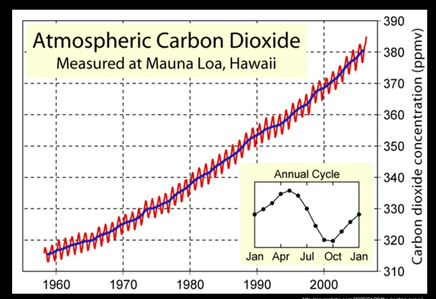
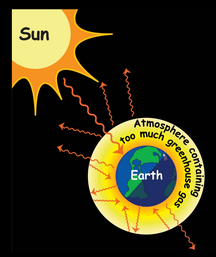
The Physical Analysis of Borehole Core Samples to Assess the Carbon Storage Potential of the Newark Basin

Introduction

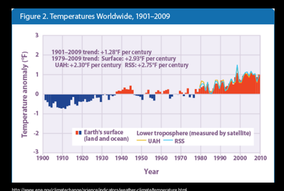


http://asymptotia.com/2008/01/28/the-keeling-curve/

In 1958, Charles David Keeling began measuring carbon dioxide concentration levels in atmosphere.
The compilation of this research has become known as the infamous **Keeling Curve**, showing a dramatic increase in atmospheric CO_2 concentration over past few decades.



http://spaceplace.nasa.gov/greenhouse-gas-attack/greenhouse-gas-drawing-sg.png



http://www.epa.gov/climatechange/science/indicators/weather-climate/temperature.html

- Atmospheric CO_2 concentrations higher than they have been in the past 800,000 years
- **Greenhouse Gas Effect** ➡ increase average global temperature
  - Detrimental impacts on the environment

EPA, 2012; Kristof, 2012; Schmidt, 2007

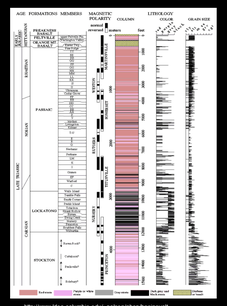
http://environment.nationalgeographic.com/environment/global-warming/gw-overview/

http://www.weatherquestions.com/Hurricane-Sandy-Satellite-Photo-Gallery-and-Videos-of-Hurricane-Sandy-Photos-and-Videos-of-Hurricane-Sandy.jpg

Research Questions

Does the Newark Basin contain layers of porosity suitable for carbon sequestration?
If so, what is the carbon storage potential of the suitable layers?

Newark Basin Log



http://www.ldeo.columbia.edu/~polsen/nbcp/basinevolutk.html

Sample List

core	sampled depth (ft)	color	grain size	sample #
Martinsville	577.00-577.25	gray	claystone, mudstone	1
	1030.50-1030.70	green	basalt	2
	2468.80-2468.95	red	siltstone, fine sandstone	3
Somerset	2683.50-3683.60	red	siltstone, fine sandstone	4
Rutgers	599.90-600.00	gray	mudstone	5
	1859.10-1859.20	red	mudstone, siltstone	6
	2011.95-2012.00	black	mudstone	7
	2242.40-2242.45	gray-black	mudstone	8
	2788.70-2788.80	gray-black	mudstone	9
Titusville	76.15-76.20	gray-black	mudstone	10
	1766.25-1766.30	red	fine sandstone	11
	2586.40-2586.45	gray-black	mudstone	12
Nursery	360.20-360.25	black(gray)	claystone (mudstone)	13
	917.60-917.70	gray-black	mudstone	14
	1357.05-1357.15	red	siltstone	15
	1738.75-1738.80	black	mudstone	16
Princeton	521.50-521.55	purple-gray	fine sandstone	17
	826.50-826.55	gray-black	siltstone	18
	1432.95-1433.00	purple-gray	coarse sandstone	19
	2082.95-2083.00	gray	fine sandstone	20

Author photos

Calculations & Corrections

Dry Weight

1. String correction: Subtract weight of string
2. Air buoyancy

$$\rho(\text{air}) = \frac{3.4848\,(p - 0.0037960\,U \cdot e_s)}{273.15 + t} \times 10^{-3}$$

where

p = air pressure (kPa),
U = relative humidity (%),
t = temperature (°C),
e_s = saturation vapor pressure (kPa),

$$e_s = 1.7526 \times 10^{8} \exp\left[-5315.56/(t + 273.15)\right].$$

$$m = w\left(\frac{1 - \rho(\text{air})/\rho(\text{weights})}{1 - \rho(\text{air})/\rho(\text{sample})}\right)$$

