Depositional Environments and Sequence Stratigraphy of Carbonate Mudrocks Using Sedimentology, Multi-Scale Electrofacies Visualization, and Geochemical Analyses: Tuwaiq Mountain and Hanifa Formations, Saudi Arabia*

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Abstract

Depositional interpretation and sequence stratigraphic analysis of carbonate mudrocks require numerical analysis and data integration to achieve quantitative, predictive stratigraphic and geochemical models. To demonstrate proof of concept, a depositional and sequence stratigraphic analysis has been made of a basinal interval of the Tuwaiq Mountain and Hanifa formations, Saudi Arabia. Conventional geologic interpretation, automated electrofacies analysis, and geochemical interpretation are integrated using quantitative means. Cluster analysis of well-logs using self-organizing maps and hierarchical clustering allowed for a multiscale electrofacies analysis. This is useful for identifying major lithological surfaces, which commonly correspond to sequence stratigraphic surfaces. Geochemical data was used for depositional environment interpretation, such as sediment provenance, redox, and paleoproductivity conditions. Factor analysis was used to group element data. Redox and paleoproductivity indices were calculated using electrofacies clustering of different elemental groups. Electrofacies analysis shows good correlation with the lithofacies. Five major lithofacies have been identified in the studied interval. The majority of the interval is interpreted to have been deposited as gravity-flow deposits in an outer ramp setting. Two major sequences have been identified in the Tuwaiq Mountain Formation. The first is composed of the Atash, Hisyan, and Baladiyah (T1) members. The second corresponds to the Maysiyah (T2), and Daddiyah (T3) members. Two major depositional sequences have been identified in the Hanifa Formation corresponding to the Hawtah and Ulayyah members. The uppermost

bioturbated packstones of the Ulayyah Member are interpreted to be a lowstand systems tract with subsequent restriction leading to the deposition of anhydrite. In the studied interval, total organic carbon content (TOC) correlates well with suboxic to anoxic intervals that have high paleoproductivity. Complete anoxia is not a prerequisite for organic matter preservation. High TOC intervals are mainly in transgressive systems tracts.

Selected References

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June 2nd, 2015

Study Objective and Organization

Linkage between small and large scale characteristics in carbonate mudrocks

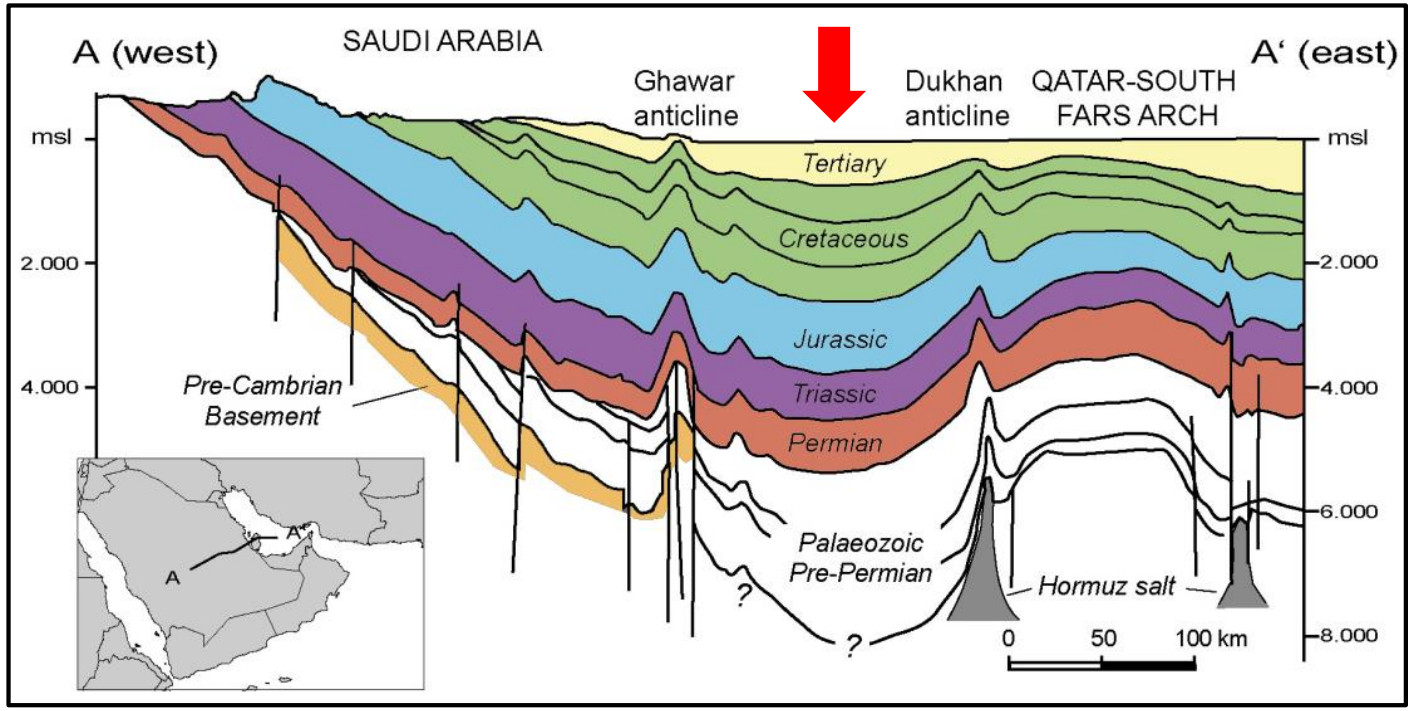
Sequence Stratigraphy & Depositional Environment → Cyclostratigraphy in Laminations → Micrite, Microporosity and TOC

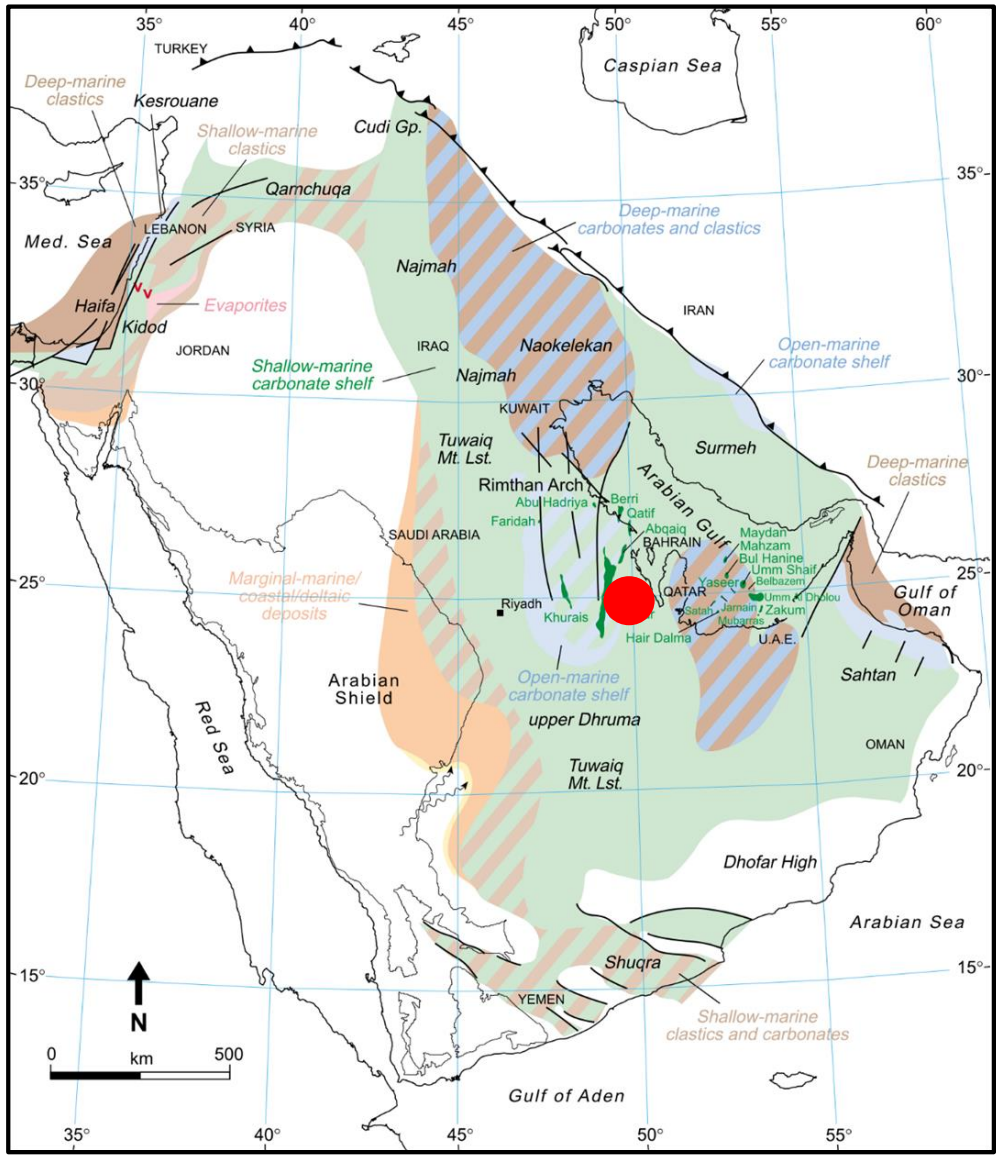
- Build the stratigraphic framework for the interval and understand the depositional environment. Can we predict total organic content from it?
- Create fast efficient workflows for studying mudrocks

General Setting and Location

The study interval is the Tuwaiq Mountain and Hanifa formations, Arabian Peninsula. They were deposited in a broad open platform system.

