Assessing Risks of Unconventional Shale Oil and Gas Development to Groundwater Resources
(评估非常规页岩油气开发对地下水资源的风险)

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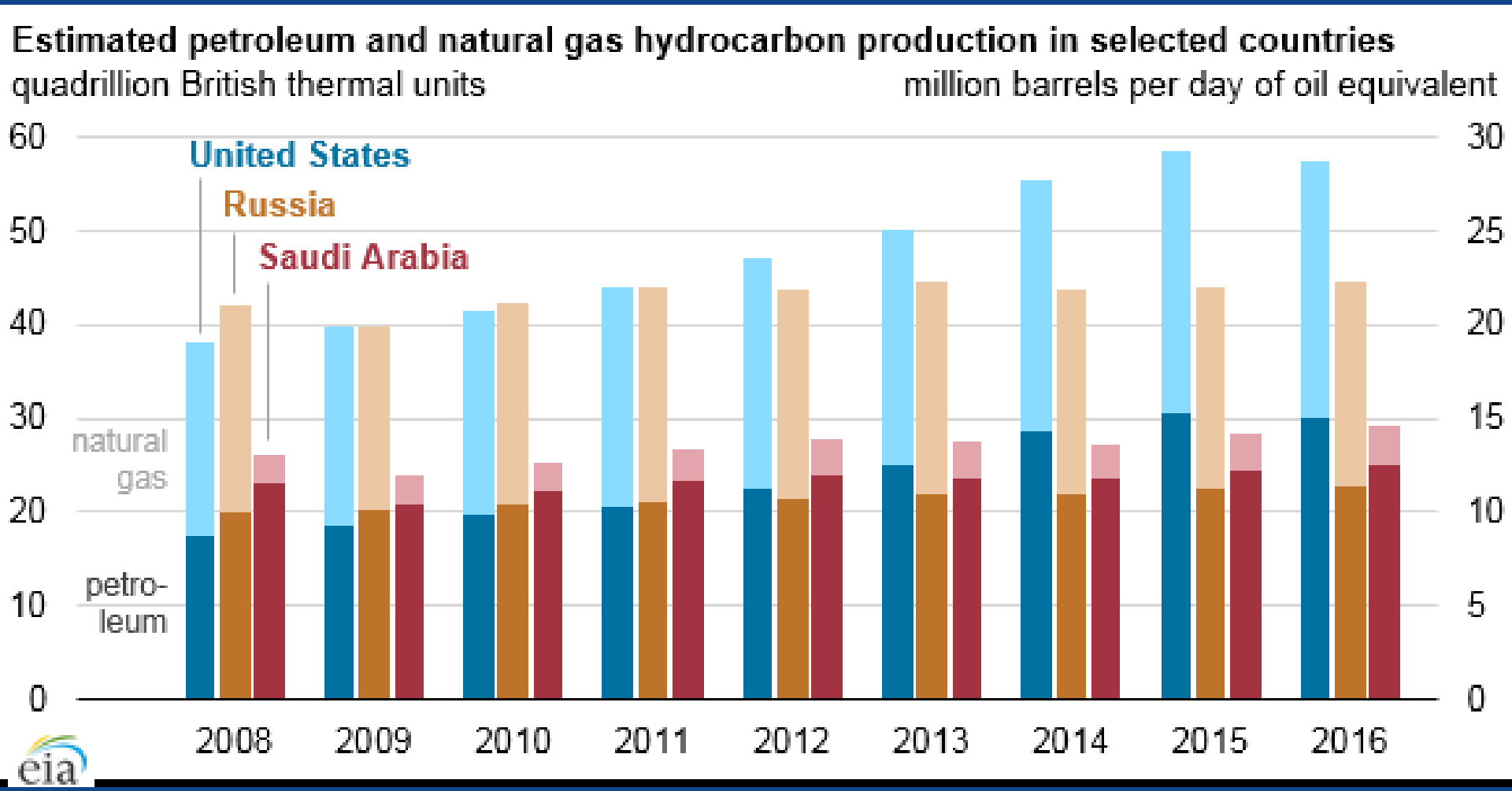
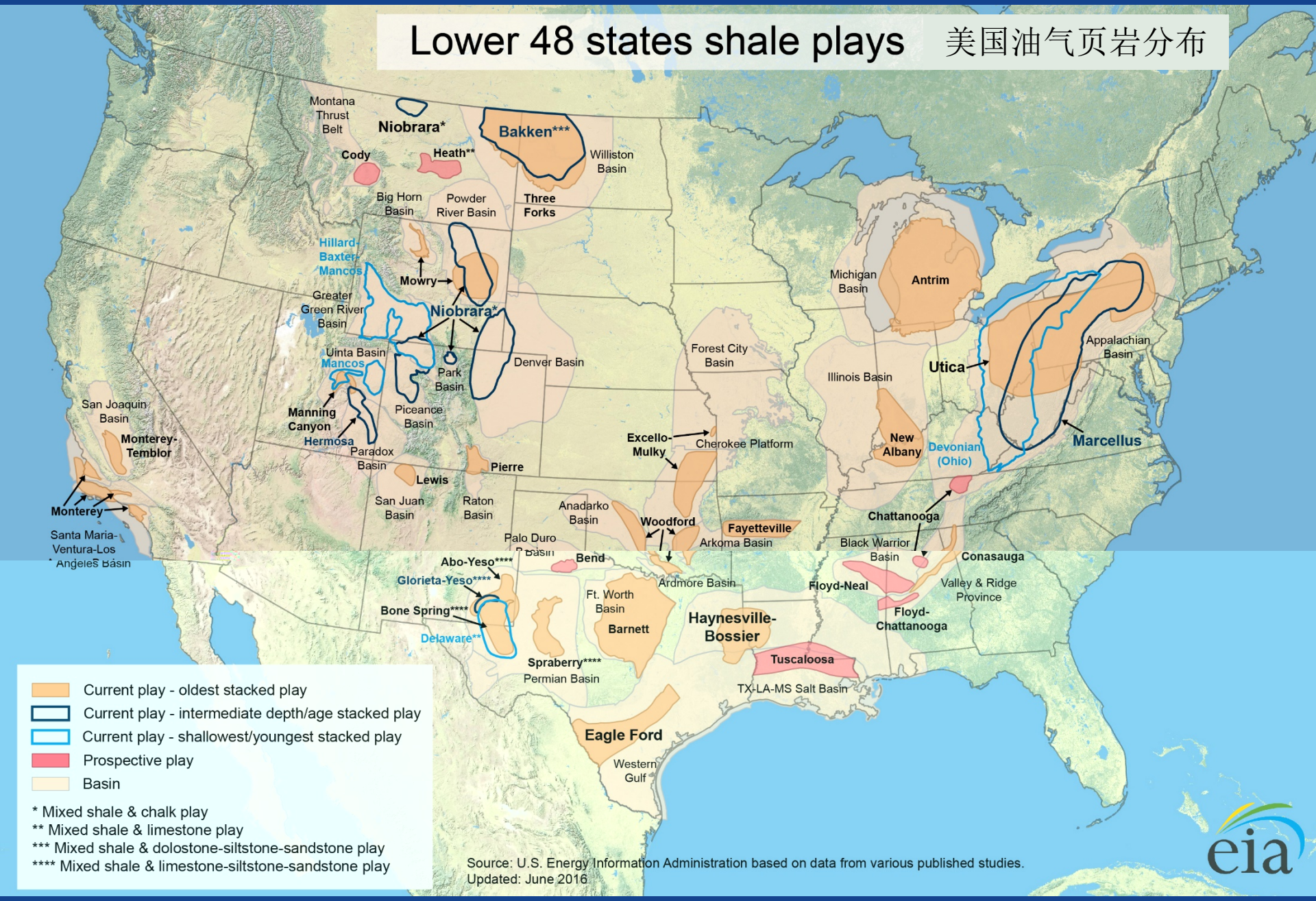
地下水论坛 2017.7 合肥

