Insights into the Internal Architecture of the Paskapoo Formation

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Introduction

The Paleogene-age Paskapoo Formation (Fm.) is an eastward-tapering wedge of interbedded nonmarine sandstone, siltstone and mudstone, with minor amounts of coal and bentonite. In its simplest form, the internal architecture of the Paskapoo Fm. can be described as individual and stacked sandstone channel or splay complexes encased in fine-grained sediment.

Attempts to define regionally identifiable or correlatable surfaces within the formation have proved to be difficult though subdivisions based on relative sandstone concentrations have been proposed as means to subdivide the formation. Demchuk and Hills (1991) divided the Paskapoo Fm. into three members based on lithology observed in outcrop and core: the lowermost Haynes Member, consisting largely of thick, locally conglomeratic, medium- to coarse-grained sandstone; the middle Lacombe Member, consisting of interbedded siltstone, mudstone, shale and coal, with subordinate sandstone and conglomerate; and in the highest elevations in northwest-central Alberta, the uppermost Dalehurst Member, characterized and marked by the occurrence of thick coals. Similarly, Jerzykiewicz (1997) informally divided the Paskapoo Fm. into lower and upper members based on relative sandstone content. More recently, Hamblin (2007a–c) published detailed core and outcrop descriptions, and found it useful to adopt the member stratigraphy of Demchuk and Hills (1991) to orient the reader.

The Alberta Geological Survey (AGS) maps and inventories nonsaline and saline groundwater resources in Alberta. Though there is only a single groundwater resource, with gradations of salinity, the AGS program structures its activities based on relative groundwater salinity to ensure a strong linkage between AGS outcomes and Alberta's policy and regulatory framework for groundwater. This study supports the goals of AGS by assessing the distribution of sandstone abundances within the Paskapoo Fm, ultimately toward creating hydrogeological models to define major aquifers. An abundance of digital subsurface information from oil and gas industry geophysical logs enables us to explore the internal architecture of the Paskapoo Fm. from a non-stratigraphic, numerical approach. Through digital analysis of borehole logs and the application of different modeling methods we are able to render views of the internal architecture at multiple scales of resolution, each providing different insights into the distribution and degree of internal hydraulic connectivity of sandstone units.

Methodology

To help understand the internal architecture, we constructed a three dimensional block model which we later sliced to show relative degree of sandiness at different locations and depths in the formation. We consider slice mapping showing the proportion of sandstone to have importance because hydraulic properties are generally correlated with lithology. Newly acquired stratigraphic data permitted us to map the base of the Paskapoo Fm., or top of Scollard Fm. and slice maps were constructed in 25 m thick slices parallel to that surface. We recognized that this choice builds in a bias by encouraging the assumption that the Paskapoo Fm. beds were deposited parallel to the top of the Scollard Fm., which is probably true for the lowest and oldest beds of the Paskapoo Fm. We chose the 25 m slice thickness to be greater than the reported average maximum thickness of single sandstone bodies, which in previous studies has been reported as 15 m (Chen et al, 2007).

About 2000 geophysical logs were selected from an initial dataset of about 40,000 oil and gas industry logs, from which we calculated the degree of sandiness from the natural-gamma-ray responses. For each log, we summed the thickness of every sand body with a gamma-ray value equal to or less than 75 API (Parks and Andriashek, 2009 describes the reasons for choosing this cutoff value) and expressed that total as a proportion of the 25 m thick interval. We did not do these calculations for those sections of a log that did not span the entire 25 m slice interval. Quality-control steps included corrections for factors such as gamma-ray readings through casing, missing intervals where no gamma-ray measurements were collected, and mislabelled log curves in source files. A 3D block model with a cell size of 1 km x 1 km x 25 m was constructed from the sandiness data using simple kriging (Deutsch and Journel, 1998). This is the finest scale that was practical to use for the entire formation. Slices were extracted from the block model and plotted as maps, each representing a constant height above the base of the Paskapoo Fm. These maps show sand abundance at different locations within a given slice.

To help interpret the hydraulic characteristics of the sandiness values in the slice maps, smaller scale block models (mini-models, McLennan et al, 2006) were created using sequential indicator simulation (SIS, Deutsch and Journel, 1998). The cell size in the mini-models is 100m x 100m x 2.5m, exactly 10% of the size of the larger sandiness model cells in each dimension. Each cell in a mini-model was assigned an indicator of either one or zero (entirely sand or entirely mud) and a permeability value corresponding to the indicator. We selected a constant permeability value for sand and another constant permeability for mud from accepted literature (Freeze and Cherry, 1979). A subset of 10 x 10 x 10 cells in a mini-model makes up the internal architecture of a larger cell with the same proportion of sand as the number of sand indicators in the subset. The mini-model permeability values were then upscaled to the sand-slice scale and by this method we related the sandiness of the sand slices to effective permeability.

The mini-models were unconditionally simulated with SIS using a variogram calculated from gamma-ray log sandiness data averaged to 2.5 m. The mini-models do not correspond to a specific location in the Paskapoo formation but are representative of the spatial structure of the sand and clay. The 2.5 m scale is the finest scale that could be practically simulated. At larger scales the data are less representative of discrete sand or clay units.

Results

Sand abundance maps of the first few slices above the top of the Scollard Fm. reveal large areas where net sand abundances exceed 50%, consistent with a regionally extensive lowermost sandstone unit (Haynes Member, Demchuck and Hills, 1991; Lower Paskapoo, Jerzykiewicz, 1997) defined by previous studies. This method is able to highlight distributions of thick sand by varying sand-percent cutoff values in the map display and provides insight into possible structural controls on erosion and infill of this lowermost unit. Figure 1 shows the sand slice covering the interval of 25-50 m above the top of the Scollard Fm, in the Haynes Member.

