[PS]Evidence of Several Charges of Migrated Gas in Austin Chalk, Eagle Ford, and Buda Reservoirs on the San Marcos Arch*

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Search and Discovery Article #80715 (2020)**
Posted February 24, 2020

*Adapted from poster presentation given at 2019 AAPG Annual Convention and Exhibition, San Antonio, Texas, May 19-22, 2019. Please see closely related article, "Production of Migrated Oil from Horizontal Wells Landed in the Eagle Ford on the San Marcos Arch," Search and Discovery article #80644.
 DOI:10.1306/80715Kornacki2020

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Abstract

Geochemical data measured on mud-gas samples indicate: (1) high-maturity wet gas generated by Eagle Ford (EF) source-rock (SR) beds migrated laterally and updip to different stratigraphic levels at two wells located on the San Marcos Arch in Gonzalez County; and (2) a distinct dry gas charge (principally isotopically-heavy methane) generated by a different SR is present in Upper Cretaceous and Lower Cretaceous intervals. These gas charges probably influence the GOR of oil in Upper Cretaceous reservoirs and their drive mechanism. Oil and wet gas migrated updip toward the San Marcos Arch via the Buda Formation, and then vertically into the Austin Chalk via faults penetrating the EF Formation: i.e. oil fingerprinting results indicate the Austin Chalk contains a migration mixture of oil generated by local and distant EF SRs.

Geochemical data measured on mud-gas samples collected from the Anacacho Formation through the Georgetown Formation at two vertical monitor wells were used to identify the top of one of these gas charges, where an abrupt change occurs in the C isotopic composition of methane, ethane, and propane (which are heavier below that boundary). This feature is present ≈30 ft below the top of the Buda Formation at Well #1. But it occurs at a much higher stratigraphic level (≈180 ft above the base of the Austin Chalk) at Well #2 located ≈7.5 miles northeast of the other well (where EF SR beds are ≈700 ft deeper than at Well #1). The boundary in the middle Buda Formation corresponds to two good gas shows at Well #1, where the methane/ethane ratio increases from 5.6-8.0 (in the upper Buda Formation and the overlying Eagle Ford Formation) to 9.8-11.4 at those gas shows. Haworth ratios indicate the presence of wet gas, and fractures are present in the Buda reservoir.

The middle Buda apparently is the regional carrier bed through which light oil and wet gas generated by deeper EF SR beds sequentially migrated updip: e.g. a ≈35°API oil sample produced from the Buda reservoir at Well #1 apparently is gas-washed because it is depleted in compounds more volatile than nC_{11}. Another good wet gas show occurs in Well #1 ≈25 ft below the top of the Georgetown Formation, where the mud logger observed dull yellow fluorescence and "asphalt" - probably EF oil that migrated into that zone. A good show of wet gas (identified using Haworth ratios) occurs in the Austin Chalk at Well #2 just below the top of the isotopically-heavy gas charge. Furthermore, in all mud-gas samples collected at Well #1 from the Austin Chalk (and deeper intervals) the C isotopic composition of methane is ≈7.5 per mil

heavier than predicted using the C isotopic composition of ethane and propane. This also is true for mud-gas samples collected above and below the boundary marking the appearance of high-maturity gas in the middle Buda Formation. Methane in mud-gas samples obtained at Well #2 is ≈6.0 per mil heavier than expected. An additional very dry gas charge explains these results.

Abstract

The composition of mud-gas samples indicate: (1) wet gas generated by **Eagle Ford (EF)** and **Smackover** source-rocks (SRs) migrated to different stratigraphic levels at two wells located in Gonzalez County on the San Marcos Arch; and (2) a distinct dry gas charge that largely contains isotopically-heavy methane generated by a very mature SR also is present in Upper and Lower Cretaceous intervals. These gas charges probably influence the GOR of oil in Upper Cretaceous reservoirs and their drive mechanism. **EF** oil and wet gas migrated updip towards the San Marcos Arch via the **Buda Formation**, and then vertically into the **Austin Chalk** via faults penetrating the **EF Formation**: i.e., oil fingerprinting results indicate the **Austin Chalk** contains a migration mixture of light migrated oil, and heavier oil generated locally by **Eagle Ford** SRs. Geochemical data measured on mud-gas samples collected at two vertical monitor wells from the **Anacacho Formation** through the **Georgetown Formation** were used to identify the top of higher-maturity gas charges, where an abrupt change occurs in the C isotopic composition of methane, ethane, and propane (which are heavier below that boundary). This feature is present ≈30 ft below the top of the **Buda Formation** at the SW Monitor Well. But it occurs at a much higher stratigraphic level – at the top of the **Austin Chalk** – at a different monitor well (located ≈7 miles NE of the other well) where **EF** SR beds are ≈700 ft deeper. The boundary in the middle **Buda Formation** corresponds to two good gas shows at the SW Monitor Well where the methane/ethane ratio increases from 5.6-8.0 (in the upper **Buda Formation** and the overlying **EF Formation**) to 9.8-11.4 at those shows. Haworth ratios indicate the presence of wet gas, and fractures are present in the **Buda** reservoir. The **Buda Formation** is the regional carrier bed through which light **EF** oil and wet gas generated by deeper SR beds sequentially migrated updip: e.g., a ≈35°API gas-washed oil sample produced from the **Buda** reservoir at the SW Monitor Well is depleted in compounds more volatile than C_{11}. A good wet-gas show also occurs in this well ≈25 ft below the top of the **Georgetown Formation**, where the mud logger observed dull yellow fluorescence and "asphalt" (oil that migrated into that reservoir). Another good wet-gas show occurs in the **Austin Chalk** at the NE Monitor Well just below the top of the higher-maturity gas charge. Furthermore, in all mud-gas samples collected at the NE Monitor Well from the **Austin Chalk** (and deeper intervals) the C isotopic composition of methane is ≈3-6 per mil heavier than predicted using the C isotopic composition of ethane and propane. At the SW Monitor Well, methane in mud-gas samples collected in the high-maturity **Smackover** wet gas charge is ≈8 per mil heavier than predicted, and methane is ≈4-7 per mil heavier than predicted in mud-gas samples collected in the overlying **Eagle Ford** wet gas charge. An additional pervasive charge of very mature dry gas explains these observations.

