# Regional Hydrogeological Characterization in the Northeastern Margin of the Williston Basin, Saskatchewan-Manitoba, Canada

Dan Palombi*
Alberta Innovates – Technology Futures, Edmonton, Alberta, Canada
Dan.Palombi@albertainnovates.ca

and

Ben Rostron
Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta, Canada

## Introduction

The Williston Basin hosts one of the largest regional groundwater flow systems in North America. Understanding its regional hydrogeology is essential because the Williston Basin contains many natural resources that are impacted by the flow system in Saskatchewan and Manitoba. A diverse range of economic resources such as freshwater, potash and hydrocarbons are present within the rocks of the basin. More recently, hydrogeological characterizations have been utilized in assessing deep saline aquifers and depleted oil reservoirs for $CO_2$ storage and nuclear waste disposal in the Williston Basin (Whittaker et al., 2004; Brunskill, 2006), further emphasizing the need for detailed regional hydrogeology investigations. Previous hydrogeological studies in the basin have not been integrated across provincial boundaries and have used outdated geological frameworks.

Thus a new hydrogeological and hydrochemical characterization of the northeastern corner of the Williston Basin has been undertaken. This project was titled “The Williston Basin Architecture and Hydrocarbon Potential Project” and was a joint project involving the provincial governments of Saskatchewan and Manitoba, the federal government, and the University of Alberta under Natural Resources Canada’s targeted geoscience initiatives (TGI-2) (Kreis et al., 2004). The hydrogeology objectives were to identify driving forces, determine flow directions, and characterize the composition and distribution of subsurface waters in the basin for the entire sedimentary succession.

## Methodology

The TGI-2 project study area ranges from longitude $106^0$W through $96^0$W, is bounded to the south by the Canada-USA border, and to the north and northeast by the edge of Phanerozoic cover within the Williston Basin (Figure 1). The study area represents a cross-border analysis of Saskatchewan and Manitoba with an emphasis on areas outside the traditional limits of hydrocarbon production and incorporates the erosional edge of the Williston Basin.

The hydrochemistry and hydrodynamics of the regional aquifers were interpreted using distributions of salinity and hydraulic heads. Variations in major ion chemistry of the formation water was analyzed and classified into water types. The lateral and vertical flow patterns were assessed using trends of hydraulic head distributions as well as plots of pressure variation with depth. Density-dependent fluid flow is important in certain aquifers because downdip flow decreases the upward driving force for cross-formational flow and enhances hydrocarbon trapping capacities. A quantitative analysis of variable density groundwater flow has been completed for all the aquifers in the succession.

