Quantitative Assessment of Karst Pore Volume in Carbonate Reservoirs Using Discrete Karst Networks*

Fermin Fernandez-Ibanez[1], Paul J. Moore[1], and Gareth D. Jones[1]

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[1]ExxonMobil Corporation, Houston, TX (fermin.fernandez.ibanez@exxonmobil.com)

Abstract

Evaluating uncertainty in karst pore volume is a current industry challenge that is critical for field development planning and optimizing recovery. Hydrocarbon pore volume in karst can be significant in large super giant fields. Although a wide variety of karst features and the geological processes that describe their morphology has previously been described in many studies, understanding exactly how to translate this knowledge of karst into practical guidelines for the assessment of pore volume in carbonate reservoirs remains an industry challenge. We present a robust model-assisted characterization workflow that integrates well data, seismic data (if available), drilling data, geological concepts from modern and ancient outcrop analogs, and the application of Discrete Fracture Network technology, to explicitly model karst features. These Discrete Karst Network (DKN) models serve as powerful visualization and communication tools in addition to quantifying the karst pore volume. The model-assisted characterization workflow presented is specifically designed for the rapid evaluation of multiple viable geologic scenarios in recognition of the inherent uncertainty in karst morphology, fill, and sampling bias. DKNs rely on a karst intensity property that honors well data and is distributed in a full field model to reflect the conceptual models of different karst styles. These results are populated with reservoir properties for volumetric predictions. The DKN approach also has the ability to simultaneously model karst and fractures to determine effective reservoir properties for Dual Porosity, Dual Permeability flow simulations. We present nomograms to facilitate fast practical estimates of karst abundance and porosity, as well as cave area estimates from volumes lost while drilling to help condition the model inputs. A synthetic reservoir case study with varying degrees of karst that is interpreted to be coastal in origin is used to demonstrate the workflow.

References Cited

Fernandez-Ibanez, F., P.J. Moore, and G.D. Jones, 2019, Quantitative Assessment of Karst Pore Volume in Carbonate Reservoirs: American Association of Petroleum Geologists Bulletin, v. 103/5, p. 1111-1131.

Fernandez-Ibanez, F., J.M. DeGraff, P.J. Moore, L. Ahdyar, and A. Nolting, 2019, Characterization of Non-Matrix Type and Flow Potential Using Lost Circulation Information: Journal of Petroleum Science and Engineering, v. 180, p. 89-95.

Wacker, M.A., 2010, Tools and Data Acquisition of Borehole Geophysical Logging for the Florida Power and Light Company Turkey Point Power Plant in Support of a Groundwater, Surface-Water, and Ecological Monitoring Plan, Miami-Dade County, Florida: U.S. Geological Survey Open-File Report (appendix) 2010-1260, 5 p.

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[1] *ExxonMobil Upstream Reasearch Company*

[2] *ExxonMobil Integrated Upstream Solutions*

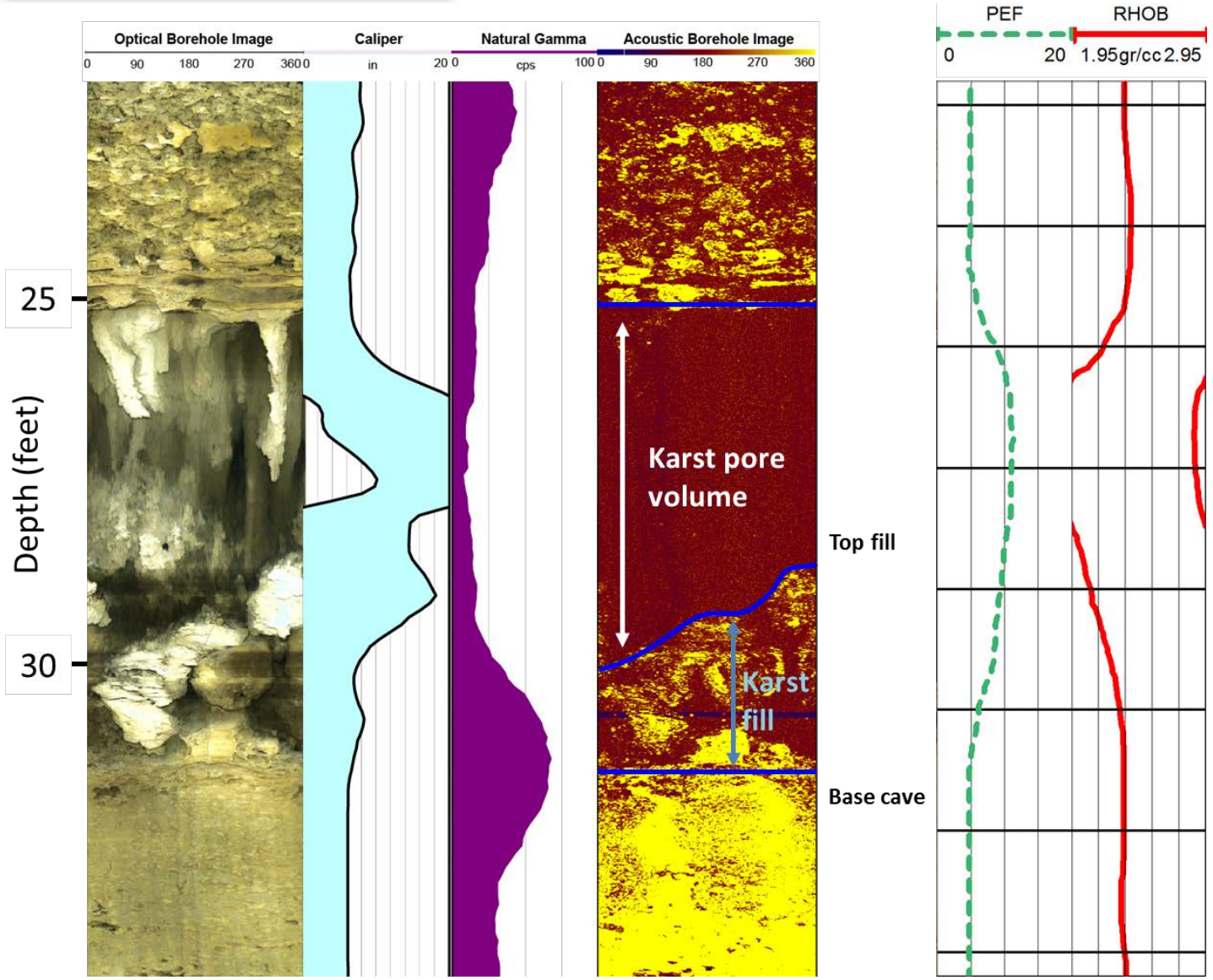
ExxonMobil

Objectives and Workflow

- Evaluate **resource size and dynamic performance uncertainty** in carbonate reservoirs with karst

- **Three-steps** approach:
  - **Multidisciplinary characterization** of static and dynamic subsurface reservoir data
  - Genetic **process-based interpretation** of karst features
  - **Model Assisted Characterization**