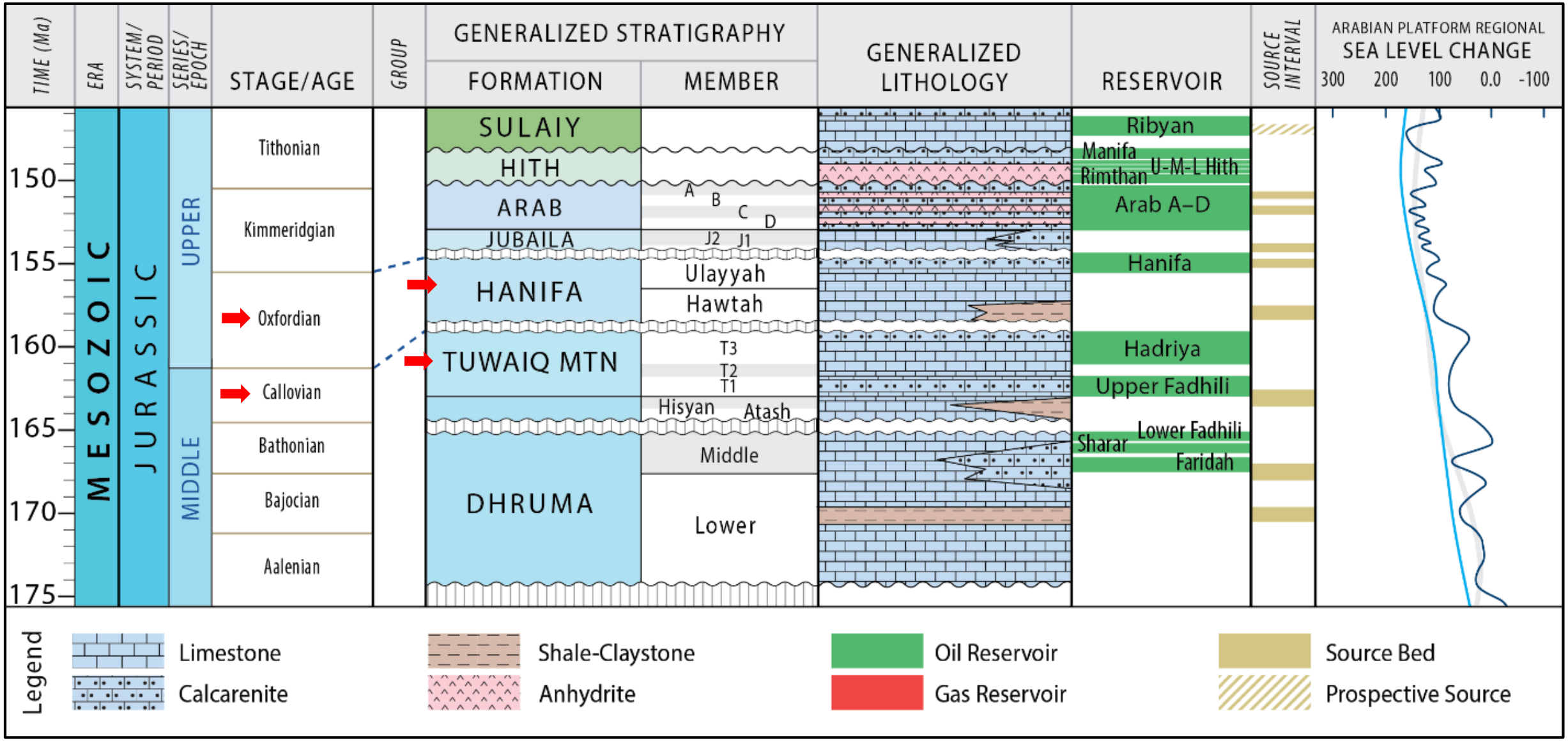
Perotti et al (2011)





Ziegler (2001)

General Setting and Location



Cantrell et al. (2014)

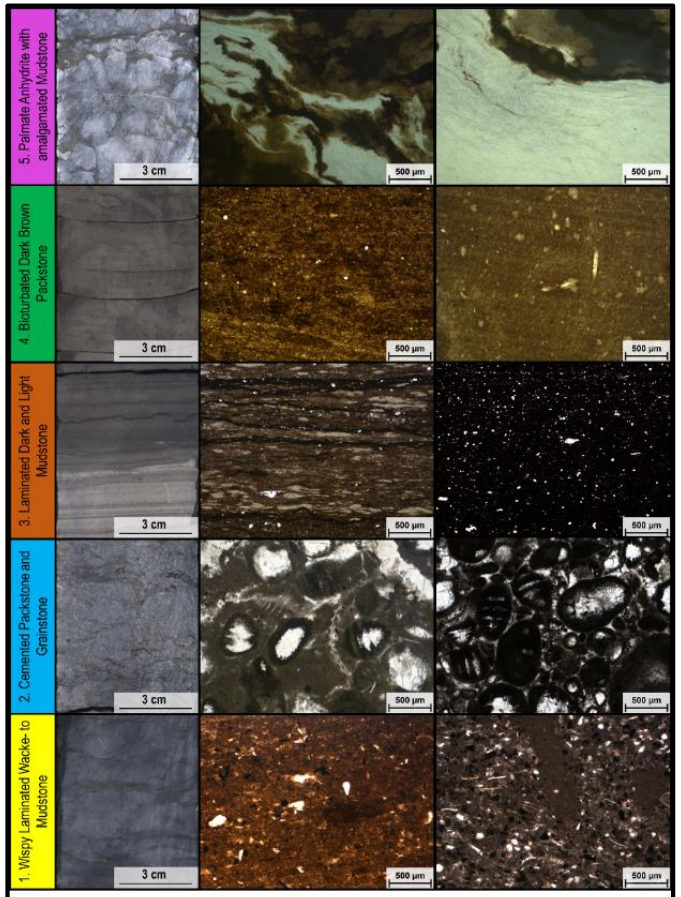
Large Scale Heterogeneity

Hypothesis:

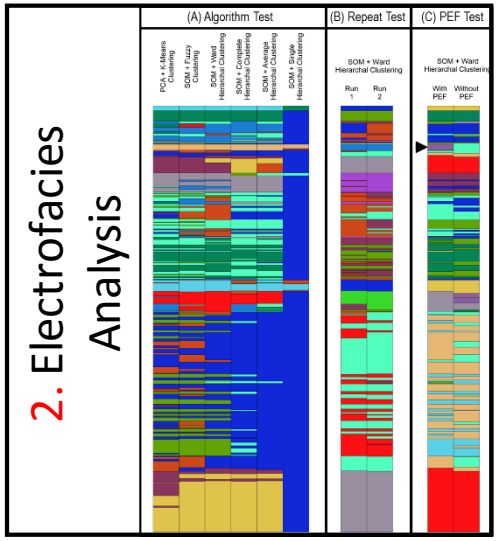
Large scale lithofacies in carbonate mudrocks are controlled by depositional processes.

Test:

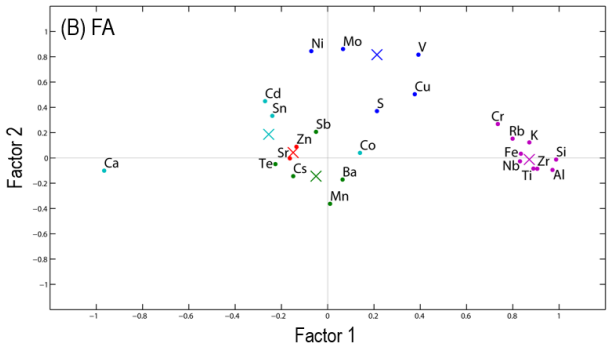
Interpret sediment source, depositional setting, and sequence stratigraphic framework and correlate the results with defined lithofacies.