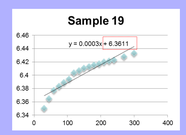
Guide

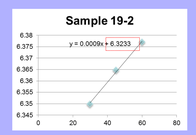
Impact of Air Buoyancy Correction on Mass

Sample	Air T	Original Dry WT	Corrected Mass
1	24	27.643	27.651
2	23.7	21.413	21.418
3	23.5	17.960	17.965
4	23.5	16.376	16.381
5	23.5	11.736	11.740
6	23.5	16.760	16.765
7	23.3	10.791	10.794
8	23.2	14.868	14.872
9	22.8	20.611	20.617
10	23	16.315	16.319
11	23	13.407	13.411
12	23	18.774	18.779
13	23	18.025	18.031
14	23	15.088	15.092
15	23	17.486	17.491
16	23	21.204	21.210
17	23	16.196	16.200
18	23	10.076	10.079
19	23	10.906	10.909
20	23	14.808	14.812

Submerged Weight

3. Projected weight at time of initial submersion (no saturation)





Impact of Adapted Trendlines on Select Samples' Submerged Weight

Sample	Original Subm. WT	Adapted Subm. WT
3	2.653	2.651
5	2.624	2.623
6	2.688	2.687
19	2.399	2.379
20	2.447	2.433

Methods

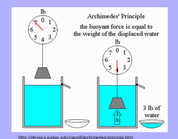
Measurement of Bulk Density

(g/cm³)

$$\frac{\text{Dry Weight}}{\text{Volume}}$$

(Weight of Displaced Fluid ÷ Density of Fluid)

1. Dry Weight
   - ~ Dried samples 24+ hours at 100°C
2. Submerged Weight ➡ Volume
   - ~Archimedes' principle
   - ~Instantaneous saturation: timed saturation & projected submerged weight



http://physics.weber.edu/carroll/pc/archimedes/principle.htm

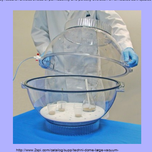
Measurement of Porosity

(%)

$$\frac{\text{Volume of Void}}{\text{Volume of Body}}$$

1. Dry Weight
2. Submerged Weight
3. Saturated Weight
   - ~Under vacuum 150 hours
   - ~Instantaneous saturation: Saran wrapped samples and weighed

http://earthquakes.doi.org/research/articles/effects-of-permeability-and-porosity-on-fluid-induced-seismicity.html



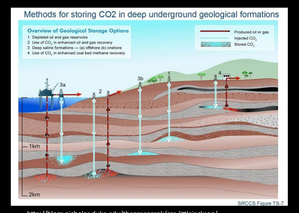
http://www.2spi.com/catalog/supp/feathm-dome-degas-vacuum-desiccator.php

Temperature: 23°C
Density of Water: 0.9975 g/cm³

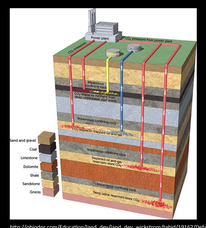
http://allthuse.blogspot.com/2007/02/polar-bears-on-melting-ice-cap-photo.html

http://knowledge.allianz.com/?119/what-is-global-warming

Carbon Sequestration



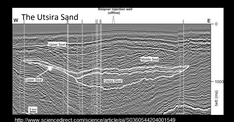
http://blogs.nicholas.duke.edu/thegreengrok/ccs-littlejackson/



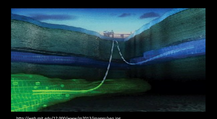
http://ohiodnr.com/Education/land_dev/land_dev_wickstrom/tabid/19162/Default.aspx

- Storage of CO_2 in geologic formations for long-term isolation from the atmosphere
  - Necessities: High permeability and solid caprock
- Utsira Sand, Sleipner field, Norway: effectively sequestering CO_2 in extremely porous sandstone saline aquifer since 1996

