NURE Legacy Groundwater Data: Evaluation of Basin-Scale Factors Influencing Shallow Brine and Halite Groundwater Impacts

Presented by:

Garth T. Llewellyn, PG, LSRP

Appalachia Hydrogeologic & Environmental Consulting, LLC

Presentation Outline

Background

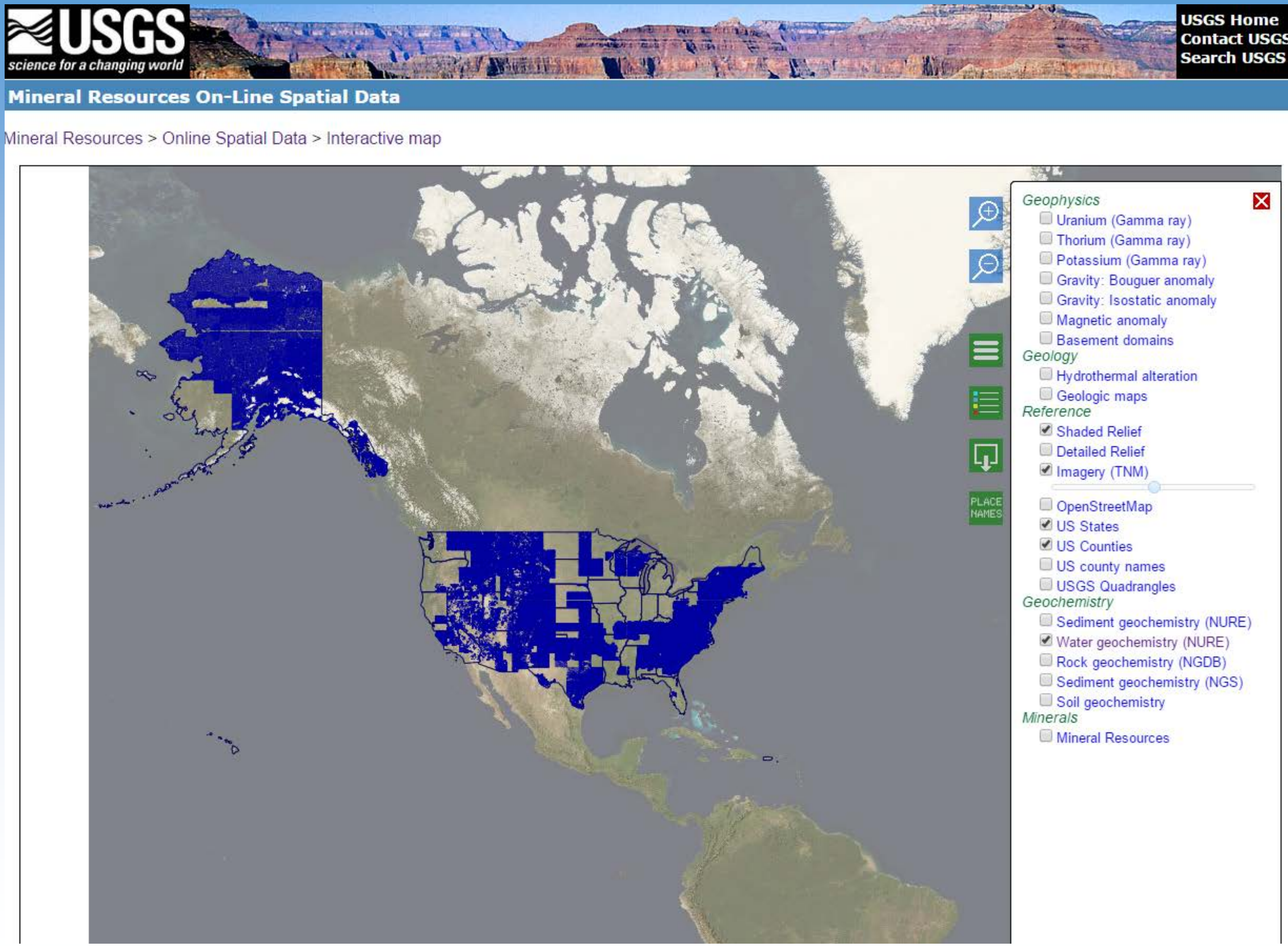
- What is the NURE dataset and why is it useful?
- Halite Deposits…What can they tell us?
- Theories for broad-scale fluid migration in the Appalachian Basin.

NURE Data Geospatial and Statistical Evaluation

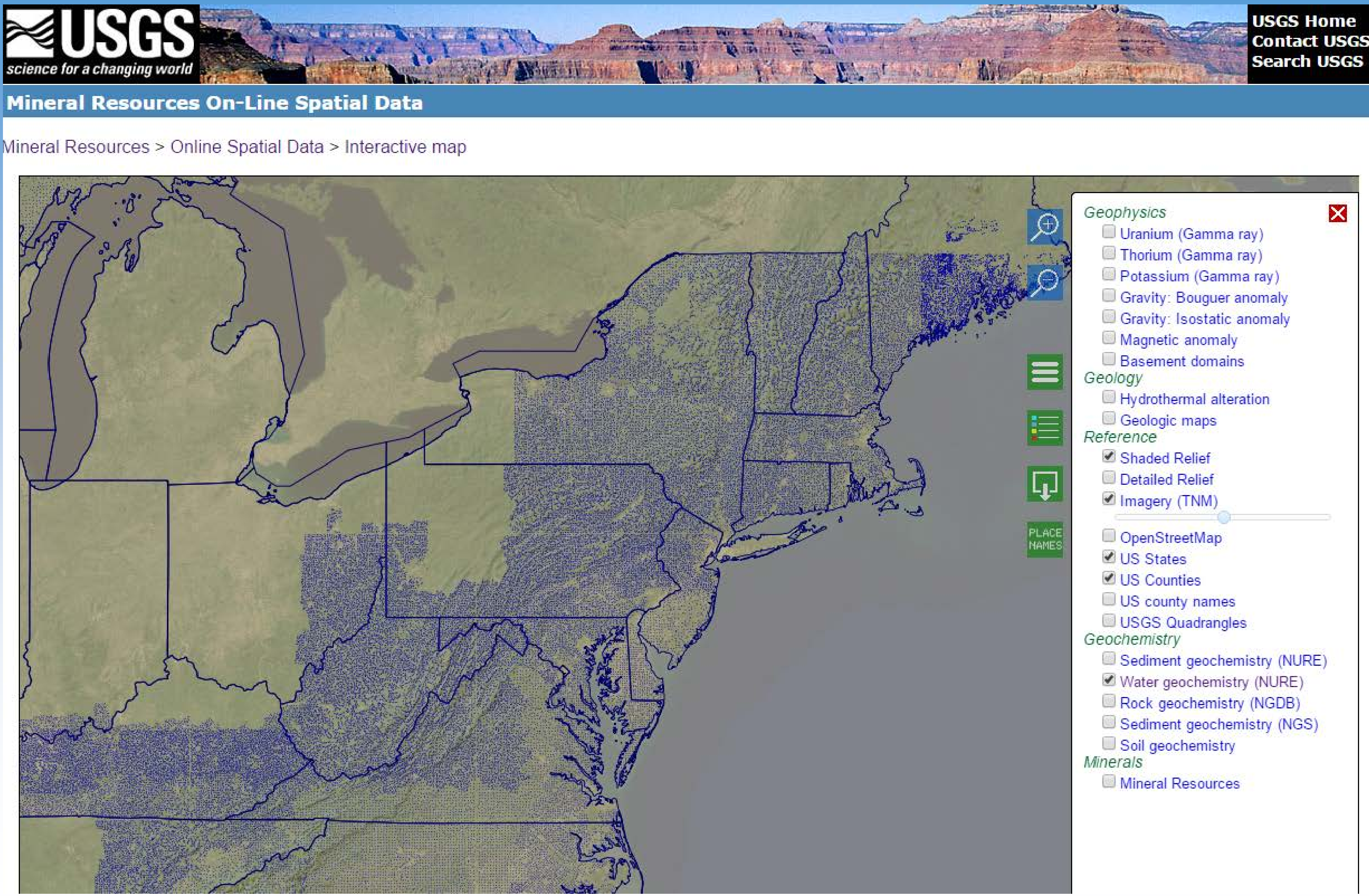
- Distinguishing Cl sources using Cl/Br ratios.
- Incremental Spatial Autocorrelation
- Geospatial Exploratory Analyses
- Basin-scale Cl signature correlations