1. Conventional Lithofacies Description

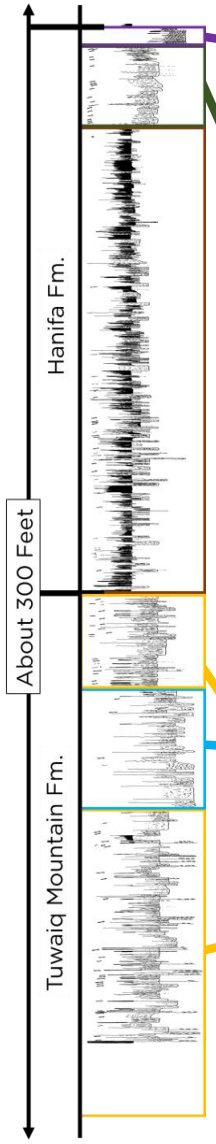


2. Electrofacies Analysis

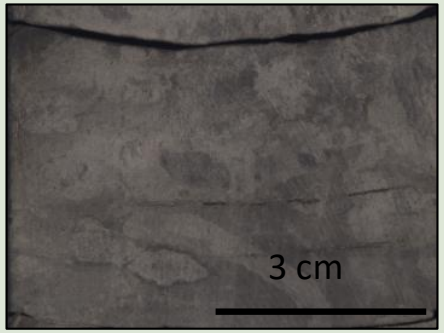


3. Geochemical Data Analysis

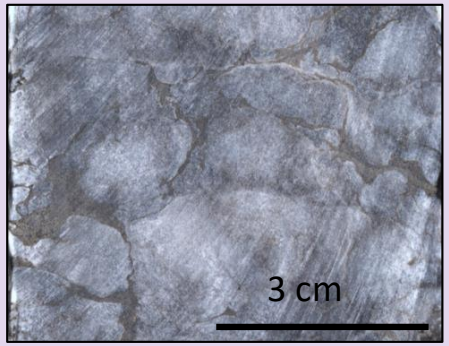
Lithofacies



4.
Bioturbated Dark Brown Packstone to Wackstone

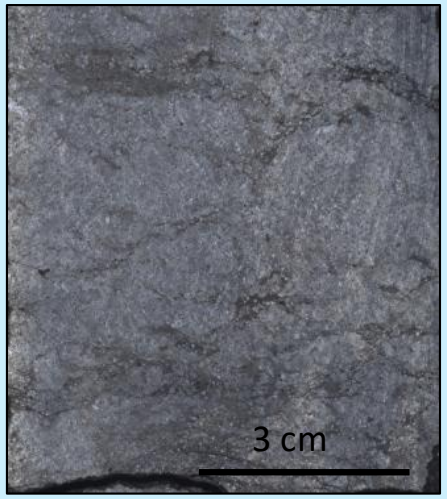


5.
Palmate Anhydrite

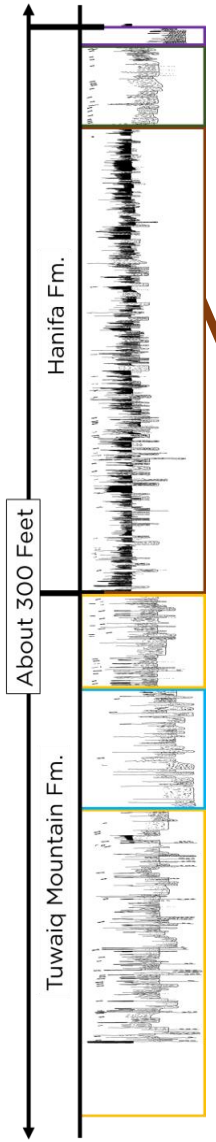


1.
Wispy Laminated Wacke- to Mudstone

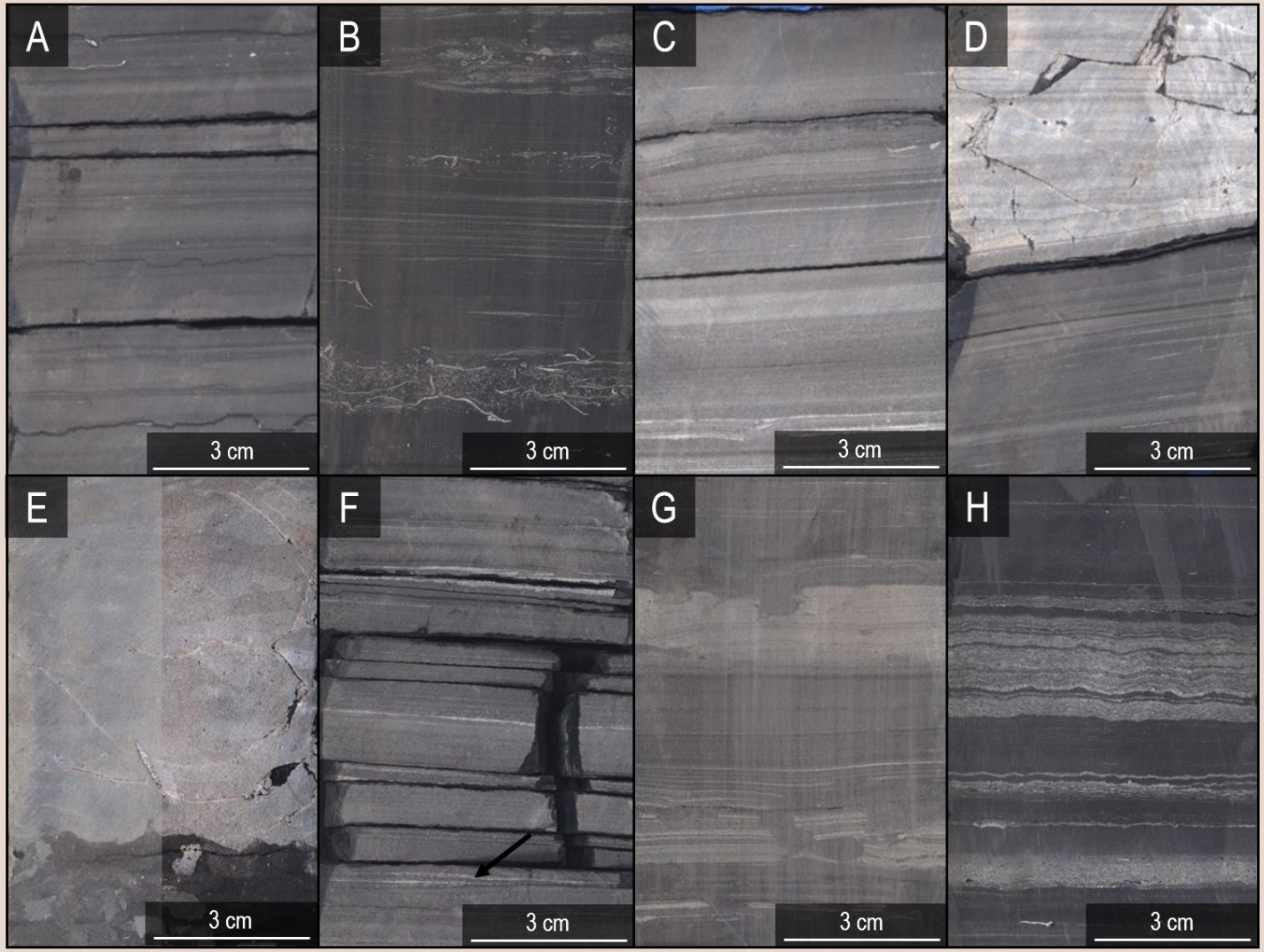
2.
Cemented Packstones and Grainstones



Lithofacies

