Enhanced Oil Recovery and CO_2 Resource Studies at the U.S. Geological Survey

P. D. Warwick and U.S. Geological Survey Geologic Carbon Dioxide Storage Resources Assessment Team

The 12th Annual (2014) EOR Carbon Management Workshop – Midland, Texas
Part of the Annual CO_2 Conference Week December 8-12, 2014

U.S. Geological Survey
Department of the Interior

Outline for Presentation

- Energy Independence and Security Act
- Helium Stewardship Act of 2013
- Current activities associated with CO_2-EOR
- Current activities associated with natural CO_2
- Current activities associated with natural He
- Summary

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Energy Independence and Security Act 2007

TITLE VII—CARBON CAPTURE AND SEQUESTRATION

Subtitle B—Carbon Capture and Sequestration Assessment and Framework

SEC. 711. CARBON DIOXIDE SEQUESTRATION CAPACITY ASSESSMENT.

(b) METHODOLOGY— …shall develop a methodology for conducting an assessment under subsection (f), taking into consideration—

(1) the geographical extent of all potential sequestration formations in all States;

(2) the capacity of the potential sequestration formations;

(3) the injectivity of the potential sequestration formations;

(4) an estimate of potential volumes of oil and gas recoverable by injection and sequestration of industrial carbon dioxide in potential sequestration formations;

(5) the risk associated with the potential sequestration formations; and

(6) the work done to develop the Carbon Sequestration Atlas of the United States and Canada that was completed by U.S. Department of Energy (DOE).

(c) COORDINATION—

(1) Federal Coordination

(2) State Coordination

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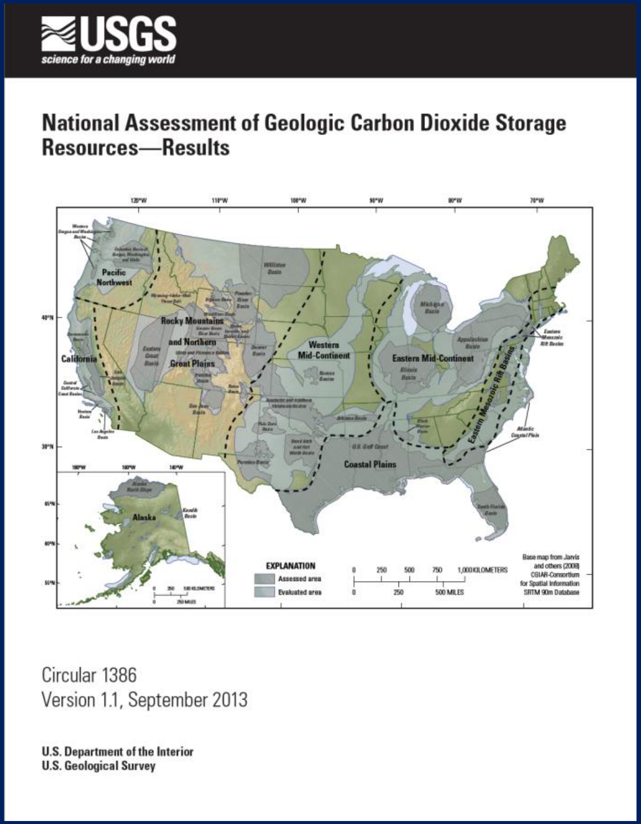
USGS National Assessment of Geologic Carbon Dioxide Storage Resources

by U.S. Geological Survey Geologic Carbon Dioxide Storage Resources Assessment Team, 2013a,b,c



Three companion assessment reports:

a. Data - USGS Data Series 774:
http://pubs.usgs.gov/ds/774/

b. Results - USGS Circular 1386:
http://pubs.usgs.gov/circ/1386/

c. Summary - Fact Sheet 2013–3020:
http://pubs.usgs.gov/fs/2013/3020/

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Helium Stewardship Act of 2013
Public Law 113–40—OCT. 2, 2013

SEC. 16. HELIUM GAS RESOURCE ASSESSMENT.

