Regional groundwater water study of the Paskapoo Formation, SW Alberta

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ABSTRACT
The Paleocene Paskapoo Formation is a nonmarine unit comprised of thick-bedded sandstone, sandy mudstone and siltstone, that extends over 10,000 km of southwestern Alberta. The Paskapoo is the most important groundwater supply in the Province, as well as the single most important aquifer system in the Canadian Prairies as a whole. Most groundwater production from the Paskapoo occurs from fluvial sand channels that have a poorly understood distribution. Measured matrix permeabilities from sand units show four orders of magnitude variability. A basal sheet sand in the Paskapoo tends to show consistently high permeabilities whereas higher channel sands tend to have low values. Fracturing in channel sands likely plays an important role in production. Measured fracture density show an inverse relationship with bed thickness, suggesting that thinner sands may have greater production potential. Groundwater quality tends to be good in the western portion of the aquifer and degrades eastward, with notable increases in Na and SO_4.

RÉSUMÉ
Étude régionale des eaux souterraines de la formation Paskapoo, SO de l'Alberta

1. INTRODUCTION

The Paskapoo Formation, covering over 100,000 km^2, is the most significant source of groundwater in Alberta (Fig. 1). Given the importance of this unit to rural, industrial, and municipal development in southern Alberta, the aquifer system was selected for study as part of the Geological Survey of Canada's project on Assessment of Regional Aquifers. This paper reviews the current understanding of the hydrostratigraphy of the Paskapoo and results of the research program to date.

2. BACKGROUND

The Paskapoo Formation is equivalent to other major aquifer systems in the interior plains of North America, including the Porcupine Hills Formation of southwestern Alberta, the Ravenscrag Formation of southern Saskatchewan, the Fort Union Formation of Montana and North Dakota and the Turtle Mountain Formation of southernmost Manitoba. While not a continuous aquifer per se, regional trends in hydrogeological properties and geochemistry can be characterised. In the Plains, the Formation has an erosional base with thick sandstone beds overlying the Ardley Coal Zone of the underlying Scollard Formation, and its upper limit is the land surface, except on localized plateaus where younger Tertiary gravels are present. There are no continuous outcrop sections exposing the entire unit, which is up to 850 m thick (Jerzykiewicz, 1997). In general, the Paskapoo is dominated by nonmarine sandy mudstone and siltstones units, with interbedded thick-bedded sand channels.

Figure 1. Map showing the regional extent of the Paskapoo Formation in southern Alberta.

The thickest and youngest preserved portions of the Paskapoo Formation occur in the northern portion of the outcrop belt. There are two proposed subdivisions of the Paskapoo Formation. One classification divides it into the Haynes, Lacombe, and Dalehurst members (Demchuck and Hills, 1991). A second classification divides it into two overall upwards fining units (Jerzykiewicz, 1997). These differing stratigraphic organizations need to be resolved in future

3. STRATIGRAPHY

The Paskapoo Formation is commonly referred to as a sandstone unit, due to resistant sand channels forming the majority of outcrops. In reality it is dominated by fine-grained siltstones and mudstones. Based on initial geophysical well log interpretation, the formation averages ~30% net sand volume (Fig. 2). These sands form the principal storage of water in the aquifer system.

3.1 Basal amalgamated sandstones

In areas north of Calgary the basal member of the Paskapoo Formation is formed from amalgamated and stacked fluvial sands, which together merge into a regionally extensive sandstone-dominated member (Haynes). This ~50 m-thick unit is characterized by medium to coarse grained sandstones with conglomeratic lag deposits at the base of individual channels. These sands are usually massive but may contain minor trough and planar cross-bedding and rare ripple laminations (Demchuck and Hills, 1991).

3.2 Sand channels

Above the basal amalgamated sandstones, the characteristic channel sandstones of the Paskapoo Formation range up to 15 m, but are typically 5-10 m thick, and are lenticular, pinching out laterally over 100-150 m or more. They have sharp, erosional bases with lags of large siltstone rip-ups, pelecypod and gastropod shells, leaf and wood fragments and reptile/mammal bones and teeth. Grain size ranges from very fine to very coarse sandstone, but typically is fine to medium grained sandstone and there is commonly a slight fining-upward trend at the tops of units. The sandstones are generally uniform, well sorted, calcareous, with trough cross-bedding, horizontal lamination, large low-angle lamination and minor ripple cross lamination at the tops.