1. INTRODUCTION: THE REGIONAL AND LOCAL MIGRATION OF EAGLE FORD OIL INTO UPPER CRETACEOUS RESERVOIRS ON THE SAN MARCOS ARCH

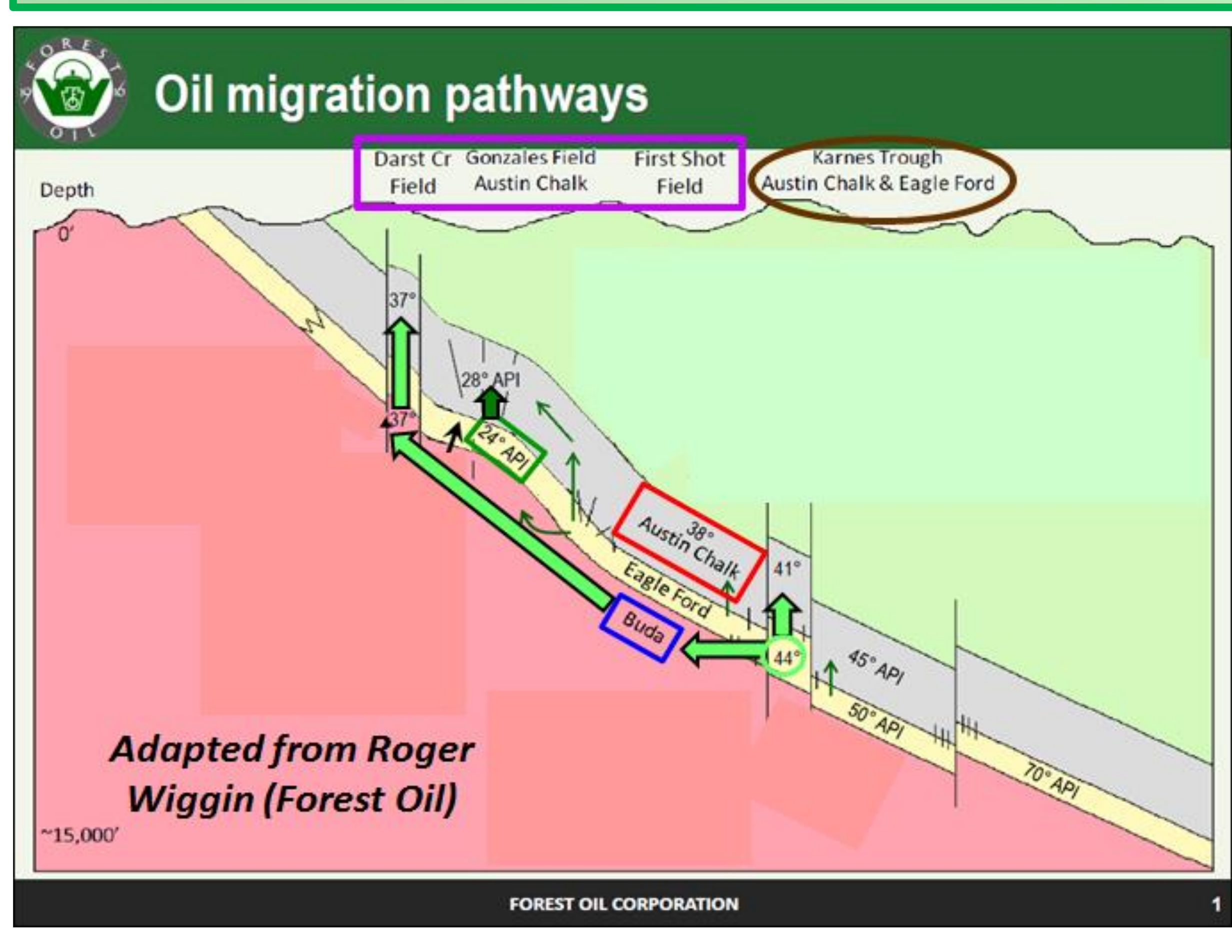


Figure 1. Model of the migration of Eagle Ford oil into the Austin Chalk and Buda reservoirs.

Crude oil in the **Austin Chalk** and the **Buda Formation** was generated by source-rock (SR) beds in the **Eagle Ford Formation** (Zumberge et al., 2016). The occurrence of light oil (≥30°API) where **Eagle Ford** SRs are in the early oil window is explained by the updip migration of high-maturity oil via fractures in the **Buda** regional carrier bed (Figure 1).

If the **Buda** is the regional carrier bed, light **Eagle Ford** oil has to migrate vertically through that interval to charge the **Austin Chalk**. Ferrill et al. (2017) described the presence of fluorescent oil fluid inclusions in a cemented fault that penetrates immature **Eagle Ford** SR beds at an outcrop in south Texas. Kornacki (2018) showed that a 30°API oil produced from the **Austin Chalk** is a 75:25 migration mixture of heavy **Eagle Ford** oil generated locally and much lighter migrated **Eagle Ford** oil (Figure 2).