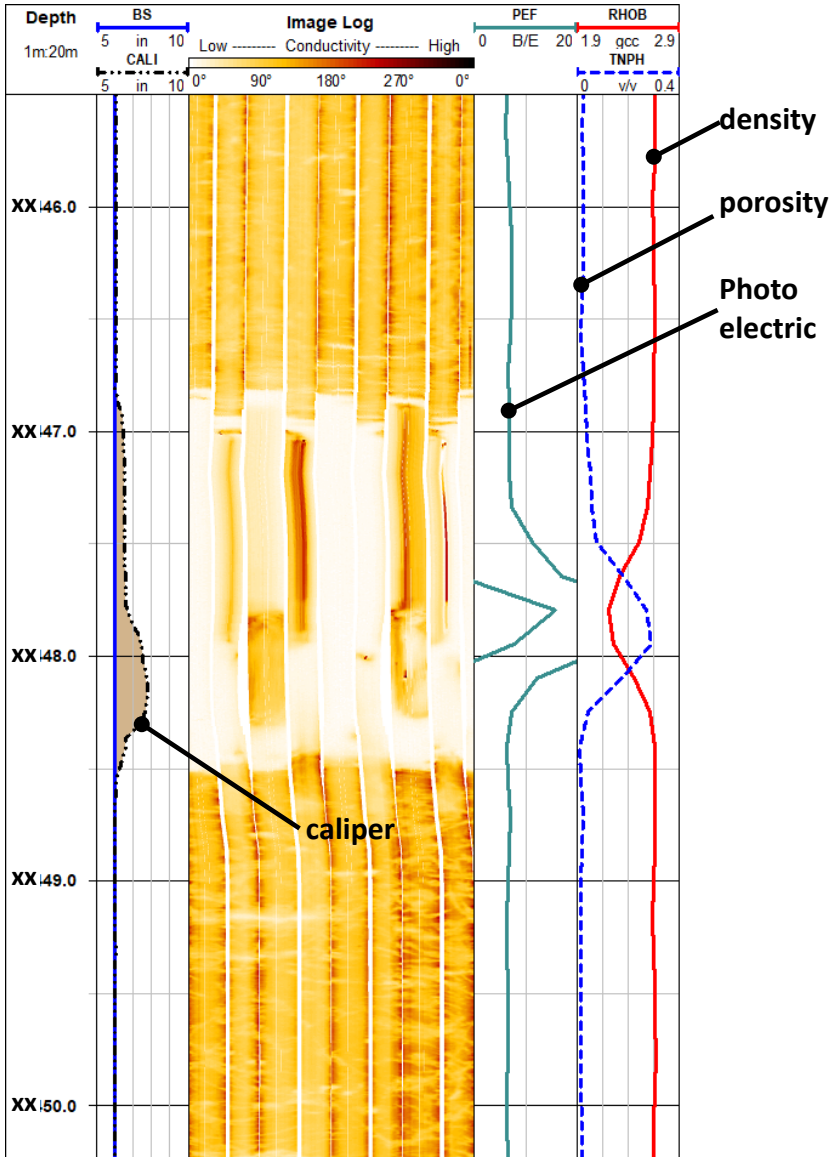
Wireline Response to Karst

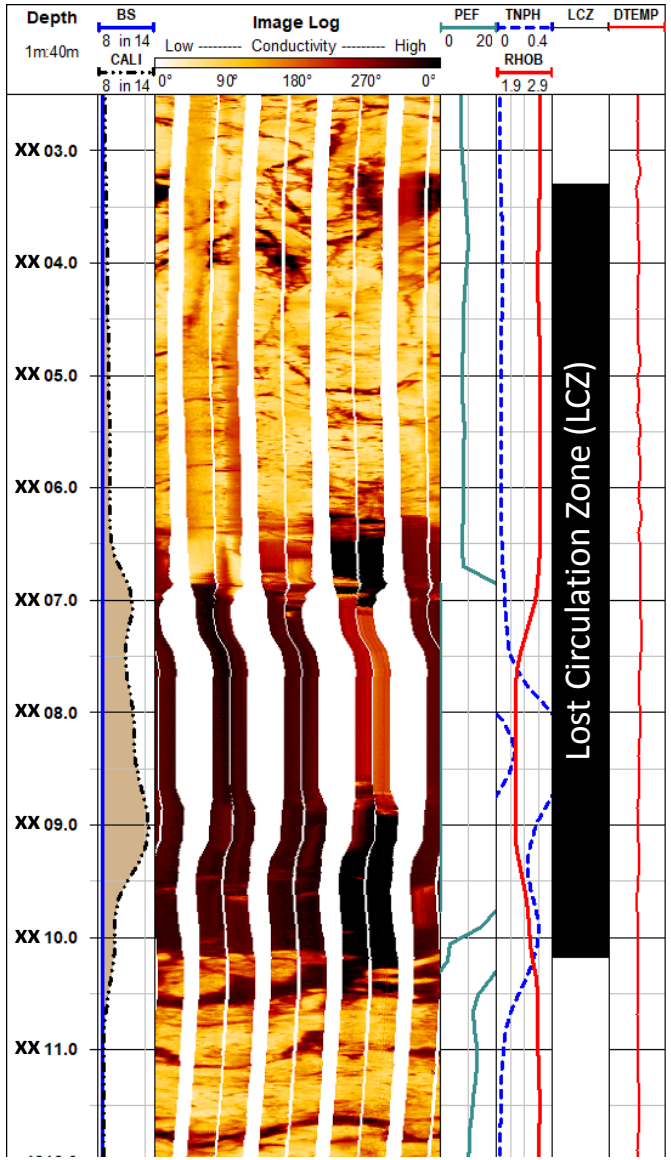


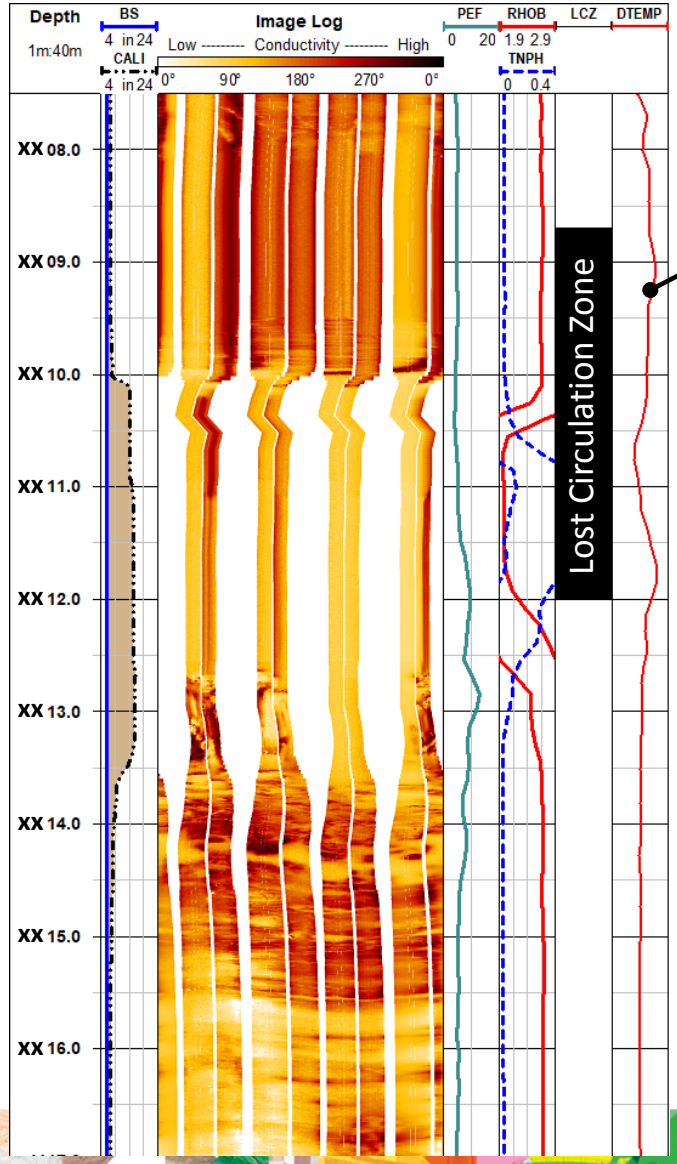
Wacker, 2010

- Image & wireline logs used to define top and base of “caves”
- Lost circulation zones and PLT as dynamic indicators
- Flank margin caves in isolated carbonate build-ups (as an example)

Subsurface Examples of Karst







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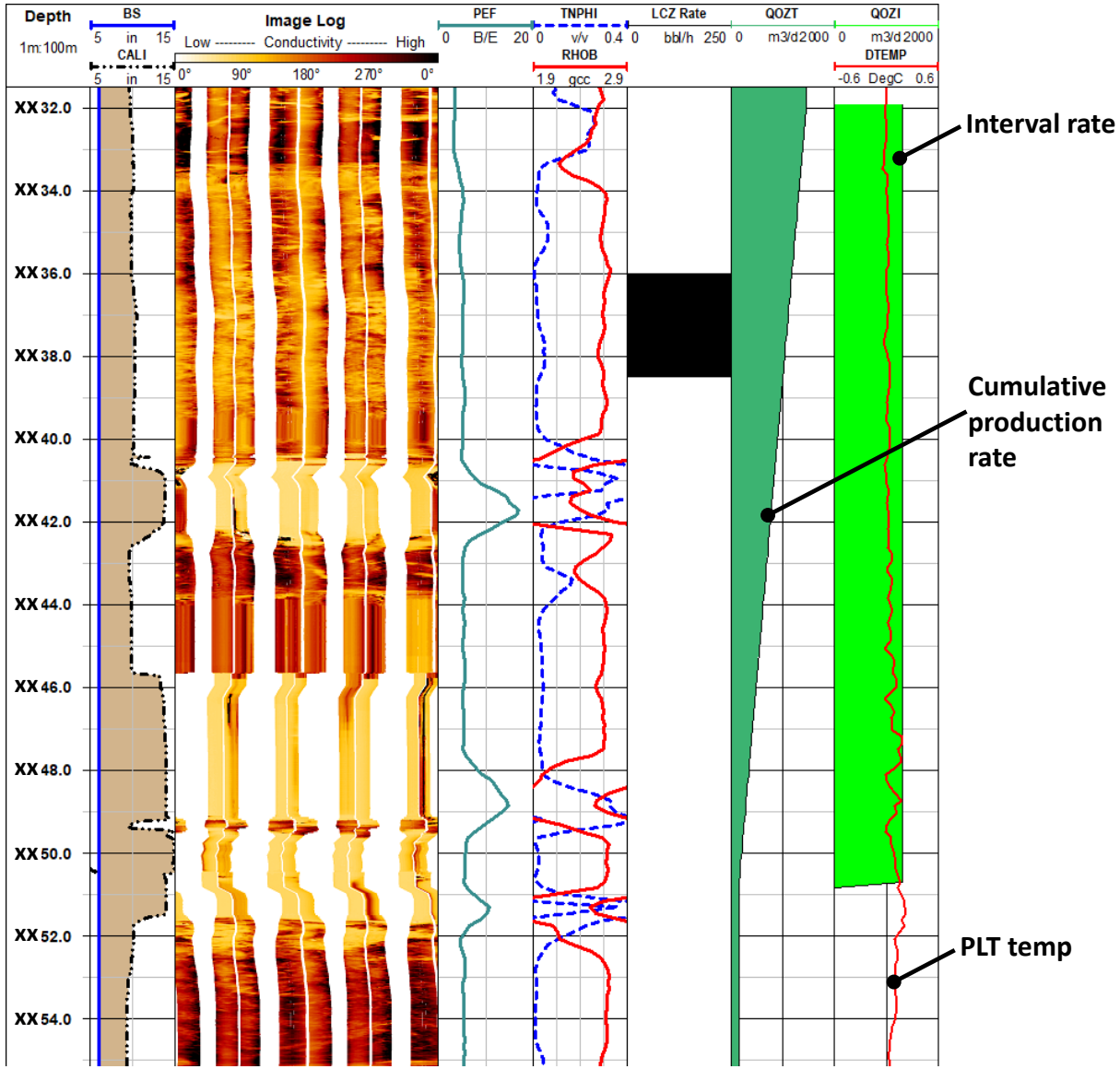

