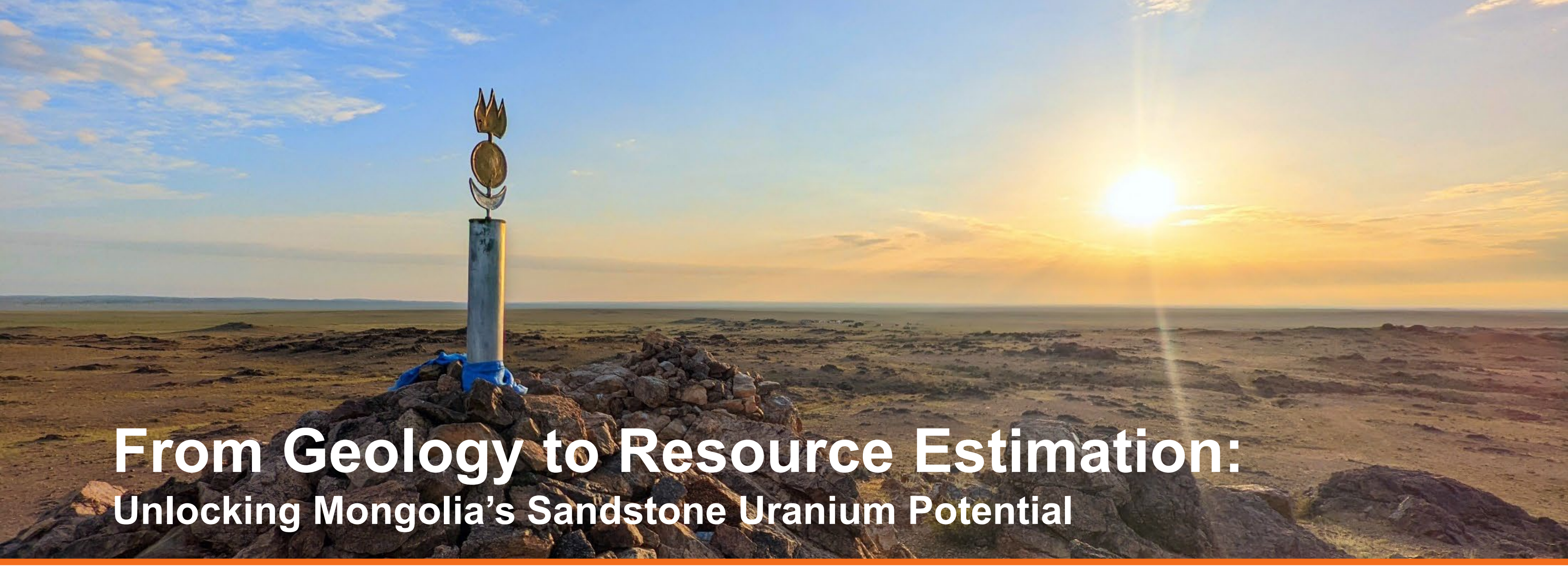

From Geology to Resource Estimation:

Unlocking Mongolia’s Sandstone Uranium Potential

SMEDG talk: 26 June 2025

Oliver Willetts, SRK Consulting Australia

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Geology

Regional, local and uranium geology

Geology

Regional, local and uranium geology

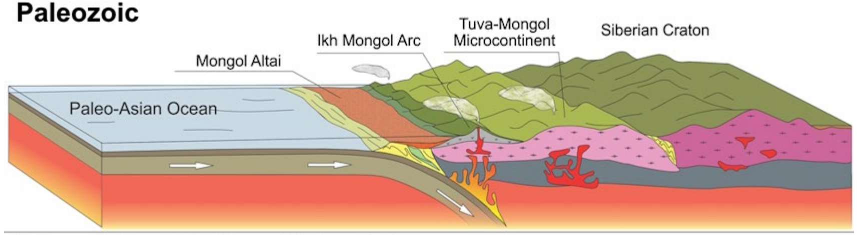
Geology

Regional, local and uranium geology

Regional geology

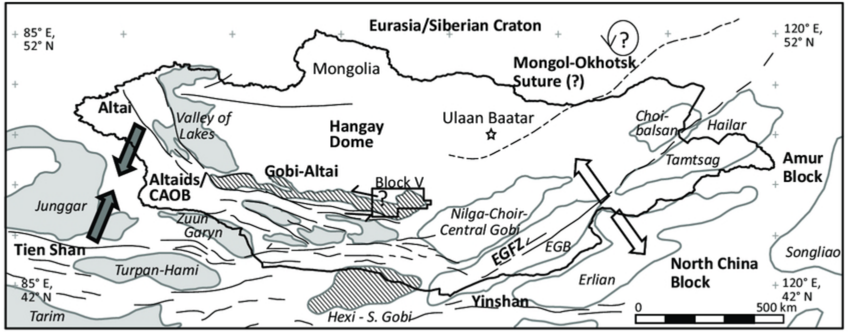
Palaeotectonic units of Eurasia (van Niekerk (2024))

Paleozoic



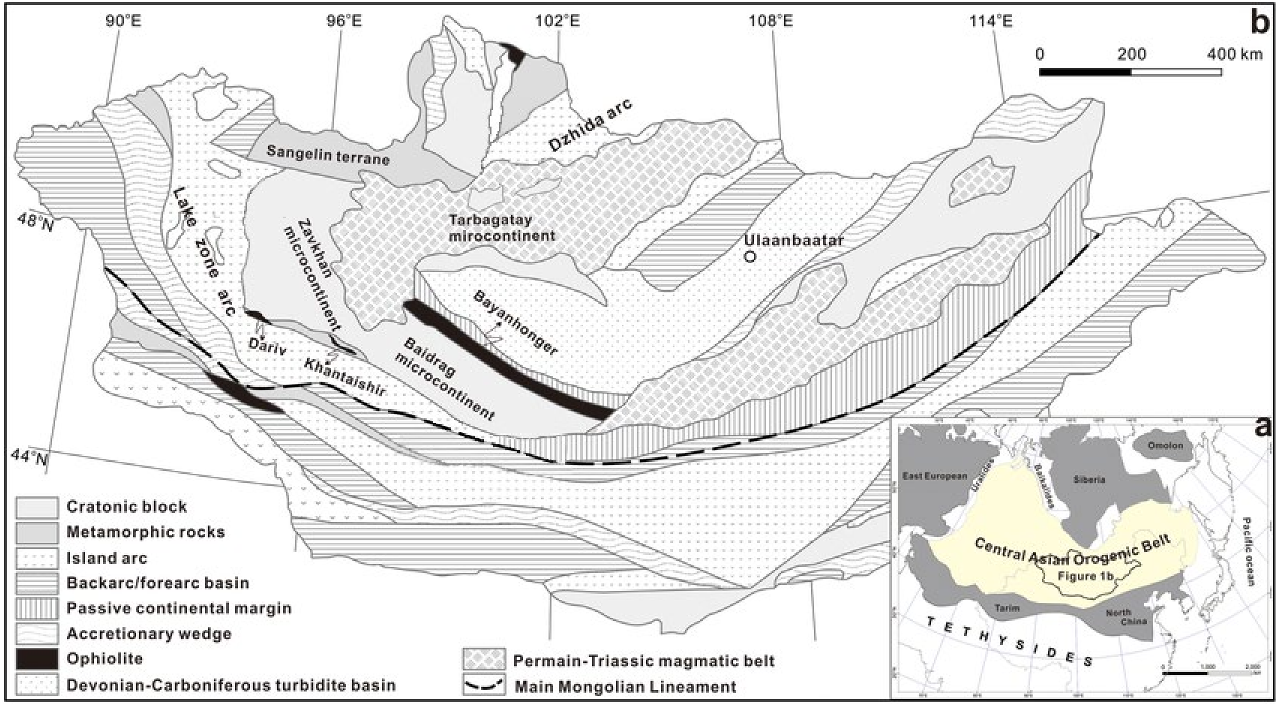
Batkhuyag E, Tserendash N, Tumen-Ulzii O, et al., 2024

