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Net-to-gross sandstone characterization of shallow bedrock units for regional hydrogeological mapping in central and southern Alberta

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Summary

Regional-scale groundwater studies are currently underway at the Alberta Energy Regulator/Alberta Geological Survey (AER/AGS) to evaluate and inventory Alberta's groundwater resources. In many parts of the province, shallow Upper Cretaceous−Paleogene strata constitute important aquifer zones that are relied upon by industrial, municipal, domestic, and agricultural water users. To support the hydrogeological mapping and numerical modelling initiatives in the shallow subsurface, a more thorough examination of the geological framework of this interval is required. Net-to-gross sandstone slice maps provide information about the heterogeneity of shallow bedrock formations and the distribution of potentially permeable sandstone-bodies nested within these units. Digital gamma-ray logs, including normalized through-casing gamma-ray logs, are used to create the net-to-gross sandstone slices at approximately 20 m intervals, which aid in characterizing the connectivity between sandstone-bodies and their lateral extent. These slice maps contribute necessary information for hydrogeological investigations, but also significantly improve our understanding of the detailed lithological variations within shallow bedrock formations in the province.

Introduction

Understanding the subsurface characteristics of shallow bedrock units is essential for groundwater studies, as intensely-used aquifer zones are located in near-surface bedrock strata. The shallow bedrock units are highly heterogeneous and thus geologic modelling studies are required to assign geological properties from the subsurface into hydrogeological maps and/or models to support the characterization of the regional groundwater system. 3D hydrostratigraphic models are used as a gridded geological framework to include information about the lateral extent, bulk textural characteristics, and stratigraphic position of shallow bedrock units into subsequent hydrogeological products. Within the modelled bedrock units, net-to-gross sandstone slice maps are used to further evaluate potentially permeable zones.

As part of the Provincial Groundwater Inventory Program (PGIP), hydrostratigraphic models and net-to-gross sandstone slice analysis have been conducted in two study areas in Alberta: 1) the Sylvan Lake sub-basin (SLSB; 5933 km^2) located in the Edmonton-Calgary Corridor; and 2) the Calgary-Lethbridge Corridor (CLC; 21159 km^2) (Figure 1). Targeted units for the hydrostratigraphic modelling and net-to-gross sandstone analysis include shallow Upper Cretaceous−Paleogene strata, which encompass the base of groundwater protection (i.e., nonsaline water <4000 mg/L total dissolved solids; Lemay, 2009). The Lea Park Formation (Fm) (or Pakowki Fm in southern Alberta) has been chosen as the base of the modelling domain, as it acts as a regional confining unit (Michael and Bachu, 2001).

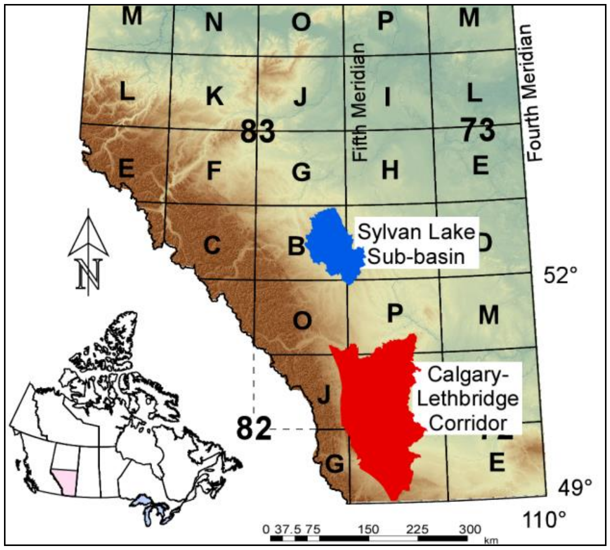

Figure 1. Location map showing the hydrostratigraphic modelling study areas in central and southern Alberta.