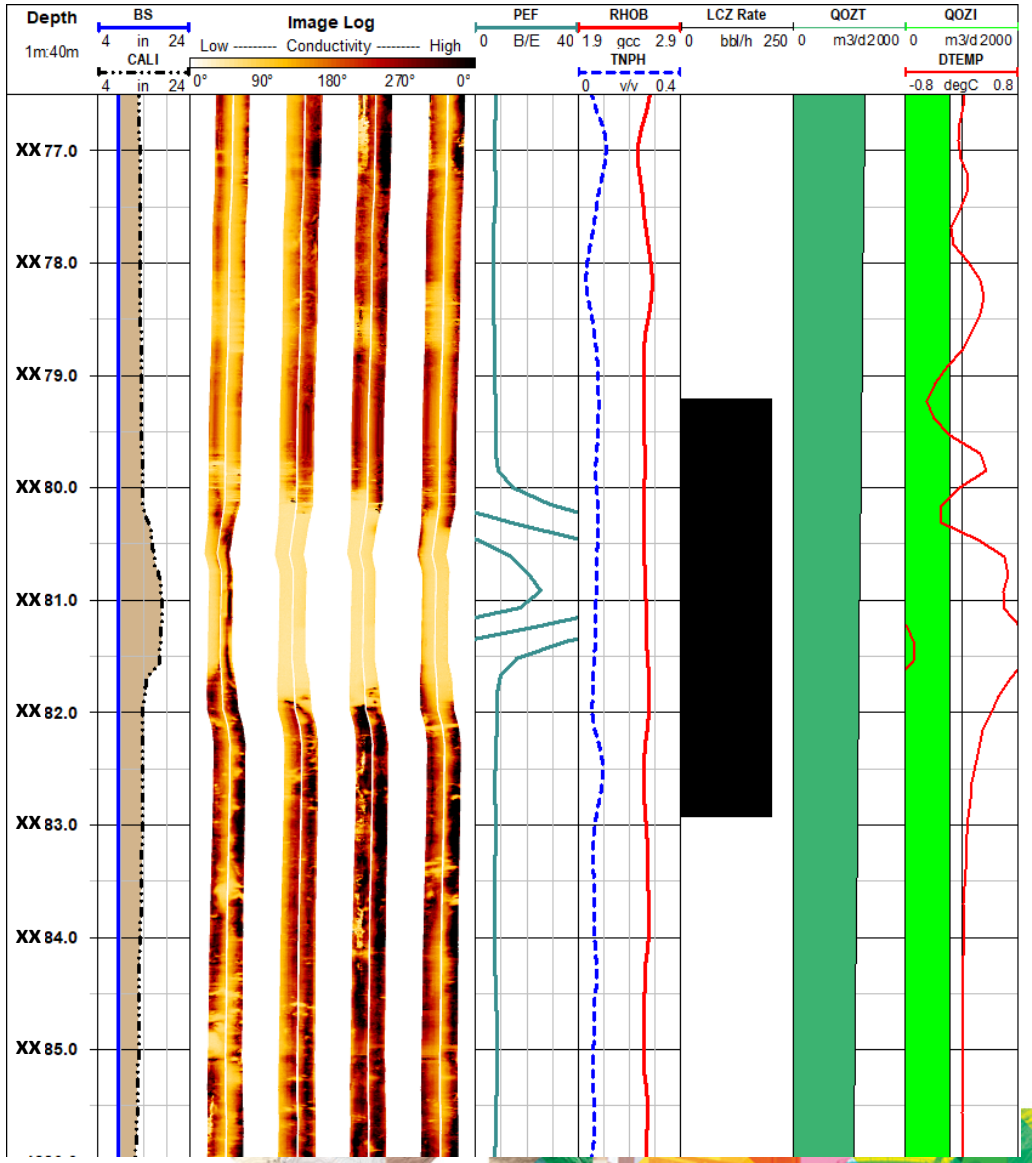

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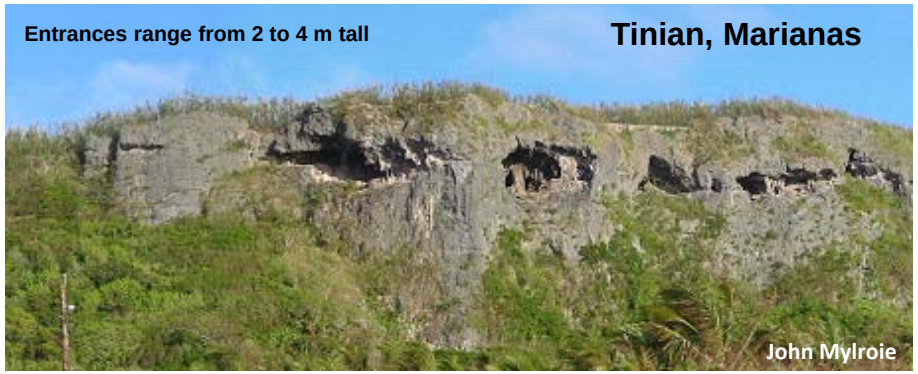
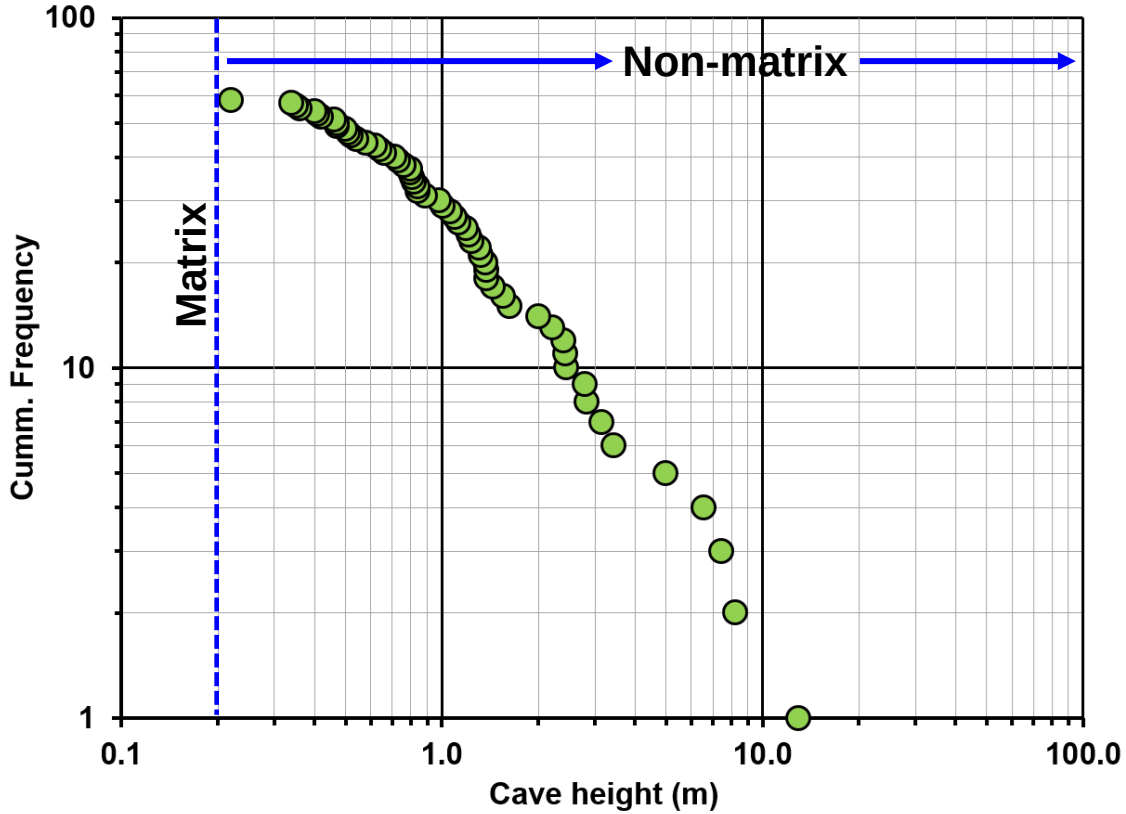
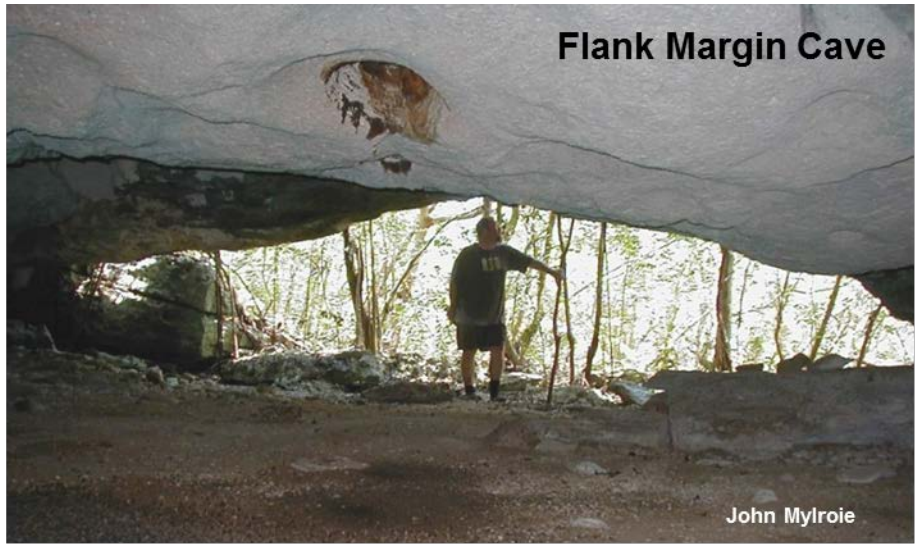
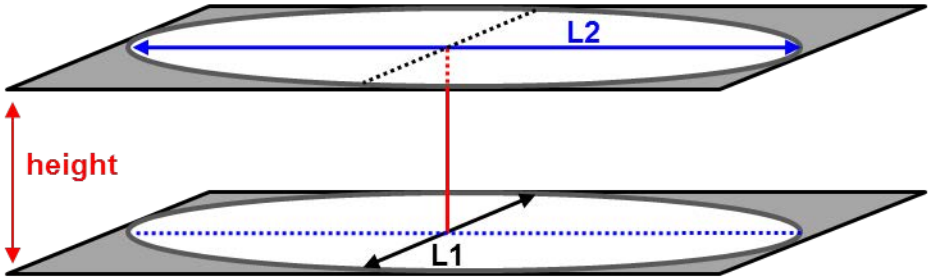
Using DFN Tools to Model Coastal Karst

