CCS Data Analytics

i) Introduction

From the technical point of view, CCS is a mature technology with more than 50 years' experience, hence it is the least expected technology to fail, however a recent report of IEEFA (2022) concluded that the failed projects considerably outnumbered the successfully implemented ones. While the technological expertise is already in place, the nature of scaling up its storage capacity is inherently interdisciplinary depending on also other socio-political dynamics of CCS. This is what the author wishes to achieve here. To detect and quantify the most important factors in the accomplishment of CCS projects and to develop models to predict the chance of the coming project success.

- Net-Zero Industry Act in EU aims to have **50 Mtpa** of CO2 storage developed **by 2030**.
- CCUS Net Zero Investment Roadmap in UK: **20 to 30 Mtpa** of CCS capacity installed **by 2030**.
- US Inflation Reduction Act concludes that: **200 to 250 Mtpa** of CO2.
- Japan's CCS Long-Term Roadmap: trajectory towards **240 Mtpa** CO2 stored **by 2050**.
- Saudi Arabia has announced a target of capturing and storing **44 Mtpa** CO2 **by 2035**.

Achieving global climate targets will require annual CO2 storage rates of approximately 1 Gt by 2030, growing to around 10 Gtpa by 2050.

Global energy-related CO2 emissions grew in 2022 by 0.9%, or 321 million tonnes, reaching a new high of more than 36.8 billion tonnes(Gt).

ii) Project Description

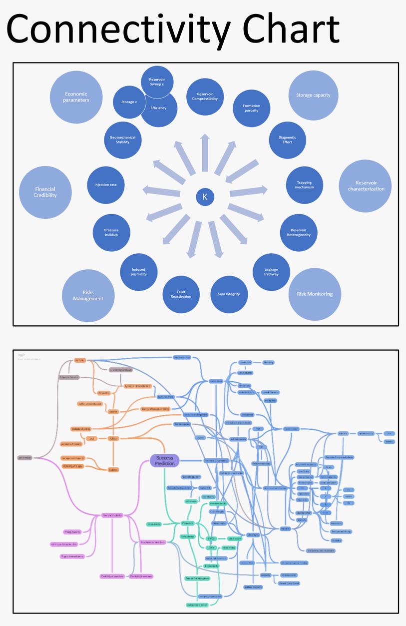
This work aims to combine all CCS datasheets into one CCS database and then through two different analytical and data-driven approaches, recognizes the most important attributes that are relevant in successful implementation of a CCS project.

iii) Methodology

Conceptual Approach

This approach is based on human insight, where the connectivity and relativeness of different attributes define the important variables. Then through constructing a project pathway, these variables are weighted and key ones will be recognized. Application of graph theory is useful here.

Figure 1. Conceptual Association & Connectivity Chart



Nodes are representing contributing attributes. where number of connections shows the impotence degree of an attribute.

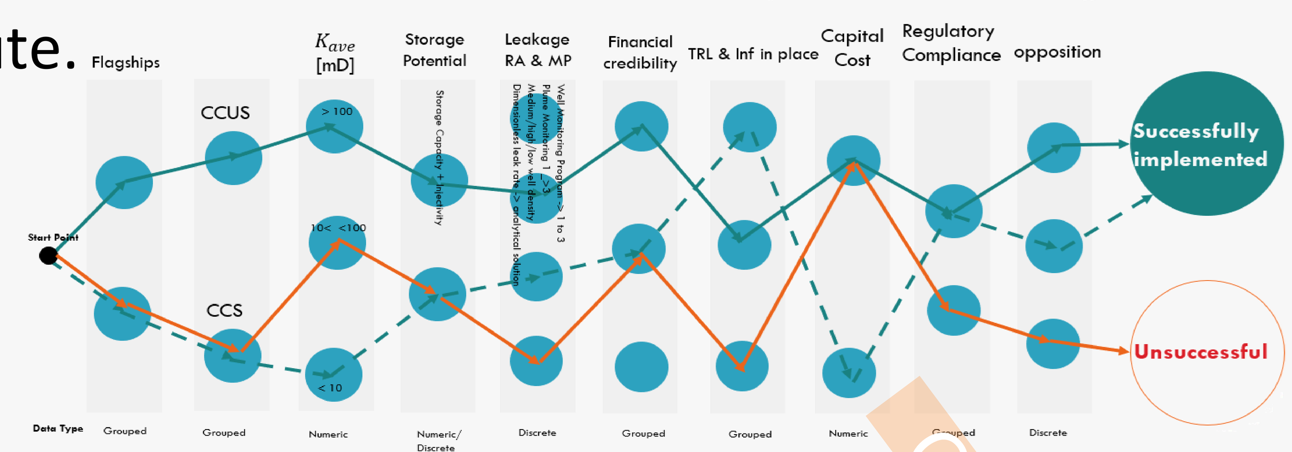
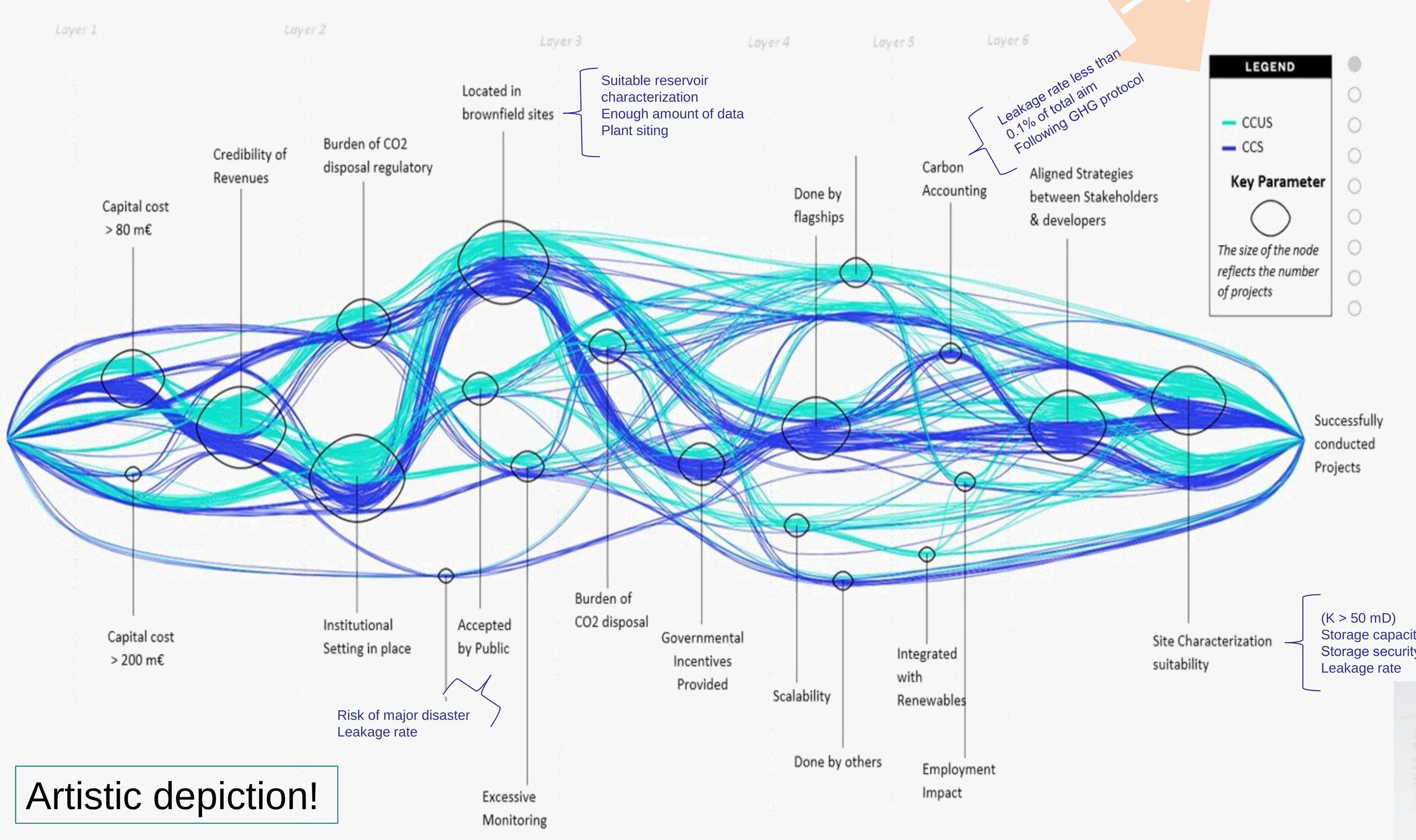


