Geochemical Characteristics and Estimation of Gas Content of the Low-Middle Mature Continental Shales: A Case Study from the Ordos Basin*

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Abstract

Widespread continental shales are the primary source rocks for the large-sized oil fields in middle and eastern China, where conventional oil production accounts for more than two thirds of total petroleum production in China. With the success of the shale gas development in the USA, China's oil industry naturally turns their eyes on the continental shales in middle and eastern China. These shales are characterized by high clay mineral content, rich organic matter abundance, and are presently still in the oil to wet gas windows and are relatively less thermal mature than those thermogeous gas shales already successively developed successively in the United States. Kerogen in that thermal maturity stage is not supposed to generate gas in large amount. In reality, some vertical wells were drilled recently in the continental shales in the Ordos Basin and produced up to 3,000 m^3 per day by fracturing, which shows significant gas resource potential, reminding us to re-examining the gas generation mode and potential in low thermal mature continental shale.

The Rock Eval (RE) pyrolysis is employed to study geochemistry of deep lacustrine shale samples from Chang-7 and Chang-9 Member of the Triassic Yanchang Formation in the southeastern part of the Ordos Basin. The results show that clay minerals account for 40% to 60% of the whole mineral composition. Vitrinite reflectance values range from 0.7% to 1.5%. Kerogen being predominantly Type II-III and an organic abundance (TOC value) averages 1.5% to 4%. Isotope data shows the gas in the Chang-7 and Chang-9 member is thermogenic in origin and appears to be cogenerated with oil. Gas content amounts to 3.62m^3/t to 5.97m^3/t, in which gas absorbed ranges from 46.8% to 55.2%. Oil volume retained in the shale ranges from 5.5 to 7.5 kg/t. Heating and pressing simulation experiments are carried out to examine the evolution of organic matter and its product, which provide mode and key parameters for predicting shale gas and oil resources and evaluate their possible producing ability.

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Question

well LP177, a vertical drill in continental shale in Ordos, produce gas up to 3000 m^3/d with fracturing, what origin is that gas? Is that viable for commercial development?

Organic matter is in the oil-wet gas window, according to Tissot hydrocarbon generation mode(1984): during that stage, oil is major product and gas is little,

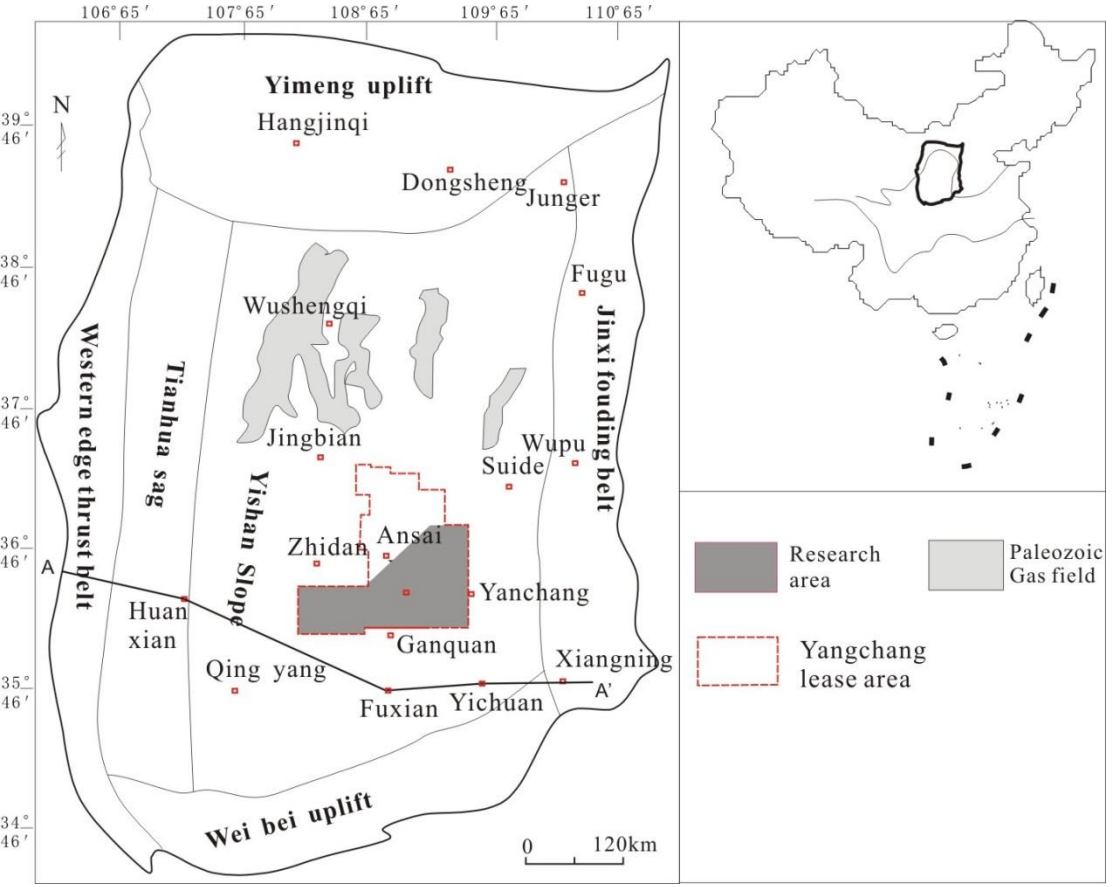
(1) Is that true in Ordos Basin?

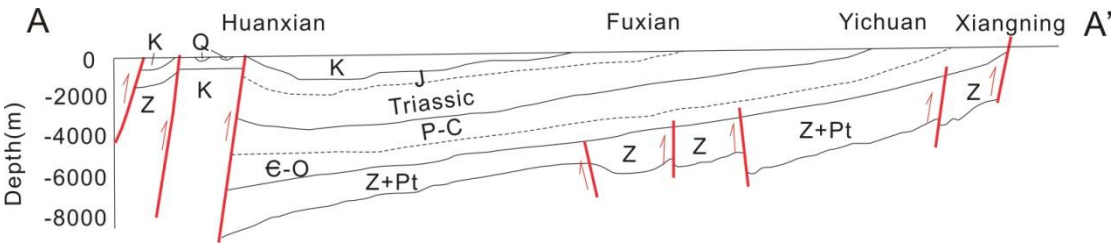
(2) How to estimate hydrocarbon resource retained within shale?

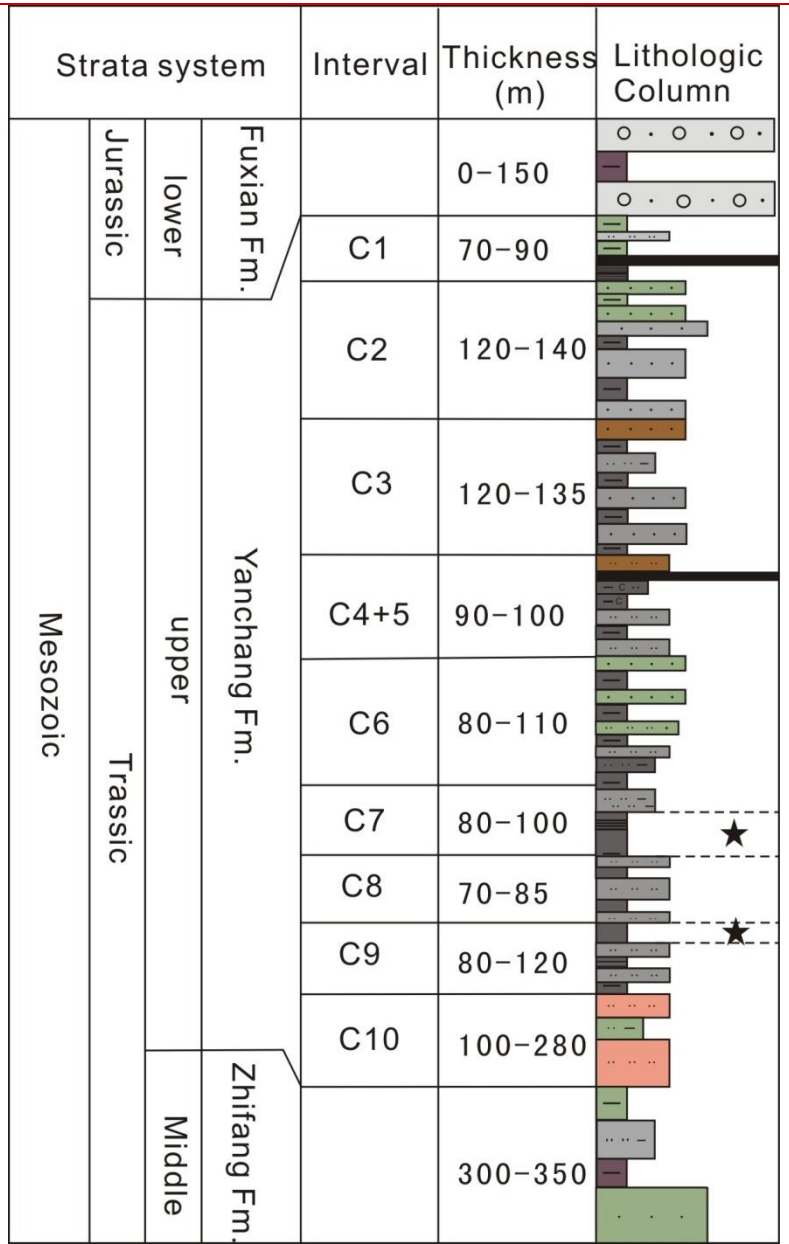
Outline

1. Geological Setting
2. Continental Shale Geochemical Characteristics
3. Gas Content and Hydrocarbon proportion
4. Summary

