

## Use of Maturity-Related Changes in Gas Isotopes in Production and Exploration of Bakken Shale Plays

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Interest in “unconventional oil shale” plays such as the Bakken has increased in recent years and mud gas composition and isotope analyses are routinely acquired to support completion and production decisions. We report here composition and isotope analyses from horizontal Bakken shale wells in North Dakota (Price and Schoell 1995) that penetrated different sections of different maturities and found that ethane carbon isotopes in oil-dissolved gases are excellent predictors of maturity of the organic matter of the source rock kerogens, thus opening opportunities for elucidation of generation and migration of oils and gases.

The 8 wells of this study are in two maturity domains based on Bakken Shale Rock-Eval hydrogen indices. The less mature domain around Squaw Gap and Bicentennial (“SGB”) has high hydrogen indices (HI~450 to 530mg/g), whereas the more mature domain around Pierre Creek, Buckhorn and Elkhorn Ranch (“PCBE”) has lower hydrogen indices (HI~170 to 270mg/g). The 31-1H well at Pierre Creek is in a transition zone between these maturity domains (Fig. 1).

Gases from the less mature SGB wells are produced with low gas/oil ratios (350 to 390) and high %C2+ concentrations (27 to 48%) whereas gases in the more mature PCBE area have higher GOR's (~560 to 720) and lower %C2+ (~30%). Carbon isotope signatures of C1 to n-C5 gas and n-C6 to n-C19 oil components clearly demonstrate that the gases are co-genetic (coeval) products derived from kerogen cracking reactions that simultaneously generated both the oils and the gases (Figure 2). These relationships suggest an indigenous origin for the oils and gases; e.g. they reside at their place of origin since their formation, meaning these gas properties define the source rock maturity “kitchen” prior to migration.

Whole oil carbon isotope values increase slightly but systematically with decreasing hydrogen indices (HI) from -30 to -29‰ (Fig.1c), which is consistent with maturation-related changes in the whole oil caused by the increasing formation of <sup>13</sup>C-depleted gaseous compounds. From this observation one might argue that the oil and gas formation is a two step process: 1) oil formed initially with insignificant gas and 2) gases formed through cracking reactions of oil components and thus are genetically truly oil-associated gases. A comparison with literature data for Bakken Shale kerogens of -28.8‰ (Lewan 1986) fits well with our oil values and suggests that the Bakken shale kerogens are relatively uniform and isotope properties in gases are predominantly driven by temperature i.e. maturity.

In the less mature wells at Squaw Gap (HI~535), the produced gas has ethane carbon values  $\delta^{13}\text{C}_2$  of -38 ‰, in contrast to  $\delta^{13}\text{C}_2$  of -34.2‰ at the more mature Elkhorn Ranch well 44-25H (Fig. 1c). Similarly, other isotopic properties such as the differences of  $\delta^{13}\text{C}_{2-3}$  and  $\delta^{13}\text{C}_{\text{C4-nC4}}$  as well as isotopic differences between gas components and oil tend to decrease with maturity, all consistent with the fundamental fact that kinetic isotope fractionations decrease with temperature. This is clearly demonstrated by the good correlation of the whole oil-ethane isotope difference with HI (Fig. 3a). In particular, ethane  $\delta^{13}\text{C}$  values are an excellent proxy for all maturity-related properties of gases and associated oils as well as rock properties such as HI with the following transfer function:  $\text{Square}(\text{HI}) = -2205216 - 65895.278 * 13\text{C}_2$  (Fig. 3b). Because it is likely that the Bakken shale kerogen is isotopically uniform at a given maturity, the excellent correlation of ethane  $\delta^{13}\text{C}$  values with those of the  $\delta^{13}\text{C}$  difference of oil and ethane suggests that the ethane  $\delta^{13}\text{C}$  values by themselves can be used as a maturity proxy for Bakken Shale kerogen.

The excellent correlation of ethane isotopes with HI in our study area are indicative of an indigenous, local source of the gases dissolved in the oils. However, in other cases Bakken sourced oils with their dissolved gases may migrate from more mature to less mature areas and the kerogen/oil/gas isotopes will not match. Therefore, our gas isotope-HI relationship can be in various ways useful in exploration and production of Bakken Shale plays:

- The comparison of HI in Lower and Upper Bakken Shale along the trace of a horizontal well with those calculated from the gas isotopes in the oils will allow:
  - a determination of the indigenous nature of the oils (no significant migration) or, if a discrepancy is found,
  - an estimate of the migration distance using existing HI distribution maps published by the North Dakota Geological Survey ([https://www.dmr.nd.gov/ndgs/Publication\\_List/pdf/geoinv/GI\\_63/gi\\_63\\_sh\\_2.pdf](https://www.dmr.nd.gov/ndgs/Publication_List/pdf/geoinv/GI_63/gi_63_sh_2.pdf))
- A lower maturity determined from gas isotopes compared to oil biomarker maturity could indicate fracture zones from which gases from the locally less mature Bakken Shale bleed into the oil that is derived from more mature Bakken source rocks.