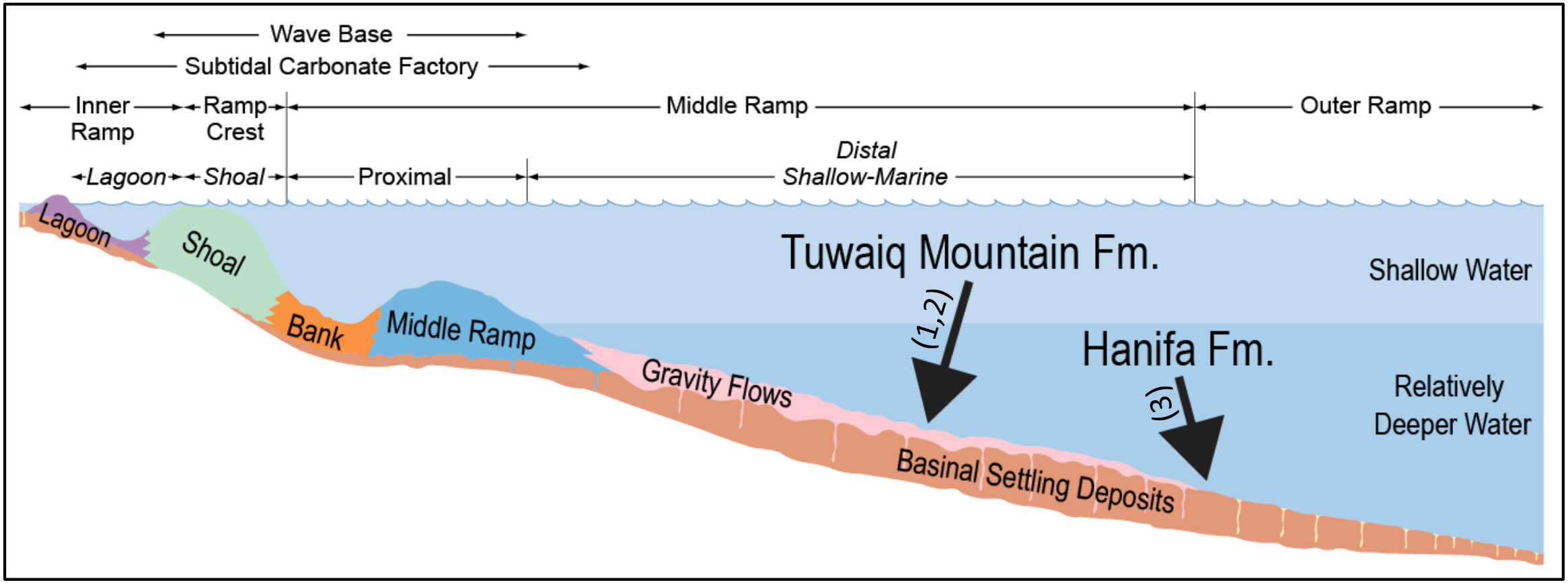


3.
Laminated Dark And Light Mudstone



Depositional Environments

The interval is interpreted to be deposited In the middle to outer ramp



Unsupervised Clustering Analysis

Cluster analysis

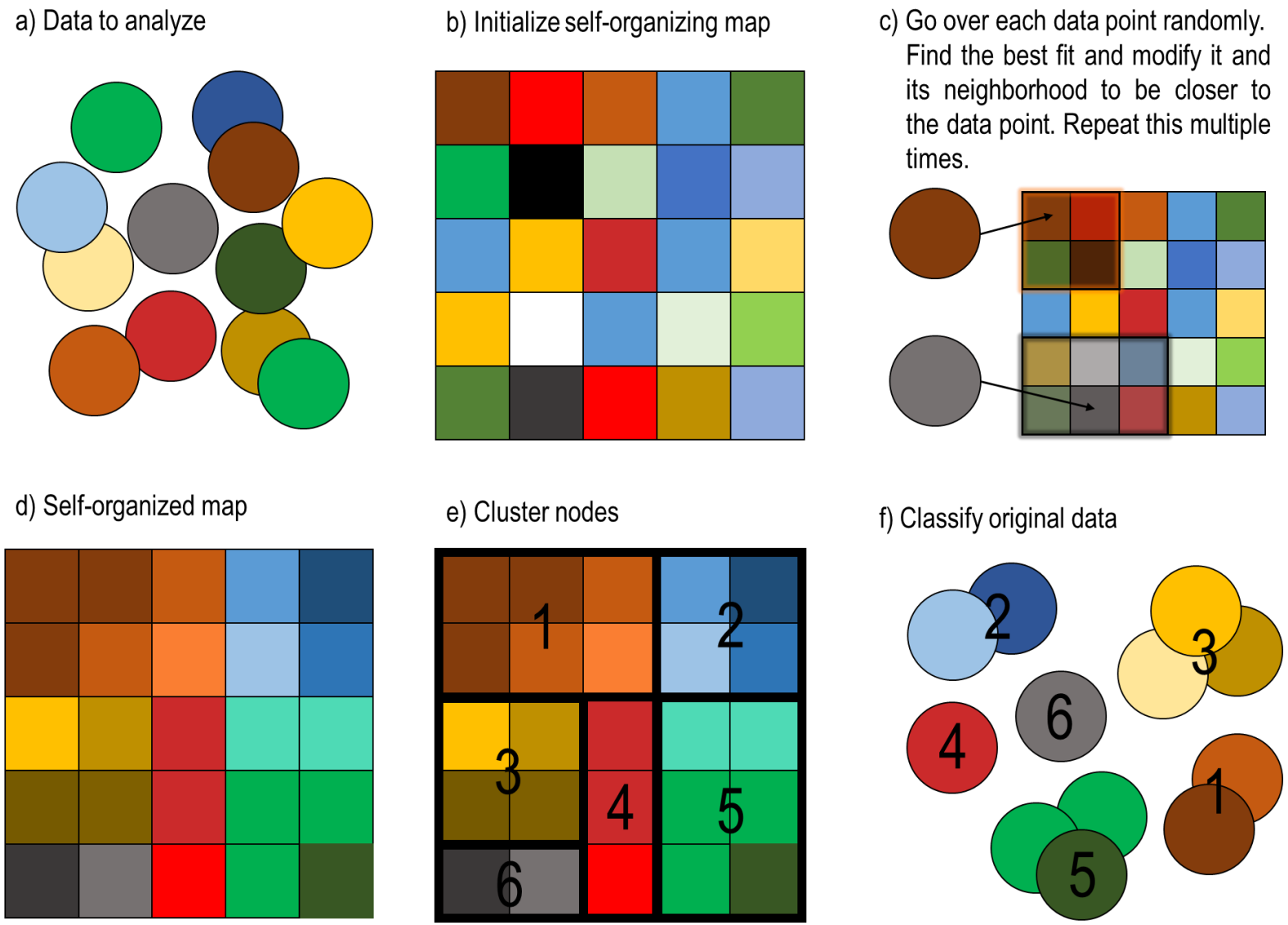
- Classifies data into groups with similar characteristics
- Analyzing dataset with large number of variables

Preferred algorithm

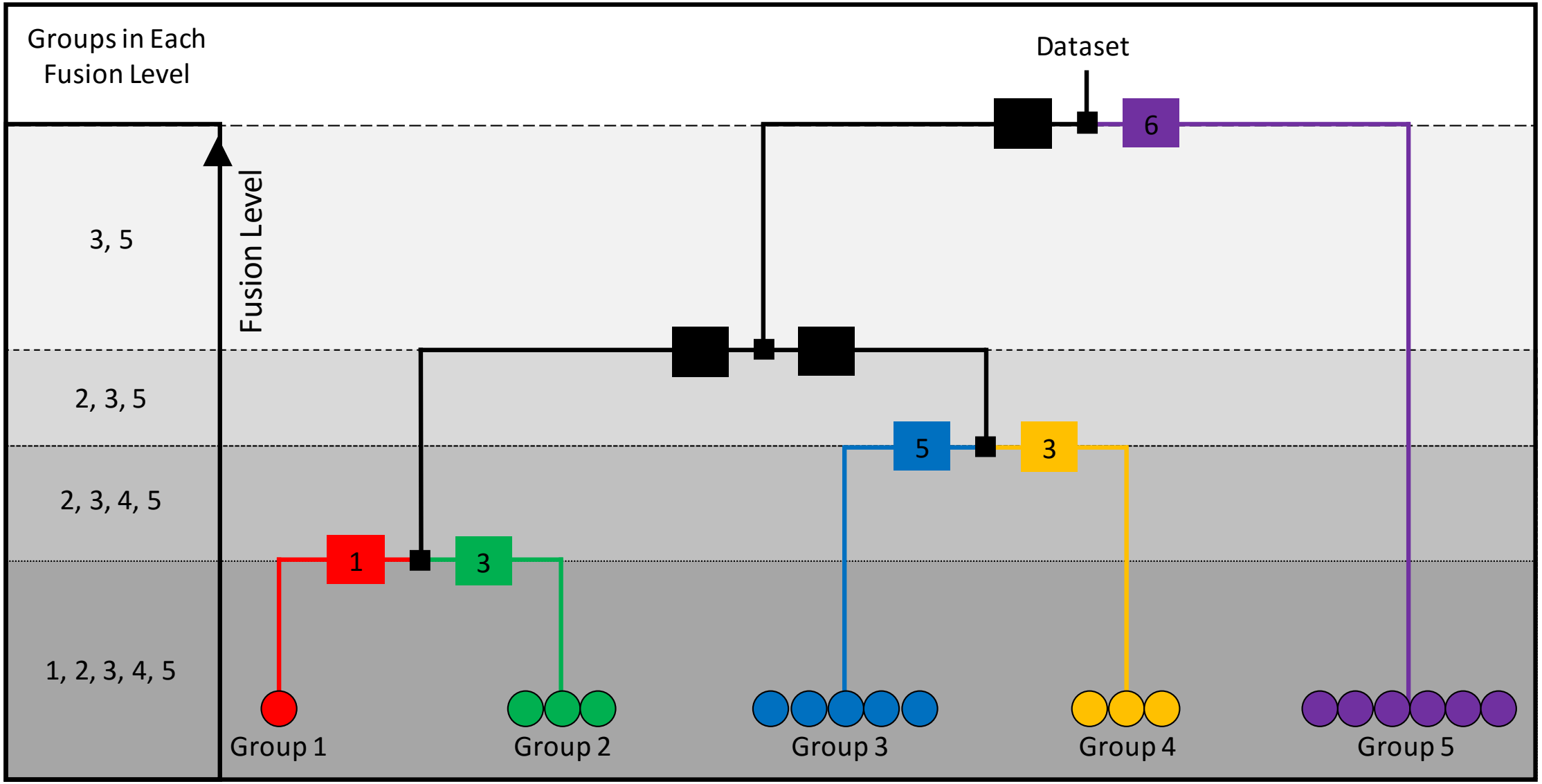
- Correlation with lithofacies
- Multi-scale visualization
- Mathematically robust

