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

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Abstract

Gas yields and isotope kinetic algorithms have be 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 lacustirine oil-prone mudstones. The second case is Paleozoic gas systems in the Ordos Basin

Reference

Dai, Jinxin, 1999, Significant advancement in research on coal-formed gas in China: Petroleum Exploration and Development [J],v.,26/3, p. 1-10.

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Map-Based Isotopic Kinetic Tool to Simulate the Generation and Accumulation History of Natural Gas(1)

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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 evolutive during the geological time; thirdly, most gas accumulation modes were intervenient between instantaneous and cumulative. Gas yields and isotope kinetic algorithms have to be used in conjunction with Interactive Basin and Petroleum System Modeling (BPSM) tool (Trinity 3D) 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 kinetics 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 fractionations for gases generated from specific source rocks (Type I lacustrine shale, Type II marine shales, 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 pyrolysis measurements to any geologic heating rate. GOR Isotopes, a PC-based software package for modeling the kinetics of natural gas generation, designed by PEER, are able to generate algorithms of gas yield and C1-C4 carbon isotope that varied with temperature or maturity.

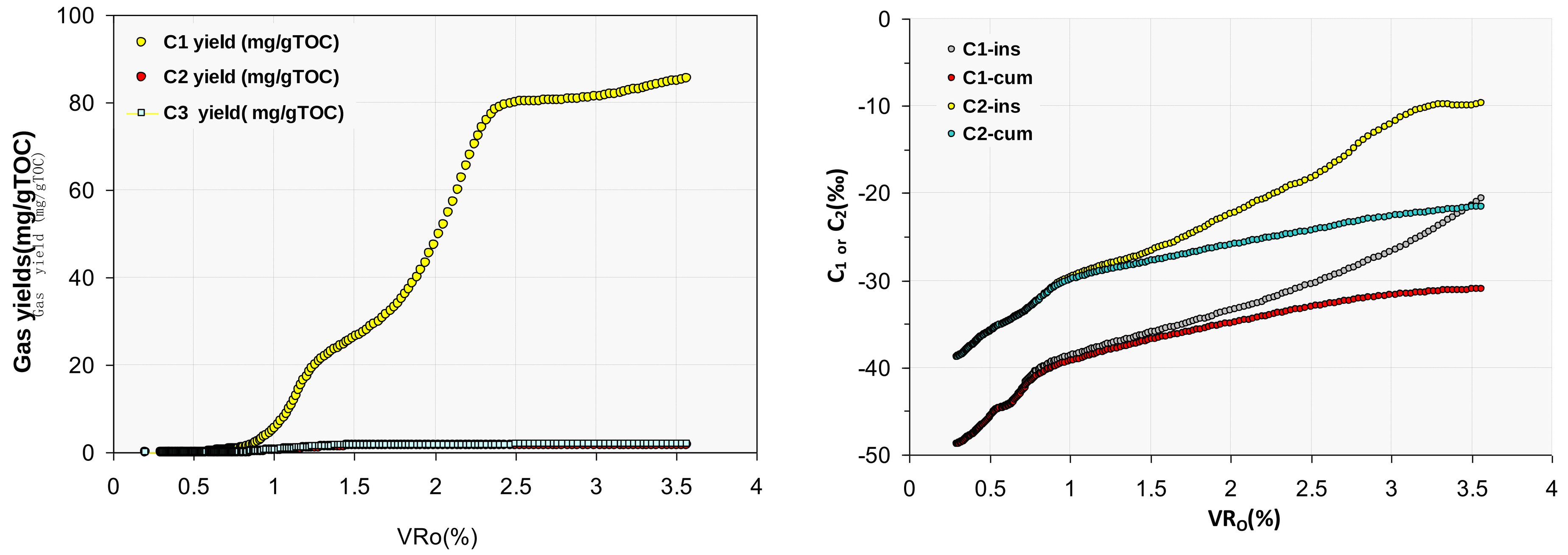

Fig.1 Gas yield and carbon isotope model for Type III coal(HIo=156mg/gTOC, initial carbon isotope of kerogen $\delta^{13}C$=-23.5‰)

New experimental data of the typical lacustrine and coal measures source rocks in Chinese basin, using the temperature-dependent fractionation of stable carbon isotopes in individual gas compounds, are calibrated with direct closed system pyrolysis measurements of quantities and isotopic compositions of gases generated from specific source rocks or through secondary cracking of oil.

