ABSTRACT:

Although geologists continue to find terrestrial rock formations that have the capacity to hold moderate amounts of carbon dioxide, the greatest potential for carbon sequestration in North Eastern United States lies in the offshore geologic formations that make up the continental shelf.

The Baltimore Canyon Trough (BCT) represents a portion of the continental shelf located approximately 80 miles south of Long Island and 50 miles east of New Jersey. Within the BCT, a 2,000 square mile study area has been established based on the availability of data from previous exploration. The recent acquisition of wireline logs from 21 wells in the study area has enabled correlation of numerous lithological units including potential carbon sequestration reservoirs and cap rocks. Porosity logs indicate some sandstone units may have multiple intervals with greater than 20% porosity. Capacity estimates calculated using this data suggest that this area may be capable of holding over 300 Gt of supercritical CO_2.

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Wireline Log Interpretations and Preliminary CO_2 Capacity Estimates for the Baltimore Canyon Trough

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The MRCSP is one of seven partnerships funded by the US Department of Energy to investigate the potential for carbon capture and storage (CCS) in the United States. During the first two phases of this project the MRCSP science team focused on compiling data and evaluating the potential for CCS in several of the terrestrial bedrock formations in the region. For example, here you can see a structure-contour map of the Mount Simon Sandstone produced by the partnership in Phase II.

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The MRCSP has not only been working for the last 8 years, it has also been growing. New York joined the partnership in 2005, and most recently, New Jersey joined the group in 2010. With the addition of these two states, along with Maryland (a member since the beginning), the MRCSP includes over 450 miles of coast line. This fact has encouraged the partnership to begin investigating the offshore CCS potential as part of its Phase III work. The focus of this research has been on the Baltimore Canyon Trough area outlined here in red.

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But before we get into the geology of the trough, I would like to take a second to look at how offshore CCS may differ from the onshore work the partnership has looked at so far. There are several here and I'm not going to get into all of them, but the first two really make a compelling argument on their own for why we should look offshore.

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The first of those two advantages is proximity to the larger CO_2 point sources. As you can see, there are several areas in the MRCSP region that have an abundance of large CO_2 emitters. One of those is the Tri-State region where several power plants and gas processing facilities are located near the coastline in NY City, Long Island, and New Jersey.

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Up to this point, the most promising formations for sequestration in NY have been located in the western part of the state, over 200 miles away. In comparison, if the Baltimore Canyon Trough is found to be suitable for CCS, it is about half that distance from NY City and even closer to New Jersey.

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Another advantage to looking offshore is the sheer size of the area available for investigation. This red outlined region is an 8,000 square mile area. That's almost as big as the entire state of New Jersey (~8700 mi^2). And although there have been 32 deep wells drilled in the area, it remains relatively unexplored and is for that reason alone worth a closer look.

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Moving on to the geology of our project area, I'm going to show you a series of paleogeographic maps that illustrate the formation of the Baltimore Canyon Trough. We begin about 245 million years ago when North America was part of the Pangea super-continent and New York was very close to the equator. You can see a rift zone beginning to form along the present day coast of North America.

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35 million years later, the rift zone has broadened and large lakes have formed at the bottom of grabens.

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Another 30 million years later (65 million years from our starting point) thinning of the continental crust along the rift zone allows entry of salt water.

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10 million years later (approximately 75 million years from our starting point) North America has completely separated from Pangea forming the earliest stages of the Atlantic Ocean.

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20 million years later, the Atlantic Ocean continues to grow. Topographic highs from the rifting are gradually eroded supplying the sediment as the continental shelf begins to take form..

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Here we have a depth to basement contour map of the area immediately east of New Jersey. You can see that the continental crust drops off dramatically from 2000 to 18000 meters in just 120 km. That’s a 46,000 foot change in depth in just 75 miles. You can consider this the side of the bowl, or basin, into which the sediments of the present continental shelf were deposited.

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Now if we compare that to this satellite image of the shelf today, you can see that there is a huge volume of space that has been filled by deposited sediments.

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Here we have an interpretive cross section of the basin. Notice the steep slope of the continental basement in agreement with the map from the previous slide. This large package of Jurassic and Cretaceous sediments which, as I will discuss, is home to multiple potential carbon sequestration targets.

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One of the first issues that became apparent when we began to take a closer look at lithology of the Baltimore Canyon Trough is that although several people had study this area before, no one had ever really given these rock units formal names. Perhaps the best attempt do so was the work of Jan Libby-French, who, in 1984, published a study in which she considered the BCT units to be homotaxial equivalents of the Scotian Shelf. This figure shows a generalized stratigraphic section of the Scotian Shelf along side the interpreted Baltimore Canyon equivalents. Note the Dawson Canyon, which is a shale or mudstone, the Logan Canyon, which is a sandstone unit that is divided into and upper and lower section by the Sable Shale, and the Naskapi mudstone and Missisauga Sand.

