

# Fingerprinting formation-waters using stable isotopes, Midale Area, Williston Basin, Canada

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## Abstract

Hydrogen and oxygen isotope compositions of formation-waters from the Williston Basin are reported from produced waters and drill stem tests for a vertical stratigraphic section near Midale, Saskatchewan. These new data, in conjunction with data from the literature, show that Williston Basin formation-waters vary substantially in isotopic composition between aquifers in the stratigraphic section and within the same aquifer regionally. These large isotopic variations enable the use of H and O isotopes in Williston Basin formation-waters to fingerprint sources of contaminant water encountered during drilling and production of hydrocarbons. © 2000 Elsevier Science B.V. All rights reserved.

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## 1. Introduction

One of the most important procedures during petroleum drilling is the routine determination of water/hydrocarbon saturations from geophysical well logs. These calculations require, and depend on, an accurate estimate of the resistivity of pure formation-water, the values of which are normally measured from samples obtained during well testing. Thus, recognition of the recovery of pure formation-water during drill-stem, swabbing, or well production-testing is critically important. Unfortunately, it is often difficult to differentiate true formation-water from drilling-fluid contaminated formation-water. One new technique for fingerprinting true formation-waters in hydrocarbon exploration and production is

the use of stable isotopes of hydrogen and oxygen (Rostron et al., 1998).

Stable isotopic compositions of formation-waters were used for fingerprinting water inflows into potash mines (Wittrup et al., 1987; Wittrup and Kyser, 1990) in the Williston Basin (Fig. 1). Formation-waters were collected from leaks into elevator shafts for each mine thus limiting the collection of formation-waters to aquifers above the Prairie Evaporite Formation (Prairie aquitard; Fig. 2), which is greater than 600 m above the Precambrian basement in the study area.

The renewed interest in deep hydrocarbon exploration in the Williston Basin (Haidl et al., 1996; Dancsok and Haidl, 1997) provides a unique opportunity to obtain samples of Paleozoic formation-waters from below the Prairie aquitard. Consequently, a brine sampling project was initiated in 1996 to obtain elemental and isotopic analyses on deep Paleozoic formation-waters from drill stem tests (DSTs) and petroleum-producing wells in the Williston Basin

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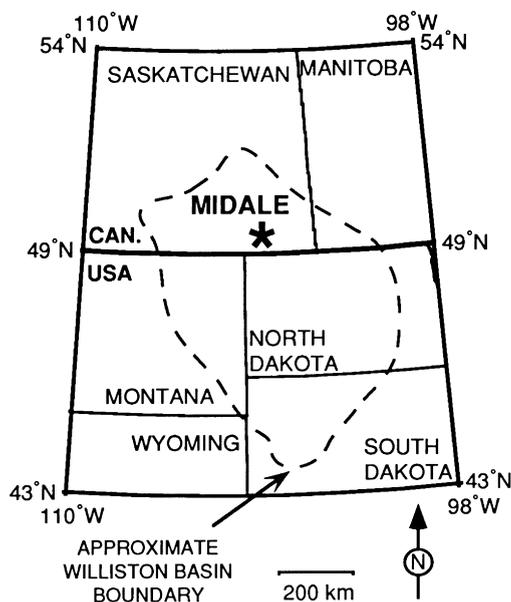


Fig. 1. Williston Basin study area. The asterisk denotes approximate location of the Midale area.

(Rostron et al., 1999). Preliminary results of the sampling program (Rostron et al., 1998) provided the first H and O isotopic data on aquifers from below the Prairie aquitard in the basin and demonstrated the potential of stable isotopes to fingerprint formation-waters in petroleum production and exploration settings.

In this paper, we provide further results from the sampling program including the first O and H isotopic data from the Bakken aquifer and strontium isotope compositions from deep Paleozoic aquifers in the Williston Basin.

## 2. Study area and methodology

Samples were collected from sub-Mississippian aquifer units in the Midale area (Fig. 2). Sixteen hydrostratigraphic units were defined, based on subsurface lithologies, estimates of rock hydraulic properties, and inferences regarding the regional flow system elsewhere in the basin.

To date, more than 200 samples have been collected across southeast Saskatchewan, eastern Montana, and western North Dakota. The data density

is the highest in the Midale area of southeast Saskatchewan (Fig. 1) and will be the focus of this paper.

Formation-waters were collected from producing oil wells with high water–oil ratios (>50%) and from DSTs sampled from the bottom of the column of recovered water. Care was taken to avoid oil fields subjected to enhanced recovery practices (water-flooding). Oil–water emulsions were sampled at the wellhead in 12 l pre-cleaned plastic jugs. The water fraction was passed through a 0.45  $\mu\text{m}$  filter and then aliquoted for field tests and laboratory analyses including temperature, density, pH, alkalinity, major and minor ions, and O, H, and Sr isotopes. Only the isotope data are reported in this paper.

