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Is Carbon Sequestration in Arizona's Future?

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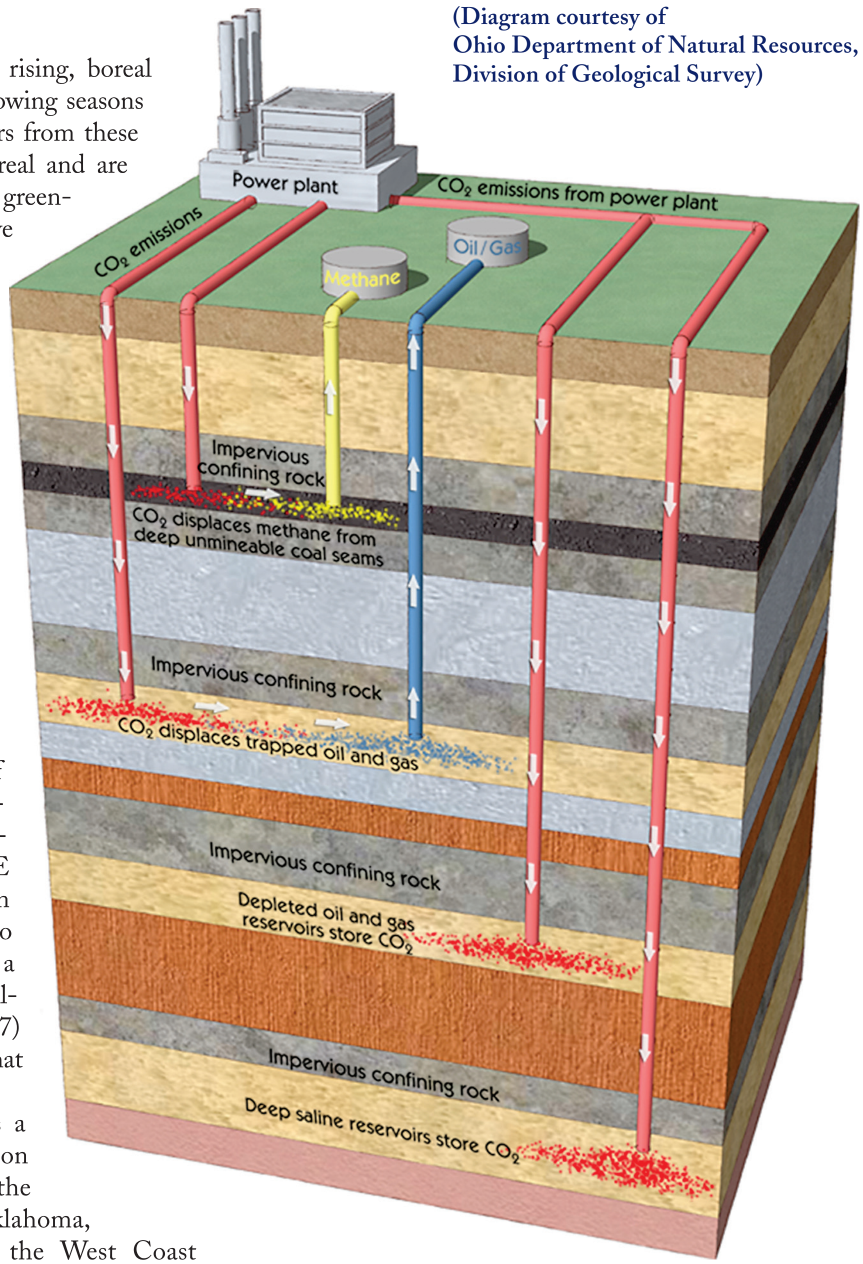
INTRODUCTION

Continental glaciers are retreating, sea levels are rising, boreal forests are shifting northward, and cold-climate growing seasons are lengthening. Although there are some dissenters from these views, many would argue that these changes are real and are caused by, or at least exacerbated by, anthropogenic greenhouse gas emissions. Worldwide, many scientists have rallied around the notion that anthropogenic greenhouse gases, led by carbon dioxide (CO_2) production, will become, or may be already, a major cause of global warming.