Mesozoic



Late Mesozoic extension in western Mongolia (Johnson, C. et al. (2014))

Mongolian uranium



Tectonic map showing the main tectonic units of Mongolia (modified from Badarch et al. (2002)).

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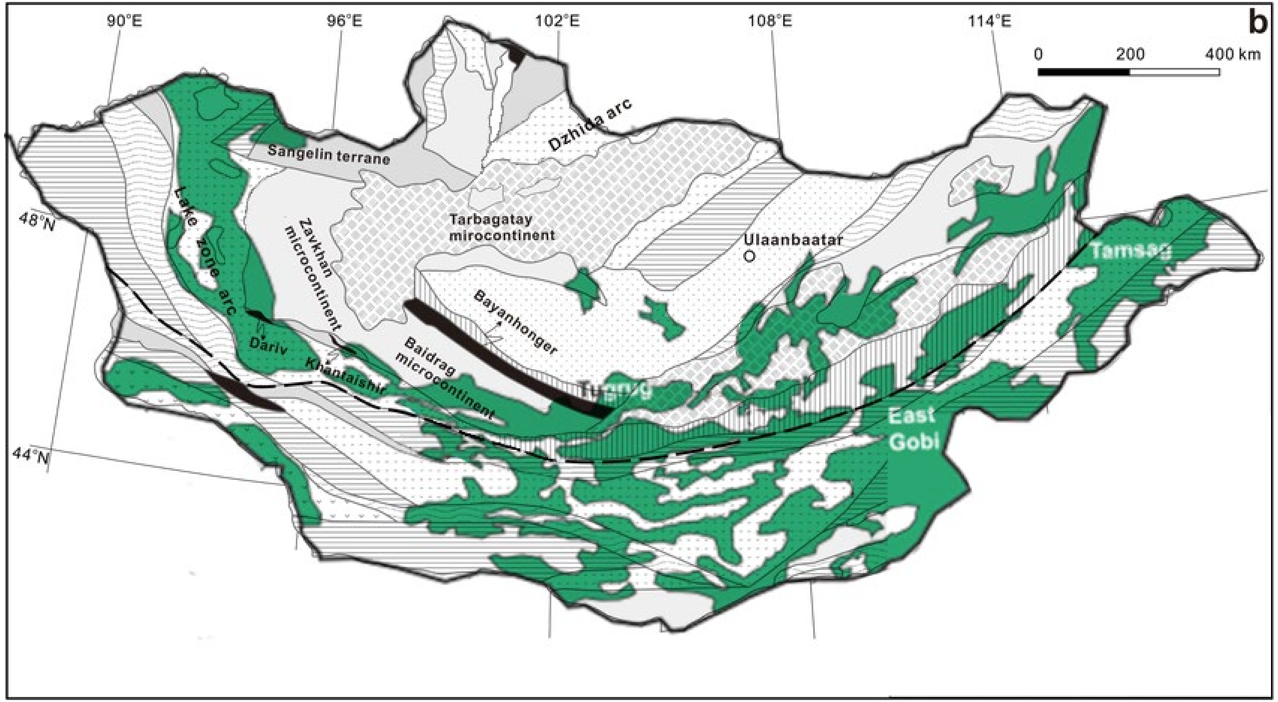
Mongolian uranium



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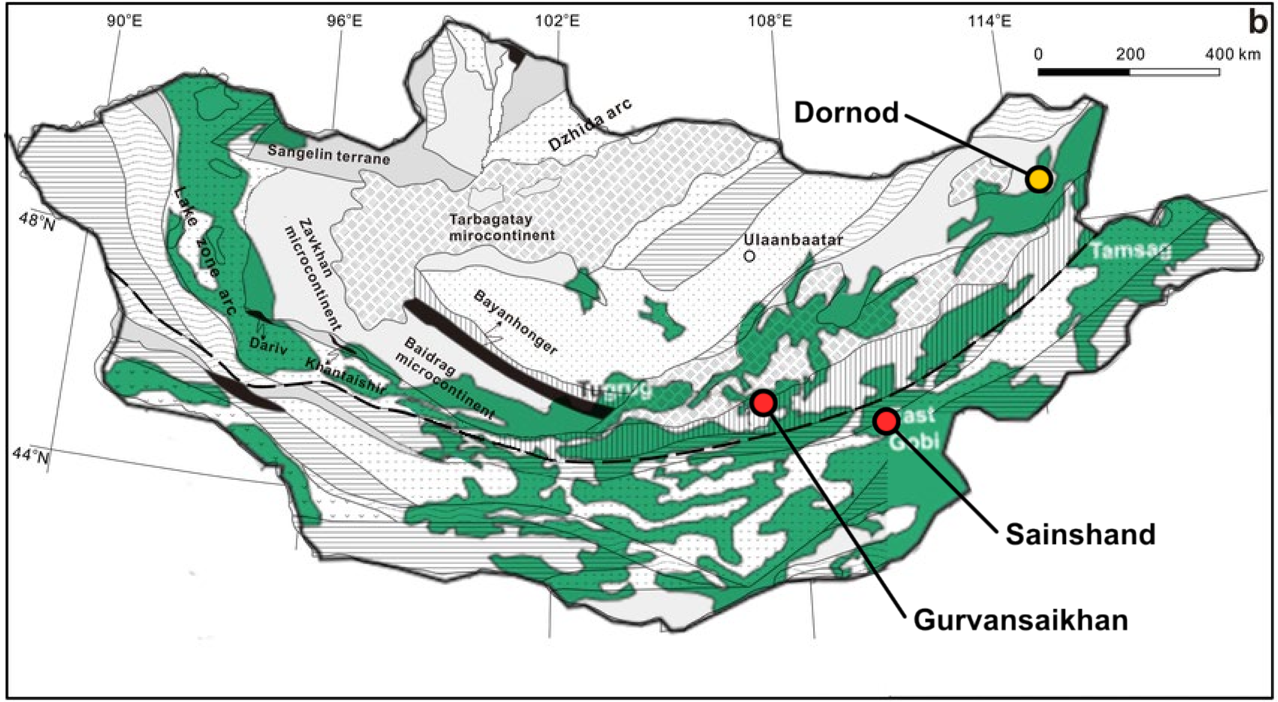
Mongolian uranium