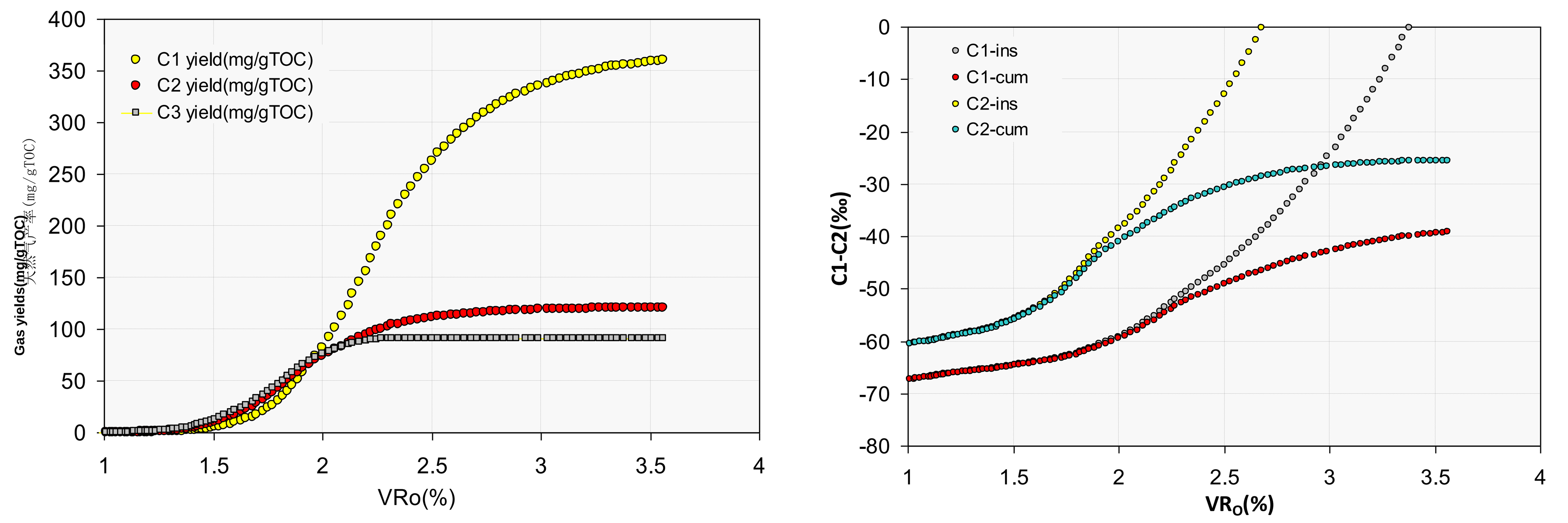

Fig. 2 Gas yield and carbon isotope model for oil cracking (oil derived from lacustrine source rocks, initial carbon isotope of oil $\delta^{13}C$ =-28.5‰)

- Gas yields and isotope kinetics algorithms include:
  - Kerogen type: Type I,Type II,Type IIII (Fig. 1)
  - Oil cracking
    - •Oil from lacustrine source rocks(Fig. 2)
    - •Oil from marine source rocks (high sulfur, low sulfur)
    - •Oil cracking+TSR
  - Kinetic organic facies: A ,B, C, D/E, 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 TOC-interval kinetic organofacies, each characterized by HI,TI,GOGI and bulk petroleum generation kinetics, have been established for lacustrine source rocks, which can be related to evaluation of source rock on wireline logs.

2. Map-Based Isotopic Kinetic Tool

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 are also calculated for expelled volume of gas from the fetch area; possible scenario of gas generation and accumulation history were postulated through comparison of measured carbon isotope data with calculated results.

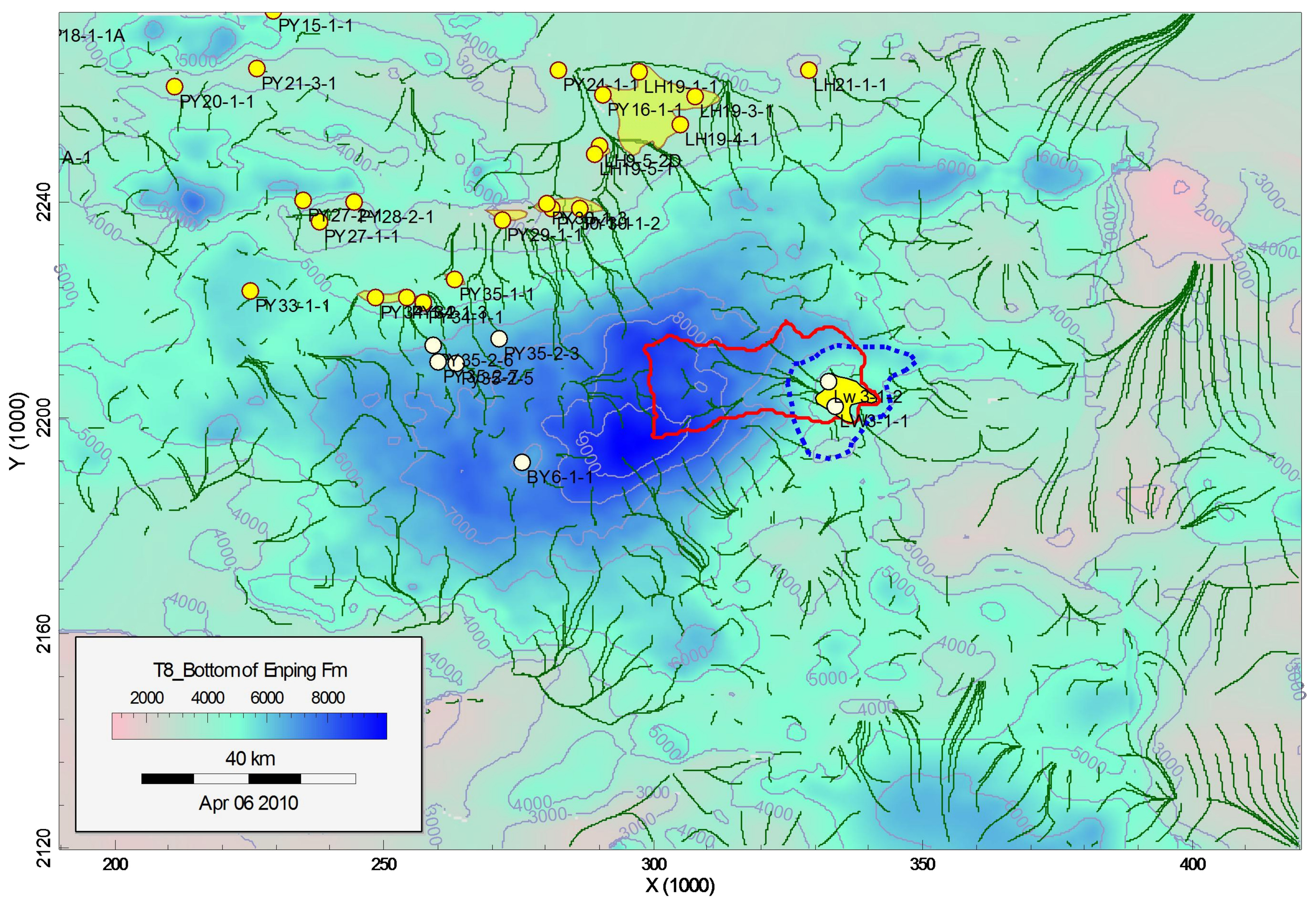

Fig. 3 Possible gas source kitchen for LW gas field in Baiyun depression, PRM basin, South China sea, short range kitchen in blue dot line area, or long range kitchen in red-line area? Geologists presumed that Eocene Wenchang Formation oil-prone lacustrine source rocks and Oligocene Enping Formation gas-prone humic-type source rocks co-existed in the Baiyun depression.