Geological sequestration involves capturing CO_2 emissions from power plants and other sources and injecting it deep underground where it is securely stored.



(Diagram courtesy of Ohio Department of Natural Resources, Division of Geological Survey)

In an effort to control CO_2 emissions, especially if and when costs are significantly reduced for capture from power plants, the U.S. Department of Energy (DOE) formed a nationwide network of regional partnerships to explore the potential of storing CO_2 – carbon sequestration – in geologic reservoirs (http://www.netl.doe.gov/technologies/carbon_seq/partnerships/partnerships.html). The DOE established three phases to the carbon sequestration initiative: a Characterization Phase (2003-2005) to identify opportunities for carbon sequestration; a Validation Phase (2005-2009) to implement small-scale field tests; and a Deployment Phase (2008-2017) to conduct large volume carbon-storage tests. What role can Arizona play?

The Arizona Geological Survey (AZGS) is a member of the Southwest Regional Partnership on Carbon Sequestration (SWP), which includes the states of Arizona, Colorado, New Mexico, Oklahoma, Utah, and parts of Texas and Wyoming and the West Coast Regional Carbon Sequestration Partnership (WESTCARB), which includes the states of Alaska, Arizona, California, Oregon, Nevada, and Washington. In Arizona,

Mission

To inform and advise the public about the geologic character of Arizona in order to increase understanding and encourage prudent development of the State's land, water, mineral, and energy resources.

Activities

Public Information

Inform the public by answering inquiries, preparing and selling maps and reports, maintaining a library, databases, and a website, giving talks, and leading fieldtrips.

Geologic Mapping

Map and describe the origin and character of rock units and their weathering products.

Hazards and Limitations

Investigate geologic hazards and limitations such as earthquakes, land subsidence, flooding, and rock solution that may affect the health and welfare of the public or impact land and resource management.

Energy and Mineral Resources

Describe the origin, distribution, and character of metallic, nonmetallic, and energy resources and identify areas that have potential for future discoveries.

Oil and Gas Conservation Commission

Assist in carrying out the rules, orders, and policies established by the Commission, which regulates the drilling for and production of oil, gas, helium, carbon dioxide, and geothermal resources.

