Refined Lacustrine Petroleum Systems Modeling and New Play Assessment: A Case Study of Baxian Sag, Bohai Bay Basin, China*

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Abstract

Baxian sag, located in the western area of Bohai Bay basin, is a mature exploration area about 2,400 km^2 with complete 3D seismic data. 1.4 billion BBL oil has been produced after thirty years of exploration, and most discovered oil accumulations were located above a depth of 3,500m. How to assess residual petroleum resources and to delineate the next play are urgent issues for further exploration. Refined source kitchen analysis indicated that the Paleogene Shahejie Formation lacustrine source rocks (Es1, Es3 and Es4) present high heterogeneity, including organic facies C, D/E and F, and maturity range from oil window to overmature stage in the deep area of the sag. The scale and phase of residual petroleum resources can be inferred through the comparison of amount and phase between expelled hydrocarbons from source kitchen and discovered oil accumulations. Oil-source correlation confirmed that oil accumulations above 3,500m depth were derived from organic facies C source rocks in the Shahejie Formation. Most hydrocarbons expelled from organic facies D/E and F source rocks have not be found. We postulate that these condensates and wet gas expelled from the Es3 and Es4 D/E and F facies source rocks efficiently accumulated at the play and prospect in the deeper scope. The spatial orderly distribution of API GOR, gas carbon isotope and diamondoids data denote the various front expelled hydrocarbon in different mature stages from organic facies C, D/E and F. This reflects the dynamic scenario of petroleum migration and accumulation from kitchen to the shallow accumulations. Therefore, the deep buried hills charged with condensate and wet gas are recommended for further exploration. Recently, Niudong-1 Well has been successfully drilled and found super-deep carbonate buried hill condensate gas reservoirs in the Mesoproterozoic Wumishan Formation, with the bottom depth about 6,500m and GOR about 875m^3/m^3. The success of Niudong-1 Well has proven our model of the condensate and wet gas efficiently accumulates in the deeper prospect.

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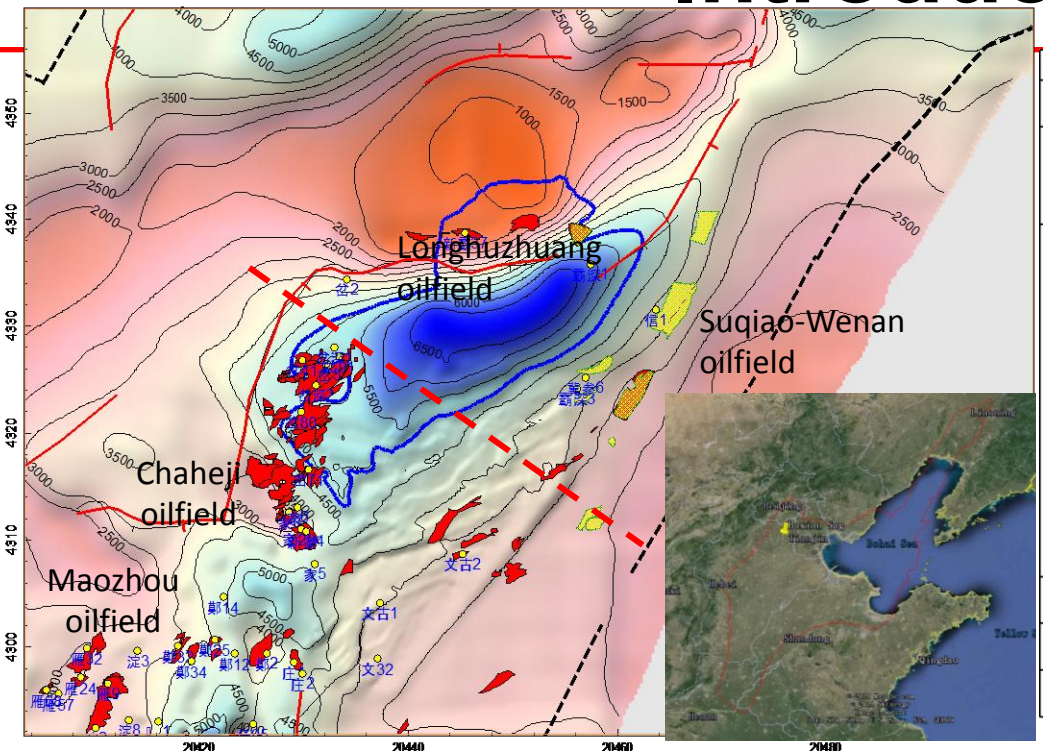
Outline

- Introduction
- Refined source kitchen analysis
- The new play assessment
- Conclusion

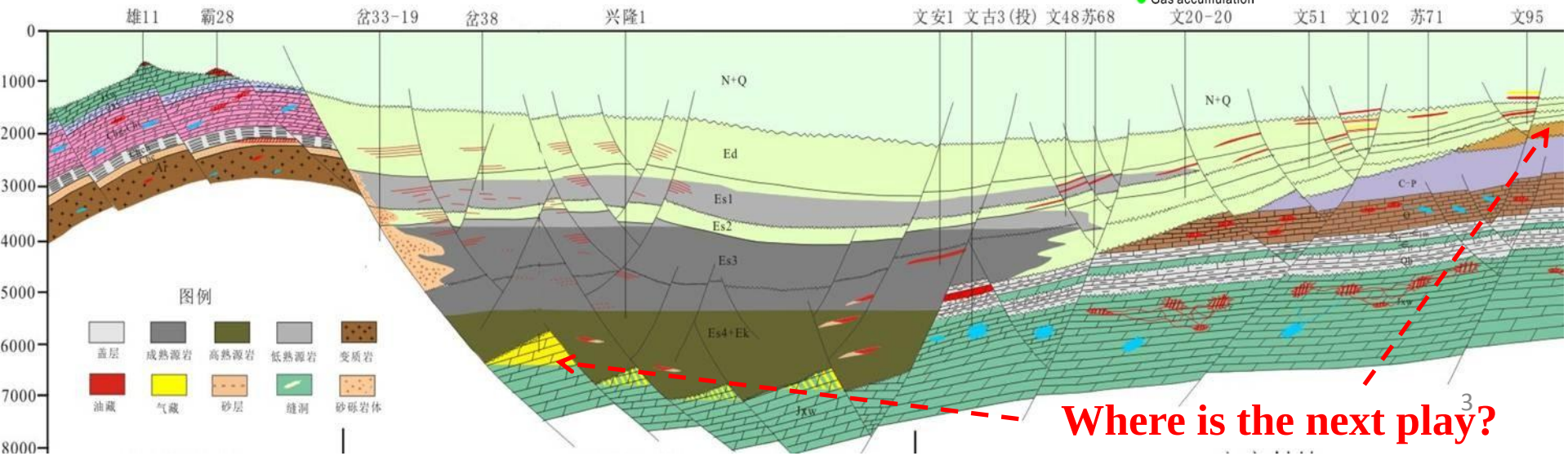
Introduction



System	Series	Formation	Member	abb.	
Quaternary		Pingyuan		Qp	
Neogene	Pliocene	Minghuazhen		Nm	●
	Miocene	Guantao		Ng	●
Paleogene	Upper Oligocene	Dongying		Ed	●
	Lower Oligocene	Shahejie	First member	Es1	● Source rock
	Upper Eocene		Second member	Es2	● ●
	Middle Eocene		Third member	Es3	● Source rock
	Lower Eocene		Fourth member	Es4	● ●
		Kongdian		Ek	● ● Source rock
Carboniferous-Permian				C-P	● ● Source rock?
Ordovician				O	● ●
Cambrian				∈	●

● Oil accumulation
● Gas accumulation

- 1.4 billion BBL oil and 0.5 TCF gas have been found
- most of discovered oil accumulations were located the depth above 3500m

