

Dolomitization and Anhydrite Precipitation by Highly Evaporated Seawater in Moderately Deep Subsurface, Permian Basin*

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Abstract

Geochemistry of existing formation waters in the Permian Basin indicate that waters associated with late Permian (Salado) halite deposition displaced most formation waters in the Permian Basin. High concentrations of dissolved magnesium result when seawater is evaporated to halite precipitation. The existing Permian Basin formation waters contain high calcium and low magnesium concentrations which is opposite of what is produced by evaporation of seawater indicating that the evaporated seawater responsible for halite deposition subsequently dolomitized large quantities of limestone. Salado halite is approximately 1500 feet thick in the Permian Basin, and that would have required the evaporation of more than 100,000 feet of seawater across the entire basin. This amount of evaporated seawater could dolomitize an average of 850 feet of limestone across the entire basin. Those waters would have descended and could have caused dolomitization in a number of areas including: (1) along fractures in the Capitan reef, forereef and slope as well as fractures and caverns in the Capitan backreef, (2) limestones deeper in the Paleozoic section, and (3) additional zones on pre-existing dolomite throughout the Permian section. Seawater evaporated through halite precipitation contains little calcium, but has substantial dissolved sulfate. As a result, calcium liberated during dolomitization could combine with the dissolved sulfate, and precipitate anhydrite, which is common in the subsurface Capitan as well as many other intervals throughout the Permian Basin. Other possible diagenetic processes associated with these highly evaporitic waters are the formation of magnesite in the Tansill (observed in the Gulf PDB-04 well), and hydrothermal dolomitization when these descending waters were heated and then ascended.

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Art Saller

Current Employer: Kosmos Energy

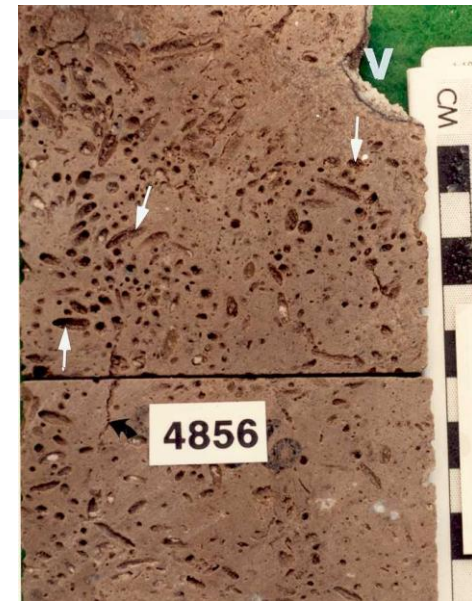
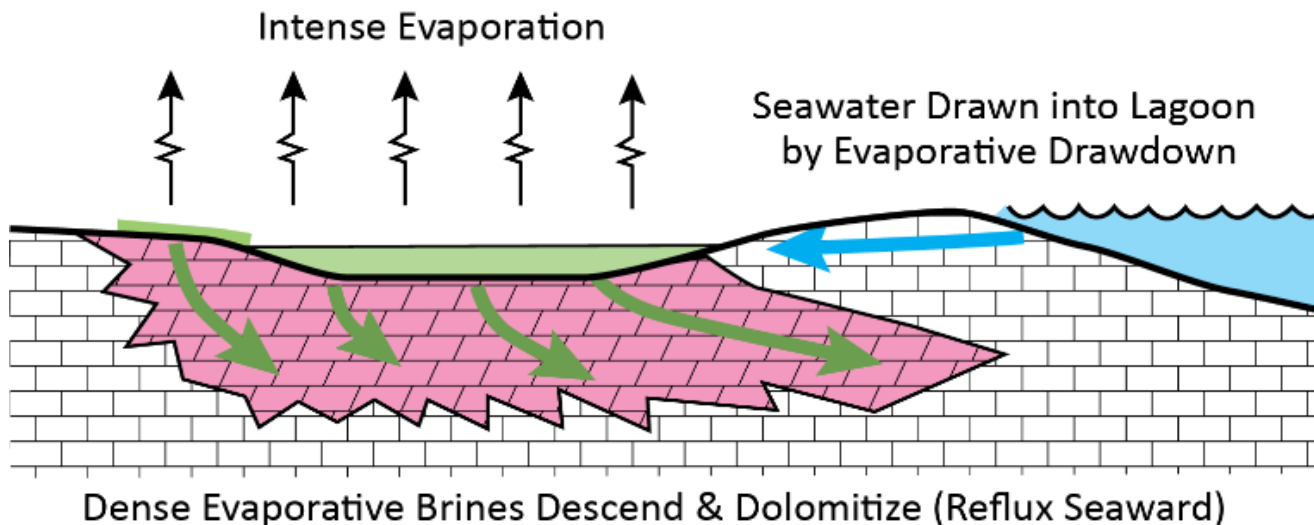
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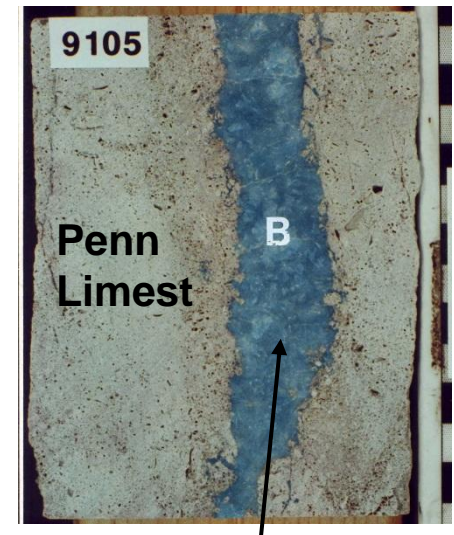


Dolomite in the Permian Basin

- Dolomitization is important for reservoir quality in many conventional reservoirs in the Permian Basin
- Most dolomitization in the Permian of the Permian Basin occurred shortly after deposition by evaporated seawater (reflux dolomitization)
- **Later stage dolomites are also present including some derived from highly evaporated seawater the precipitated Salado salt**



