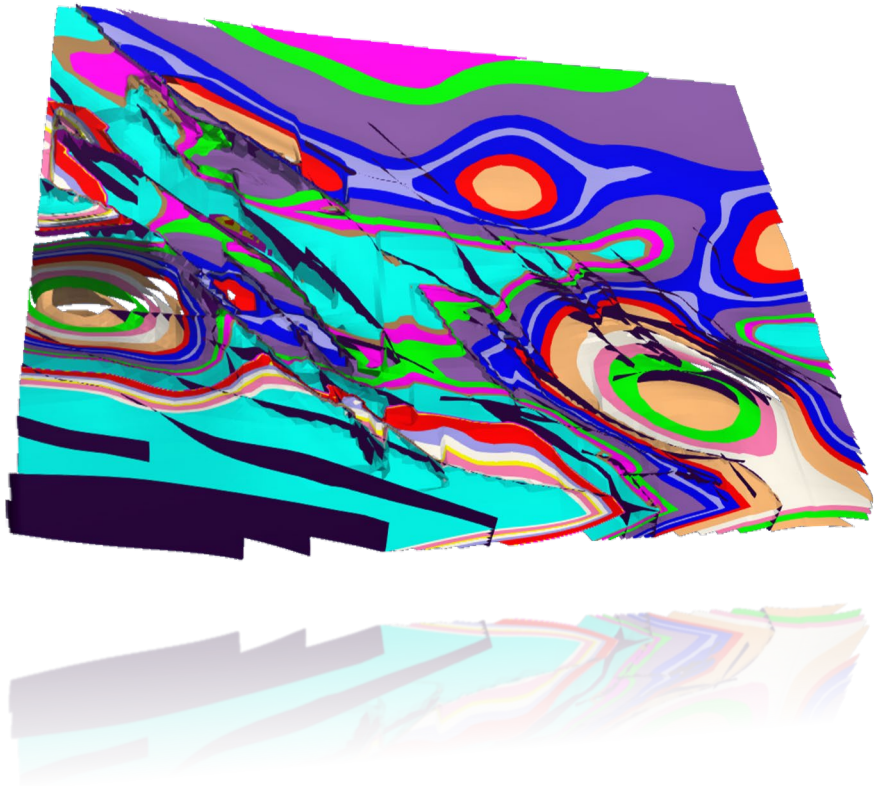
3D Geological Modelling
Use cases

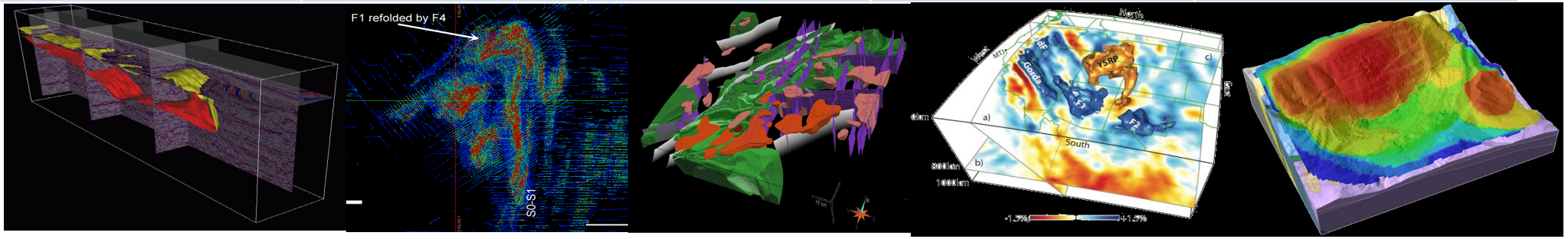
Major 3D modelling scenarios

- Engineering
- Waste storage
- Hazards
- Oil & Gas
- Understanding fundamental processes
- Mineral Resources



3D geomodelling scenarios

	Sedimentary Basins	Mines	Regional	Lithosphere	Engineering
3D Constraints	**RICH** (3D seismic, deep boreholes, gravity)	**RICH** (dense boreholes, magnetics, seismic, electromagnetics)	**POOR** (rare boreholes, surface outcrops, gravity, magnetics)	**RICH** (Teleseismic, seismic, gravity, MT)	**Rich** (GPR, drillholes)
Structural Complexity	**SIMPLE(R)**	**COMPLEX**	**COMPLEX**	**SIMPLE(R)**	**SIMPLE(R)**
Dedicated Software	Gocad 1989, Geomodeller 1999…	MicroMine 1986, Leapfrog 2003...	Noddy 1981, Gocad-Sparse 1995, Geomodeller 1999, GemPy 2019, LoopStructural 2020	Gocad 1989	Dassault Systèmes



Why study 3D Geology?

- **Structural support**: buildings, tunnels, bridges, dams, urban geology

So we need to be able to model mechanical properties (bulk strength, shear strength

But also permeability

wikipedia

INTERESTING ENGINEERING

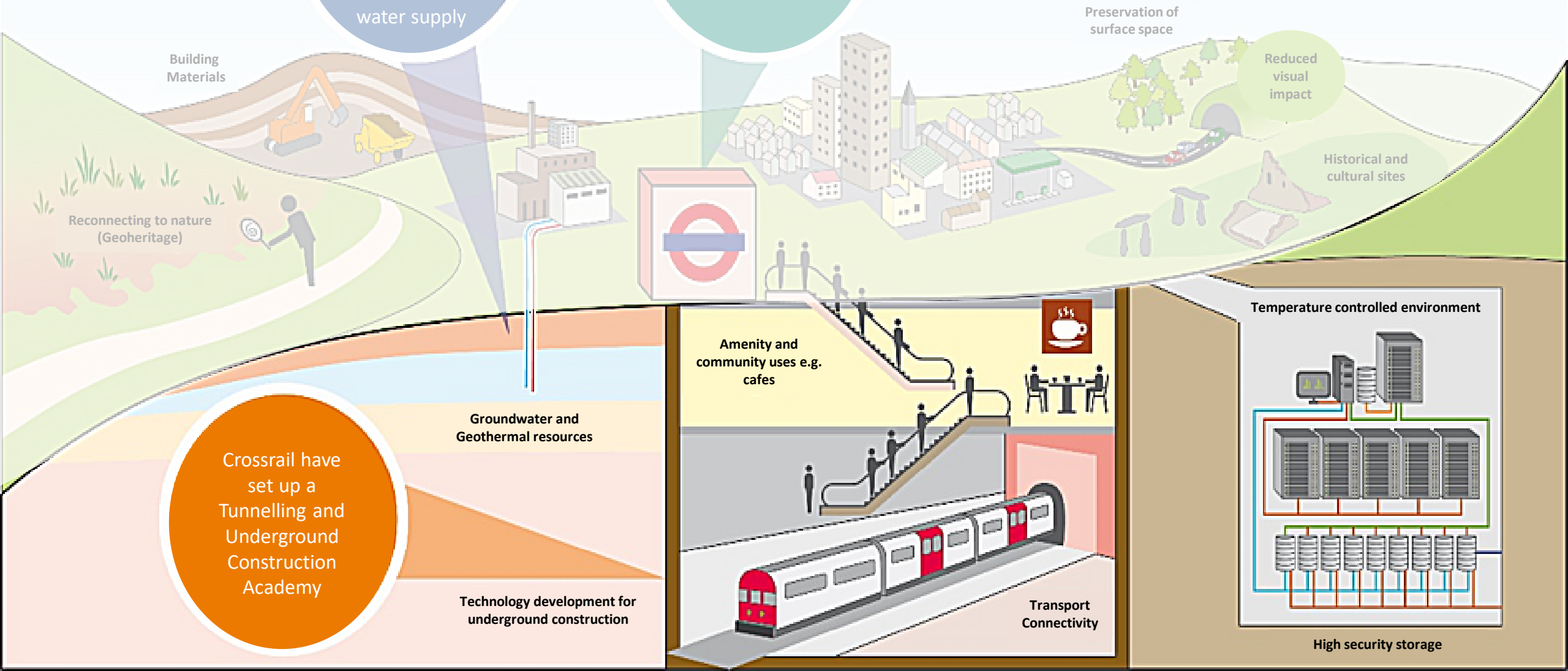
3D Urban Geology

Groundwater from the rocks beneath London and the Thames Valley supports 30% of the water supply

