Understanding the Origin of the Sub-Unconformity Diagenetic Caprock, in the Mississippian of the Williston Basin, Southeast Saskatchewan

Gemma Bates*
University of East Anglia, Norwich
g.bates@uea.ac.uk

and

Alan Kendall
University of East Anglia, Norwich, United Kingdom

Summary

Diagenetic alteration of Mississippian carbonates overlain by Lower Watrous clastics has obliterated all porosity and permeability within an altered zone. This makes it a regionally important caprock for hydrocarbon reservoirs within the area, and also a suitable site for long-term geological storage of carbon dioxide (Whittaker, 2004).

Locally, the caprock is absent where alteration did not occur or less commonly, dissolution of porosity-filling anhydrite took place. This has allowed continued upward migration of oil into overlying Lower Watrous clastics where reservoirs are widespread sandstones capped by argillaceous mudstones.

An understanding of how one of the major caprocks in the Williston Basin has formed should allow better predictions to be made about the presence and thickness of the alteration zone, and how that relates to oil occurrence. This is especially important where the alteration zone changes thickness laterally and production employs horizontal drilling.

Introduction

In the Williston Basin of southeastern Saskatchewan and Manitoba, tilted and eroded Mississippian carbonates and evaporites are unconformably overlain by redbeds of the Lower Watrous (Amaranth in Manitoba) Formation (Fig. 1). Immediately beneath the sub-Mesozoic unconformity is a 1-50 m thick, diagenetically altered zone consisting of pervasively dolomitized carbonates, with secondary anhydrite present as void-fillings, partial replacement of dolomite and near-horizontal veins after gypsum 'satin-spar' (Kendall, 1975). This diagenetic alteration, resulting in the occlusion of all porosity and permeability within the altered zone, has created an effective up-dip seal for the unconformity related stratigraphic traps for Mississippian carbonate reservoirs in southeastern Saskatchewan.

This core display will provide evidence for the coeval alteration of Mississippian carbonates and their overlying redbeds, along with possible reasons for its localized absence.

Theory

The origin and timing of the diagenetic changes that formed the regional alteration zone have long been disputed. The absence of satin-spar veins in the Watrous has been used as evidence for a

