Till geochemistry controls on underlying bedrock water quality – Paskapoo aquifer system, southern Alberta

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ABSTRACT
Groundwater of the Canadian Prairies has high sulphate content that exceeds drinking water guidelines in many regions. The Paskapoo formation shows a significant shift in groundwater chemistry from high to low sulphate, from east to west. This abrupt drop in sulphate concentration is coincident with the boundary between Cordilleran and Laurentide tills. Stable-isotope data show a strong inverse relationship between sulphate concentration and $\delta^{34}S$ of sulphate. Low-sulphate waters have high isotope values consistent with Devonian-carbonate-associated sulphate (CAS) present in Cordilleran tills, whereas high-sulphate waters have low isotope values consistent with sulphides within Laurentide till. The strong spatial association of till chemistry and underlying bedrock groundwater quality suggests that on a regional scale recharge may be dominated by local downward flow systems, with little lateral movement of groundwater.

1 INTRODUCTION

Groundwater in the northern Interior Plains of North American is characterised by very high sulphate content (e.g. van Stempvoort et al., 1994; Hendry et al., 1986; 1989; Keller and van der Kamp, 1988) often exceeding water quality guidelines for domestic and agricultural use. Previous work on these high-sulphate groundwaters, focused on shallow intertill aquifers, has shown the dominant source of sulphate is oxidation of pyrite within the glacial deposits (e.g. van Steempvoort et al., 1994; Wallick, 1981; Hendry et al., 1986; Keller et al., 1991; Mermut and Arshad, 1987). Toward the Canadian Rocky Mountains, glacial sediments thin, reducing their capacity to host aquifers, and bedrock becomes the dominant source of groundwater. Similar to groundwater within glacial sediments, bedrock aquifers are also recognized as having high sulphate concentrations (Hendry et al., 1991; Grasby et al. in review). This study examines the source and distribution of high-sulphate groundwater within a major bedrock aquifer system, the Paskapoo Formation in the western Plains.

2 BACKGROUND

The Paskapoo Formation of southern Alberta is an extensive Tertiary fluvial mudstone and sandstone complex covering ~65,000 km^2 (Fig. 1) that supplies approximately 1/3 of groundwater wells in the province of Alberta (~64,000 water wells) (Grasby et al. in review). The Paskapoo Formation is comprised of light grey, thick-bedded sandstone, with greenish sandy siltstone and mudstone, which were deposited in nonmarine environments.

Porous sandstones of the Paskapoo Formation range from very fine to coarse grain. Sandstones are dominantly litharenites, with major framework grains including quartz, feldspar, and rock fragments (mainly chert, volcanic, metamorphic and sedimentary rock fragments).

The Paskapoo Formation is overlain by tills derived from Cordilleran glaciers to the west and the Laurentide ice sheet to the east. Cordilleran tills are dominated by carbonates and pink-purple quartzite, whereas Laurentide tills are characterized by abundant granitic and gneissic pebbles/cobbles in addition to quartzite (Moran, 1979; Thompson, 1981; Jackson 1980). Glacial sediments in the study are generally thin (<10 m and as thin as 1 m) but are locally as thick as 60 m.

3 METHODS

Water samples were collected from residential water wells and analysed for major-ion geochemistry in addition to stable isotopes. Chemical analyses were conducted at the Geological Survey of Canada. Stable isotope data were determined at the University of Calgary.

Glacial sediments were examined at seven sites in an east to west profile to better define the nature of the Cordilleran and Laurentide boundaries in the study area. Sites were selected from new housing or construction development where fresh exposures of till have been made through excavation for building foundations. At each site 50 granule-to-cobble size stones were collected over a 1 metre square area, and used to characterize the bulk lithology of till material. In addition matrix material was collected for geochemical analyses.