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Here we have a cross section from the same Libby-French paper. This connects three exploratory wells in the northeast corner of the BCT that run roughly parallel to the shelf edge. Note that the rock units she has identified do show a strong correlation to Scotian Shelf sediments. There is the Mississauga sandstone and the Logan Canyon which is broken up by the Sable Shale. There's also an unnamed sandstone unit that lies within the Dawson Canyon, and an unnamed carbonate above.

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Now if we overlay the gamma ray logs from these wells it becomes clear how she picked her tops and correlated these units. She makes a compelling argument for her comparison with the Scotian Shelf.

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Here's another cross section from her study, but this time we start with the middle well from the last section and move south then east. Again a large portion of lower section filled with the sands of the Missisauga and Logan Canyon, along with this unnamed sandstone in the Dawson Canyon. One thing we didn't see in the last section is the Abenaki Limestone equivalent appears only as you approach the shelf edge.

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If we overlay the gamma ray logs again, we can see that it isn't just a bunch of arm waving and there really are some obvious curve signatures to support her picks.

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But, I would be remised if I didn't point out that these same Cretaceous rock formations outcrop on Long Island, in New Jersey, and in Maryland. And a lot of time and effort has been spent onshore giving these rocks a different set of names, like the Raritan, the Bass River, and the Magothy.

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This correlation chart was one of the first products of the MRCSP's offshore research. I credit Pete Sugarman of the NJ survey for putting all this information together and giving us a means to easily translate between these two sets of names. For those of you who are familiar with bedrock formations of the area, the Missisauga appears to correlate with the Potomac Unit 1 and may extend into the upper Waste Gate Formation. The Logan Canyon correlates to the Potomac Units 2 and 3, and that unnamed sandstone in the Dawson Canyon lines up with the Magothy.

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Although there is a large portion of the Baltimore Canyon area that remains relatively unexplored, there is also a region in this eastern section that was drilled extensively between the 1940’s and 80’s when the Federal government allowed the permitting of offshore wells along the Atlantic Margin. This area contains a majority of the available data and has therefore been the focus of our work.

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Of the 51 wells that were drilled along the US Atlantic margin, 32 were located in the Baltimore Canyon Trough. Some tested high gas flows, however none went into production and all leases have reverted back to the government.

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The amount of information available for each well varies. Some have only the basic information that you would find in a completion report. Things such as location, completion date, and TD. Those wells appear white on this map. The green dots all represent wells for which we have wireline logs. In some cases it’s just a gamma ray curve, but in most instances we have density and neutron porosity curves as well. I should mention that these two wells, the COST B-1 and B-2 wells were drilled as part of the Continental Offshore Stratigraphic Test and have been thoroughly analyzed with all data available in the public domain. These wells have quickly become two of our most valuable data points.

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So, in following the examples set by Libby French, lets take a look at some cross sections. We will begin with a run along the shelf edge connecting these 10 wells. But before we begin, I should mention that our focus here is on the Logan Canyon simply because the Missisauga is too deep. Not that it’s too deep to be a viable sequestration reservoir. Only that at an average of 9 to 10 thousand feet deep, it would certainly not be the most cost effective place to begin looking.

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Here is a structure cross section through those wells. I have to apologize that the depths on these logs are impossible for you to read. Here the top of the Upper Logan Canyon is at about 8,000 feet and this section including the upper Logan Canyon, Sable Shale, Lower Logan Canyon and Naskapi is approximately 2,000 feet. What I really want to point out here is that the Upper Logan Canyon is a very easy pick to make. The Sable Shale, although thin, is continuous and can be traced across the entire section. Also, there really isn’t much change in depth or thickness here. There’s a little bit of thinning in the Lower Logan Canyon as move northeast, but this section isn’t hung on anything, it really is that flat and uniform.

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The next cross section covers these 6 wells in the northwest region of the explored area.

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Here you can see that the top of the Upper Logan Canyon is much more variable than before. We have a high here in wells 544-2, 632-1, and 544-1 and away from that these formations drop off significantly to either side. This is a change of over 1,000 feet. We're going to take a closer look at this in a minute, but before I do…

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I want you to see that even though there's clearly something going on right there. If we take the same cross section and flatten it on the top of the Upper Logan Canyon, you can see that just as in the first cross section, the thickness of these sandstones and shales remains relatively constant. There really isn't a whole lot of thickening or thinning.

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Now let's take a look at another section through theses wells which includes part of the flat lying area from the first section and part of the high.

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As you would expect, the Logan Canyon and associated shales are much higher in the west. Here we have a change of almost 2,000 feet. But notice that this carbonate layer, that we haven't really talked about much up to this point is at almost the same depth and all the accommodation for this additional space is taken up by a thicker section of Dawson Canyon mudstones and a bit of sand.

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So what's going on here? It turns out that there's a very prominent feature here known as the Schlee Dome, or Great Stone Dome. It is detectable here on seismic and it is the cause of the uplift we see in our cross sections.