Figure 2. Constructing a Project pathway chart



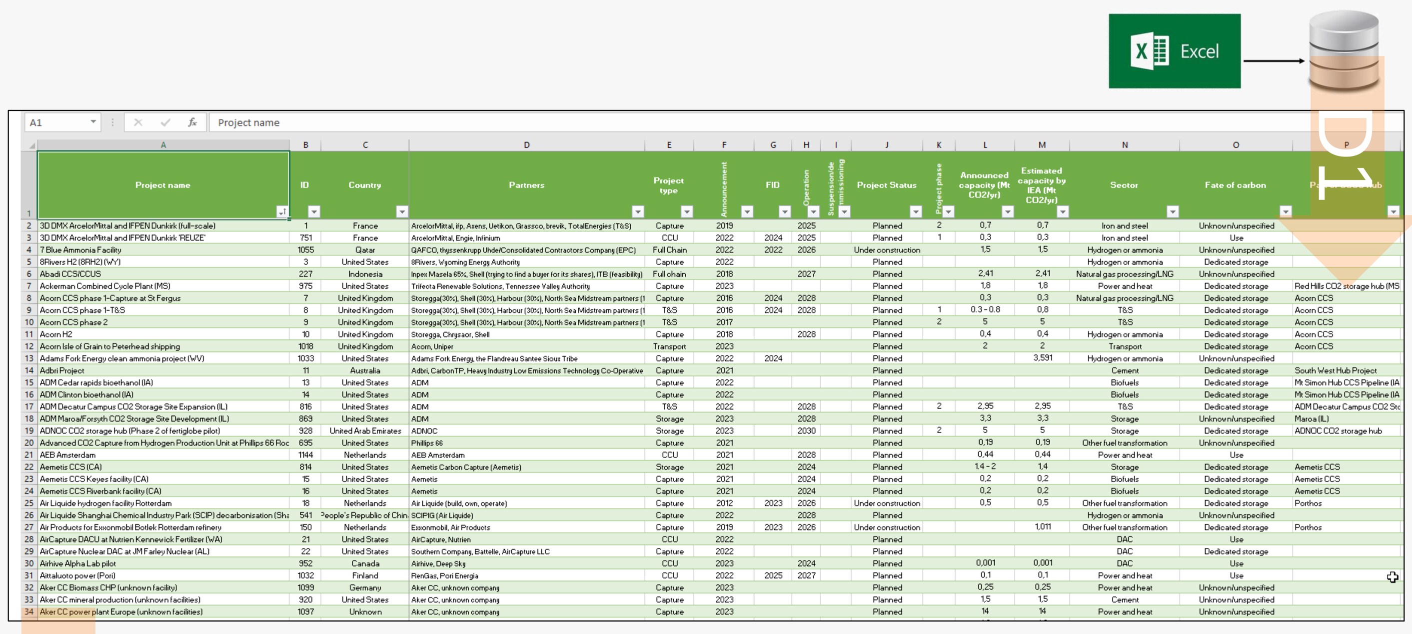
Artistic depiction!

Data-driven Approach-Conducting approximation

This approach is based on extracting insight from the data after visualization and analysis.

- This was a target-oriented problem.
- An imbalanced categorial data with 12 features with our target variable to be success/failure of a CCS project.
- The initial database was relatively raw so a pre-processing was necessary

1. Pre-processing(organizing the data, removing NaN, outlier removal) resulted into a 403 x 15 matrix with 12th features.
2. One-Hot Encoding
3. PCA was done (a Dim-reduction technique which sacrifices the accuracy as it is a linear transformation of the space)



