Geochemistry and Stable Isotopic Signatures, Including Chlorine Isotopes of the Williston Basin (Canada - U.S.A.)

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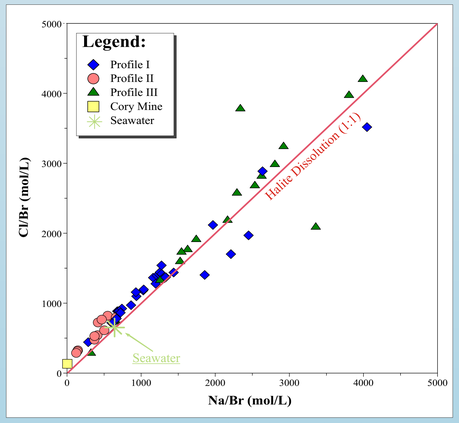

Figure 6: Cl/Br vs. Na/Br molar ratios for the Williston Basin brines..

Cl/Br molar ratios for the brines are plotted versus Na/Br in Figure 6. Many of the formation waters plot along a 1:1 line, indicating halite dissolution as the main source of solutes. Molar ratios of Cl/Br vs. Na/Br for some brines plot below the value for seawater, indicating that a component of residual evaporated seawater remains in the basin.

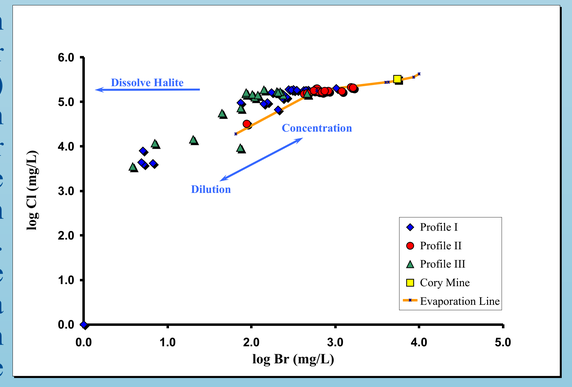

Figure 7: Log Cl vs. log Br of the Williston Basin formation waters.

Samples from Profile II (deeper within the basin) plot directly on the seawater evaporation line (data from Collins 1975). The brine associated with a potash formation at the Cory Mine in the northern part of the basin also plots directly on this line. Most formation waters from both Profiles I and III plot to the left of the evaporation line, suggesting that the main processes affecting these waters are halite dissolution, followed by dilution with less saline or meteoric waters.

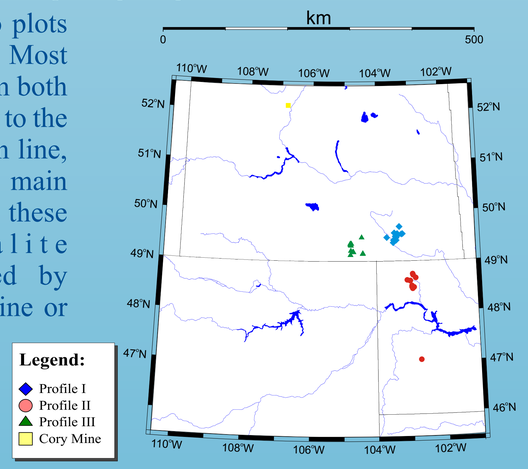

Figure 8: Sampling locations within the Williston Basin for each of the three profiles and for the formation water sampled at the Cory Mine.

Formation waters from the study area have a range of Br/Cl ratios between 0.00 and 0.01. Brines with high Cl concentrations have higher Br/Cl ratios than those with low Cl concentrations.

Figure 9 compares the Williston Basin waters with concentrated Shield brines, Michigan Basin brines and Siberian Platform brines. Most of the formation waters have high chlorine concentrations similar to those found in the Michigan Basin, but lower Br/Cl ratios.

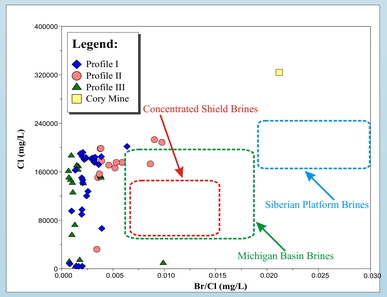

Figure 9: Cl (mg/l) versus Br/Cl and a comparison of the Williston Basin brines with different groups of brines.