3.3 Mudstones

The sand channels are interbedded with the predominant lithology of the sequence which is light grey to greenish or brownish, soft, calcareous, sandy siltstone and mudstone, with thin fine grained sandstone beds. These fine facies range up to 50 m thick, but in outcrop are more typically 1-5 m thick. Calcareous concretions, local lenses of woody coal 2-10 cm thick, and thin gastropod-rich limestones are ubiquitous ((Williams and Dyer, 1930; Allan and Sanderson, 1945; Tozer, 1956; Demchuk and Hills, 1991; Jerzykiewicz, 1997). Rarely, thin bentonites and thin lenses of laminated lacustrine claystone are present, but are typically poorly exposed (Williams and Dyer, 1930). These deposits represent vertical accretion in a widespread floodplain setting of the dominant fine grained sediment load carried by the fluvial dispersal systems.

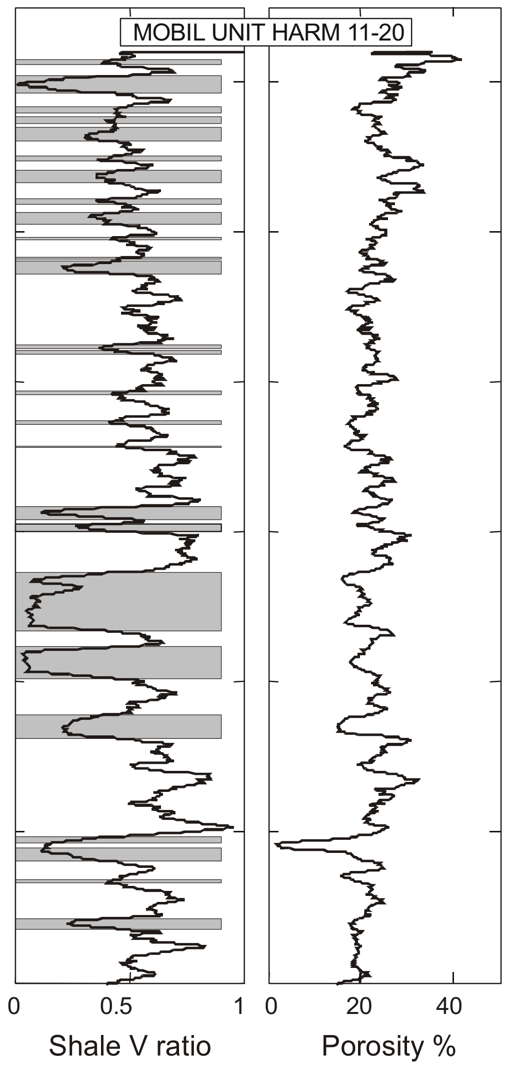

Figure 2. Example of calculated results from geophysical well log data for the Paskapoo Formation. On left is the shale volume ratio derived from gama-ray data. Sandstone beds, defined as less than 40% shale are indicated as grey boxes. Sand beds comprise ~30% of the stratigraphy with the rest being mudstones. Calculated porosity on right is derived from sonic data. Note that well-cemented sandstone layers can often have lower porosity than the formation average.

4. HYDROGEOLOGICAL CHARACTERISTICS

Within the Paskapoo Formation, water production is typically best, and in some areas exclusively, from channel sandstones and thin sand lens. However, in areas of fractured bedrock water can be produced from both primary intergranular porosity of thick porous sandstone aquifers, as well as secondary fracture porosity of all rock types including non-porous mudstone confining layers (e.g. Tóth, 1966).