….the United States Geological Survey, shall—

(1) in coordination with appropriate heads of State geological surveys—

complete a national helium gas assessment that identifies and quantifies the quantity of helium, including the isotope helium-3, in each reservoir, including assessments of the constituent gases found in each helium resource, such as carbon dioxide, nitrogen, and natural gas…

USGS is working with U.S. Bureau of Land Management (BLM) and State geological surveys

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Source of photograph: http://www.blm.gov/nm/st/en/prog/energy/helium_program.html

Carbon Sequestration – Geologic Research and Assessments (*2014 – 2018)*

Task 1: Methodology development and assessment of national CO_2 enhanced oil recovery (CO_2-EOR) and associated CO_2 storage potential

Task 2: Geological studies of reservoirs and seals in selected basins with high potential for CO_2 storage

Task 3: Natural CO_2 and helium resources and analogues for anthropogenic CO_2 storage

Task 4: Economics of CO_2 storage and enhanced oil recovery

Task 5: Storage of CO_2 in unconventional geologic reservoirs

Task 6: Induced seismicity associated with CO_2 geologic storage

Task 7: Outreach

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Methodology development and assessment of national CO_2 enhanced oil recovery and associated CO_2 storage potential

- Requested by Energy Independence and Security Act
- Goal is to develop a probabilistic assessment methodology and then estimate the technically recoverable (pre-economic) hydrocarbon potential using CO_2-EOR within the United States
- The recoverable hydrocarbon volume occupies potential pore space that may be available for sequestration of anthropogenic CO_2 in subsurface hydrocarbon reservoirs

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USGS Methodology: Volumetric Approach

Step 1: Build a comprehensive resource database for reservoirs within U.S. basins using:

- Primary data sources: IHS Energy Group (2011); IHS Inc. (2012), and Nehring Associates Inc. (2012)
- Other publicly available or donated proprietary data sets

Populate database for missing data using:

- Analogs
- Algorithms
- Simulations

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USGS Methodology: Volumetric Approach (cont.)

Step 2: The CO_2-EOR volume for each reservoir is modeled by the original oil-in-place (*OOIP*) multiplied by a recovery factor (*RF*):

$$EOR = OOIP * RF$$

Step 2.1: The largest uncertainty of the OOIP depends on the uncertainties of two basic values: rock volume and richness of OOIP per acre foot.

$$OOIP\ per\ acre\ foot = 7{,}758((Ø)(S_{oi}))/FVFo$$

where OOIP is expressed in terms of barrels per acre foot, Ø is porosity in fraction, *Soi* is initial oil saturation in fraction, and *FVFo* is the oil formation volume factor in barrels per stock tank barrel (STB).

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USGS Methodology: Volumetric Approach (cont.)

*EOR = OOIP * RF*

Step 2.3: The uncertainty of RF will be based on:

- Decline curve analysis and recoverable hydrocarbon volume
- Reservoir simulation and type curves
- Recovery factors reported in the literature

Step 3: Associated CO_2 storage resulting from CO_2-EOR will be based on:

- Reservoir simulation and type curves
- CO_2 storage (loss) reported in the literature

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USGS Methodology: Volumetric Approach (cont.)

Step 4: The assessment procedure will generate a probability for each reservoir within a play.

Step 5: The numerical distributions will be aggregated at the play, basin, region, and national levels by a process that closely follows that of the USGS national CO_2 storage assessment (U.S. Geological Survey Geologic Carbon Dioxide Storage Resources Assessment Team, 2013b) as it is described in Blondes and others (2013).

Step 6. Final probability distributions can be used to extract information about uncertainty in the results, such as means, 5th percentiles, medians or 95th percentiles.