Tectonic map showing the main tectonic units of Mongolia (modified from Badarch et al. (2002)).

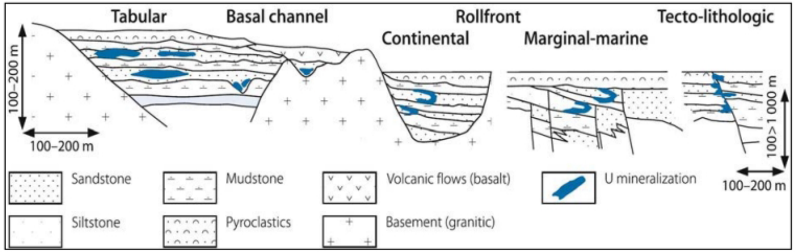
Mongolian uranium

Company/project	Deposit	Province (aimag)	Geology	Resources tU, %U
Sainshand	Zoovch Ovoo	Dornogovi	sandstone	67,706 t @ 0.022%
	Dulaan Uul, Umnut	Dornogovi	sandstone	11,006 t @ 0.022%
Dornod	Dornod	Dornod	volcanic	24,780 t
CNNC International	Gurvanbulag	Dornod	volcanic	8580 t @ 0.152%
Gurvan Saihan	Gurvan Saihan	Dundgovi	sandstone	4250 t @ 0.034%
	Haarat/Kharaat		sandstone	7288 t @ 0.026%
	Hairhan/Khairhan		sandstone	8406 t @ 0.071%
	Ulziit		sandstone	3075 @ 0.036%

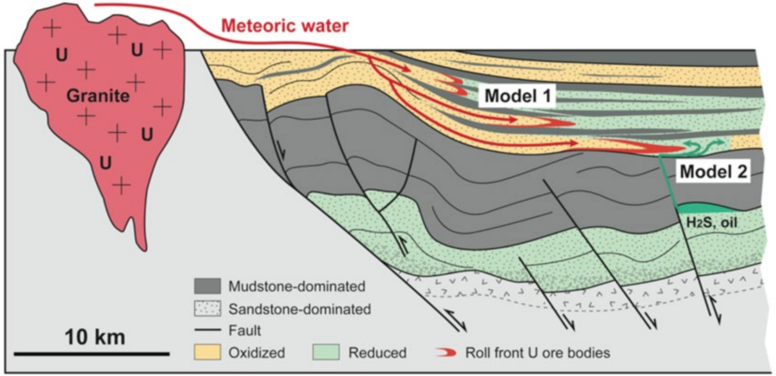
https://world-nuclear.org/information-library/country-profiles/countries-g-n/mongolia

Sandstone uranium: primer

- 28% of world uranium resources
- Found in Kazakhstan, Uzbekistan, USA, Niger, Australia and Mongolia
- Commonly low to medium grade (0.03-0.35%U)
- Small to medium orebodies in size (<=50 kt U).
- Suitability for in situ leach (ISL) mining methods.
- Uranium mobility in groundwater
  - **Transport:** via fluvial/lacustrine sequences
  - **Traps:** reducing conditions
- Form *roll-front* type deposits

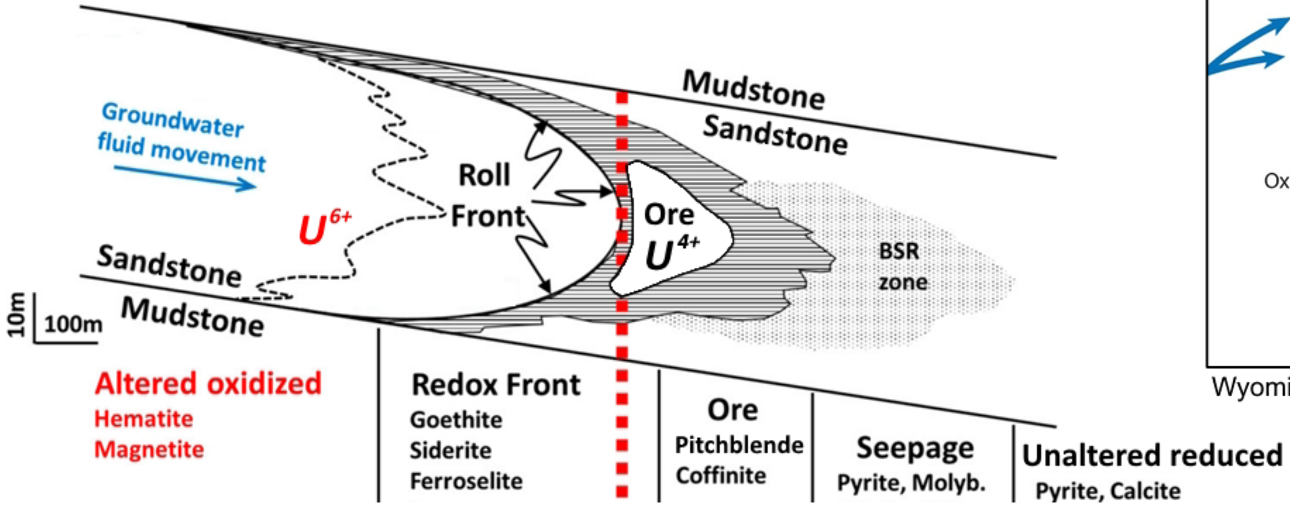


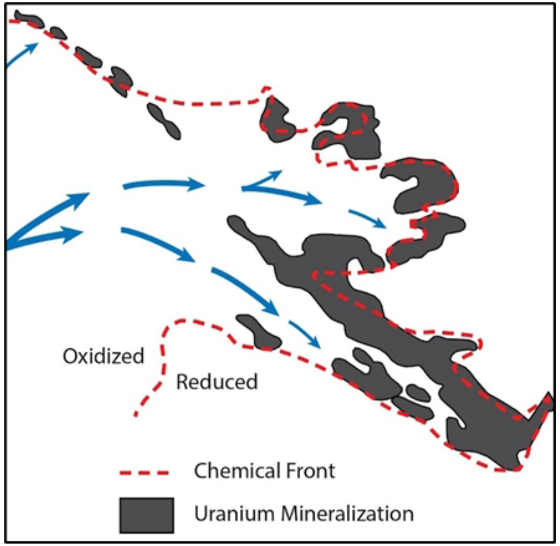
IAEA geological classification of sandstone uranium deposits (Bruneton et al. (2014))