In order to quantify the transmissivity related to primary porosity, measurements on sand beds where made in cooperation with the Alberta Geological Survey. Given potential near surface alteration of outcrop exposures, measurements where restricted to unfractured subsurface cores. Sandstone permeabilities range from 1.7×10^{-12} to 9.7×10^{-9} cm^2 with an average of 6.8×10^{-10} cm^2 (Fig. 3). As a rough trend, the basal amalgamated sandstones towards the lower part of the Paskapoo (Fig. 3) show the highest permeabilites.

5. FRACTURE PERMEABLITY

Ozaray (1972) identified a hierarchy of bedrock aquifer types within the Paskapoo in the Wabamum area: 1) friable Paskapoo sandstones yielding 2250 l/min, 2) thick, porous Paskapoo sandstones yielding 450-2250 l/min, 3) regionally characteristic Paskapoo with interbedded sandstone and siltstone yielding 100-450 l/min, 4) Paskapoo dominated by shale with thin sandstone layers and fracturing yielding 25-100 l/min, and 5) unfractured thick shales yielding 5-25 l/min. Thus, while major porous sandstone bodies form the best production zones within the Paskapoo, finer grained sands and mudstones can still have reasonable production related to fracture enhanced transmissivity.

Outcrops that are extensive enough to provide statistically reasonable sample size to examine fracture patterns are rare, however we present one example below. Here we see that fracture spacing is correlated to bed thickness (Fig. 4). This implies that thinner beds may be better production zones in some circumstances due to higher fracture-enhanced permeability. These and other regional trends in fracture patterns are still being examined.

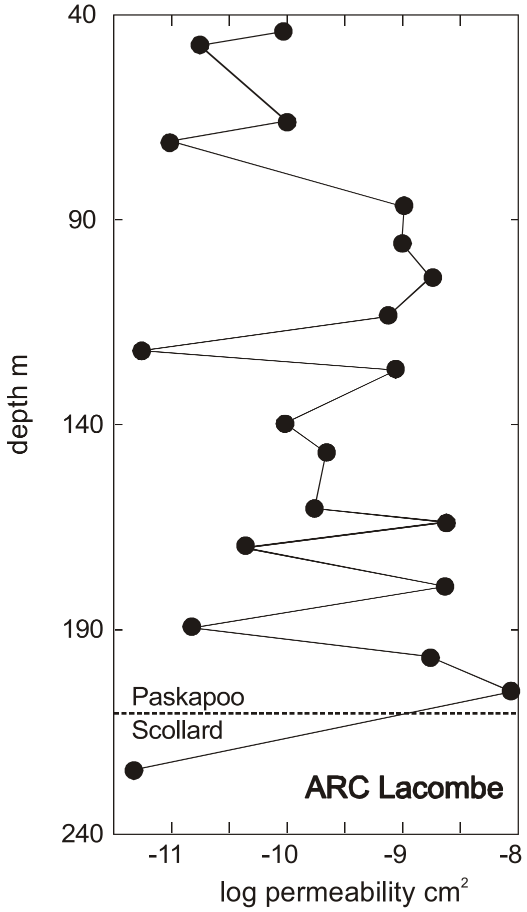

Figure 3. Vertical profile of measured permeabilities in sand beds of the Paskapoo Formation for the ARC Lacombe well.

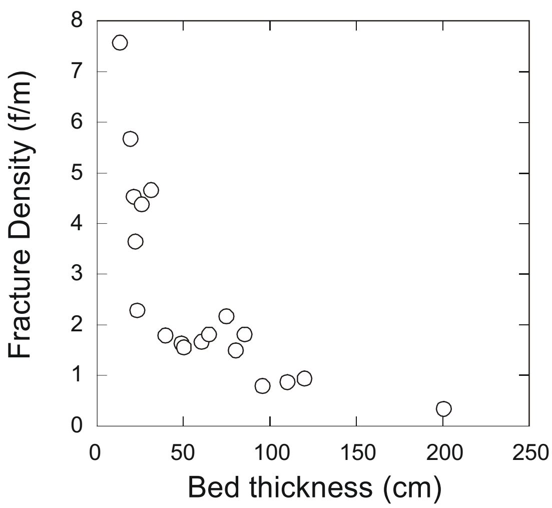

Figure 4. Plot of fracture density versus bed thickness for the Cochrane train cut.