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Screening Criteria for Reservoirs where CO_2 is either Miscible or Immiscible in the Oil

Screening criteria (units)	Miscible	Immiscible
API gravity (API)	>25 (Mosbacher and others, 1984)	≥13 to ≤22 (Hite, 2006)
Viscosity (cp)		<10 (Andrei and others, 2010)
Depth (ft)		>1,400 (Henline and others, 1985)
Reservoir Pressure (psi)	Minimum miscibility pressure ≤ fracture pressure - 400	

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Natural CO_2 and Helium Resources - Analogs for Anthropogenic CO_2 Storage

- To evaluate the potential geologic risks associated with CO_2 storage
- To collect samples of gas and produced water from wells producing CO_2 (>~10%) to define the origin, migration history, and ultimate fate of natural CO_2 and associated He
- To determine the origin of CO_2 that is in natural gas reservoirs by using geochemical and isotopic analyses of gas and reservoir rocks
- Conduct field and rock core investigations to help determine the degree and rate of CO_2-derived diagenesis (mineralization, recrystallization, dissolution, bleaching) that has occurred in the reservoir rocks
- Estimate natural CO_2 resources that may be available, and that might compete with anthropogenic CO_2 resources, for use in CO_2-EOR
- To work with BLM to evaluate the distribution of natural helium resources in the United States

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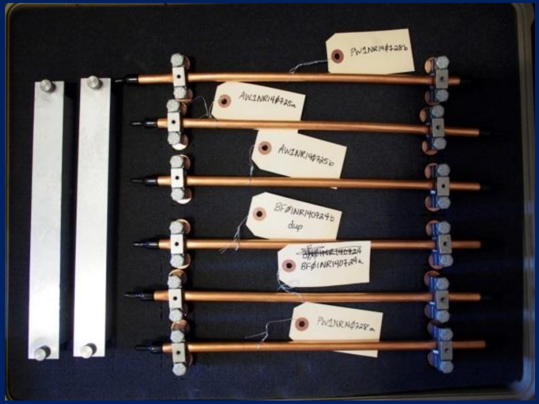
Natural CO_2 and Helium Resources - Analogs for Anthropogenic CO_2 Storage (cont.)

Can we develop a total carbon dioxide/helium system model that can be used in a national assessment of *undiscovered* CO_2 and helium resources?

Gas sample cylinders



Noble gas sample tubes

Produce water sample collection

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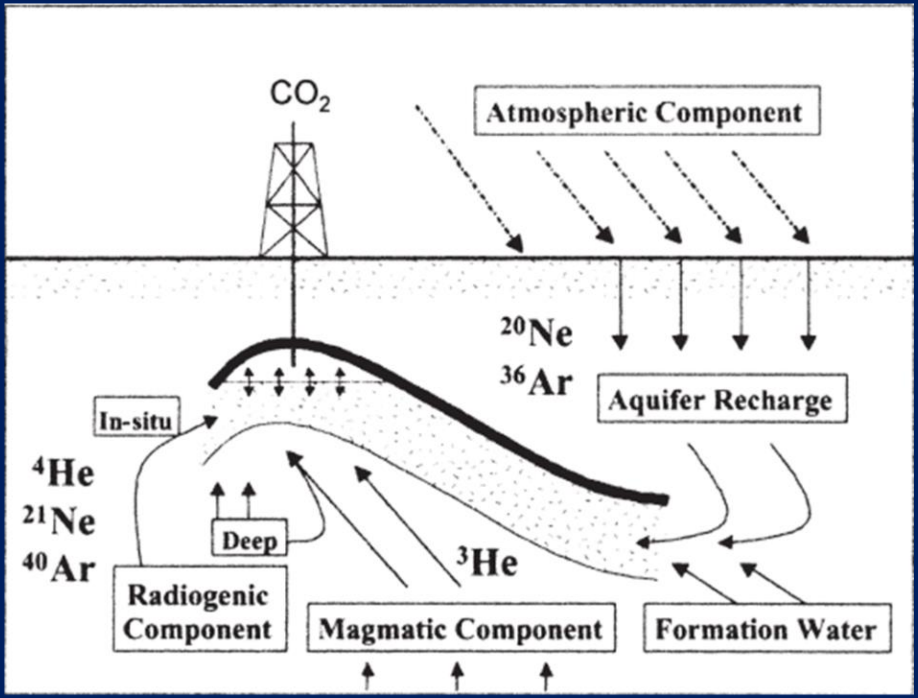
Potential sources of CO_2 in petroleum reservoirs (Thrasher and Fleet, 1995)