There are 11 underground lines connecting 270 stations across London

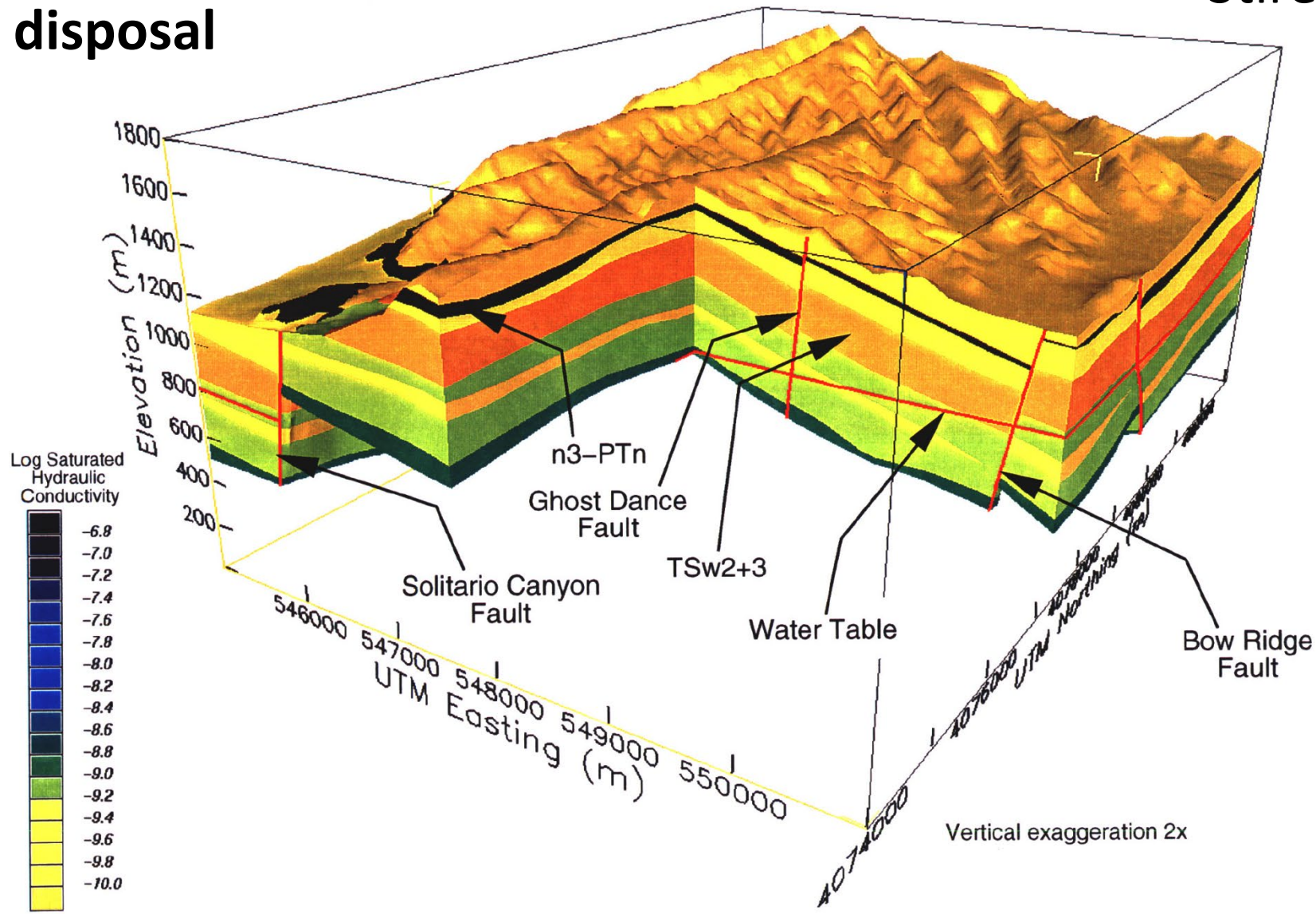
So we need to be able to model mechanical properties (bulk strength, shear strength

But also permeability



Waste disposal

Stirewalt and Henderson, 1995



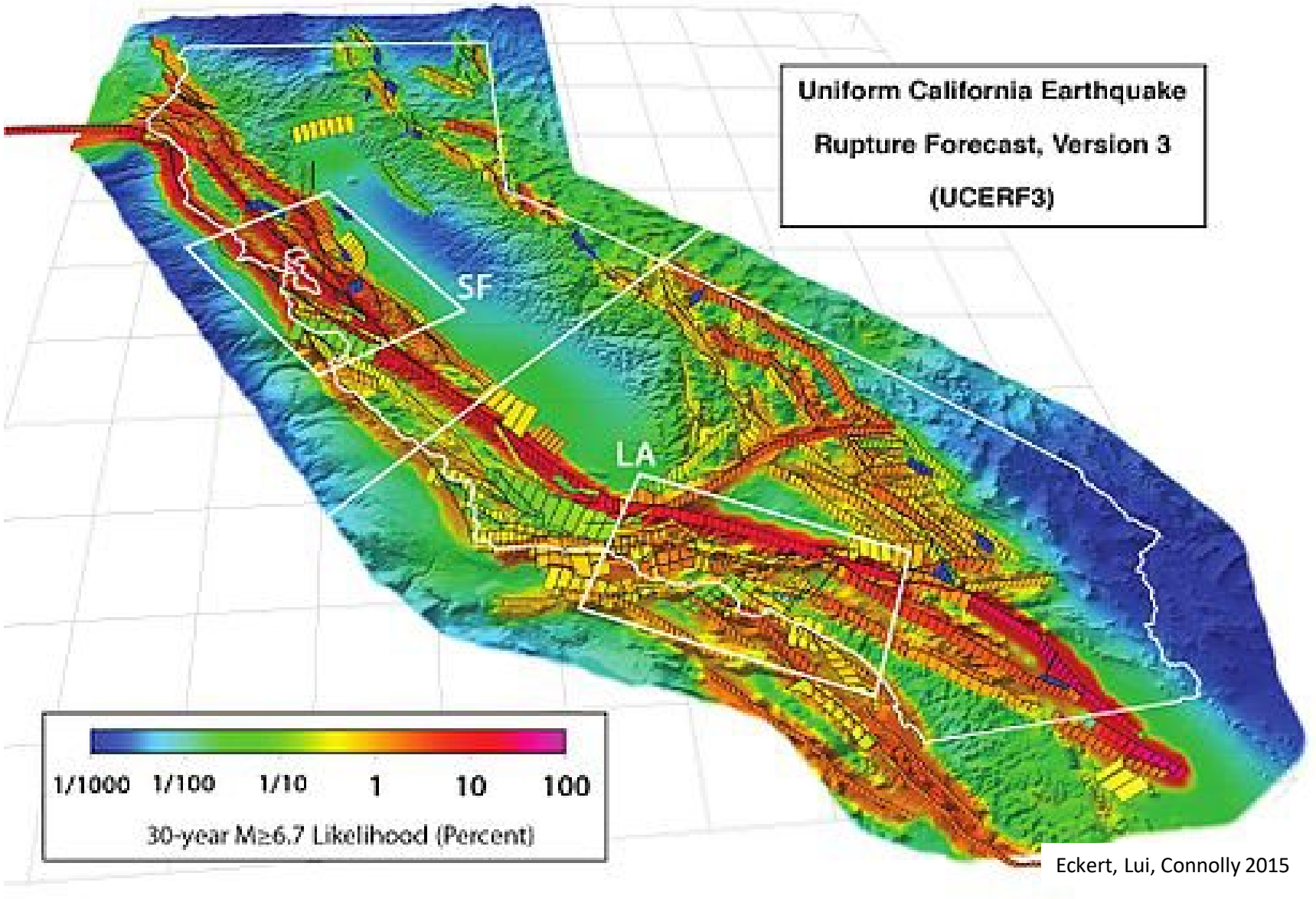
So we need to be able to model mechanical properties (bulk strength, shear strength

But also permeability

G. Stirewalt and B. Henderson, 1995, A Three-dimensional Geological Framework Model for Yucca Mountain, Nevada, with Hydrologic Application: Report to Accompany 1995 Model Transfer to the Nuclear Regulatory Commission

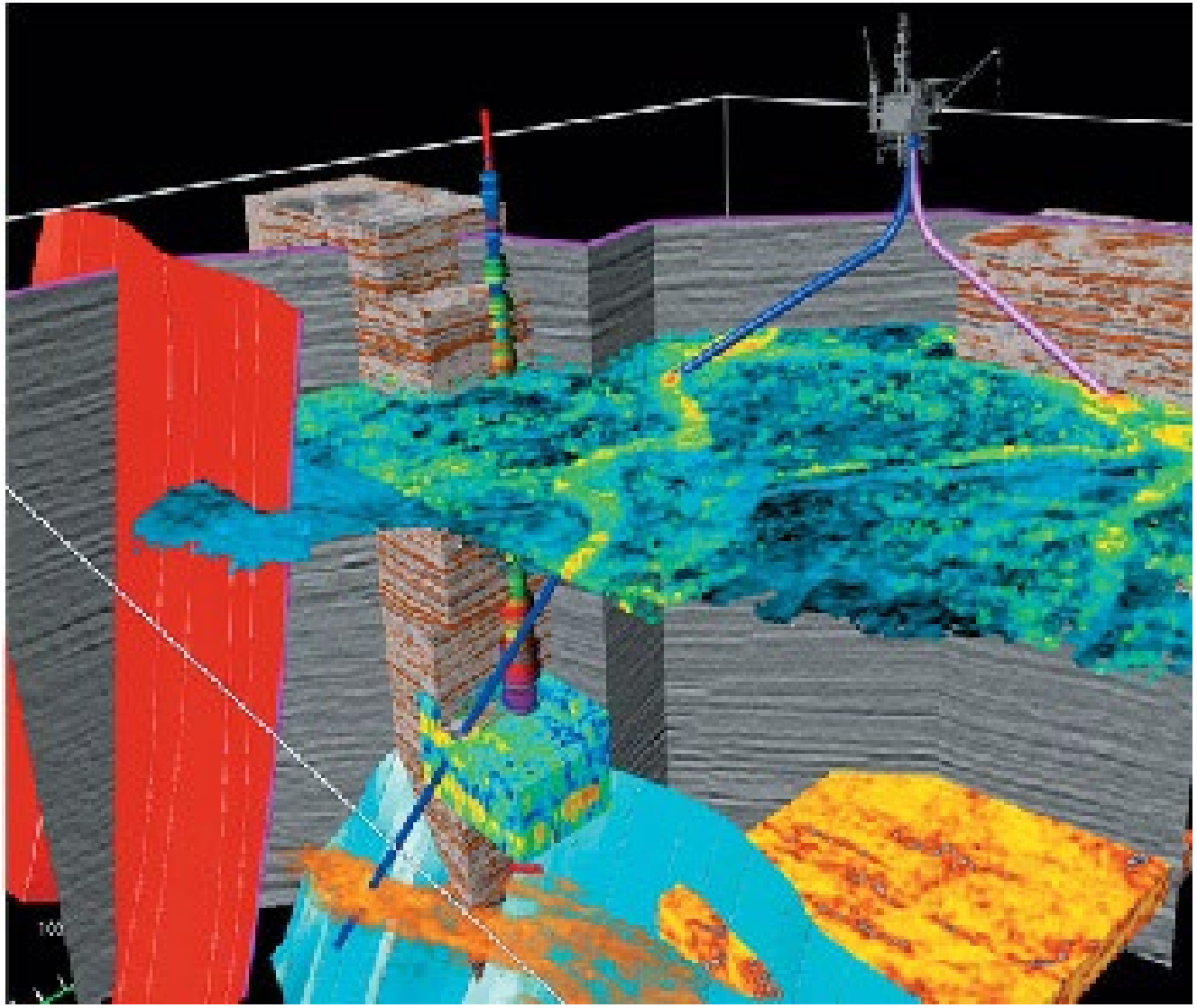
Why study 3D Geology?

