Map-Based Isotopic Kinetic Tool to Simulate the Generation and Accumulation History of Natural Gas*

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Search and Discovery Article #40625 (2010)
Posted November 5, 2010

*Adapted from poster presentation at AAPG Annual Convention and Exhibition, New Orleans, Louisiana, April 11-14, 2010

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Abstract

Gas yields and isotope kinetic algorithms have been used in conjunction with basin modeling (Trinity) to quantify gas generation in the source kitchen and fetch area and accumulation history in the play and prospect. Gas yields and isotope kinetic algorithms are derived from GOR technique and new experimental data of the typical lacustrine and coal measures source rocks in Chinese basin. They use the temperature-dependent fractionation of stable carbon isotopes in individual gas compounds calibrated with direct closed and open system pyrolysis measurements of quantities and isotopic compositions of gases generated from specific source rocks or through secondary cracking of oil. Charge volume history of the play and prospect are calculated from expelled volumes from the fetch areas; on the other hand, gas composition and carbon isotope in the mode of instantaneous, cumulative and intervenient also are calculated for expelled volume gas from the fetch area. Possible scenarios of gas generation and accumulation history were postulated through comparison of measured carbon isotope data with calculated results. Two case studies are presented to illustrate the new map-based chemical kinetic quantitative tool to determine the origin of natural gas, source kitchen and fetch area, and charge history. The first case is Qingshen gas field in Xujiaweizi rift depression, Songliao Basin, where half of the gas samples show the peculiar reversal in the distribution of the carbon isotopic values of the hydrocarbon gases with increasing carbon number. The origin of natural gas is controversial, whether mixing of gases generated from variable source kitchen at different thermal maturity levels or significant contribution of abiogenic gases. Our results indicate that the peculiarity and variability of carbon isotope in this area were related to the stratigraphic and thermal-history variability of Upper Jurassic-Lower Cretaceous coals and associated dark mudstones, and minor lacustrine oil-prone mudstones. The second case is Paleozoic gas systems in the Ordos Basin

Reference

The complexity and variability of gas composition and isotope geochemistry in basin depend on the type and maturation of source rock, size and distribution of fetch area, and gas accumulation mode (instantaneous, cumulative or intervenient); firstly, stratigraphic variability of source rocks impacts the quantity and quality of gas generated; secondly, fetch area of the gas accumulation was evolved during the geological time; thirdly, most gas accumulation modes were interdependent between instantaneous and cumulative. Gas yields and isotope kinetic algorithms have to be used in conjunction with Interactive Basin and Petroleum System Modeling (BFSM) tools to quantify gas generation in the source kitchen and fetch area, and to constrain the gas charge and accumulation history in the play and prospect. Case studies are presented to illustrate the new map based on chemical kinetic-quantitative tool to determine the origin of natural gas, source kitchen and fetch area, and charge history.

1. Gas yields and isotopic kinetic algorithms

Gas yields and carbon isotope kinetic algorithms of various type of source rocks and oil cracking have been established, based on direct closed-system and open-system pyrolysis measurements of quantities and isotope fracations for gases generated from specific source rocks (Type I lacustrine shale, Type II marine shale, Type III coal and carbonaceous shales) and oil cracking (marine oil and lacustrine oil). With the application of kinetic calculations of hydrocarbon generation we can extrapolate the high-temperature carbonaceous shales) and oil cracking (marine oil and lacustrine oil). With the application of direct closed-system pyrolysis measurements of quantities and isotopic compositions of gases generated from specific source rocks or through secondary cracking of oil, gas yields and isotope kinetic algorithms include:

- Kerogen type: Type I, Type II, Type III
- Oil cracking
- Oil from lacustrine source rocks
- Oil from marine source rocks
- Kinetic organic facies: A, B, C, D, F
- Stratigraphic variability of source rocks significantly impacts the gas yields and carbon isotope. Simple statistic of geochemical screen analysis data or more complicated chemical kinetic model cannot solve the problem of heterogeneity of source rocks. We have revealed that universal covariant relationship of HI and TOC exists for lacustrine and marine mudstone source rocks, to a less degree for terrestrial source rock. Therefore, characterization of type or hydrocarbon potential of source rocks can be simplified to their counterpart TOC description. HI distribution and activation energy are peculiar for different TOC-interval (0.5-1%, 1-2%, 2-3%, more than 3%) mudstone, Four covariant relationship of HI and TOC exists for lacustrine and marine mudstone source rocks, to a less degree for terrestrial source rock. Therefore, characterization of type or hydrocarbon potential of source rocks can be simplified to their counterpart TOC description. HI distribution and activation energy are peculiar for different TOC-interval (0.5-1%, 1-2%, 2-3%, more than 3%) mudstone, Four covariant relationship of HI and TOC exists for lacustrine and marine mudstone source rocks, to a less degree for terrestrial source rock. Therefore, characterization of type or hydrocarbon potential of source rocks can be simplified to their counterpart TOC description.

