Stable Sr isotopic composition ($\delta^{88}Sr$) as a new hydrological tracer: a Williston Basin example

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The Williston Basin has produced oil and gas from permeable sedimentary rocks for more than 60 a. Horizontal drilling and hydraulic fracturing of the 359-Ma tight Bakken Shale have resulted in recent increases in production of oil with an estimated several billion barrels of recoverable reserves (Gaswirth & Marra, 2014). Oil production on such a massive scale raises the risk of an accidental release of coproduced formation water (brine) into the environment and requires the use of tracers that can distinguish between the brine sources. Radiogenic $^{87}Sr/^{86}Sr$ is widely used in hydrological studies to determine potential sources of groundwater contamination. Traditionally, the stable Sr isotopic ratio ($^{88}Sr/^{86}Sr$) has been used only to correct for isotopic fractionation during laboratory analyses. New analytical advances have detected natural mass-dependent Sr isotope fractionation. We used a double spike TIMS method (Neymark et al., 2014) for analysis of paired $^{87}Sr/^{86}Sr$ and $\delta^{88}Sr$ (defined as the permil deviation from $^{88}Sr/^{86}Sr$ in SRM-987 NIST standard) in surface water, shallow groundwater, and brines from the Bakken Formation (tight black shale/siltstone) and Missi-ssippian Charles Formation (permeable dolomitic limestone).

The Charles Formation brines show lower $^{87}Sr/^{86}Sr$ (0.7079 to 0.7089) and $\delta^{88}Sr$ (0.04 to 0.19 ‰, n=6) values than Bakken brines (0.7098 to 0.7111 and 0.54 to 1.44 ‰, respectively; n=10). Fields of the Sr isotopic data do not overlap, thus allowing identification of brine sources and of potential formation water cross flow between the stratigraphic units.

$^{87}Sr/^{86}Sr$ and $\delta^{88}Sr$ data for water samples from Goose Lake oil field in Williston Basin confirmed previous results by Peterman et al. (2012) that traditional $^{87}Sr/^{86}Sr$ can detect small amounts of Charles Formation brine contamination. However, the combination of radiogenic and stable Sr isotopic data, both insensitive to surface water evaporation, shows a more straightforward binary mixing relationship compared to $^{87}Sr/^{86}Sr$ vs. 1/[Sr] systematics. Our data demonstrate the potential of $\delta^{88}Sr$ as a new sensitive isotopic tracer in brine-groundwater systems.

[1] Gaswirth & Marra, 2014, *Oil & Gas J.*, **Jan. 6**, 48-53. [2] Neymark *et al* 2014, *JAAS*, **29**, 69-75. [3] Peterman *et al* 2012, *Appl. Geoch* **27**, 2403–2408.