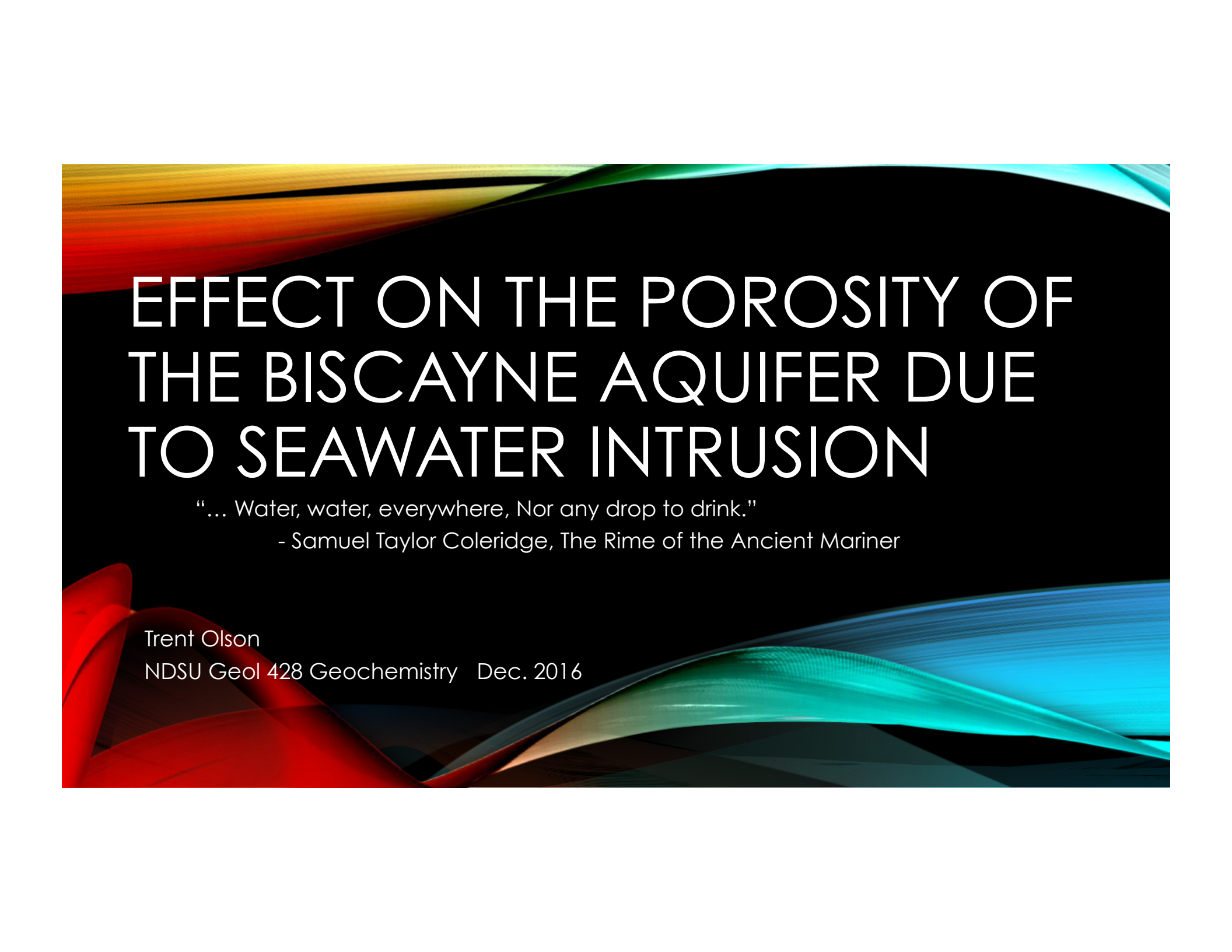




EFFECT ON THE POROSITY OF THE BISCAYNE AQUIFER DUE TO SEAWATER INTRUSION

“... Water, water, everywhere, Nor any drop to drink.”