## REFERENCES

- Lewan M.D. (1986), Stable carbon Isotopes of amorphous kerogens from Phanerozoic sedimentary rocks. *Geochim. Cosmochim. A.* 50, 1583-1591.
- Price, L.C. and M. Schoell (1995), Constraints on the origins of hydrocarbon gas from compositions of gases at their site of origin. *Nature*, **378**: p. 368-371.

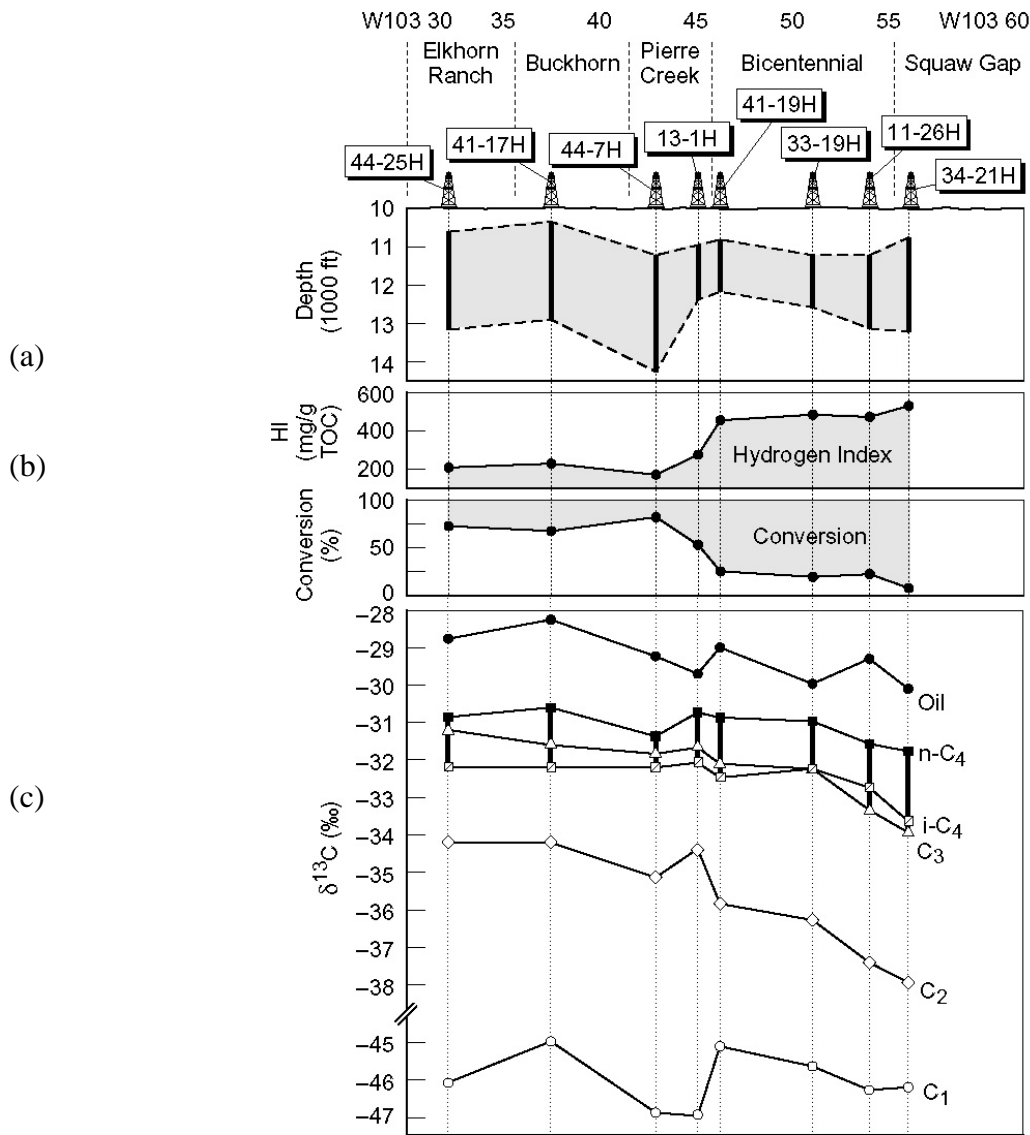


Figure 1 - Variations of isotopes in gases from Bakken Shale horizontal wells  
 a) Length of horizontal well  
 b) Hydrogen Index and calculated conversion using an initial HI of 700mg.g TOC  
 c) Carbon isotopes of oil and gas components C1 to C4