Classification Model	F1 Score
Naïve bayes	0,176
LDA	0,565
Decision Tree	0,648

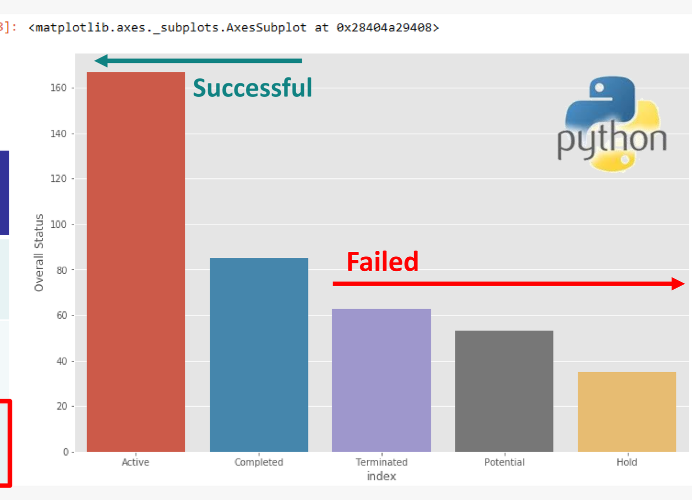
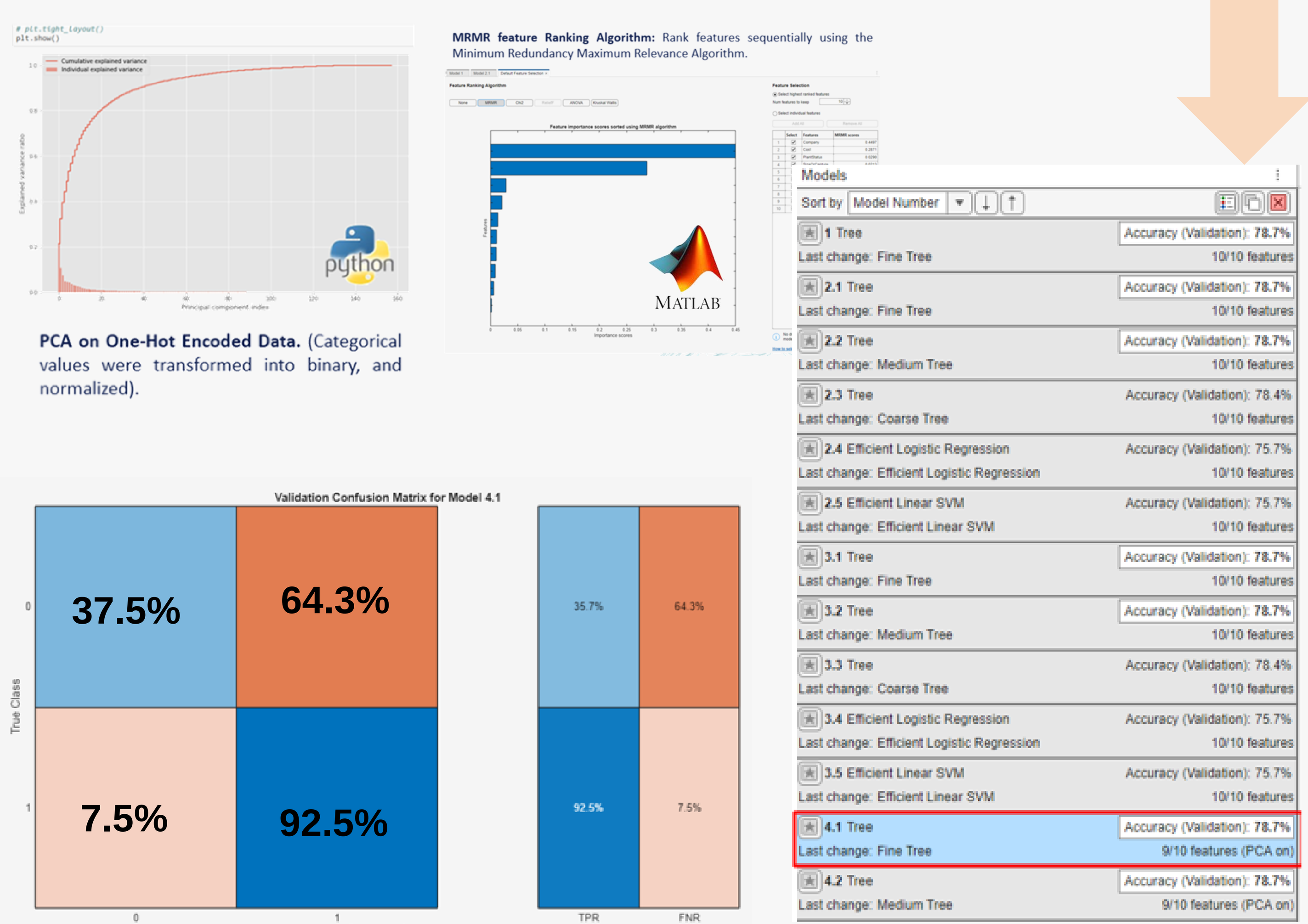


Figure 3. Establishing the back-end Platform for CCS data analytics

Data-driven Approach-PCL implementation



iv) Results & verification

To validate the outcome, both approaches need to detect same key variables as the most influential attributes of a CCS project.

Results will also be verified via 'train-validation-test split' approach.

The 10 most important KPIs so far, are:

- Capture Efficiency
- Carbon Accounting
- Total Cost
- Storage Capacity
- Leakage Rates
- Regulatory Compliance
- Public Acceptance(location)
- Environmental Impact (location)
- Financial Viability
- Risk Management & Monitoring
- Reservoir Characterization

Figure 4. Project Pathway chart for 40 successful projects

CCS Booster & Bespoke Lab

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Improving Mineral Detection Through Topological Investigation

Introduction & Recap (2020-2021)

Traditional mineral investigation techniques are normally destructive and although providing useful information, they come with disadvantages some of which cannot be ignored. An example is the mechanical damage in the preparation process of SEM scanning. Moreover, the destructive methods inherently prevent us from directly comparing unique samples prior to and after a particular test.

DAWI (Digital Assessment of Well Integrity) is an initiative of the CDC chair with the objective of reducing the assessment time of samples (cement, rock(core, cuttings). The theme involves the development of a non-destructive & comprehensive; yet fast workflow for the reliable estimation, and simulation of the petrophysical, geomechanical, and mineralogical characteristics of cement, rock and eventually other elements of well integrity.

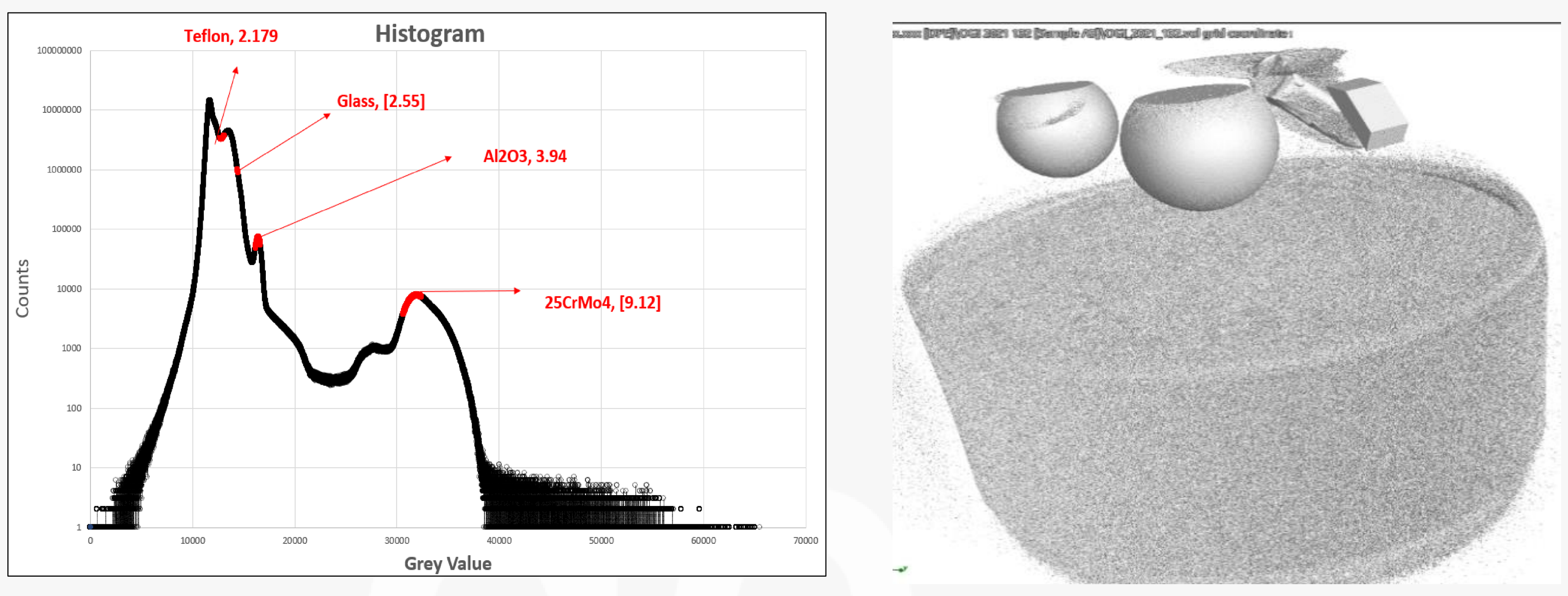


Figure 1. Conceptual Association & Connectivity Chart

Ref Material	Grey value	Std. deviation	Density [g/cm³]
Teflon	12943.88	192.01	2.179
Glass	14648.46	214.91	2.55
Al2O3	16441.85	244.09	3.94
25CrMo4	31557.09	892.04	9.12

