Suitability of Central Utah's Navajo Sandstone for Disposal of Mined Hydrocarbon Water

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Abstract Water produced with coalbed methane in central Utah is disposed of primarily by injecting it into the Navajo Sandstone. High injection pressures have reversed the vertical hydraulic gradient from downward to upward, so the produced water may eventually mix with shallow groundwater. Three subsurface faults were identified, but shale smear factor calculations suggest that the fault sealing potential is high. Furthermore, chemical analyses of water samples from nine saltwater disposal wells and four shallow freshwater wells demonstrate that no mixing has occurred. Finally, the time estimated for the produced water to migrate to the surface is at least 2,000 years.

Keywords coalbed methane, water disposal, faults, hydrochemistry, Navajo Sandstone, Utah

Introduction

Coalbed methane is produced from the Ferron Sandstone in the Drunkards Wash, Helper and Buzzard Bench gas fields in central Utah (fig. 1) by pumping water from wells to lower the fluid pressure and cause methane to desorb from the coal, which then flows as a gas to the wells. Water from these three gas fields is very high

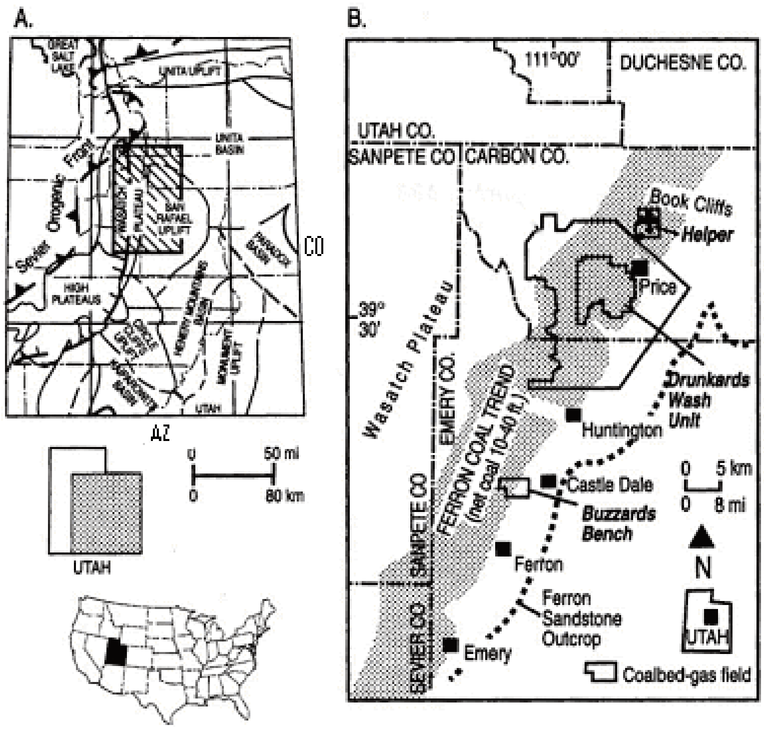

***Fig. 1** Location map of study area (A). Location map of the Drunkards Wash, Buzzard Bench and Helper gas fields (B) (Randall 2009).*

in total dissolved solids (TDS), especially sodium and chloride, and is disposed of by injecting it at depth, primarily into the Navajo Sandstone.

This research has been conducted to determine if the produced water is being safely sequestered from shallow groundwater. Structural data have been collected and analyzed to identify any subsurface faults. Chemical analyses of water samples from saltwater disposal wells (SWD) and shallow freshwater wells have been compared to determine if any mixing has occurred.

Methods

The structural analysis was accomplished using 418 digital well logs provided by ConocoPhillips in the Drunkards Wash gas field (fig. 2). Thirty-one east-west cross sections were constructed using the computer program PETRA to identify faults that displace sandstones at depth but not the shales overlying them. Gas and water production from faulted areas and areas where faults are thought not to exist have been compared as an estimate of the relative amount of fracturing.