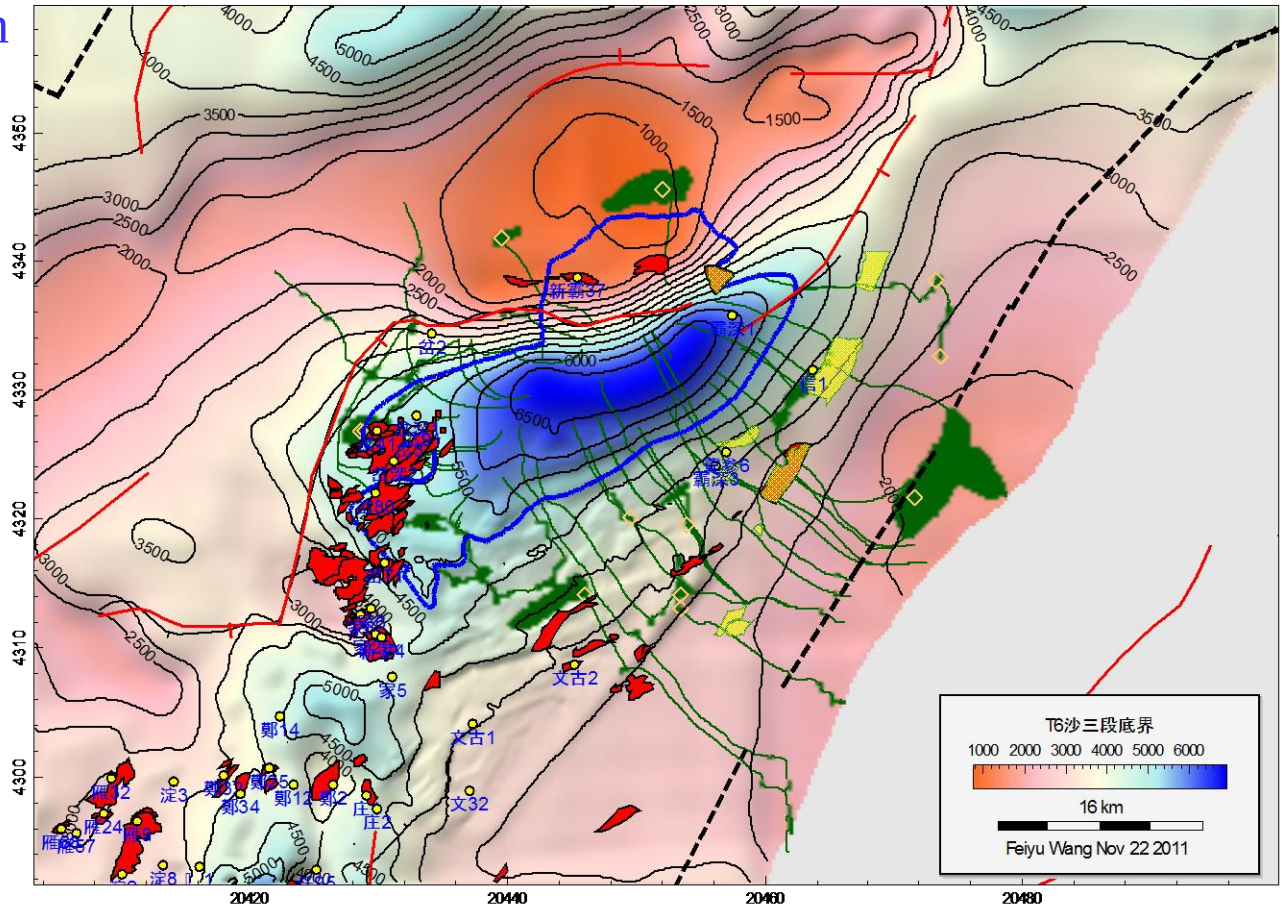


Where is the next play?

Introduction

- Compared expelled hydrocarbon from source kitchen with discovered oil accumulations:
  - The amount
  - Composition (Phase of hydrocarbon)
  - Spatial distribution

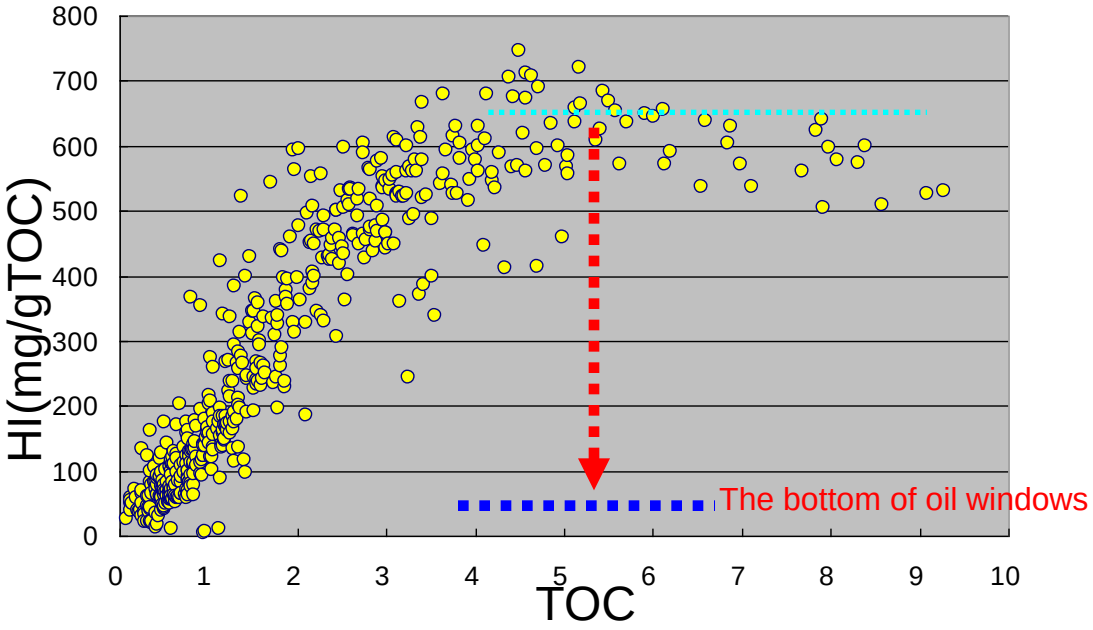
Refined Lacustrine Petroleum Systems Modeling



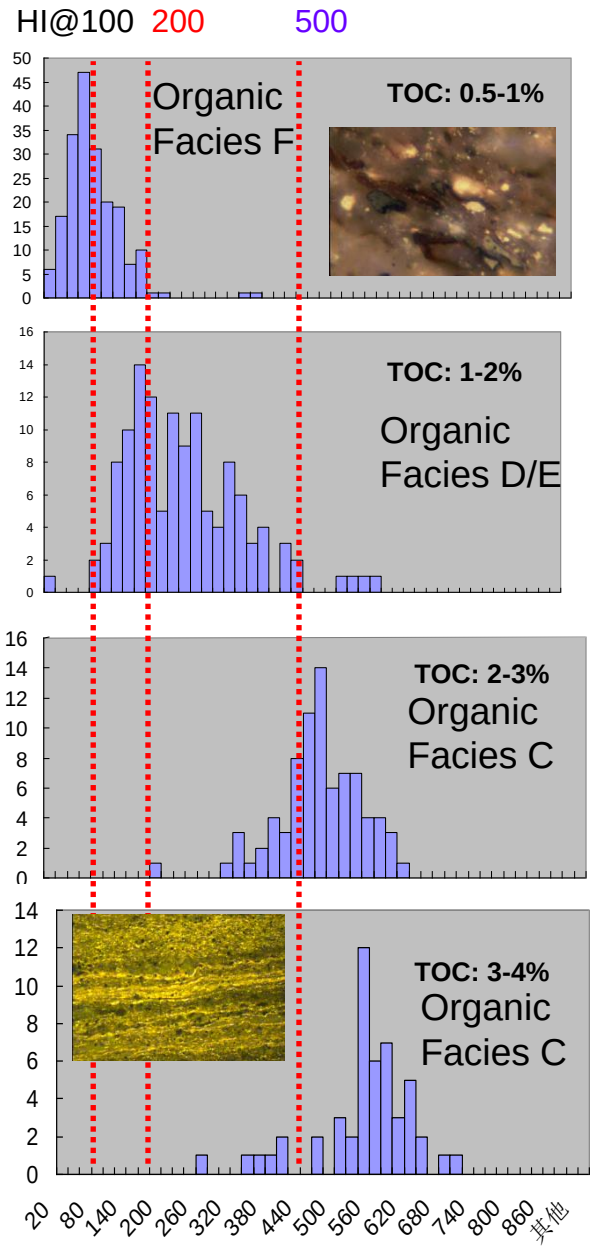
Niu-38 well Es3@ (2770～3376m) 606m source rock, 605 samples.

