# Estimating groundwater salinity using the Alger-Harrison method in the Hill Country Trinity Aquifer, Texas

*Theme 4, Session 16*
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*2021 GeoGulf Meeting*

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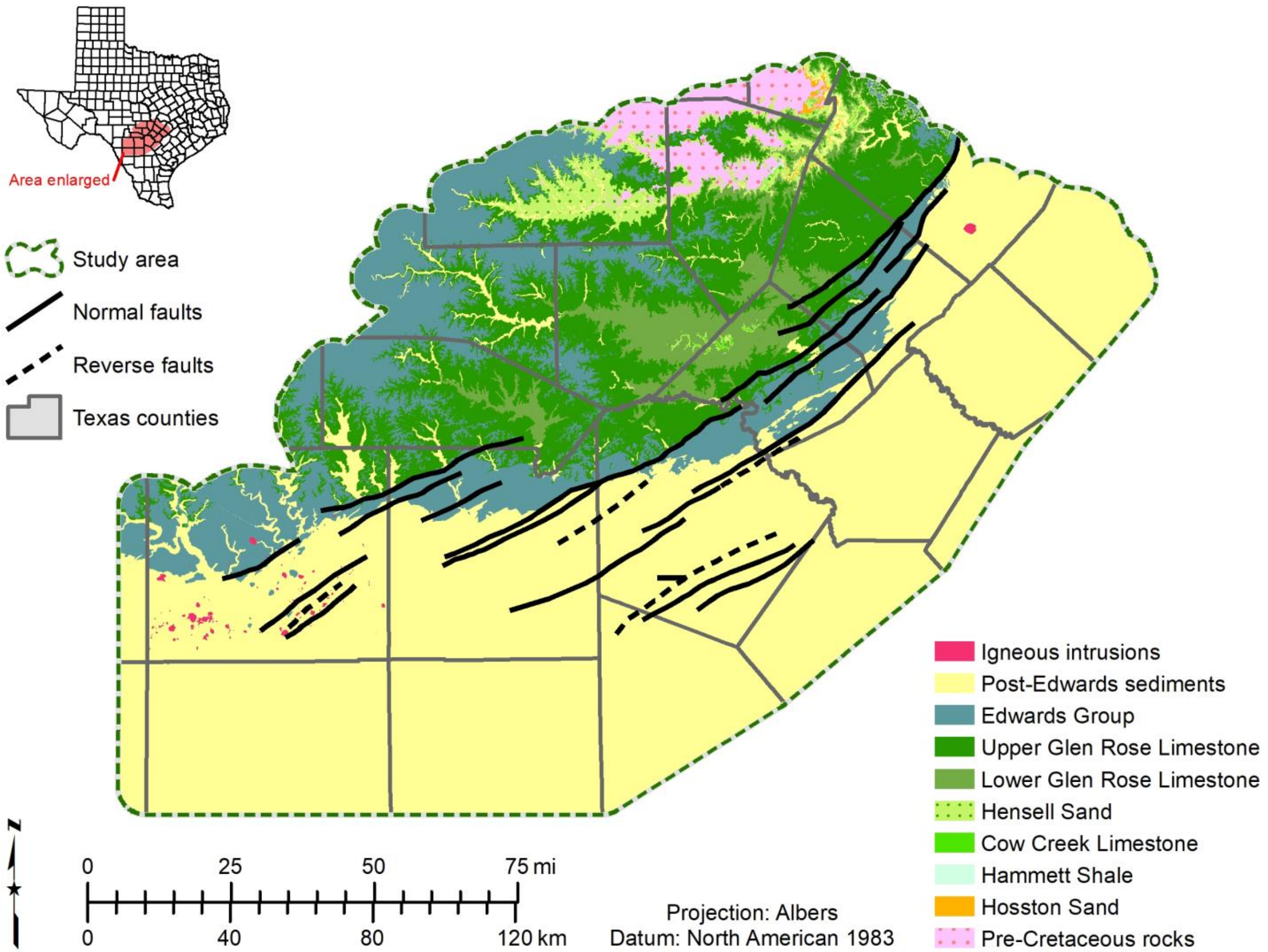
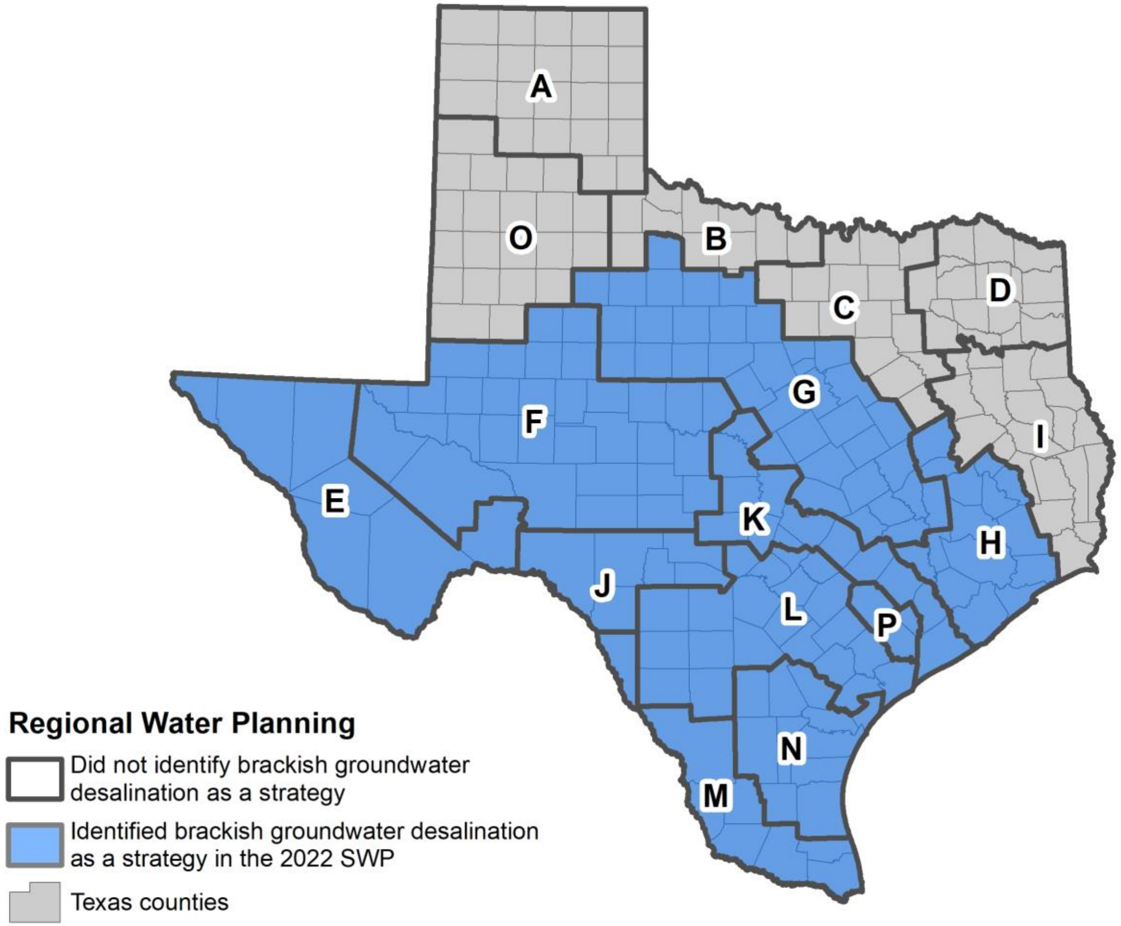
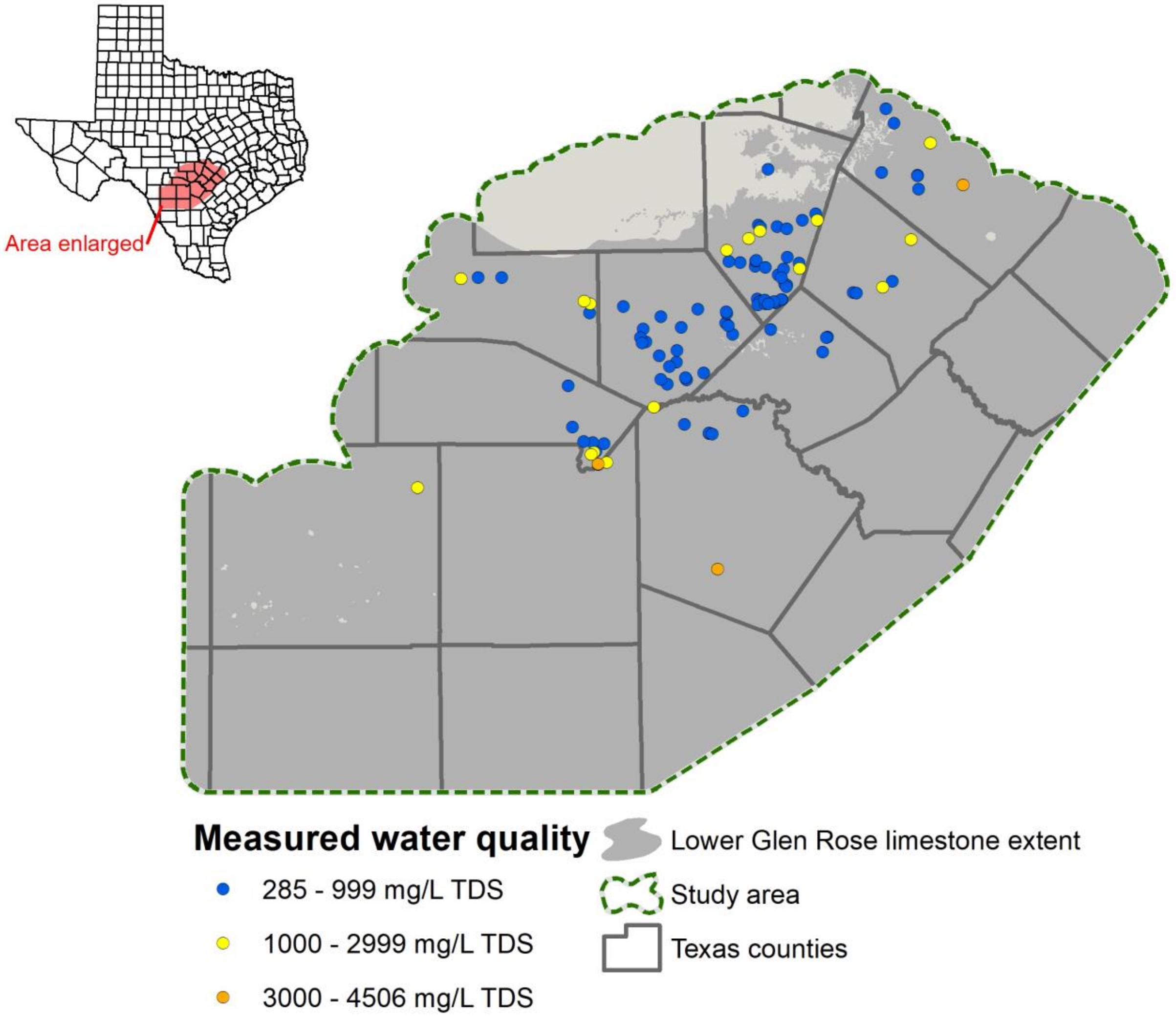
# Study goals and background