Table 1 Carbon isotopic data of natural gas from LW gas field

Well No	Depth(m)	C1	C2	C3	iC4	nC4	CO2
LW3-1-1Sa	3070	-37.1	-29.0	-27.2	-27.1	-27.1	-5.7
LW3-1-1	3144.5	-36.6	-29.1	-27.4	-26.8	-26.8	-6.1
LW3-1-1Sa	3189.5	-36.8	-28.9	-27.5	-26.9	-26.9	-5.7
LW3-1-1	3499.5	-36.6	-29.6	-29.1	-28.1	-28.1	-7.8

Map-Based Isotopic Kinetic Tool to Simulate the Generation and Accumulation History of Natural Gas(2)

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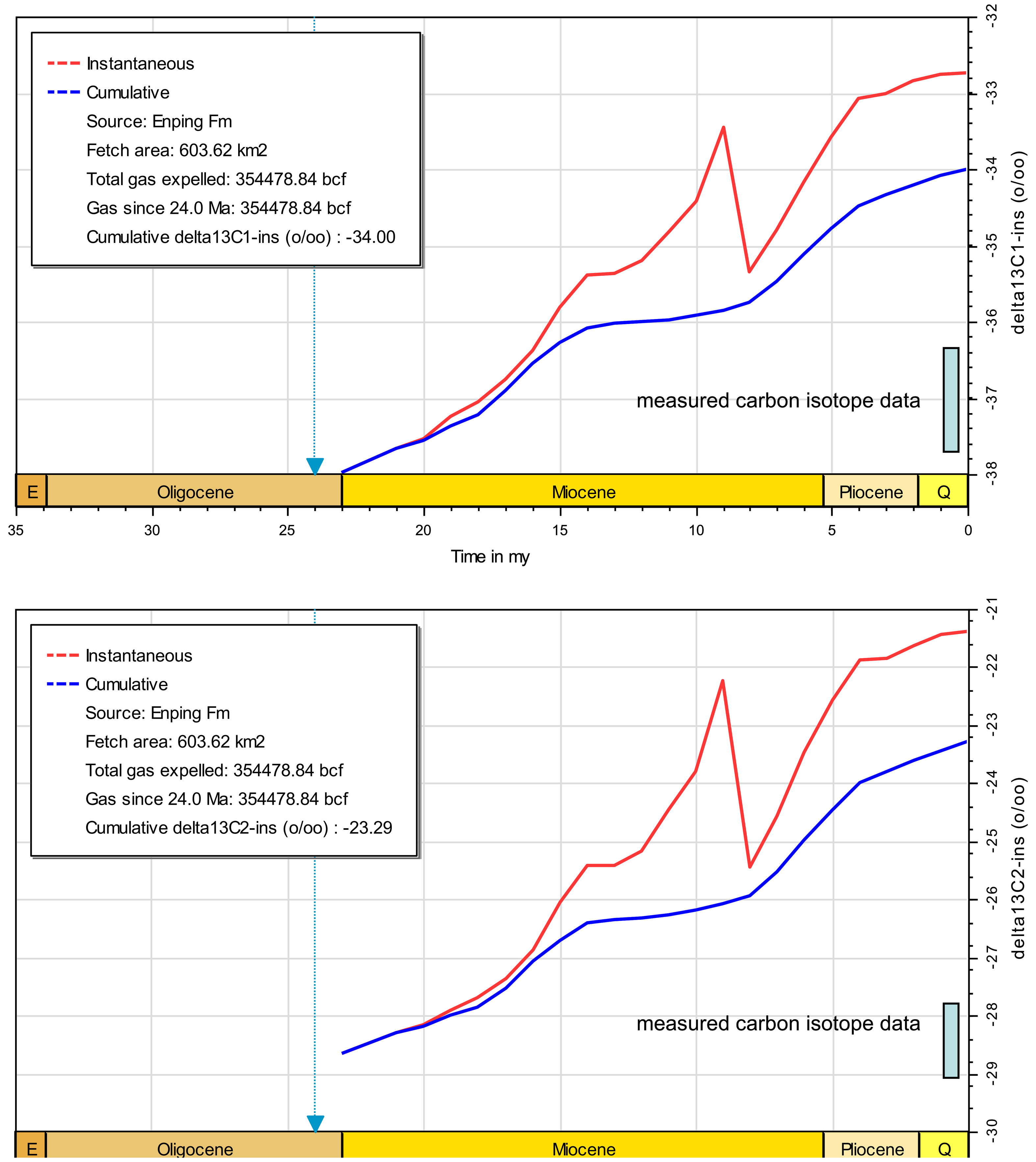

Fig. 4 C1 and C2 isotopic value of expelled gas from the long range kitchen in red-line area; the cumulative gas from the long range source kitchen is much heavier than natural gas from LW gas field, indicating that natural gas from LW gas field was derived from (1) the early phase gas of the long range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

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 (Dai,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.