Minerals	Density [g/cm3]	% Weight		% under/over estimation
		By µCT	Traditional Method	
Tectosilicates	2.2-4.35	48.40	74.8	-35%
Carbonates	2,7 & 2,8	9.96	9.4	+5,9%
Clay Minerals • Smectites • Illite • Kaolinites • Chlorites • Muscovites	2.0 -2.06 2.6-2.9 2.61-2.68 2.6-3.3 2.77-2.88	32.52	14,1	+130%
Rest • Heavy metals • Organic materials	> 4,65	9.11	1.7	+435%

Table 1 &2. UP>The calculated gray value and its standard deviation for the reference materials. DOWN> The comparison of mineral phase calculations between µCT calculation and X-ray diffraction measurements

Feasibility study I: µ-Fluidics (2020)

Microfluidics is the science of studying fluids that are restricted to a specific predefined sub-millimeter dimension and geometry. This science is a wide area covering mathematics, physics, engineering, biotechnology and other sciences. The geometry is provided by micromodels which are artificial 2D models of a porous medium and are commonly used to investigate and visualize small-scale physical, chemical, and biological processes.

Morphological image analysis proved to be extremely useful in obtaining valuable information from the microfluidic experiments. Extraction of interface perimeter as well as areal sweep plus remain oil inside it and separation of fluid phase from the surrounding pore space are some outstanding examples of its application.

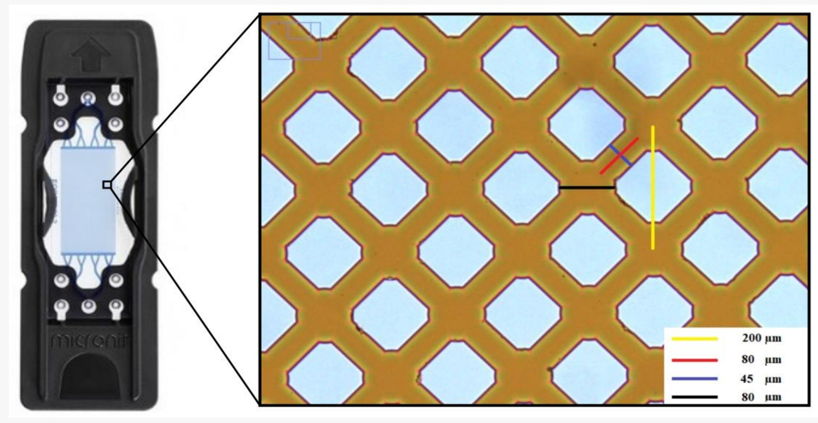


Figure 2. left) the uniform micromodel chip inside the black cartridge, and right) a zoomed-in area over the porous medium and its geometry.