$\delta^{13}C_{CO_2}$ ‰	Source
+15 to -30	Bacteria
-10 to -25	Kerogen maturation
2 to -2	Marine carbonates
-10 to -20	Contact metamorphism in coals
-5 to -15	Thermochemical sulfate reduction
+2 to -12	Contact metamorphism in carbonates
0 to -15	Regional metamorphism
-4 to -7	Mantle degassing



Sources of noble gases (Cassidy and Ballentine, 2006)

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Natural CO_2 and Helium Resources - Analogs for Anthropogenic CO_2 Storage (cont.)

Areas of focus:

- California Basins
- Northern Rocky Mountains
- Southern Rocky Mountains
- Southwestern Permian Basin, TX
- Jackson Dome, MS
- Eastern United States

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Natural CO_2 Source Analogs – Southwestern Permian Basin

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- Producing gas wells with greater than 10% CO_2 were identified using the U.S. Bureau of Mines and BLM geochemical databases and the Texas Railroad commission website: http://www.rrc.state.tx.us/

- Hot springs in the study area were located and we are in the process of contacting current owners to get permission to sample the hot springs

- Hot spring and well sampling planned for 2014 - 2015

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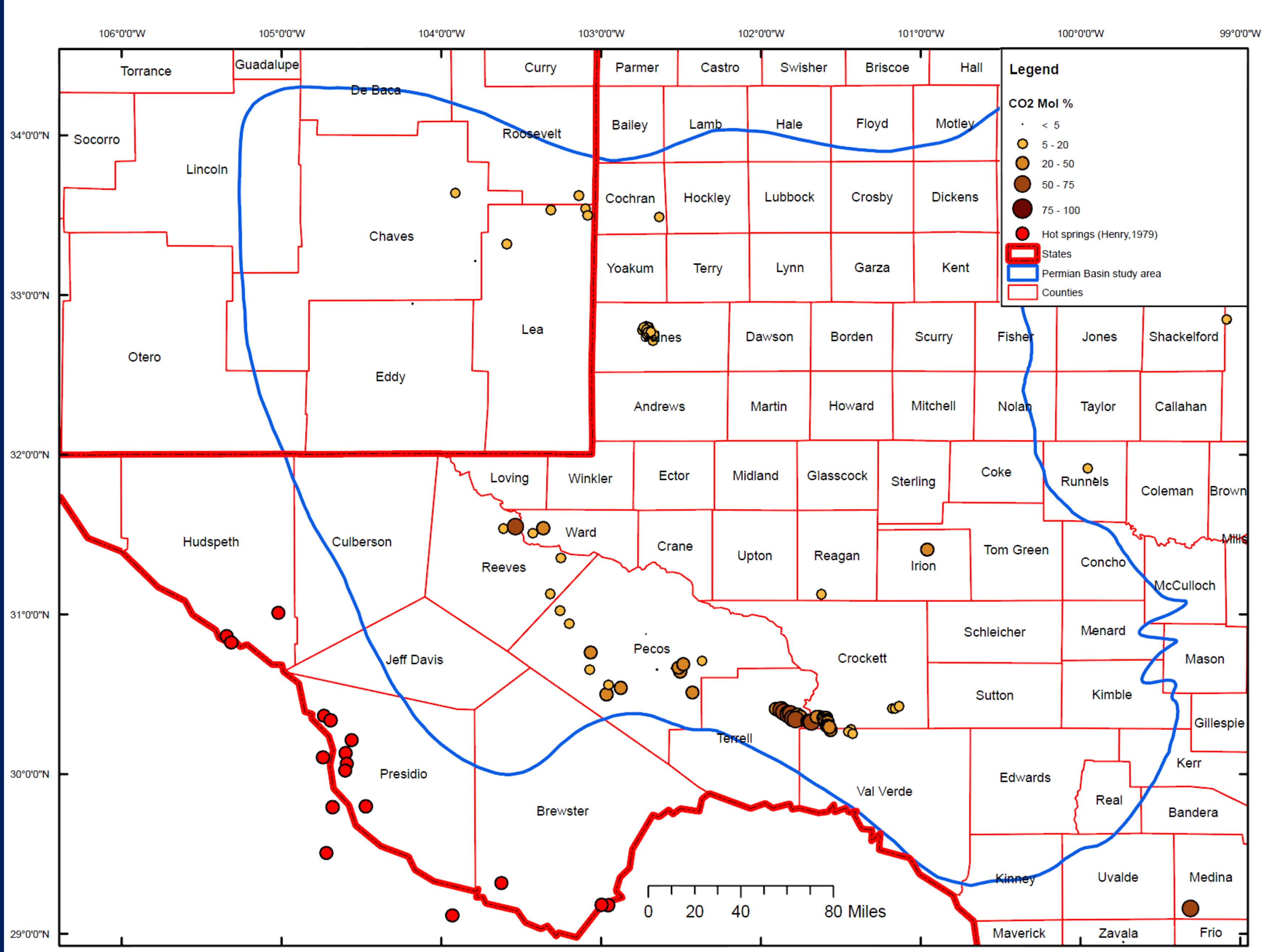
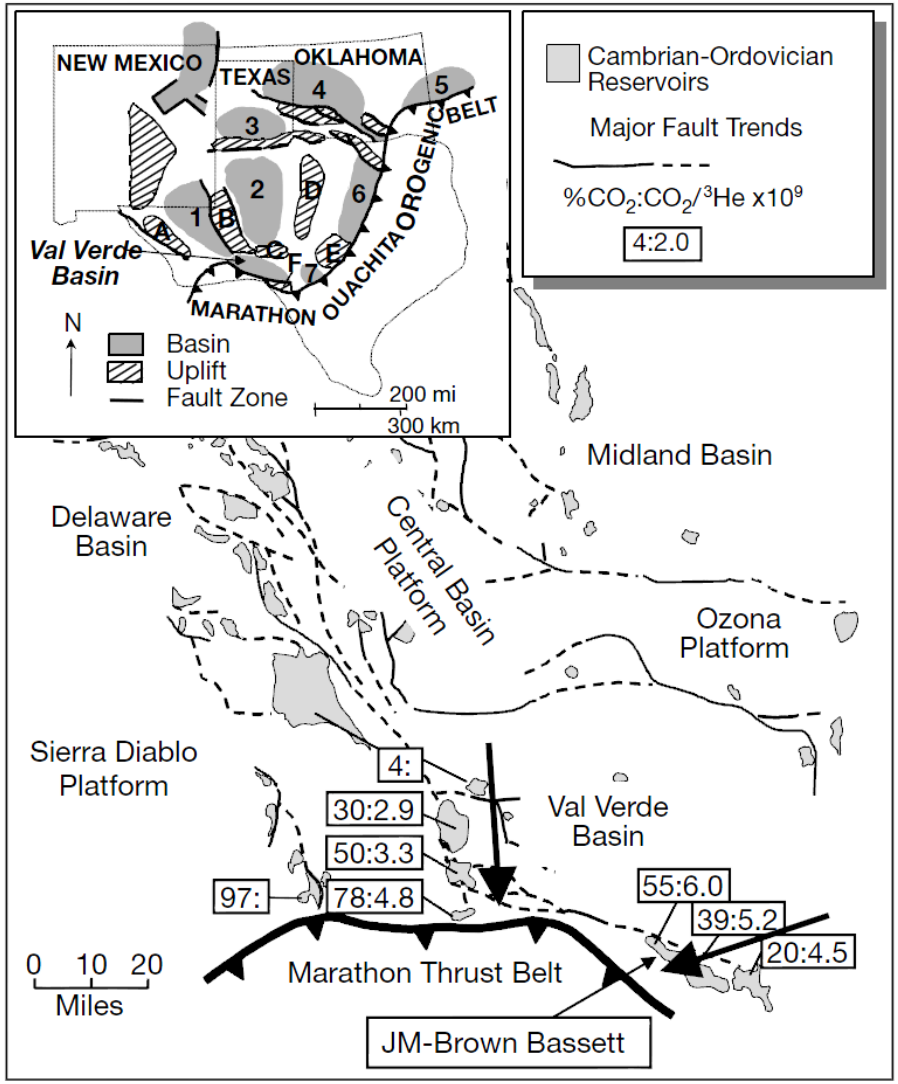


