Predicting Original Gas in Place and Optimizing Productivity by Isotope Geochemistry of Shale Gas

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Summary

Carbon and hydrogen isotope compositions are two main parameters to eavaluate natural gas. They carry information of different physical and chemical processes associated with its generation, accumulation and production. In our recent work, the fractionation of gas isotopes are quantitatively investigated during generation, adsorption/desorption and diffusion of shale gas. Using these results, the main features of shale gas plays can be predicted from gas isotope compositions, including original gas in place (OGIP), fluid properties and production decline. This method provides efficient way to evaluate shale gas resources and broaden the application of gas isotope.

Introduction

Evaluation of original gas in place (OGIP) and optimizing productivity are main issues of shale exploration and development. Research on gas isotope composition plays an important role in these works. The reason is, carbon and hydrogen isotope compositions of hydrocarbon gases are basic geochemical parameters in natural gas; these parameters are influenced by 1) isotope composition of precursors, 2) kinetic isotope effects during oil and gas formation, and 3) fractionation during flow/migration. Shale gas is reservoired in source rock, with high organic content, low permeability and small pore size, rending special processes of gas generation and movement. These bring difficulties to explain the gas isotope parameters.

Isotope fractionation during shale gas generation

In conventional gas reservoirs, the variation of gas isotope composition is mainly determined by kerogen isotope composition, maturity and charging efficiency (more cumulative or more instantaneous), with well-established kinetic model (Tang et al., 2000). For shale gas, residual oil in shale may convert to gas; water may involve in the conversion. Products from different chemical processes make the isotope composition deviate from conventional models, for example the "rollover" of carbon isotope composition of ethane and propane (Zumberger et al., 2009). But using carbon and deuterium isotope composition of methane, we can distinguish the cumulative and instantaneous preservation of shale gas of different maturity, as shown in Figure 1. Most shale gas samples are more close to the instantaneous curve. It indicates that a sufficient charging will bring about the expulsion of early generated gas.
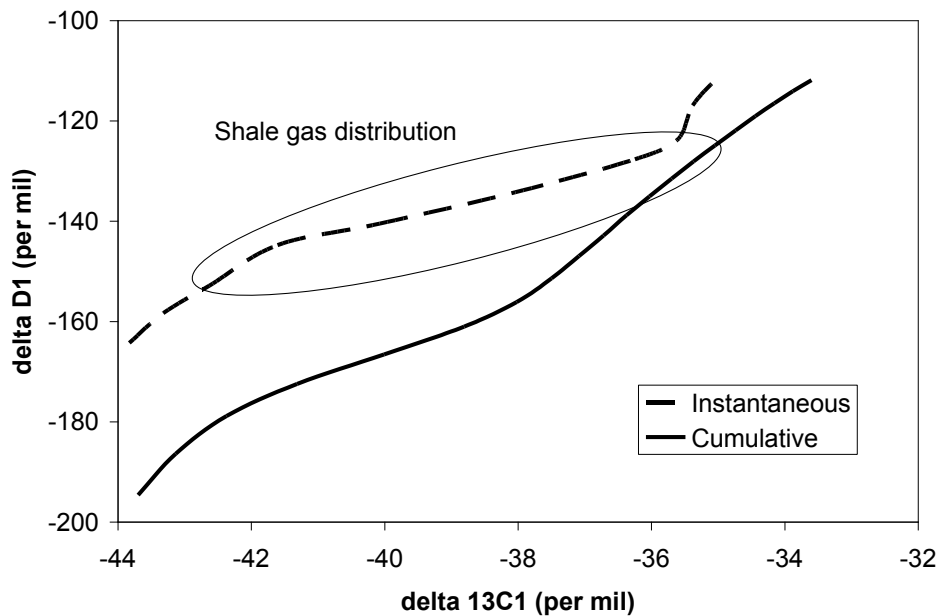
Figure 1: Using carbon and hydrogen isotope composition of methane to distinguish the cumulative and instantaneous condition of shale gas.

Using advanced kinetics isotopic fractionation integrated with geology and other geochemical parameters, we established a model to predict original gas in place (OGIP) and gas saturation in shale rocks.

Isotope fractionation during Adsorption/Desorption of gas in shale

Gas is stored in shale source rocks in two important forms: 1) as bound gas, adsorbed on or within the matrices of organic matter and rock; 2) as free gas in pore spaces or in fractures created either by organic matter decomposition, diagenetic, or tectonic processes, or dissolved in fluid in the pore systems.

During the shale gas production, the gas recovery is actually impacted by the availability of the free and desorbed gases. At early production period, the free gas is dominant because it can migrate through the fracture system (either natural or stimulated). With the progress of gas production, the free gas is gradually replaced by desorbed gas, which is released from organic matrixes. The decline production curve results from the dynamic mixing of the fracture gas depletion and the desorbed gas release, which is hard to predict by a priori production data.

