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Helium and Low to Very Low Methane Gas Fields in Northeast Arizona

James H. Ballard[1]

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[1]Occasional Consulting

Abstract

The distributions of subsurface helium, methane and nitrogen in northeast Arizona illustrate an interaction between hydrocarbon migration and basement-derived gas. The hydrocarbon system is largely within the Paradox basin to the north. Oil and gas migrated up the flank of the basin onto the plunging nose of the Defiance Uplift to the small oil and gas fields in Arizona. Helium, nitrogen and other gases most likely migrated vertically along faults and fractures into the sedimentary section. This does not rule out lateral motion in the reservoirs, but differs from studies of the Mid-Continent documenting sedimentary sources and very long accumulation times. Northeast Arizona has much higher concentrations of helium and nitrogen in Late Cretaceous to Early Paleogene traps. It also has only limited isotope work, proven to be essential in understanding these systems. Here, fields farther from the Paradox basin have less methane (and more nitrogen). The percentage of helium is relatively constant (5%). Three gas migration models are discussed in relation to these distributions.

Introduction

The Defiance Uplift is a major feature on the Colorado Plateau. It formed as part of the Cordilleran orogeny, reactivated from the roots of a Pennsylvanian mountain range. Individual structural highs are related to basement reverse faults. Where there is a thick sedimentary section, monoclinal folds developed over the deep faults. The top Mississippian structure, shown in later figures, may be deep enough for many faults but only a few can be documented. The Cordilleran orogeny is associated with granitic intrusions. The crust and upper mantle have also been active since that time. Younger mafic dikes and sills, as well as eroded diatremes, are present in the region. These intrusions followed pathways from the upper mantle. The crust and upper mantle are sources of helium; the predominant source of helium here is the granitic crust (He isotope ratios, Halford, 2018).

The pre-Pennsylvanian section has helium and low to very low amounts of methane gas. The Devonian contains important reservoirs. At the base, the Aneth formation includes porous dolomite. The McCracken Sandstone, part of the Elbert formation, is above the Aneth. The Mississippian Leadville Limestone also contains important reservoirs, porous zones in dolomite below the main limestone. The carbonates and shales are relatively effective seals. To the south, the uplift of the area in the Pennsylvanian resulted in the complete erosion of the pre-Pennsylvanian section off what is now part of the Defiance Uplift. To the north, the section extends underneath the younger deposits of the Paradox basin. There are additional helium-rich accumulations in Utah and Colorado (Wiseman, 2019).

Gas Compositions

Figure 1 shows the relative abundance of helium, methane and nitrogen in the pre-Pennsylvanian section. The gas analyses are from the AOGCC well files (also see Rauzi, 2005). Note the helium is around 5%. Although even one percent difference is very significant economically, the limited sampling and various reporting may not be that accurate here. Helium is present in all the pre-Pennsylvanian structural traps. The largest amount of methane is nearly 50%, but that is considered low. The more methane the better; methane can be sold and nitrogen has little value. There are trends of decreasing methane and increasing nitrogen to the south. Fields are labeled; EBB-East Boundary Butte, T-Tohache, BR-Black Rock, DBK-Dineh Bi Keyah, and can be located on subsequent maps. Even methane in associated gas is reduced.

Figure 2 shows the relative abundance of methane, carbon dioxide and nitrogen in the pre-Pennsylvanian reservoirs. Tohache has the most carbon dioxide at 22%. Other areas that have around 10% carbon dioxide (EBB and DBK) are widely separated.

Contours of the amount of methane are shown on Figure 3, which covers the northern part of the area with the Four Corners of states. There are three structural highs of interest. In the area with the most methane, along the border with Utah, is the East Boundary Butte field. It extends into Utah, but maps show it as a closure separate from the Boundary Butte field farther northwest (AOGCC well file 0481, and Dunn, 1978). East Boundary Butte produced oil and gas from the Pennsylvanian. One well has a posted gas composition from the Leadville; 47% methane, some ethane, 4.4% helium, 10% CO_2, 37% nitrogen, and it was tested at 1800 mcfg/d. A well farther east reported non-flammable gas (NFG) in the Leadville. The field looks like a candidate for re-development.