Methods

To perform net-to-gross sandstone slice mapping in shallow bedrock units, high-quality near surface data were utilized. Digital gamma-ray logs recorded through-casing to approximately 20 m of the land surface provide a wealth of information, although due to their muted log response, normalization (after Quartero et al., 2014) was necessary to ensure the geophysical signature was representative of the bedrock strata. Digital gamma-ray logs recorded below casing were then merged with the through-casing normalized digital gamma-ray logs to achieve complete log coverage from land surface through the interval of interest. A gamma-ray cut-off of ≤75 API was used to calculate the net-to-gross sandstone ratio and establish the amount and depth of coarse-grained materials in a well.

Using the net-to-gross sandstone ratio calculated for each normalized digital gamma-ray log and many accompanying logs at greater depths, a series of stacked net-to-gross sandstone slices were interpolated at approximately 20 m intervals with increasing elevation from selected datums. Datums were chosen to honour the regional trend of a formation and ensure that the angle at which slices cut through a formation was appropriate to determine the continuity of sandstone-bodies. In the SLSB, the Paskapoo Fm subcrops across the entire study domain, thus wedge-shaped slices with variable thicknesses (approximately 20 m towards the deformation front and >1 m towards the eastern edge of the Paskapoo Fm) were propagated up from a fifth-order trend surface from the base of the Paskapoo Fm (Figure 2a). In the CLC, slicing was performed using three different datums, as numerous formations subcrop at the bedrock topography interface. Slicing was conducted from: 1) Milk River Fm−Bearpaw Fm- lower tongue; 2) Bearpaw Fm- lower tongue−St. Mary River /Horseshoe Canyon Fm; and 3) St. Mary River /Horseshoe Canyon Fm−bedrock topography. Slicing in the CLC was performed to create approximately 20 m slice intervals with wedge-shaped slices of variable thickness where nescessary.

The high-resolution vertical discretization of the modelled bedrock units using the stacked net-to-gross sandstone slices (Figure 2a) allowed for the analysis and subsequent merging of presumably connected zones that may function as aquifers. Merging of net-to-gross sandstone slices based on natural geologic patterns disregarding the formation boundaries, as outlined by the 3D hydrostratigraphic model, established the geometry, orientation, and stacking arrangement of sandstone-bodies (Figure 2b). Polygons zonating where a merged zone had ≥0.60 net-to-gross slice contour values were also used (Figures 2c & 2d) to delineate the lateral extent of a sandstone-body, which was interpreted to contain potentially high permeability based on the connectivity of sandstone-bodies in 2D. All merged slices and polygons were formatted for input into hydrogeological mapping/modelling products in the study areas.

Examples

Within the SLSB and CLC, thirty-six and eighty-one net-to-gross sandstone slice maps were created respectively. The slice maps in both studies were merged into zones that were characterized by overall similar net-to-gross sandstone values and showed comparable geologic patterns. Three main merged zones in the Paskapoo Fm of the SLSB were identified from the thirty-six slices (Figure 2a-d), which fits into the three-fold formal lithostratigraphic subdivision of the Paskapoo Fm proposed by previous researchers (e.g., Demchuk and Hills, 1991). Slicing results demonstrate that single- and multistorey sandstone bodies nested within the Paskapoo Fm show the possibility of preferential pathways for fluid flow along linear channel trends. These potential channel trends are especially prevalent in the lower merged zone (Figures 2c & 2d), where westward-trending linear features have higher sandstone volumes (net-to-gross ratios) than other portions of the Paskapoo system.