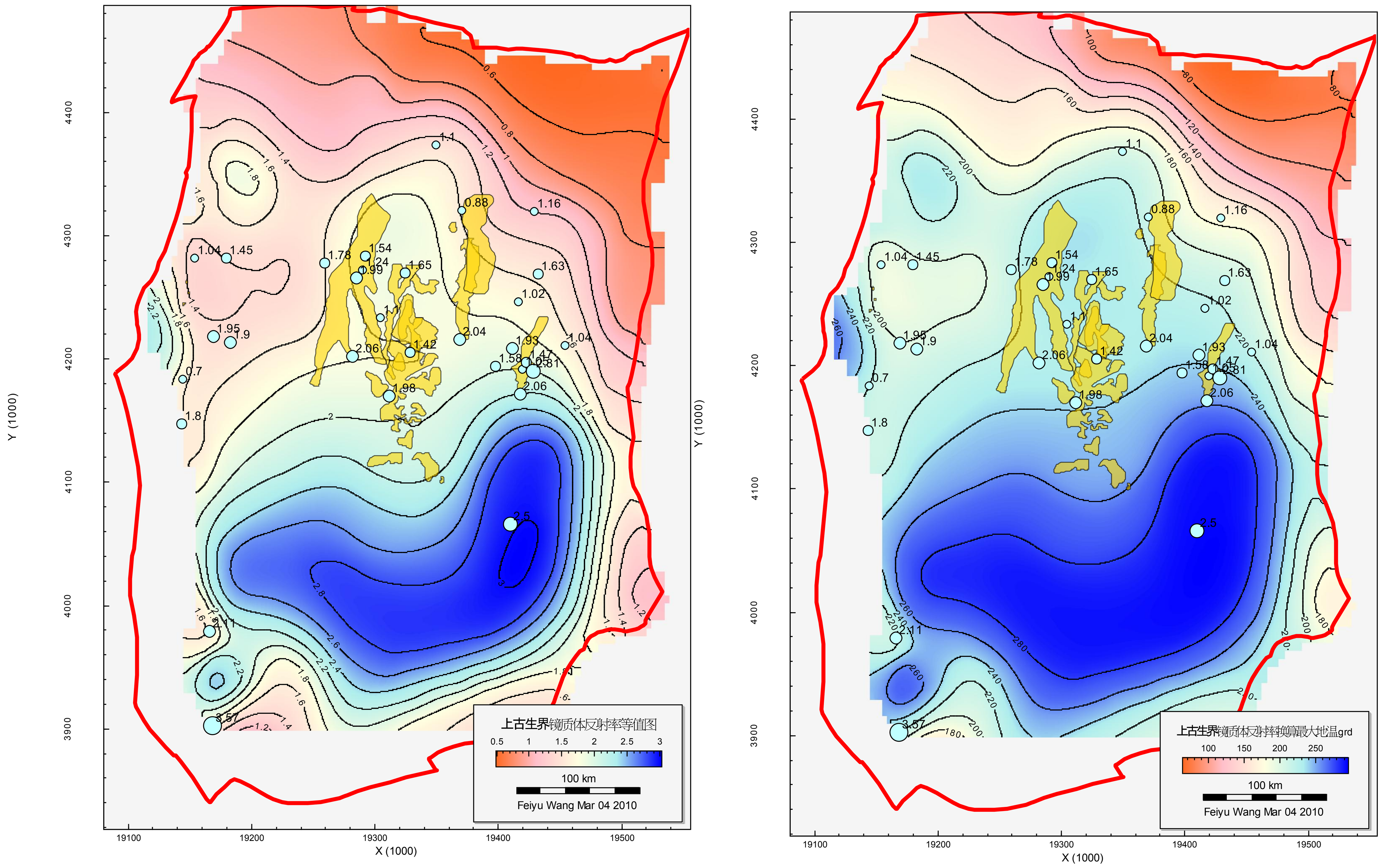

Fig. 5 Isoline of VRo (left) and maximum paleotempreture (℃) (right) of Pennsylvanian–Permian coal measures distribution; yellow areas are Paleozoic gas fields; blue circle are measured VRo data.

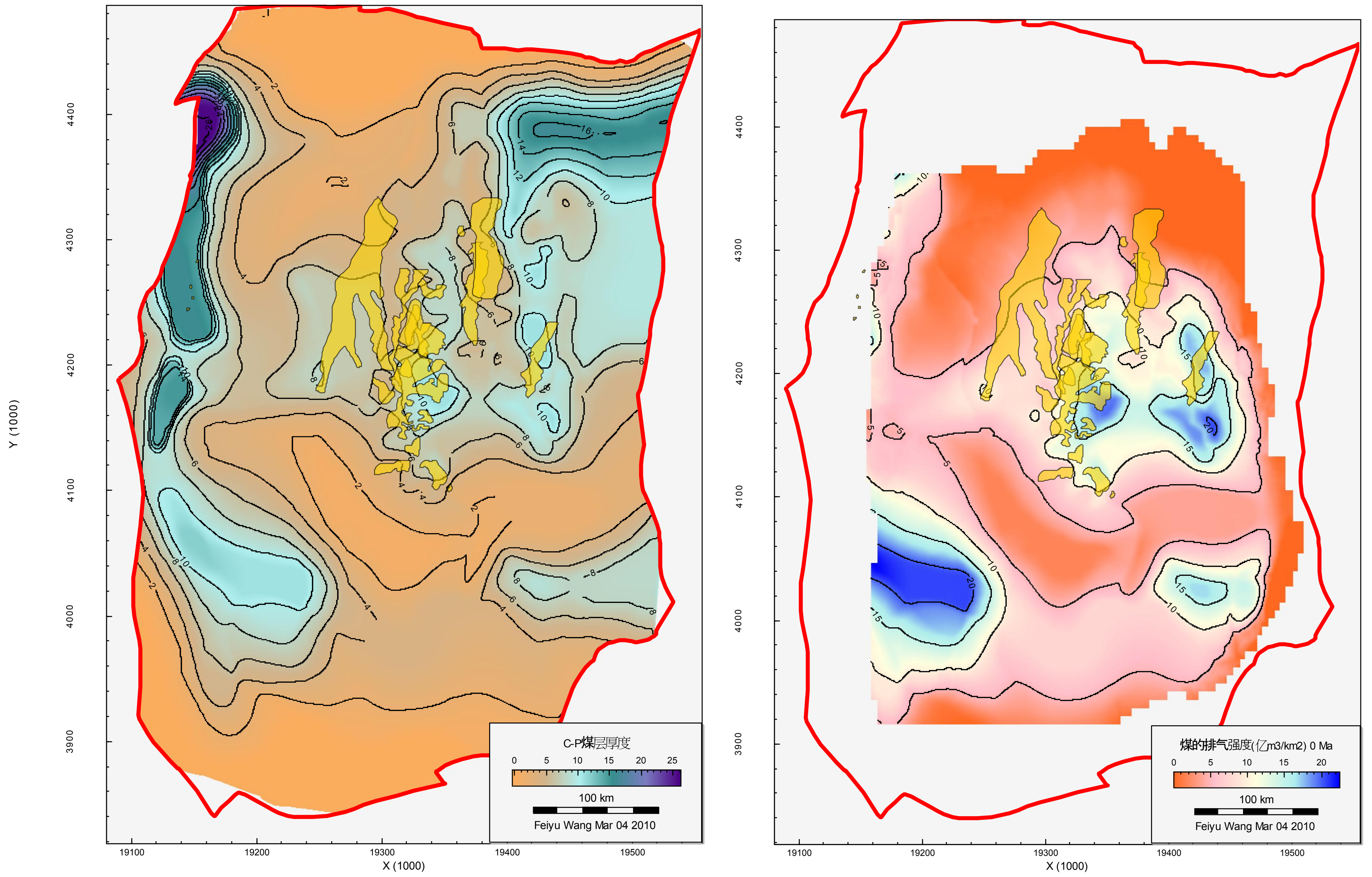

Fig. 6 Isopach of Pennsylvanian–Permian coal seams (left) and gas expulsion map (10^8 m^3/km^2) of Pennsylvanian–Permian coal measures (right)

