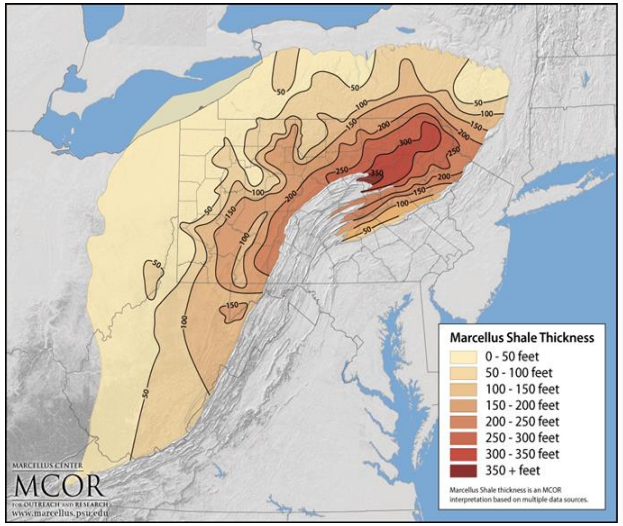

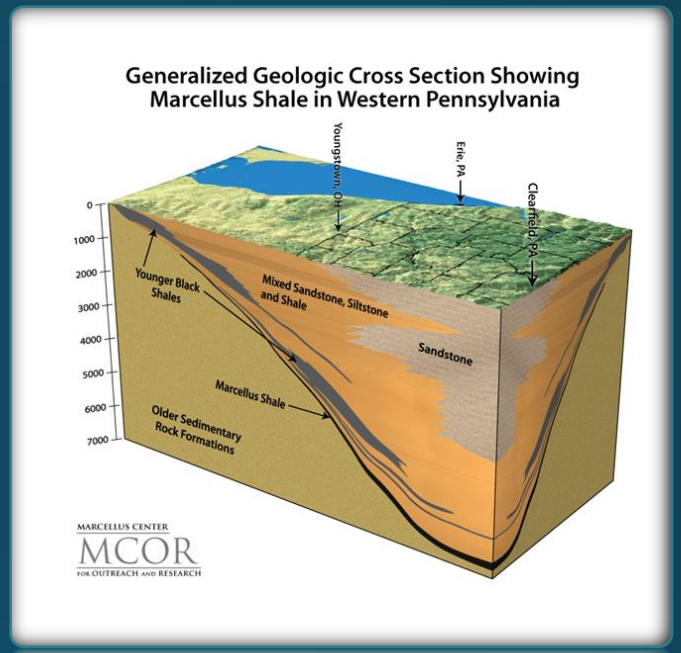

Authors:

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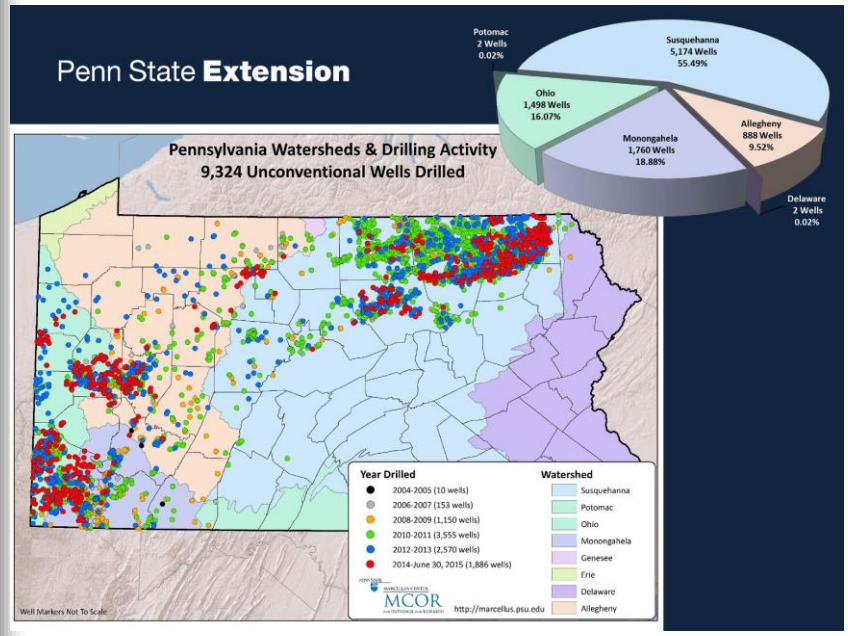
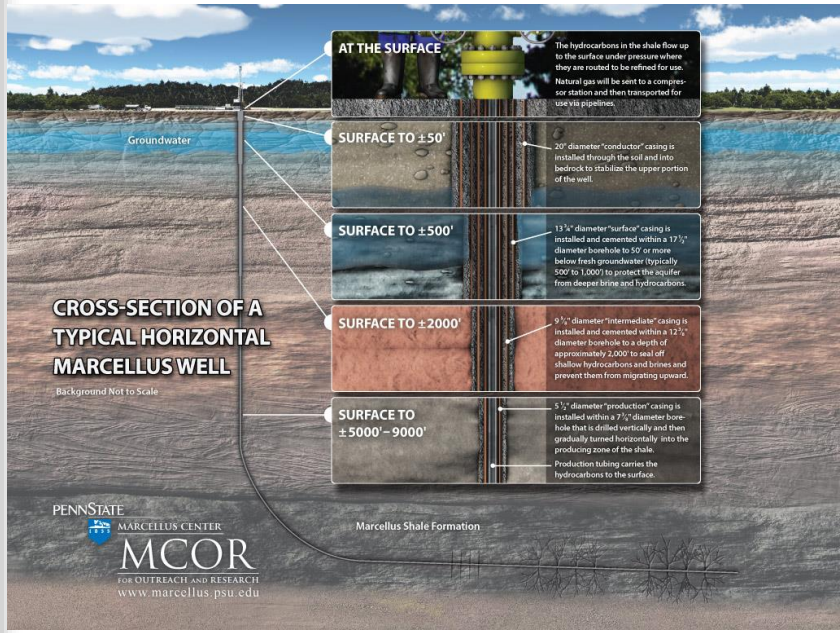
Sequence stratigraphy and the depositional environments of the Shamokin (Union Springs) Member, Marcellus Formation, and the associated strata in the middle Appalachian Basin.

Background

- Marcellus Shales extend from New York, under Pennsylvania, east to Ohio and south to West Virginia. Production primarily occurs in Pennsylvania.
- Significant source of natural gas production:
  - Wells: 9324+
  - May contain up to 500 Trillion Cubic Feet (tcf)
  - Single largest source of natural gas in the U.S.
  - Potentially second largest in the world
- Unconventional Reservoir:
  - Gas remains trapped in source shales
  - Requires unconventional methods to produce
    - Horizontal wells
    - Fracking





Introduction: Creating the Basin

- Ancient North America collides with Acadian microplate ~420 Mya
- Among the first of the Appalachian mountain building events
- Formed a foreland fold-thrust load basin
  - Mountain building increased crust weight
  - Compressional forces caused flexure
- Warm equatorial waters flooded the shallow basin
- Marine life flourished

Building the Shale

- The Union Springs member formed around ~390 Mya, over a period of 5 My
- Preservation of Organic Material:
  - Stratified, anoxic water
  - Limited water circulation
  - Deltaic sediments covered organic material
- Rising base levels + subsidence increased basin accommodation
  - Allowed sediment layers to grow thicker
- Falling base levels ended Union Springs deposition