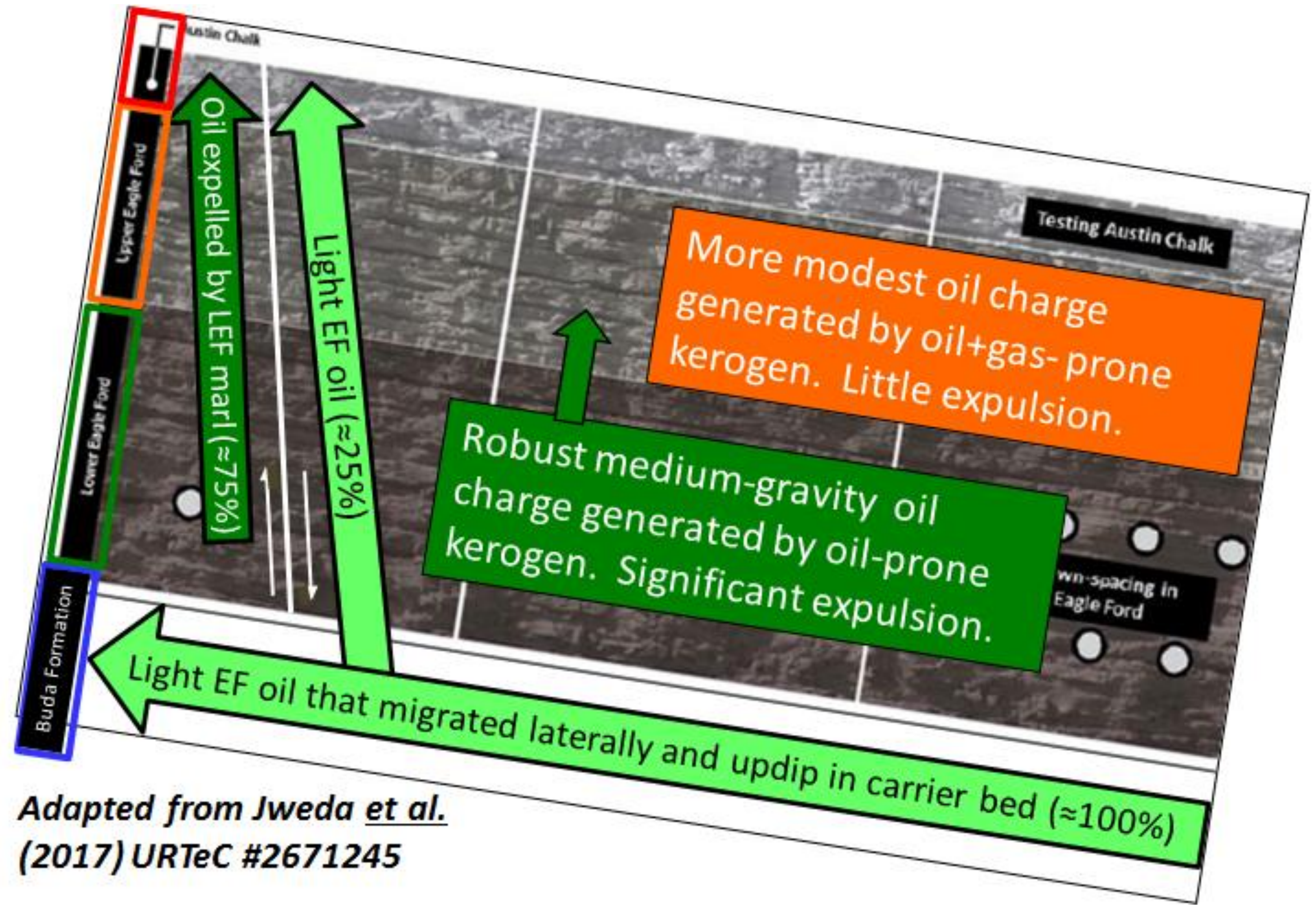


Figure 2. HC charge model for the Austin Chalk, Upper Eagle Ford, Lower Eagle Ford, and Buda Formation on the San Marcos Arch.

2. THE MIGRATION OF NATURAL GAS INTO SOURCE-ROCK RESERVOIRS

Oil and natural gas readily migrate through impermeable SR reservoirs via fractures and faults. Can they also charge those reservoirs by migrating into their matrix and organic porosity? Some wells landed in the Woodford Formation in the Anadarko Basin produce excess natural gas with methane that is anomalously enriched in isotopically-heavy C. This has been explained by the presence of an additional charge of very mature dry gas that migrated into that reservoir (Kornacki et al., 2016). Because methane is the smallest HC molecule, dry gas probably is the best candidate to charge a tight reservoir that contains oil or gas. We now report evidence of additional natural gas charges into several Cretaceous reservoirs on the San Marcos Arch in south Texas (Figure 3).