- Hill Country portion of the Trinity Aquifer
- Map stratigraphy, water quality, aquifer parameters
- estimate aquifer salinity, brackish groundwater volumes
- full report and GIS data to be released next year



# Why map aquifer salinity?




- by 2070 groundwater desalination is projected to provide 156,897 acre-feet/year (2% of total supply)

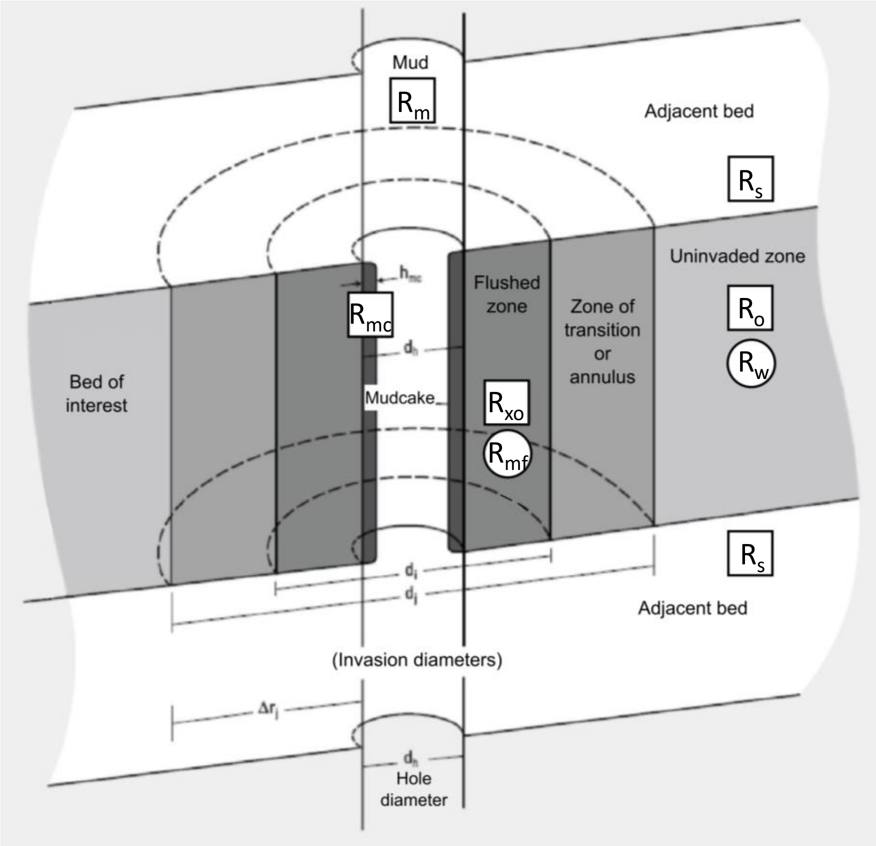
# Typical BRACS study

- acquire data and process into BRACS database
- map stratigraphy
- assign aquifer codes
- clastic aquifers: map net sands
- **estimate** and map **aquifer salinity**
- produce groundwater volume estimates

| Salinity class | Total dissolved solids concentration (TDS, mg/L) |
|---|---|
| Fresh | 0 < TDS < 1,000 |
| Slightly saline | 1,000 ≤ TDS < 3,000 |
| Moderately saline | 3,000 ≤ TDS < 10,000 |
| Very saline | 10,000 ≤ TDS < 35,000 |
| Brine | 35,000 ≤ TDS |

Winslow and Kister, 1956

# How did we estimate salinity?




modified from Schlumberger, 2009

- Resistivity ratio method (Alger and Harrison, 1989)
- requires shallow ($R_{xo}$) and deep resistivity ($R_o$) tool
- requires mud filtrate resistivity ($R_{mf}$) measurement
- calculate water resistivity ($R_w$), convert to conductivity ($C_w$), then use TDS-$C_w$ relationship to convert to TDS (mg/L)

**Basic derivation of the Alger-Harrison method**

1. $R_o = R_w \cdot \frac{a}{\phi^m}$ & $R_{xo} = R_{mf} \cdot \frac{a}{\phi^m}$

2. $\frac{R_o}{R_w} = \frac{a}{\phi^m}$ & $\frac{R_{xo}}{R_{mf}} = \frac{a}{\phi^m}$

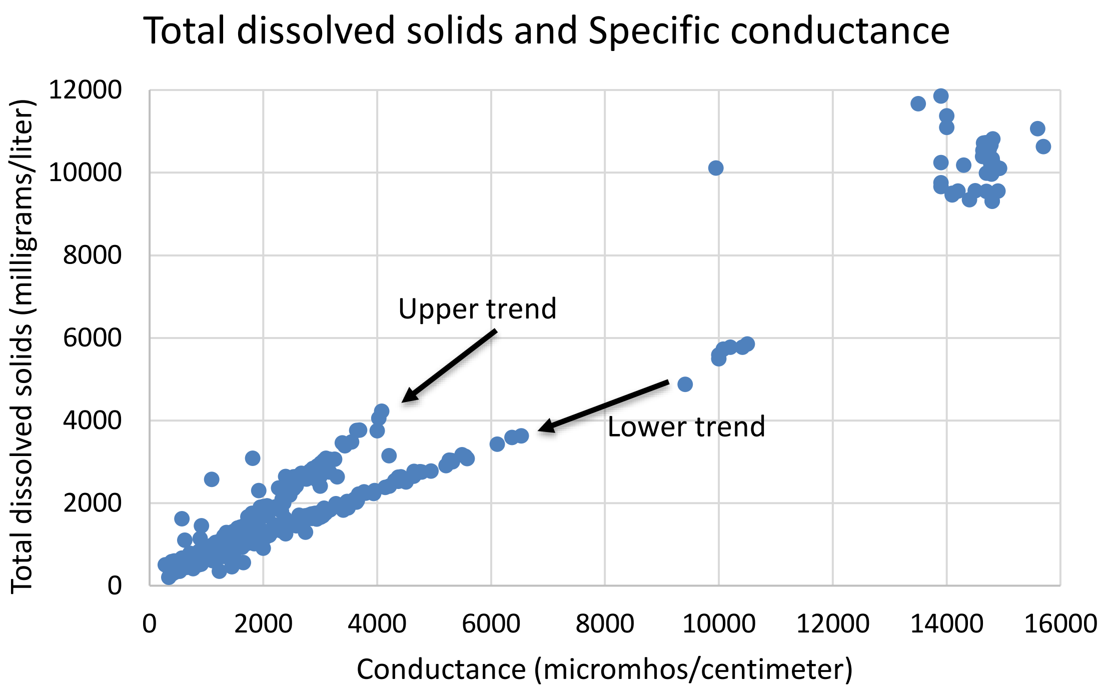
3. $\frac{R_o}{R_w} = \frac{R_{xo}}{R_{mf}}$

4. $R_w = \frac{R_o \cdot R_{mf}}{R_{xo}}$

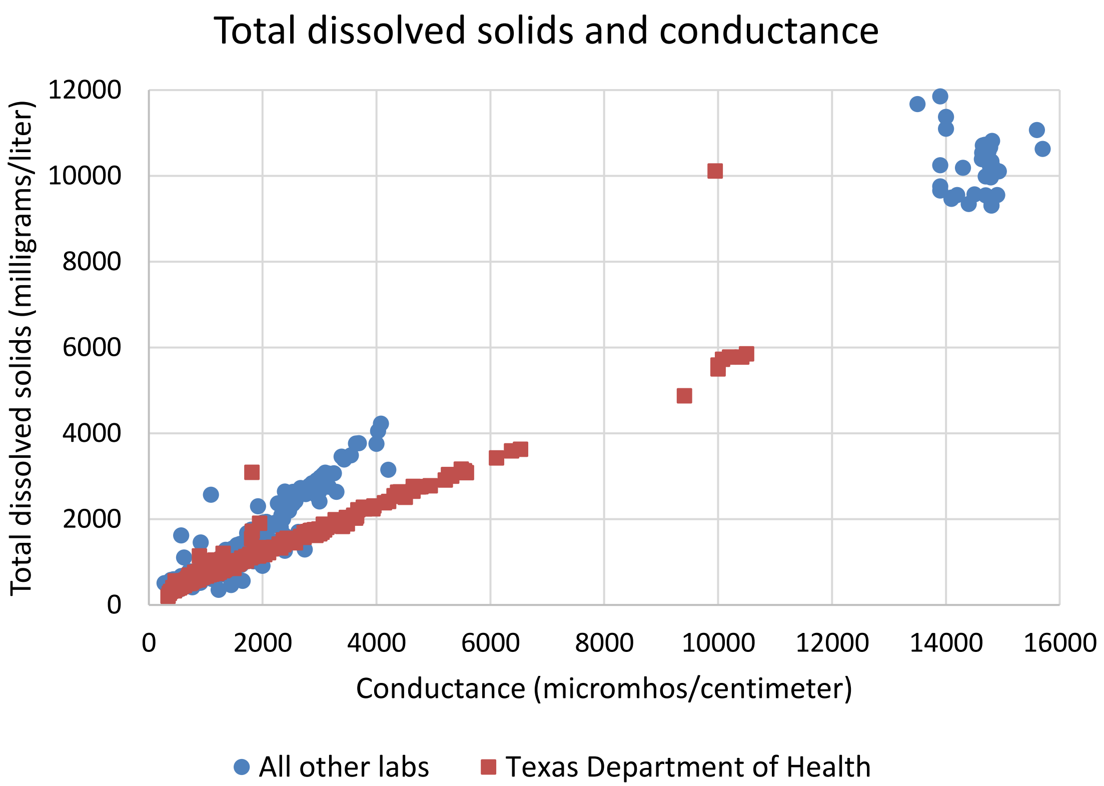
# New (to us) approach: TDS-$C_w$ relationship