The potential for clay as well as shale smearing for the faults also has been evaluated using an algorithm developed by Lindsay *et al.* (1993) called the shale smear factor (SSF). It is calculated by dividing the fault throw by the thickness of the clay/shale bed.

Nine SWD wells in the Drunkards Wash, Helper and Buzzard Bench gas fields were sampled because of their proximity to shallow freshwater wells (fig. 2). Two samples were collected from each SWD well and analyzed for: (1) major ions; and (2) the stable isotope ratios of deuterium (^2H) to hydrogen (D/H) and ^{18}O to ^{16}O ($^{18}O/^{16}O$).

Four shallow freshwater wells were also sampled (fig. 2), and were analyzed for major ions and the stable isotope ratios D/H and $^{18}O/^{16}O$. The four wells are completed either in alluvium or the Upper Blue Gate Shale Member of the Mancos Shale.

Results

Three subsurface, north-south trending, downward to the west normal faults have been located in the Drunkards Wash gas field from the structural cross sections. An anticline has also been identified near the southern boundary of the gas field. These four structural features have been labeled alphabetically from north to south (fig. 3). Control areas where no faults are thought to exist have been designated adjacent to each faulted area (fig. 3).

The 24th-month average gas production per well and the maximum gas production of the highest producing well in the faulted and control areas are compared in Table 1, as are the average maximum water production per well and the maximum water production for the well with the highest production. The gas and water production data were obtained from the Utah Division of Oil, Gas and Mining (UDOGM) website (http://linux1.ogm.utah.gov).

The gas and water production data for the faulted and control areas have been compared using the Mann-Whitney nonparametric statistical test. Areas A, B and C show a statistically significant difference between faulted and control areas for both gas and water production. The probability of exceedence for gas production is <0.003 for area A, <0.0001 for area B and <0.001 for area C, whereas water production is <0.05, <0.0001 and <0.003 for areas A, B and C, respectively. This suggests that the faulted areas have higher fracture densities than their associated control areas.

The amount of throw for each fault has been measured from the offset of the beds shown on the cross sections. Fault throws range from a maximum of 40 m to a minimum of 3 m, both for fault B. Fault throws for faults A and C range from 33 to 5 m and 36 to 4 m, respectively.

Gamma ray logs for three wells, one each from areas A, B and C, were used to identify the net shale thickness along each fault. These three wells were selected based on their proximity to their respective faults, and the well log intervals chosen were selected specifically to