Stable isotope ratios of gases would provide a unique way to quantitatively differentiate the contribution of the two kinds of gases. A methane molecule with ^{12}C atom has smaller adsorption energy and a higher diffusivity compared with a methane molecule with ^{13}C atom. Therefore, the production gas enriches of ^{12}C at the early production period (carbon isotope composition more "light"), and the concentration of ^{13}C increases during production (carbon isotope composition becomes more "heavy"). This is similar when hydrogen isotope is considered, and the signal/noise ratio of hydrogen isotope composition is more favored. Therefore, the change of isotope composition provide a composite curve of free and bound gases, which is critical on optimal timing of re-stimulation on the fracture systems, in order to maximize the gas recovery.
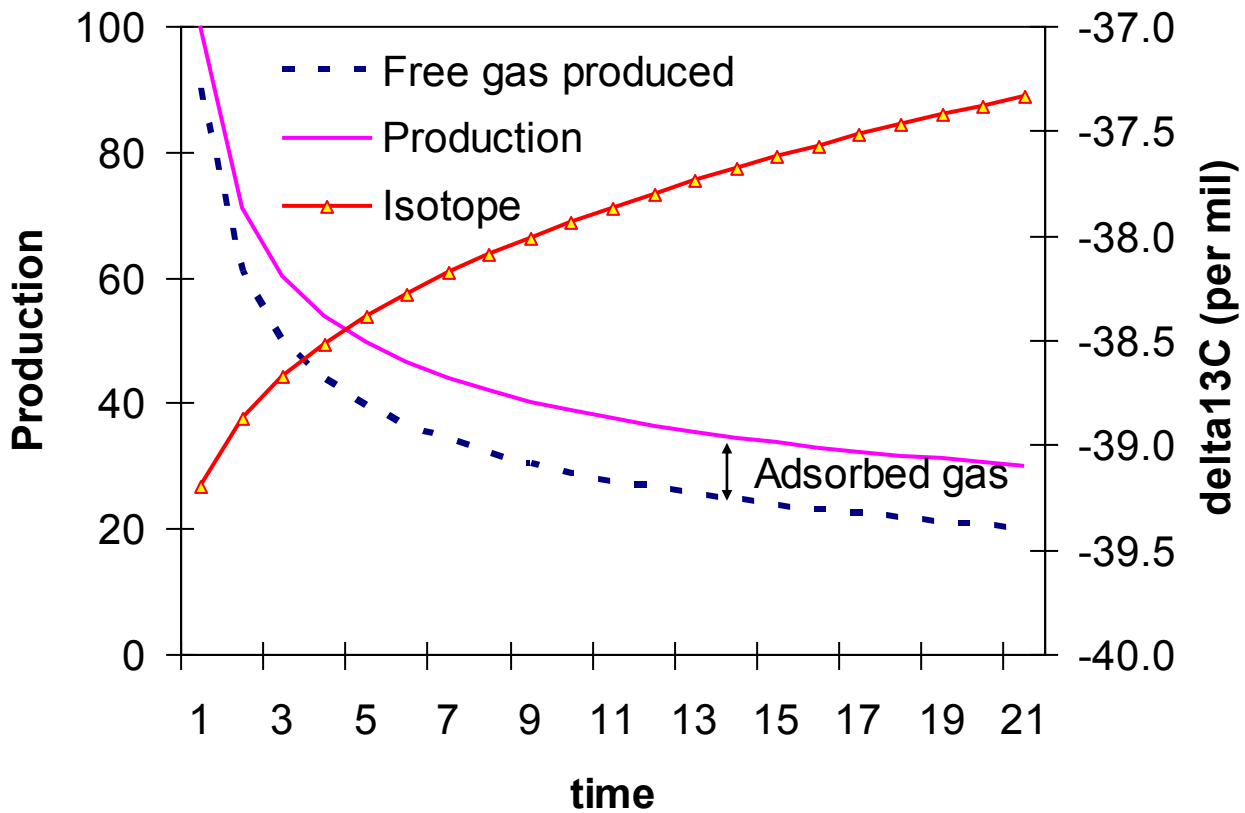
Figure 1: Model of using carbon isotope composition to distinguish the free gas and adsorbed gas during production.

Isotope fractionation due to gas diffusion in shale

Diffusion during shale gas production may have an obvious isotope fractionation effect. When the production of a well is stabilized, the diffusion of gas in shale rock towards the well bottom can be regarded as static. If diffusion is the only mass transfer process, the isotope fractionation can be expressed as

$$\Delta_{0-L} = \delta_0 - \delta_L = \frac{p_L}{2(p_0 + p_L)} \ln\left(\frac{^{12}M}{^{13}M}\right) \text{ x } 1000 \text{ ‰}$$

<div align="right">

Eq. 1
</div>

where p is pressure; subscript 0 and L refers to the place at the well and at the drainage radius of shale gas reservoir, respectively; ^{12}M and ^{13}M are the molar mass of the compound without and with a ^{13}C atom, respectively.

According to Eq. 1, the values of Δ_{0-L} of CH_4, C_2H_6 and C_3H_8 can be up to -30 ‰, -16 ‰ and -11 ‰, respectively, when $p_0 << p_L$. This is the extreme case with only diffusion as mass transfer process, without contribution of convection, which has no significant isotope effect.

To obtain high-density isotope data for differentiating the free gas and bound gas during the gas shale production, we developed a field gas isotope spectrometer to measure gas isotopes in-situ, based on the

exiting laser-based isotope measurement technology. Meanwhile, we also investigated the isotope fractionation of the physical and chemical processes during shale gas generation, partition and moving (during production). With the effective isotope data interpretation tool, the sweet spots, overpressure and production can be predicted, and the gas shale and tight sand production and exploitation through field test and deployment can be optimized.

References

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