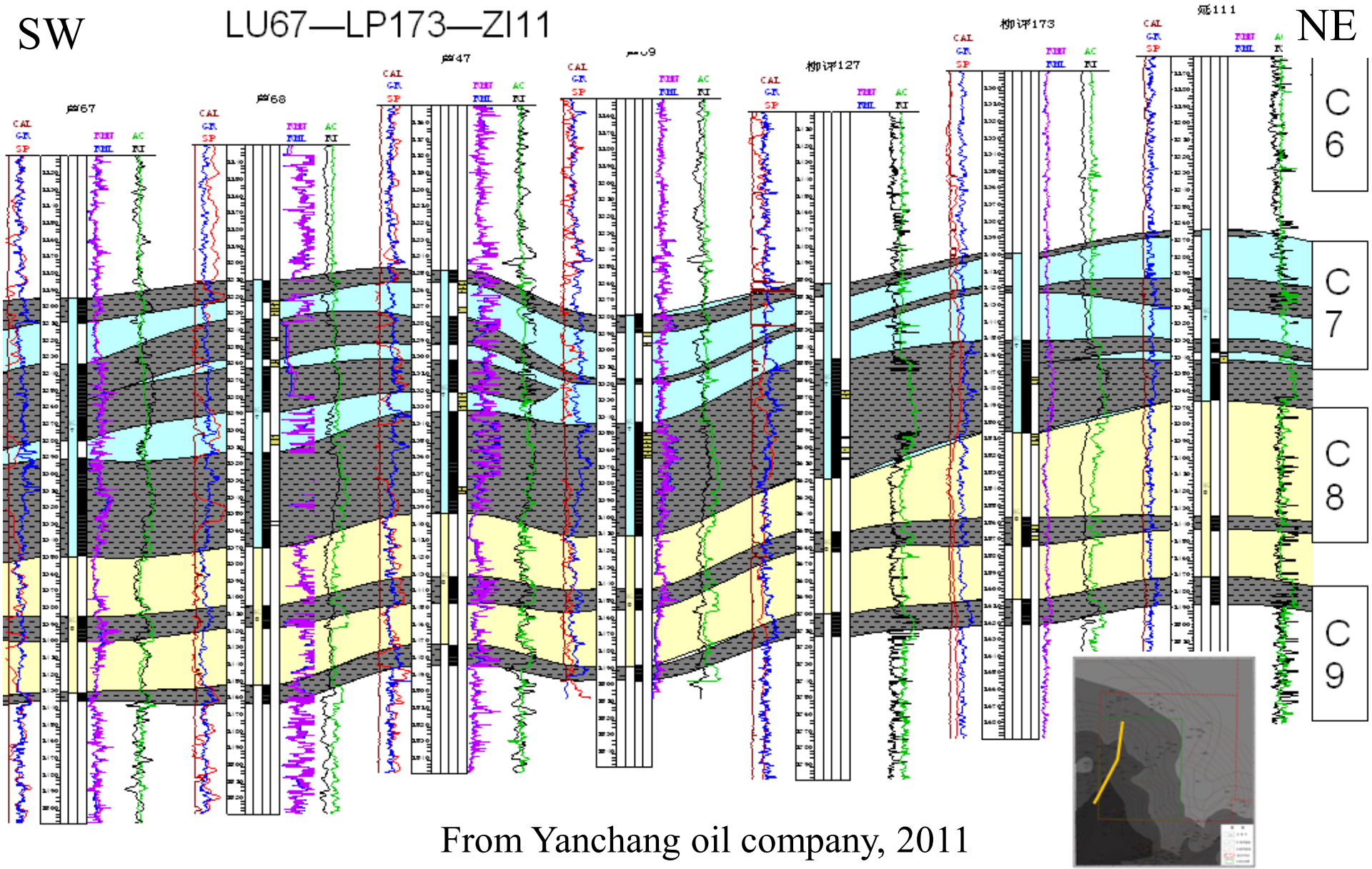
Geological Setting







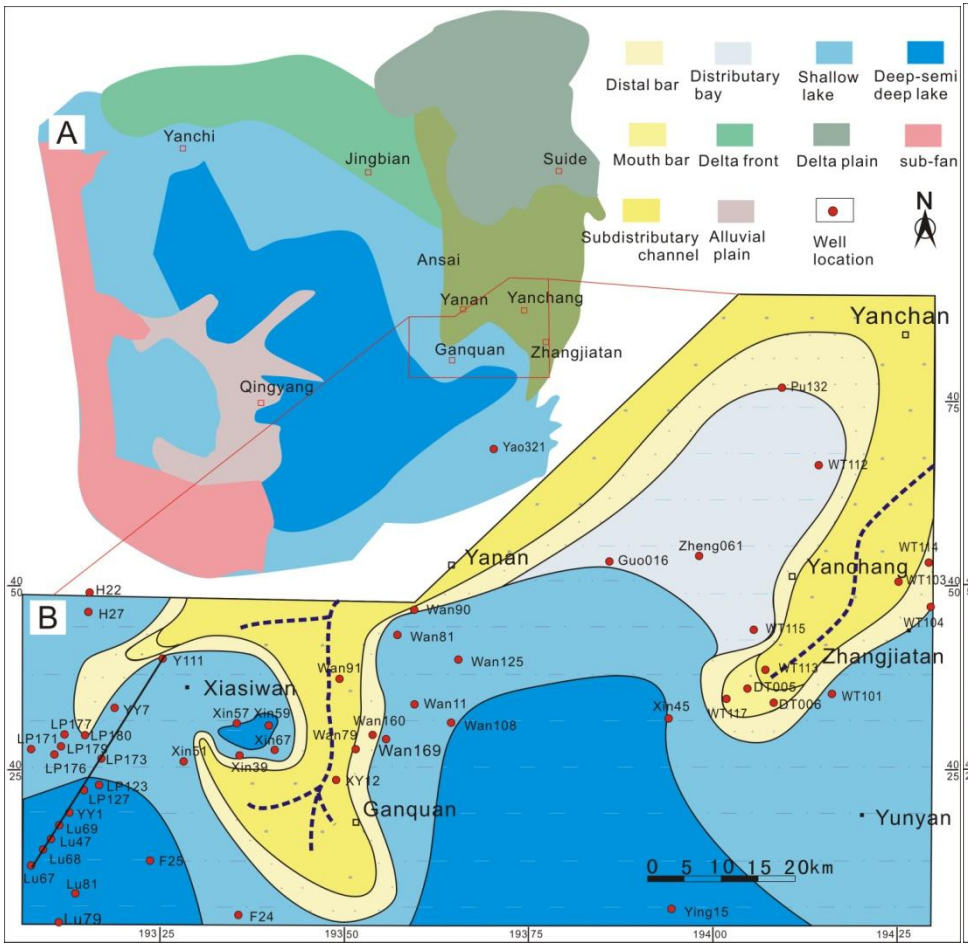
Lacustrine Shale Spatial Distribution



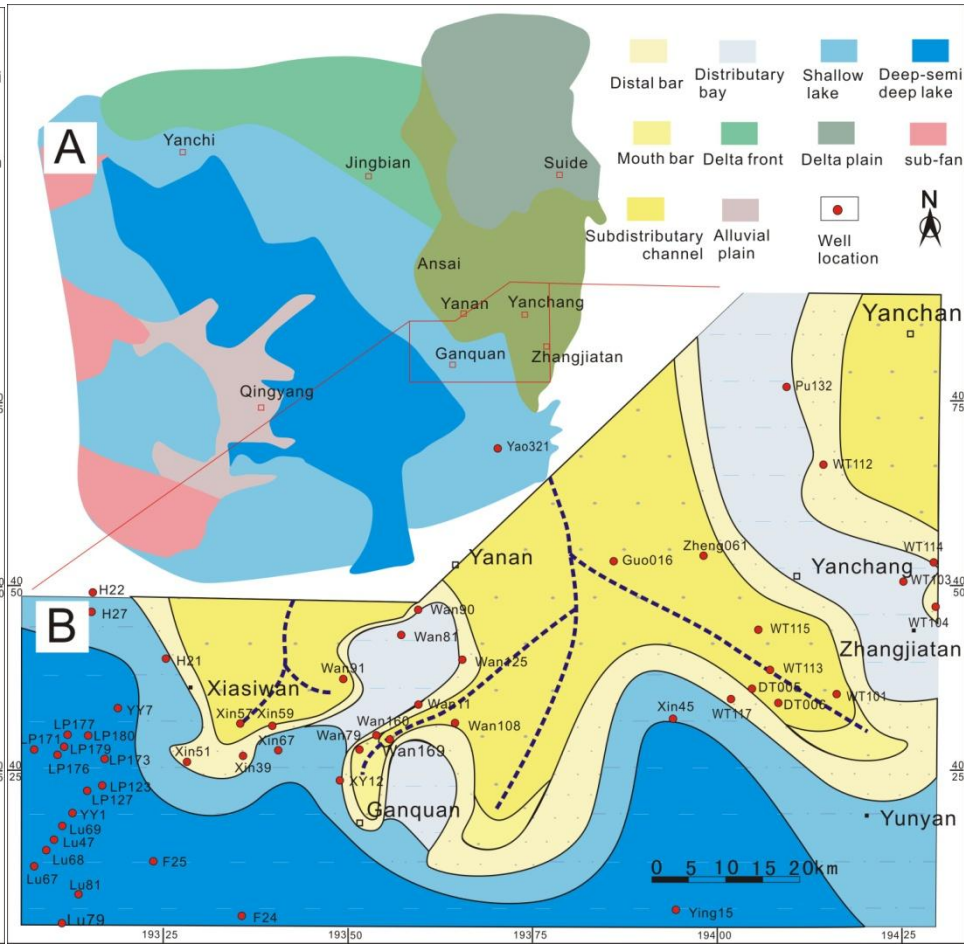
From Yanchang oil company, 2011