4 RESULTS

4.1 Groundwater geochemistry

Groundwater of the Paskapoo Formation has a broad range in total dissolved solids (TDS) content, from 375 to 2500 mg/l and an average of 1000 mg/l. Consistent with regional trends shown by Grasby et al. (in review), water in the western portion of the Paskapoo has lower TDS as compared to the eastern part (Fig. 2) An abrupt increase in TDS occurs across an approximately N-S trending line, coincident with the till boundary defined below. The bulk water geochemistry varies with TDS across the aquifer, ranging from Ca-Mg-HCO_3, to Na-HCO_3, to Na-SO_4 waters (Fig. 4). With only rare exceptions, Cl forms a minor component of water chemistry. Ca and Mg are dominant in the western portion of the aquifer and show a strong linear relationship. The lowest TDS waters are Ca-dominated, and the Na/Ca ratio tends to increase with increasing TDS.

Concentrations of sulphate across the Paskapoo range over 3 orders of magnitude, from 1 to >1000 mg/l. Highest sulphate values are found in the southeastern portion of the aquifer (Fig. 3). A plot of sulphate concentration versus $\delta^{34}S$ shows that low-sulphate waters can have a broad range in stable-isotope composition, from +15 to -15‰ (Fig. 4). However, for SO_4 values exceeding 50 mg/l, stable-isotope values are always less than 0‰, with the majority of high-sulphate waters having $\delta^{34}S$ values averaging around -10‰.

4.2 Till Characteristics

Pebble counts from till profiles show a distinct east-west transition in dominant rock type, from eastern sections with <5% carbonates and >30% granitic/metamorphic pebbles, to western sections with >60% carbonates and 0% granitic/metamorphic component. These end member values are consistent with regional descriptions of Cordilleran and Laurentide tills by Jackson (1980) and demonstrate that a relatively abrupt till boundary does occur within the study area. Based on the occurrence of granitic/metamorphic pebbles, the edge we define for Laurentide till is approximately coincident with the north/south trending boundary defining the drop in SO_4 concentration near Calgary. This is also consistent with the mapping of Moran (1979).

When analysed, total sulfur in the till matrix in most western samples were below detection limits. The eastern most localities showed very low values of 0.002 to 0.005%.

Within our study area the entire observed sections were oxidized, as manifested by red iron-oxide staining. In cores collected in the study area the oxidized zone extends through glacial sediments into underlying bedrock, where distinct redox boundaries within the bedrock are observed from 6 to 13 m depth. Thus, while only the upper portion of thicker drift regions in the central and eastern prairies were oxidized (Keller et al., 1986; Remenda, 1993; Hendry et al., 1986), in regions of thinner drift cover it appears that the oxidation front extends through the entire profile into bedrock. The depth from surface to the redox boundary in bedrock is consistent with the range observed in thick glacial sediments further east. This supports the interpretation that this redox boundary represents a regional paleo-water table established during drier mid-Holocene conditions (Remenda and Birks, 1999).

5 DISCUSSION

The observation of a distinct east-to-west drop in sulphate concentration of groundwater within the Paskapoo precludes an intra-aquifer source of sulphate. There are no lateral facies changes that could account for this as the Paskapoo was dominated by SW-NE- directed transport directions (Grasby et al. in review). Likewise, high and low sulphate levels within the Paskapoo are observed irrespective of whether the water is produced from oxidized or unoxidized portions of the aquifer. Our results also show that TS content of unweatherd Paskapoo rocks are an order of magnitude lower than that reported for unweathered portions of the overlying Laurentide till (0.35%) by (Van Stempvoort et al., 1994). We conclude that Paskapoo rocks do not contain readily oxidized sulphur, and thus weathering of the Paskpaoo does not contribute to the dissolved sulphate load of aquifer waters.

The only significant correlation we observe with the N-S boundary of high sulphate waters is the spatial relationship with the boundary between Cordillera and Laurentide tills.