Significance

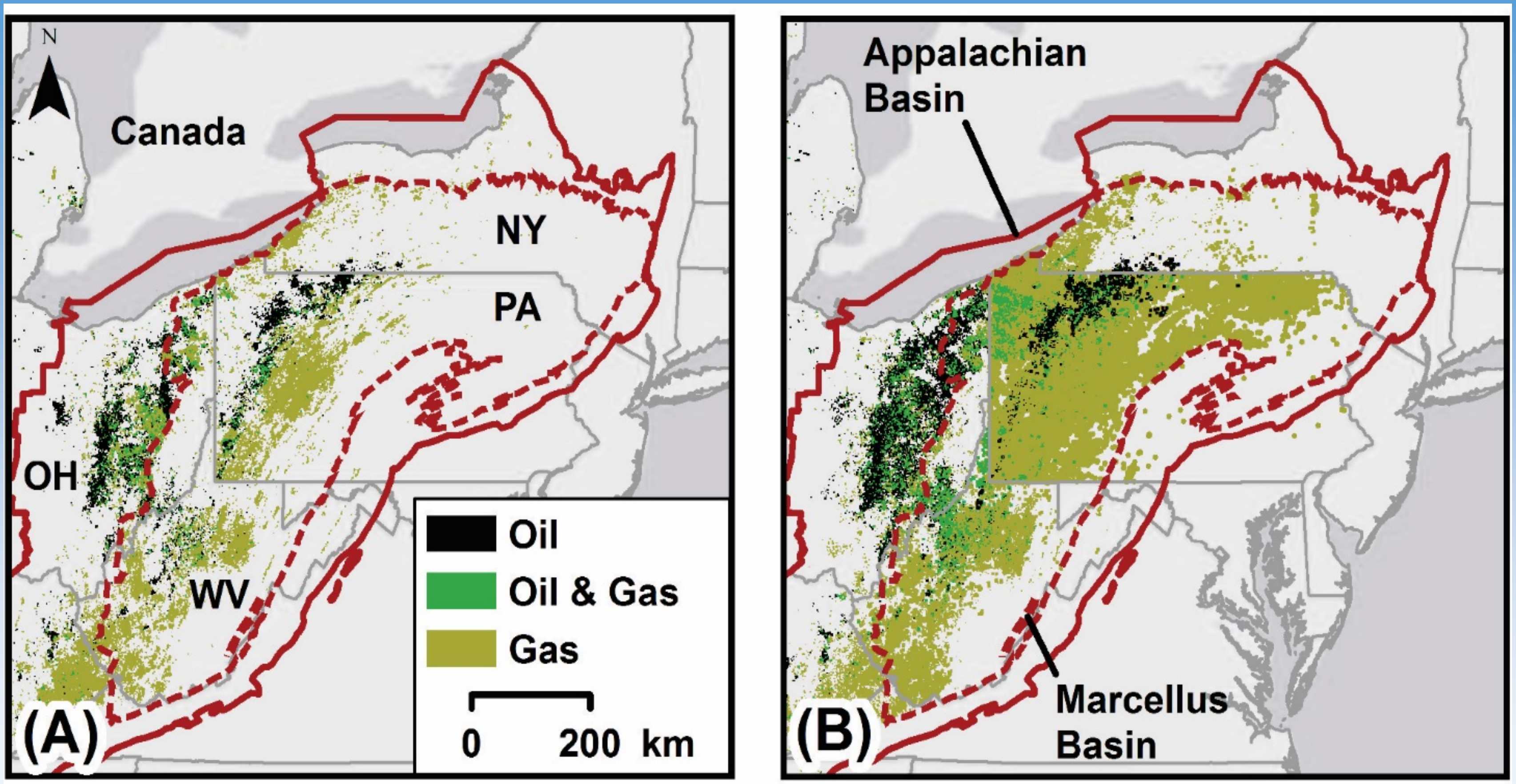
National Uranium Resource Evaluation (NURE)



National Uranium Resource Evaluation (NURE)



Oil & Gas Drilling Development



Oil and gas drilling development in New York, Ohio, Pennsylvania and West Virginia (A) pre-1900s - 1980 and (B) 1981 – 2014. NURE sample collection spanned from 1977 to 1980. Oil and gas drilling development compiled from Biewick (2008) and PADEP (2014).

Presentation Outline

Background

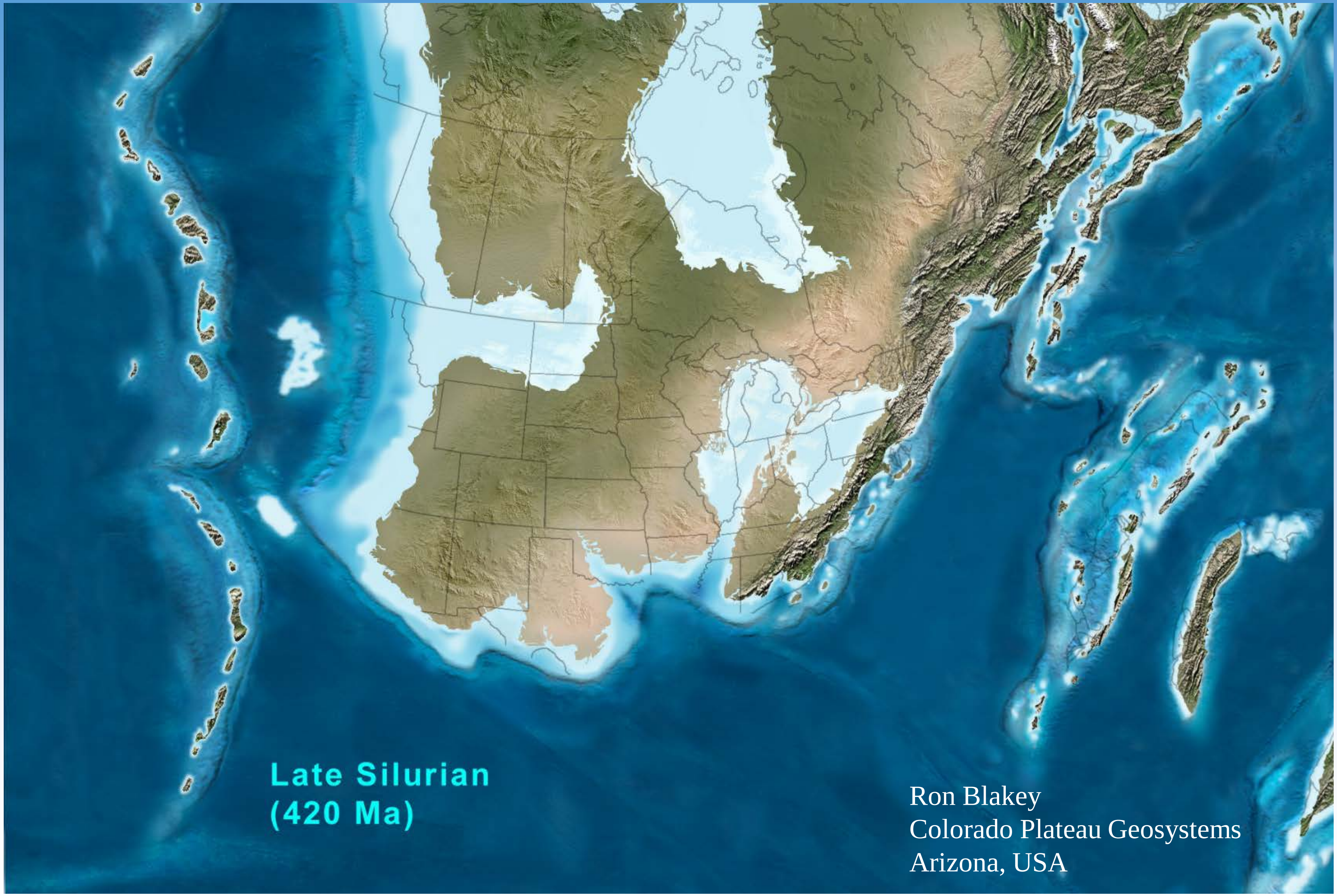
- What is the NURE dataset and why is it useful?
- Halite Deposits…What can they tell us?
- Theories for broad-scale fluid migration in the Appalachian Basin.