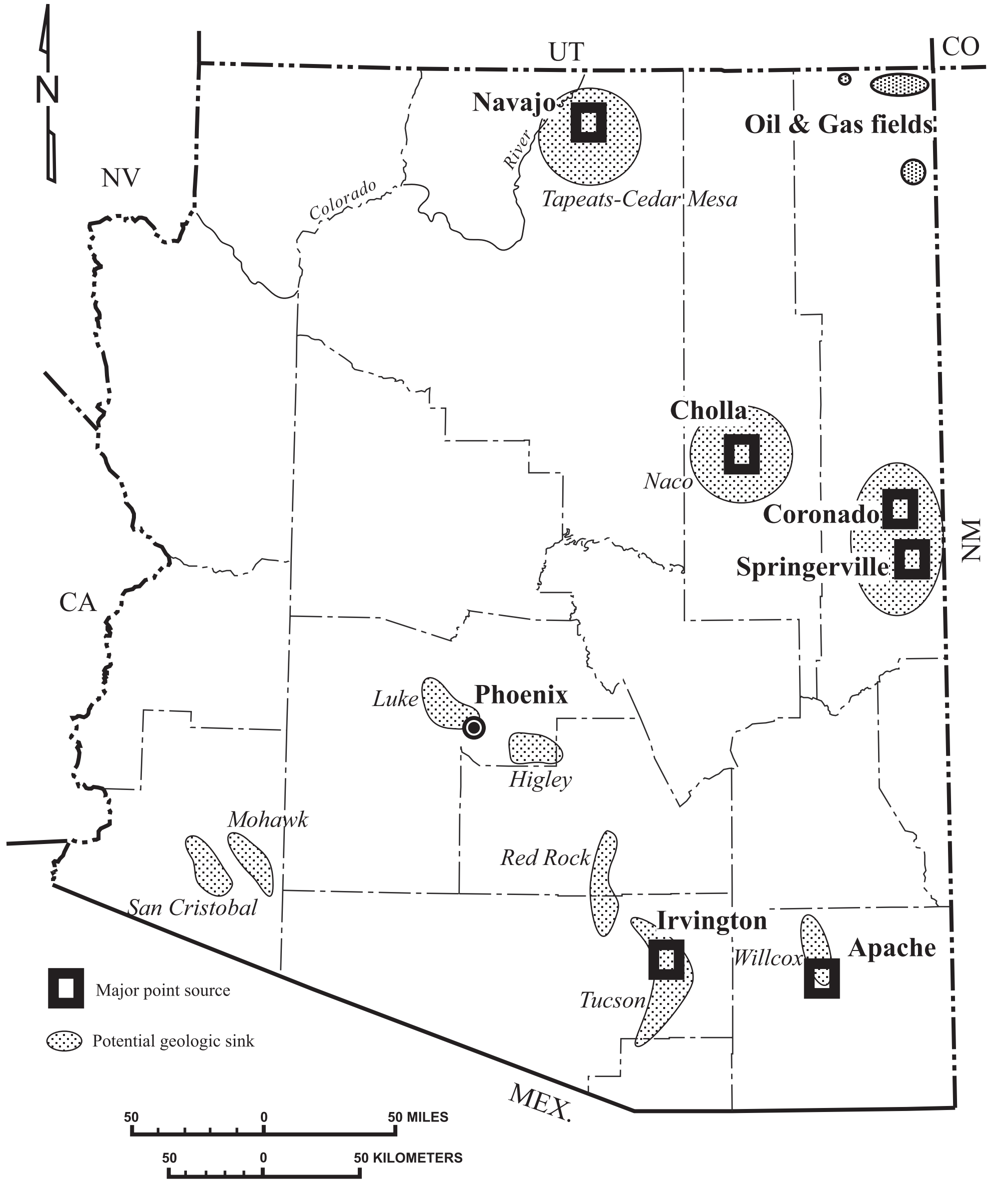


Figure 1. Major point sources and potential geologic sinks in Arizona

the AZGS investigated potential geologic carbon-sequestration sites during the characterization phase by compiling data on potential geologic sinks such as oil and gas fields, deep reservoirs not associated with oil and gas, and unminable coal seams.

A good geologic sink is close to a CO_2 emission source, has porous and permeable (reservoir) rock surrounded by impermeable (seal) rock to prevent leakage, is preferably deeper than 2,600 ft so that (hydrostatic) overburden pressure will keep the CO_2 in a high-density, liquid-like state, and has a large reservoir volume.

No sites for small-scale field tests were identified in Arizona by the SWP, but WESTCARB identified three potential sites to investigate the storage capacity of deep reservoirs beneath power plants in northern Arizona. One validation-phase test is scheduled to begin in the first half of 2008. Neither the SWP nor WESTCARB identified any areas in Arizona for deployment phase tests.

Major utility point sources of CO_2

The six major utility point sources in Arizona discharged 41 million metric tons of CO_2 in 2002 (Table 1). The Navajo Generating Station near Page was the leader, discharging 18 million metric tons of CO_2. The Cholla plant came in a distant second at eight mil-

Table 1. Potential Carbon Sequestration Capacity for Arizona (in Million Metric Tons)

	CO_2 Emissions in 2002	Total Geologic Sink Capacity
Navajo	18	24,094
Cholla	8	401
Springerville	6	18
Coronado	5	18
Apache	3	629
Irvington	1	186
Red Rock	0	366
Higley	0	469
Luke	0	386
Mohawk	0	688
San Cristobal	0	252
Oil & gas fields	0	14
Total	***41***	***27,521***

lion metric tons. All six major utility point sources are located over potential deep reservoirs. None of the major utility point sources are located near oil and gas fields.