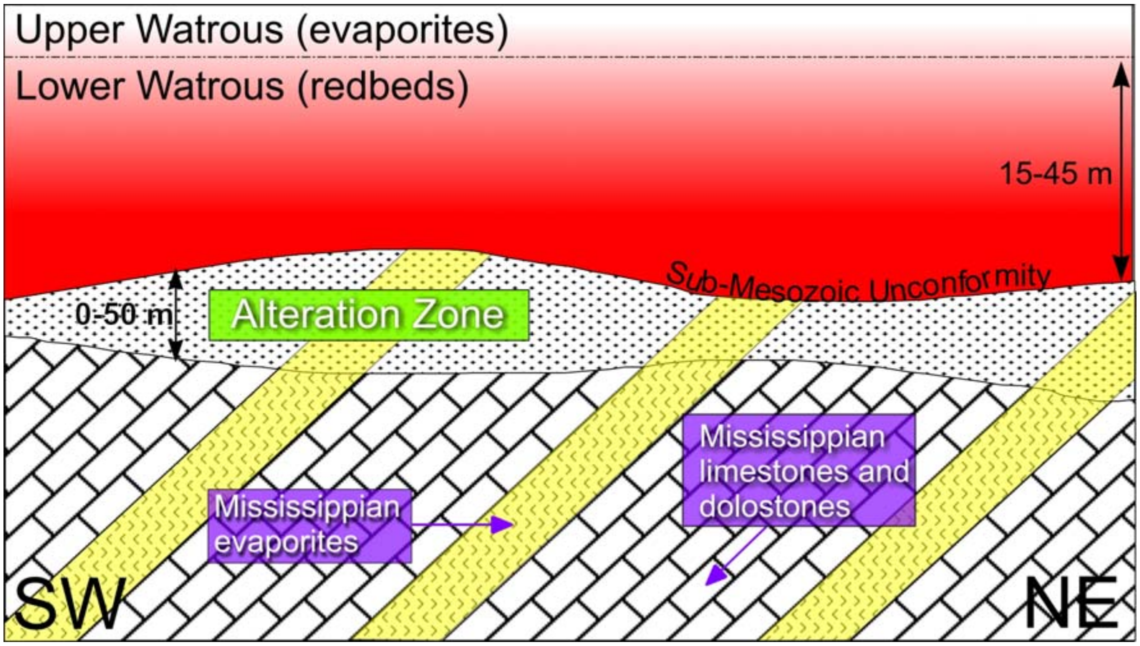

Figure1: Diagrammatic cross-section showing relationships of Mississippian and Watrous strata in relation to regional unconformity (adapted from Bates *et al*., 2007).

pre-unconformity formation, but this does not offer a satisfactory explanation for the reciprocal relationship that exists between the thickness of the alteration zone and the redbeds (McCamis, 1958) nor the fact that the alteration zone does not extend beyond its Watrous cover. McCamis (1958) proposed a post-unconformity origin, with formational brines descending from the Upper Watrous (Fig. 1). This was considered unlikely by Kendall (1975) due to the relatively low porosity and permeability of the argillaceous redbed sediments. Kendall (1975) suggested ascending deep, basinal brines were prevented from further vertical migration by the impermeable redbeds, resulting in thicker altered zones being developed where groundwaters were constricted as Mississippian carbonates thinned towards the edge of the basin.

The strontium isotope composition of anhydrite was determined through a typical core (4-34-8-33W1) from the Parkman Field, with red, dolomitic Watrous, unconformably overlying a 5.7 m thick alteration zone, which has an abrupt basal contact with the underlying Mississippian limestone (Bates *et al*., 2007). It shows radiogenic values for redbed sulfate ($^{87}Sr/^{86}Sr$ of 0.708475 ± 0.000195; 2-sigma). Former satin-spar veins from the alteration zone show more radiogenic values ($^{87}Sr/^{86}Sr$ = 0.708274 ± 0.000206) than if the sulfate were sourced directly from Mississippian evaporites of Visean age ($^{87}Sr/^{86}Sr$ = 0.70765 to 0.70795; values from McArthur *et al*., 2001). This data can be explained by a mixing of the redbed brines with groundwaters that have come into equilibrium with the Mississippian system immediately beneath the unconformity, which is inconsistent with a pre-redbed formation.

Alteration Zone Absence

Local and sporadic absence of the alteration zone occurs where dolomitization and anhydritization of Mississippian limestone has not taken place, or where subsequent dissolution of porosity-occluding anhydrite has produced an ineffective caprock seal, allowing hydrocarbon migration into overlying redbeds.

Figure two identifies a 'typical' alteration zone (briefly described on previous page) to compare with three anomalous cores each revealing different diagenetic histories.