Depositional environment

C9 sedimentary facies



C7 sedimentary facies



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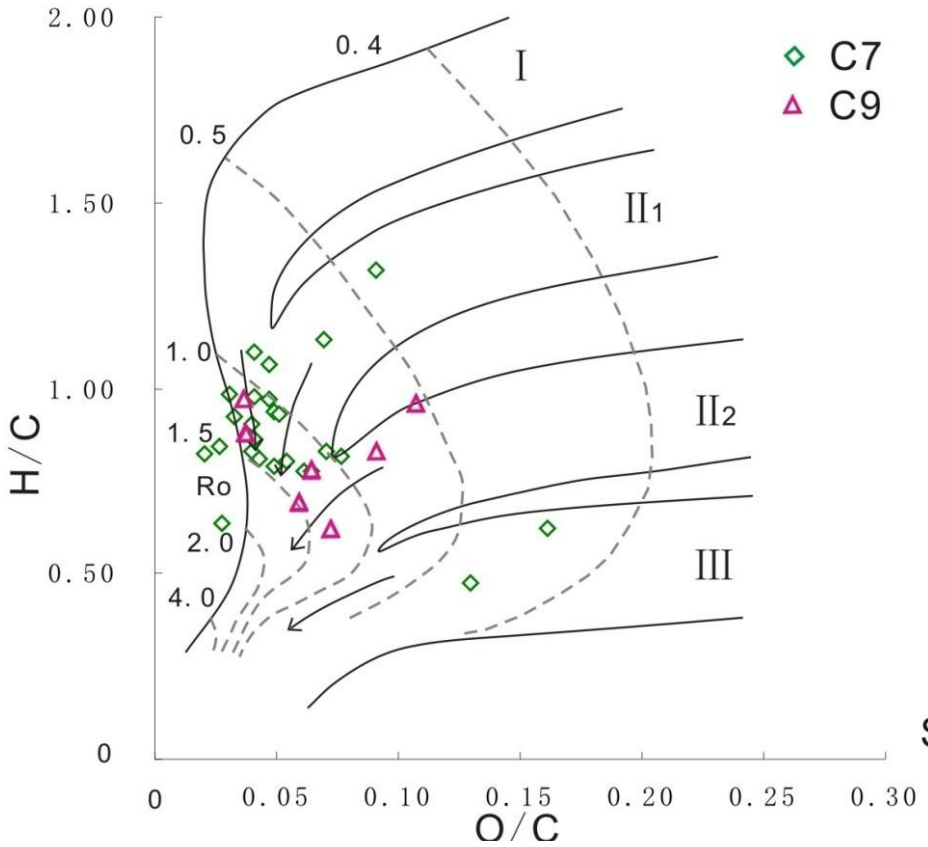
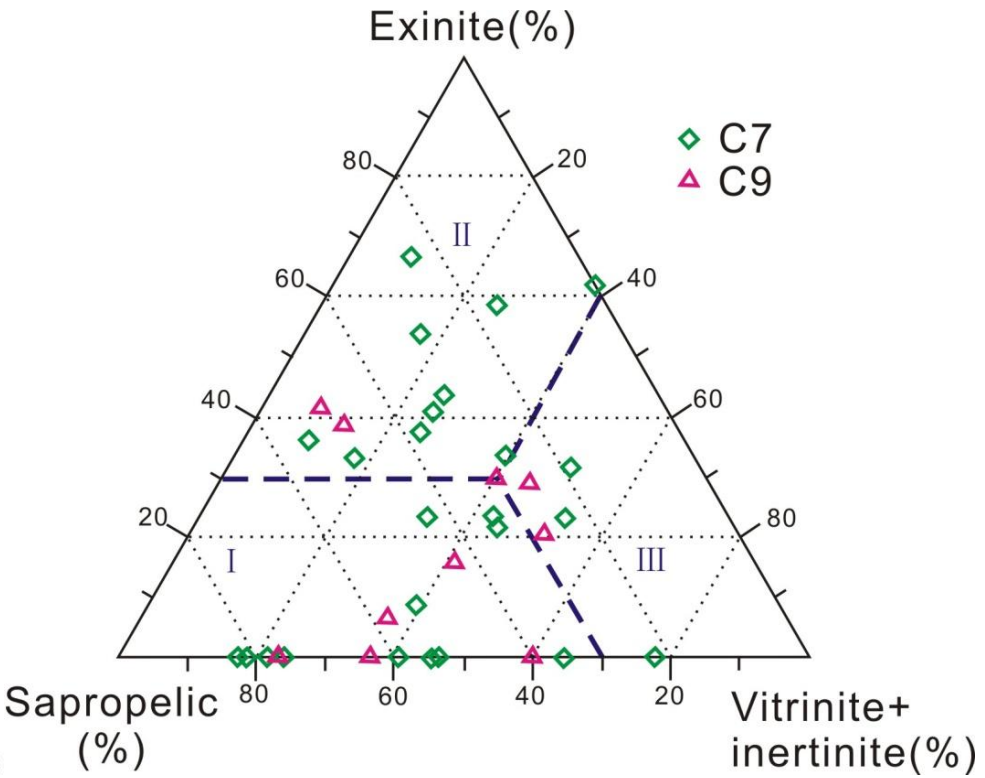
Geochemical characteristics

