FROM THE TUSCARORA SANDSTONE TO THE BUBBLES IN YOUR BEVERAGE: NATURALLY-OCCURRING CO_2 IN THE INDIAN CREEK FIELD, KANAWHA COUNTY, WV

CONTRACT DE-FE0026585

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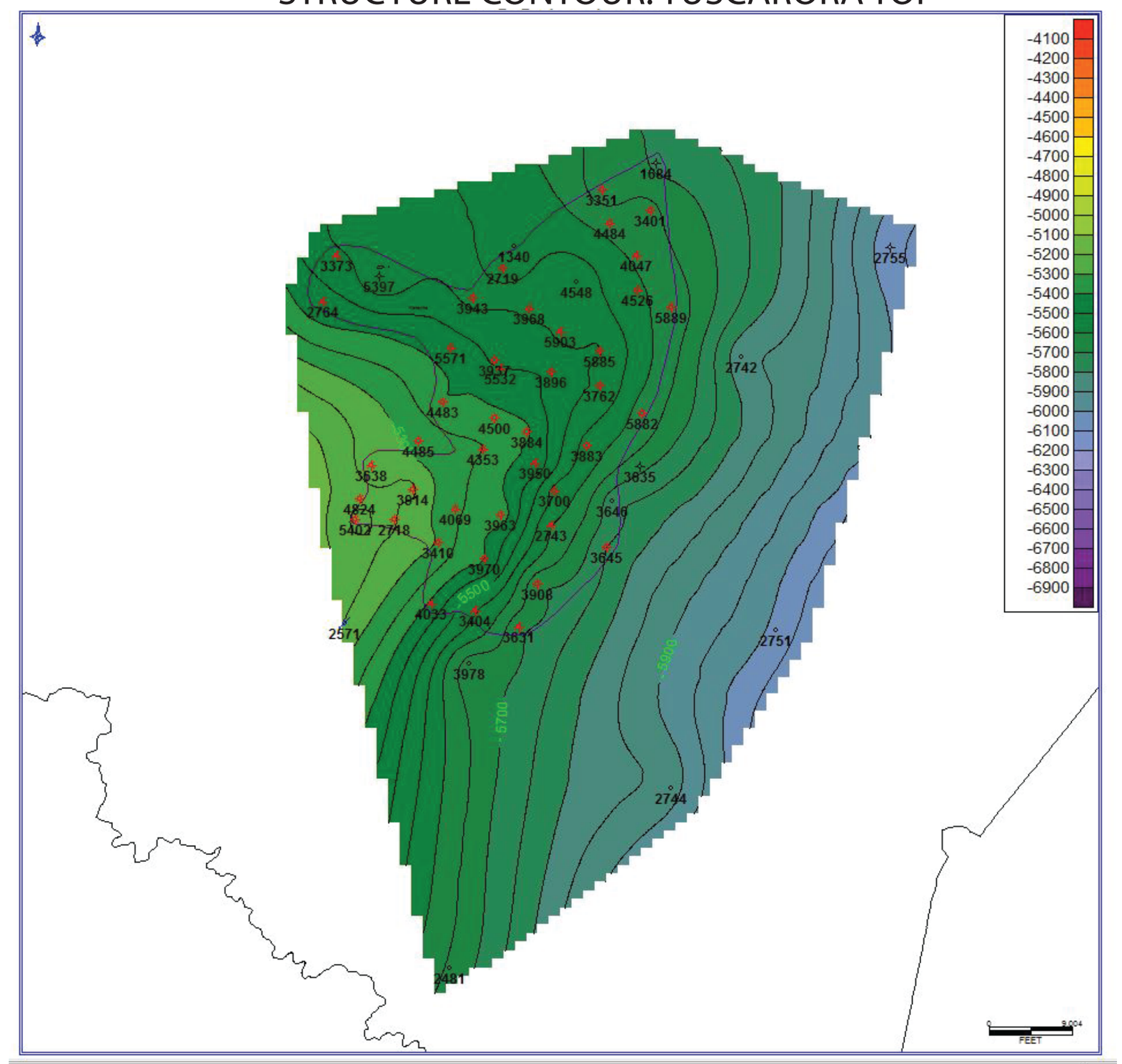
ABSTRACT

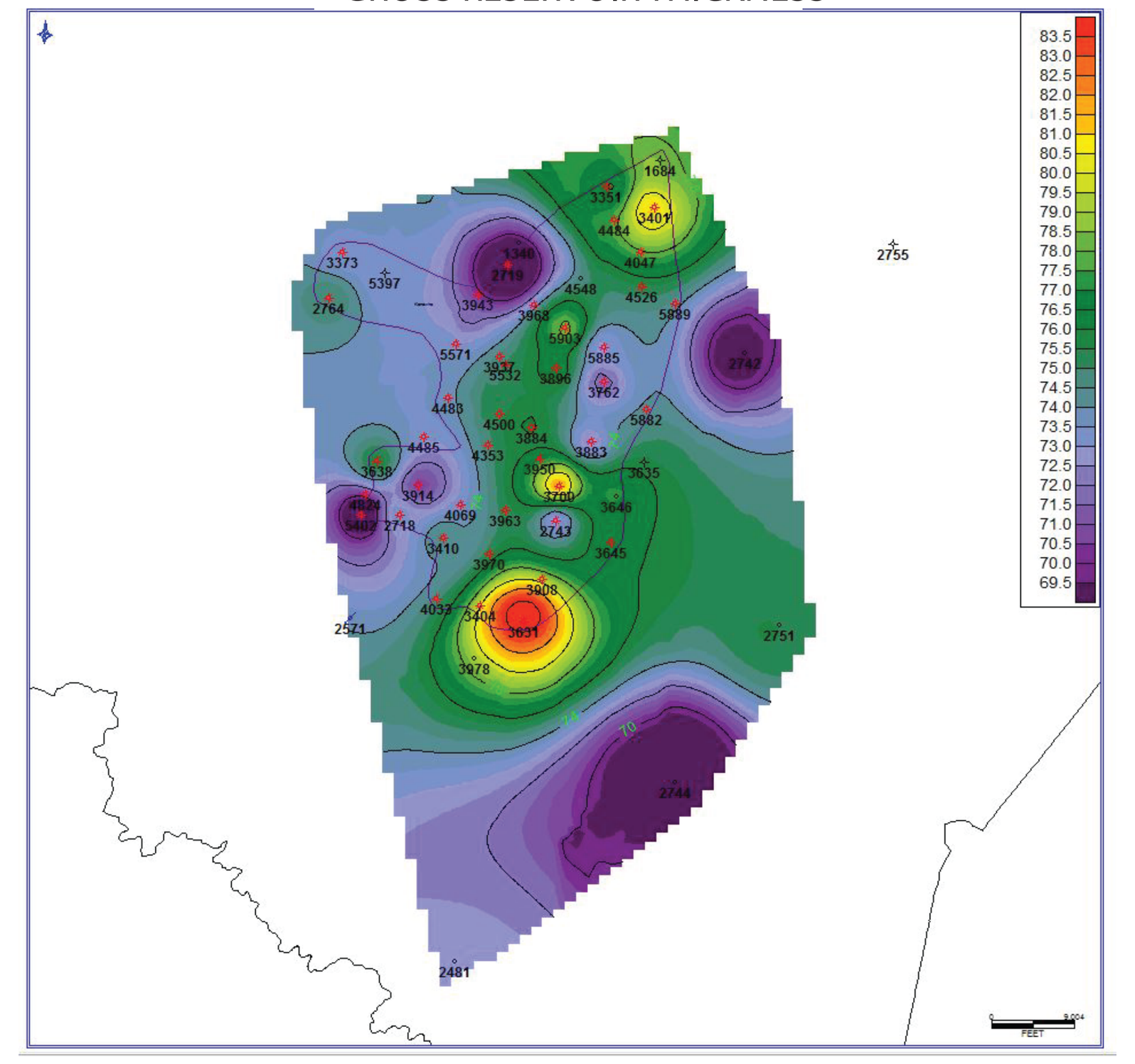
The Tuscarora Sandstone in the Indian Creek field produces commercial volumes of food-grade carbon dioxide (CO_2) as a constituent of the natural gas stream. Presence of naturally-occurring CO_2 presents a unique opportunity to examine an analog for long-term carbon storage, but the mechanisms of its generation and trapping are not fully understood. As part of a research project funded by the U.S. Department of Energy, geoscientists from Battelle Memorial Institute and the West Virginia Geological Survey examined thin-sections, well logs, drilling and completion reports and core from wells inside the Indian Creek field and compared these data to wells from nearby fields that do not produce significant amounts of CO_2 in gas accumulations. Geologic cross-sections and isopach maps of the Tuscarora were augmented with Computed Tomography (CT) scans of the cores to assess potential fracture networks and migration pathways.