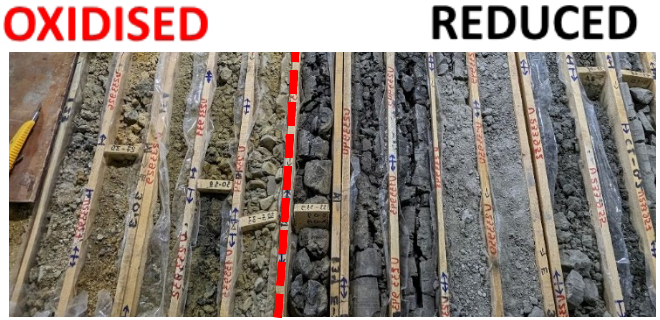
Conceptual model of sandstone uranium deposit genesis (Bonnetti, Christophe et al. (2020).)

Roll front model

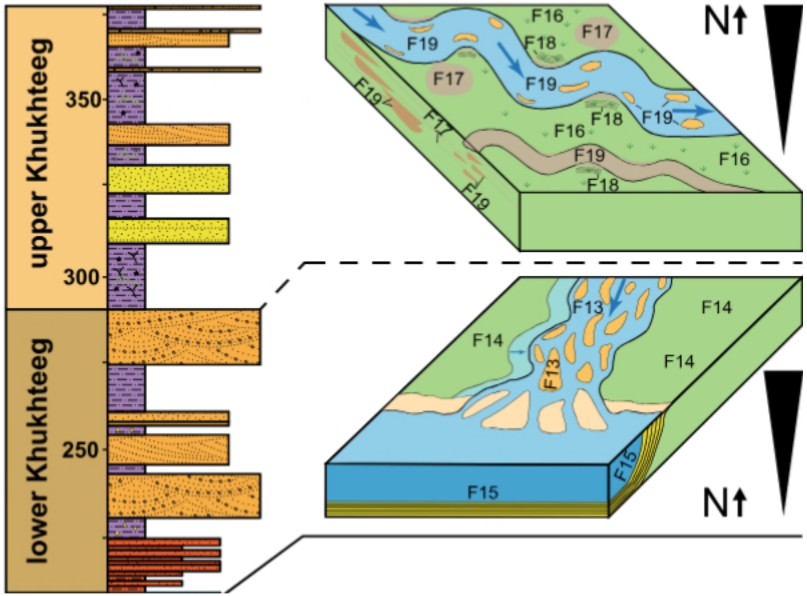




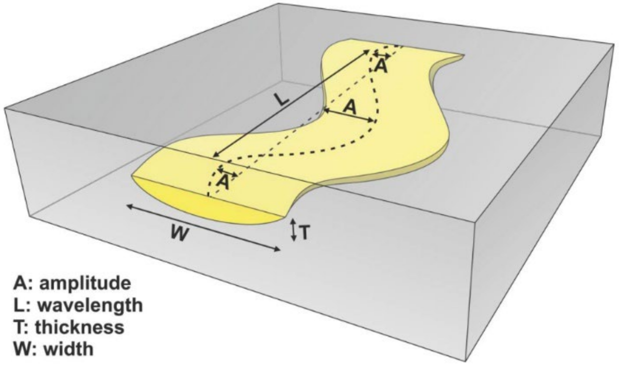
Wyoming State Geological Survey



Palaeoenvironment



Type stratigraphy and depositional environments for palaeochannel deposits (Van Niekirk et al. (2025))



Morphometric parameters of fluvial channel bodies (Colombera et al. (2019))

Exploration

Drilling, logging and sampling

Drilling techniques

	Diamond	Sonic	RC/MudR	Auger
Sample type	Core	Core	Chips	Bulk
Sample quality	+++	++++	+	++
Hole profile	+++	++++	++	+
Depth	500m+	<=200m	<=500m	<=20m
Speed	🐰 🐰	🐰 - 🐌	🐆 🐆 🐆	🐌
Strength	Ubiquitous	Unconsolidated	Speed	Sample size
Weakness	Fluids	Specialised	Smearing	Slow & shallow
Cost	$$$	$$$$	$$	$$

Precise ground transitions

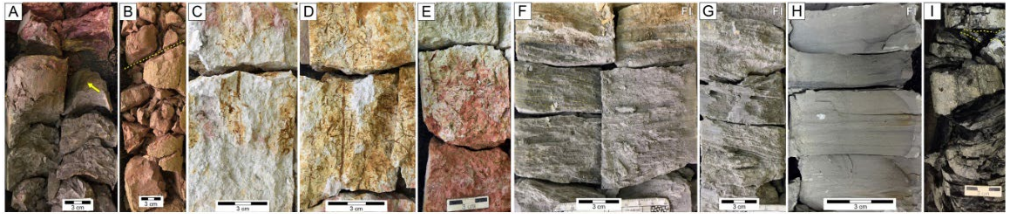
River bottom gravel

Alluvial sands sonic sample

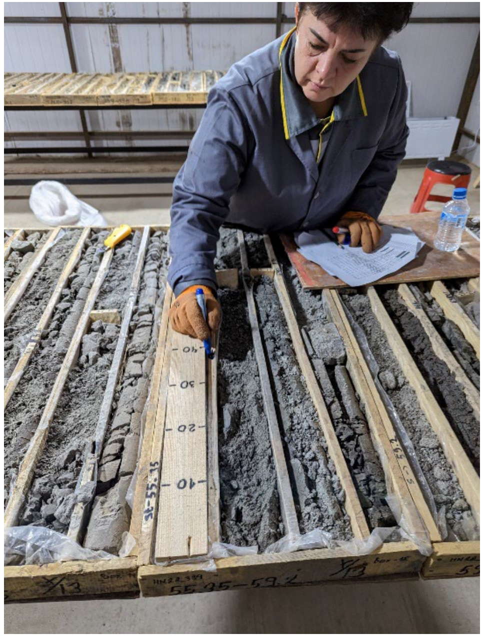
https://www.boartlongyear.com/insite/getting-the-most-out-of-sonic-drilling/