- **Hazard**: earthquakes, volcanoes, landslides



Eckert, Lui, Connolly 2015

Sedimentary Basins



So we need to be able to model:

- Distributions of lithology, stratigraphy
- Mechanical properties: bulk strength, shear strength
- Density
- Porosity-Permeability in 4D
- Fault network
- Grain size

GeoEnergy

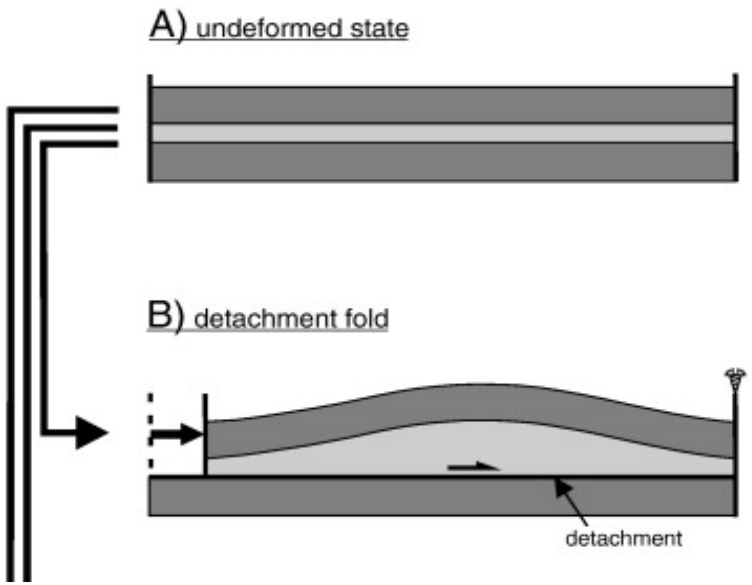
Science: geometry->kinematic->dynamic->processes

Assumed Process Model

x=17.5, y=140.0, z=-240.0

geometry

x=x-δx, y=y, z=z+sin(x)



kinematics

Brandes & Tanner 2014

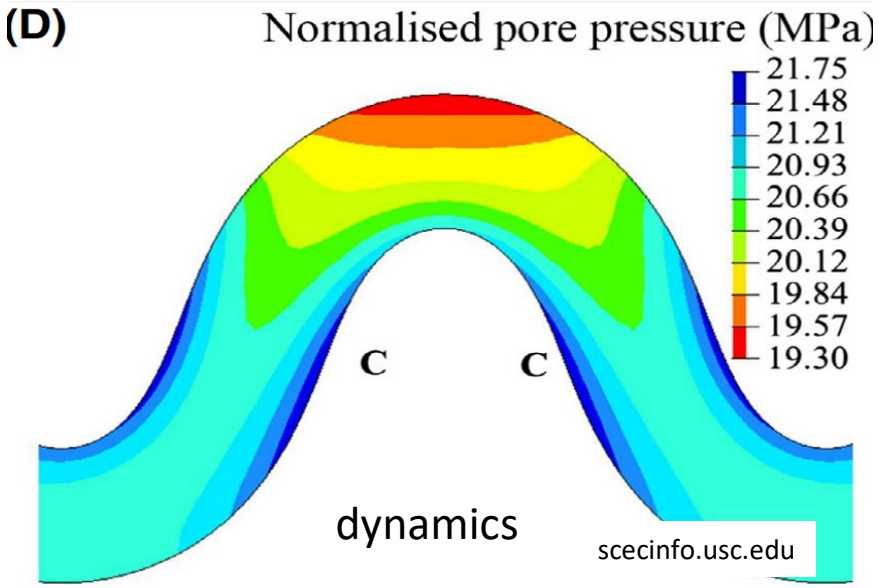
Equation connecting stress and strain

$$\varepsilon(t) = \frac{\sigma(t)}{E_{\text{inst,creep}}} + \int_0^t K(t-t')\dot{\sigma}(t')dt'$$

Diffusion equation for the pore pressure, P_P, is given by:

$$\frac{Kk_x}{\mu_f}\frac{\partial^2 P_p}{\partial x^2} + \frac{Kk_z}{\mu_f}\frac{\partial^2 P_p}{\partial z^2} - \frac{\partial P_p}{\partial t} + \dot{\sigma}^{iso} = 0,$$

$k_{x,z}$ represents the permeability components, μ_f the fluid (i.e. water) viscosity and K the bulk modulus



dynamics

scecinfo.usc.edu

Resource and exploration of mineral resources:

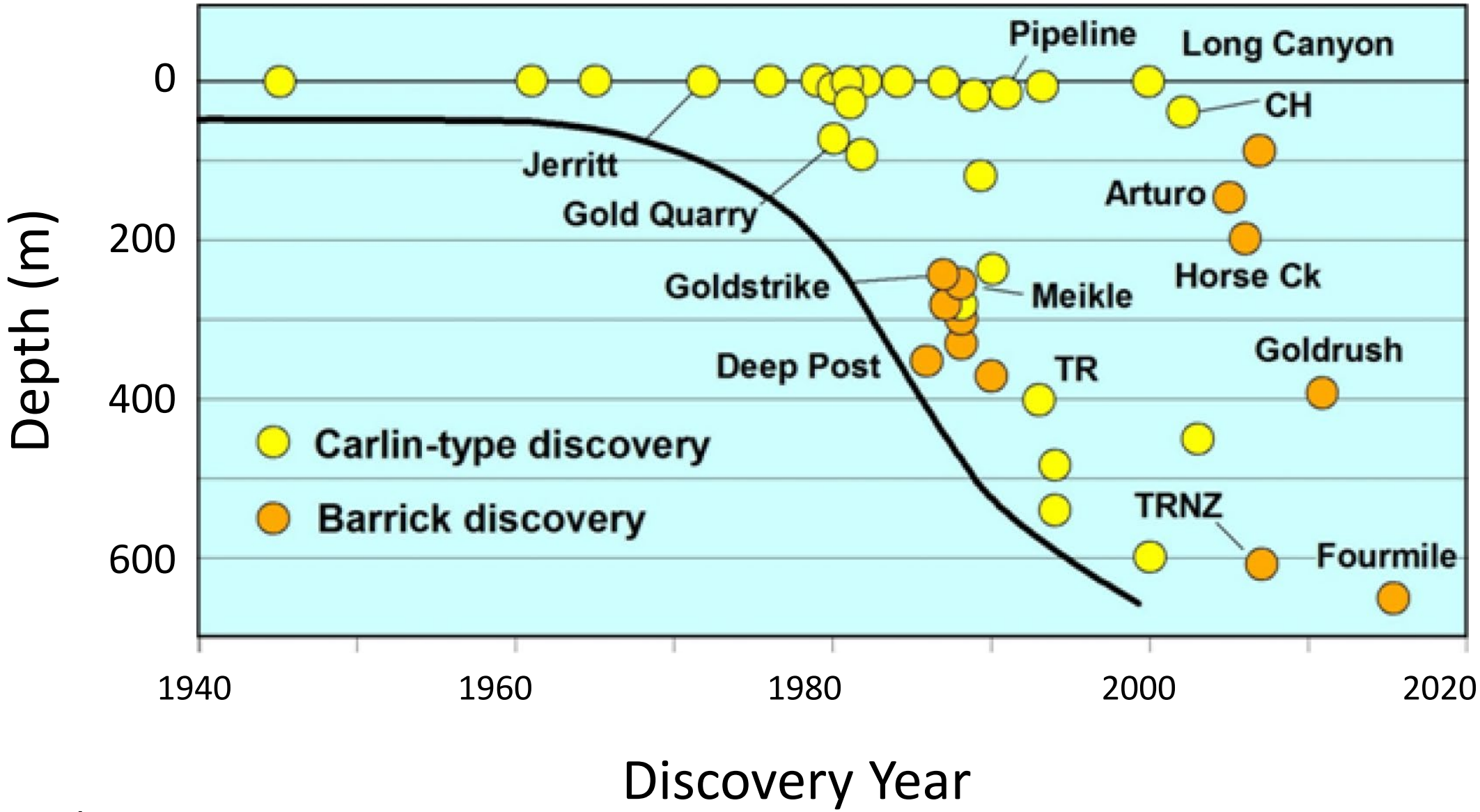
- **Rocks as resources** (Industrial, gold)

