

Salinity reversal and water freshening in the Eagle Ford Shale

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Abstract

Effective, considerate shale play water management support operations and protect the environment. A parameter often overlooked is total dissolved solids (TDS). Knowledge of TDS is important to meet these dual goals. Subsurface TDS typically increases with depth. However, produced-water samples from the Eagle Ford Shale show a strong TDS decrease by a factor of ~ 10 with increasing well depth ($\sim 200,000$ ppm at ~ 2.5 km to $18,000$ ppm at ~ 3.6 km). Water stable isotopes strongly suggest that the low TDS is not due to dilution by meteoric water. Rather, it is attributed to smectite-to-illite conversion, in which the smectite interlayer water is released into the pore space. Depth, temperature, and other related indicators (source for K, excess silica) support such a mechanism. In addition, water-isotope patterns and $87\text{Sr}/86\text{Sr}$ ratios suggest a conversion operating in a closed system. Order-of-magnitude calculations show that the 8% of mixed-layer clay present on average in the Lower Eagle Ford Shale is sufficient to dilute brines to observed levels. Stakeholders could then have a more optimistic outlook on water recycling and on using produced water for other uses (irrigation, municipal) because the low salinity is an intrinsic property of the formation rather than due to short-term mixing.

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1- Summary

- Eagle Ford Shale (EFS) is an unconventional play in South Texas with gas, condensate, volatile oil, and oil windows at depth ranging from 6,000 ft to 12,000 ft (1800-3700 m) (Fig. 1)
- The amount of produced water (PW) per unit volume of oil/gas is relatively small (more than in the Marcellus and Bakken but less than in the Barnett and Permian Basin)
- Total dissolved solids (TDS) values range from expected values at large depths (>100,000 mg/L) to brackish (10-20,000 mg/L)
- The EFS is a marl with a strong volcanoclastic influence
- It is hypothesized that smectite/illite (S/I) conversion is responsible for the low TDS values
- Recycling and reuse of PW are made easier when TDS is lower

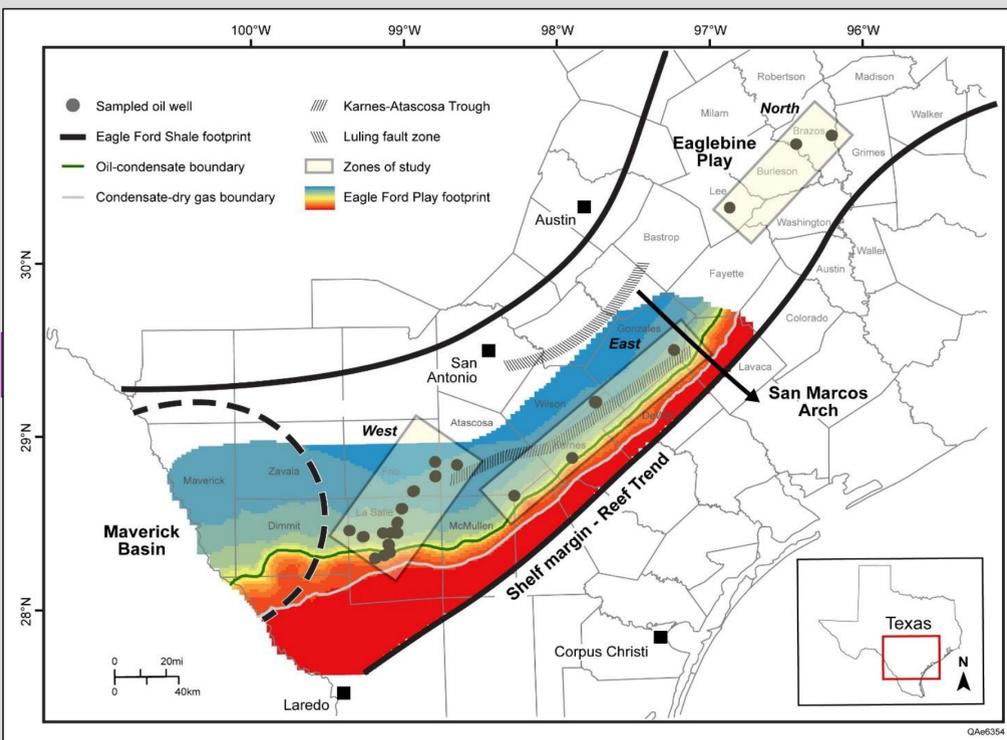


Figure 1. Location map showing the 22 sampled wells and oil, condensate, and gas windows which are color-coded by API gravity from ~30 (blue) in oil to ~65 (red) for dry gas. Samples were taken in the oil window. We define 3 zones: (1) west zone, which represents a along-dip profile of the TDS; (2) east zone, which represents an along-strike profile; and (3) north zone in the so-called Eaglebine play where the EFS transitions to the more sandy facies of the Woodbine Formation. The wells sampled (but one) were completed in 2013-2016.

Some of this material is published in Nicot et al., 2018, Salinity reversal and water freshening in the Eagle Ford Shale, Texas, USA: ACS Earth and Space Chemistry, v. 2, no. 11, p. 1087-1094.