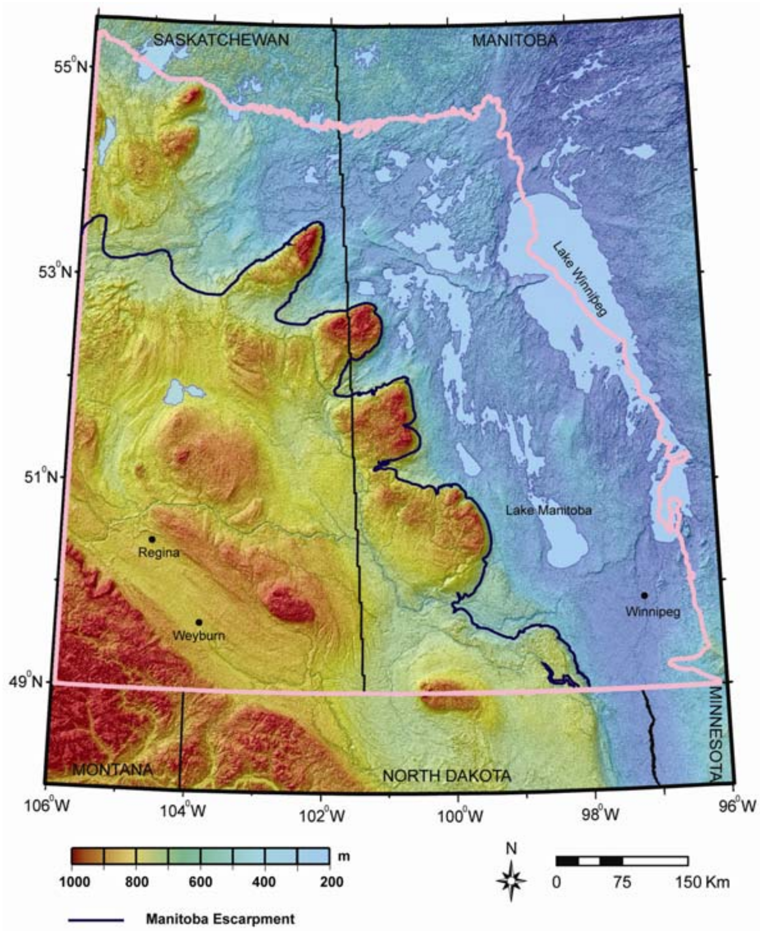


Figure 1: Digital elevation model in the northeastern portion of the Williston Basin. The TGI-2 study area is outlined in pink and the Manitoba escarpment is shown by a dark purple line.

## Results

An updated geological framework was refined into a hydrostratigraphic column consisting of 20 major aquifers and 13 aquitards (Figure 2). Detailed mapping of water chemistry and hydraulic heads has been conducted on aquifers ranging in age from Cambrian to the upper Cretaceous. A large variation of formation waters are found both within and across the aquifers. Mapped formation water salinities range from 2 to 470 g/L and indicate significant density variations between formations and across the area. Four distinct formation water types have been identified on the basis of major ion chemistry: (1) Na-Cl brines, (2) Na-$SO_4$ brackish water, (3) Ca-$SO_4$ freshwater, and (4) Na-$HCO_3$ freshwater. The spatial distribution and chemical signature of the water types provides evidence of the origin and evolution of the regional groundwater flow system (Figure 3). Recharge water types of both meteoric and glacial origin, mainly Ca-$SO_4$ and Na-$HCO_3$, have been identified in the southwestern and north-northeastern margins of the study area. In the deeper strata of the Williston Basin, dense Na-Cl brines are the dominant formation water derived mainly by halite dissolution and water-rock interactions. Cross-formational flow and vertical hydraulic communication has been found in areas of weak aquitard competency or in the presence of salt dissolution. The Prairie Evaporite Formation forms a competent barrier and hydraulic separation from overlying and underlying aquifers. However, in its absence or when aquitards become comparatively thin vertical flow has been found. Evidence of the Watrous aquitard also being weak has been observed with salinity distributions and vertical pressure gradients.

