PS Examination of the Queenston Delta in Central New York for Geologic Carbon Dioxide Storage*

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Abstract

The late Ordovician Queenston Delta of central New York is composed of the Oswego and Queenston formations, and a statewide reconnaissance by the New York State Museum highlighted it as a potential target for subsurface geologic carbon dioxide storage. The Oswego Formation is un-fossiliferous greenish-gray sandstones, siltstones, and shales that were deposited in offshore shelf to intertidal environments. The conformably overlying Queenston Formation is a sequence of shales and sandstones primarily deposited in non-marine conditions. An unconformity separates the Queenston Formation from the overlying Medina Group. Well log data indicate that both the Queenston and Oswego formations thicken to the southwest region of the study area.

Based on analysis of fifty-two central New York well log suites (gamma, neutron, sonic, and density logs from Broome, Cayuga, Chenango, Chemung, Schuyler, Seneca, Steuben, Tioga, and Tompkins Counties) of the Queenston and Oswego formations, we divide the two formations into thirteen discrete petrophysical zones (Queenston A-F, Oswego A-G). Porosity, density, thin section, and limited permeability data suggest that the zones with the best carbon dioxide storage potential are Queenston B and C, which are located near the top of the Queenston Formation. Though Queenston A is a texturally mature, medium-grained quartz sandstone, it is well cemented with little porosity, and erosionally and depositionally thins eastward. Queenston B is a medium to coarse-grained quartz sandstone with few shaley beds. Queenston C is more variable, ranging from a very fine to coarse sandstone with varying degrees of hematite cement. Both Queenston B and C thin to the east and shale content increases westward. For both zones, neutron and sonic porosities are greatest in the center of the study area. Queenston A, B, and C all have intra-granular quartz porosity, which may have formed from leaching during a period of exposure prior to the deposition of the Medina Group. Though neutron logs suggest porosity may increase with depth in the Oswego Formation, thin section and sonic log data imply instead that the high neutron log values may be affected by shale water content. Shale and well-cemented sandstone in the lower portion of the overlying Medina Group could serve as an immediate seal. Although in general the Medina Group has little inter-granular porosity, assessment of its sealing potential awaits study of its fracture permeability.

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I. Abstract

A statewide reconnaissance by the New York State Museum highlighted the Upper Ordovician Queenston Formation as a potential target for subsurface geologic carbon dioxide storage. We explore in greater detail the total pore volume and lateral variability of the Queenston Formation in Central and Western New York.

The Queenston Formation is a thick sequence of shales and sandstones primarily deposited in non-marine conditions. Well log data indicate that the Queenston Formation thickens to the southwest region of the study area.

Based on sparse well log, core, and seismic data in Central New York, the Queenston Formation is primarily braided stream sandstone deposits. The unit grades westward into muddier distributary channel, beach, and marine deposits. A series of transgressions and regressions cause porosity to increase toward the top of the formation in the study area.

Seismic and core data suggest that in a 5 mile x 5 mile area surrounding the AES Cayuga coal-fired power plant, the Queenston Formation can sequester approximately 45 M metric tons of CO_2 (~ 19 years of CO_2 production.)

