Abstract

Reservoir characterization workflows are traditionally manual, time-consuming, and prone to interpreter bias. While the early application of machine learning automated several discrete interpretation tasks, these systems remain fragmented, relying heavily on manual integration. This research proposes that achieving true workflow automation in geosciences requires designing an autonomous system around four foundational requirements: (1) computational efficiency, (2) end-to-end autonomy, (3) scalability across basins, and (4) methodological flexibility.

To address the computational efficiency, Autoregressive Vision Transformer (ARViT), a multitasking model, was developed to jointly predict lithology, porosity, and water saturation from wireline logs. By employing self-attention and sequential modelling, ARViT achieved 96.51% lithology accuracy and low MSEs (0.004, 0.005) in petrophysical predictions, reducing computational cost threefold compared to independent models. Transformers proved effective at learning complex spatial and sequential relationships within data. Recognising its superior performance over established networks such as ANN and RNN, the transformer architecture was retained as the core modelling choice throughout this research.

Building on this foundation of transformers, the concept of end-to-end autonomy was extended to structural interpretation. Geological Beddings and Fractures Detection Transformer (GeoBFDT), a transformer-based model, was developed to automatically detect and parameterise fractures and bedding planes in borehole image logs. The model achieved ~90% dip and ~92% azimuth accuracy, effectively eliminating manual post-processing. Recognising GeoBFDT's success in end-to-end detection, it was further reformulated into a two-stage detection and correlation framework to address basin-scale scalability. This framework detects changes in depositional environments from wireline logs and correlates them via similarity mapping, achieving 95% accuracy and an F1 score of 87%, thereby enabling cross-basin transferability.

Extending the workflow toward methodological flexibility, the study further characterized vugs from borehole images to complement fracture analysis. A novel computer vision pipeline was introduced, combining Gaussian-adaptive thresholding and Laplacian-based contrast filtering to quantify vug count, area, circularity, and azimuthal distribution, providing new insights into reservoir heterogeneity and diagenetic processes.

Finally, considering all four foundational requirements, a unified agentic AI framework was proposed, capable of incorporating all four developed methodologies based on a microservices architecture. Orchestrated by a large language model, the system autonomously interprets geoscientist queries, retrieves relevant data, executes the appropriate models, and generates structured multi-modal reports. This unified framework represents one of the first demonstrations of an agentic AI system for workflow automation in reservoir characterization, laying the foundation for future research. Its modular yet interconnected design supports faster, consistent, and cost-effective reservoir characterization while significantly reducing human bias and interpretation latency.