Grayburg S Cowden



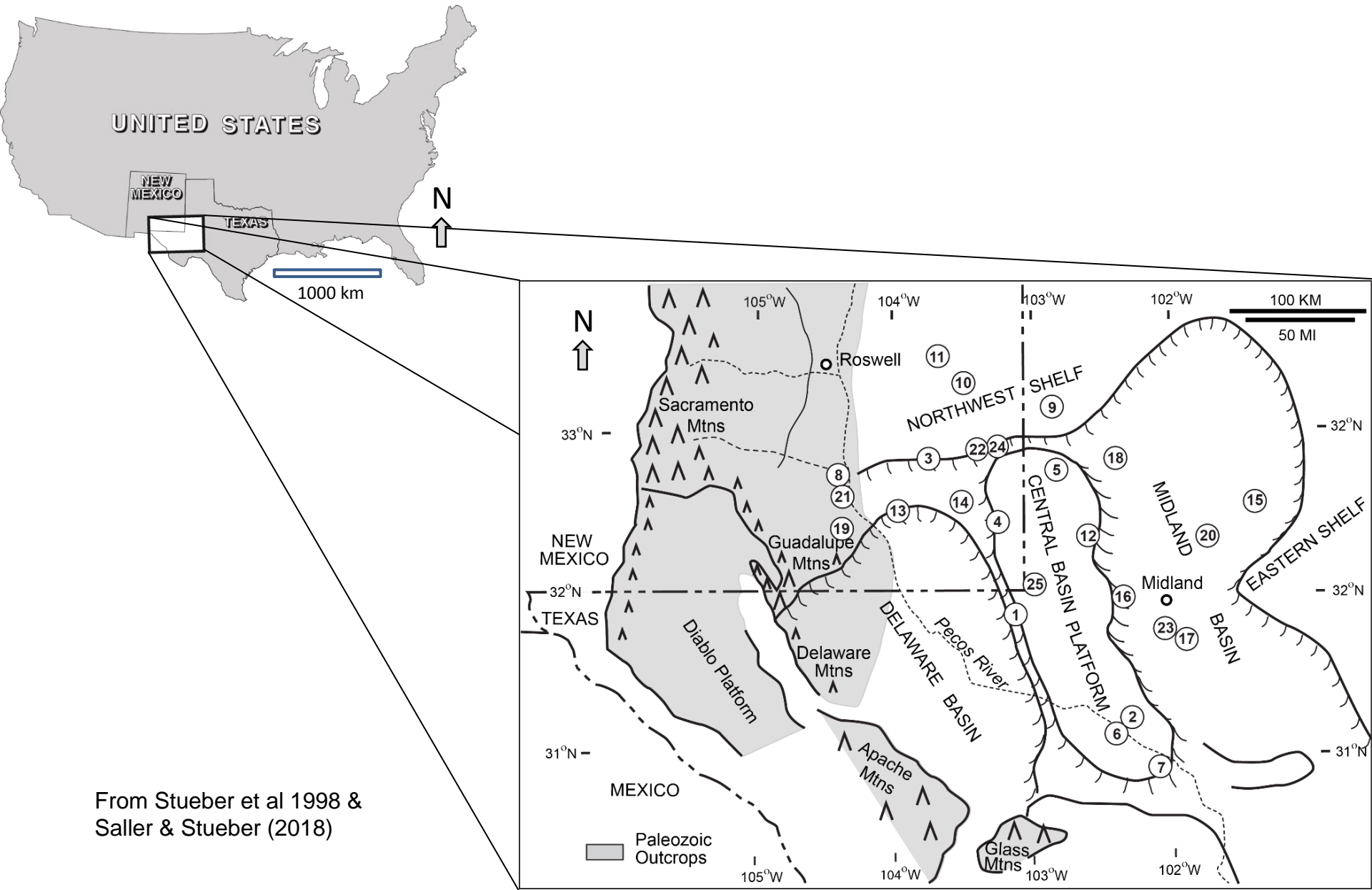
Late Fe dolomite

Dolomitization & Anhydrite Precipitation by Highly Evaporated Seawater in Moderately Deep Subsurface

Topics to be discussed

- Two main Permian Basin formation waters
 - Late Permian highly evaporated seawater
 - Neogene meteoric water from SE New Mexico
- Evaporating seawater to halite saturation results in large amounts of dissolved Mg (McCaffrey et al, 1987)
- Formation water chemistry indicates dolomitization by the late Permian highly evaporated seawater that descended into the basin
- Volumetrics of late Permian seawater evaporating to form Salado salt indicate substantial volumes of Mg & dolomite could form
- Highly evaporated seawater has abundant SO_4 causing CaSO_4 precipitation when Ca is liberated during dolomitization
- Moderately late dolomitization and anhydrite precipitation are common in the Permian Basin
- Similar formation water chemistries in other evaporitic basins suggest similar processes in other basins

Formation waters were sampled & analyzed across the Permian Basin by Alan Stueber



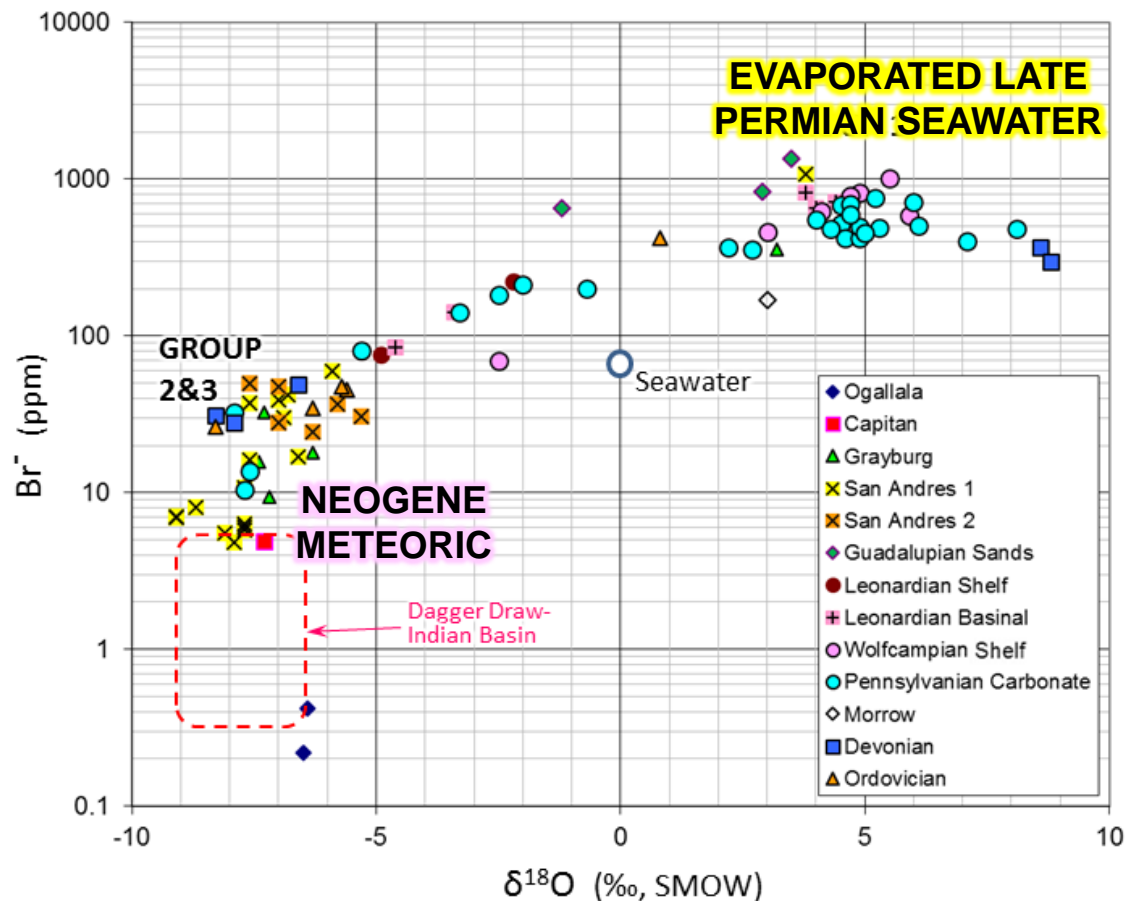
From Stueber et al 1998 &
Saller & Stueber (2018)