II. Study Area

Figure 1

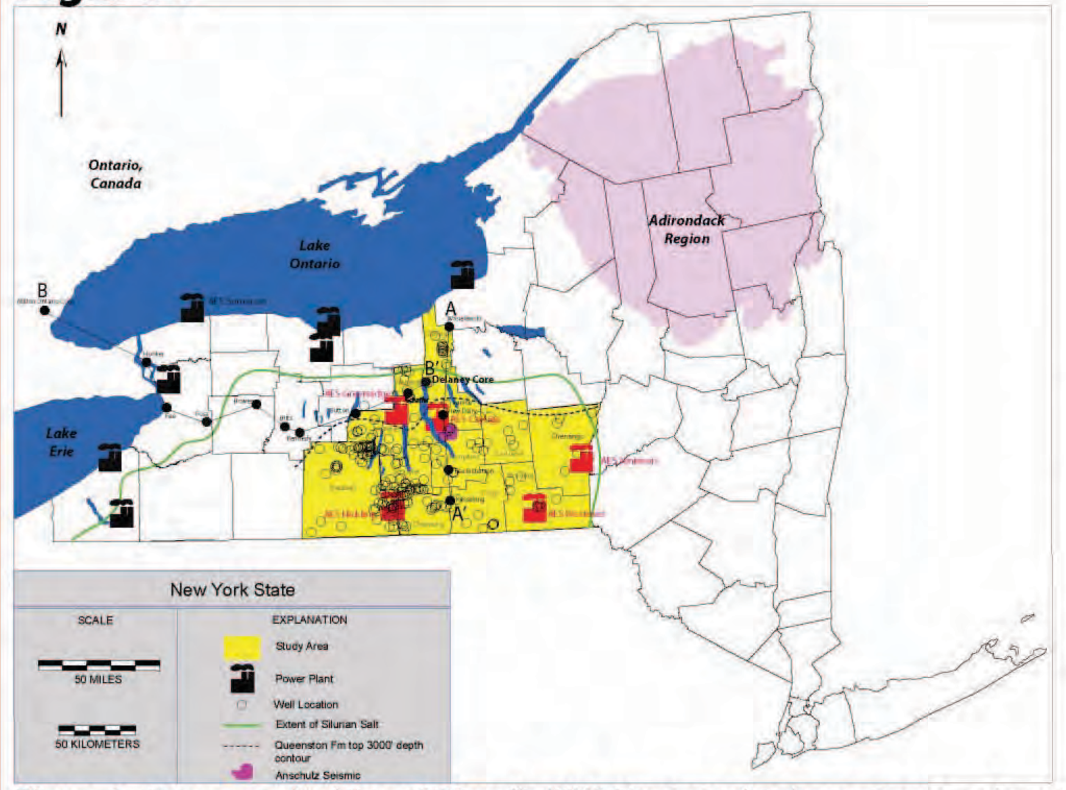

Figure 1. Data consulted from 269 wells (NYS Museum database www.esogis.com) from an 11 county area (yellow) surrounding five AES power plants. Regional cross section (B-B', Figure 4) relates our Central New York study area to Western New York and Ontario outcrops. Anschutz Exploration Corporation provided seismic data in Cayuga and Tompkins Counties. The Silurian Syracuse Salt (south of green line) will be studied for seal potential. The N-S cross section (A-A') is shown in Figure 2.

Figure 2

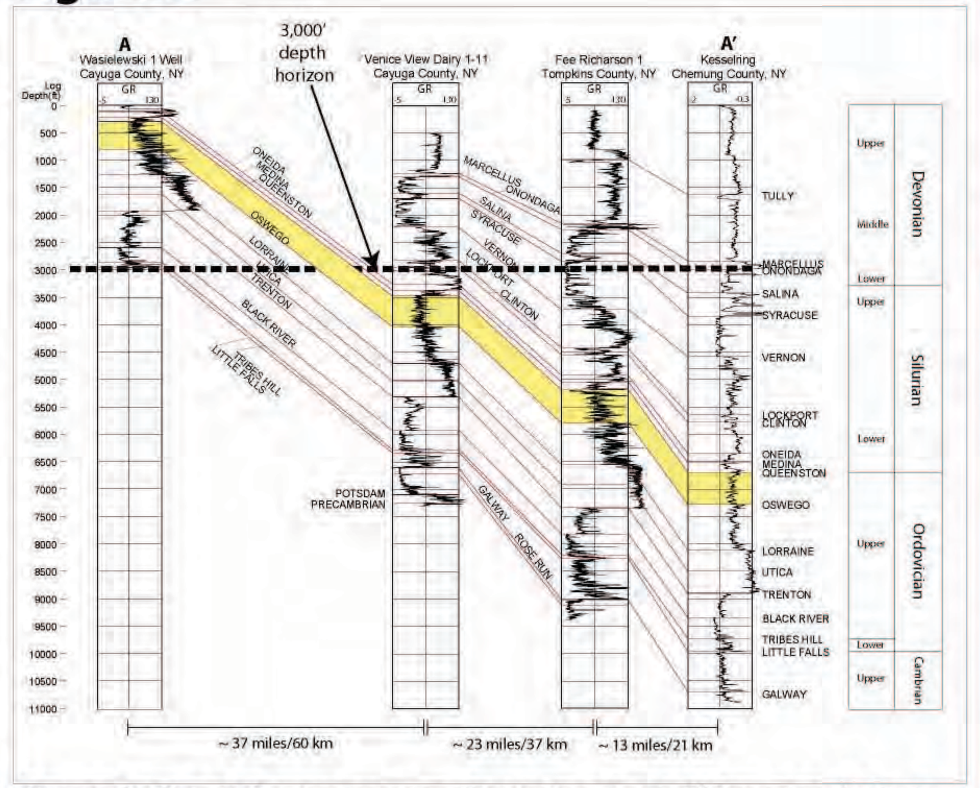

Figure 2. This N-S cross section illustrates the 1-2° S regional dip in the study area. The Queenston Formation (yellow) top reaches the 3000 foot depth contour necessary for supercritical CO_2 storage south of the black dashed line in Figures 1 and 3.