Structural vs functional materials

kitchenatquality.com.au

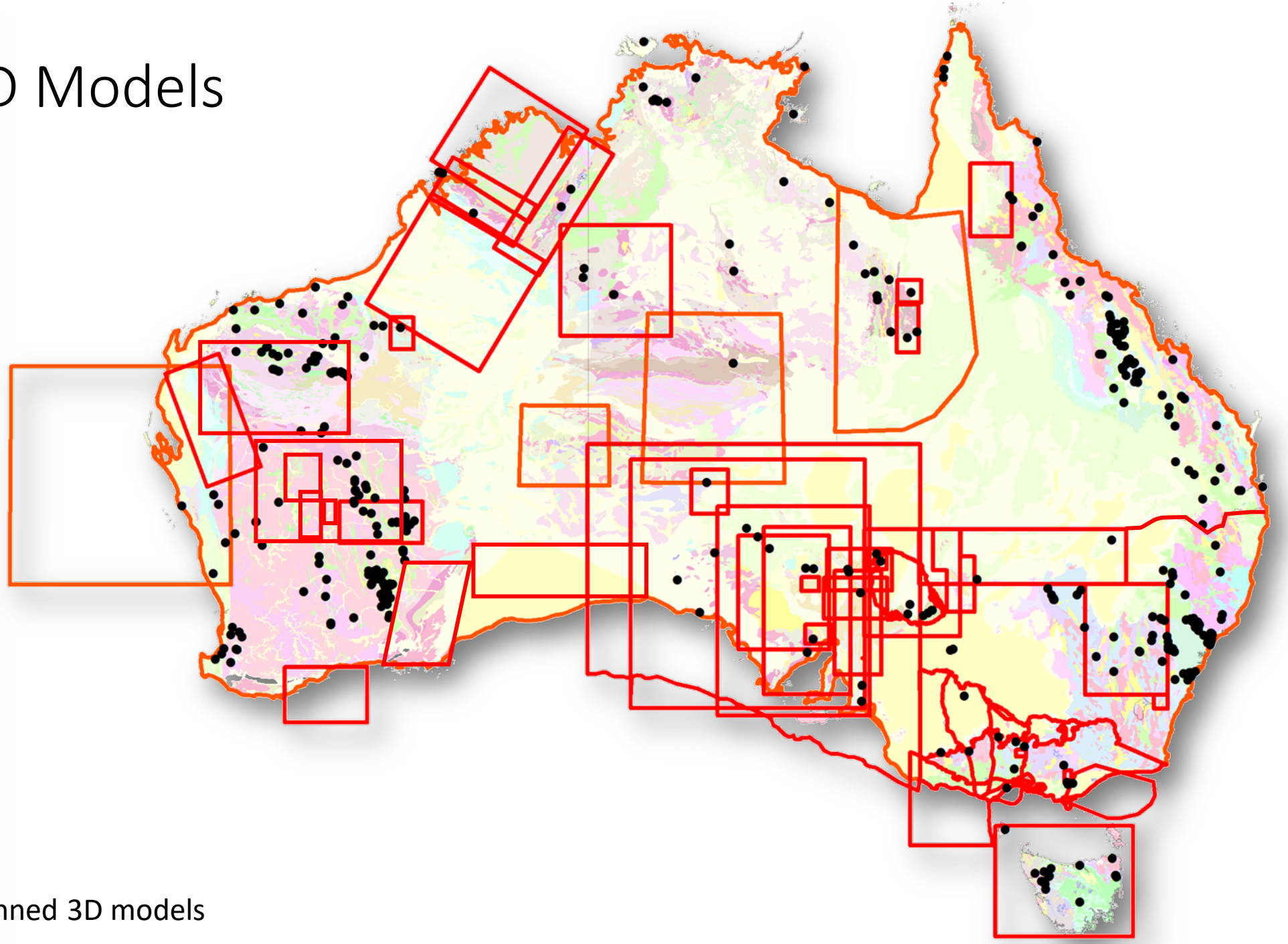
goldrushnuggets.com

Nevada Gold discoveries



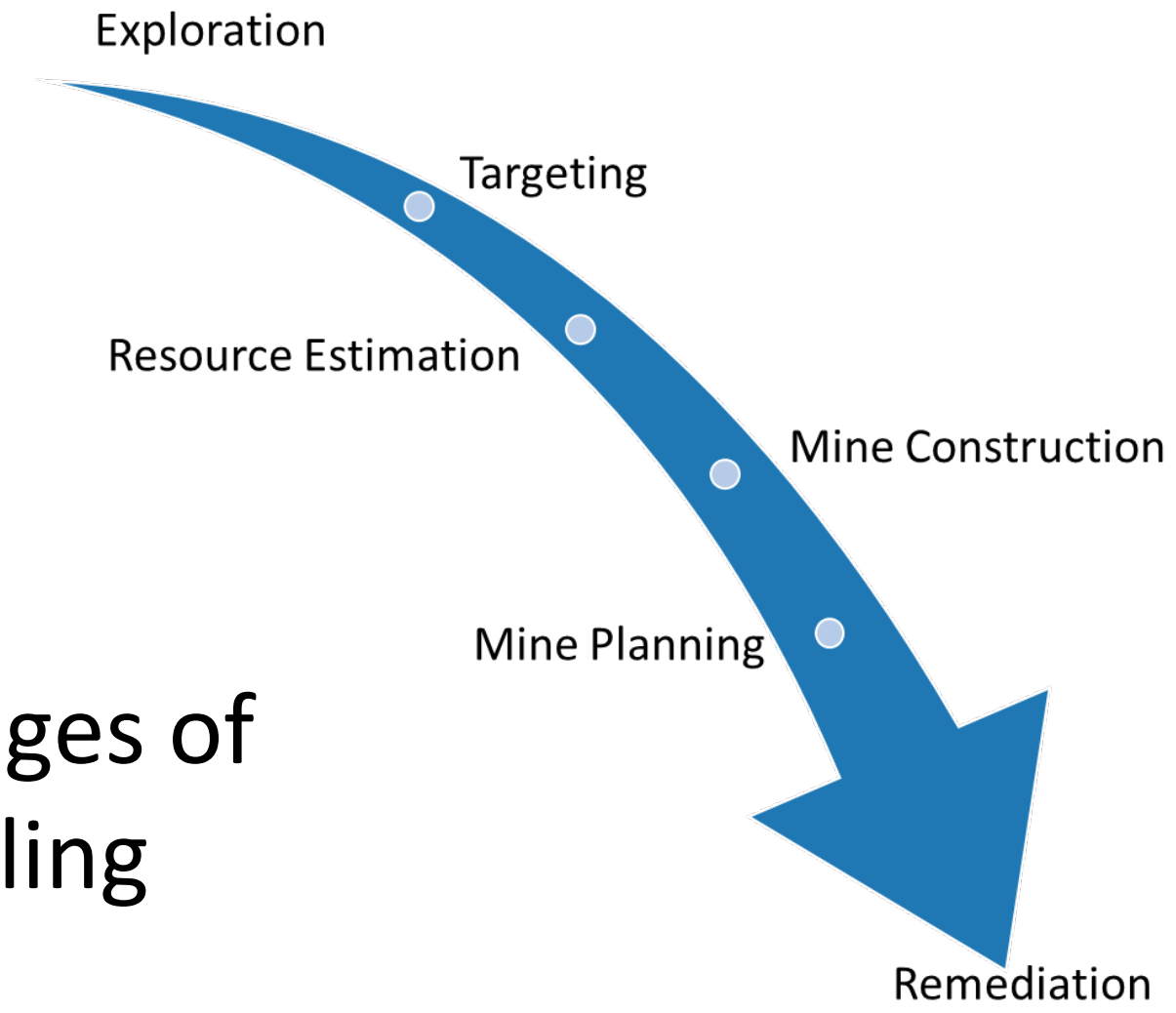
Source: Barrick

Onshore 3D Models of Australia



- Active Mines
- Existing or planned 3D models

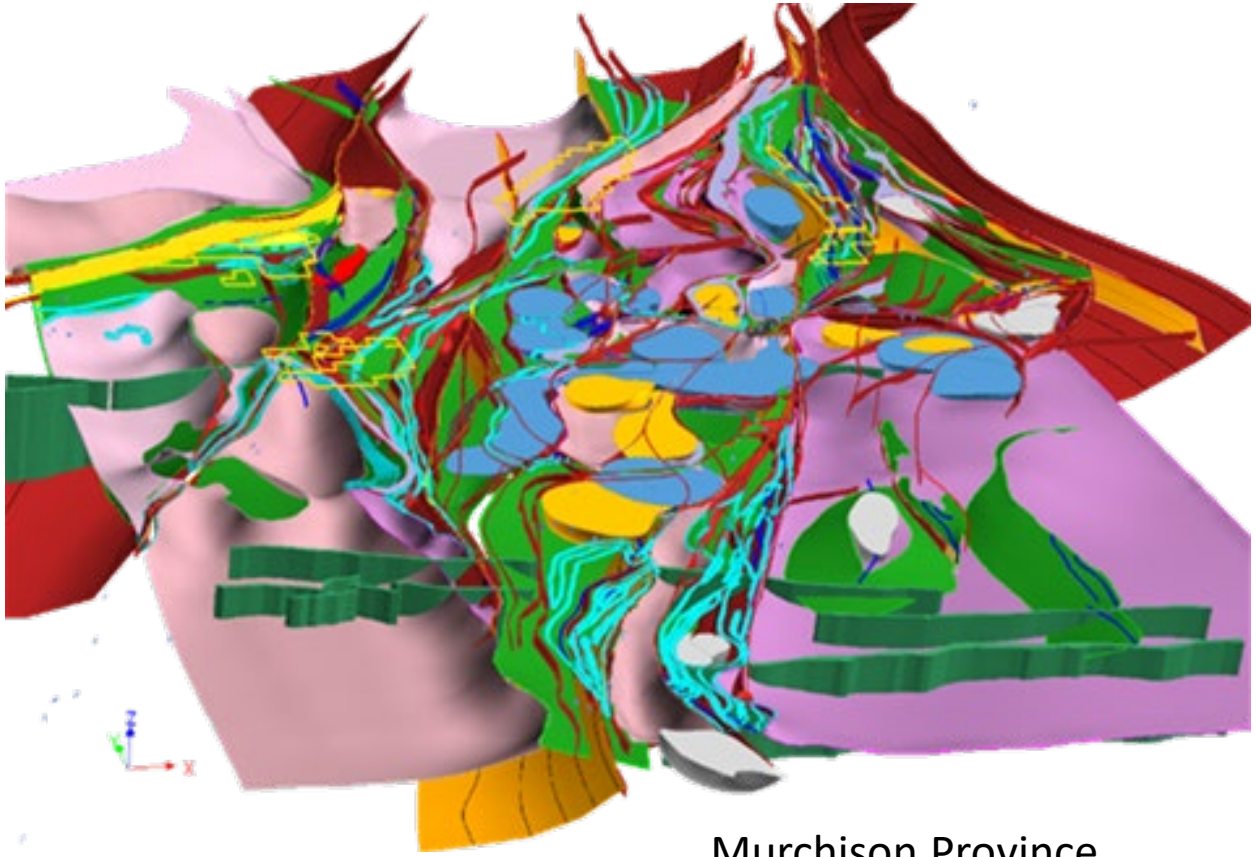
Different stages of 3D modelling



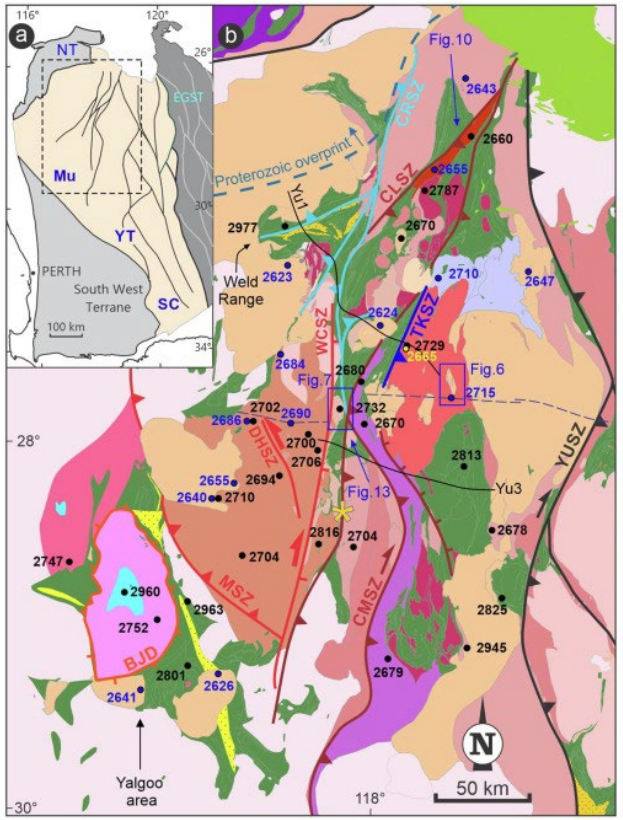
Regional Minerals Exploration

So we need to be able to model:

- Distributions of lithology and stratigraphy
- Alteration
- Petrophysics
- Permeability
- Fault network



Murchison Province

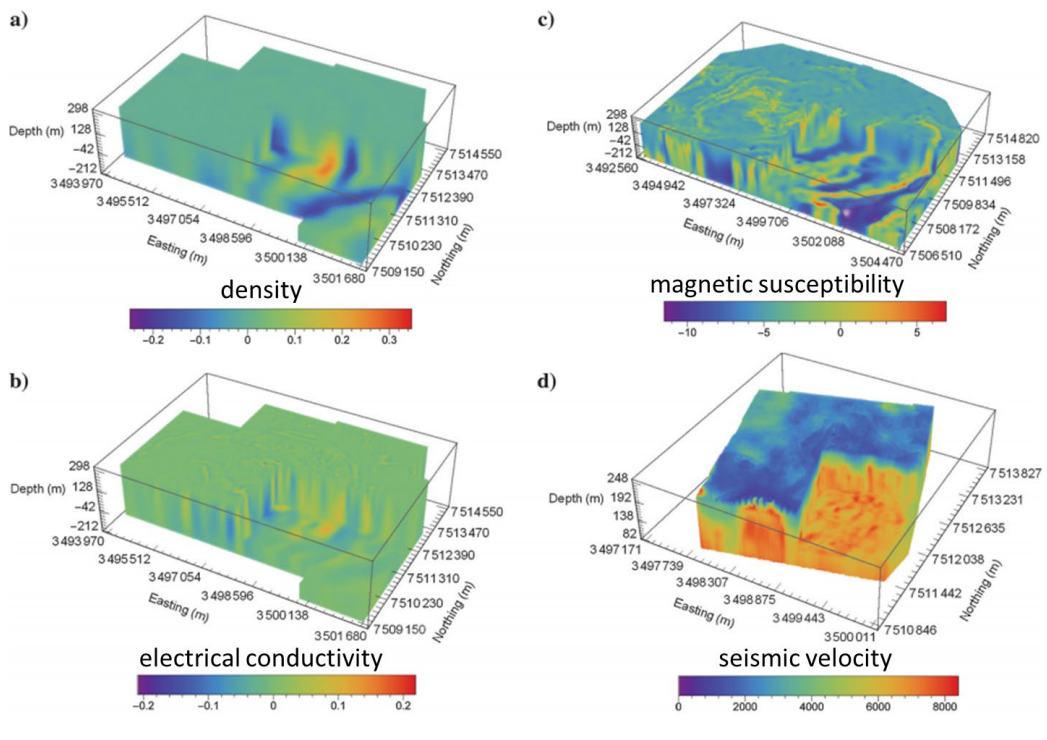


Zibra, 2020

modelearth.net.au

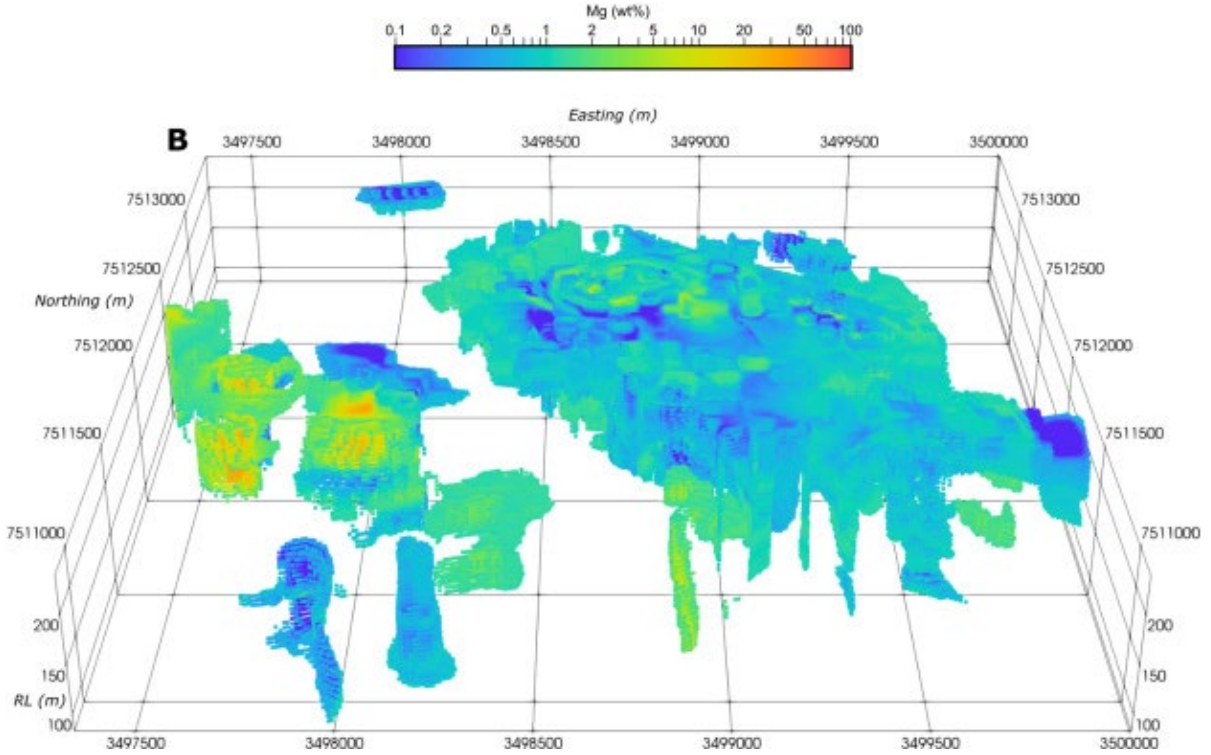
Mine Models – Petrophysics & Chemistry

Kevitsa Mine, Finland



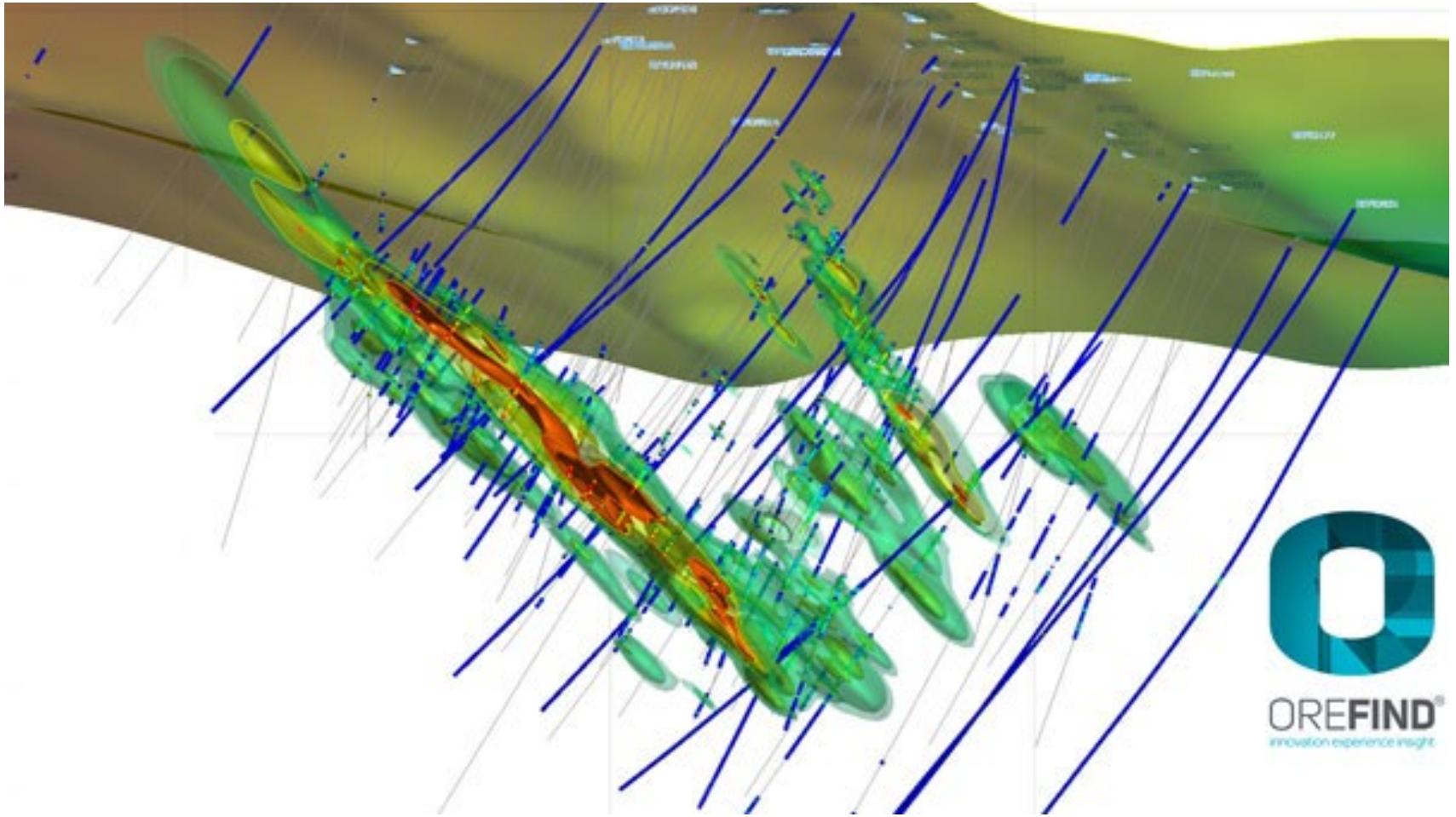
Horrocks et al., 2018

Mg content



Horrocks et al., 2021