Kentucky Geological Survey

Which country is the top producer of petroleum and natural gas?
哪个国家产油气最多？

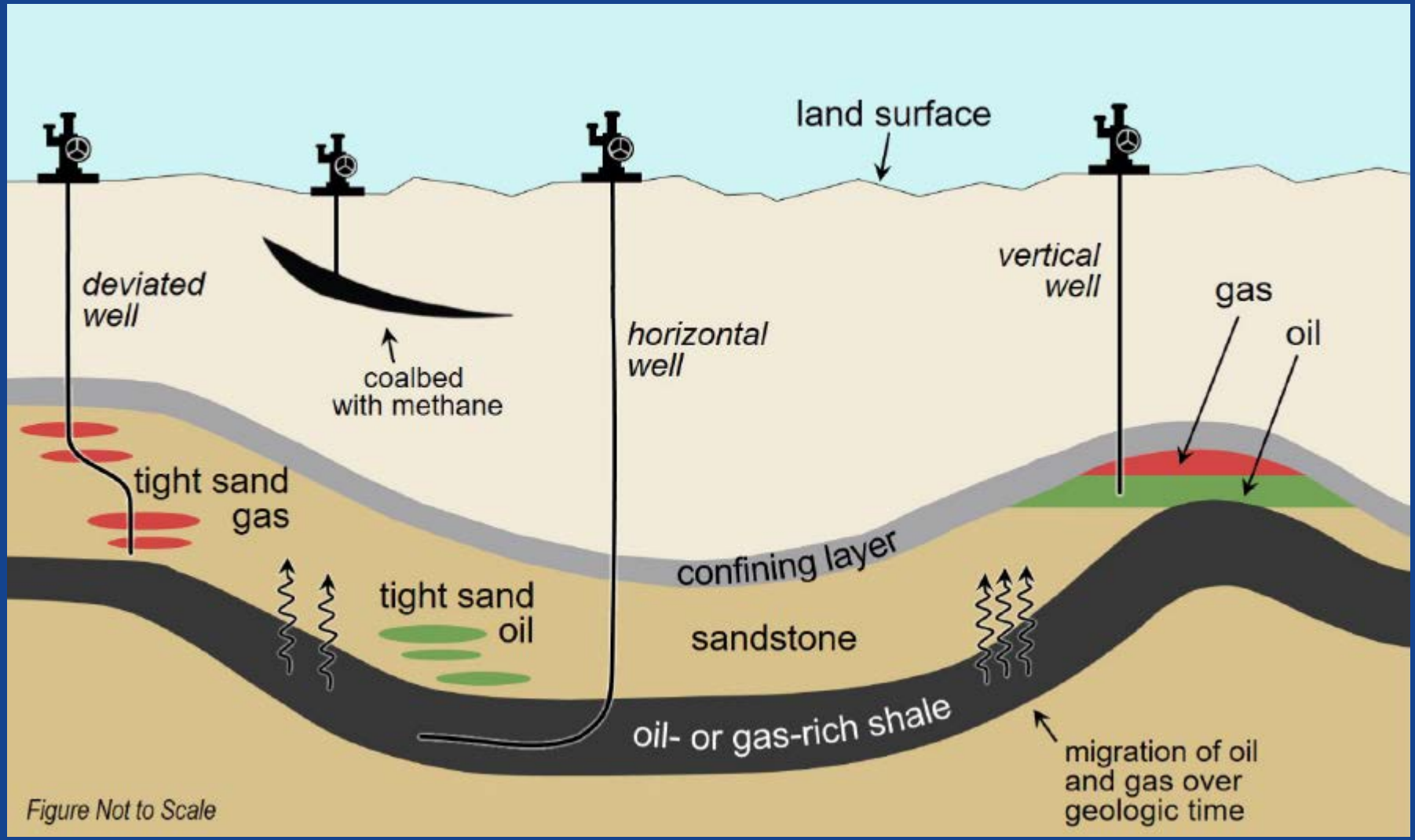


Lower 48 states shale plays 美国油气页岩分布



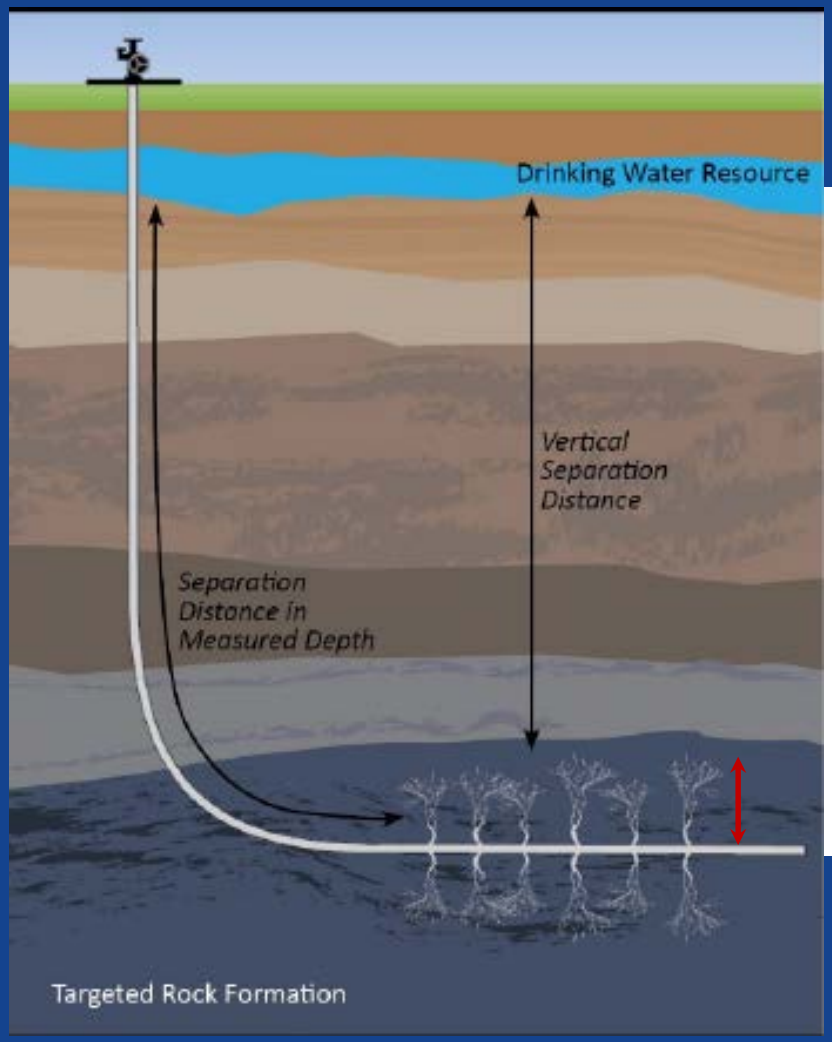
Source: U.S. Energy Information Administration based on data from various published studies.
Updated: June 2016

Horizontal Well and Hydraulic Fracturing (水平井和水力压裂法)

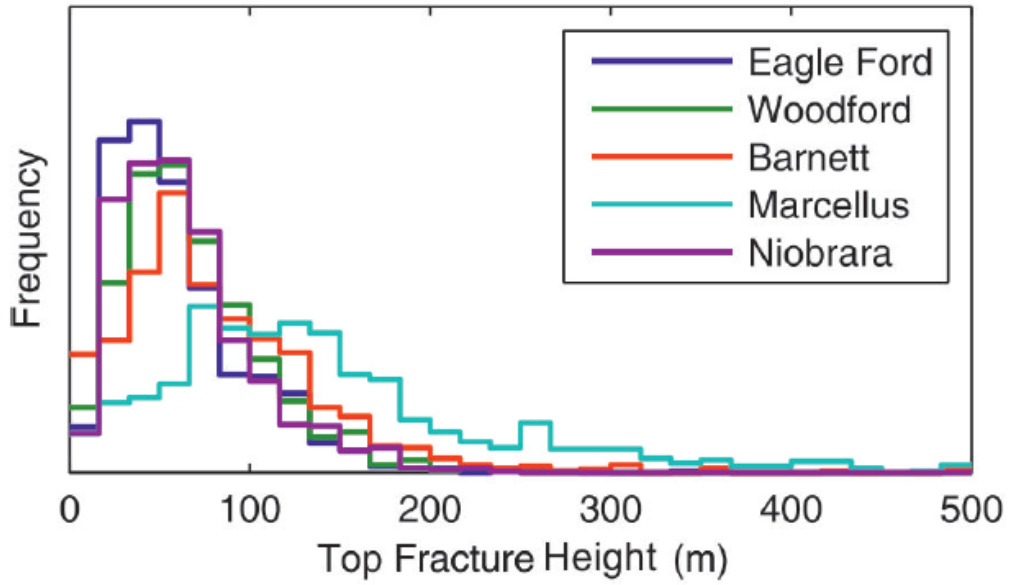


US EPA (2017)

Fractures (压裂裂隙)



US EPA (2017)