- established direct relationships of TDS and $C_w$
  - no NaCl equivalents and ‘ct’ factor
  - summed $Ca^{2+}$, $Mg^{2+}$, $K^+$, $Na^+$, $Sr^{2+}$, $SiO_2$, $HCO_3^-$, $CO_3^{2-}$, $Cl^-$, $SO_4^{2-}$, $F^-$, $NO^{3-}$
  - full bicarbonate value
- NaCl equivalents **do not** capture effects of ion pairing and complexing
- fit data with linear or second-degree polynomial equations
- assumed WQ beyond our data control is increasingly NaCl dominated (synthetic data)

# Challenges: TDS-$C_w$ relationship



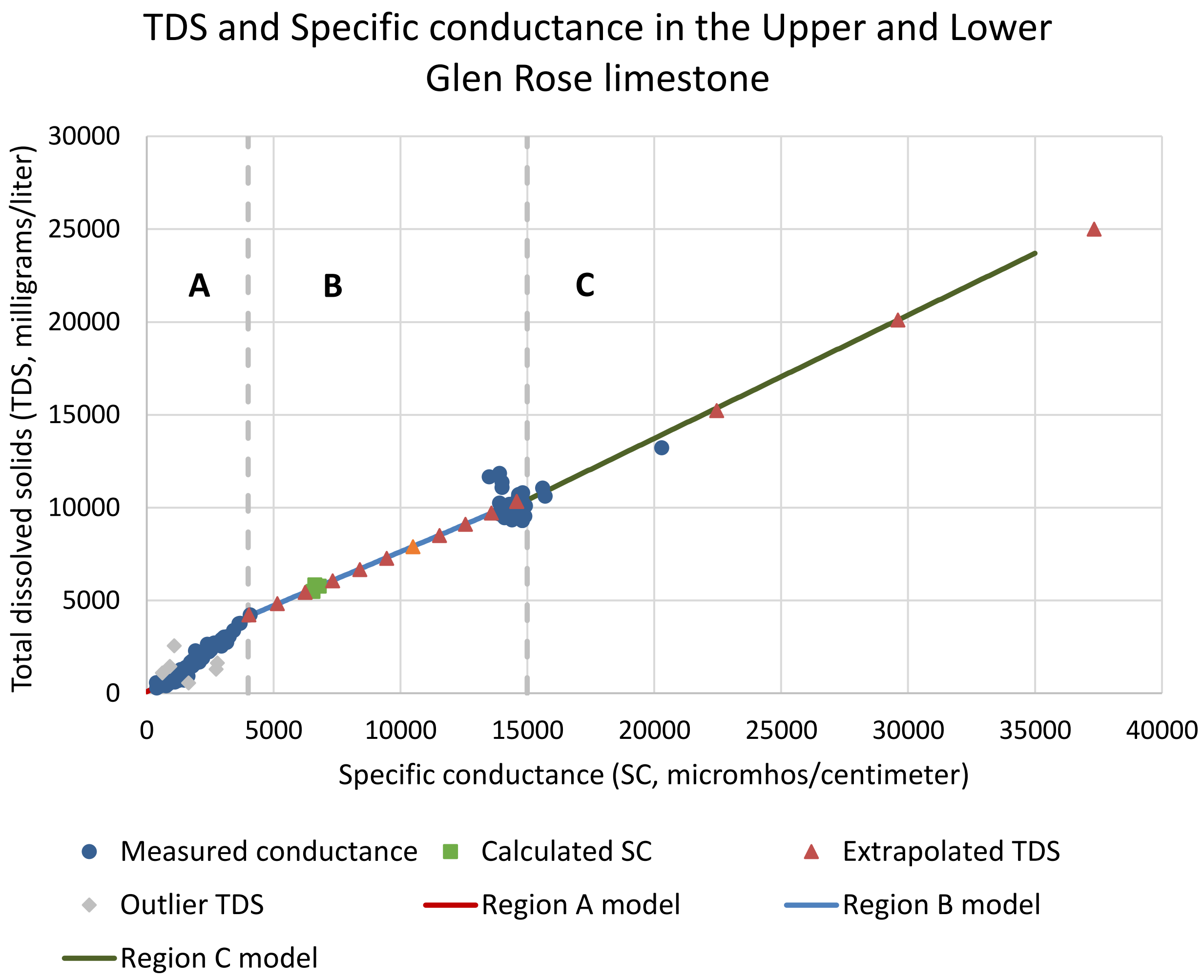

- geographically distinct water populations?
- redox conditions?
- field sampling protocol?
- something else?