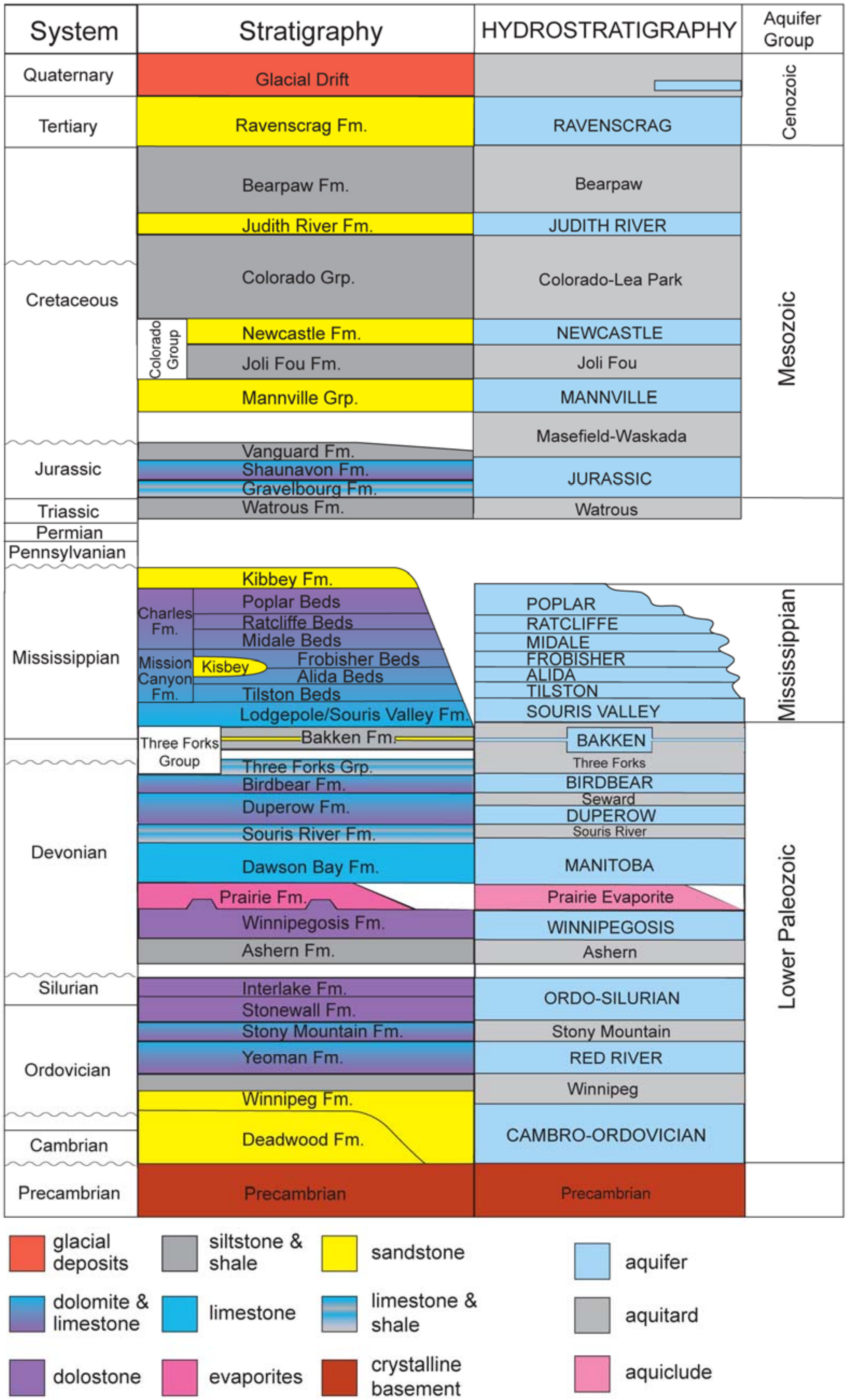


Figure 2: Lithostratigraphic and hydrostratigraphic chart of the sedimentary succession in the northeastern margin of the Williston Basin.