The two major till types which meet over the Paskapoo Formation were deposited by continental ice sheets that originated from two distinct regions of Canada. The Laurentide Ice, which originated in the Hudson Bay area, transported igneous and metamorphic rock from the Canadian Shield, whereas Cordilleran tills were derived from the Canadian Rocky Mountains whose front ranges are dominated by Paleozoic carbonate rocks. Previous work has shown that both groundwater and surface waters originating from Devonian carbonates have sulphate contributed by anhydrite dissolution (Grasby and Hutcheon, 2000; Grasby et al., 2000) with characteristic $\delta^{34}S$ values of ~20‰, similar to values associated with low-sulphate groundwaters in the Paskapoo Formation.

Van Stempvoort et al. (1994) show TS content of thick unweathered Laurentide deposits to the SE of our study area to be 0.35%, the majority of which is pyrite-associated S. The low TS levels of oxidized till in our study area (0.002%) suggests significant sulphide oxidation has occurred. Van Stempvoort et al. (1994) also show $\delta^{34}S$ of this pyrite to be -11.4‰, consistent with values observed in high-sulphate groundwaters of the Paskapoo Formation. Stable isotope data thus suggests that distinctly higher sulphate levels in the eastern portion of the Paskapoo Formation is a function of recharge through overlying pyrite-rich Laurentide till as compared to western portions of the Paskapoo that are recharged through Cordilleran till and have associated low-sulphate levels.

6 CONCLUSIONS

We show here stable-isotope data which suggest that oxidation of pyrite has generated high-SO_4 groundwater in bedrock aquifers underlying Laurentide, but not Cordillera glacial sediments. This demonstrates how for aquifer systems that are dominated by local recharge processes, rather than a regional flow system, composition of overlying glacial sediments strongly influences subsequent bedrock groundwater quality. An interesting observation in our area is that the redox front has moved entirely through the glacial sediments into bedrock, greatly reducing TS levels as compared to unoxidized till further to the east. This suggests that postglacial oxidation and degradation of groundwater quality is likely a transient affect.

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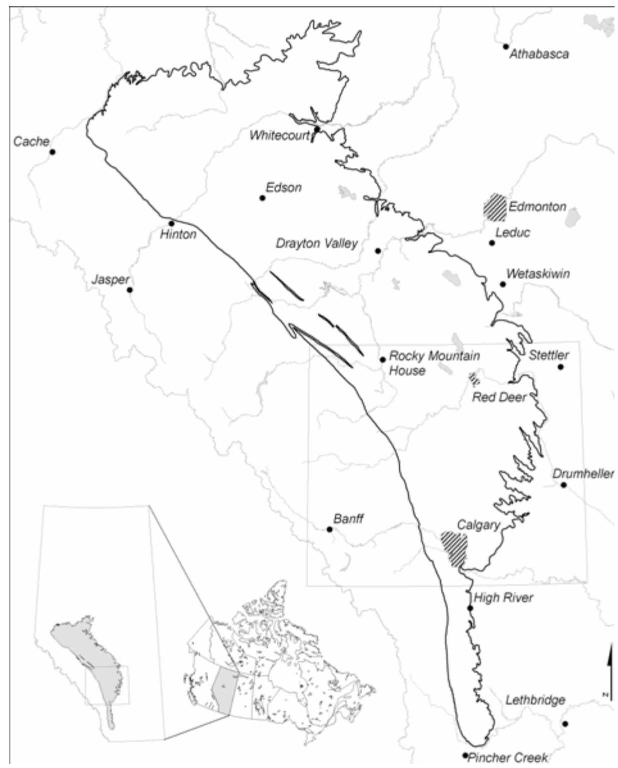

Figure 1. Distribution of the Paskapoo Formation in southern Alberta.