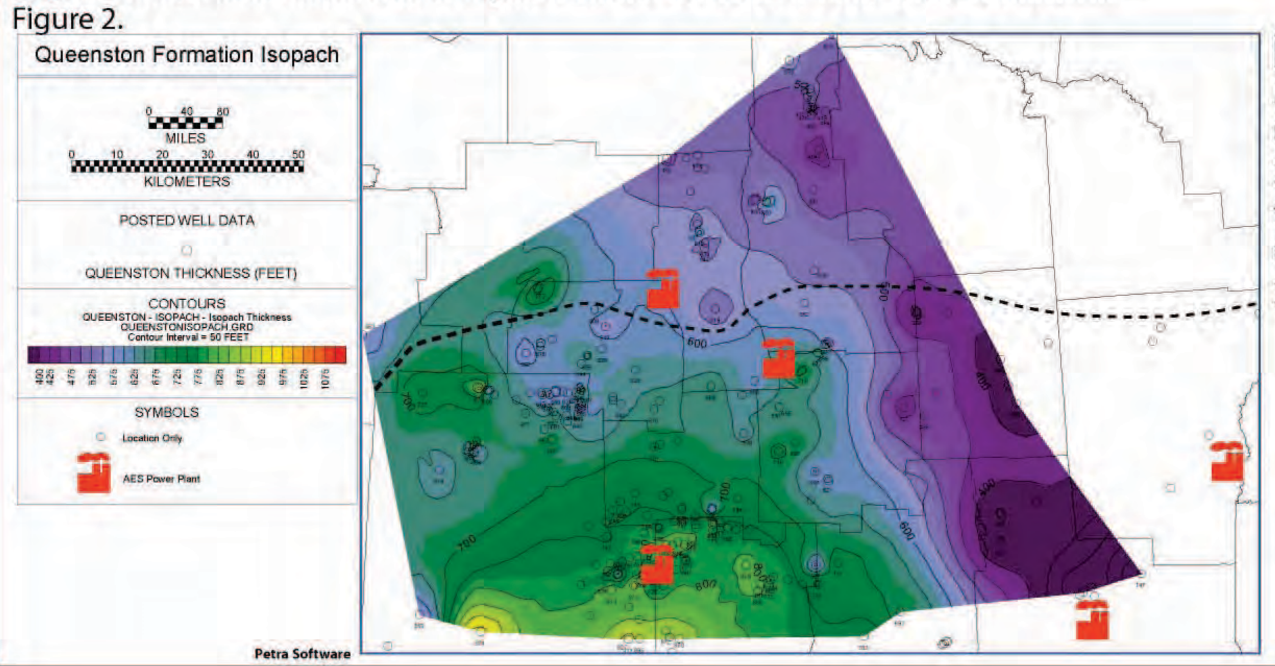

Figure 3

An isopach map from well log data indicates that the Queenston Formation thickens from approximately 350 feet in the eastern part of the study area to greater than 800 feet in the western part. The top of the Queenston Formation reaches depths greater than 3000 feet south of the black dashed line.