Two Types of Permian Basin Formation Waters

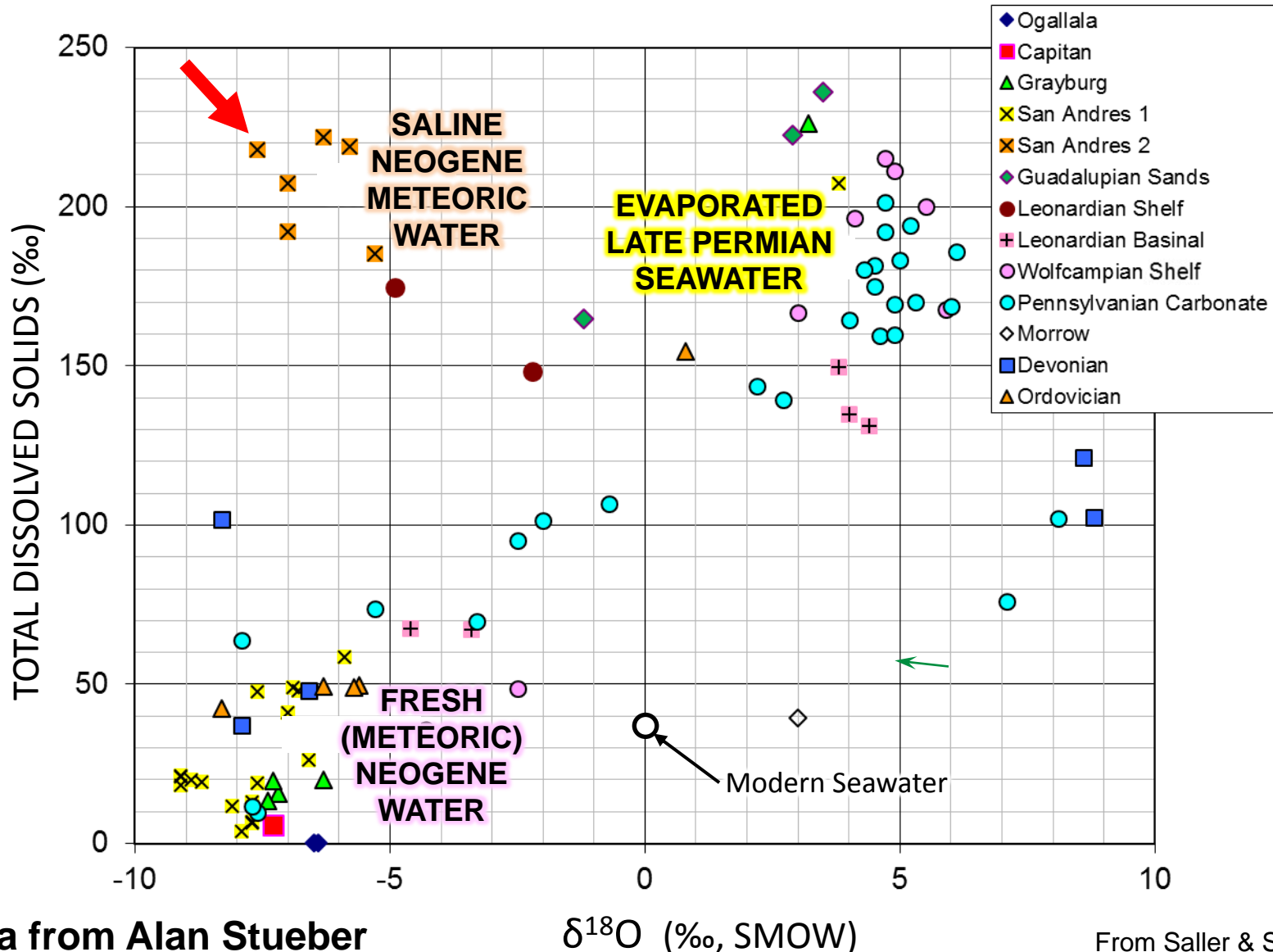
- (1) Late Permian Highly Saline water
 - High Br, $\delta^{18}\text{O}$, $\text{Cl} > \text{Na}$, $\text{Ca} > \text{SO}_4$
- (2) Neogene water identified by low (meteoric) δH & $\delta^{18}\text{O}$

Highly saline Permian waters are still present where Neogene meteoric waters have not displaced them