Problem & Goals

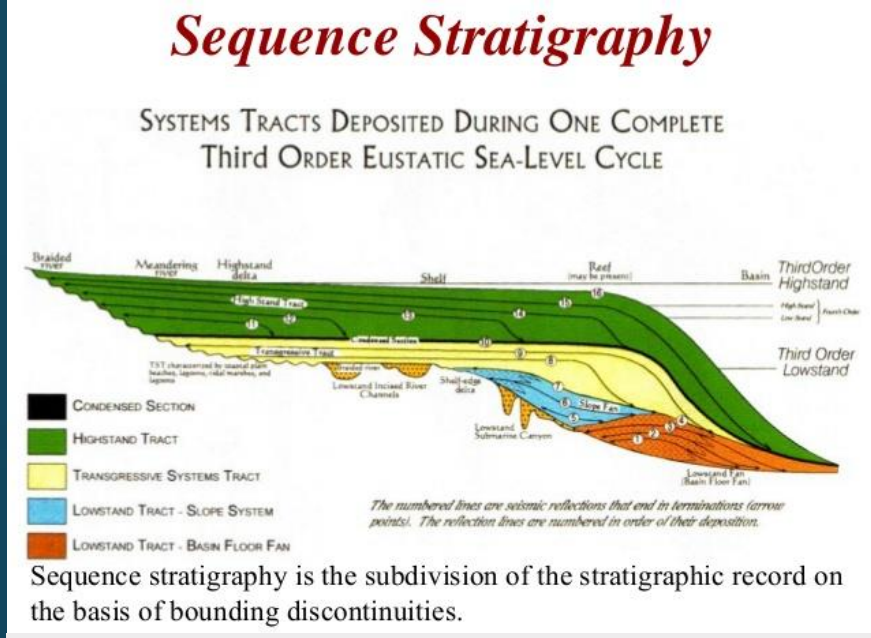
Problem: Well production varies from 1 to 10 mmcf/ day

Goals:

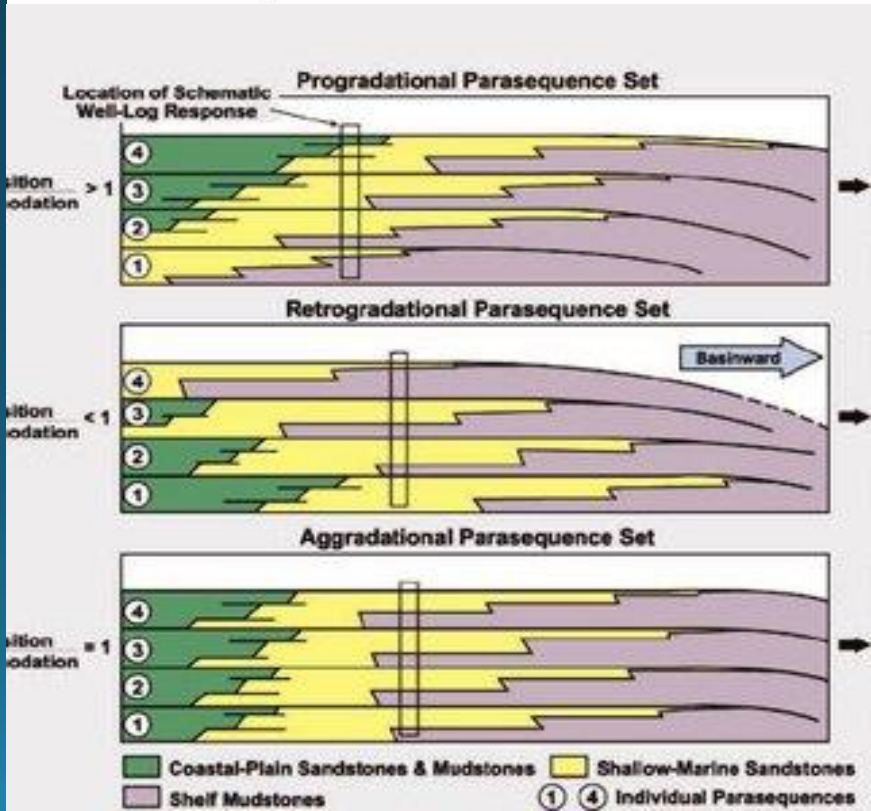
1. Define and describe the lithofacies and associated depositional processes and system tracts of the lower Marcellus and associated formations
2. Construct a sequence-stratigraphic framework for predicting the lateral and vertical variability of the economically significant lithofacies in this interval

Basin Analysis: Sequence Stratigraphy

- Determine the order of deposition of sediments
- Determine how and why
  - Rise and fall of sea level (accommodation)
  - Increase or decrease in deposition (sediment supply)
- Works within chronostratigraphic framework
- Sediments are deposited in cyclical sequences
  - Bounded by unconformities
- Sequences subdivided into tracts and parasequences
  - Lowstand Tract: low base level
  - Transgressive Systems Tract: rising base level
  - Highstand Tract: high base level
  - Falling Stage Systems Tract: falling sea level