NURE Data Geospatial and Statistical Evaluation

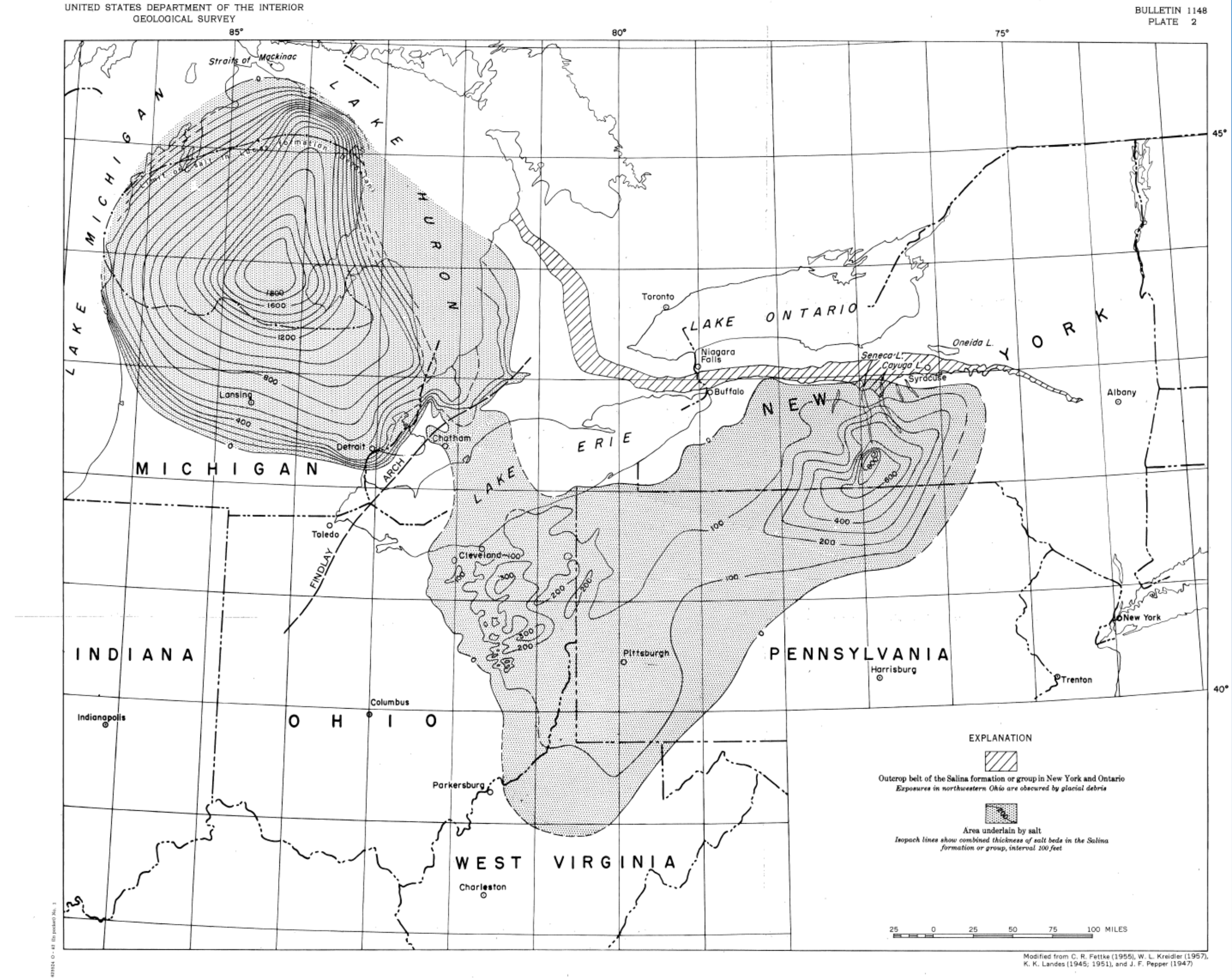
- Distinguishing Cl sources using Cl/Br ratios.
- Incremental Spatial Autocorrelation
- Geospatial Exploratory Analyses
- Basin-scale Cl signature correlations

Significance

Seawater Evaporation

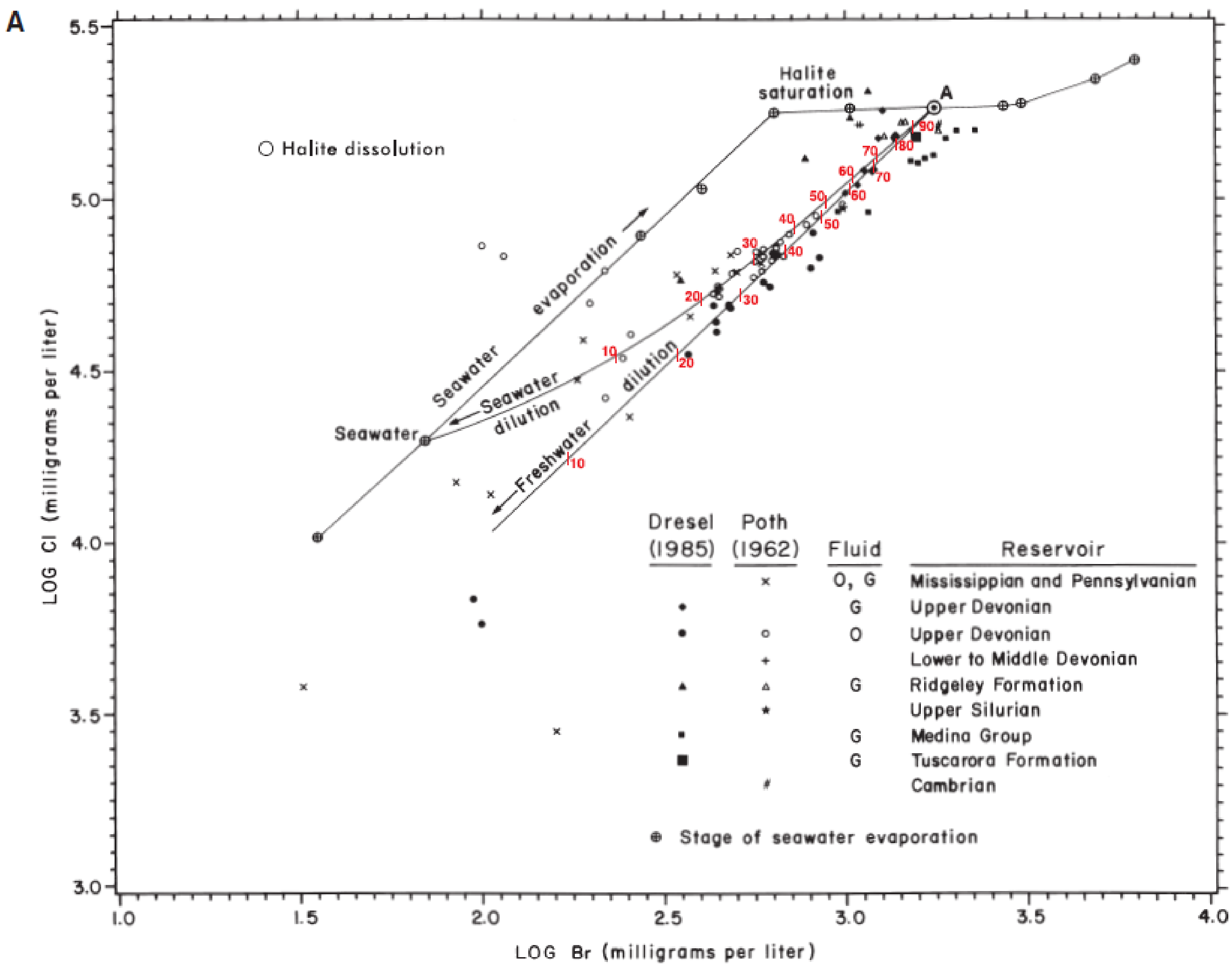


Principal Halite Deposits (Pierce & Rich, 1962)



MAP SHOWING AGGREGATE THICKNESS OF SALT BEDS IN THE SALINA FORMATION OR GROUP

Seawater Evaporation



Plots of log Cl versus log Br and log MCl_2 (see text for definition) for samples of Dresel (1985) and Poth (1962). Lines are plots of these components for seawater evaporation and for dilution of composition A with freshwater and seawater. The red numbers on these curves are percent of A, which has the following composition: Cl = 177,830 mg/L, Br = 1,700, Na = 78,500, Ca = 31,600, Mg = 3,390, and K = 320; MCl_2 = 1,800 meq/L. A. Plot of log Cl versus log Br. The point labeled “halite dissolution” is the Br:Cl ratio resulting from post-depositional dissolution of halite in low-salinity water. B. Similar plot for log Cl versus log MCl_2.