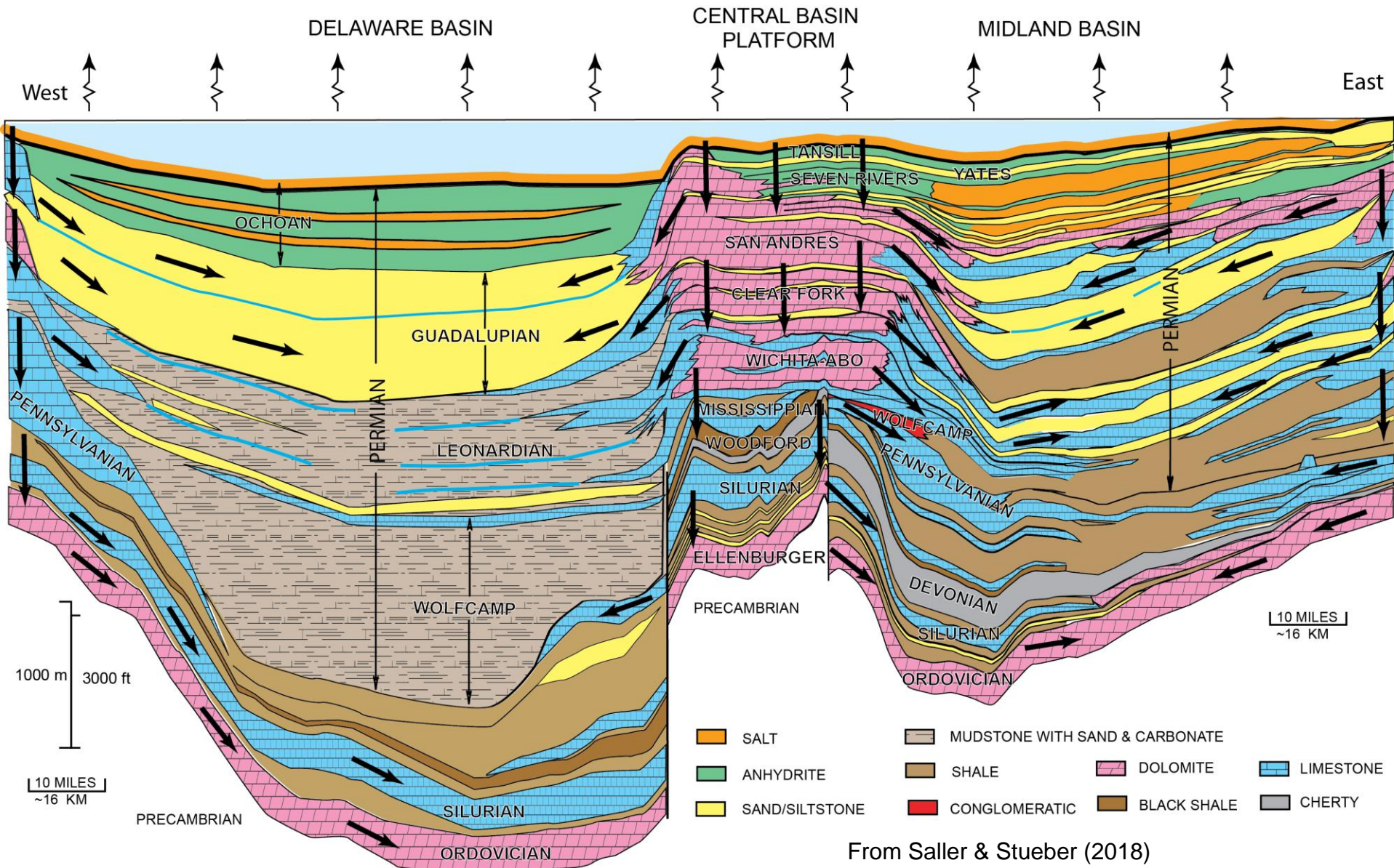
Data from Alan Stueber



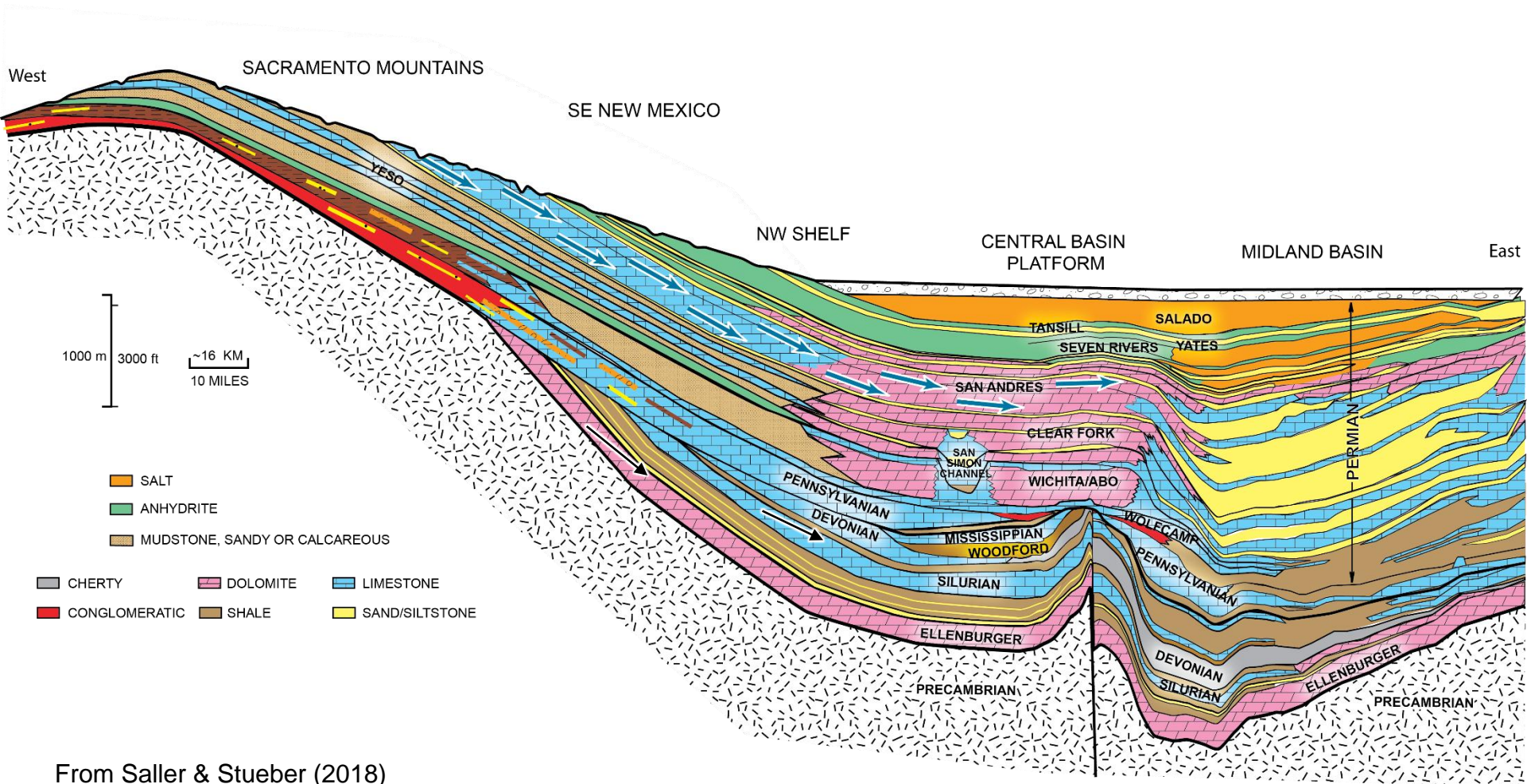
Some Neogene Meteoric Formation Waters Have High Salinities Because they Dissolved Nearsurface Salts as they Descended into the Basin



Highly Saline Waters Formed & Descended during Deposition of Late Permian Salado Salt



Neogene Uplift formed Mountains in SE New Mexico. Meteoric Water from those Mountains Flows into the Permian Basin Displacing Saline Permian Water in Many Intervals

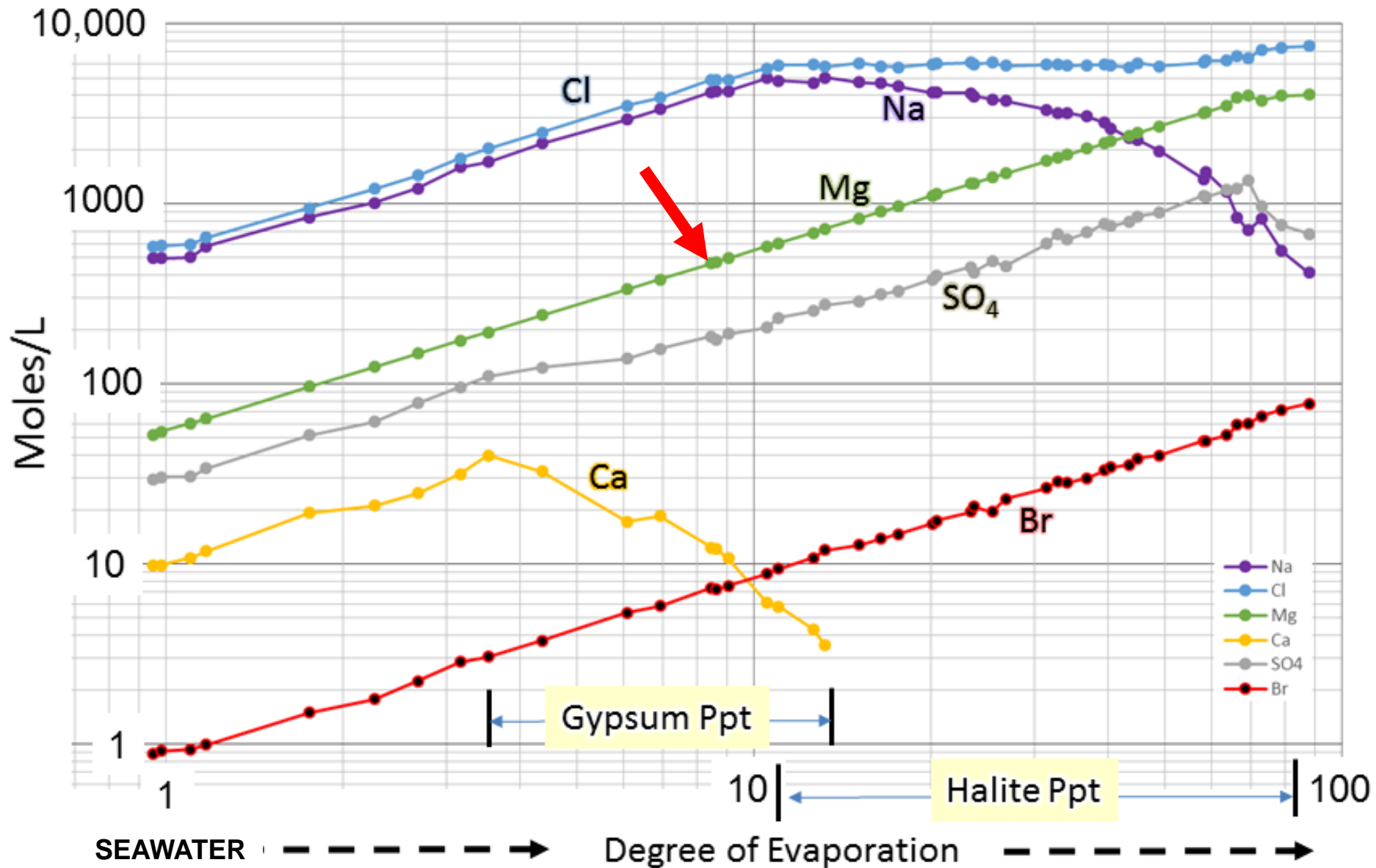


From Saller & Stueber (2018)