Sequestration capacity of geologic sinks in Arizona

We estimated that the total CO_2 sequestration capacity of geologic sinks in Arizona was about 27,520 million metric tons (Table 1). Deep reservoirs on the Colorado Plateau of northern Arizona and the intermountain basins of southern Arizona account for essentially all of this capacity even though they have greater uncertainty as to CO_2 retention effectiveness as compared to the oil and gas fields (Figure 1). We did not estimate the CO_2 sequestration capacity of coal because the deepest Arizona coal deposits are less than 2,000 ft, which is too shallow to keep CO_2 in a liquid-like state.

Oil and Gas Fields. There are 14 small oil and gas fields in northeastern Arizona (Figure 1) with total CO_2 sequestration capacity of about 14.1 million metric tons (less than one thousandth of the total for Arizona). Only two of the fields are large enough to be considered by the SWP as preferable geologic sink candidates. These two are the Dineh-bi-Keyah field with a cumulative past oil production of 18.3 million barrels and the East Boundary Butte field with a cumulative past gas production of 10 billion cubic feet. The total estimated sequestration capacity of Dineh-bi-Keyah and East Boundary Butte is 11 million metric tons, which is sufficient for three months of Arizona CO2 emissions at current emission rates. Neither field is in close proximity to a major point source of CO_2.

Deep reservoirs. The total maximum CO_2 sequestration capacity for the ten deep reservoirs identified in Table 1 is estimated at 27,500 million metric tons. Three of the deep reservoirs are in rocks of Paleozoic age near Page, Holbrook, and St. Johns in northern Arizona. The remaining seven are basin-fill sediments located in the Tertiary basins of southern Arizona. Six of the deep reservoirs underlie major utility point sources of CO_2 including the Navajo, Cholla, Coronado, and Springerville power plants in northern Arizona, and the Apache and Irvington power plants in southern Arizona (Figure 1).

The paucity of deep drill holes, particularly in the Tertiary basins, greatly limits our knowledge of potential deep reservoirs. We estimated porosity, depth and thickness on driller's descriptions and old electrical logs from the limited number of deep wells that were available. We used the 3,000 ft depth-to-bedrock contour to estimate the area of the deep reservoirs in the Tertiary basins that are deeper than the 2,600 ft depth needed to keep the CO_2 in a near-liquid state.

Navajo Generating Station

The Navajo Generating Station (NGS) receives special focus here because it produces nearly 50 percent of stationary point-source CO_2 emissions in Arizona (Table 1). The 2,400 MW coal-fired NGS is approximately five miles southeast of Page on property leased from the Navajo Nation.

Potential CO_2 sequestration reservoirs underlying the NGS include the Kaibab Limestone, Coconino Sandstone, and Cedar Mesa Sandstone of Permian age; the Redwall Limestone of Mississippian age; and the Tapeats Sandstone of Cambrian age. Important reservoir seals are the Muav Limestone, Bright Angel Shale, Organ Rock Shale, and Chinle and Moenkopi Formations. Table 2 shows the estimated reservoir and seal depths and thicknesses underlying the NGS.

There are no deep exploratory wells in the immediate vicinity of the NGS. Formation depths and thickness