- Samuel Taylor Coleridge, *The Rime of the Ancient Mariner*

Trent Olson

NDSU Geol 428 Geochemistry Dec. 2016



THE BISCAYNE AQUIFER OVERVIEW

- Located in Southeast Florida
- Provides water for 4 million people
- Sole Source aquifer
- 7770 km²
- Seawater Intrusions very common



GEOLOGY OF THE BISCAYNE AQUIFER

- Miocene to Holocene age siliciclastic and carbonate sediments
- 50 to 82 m thick
- Unconfined aquifer
- Transmissivity of 0.4 to 3.1 m²/s

STRATIGRAPHY OF THE BISCAYNE AQUIFER

- Pamlico sand
- Miami Oolite
- Anastasia Formation
- Key Largo Limestone
- Fort Thompson Formation
- Tamiami Formation

Image Courtesy
of the USGS

Series		Geologic formation or lithostratigraphic unit		Lithology	Hydrogeologic unit	Approximate thickness, in feet		
Holocene to Pliocene	Holocene-age undifferentiated and Pleistocene-age formations ¹			Quartz sand; silt; clay; shell; limestone; sandy shelly limestone	Surficial aquifer system	Biscayne aquifer	200–450	
	Tamiami Formation ²		Stock Island Formation ³	Silt; sandy clay; sandy, shelly limestone; calcareous sandstone; and quartz sand/ planktic foraminiferal limestone		Confining beds		Gray limestone aquifer
Miocene to possibly Late Oligocene	Hawthorn Group	Peace River Formation		Interbedded sand, silt, gravel, clay, carbonate, and phosphatic sand	Intermediate confining unit	Confining unit	500–830	
		Arcadia Formation	Upper	Carbonate mudstone to grainstone; claystone; shell beds; dolomite; phosphatic and quartz sand; silt; and clay				
			Lower	Sandy, molluscan limestone; phosphatic quartz sand, sandstone, and limestone				
Eocene	Middle	Avon Park Formation	Upper	Fossiliferous, lime mudstone to packstone and grainstone; dolomitic limestone; and dolomite; abundant cone-shaped benthic foraminifera	Focus of this study Floridan aquifer system	Upper Floridan aquifer (UFA)	40–350	
						Middle	Upper	150–500
			Lower					Avon Park permeable zone
			Lower				Middle semiconfining unit 2 (MC2)	344–670
	Early	Oldsmar Formation				Lower Floridan aquifer (includes permeable zones and confining units)	1,700–2,000	
						Sub-Floridan confining unit	1,200?	
Paleocene		Cedar Keys Formation	Dolomite and dolomitic limestone					
			Massive anhydrite beds					

¹ Pleistocene-age formations in southeastern Florida (Palmico Sand, Miami Limestone, Anastasia Formation, Fort Thompson Formatt

² Tamiami Formation (Pinecrest Sand Member, Ochopee Limestone Member).

³ Stock Island Formation, after Cunningham and others, 1998.

EXPLANATION

LF1 Uppermost permeable zone of the Lower Floridan aquifer

¹ Pleistocene-age formations in southeastern Florida (Pamlico Sand, Miami Limestone, Anastasia Formation, Fort Thompson Formation)

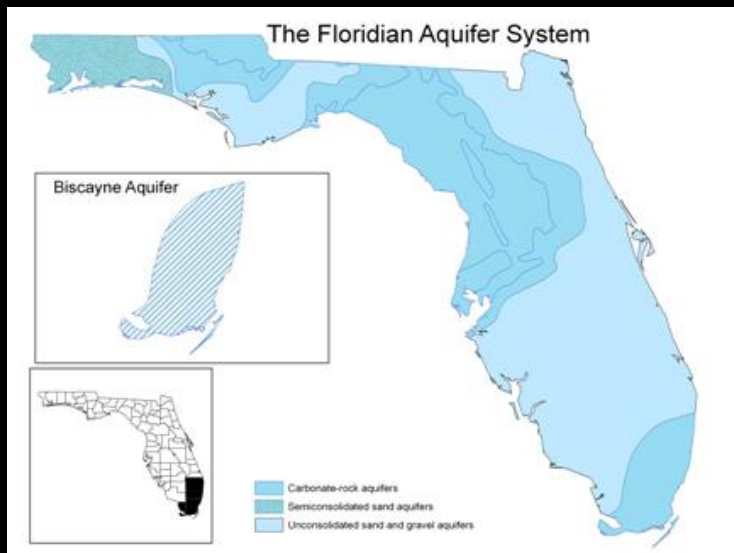
² Tamiami Formation (Pinecrest Sand Member, Ochopee Limestone Member).

³ Stock Island Formation, after Cunningham and others, 1998.