2. Map-Based Isotopic Kinetic Tool

The complexity and variability of gas composition and isotope geochemistry in basin depend on the type and maturation of source rock, size and distribution of fetch area, and gas accumulation mode (instantaneous, cumulative or intervenient); firstly, stratigraphic variability of source rocks impacts the quantity and quality of gas generated; secondly, fetch area of the gas accumulation was evolved during the geological time; thirdly, most gas accumulation modes were interdependent between instantaneous and cumulative. Gas yields and isotope kinetic algorithms have to be used in conjunction with Interactive Basin and Petroleum System Modeling (BFSM) tool to quantify gas generation in the source kitchen and fetch area, and to constrain the gas charge and accumulation history in the play and prospect. Case studies are presented to illustrate the new map based on chemical kinetic-quantitative tool to determine the origin of natural gas, source kitchen and fetch area, and charge history.
3. Case Studies-1 Paleozoic gas systems in Ordos Basin

Two case studies will be presented to illustrate the new map based on chemical kinetic quantitative tool to determine the origin of natural gas, source kitchen and fetch area, charge history. The first case is the Paleozoic gas systems in Ordos Basin. The upper Paleozoic coal measures are source rocks for the gas field (Zai, 1999), but many geologists suggested that source kitchen was mainly located in the south area, and natural gas migrated long distance from the south source kitchen to the present gas accumulation area. Our new map based on chemical kinetic analysis indicates that short range is peculiar to the gas generation, migration and accumulation in the Paleozoic gas systems in Ordos Basin.

Fig. 4  C1 and C2 isotopic value of expelled gas from the long range kitchen in red-line area, the cumulative gas from the long range source kitchen is much heavier than natural gas from LW gas field, indicating that natural gas from LW gas field was derived from (1) the early phase gas of the long range kitchen,(2) the short range kitchen, dry and heavier natural gas from high and overmature kitchen existed in the down dip direction of LW gas field.
3. Case Studies-2 Qingshen gas field, Songliao Basin

The second case is Qingshen gas field in Xujiawei rift depression, Songliao Basin, where half of gas samples show peculiar reversal in the distribution of the carbon isotopic values of the hydrocarbon gases with increasing carbon number; the origin of gas is controversial whether mixing of gases generated from variable source kitchen at different thermal maturity levels or significant contribution of abiotic gases; our results indicate that the peculiarity and variability of carbon isotope in this area are related to the stratigraphic and thermal history variability of Upper Jurassic-Lower Cretaceous coals and associated dark mudstones, and minor lacustrine oil-prone mudstones. C1 is mainly from coal measures, and C2 originated from oil cracking.

Fig. 8 Distribution of δ13C1 and δ13C2, value of Paleozoic natural gas accumulation (left) and explanation model of gas generation from coal measures (Type III) (right), indicating Pennsylvanian-Pennian coal measures as predominant source rocks, gas charge in short range cumulative model; the relative variation of δ13C1 and δ13C2 value in gas field reflects replacement of gas from different maturity phase.

Fig. 9 Sulge gas field (gray area) and distribution of δ13C2, value of Paleozoic natural gas accumulation (left) and scenarios of short range gas generation, migration and accumulation (right) through comparison of measured carbon isotopic data with calculated results; in the calculation case, gas fetch is similar to the gas field distribution.

Fig. 10 Distribution of Qingshen gas field in Xujiawei rift depression, Songliao Basin, and variation in value of δ13C1 (left) and δ13C2 (right) in natural gas, with the peculiar reversal in the distribution of the carbon isotopic values of the hydrocarbon gases with increasing carbon number in Xushen, Xudong, Changda and Zhaozhou.

Fig. 11 Cross section of Xujiawei rift depression, Songliao Basin (left), and scenarios of gas generation, migration and accumulation for Xushen gas field (right); C1 mainly from coal measures and C2 originated from oil cracking. Gas accumulation began about 110 Ma.