# 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

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# THE BISCAYNE AQUIFER OVERVIEW

- Located in Southeast Florida
- Provides water for 4 million people
- Sole Source aquifer
- 7770 $km^2$
- 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 $m^2/s$

# STRATIGRAPHY OF THE BISCAYNE AQUIFER

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

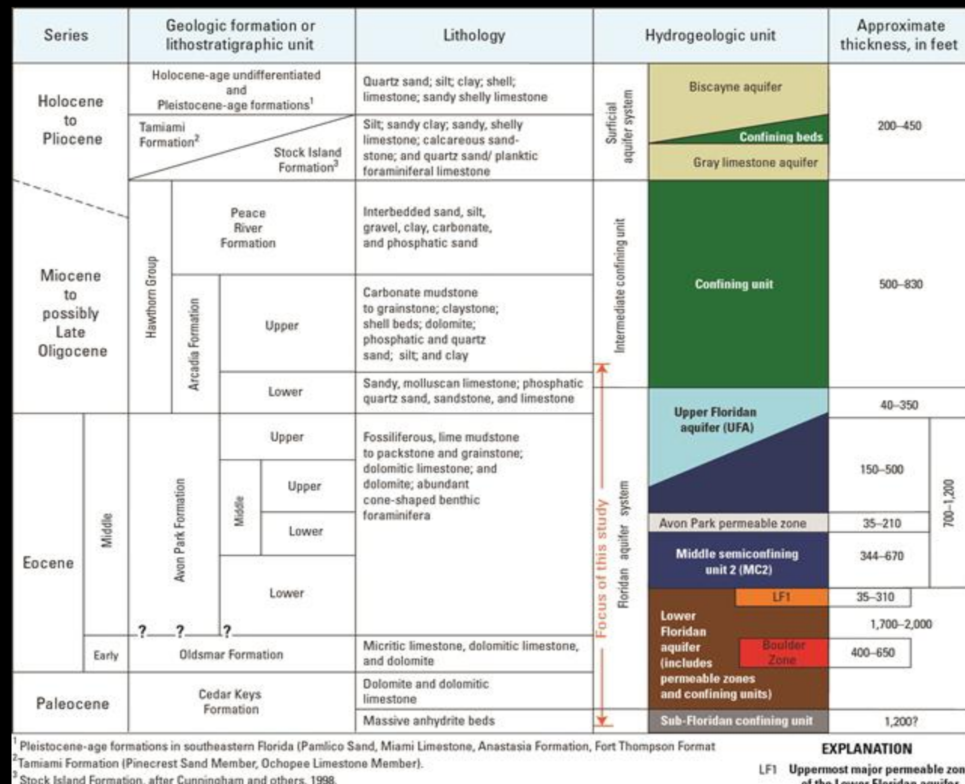
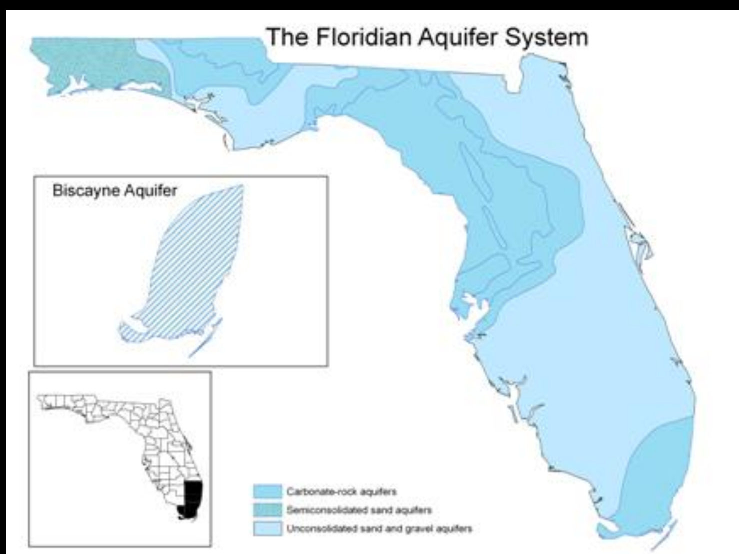
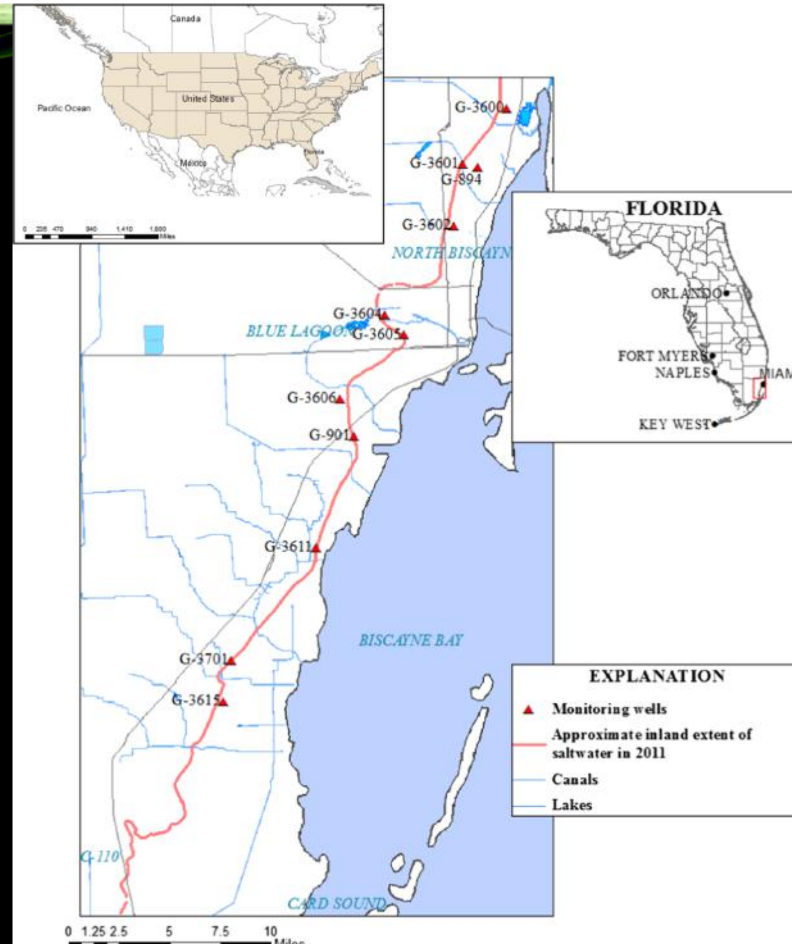



