Saskatchewan Phanerozoic Fluids and Petroleum Systems Assessment: 2010 Update

A. Melnik [1], B. Rostron [1], S. Bend [2], A. Marsh, M. Yurkowski, and S. Whittaker [3]

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Abstract

The Saskatchewan Phanerozoic Fluids and Petroleum Systems (SPFPS) assessment project is a five-year interdisciplinary collaborative project aimed at improving the understanding of hydrocarbon generation, migration, and entrapment in the subsurface of Saskatchewan. The SPFPS project involves compiling newly acquired and previously existing data that will facilitate more accurate resource assessments for government and industry, ongoing exploration and development strategies, and further evaluation of Saskatchewan's CO_2 storage capacity. Results obtained in 2010 include: creation of a searchable database of publicly available organic geochemical data from Saskatchewan; preliminary hydrogeology and hydrochemistry of some of the aquifers in southwestern Saskatchewan; and preliminary structural and stratigraphic maps of the province.

Keywords: Phanerozoic, fluids, SPFPS, hydrochemistry, hydrogeology, Duperow, Birdbear, Shaunavon, Mannville, Belly River, organic petrology, southwestern Saskatchewan.

1. Introduction

The Saskatchewan Phanerozoic Fluids and Petroleum Systems (SPFPS) assessment project was initiated in 2009 as a collaboration between the Petroleum Geology Branch of the Saskatchewan Ministry of Energy and Resources (SMER), the University of Alberta, and the University of Regina. The project has two main objectives: 1) to improve the understanding of how and where hydrocarbons in the Saskatchewan subsurface were generated, and where and when they migrated over geological time to help determine where they are most likely trapped at present time; and 2) to provide data that will help create more accurate resource assessments for government and industry, formulate exploration and development strategies for industry, and help screen for and determine capacities of potential CO_2-storage sites in Saskatchewan (Whittaker *et al.*, 2009). The study area encompasses all of southern Saskatchewan south of the Precambrian Shield edge. In addition, relevant data from selected neighbouring portions of the Western Canada Sedimentary Basin and its U.S.A. equivalent will be utilized.

The SPFPS project work plan is outlined in Whittaker *et al.* (2009). Research was initiated in 2009, and from then until mid-2010, progress has been achieved in four main areas: a) regional hydrogeology and hydrochemistry of southwestern Saskatchewan; b) geothermics of the Williston Basin; c) petroleum geochemistry; and d) integration of existing stratigraphic data for Saskatchewan. Brief descriptions of these results form the basis for this paper.

2. Regional Hydrogeology and Hydrochemistry of Southwestern Saskatchewan: Preliminary Results

This topic is the basis of the M.Sc. thesis of Anatoly Melnik at the University of Alberta. Research work was initiated in January 2009, with the objective of mapping the hydrogeology and hydrochemistry of southwestern Saskatchewan (Figure 1, area "A"). The results will be combined with previously mapped areas by the University of Alberta Hydrogeology Group (Figure 1) and ongoing hydrogeological mapping of the northwestern portion of Saskatchewan's Phanerozoic sediments done by the Petroleum Geology Branch of SMER.

[1] University of Alberta, Department of Earth and Atmospheric Sciences, 1-26 Earth Sciences Building, Edmonton, AB T2G 2E3.
[2] University of Regina, Department of Geology, 3737 Wascana Parkway, Regina, SK S4S 0A2.
[3] Petroleum Technology Research Centre, 6 Research Drive, Regina, SK S4S 7J7.

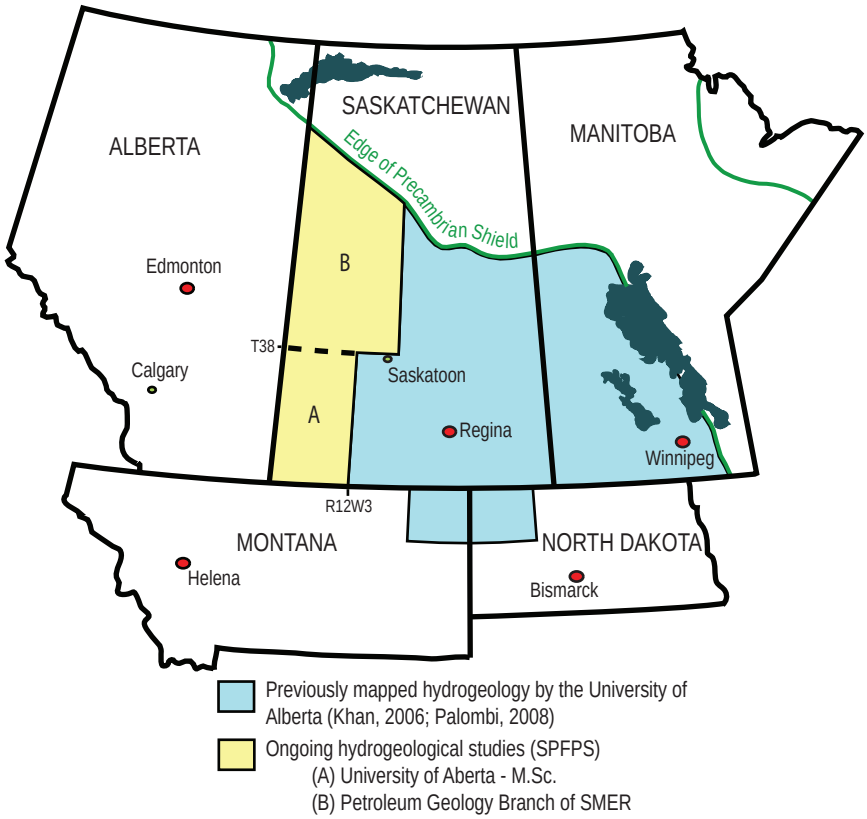

Figure 1 - Hydrogeological study areas.