BHT@105-125 ℃, the early oil window stage.

- HI and TOC have a significantly positive corelation in the lacustrine source rock



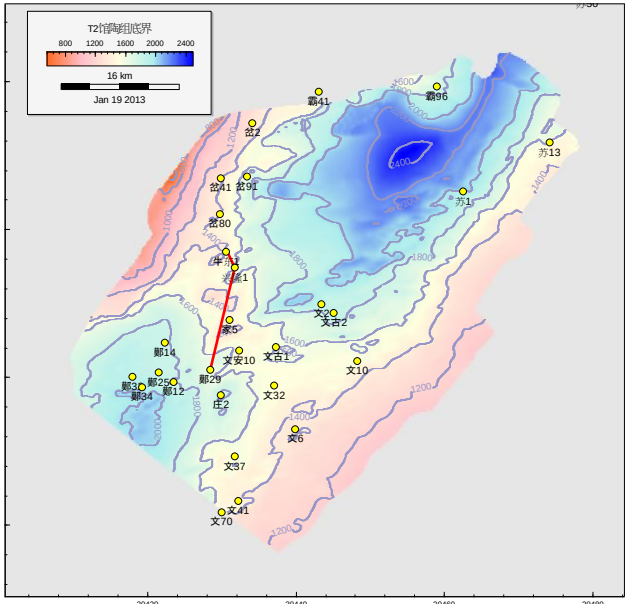
Organic Facies	TOC (%)	HIo (mg/gTOC)	A (s^{-1})	E 均值 (kJ/mol)	E 均值 (kcal/mol)	σ_E (kJ/mol)
C	> 2	650	$2.44e^{13}$	221.4	53.0	3.9
D/E	1-2	333	$4.97e^{13}$	228.2	54.6	7.9
F	0.5-1	156	$1.23e^{13}$	259.1	62.0	6.6

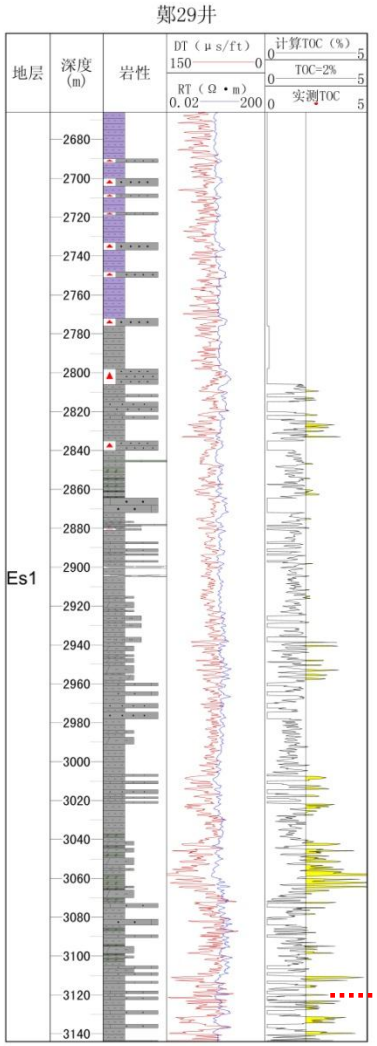


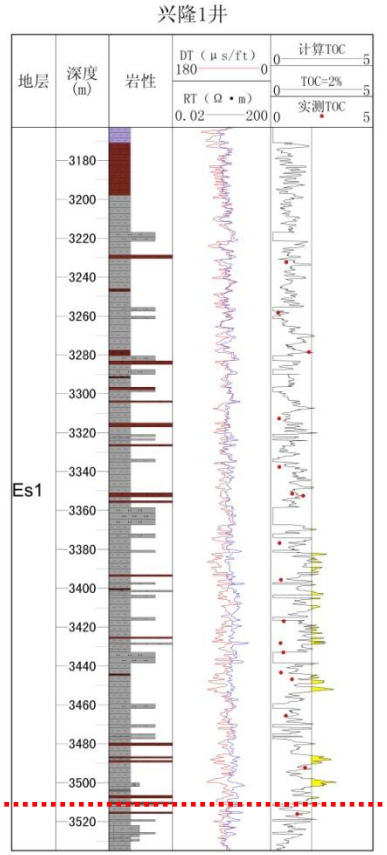
Evaluation of the different TOC source rock by well-logging

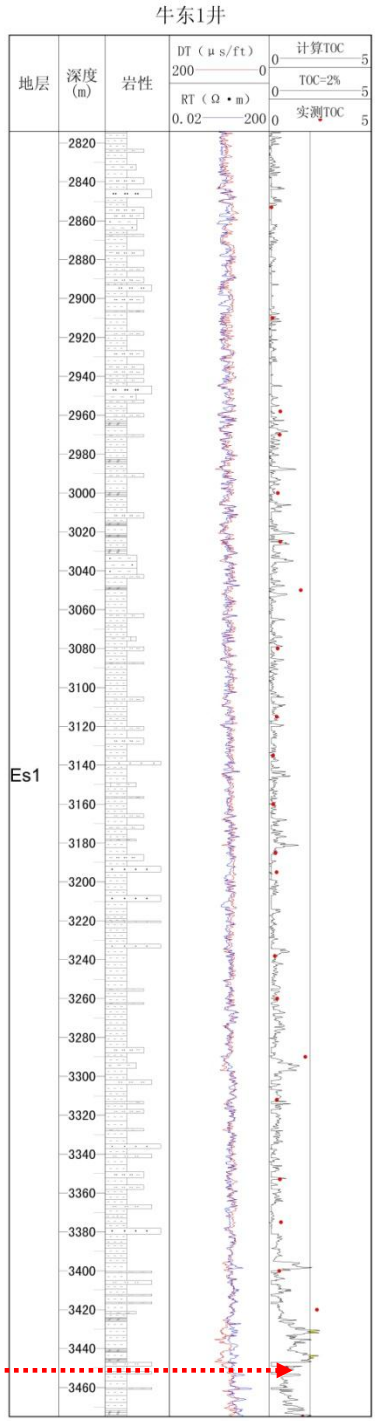
- Paleogene Shahejie Formation lacustrine source rocks :
  - Es1
  - Es3
  - Es4-Ek

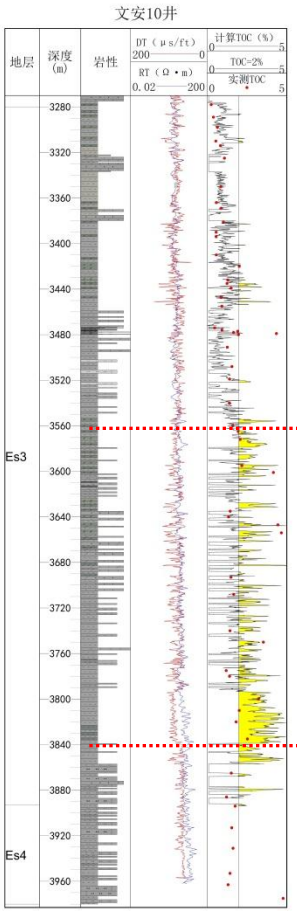
- In the Es1, the organic facies C source rock becomes gradually reduced Northward.