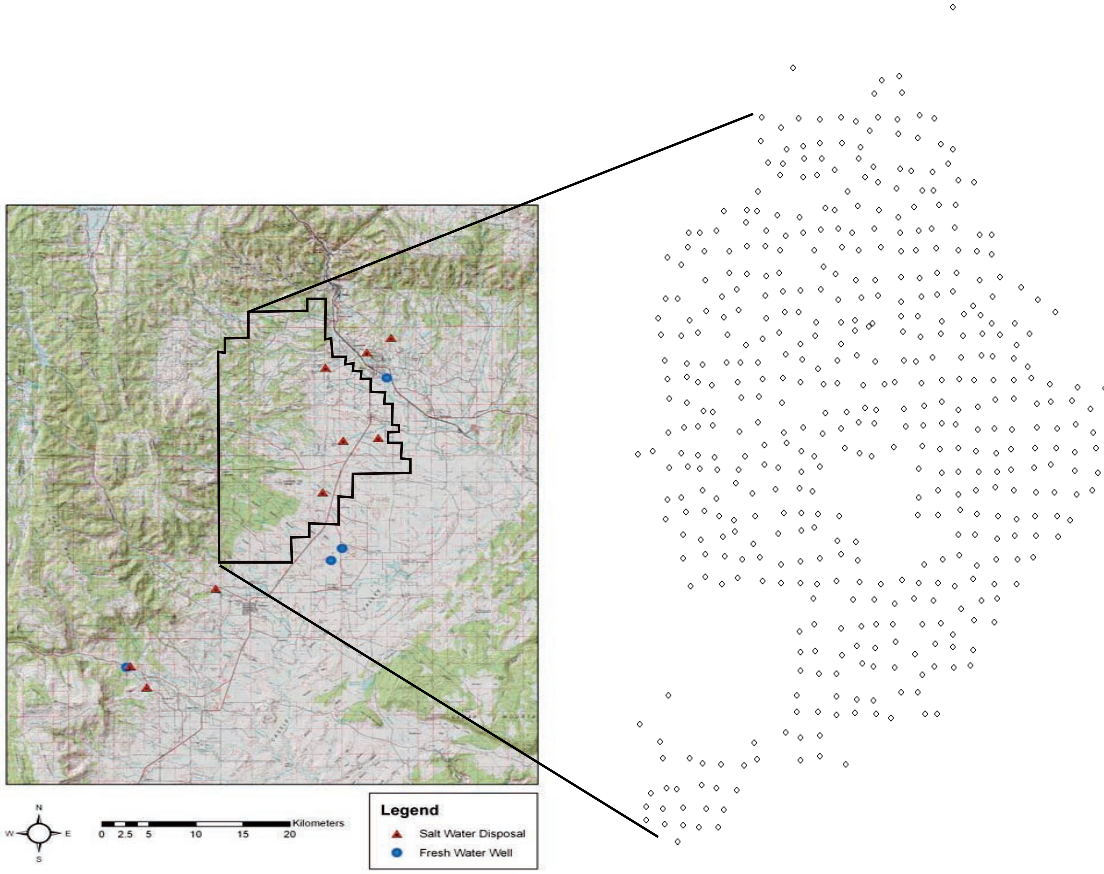

***Fig. 2** Map showing the locations of the four shallow freshwater wells, nine SWD wells, and the wells in the Drunkards Wash gas field used in the structural analysis.*

see the rocks above, below and within the Ferron Sandstone. Well logs were obtained from the UDOGM website.

The top 76 m of the log for the well in area A from 670 to 850 m has been identified as a single shale unit. The log for the area B well from 520 to 670 m shows 35 m of shale near the top and 23 m at the bottom; thus, a shale thickness of 58 m has been interpreted from this log. The top 116 m of the log for the area C well from 870 to 1,070 m appears to be almost entirely shales.

Calculated SSF values using the shale thickness and maximum throw for each faulted area are 0.43, 0.69 and 0.31 for areas A, B and C, respectively. Because the SSF values are all less than one, it can be presumed that the likelihood of fault sealing is quite high (Lindsay *et al.* 1993).

Concentrations of TDS, sodium and chloride for all nine SWD samples range from 4,278 to 14,244 mg/L, 2,400 to 4,106 mg/L and 1,117 to 9,974 mg/L, respectively, and are much higher than those for three of the four freshwater samples, which range from 843 to 1,595 mg/L, 117 to 225 mg/L and 69.1 to 94.6 mg/L, respectively. However, one freshwater sample has TDS, sodium and chloride concentrations of 11,337 mg/L, 3,382 mg/L and 7,619 mg/L, respectively, for TDS, sodium and chloride.

Delta D and $\delta^{18}O$ values for the SWD well samples range from -40 to -90 ‰ and from -1.3 to -9.9 ‰, respectively, and from -109 to -117 ‰ and -13.8 to -15.1 ‰, respectively, for the fresh-

Area	Number of Wells	Avg. 24th Month Gas Production/ Well (mcf)	Max. 24th Month Gas Production of Single Well (mcf)	Avg. Max. Water Production/ Well (barrels)	Max. Water Production from Single Well (barrels)
A	14	411	1,024	4,075	18,926
A-control	15	66	206	755	3,614
B	19	684	1,382	2,966	10,031
B-control	20	175	516	1,241	6,306
C	24	587	979	2,834	6,510
C-control	24	263	555	816	2,598