Pores in thin-sections af Tuscarora taken from a well inside the field exhibit thin, incomplete, linings of calcite that appear to be an early cement partially dissolved by later pore fluids to produce CO2. A second possibility for CO2 generation is suggested by the presence of pores lined with framboidal pyrite typically associated with bacterial degradation of organic matter such as hydrocarbons. Thin-sections taken from a core outside the Indian Creek field are characterized by bedding-parallel stylolites, often filled with heavy minerals and/or clays, as well as thick quartz overgrowths, and sutured graincontacts. Sediments in this core are burrowed; the burrows are filled with very fine to silt-sized quartz. Porosity is fracture-enhanced and contained within burrows rather than the matrix. Though there aremultiple areas of gas production from the Tuscarora Sandstone, commercial production of the CO2 isunique to the Indian Creek field in the Appalachian basin, providing a natural laboratory for the effects of potential carbon storage

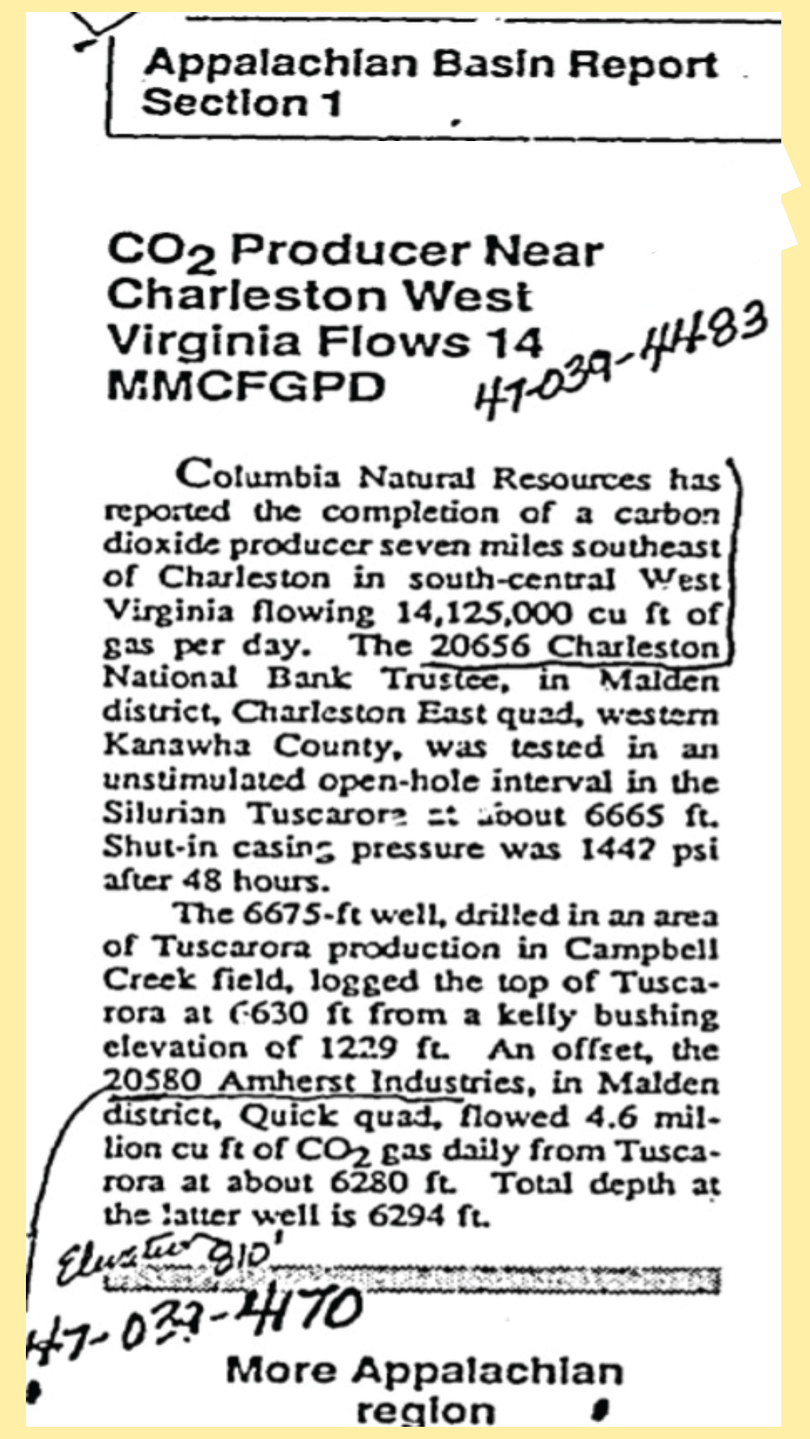
STRUCTURE CONTOUR: TUSCARORA TOP



GROSS RESERVOIR THICKNESS



LOCATION AND GAS GRAVITY

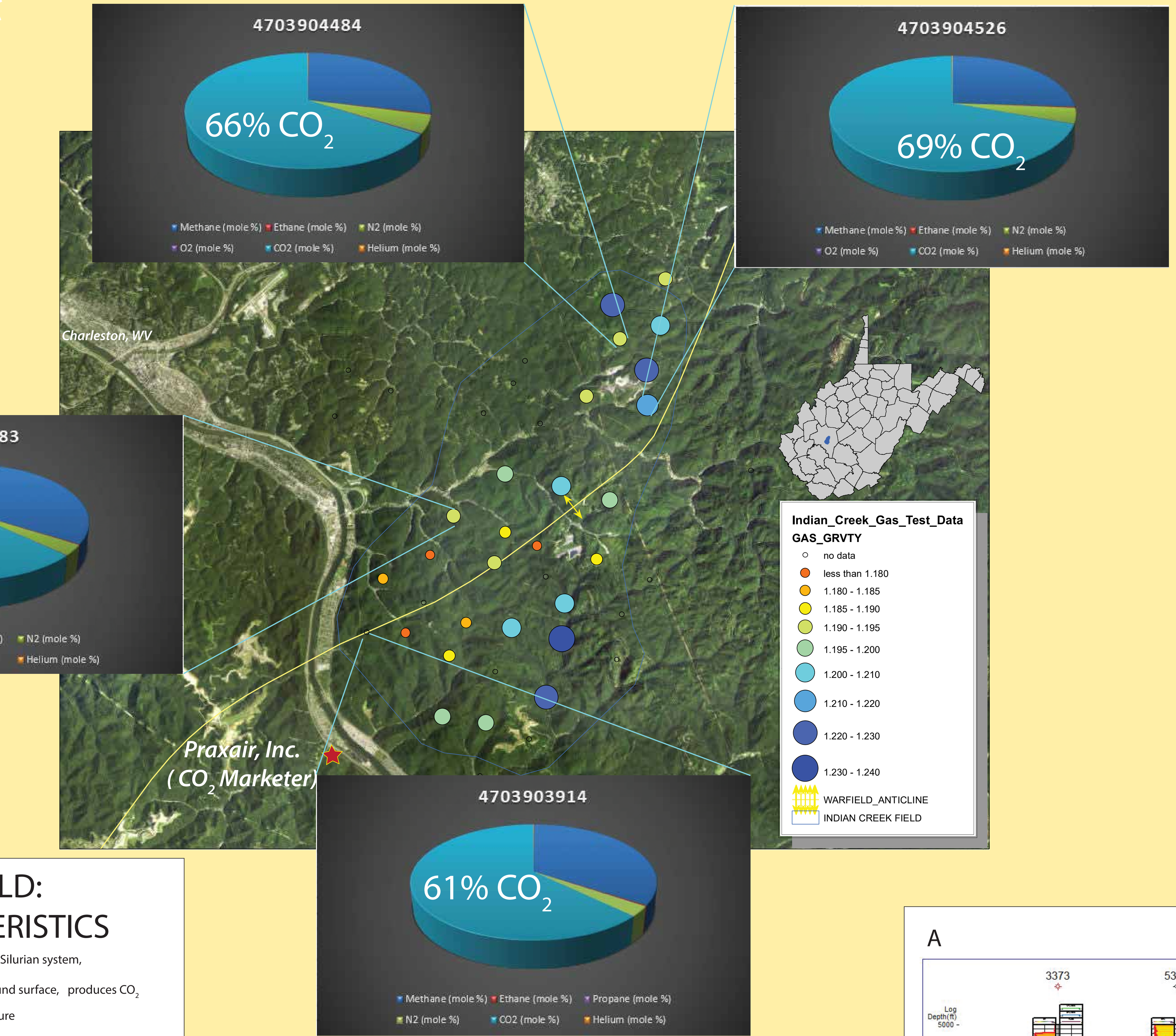

Appalachian Basin Report Section 1

CO2 Producer Near Charleston West Virginia Flows 14 MMCFGPD 47-039-4483