Arts, 2008; Goldberg, 2008

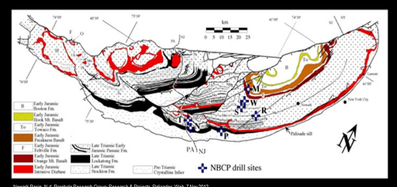


http://www.sciencedirect.com/science/article/pii/S0300544204001549



http://web.mit.edu/12.000/www/m2013/maps/ves.jpg

The Newark Basin



Newark Basin. N. d. Borehole Research Group-Research & Projects, Palisades. Web. 7 Nov 2012

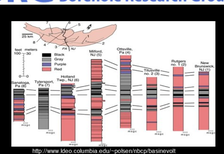
- Sedimentary rift basin covering over 7,000 km²
- Located in close proximity to high-emitting CO_2 states (NJ, NY, PA)
- TriCarb Project currently assessing the basin's CO_2 injectivity, storage capacity, and sequestration effectiveness

TriCarb, 2012; Olson, 1996

The Newark Basin Coring Project

http://www.ldeo.columbia.edu/BRG/

BRG Borehole Research Group



http://www.ldeo.columbia.edu/~polsen/nbcp/basinevolution.html

- Drilling project from 1989-1994 to recover record of ancient continental climate change and reveal the history of the Newark Basin
- Recovered over 6,770m of continuous cores from 7 sites and geophysical borehole logs

Burgdorff, 2012; Matter, 2006; Goldberg

Bulk Density

$$\frac{\text{Dry Weight}}{\text{Volume}}$$

(Weight of Displaced Fluid ÷ Density of Fluid)

Weight of Displaced Fluid = (Dry WT– Submerged WT)

- ÷density of water
- –volume of string

Porosity

$$\frac{\text{Volume of Voids}}{\text{Volume of Body}}$$

- Volume of Voids = (Saturated WT– Dry WT) ÷ density of water
- Volume of Body = (Dry WT– Submerged WT) ÷ density of water

Results

Lab Data

Results		
Sample	Bulk Density (g/cm³)	Porosity
1	2.678	0.4%
2	2.914	1.6%
3	2.649	
4	2.713	2.6%
5	2.622	5.5%
6	2.686	
7	2.692	1.9%
8	2.708	0.9%
9	2.727	1.6%
10	2.660	3.5%
11	2.776	1.2%
12	2.672	0.6%
13	2.647	0.8%
14	2.707	1.0%
15	2.697	0.6%
16	2.717	1.5%
17	2.763	0.5%
18	2.699	1.3%
19	2.378	10.6%
20	2.432	10.3%

- Porosities: 0-5%
- Ideally 20-25%
- Sample 19: 10.6%
  Sample 20: 10.3%

Quartz Calibration

Quartz (calibration measurements)					
Date	Air T	Water T	Dry WT	Sub WT	Density
24-May	23.2	22.7	12.687	7.5058	2.441
24-May	23.2	23.2	12.6875	7.913	2.640
24-May	23.2	23	12.709	7.9085	2.639
24-May	23	22.9	12.6717	7.895	2.645
4-Jun	23.2	23	12.6712	7.8986	2.647
4-Jun	23	23	12.6715	7.8984	2.647
6-Jun	23.2		12.671	7.8989	2.647
6-Jun	23.2	23	12.6707	7.8956	2.645
12-Jun	23	22.9	12.6706	7.8964	2.646
12-Jun	23.2	23	12.6706	7.8957	2.646
13-Jun	23.5	23	12.6709	7.9074	2.652
13-Jun	23.5	23	12.6709	7.8972	2.646
26-Jun	22.8	22.8	12.6709	7.8926	2.644
26-Jun	23.2	23	12.6737	7.9116	2.653
26-Jun	23.5	23	12.6756	7.9029	2.648
28-Jun	22.8	23	12.6714	7.901	2.648
28-Jun	23	23	12.6703	7.8979	2.647
				Average:	2.647
				Stan. Dev:	0.003

Calculations applied to quartz measurements to measure accuracy & precision

- Actual density of quartz: 2.648 g/cm³

Borehole Data

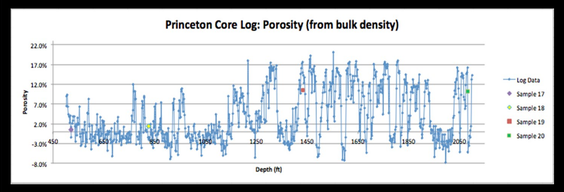
Borehole Log: record of a geologic formation penetrated by a borehole or well

-Correlates depth/thickness of layers with properties (such as bulk density, porosity, etc.)