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The Schlee Dome is interpreted to be associated with an intrusive igneous dike swarm. And it was an area of interest when the oil and gas industry began to explore the Baltimore Canyon Trough Area.

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Although no hydrocarbons were found in economic quantities, it was noted by Prather and others that this feature represents a significant structural closure. This is definitely an area we will be taking a closer look at as our research continues.

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So, let’s move on and try to make some capacity calculations based on what we know. The first thing we need is a reservoir thickness. Based on the tops we’ve picked in the wireline logs, the Upper Logan Canyon ranges from about 800 to 1100 feet thick with an average of 932 feet. The Lower Logan Canyon is a bit thinner. It ranges from about 450 to 1000 feet with an average of 650 feet. Together that’s approximately 1500 feet of potential reservoir rock.

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Next we need an area. I started this talk by saying that the Baltimore Canyon Trough covers an area of about 8000 square miles. But at this point it would be foolish to project the characteristics we’ve seen in the smaller 2000 square mile region across this entire area.

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So instead we will continue to focus on this 2,000 square mile area encompassing the majority of our well data.

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We also need some porosity data. I mentioned earlier that the two COST wells drilled in this area have been extensively studied. This includes porosity and permeability measurements derived from core samples. At this point pulling porosity values directly off the neutron logs is a bit risky. We’d like to start laboratory derived values, but you can see here that neutron porosity values do appear to agree with the measured porosity in the Upper and Lower Logan Canyon with values between 20 and 30%. We’re going to play it safe and use the low end 20% as our porosity.

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Next we need to know the pressure so that we can calculate the density of CO_2 under sequestered conditions. As it turns out, CO_2 has a maximum density of 700 kg/cubic meter, or 43.7 pounds per cubic foot. This density is reached at a depth of about 2.5km or 8,200 feet. And since the Logan canyon sandstones occur at or below this depth we should be able to use the maximum density of CO2 (43.7) in our capacity calculations.

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We also need to consider how much of the in situ formation fluid we intend to displace. The convention used by the MRCSP thus far has been to calculate capacities at 1, 2.5 and 4% displacement. Here we have our capacities based on those numbers. On the low side, this area has an estimated capacity of over 3,000 million metric tons or 3 gigatons. On the high side we have over 13,000 million metric tons. Now to put that into perspective, the cumulative CO_2 output for 7 states closest to this area is 180 million metric tons (Need to double check this number). This means that the our target area could potential hold as much as 19 to 77 years of CO2 output from these states at current rates.

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If we throw caution to the wind and apply these numbers to the larger 8,000 square mile area, we get capacities upward of 55,000 million metric tons or 307 years of capacity.

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There are just a few more things I want to touch on quickly. One is the role that salinity play on the storage of CO_2 over time. The immediate storage mechanism is displacement of formation fluids, but over time, that carbon dioxide dissolves into the formation fluid. This graph shows that the solubility of CO_2 in brine decreases dramatically with increased salinity. This has been one of the hardest things to deal with when looking onshore in New York. All of the reservoir quality rocks have such high salinities that very little CO_2 will dissolve. But these offshore formations have much lower salinities; between 4 and 8 wt%. This means that much more of the CO_2 will go into solution.

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A team of scientists at Berkeley Labs are currently looking into dissolution and convection of sequestered CO_2. We know that injected CO_2 forms a plume at the top of the reservoir (this is nothing new) but as that CO_2 diffuses into the formation brine, it becomes denser than CO_2 free brine and begins to sink. This churns up fresh brine creating a convection that encourages more CO_2 to dissolve.

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One last thing before I finish. These 3 wells drilled off the shelf edge on the continental slope…

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have penetrated a prograding carbonate reef which is equivalent to the Abenaki formation according to Libby French. Eliuk and Prather published a study of these carbonates in 2008 and found porosities of over 10%. This is another potential sequestration target that we will be investigating in the future.

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So, just to go over some conclusions quickly. The advantages of offshore sequestration include proximity of large point sources, a vast area of potential reservoir, and lower salinities should increase capacity. We have followed the precedent set by Libby French and applied the formation names of the Scotian Shelf to the Baltimore Canyon Trough formations. We have correlated the available wireline logs and found the Upper and Lower Logan Canyon to be continuous over the 2000 square mile study area. The Logan Canyon has porosity and permeability values that are favorable for co2 storage. Depending on how far to want to project those values we could be looking at storage capacities in excess of 50 gigatons. And features such as the Schlee dome and Abenaki reef are areas we'd like to take a closer look at.

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As our work continues, we need to take a closer look at the Shale units and their viability as sealing layers. We'd like to do some modeling. As I said before we want to take a closer look at the Schlee Dome and carbonate reefs. But most importantly, we need to work with the wireline logs more and try to get some porosity values that we are confident in. And we need to look at the seismic data that is available to see if we really can project these units across the larger 8,000 square mile area.