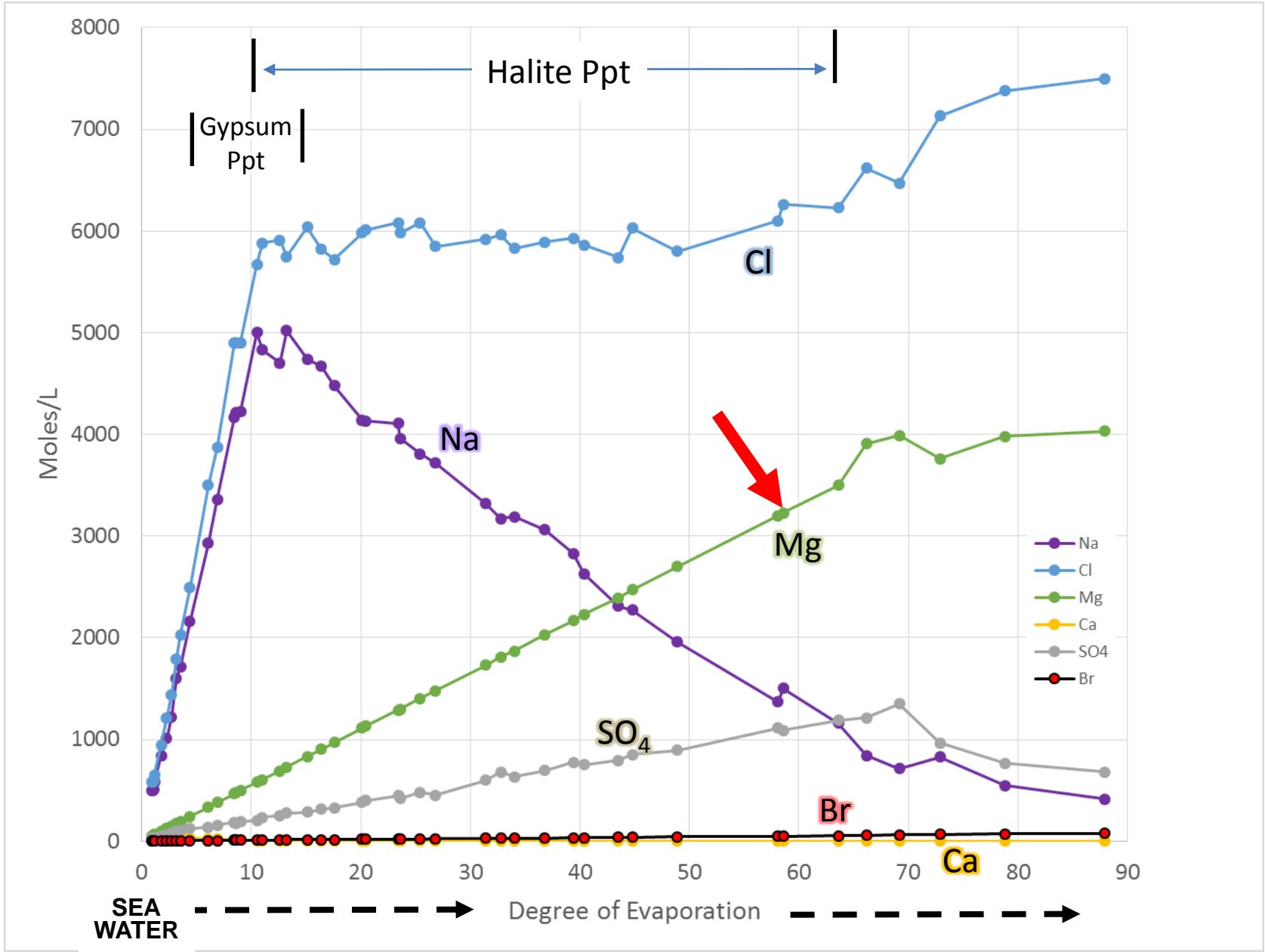
Dolomitization & Anhydrite Precipitation by Highly Evaporated Seawater in Moderately Deep Subsurface

- Two main Permian Basin formation waters
 - Late Permian highly evaporated seawater
 - Neogene meteoric water from SE New Mexico
- **Evaporating seawater to halite saturation results in large amounts of dissolved Mg (McCaffrey et al, 1987)**
- Formation water chemistry indicates dolomitization by the late Permian highly evaporated seawater that descended into the basin
- Volumetrics of late Permian seawater evaporating to form Salado salt indicate substantial volumes of Mg & dolomite could form
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Evaporating seawater produces large amounts of dissolved Mg (data from McCaffrey et al, 1987)



Evaporation of Seawater (data from McCaffrey et al, 1987)

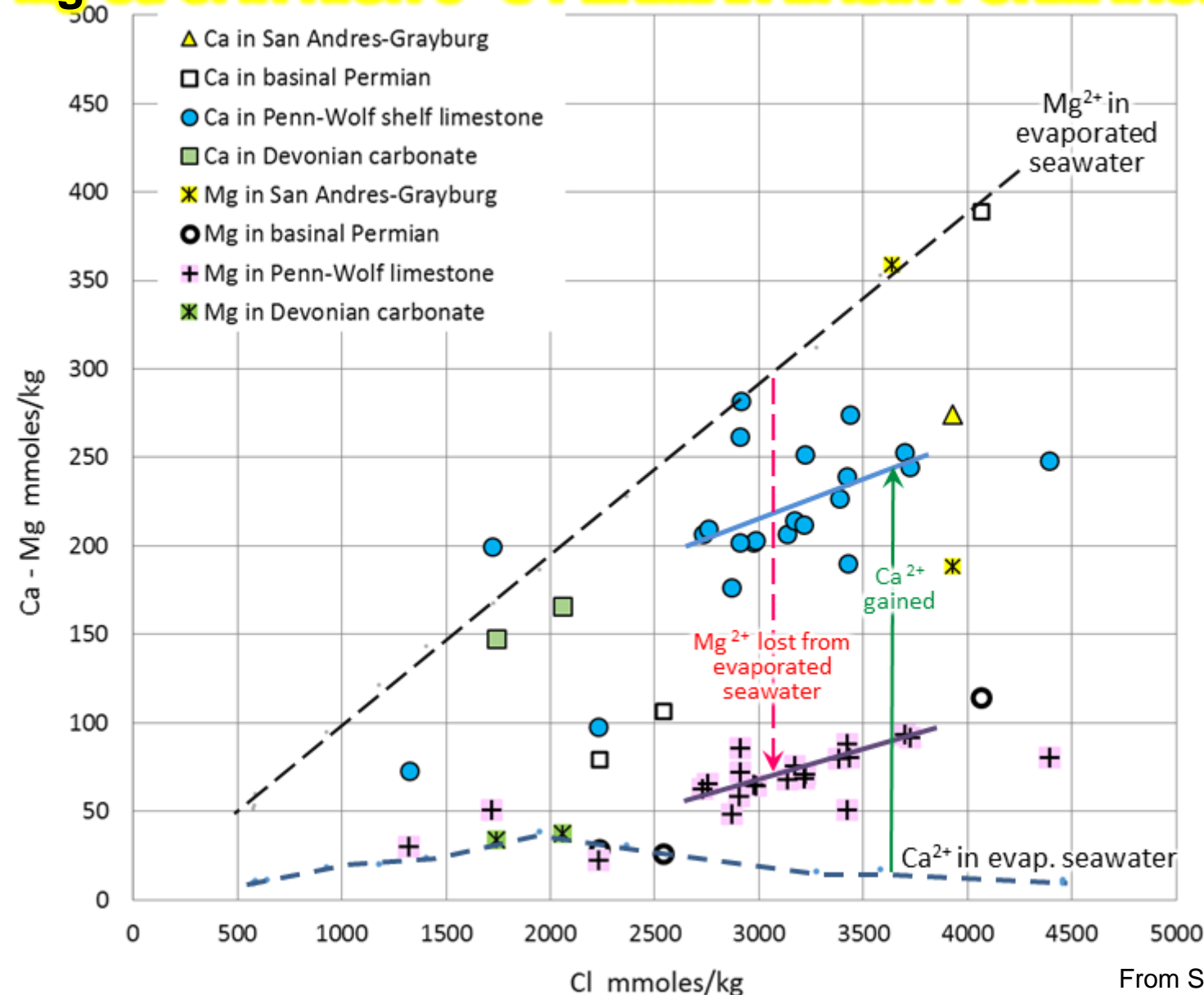


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Formation water chemistry indicates dolomitization by late Permian evaporated seawater that descended into the basin