Newark Basin Coring Project

-Geophysical logs for the 7 continuous cores

-Converted bulk density log to porosity log for Princeton core (450 ft-3000 ft)



Plotted samples 19 and 20 to identify depths of porosity layers:

Sample 19: 1416-1442 ft (26 ft)

Sample 20: 2072-2084 ft (12 ft)

Storage Potential

$$Q = V * \phi * e * \rho$$

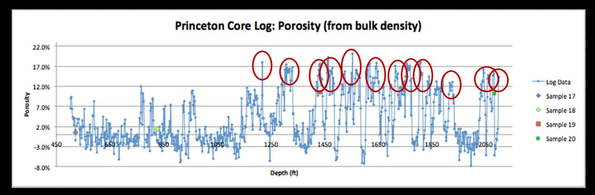
V – total volume of reservoir (km³)

ρ – CO_2 density (kg/m³)

e – storage efficiency (%)

ϕ – reservoir porosity (%)

Sample 19 = 91,000 $MtCO_2$
Sample 20 = 41,000 $MtCO_2$
= 132,000 $MtCO_2$



Volume
Length: 10 km
Width: 10 km
Depths: Sample 19: 0.0079 km
Sample 20: 0.0037 km

Storage Efficiency: 15%
-Average of range (2-30%)

CO_2 Density: 725 kg/m³
~Temperature increases 25°C/km
~Pressure increases 250 bar/km

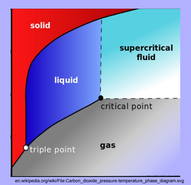
Finney

Porosity
Sample 19: 10.6%
Sample 20: 10.3%

132,000 $MtCO_2$ X 12 layers of similar porosity
=1,584,000 $MtCO_2$
(per 1.16 km³)

Discussion

- CO_2 transitions into a supercritical fluid at ~100 bar and 300 K
- Samples 19 and 20 are located at depths too close to the transition point
  ➡ Unsafe/unstable conditions
- Sequestration preferred around 3,000 ft



en.wikipedia.org/wiki/File:Carbon_dioxide_pressure-temperature_phase_diagram.svg

Finney

EPA CO_2 Emissions

- United States Environmental Protection Agency released state-by-state CO_2 emissions from 1990-2010

New York	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
	207.70	199.89	199.26	193.97	191.89	197.51	200.22	204.54	203.27	205.69	211.55	207.43	201.80	210.71	214.74	211.45	193.92	200.64	191.72	178.56	173.83
Commercial	26.82	26.47	27.53	28.20	27.67	26.92	27.76	29.62	27.69	30.18	32.05	30.65	31.19	32.73	34.69	28.55	29.37	26.65	25.70	25.34	25.02
Industrial	20.25	19.45	20.71	20.33	20.55	22.38	23.14	22.42	21.51	17.82	17.29	16.51	15.07	14.33	14.34	15.14	14.81	14.12	13.66	11.38	10.29
Residential	33.78	33.01	36.39	35.82	35.41	34.38	36.72	34.83	31.74	34.45	39.41	38.36	36.11	36.76	38.24	39.23	32.60	36.39	34.62	32.90	31.73
Transportation	64.11	62.48	61.00	62.22	60.99	62.73	65.91	65.89	66.41	66.80	67.17	67.14	68.77	73.20	75.37	73.75	74.82	74.56	75.16	72.80	69.02
Electric Power	62.78	58.48	53.64	47.40	47.27	51.10	46.66	52.15	55.91	56.65	55.63	54.77	50.65	51.68	52.11	54.77	46.32	48.92	42.58	34.14	37.76

New York Emissions 2010: **174 $MMtCO_2$**

- This investigation studied a cube of 1.16 km³ (38 ft of depth) from this extremely vast basin.
- <u>Theoretically:</u> The volume of the basin is 15E5 km³ and with 10% porosity yields a carbon storage potential of **163,000 $MMtCO_2$**

EPA, 2012

http://sustainability.asu.edu/news/gios-news/asu-epa-partner-to-engage-students-in-green-careers/

Conclusion & Future Research

- ✓ Proved existence of high porosity layers of Newark Basin
- ✓ Broadened knowledge of Newark Basin

- Further investigate depths around high porosity samples
- Study at greater depths
- Locate low-porosity caprocks
- Chemical analysis

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