a) Methodology and Data

The first phase of the project involved assembling the requisite hydrogeological and hydrochemical data. Most of these data consist of fluid pressures and water chemistry analyses obtained from drill stem tests (DSTs), well workover reports, and production tests. Additional pressure data from shallow water-well records in the Belly River aquifer, provided by the Saskatchewan Watershed Authority, were also incorporated into the dataset. Pressure and water chemistry data were collected from Accumap™, geoSCOUT™, and GeoFluids™ (chemistry only), and SMER databases. Data were compiled into digital form (*i.e.*, spreadsheets) and assigned to a preliminary hydrostratigraphic framework adapted from previous regional hydrogeological mapping in Saskatchewan (Palombi, 2008). The current working hydrostratigraphic framework (Figure 2) contains 12 major aquifers: seven Paleozoic-, one Jurassic-, and four Cretaceous-aged units.

Pressure and chemistry data were "interval-tested" against the geological framework supplied by the Petroleum Geology Branch of SMER. This was done to ensure that each data point was within an appropriate geologic formation. Then, extensive pressure and chemistry data culling was performed to ensure that only representative data were used to produce the final maps. These data were culled for poor quality (*i.e.*, extrapolation errors), production-influenced pressures (Tóth and Corbet, 1986; Barson, 1993; Rostron, 1994), and incomplete or contaminated chemical analyses (Hitchon and Brulotte, 1994) following the procedures developed by the University of Alberta Hydrogeology Group (Barson, 1993; Alkalali, 2002; Khan, 2006; Palombi, 2008). During the culling process more than 80% of data were eliminated from the dataset. Additional pressure data from water levels in the shallow Belly River aquifer from domestic water wells have been integrated with hydraulic head derived from DST pressures from this unit.

b) Preliminary Results – Fluid Flow

Pressure data for each aquifer were converted to equivalent fresh water heads (EFWH), posted, and contoured for each aquifer. Sample results are shown for four aquifers (Figures 3 to 6). Fluid flow in the deepest Paleozoic aquifers is directed primarily towards the north as indicated on the potentiometric surface of the Duperow Aquifer (Figure 3). Hydraulic heads are highest in the south and decrease northward with the inferred recharge being from topographically high areas in Montana.

Fluid flow in the southern and western parts of Jurassic-aged Shaunavon Aquifer (Figure 4) is also directed northwards. In the south-central part of study area, however, the fluid flow direction gradually shifts eastward towards a pronounced potentiometric low (Figure 4). This prominent hydrodynamic low is spatially associated with the producing Shaunavon oil and gas pools and understanding the relationship between fluid flow and hydrocarbon entrapment/production will be the focus of future work on this project.

In marked contrast to the deeper units, fluid-flow directions in the Lower Cretaceous aquifers (for example Lower Mannville, as seen in Figure 5) are directed towards the east and northeast indicating influence of inflow from the Alberta Basin across the Sweetgrass Arch (Figure 5). Fluid flow in the Belly River aquifer (Figure 6) is controlled