Columbia Natural Resources has reported the completion of a carbon dioxide producer seven miles southeast of Charleston in south-central West Virginia flowing 14,125,000 cu ft of gas per day. The 20656 Charleston National Bank Trustee, in Malden district, Charleston East quad, eastern Kanawha County, was tested in an unstimulated open-hole interval in the Silurian Tuscarora at about 6665 ft. Shut-in casing pressure was 1447 psi after 48 hours. The 6675-ft well, drilled in an area of Tuscarora production in Campbell Creek field, logged the top of Tuscarora at 6630 ft from a kelly bushing elevation of 1229 ft. An offset, the 20580 Amherst Industries, in Malden district, Quick quad, flowed 4.6 million cu ft of CO2 gas a day from Tuscarora at about 6280 ft. Total depth at the latter well is 6294 ft.

47-039-4470

More Appalachian region


4703904484
66% CO_2
Methane (mole %) Ethane (mole %) N2 (mole %)
O2 (mole %) CO2 (mole %) Helium (mole %)
4703904526
69% CO_2
Methane (mole %) Ethane (mole %) N2 (mole %)
O2 (mole %) CO2 (mole %) Helium (mole %)
4703904483
63% CO_2
Methane (mole %) Ethane (mole %) N2 (mole %)
Hydrogen (mole %) CO2 (mole %) Helium (mole %)
4703903914
61% CO_2
Methane (mole %) Ethane (mole %) Propane (mole %)
N2 (mole %) CO2 (mole %) Helium (mole %)
Charleston, WV
Praxair, Inc. (CO_2 Marketer)
Indian_Creek_Gas_Test_Data
GAS_GRVTY
no data
less than 1.180
1.180 - 1.185
1.185 - 1.190
1.190 - 1.195
1.195 - 1.200
1.200 - 1.210
1.210 - 1.220
1.220 - 1.230
1.230 - 1.240
WARFIELD_ANTICLINE
INDIAN CREEK FIELD