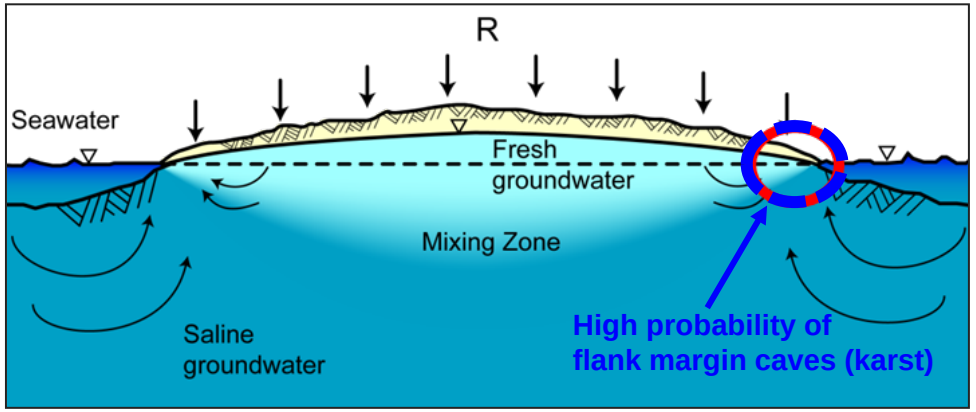


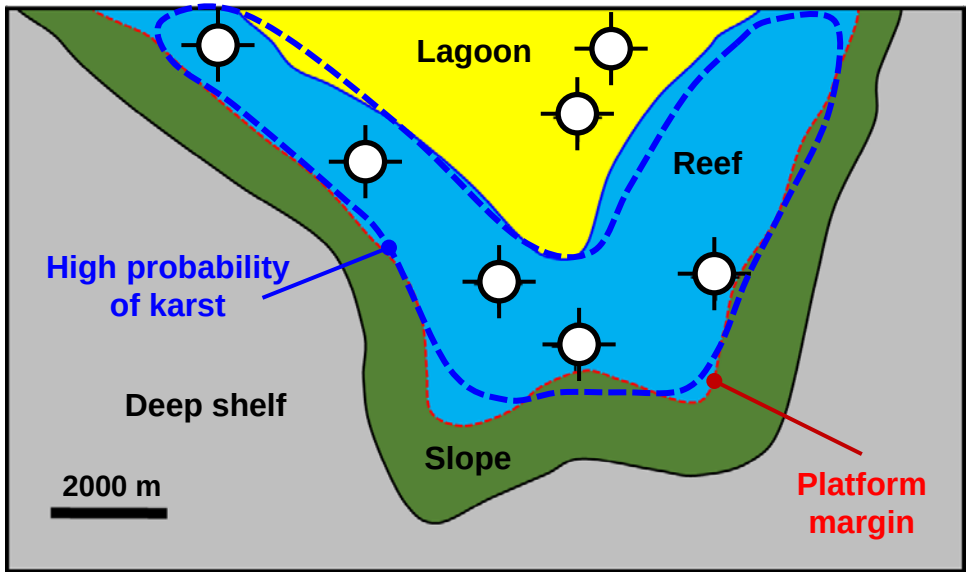


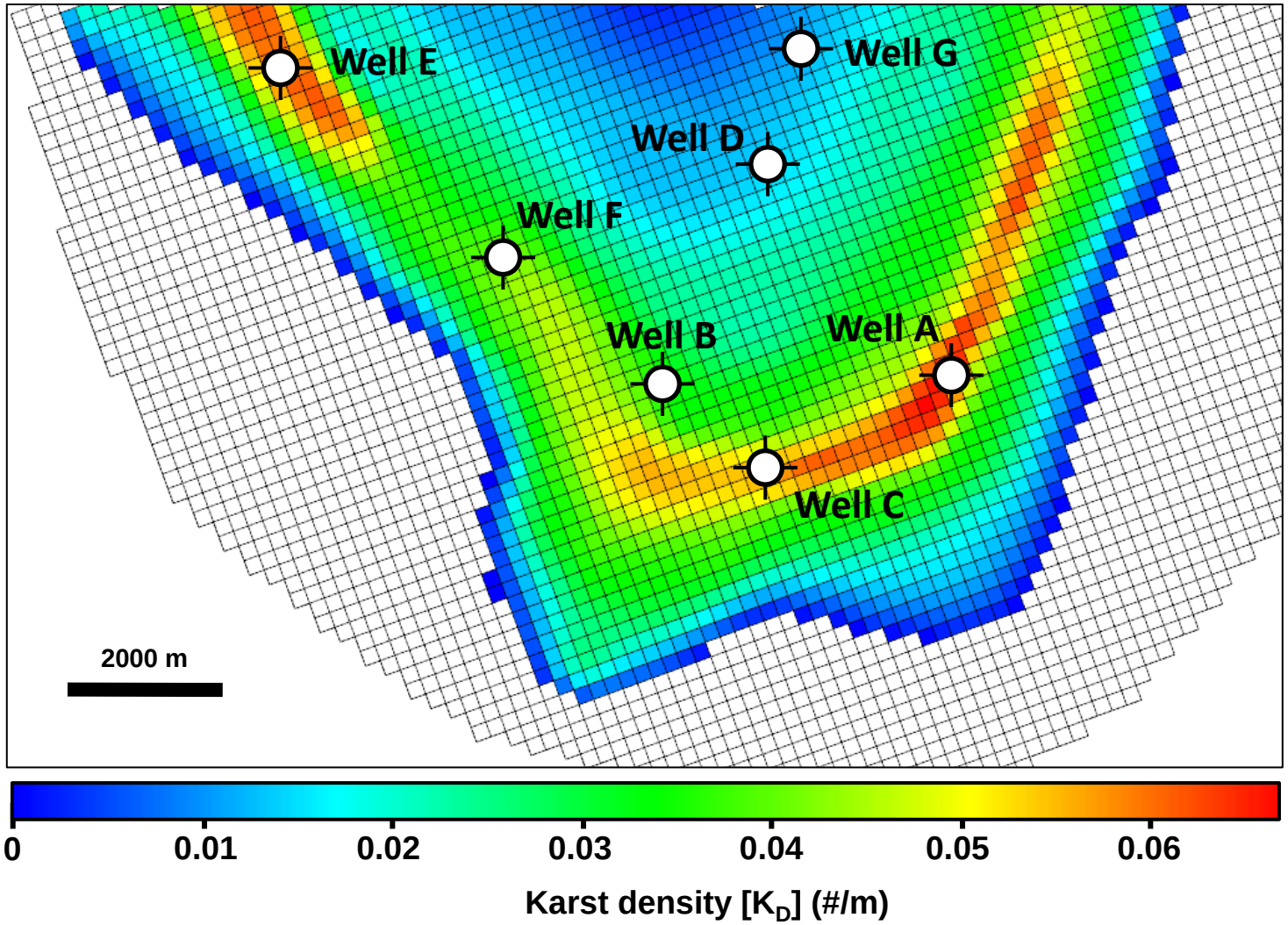




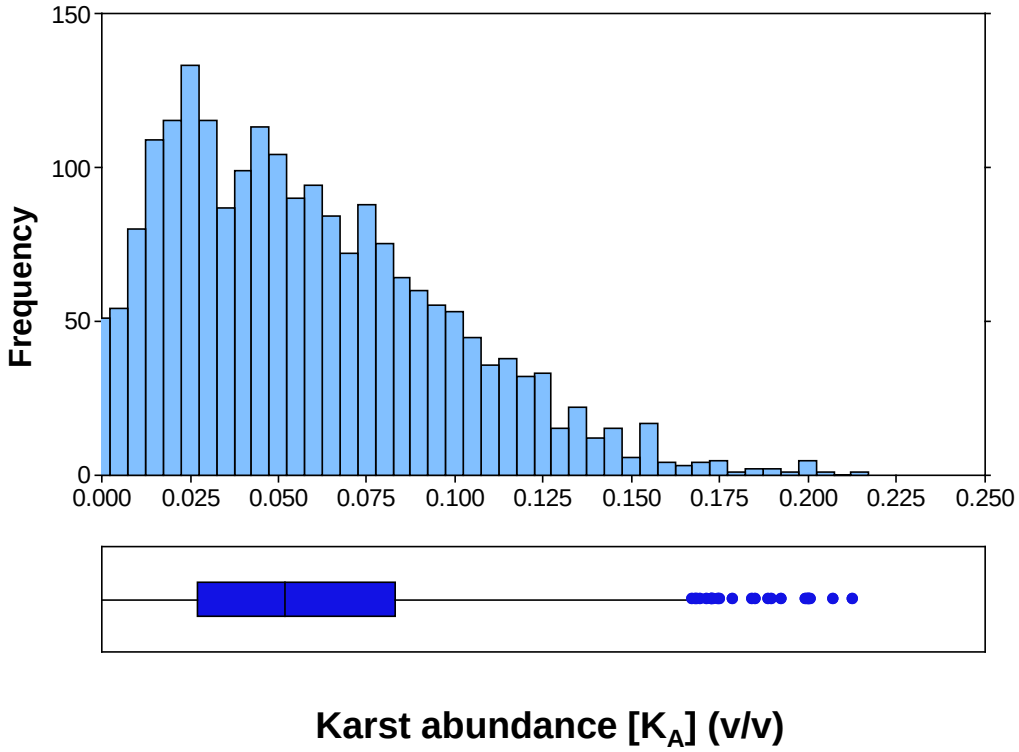
Concepts for Karst Density Prediction

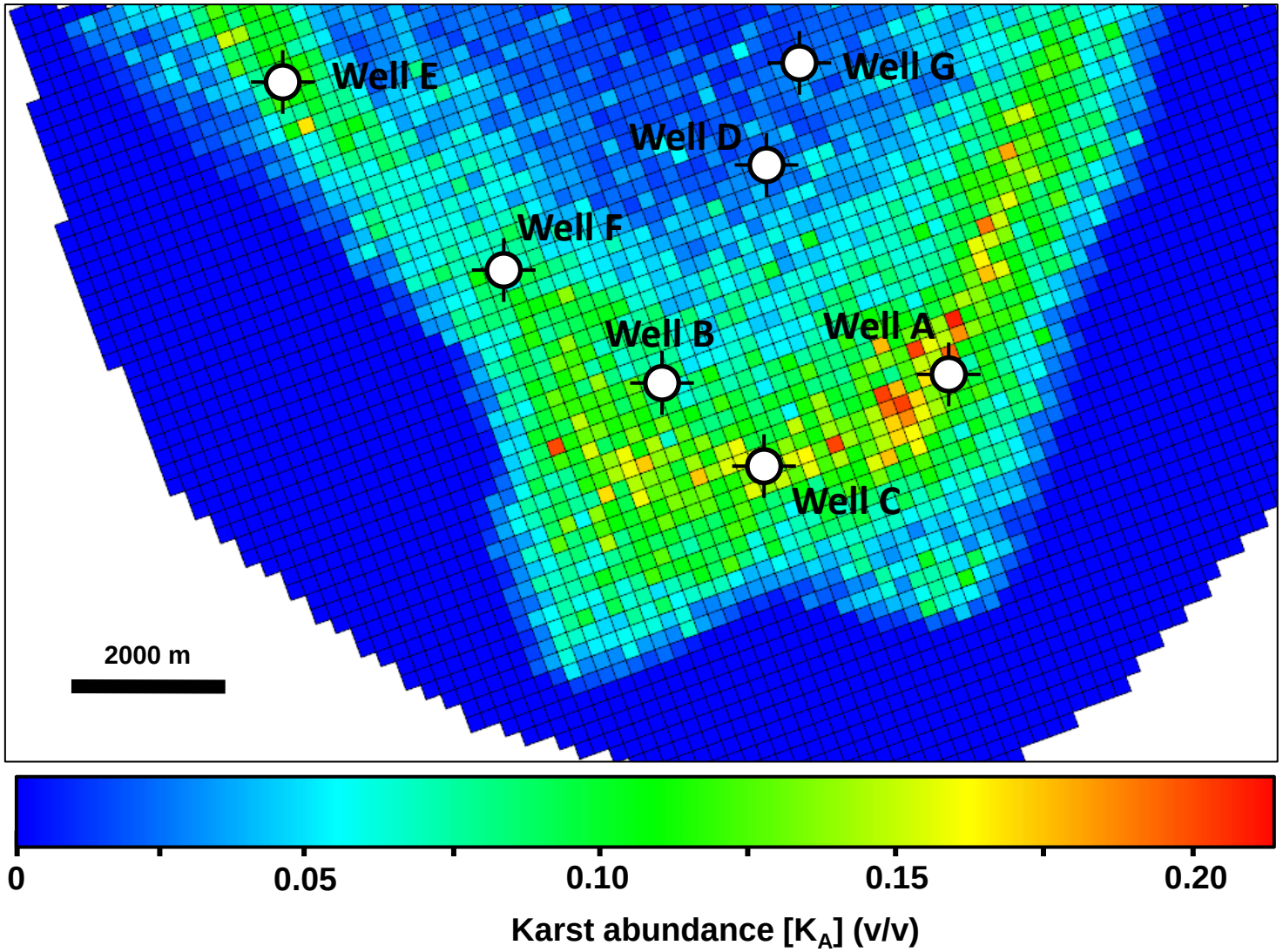






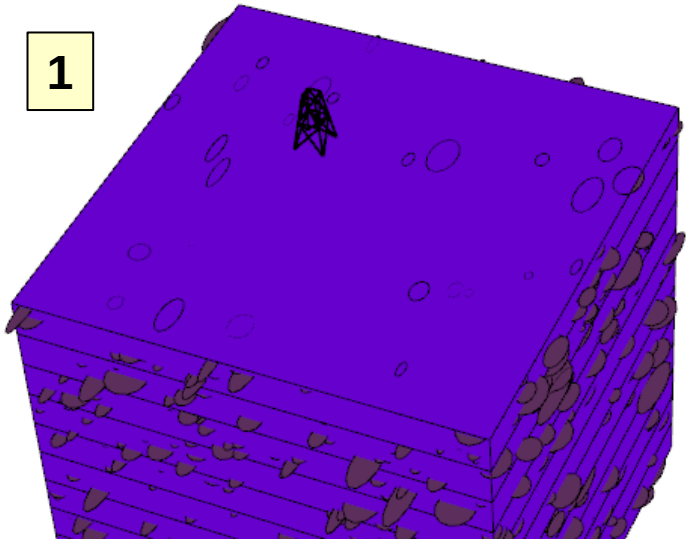
Karst Abundance: The Container



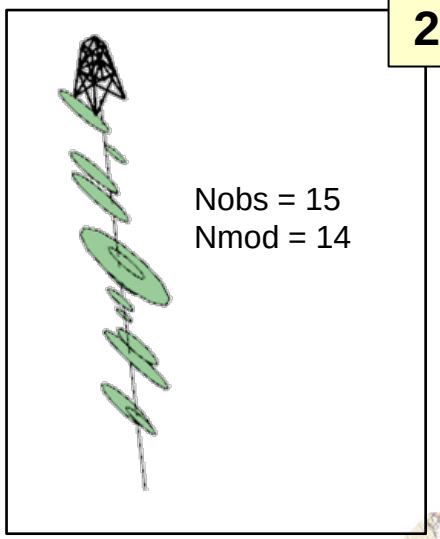


Model Validation (I)

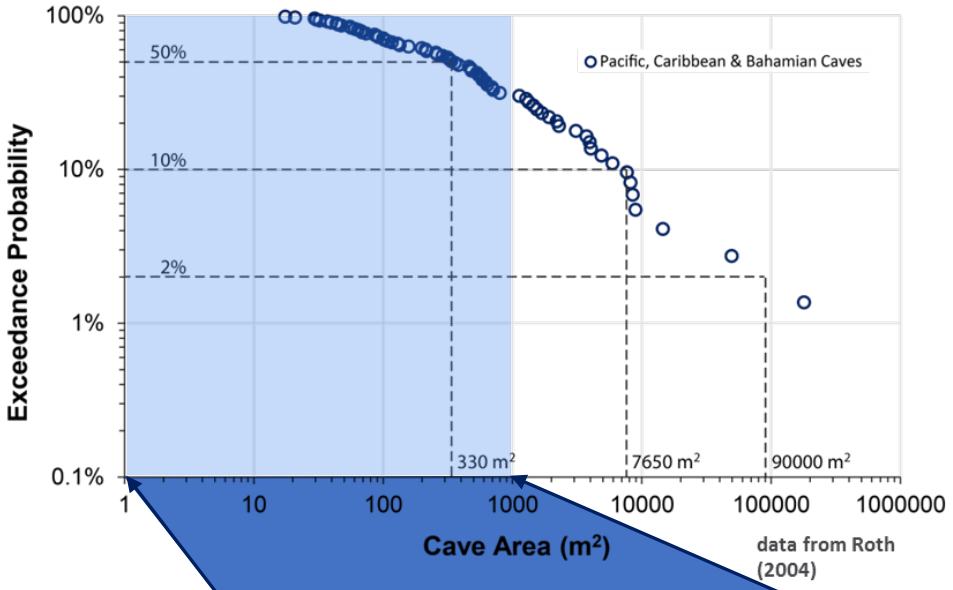
1. Discrete element model building
2. Karst density check at well locations
3. Area check against world-wide analogs