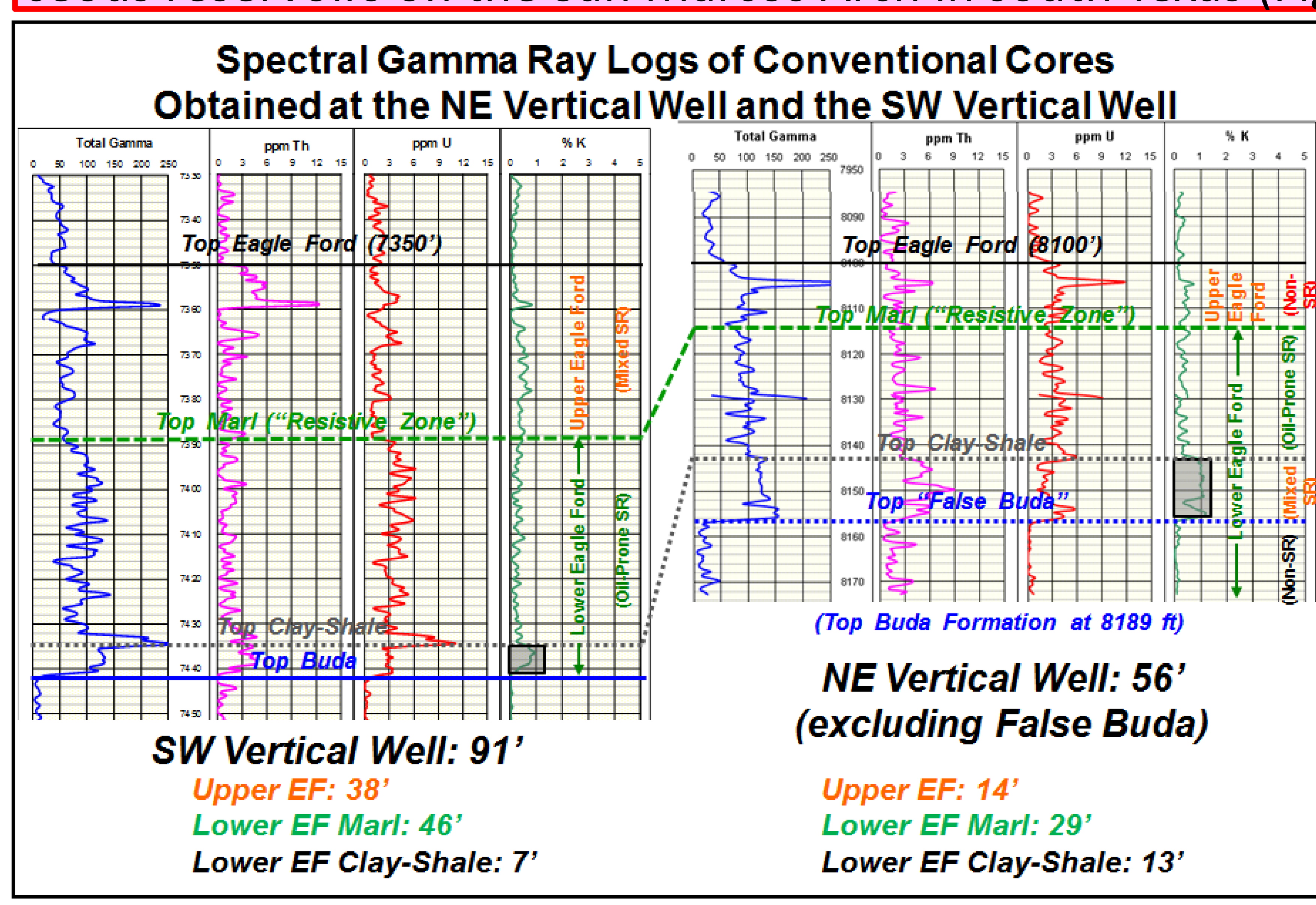


Figure 3. Stratigraphic cross section through the Eagle Ford Formation at two vertical monitor wells located ≈7.5 miles apart on the San Marcos Arch.

Evidence of Several Charges of Migrated Gas in Austin Chalk, Eagle Ford, and Buda Reservoirs on the San Marcos Arch

3. COMPOSITION OF MUD-GAS SAMPLES COLLECTED AT THE SW MONITOR WELL

The C isotopic composition of methane, ethane, and propane become heavier with increasing thermal maturity. A step change in the C isotopic composition of those compounds occurs at a depth of 7,475 ft in mud-gas