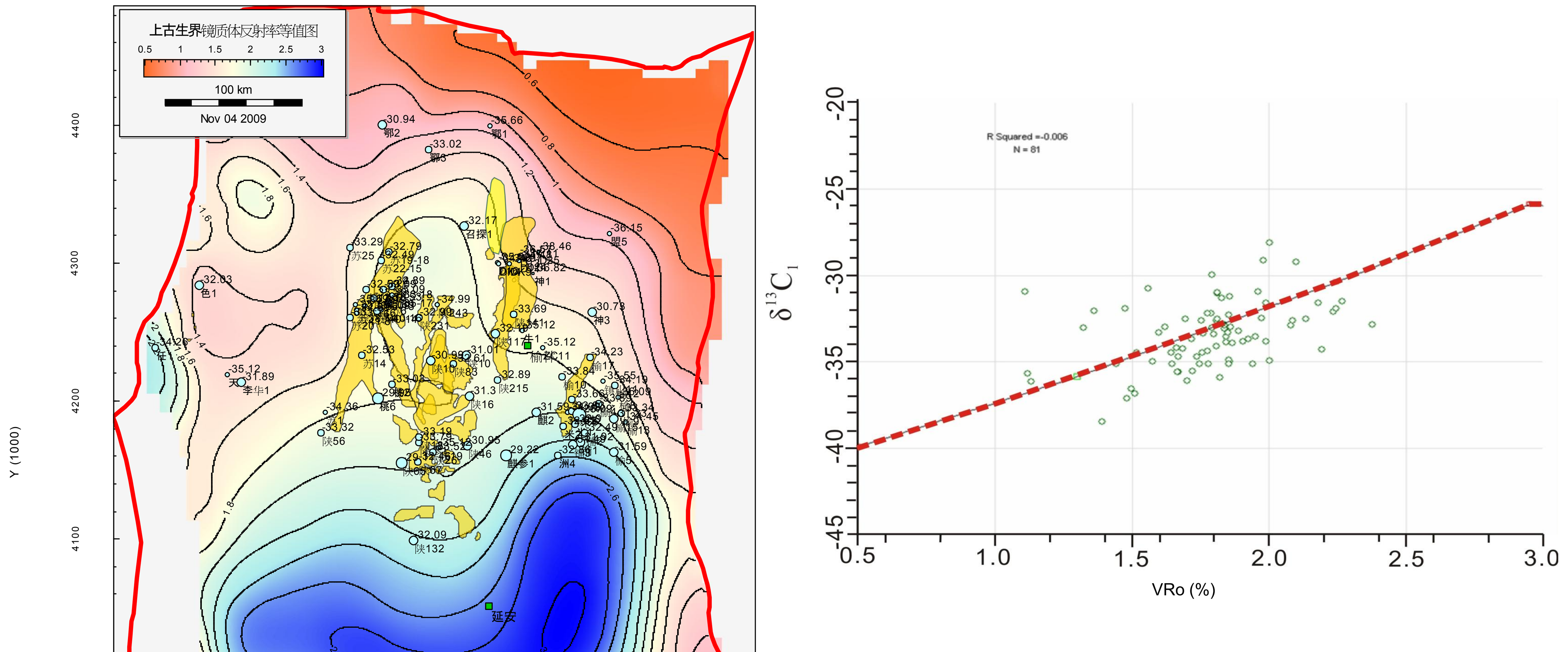

Fig. 7 Isoline of VRo of Pennsylvanian–Permian coal and δ^{13}C1 value distribution of natural gas accumulation in the dolomites of the Lower Ordovician and sandstones of Lower Permian Shanxi and Xiashihezi formations (left) and correlation between δ^{13}C1 of natural gas accumulation and VRo of in-situ Pennsylvanian–Permian coal measures (right).

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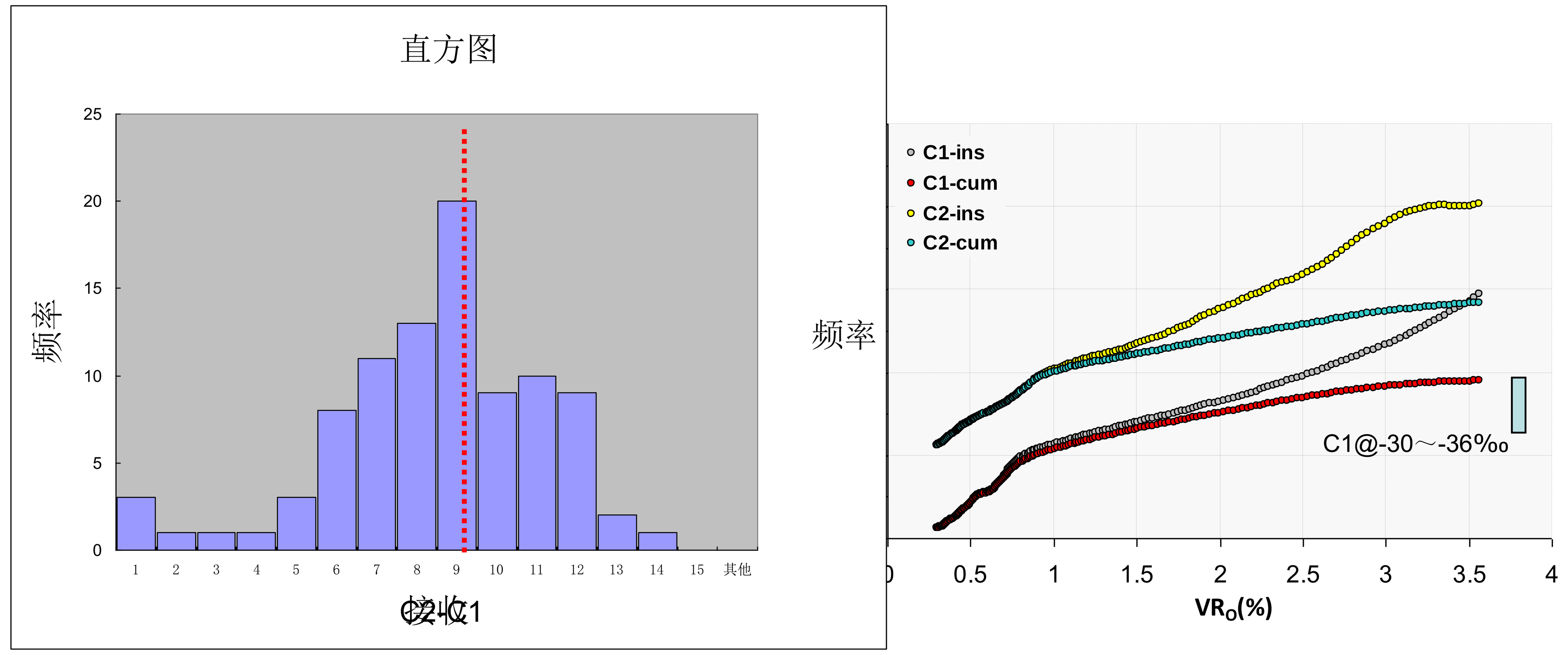