Self-Organizing Maps Neural Network

Self-organizing maps (SOM) classify large amounts of non-linear data

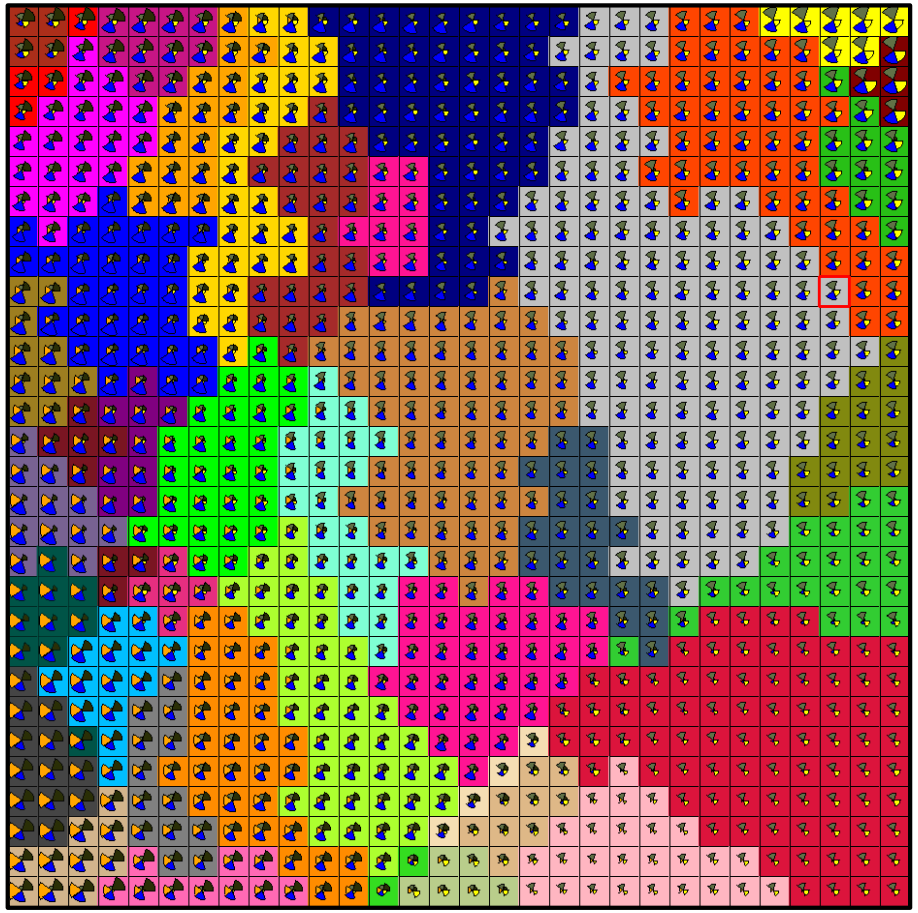


Multi-Scale Electrofacies Analysis

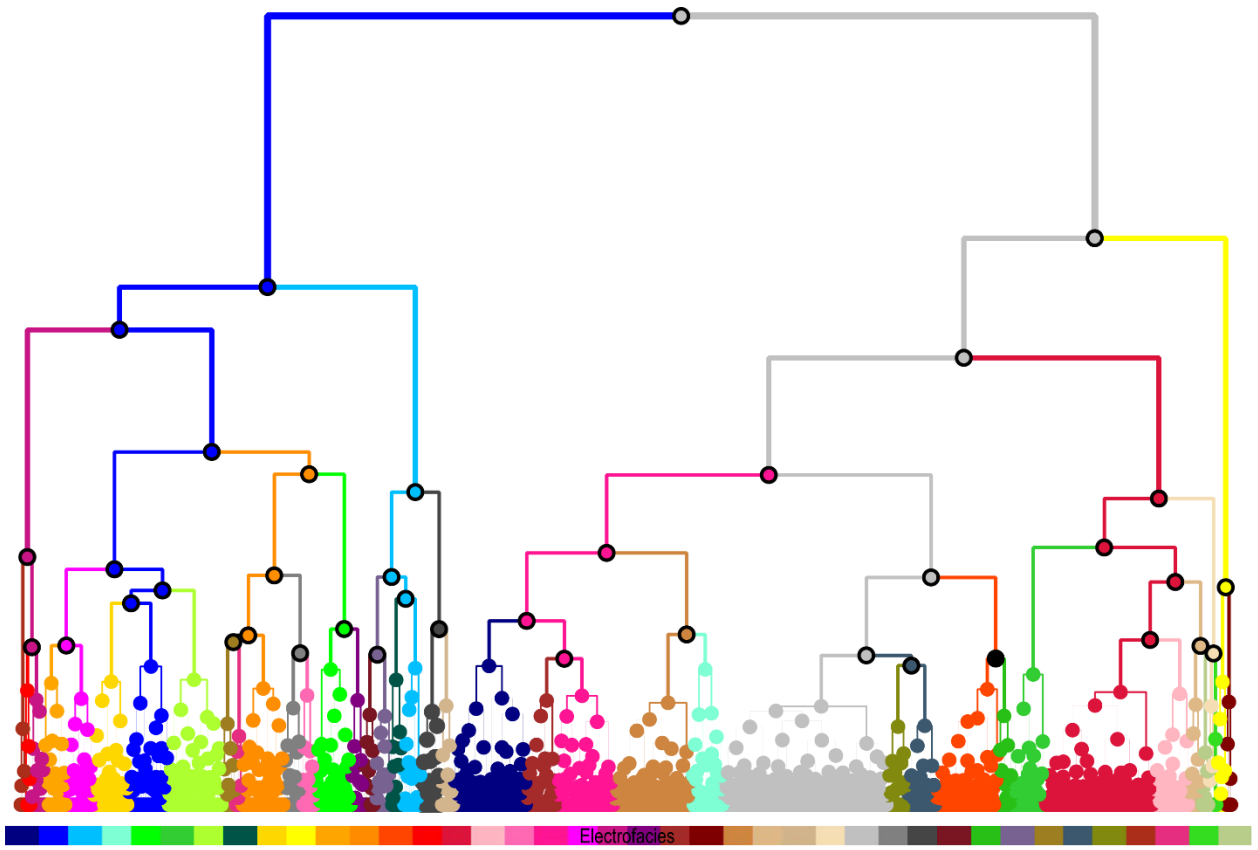


Multi-Scale Electrofacies Analysis Results

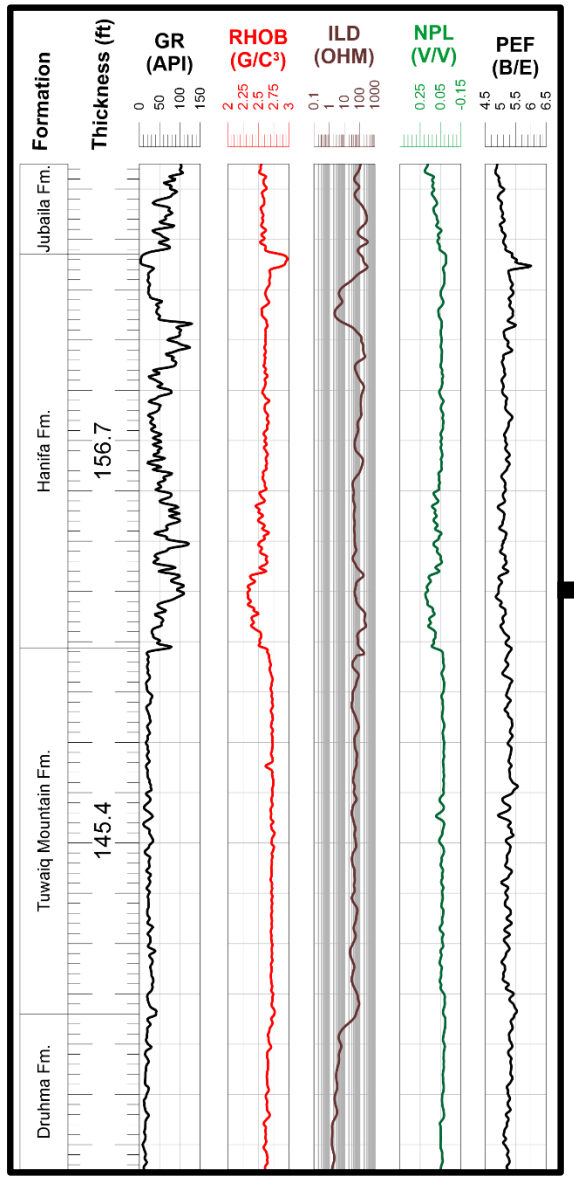
SOM Map



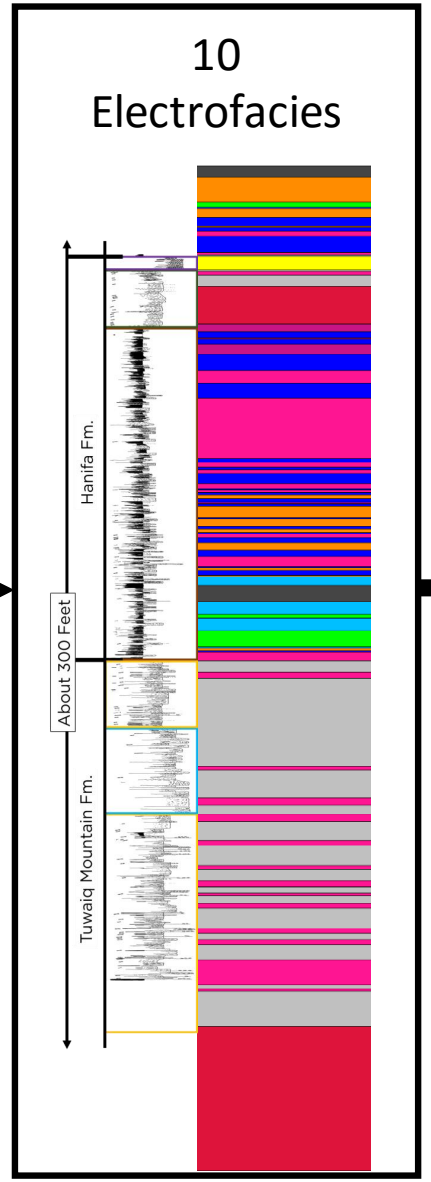
Hierarchal Clustering