samples collected at the SW Monitor Well: i.e., natural gas below the middle **Buda Formation** is more mature than the gas above that surface (Figure 4). In addition, the maturity of methane – but not ethane – seems to increase with increasing depth in distinct cycles: (1) in the **Anacacho Formation**; (2) from the basal **Austin Chalk** through the **Upper Eagle Ford Formation;** and (3) in the lower **Buda Formation**. But the maturity of methane appears to decrease with depth in the upper **Buda**.

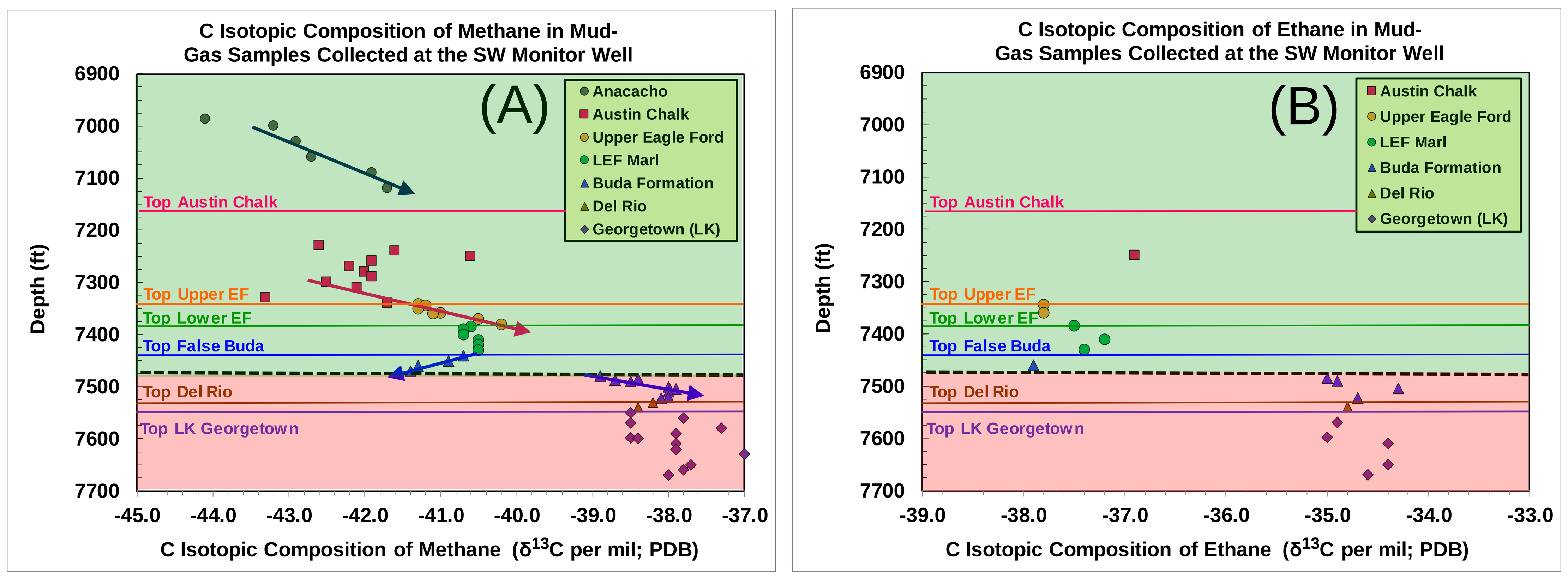
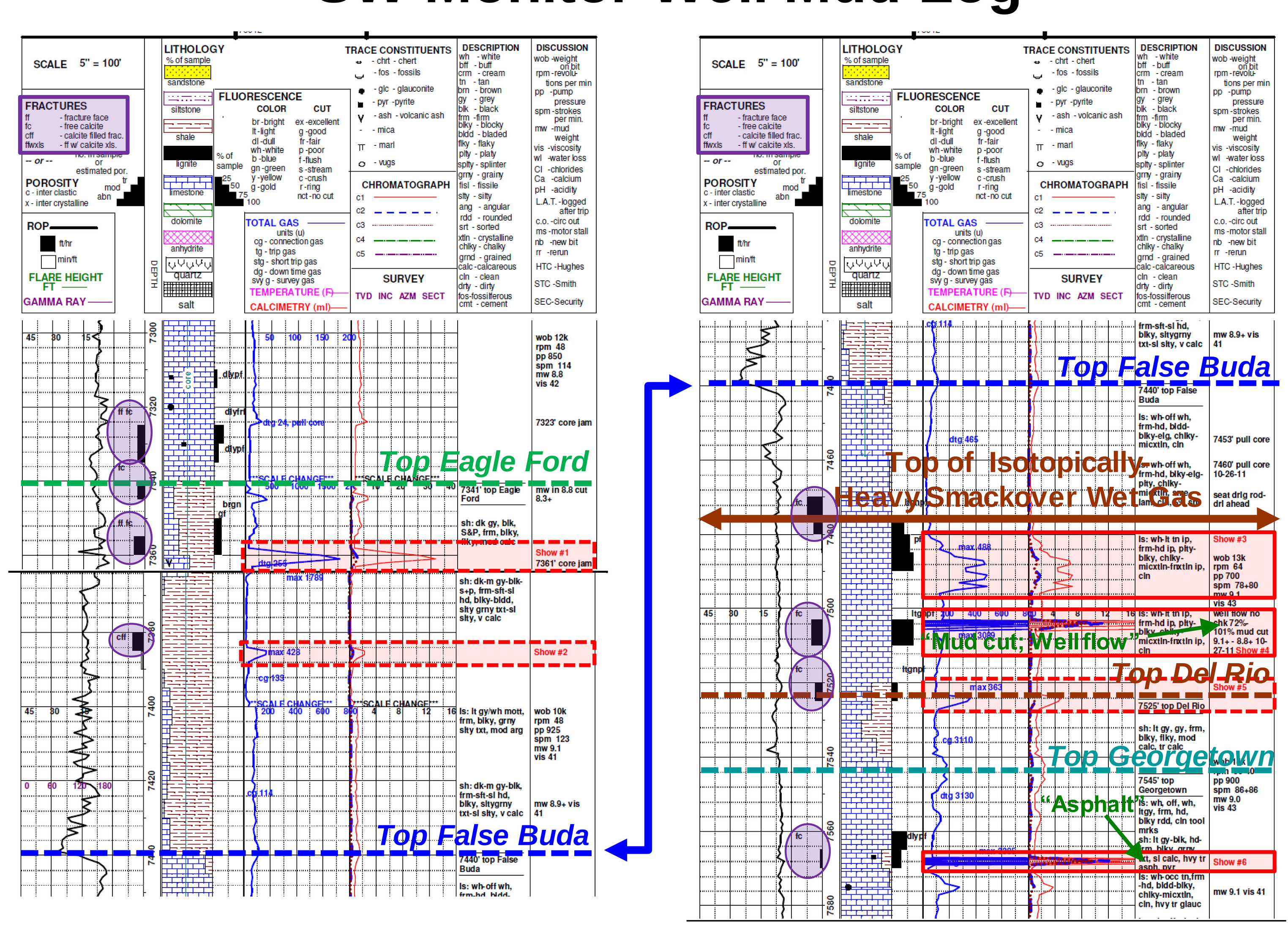