Geological data

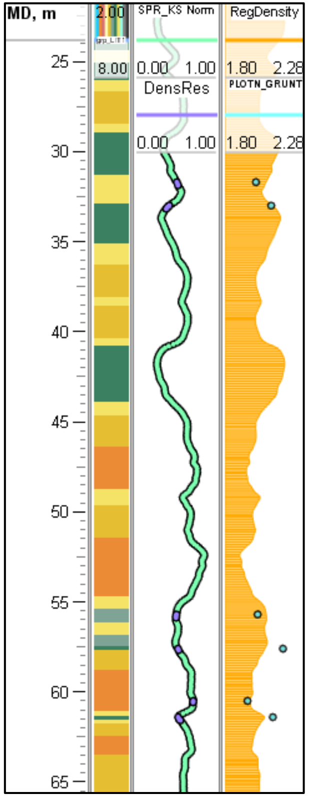
- Logged attributes
  - Facies
  - Texture
  - Granulometry
  - Organics
  - Redox/alteration
  - Colour
  - Mineralisation
- Logging practices differ globally
- Modernisation using imagery
  - IMAGO
  - ML analysis
  - Subjective measurements
  - Logging QAQC



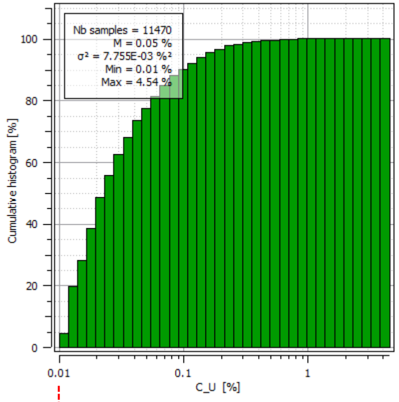
Examples of drill core colours in uranium logging (A. Dillinger, E. Chanvry, Y. Bolat et al. (2024)

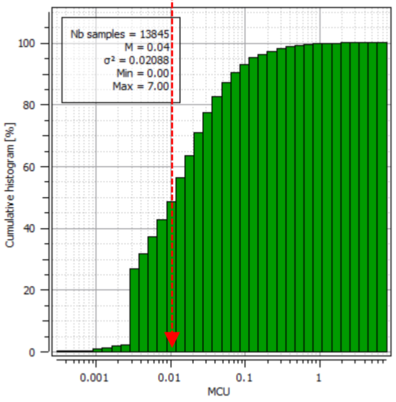


Downhole geophysics



- Typical tooling
  - Gamma (natural/multispectral)
  - Resistivity
  - Caliper
- Beware tooling sensitivity limits
  - Gamma (natural): 100 ppm
  - PFN: 200-250 ppm
  - Geological cutoffs can be below!
- Geophysics requires rigorous QAQC
- Continuous downhole data is valuable
  - Infill of density, granulometry
  - Regression or ML approaches are readily available





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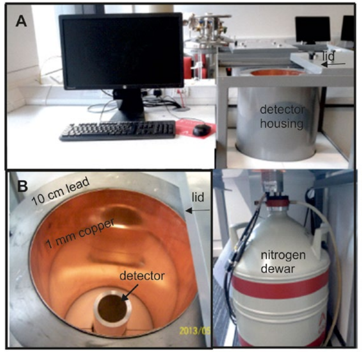
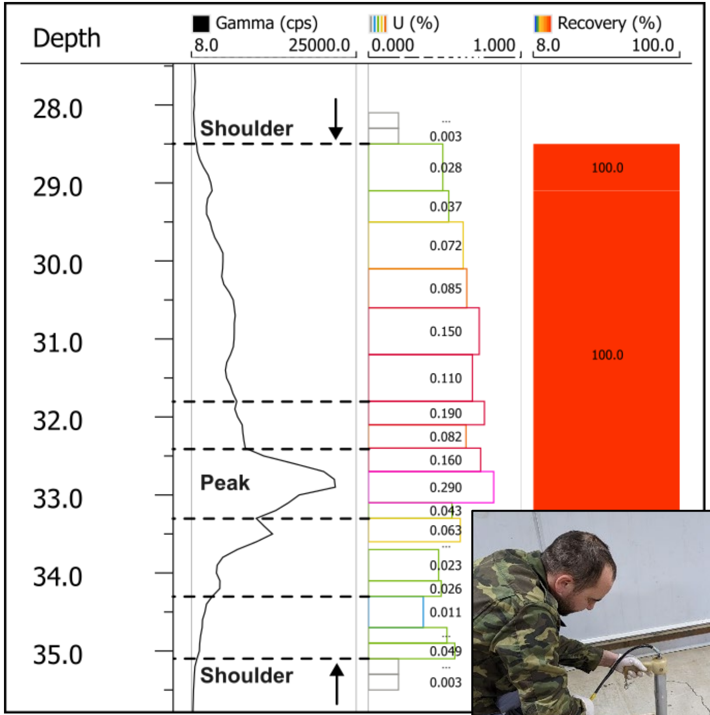
Geochemistry

- Sampling strategy:
  - Gamma sample location
  - Scintillometer confirmation
  - Voluminous sampling
- Different assay methods:
  - U grade: **XRF**
  - Disequilibrium (U, Ra): **Gamma ray spectrometry (GRS)**
- Few laboratories offer GRS analysis
  - Specialised equipment
  - International transport of radioactive materials
  - Expensive
  - Time-consuming (14K samples = 6+ months)



Mauz, B., Nolan, P. J., and Appleby, P. G.: Technical note: Quantifying uranium-series disequilibrium in natural samples for dosimetric dating – Part 1: gamma spectrometry, Geochronology, 4, 213–225, https://doi.org/10.5194/gchron-4-213-2022, 2022.