Kerogen type





Kerogen type: Ⅱ1-Ⅱ2

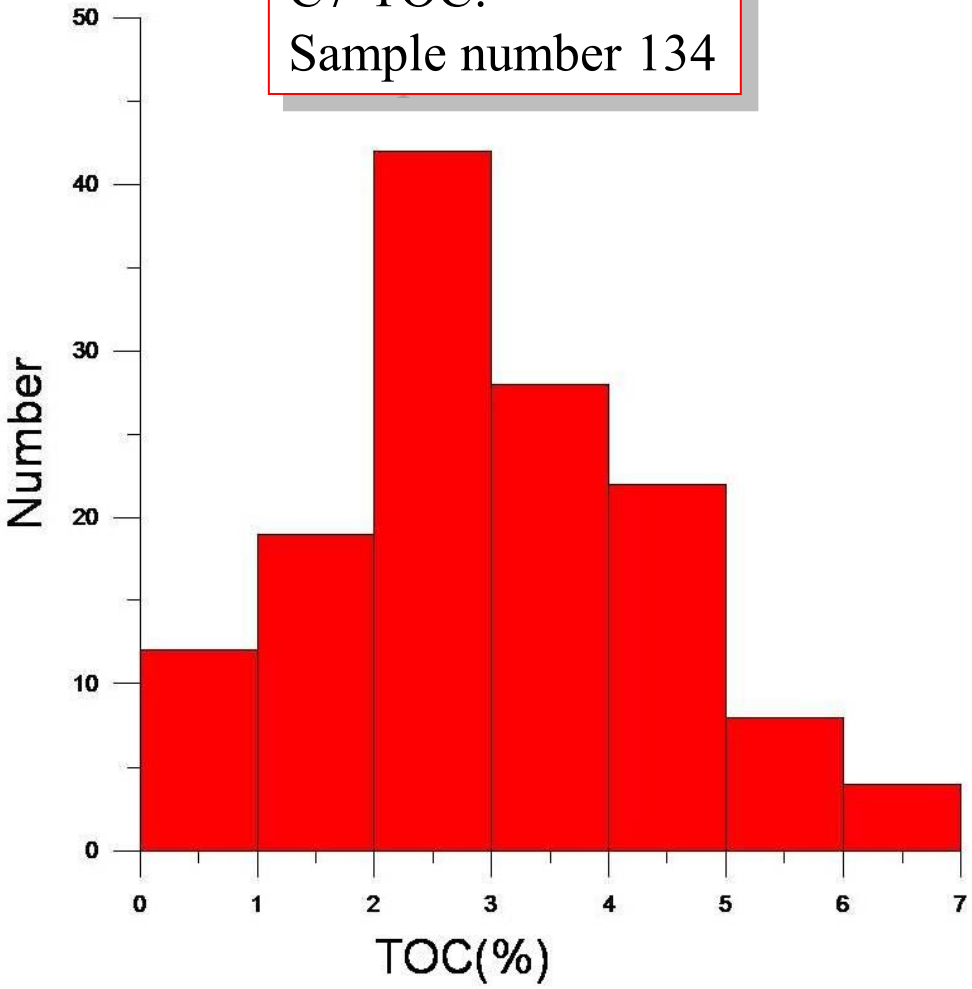
Vitrinite reflectance (Ro) ranging

0.5%-1.5%, mostly 0.8-1.5%

Kerogen type: Ⅰ-Ⅱ mostly

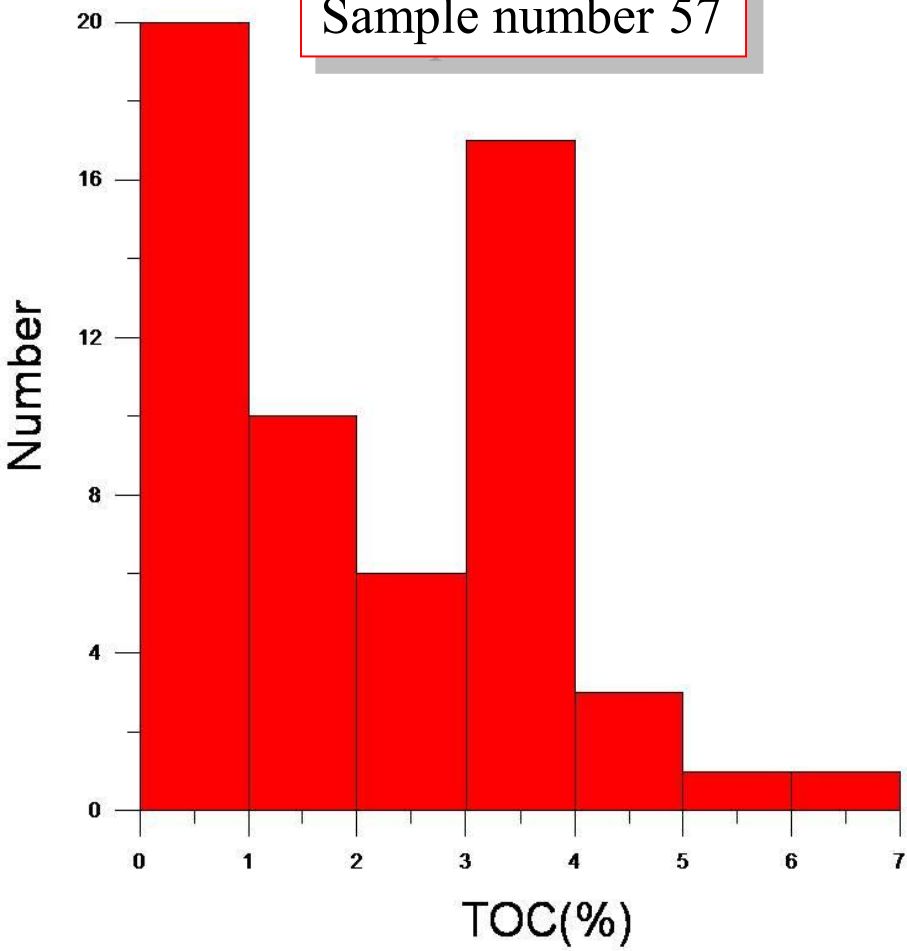
TOC Content

C7-TOC:
Sample number 134

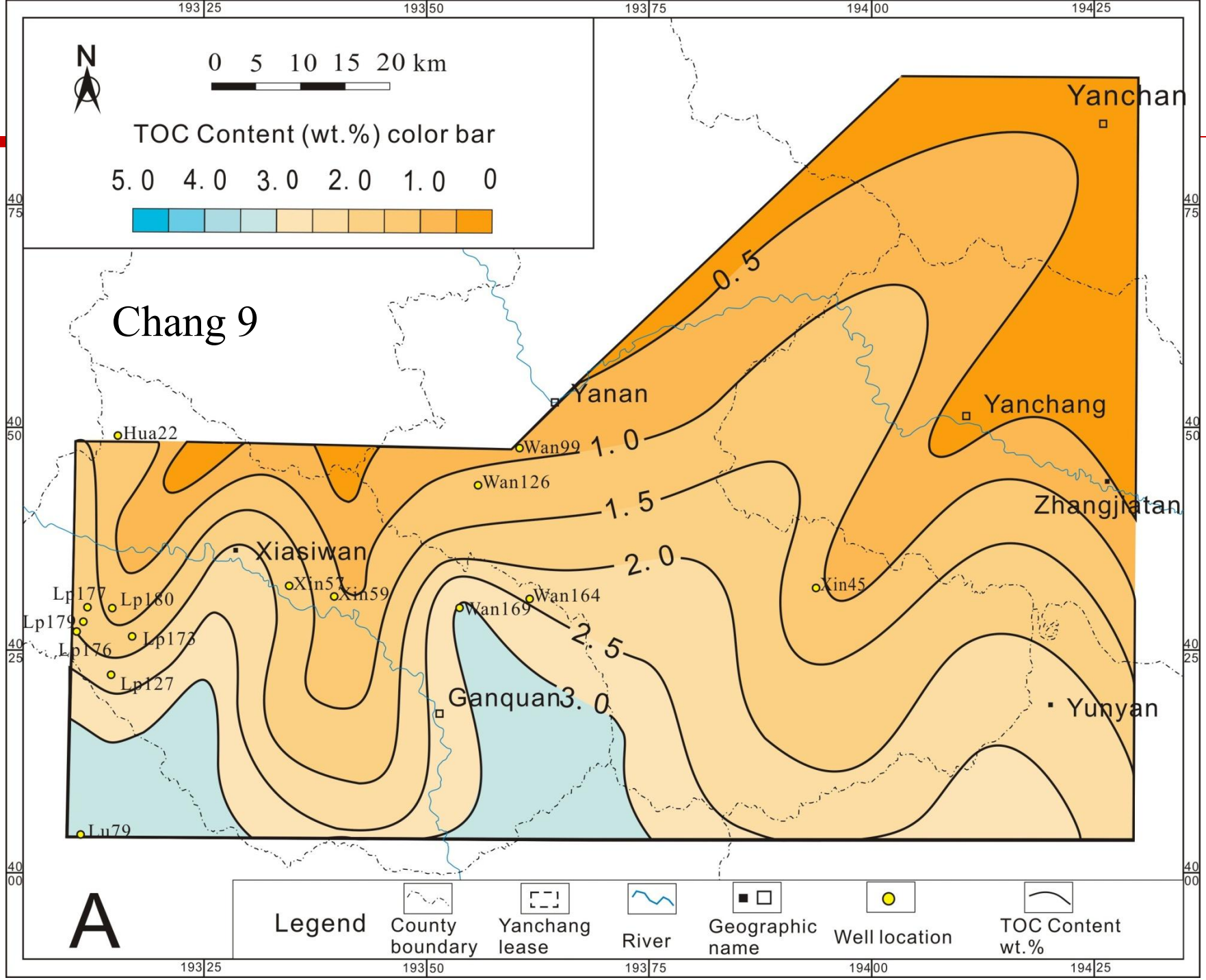


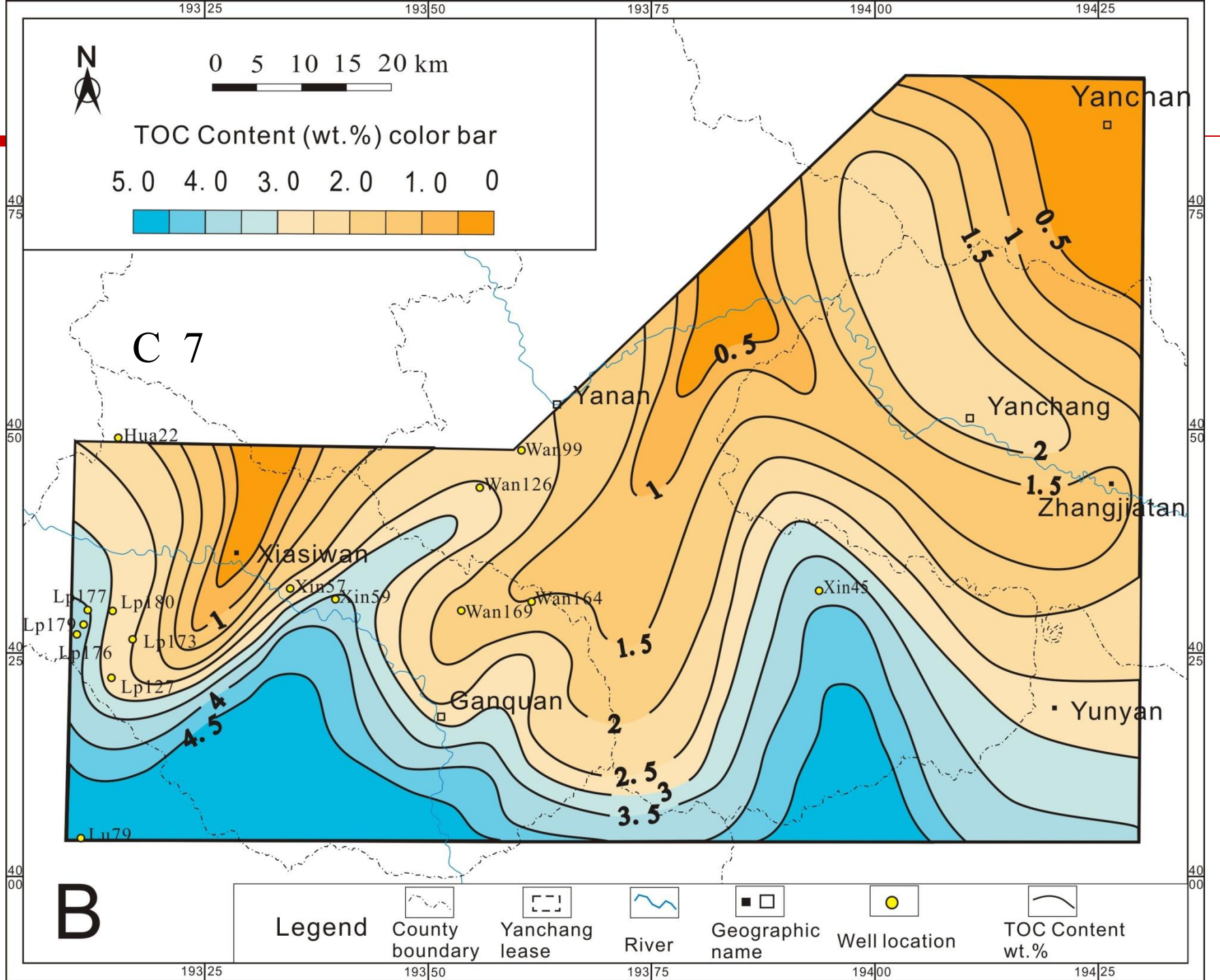
TOC content concentrate around 2-5%

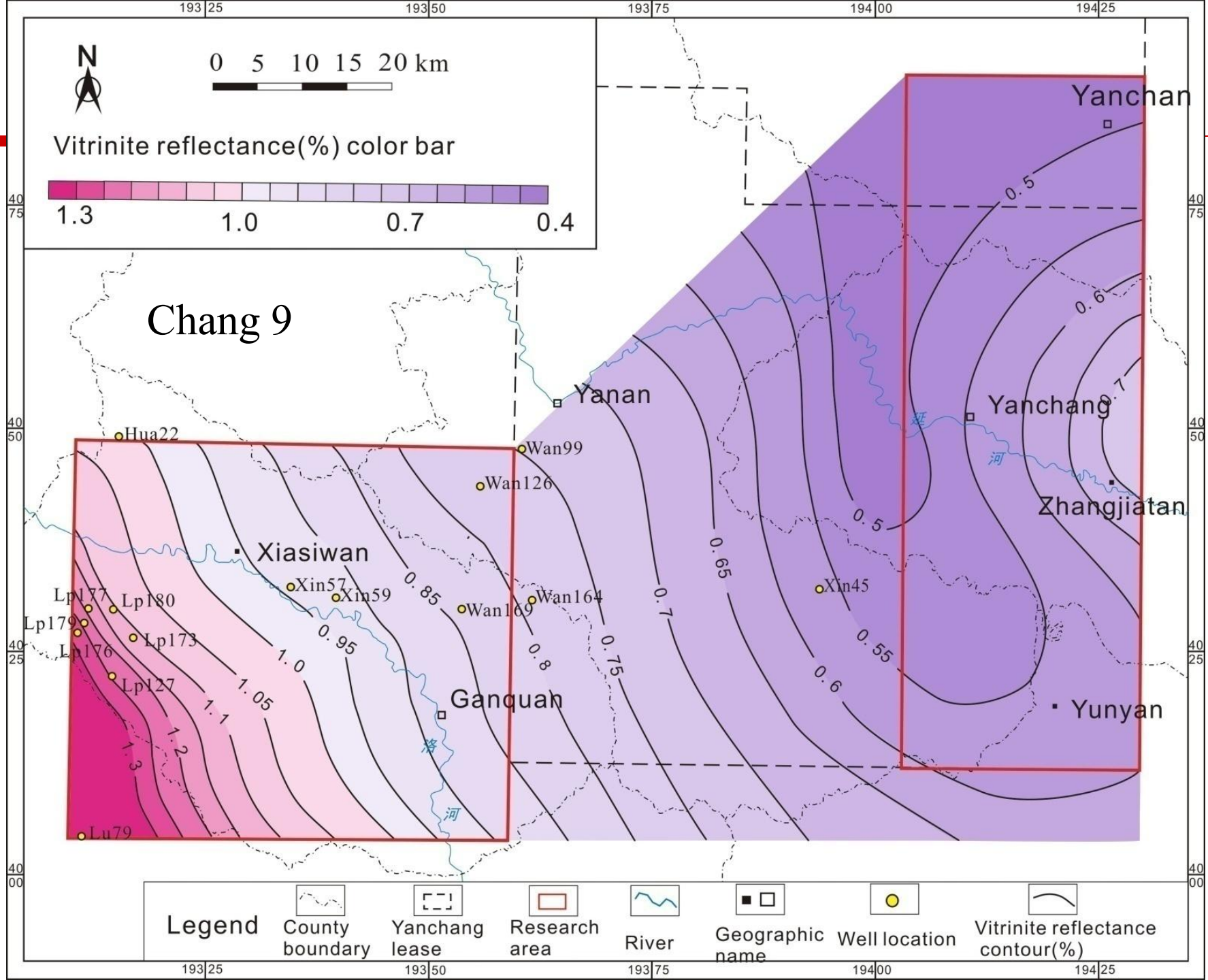
C9-TOC :
Sample number 57

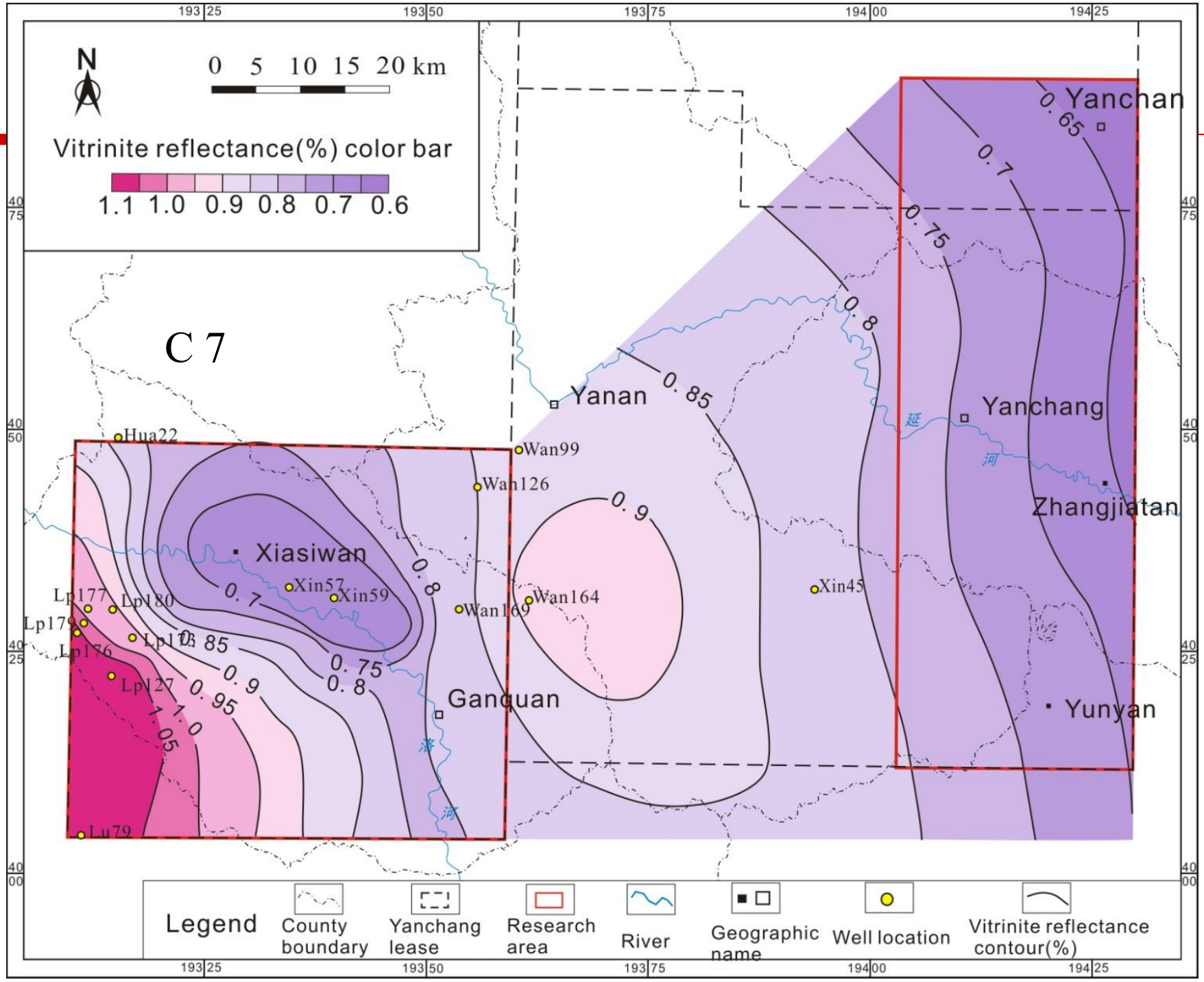


TOC content 0-1%; 2-3%


N
0 5 10 15 20 km
TOC Content (wt.%) color bar
5.0 4.0 3.0 2.0 1.0 0
Chang 9
0.5
1.0
1.5
2.0
2.5
3.0
Yanchan
Yanan
Yanchang
Zhangjiatan
Xiasiwan
Ganquan
Yunyan
Hua22
Wan99
Wan126
Xin57
Xin59
Wan164
Wan169
Xin45
Lp177
Lp180
Lp179
Lp176
Lp173
Lp127
Lu79
A
Legend
County boundary
Yanchang lease
River