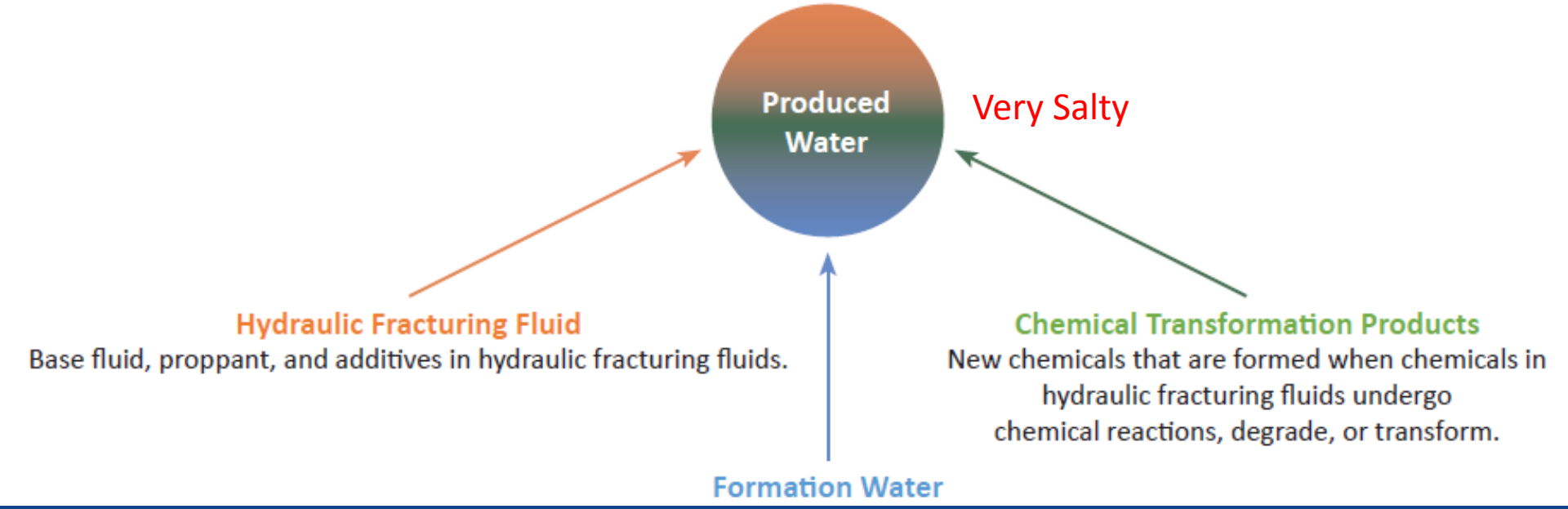


Source: Davies et al. (2012)

Water Cycle of Hydraulic Fracturing (水力压裂的水循环)

US EPA (2017)

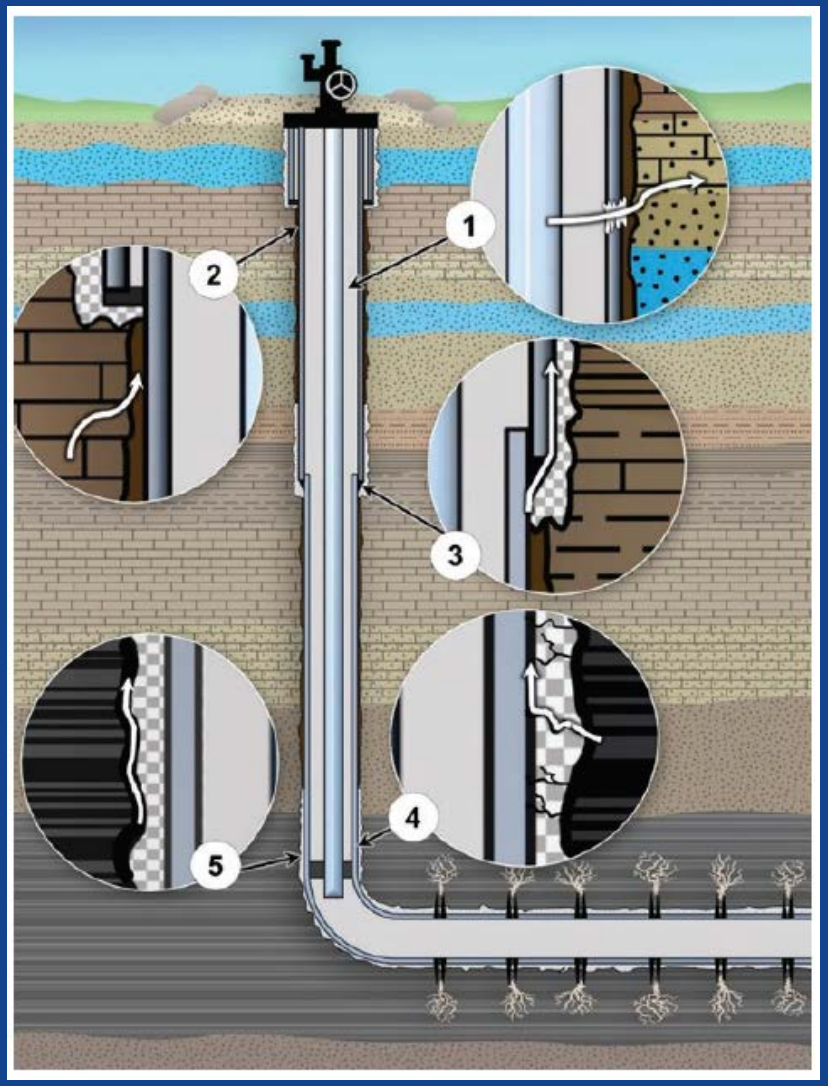
Produced Water

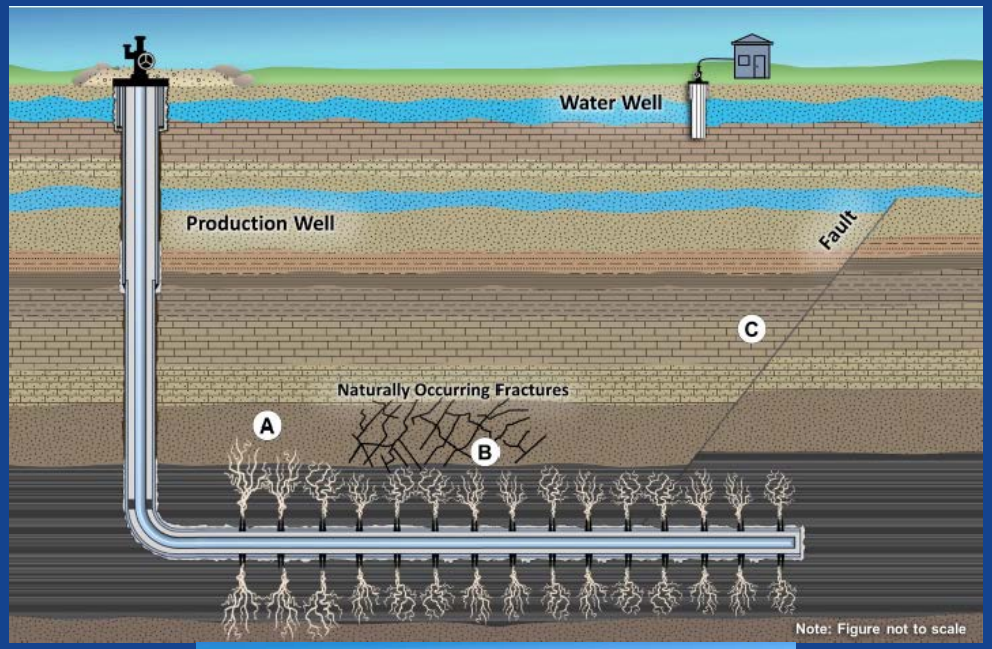


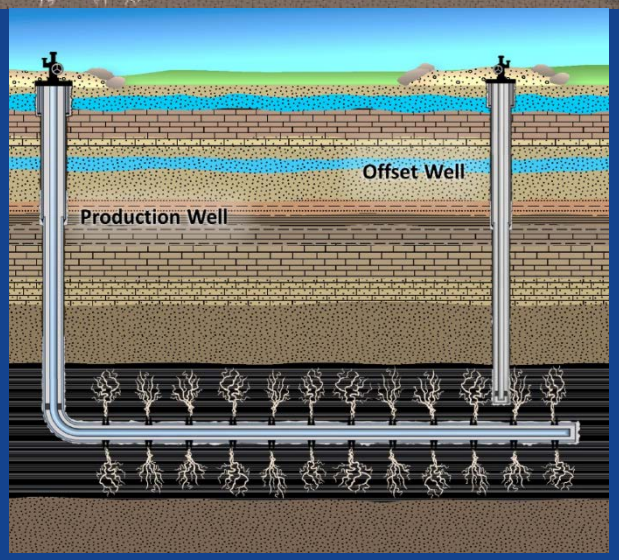
Produced Water contains

- Salts, including those composed from chloride, bromide, sulfate, sodium, magnesium, and calcium;
- Metals, including barium, manganese, iron, and strontium;
- Naturally-occurring organic compounds, including benzene, toluene, ethylbenzene, xylenes(BTEX), and oil and grease;
- Radioactive materials, including radium;
- Hydraulic fracturing chemicals and their chemical transformation products.