Presentation Outline

Background

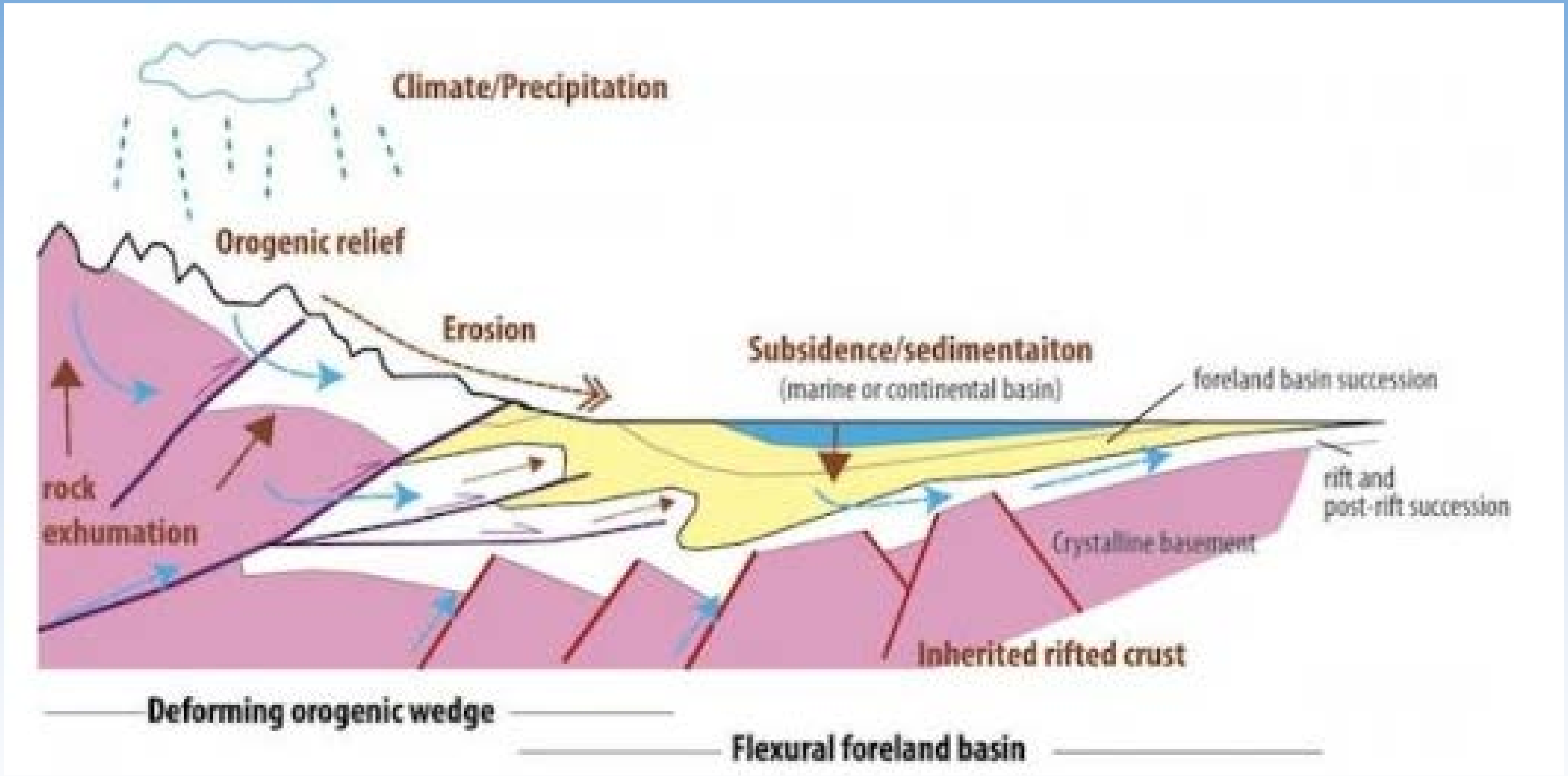
- What is the NURE dataset and why is it useful?
- Halite Deposits…What can they tell us?
- Theories for broad-scale fluid migration in the Appalachian Basin.

NURE Data Geospatial and Statistical Evaluation

- Distinguishing Cl sources using Cl/Br ratios.
- Incremental Spatial Autocorrelation
- Geospatial Exploratory Analyses
- Basin-scale Cl signature correlations