To the east, still far enough north to have significant methane in the pre-Pennsylvanian section, is the Teec Nos Pos area with a small oil and gas field and the Tohache Wash well (Figure 3). The Pennsylvanian oil and gas field is stratigraphically trapped (up-dip limit green on Fig. 3) with no apparent closure in the pre-Pennsylvanian. The Tohache well produced gas in the late 1960's from the Leadville into a small helium plant. The structural closure is poorly defined. The well initially produced some oil from the Aneth, it had a low GOR (reported) and no gas analysis is available. Two Leadville gas analyses average 24% methane, some ethane, 6% helium, 22% CO_2 and 45% nitrogen. The initial potential from the Leadville was 3202 mcfg/d, but it was produced at a much lower rate, totaling 385,774 mcfg (gross) within two years. Production stopped because of market conditions (Spencer, 1978) and/or processing problems due to the amount of CO_2 (Casey, 1983). It looks like reserves were abandoned.

The large structural high in the center of Figure 3 has two designated fields. The Dry Mesa field and part of the Black Rock field at the northwest end produced oil from the Leadville. The locations of the saddle between the fields and the reverse fault are supported by seismic data (map in AOGCC 0717). The closures are low-relief. Dry Mesa reported very little gas. Two oil wells in northwest Black Rock had associated gas that averaged only 11% methane, some heavier hydrocarbons, 5% helium, 3% CO_2 and 76% nitrogen. At the southeast end of

Black Rock, little oil is reported in the Leadville. It is not a simple gas cap; there may be fault-bound compartments. Two close-by wells in southeast Black Rock reported methane at 2% and 18% from the Leadville (Fig. 3). These could be averaged for the regional methane contours. However, the 2% analysis value may not be valid (AOGCC 0598, oxygen and irregular distributions of methane, ethane and propane). The 18% methane and 8% helium are left uncertain. Most of the wells were completed in the Pennsylvanian. The Devonian section is unusually thin. The nitrogen content follows a very similar pattern as the methane content on Figure 3, but going from 37% nitrogen at East Boundary Butte, an average of 45% at Tohache and 76% at Black Rock. The percentage of CO_2 does not show a smooth trend, and helium is fairly constant.

The gas in the pre-Pennsylvanian section to the south is very low in methane. See Figure 4. The major structure plunging to the northwest includes Dineh Bi Keyah field, Arizona's largest. It has produced over 18 million barrels of oil and 6 bcfg from a stratigraphic trap, an Oligocene igneous sill in the Pennsylvanian section (green outline). The associated gas had helium, nitrogen and reduced methane.

Several wells in the main field area tested gas in the McCracken and/or the Aneth. These were drill stem tests, higher rates came from wells to the southeast of the field with aggressive well completions. The structural closure is not completely defined, there is likely a sealing fault to the southeast. A small amount of gas is produced for helium. A single well started reporting helium production from the Devonian 2003, two more wells in 2014 and 2015 (red well numbers on Fig. 4). By 2020, the helium well count increased to nine by recompleting older wells. Reported production is about 200 mcfg/d (gross). Recent gas samples averaged 5.6% helium, 1% methane, 13% CO_2, 78% nitrogen.

To the southeast of Dineh Bi Keyah, there are additional discoveries in the Devonian. Several wells missed the sill in the late 1960's. One of them (0393) tested the McCracken at 1579 mcfg/d, with 5% helium, 2% methane, 7% CO_2 and 83% nitrogen. Two additional wells, higher on structure to the southeast, discovered a large accumulation (Fig. 4) that has not been produced. The anticline continues into New Mexico, where a similar-sized structural high was drilled and found helium-rich gas (wells 20197 and 20124). This trend looks like it should be evaluated for development. It is at high elevation in the Chuska mountains. Nearby fields in New Mexico (North and South Beautiful Mountain, Tocito) also have helium and very low methane gas in the pre-Pennsylvanian section (Broadhead, 2004).

Discussion

Figure 5 shows possible explanations or models for the distributions of the subsurface gases in northeast Arizona. The diagrams represent about fifty miles south to north. Traps in the Pre-Pennsylvanian section are shown at three fields. The actual thickness of the Pre-Pennsylvanian is 300 to 700 feet thick in the fields, and absent farther south. Black Rock has the thinnest section. Each field has a representative gas composition listed. Given early hydrocarbon generation in the Paradox basin, oil and hydrocarbon gas probably filled the traps first, and could still be migrating from the north (Peterson, 1989). Basement gas has displaced any oil and nearly all the hydrocarbon gas in the southern traps, but this process is incomplete in the north. The amount of helium is fairly uniform in all of the pre-Pennsylvanian traps. In the absence of lateral migration (1), basement gas may pass directly into the reservoir and traps along faults and fractures. This is the simplest model discussed in the literature. The distribution of nitrogen suggests that local sources provide less nitrogen in the north. The amount of carbon dioxide has an irregular distribution and may be best explained by variation between local sources.