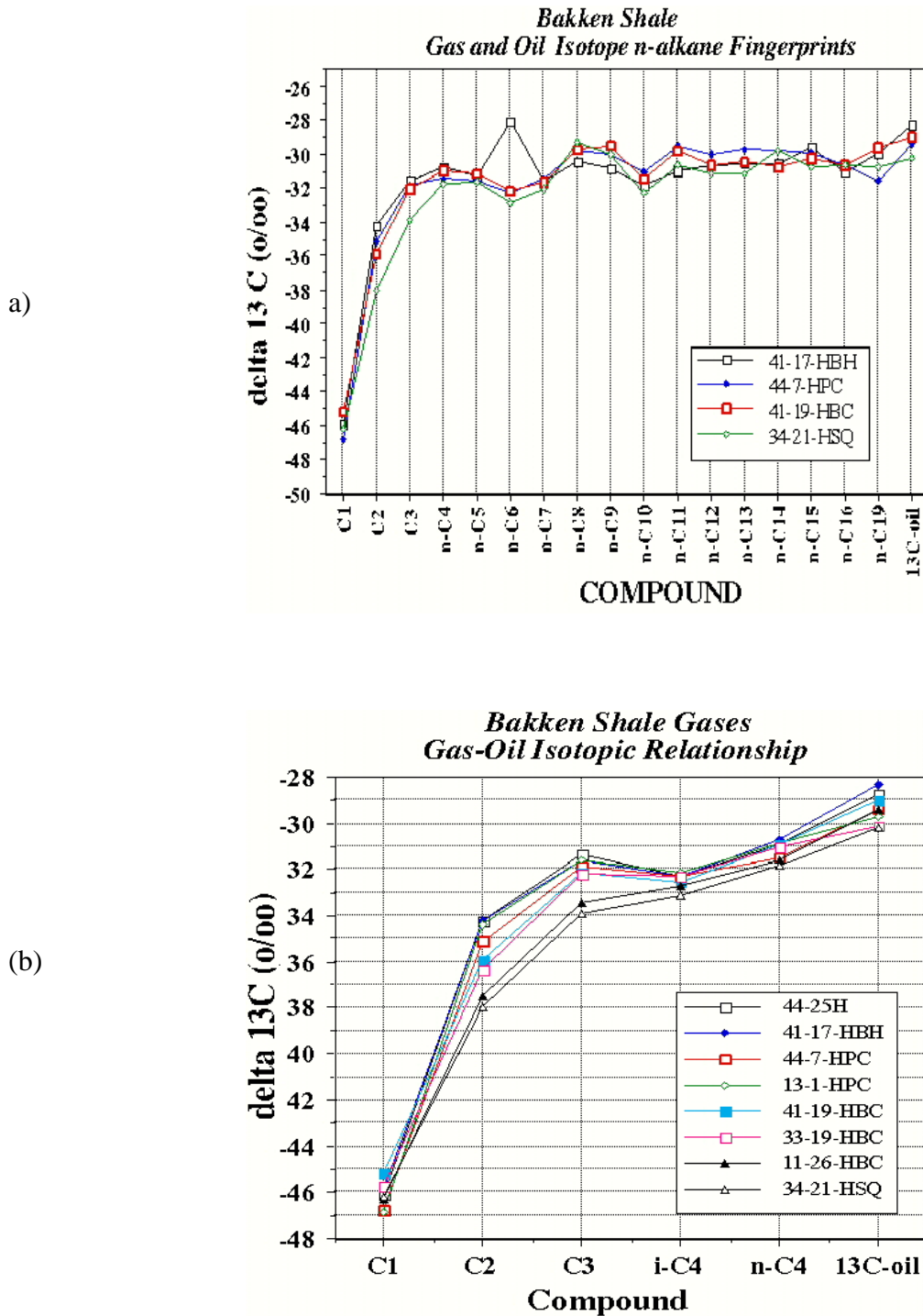


Figure 2

- a) Comparison of carbon isotope values of n-alkanes from gases (C1 to C5) and oils (C6 to C28) as well as bulk  $^{13}\text{C}$  of whole oils. The  $^{13}\text{C}$  value of hexane for the 41-17HBH is an outlier.
- b) Carbon isotopes of gas compounds of Bakken Shale gases