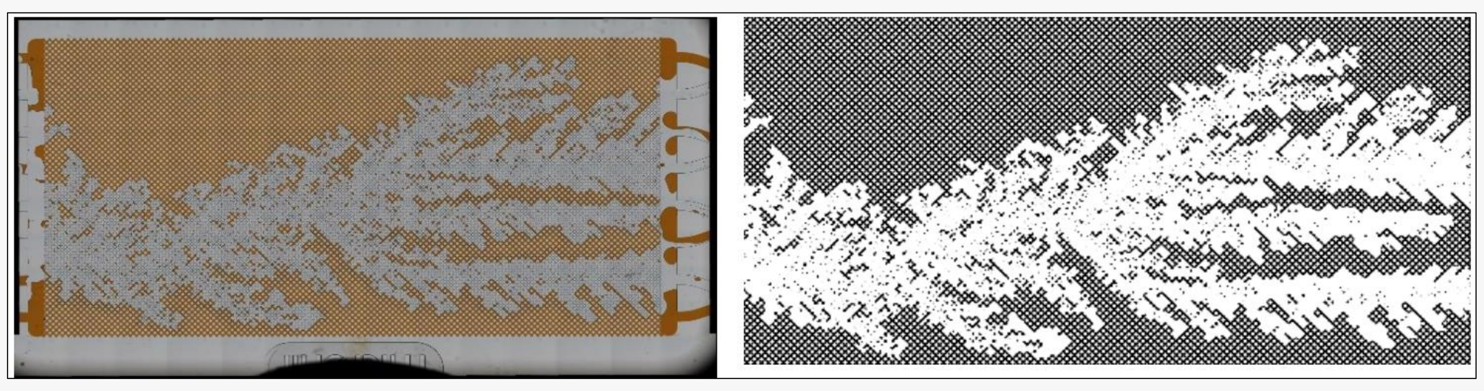


Figure 3. left) original RGB image and right) the processed image

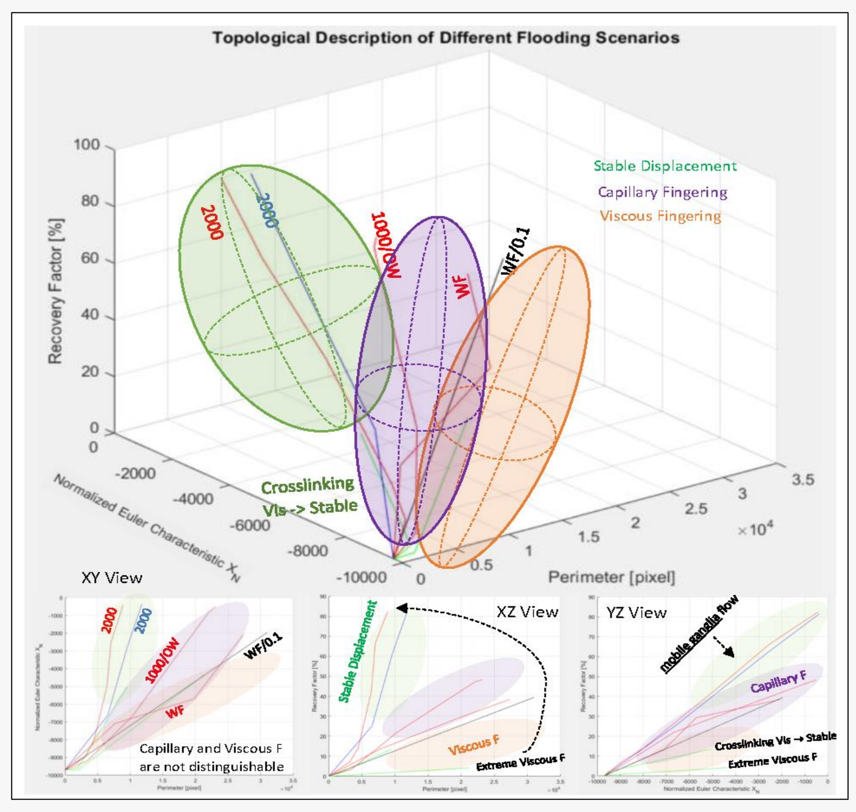
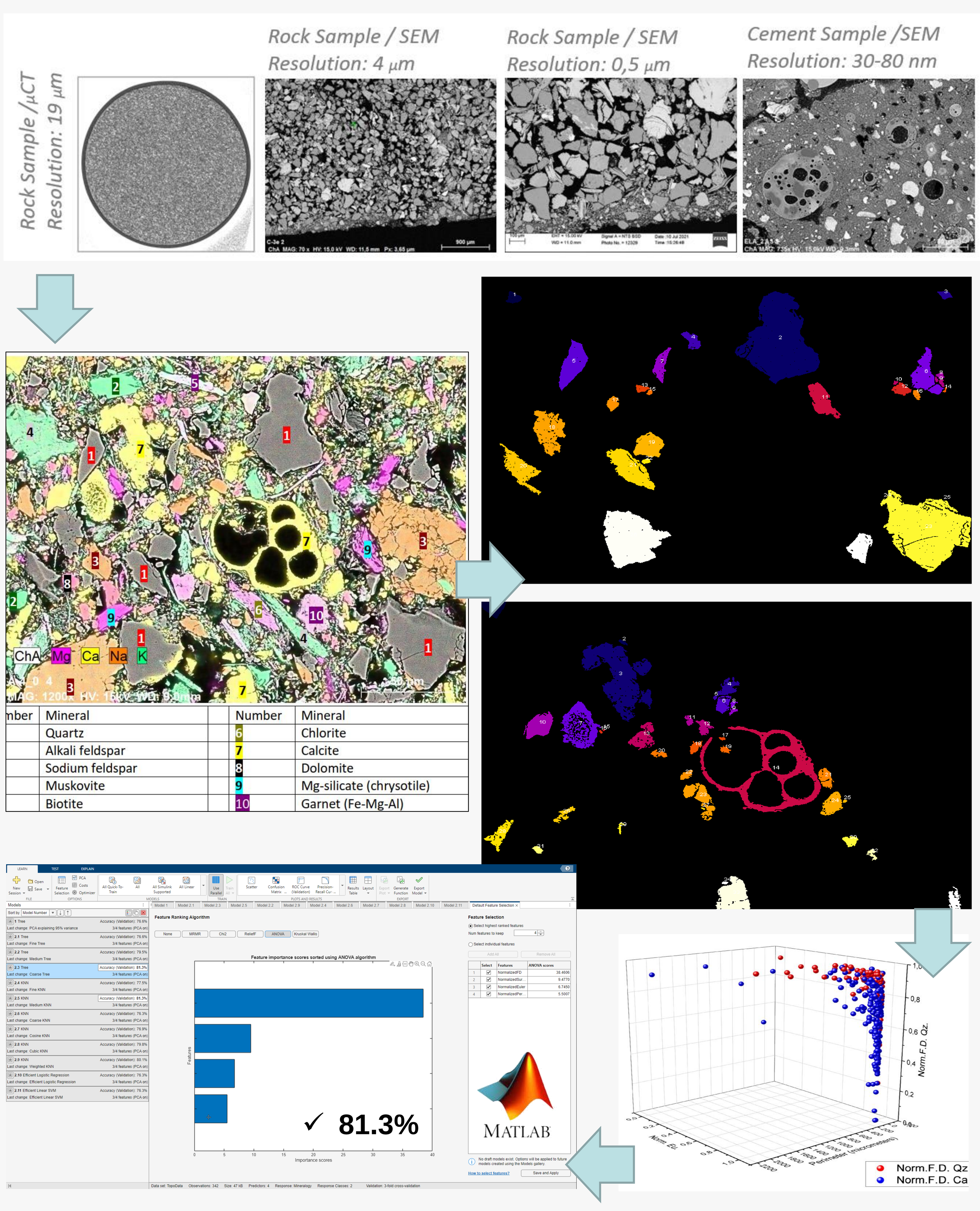


Figure 4. The 3D topological description of the flooding. Notice that the XZ view distinguishes the zone better than the other two, showing the sensitivity of both RF and Perimeter to the types of displacement.

Feasibility Study II: SEM (2023-2024)

We know that the combination of geometrical & topological parameters can unequivocally describe a shape as was proofed by the µ-fluidics study. In the current study we are exercising similar investigation on mineral masses which can be found in 2D SEM images. Should a trend be seen, these findings then will similarly be extended to 3D µCT datasets and will be combined with the density-attenuation model, to improve its accuracy.

Figure 5. Methodology to develop a topological model for mineral classification



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Connectivity Chart:

Attribute oriented for Permeability

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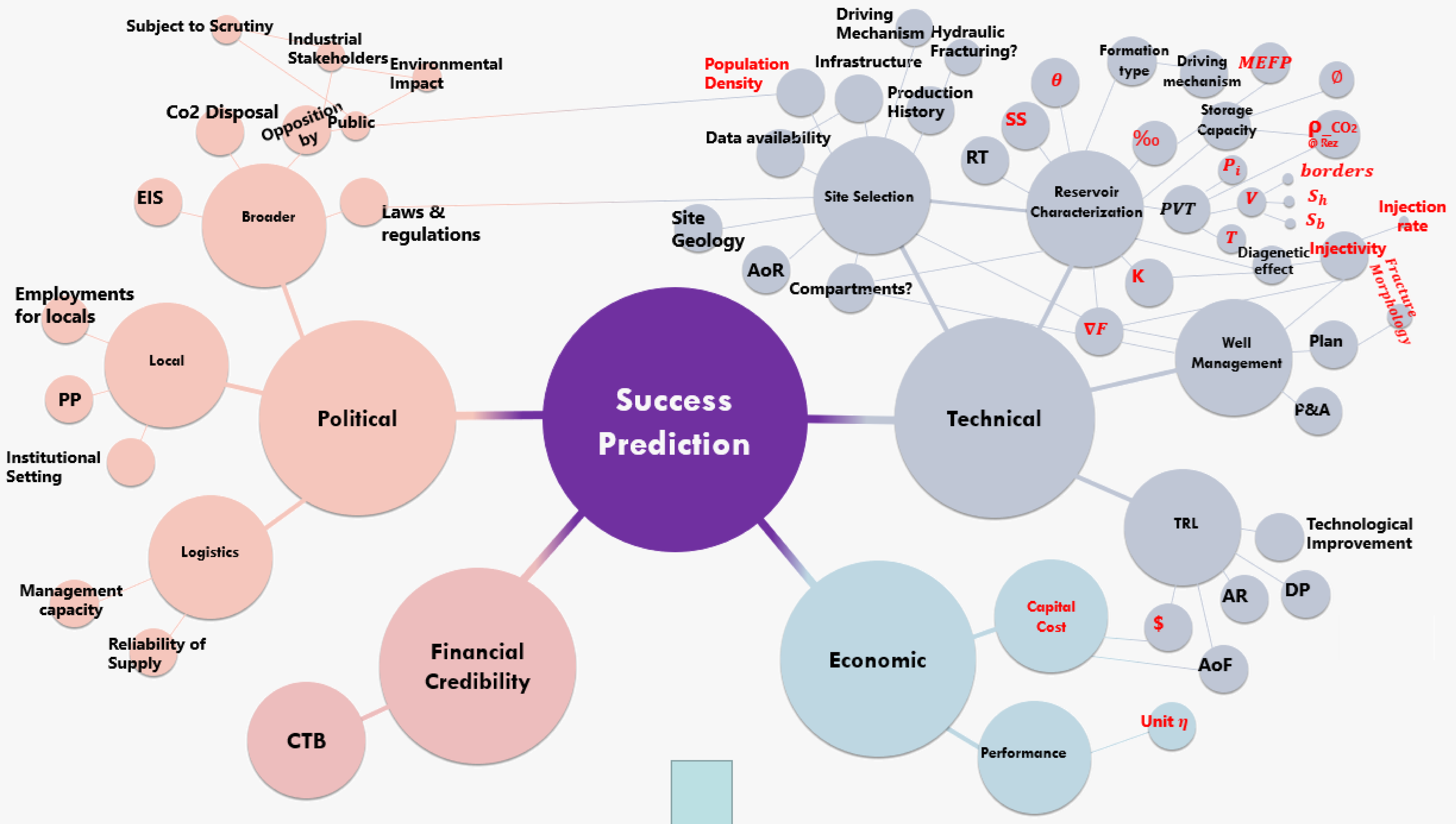
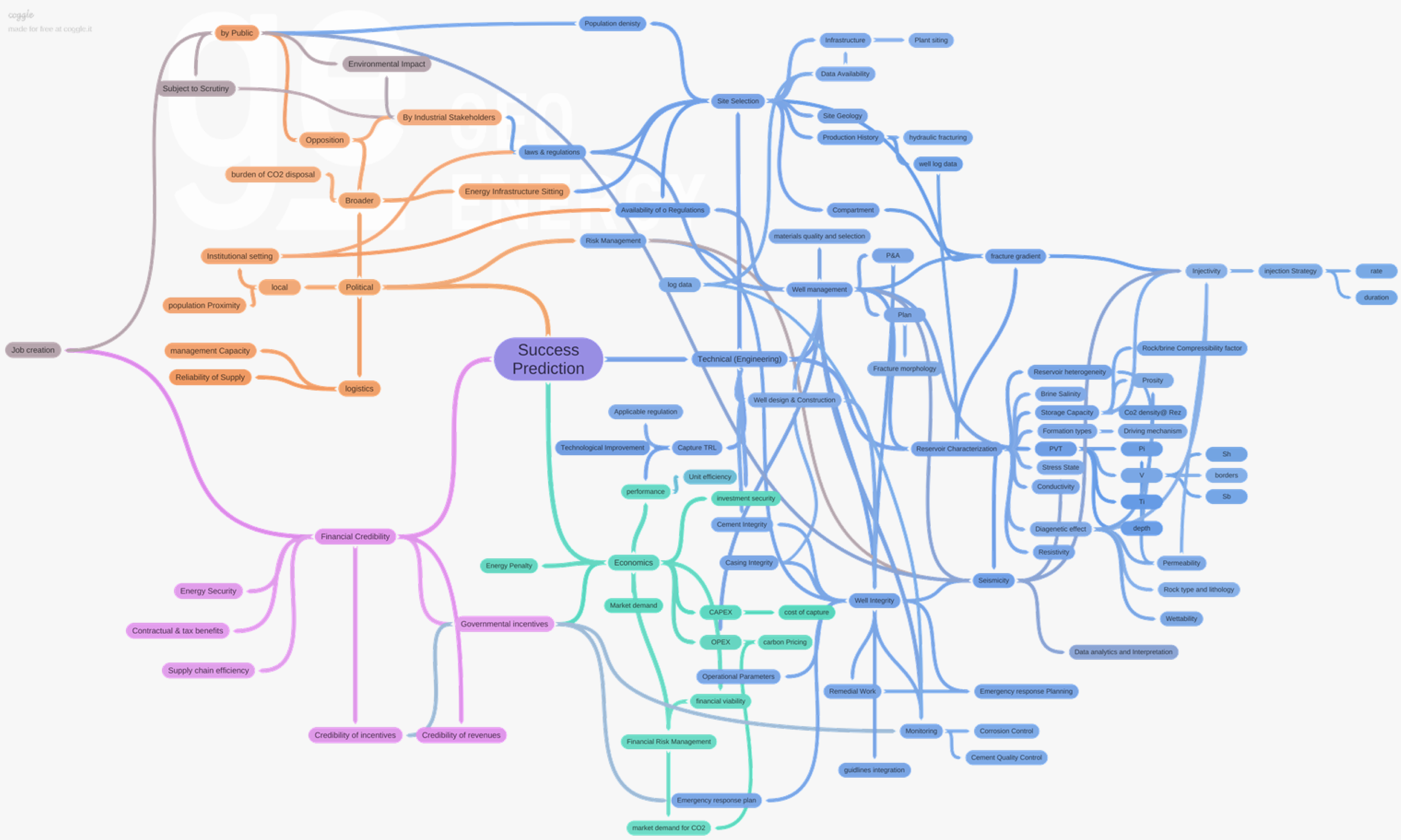
Connectivity Chart:





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Necessary Terminology

Analytical/Conceptual Approach	Data Analytics Approach

- **Attribute**

Any factor that has a role in implementation of a CCS project. Cases in point are project cost, project type (CCS vs CCUS), capture type, reservoir porosity and permeability, public opposition, governmental incentives and etc.

- **Association**

Indicates the relativeness between attributes and disciplines. For example porosity is related (associated) to reservoir properties which in turn related to technical data group.

- **Discipline**

Four major groups of the type of the attributes. Including technical, political, financial credibility and economic.

- **Connectivity chart**

Visualizing chart of the associations between attributes

- **Scale leaf (in connectivity chart)**

Different layers in the connectivity chart. First leaf is called discipline and the second leaf is characteristics

- **Connection**

This is equal to association once the connectivity chart is plotted for one variable.

- **Project path**

A chart showing the variety of the paths different project can reach successful implementation of CCS.

- **Layer (in projects pathway chart)**

A collection of the hub nodes which highlights the importance of parameters of characterization.

- **Feature**

In ML and pattern recognition, a feature is an individual measurable property of a phenomenon. For example in our case, if a project is EOR, its feature is CCUS.

- **Target variable**

This is the status of the project which is currently grouped under five categories namely, active, completed, terminated, potential and hold.

- **Algorithm**

A recipe that allows computers to learn and make predictions from data. Currently we are using three different algorithms.

- **Techniques**

Methods to used to simplify a large data set into a smaller set while still maintaining significant patterns and trends.

- **Model**

A model is a program that can find patterns or make decisions from a previously unseen dataset. In our case. Our model is an EDA (Explanatory Data Analysis) model with the objective of predicting the outcome of a CCS project.