Figure 4. C isotopic composition of methane (A) and ethane (B) in high-maturity (pink) and lower-maturity (green) mud-gas samples collected at the SW Monitor Well.

The mud log for the SW Monitor Well indicates that fractures and gas shows commonly occur in the middle and lower **Buda Formation** at and below the surface that marks the top of the higher-maturity gas charge. Those fractures probably allowed light **Eagle Ford** oil – and a later wet gas charge – to migrate updip.

SW Monitor Well Mud Log



The mud logger also observed "asphalt" (i.e., probably viscous migrated oil) at a strong gas show where the deeper Lower Cretaceous **Georgetown Formation** is fractured (Figure 5).

Figure 5. Mud log for the SW Monitor Well, identifying gas shows (red boxes) and fractures (purple ovals).

A 36°API oil sample (generated by **Eagle Ford** SR beds) obtained from the **Buda** reservoir at this monitor well is gas-washed (i.e., depleted in volatile HC compounds) (Figure 6). This shows that free gas migrated through the **Buda Formation** after it was charged with light **EF** oil. But the oil produced from the **Austin Chalk** at this well is not gas-washed.

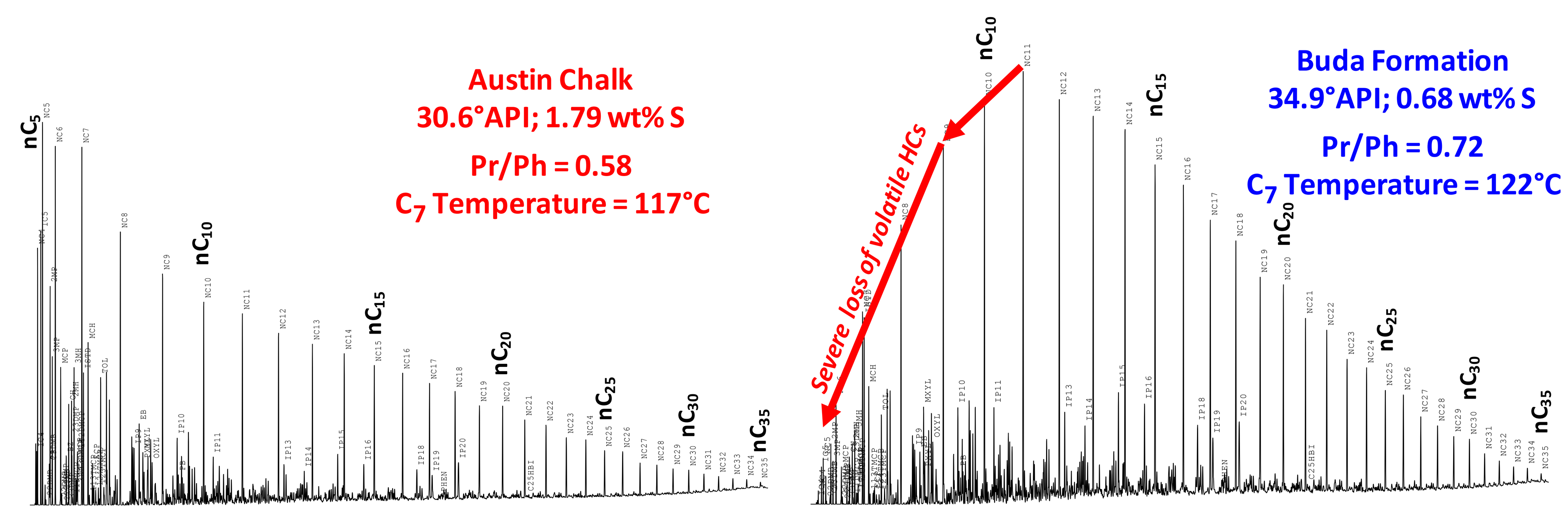


Figure 6. HRGCs and geochemical source and maturity parameters measured on oil samples produced from the SW Monitor Well.

The lower-maturity mud-gas samples collected at the SW Monitor Well exhibit an unusual feature: i.e., the C isotopic composition of methane becomes lighter as the methane/ethane ratio increases – which is opposite the thermal maturity trend. This feature is explained if those gas samples also contain a modest amount of light microbial methane (Figure 7). The amount of microbial methane in these reservoirs changes in the following manner: **Anacacho Formation** > **Austin Chalk** > **Upper Eagle Ford** > **Lower Eagle Ford** ≈ Upper **Buda Formation**.

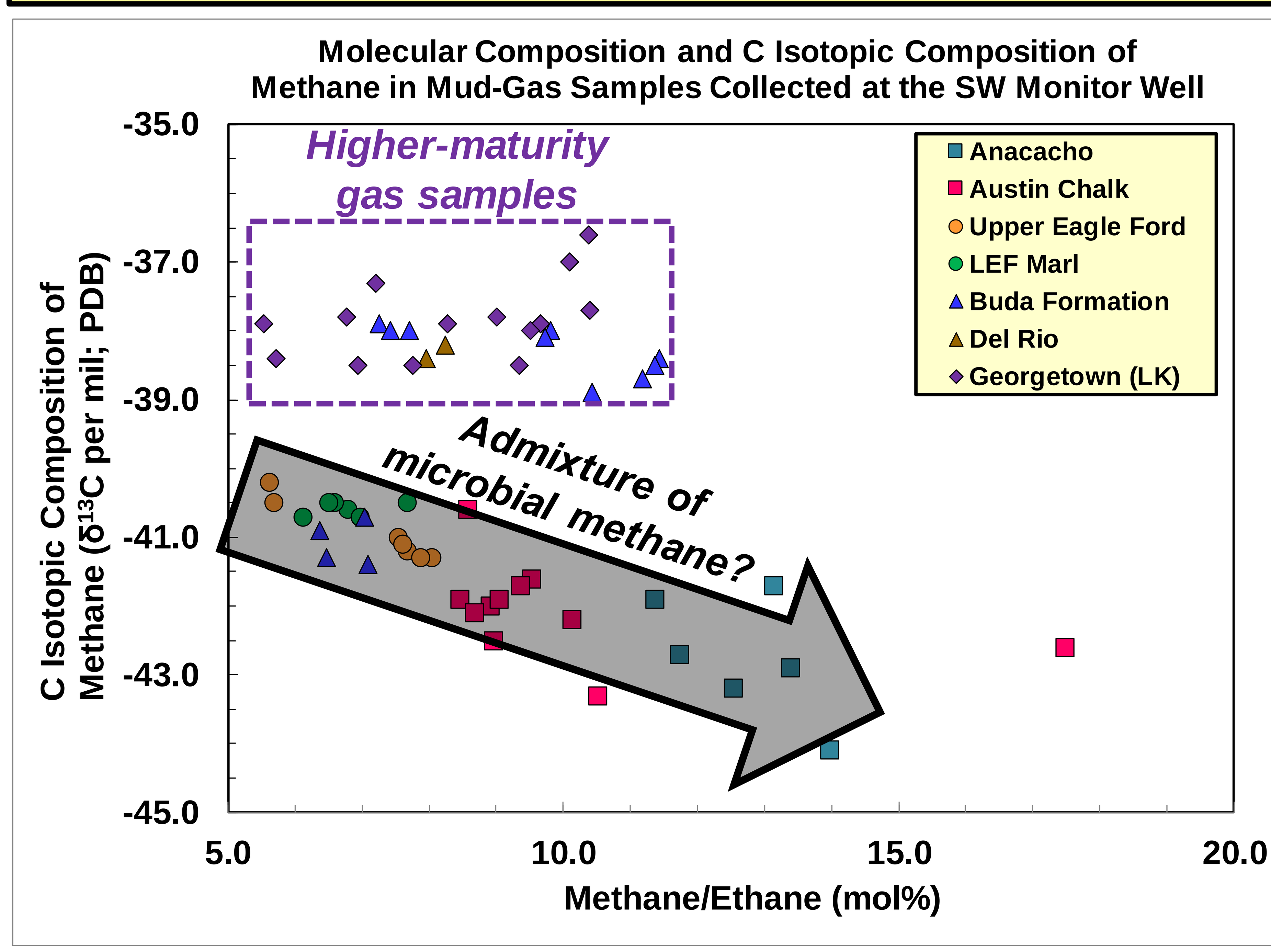


Figure 7. Molecular composition and C isotopic composition of mud-gas samples collected at the SW Monitor Well.

Acknowledgements: We thank Roger Wiggin for sharing ideas about the migration of oil and gas on the San Marcos Arch. We also thank Auterra Resources LLC and Stratum Reservoir for permission to publish these results.

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4. COMPOSITION OF MUD-GAS SAMPLES COLLECTED AT THE NE MONITOR WELL

A step change also occurs in the C isotopic composition of methane in mud-gas samples collected at the NE Monitor Well, which become isotopically heavier at a depth of 7,950 ft (Figure 8). This surface occurs at a much higher stratigraphic level (i.e., at the top of the **Austin Chalk**) than at the SW Monitor well, but 425 ft deeper. The C isotopic composition of ethane and propane were not measured in mud-gas samples collected above that surface, but it is reasonable to infer that the isotopic composition of those compounds also are lighter in the **Anacacho Formation**.