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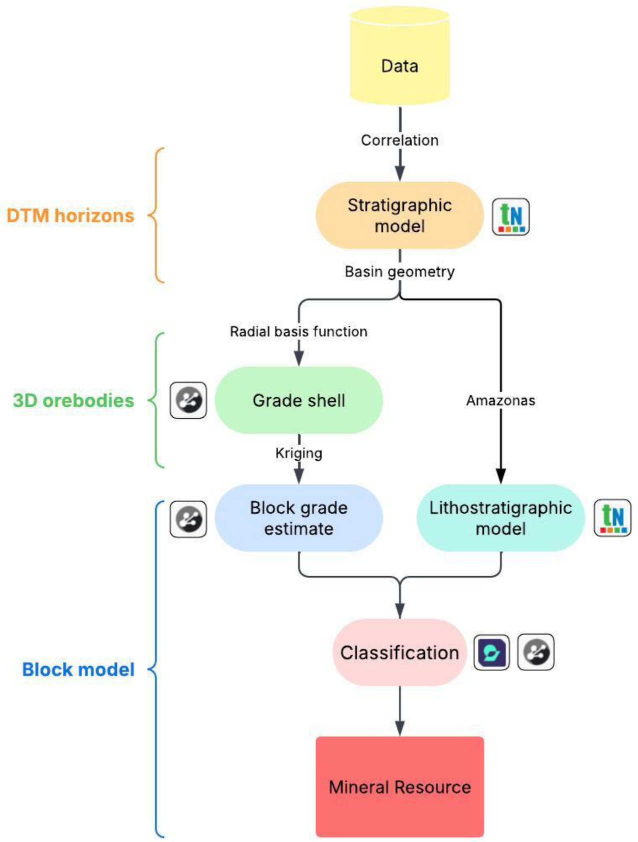
Modelling and estimation

Modelling challenges, lithostratigraphic modelling, grade estimation

Modelling challenges

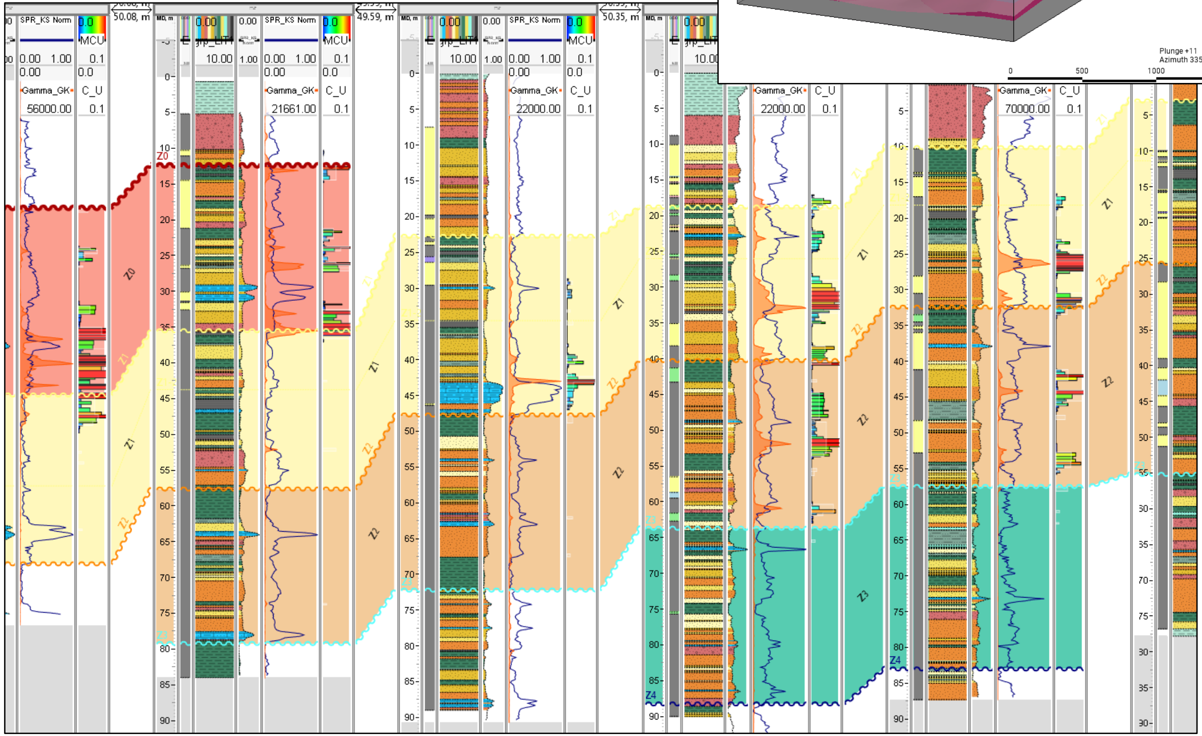
- Large volumes of multimodal data
- Software modelling environment:
  - Effective, clear 2D & 3D visualization
  - Data cleansing & conditioning
  - Geophysics processing
- Hybrid workflow:
  - Stratigraphic model: geological logging + geophysics
  - 3D orebody modelling: uranium grade/grade-thickness
- Correlation is technically challenging for large datasets
  - Consistency across drilling generations
- Complex domaining with interbedding and partially-confined systems

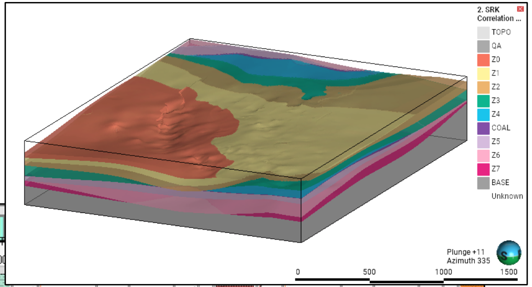
tNavigator
Leapfrog
Micromine



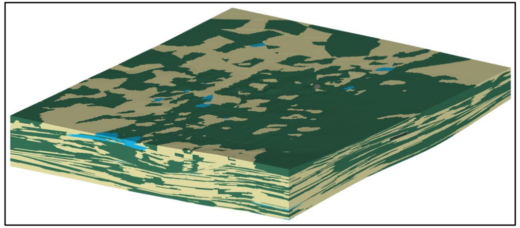
Stratigraphic correlation

- Depositional rhythmic sequences
  - Geophysics
  - Geology logging
  - Geochemical analysis
  - Marker horizons
  - Radioactive tracer
- 3D realization of basin stratigraphic geometry
  - Stratigraphic domains
  - Trend surfaces