III. Queenston Formation Regional Cross Section (Figure 4)

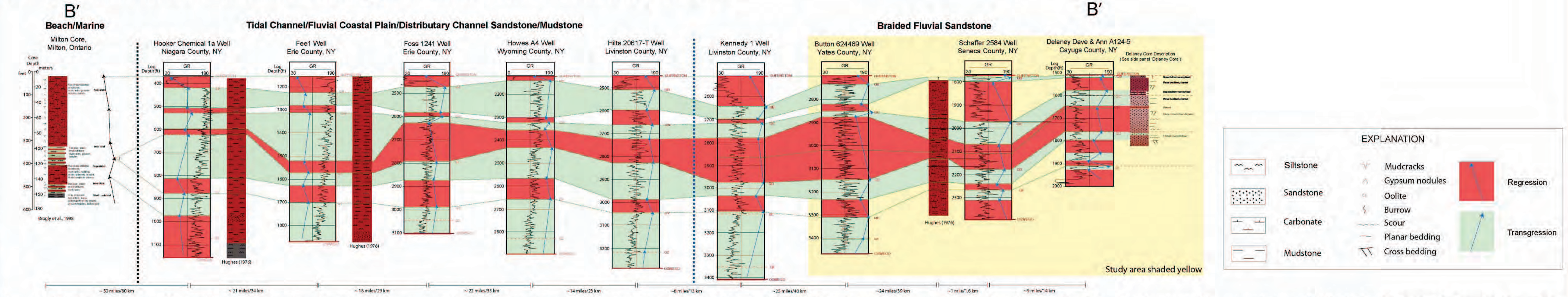

Figure 4. Well log, core (see side panel **Delaney Core**), and cuttings data suggest that the Queenston sandstone in Central New York (east of vertical blue dashed line) was deposited in a braided fluvial setting dominated by regessive trends (shaded orange). The Queenston Formation grades from a braided fluvial sandstone system in Central New York into a muddier meandering distributary or tidal channel system in Western New York (between black and blue dashed lines), where it is dominated by transgressive deposits (shaded green). Shoreface and marine deposits are found in Ontario, Canada (Brett, 1996; Brogly et al., 1998). The transgressive/regressive trends suggest that tectonic subsidence affected baselevel change to the east, and baselevel was primarily affected by sea level fluctuations to the west. Petrophysical Zones (QA-QF in Central NY, QW-QZ in Western NY) were mapped throughout the study area (yellow background) and to the west based on variations in gamma, neutron, and density logs. This implies that the Queenston Formation would not have adequate porosity west of Livingston County, where it begins grading into muddier facies.

III. Seismic Facies

Figure 5

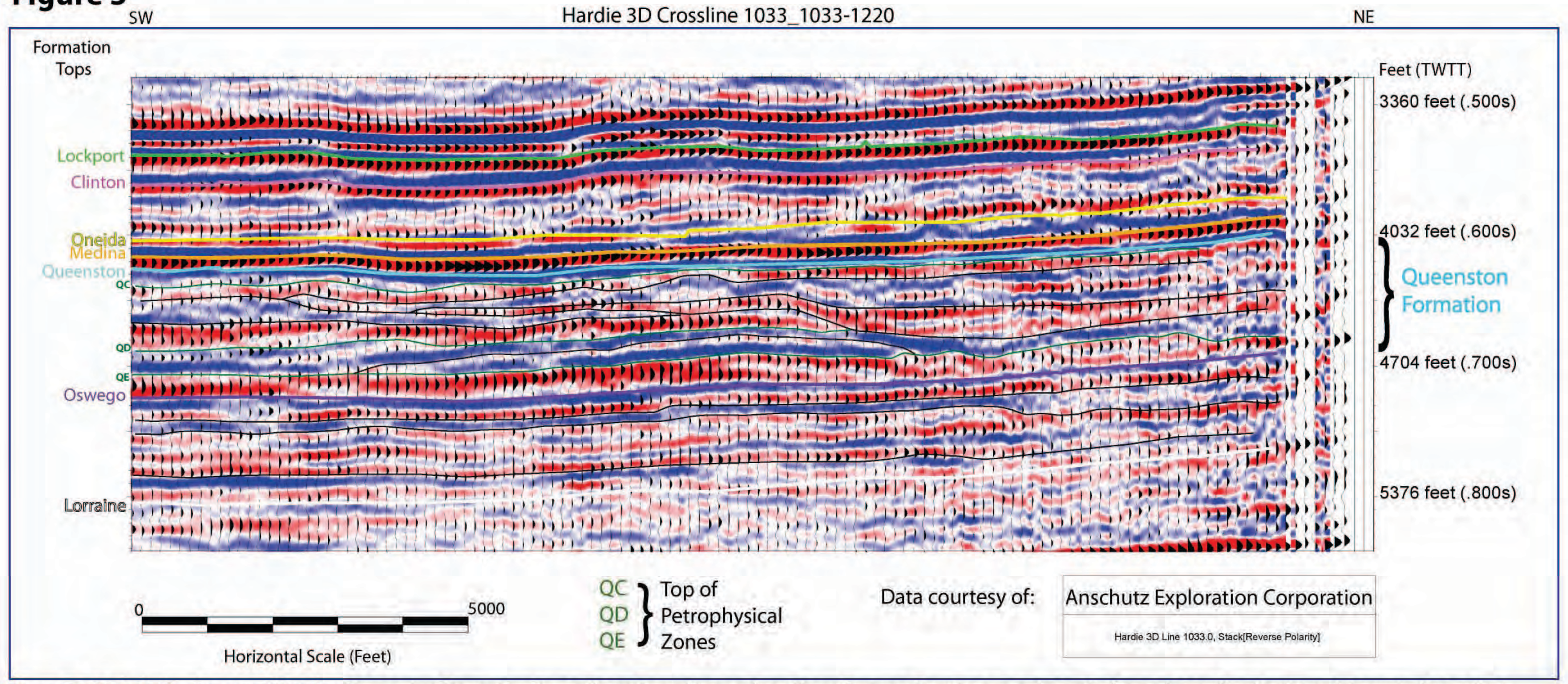

Figure 5. Seismic facies reveal that the Queenston Formation in northern Tompkins and southern Cayuga Counties was deposited in a channelized setting. Integrated core, thin section (see side panel **Delaney Core**), seismic, and well log data imply that the Queenston Formation in Central New York is a braided fluvial deposit. In the seismic data, petrophysical zone QC appears to have several erosional surfaces. This zone has the highest porosity in the Delaney Well core and is interpreted as an Fe_2O_3 -rich paleosol.