- analytical method
- ‘diluted conductance’
- disrupts ion pairing/complexing

# Solution and Results: TDS-$C_w$ relationships

- U.S.G.S. PHREEQC to calculate specific conductance
  - sparse produced water samples
  - some saline samples




- UG or LG; $C_w \leq 4{,}000$ (Region A)

$$TDS = 9 \cdot 10^{-5} \cdot (C_w)^2 + 0.6622 \cdot C_w + 76.044$$

- UG, LG, HE, or CC; $4{,}000 < C_w \leq 15{,}000$ (Region B)

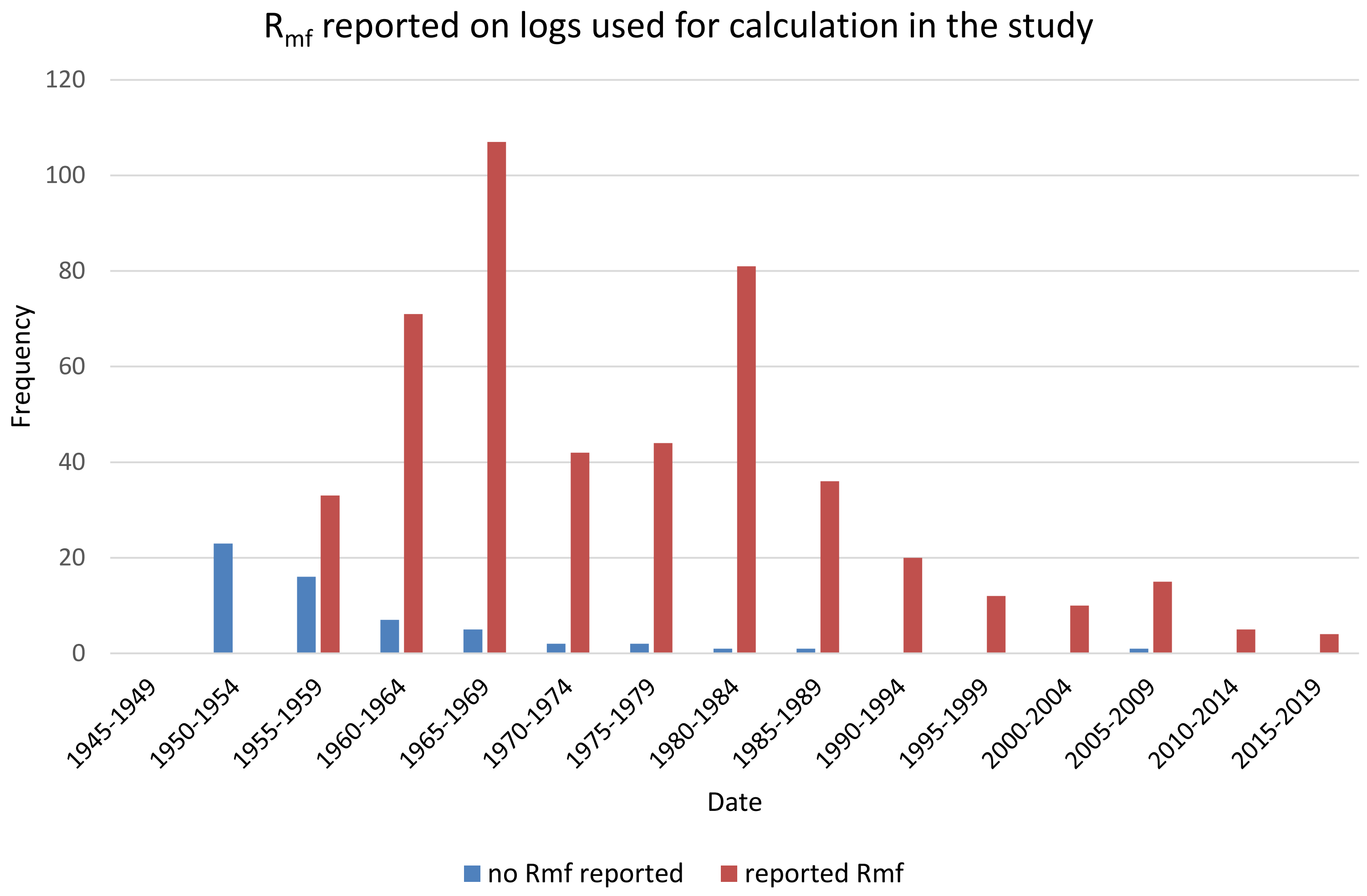
$$TDS = 0.5801 \cdot C_w + 1826.5$$

- UG, LG, HE, or CC; $C_w > 15{,}000$ (Region C)

$$TDS = 0.6644 \cdot C_w + 442.87$$

# Challenges: log-header $R_{mf}$ values

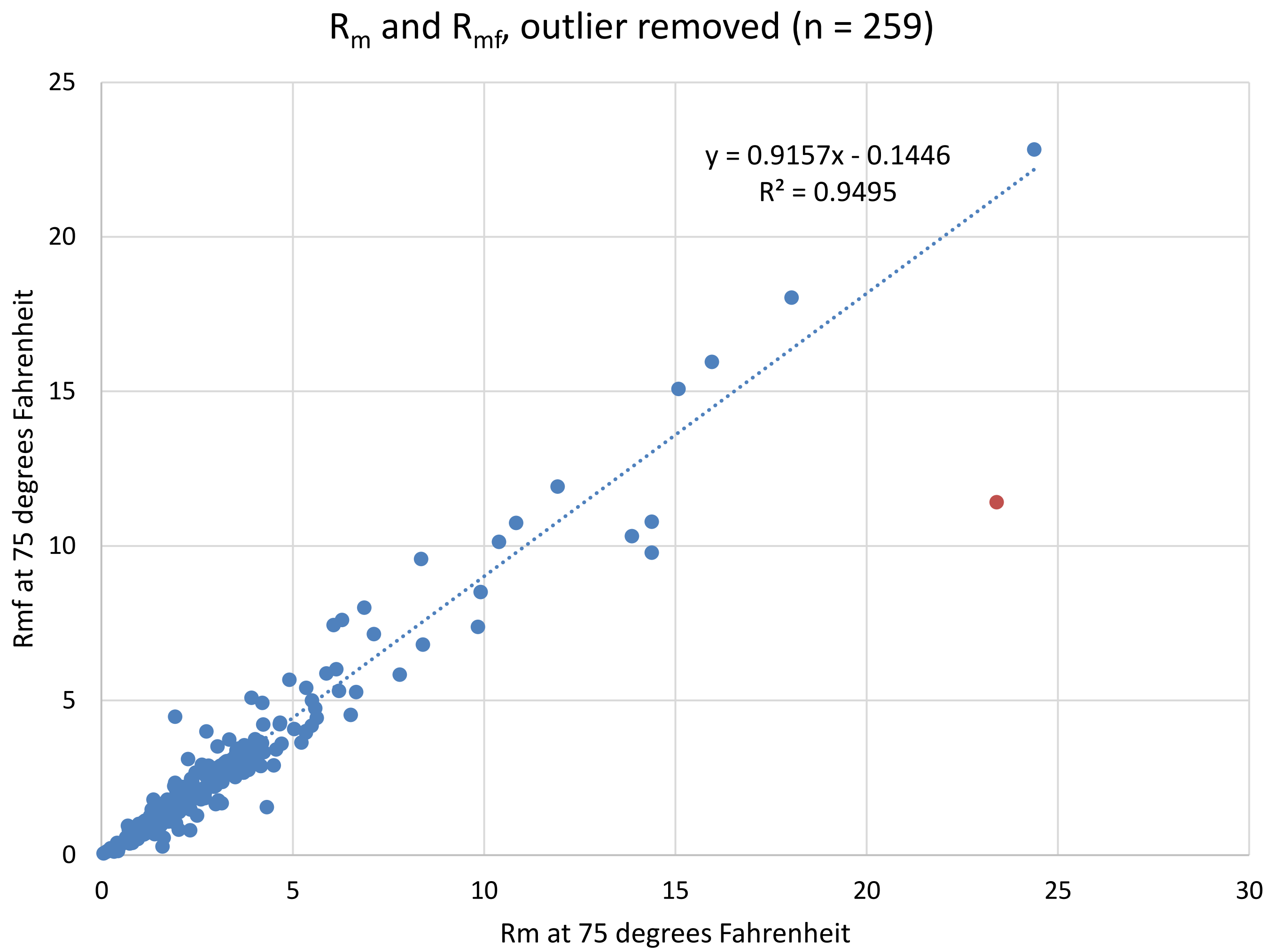
- measurement quality from log header alone?
- Lowe and Dunlap (1986) – $R_{mf}$ can be off by up to 40%
- logs prior to about the 1960s do not commonly report $R_{mf}$

