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AI-driven basin-scale 3D geological modelling of the Western Canadian Sedimentary Basin from formation top data

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Summary

Rapid advances in artificial intelligence for implicit 3D geological modelling are expanding both the scale and complexity of subsurface representations that can be generated from scattered observations and knowledge-based constraints. These developments are particularly relevant to geoenergy applications that require basin-scale structural and stratigraphic context, including reservoir characterization, critical minerals prospectivity, carbon sequestration, and geothermal assessment. We present a preliminary basin-scale 3D geological model of the Western Canadian Sedimentary Basin (WCSB) derived from the Atlas 2027 formation top compilation, one of the most extensive regional subsurface datasets assembled for Canada. The 3D model is constructed using our AI-based GeoINR workflow, which we describe and potentially extend to enhance predictive accuracy across the WCSB by integrating additional geological knowledge (e.g., maps and cross-sections) and existing regional models.

Method

The Atlas 2027 project (https://atlas2027.ca/) has assembled an exceptionally extensive three-dimensional subsurface dataset and knowledge base, spanning geological observations, interpretations, and derived products. Converting this heterogeneous, multi-jurisdictional information into coherent geologically representative 3D models to support interpretation and resource decision making requires new methods that can (i) scale to large datasets, (ii) respect geological relationships, and (iii) be updatable as data and interpretations evolve over time. To address these requirements, we employ GeoINR (Hillier et al., 2023), an implicit neural representation (INR) modelling approach that uses multilayer perceptrons (MLPs) to learn continuous implicit scalar fields from spatial coordinates, constrained by geological interface observations, unit constraints, and structural orientation data. GeoINR extends prior INR-based implicit modelling by explicitly supporting unconformities, enforcing stratigraphic relations and global smoothness through dedicated loss terms, and improving optimization through geometrical initialization of learnable variables.

For basin-scale modelling, formation top picks are harmonized into stratigraphic intervals and converted into within-unit (intraformational) constraints along well trajectories. In total, approximately 35 million stratigraphic relationship constraints are used to train the model. Spatial coordinates are transformed into a numerically stable reference frame suitable for large

geographic extents, and training is performed using cloud computing infrastructure to accommodate the scale of the dataset and model evaluation.

After training, scalar fields are evaluated on a regular three-dimensional voxel grid and combined within stratigraphic domains defined by unconformities. Boundary iso-values associated with stratigraphic intervals are learned during training rather than prescribed, reducing sensitivity to heuristic iso-value assignment and improving robustness to spatially variable unit thickness (Hillier et al., 2023). Finally, geological horizons are extracted and progressively truncated by younger unconformities to produce stratigraphically consistent surface meshes suitable for visualization and downstream geoenergy applications.

Results

Application of GeoINR results in a preliminary, near basin-wide model of the WCSB derived from the Atlas 2027 formation top dataset. Initial results indicate that the workflow can process large volumes of formation top observations and generate stratigraphic surfaces and volumetric unit assignments over geographically extensive domains, while maintaining consistency with the stratigraphic ordering of the input stratigraphic column.

Model quality is assessed through (i) cross-validation on withheld formation top observations (distance residuals), (ii) inspection of horizon continuity and erosion/onlap relationships in cross-sections, and (iii) targeted comparison against existing published regional WCSB models where overlap exists. These evaluations are used to identify regions requiring improvement and to prioritize additional data and knowledge constraints for subsequent iterations.

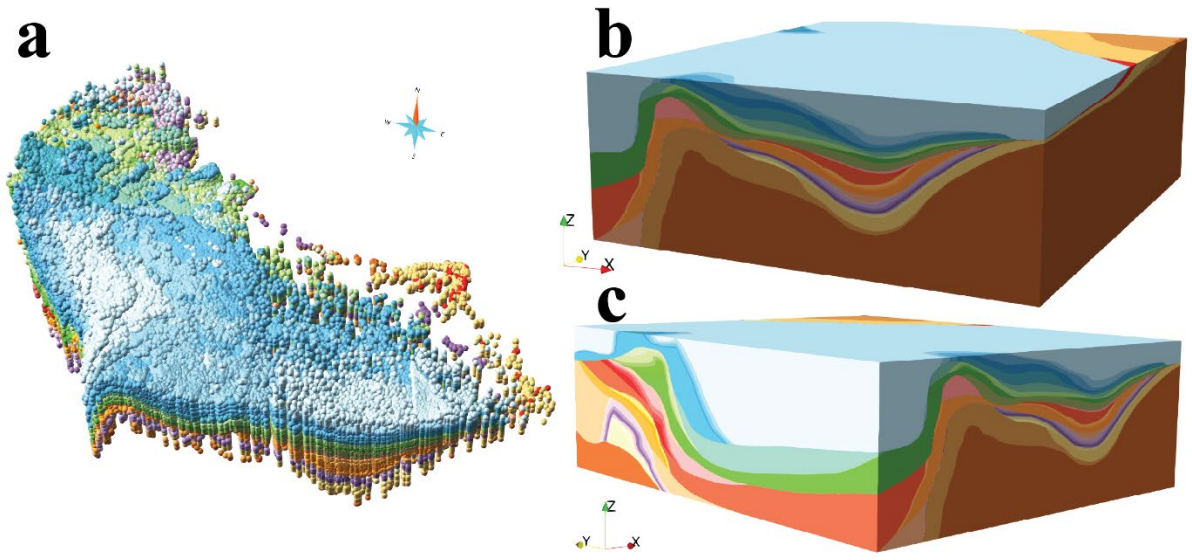


Figure 1. Preliminary basin-wide 3D WCSB model. (**a**) Quality controlled formation top dataset used for modelling. (**b**, **c**) Two 3D perspectives of the gridded volumetric model.

Novel Information

The work demonstrates that modern INR-based AI workflows can be deployed at basin scale to rapidly construct and iteratively update stratigraphic framework models from large formation top compilations, providing an efficient alternative to labour intensive workflows for initial basin-wide representations.

Ongoing development will focus on (i) integrating basin-wide geological map interpretations (e.g., subcrop limits and “zero-edge” outlines), and (ii) leveraging smaller, high-quality published WCSB models as priors through transfer learning.

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References

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