Image Courtesy of the USGS

# LOCATION OF THE SEAWATER INTRUSION IN THE BISCAYNE AQUIFER

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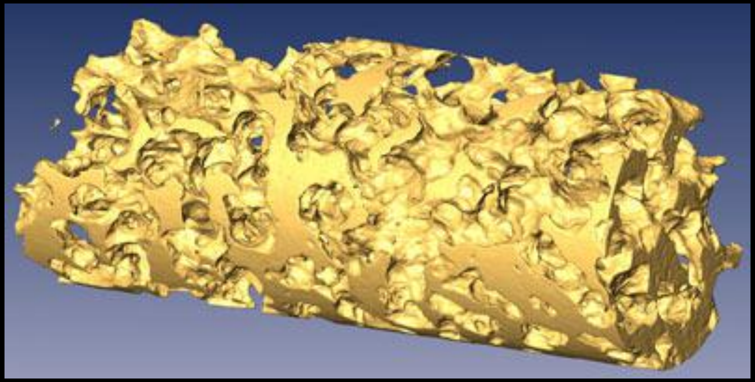
Base maps are from South Florida Water Management District, Miami-Dade County, USGS and ESRI digital data

# 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.

Mount, G. J., and Comas X., 2014

# 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

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# 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 |

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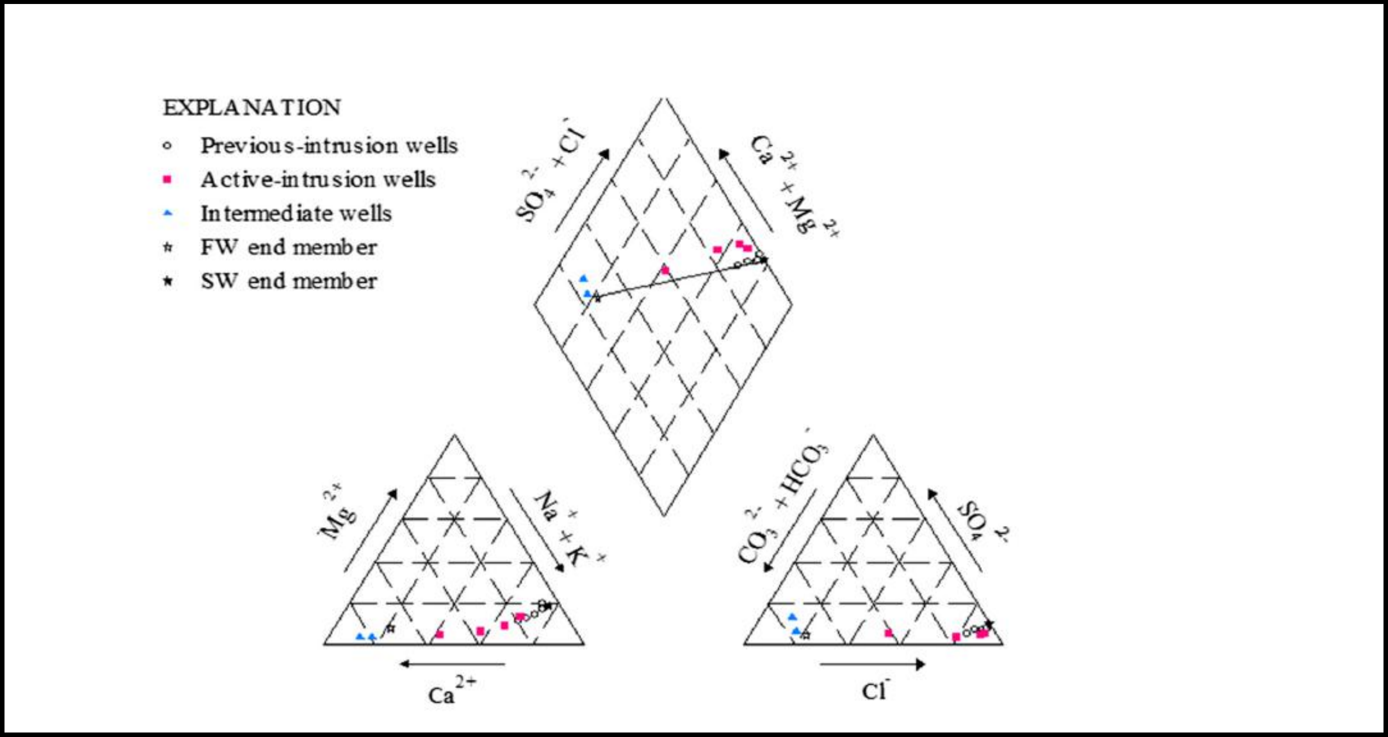
# PIPER DIAGRAM

