Mantle-derived methane homologue, carbon dioxide and helium in natural gases from Songliao Basin, China

W. Xianbin
L. Chunyuan
C. Jianfa
W. Lingjun

Lanzhou Institute of Geology, Chinese Academy of Sciences, Lanzhou 730000, China

G. Zhanqian

Daqing Institute of Petroleum Exploration, Daqing Petroleum Exploration Bureau, Daqing 163000, China

Whether abiogenic (inorganic) actions can form petroleum and natural gas reservoirs has been a debatable problem for over a century in the academy circle. Gold (1979) proposed deep-earth gas hypothesis. Wang (1983, 1989, 1997) discussed the geochemical characteristics of deep-earth gas. Jenden *et al.* (1993) proposed three specific analytical criteria to identify mantle-derived hydrocarbons in oil and gas field. The isotopic composition characteristics of methane homologue, carbon dioxide and helium in natural gases from Songliao Basin, China will be discussed in this paper.

Changde and Zhaoxi natural gas field

The crucial reason why there was no important breakthrough in abiogenic hypothesis of natural gas origin for over a century is that there was no unambiguous evidence discussed and proposed showing that a certain commercial gas reservoir is abiogenic. However, the recent study indicates that geochemical characteristics along with geological-geophysical data in several gas wells in the Changde and Zhaoxi gas reservoirs, the Songliao Basin provides the basis for reservoiring of abiogenic natural gas in this area.

Carbon isotopic distribution in methane

$\delta^{13}C$ values of methane from 120 commercial gas samples in 56 wells in Songliao Basin can be classified into 3 groups: (1) $\delta^{13}C = -55‰ \sim -40‰$ (accounting for 35% of total samples); (2) $\delta^{13}C = -40‰ \sim -25‰$ (accounting for 43% of total samples); (3) $\delta^{13}C = -25‰ \sim -15‰$ (accounting for 22% of total samples). Group (1) and (2) mainly reflect the feature of carbon isotopic composition of methane in natural gas in different thermal evolution stages; Group (3), with the heaviest isotopic composition, reflect characteristics of carbon isotopic composition of abiogenic methane. $\delta^{13}C$ values of methane in several wells in the Changde and Zhaoxi gas reservoirs all fall in group (3).

Carbon isotope variations among the C_1 to C_4 hydrocarbons

$\delta^{13}C$ values of biogenic light hydrocarbon gases degraded from complicated hydrocarbons present a normal form: $\delta^{13}C_1 < \delta^{13}C_2 < \delta^{13}C_3 < \delta^{13}C_4$, occurring in the majority of commercial gases. Jenden *et al.* (1993) tried to find abiogenic gas reservoirs with reverse distribution of $\delta^{13}C$ values from 1699 commercial gases but in vain. Carbon isotope variations among the C_1 to C_4 hydrocarbons in several wells in the Changde and Zhaoxi gas reservoir in the Songliao Basin presents the form of abiogenic gas, i. e. $\delta^{13}C_1 > \delta^{13}C_2 > \delta^{13}C_3 > \delta^{13}C_4$, for example, $\delta^{13}C$ of C_1, C_2,C_3 and C_4 in Fangshen-4 well is $-16.7‰$, $-19.2‰$, $-24.3‰$ and $-25.8‰$, respectively.

Helium isotope ratios

Helium in natural gas can be approximately divided into two types: crust helium and mantle helium (Wang, 1989). $R/R_A > 0.1\ R_A$ (R_A = atmospheric ratio) possible indicate the presence of mantle-derived. $^3He/^4He$ ratios of the Changde and Zhaoxi gas reservoirs vary between 0.19 and 1.59 R_A, wherein the ratio in Fangshen-5 well and Fangshen-7 well is 1.53 and 1.59 R_A respectively, providing evidence of helium isotope for the reservoiring of abiogenic gas.

Reservoiring condition

The Songliao Basin is a tensional basin formed in a tensional stress field where the mantle uplifted and the crust became thin by tension. In this area, translithospheric fracture is developed and rheosphere in the middle is uplifted as high as 80 km, with a magma batch at the depth of 16–19 km under the center of the basin (with low density, low speed and low resistance). Its surface heat flow is about 95 mW/m^2 and its present mean geothermal gradient is 42°C/km. The diapirism of the uplifting mantle would definitely make the lithosphere rise, and make the cover crust activate under a rising temperature, stretch and become thinner; thus the spheres separated so that it is fit for the mantle materials to enter the crust along the translithospheric rifts. This can be proven by a large amount of Neocene and Quaternary alkaline basalt with ultramafic xenolith from the upper mantle distributed in the cross of the NE and NW rifts in the Songliao Basin. The Changde and Zhaoxi gas reservoir are located on the two sides of the translithospheric rift above the central rise. Therefore, the underlying magmatic activity and the translithospheric rift provide source and path for these two abiogenic gas reservoirs.

All of the Fangshen-1 through Fangshen-7 wells in the Changde gas reservoir reached the basement and obtained economic oil and gas flow. Trap area of the gas reservoir and geological reserve it controls are 146 km^2 and 45.73×10^8 m^3 respectively, while trap area and geological reserve of the Zhaoxi gas reservoir are 130 km^2 and 23.10×10^8 m^3 respectively, indicating a probability of abiogenic hydrocarbon accumulating and reservoiring under suitable geological conditions.

The discovery of the Changde and Zhaoxi reservoirs in the Songliao Basin provided a successful example for the exploration of abiogenic natural gas, which is divergent with the opinions of Jenden *et al.* (1993).

Wanjinta CO_2 gas field

The volcanic activity in Mesozoic and Cenozoic era provide a path and material source for the accumulation of Wanjinta CO_2 gas reservoir located at the marginal of the Songliao Basin. In the area, CO_2 concentration of Wan-2, Wan-4, Wan-6 and Wan-9 well is up to 90–99%. The carbon isotope composition of carbon dioxide and isotope composition of noble gas in these wells show the isotope composition characteristics of mantle.

The $\delta^{13}C$ of carbon dioxide in these wells ranges from −4.0‰ to −8.8‰.

The helium isotopic ratios in these wells are between 3.34 and 4.96 R_A.

$^{20}Ne/^{22}Ne$ and $^{21}Ne/^{22}Ne$ ratios in these wells are 9.94 to 10.9 and 0.031 to 0.051 respectively.

$^{40}Ar/^{36}Ar$ ratios in these wells are from 3500 to 7700.

^{129}Xe and $^{132\text{-}136}Xe$ are observed in Wan-6 wells and ^{129}Xe is excesses (up to 3%) relative to fission ^{129}Xe(Xu *et al.*,1995).

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