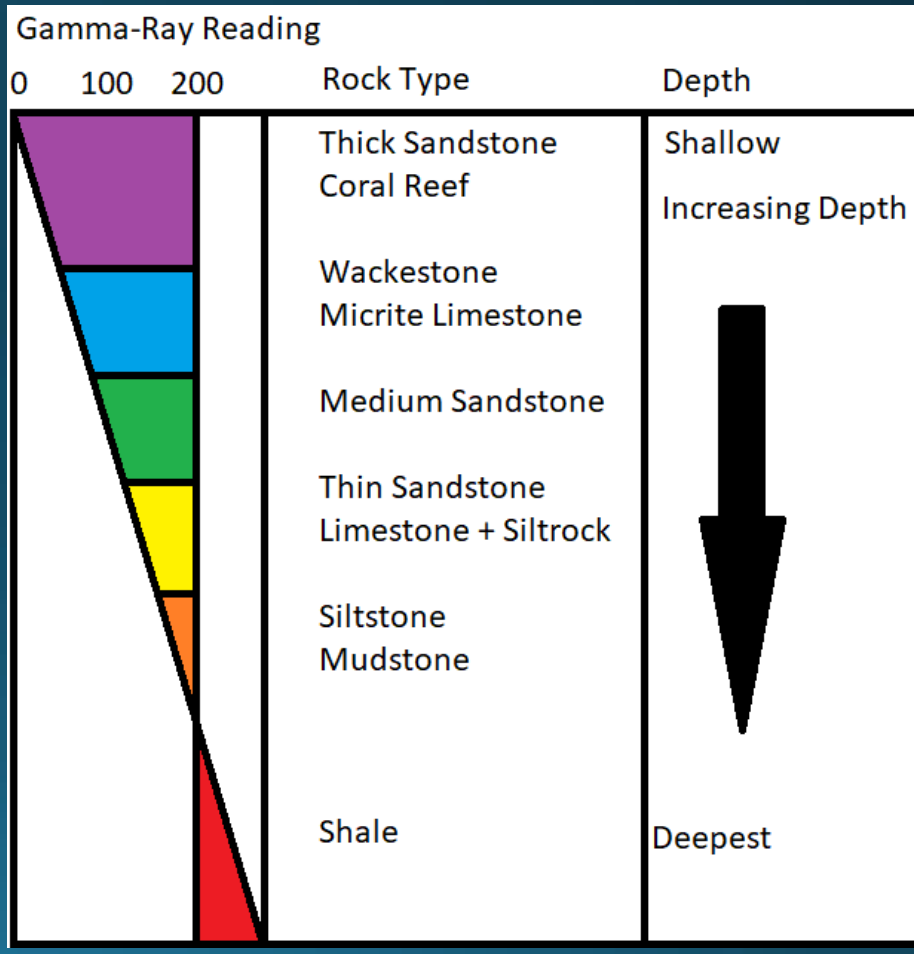


Sequence stratigraphy is the subdivision of the stratigraphic record on the basis of bounding discontinuities.