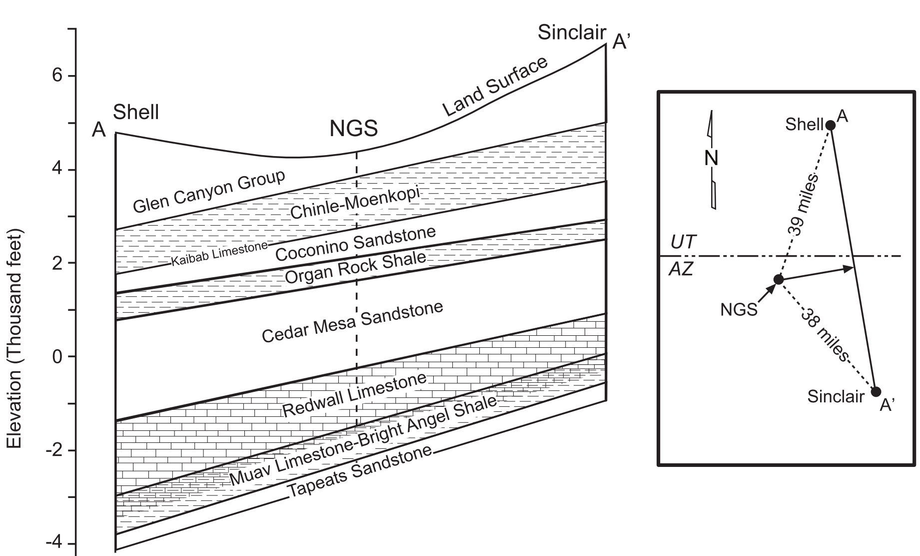


Figure 2. Potential deep reservoirs beneath Navajo Generating Station

Table 2. Stratigraphic units beneath Navajo Generating Station			
Formation Name	Elevation of Formation top above sea level (ft)	Depth to top of Formation (ft)	Estimated Formation Thickness (ft)
Chinle-Moenkopi	3825	525	1155
Kaibab Limestone	2670	1680	15*
Coconino Sandstone	2655	1695	555
Organ Rock Shale	2100	2250	455
Cedar Mesa Sandstone	1645	2705	1315
Redwall Limestone	-235	4585	545
Muav Limestone-Bright Angel Shale	-1525	5875	615
Tapeats Sandstone	-2140	6490	330
* Assumes Kaibab pinches out at the Sinclair Oil Navajo Tribal #1 well			

estimates below the NGS are projected from formation tops in the Shell Soda Unit #1 well in Utah and the Sinclair Oil Navajo Tribal #1 well in Arizona. The Shell and Sinclair wells are approximately 39 miles northeast and 38 miles southeast of the NGS, respectively. Figure 2 illustrates the location of the two wells and the subsurface geology at the NGS.

Kaibab Limestone and Coconino and Cedar Mesa Sandstones. The Kaibab Limestone and Coconino Sandstone are the chief groundwater aquifers on the southern part of the Colorado Plateau where the two strata are connected hydraulically and form the C-multiple aquifer system. The Kaibab and Coconino are not used as aquifers on the northern part of the Colorado Plateau. The Kaibab Limestone is not present in the Sinclair well and, assuming the unit pinches out at the well, is of negligible thickness (15 ft) beneath the NGS. The projected Coconino Sandstone thickness below the NGS is approximately 550 ft.

The Kaibab and Coconino are above a depth of 2,600 ft in the vicinity of the NGS (Table 2, Figure 2) making them unsuitable geologic reservoirs for carbon sequestration.

The Cedar Mesa Sandstone, at a depth of about 2,700 ft, is the shallowest deep reservoir below the preferred depth of 2,600 ft and underlies approximately 455 ft of Organ Rock Shale, which is a good seal that would prevent the potential escape of sequestered CO_2. The Cedar Mesa Sandstone is projected to be about 1,300 ft thick below the NGS.

Redwall Limestone. The Redwall Limestone, at a projected depth of about 4,585 ft below the NGS, is deep enough to keep sequestered CO_2 in a near liquid state. Permeability and porosity in the Redwall is mostly in the form of numerous solution channels and cavities. The Redwall is about 540 ft thick in the Sinclair well and 595 ft thick in the Shell well. The estimated thickness underlying the NGS is 545 ft.