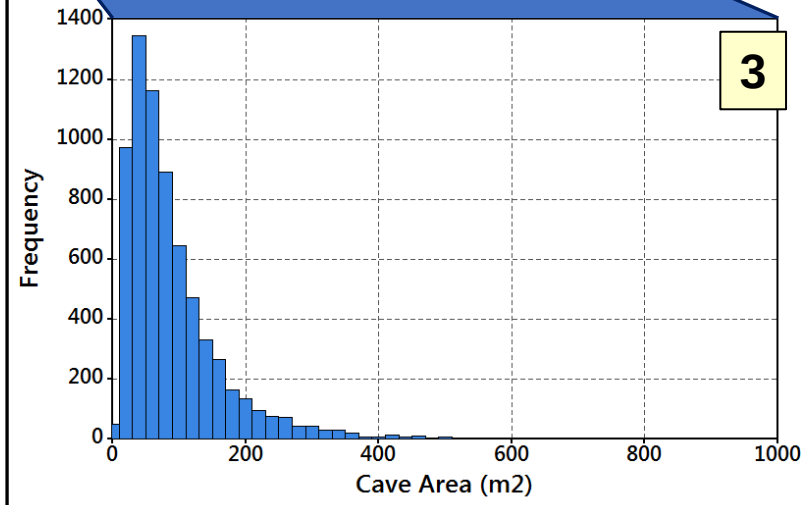


Discrete Karst Element Model



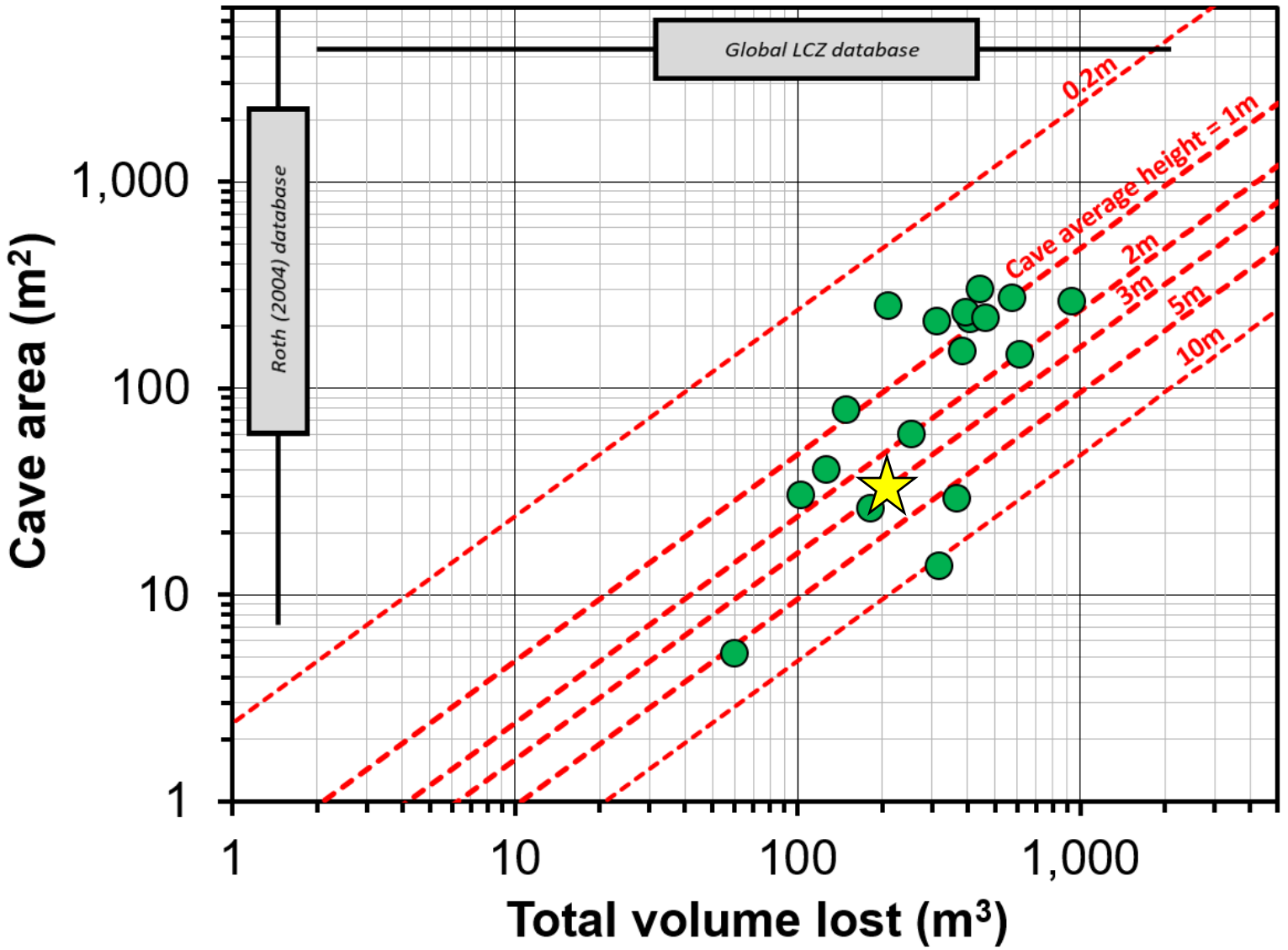
Density check

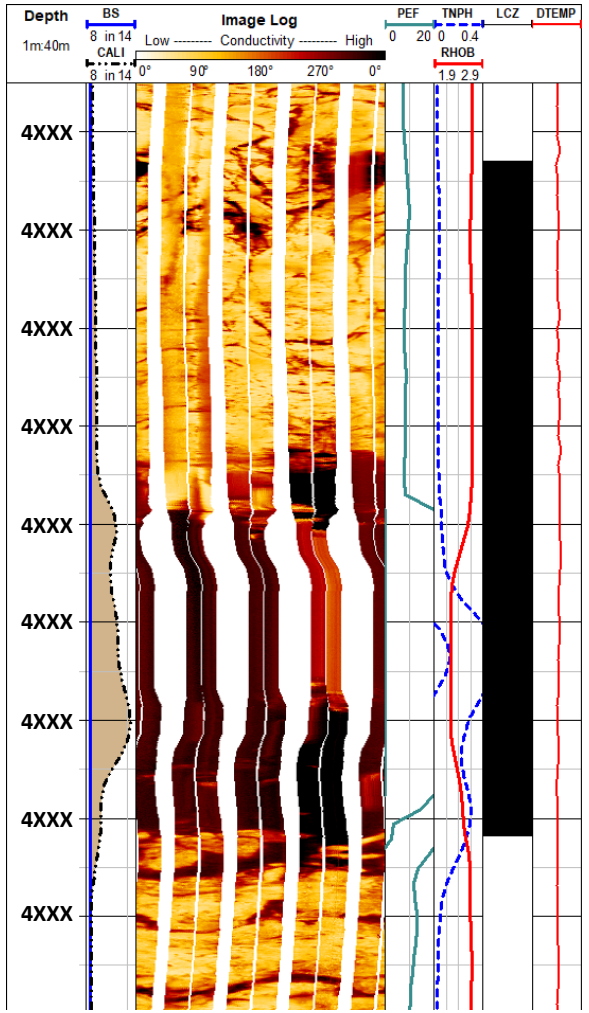




Area check

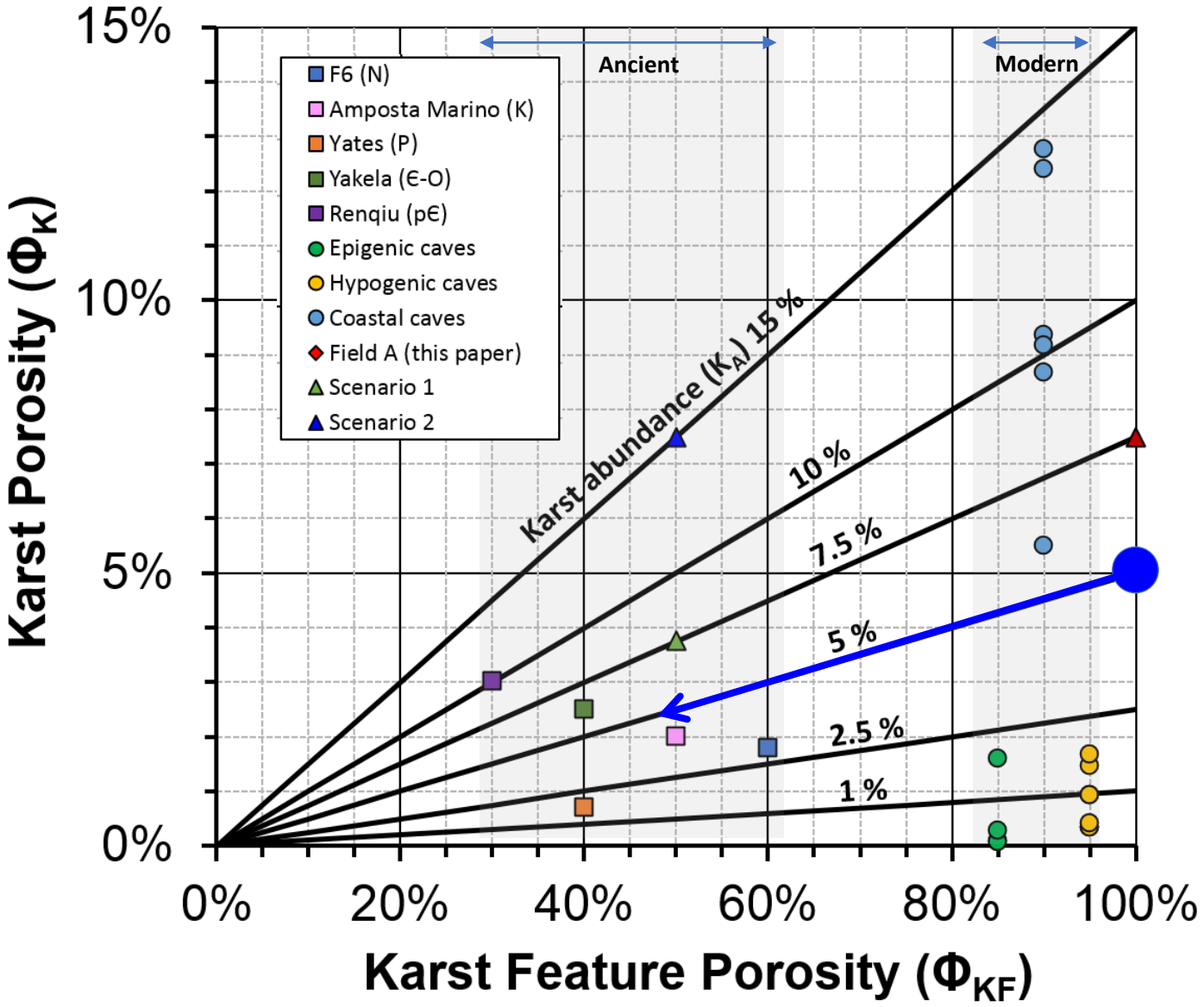
Validation (II): Lost Circulation Volume

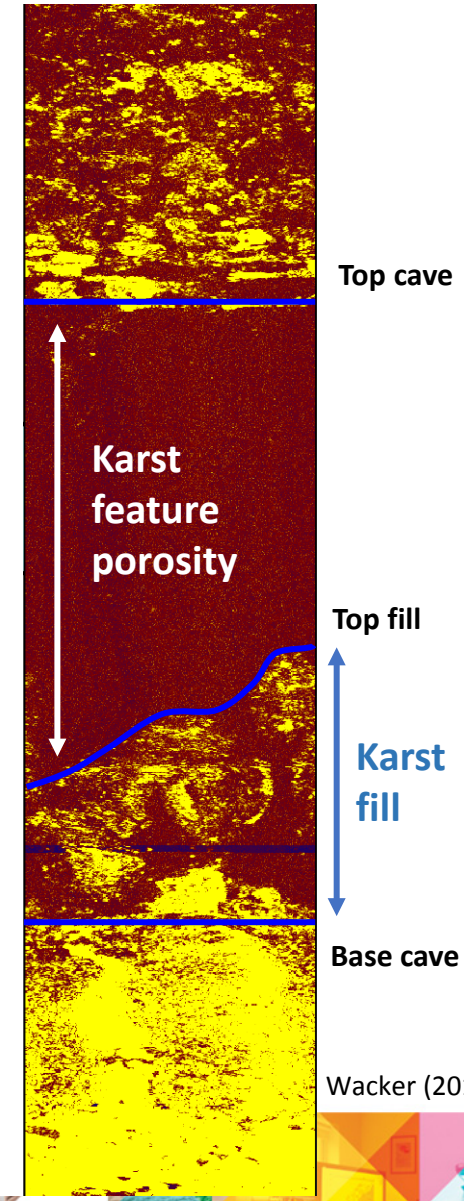




210 m^3 lost
3 m tall cave

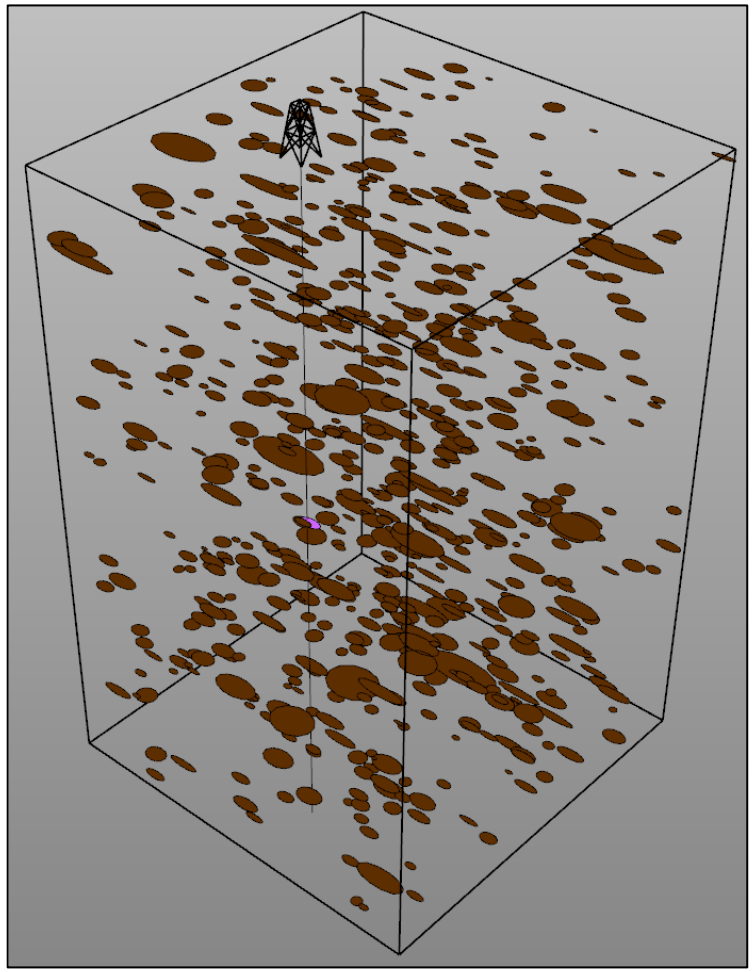
Karst Fill: Filling "The Container"