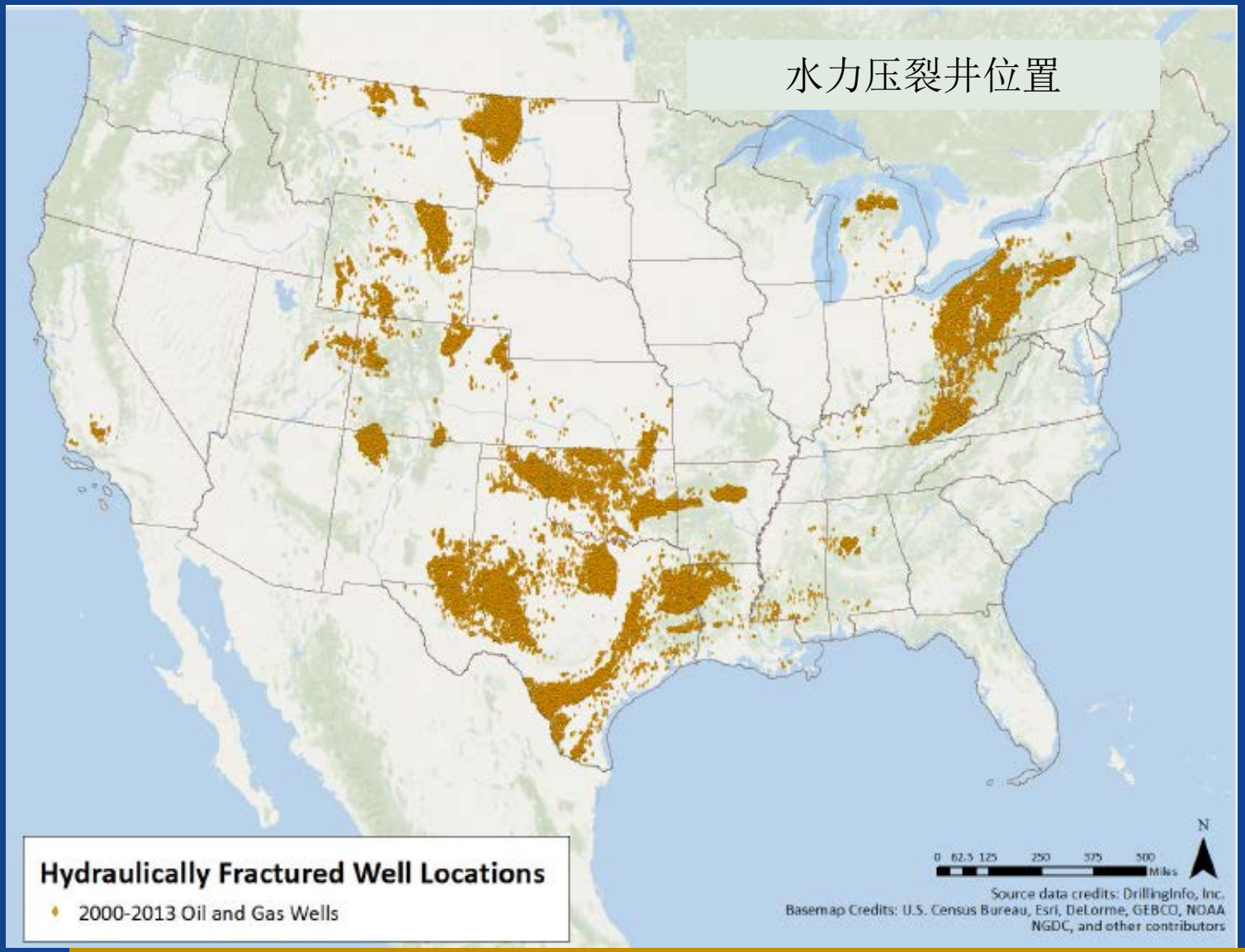
Potential Pathways of Fluid Migration
(流体迁移的潜在途径)







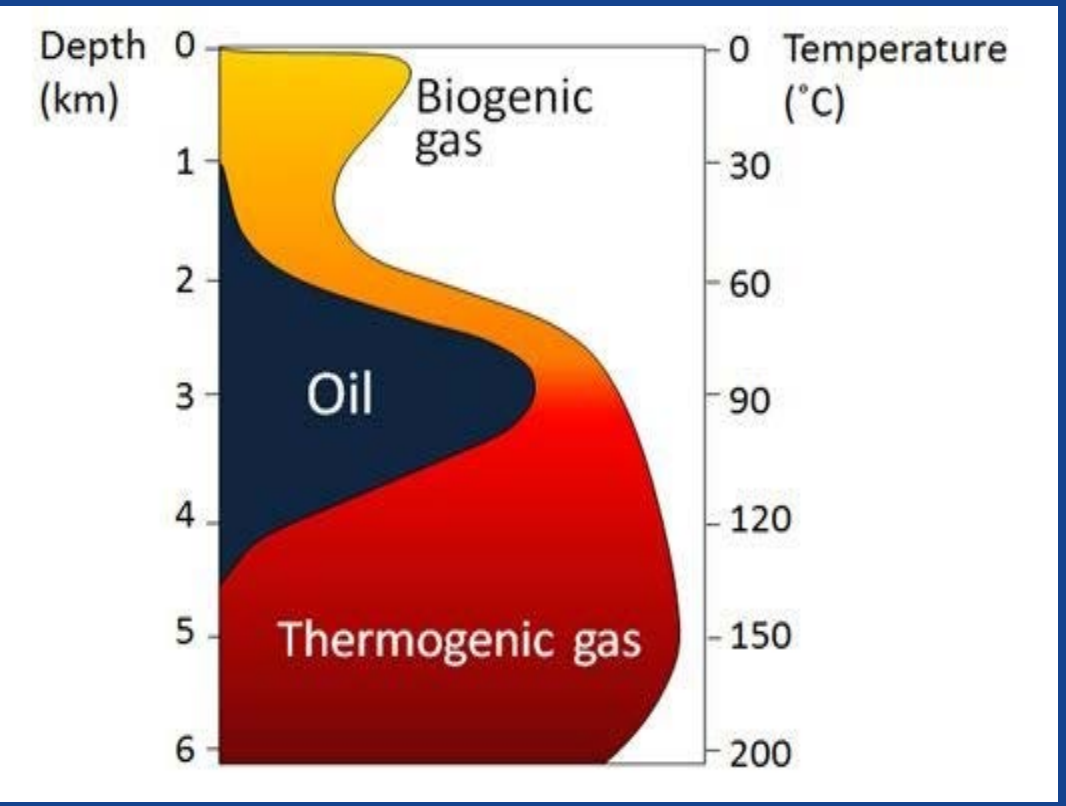
US EPA (2017)



275,000 wells were drilled and hydraulically fractured between 2000 and 2013. About 25,000 to 30,000 new wells were hydraulically fractured each year in the United States from about 2011 to 2014.

US EPA (2017)

How is Methane Formed? (甲烷是如何形成的？)



www.petropedia.com

Biogenic (生物成因):

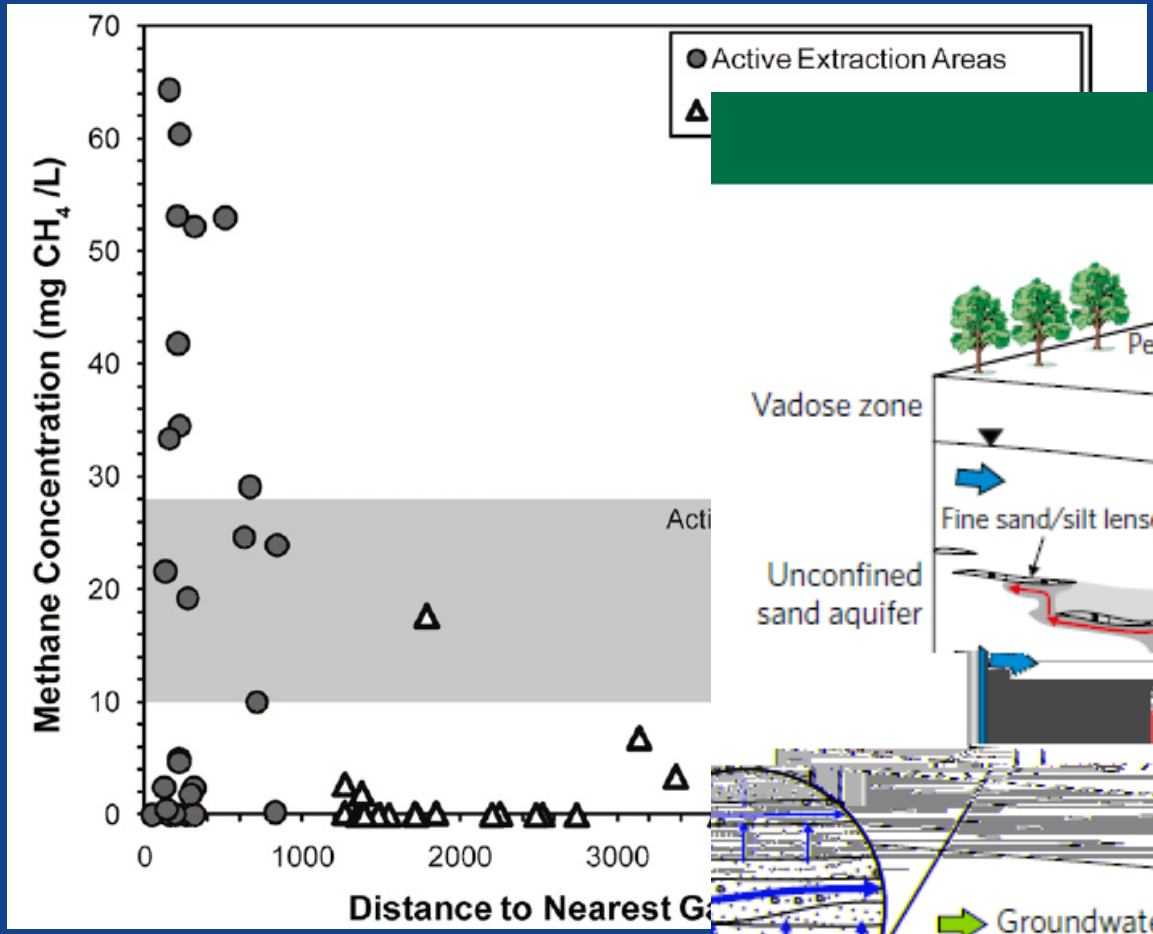
Biogenic gas is produced from bacterial activities near the earth surface (10s of meters). Biogenic gas is overwhelmingly methane (≥ 99%).