INDIAN CREEK FIELD: GEOLOGIC CHARACTERISTICS

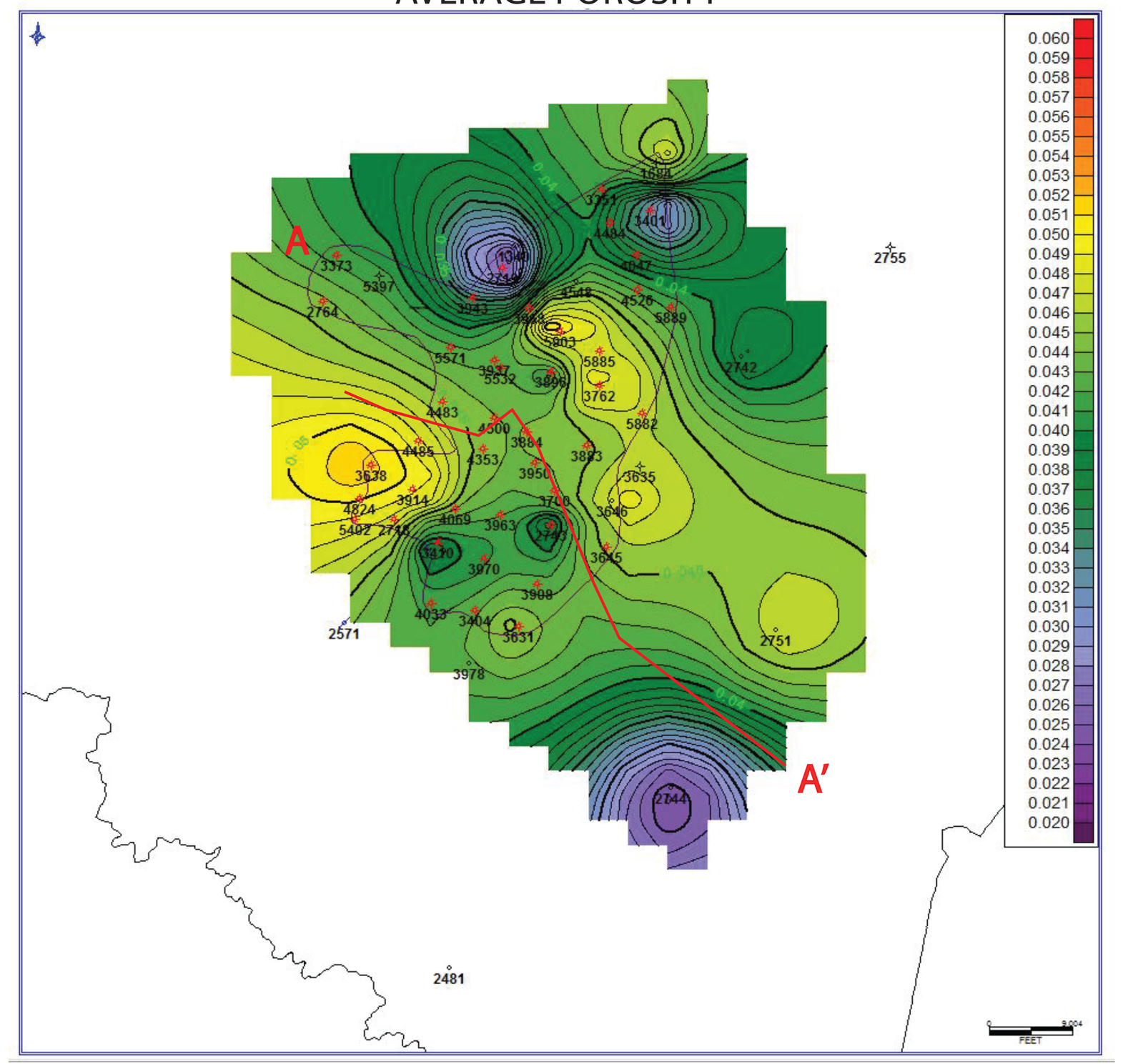
The Tuscarora Sandstone, stratigraphically positioned at the base of the Silurian system, and encountered at depths ranging from 6,153 ft to 7,122 ft. below ground surface, produces CO_2 as a portion of the natural gas stream in the Indian Creek field. This feature is unique to the Indian Creek field; other Tuscarora gas fields may produce minor amounts of CO_2, but the volumes are appreciably smaller (Avary, 1996).

In this area, the Tuscarora is a white to variegated red, green, and gray, quartz-cemented, fine to coarse-grained sandstone. The high quartz content gives the reservoir an extremely brittle quality, and both horizontal and vertical fractures are observed. Sandstone beds are massive, and are commonly separated by shale interbeds. Carbonate content is low, generally below 5%. Accessory minerals, such as tourmaline and zircon, are observed in trace to minor amounts. Sedimentary structures include low-angle to horizontal beds, occasionally graded; cross-beds; ripples; and dish structures (Bruner, 1983). Sandstone beds are both coarsening and fining-upward.

Given the "tight" nature of the reservoir, porosity and permeability are generally low, but areas of enhanced porosity, both primary and secondary, are observed. Porosity ranges from <1% to ~30% by visual estimate. Average porosity ranges from approximately 5% to 10%. Permeability is similarly variable, and is closely related to fracture networks.

Gas production in the Indian Creek field is related to position on the Warfield anticline, which is the easternmost major anticline in the Rome Trough. The nose of the anticline plunges slightly to the northeast, and production of both methane and CO_2 is highest on the flanks of the anticline nearing the nose. Wells located farther down-dip on the structure commonly produce water. The field is bounded to the east by the southeastern boundary fault of the Rome Trough.

AVERAGE POROSITY



COMPARISON OF NATURAL CO_2 SOURCES IN THE UNITED STATES

DOE/NETL 2014/1637 Working Paper (DiPietro et al., 2014)