Fig. 8 Distribution of δ13C_2- δ13C_1 value of Paleozoic natural gas accumulation (left) and explanation model of gas generation from coal measures (Type III) (right) , indicating Pennsylvanian–Permian coal measures as predominant source rocks, gas charge in short range cumulative mode; the relative variation of δ13C_2 and δ13C_1 value in gas field reflects emplacement of gas from different maturity phase.

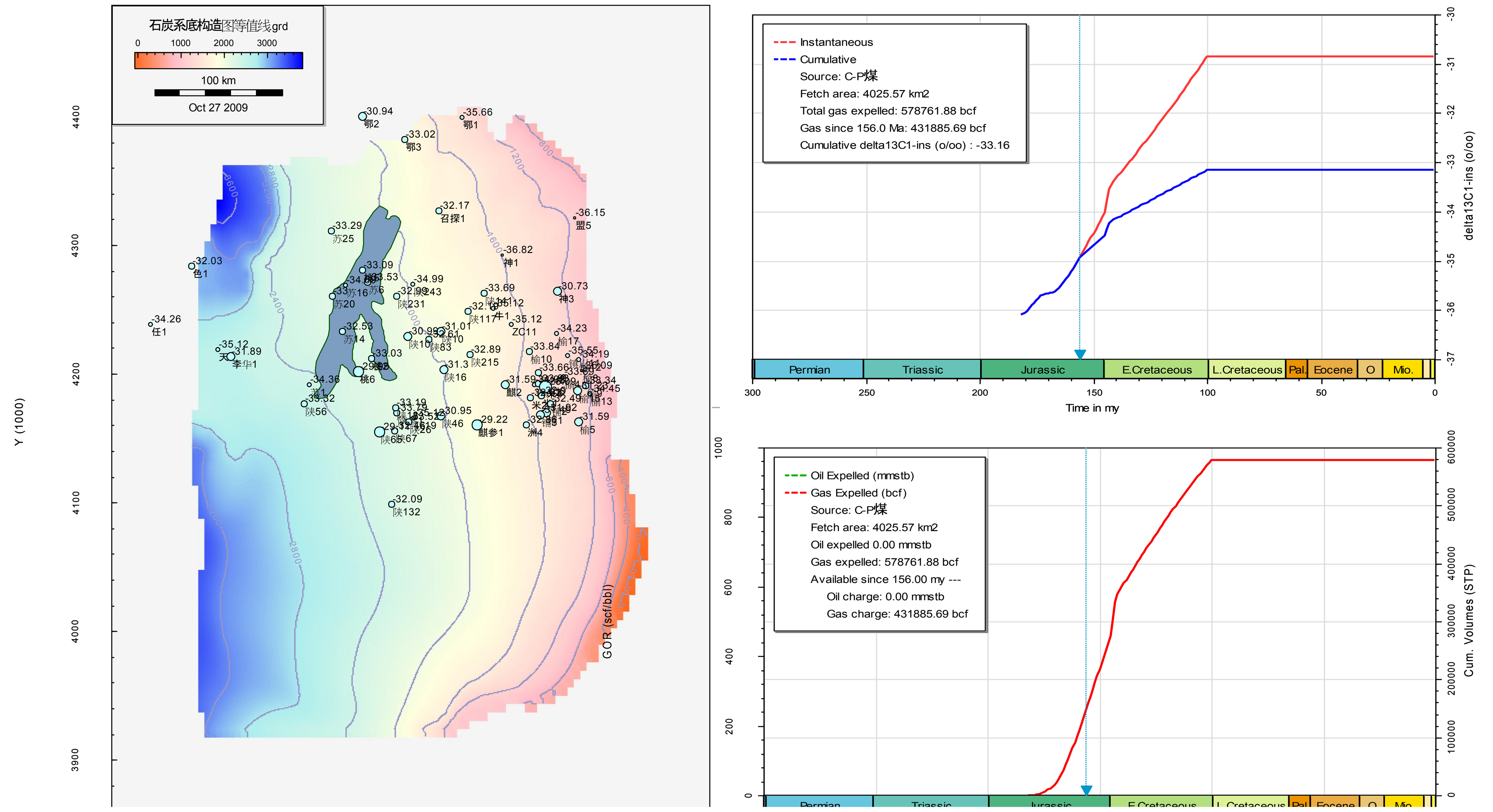

Fig. 9 Sulige gas field (gray area) and distribution of δ$^{13}C_1$ value of Paleozoic natural gas accumulation (left) and scenarios of short range gas generation, migration and accumulation (right) through comparison of measured carbon isotope data with calculated results; in the calculation case, gas fetch is similar to the gas field distribution.