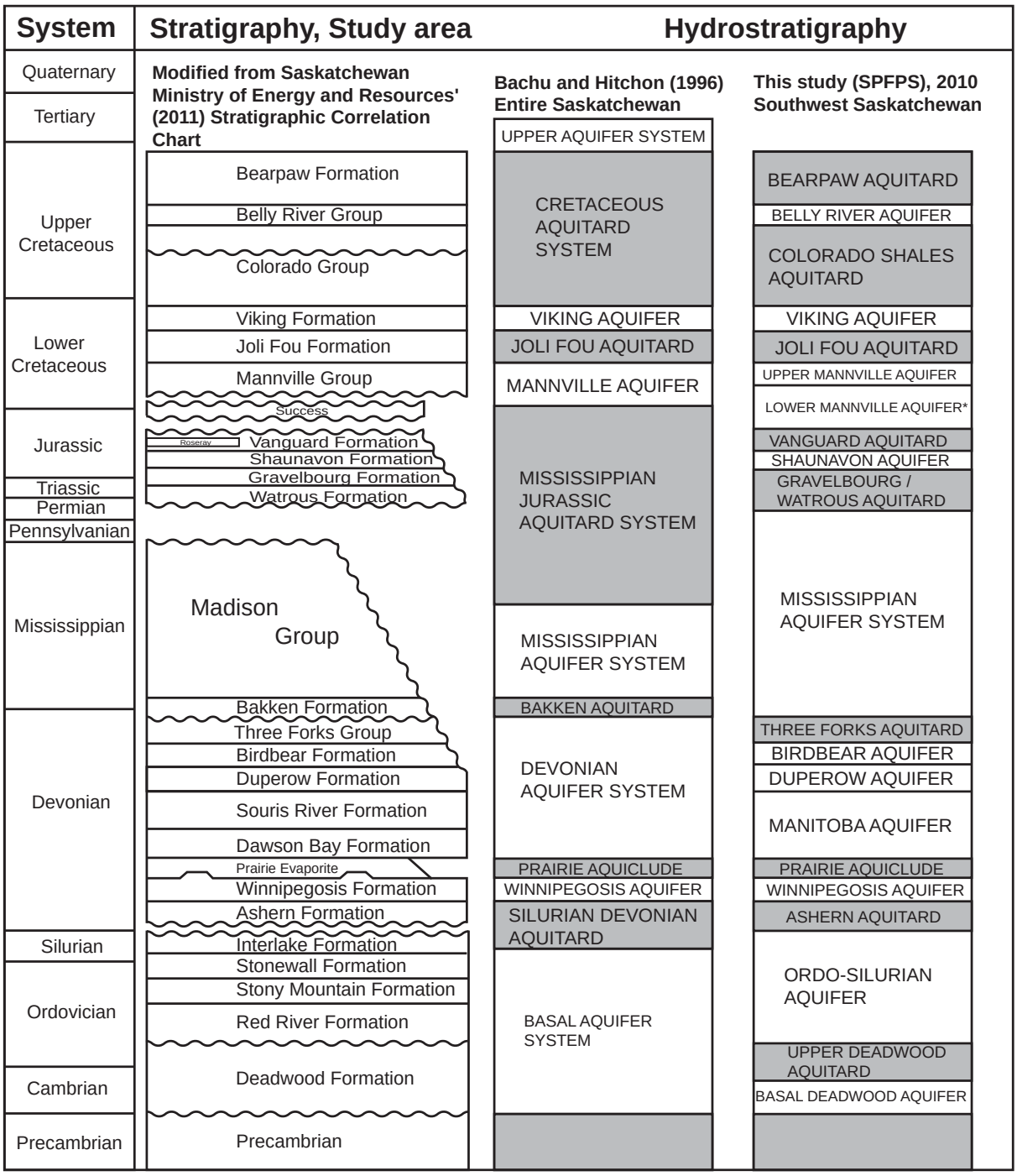

Figure 2 - Stratigraphy (modified from Saskatchewan Ministry of Energy and Resources' (2011) stratigraphic correlation chart) and preliminary hydrostratigraphy of southwestern Saskatchewan.

by local topography, with flow directed away from topographic highs mainly towards low-lying subcrop and eroded areas around the South Saskatchewan River.

Further refinement of these maps, combined with preparation and interpretation of hydraulic cross sections will be the next phase of the work in this area.

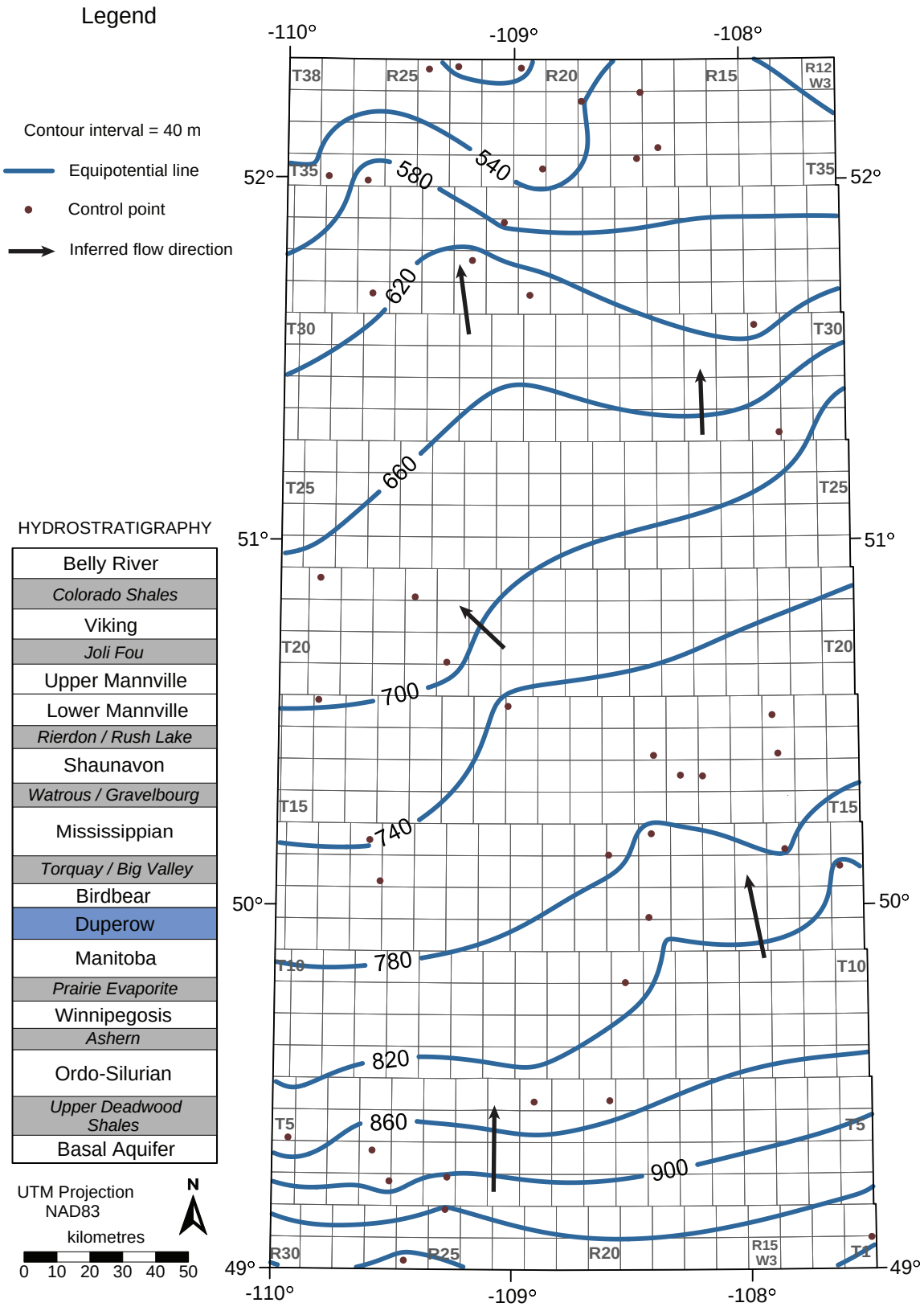

Figure 3 - Potentiometric surface map of the Duperow aquifer. Contours are metres of EFWH. Colours on the hydrostratigraphic column: white, aquifer; grey, aquitard.