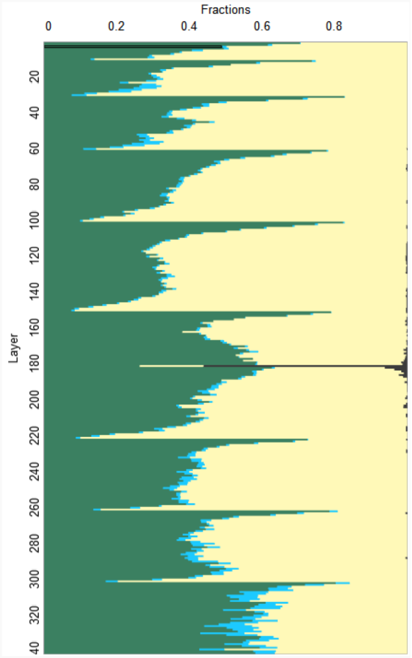




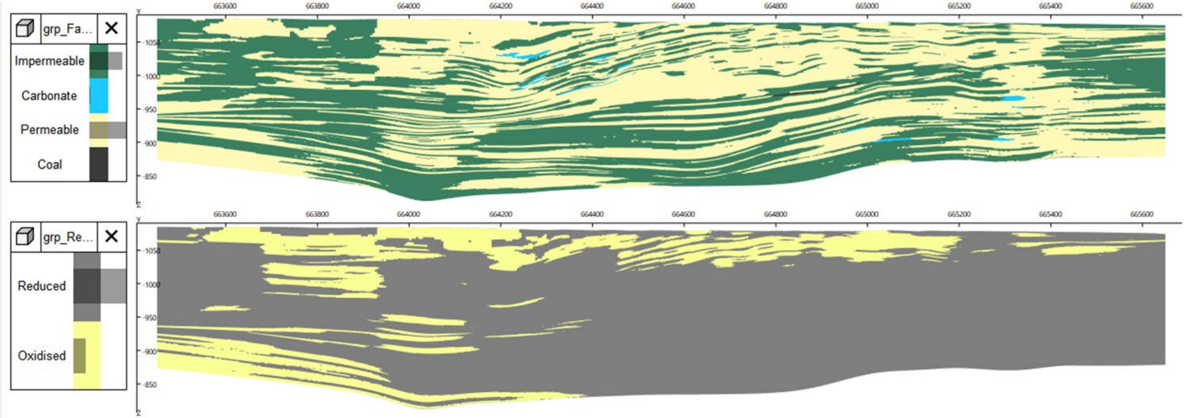
Lithostratigraphic modelling



Vertical proportion curve

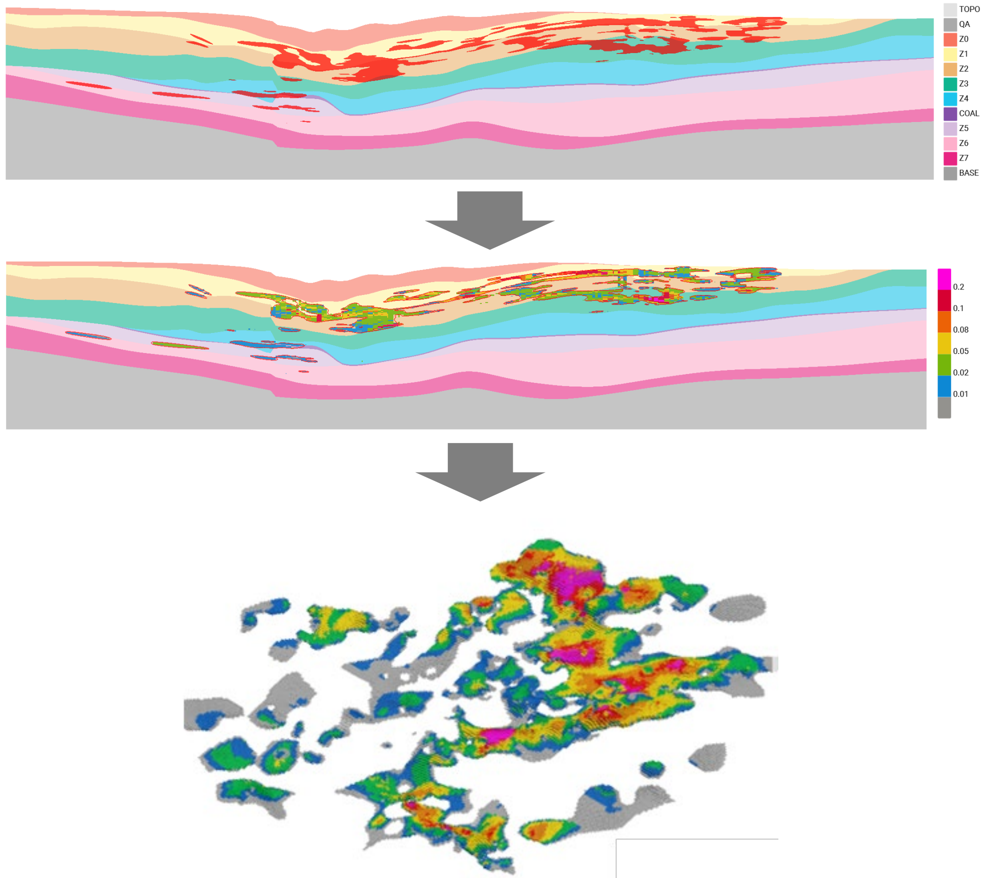


3D lithostratigraphic model



Grade estimation

- Grade shell delineates anomalous mineralisation
  - Gross mineralised volume
  - Well-populated domain
  - Radial basis functions
- Block model inside grade shell
  - Block grade estimation
  - Geostatistical approach
  - Density, granulometry
- Grade shell & grade oriented to stratigraphy
  - Structural trends
  - IJK search space (flattening)