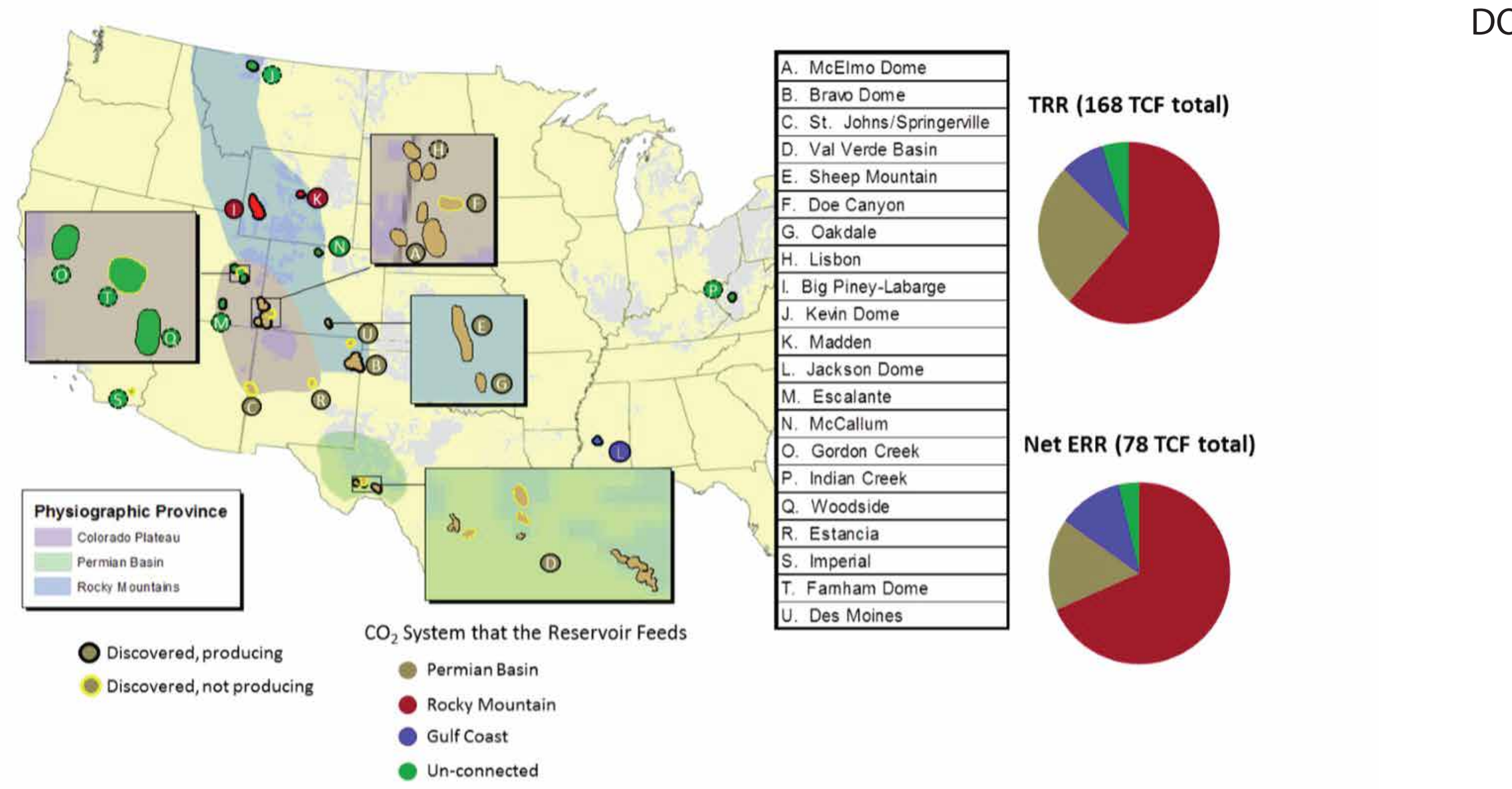
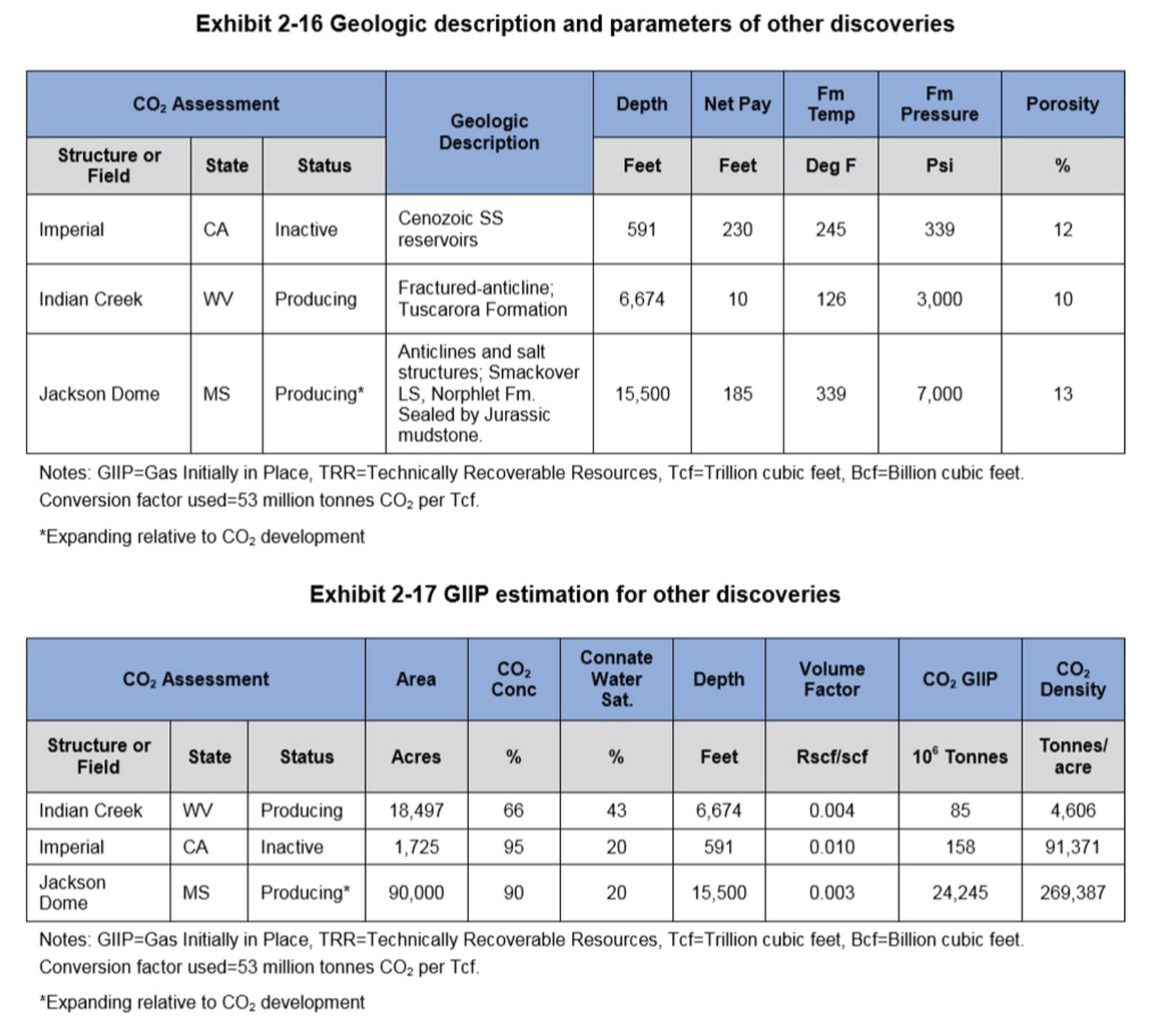