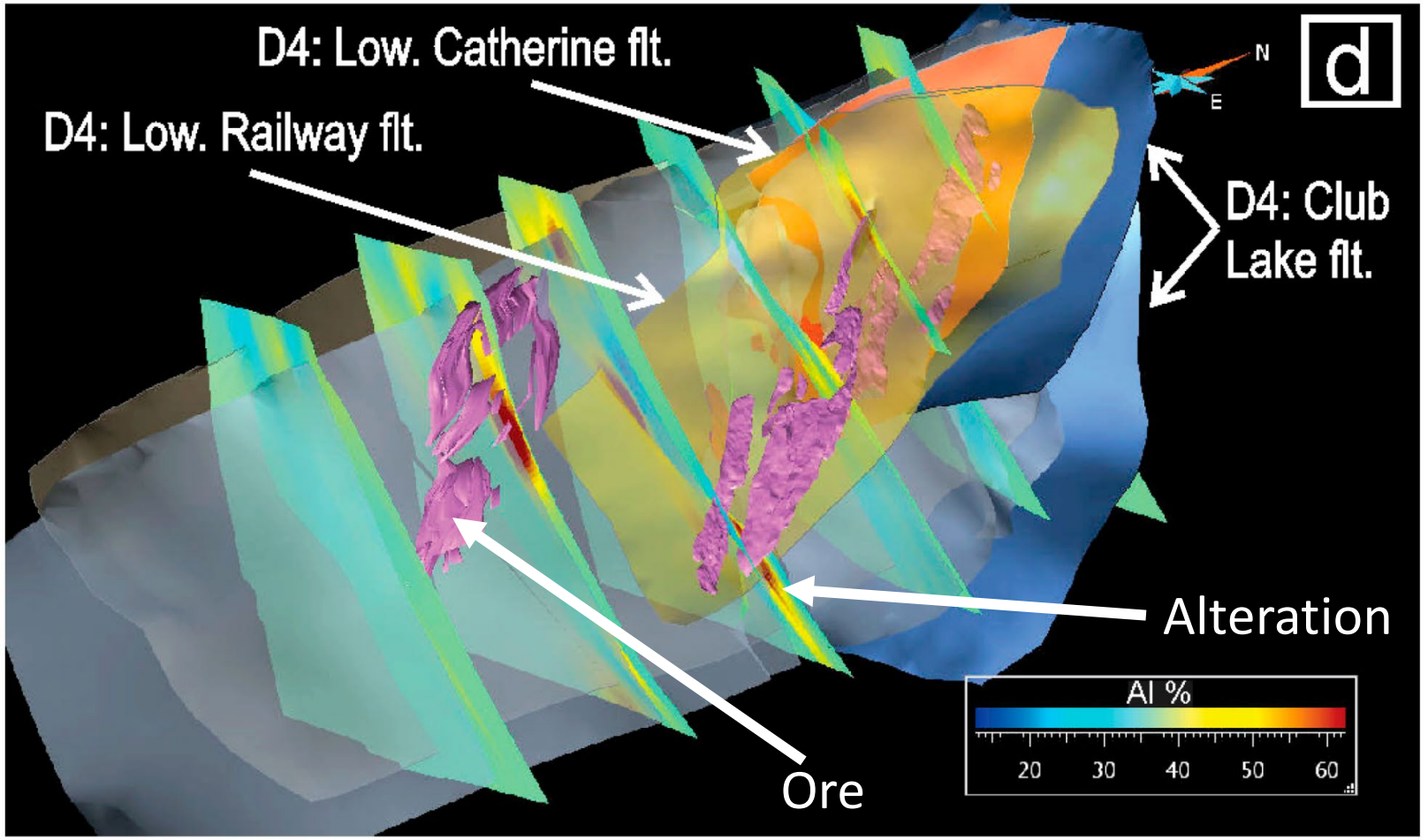
Mine Models - Ore Grade



- grade

J. Cowan

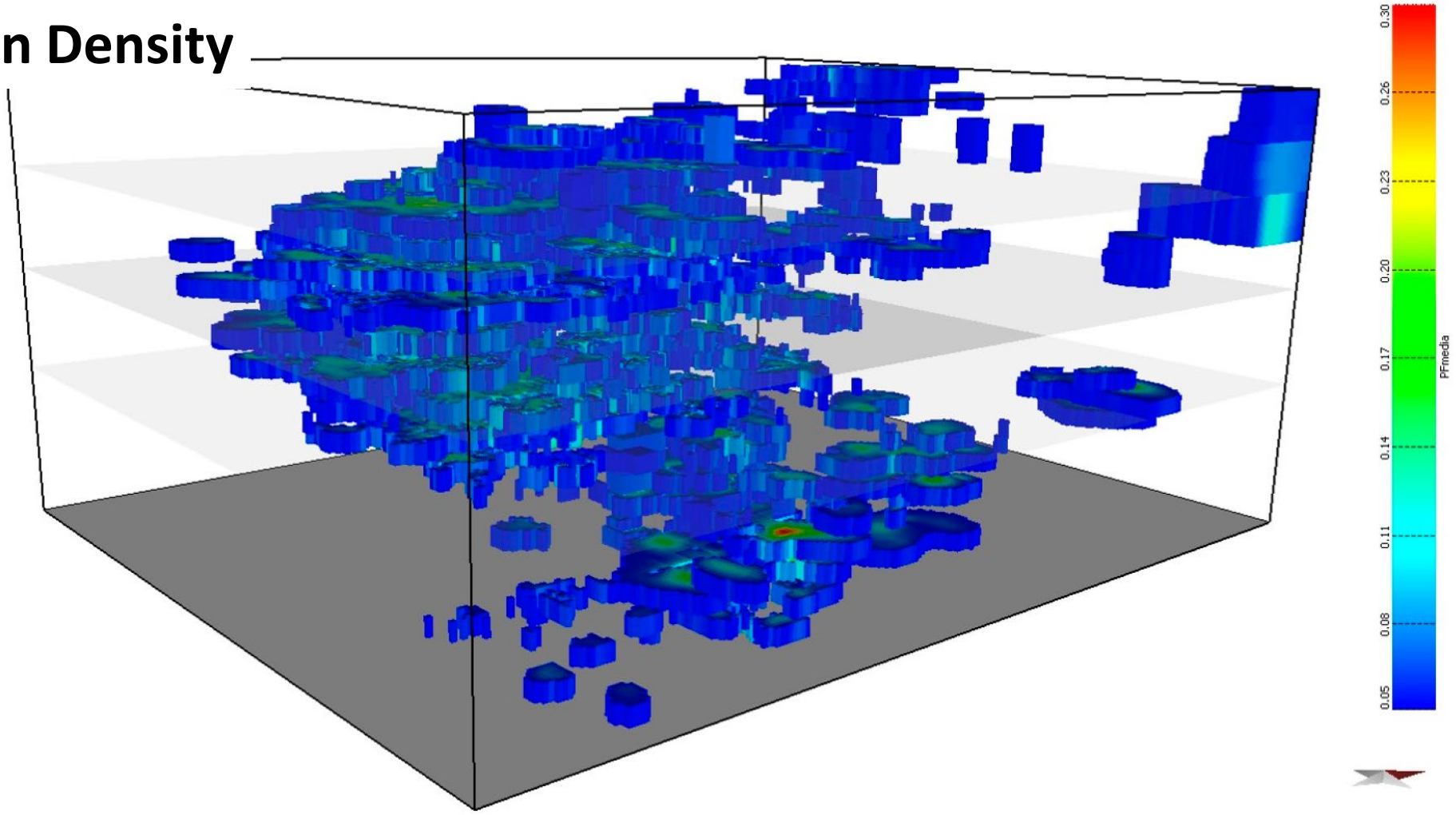
Mine Models
- Alteration



- Lithology
- Structure
- Ore
- Alteration

Schetselaar et al, 2017 Integrated 3D Geological Modeling to Gain Insight in the Effects of Hydrothermal Alteration on Post-Ore Deformation Style and Strain Localization in the Flin Flon Volcanogenic Massive Sulfide Ore System