Isotopes

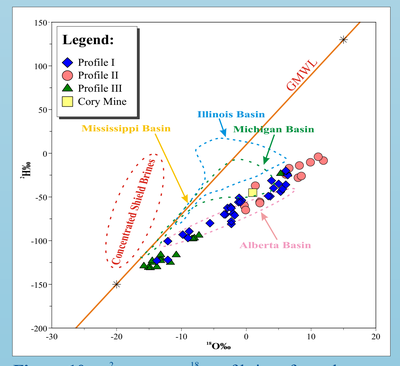

Figure 10: ^{2} versus ^{18} of brines from the Williston Basin.

The ^{2}H of the formation waters ranged between -4‰ and -130‰. The ^{18}O ranged between +12‰ and -16‰. All of the formation waters fall below the GMWL.

The hydrogen and oxygen isotopic signatures of these formation waters are different from concentrated Shield brines, but are similar to those from the Alberta Basin.

The majority of the formation waters have Cl^- concentrations in the range of 100 000 to 200 000 mg/L, and ^{37}Cl values that range from -0.6 to +0.5‰. A larger spread in the ^{37}Cl signatures of between -1.0 and +0.7‰ is observed for formation waters with Cl^- concentrations below 100 000 mg/L. This larger range may reflect dilution of the formation waters by a diverse group of allocthonous fluids. Overall, the range of ^{37}Cl signatures measured is similar to that reported by Eastoe et al. (2001) for formation waters from the Gulf Coast Basin (-1.9 to +0.7‰).

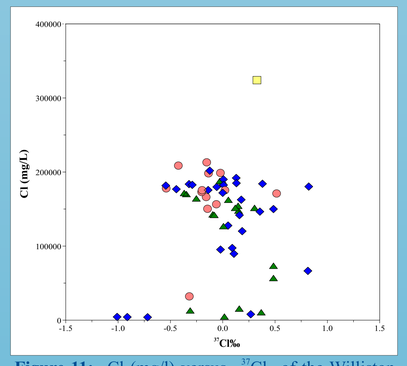

Figure 11: Cl (mg/l) versus ^{37}Cl of the Williston Basin brines.

Formation waters from shallower depths in profiles I and II generally have the most negative ^{18}O signatures. Brines from profile II deeper within the basin are the most enriched in ^{18}O. There is a general trend of increasing ^{18}O with depth, which is most pronounced for the samples in Profiles I and II. The more positive ^{18}O signatures of brines from deeper within the basin may be a result of evaporation, and/or reflect longer residence times and consequently, more extensive rock-water interaction.

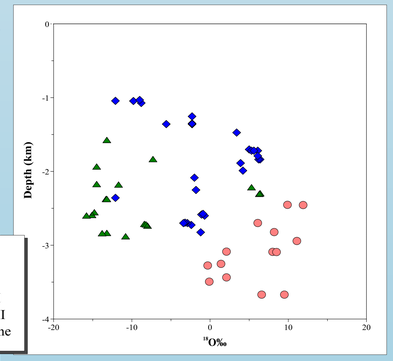

Figure 12: ^{18}O signatures versus depth of the Williston Basin brines.

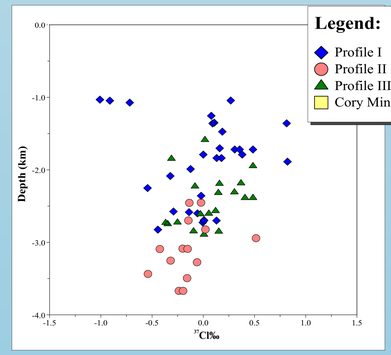

Figure 13: ^{37}Cl signatures versus depth of the Williston Basin brines.

The ^{37}Cl signatures of the formation waters tend towards more depleted signatures with increased depth in the basin. Brines from shallower depths in profiles I and III have ^{37}Cl values ranging from SMOC (0‰) to approximately +0.7‰. Deeper in the basin (waters from profile II), most of the brines have ^{37}Cl signatures between -0.6‰ and SMOC. The expected ^{37}Cl values for evaporated seawater are between -0.9 and 0.0‰ (Eggenkamp et al., 1995). The more negative ^{37}Cl signatures of the deep formation waters are within this range, and may reflect an evaporated seawater source for these brines.

Conclusion

The relationship between Cl and Br in formation waters from deeper within the basin (Profile II) suggests that these waters are derived from seawater that has undergone different degrees of evaporation. The ^{37}Cl signatures of these waters (between 0.0 and -0.5‰) are within the range expected for evaporated seawater.

Acknowledgments

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