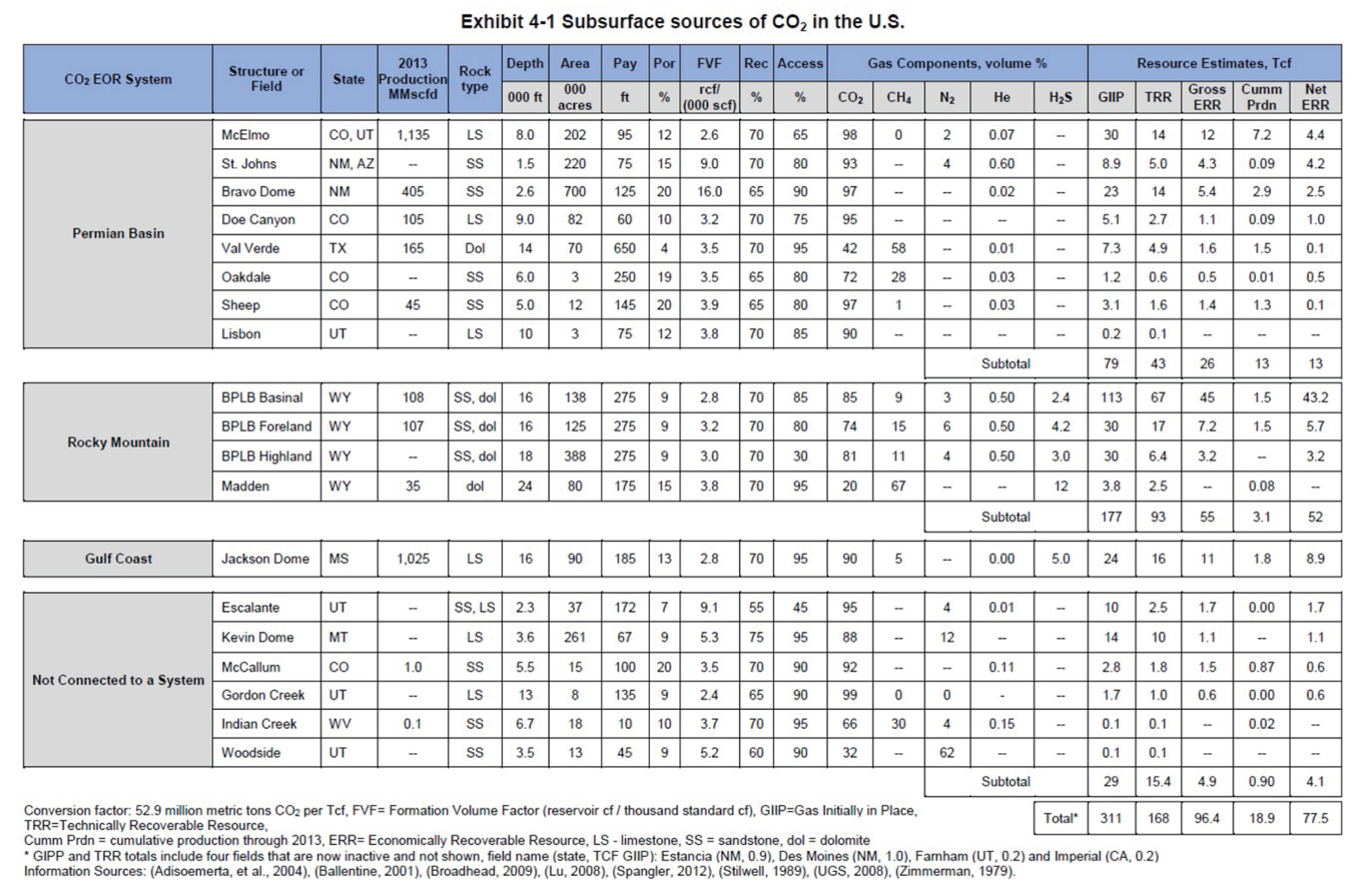