Figure 6

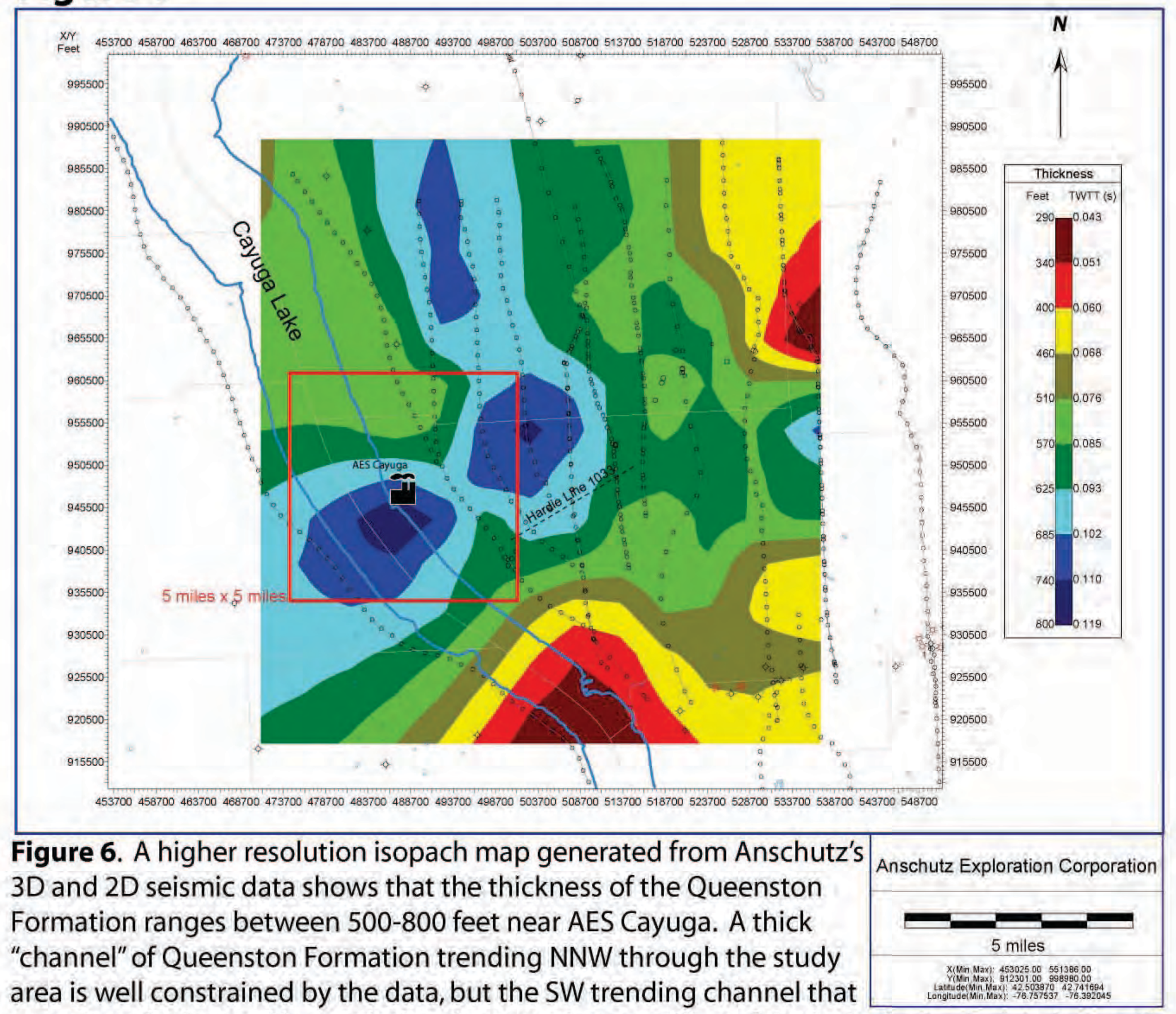

Figure 6. A higher resolution isopach map generated from Anschutz's 3D and 2D seismic data shows that the thickness of the Queenston Formation ranges between 500-800 feet near AES Cayuga. A thick "channel" of Queenston Formation trending NNW through the study area is well constrained by the data, but the SW trending channel that appears to be located beneath the plant may be an artifact of the lack of seismic data below Cayuga Lake. The red square outlines a 5 x 5 mile area surrounding AES Cayuga that is used for calculating the static CO_2 storage capacity of the Queenston Formation.