Table 1 *Summary of gas and water production for faulted and control areas.*

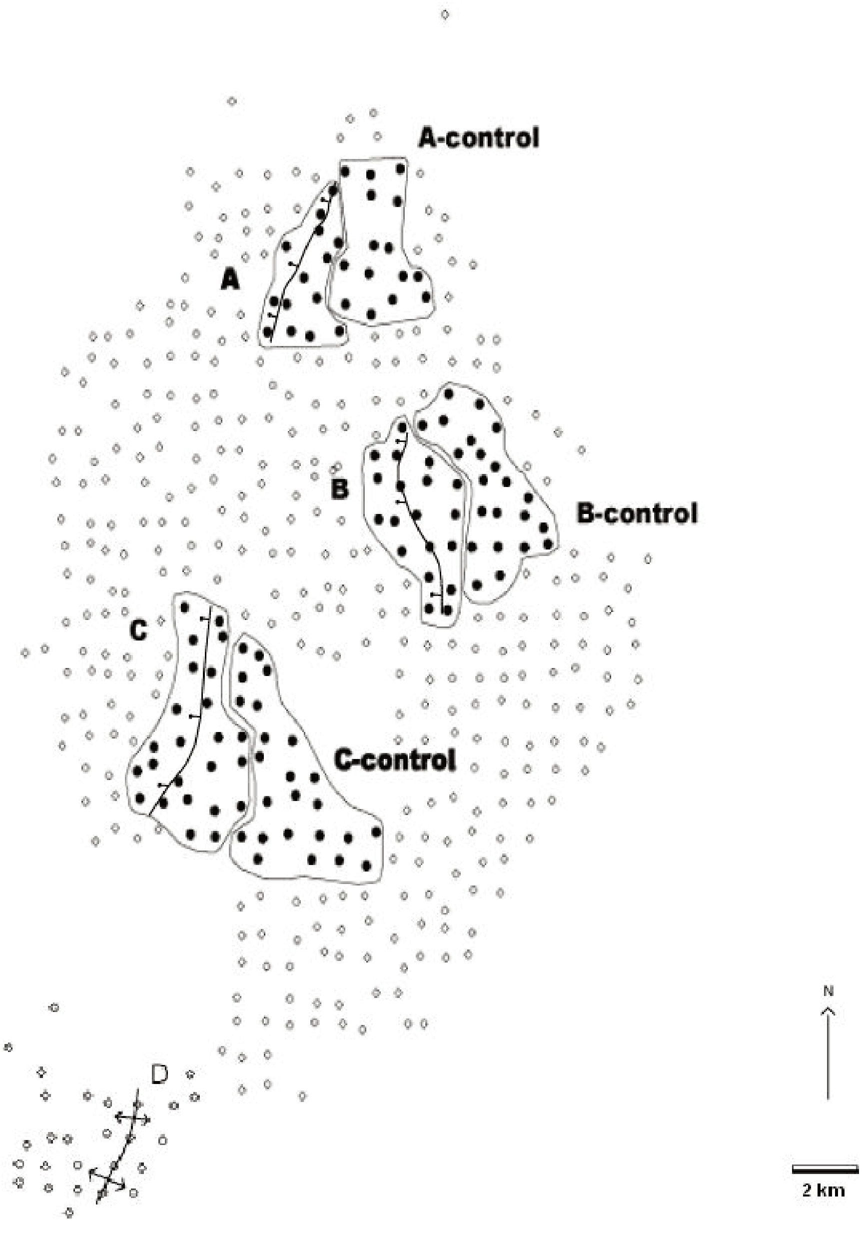

Fig. 3 *Faulted areas and associated control areas for gas and water production.*