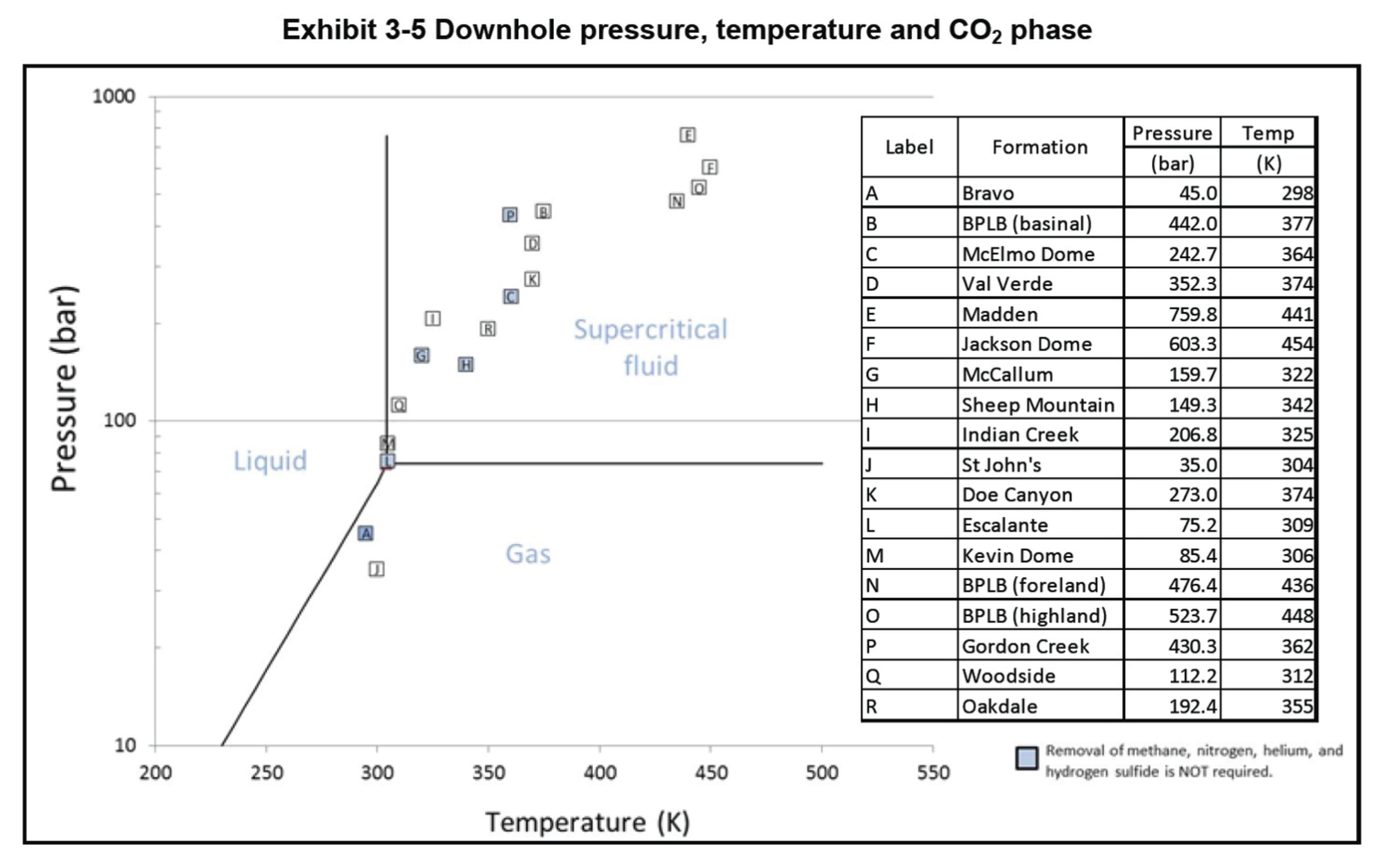
Exhibit 3-11 Produced CO_2

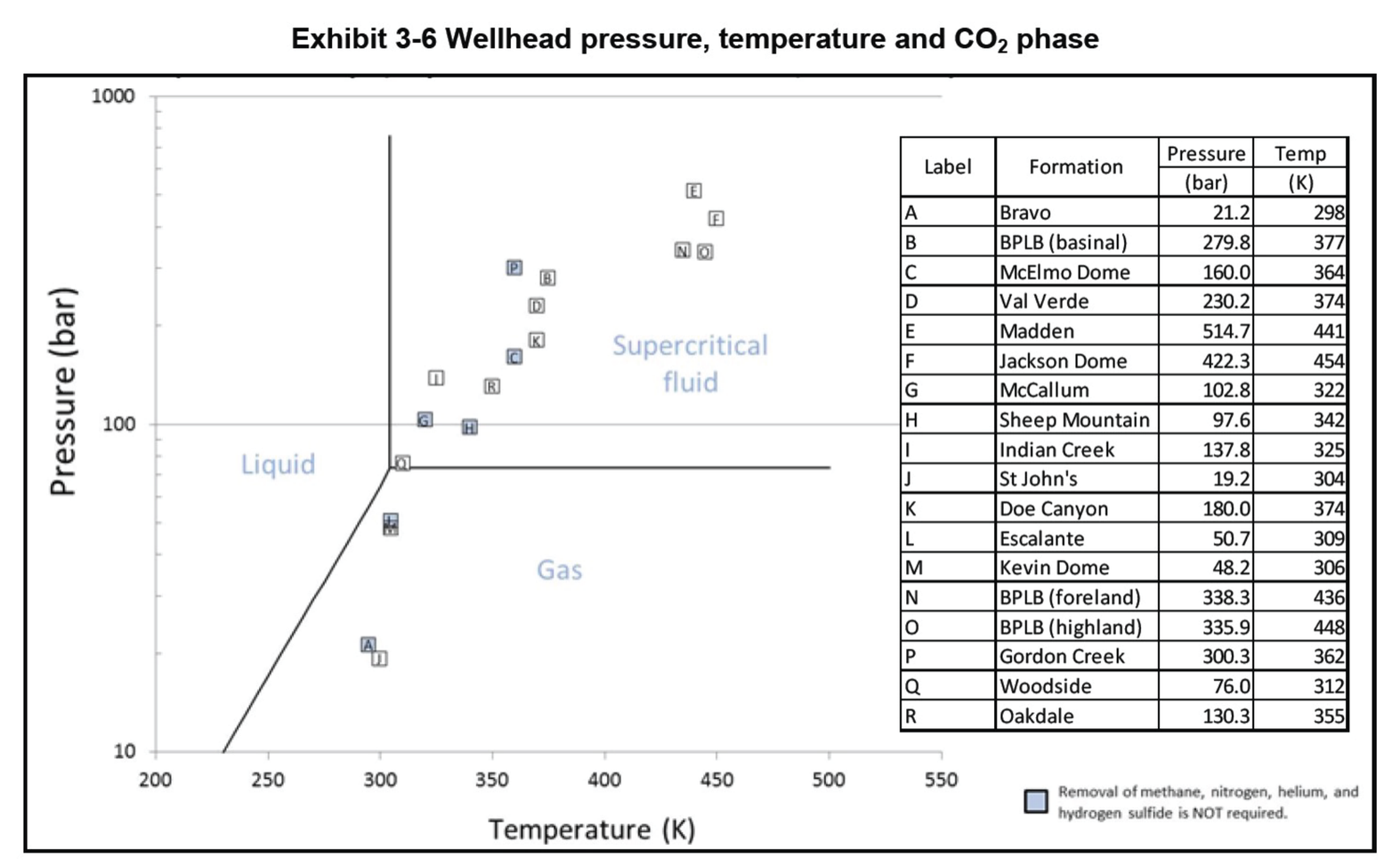
Structure or Field	Produced CO_2 (Bcf)	Structure or Field	Produced CO_2 (Bcf)
McElmo Dome	7,200	Indian Creek	20
Bravo Dome	2,900	Estancia	14
Val Verde Basin	1,500	Oakdale	5
Jackson Dome	1,800	Farnham Anticline	5
Big Piney-LaBarge Basinal	1,500	Escalante Anticline	1
Big Piney-LaBarge Foreland	1,500	Gordon Creek	1
Sheep Mountain	1,300	Imperial	1
McCallum	871	Kevin Dome	-
Doe Canyon	90	Lisbon	-
St. Johns/Springerville	90	Woodside	-
Madden	80	Big Piney-LaBarge Highland	-
Des Moines	20		
		Total	18,851