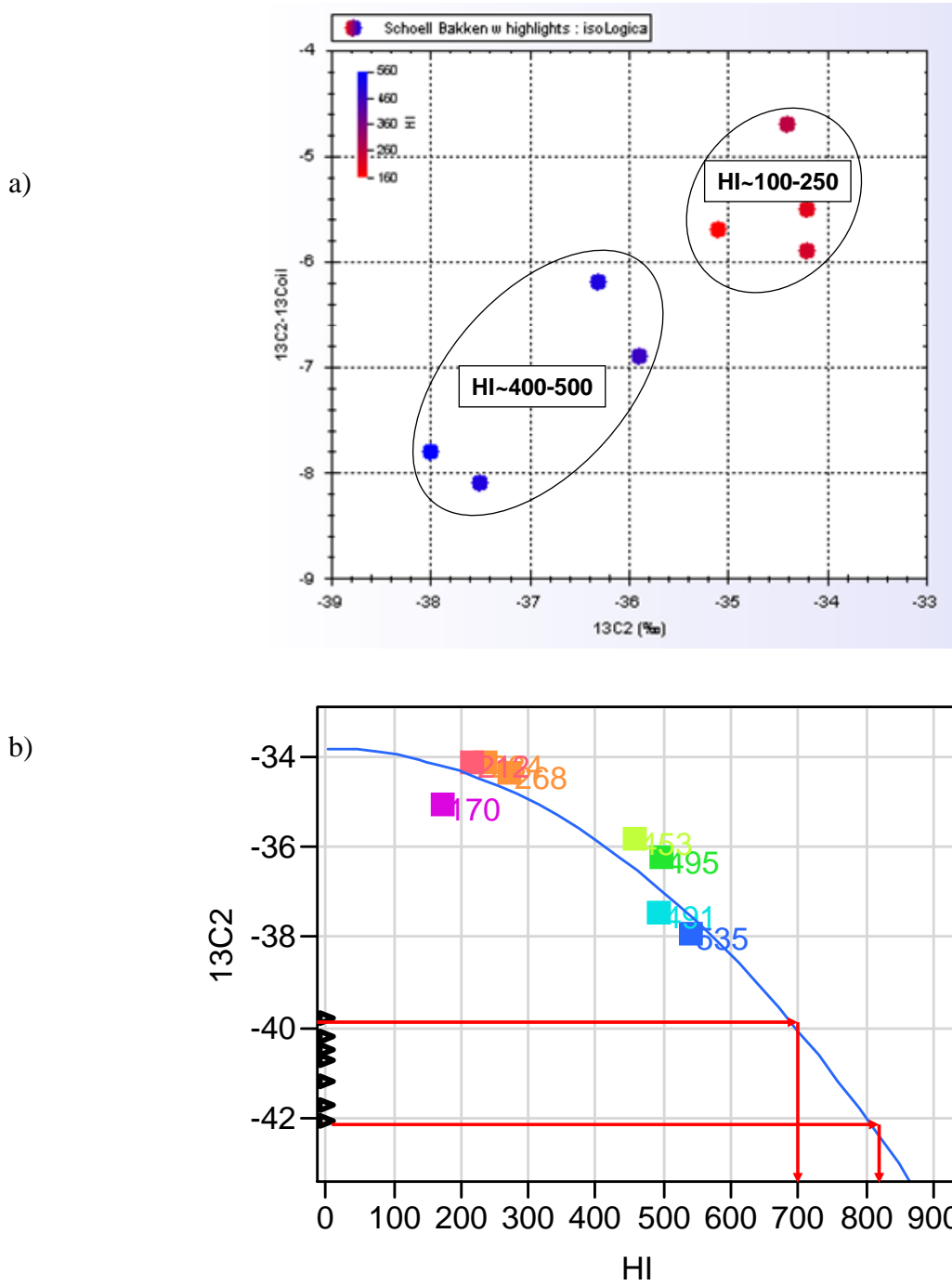


Figure 3

- a) Correlation of ethane carbon isotope values with those of the isotopic difference between whole oil and ethane. Color coding is HI (Hydrogen Index)
- b) Correlation of the ethane carbon isotope values and Hydrogen Index (HI) and extrapolation for the determination of HI values of gases with different  $^{13}\text{C}_2$  values