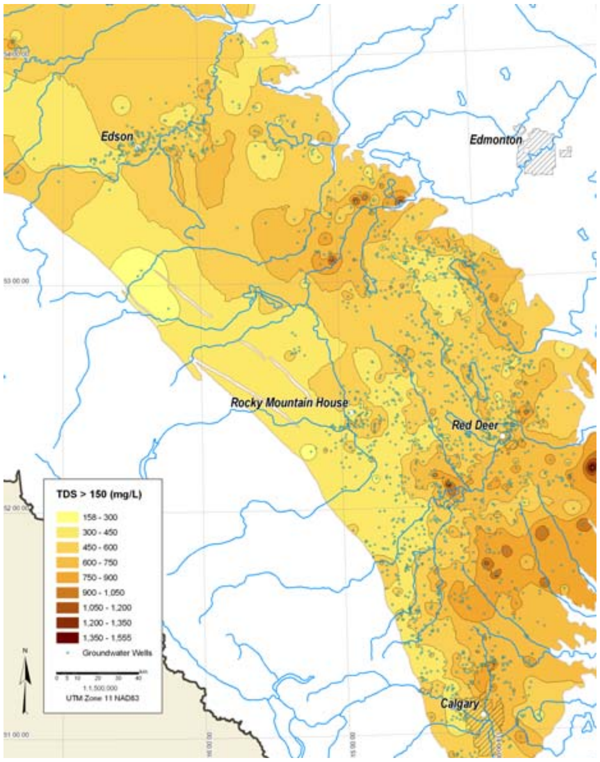

Figure 2. Regional trends in total dissolved solids (TDS) of groundwater in the Paskapoo Formation.

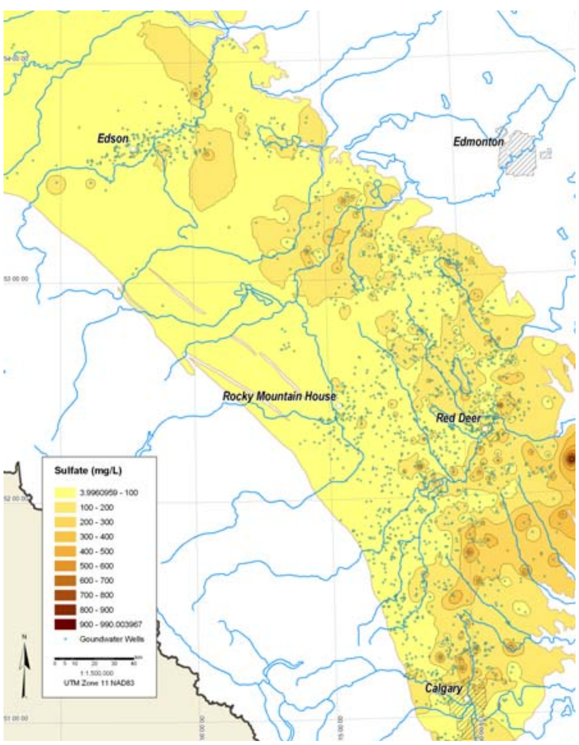

Figure 3. Regional trends in dissolved sulphate concentrations in the Paskapoo Formation.

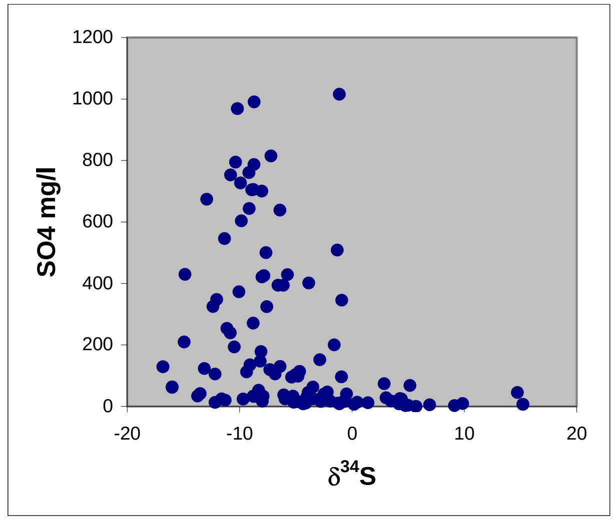

Figure 4. Plot of sulphate concentration versus sulphur isotope values for dissolve sulphate.