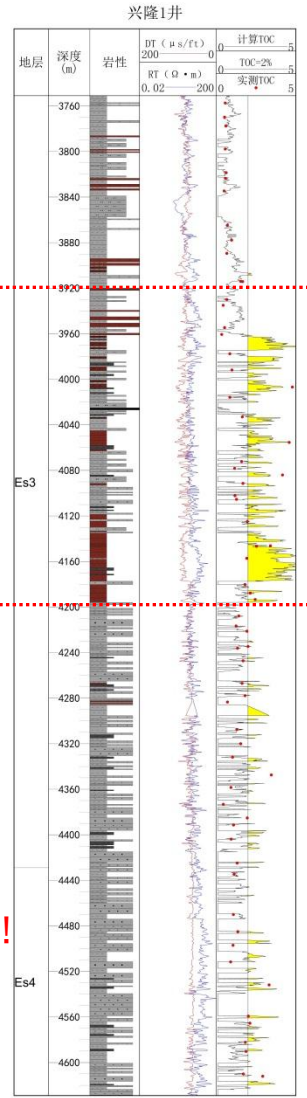


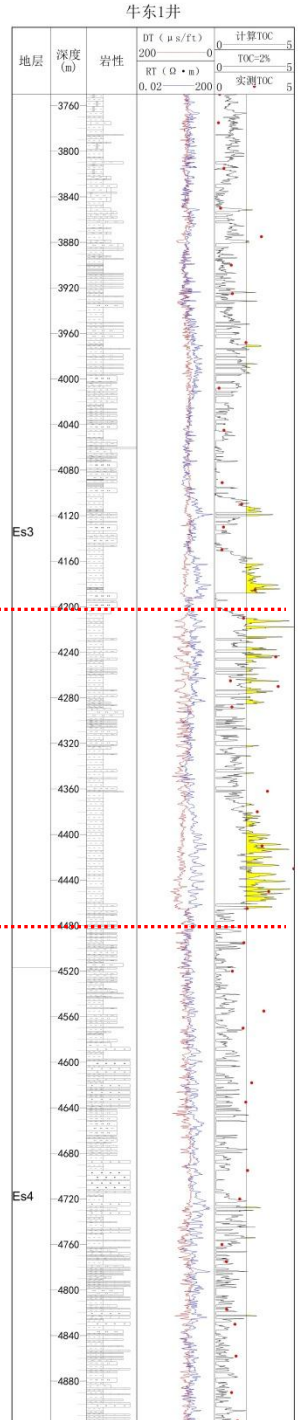






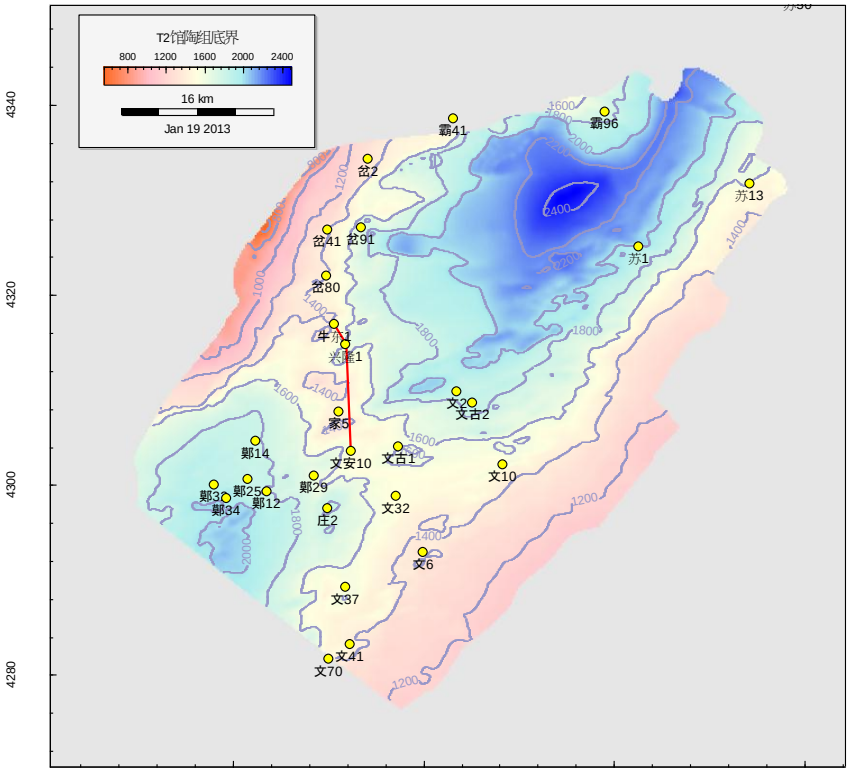






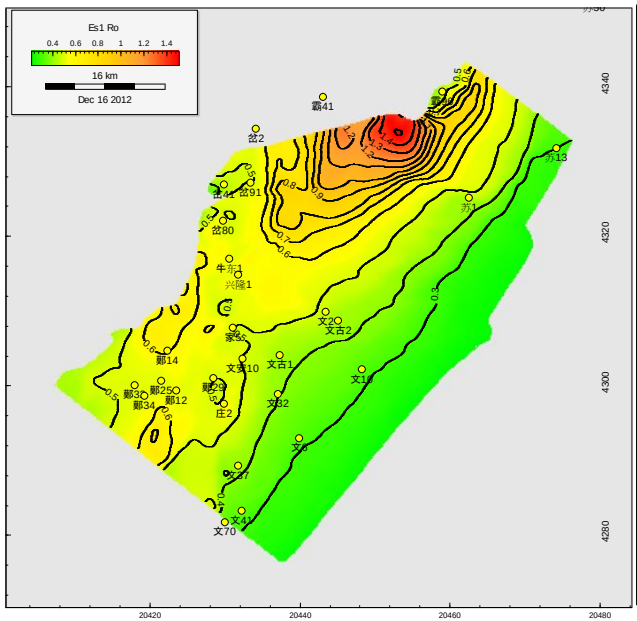
Highly heterogeneity!

- The organic facies C source rock developed mostly in Es3, and Es1 second
- In the Es4-Ek, the main types of source rock are organic facies D/E and F

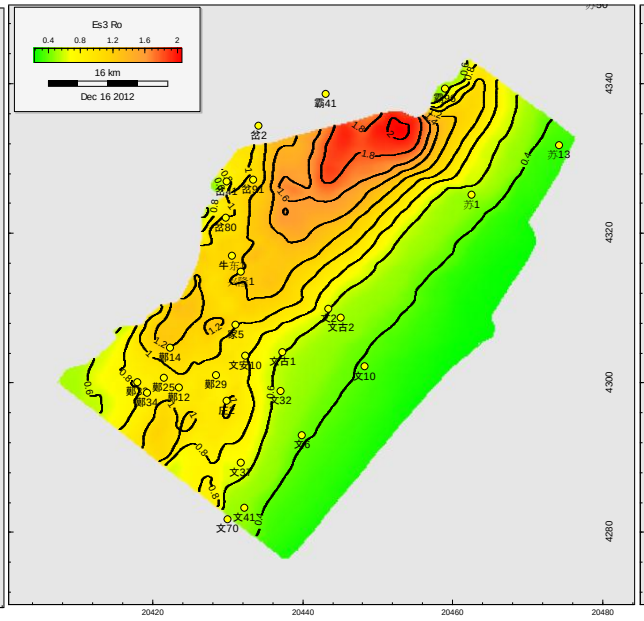


Thermal maturity of the source rock

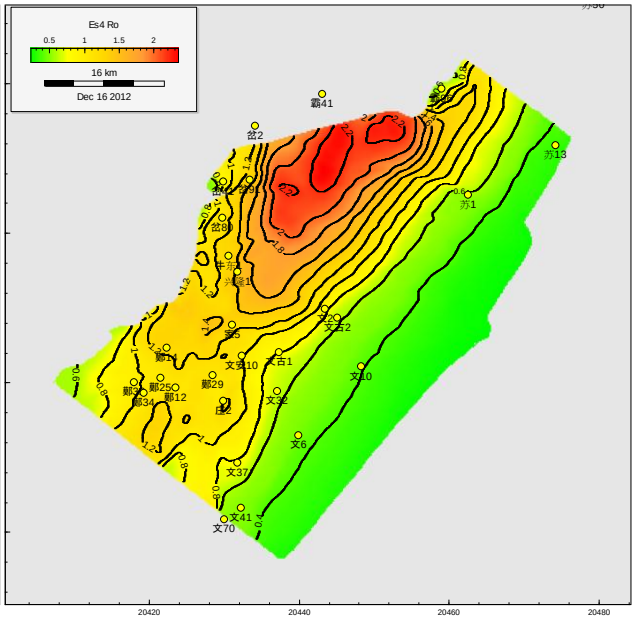
Maturity range from oil windows to overmature stage in the deep area of sag