The smooth, inverse relationship between methane and nitrogen suggests lateral migration. Lateral migration can be up-dip or down-dip. Since the traps with remaining hydrocarbons are to the north, basement gas may be migrating down-dip, north (2) with groundwater. The active sources would be high on the Uplift. This model fits the distributions of methane and nitrogen, but not that of helium. It may be an example of the amount of helium reaching a maximum due to leakage through the seal. A lot of helium would have leaked from the southern traps. Aquifer flow is not easy to document here, but isotope work (Ar and Ne, Halford 2018) suggests interaction with groundwater for gas samples from Dineh Bi Keyah. Additional samples from farther north could validate this model.

If helium and nitrogen are migrating up-dip from a primary source in the north, it is difficult to explain the distributions of nitrogen and methane. One would think that the northern traps would have the most basement gas. However, there could be a continued influx of hydrocarbon gas going up-dip. It is much simpler to consider hydrocarbon migration over or reduced to a very small amount. If methane gas is still migrating in, this can be combined with basement gas models, for example simple vertical migration (3). Methane gas from the Paradox basin possibly dilutes the basement gas, especially the nitrogen, in the northern traps. The effect would have to diminish to the south, farther from the source, to match the observed distributions of methane and nitrogen. One aspect of this model is that methane and nitrogen in the northern traps might be in a sort of balance. The nitrogen might not build-up and displace all of the hydrocarbons, as in the first two models.

These models are presented just for discussion, a larger data set is needed. Multiple processes may be at work.

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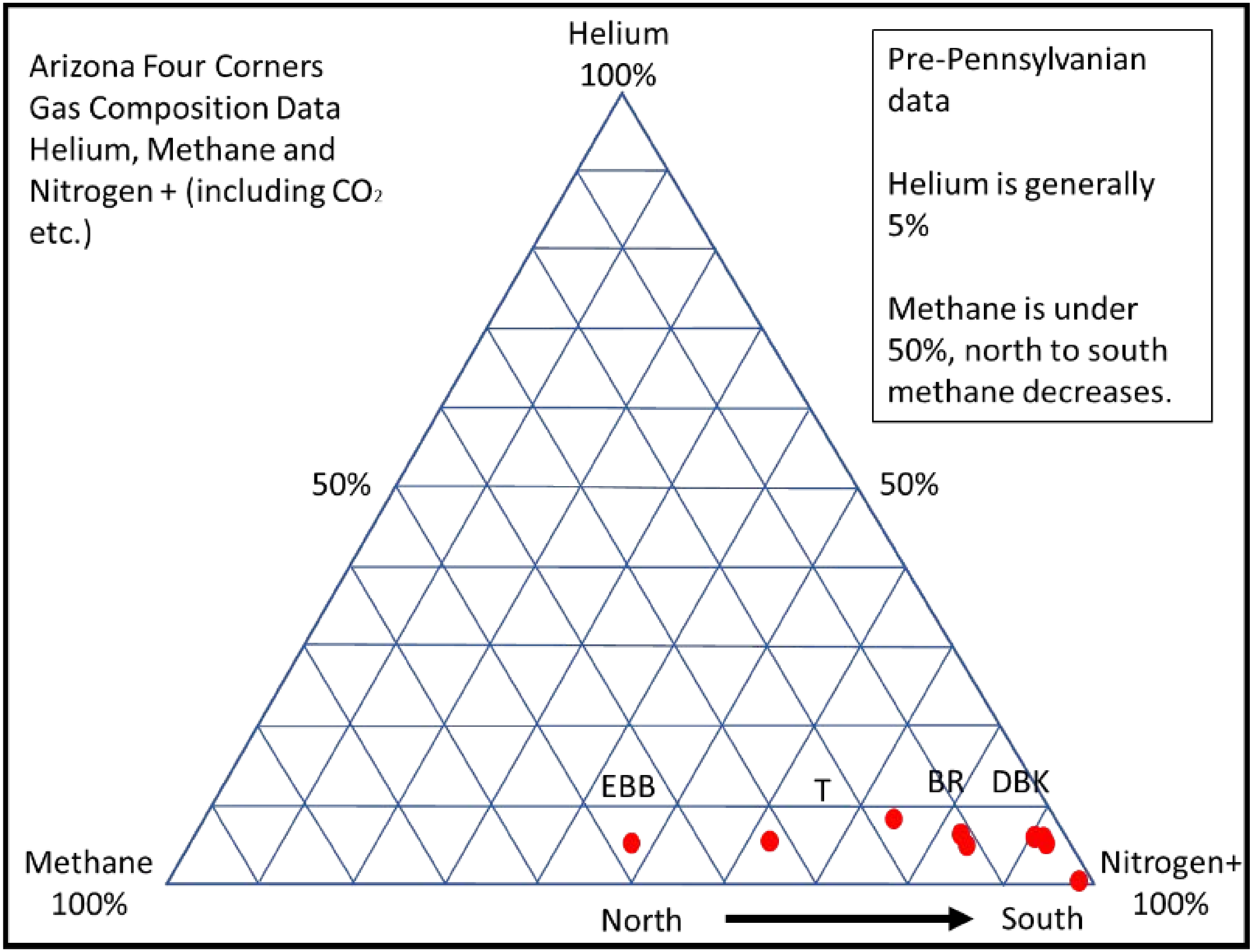