2- Sampling



Figure 2. Oil and produced water were sampled at the wellhead or separator

Fluids were collected in a sealed Al container (see Fig. 2) and water pipetted in the lab for IC (major ions), ICP (trace metals), Sr isotopes, water isotopes analyses. Water samples were centrifuged to eliminate oil droplets

There are two ways to drop TDS of the samples: (1) samples are a mix of injected hydraulic fracturing (HF) water and actual formation water; isotope analyses rule this out (Fig. 3); (2) water condensation from produced gas; the facts that very little gas is produced and TDS values are consistent in repeat samples rule this out too.

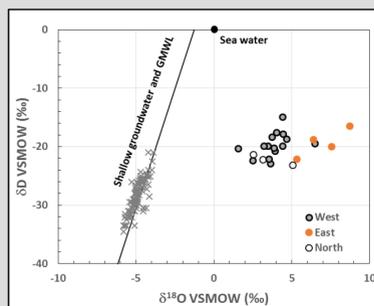


Figure 3. Water isotopes of local shallow groundwater (assumed to have been used for HF) and of PW. There is no obvious mixing trend.

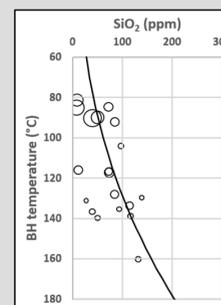
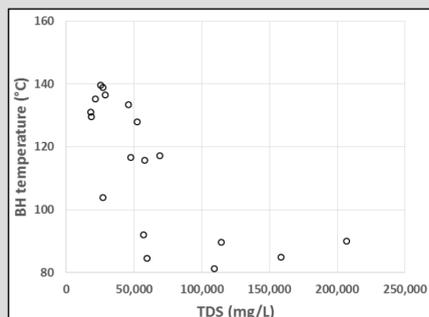
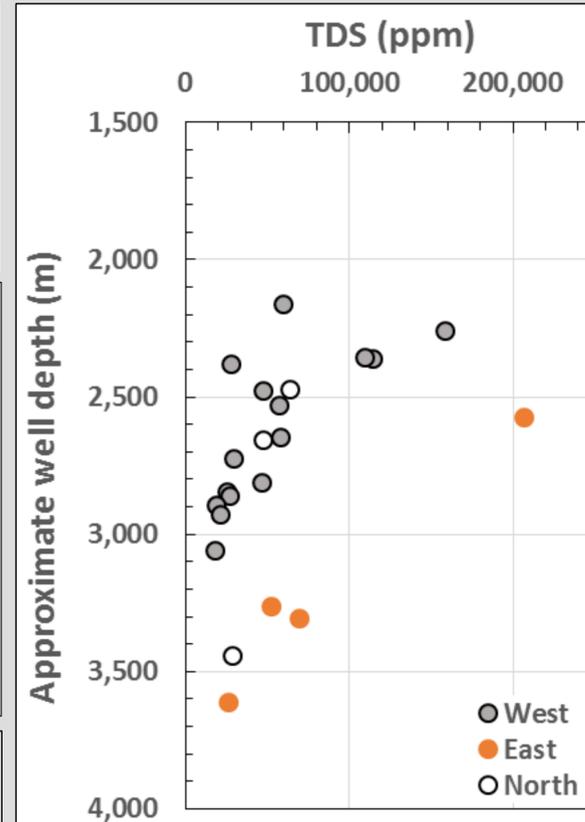


Figure 5. Silica concentration as a function of temperature; bubble size proportional to TDS. Solid line represents silica solubility

Figure 4. TDS is clearly correlated with temperature and starts decreasing at the usually accepted onset of S/I conversion (which occurs in the 80-120°C range)



3- Results and Discussion



The three zones show the same strong decreasing trend of TDS with depth. TDS starts decreasing when temperature is over 80°C (Fig. 4).

An excess silica (Fig. 5) is also observed according to the reaction: Smectite + Al + K → Illite + Silica + Exchangeable cations (Mg, Ca, Na, Fe) + H₂O

K is believed to be sourced from detrital illite and K-feldspar. The EFS is carbonate rich but illite/smectite mixed-layer clays are also abundant at relatively shallow depth (before the S/I conversion) (~10% volume).

Water budget (water content of 6% – porosity × saturation) is consistent with amount of water potentially released.

S/I conversion in the EFS does not come as a surprise because it has been documented in several Gulf Coast formations.

Other mechanisms can be invoked to explain the low TDS such as kerogen dehydration (dismissed) or invasion from external water through natural or induced cross-formational flow, in particular from the overlying large sandy Carrizo-Wilcox (CZWX) aquifer. Sr isotope ratios suggest that no such invasion occurred (Fig. 6)

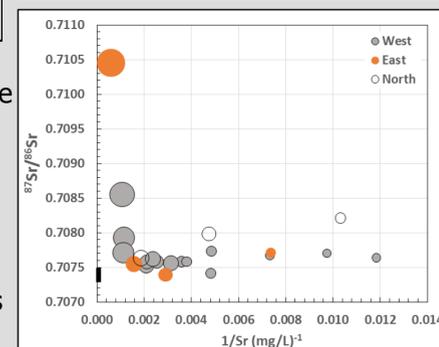


Figure 6. Sr isotope ratio as a function of reciprocal Sr conc. Bubble size is proportional to TDS. Range of seawater ⁸⁷Sr/⁸⁶Sr ratio during EFS deposition is shown by the small black box. EFS Sr ratio is consistent with a slightly radiogenic original ratio with no input from the CZWX. CZWX typically shows a higher Sr ratio in the 0.708-0.713 range. High TDS and high Sr ratio outliers are believed to be linked to fluids migrating up through fault zones.

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