EXPLANATION

LF1 Uppermost major permeable zone of the Lower Floridan aquifer

LOCATION OF THE SEAWATER INTRUSION IN THE BISCAYNE AQUIFER

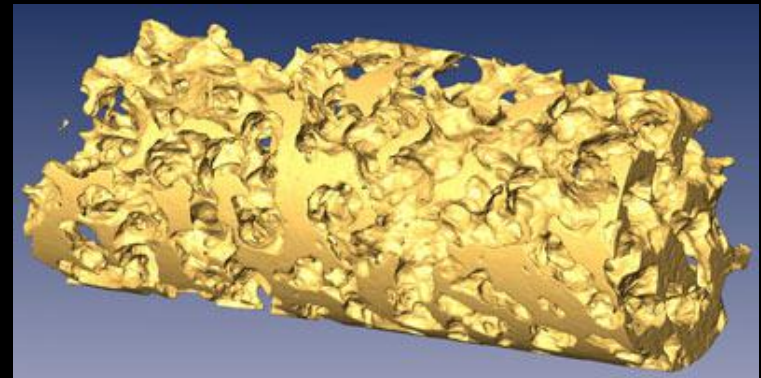


Habtemichael, Y. T. and Fuentes, H. R.

Base maps are from South Florida Water Management District, Miami-Dade County, USGS and ESRI digital data

POROSITY AND PERMEABILITY

- Porosity Method:
 - Whole core measurement: 5.0 to 60% porosity
 - GPR on Miami Limestone: 40% to 50% porosity
- Permeability Method:
 - LBM $10^{4.18}$ to $10^{7.43}$ darcys



CT-scan of a core from an unspecified unit of limestone. Florea, Lee, through the USGS.



GROUNDWATER SAMPLING METHOD

- 34 monitoring sites used by Prinos, et al. (2014)
- Submersible pump, suction pump, and kenmerer water sampler
- Depths of 23.2 m to 61 m
- Sampled every 1.5 m
- Data collected from July to September used to constrain data
- Wells within 8.5km of Turkey Point Nuclear Plant's cooling canals excluded
- Data containing sewage markers exluded

WATER ANALYSIS OF SELECTED WELLS

Table 1 Water quality of wells selected in the study

Sample	Well depth (m)	Sample interval (m)	Temperature °C	PH	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cl mg/L	SO ₄ mg/L	Alkalinity as CaCO ₃ mg/L	% SW ^a
G-3606	36.6	1.5	26.0	6.99	104	2.7	25.7	1.03	36.3	19.4	238	0.0
G-894	23.2	0.5	25.8	7.25	80	2.7	13	1.21	18.4	28.8	165	0.1
G-3600	61.0	1.5	25.5	6.95	487	1120	7820	312	15,400	1910	258	81.0
G-3601	57.9	1.5	24.6	6.85	165	61.4	676	16.3	1350	121	255	6.9
G-3602	48.8	1.5	25.3	6.90	264	199	1990	50.4	4050	423	256	21.2
G-3604	36.6	1.5	26.2	7.09	224	312	2600	87.9	5330	643	219	27.9
G-3605	33.5	1.5	26.7	6.93	182	90.5	955	26.1	1940	232	226	10.0
G-3611	30.5	1.5	25.3	7.08	97	4.8	88.3	2.52	175	24.2	192	0.7
G-3615	24.4	1.5	25.3	6.76	264	58.3	768	11.2	1780	111	180	9.2
G-3701	25.3	1.5	25.1	7.06	132	14.2	244	2.02	566	34.7	162	2.8
G-901	29.3	0.4	25.6	7.04	273	121	1200	19.2	2590	206	167	13.5

Data are extracted from Prinos et al. (2014)

^a %SW is seawater fraction in the sample calculated based on its chloride concentration

COMPOSITE WATER ANALYSIS

- Freshwater(FW) is an average of the selected data sets.
- Seawater(SW) is an average calculated by Hem (1985)
- pH 8 selected for SW to mirror Biscayne Bay.