Significance

Basin Fluid-Flow Mechanisms – Sediment Compaction Drive



Basin Fluid-Flow Mechanisms – Gravity Drive

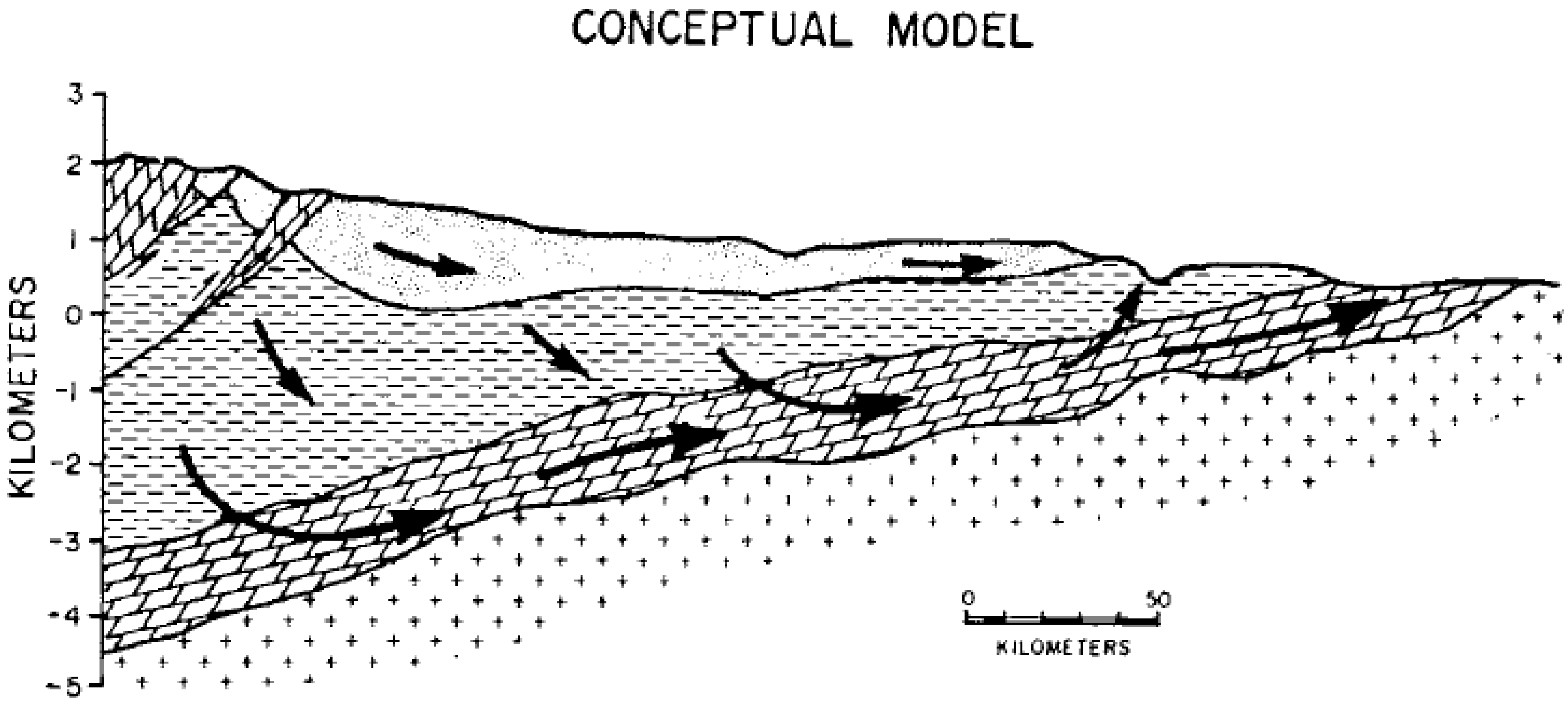


Fig. 3. Conceptual model of gravity-driven fluid flow in sedimentary basins. The driving mechanism for flow is the sloping water table which is assumed to be a subdued replica of the topography. The water-table configuration and the subsurface permeability distribution control the geometry of the flow system.

Garven & Freeze, 1984

Basin Fluid-Flow Mechanisms – Thrust-Induced or Tectonic Drive

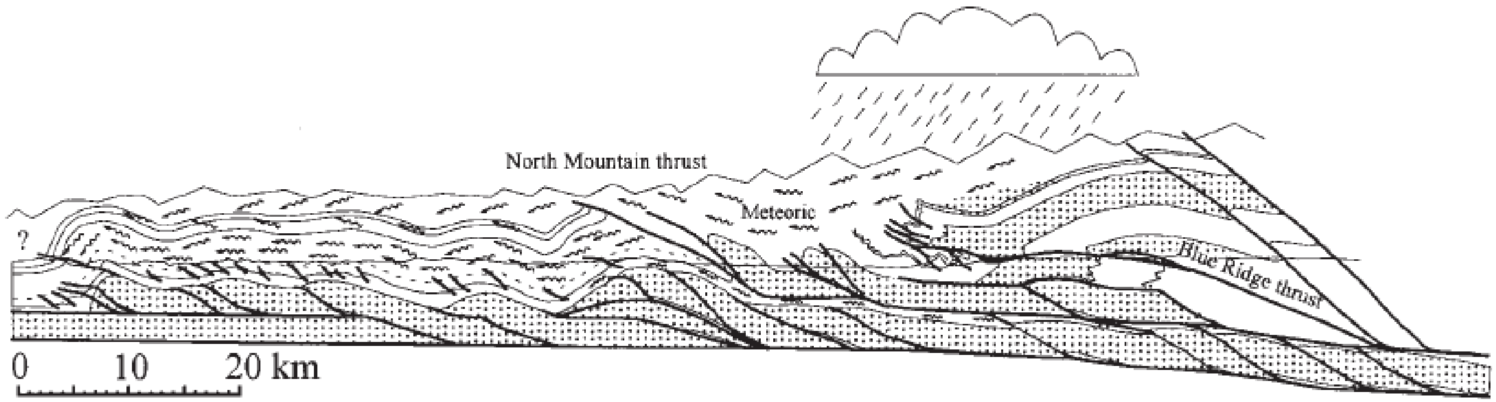


Figure 16. Regional cross section based on A–A′ in Figure 1B and Evans (1989), showing hypothetical topography immediately after emplacement of Blue Ridge thrust sheet. Wavy lines with arrowhead are used to depict relative flow of synorogenic migrating fluids and interformational mixing.

Evans & Battles, 1999

Presentation Outline

Background

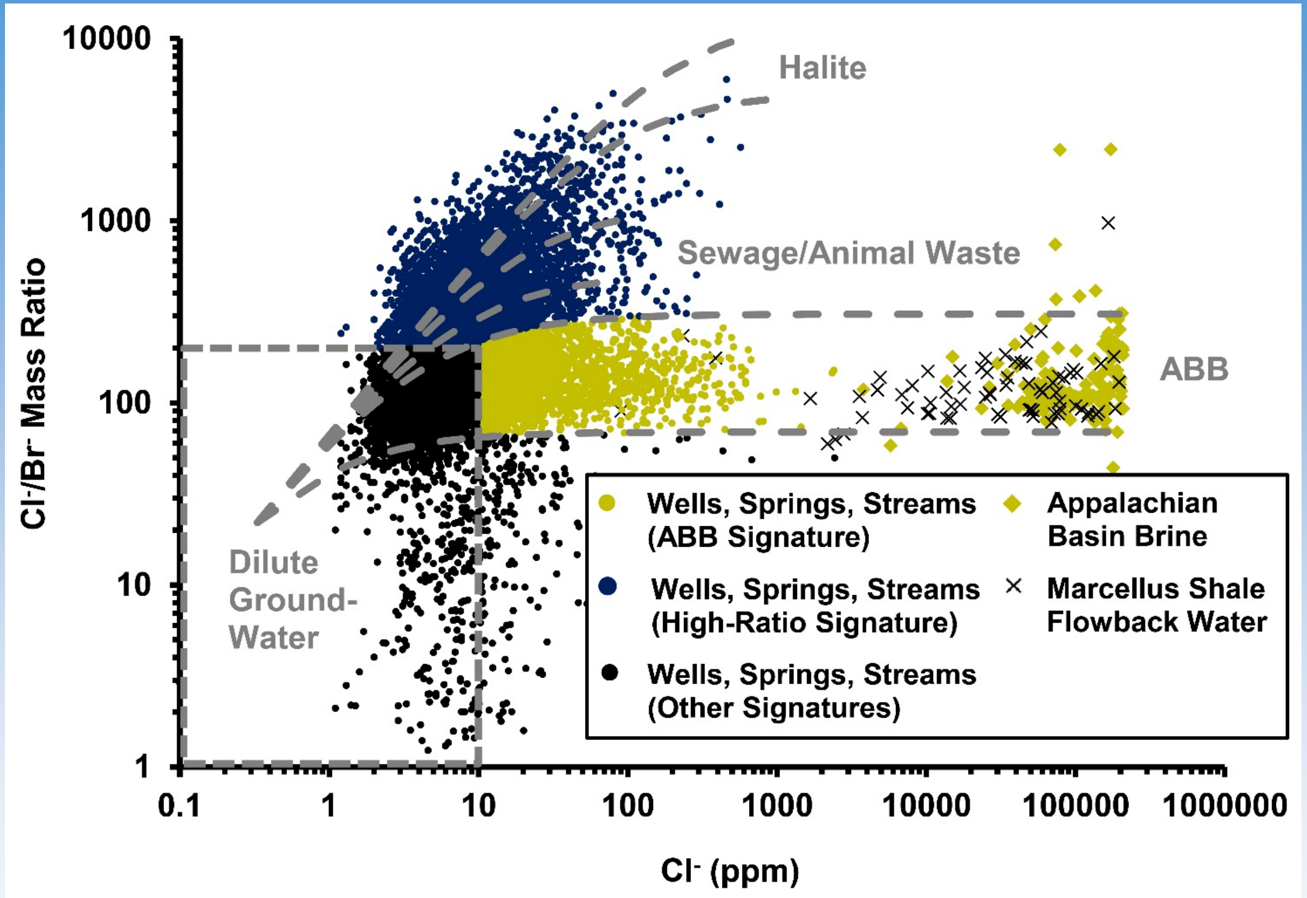
- What is the NURE dataset and why is it useful?
- Halite Deposits…What can they tell us?
- Theories for broad-scale fluid migration in the Appalachian Basin.