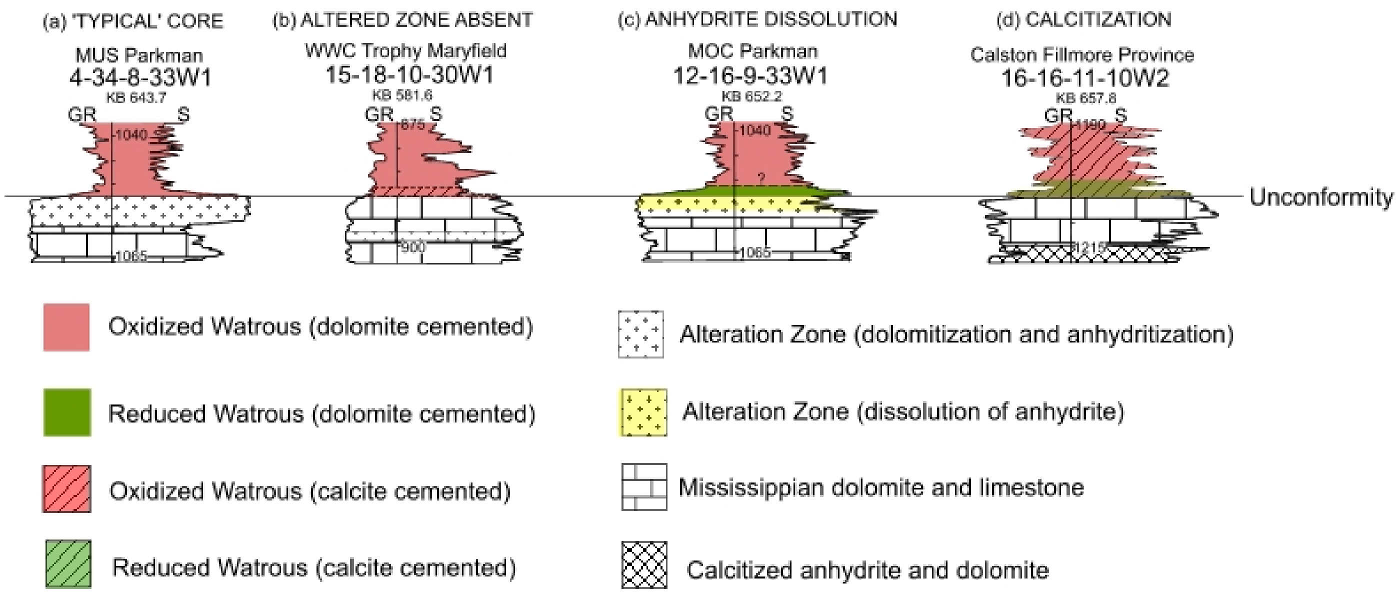

Figure2: Comparative cores demonstrating anomalous wells with alteration zone absent.

In the Maryfield (15-18-10-30W1) core the alteration zone is present ~6.5 m beneath the unconformity (Fig. 2b), with unaltered limestone immediately subjacent to Lower Watrous redbeds, suggesting lateral migration of the diagenetic fluids. The basal redbed unit contains a chert and limestone breccia, with primary calcite cement. A transition from calcite to dolomite cements exists only a few meters above the unconformity. This altered zone, along with Mississippian dolomite, is an effective caprock with no hydrocarbons having migrated above it, evident by the lack of oil staining or reduction of redbeds.

In the Calston Fillmore Province core (16-16-11-10W2) the limestone immediately beneath the unconformity remains unaltered and Mississippian anhydrite has been replaced by calcite (Fig. 2d). This formed by reaction with a different formational fluid, probably concurrent with the timing of the alteration zone (Kendall, 2001). The entire redbed unit is cemented by calcite instead of the more usual dolomite cement. Absence of the caprock has enabled hydrocarbons to enter a few meters into the basal Watrous.

Localized evidence of failure of the caprock seal exists in the Parkman Field (12-16-9-33W1). Dissolution of pore-filling anhydrite within the alteration zone occurred after its formation, resulting in porosity which allowed hydrocarbons to migrate through the alteration zone into the overlying Watrous (Fig. 2c). Importantly, the basal Watrous sediments here are dolomitic, although green. This supports an interpretation involving coeval dolomitization of the Watrous sediments and the underlying alteration zone, followed by partial dissolution of anhydrite from the alteration zone.

Caprock Formation

1. Prior to Watrous sedimentation radiogenic brines (created by interaction with the Watrous redbeds) had not yet formed and expelled basinal brines were free to continue upward migration (Fig. 3.1).
2. After redbed sedimentation began, downward percolating brines met upward migrating water to form a mixing zone (Fig 3.2).
3. As the redbeds infill the palaeo-lows forming an alteration zone immediately beneath the unconformity, brines also migrate laterally with the palaeohighs being subjected to the dense brines for a longer time period, resulting in a thicker alteration zone (Fig. 3.3).