Figure 1. Helium, Methane and Nitrogen.

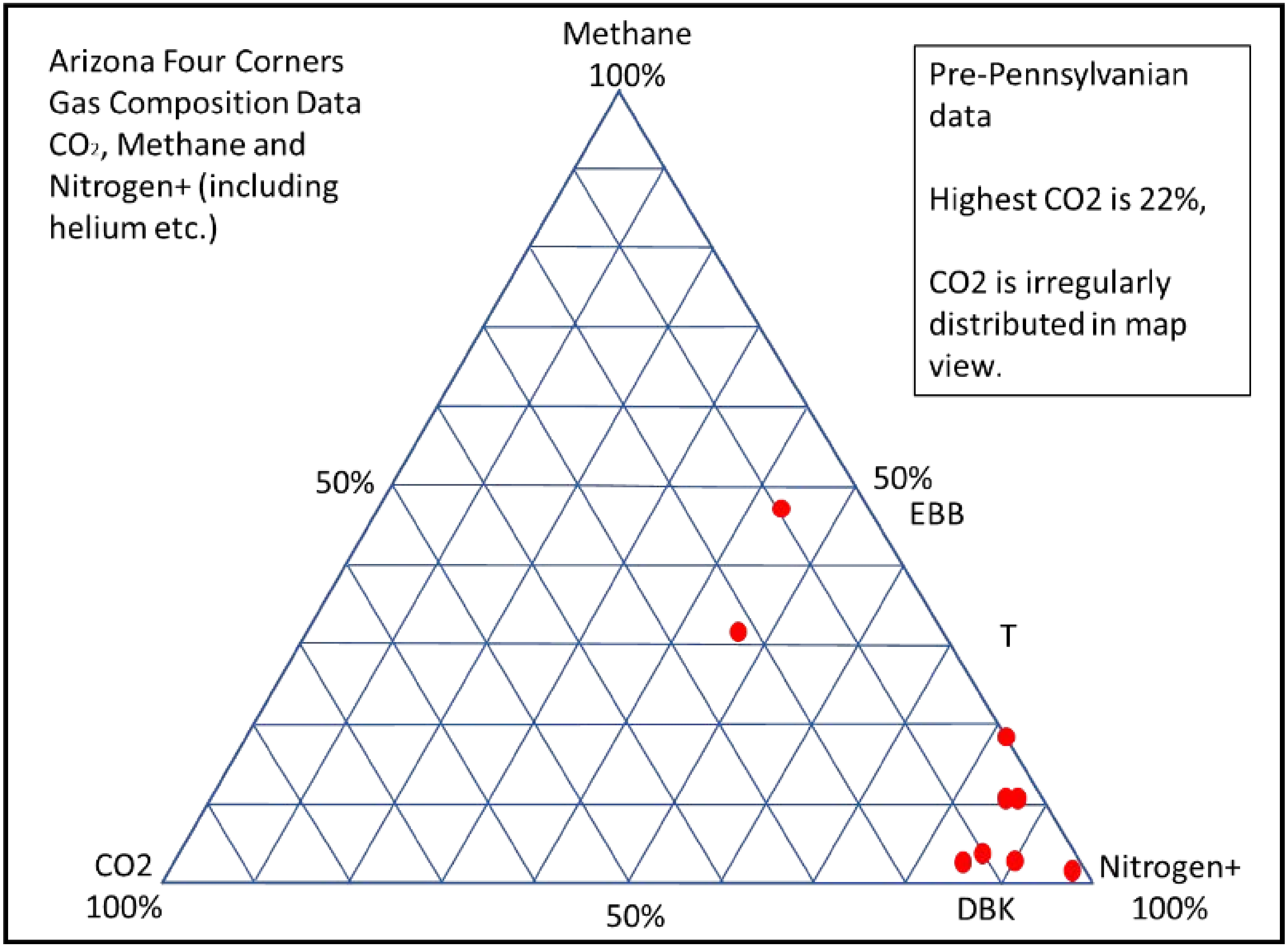

Figure 2. Methane, Carbon