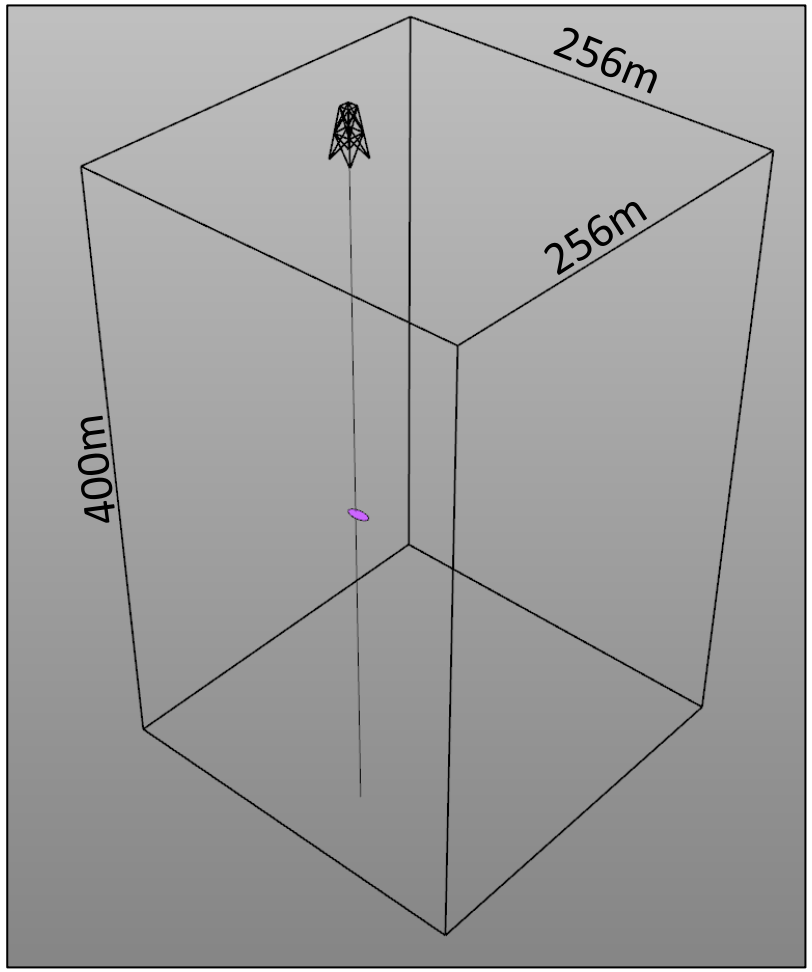


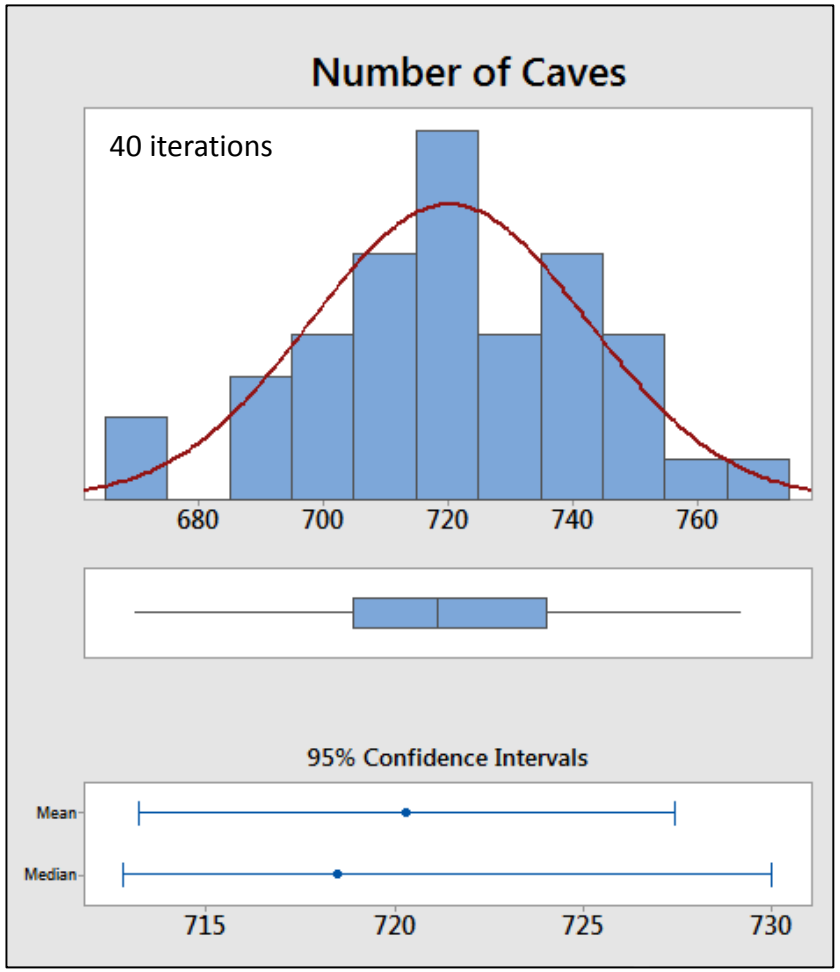


Wacker (2010)

Relevance of Intersecting a Cave







Conclusions

- Evaluating **resource size and dynamic performance uncertainty** in carbonate reservoirs with karst is a fundamental **industry challenge**
- Multidisciplinary data integration and karst evaluation from a **process-based approach** is a critical step in distributing abundance of karst features in the reservoir
- **Discrete "Karst" Networks** (DKN) can be used to populate different styles of karst. Flow-based scale averaging is used to calculate effective properties
- The advantage to using DFN type tools is that **the total non-matrix system** (fractures and karst) can be flowed to obtain combined effective properties and build DPDK models

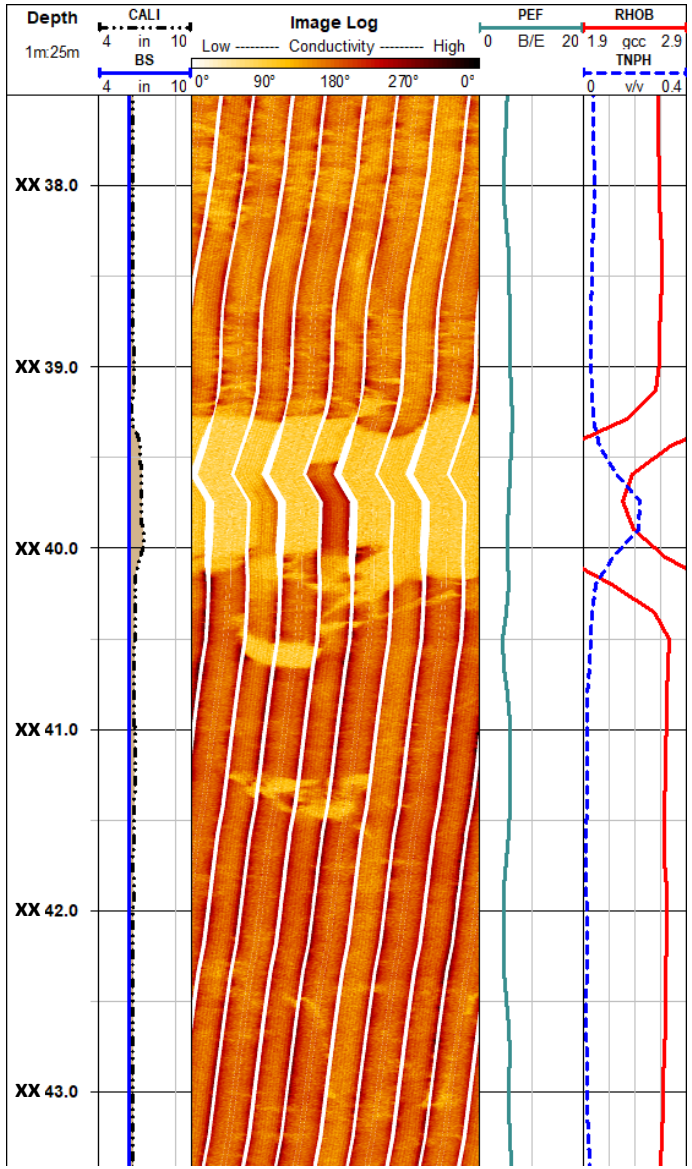
Thank you!

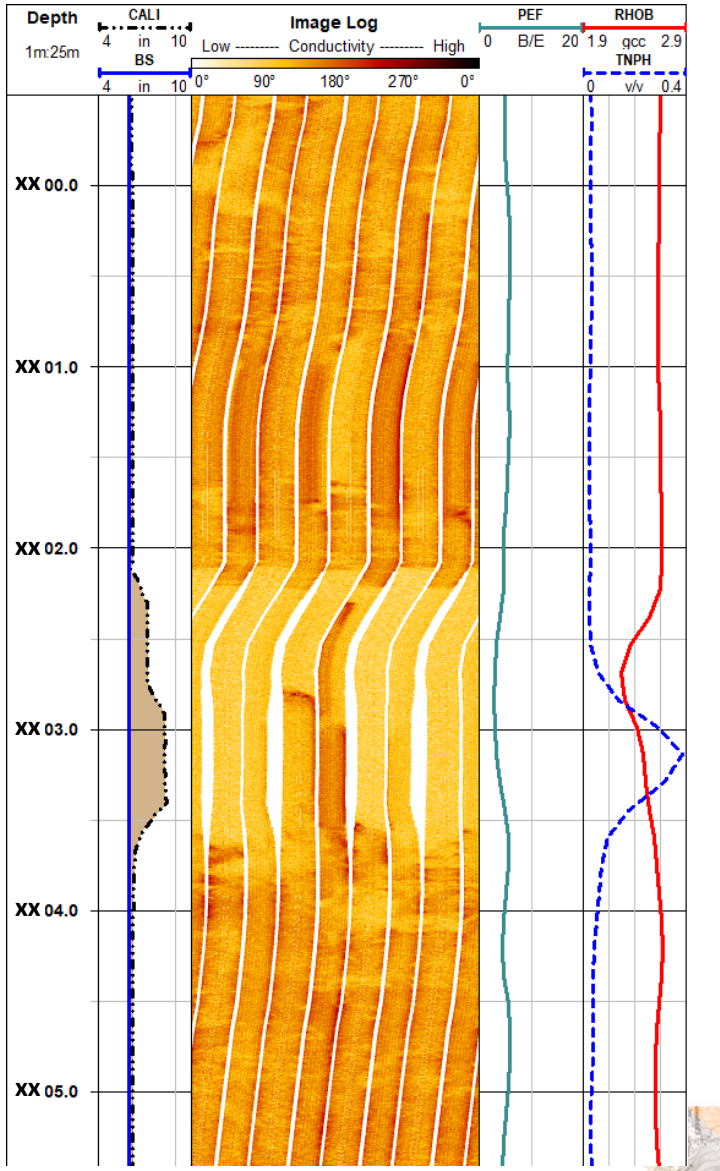
For more details on this work:

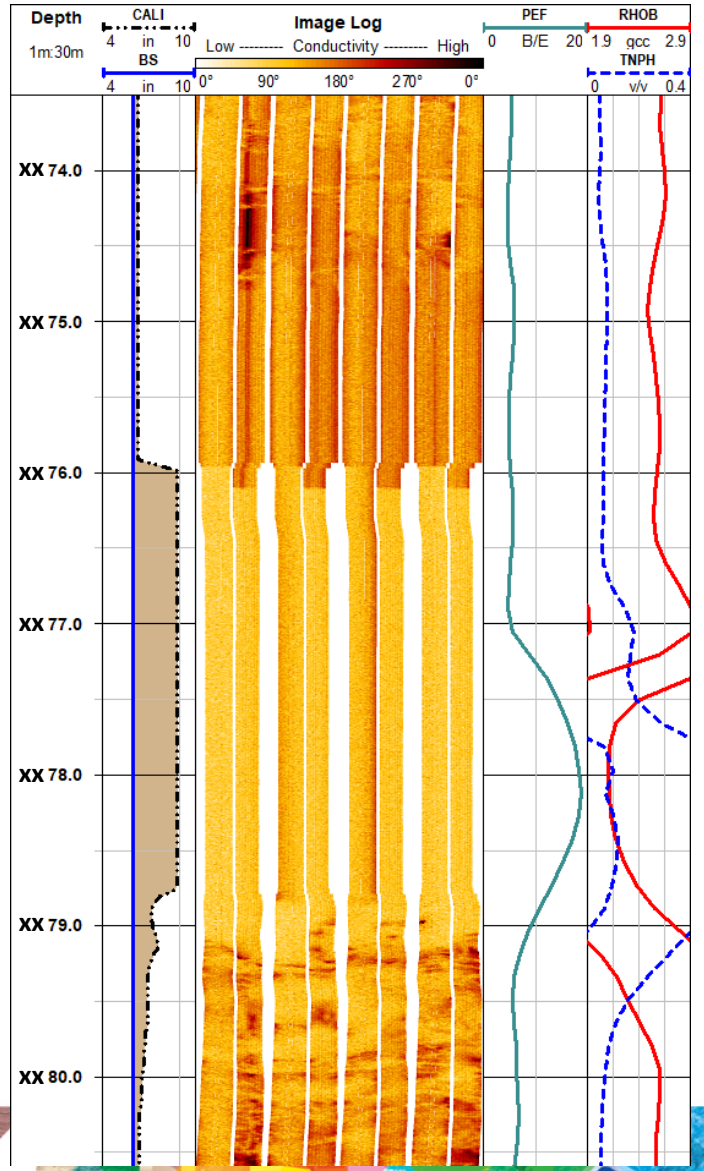
Fernandez-Ibanez et al. (2019) - AAPG Bulletin

Fernandez-Ibanez et al. (in press) – Journal of Petroleum Science and Engineering