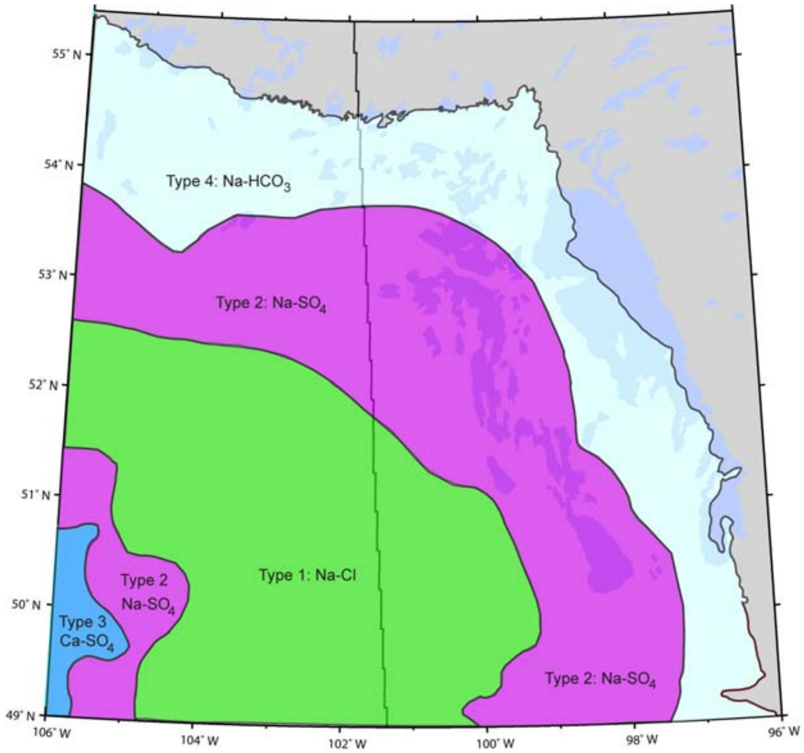


Figure 3: Schematic representation of water types in the Lower Paleozoic aquifers.

Flow directions in the Lower Paleozoic aquifers determined from hydraulic head distributions indicate predominantly updip flow of formation waters from SW to NE imparted by the basin configuration. Mississippian aquifers generally flow from west to east and display both pressure and chemical variations laterally and vertically throughout. The Mesozoic aquifers are regionally underpressured and flow systems are considerably affected by outcrops along the Manitoba escarpment and the net unloading effect during the retreat of the Laurentide ice-sheet. Overall, the central Williston Basin exhibits lateral flow parallel to aquifer confining surfaces. Vertical flow and hydraulic communication is evident toward the basin margins, in areas of salt dissolution and weak aquitards. Regions of downdip flow (flow reversals) are generally only found in southern Saskatchewan. This suggests that brine migration patterns are in a transient state of readjustment following the Laramide orogeny. These brines are gravitationally unstable in the present-day dynamics of the Williston Basin.

## Conclusions

Detailed geological and hydrogeological mapping has revealed significantly different water chemistry and fluid flow regimes within and between aquifers in the northeastern margin of the Williston Basin. Four water types have been identified in Saskatchewan and Manitoba representing specific basinal events in the history of the Williston Basin. Cross-formational flow has been found to occur in response to salt dissolution and in areas of weak aquitards. Regions having predominantly downdip flow directions have been identified using density-dependent fluid flow analyses.

## Acknowledgements

The authors gratefully acknowledge funding of the TGI-2 project received from Natural Resources Canada. The authors wish to also thank all of the geoscientists and geologists at the Ministry of Energy in Saskatchewan and at Manitoba Innovation, Energy and Mines Petroleum for the geological characterization they provided in the TGI-2 project.

## References

Brunskill, B., 2006, Discussion of an Option for Geological Storage of Used Nuclear Fuel Beneath the Williston Basin of Southern Saskatchewan, *in:* Summary of Investigations 2006, Volume 1, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2006-4.1, CD-ROM, Paper A-4, 8p.

Kreis, L. K., Beauchamp, B., Bezys, R., Martiniuk, C., and Whittaker, S., 2004, Williston Basin architecture and hydrocarbon potential in eastern Saskatchewan and western Manitoba, *in:* Summary of Investigations 2004, Volume 1, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2004-4.1, CD-ROM, Paper A-3, 5p.

Whittaker, S., Rostron, B. J., Khan, D., Hajnal, Z., Qing, H., Penner, L., Maathuis, H., and Goussev, S., 2004, IEA GHG Weyburn $CO_2$ Monitoring & Storage Project Summary Report 2000-2004, *in:* M. Wilson and M. Monea, eds., Seventh International Conference on Greenhouse Gas Control Technologies, Petroleum Technology Research Centre, v. 1, 273p.