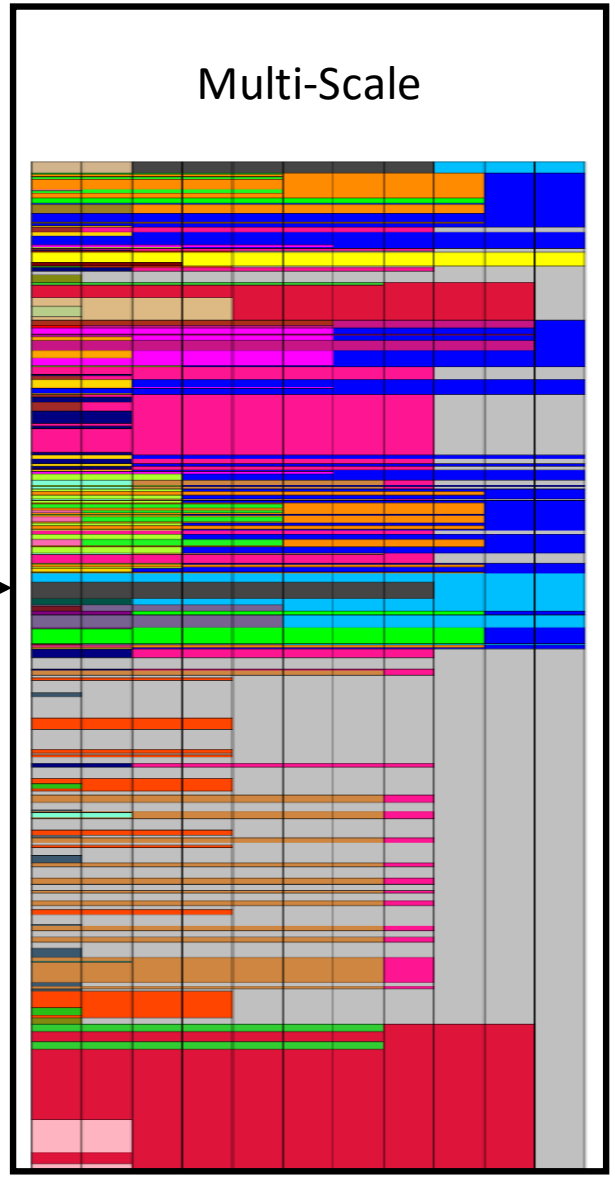
Multi-Scale Electrofacies Analysis



Electrofacies

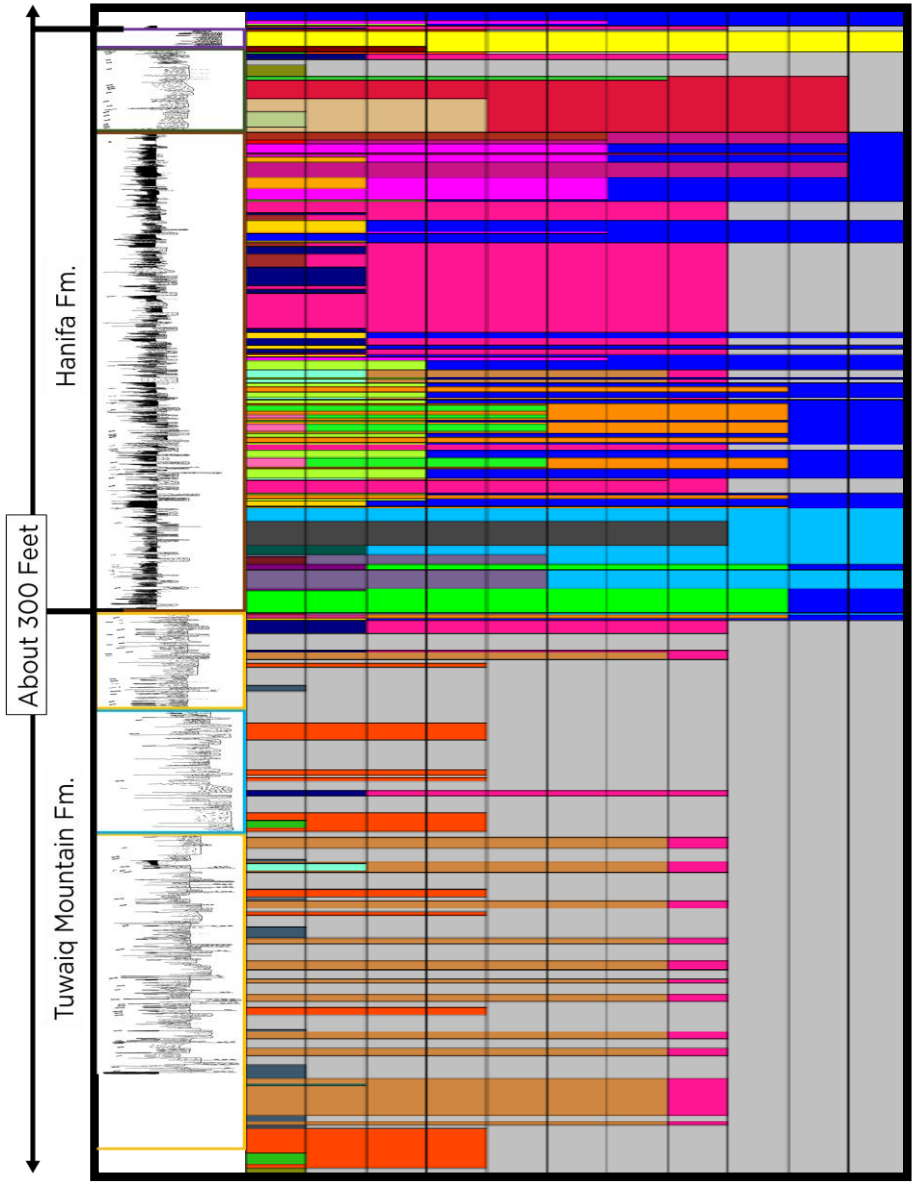


Multi-Scale



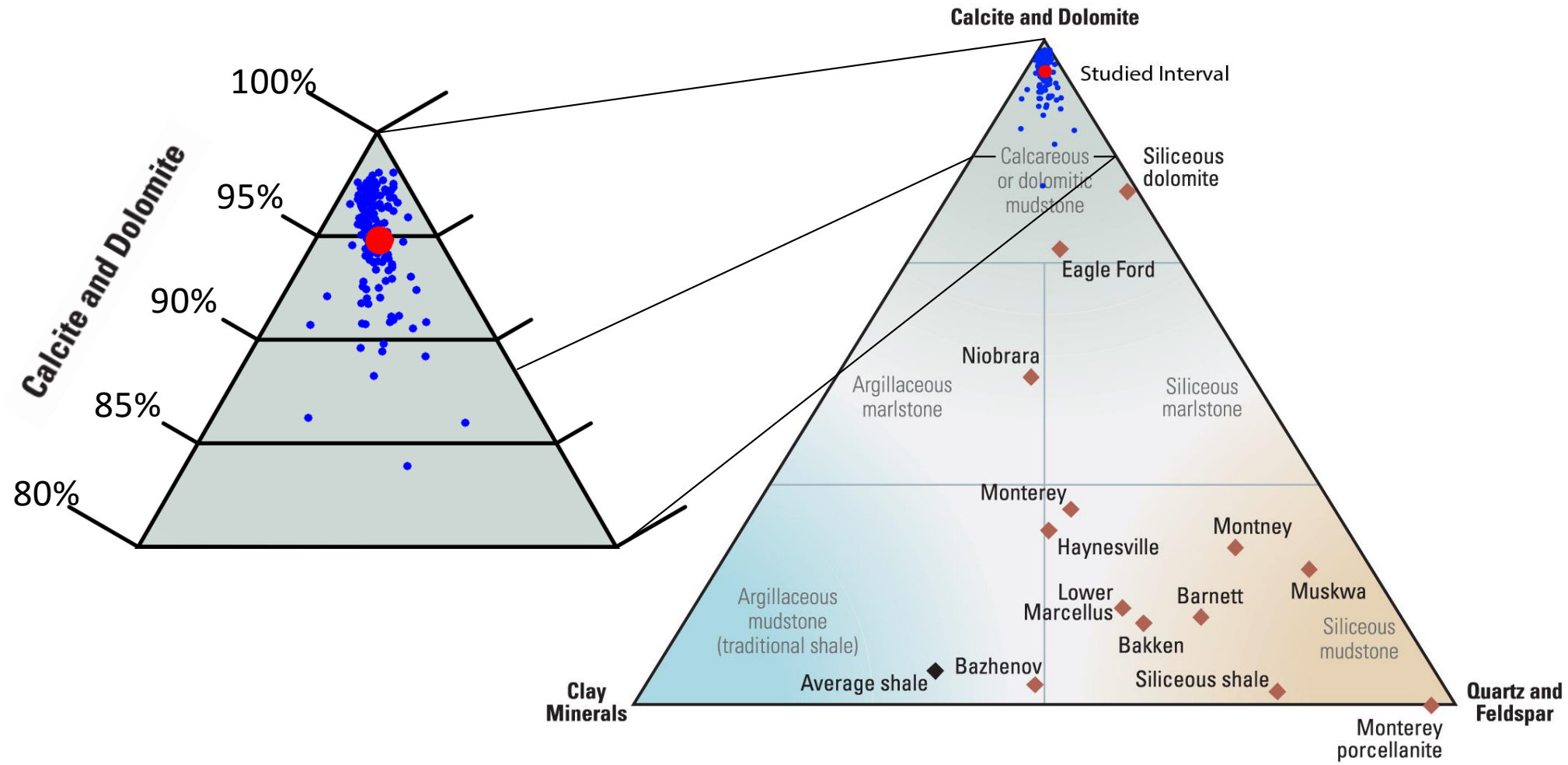
Results

Results correlate well with core description



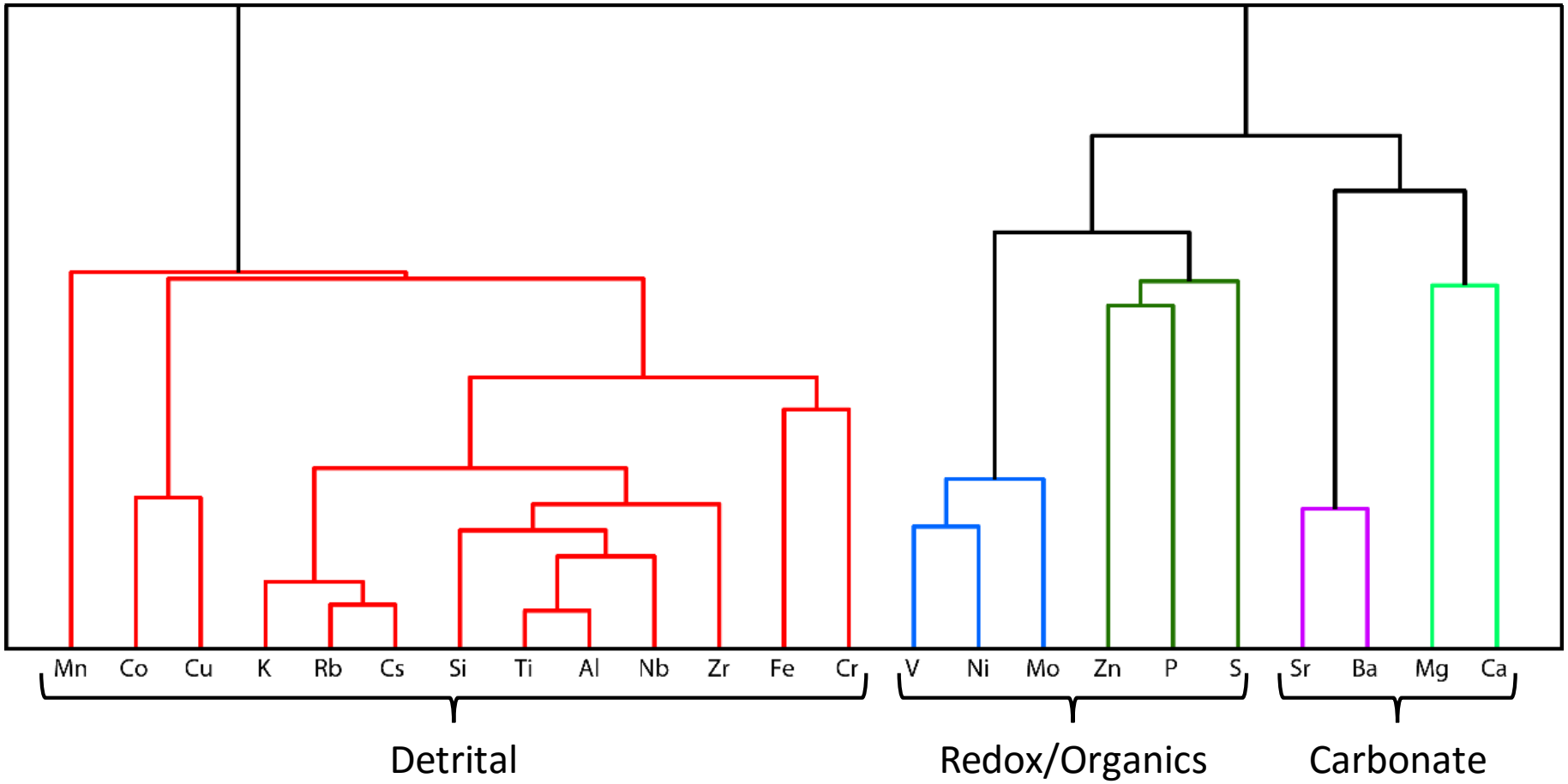
Geochemical Analysis

The interval is predominantly compose of carbonate



Geochemical Analysis