Mg-Ca-Cl IN HIGH $\delta^{18}\text{O}$ PERMIAN BASIN FORMATION WATERS



Moles of Mg lost from evaporated seawater is similar to, but commonly slightly more than moles of Ca gained

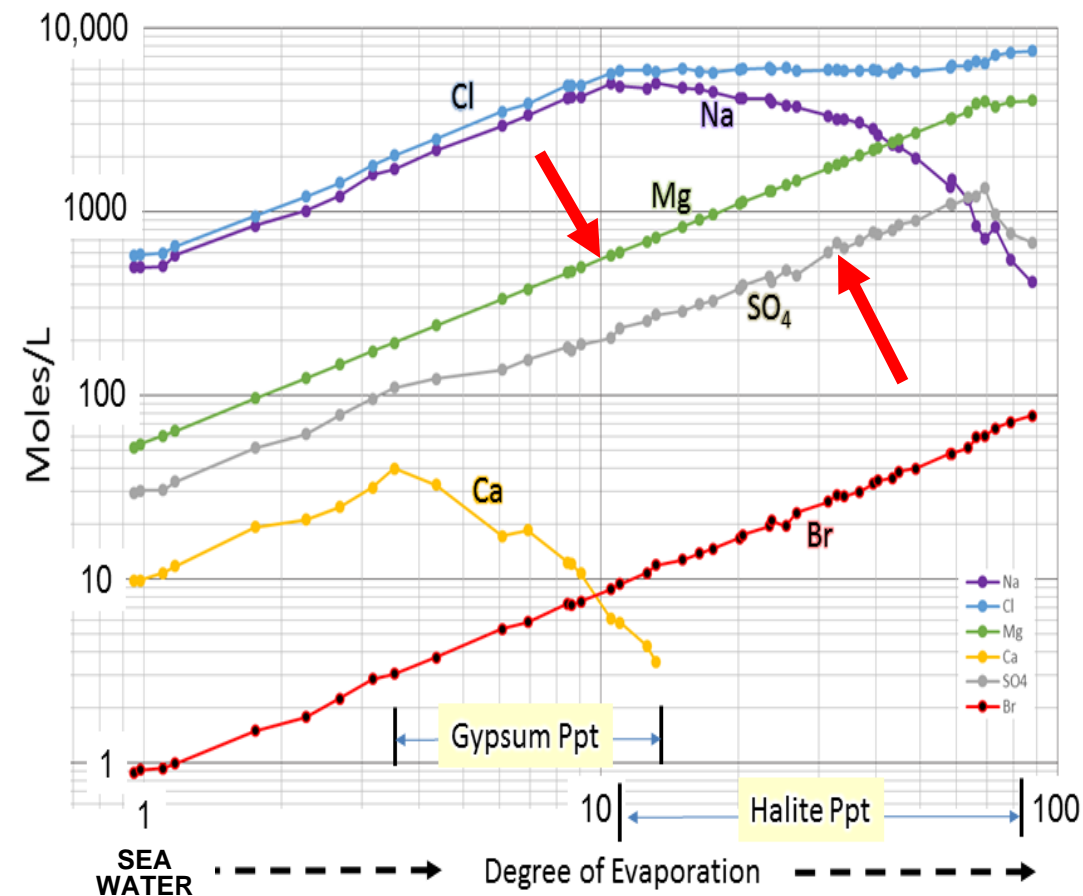
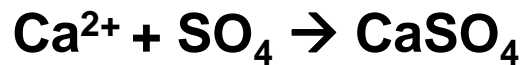
Volumetrics of late Permian seawater evaporating to form Salado salt indicate substantial volumes of dolomitization

- 1500 feet (~500 m) of Upper Permian Salado Fm (dominantly salt)
- 1 m of salt require ~70 m of evaporated seawater
- 500 m of Salado salt requires ~35,000 m of seawater
- 50 mmoles of Mg/liter: 1 m³ of SW has 50 mole
- 35,000 cubic m of seawater contains 1,750,000 moles of Mg
- Dolomitize 3,500,000 moles of CaCO₃
- 3,500,000 moles of CaCO₃ * 100 g/mole = 350,000,000 g
- 350,000,000 g / 2.7 g/cc = 130,000,000 cc of CaCO₃
- 130,000,000 cc of CaCO₃ = 130 cubic m
- **Mg from Salado depositional brine could dolomitize 130 m of limestone across the basin**

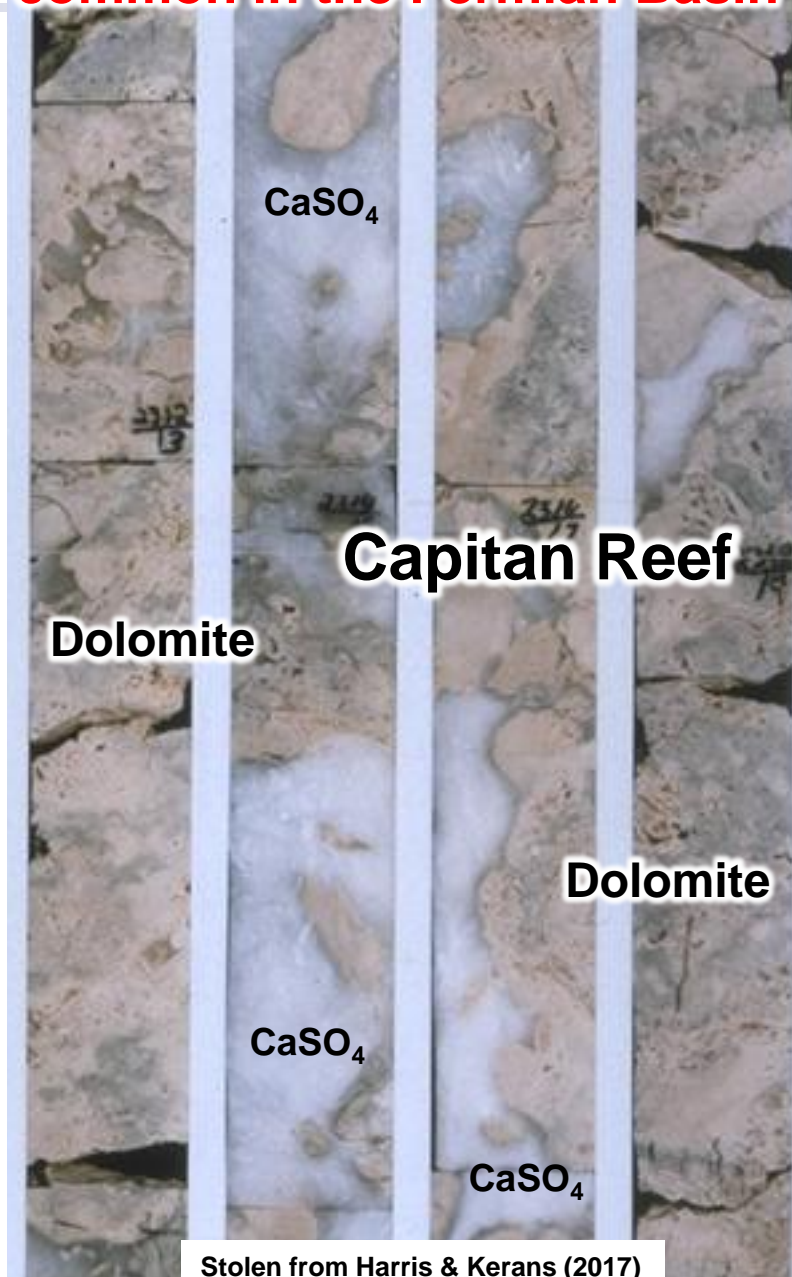
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Highly evaporated seawater has abundant SO_4 & little Ca causing CaSO_4 precipitation when Ca is liberated during dolomitization