Geographic name
Well location
TOC Content wt.%
193 25
193 50
193 75
194 00
194 25
40 75
40 50
40 25
40 00


N
0 5 10 15 20 km
TOC Content (wt.%) color bar
5.0 4.0 3.0 2.0 1.0 0
C 7
Yanchan
Yanan
Yanchang
Zhangjiatan
Xiasiwan
Ganquan
Yunyan
Hua22
Wan99
Wan126
Xin57
Xin59
Wan164
Wan169
Xin45
Lp177
Lp180
Lp179
Lp173
Lp176
Lp127
Lu79
0.5
1
1.5
2
2.5
3
3.5
4
4.5
193 25
193 50
193 75
194 00
194 25
40 75
40 50
40 25
40 00
B
Legend
County boundary
Yanchang lease
River
Geographic name
Well location
TOC Content wt.%

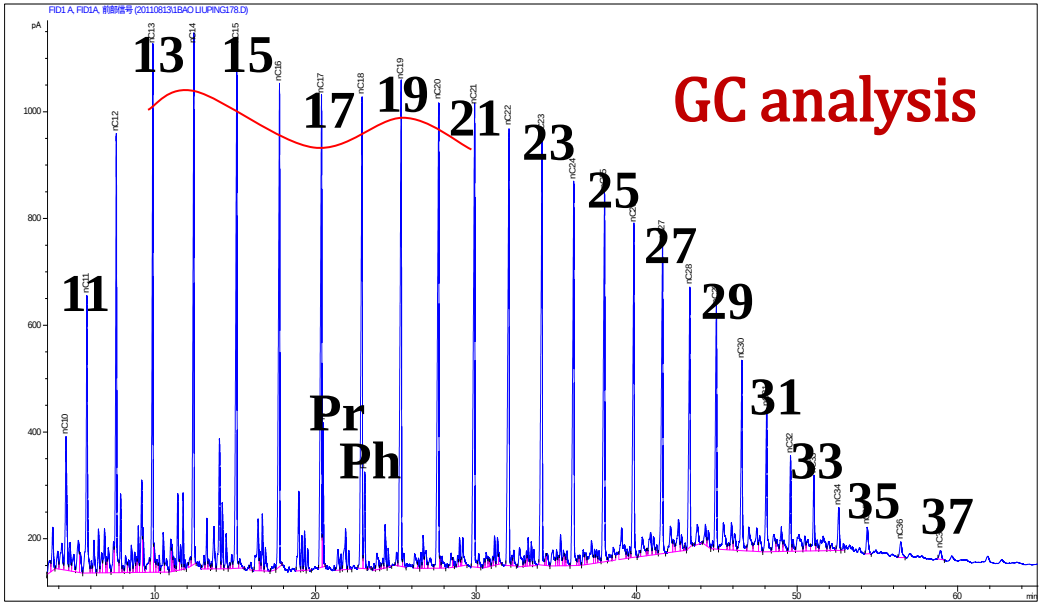

N
0 5 10 15 20 km
Vitrinite reflectance(%) color bar
1.3
1.0
0.7
0.4
Chang 9
Yanchan
Yanan
Yanchang
Zhangjiatan
Yunyan
Xiasiwan
Ganquan
Hua22
Wan99
Wan126
Wan164
Wan169
Xin57
Xin59
Xin45
Lp177
Lp180
Lp179
Lp173
Lp176
Lp127
Lu79
0.5
0.6
0.7
0.65
0.55
0.75
0.8
0.85
0.95
1.0
1.05
1.1
1.2
1.3
Legend
County boundary
Yanchang lease
Research area
River
Geographic name
Well location
Vitrinite reflectance contour(%)


N
0 5 10 15 20 km
Vitrinite reflectance(%) color bar
1.1 1.0 0.9 0.8 0.7 0.6
C 7
Yanchan
Yanan
Yanchang
Zhangjiatan
Yunyan
Ganquan
Xiasiwan
Hua22
Wan99
Wan126
Wan164
Wan169
Xin57
Xin59
Xin45
Lp177
Lp180
Lp179
Lp176
Lp127
Lu79
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1.0
1.05
Legend
County boundary
Yanchang lease
Research area
River
Geographic name
Well location
Vitrinite reflectance contour(%)

Outline

1. Geological Setting
2. Continental Shale Geochemical Characteristics
3. Gas Content and Hydrocarbon Proportion
   - Free gas
   - Dissolved gas
   - Absorbed gas
   - Gas/Oil Ratio (GOR) within the shale
4. Summary