NURE Data Geospatial and Statistical Evaluation

- Distinguishing Cl sources using Cl/Br ratios.
- Incremental Spatial Autocorrelation
- Geospatial Exploratory Analyses
- Basin-scale Cl signature correlations

Significance

Distinguishing Cl Sources Using Cl/Br Ratios



Cross-plot of Cl/Br mass ratio vs. Cl^- for NURE data and conservative end-member mixing curves. Dilute groundwater end-member: Cl^-: 0.33, Br^-: 0.015, (Mullaney et al. 2009). Halite upper mixing curve end-member: Cl^-: 20,000, Br^-: 1.482, (Panno et al. 2006, Mullaney et al. 2009). Halite lower mixing curve end-member: Cl^-: 20,000, Br^-: 4, (Granato 1996, Mullaney et al. 2009). Brine upper mixing curve end-member: Cl^-: 196,389, Br^-: 640, (Kelley et al. 1973). Brine lower mixing curve end-member: Cl^-: 190,808, Br^-: 2,760, (Kelley et al. 1973). All units in ppm. Appalachia Basin brine samples from Poth 1962, Kelley et al. 1973, Dresel 1985 and Osborn and McIntosh 2010. Marcellus Shale flowback water samples from Hayes 2009, PADEP 2010 and PADEP 2011.

Presentation Outline

Background

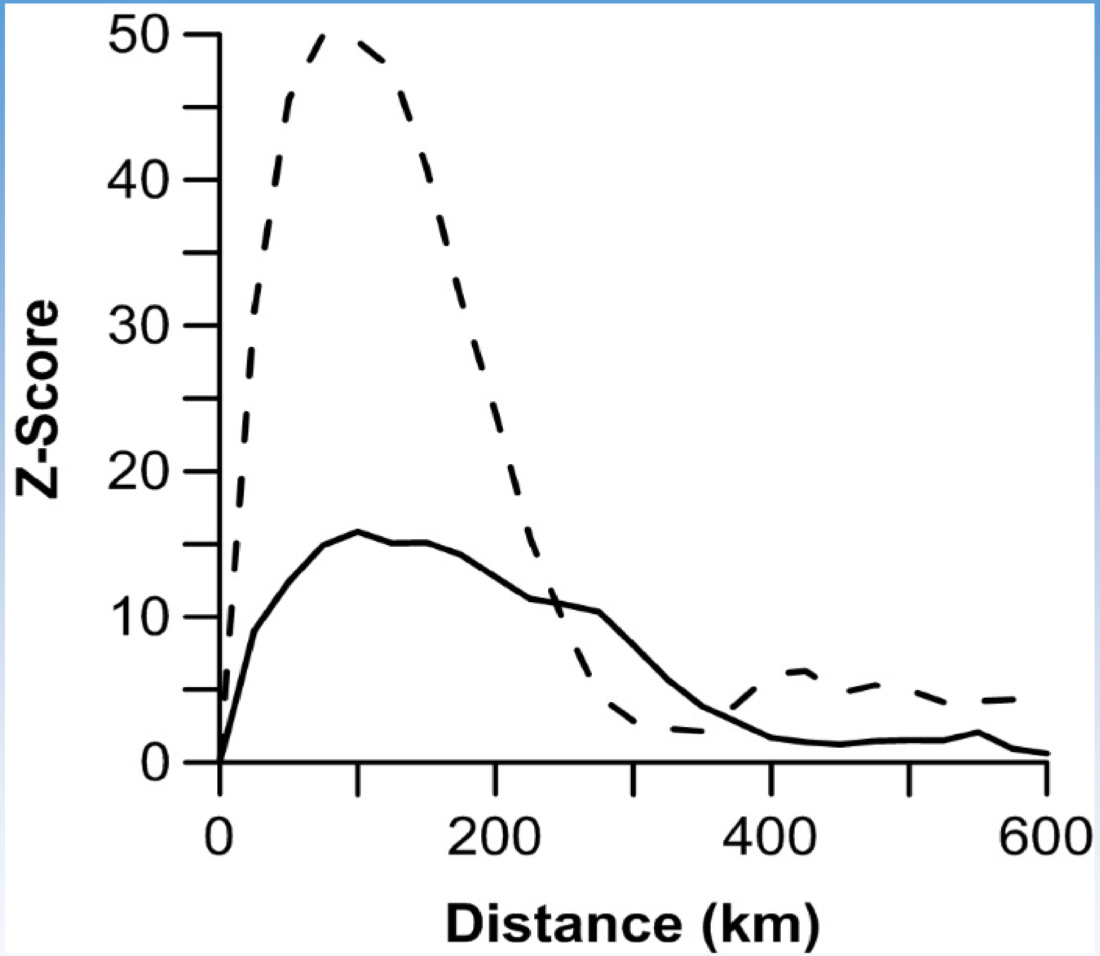
- What is the NURE dataset and why is it useful?
- Halite Deposits…What can they tell us?
- Theories for broad-scale fluid migration in the Appalachian Basin.

NURE Data Geospatial and Statistical Evaluation

- Distinguishing Cl sources using Cl/Br ratios.
- Incremental Spatial Autocorrelation
- Geospatial Exploratory Analyses
- Basin-scale Cl signature correlations

Significance

Incremental Spatial Autocorrelation



Incremental spatial autocorrelation for ABB (solid line) and high-ratio Cl^-/Br^- (dashed line) signatures. Statistically significant (99% confidence level) Z-score peaks at 100 km.

Presentation Outline

Background

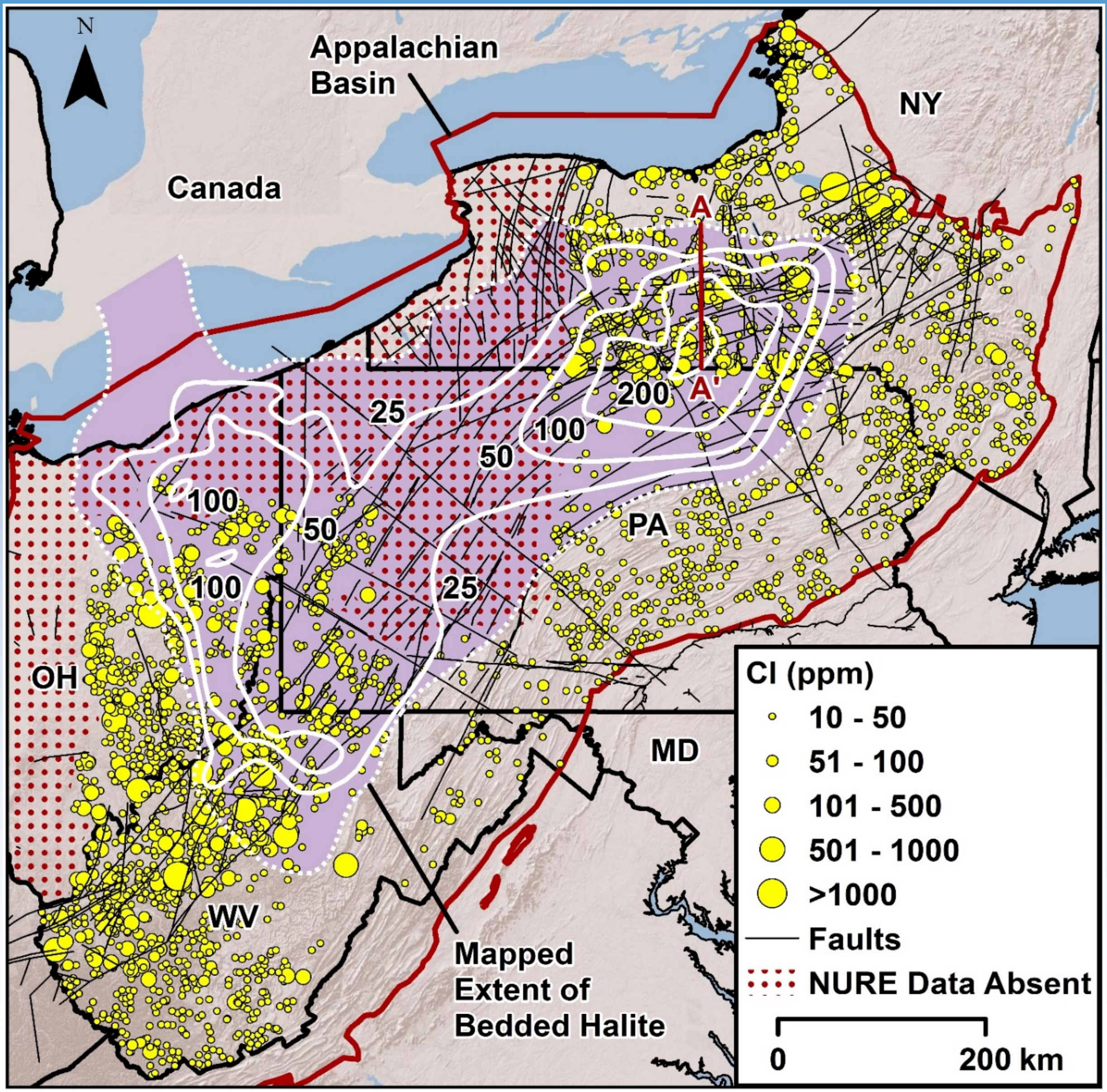
- What is the NURE dataset and why is it useful?
- Halite Deposits…What can they tell us?
- Theories for broad-scale fluid migration in the Appalachian Basin.