Mine Models – Vein Density

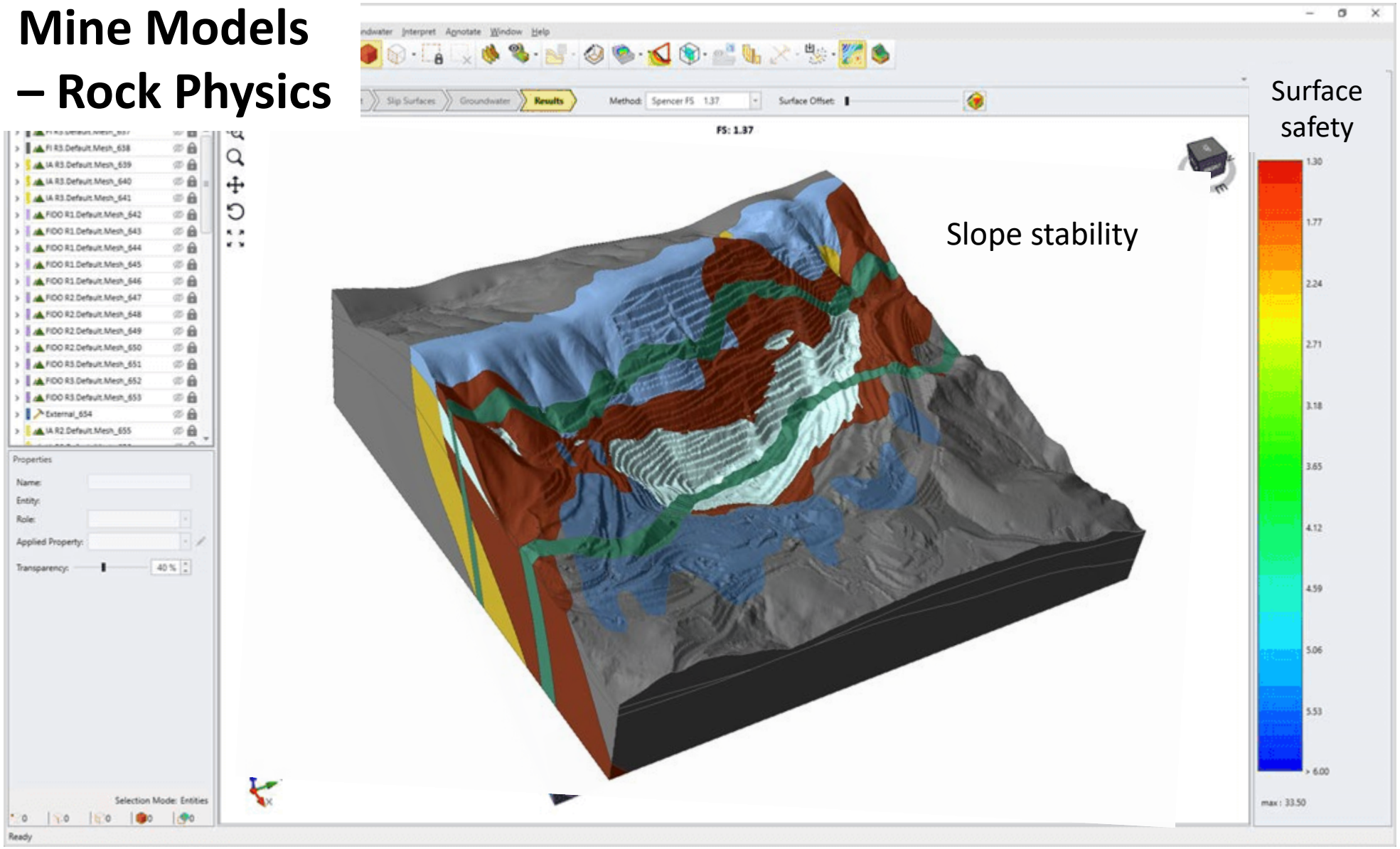


Vein proportion >5% vein

(a)

Sanches et al., 2017. A 3D Geological Model of a Vein Deposit Built by Aggregating Morphological and Mineral Grade Data