Gas and oil coexist within the shale

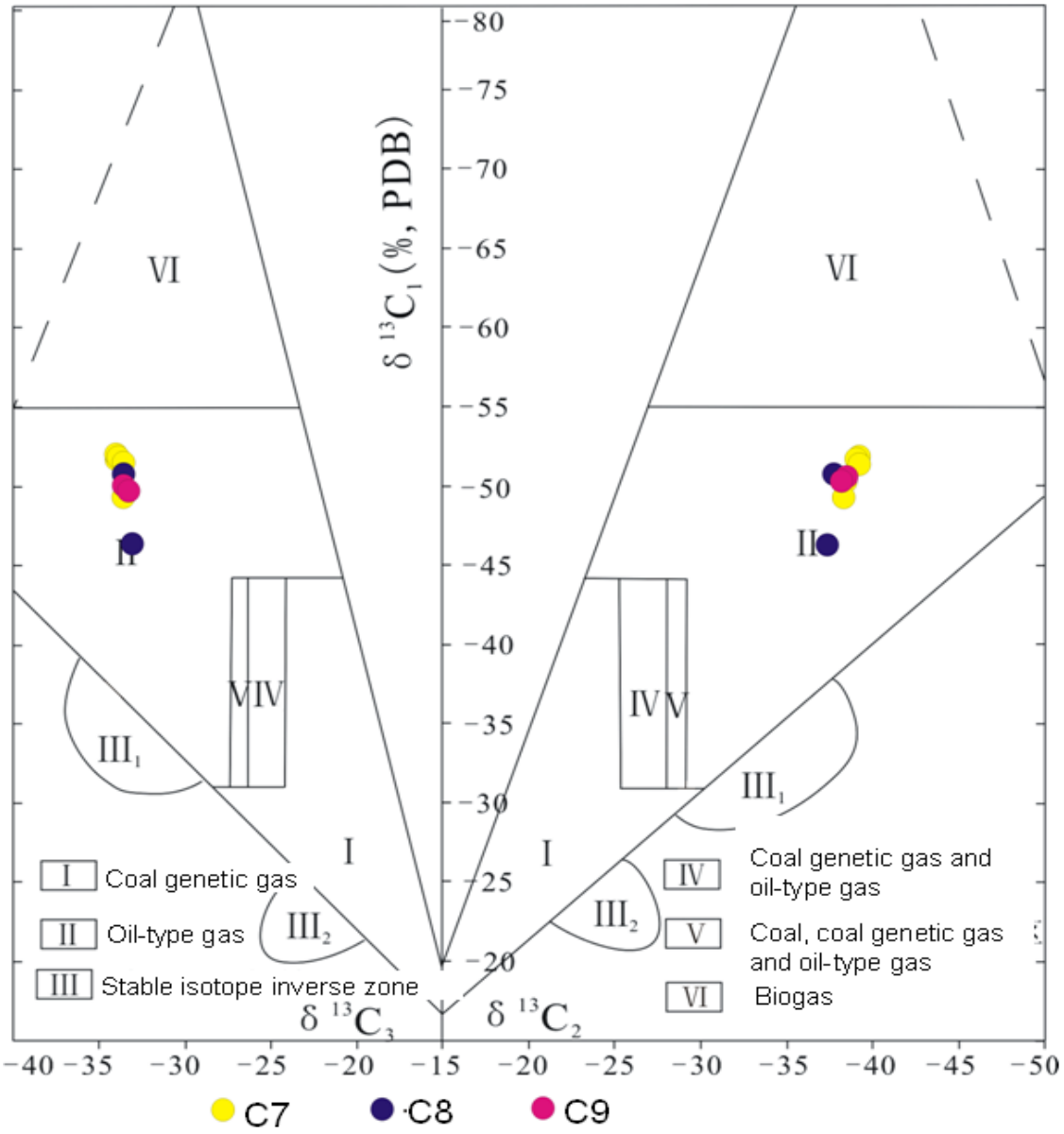


Shale gas composition-Wet gas

Sample No.	strata	Depth (ft)	Gas composition(%)									
			N_2	CO_2	C_1	C_2	C_3	iC_4	nC_4	iC_5	nC_5	C_6+
1	C7	5675.85	0.23	1.07	75.38	12.81	7.29	0.58	1.73	0.26	0.34	0.3
2	C7	5675.85	1.09	0.95	76.03	12.05	6.86	0.55	1.63	0.24	0.32	0.27
3	C7	5675.85	0	1.25	76.84	12.09	6.84	0.54	1.61	0.24	0.32	0.26
4	C7	5839.90	1.48	0.6	76.16	12.35	6.46	0.58	1.51	0.25	0.32	0.27
5	C7	5839.90	0	1.15	75.95	13.54	6.85	0.59	1.35	0.2	0.21	0.15
6	C7	5839.90	0	0.85	70.48	16.15	9.36	0.72	1.83	0.24	0.24	0.12
7	C9	6108.92	0	0.39	70	16.02	9.86	1.02	2.06	0.29	0.26	0.08
8	C9	6108.92	4.75	0.32	69.06	13.76	8.73	0.94	1.85	0.27	0.23	0.08

C7-Chang 7; C9-Chang 9; N_2-Netrogen; C_1-Methane; C_2-Ethane; C_3- propane; iC_4-iso butane; nC_4-n-butane; iC_5-iso-pentane; n C_5-n-pentane; C_6+- heavy hydrocarbon with carbon number is more than six.

Gas Genesis: Oil-Type Gas



Gas content and gas proportion

Gas content = Free gas + Dissolved gas + Absorbed gas

Calculated from pore volume

Canister desorption And isothermal simulation

Canister desorption equipment: Portable gas desorption equipment made by CUGB

Methane isotherm are undertaken with Schlumberger Terra Tek ISO-300 isothermal apparatus

Free phase gas calculation methods:

$$Q_{\text{free}} = \frac{\phi_g S_g}{B_g}$$

ϕ_g -Porosity,% Sg -Gas saturation, %;

Bg -Gas volume coefficient converted from underground to ground

Gas adsorption obtained by Langmuir equation

$$G_s = VL \times P/(P + PL)$$

Where:

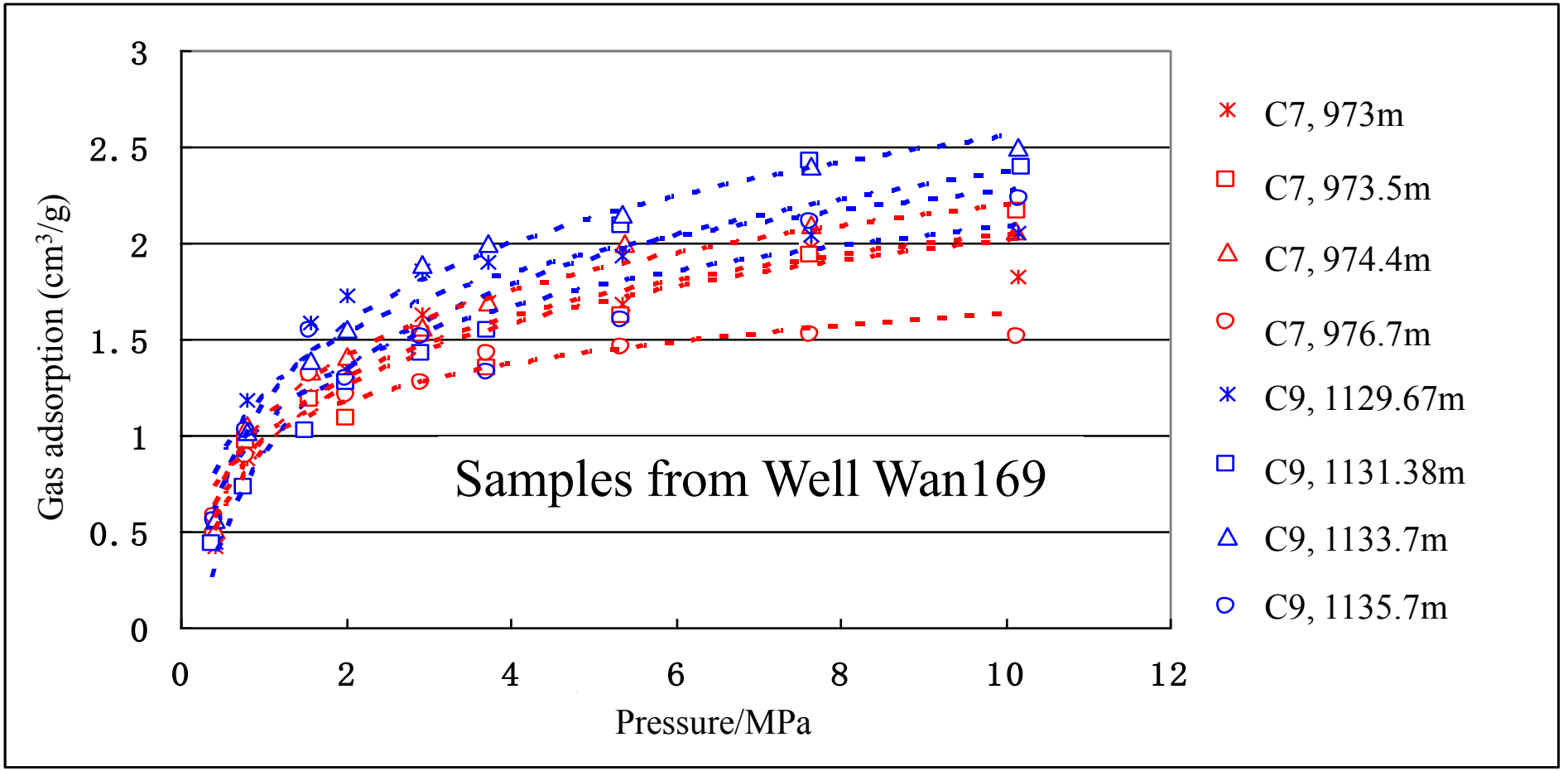
G_s = Gas storage capacity (scf/ton)

VL = The Langmuir Volume (scf/ton) is the maximum amount of gas that can be adsorbed at infinite pressure