NURE Data Geospatial and Statistical Evaluation

- Distinguishing Cl sources using Cl/Br ratios.
- Incremental Spatial Autocorrelation
- Geospatial Exploratory Analyses
- Basin-scale Cl signature correlations

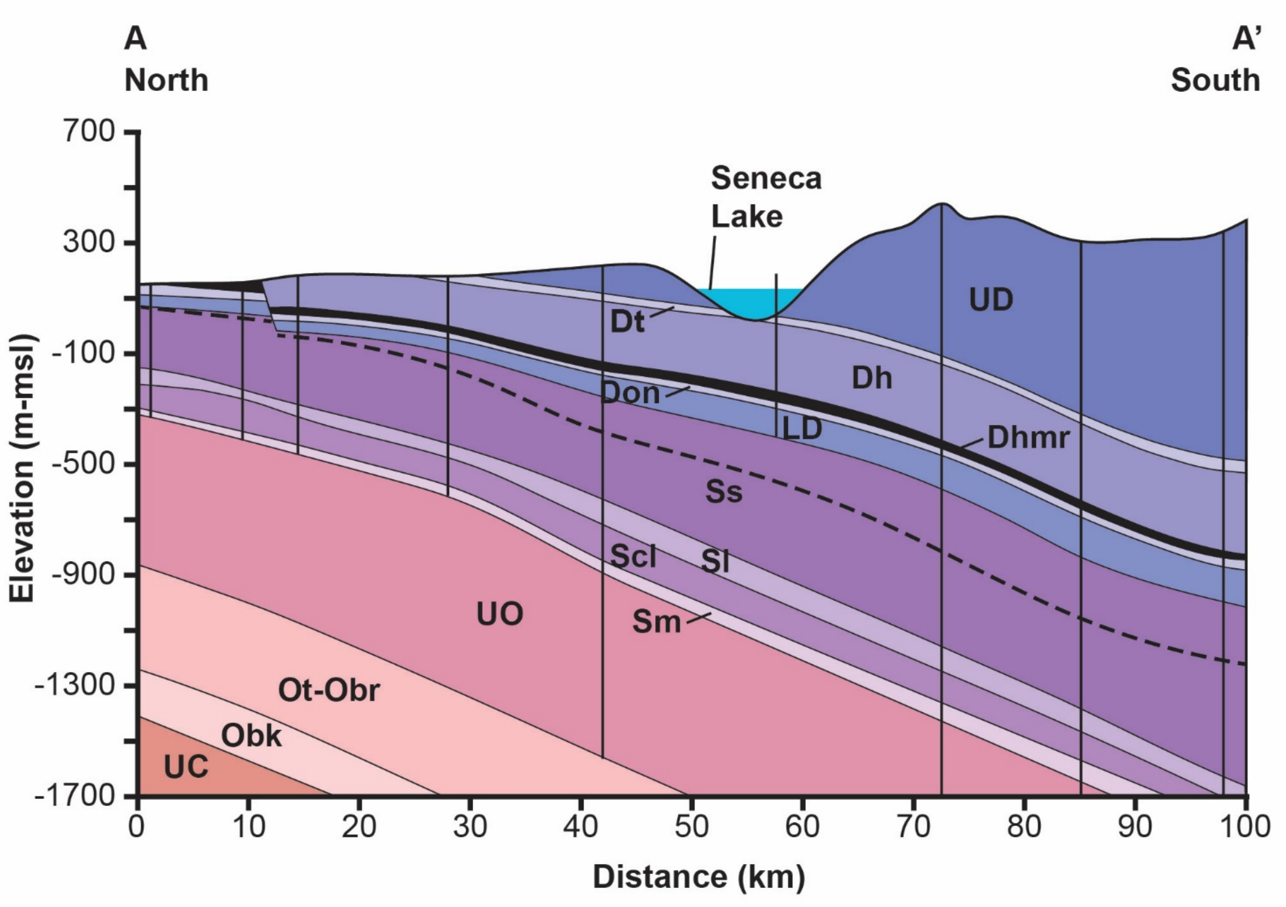
Significance

Geospatial Exploratory - ABB



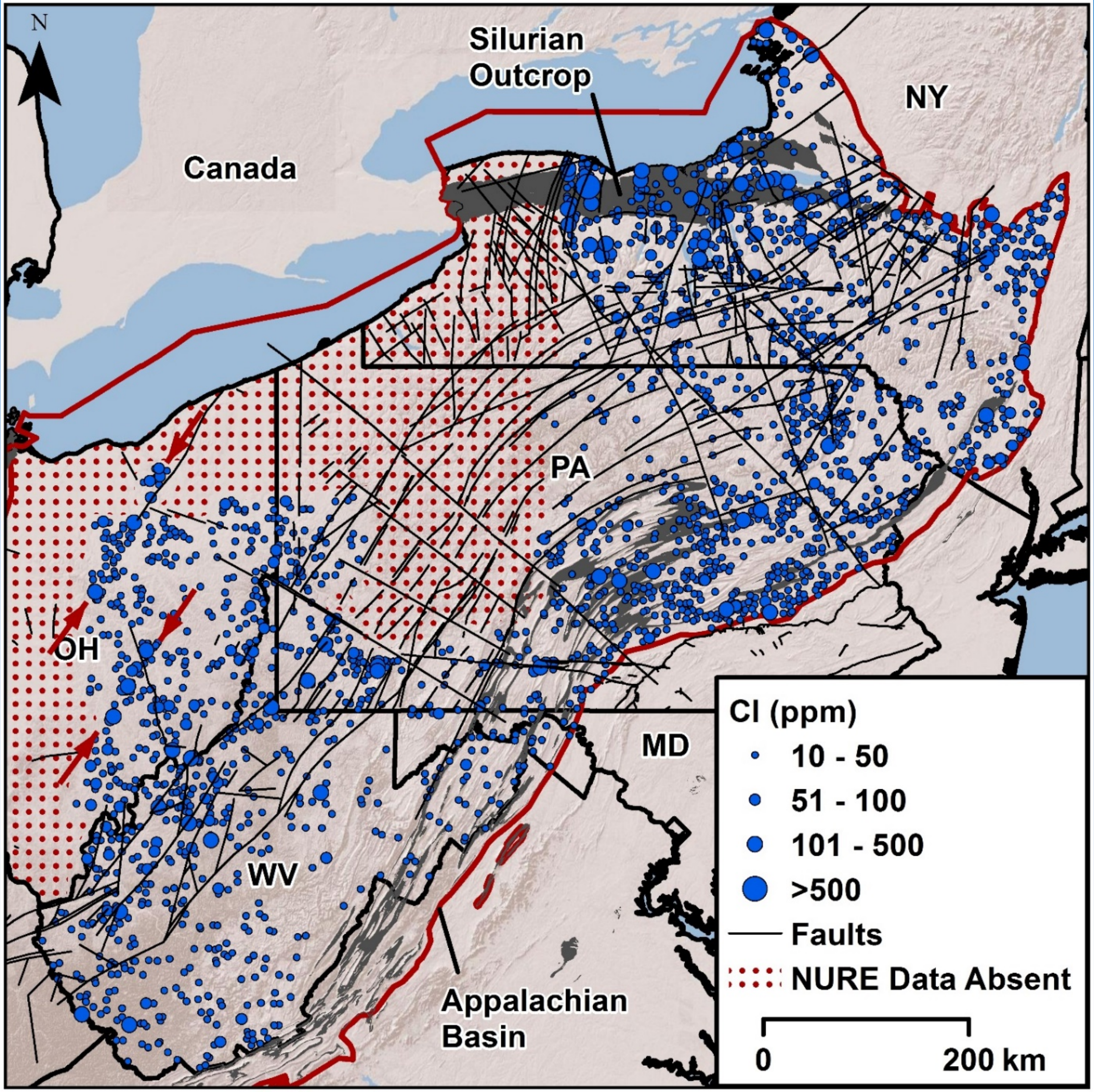
Distribution of NURE geochemical data with ABB signatures, faults and Salina Fm. bedded halite. Salina Fm. bedded halite isopach contours (white) in meters based on Pepper (1947), Pierce and Rich (1962) and Smosna et al. (1977). Faults compiled from Jacobi (2002), Alexander et al. (2005), Patchen et al. (2006) and Llewellyn (2014). MD: Maryland. NY: New York State. OH: Ohio. PA: Pennsylvania. WV: West Virginia.