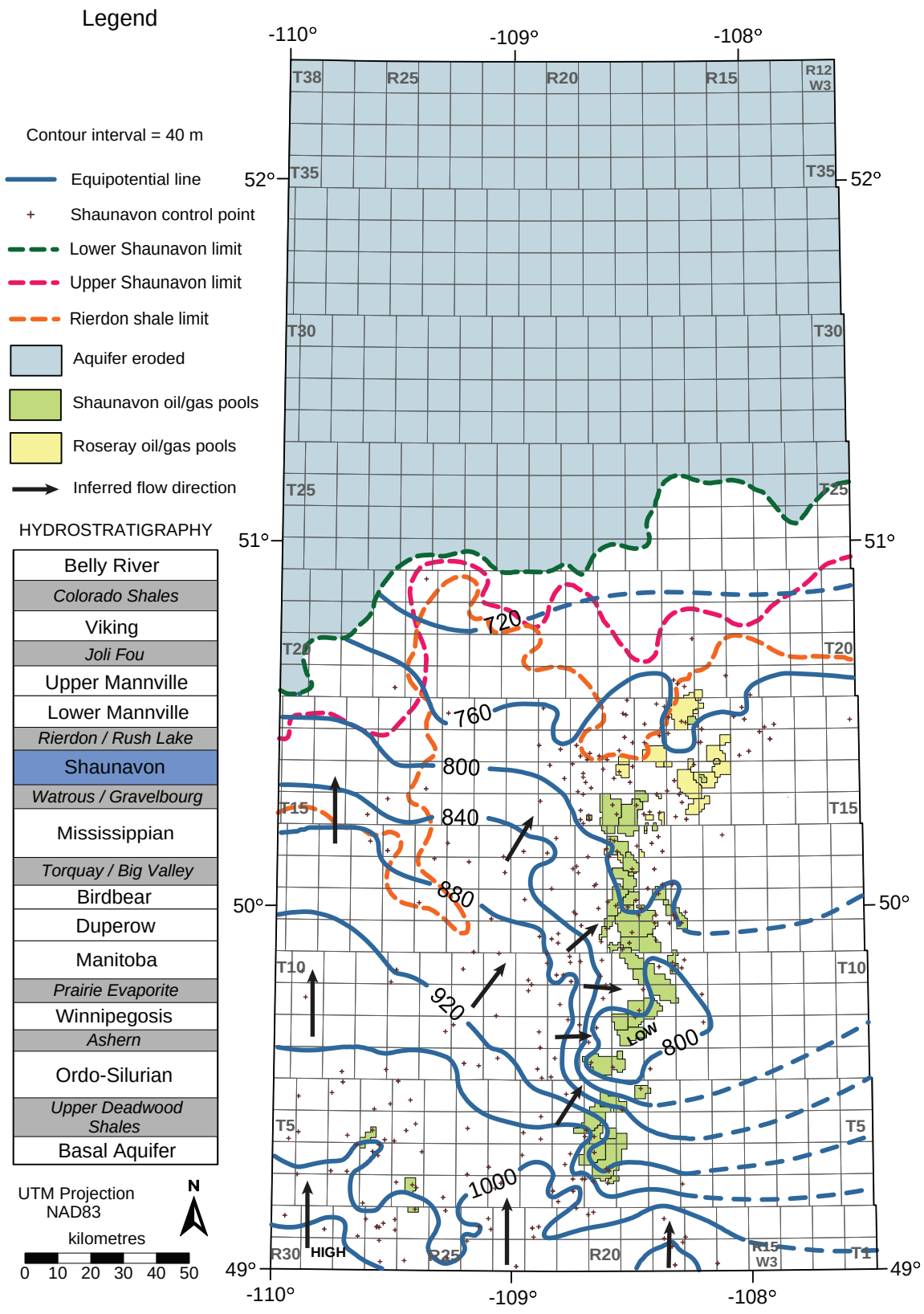

Figure 4 - Potentiometric surface map of the Shaunavon aquifer. Contours are metres of EFWH. Colours on the hydrostratigraphic column: white, aquifer; grey, aquitard.