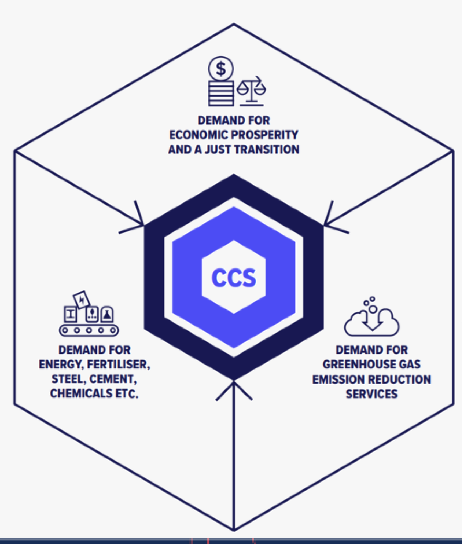
Project Methodology

Analytical/Conceptual Approach

- **Based on:**
  - Human logic
  - Application of graph theory
  - Manual extraction of data from all available sources and combine them into one database
- ✓ **Advantages:**
  - ✓ Sensible results
  - ✓ Attributes are representative
- × **Disadvantages**
  - × Time-consuming
  - × Limited Database
  - × Not directly related to data
- **Current Status:**
- A database including successfully implemented 40 projects
- 10 Key data have been extracted
- Through a project pathway chart, the key data are updated to be more representative of the implemented projects
- **Room to improve:**
- Key data could be updated after the improvement of database, visualization of more project pathways and confirmation of layers
- Atomization of the process is possible

Data Analytics Approach

- **Based on:**
  - Machine learning Algorithms
  - Application of statistical theory
  - Using the already provided datasheets and combine them into a database
- ✓ **Advantages**
  - ✓ Fast and reliable methodology
  - ✓ More room to maneuver
- × **Disadvantages**
  - × Attributes of database are not fully representative
  - × Making sense of the results are necessary
- **Current Status**
- Initial datasheet included 413 projects and 39 attributes which reduced to 403 project with 12 attributes after pre-processing.
- 3 ML algorithms were used with the highest accuracy of 65%
- **Room to improve:**
- better initial dataset qualitatively and quantitatively will improve the models outcome
- There could be more algorithms to apply
- Application of fine-tuning process.



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Main Deliverables of Core Analysis

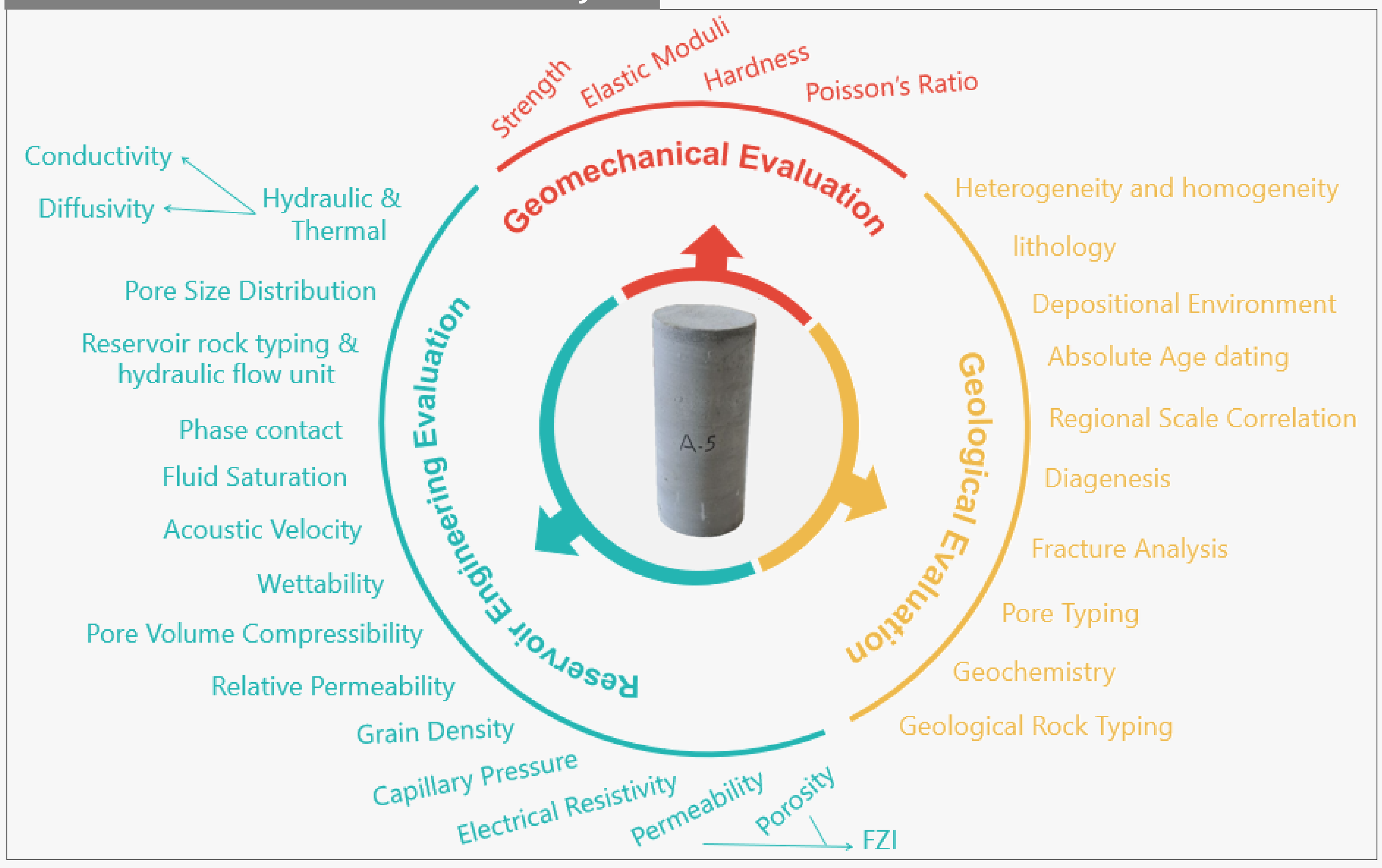

Figure 6.

Main Deliverables of DAWI (initial stage- cement/rock-cutting assessment)