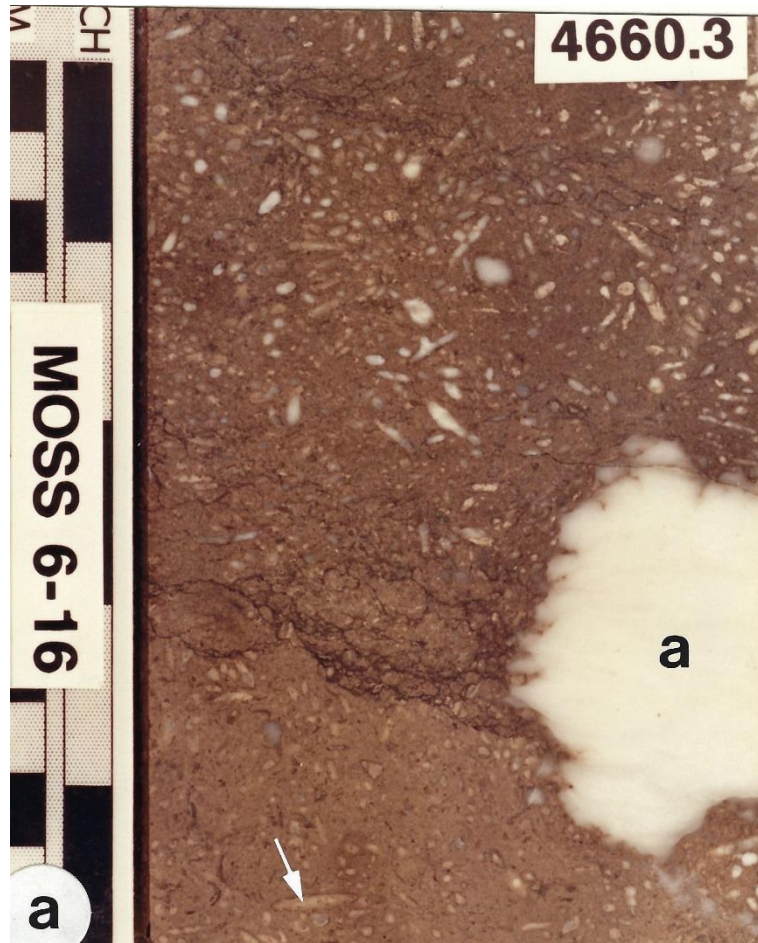


Moderately late dolomitization & anhydrite precipitation are common in the Permian Basin



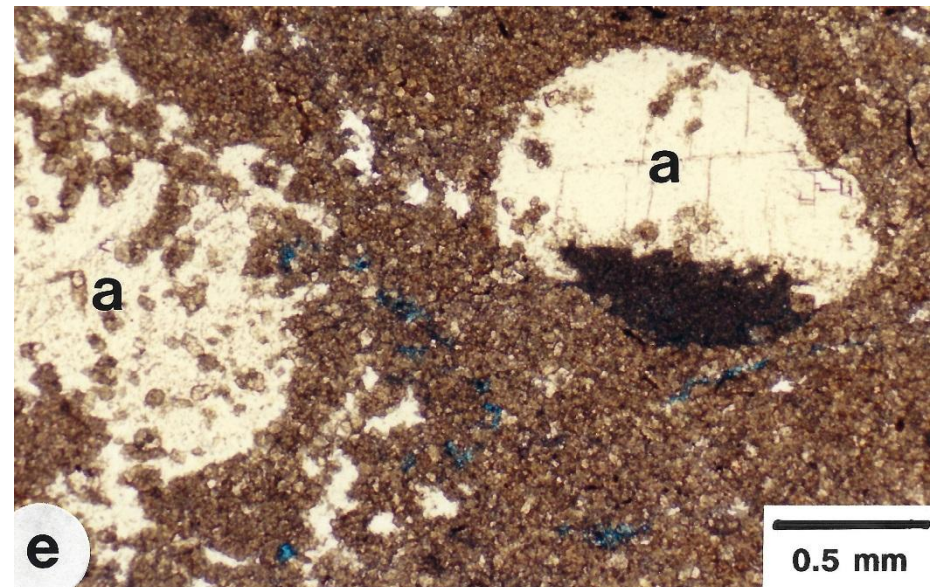
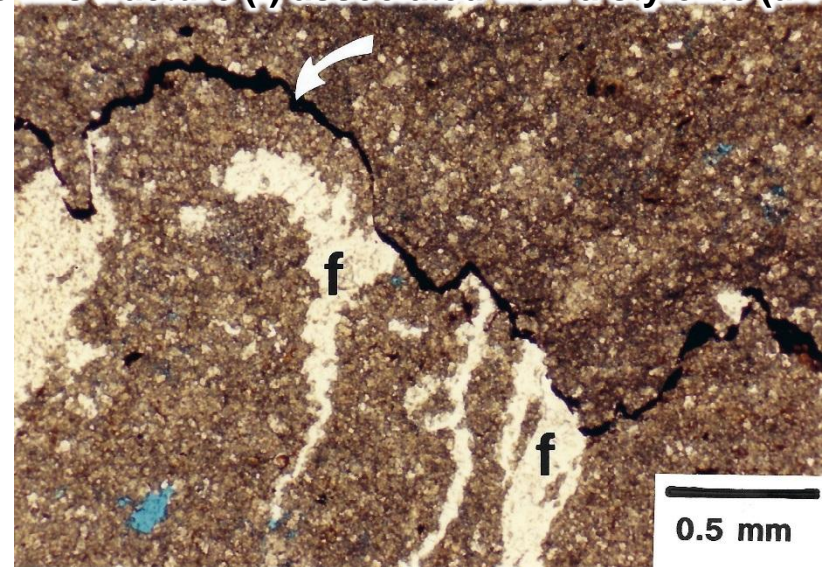
Stolen from Harris & Kerans (2017)

Moderately late dolomitization and anhydrite precipitation are widespread in the Permian Basin