Thermogenic (热成因):

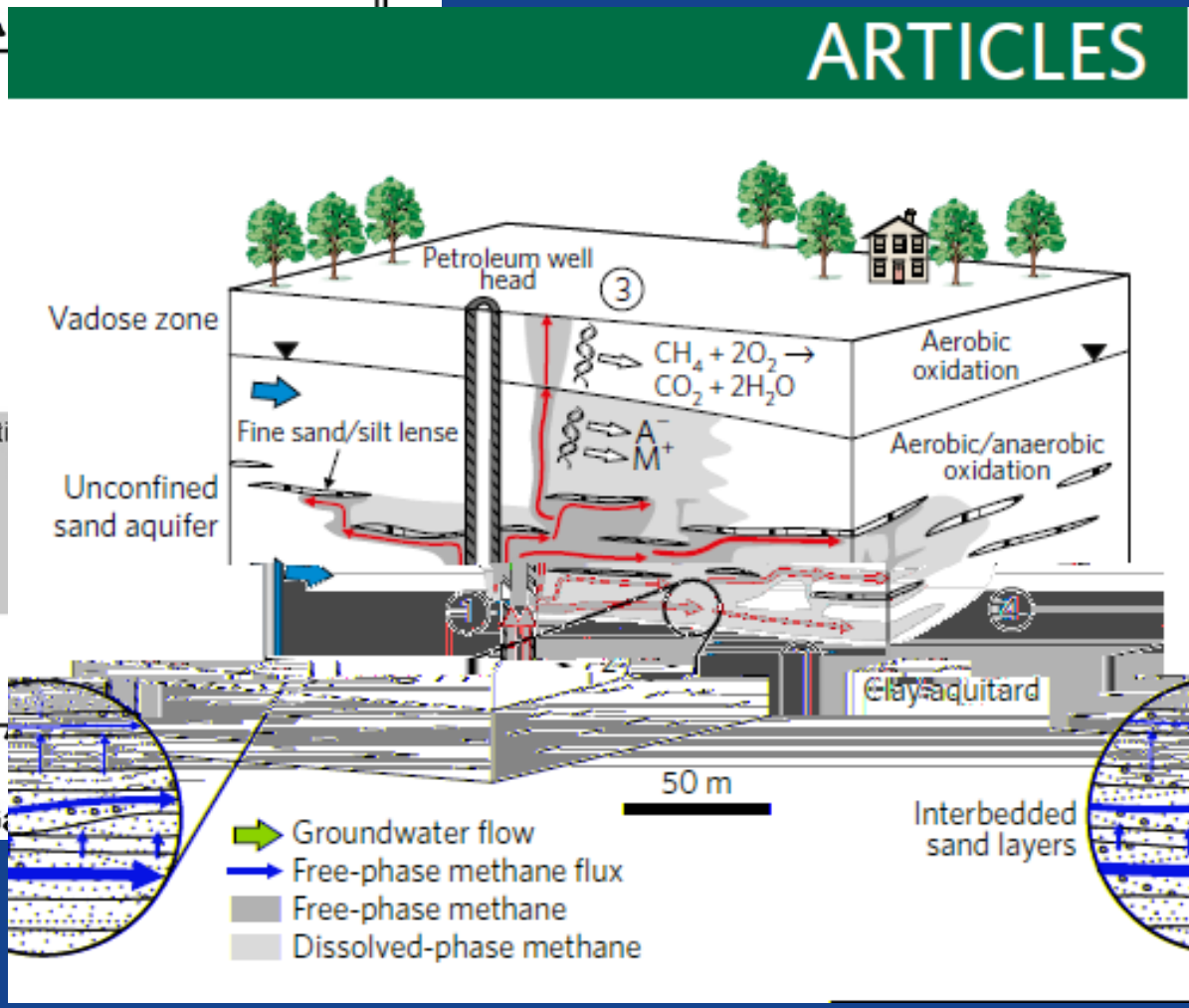
Thermogenic natural gas occurs at depths exceeding 1,000 m and is generated from chemical reactions under high temperature and high pressure without the presence of micro-organisms. Thermogenic gas contains a large percentage of non-methane hydrocarbons, including ethane, propane, etc.

https://pubs.usgs.gov/of/1996/of96-272/ch03s07.html

Methane in Shallow Groundwater
(浅层地下水中的甲烷)



Osborn et al. (2011), PNAS



Cahill et al. (2017), Nature Geoscience

Methane in Shallow Groundwater (浅层地下水中的甲烷)

USGS science for a changing world

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Unconventional Oil and Gas Production Not Currently Affecting Drinking Water Quality

Release Date: MAY 31, 2017

Decades or longer may be needed to fully assess the effects of unconventional oil and gas production on the quality of groundwater used for drinking water in Arkansas, Louisiana, and Texas

A new U.S. Geological Survey study shows that unconventional oil and gas production in some areas of Arkansas, Louisiana, and Texas is not currently a significant source of methane or benzene to drinking water wells. These production areas include the Eagle Ford, Fayetteville, and Haynesville shale formations, which are some of the largest sources of natural gas in the country and have trillions of cubic feet of gas.