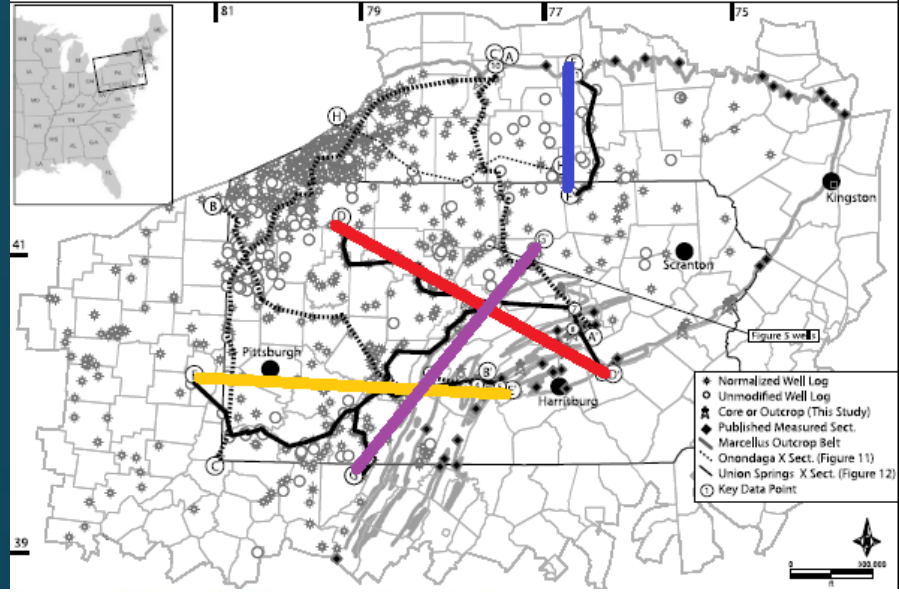


Methodology

- Extensive data collection:
  - 23 outcrops
  - 8 well cores
  - 1000+ well logs
- Primarily used Gamma-Ray data
- Selection of sub-Onandaga unconformity as datum
  - Usage of ash layers to aid well log correlation