Dioxide and Nitrogen

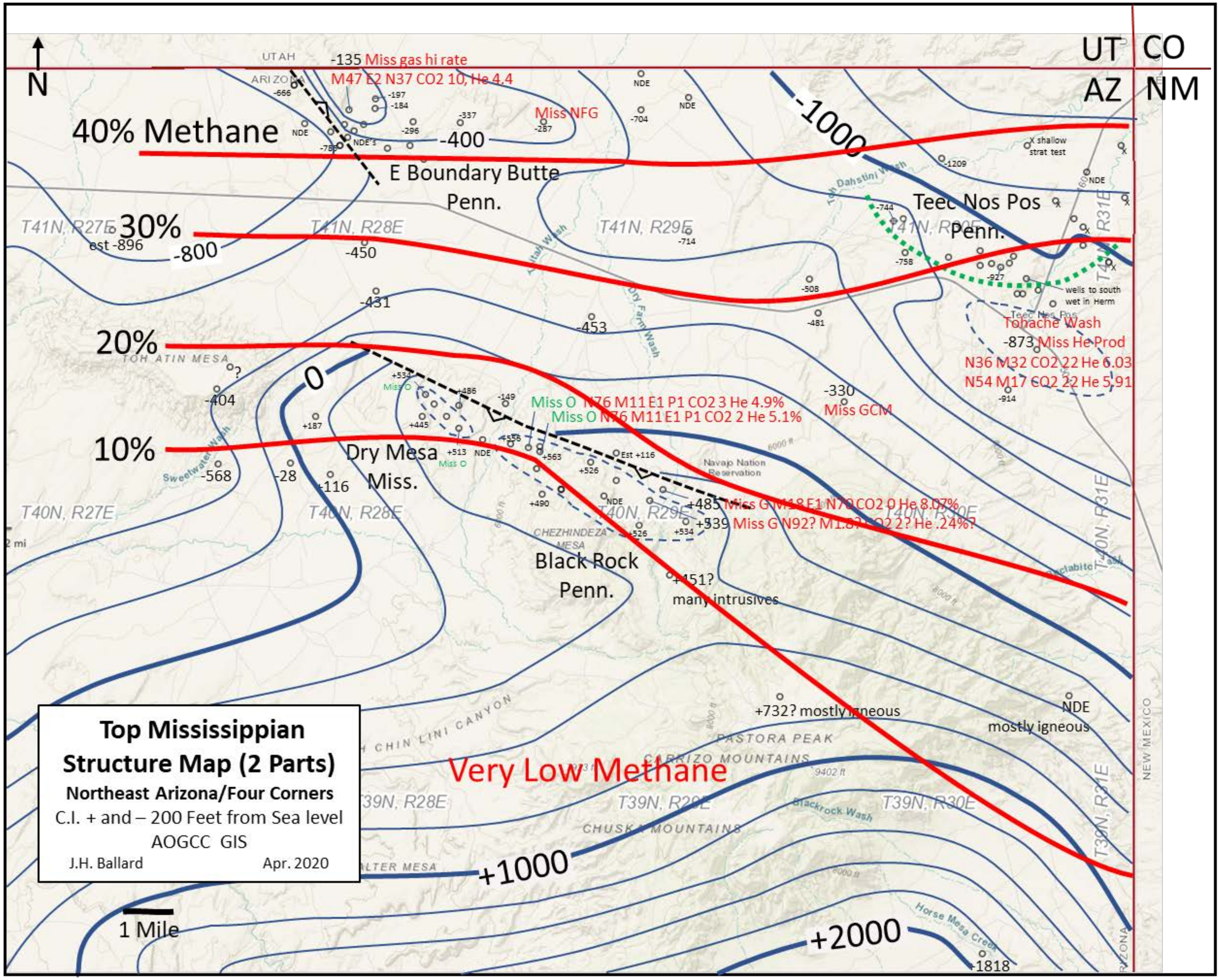

Figure 3. Mississippian Structure Map with Methane %.