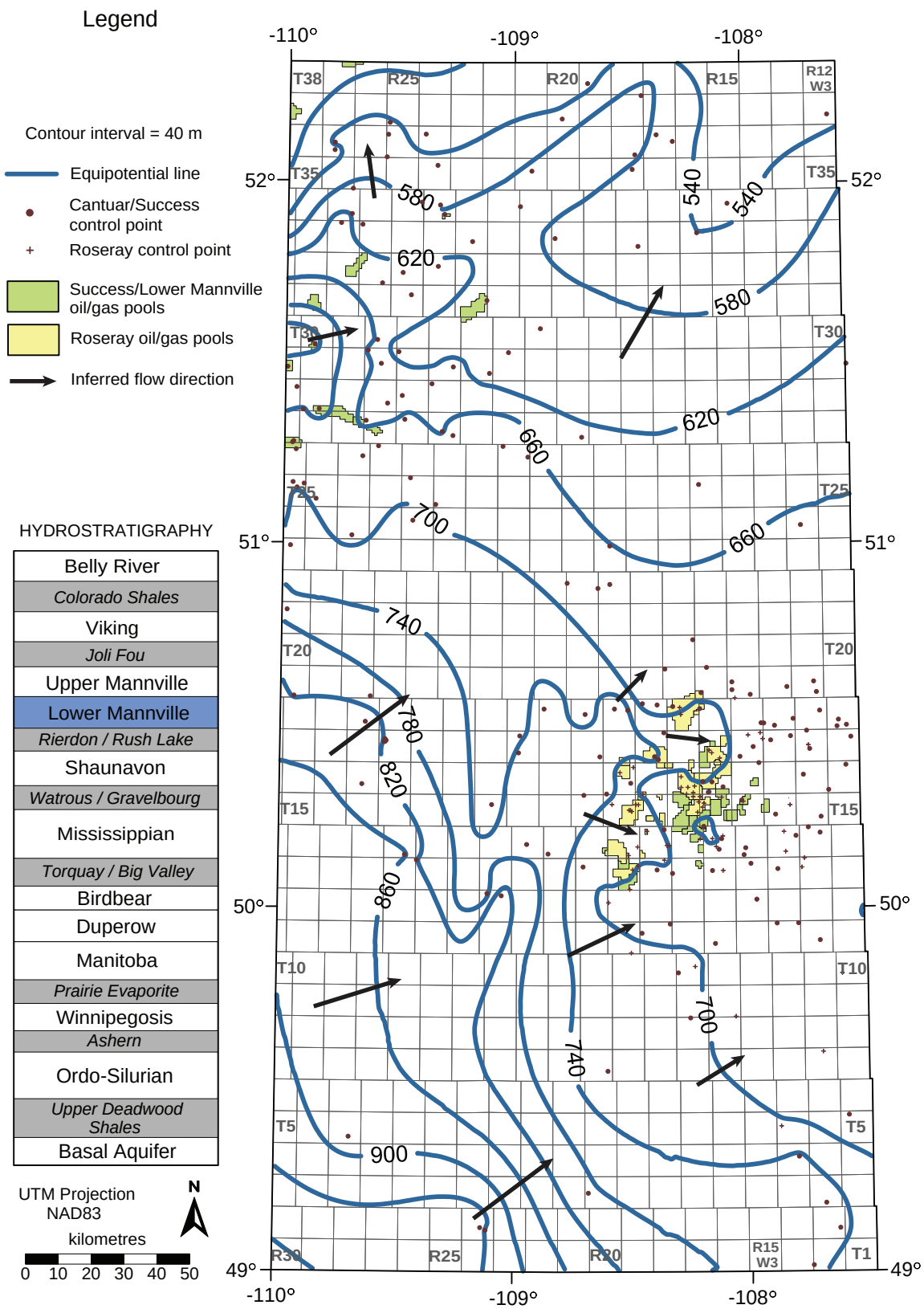

Figure 5 - Potentiometric surface map of the Lower Mannville aquifer. Contours are metres of EFWH. Colours on the hydrostratigraphic column: white, aquifer; grey, aquitard.