Progressively higher slices above the Scollard Fm. top reveal a large area of a relatively non-sandy unit above the Haynes Member, consistent with the general muddy characteristics of the Lacombe Member. Whereas previous studies have not discussed lithological subdivisions within the Lacombe Member, sizable areas of thick sand can be discerned from the slice maps which may have regional significance for groundwater development.

Minimodels provide a basis for determining the distribution of permeability or hydraulic conductivity values for a given cell sand value. This distribution can be used to quantify the uncertainty in hydraulic characteristics of the model cell, and the cell uncertainty can be carried forward to uncertainty in the aquifer system. Figure 2 shows the relationship between the mini-model subsets of 10 x 10 x 10 cells (or one sandiness model cell) and vertical permeability.

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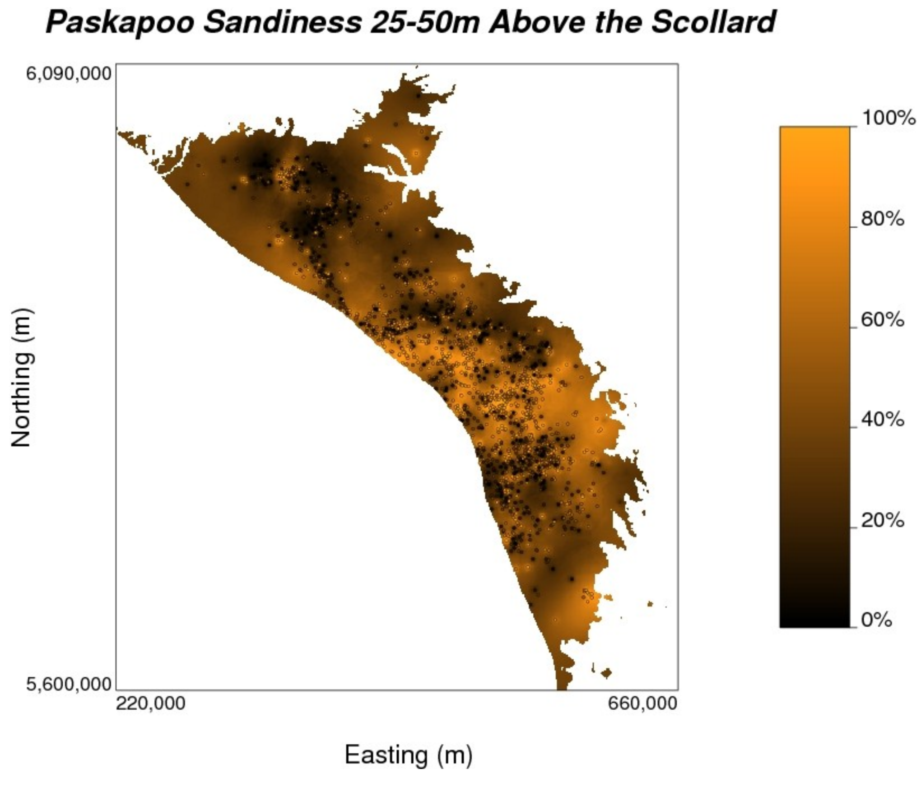

Figure 1: Sandiness in the interval 25-50 m above the top of the Scollard Fm.

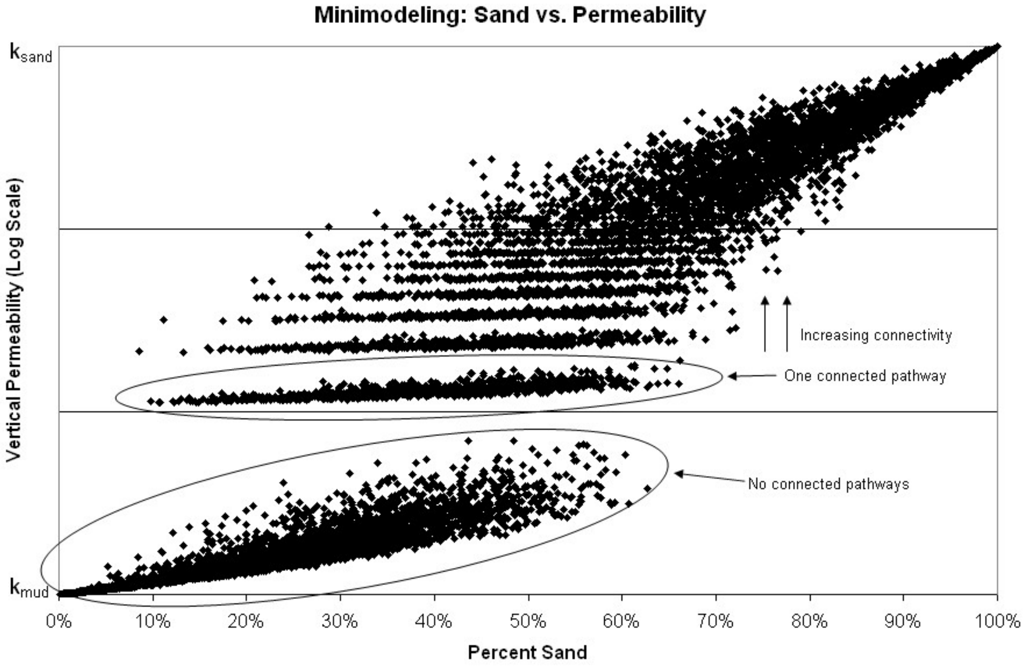

Figure 2: Relationship between sandiness and vertical permeability for mini-model subsets of 10x10x10 cells.