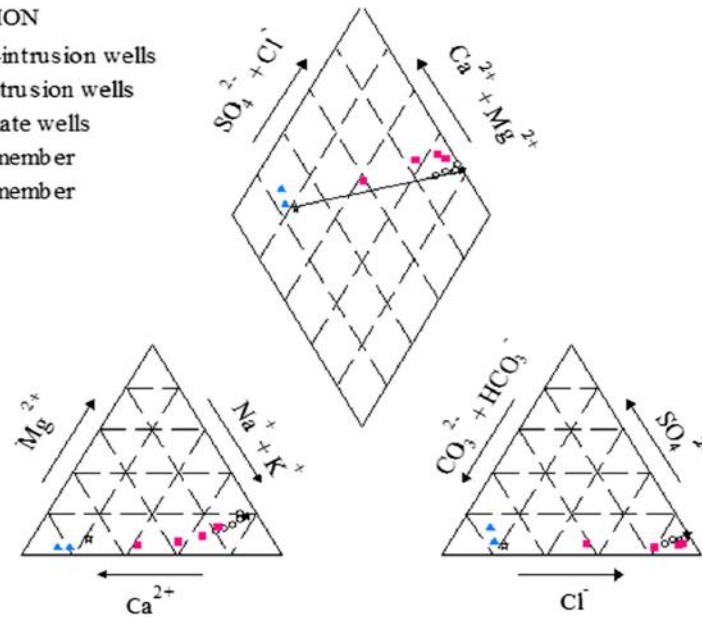
Table 2 Temperature (T) and chemical compositions of the freshwater and saltwater end members used in modeling (Hem 1985)

	T (°C)	PH	Cl ⁻ mg/L	SO ₄ ²⁻ mg/L	Ca ²⁺ mg/L	Na ⁺ mg/L	Mg ²⁺ mg/L	K ⁺ mg/L	HCO ₃ ⁻ mg/L	Log(pCO ₂)
FW	28.5	7.4	39	11.6	75.4	24.9	5.3	3.6	234.2	-1.69
SW	25.0	8.0	19,000	2700	410	10,500	1350	390	66.6	-3.13

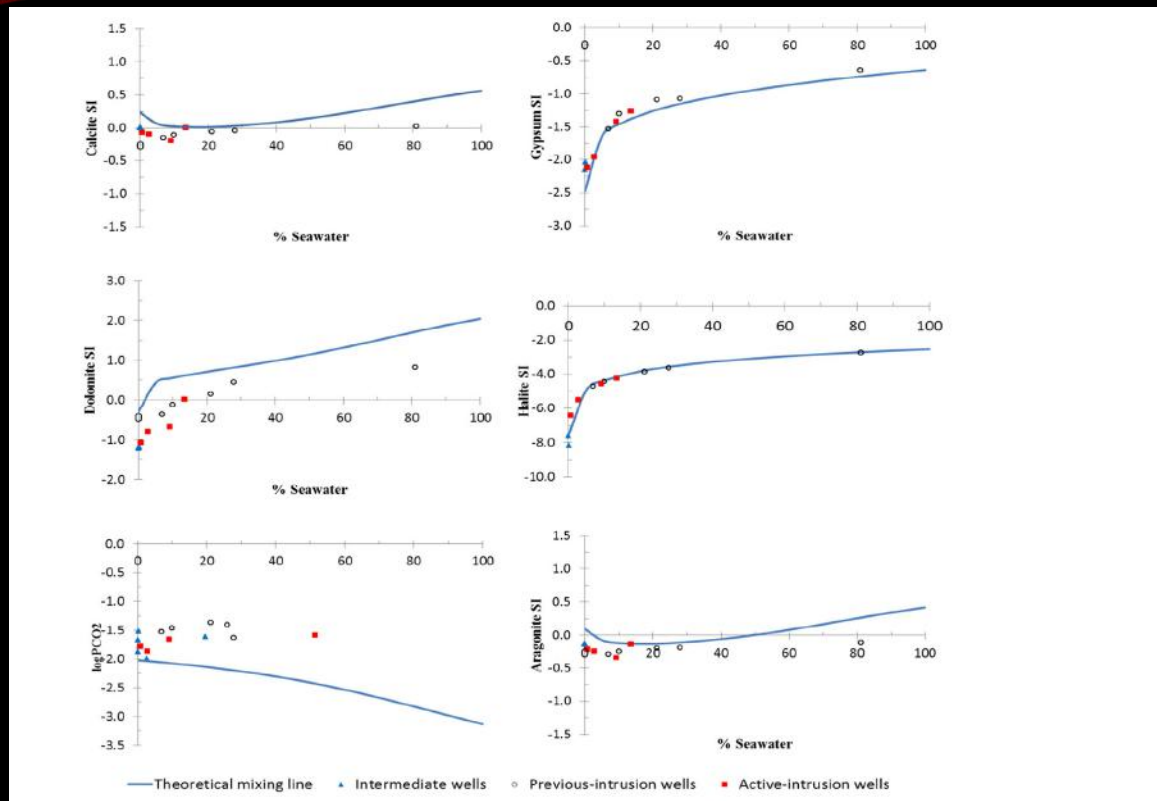
PIPER DIAGRAM

EXPLANATION

- Previous-intrusion wells
- Active-intrusion wells
- ▲ Intermediate wells
- * FW end member
- ★ SW end member