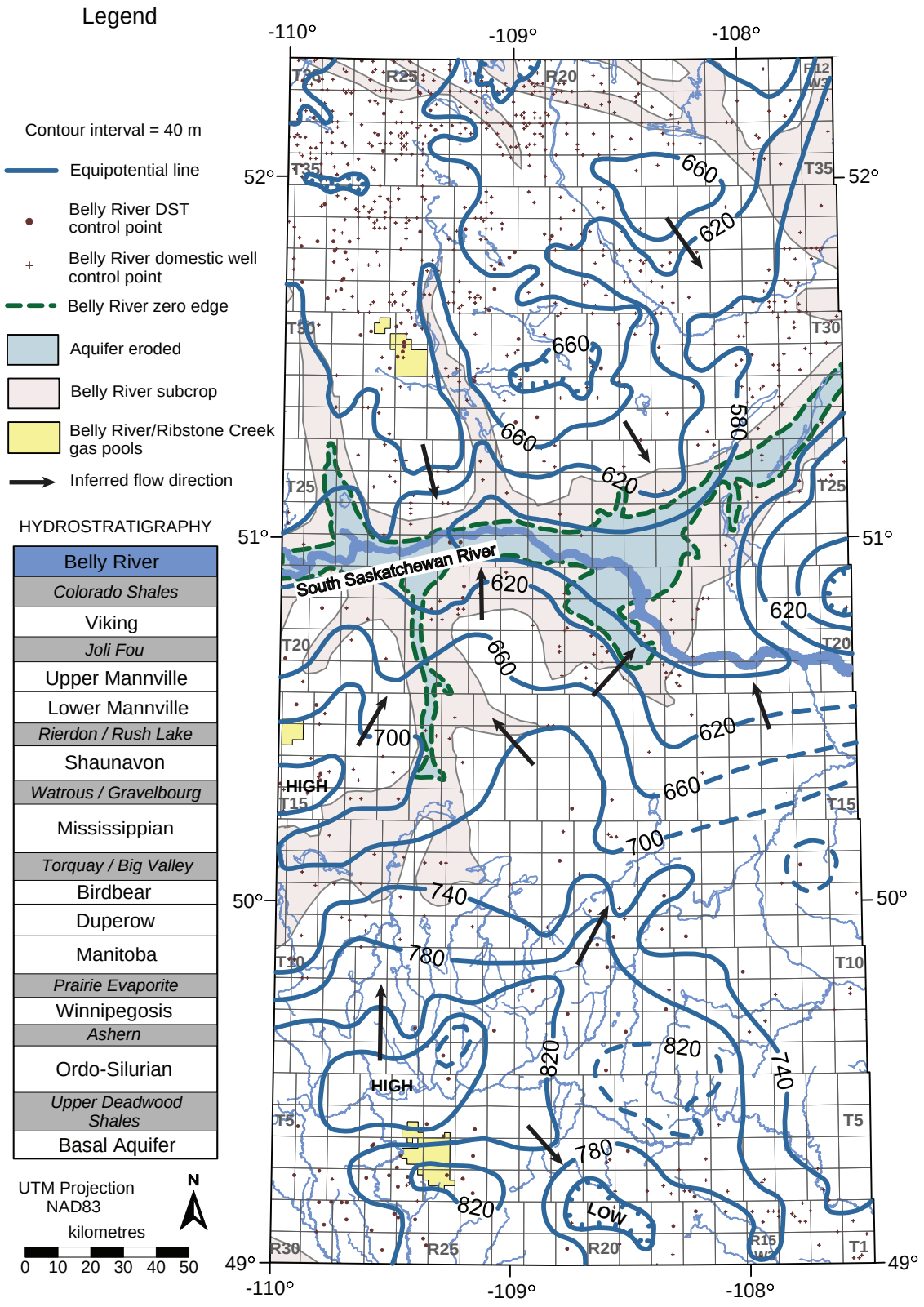

Figure 6 - Potentiometric surface map of the Belly River aquifer. Contours are metres of EFWH. Colours on the hydrostratigraphic column: white, aquifer; grey, aquitard.

c) Preliminary Results – Hydrochemistry

Hydrochemical data for each aquifer were posted and contoured for each aquifer. Sample results are shown for two aquifers (Figures 7 and 8). Overall the geochemical trends for deep Paleozoic (Basal, Ordo-Silurian, Winnipegosis, and Manitoba) aquifers are similar to those shown by the total dissolved solids (TDS) values in the Basal Aquifer (Figure 7). Total dissolved solids values range from less than 10 g/L in the south to over 300 g/L in the north, with the highest salinity (>200 g/L) values found in areas where the Prairie Evaporite is present. In the southern part of study area, where TDS values are no more than 50 g/L, the water chemistry appears to be diluted by freshwater recharge from Montana highlands. Shallower Paleozoic aquifers, in particular the Duperow, Birdbear (*e.g.*, Figure 8), and Mississippian aquifers, have very low salinities in the south, typically less than 10 g/L, further indicating strong dilution by recharge from the south.

Hydrogeochemical mapping of Jurassic and Cretaceous aquifers is ongoing.

3. Geothermics of Saskatchewan

Work on this project was initiated in September 2009 by Tibor Lengyel, an M.Sc. student at the University of Alberta, with the objective of mapping the geothermics of Phanerozoic strata in Saskatchewan.

There have been several previous studies of the geothermics of Saskatchewan (*e.g.*, Majorowicz *et al.*, 1986; Jessop and Vigrass, 1989; Bachu and Burwash, 1994), so the first task in this project has been a literature review of the previous work. Second, on-going work has been directed towards creating a digital dataset of temperature data for the basin. These data were derived from DSTs, downhole pressure surveys, and temperature logs. In addition, the widely available bottom-hole–temperature data reported on well-log headers, which are commonly subject to inaccuracies (Lanchenbruch and Brewer, 1959; Beck and Balling, 1988), are being assessed. Significant time has been spent comparing different sources and types of data, as well as different temperature correction and evaluation methods (*e.g.*, Horner method, Bullard method, statistical analysis, *etc.* of Lanchenbruch and Brewer, 1959). Ongoing work is targeted towards compiling a downhole temperature database for Saskatchewan.

4. Organic Geochemistry and Organic Petrology

The goal of this study is to address gaps in the distribution and type of existing organic geochemical data available for the basin, to generate new data for oil-oil and oil–source rock correlations and the identification of migration fairways. The initial focus is on those formations known for their hydrocarbon generation including the Winnipeg/Deadwood, Ratner, Dawson Bay, Bakken, and Shaunavon.

The initial part of this project consisted of compiling pre-existing and previously published data into a database for use by industry, government, universities, and other institutions. Data, collated from theses, reports, and previously published sources is at present undergoing review for variations in methodology or data treatment that may effect the comparison of data created by differing labs (DeVanney and Stanton, 1994). This part of the project is near completion. The next phase of the study will involve the generation of new data through analysis of available drill cuttings and core samples to fill geographic and stratigraphic gaps in data. Analyses will include: Rock Eval™ pyrolysis, vitrinite reflectance, petrographic analysis (*i.e.*, organofacies), gas-chromatography, and gas chromatography–mass spectrometry (biomarker) analysis. Oil-oil and oil–source rock correlations will be made using the new and existing data to provide new information regarding oil generation and distribution, as well as inputs for petroleum system modelling. Source rock potential will be initially assessed using Rock Eval™ pyrolysis, petrographic analysis, and vitrinite reflectance with the intent of identifying and delineating source rock potential as mappable organofacies, an approach that has aided successful exploration strategies worldwide. It is anticipated that our enhanced understanding of fluid flow and hydrochemistry, augmented by oil-oil and oil-source correlations will aid in the identification of migration fairways and the petroleum systems of Saskatchewan.