V. Queenston Formation Static CO_2 Storage Potential

From seismic, core, and well log data, we calculate the static CO_2 storage volume for a 5 mile x 5 mile area surrounding the AES Cayuga powerplant. We assume that based on the stratigraphic model and seismic data, the Queenston Formation has similar properties to that of the Delaney core, with an average porosity of 10%. Estimated reservoir temperature (104°F, 40°C) and pressure (1050 psi, 73 bars) indicate that the CO_2 density will be ~48 lbs/ft^3. Optimistically, CO_2 will displace 5% of the formation water, so water saturation is 95%. Using these values and an average thickness of 600 feet for the Queenston Formation, we can calculate the static CO_2 storage mass with the equation below.

55.46 lbs/ft^3 → CO_2 Density; 600 feet → Reservoir Thickness; 16,000 acres → Reservoir Area; 10% → porosity; 95% → water saturation

$$\text{CO}_2\ \text{Sequestration Mass} = \frac{\text{CO}_2\ \text{Density} \times \text{Reservoir Thickness} \times \text{Reservoir Area} \times \text{porosity} \times (1 - \text{water saturation})}{2200}$$

Conversion factor (1 metric ton = 2200 lbs)

= 45.5 million metric tons

from *SPE Monographs, Vol 22*

AES Cayuga emits 2.4 M metric tons of CO_2 each year. Based on the above static storage capacity estimate, the Queenston Formation could theoretically sequester approximately 19 years of CO_2 output in its pore space. Further geochemical, fluid flow, and fracture modelling for CO_2 storage in the Queenston Formation are currently being investigated at Cornell University, SUNY Buffalo, and UC Long Beach.