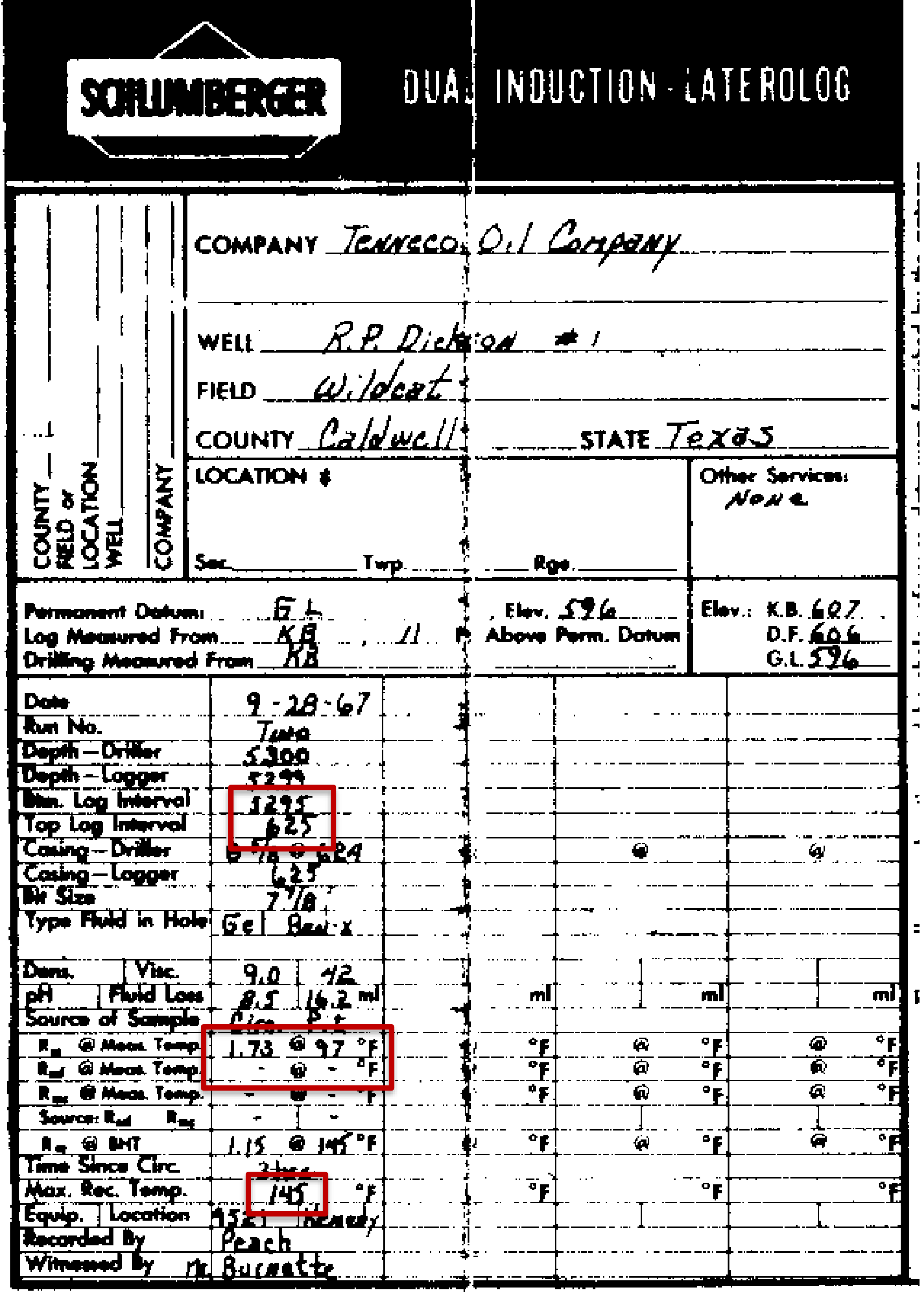


# Solution and Results: $R_m$-$R_{mf}$ relationship

- added log run data to BRACS
- normalized to 75 degrees Fahrenheit
- performed linear regression of $R_{mf75}$ and $R_{m75}$

$$R_{mf75} = 0.9157 \cdot R_{m75} - 0.1446$$





SCHLUMBERGER DUAL INDUCTION - LATEROLOG

COMPANY Tenneco Oil Company

WELL R.P. Dickson #1

FIELD Wildcat

COUNTY Caldwell STATE Texas

LOCATION

Other Services: None

Sec. Twp. Rge.