Es1 thermal maturity
Ro 0.4~1.4



Es3 thermal maturity
Ro 0.8~2.0



Es4 thermal maturity
Ro 0.8~2.3

The hydrocarbon generation kinetics

- Five source rock samples for gold-tube pyrolysis experiments :
  - TOC>2% (Organic facies C)
  - TOC 1-2% (Organic facies D/E)
  - Coal and carbargilite (Organic facies F)

- C_{1-5}
- C_{6-14}
- C_{14+}

The parameters of oil generation kinetics of different facies source rock

No.	Organic facies	Kerogen type	HI	A (s^1)	E mean (KJ/mol)	σ_E (KJ/mol)
H1	C	Ⅰ	620	$2.44e^{13}$	220.4	4.9
H2	C	Ⅰ	575	$2.44e^{13}$	218.4	6.9
H3	D/E	Ⅱ	350	$4.97e^{13}$	225.2	7.5
H4	F	Ⅱ	145	$1.23e^{13}$	255.1	9.6
H5	D/E	Ⅱ/Ⅲ	252	$3.64e^{13}$	230.2	7.5

The parameters of gas generation kinetics of different facies source rock

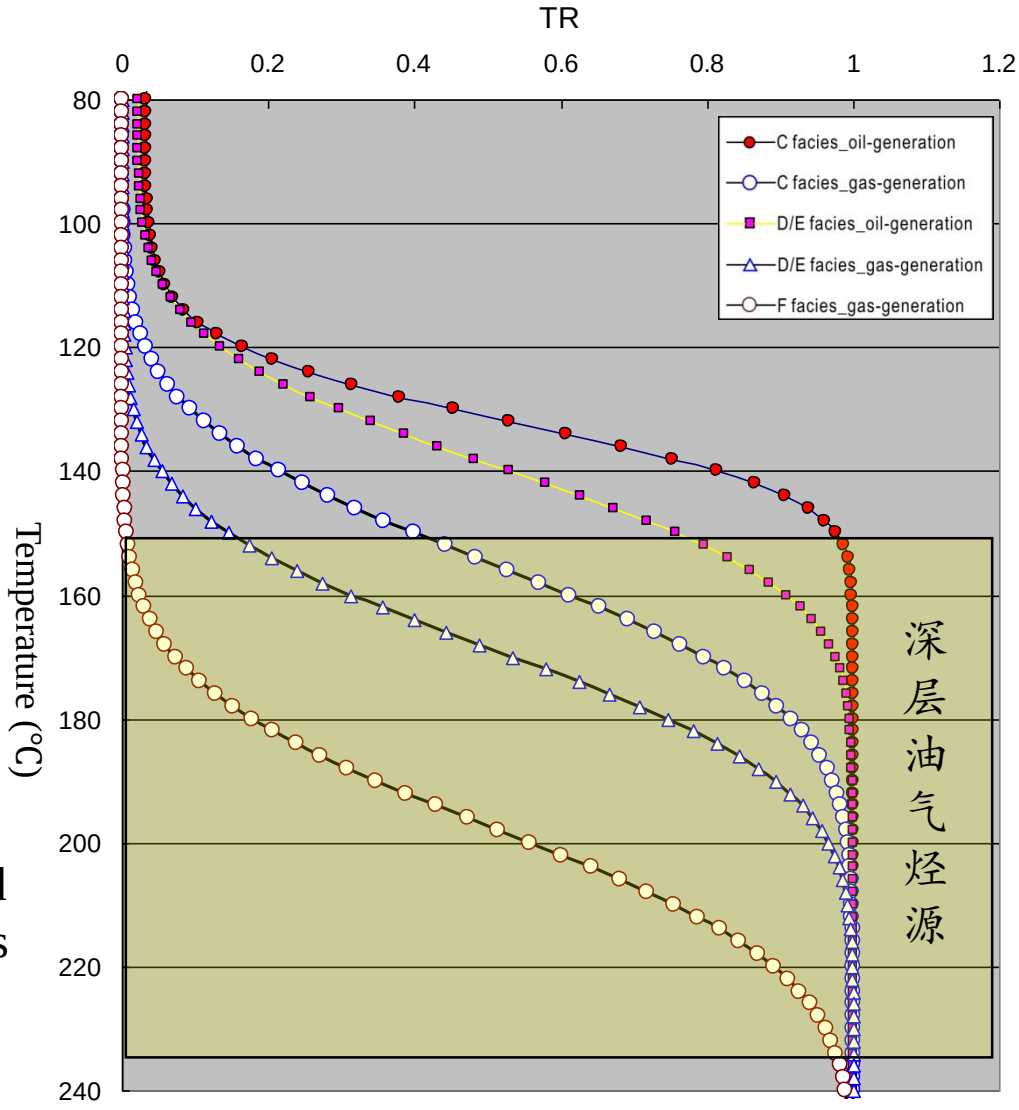
No.	Organic facies	Kerogen type	HI	A (s^1)	E mean (KJ/mol)	σ_E (KJ/mol)
H1	C	Ⅰ	620	$2.29e^{13}$	254.4	12.1
H2	C	Ⅰ	575	$2.29e^{13}$	255.4	12.5
H3	D/E	Ⅱ	350	$1.96e^{13}$	254.2	9.3
H4	F	Ⅱ	145	$1.93e^{13}$	274	15.1
H5	D/E	Ⅱ/Ⅲ	252	$1.96e^{13}$	260.2	9.3

The hydrocarbon generation kinetics

GOR, API, C_1/C_{2+}, $\sigma^{13}C$ increasing

- Organic facies C expelled oil at 110 ～120℃
- Organic facies D/E expelled oil and gas at 130 ～140℃
- Organic facies F expelled only gas at 150 ～160℃ (condensate and wet gas)