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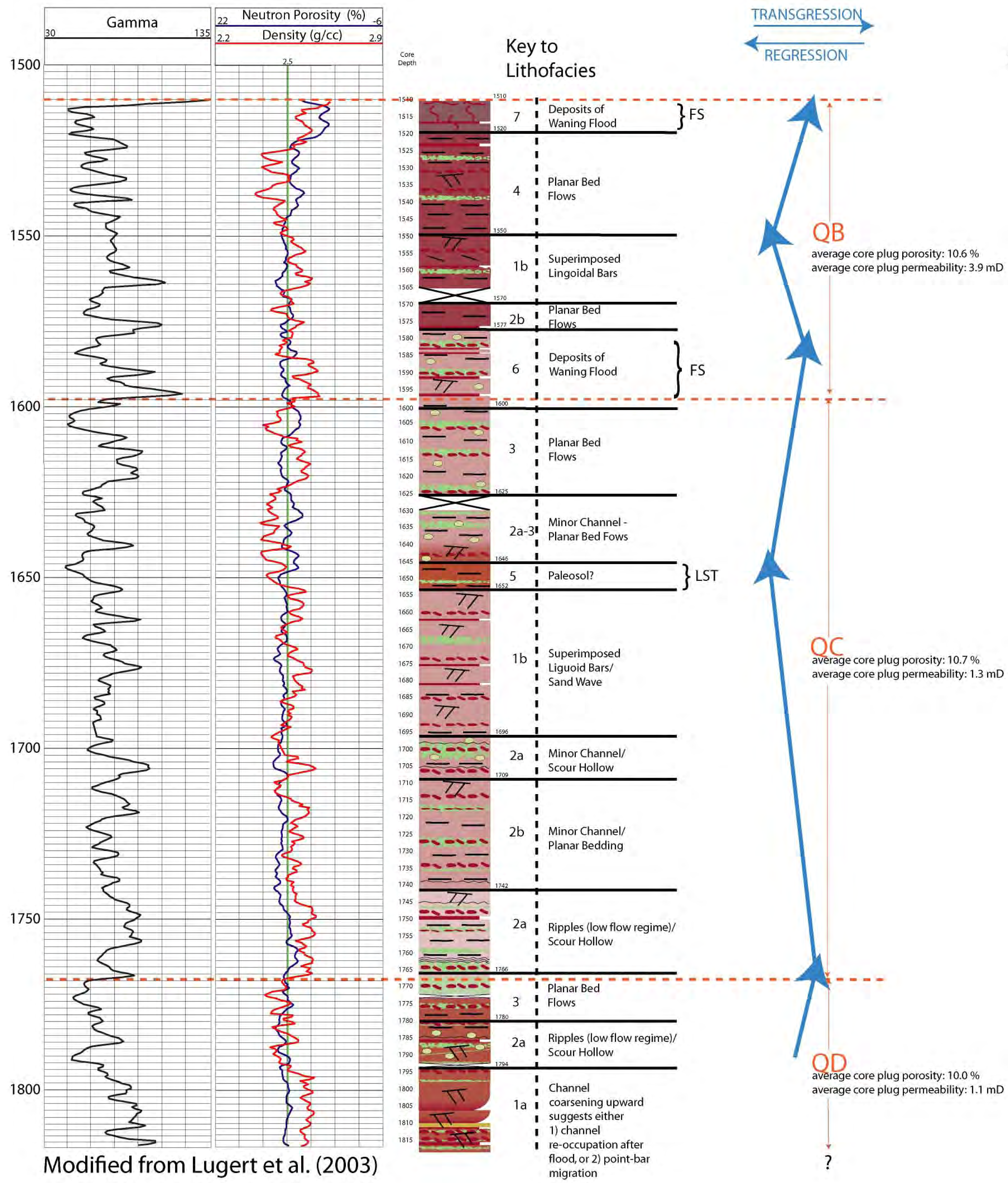
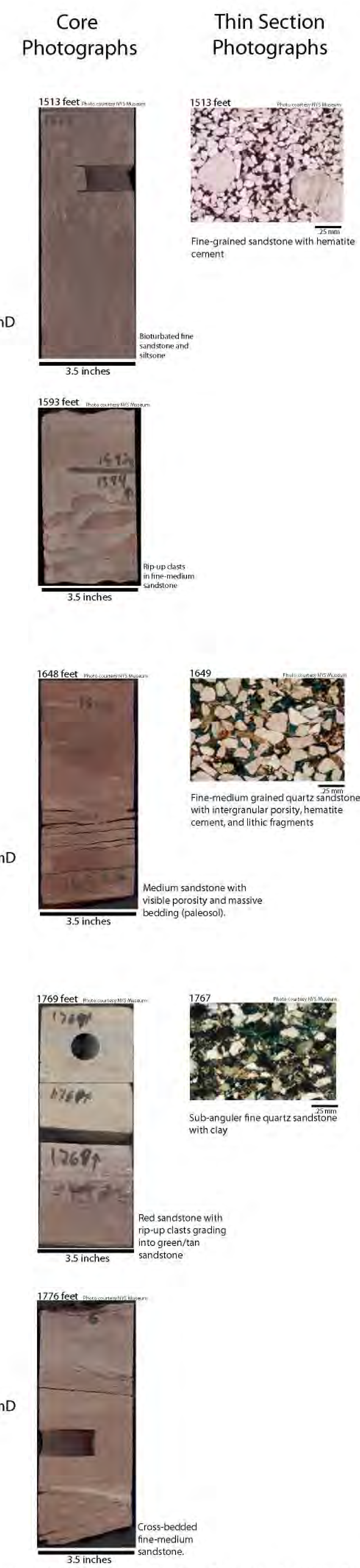
Queenston Delaney Well Core Description
Cayuga County, New York