Elemental analysis can be visualized using hierarchical clustering

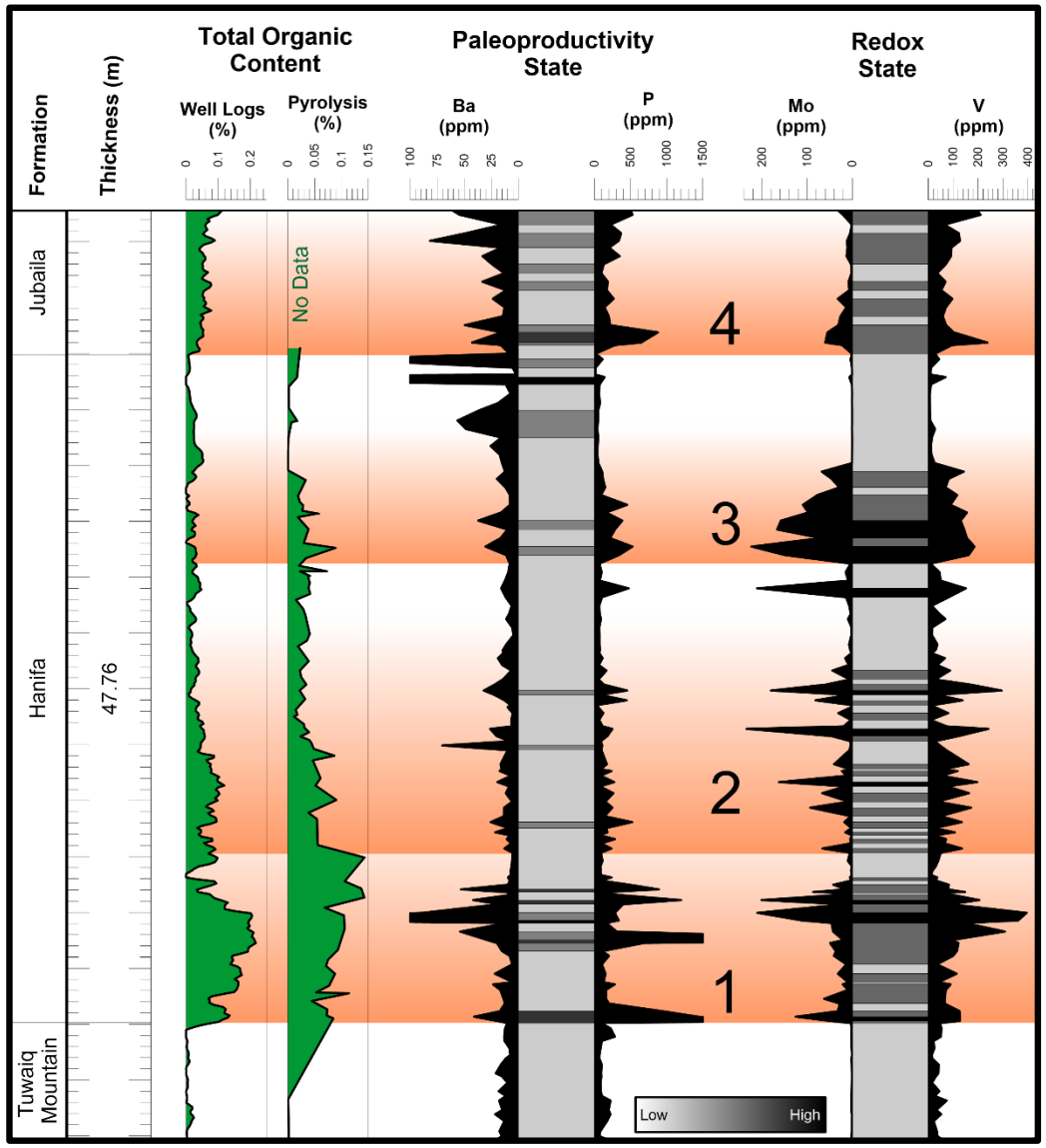


Redox and Paleoproductivity Conditions

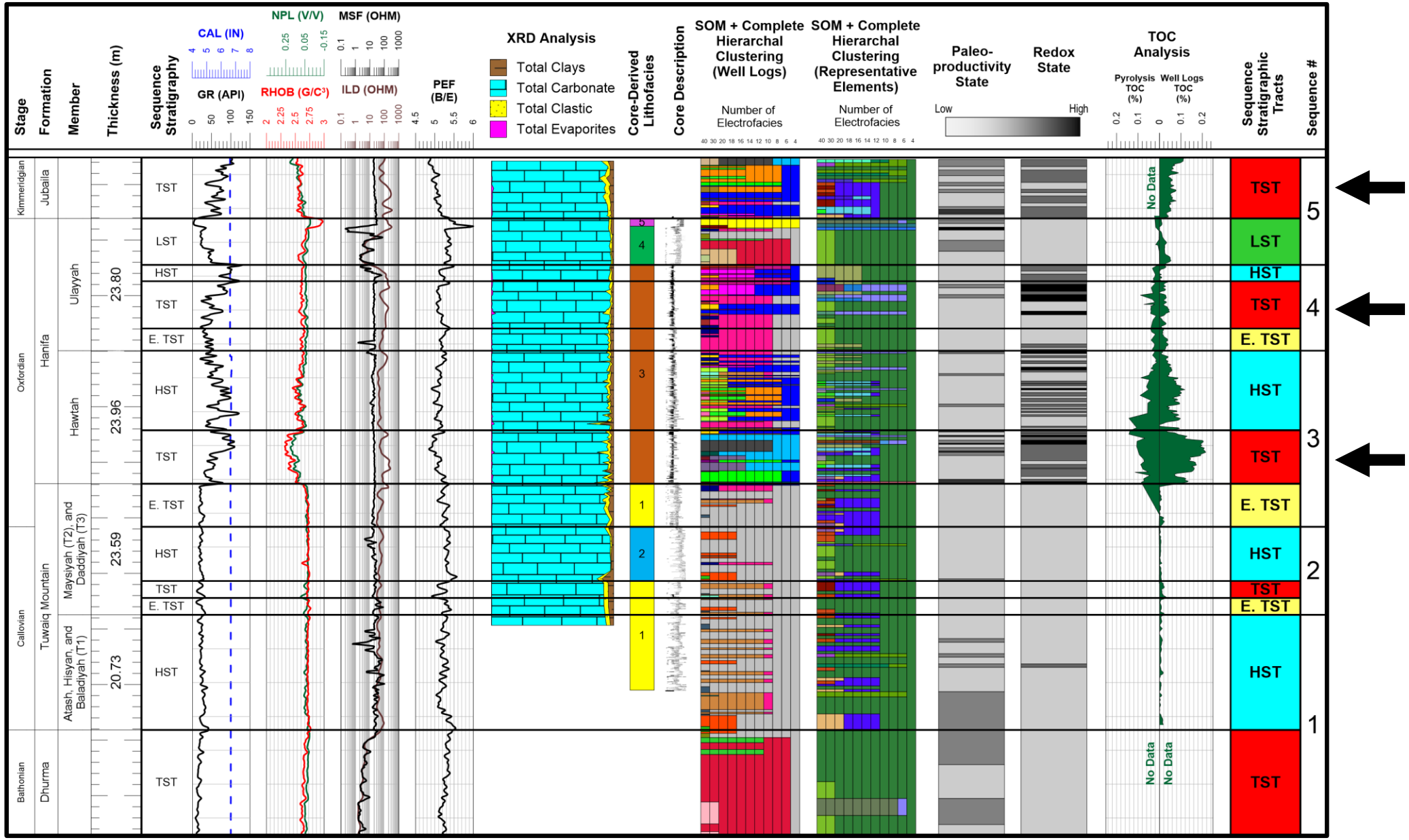
Paleoproductivity proxies (Ba, Sr, P) and redox proxies (Mo, V, and Ni) are used to define environmental condition related electrofacies.

Organic content related to:

- Relatively high paleoproductivity
- Reducing conditions.