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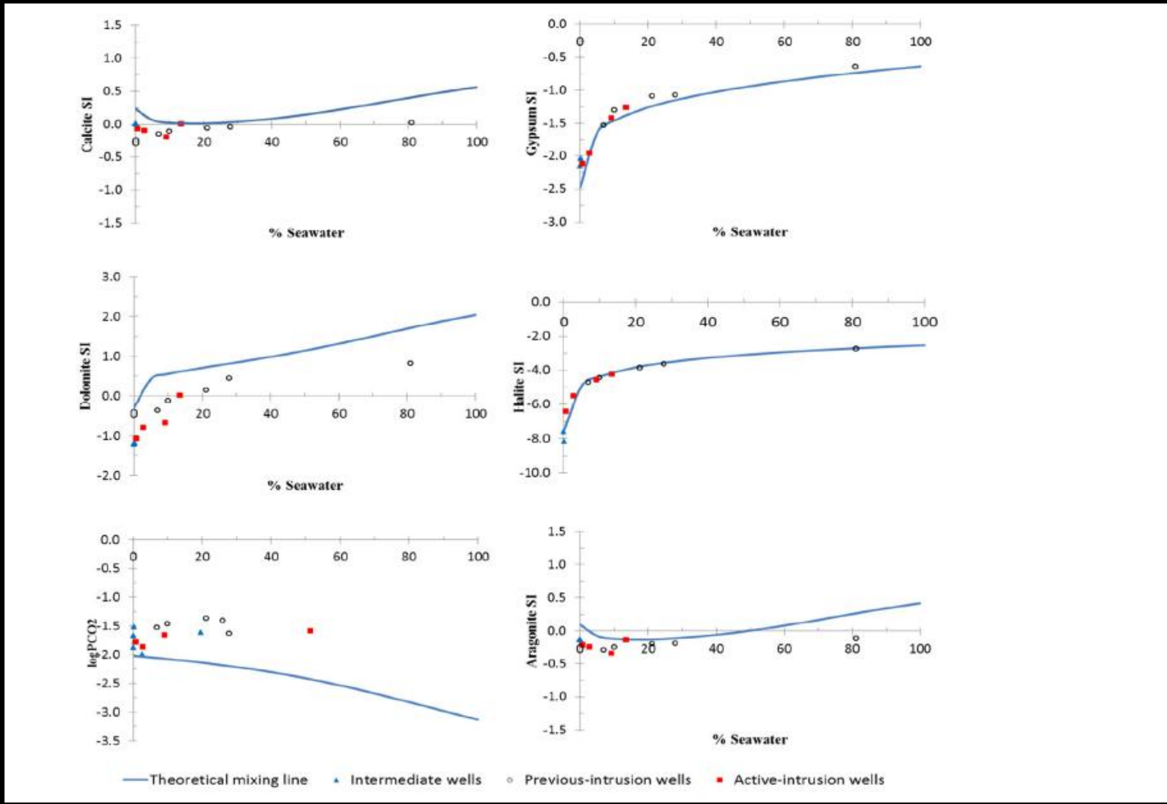
# SI OF VARIOUS MINERALS

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# 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 | CaSO4 |
| Aragonite | -0.56 | -8.91 | -8.34 | CaCO3 |
| Calcite | -0.42 | -8.91 | -8.48 | CaCO3 |
| Dolomite | 0.05 | -17.06 | -17.11 | CaMg(CO3)2 |
| Gypsum | -0.74 | -5.32 | -4.58 | CaSO4 * 2H20 |
| 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 | CaSO4 |
| Aragonite | -0.24 | -8.58 | -8.34 | CaCO3 |
| Calcite | -0.09 | -8.58 | -8.48 | CaCO3 |
| Dolomite | 0.57 | -16.54 | -17.11 | CaMg(CO3)2 |
| Gypsum | -0.65 | -5.23 | -4.58 | CaSO4 * 2H20 |
| 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 | CaSO4 |
| Aragonite | 0.07 | -8.27 | -8.34 | CaCO3 |
| Calcite | 0.21 | -8.27 | -8.48 | CaCO3 |
| Dolomite | 1.18 | -15.92 | -17.11 | CaMg(CO3)2 |
| Gypsum | -0.65 | -5.23 | -4.58 | CaSO4 * 2H20 |
| 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