Hydrogen isotope measurements were performed on  $\text{H}_2$  gas using the uranium reduction method of Bigeleisen et al. (1952). Oxygen isotope measurements were performed by the  $\text{CO}_2$ – $\text{H}_2\text{O}$  equilibration method following the procedure of Roether (1970). Samples were equilibrated for over 48 h in a shaker bath at 25°C to ensure equilibrium between  $\text{CO}_2$  and formation-waters with high ionic strengths. Analytical reproducibility of  $\delta\text{D}$  and  $\delta^{18}\text{O}$  values, based on replicates of our high TDS formation-water standard, is  $\pm 2.3\text{‰}$  VSMOW and  $\pm 0.14\text{‰}$  ( $1\sigma$ ), respectively. Corrections for the “salt effect” of Sofer and Gat (1972) were not applied to the O isotope data.

## 3. Isotope stratigraphy, Midale area

The average H, O, and Sr isotope compositions for each aquifer listed with respect to depth are shown in Table 1. The most notable results are: (1) each aquifer possesses a unique isotopic fingerprint; (2) the extremely D and  $^{18}\text{O}$  enriched waters of the Birdbear ( $\delta\text{D} = -31\text{‰}$ ,  $\delta^{18}\text{O} = 5.6\text{‰}$ ) and Duperow ( $\delta\text{D} = -22\text{‰}$ ,  $\delta^{18}\text{O} = 6.1\text{‰}$ ) aquifers, which are positioned at mid-stratigraphic level within the basin approximately 1 km above the Precambrian basement (Fig. 2); and (3) the significant Sr isotopic difference between the Cambro-Ordovician and overlying aquifers. Normally, it is expected that formation-waters with the highest  $\delta\text{D}$  and  $\delta^{18}\text{O}$  values will be associated with aquifers from the deepest parts of the basin. This is clearly not the case in this basin. The origin of these isotopic compositions is the subject of on-going study.

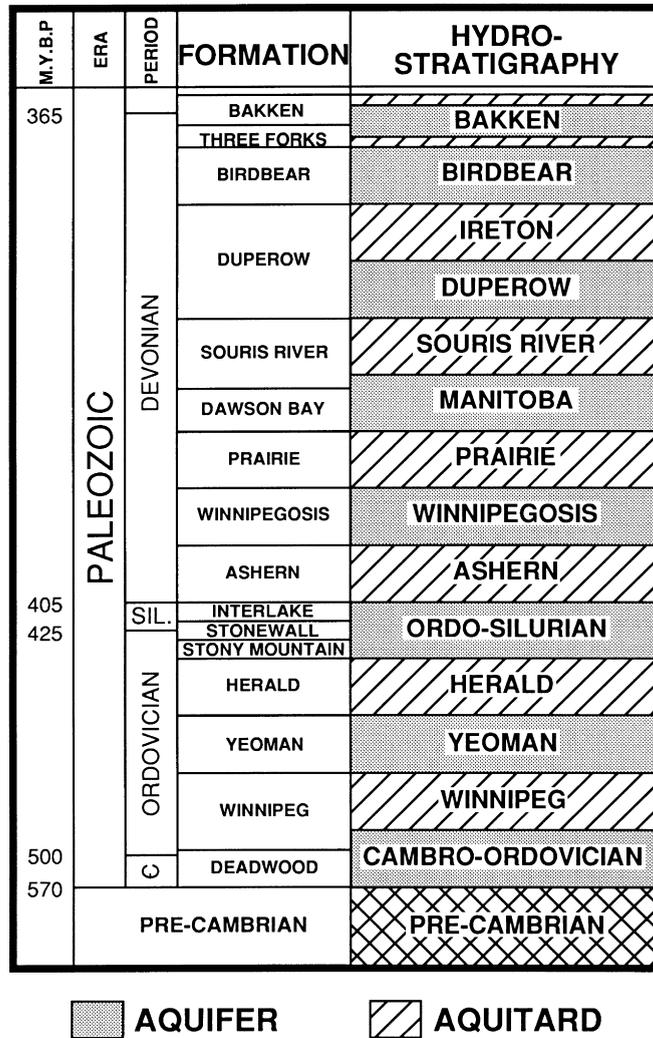


Fig. 2. Hydrostratigraphy of the pre-Mississippian strata in the Williston Basin.