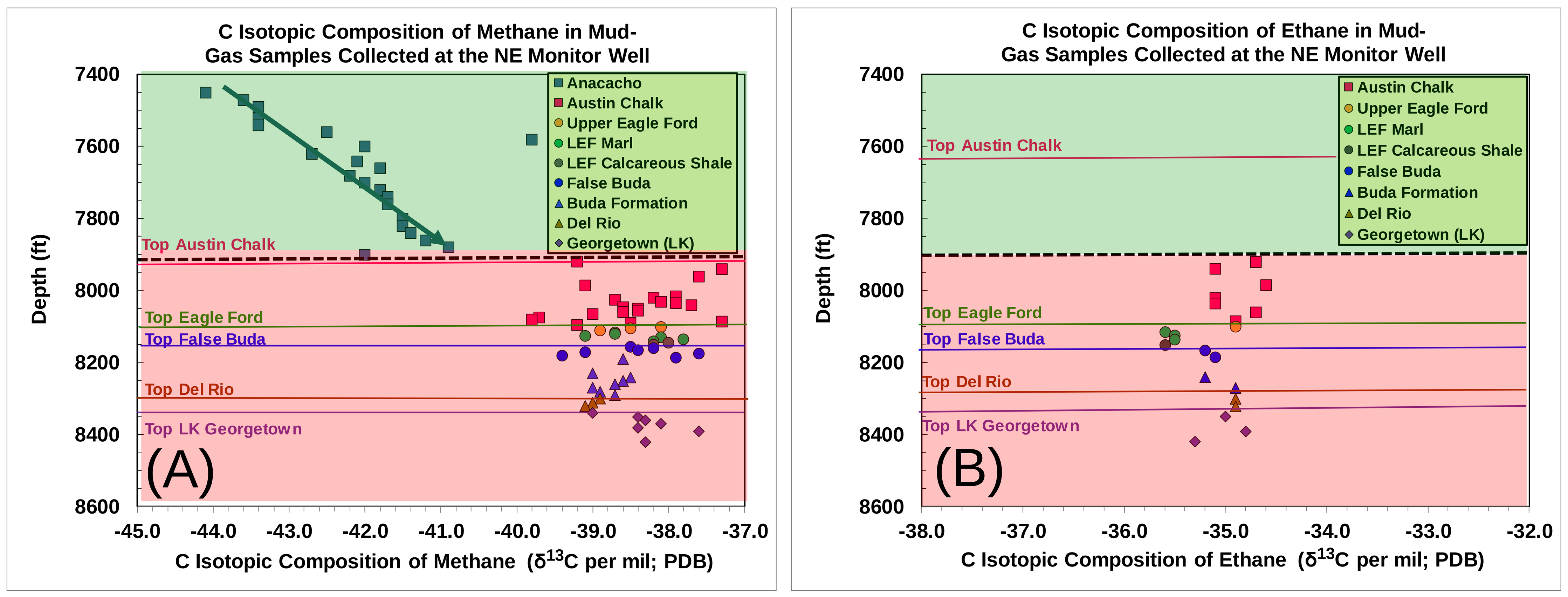

Figure 8. C isotopic composition of methane (A) and ethane (B) in high-maturity (pink) and lower-maturity (green) mud-gas samples collected at the NE Monitor Well.