5. Stratigraphic Data

Stratigraphic data has been integrated from two recent regional stratigraphic framework projects. The intergovernmental and interprovincial Williston Basin Architecture and Hydrocarbon Potential (TGI 2 Project [4]); contains stratigraphic well data for the entire Phanerozoic throughout the eastern half of the province (east of the 3rd Meridian), while the Petroleum Technology Research Centre's (PTRC) Western Stratigraphic Framework

[4] URL <http://www.gov.mb.ca/stem/mrd/geo/willistontgi/database.html>.

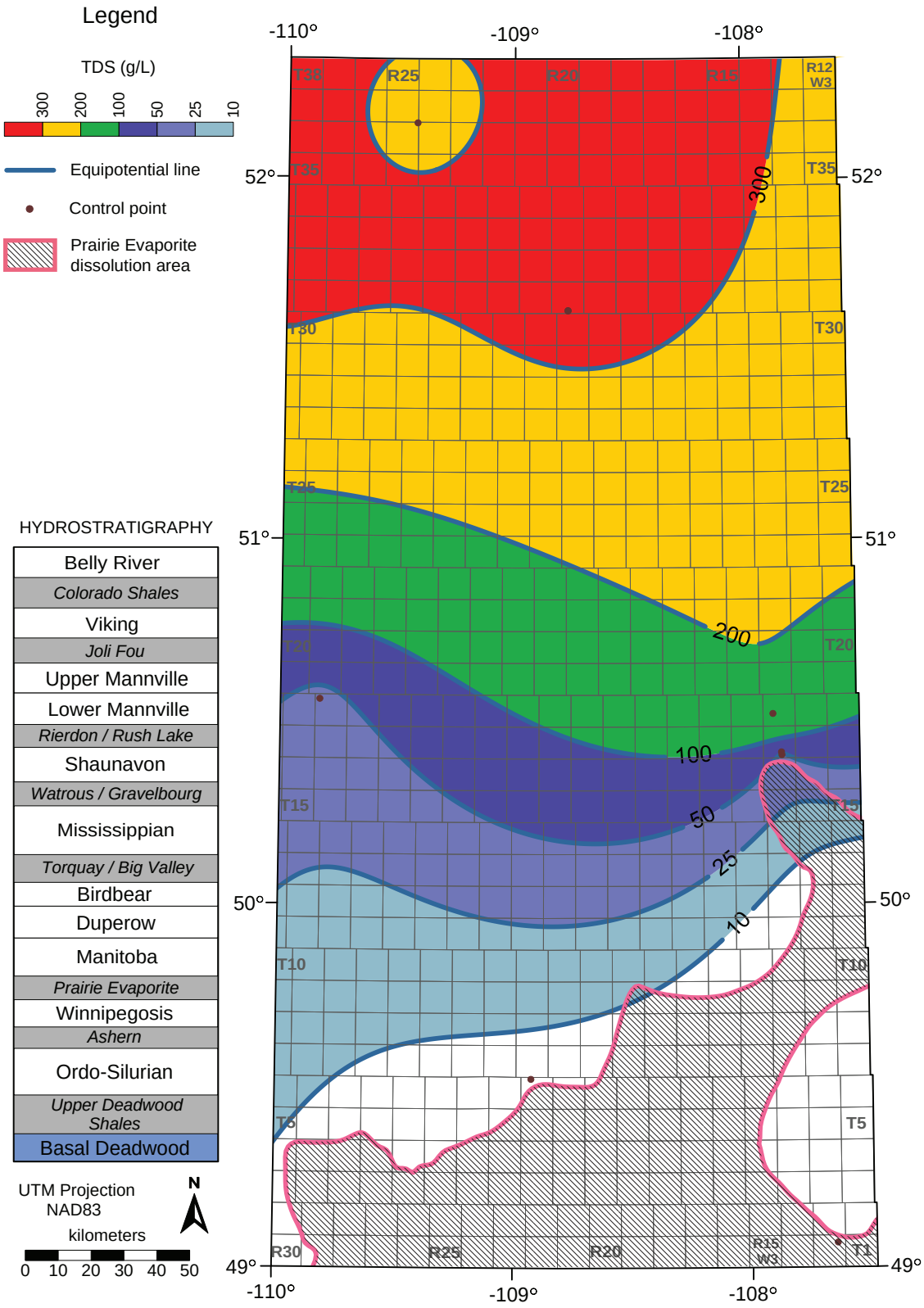

Figure 7 - Total dissolved solids map of the Basal Deadwood aquifer. Colours on the hydrostratigraphic column: white, aquifer; grey, aquitard.