3. Case Studies-2 Qingshen gas field, Songliao Basin

The second case is Qingshen gas field in Xujiaweizi 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 natural gas is controversial whether mixing of gas 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 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.

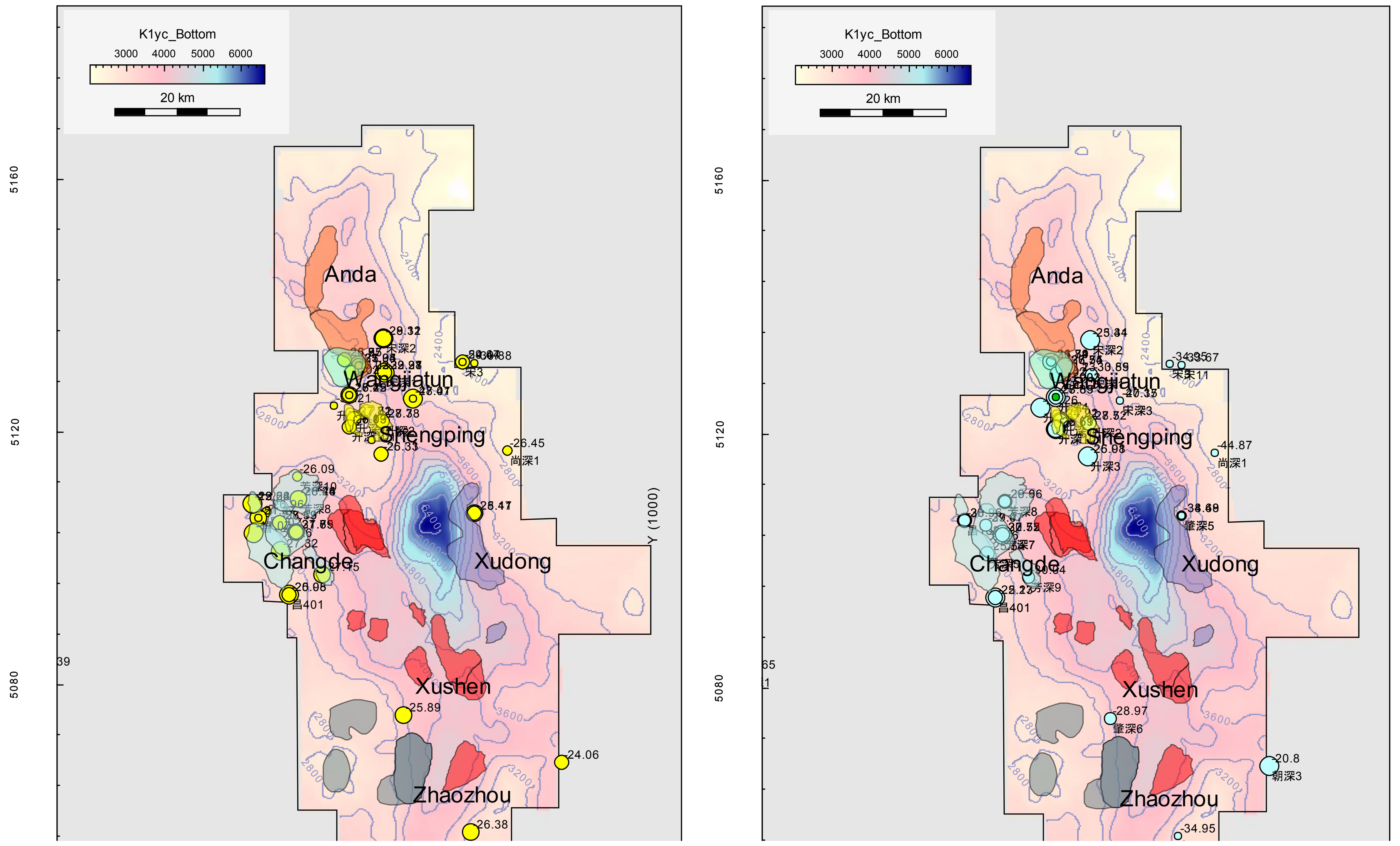

Fig. 10 Distribution of Qingshen gas field in Xujiaweizi rift depression, Songliao Basin, and variation in value of δ13C1 (left) and δ13C2 (right) in natural gas, with the peculiar reversal in the distribution of the carbon isotopic values of the hydrocarbon gases with increasing carbon number in Xushen,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