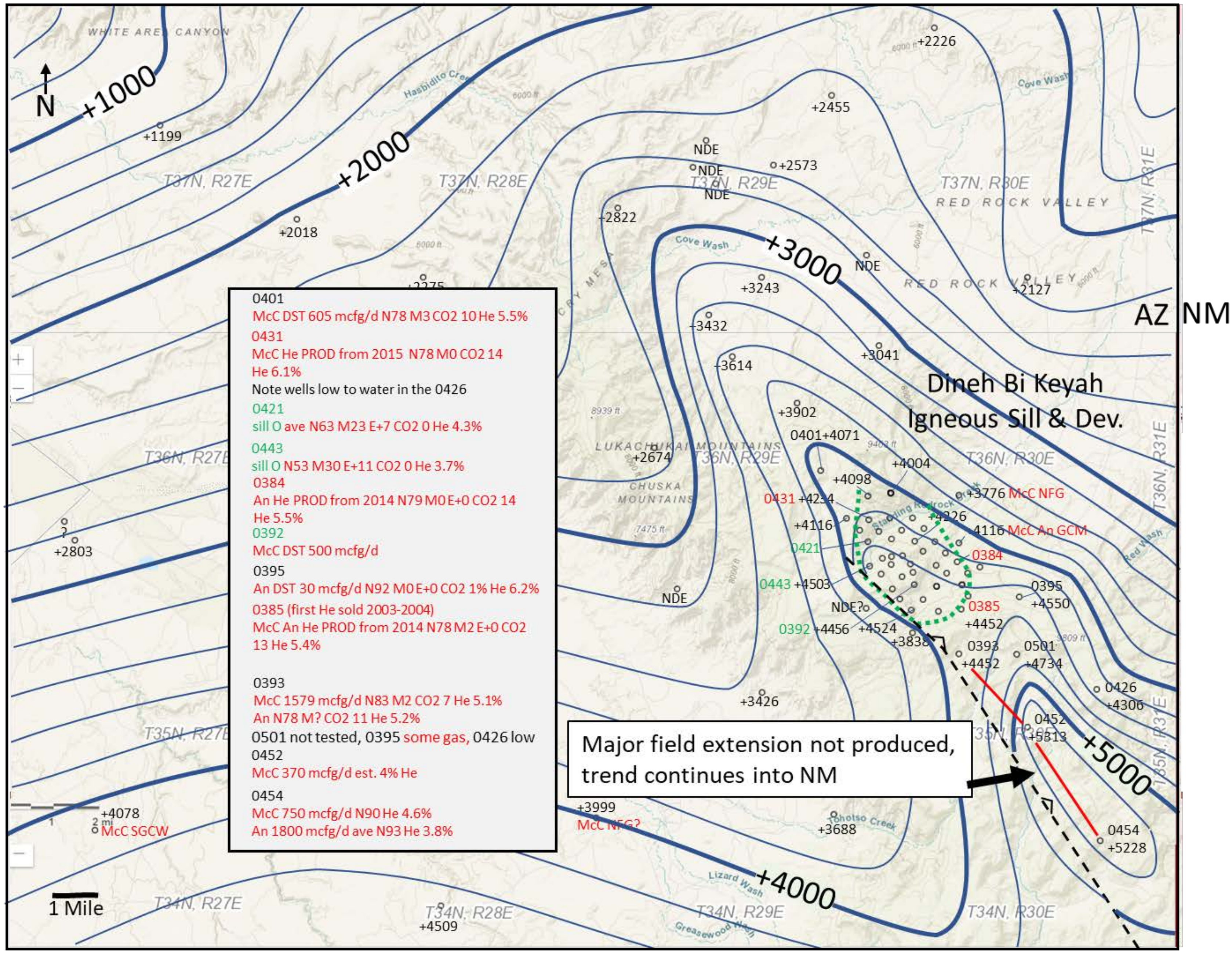

Figure 4. Mississippian Structure Part 2, South of Figure 3.