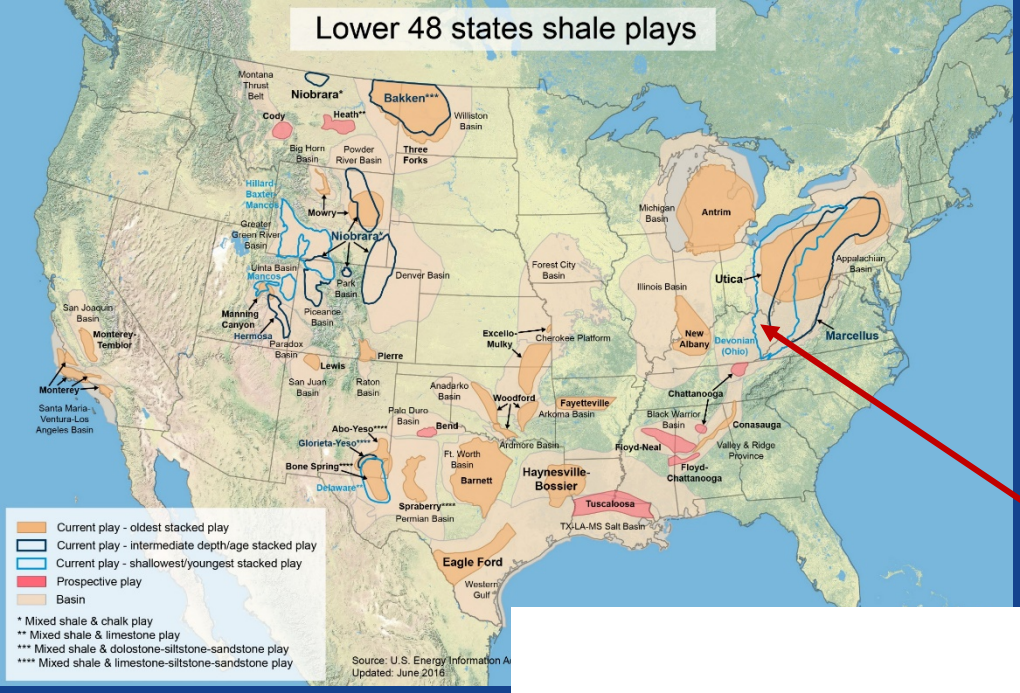
Contacts

Department of the Interior,
U.S. Geological Survey

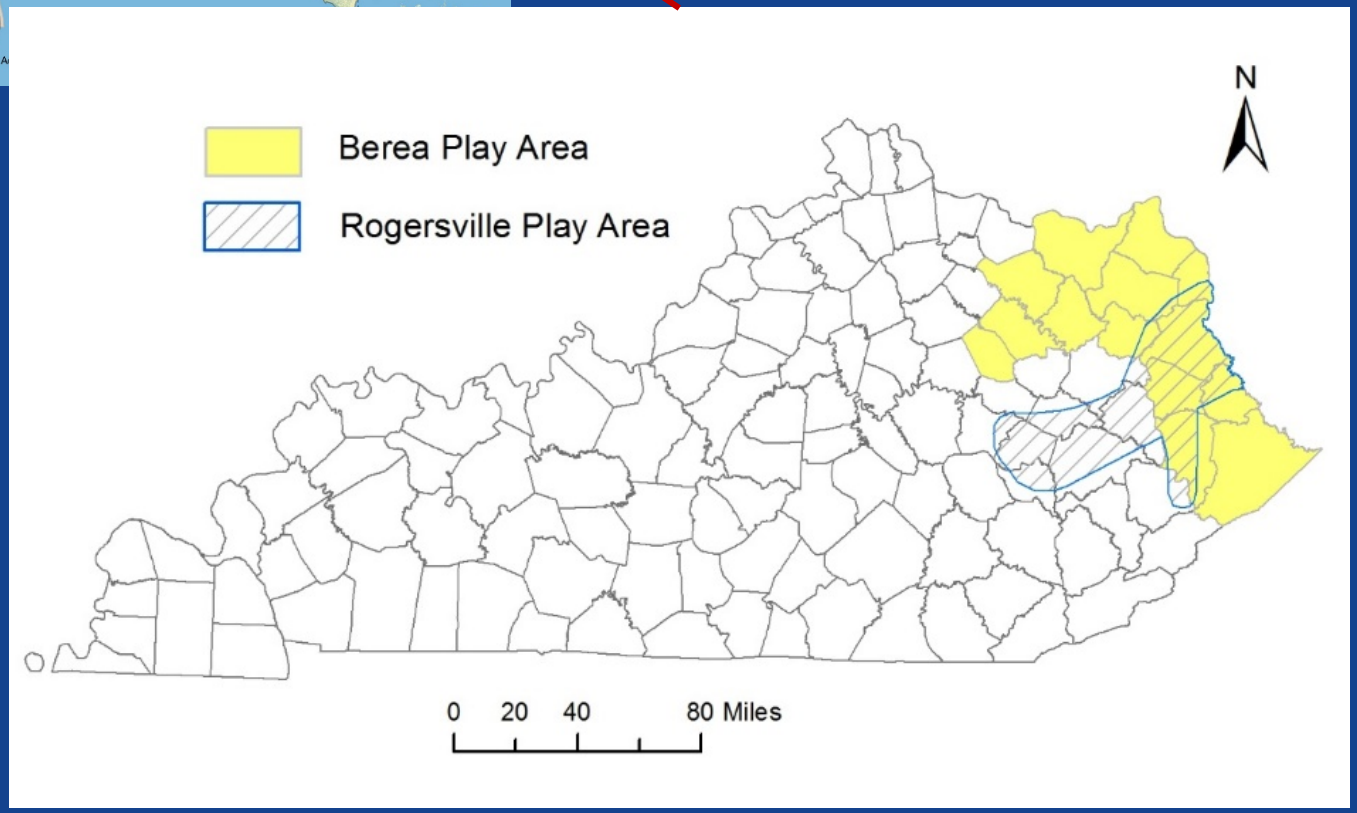
Office of Communications and Publishing
12201 Sunrise Valley Drive
Reston, VA 20192
United States

McMahon (2017), EST

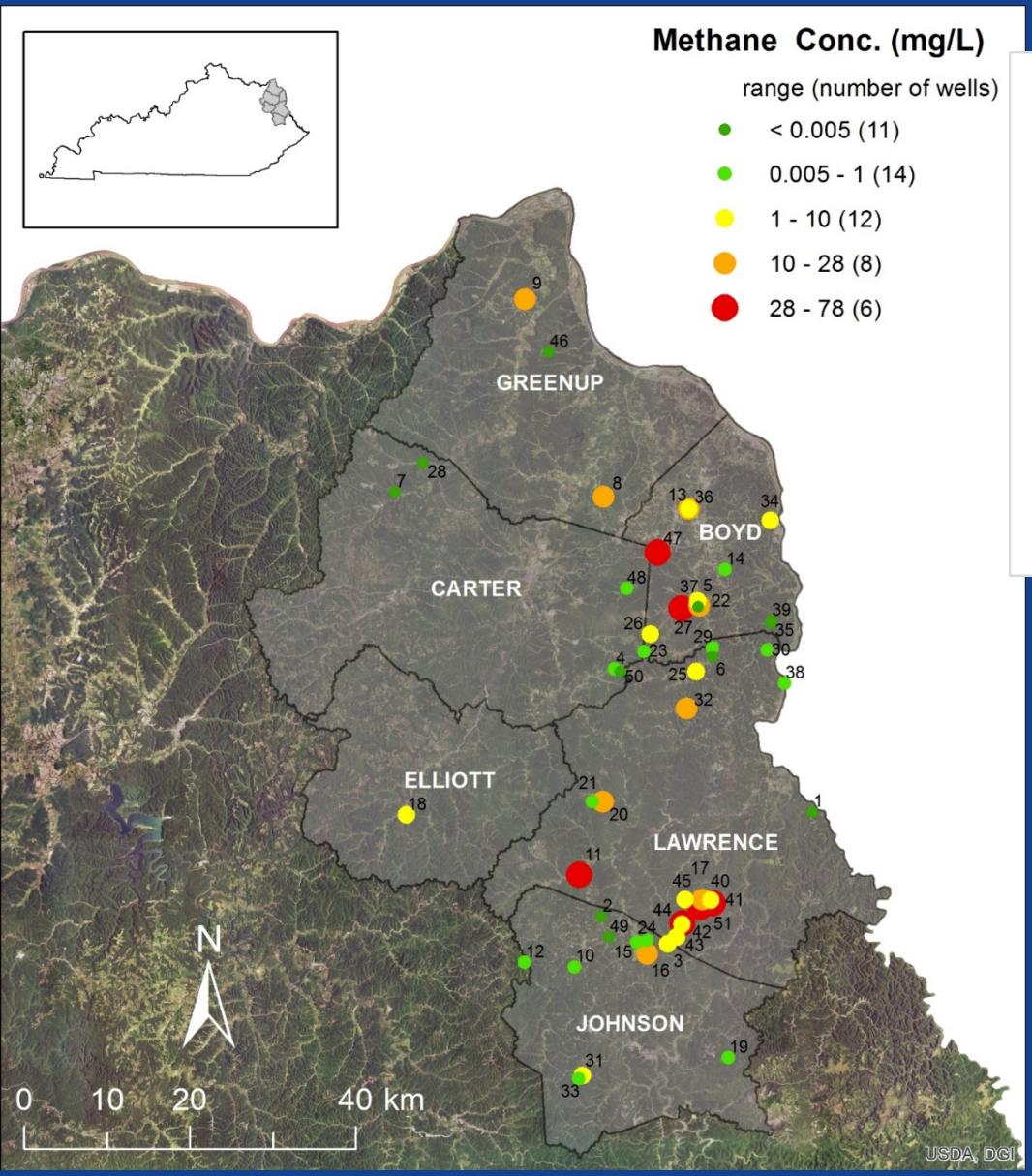
"Methane concentrations were not spatially correlated with hydrocarbon well locations in any of the study areas"

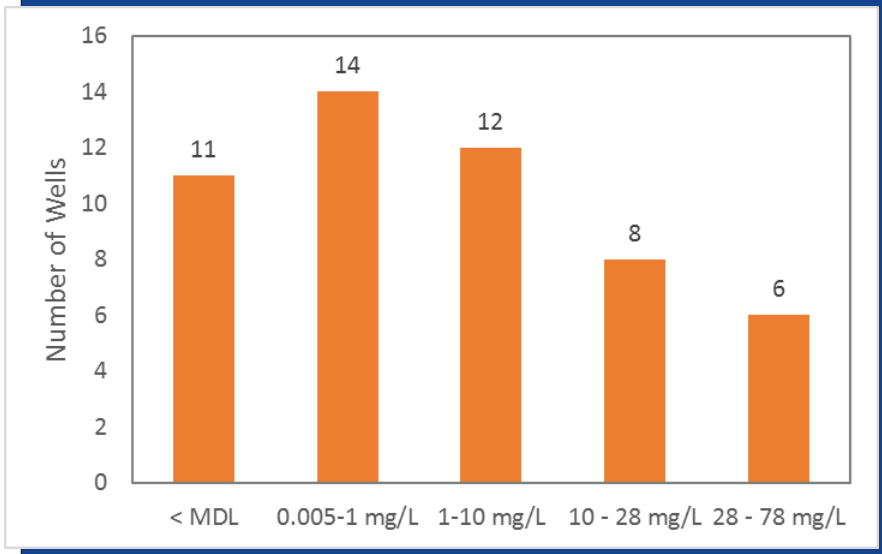


Study Area (研究区)



Dissolved Methane Distribution (溶解甲烷分布)





- **78%** of wells have detectable methane (MDL: 5 µg/L).
  - **51%** wells > 1 mg/L
  - **27%** wells >10 mg/L
  - **12%** wells >28 mg/L