Tapeats Sandstone. The Tapeats Sandstone, with approximately 6,500 ft of overburden, is the deepest reservoir under consideration for CO_2 sequestration at the NGS. It is not considered an aquifer due to its depth and salinity. The Hopi have used seeps from the Tapeats near the mouth of the Little Colorado River as a source of salt. Lenses of conglomerate near the basal contact of the Tapeats may enhance its reservoir volume. The Sinclair well did not fully penetrate the Tapeats but the Shell well penetrated 215 ft of Tapeats. The estimated thickness underlying the NGS is 330 ft.

Other Generating Stations

The Cholla power plant is underlain by potential sequestration reservoirs in the Naco Limestone of Pennsylvanian age. Injection targets include carbonate or clastic rocks within the Naco at depths of 2,500 to 3,000 ft., and possibly Devonian-age rocks below 3,000 ft. Extensive salt deposits may provide effective seals. The Naco is estimated to be about 900 ft thick at the Cholla power plant.

The Coronado and Springerville power plants overly porous and permeable clastic rocks of Permian age. However, shallow depths to the potential reservoir rocks, generally less than 2,600 ft to granite, and low (hydrostatic) overburden pressures are issues that need further evaluation at these sites.

The Apache and Irvington power plants near Wilcox and Tucson, respectively, are located on thick, basin-fill clastic deposits of Tertiary age. The basin-fill deposits are potential sequestration reservoirs with injection targets ranging from 2,500 to 6,000 ft.

Conclusion

Deep reservoirs offer good potential for carbon sequestration near existing and possible future power plants in Arizona. All that is needed now is additional drilling and coring to obtain direct information about the thickness and extent of the potential reservoir rocks and seals and to confirm the capacity of these geologic sinks.

—continued on page 5

FYI: We did not publish a winter-2007 issue (Vol. 37, No. 4) of Arizona Geology.

—*continued from page 4*

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Dramatic Increase in Oil & Gas Leasing in Arizona 2007-2008

Oil, natural gas, helium, and carbon dioxide (CO_2) prices are on the rise. In Arizona, the acreage being leased is increasing, too. Between January and December 2007, State and Federal land leased for oil and gas increased nearly three fold from 401,000 to 1.075 million acres. The biggest increase is for oil and natural gas in northern Arizona.

So far in 2008, Arizona's Oil and Gas Commission issued 21 permits to drill, with ten wells drilled; in 2007 three permits were issued and eleven wells were drilled. We anticipate that permitting and drilling activity will remain strong throughout 2008. So far, all activity involves CO_2 and helium between St. Johns and Springerville in west-central Arizona. The biggest use of CO_2 is for enhanced recovery in old oil fields.

Landslide closes Hy 87 near Payson. For AZGS preliminary reports, images, annotated aerial photographs, Geology of the Kitty Joe Canyon Area & more visit us at www.azgs.az.gov/hazard_hwy87landslide_mar08.html

AZGS Presentations @ GSA Cordillera-Rocky Mtn Section, March 19-21

Abstracts available online through Geological Society of America at http://gsa.confex.com/gsa/2008CD/finalprogram/

Title	Authors
Arizona Geological Survey Earth Fissure Mapping Program	Todd C.Shipman, Mimi Diaz, Mike Mahan, and Bryan Macfarlane
Informing the Public of a developing geologic hazard in rapidly Urbanizing areas of South-Central Arizona	Todd C.Shipman, Michael Conway, and Mimi Diaz
The Espiritu Canyon Shear Zone in the Footwall of the San Pedro – Catalina Detachment Fault East of Tucson, Arizona: an Exhumed, Deep-Seated Segment of the San Xavier Detachment Fault?	Stephen M. Richard
Influence of the Maria Fold and Thrust Belt on Styles of Oligo-Miocene Extension in Western Arizona: Application of Critical-Taper Theory	Jon E. Spencer
Silver Creek Caldera, Probable Source of the Miocene Peach Spring Tuff, Oatman Mining District, Arizona	Charles A. Ferguson

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Come see us! (www.explorearizona.org; 602.417.9300)

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