Results:
Union Spring Member



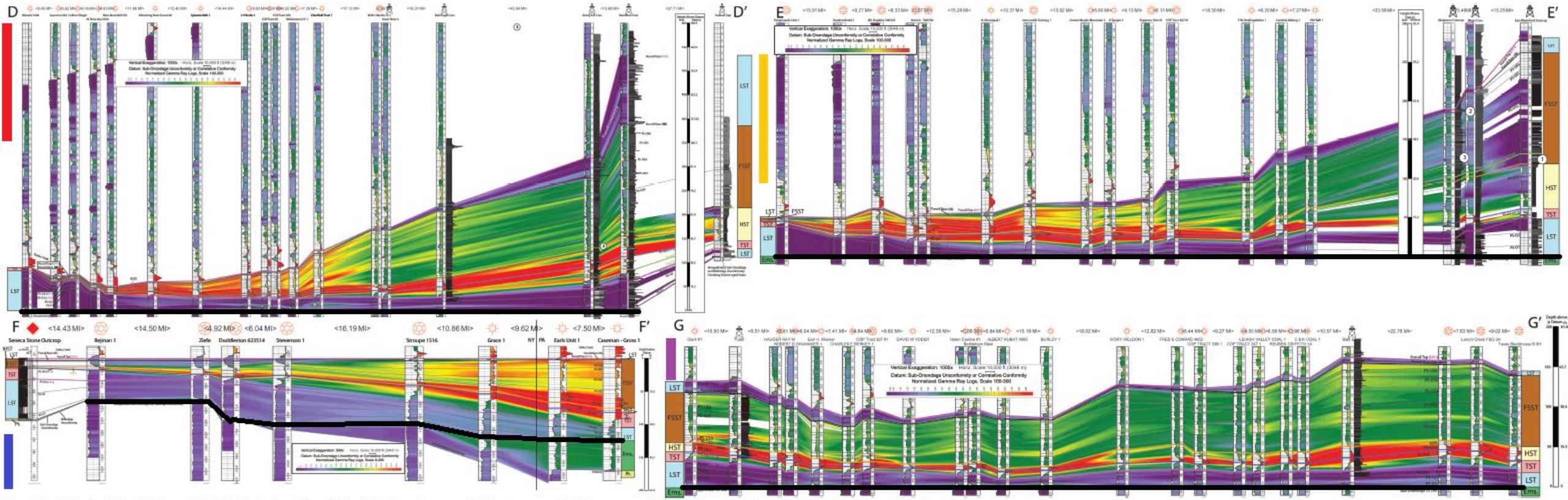
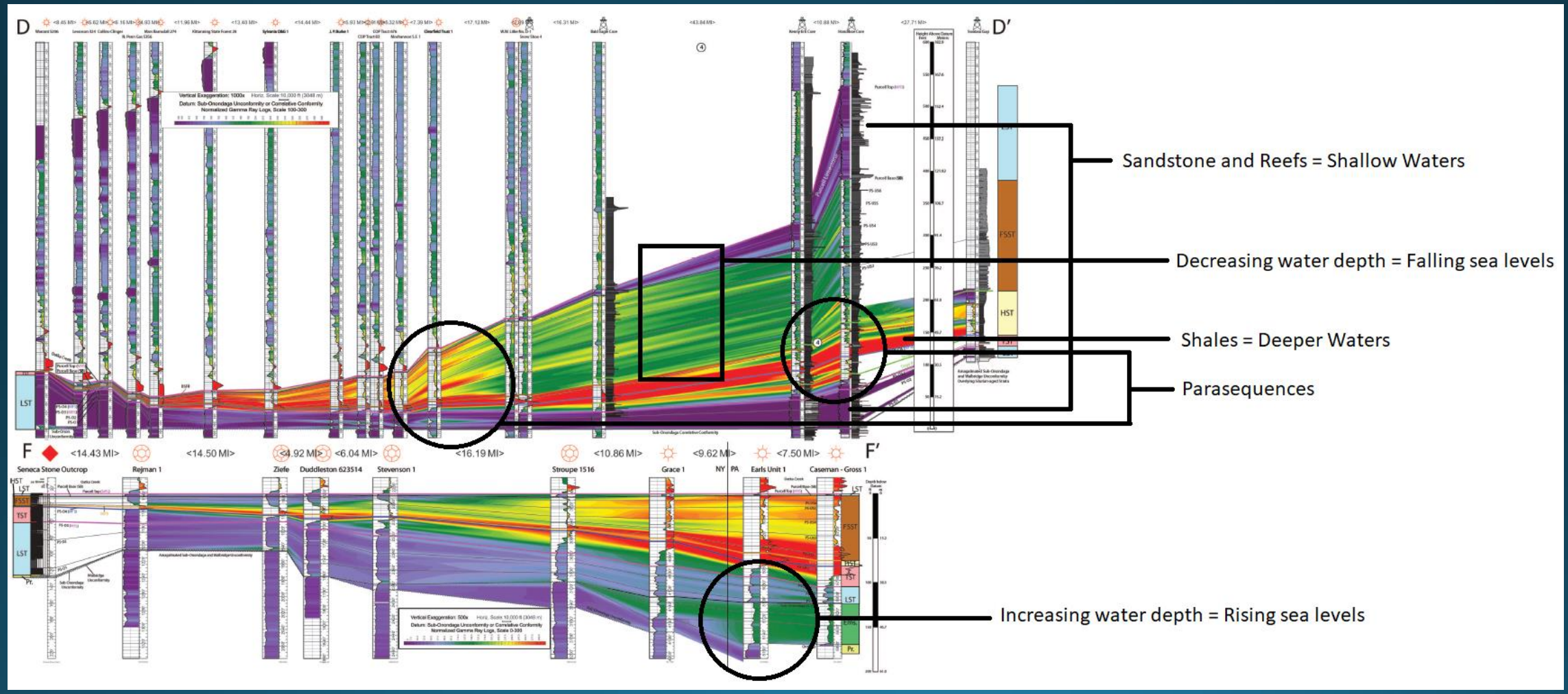


Figure 12. Correlated lines of section in the Union Springs and Purcell units, Marcellus Formation (see Figure 1 for line locations). LST = lowstand systems tract; HST = highstand systems tract; FSST = falling-stage systems tract; TST = transgressive systems tract; CC = correlative conformity; Ems. = Emsian strata; Pr. = Pragian strata.

