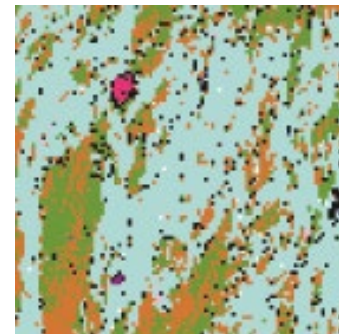
Hyperspectral data identify the spectrally dominant mineral(s) in each pixel (pixel size: 500 x 500 μm).



chlorite
+
white
mica

5 cm

SEM-based Quantitative Automated Mineralogy (pixel size: 5 x 5 μm)



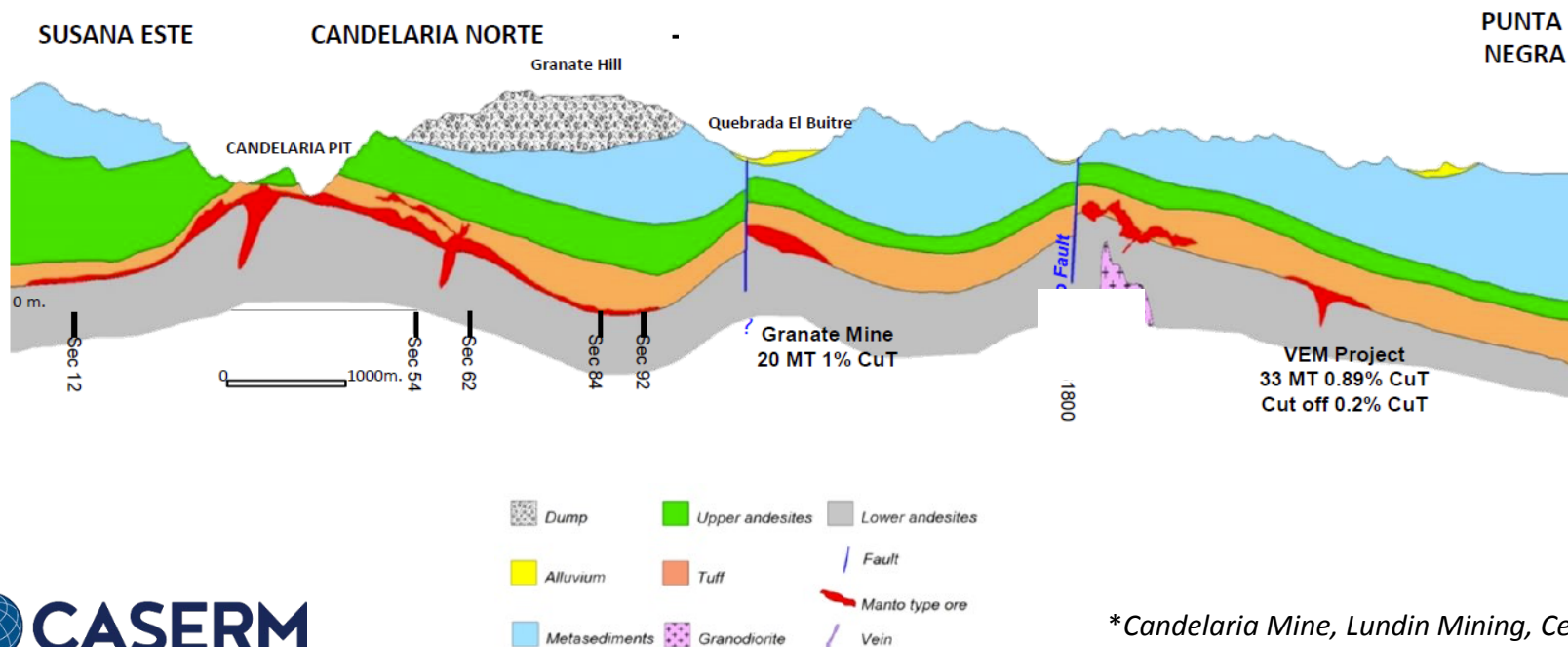
Muscovite
Biotite
Chlorite
Monazite

500 μm

Graham et al., 2018.

Distal signatures and vectors of hydrothermal systems in carbonates

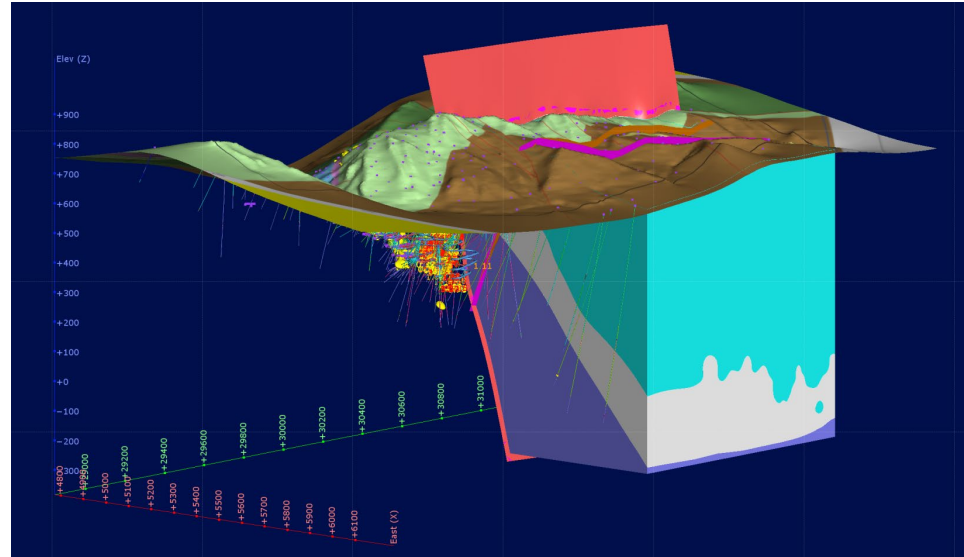
- Goal is to find distal signatures of and vectors towards hydrothermal ores in carbonate host rocks.
- Multidisciplinary research team includes faculty with expertise in statistics, field geology, geochemistry and industry collaboration*



*Candelaria Mine, Lundin Mining, Center Member

Research Method

- Develop statistical spatial trend searching methods to get vectors.
- Apply methods to a known data set
- Assess whether ML appropriate tool to get pattern recognition with a data set from multiple deposits.
- **In progress:** data set is not sufficient for universally applicable methodology, additional data collection in progress. Statistical trends being compared with manual observations.



Challenges for Mineral Resources

Increasing mineral exploration success rate and decreasing development time and costs requires a long-term vision and sustained investment in innovative research:

- a well-defined subsurface problem suited for ML approaches
- interdisciplinary team approaches required

Data availability and quality:

- minimal industry-wide sharing and limited open source
- spatial resolution and distribution
- acquisition is costly and slow
- appropriate, meaningful, accurate
- structured vs. unstructured

Deliverables:

- visualization and interrogation of product
- rapid updates of training sets and predictions
- industry requirement for fast deliverables requires rethinking of how we do research in academia

Additional Information

Web site: <https://caserm.mines.edu/>

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