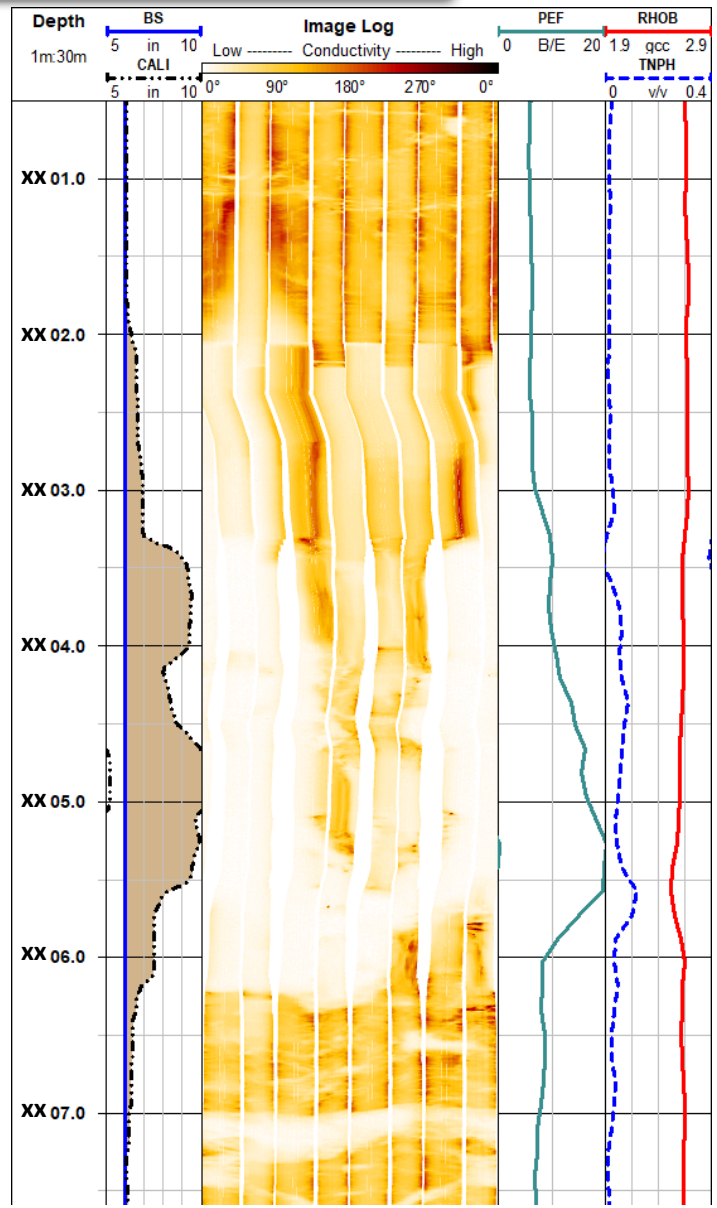
Subsurface Examples

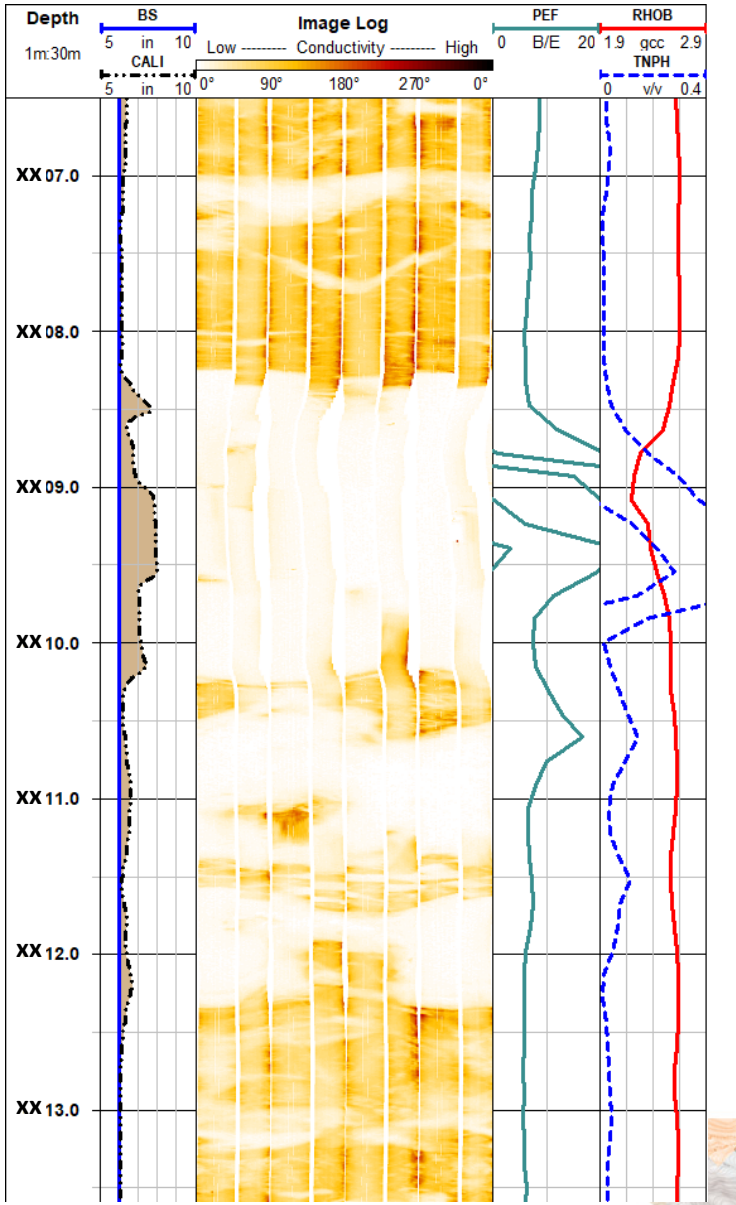


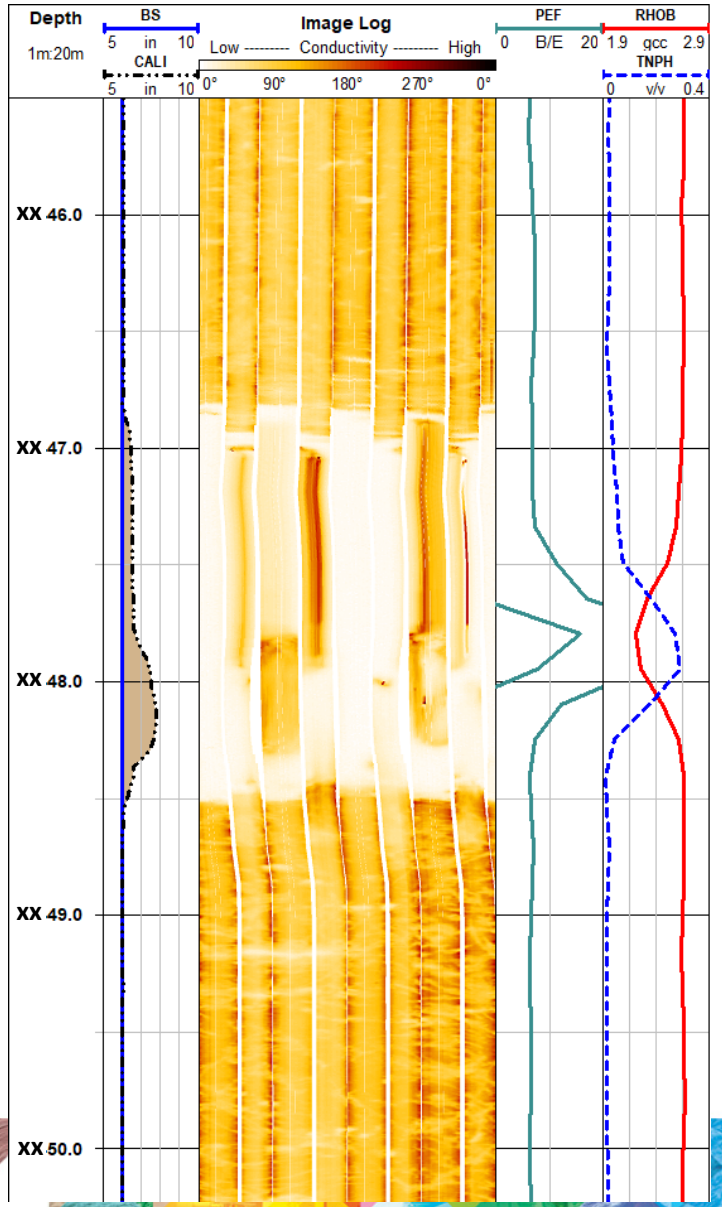




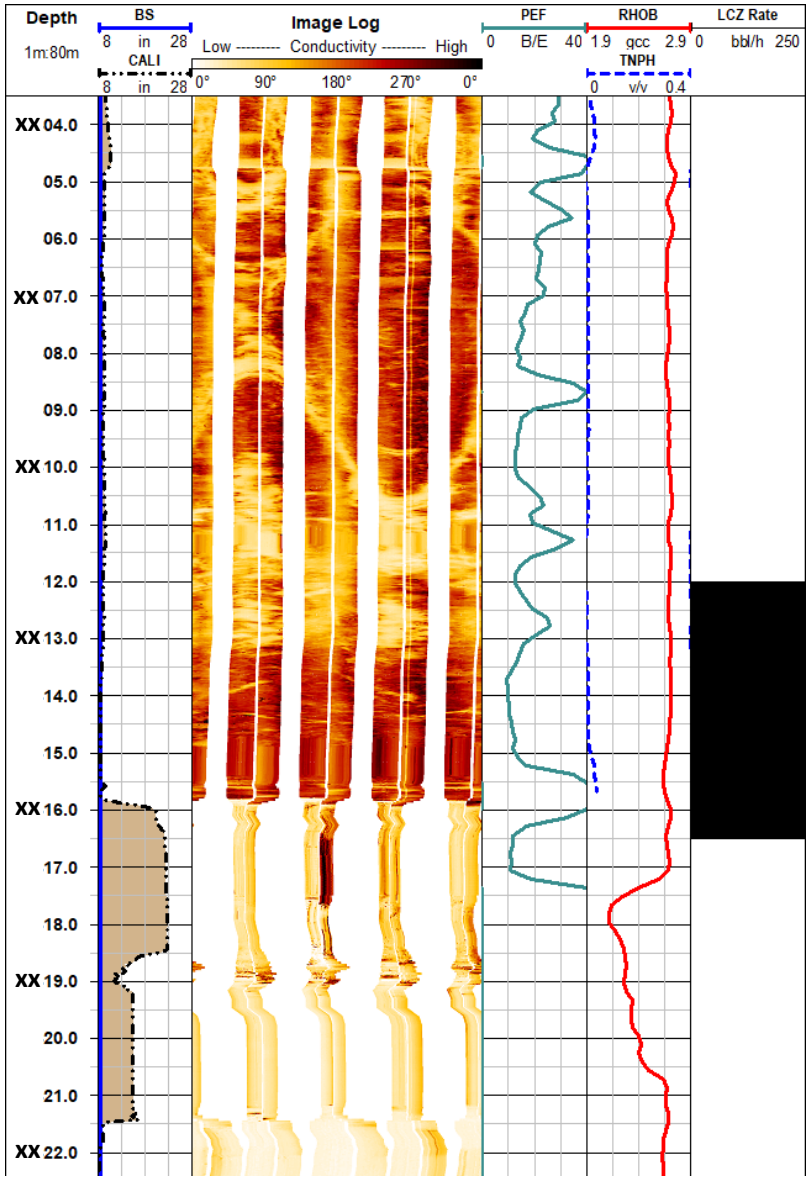
Subsurface Examples

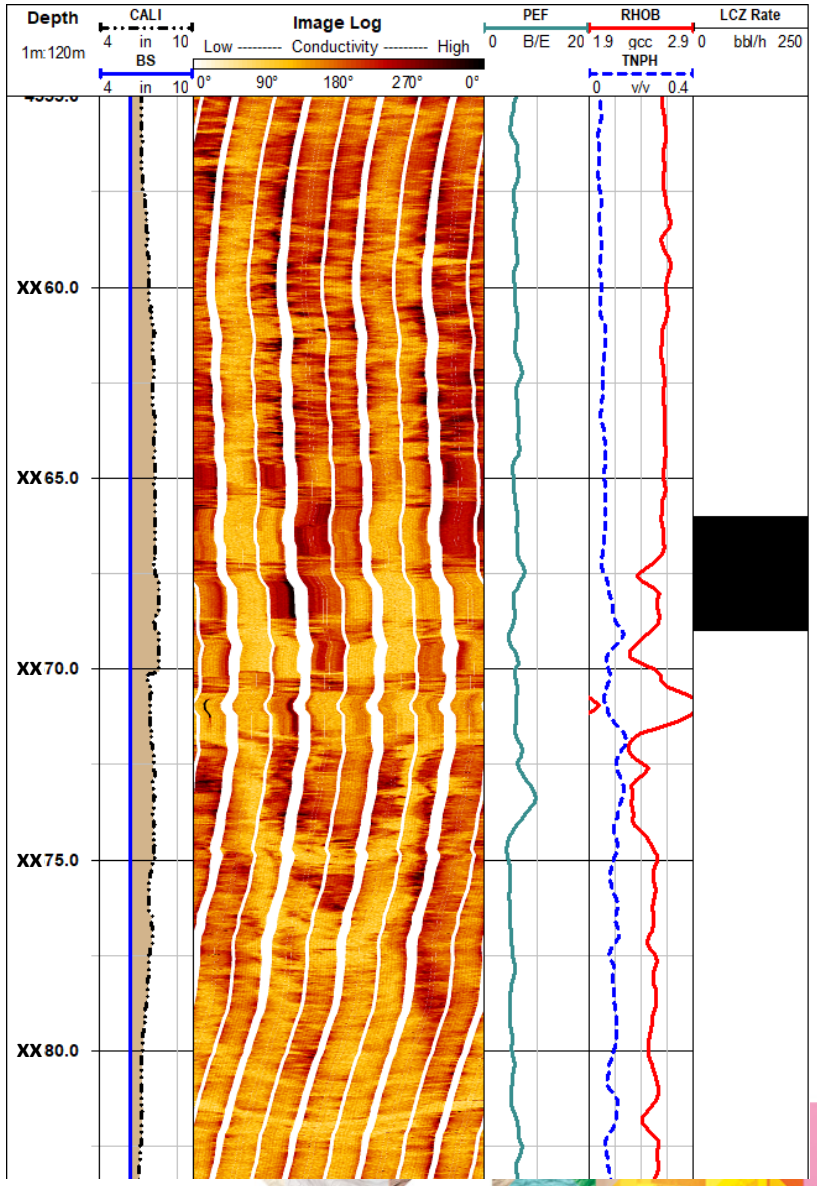




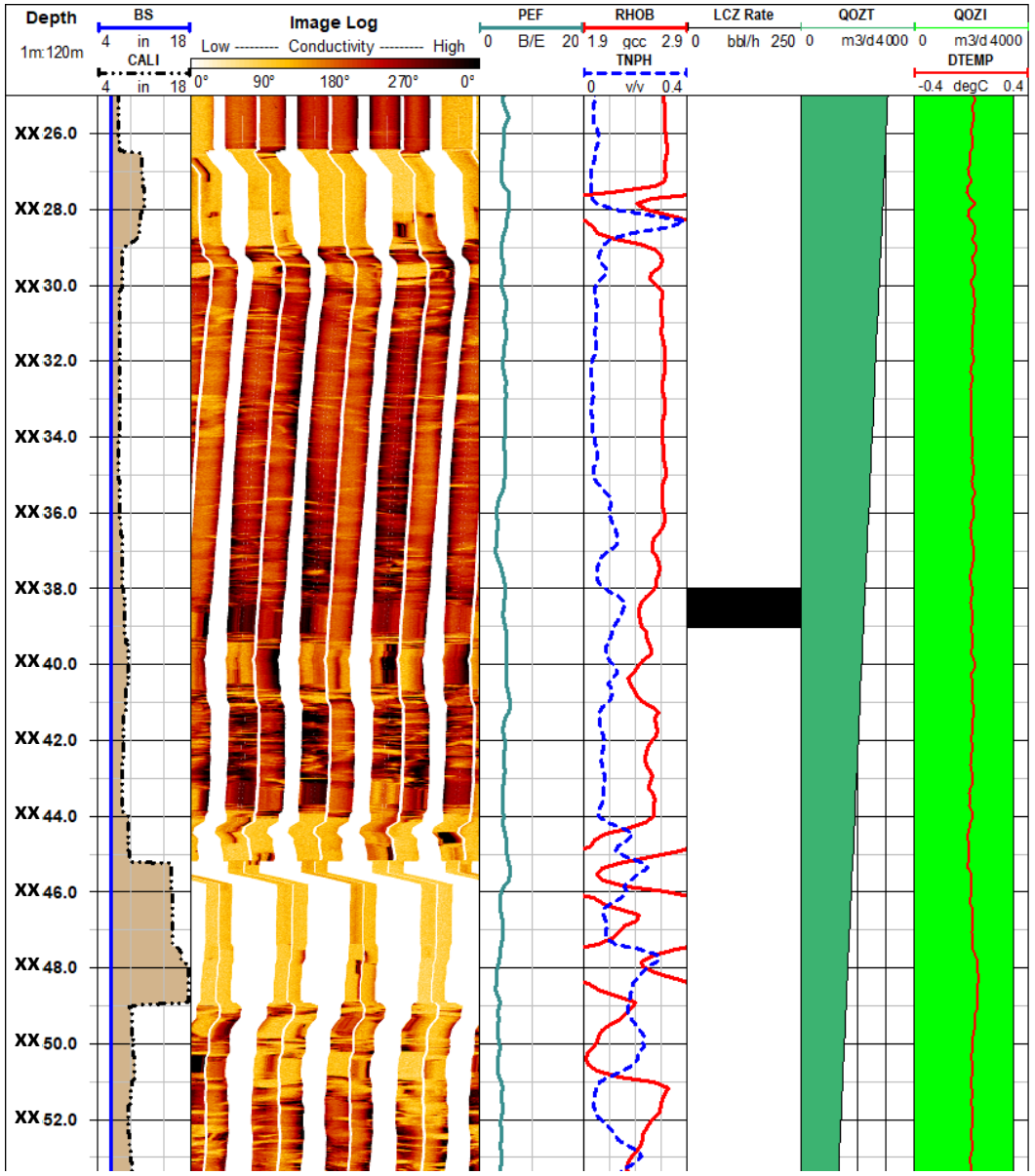


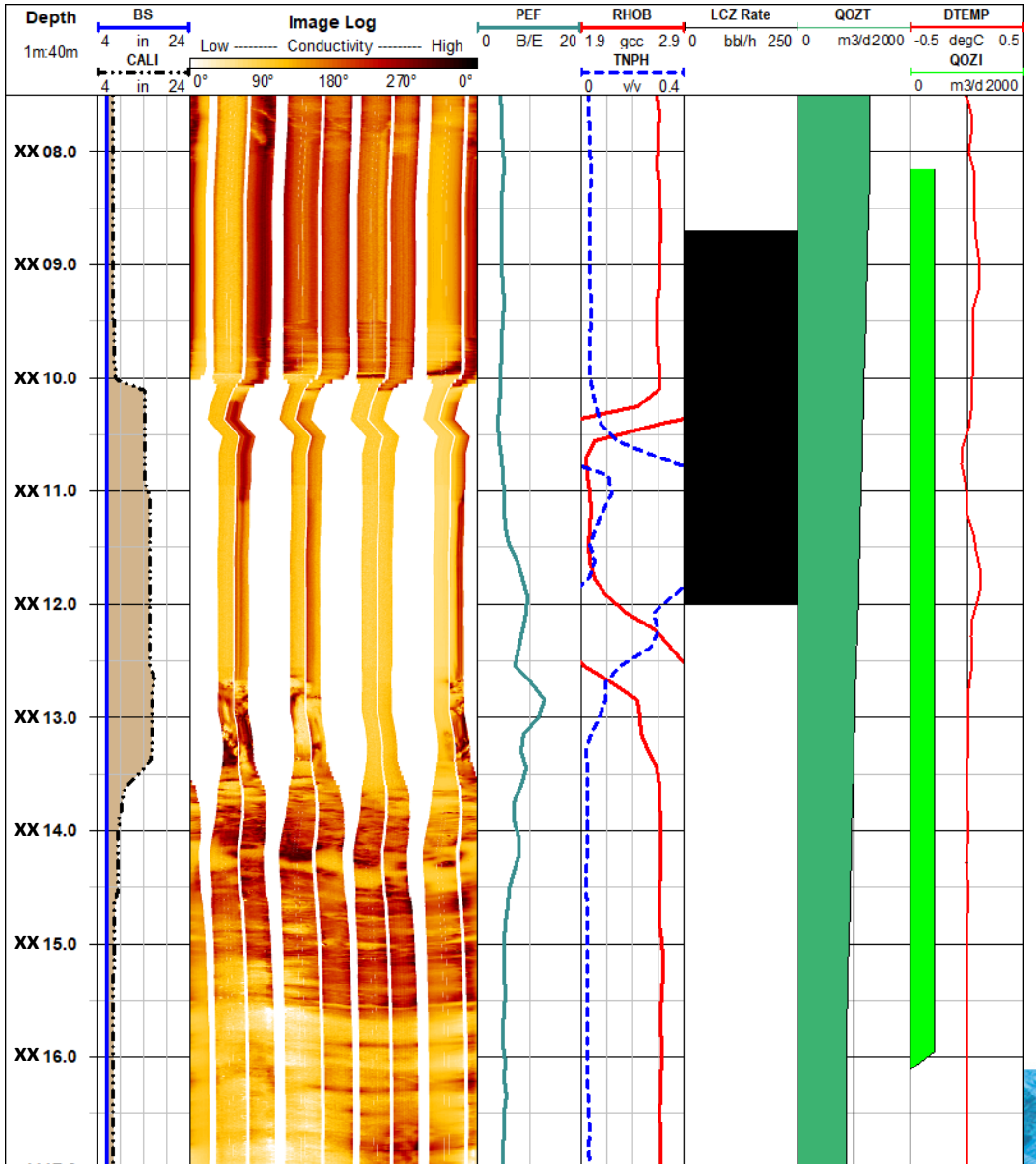
Subsurface Example





Subsurface Example





Sensitivity Analysis