6. WATER CHEMISTRY

The Paskapoo Formation shows a broad range in background water quality. The total dissolved solids vary from 10 to 6800 mg/l. Waters range from Ca-HCO_3 to Na-SO_4 types. There is distinct trend of increasing SO_4 and Na concentrations (Fig. 5). The most notable trend in water quality in the Paskapoo Formation is the occurrence of high sulphate waters in the eastern portion of the outcrop belt. Figure 6 shows wells with sulphate exceeding the drinking water standard of 500 mg/l. Figure 6 also shows that the high sulphate levels tend to be restricted to portions of the Paskapoo underlying tills of the eastern Laurentide Ice sheet. While not confirmed yet by stable isotope data, it is hypothesised that these high sulphate values are related to oxidation of sulphides of overlying tills (eastern tills have higher sulphide content than the Cordilleran tills). If confirmed this would imply that recharge must be local and regional flow systems within the Paskapoo are limited, as water chemistry would be influenced by the mineralogy of overlying tills.

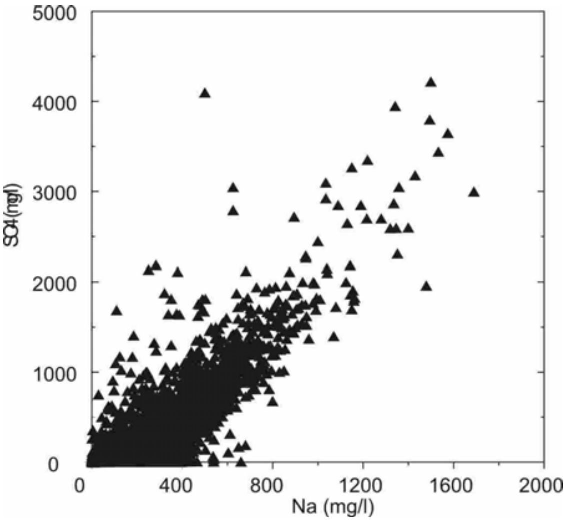

Figure 5. Plot of Na and SO_4 concentrations for groundwaters in the Paskapoo (based on data from Alberta Environment).

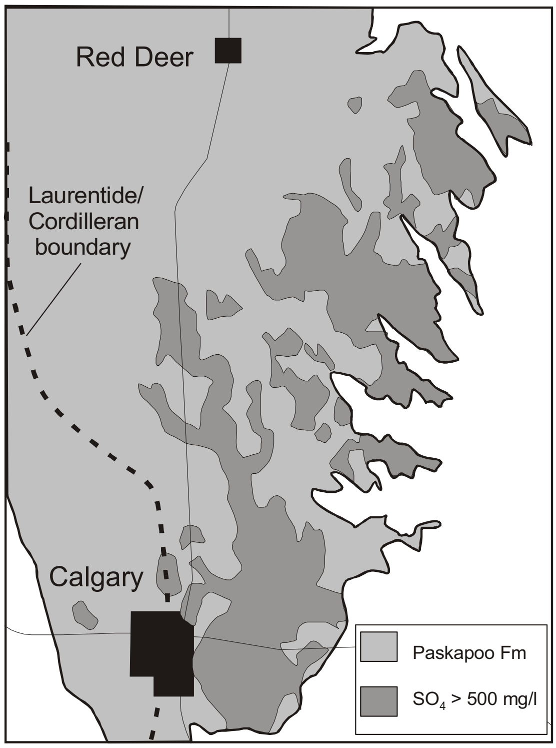

Figure 6. Map of the southern portion of the Paskapoo outcrop belt showing zones where SO_4 levels exceed 500 mg/l.

7. CONCLUTIONS

The Paskapoo Formation is an important aquifer system in southern Alberta. Initial work to date shows it is a complex system with high variability in hydrogeological properties and geochemistry. Ongoing research will better define this natural variability, which will in turn aid proper management of this important water resource.

8. REFERENCES

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