Region Coding: Colorado Plateau, Rocky Mountains, Permian Basin, Other



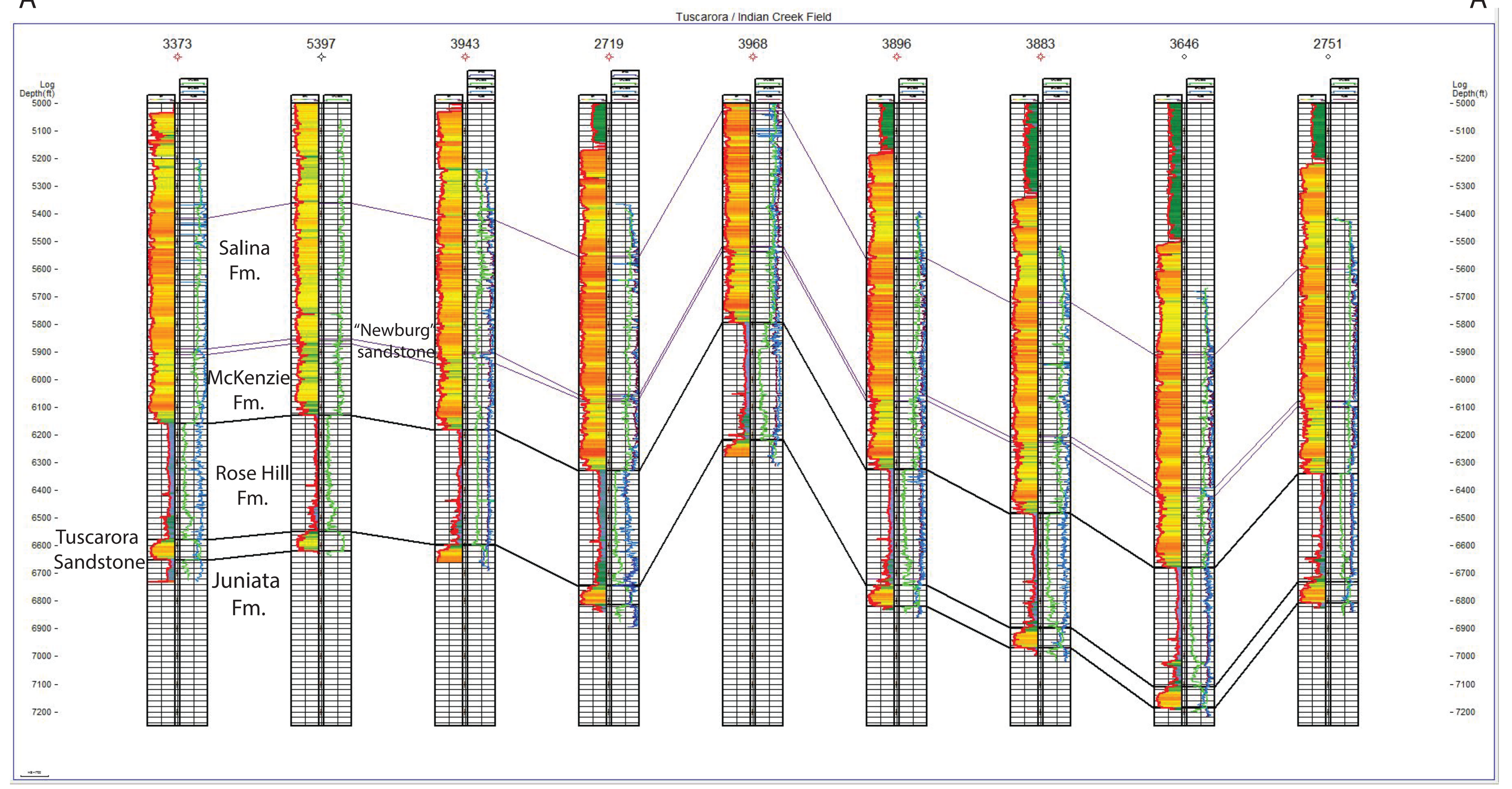




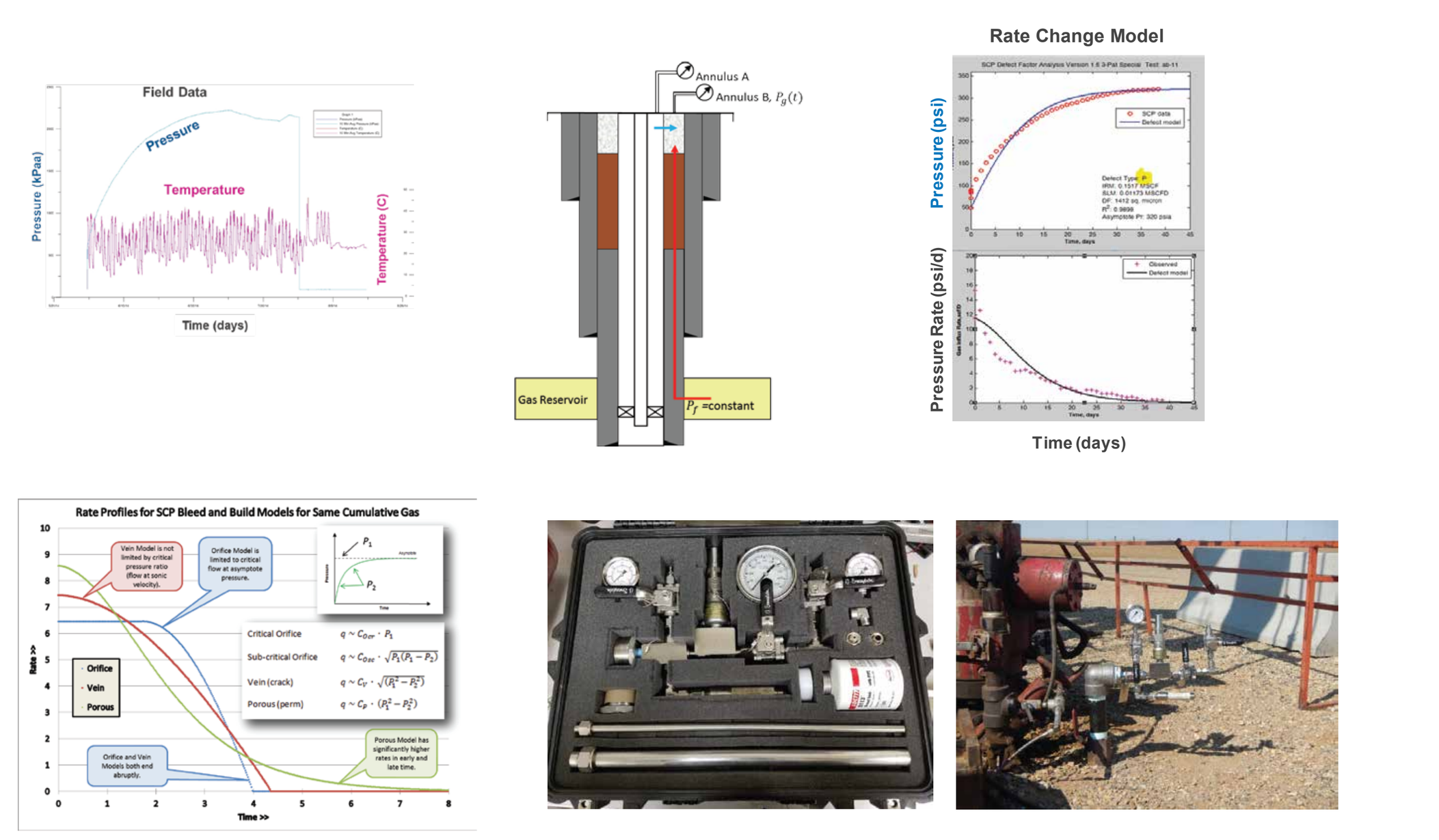


When compared to other subsurface sources of carbon dioxide, the Indian Creek field is the only natural CO_2 source in the Appalachian basin. Unlike many western sources, It is unconnected to a CO_2 system. Reservoir temperature in the Indian Creek field is approximately 120 degrees Fahrenheit at depth and bottomhole pressures measure between 2500 and 2700 psi, indicating a supercritical CO_2 phase. The volume of CO_2 produced in the Indian Creek field is much lower than western sources, but due to proximity to market, it remains an economically viable source (DiPietro et al., 2014).

EAST-TO-WEST STRUCTURAL CROSS_SECTION



WELLBORE INTEGRITY: SUSTAINED CASING PRESSURE TESTING



A primary objective of this research was to develop and validate a program for identifying and characterizing wellbore integrity in legacy oil and gas wells for CO2 storage applications. As a naturally-producing CO2 reservoir, the Indian Creek field presented a unique opportunity to analyze the potential effects of prolonged exposure to CO2, and the nature, depth, and severity of well defects. These downhole effects are measurable by analysis of "sustained casing pressure" or vent flow gas, whereby gas migrates through casing/cement into the deep or production 'B' annulus. Pressure vs. time and rate vs, time can be analyzed for information on nature of defect, severity, and location. A sustained casing pressure testing kit was constructed by Battelle, and was used to test wells in both the Michigan and Willison basins. Unfortunately, the research team was unable to gain access to the Indian Creek field to perform similar tests.