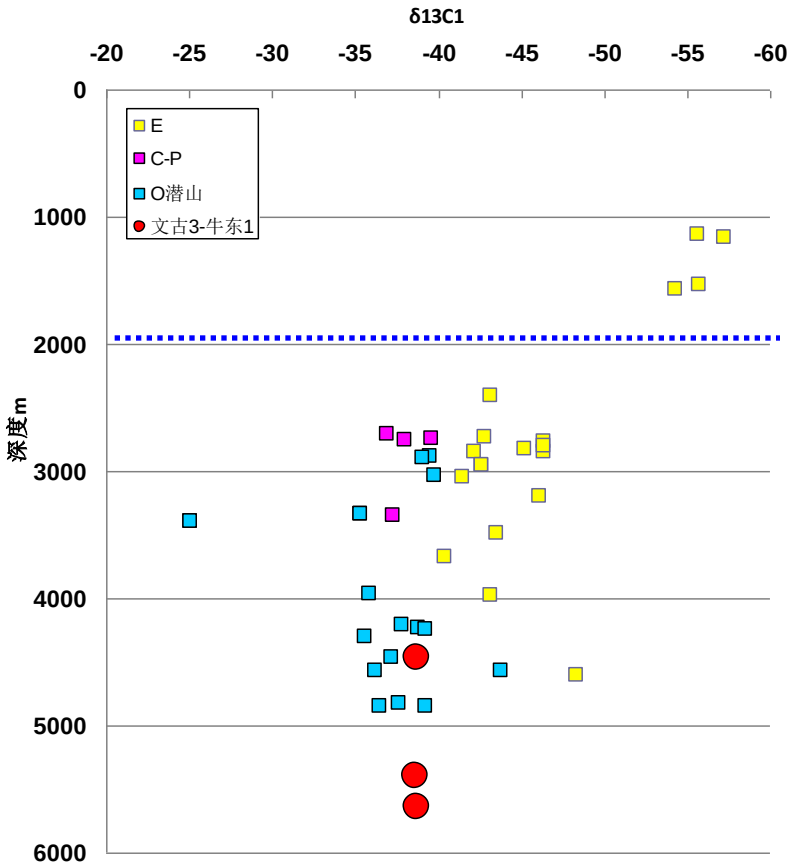
- The earlier expelled hydrocarbon should be accumulated in the shallow reservoirs
- The latter ones should be in the deeper reservoirs!

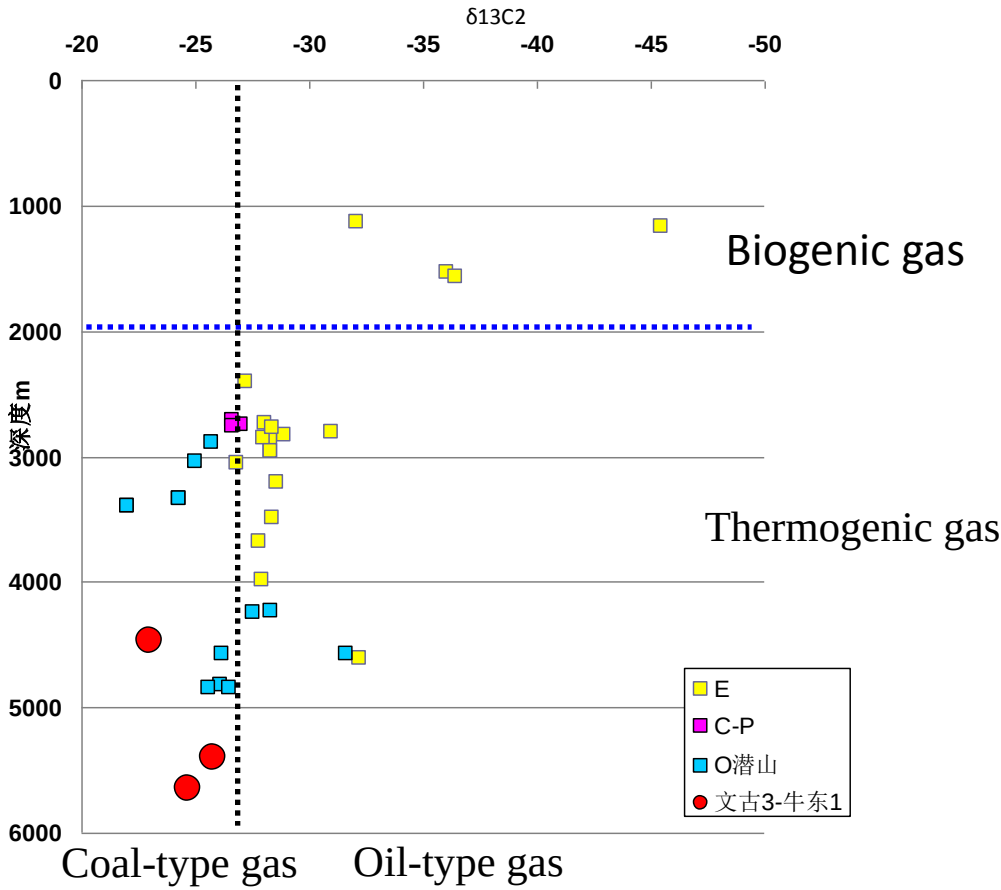


The origin of natural gas

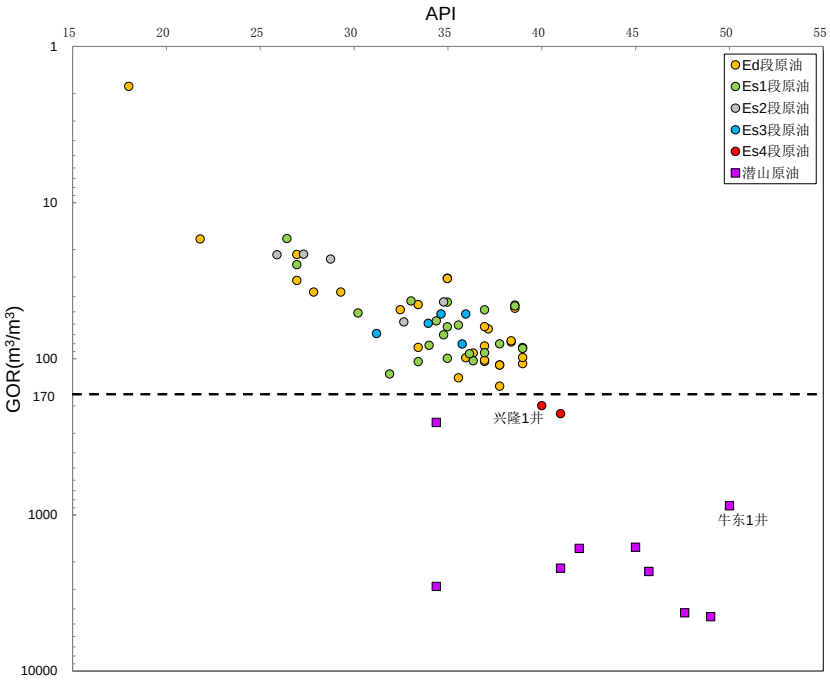
Depth increasing

- Shallower biogenic gas
- Oil-type gas
- deeper coal-type gas (derive from D/E and F facies source rock)