SI OF VARIOUS MINERALS



Habtemichael, Y. T. and Fuentes, H. R. 2016, page 204



GEOCHEMICAL ANALYSIS METHODS

- Input composite solutions into Phreeqc
- Mix the Solutions at a 20% FW to 80% SW to replicate the greatest seawater intrusion extent observed for trial 1.
- Trial 2 and 3 were individual analysis of sampling wells.
- Equilibrate the mix solution for calcium bearing minerals to determine changes in quantities in solution

OUTPUT OF MIXED SOLUTION – TRAIL 1

Phase	SI	Log IAP	Log K(298, 1 atm)	Formula
Anhydrite	-1.02	-5.31	-4.29	CaSO ₄
Aragonite	-0.56	-8.91	-8.34	CaCO ₃
Calcite	-0.42	-8.91	-8.48	CaCO ₃
Dolomite	0.05	-17.06	-17.11	CaMg(CO ₃) ₂
Gypsum	-0.74	-5.32	-4.58	CaSO ₄ * 2H ₂ O
Halite	-2.69	-1.11	1.57	NaCl

EQUILIBRIUM PHASES – TRIAL 1

Precipitation only

Phase	SI	Log IAP	Log K	Initial	Final	Grams
Aragonite	-0.59	-8.93	-8.34	0 mol	0 mol	0 g
Calcite	-0.45	-8.93	-8.48	0 mol	0 mol	0 g
Dolomite	0.00	-17.11	-17.11	0 mol	1.45E-4 mol	2.7E-4 g
Gypsum	-0.75	-5.33	-4.58	0 mol	0 mol	0 g

SELECTED OUTPUT - TRAIL 2

Well G-3600

Phase	SI	Log IAP	Log K(298, 1 atm)	Formula
Anhydrite	-0.93	-5.22	-4.29	CaSO ₄
Aragonite	-0.24	-8.58	-8.34	CaCO ₃
Calcite	-0.09	-8.58	-8.48	CaCO ₃
Dolomite	0.57	-16.54	-17.11	CaMg(CO ₃) ₂
Gypsum	-0.65	-5.23	-4.58	CaSO ₄ * 2H ₂ O
Halite	-2.72	-1.15	1.57	NaCl

EQUILIBRIUM PHASE – TRIAL 2

Precipitation only

Phase	SI	Log IAP	Log K	Initial	Final	grams
Aragonite	-0.52	-8.86	-8.34	0 mol	0 mol	0 g
Calcite	-0.38	-8.86	-8.34	0 mol	0 mol	0 g
Dolomite	0.00	-17.11	-17.11	0 mol	1.22E-4 mol	2.23E-2 g
Gypsum	-0.65	-5.23	-4.58	0 mol	0 mol	0 g

SELECTED OUTPUT – TRAIL 3

Increased HCO_3^- concentration

Phase	SI	Log IAP	Log K(298, 1 atm)	Formula
Anhydrite	-0.94	-5.22	-4.29	CaSO_4
Aragonite	0.07	-8.27	-8.34	CaCO_3
Calcite	0.21	-8.27	-8.48	CaCO_3
Dolomite	1.18	-15.92	-17.11	$\text{CaMg}(\text{CO}_3)_2$
Gypsum	-0.65	-5.23	-4.58	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$
Halite	-2.72	-1.15	1.57	NaCl

EQUILIBRIUM PHASES – TRIAL 3

Phase	SI	Log IAP	Log K	Initial	Final	Grams
Aragonite	-0.53	-8.87	-8.34	0 mol	0 mol	0 g
Calcite	-0.38	-8.87	-8.48	0 mol	0 mol	0 g
Dolomite	0.00	-17.11	-17.11	0 mol	5.5E-4 mol	0.10 g
Gypsum	-0.67	-5.25	-4.58	0 mol	0 mol	0 g



REFERENCES

- Habtemichael, Y. T. and Fuentes, H. R., 2016. Hydrogeochemical Analysis of Processes Through Modeling of Seawater Intrusion Impacts in Biscayne Aquifer Water Quality, USA. *Aquatic Geochemistry*: v. 22, p. 197-209
- Mount, G. J., and Comas X., 2014. Estimating porosity and solid dielectric permittivity in the Miami Limestone using high-frequency ground penetrating radar (GPR) measurements at the laboratory scale, *Water Resour. Res.*, 50, 7590–7605