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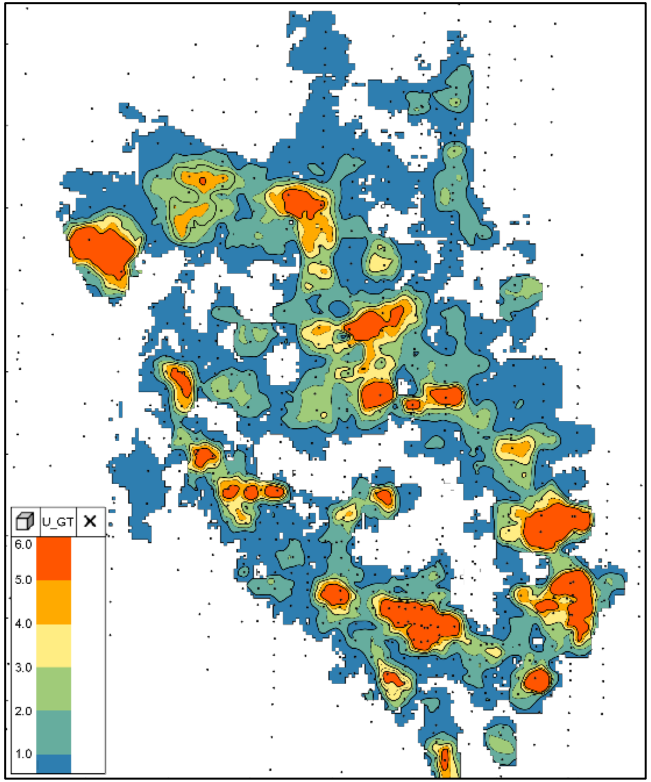
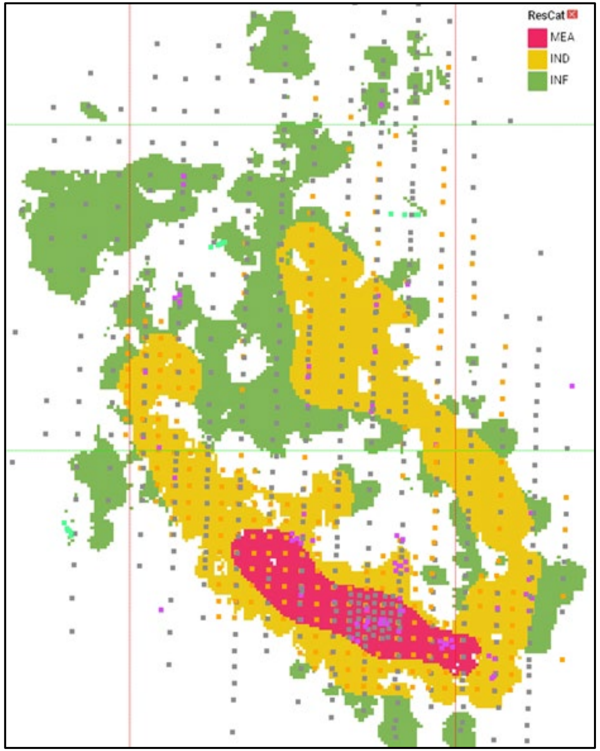
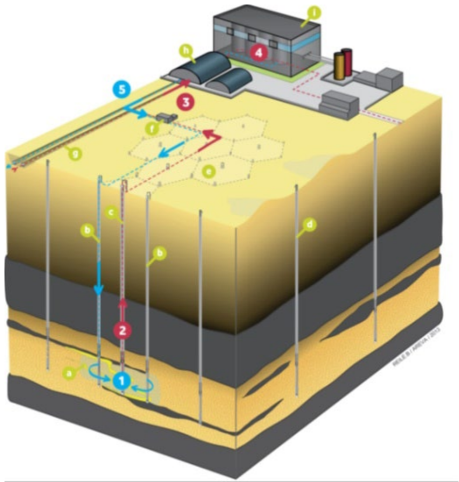
Classification



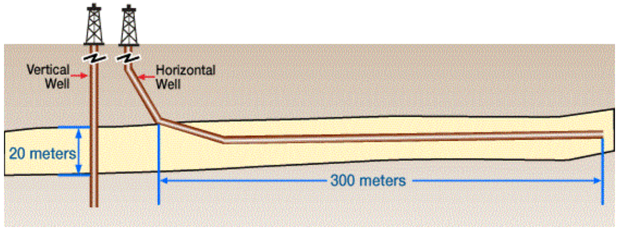
- Lithostratigraphic model
  - Permeable facies
  - Reduced/transitional
- Reporting grade cutoff
  - Grade
  - Grade-thickness
- Classification
  - Geological continuity
  - Grade continuity
  - Data quality
  - Data distribution

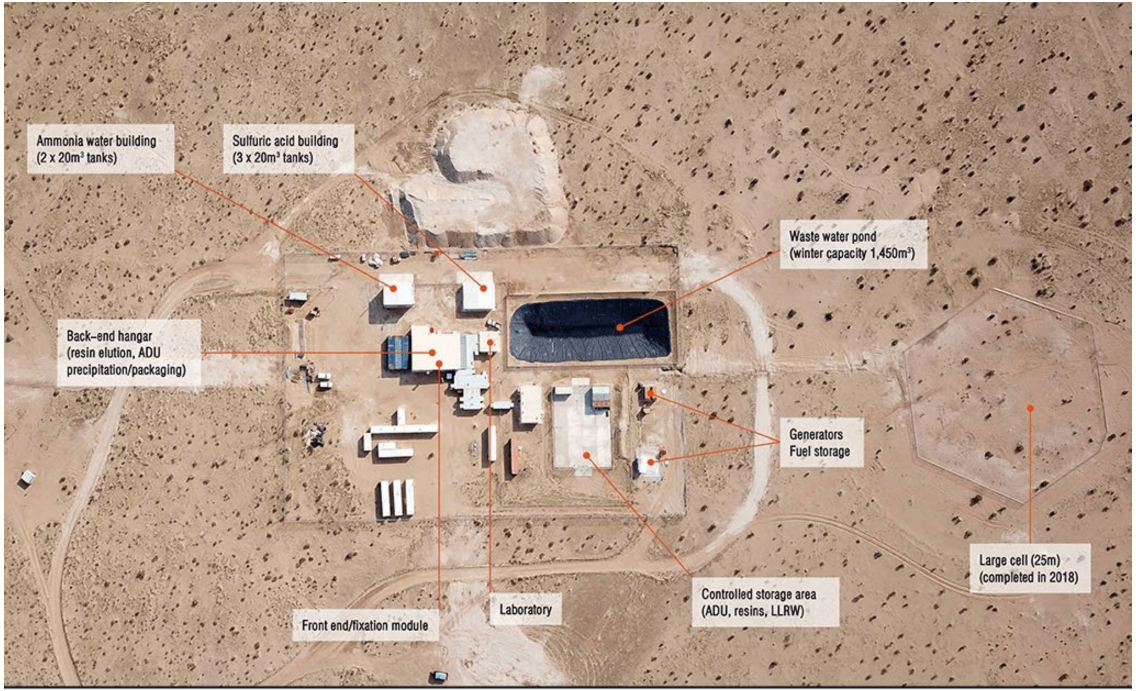


ISL extraction



ISL uranium mine schematic (AREVA (2013))





Zoovch Ovoo ISL Pilot Facility (https://badrakhenergy.com/en/zuuvch-ovoo-project/)

Conclusions

- **Innovations in stratigraphic and grade modelling:**
  – Hybrid workflows help improve lithostratigraphic models and resource estimations in complex sedimentary environments.
- **Opportunities to improve data quality:**
  – Use of quality imagery, IMAGO and ML techniques
  – Rigorous QAQC protocols essential
- **In Situ Leach (ISL) Mining:**
  – Cost-effective and environmentally sensitive approach to uranium extraction.
- **Insights from oil and gas industry:**
  – Uncertainty testing, geosteering, dynamic modelling, reservoir engineering and ISL simulation

Final thoughts

Final thoughts

Thanks

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