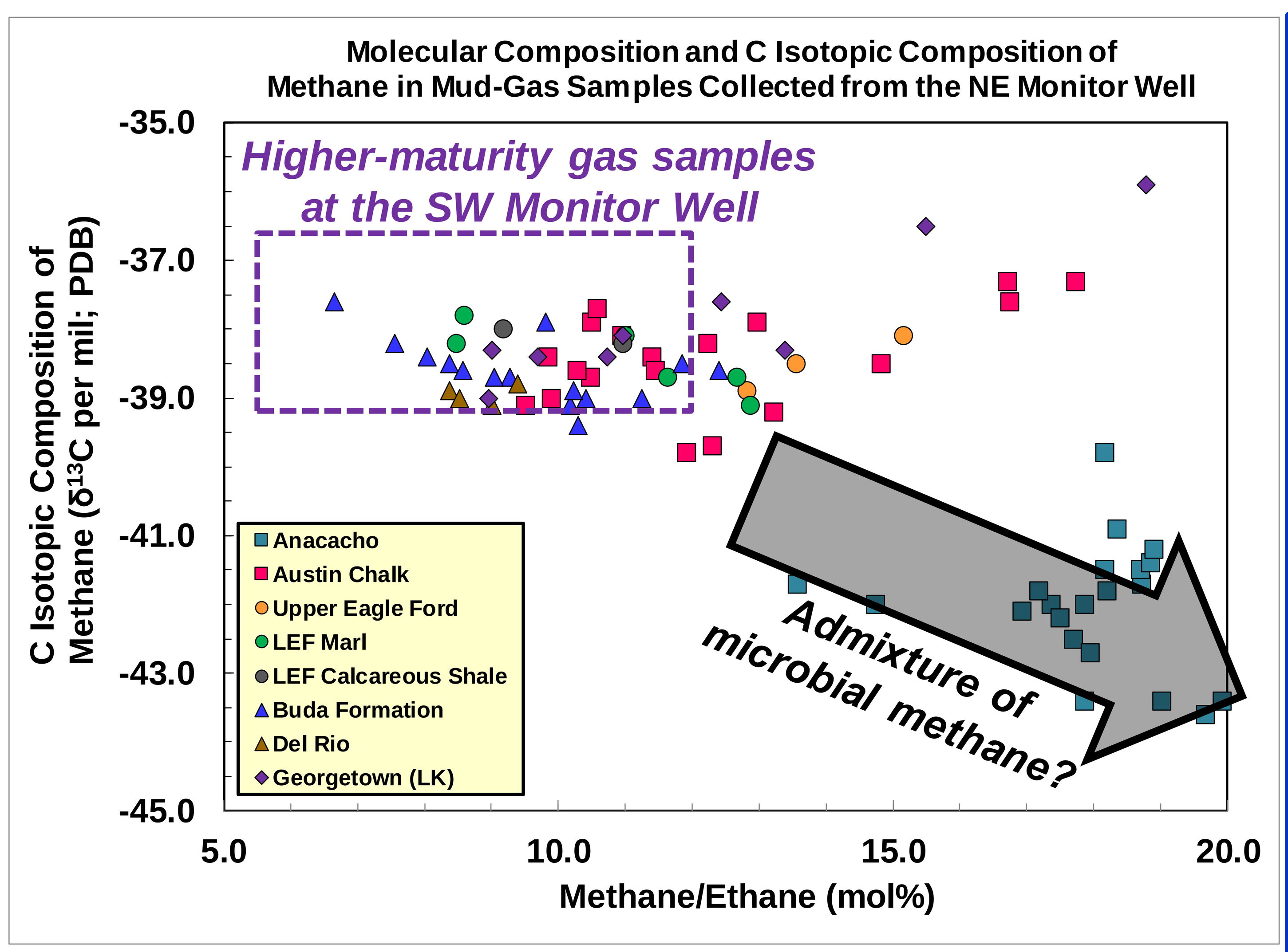

Figure 9. Molecular and C isotopic composition of mud-gas samples collected at the NE Monitor Well.

The C isotopic composition of the high-maturity mud-gas samples in both monitor wells is similar. But many mud-gas samples collected at the NE Monitor Well are moderately drier: i.e., they have higher C_1/C_2 ratios Mud-gas samples collected from the **Anacacho Formation** may contain a small amount of microbial methane.

5. EVIDENCE OF A PERVASIVE ADDITIONAL CHARGE OF VERY DRY THERMAL GAS

The C isotopic composition of the kerogen that generated a gas sample can be estimated by extrapolating a line drawn through the composition of C_1-nC_5 compounds shown on the x-axis at the point 1/carbon number of each gas compound (Chung et al., 1988). This method also can be used to identify gas samples that contain anomalously light or heavy methane compared to the C isotopic composition of the C_{2+} compounds.

The C isotopic composition of methane in both types of mud-gas samples collected at the SW Monitor Well (and in high-maturity samples collected at the NE Monitor Well) is heavier than predicted – evidence of a pervasive charge of very mature dry gas that contains very heavy methane. In addition, the high-maturity wet gas charge at the SW Monitor well probably was generated by **Smackover** SR beds that contain heavier kerogen than the **EF** SR beds that generated the lower-maturity wet gas charge at that well, and the high-maturity wet gas charge at the NE Monitor Well.

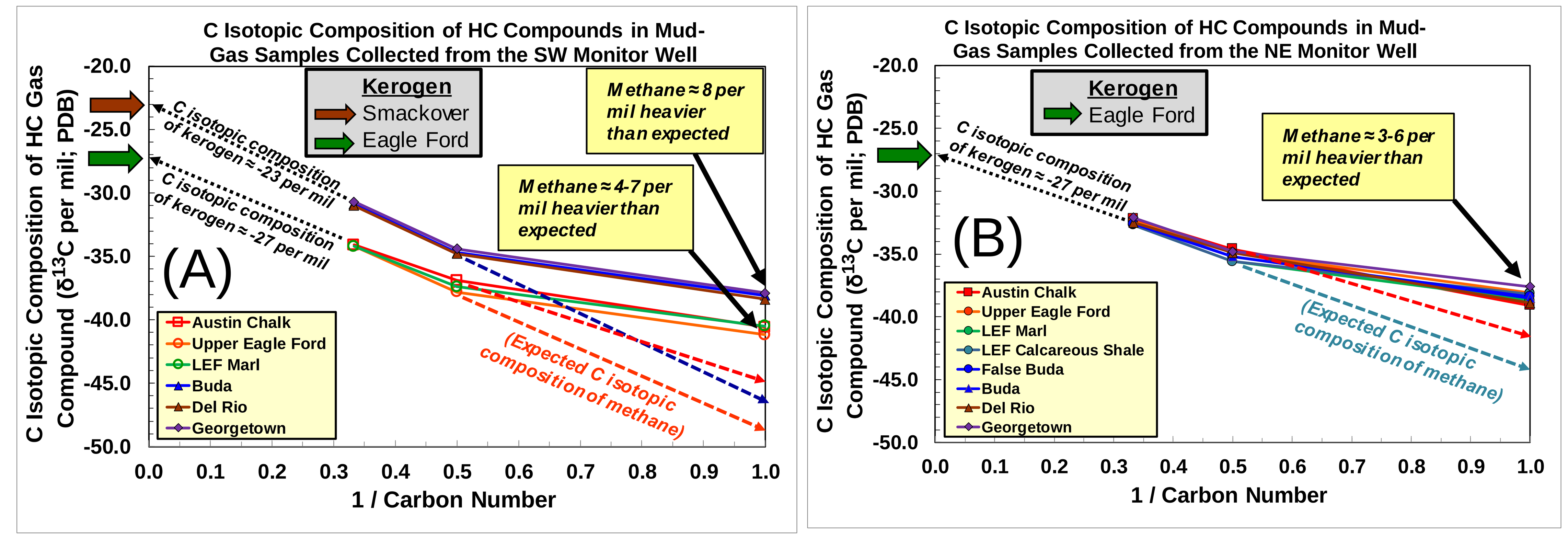

Figure 10. Chung diagrams for mud-gas samples collected at the SW Monitor Well (A) and the NE Monitor Well (B). Solid arrows show the composition of kerogen that generated the gas.

The HC charge history of Cretaceous reservoirs on the San Marcos Arch is: (1) Sequential charges of medium-gravity and light oil generated by downdip **Eagle Ford** SR beds into reservoirs that contained microbial methane; (2) A medium-gravity oil charge generated locally by **Eagle Ford** SR beds; (3) A **Smackover** wet gas charge (present only at the SW Monitor Well); and (4) A pervasive dry gas charge at both wells generated by a very mature SR.

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