Interpretation:
Union Springs Member



Putting it all Together

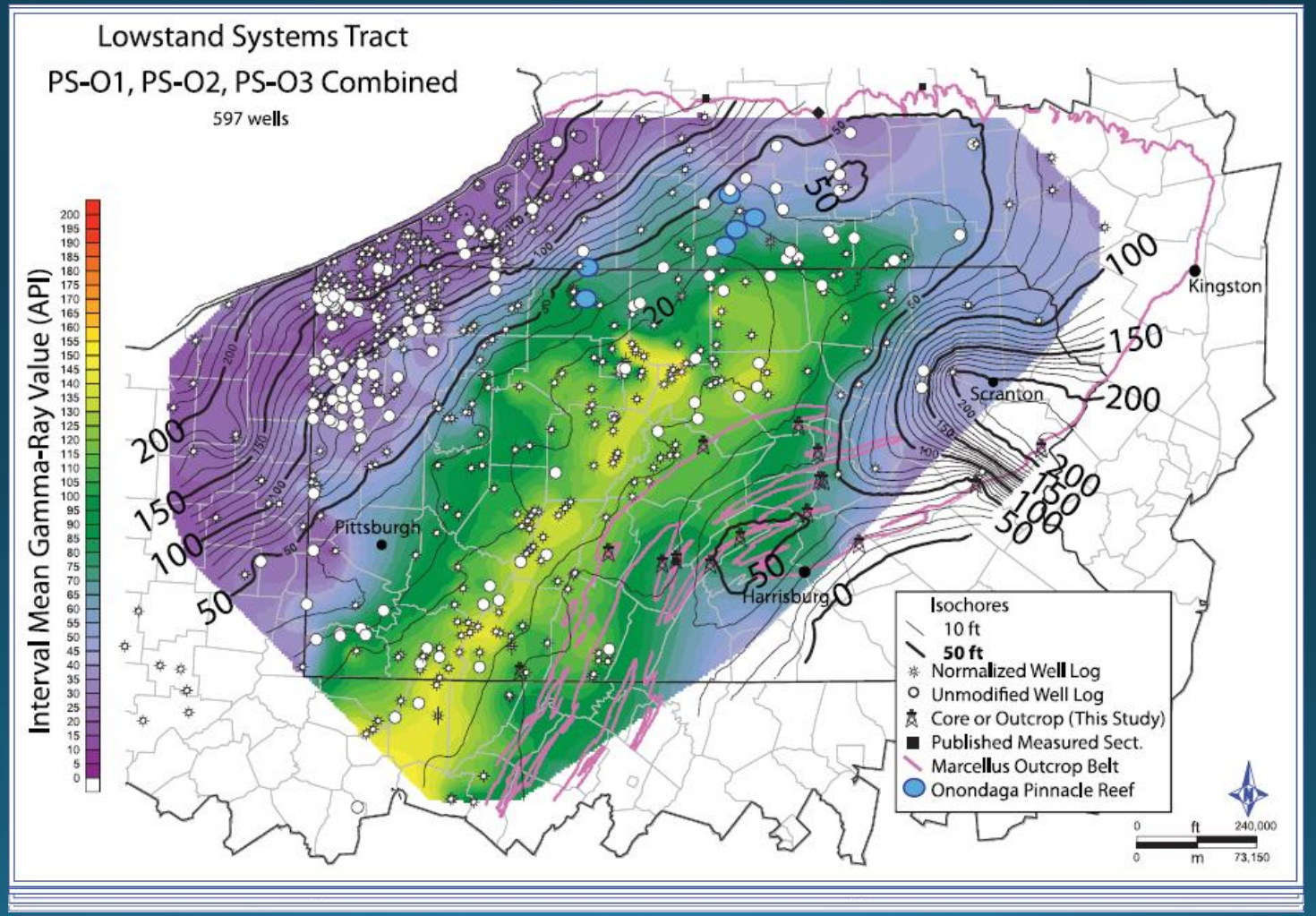
Lowstand Systems Tract:
- Start of sequence
- Low Eustatic Sea Level

Transgressive Systems Tract:
- Rising Eustatic Sea Level

Highstand Systems Tract:
- Peak Eustatic Sea Level

Falling Stage Systems Tract:
- Falling Eustatic Sea Level

Return to Lowstand Systems Tract, Begin Next Depositional Cycle



Conclusion & Summary

- The Union Springs member of the Marcellus Shales is a single third-order depositional sequence consisting of 10 parasequences
  - 3 parasequences in the Lowstand Systems Tract (low sea level)
  - 1 in the Transgressive Systems Tract (rising sea level)
  - 1 in the Highstand Systems Tract (highest sea level)
  - 5 in the Falling Stage Systems Tract (falling sea level)
- Shales were deposited over about 5 My, during a period of regional (North America) sea level change
- Parasequences created due to localized sea level change
- The overlying Purcell Member follows this pattern