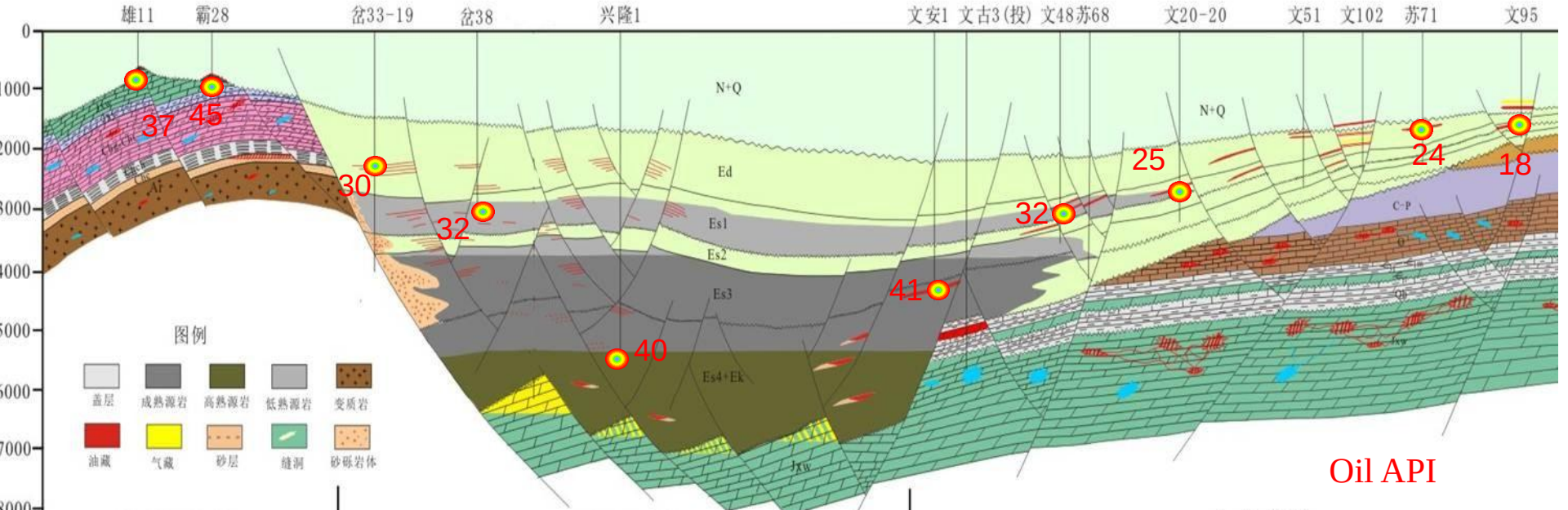


oil-source rock correlation

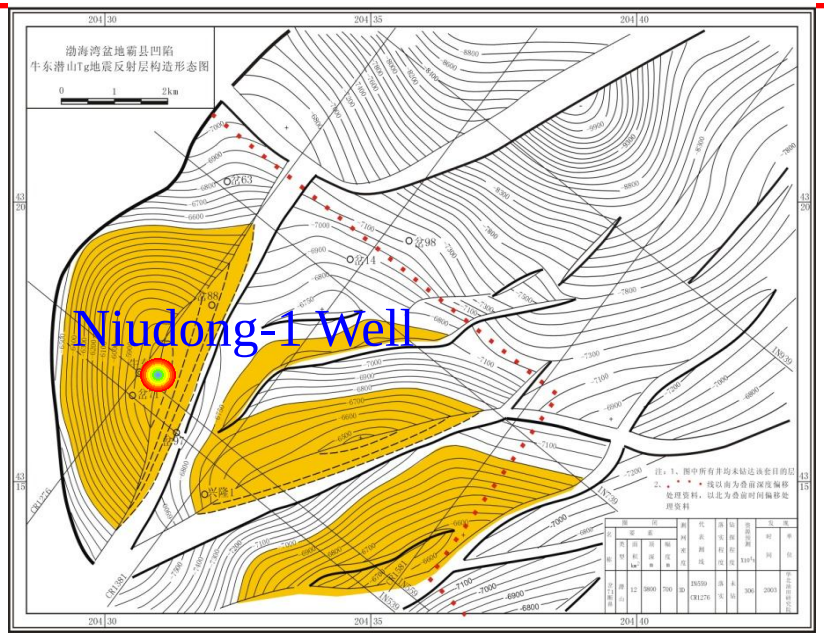


According to the physical nature of the oil (API and GOR), divided which into two categories:

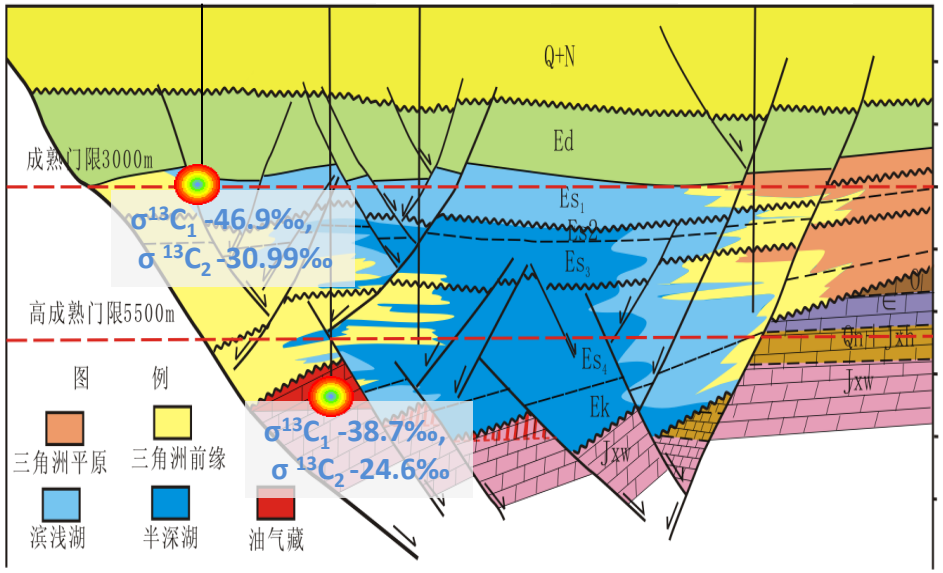
- shallow accumulations (Ng-Es3)
- deeper accumulations (buried hill, Es4 and C-P)