Methane(CH_4) Isotopes (δ^2H and $\delta^{13}C$)
甲烷同位素

$$\delta^2\mathrm{H}(‰) = \left[\frac{\left({}^2\mathrm{H}/{}^1\mathrm{H}\right)_{\mathrm{sample}}}{\left({}^2\mathrm{H}/{}^1\mathrm{H}\right)_{\mathrm{standard}}} - 1 \right] \times 1000$$

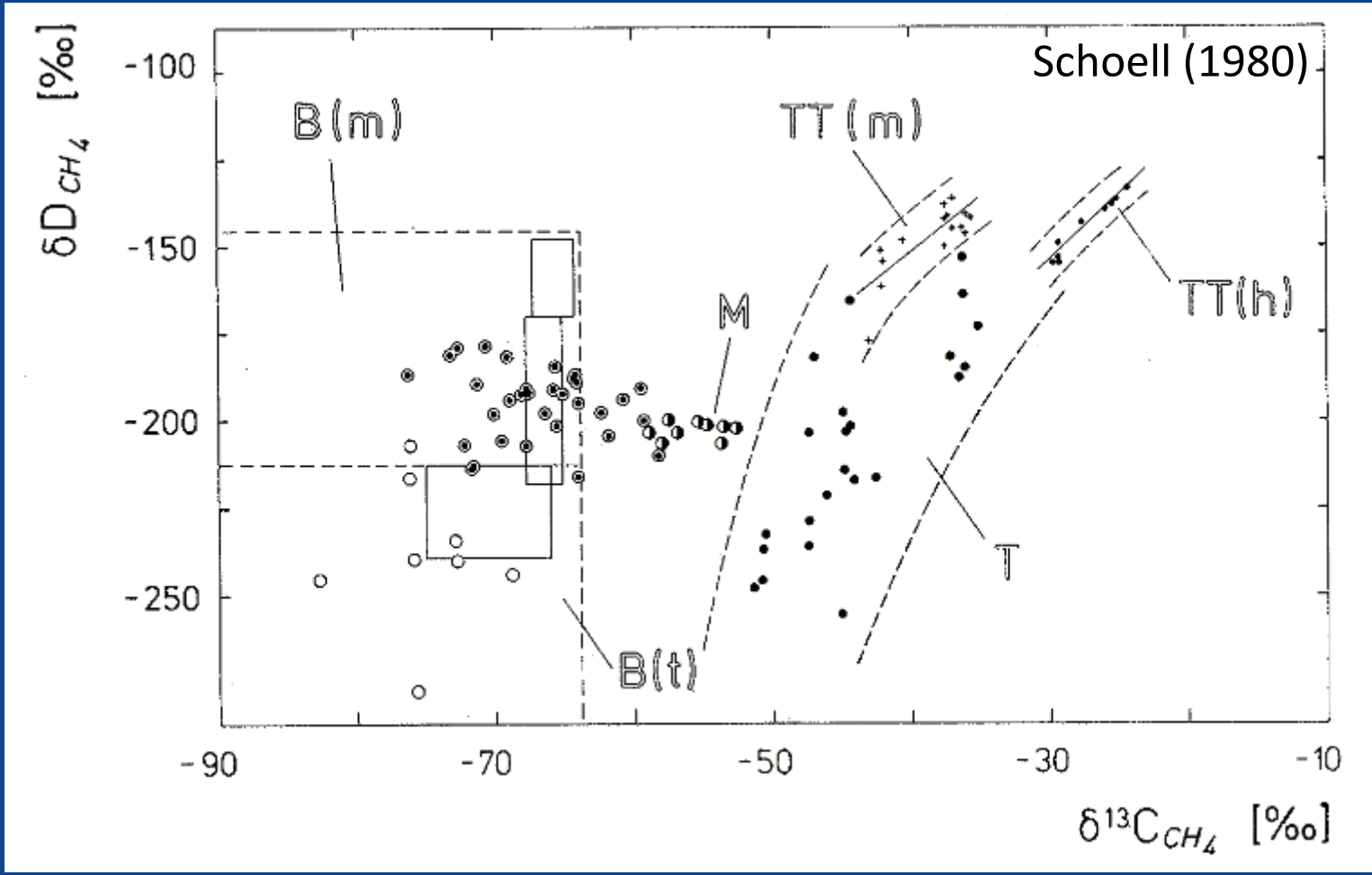
$$\delta^{13}\mathrm{C}(‰) = \left[\frac{\left({}^{13}\mathrm{C}/{}^{12}\mathrm{C}\right)_{\mathrm{sample}}}{\left({}^{13}\mathrm{C}/{}^{12}\mathrm{C}\right)_{\mathrm{standard}}} - 1 \right] \times 1000$$

Standard:

Hydrogen isotopes: standard mean ocean water (SMOW)

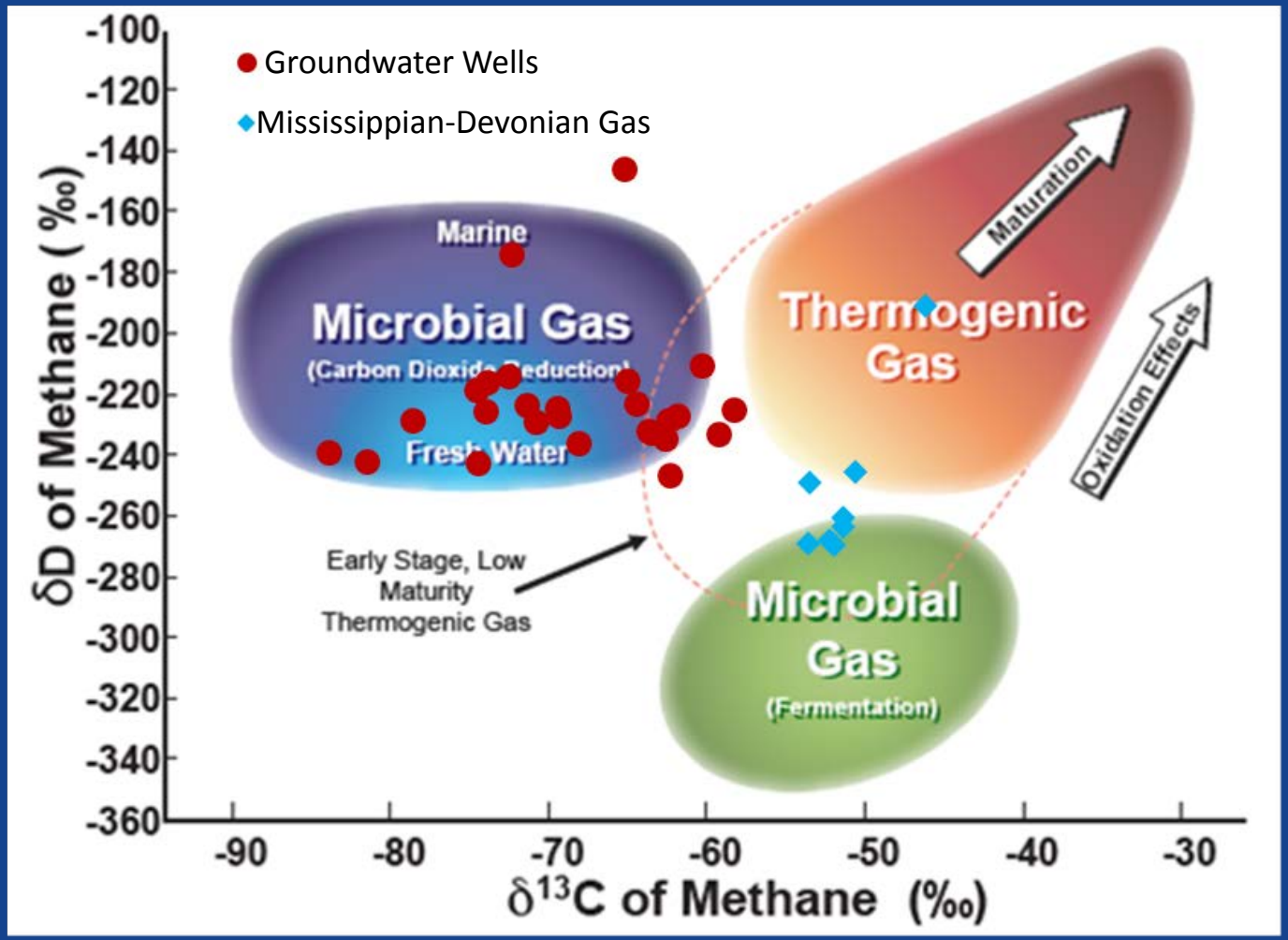
Carbon isotopes: Vienna Pee Dee Belemnite (VPDB)