Brown dots represent gas data collected from wells that produced >10% CO_2 (USGS, 2009). Additionally, natural hot springs (red dots) located along the southwestern margin of the basin may contain elevated CO_2 concentrations (Henry, 1979).

- Regional increase in CO_2 content towards the Marathon thrust belt (MBT)
- Average of about 3% in the basin center to as high as 97% on the foredeep margin of the thrust belt

From Ballantine and others (2001, Nature)



- The JM-BB samples with the lowest $CO_2/^3He$ preserve the latest stages of outgassing, and will be the nearest to the magmatic source
- The JM-BB field the lowest $CO_2/^3He$ values are found in the samples with the lowest CO_2 content and are furthest from the MTB
- This trend is reflected on the regional scale (map at left), suggesting that the CO_2 source is to the north or east of the MTB (Ballentine and others, 2001)

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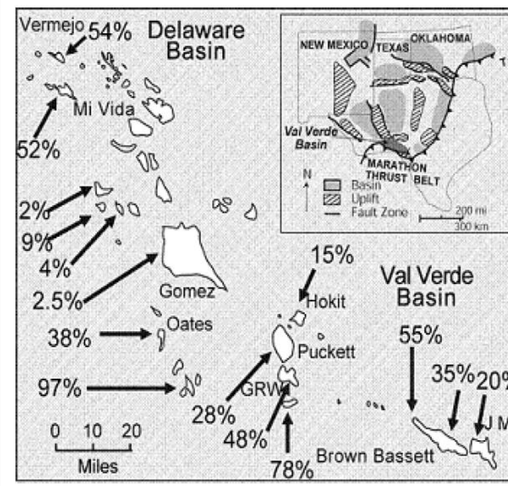

Brennan and others (2005)

Location of the JM-Brown Bassett (JM-BB) natural gas field. Arrows show the direction of the regional increase in CO_2 content and $CO_2/^3He$ ratio towards the Marathon thrust belt (MTB). CO_2 and ^3He data for the JM-BB field are from Ballentine and others (2001). Other data are from Chevron (unpublished). Inset, basins: 1, Delaware; 2, Midland; 3, Palo-Duro; 4, Anadarko; 5, Arkoma; 6, Ft Worth; 7, Kerr. Uplifts: A, Sierra Diablo; B, Central basin; C, Ozona; D, Concho arch; E, Llano; F, Devils River. (Figure from Ballentine and others, 2001.)

USGS Activities to Implement a National Helium Assessment

- USGS and BLM are in the process of building a combined DOI natural gas geochemical database that could be used for a national assessment of helium resources. The database will include both national and international data on helium occurrence in geologic formations. An on-line, map-based data portal is being designed.

- A request for State participation was made at the 2014 annual meeting of the Association of American State Geologists to contribute to the natural gas geochemical database. Several State geological surveys are compiling data to be incorporated in the database.

- USGS and BLM plan to work together to assess *discovered* and *undiscovered* national CO_2 and helium resources.

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Summary

- The USGS is developing a probabilistic assessment methodology and then will estimate the technically recoverable hydrocarbon potential using CO_2-EOR within the United States

- Natural CO_2/helium studies are now underway in various parts of the United States to better understand total carbon dioxide/helium systems

- The USGS is building a national geochemical database that can be used to evaluate the occurrence and distribution of He and CO_2 resources occurring in natural gas reservoirs in the country

- The USGS welcomes the opportunity to sample gas wells that are producing >10 percent CO_2

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http://energy.usgs.gov

http://go.usa.gov/8X8 (USGS geologic CO_2 project website)

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