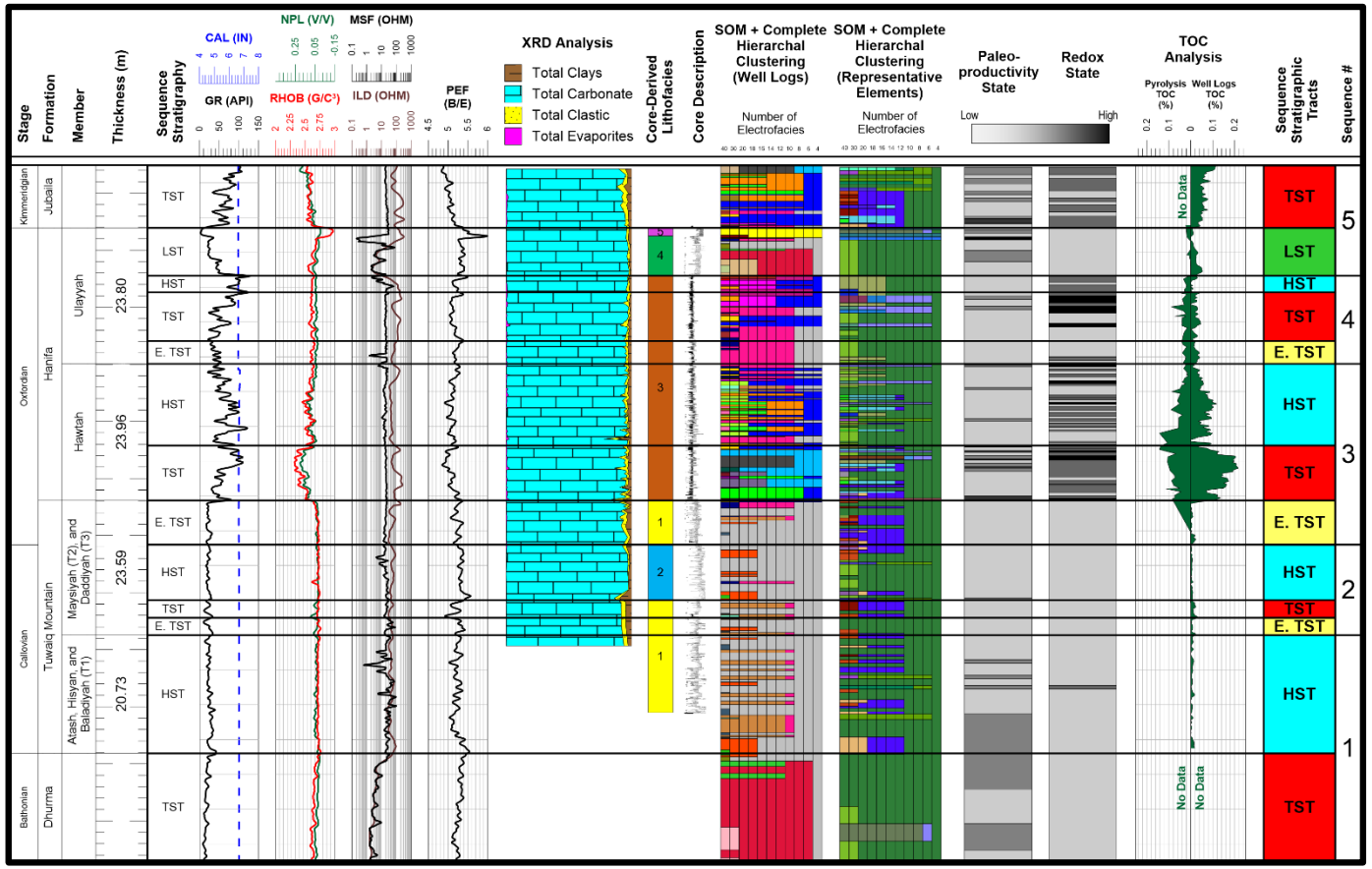


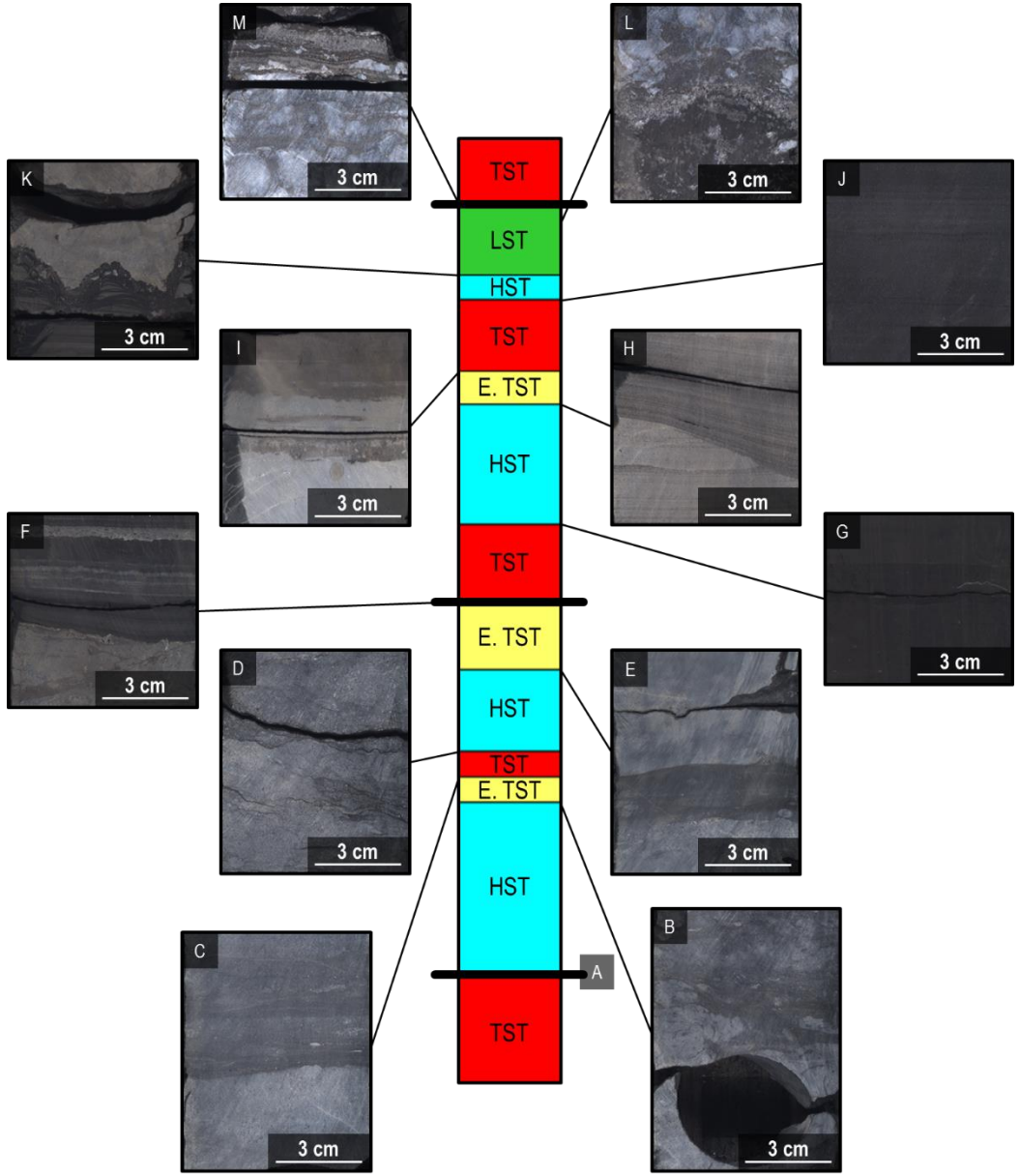
Sequence Stratigraphy



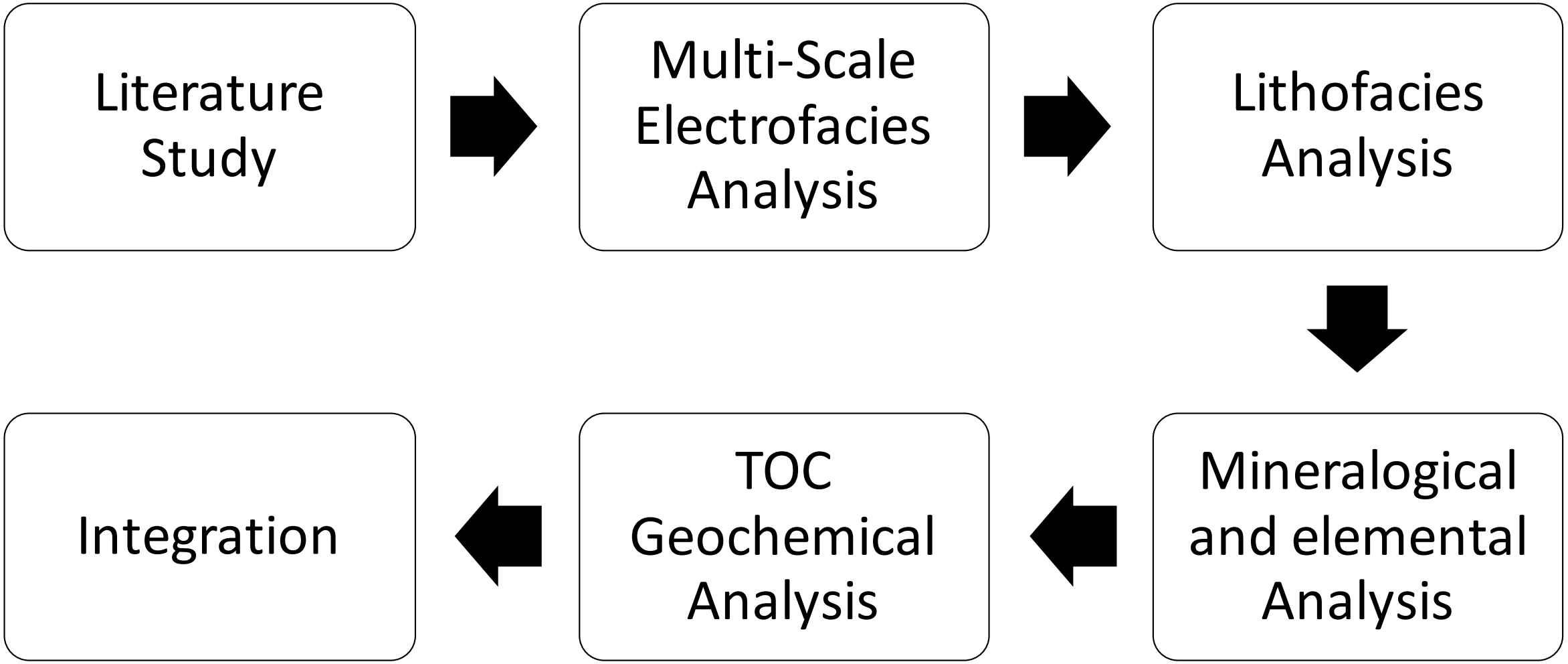
Contacts

Some contacts are more prominent than others in core





General Workflow



Summary

Study Area Summary

- A sequence stratigraphic framework is proposed for the studied interval.
- Organics are concentrated at the transgressive system tract at the base of the Hanifa Formation.
- Organics are associated with high paleoprodcutivity in reducing state.

Workflows Summary

- Multi-scale electrofacies analysis is a useful guide for lithofacies and sequence stratigraphic analysis.
- Geochemical analysis is useful for paleoenvironmental interpretation.

Acknowledgements

We would like to acknowledge Saudi Aramco for providing the data and giving the permission to publish it, and Schlumberger (SDR) for allowing me to use their facility for microscopic work.

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