Permanent Datum: G.L. Elev. 596

Log Measured From KB 11 Ft. Above Perm. Datum

Drilling Measured From KB

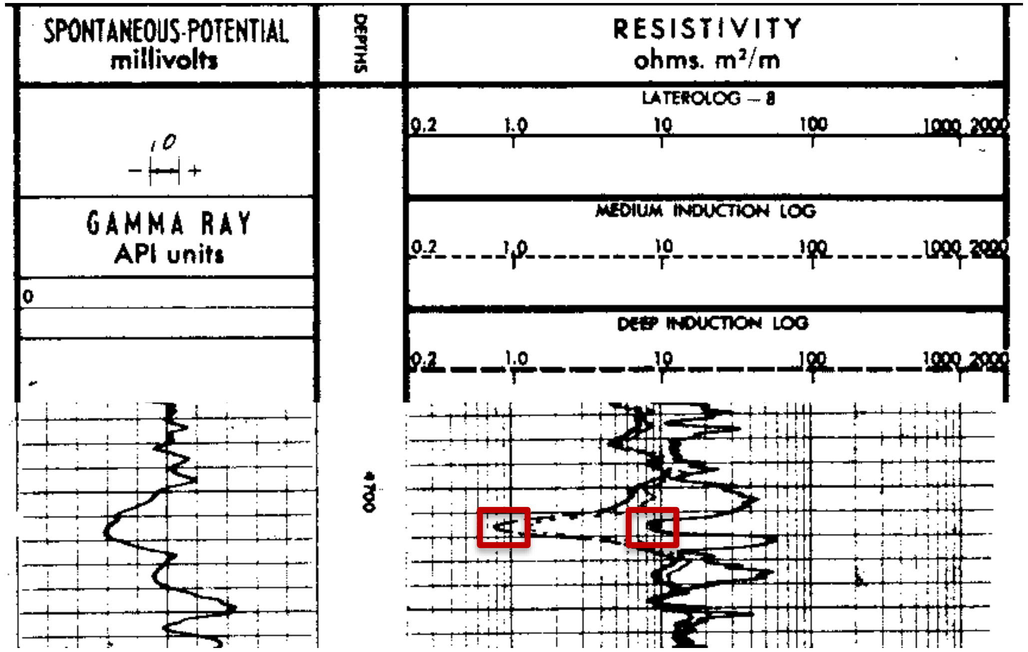
Elev.: K.B. 607 D.F. 606 G.L. 596

| | |
|---|---|
| Date | 9-28-67 |
| Run No. | Two |
| Depth – Driller | 5300 |
| Depth – Logger | 5299 |
| Btm. Log Interval | 5295 |
| Top Log Interval | 625 |
| Casing – Driller | 8 5/8 @ 624 |
| Casing – Logger | 625 |
| Bit Size | 7 7/8 |
| Type Fluid in Hole | Gel Ben-x |
| Dens. / Visc. | 9.0 / 42 |
| pH / Fluid Loss | 8.5 / 16.2 ml |
| Source of Sample | Circ. Pit |
| $R_m$ @ Meas. Temp. | 1.73 @ 97 °F |
| $R_{mf}$ @ Meas. Temp. | - @ - °F |
| $R_{mc}$ @ Meas. Temp. | - @ - °F |
| Source: $R_{mf}$ $R_{mc}$ | - - |
| $R_m$ @ BHT | 1.15 @ 145 °F |
| Time Since Circ. | 2 hrs |
| Max. Rec. Temp. | 145 °F |
| Equip. / Location | 4521 / Kennedy |
| Recorded By | Peach |
| Witnessed By | Mr. Burnette |

# Estimating TDS process summarized

1. Calculate corrected bottom hole temperature: **TBH (corrected) = 162.8**
2. Calculate $R_{mf}$ if not provided: $\mathbf{R_{mf75} = 1.9}$