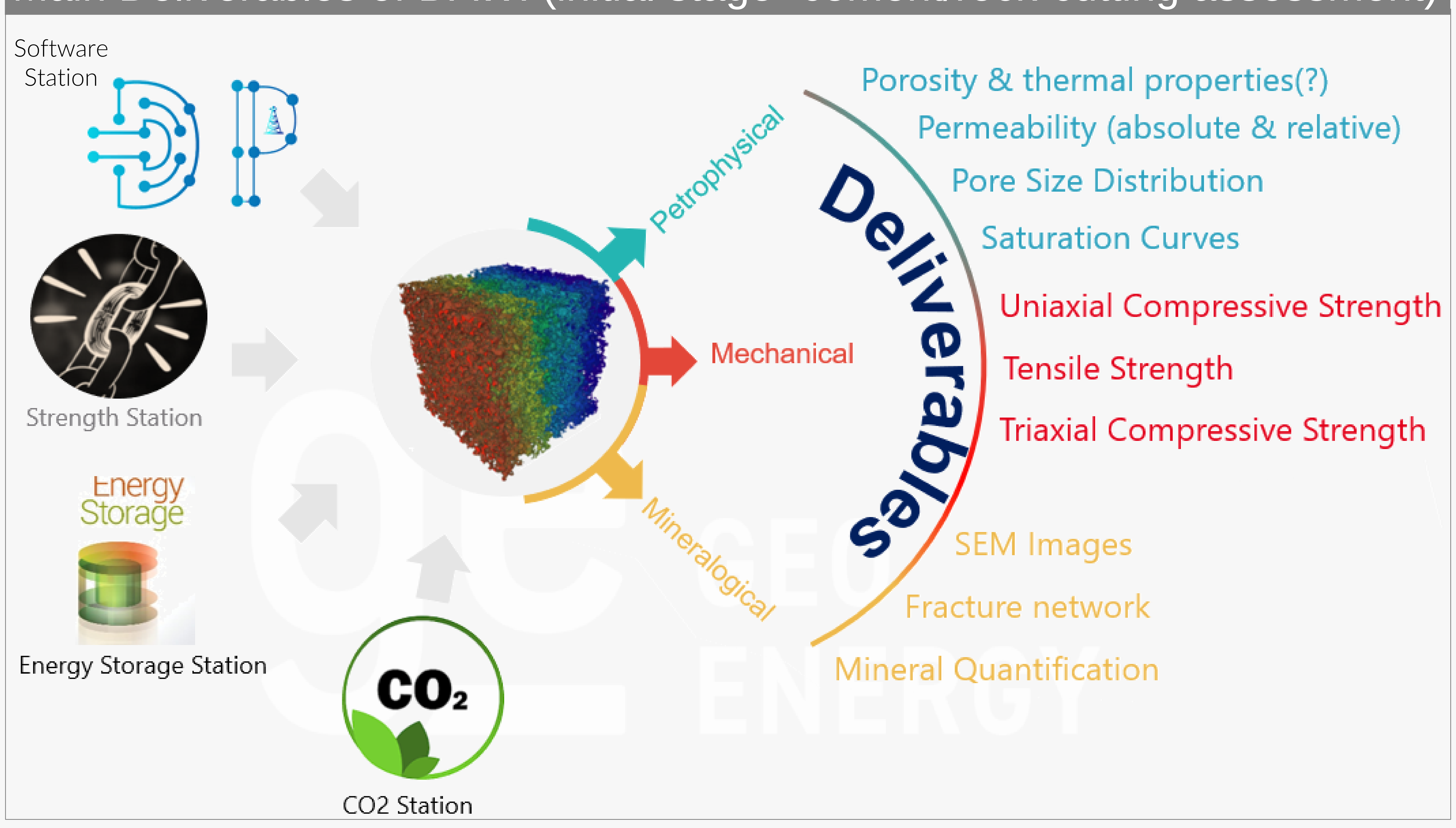

Figure 7.

Main Deliverables of DAWI (initial stage- cement/rock-cutting assessment)

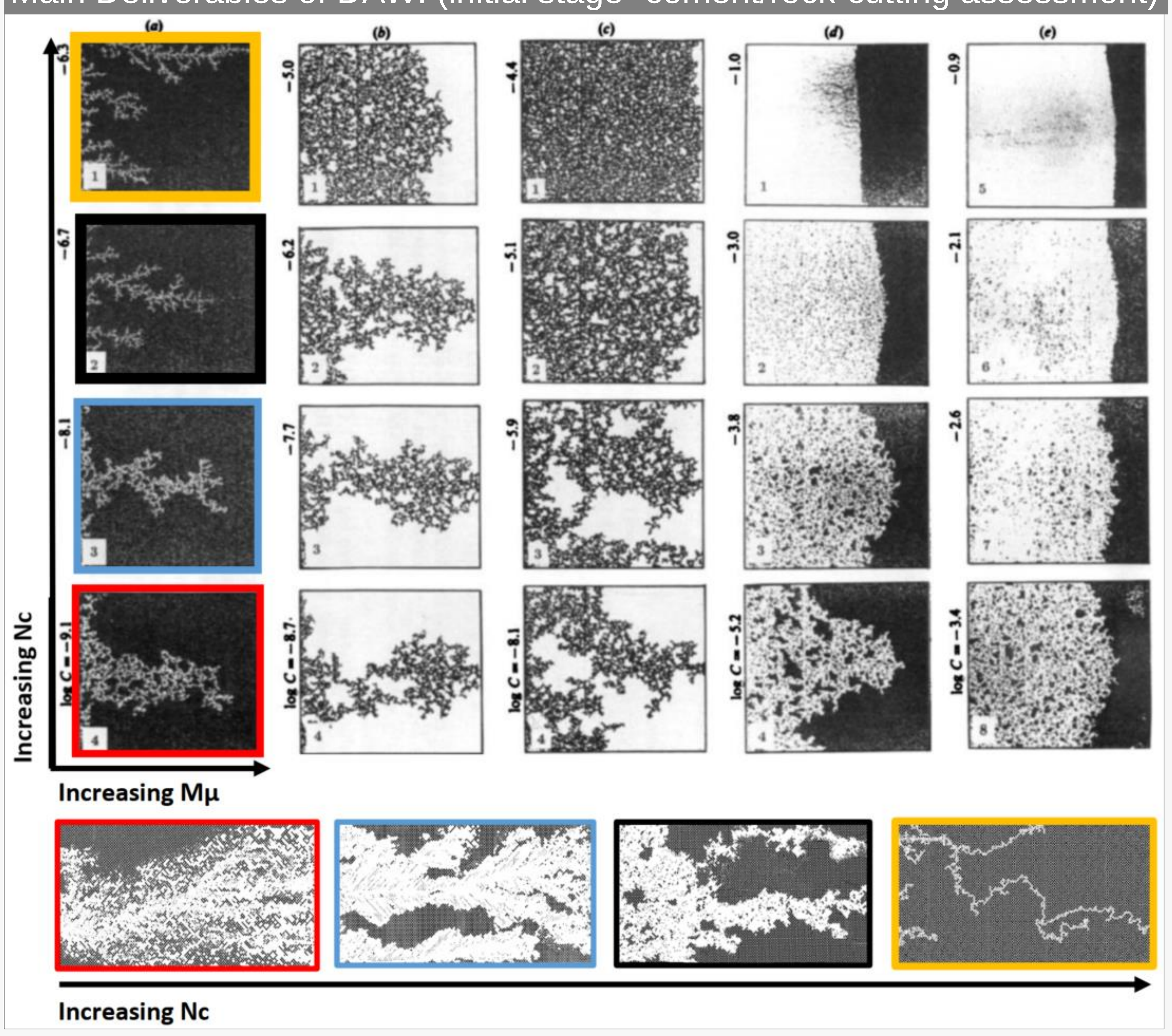

Figure 8. Up) Viscous (1) to capillary (4) fingering according to the work of Lenormand et al. [1988]. (a) Air is displacing a very viscous oil at log Mμ=-4.7. (b) Mercury is displacing hexane at log Mμ=0.7. (c) Mercury displacing oil at log Mμ=1.9. (d) Glucose solution is displacing oil at log Mμ=2 and various Capillary number: from stable displacement analyzed capillary fingering.
Down) The experimental waterflooding at different rates of red:0.0019, Blue: 0.01 and Black: 0.1 [ml/hr] plus the made-up scenario. Their approximate positions on the Lenormand range is also shown by their respective colors indicating cases of "Red: capillary fingering" and "Amber: viscous fingering''.

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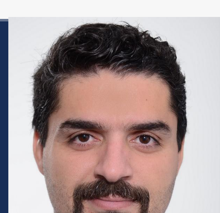

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