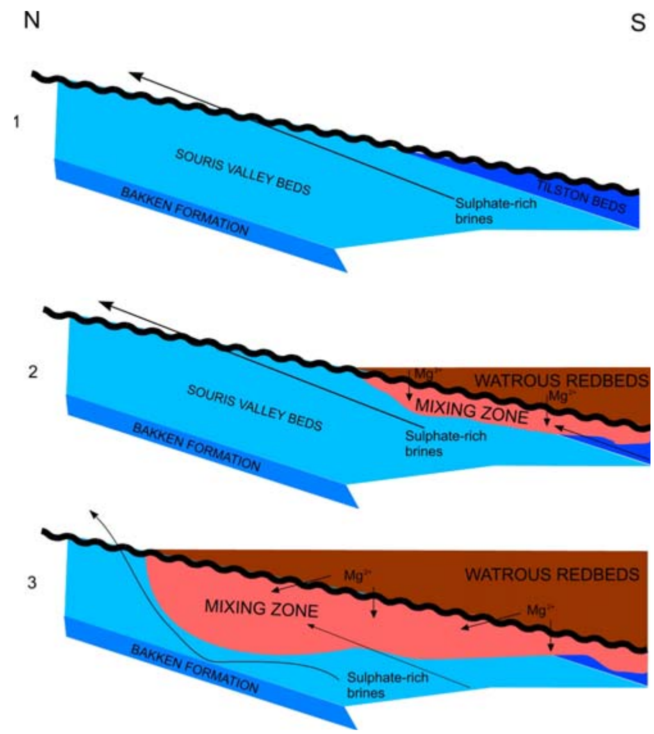

Figure3: Alteration zone formational model

Conclusions

An origin where the sub-unconformity caprock forms coevally with early diagenetic alteration of the redbeds is supported by a genetic link between the regional presence of the altered zone dolomite and the dolomitic cement of the basal redbeds, together with supporting stratigraphic and geochemical evidence.

Where the Lower Watrous is thick the alteration zone is thin or absent, whereas the palaeo-highs which often contain the largest reservoirs are most likely to be capped by a thicker alteration zone. At the zero edge of the Lower Watrous the alteration zone is absent. Where the alteration fails as a caprock, argillaceous sediments of the Lower Watrous commonly allow only limited hydrocarbon migration into the unit. Watrous oil production occurs where there is a combination of caprock absence/failure and porous sandstones in the basal Watrous.

Acknowledgements

The authors wish to thank Saskatchewan Industry & Resources for access to core, and their staff and John Lake for discussions.

References

Bates, G.S., Kendall, A.C. & Millar, I.L., 2007, Contemporaneous alteration of lower Watrous clastics and the sub-unconformity alteration zone in southeastern Saskatchewan: petrographic and geochemical evidence: *in* Summary of Investigations 2007, Volume 1, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2007-4.1, Paper A-7, 10p.

Kendall, A.C., 1975, Anhydrite replacements of gypsum (satin-spar) veins in the Mississippian caprocks of southeastern Saskatchewan: Canadian Journal of Earth Science, **12**, 1190-1195.

Kendall, A.C., 2001, Late diagenetic calcitization of anhydrite from the Mississippian of Saskatchewan, western Canada: Sedimentology, **48**, 29-55.

McArthur, J.M., Howarth, R.J. and Bailey, T.R., 2001, Strontium isotope stratigraphy: LOWESS Version 3: best fit to the marine Sr-isotope curve for 0-509 Ma and accompanying look-up table for deriving numerical age: Journal of Geology, **109**, 155-170.

McCamis, J.G., 1958, Anhydritization in the Mississippian Souris Valley Beds of the Broadview Area, Saskatchewan: Unpub. MSc thesis, University of Saskatchewan, Saskatoon, 33p.

Whittaker, S., 2004, Investigating geological storage of greenhouse gases in southeastern Saskatchewan: the IEA Weyburn CO_2 monitoring and storage project: *in* Summary of Investigations 2004, Volume 1, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2004-4.1, Paper A-2, 12p.