Anhydrite (a; white) fills dissolved fusulinids

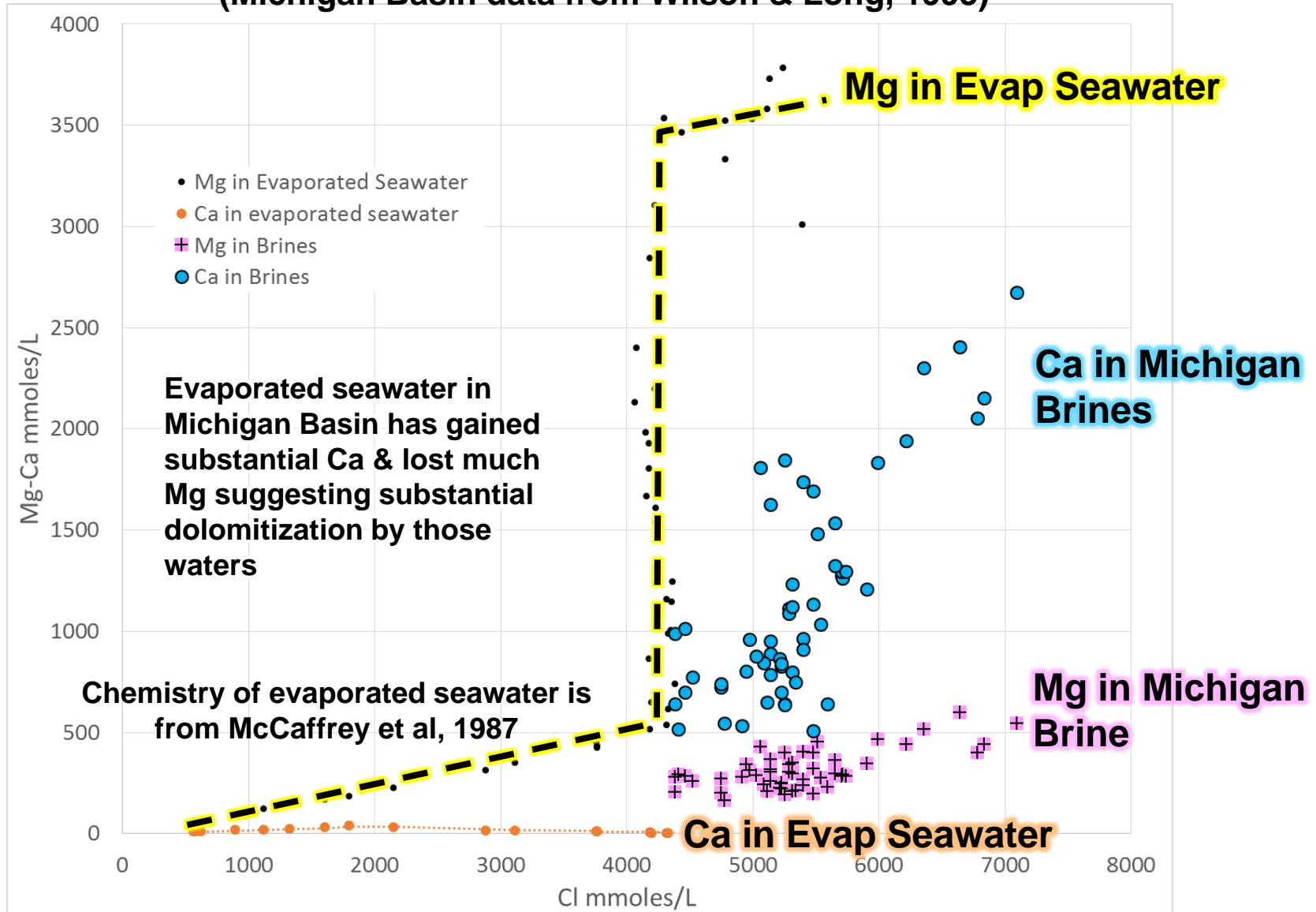
Anhydrite fills fracture (f) associated with a stylolite (arrow)



Similar formation water chemistries in other evaporitic basins suggest similar processes in other basins

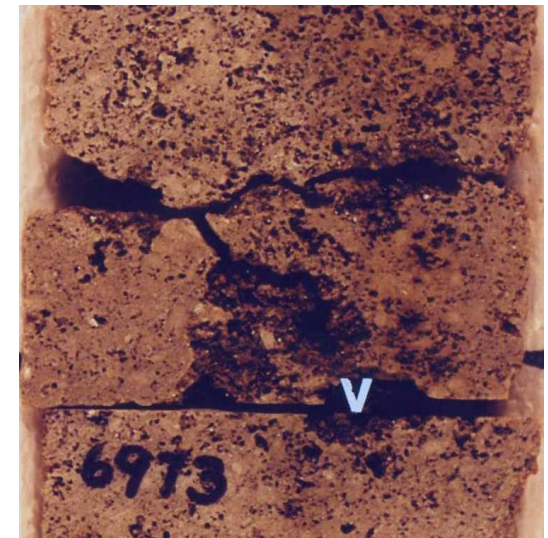
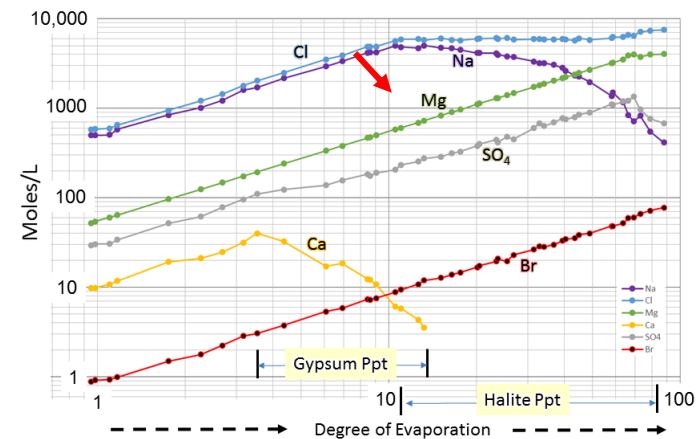
SALINE FORMATION WATERS FROM THE MICHIGAN BASIN

(Michigan Basin data from Wilson & Long, 1993)



Summary: Dolomitization & Anhydrite by Highly Evaporated Seawater in Moderately Deep Subsurface

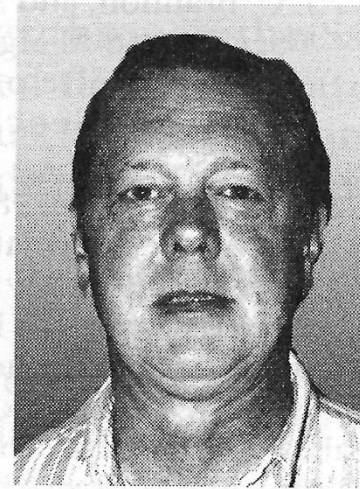
- Late Permian highly evaporated seawater displaced formation waters in the Permian Basin
- Evaporating seawater to halite saturation resulted in large amounts of dissolved Mg
- Current formation water chemistry indicates dolomitization by the late Permian highly evaporated seawater that descended into the basin
- Volumetrics indicate late Permian seawater evaporating to form Salado salt could form substantial volumes of Mg & hence dolomite
- Highly evaporated seawater has abundant SO_4 causing CaSO_4 precipitation when Ca is liberated during dolomitization
- Moderately late dolomitization and anhydrite precipitation are common in the Permian Basin
- Similar formation water chemistries in other evaporitic basins suggest similar processes in other basins



Late, Hydrothermal Dolomite,
Penn, Horseshoe Atoll

Alan Stueber

Alan Stueber received B.S. and M.A. degrees from Washington University (St. Louis) and a Ph.D. from the University of California at San Diego. He has held academic positions at Miami University (Ohio) and Louisiana State University, and currently teaches geology and hydrology courses at Southern Illinois University (Edwardsville). His present research interests involve geochemical studies of groundwaters and saline formation waters.



1937-2009

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