Table 1  
Stable isotopic compositions of formation-water in pre-Mississippian aquifers, Midale area, Williston Basin

Aquifer	$\delta^{18}\text{O}$ (‰)			$\delta\text{D}$ (‰)			$^{87}\text{Sr}/^{86}\text{Sr}$		
	Average	Range	<i>n</i>	Average	Range	<i>n</i>	Average	Range	<i>n</i>
Bakken	5.3	5.0 to 5.6	4	-39	-44 to -35	4	0.70956	na	1
Birdbear	5.6	4.6 to 6.5	5	-31	-37 to -20	5	0.70866	na	1
Duperow	6.1	5.3 to 6.9	2	-22	-27 to -17	2	-	-	-
Winnipegosis	-1.8	na	1	-71	na	1	-	-	-
Ordo-Silurian	-2.5	-3.0 to -1.9	2	-72	-76 to -69	2	-	-	-
Yeoman	-1.1	-1.9 to -0.4	15	-60	-64 to -56	15	0.71008	0.70988–0.71041	3
Cambro-Ordovician	-2.9	-3.4 to -2.4	4	-71	-76 to -67	4	0.71450	0.71341–0.71520	3

These isotopic data are useful for fingerprinting formation-waters because of the depleted  $\delta D$  and  $\delta^{18}O$  values of precipitation in the Williston Basin. Average isotopic compositions for shallow groundwaters in Saskatchewan (<500 m) are:  $\delta D = -152 \pm 10\%$  and  $\delta^{18}O = -18.9 \pm 1.4\%$  (McMonagle, 1987). Stable isotopes of O and H can be used to differentiate between drilling fluids and formation fluids since most drilling fluids are simple artificial mixtures of meteoric water and other chemicals.

#### 4. Fingerprinting examples

Knowledge of the isotope hydrostratigraphy of the Williston Basin can have many practical benefits for the oil industry. Petroleum exploration and production companies can use the fingerprinting concept to troubleshoot common problems encountered during drilling and production by comparing recovered samples against the pre-determined formation-water fingerprint. The isotope hydrostratigraphy of the Midale area will be used to illustrate this application with three examples.

In the first example, a DST was conducted in the Yeoman Formation in a well in the Midale area. Large fluid recoveries (approximately  $4.8 \text{ m}^3$  of “brine”) from the DST indicated the test was successful. A fluid sample analyzed for chemical composition indicated a “typical” salinity of formation-water from this depth in the basin. However,  $\delta^{18}O$  and  $\delta D$  analyses for this DST sample yielded  $-12.1$  and  $-144\%$ , respectively, in contrast to typical isotopic values from the Yeoman aquifer of  $-1.5$  and  $-62\%$  (Table 1). The isotopic data show that the DST fluid is composed of a large component of drilling mud prepared with near surface groundwaters or surface meteoric waters. In this case, salinity data from the DST-derived fluid cannot be used reliably for water–oil saturation calculations.

In the second example, a well producing oil and water (94% WOR) from the Yeoman Formation in the Midale area was sampled for isotopic analysis. Salinity of the produced water was measured at 255,000 mg/l, not unusual for brines from the Yeoman Formation in southeast Saskatchewan. Stable isotopes on the produced water from this well were measured to be  $-10.1$  and  $-108\%$  for  $\delta^{18}O$  and  $\delta D$ ,

respectively. As above, comparison with typical isotopic values from the Yeoman aquifer shows that the produced brine is not formation-water from the Yeoman aquifer. Since there was not an active water-flood at the time of sampling, the well is producing water from an unknown horizon, at least shallower than the Bakken aquifer. Remedial action on the tubing or casing string may reduce the water–oil ratio (WOR) and improve the economics of this well.

In the final example, a well producing oil and water (90% WOR) from the Winnipegosis Formation located approximately 50 km east of the Midale area was sampled for stable isotopes. Stable isotopic signatures of the produced water from this well were measured to be  $-10.5$  and  $-115\%$  for  $\delta^{18}O$  and  $\delta D$ , respectively. Clearly, even with allowances for some lateral variability, a large component of the produced water is not from the Winnipegosis aquifer. This well is also producing water from an unknown horizon, at least shallower than the Bakken aquifer and remedial action may reduce the water–oil ratio and improve the economics of this well.

#### 5. Conclusions

Isotopic signatures of formation fluids from seven main aquifers in southeast Saskatchewan, were measured on fluid samples from wells and DSTs. As a group,  $\delta^{18}O$  values range from  $-2.9$  to  $6.1\%$ , and  $\delta D$  values range from  $-72$  to  $-22\%$ , relative to SMOW. There is no systematic pattern of increasing isotopic composition with depth as observed for shallower formations in the Williston Basin. Knowledge of the isotope hydrostratigraphy in an exploration area may be used by petroleum companies to identify drilling-fluid contamination in DST samples and to save production costs by improving hydrocarbon production efficiency.

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