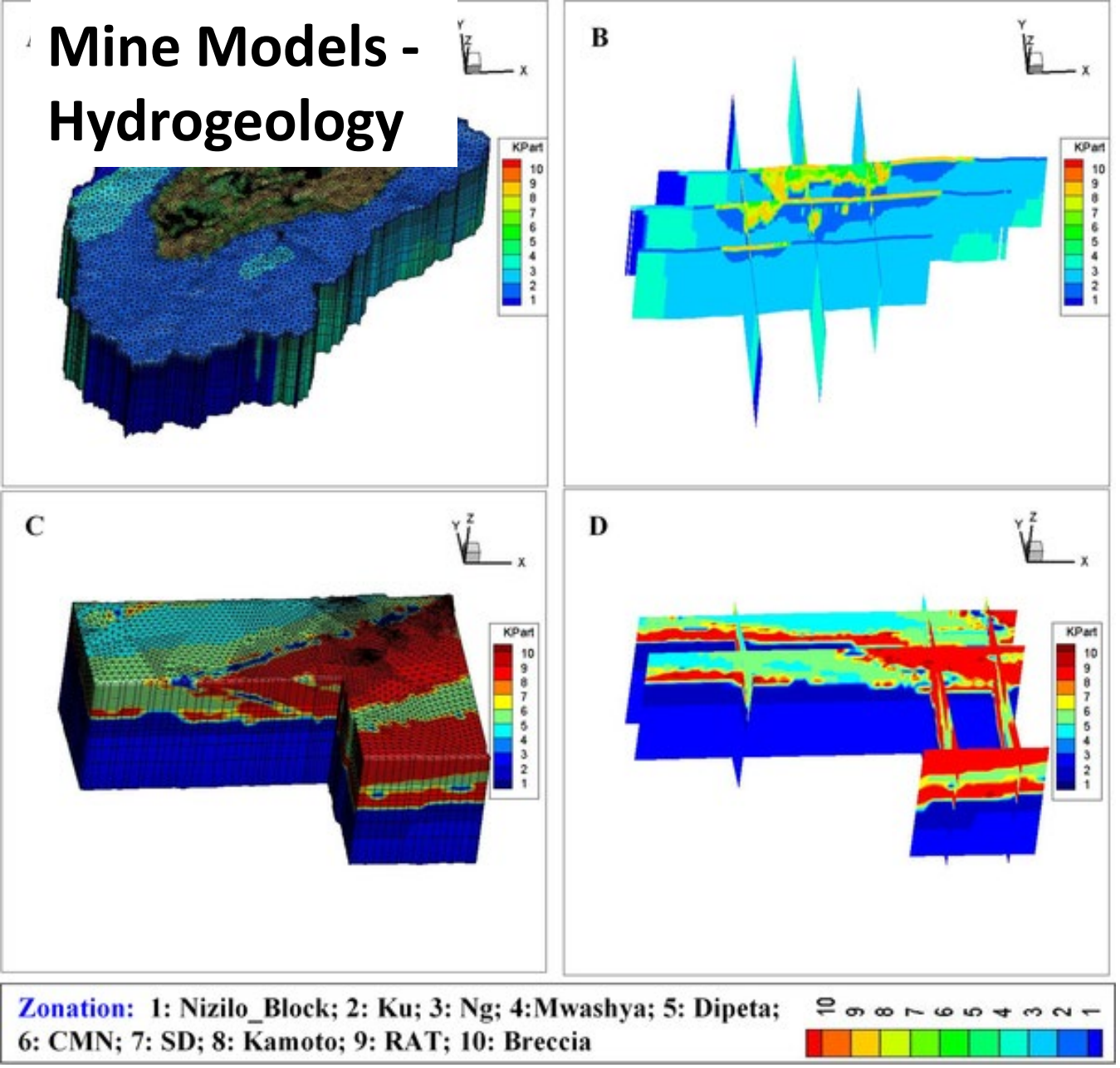
Mine Models – Rock Physics

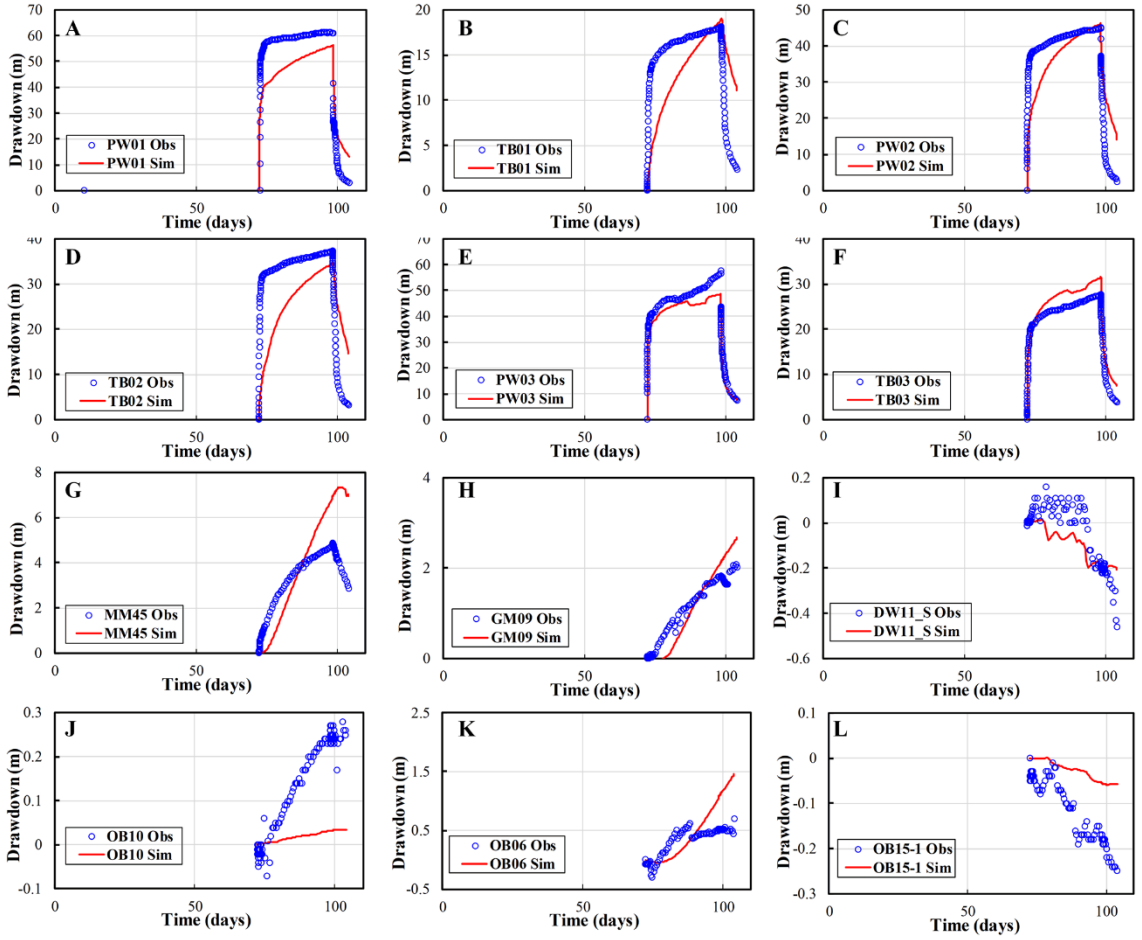


- Young's Modulus
- Shear Modulus
- Porosity/permeability
- Anisotropy

Bretas and Vilela. www.rocscience.com/

Mine Models - Hydrogeology



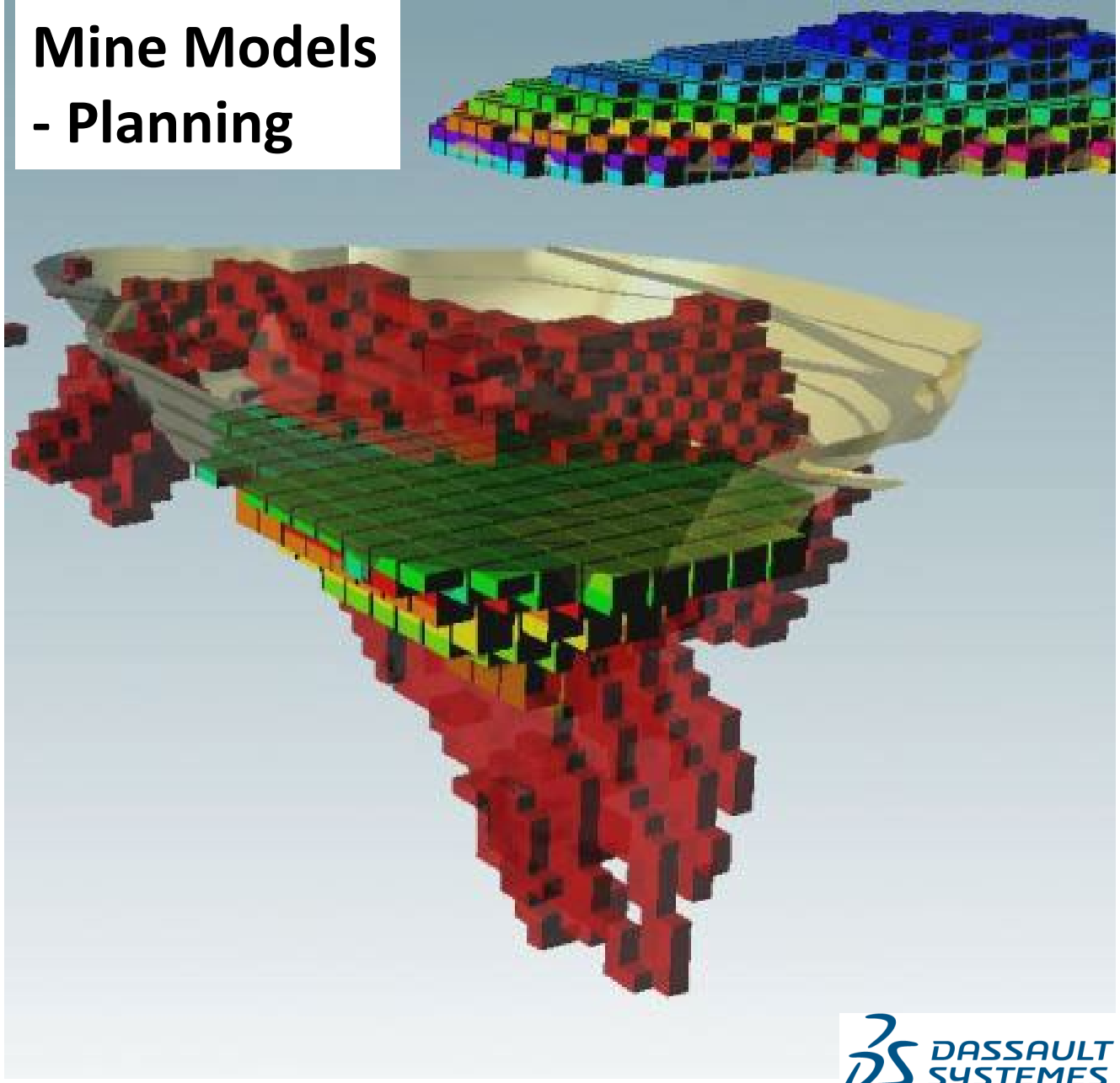


Comparison of simulated and observed drawdown in 12 observation wells

- Lithology
- Permeability
- porosity

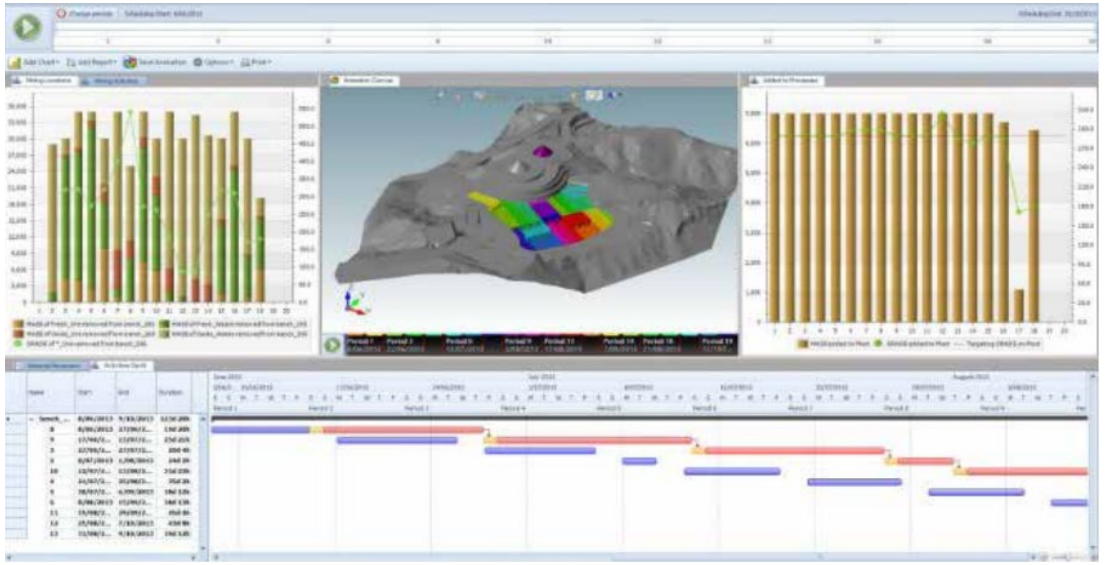
Hu et al. (2020) Estimating dewatering in an underground mine by using a 3D finite element model. PLOS ONE 15(10): e0239682.

Mine Models - Planning



Block models for mine scheduling

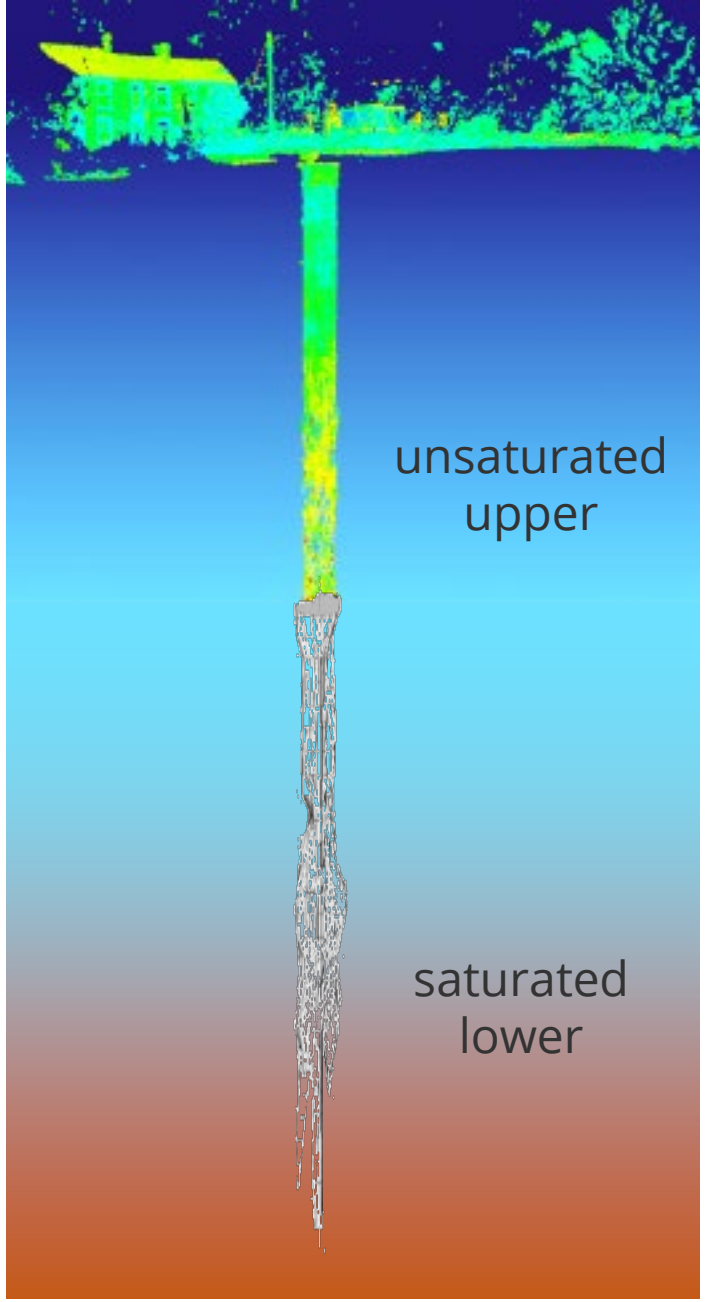
- Grade
- Geometallurgy
- Geomechanical
- Lithology



Coal Mine Shaft Remediation

3D Laser Survey

Sonar Survey



https://www.earthsciencepartnership.co.uk/projects/remediation-coal-mine-shaft/

Even if we restrict ourselves to models associated with minerals we have significant variations in what defines our 3D model:

Property

- Chemistry
- Ore Grade and Geometallurgy/ Microstructure
- Mineralogy/ Alteration
- Lithology and Stratigraphy
- Petrophysics & Rock physics
- Structures & Structure density

Description of property

- Surfaces
- Block Models
- Iso-surfaces
- Connectivity
- Scale