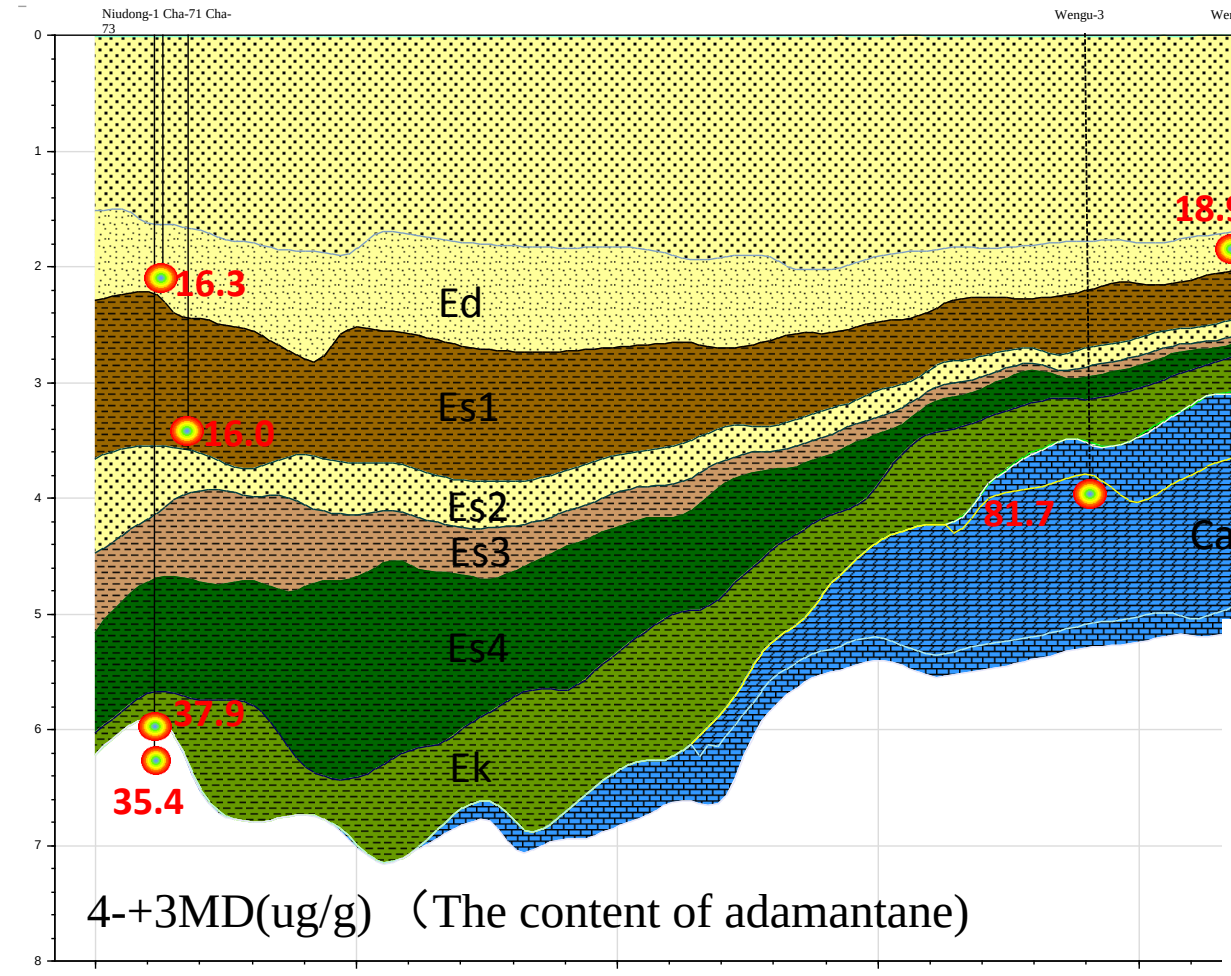
Niudong-1 Well

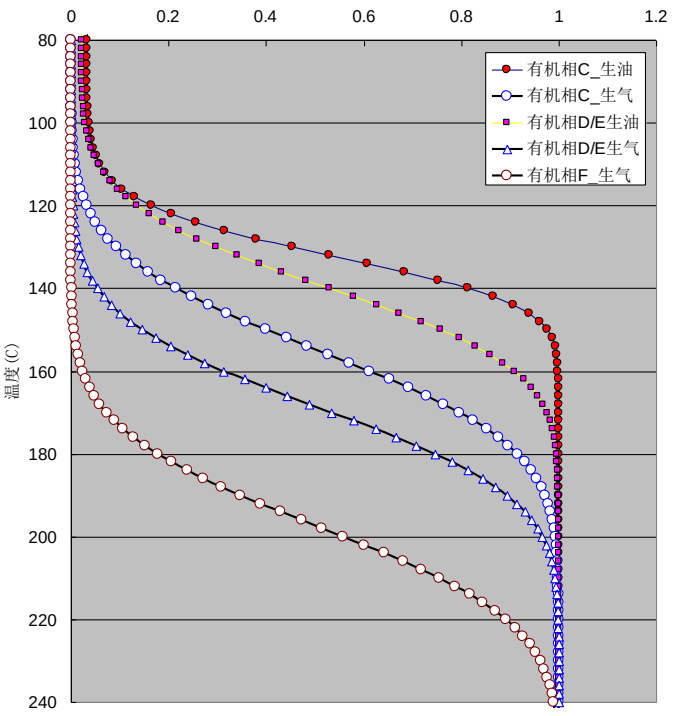


Cha-33 Niudong-1 Xinglong-1 Wenan-1



- Niudong-1 Well have been successfully drilled and found a super-deep carbonate buried hill condensate gas reservoirs in the Mesoproterozoic Wumishan Formation, with the bottom depth about 6500m (BHT@201℃) and GOR about 875m^3/m^3 , API@50
- Oil 4043.4 bbl/day; Gas 0.02 bcf/day.

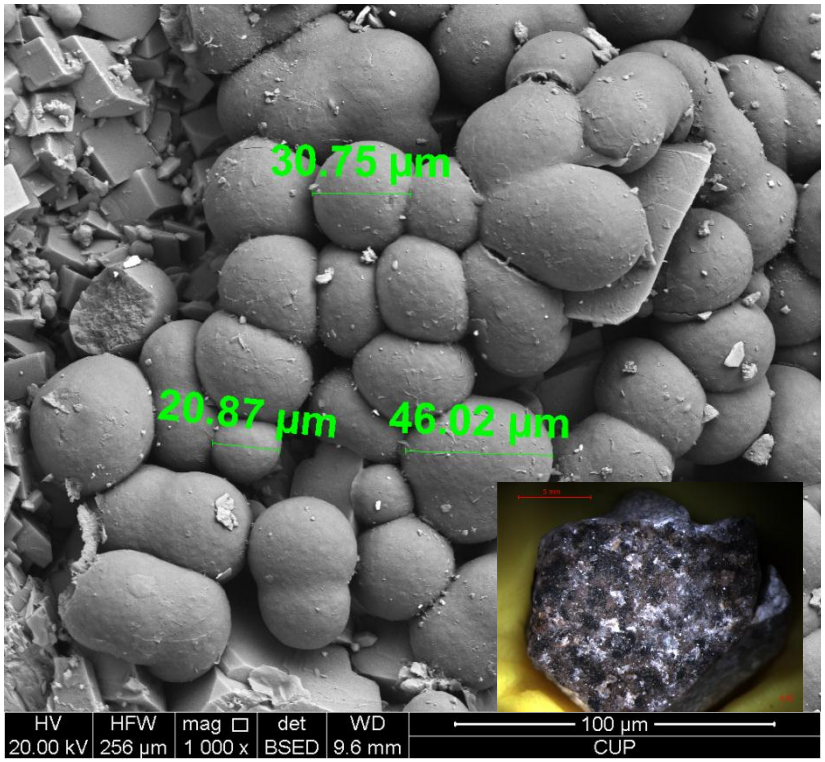


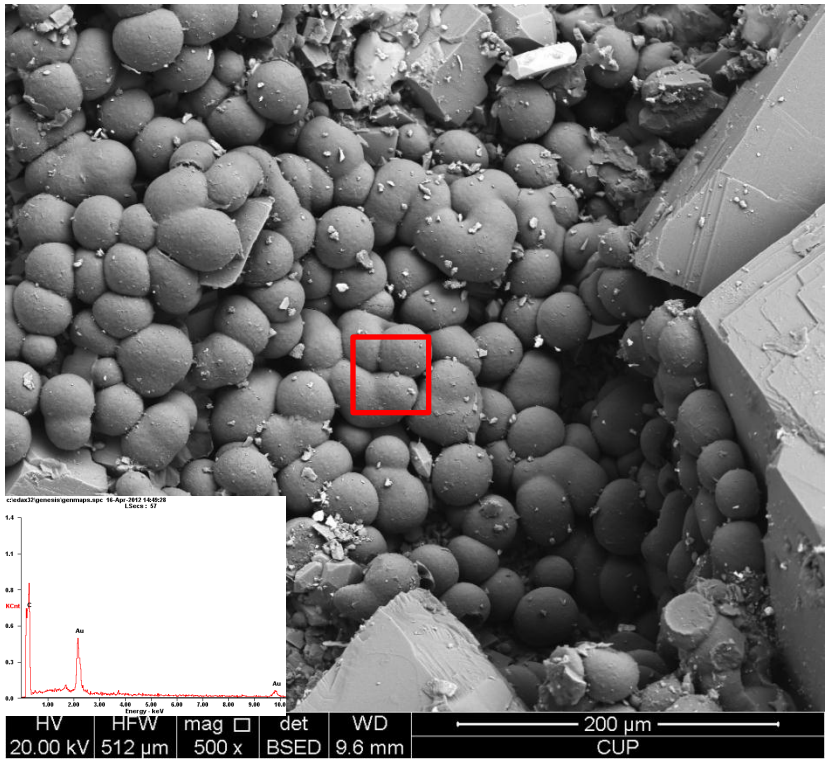


- There are two stages of hydrocarbon charge in Niudong-1 well：
  - The former stage of oil charge has lower GOR
  - The latter stage of hydrocarbon is mainly gas and condensation- gas
  - The former stage of oil charge was displaced to the shollower by the latter hydrocarbon

Symbol of gas accumulations forming under high temperature conditions

- **Pyrolytic carbon or Peloid interphase?**
  - Gaseous hydrocarbon was converted to pyrolytic carbon during pyrolysis
  - Liquid hydrocarbon was converted to peloid interphase during pyrolysis
  - Pyrolytic carbon is produced by Chemical vapor deposition
    - Chemical vapor deposition (CVD) is a chemical process in which reactants react in gaseous condition, and the solid productions deposited on the surface of heating solid matrix





Conclusions

- The shallow accumulations with low API and GOR derived from Es3 and Es1 oil-prone source rock (C facies), and the oil deriving from which is expelled in the early oil windows stage
- The deep buried hills charged with condensate and wet gas is generated in the high temperature stage
- The hydrocarbon from gas-prone source rock (D/E and F facies) is highly efficiently accumulated in deep buried hills
- The next plays are deeper reservoir witch adjacent to source kitchen and distal end of slope area