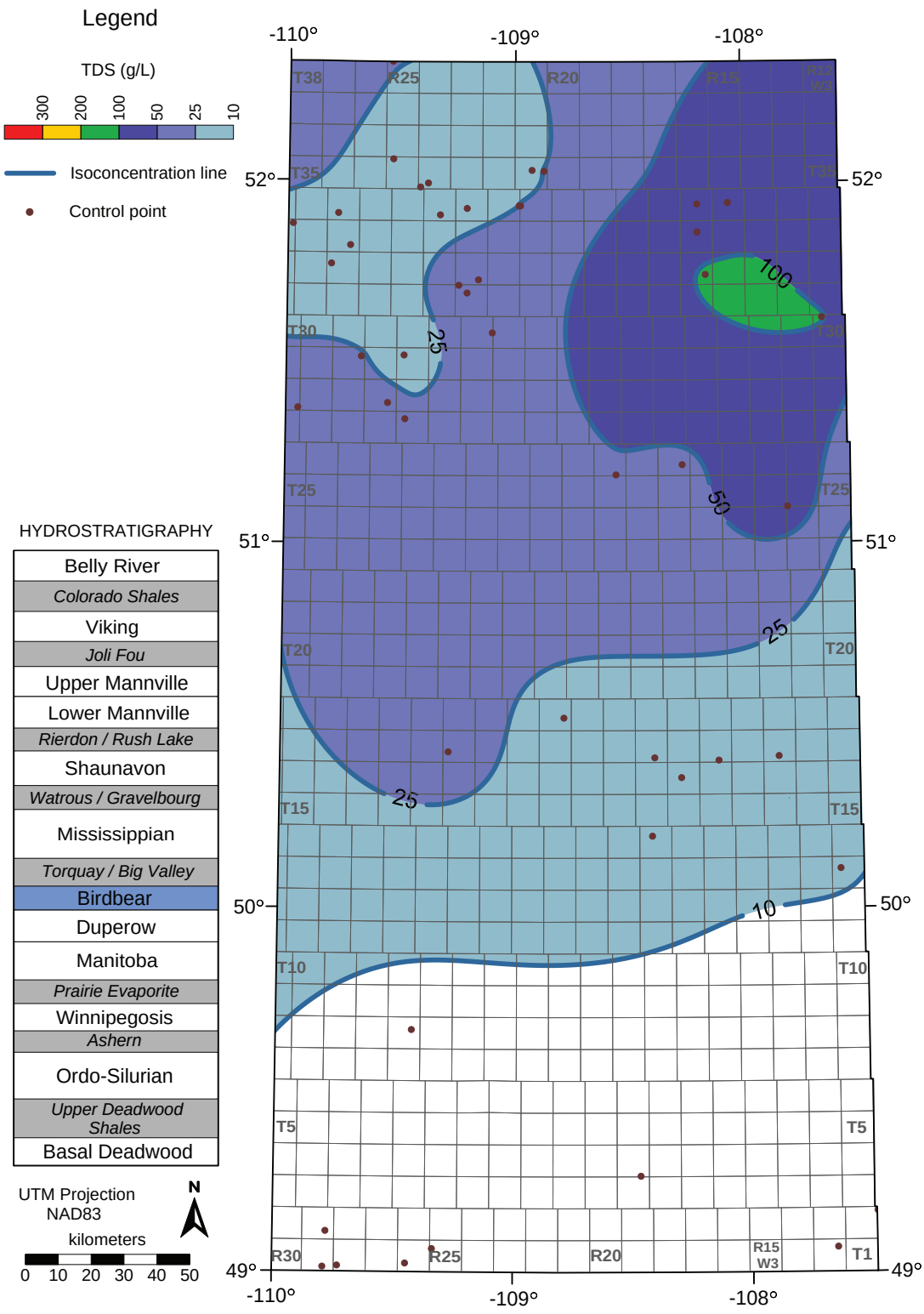

Figure 8 - Total dissolved solids map of the Birdbear aquifer. Colours on the hydrostratigraphic column: white, aquifer; grey, aquitard.

Projects (Phases 1 [5] and 2 [6]) includes data from the same strata for the entire western half of Saskatchewan (Rge. 1 to 30W3). To date, preliminary structure and isopach maps have been created for all major surfaces using Golden Software's Surfer® 9. All of the maps were gridded and posted using well point data projected in UTM NAD83, zone 13 (extended) Central Meridian 105. These projected well point data were converted from their original WGS84 latitude-longitude geographic coordinates using Blue Marble Geographics' geographic calculator.

Upon review of the preliminary structure and isopach maps, it has been determined, for contouring purposes, that data from wells from two ranges into both Manitoba to the east and Alberta to the west, as well as five townships into both North Dakota and Montana should be included in the stratigraphic database. These data will not be visible on the final maps, however they are necessary to eliminate undesirable 'edge effects' at the provincial boundaries. Data for the two ranges into Manitoba, the five townships into North Dakota, and the five townships into Montana as far west as the 3rd Meridian will be integrated from the TGI 2 Project. The data for the remainder of the five townships into Montana and the two ranges into Alberta will be derived from the picking of all of the major stratigraphic surfaces from geophysical well logs. The wells to be used for these areas in Montana and Alberta will coincide with those used by University of Alberta researchers in the regional hydrogeology and hydrochemistry studies, with any data gaps being filled using one or two of the deepest wells available within a given township.

6. Summary

The SPFPS project will improve our understanding of hydrocarbon generation, migration, and entrapment in the Saskatchewan subsurface through a series of multi-disciplinary studies in stratigraphy, hydrogeology, geothermics, and petroleum geochemistry. Since the project's initiation, hydrogeological, geochemical, and stratigraphic data have been compiled and preliminary hydrogeological maps and structural and stratigraphic maps have been created.

The hydrogeological studies of south- and northwestern Saskatchewan will be completed by construction of fresh water and density-corrected driving force maps and representative vertical hydraulic cross sections. These results will be combined with previously mapped hydrogeology of southeastern Saskatchewan and used to produce a complete regional characterization of subsurface fluid flow in the entire province.

Ongoing work in petroleum geochemistry coupled with an enhanced understanding of fluid flow and hydrochemistry, will lead to a better understanding of the petroleum systems within the province.

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