Geospatial Exploratory - ABB



Cross-section of Upper Devonian through Upper Cambrian strata in south-central New York. Map view illustrated in Figure 3. UD: Upper Devonian, undivided; Dt: Tully Limestone; Dh: Hamilton Group; Dhmr: Marcellus Shale; Don: Onondaga Limestone; LD: Lower Devonian, undivided; Ss: Salina Group; Sl: Lockport Dolomite; Scl: Clinton Group; Sm: Medina Group; UO: Upper Ordovician, undivided; Ot-Obr: Trenton-Black River Limestone; Obk: Beekmantown Group; UC: Upper Cambrian, undivided. Dashed line indicates aggregate thickness of bedded halite throughout the Salina as measured from the Lower Devonian contact (Pierce & Rich 1962). Vertical lines indicate oil and gas well log control.

Geospatial Exploratory – High-Ratio



Distribution of NURE geochemical data with high-ratio Cl^-/Br^- signatures, faults and Silurian bedrock outcrops. Cl^- [ ] < 10 ppm omitted for clarity. Red arrows indicate high Cl^- [ ] linear trends oriented NE-SW with one paralleling a fault. Silurian outcrop dataset from Garrity and Soller (2009). Faults compiled from Jacobi (2002), Alexander et al. (2005) and Patchen et al. (2006). MD: Maryland. NY: New York State. OH: Ohio. PA: Pennsylvania. WV: West Virginia.

Presentation Outline

Background

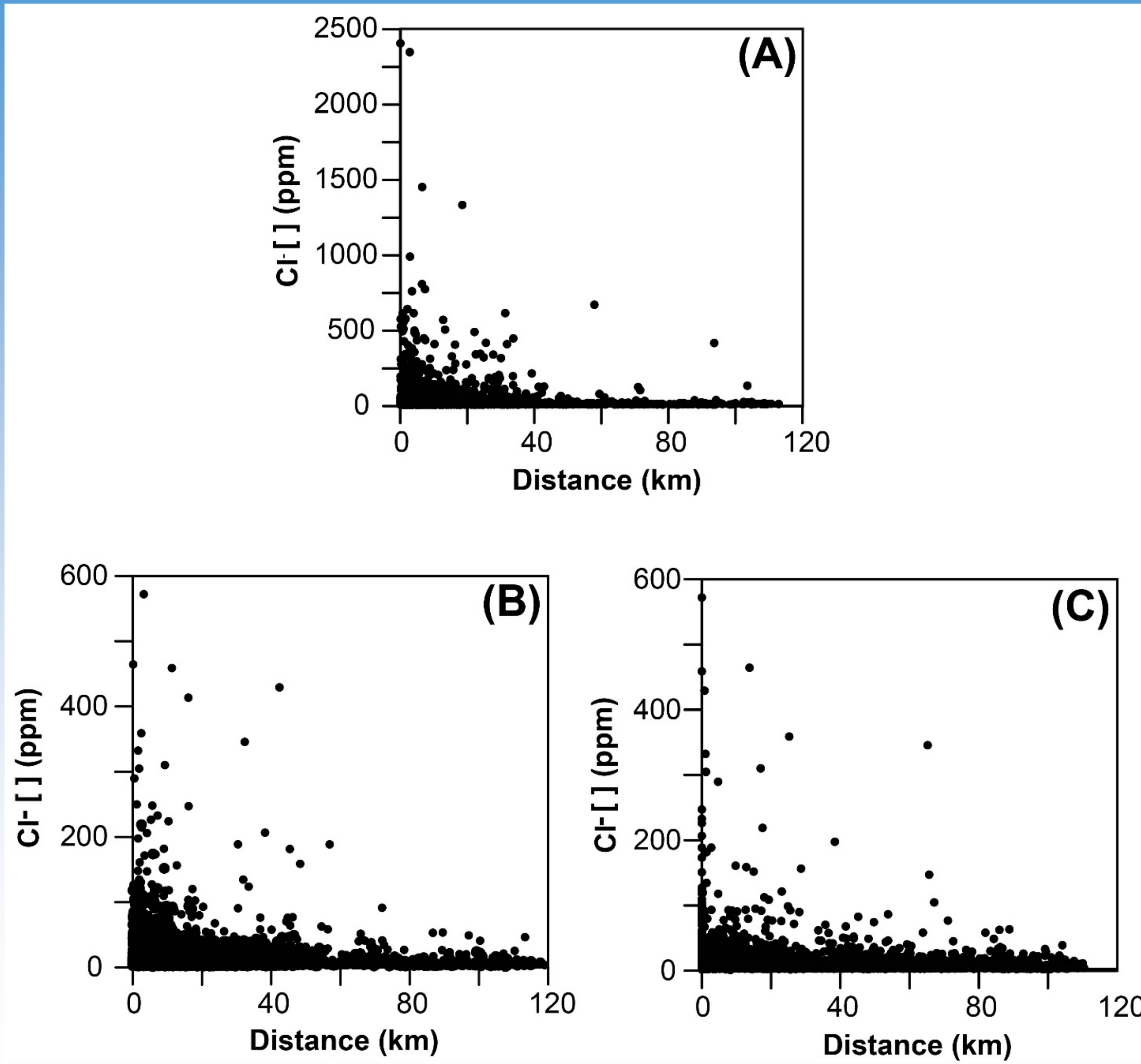
- What is the NURE dataset and why is it useful?
- Halite Deposits…What can they tell us?
- Theories for broad-scale fluid migration in the Appalachian Basin.

NURE Data Geospatial and Statistical Evaluation

- Distinguishing Cl sources using Cl/Br ratios.
- Incremental Spatial Autocorrelation
- Geospatial Exploratory Analyses
- Basin-scale Cl signature correlations

Significance

Basin-Scale Cl-Signature Correlations



Cross-plots for

(A) ABB signature Cl^- [ ] vs. fault distance,

(B) high-ratio Cl^-/Br^- signature Cl^- [ ] vs. fault distance and

(C) high-ratio Cl^-/Br^- signature Cl^- [ ] vs. Silurian outcrop distance.

Statistical Correlations (Spearman rho)

ABB: Cl [] & fault dist
Spearman rho = -0.143
P-value: <0.001

High-Ratio: Cl [] vs fault dist
Spearman rho = 0.002
P-value: 0.906

High-Ratio: Cl [] vs Silurian
Spearman rho = -0.030
P-value: 0.031

Significance

- Powerful baseline tool for identifying areas likely or unlikely to be impacted by ABB-related compounds.
- Better understanding of basin hydrodynamics.
- Geochemistry as another line of evidence for identifying structure?

Thank you……Questions?