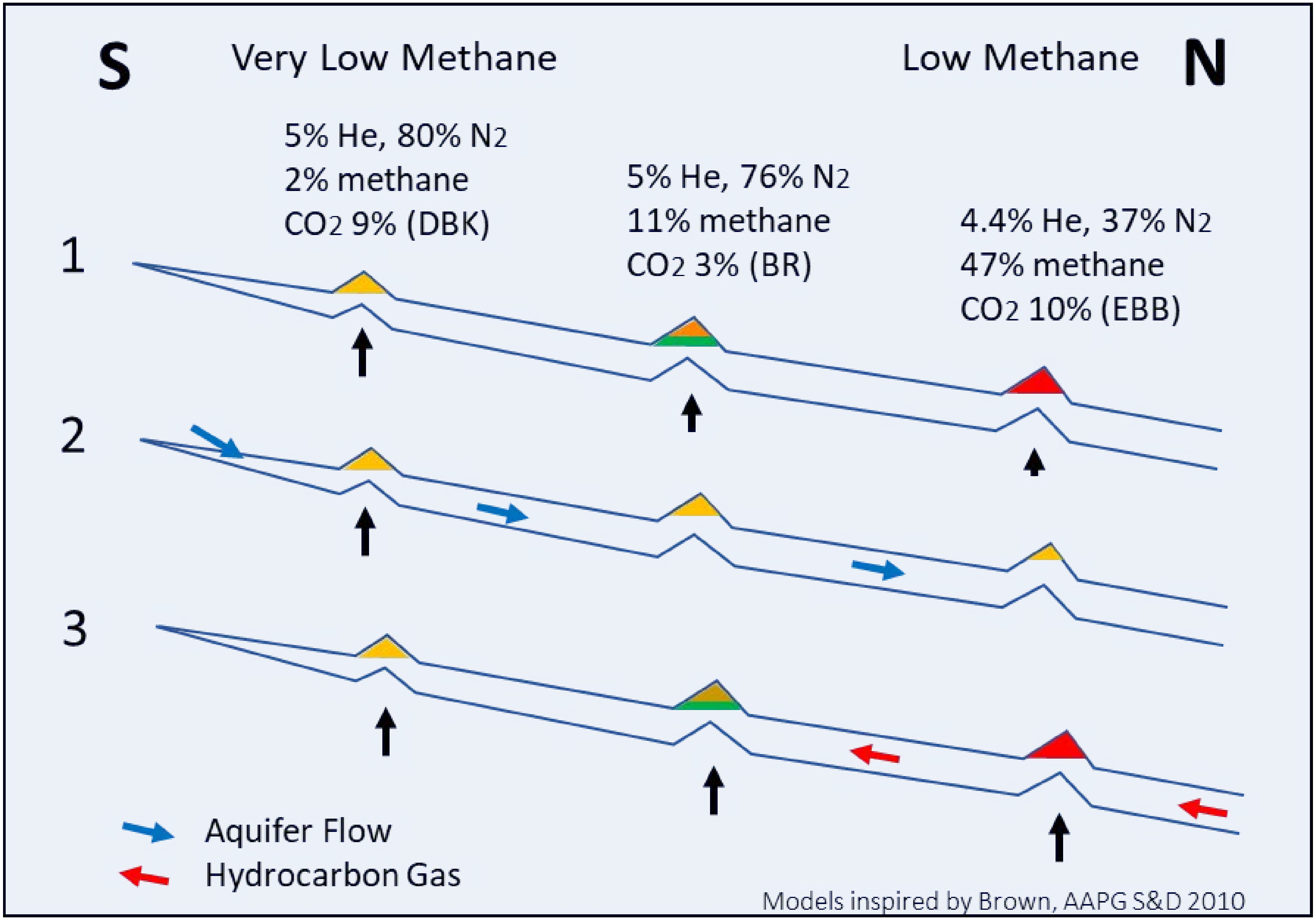

Figure 5. Migration Models.