Methane(CH_4) Isotopes (δ^2H and $\delta^{13}C$)
甲烷同位素



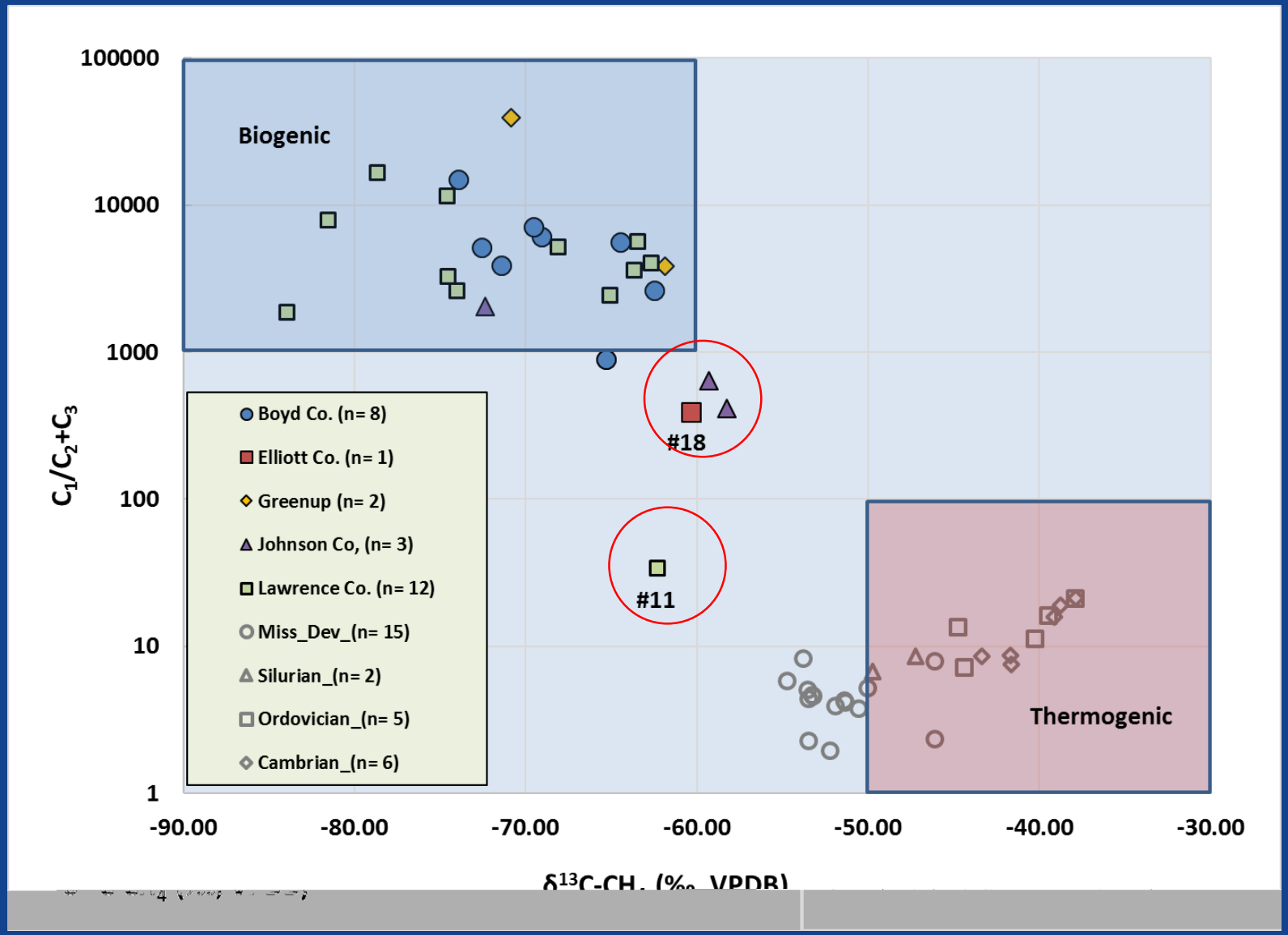
B(m): biogenic marine
B(t): biogenic terrestrial
M: mixed gas
TT(m): thermogenic marine-sapropelic
TT(h): thermogenic humic terrestrial
T: wet gas (C_{2+}> 5%)

Methane Origin （甲烷来源）

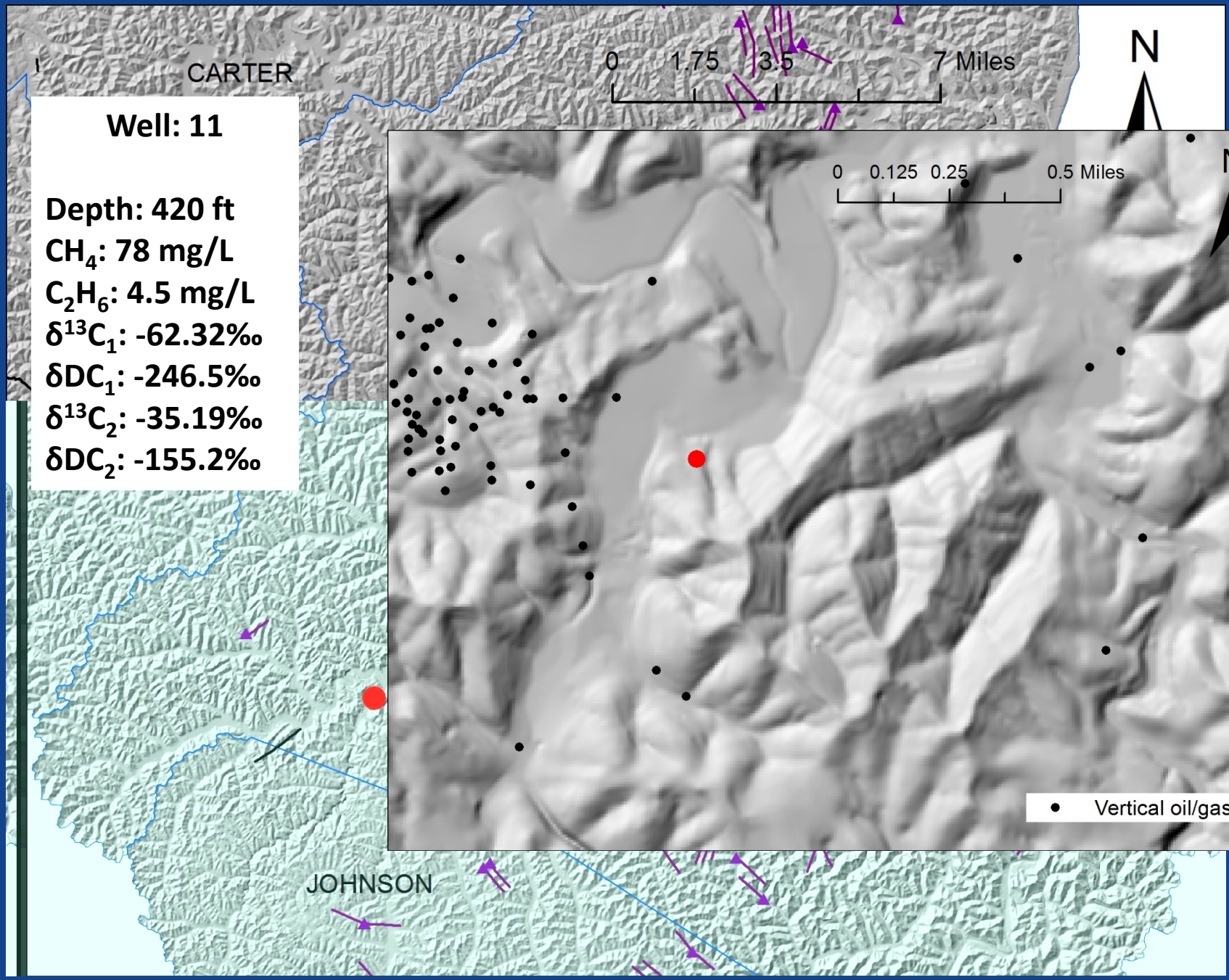


(Image source: Isotech)
The image is based on Whiticar (1999)

Gas Wetness vs $\delta^{13}C\text{-}CH_4$ (气体湿度跟碳13的关系)



Gas wetness ($C_1/(C_2 + C_3)$) versus $\delta^{13}C\text{-}CH_4$. Dissolved gases in groundwater are shown with filled symbols, whereas gases from eastern Kentucky oil and gas reservoirs are shown with unfilled symbols.



Well: 11

Depth: 420 ft
CH_4: 78 mg/L
C_2H_6: 4.5 mg/L
$\delta^{13}C_1$: -62.32‰
δDC_1: -246.5‰
$\delta^{13}C_2$: -35.19‰
δDC_2: -155.2‰

Conclusions (结论)

- **Methane is a relatively common occurrence in shallow groundwater in Berea and Rogersville play areas of eastern Kentucky.**
- **Methane in groundwater is primarily generated from microbial sources.**
- **Methane is associated with hydro-geochemical conditions. Elevated methane concentrations were found more common in sodium-rich water and reducing redox conditions.**

Acknowledgements

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NETL

GSI ENVIRONMENTAL

UK Ag EXTENSION

ENVIRONMENTALLY FRIENDLY DRILLING

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