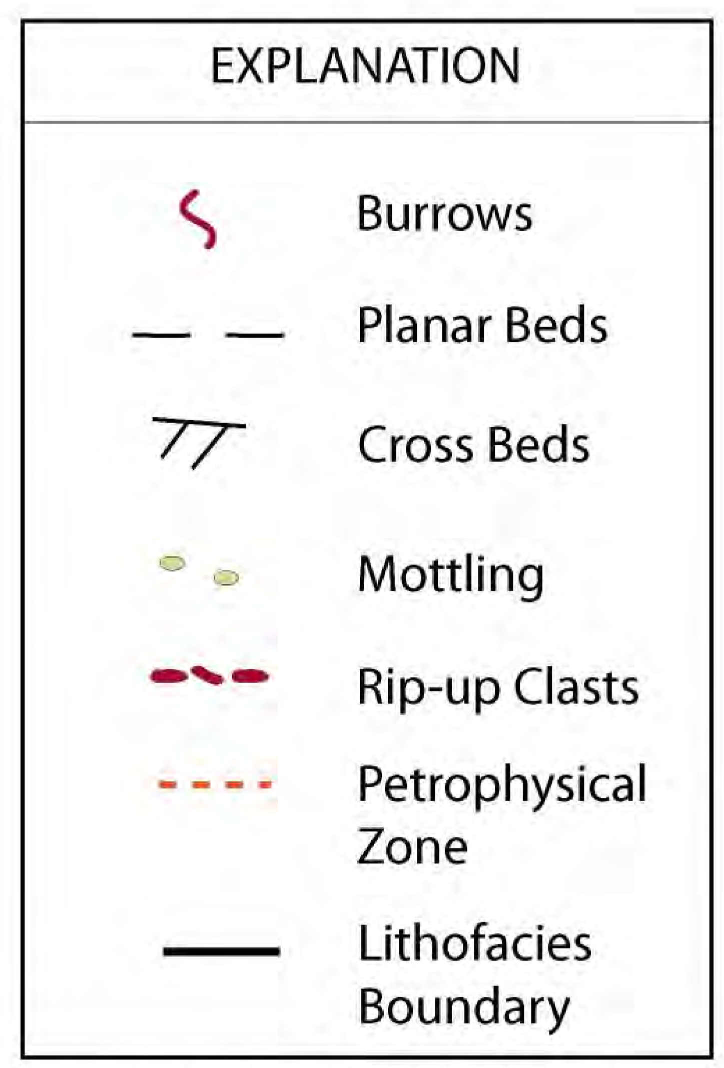
Modified from Lugert et al. (2003)



LITHOFACIES

	Description	Interpretted Depositional Environment
1a	-Medium grained sandstone -Reddish brown with some tan layers -Well laminated cross beds and cross laminae -Coarsening upward sequences -Not bioturbated: one long burrow -Rip-up clasts, some reduced (reduced prior to rip-up) -Scours	Channel coarsening upward suggests either 1) channel re-occupation after flood, or 2) point-bar migration
1b	-Fine-medium grained sandstone -Dark red sandstone -Low-high angle planar cross beds	Superimposed Lingoidal Bars
2a	-Medium grained sandstone -Reddish purple brown -Planar bedding -Rip-up clasts, some reduced (reduced prior to rip-up) -Mottling	Minor Channel/ Scour Hollow
2b	-Medium grained sandstone -Dark red -Planar bedding -Visible porosity	Planar Bed Flows
3	-Medium grained sandstone -Reddish purple brown and pale greenish tan -Planar bedding -Rip-up clasts -Reduced zones -Mottling	Planar Bed Flows
4	-Medium grained sandstone -Dark red -Planar bedding with some cross bedding -Rip-up clasts -Several green sandstone layers	Planar Bed Flows
5	-Medium grained sandstone -Brownish red -Massive bedding	Paleosol?
6	-Interbedded medium grained sandstone and siltstone -Reddish purple brown and dark brown -Planar bedding -Rip-up clasts -Mottling	Deposits of Waning Flood
7	-Fine grained sandstone with clay interbeds -Very dark red-brown -Rippled -Burrows	Deposits of Waning Flood

after Miall (1977)



The Delaney Core from Cayuga County, the only core containing the Queenston Formation in our study area, reveals 182 feet thickness of sandstone (core does not exist deeper than 1816 feet). The cored strata are primarily composed of fine-medium quartz sandstone with hematite cement. Cross and planar beds are the dominant sedimentary structures throughout the core and rip-up clasts are common. There is one silt-dominated burowed interval at the top of the core, and one interbedded sandstone and siltstone zone at 1570 feet depth. There are no fossils in this core, and trace fossils (burrows) are rare. Color depicted in this figure represents approximate color variations in the actual core. Relatively low gamma log measurements correspond to the sandstone lithofacies, and peaks in the log are primarily associated to flooding surfaces, although rip-up clast rich layers appear to affect the gamma count. The density and neutron logs generally have an inverse relationship.

We used facies models pioneered by Miall (1977) to interpret the lithofacies and sedimentary structures in the Delaney core. Porosity and permeability data for the Delaney Well core could be compared to facies and system tracts. The flooding surface (FS) and lowstand system tracts (LST) were identified by core properties, and the transgression/regression arrows were drawn based well log and core variations.

In the Delaney and other wells, several distinct petrophysical zones (zones QA-QF, some zones are missing in this core) are revealed in gamma, neutron, and density logs, and these zones correspond to changes in lithology in the Delaney Core. The zones in the Delaney Well core with the highest average porosity and permeability are QB and QC, which are intervals of lateral variability produced by channel incision, although all zones have similar values (the entire length of zone QD is not represented by the core). We hope to further refine our CO_2 storage estimates by mapping individual zones within the Queenston Formation, which will also provide clues to the migration of depocenters during the Queenston time.