# Estimating TDS process summarized



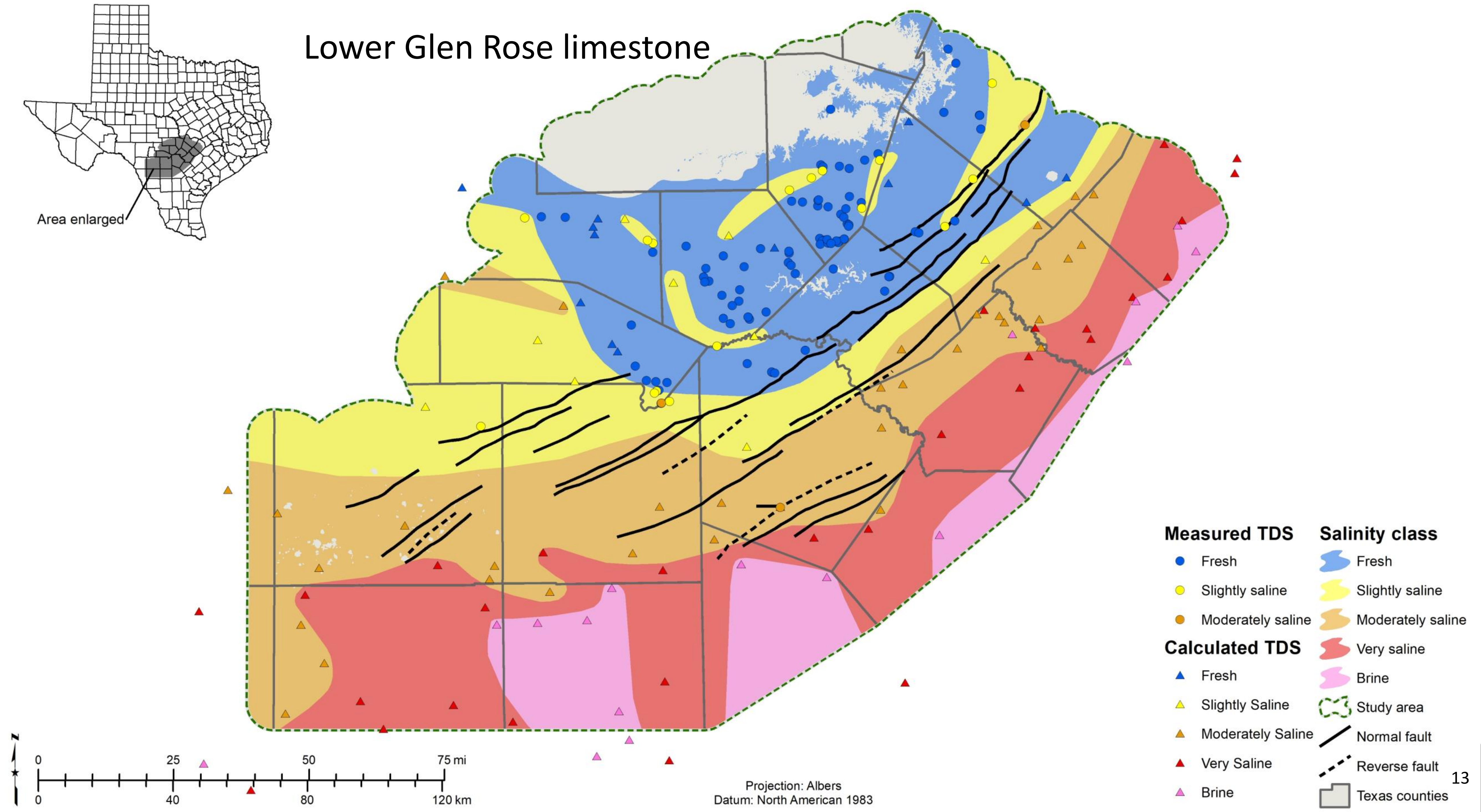

$$R_w = \frac{R_o \cdot R_{mf\_Tf}}{R_{xo}}$$

UG, LG, HE, or CC; $C_w > 15{,}000$

$$TDS = 0.6644 \cdot C_w + 442.87$$

1. Calculate corrected bottom hole temperature: **TBH (corrected) = 162.8**
2. Calculate $R_{mf}$ if not provided: **$R_{mf75}$ = 1.9**
3. Select depth to analyze and read $R_o$ and $R_{xo}$ from log: **$R_o$ = 0.8; $R_{xo}$ = 8**
4. Calculate $R_{mf}$ at calculation depth using geothermal gradient calculated from 30-year average surface temp and corrected bottom hole temp: **$R_{mf\_Tf}$ = 1.03**
5. Calculate $R_w$: **$R_w$ = 0.1**
6. Convert $R_w$ to $R_{w75}$: **$R_{w75}$ = 0.19**
7. Calculate $C_{w75}$ from $R_{w75}$: **$C_{w75}$ = 52631.58**
8. Convert $C_{w75}$ to TDS using formation and $C_w$ range equation: **TDS = 35411**

# Lower Glen Rose limestone



# Conclusions

- direct TDS-$C_w$ relationships more accurately estimate TDS
- PHREEQC can help expand measured water quality dataset by calculating $C_w$
- Estimating $R_{mf75}$ from $R_{m75}$ is useful for older geophysical logs
- Users should be critical of log-reported $R_{mf}$ values when using the Alger-Harrison method
- Users should be critical of historical data
- More saline measured water quality samples (both value and range) will improve TDS-$C_w$ relationships

# Questions?

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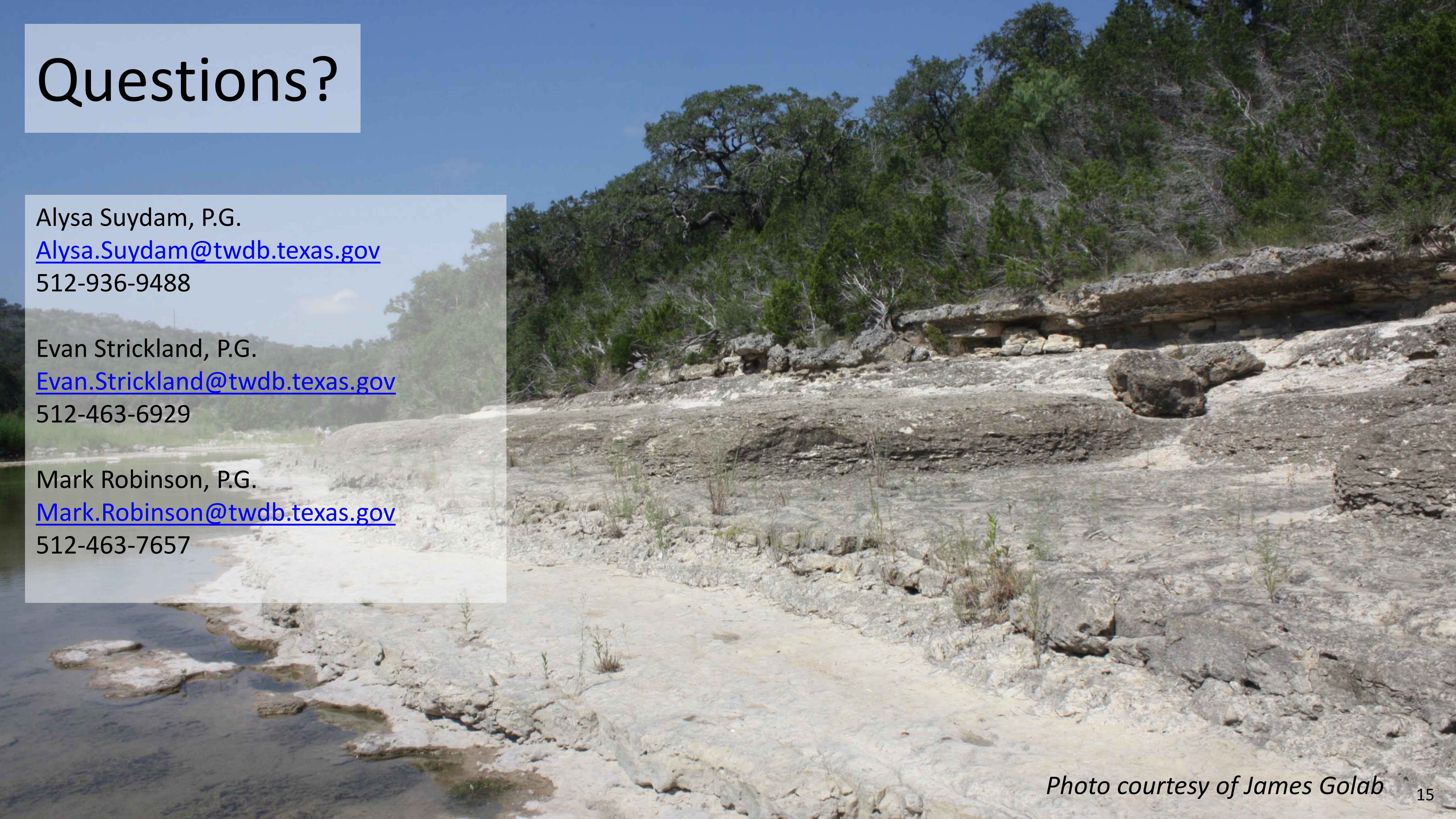

*Photo courtesy of James Golab*

# References


- Alger, R.P., and Harrison, C.W., 1989, Improved fresh water assessment in sand aquifers utilizing geophysical well logs: The Log Analyst, v. 30, no. 1, pp. 31-44.
- Lowe, T.A., and Dunlap, H.F., 1986, Estimation of mud filtrate resistivity in fresh water drilling muds: The Log Analyst, v. 27, no. 2, March-April, pp. 77-84.
- Schlumberger, 2009, Log interpretation charts: Schlumberger, Houston, Texas.
- Winslow, A.G., and Kister, L.R., 1956, Saline-water resources of Texas: U.S. Geological Survey Water-Supply Paper 1365, 105 p.