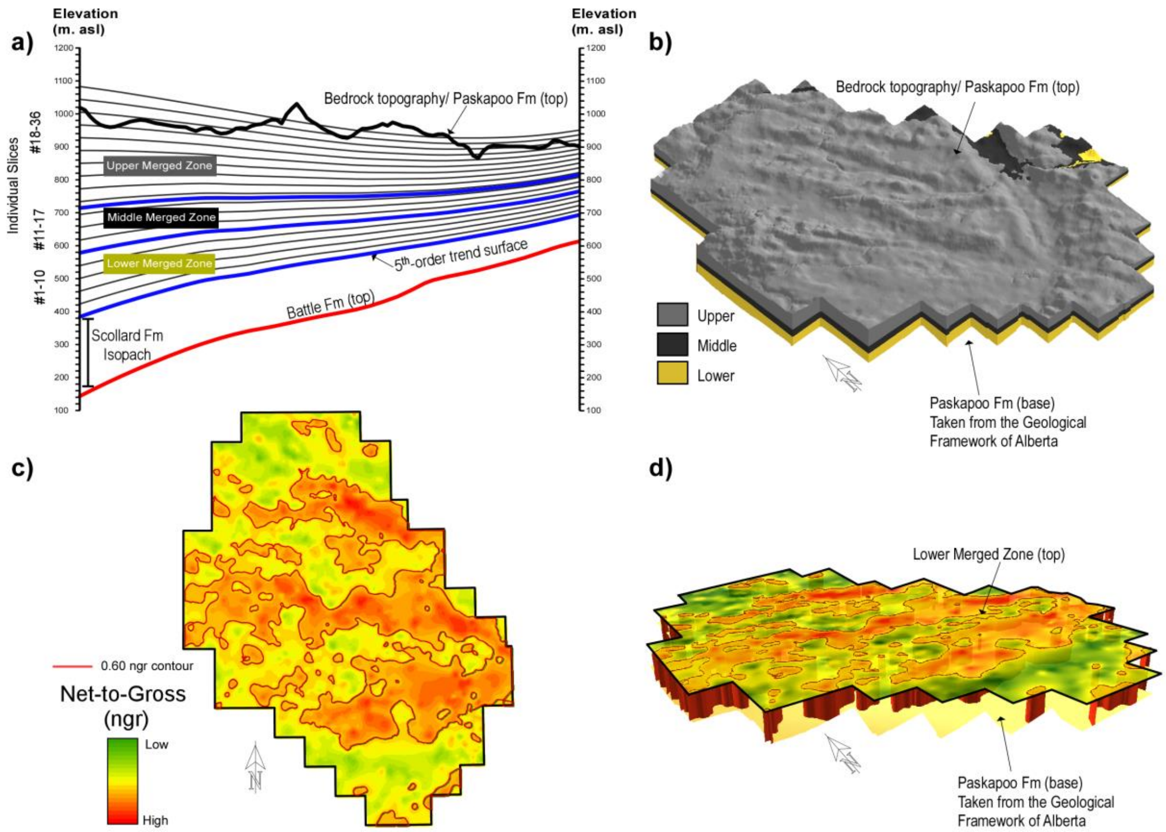

Figure 2. a) Cross-section showing the wedge-shaped geometry of the slices propagated through the Paskapoo Fm in the SLSB. **b)** 3D model of the three merged zones in the Paskapoo Fm. **c)** Plan view of the lower zone net-to-gross sandstone values as well as the ≥0.60 net-to-gross contour. **d)** The ≥0.60 net-to-gross ratio cut-off shown in **(c)** was used to produce polygons of sandstone-bodies that maintain a constant lateral shape throughout the entire volume and vertically thin to the east with decreasing slice thickness (from Atkinson and Glombick, 2015).

Fourteen main zones were created for the CLC (the CLC includes numerous slices and zones when compared to the SLSB, as the depth of investigation was much greater). Preliminary results from the CLC slicing highlights regional trends including: large sandstone-bodies in the basal portion of the Belly River

Group; the Bearpaw Fm characterized by overall low net-to-gross values; and small, discontinuous sandstone-bodies distributed through the St. Mary River/Horseshoe Canyon Fm. Data paucity reduced the capacity to evaluate much of the upper portion of the Willow Creek/Scollard Fm and Porcupine Hills/Paskapoo Fm in the CLC.

Conclusions

Digital gamma-ray logs and normalized digital gamma-ray logs through-casing were used to improve the understanding of highly-heterogeneous shallow bedrock units through net-to-gross sandstone slice analysis. The evaluation of the internal composition of modelled bedrock units provides important information on the orientation and dimensions of sandstone-bodies, which may act as potential aquifers. This information provides improved understanding for groundwater studies to support PGIP at the AER/AGS and may help focus local-scale investigations for further subsurface studies or correlations within shallow bedrock units.

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