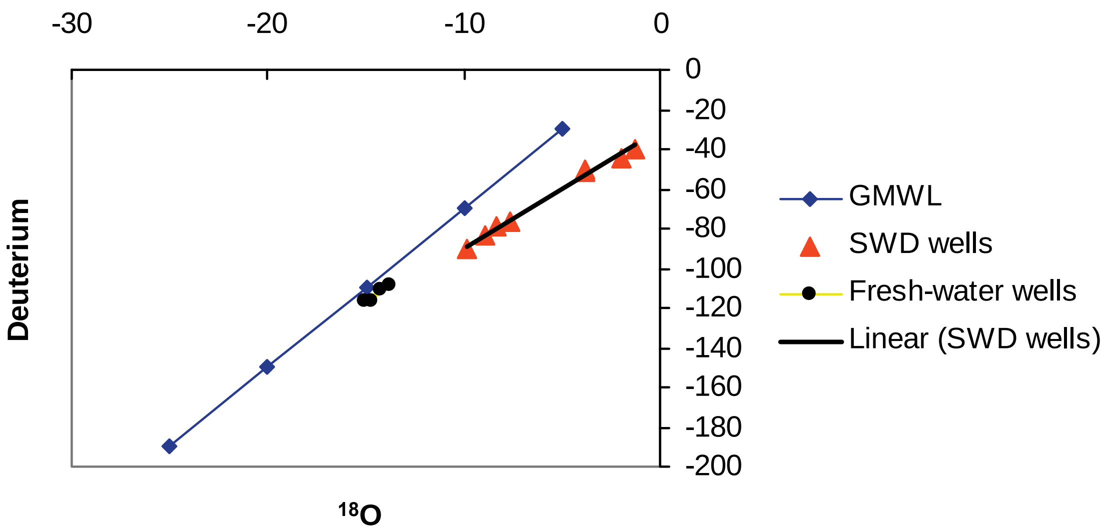

Fig. 4 *Delta D and δ18O for SWD and shallow freshwater wells.*

water well samples. The four freshwater samples lie near the global meteoric water line (GMWL; fig. 4). However, the nine SWD samples plot far from the GMWL (fig. 4).

Discussion

The high TDS, sodium and chloride concentrations in the anomalous shallow freshwater well may be due to: (1) produced water mixing with shallow groundwater along a nearby fault; or (2) the well being completed in a formation that contains high concentrations of soluble salts. This well is completed in the Upper Blue Gate Shale Member of the Mancos Shale. Lines and Morrissey (1983) stated that water in the Blue Gate contains about 20,000 mg/L of TDS. Chemical analyses have also been done for two shallow freshwater wells identified as being completed in the Mancos Shale. One well is completed in the Blue Gate Member and has a TDS concentration of 4,040 mg/L (Waddell *et al.* 1978). The other well is only listed as being completed in the Mancos and has a TDS concentration of 6,964 mg/L (Sumison 1979).

Isotope data for D and ^{18}O are unambiguously distinct for the two types of water samples (see fig. 4). This provides additional evidence that the Upper Blue Gate Shale is the most likely source of the high TDS, sodium and chloride concentrations in the anomalous shallow freshwater well.

Injection of produced water has reversed the vertical hydraulic gradient from downward to upward. Reversal of the vertical hydraulic gradient may eventually cause the produced water to migrate upward and mix with shallow groundwater, and ultimately reach the surface.

The time required for the produced water to migrate from the Navajo Sandstone to the Upper Blue Gate Shale member of the Mancos Shale has been estimated by Randall (2009). The time estimated is approximately 730,000 days, or 2,000 years.

Conclusions

Three faults have been identified in the Drunkards Wash gas field. Wells in all three faulted areas produce more gas and water than wells in their respective control areas, presumably due to higher fracture densities. However, SSF calculations indicate that the likelihood of fault sealing is quite high.

Three of the four shallow freshwater wells sampled have low TDS, sodium and chloride concentrations, demonstrating that no mixing is occurring. The high concentrations for the fourth well are due to the dissolution of soluble minerals in the Upper Blue Gate Shale Member of the Mancos Shale.

Delta D and $\delta^{18}O$ values for the four shallow freshwater wells plot near the GMWL (fig. 4), indicating that meteoric water is the most likely source of recharge. However, all nine SWD wells plot far from the GMWL (fig. 4), implying that they have a different recharge source.

Because high injection pressures have reversed the vertical hydraulic gradient from downward to upward, mixing of produced water with shallow groundwater may eventually occur. However, the amount of time required for the produced water to migrate from the Navajo Sandstone to the Upper Blue Gate Member of the Mancos Shale is approximately 2,000 years, much longer than the life of the gas field.

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