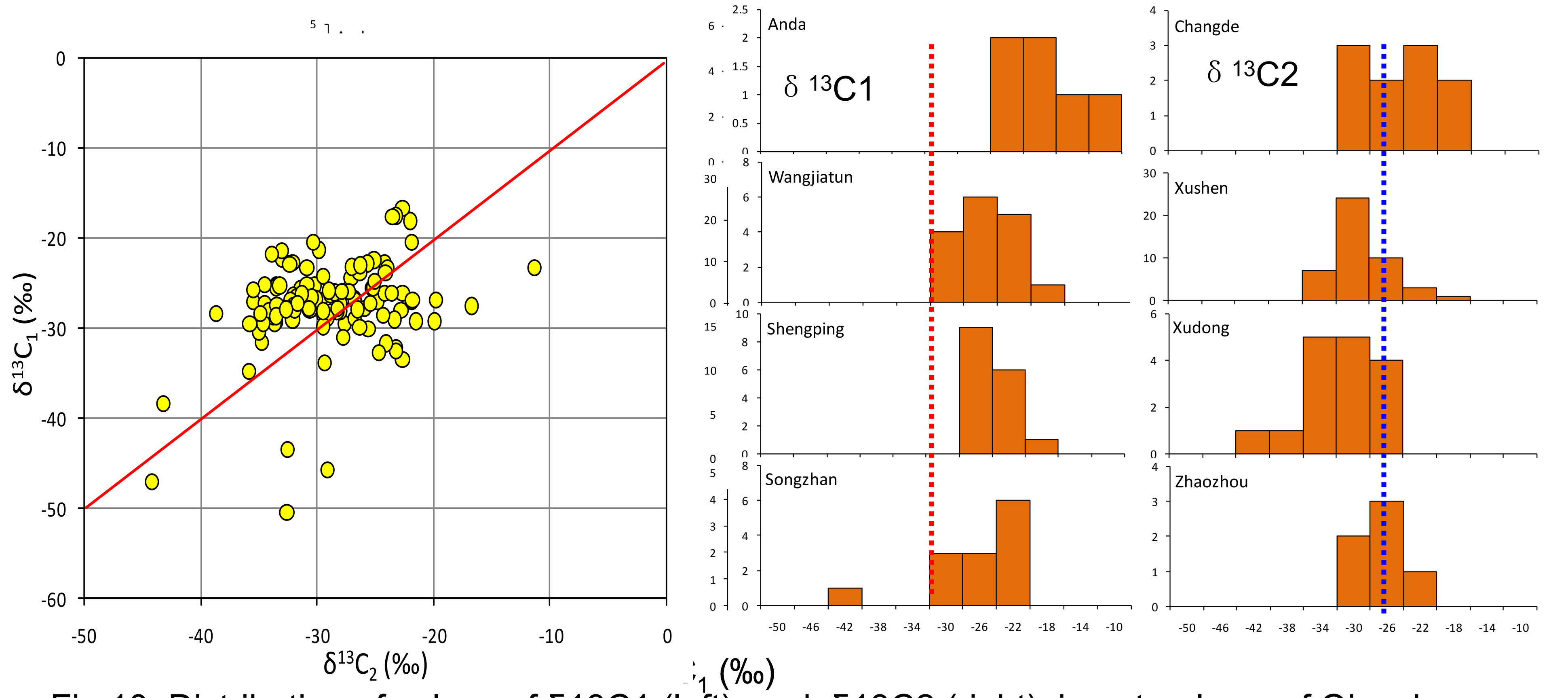

Fig 10 Distribution of values of δ13C1 (left) and δ13C2 (right) in natural gas of Qingshen gas field, in Xujiaweizi rift depression, Songliao Basin, with the peculiar reversal in the distribution of the carbon isotopic values of the hydrocarbon gases with increasing carbon number in Xushen, Xudong, Changda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

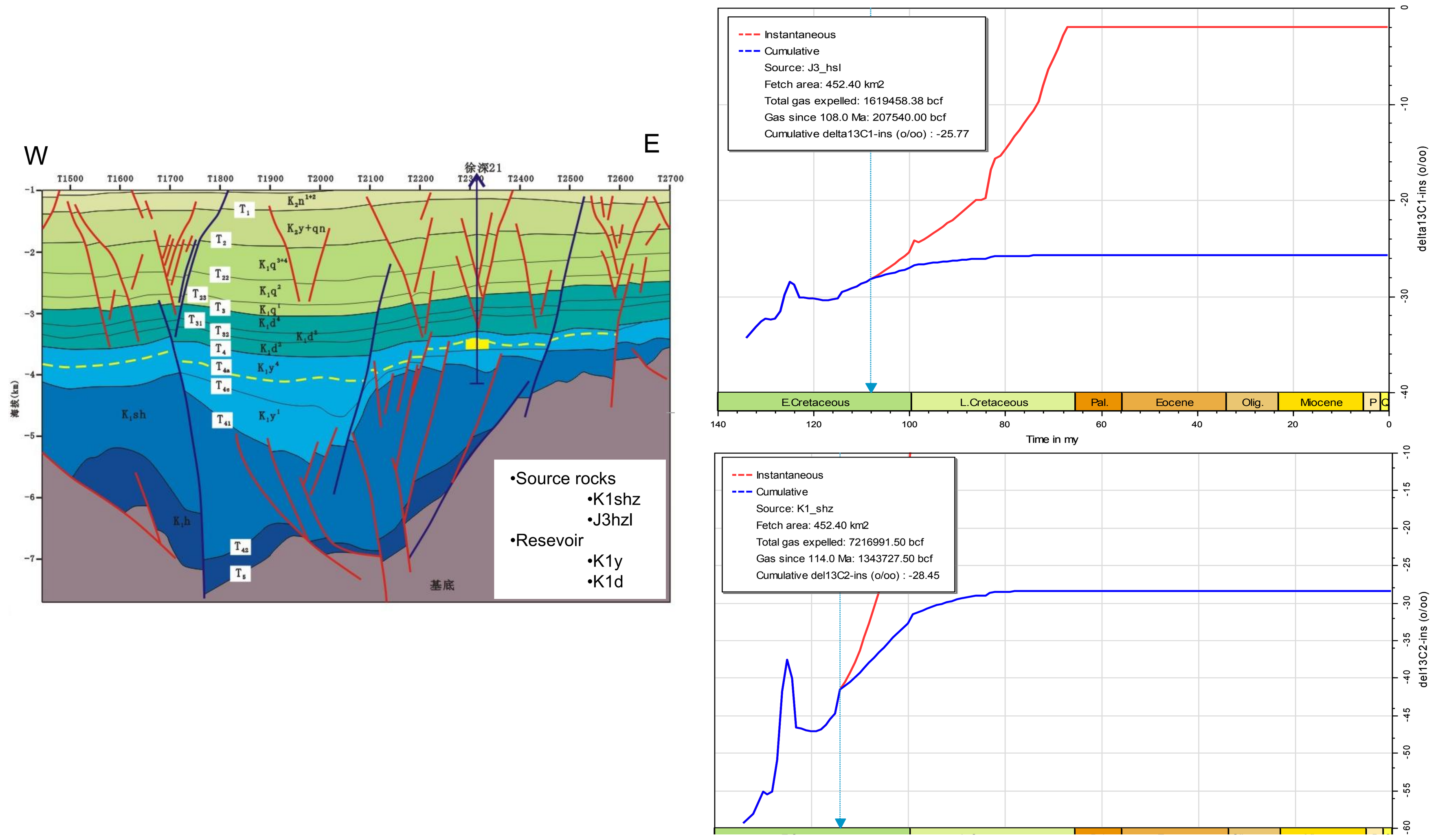

Fig. 11 Cross section of Xujiaweizi rift depression, Songliao Basin (left), and scenarios of gas generation, migration and accumulation for Xushen gas field (right); C1 mainly from coal measures, and C2 originated from oil cracking. Gas accumulation began about 110 Ma.