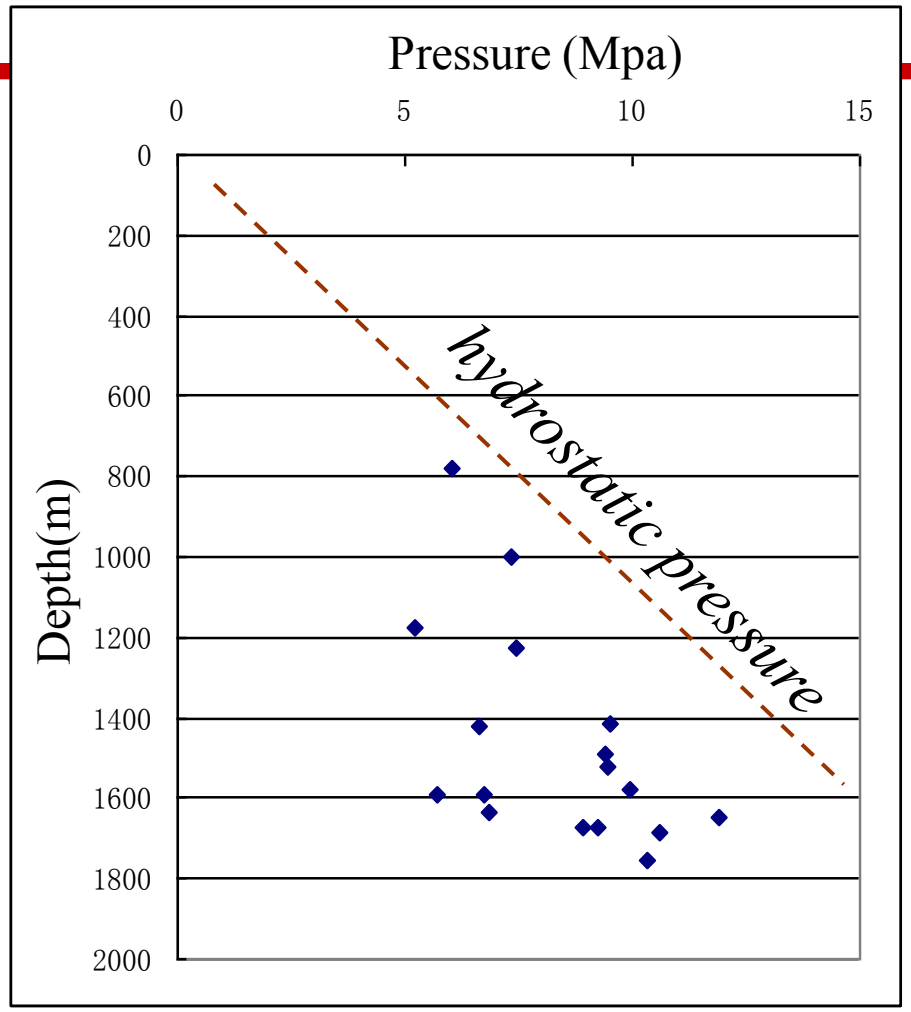
P = Absolute pressure (psia)

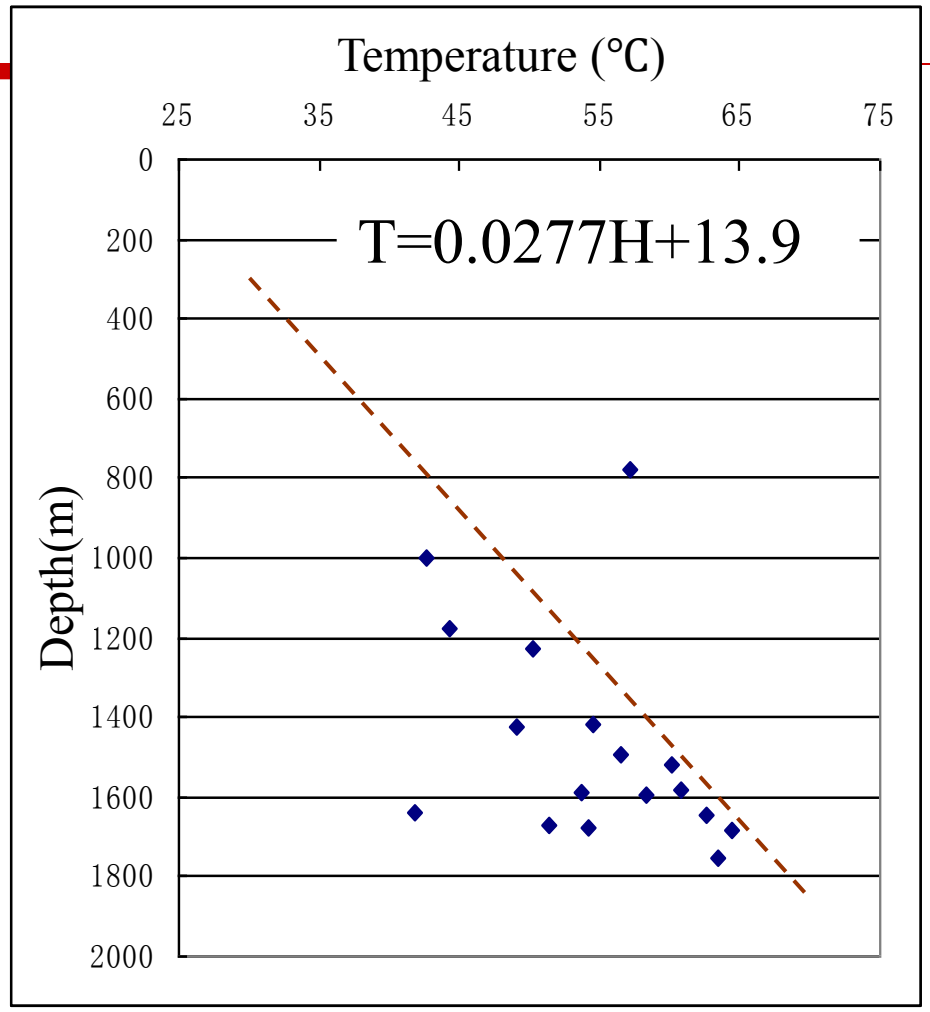
PL = The Langmuir pressure (psia) affects the curvature of the isotherm and corresponds to the pressure at which half of the VL is adsorbed.

Isotherm simulation experiments:



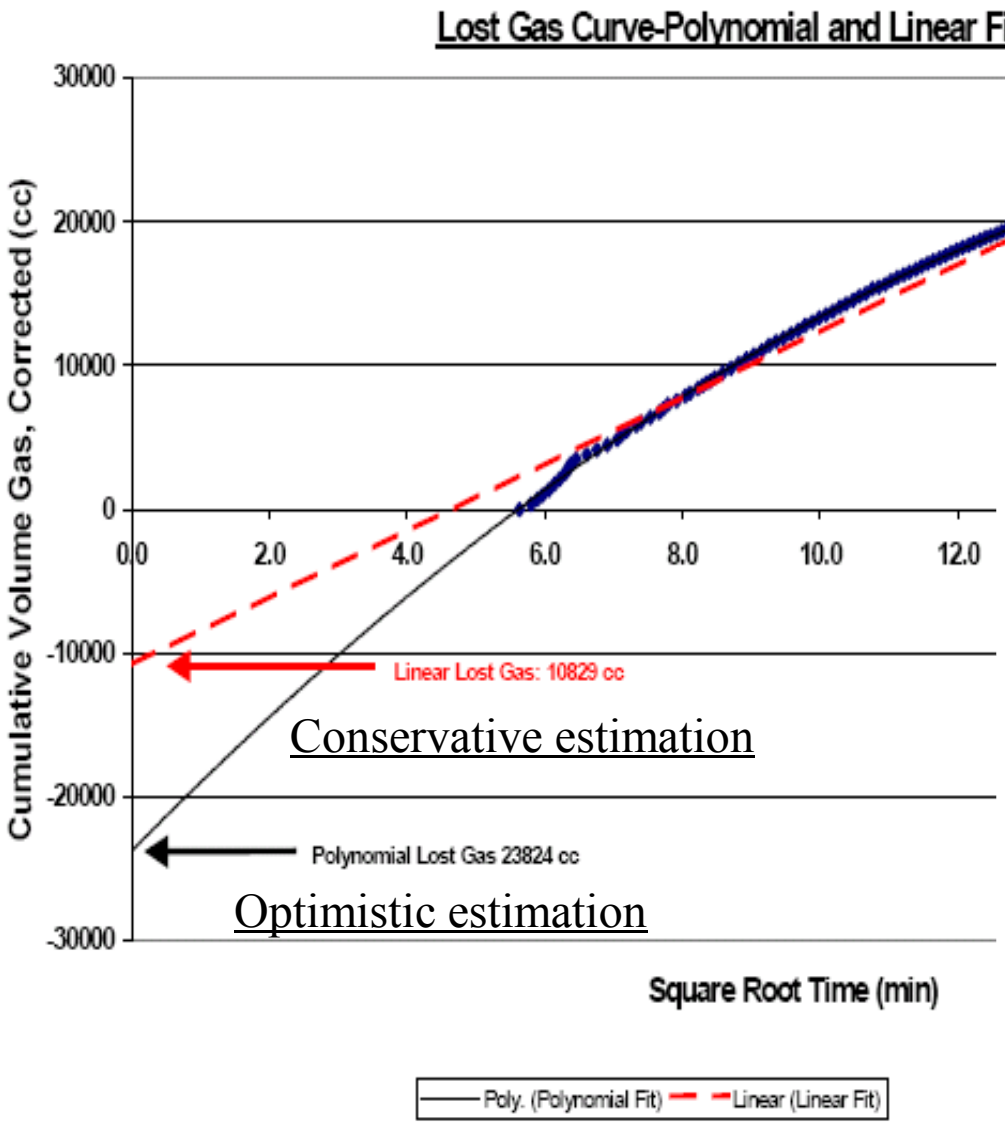
The gas absorbed under the pressure of 10 Mpa regarded as the saturated gas Which range from 1.5-2.5 m^3/t





The formation pressure is underpressure with average pressure index 0.56; Temperature gradient 2.77°C/100m

Canister Gas desorption= desorbed gas +dissolved gas



Lost gas estimation is the key to gas content measurement, which is can not measured directly, with some uncertainty

Linear and polynomial curve fit are roughly estimation of the bottom and top limit of lost gas

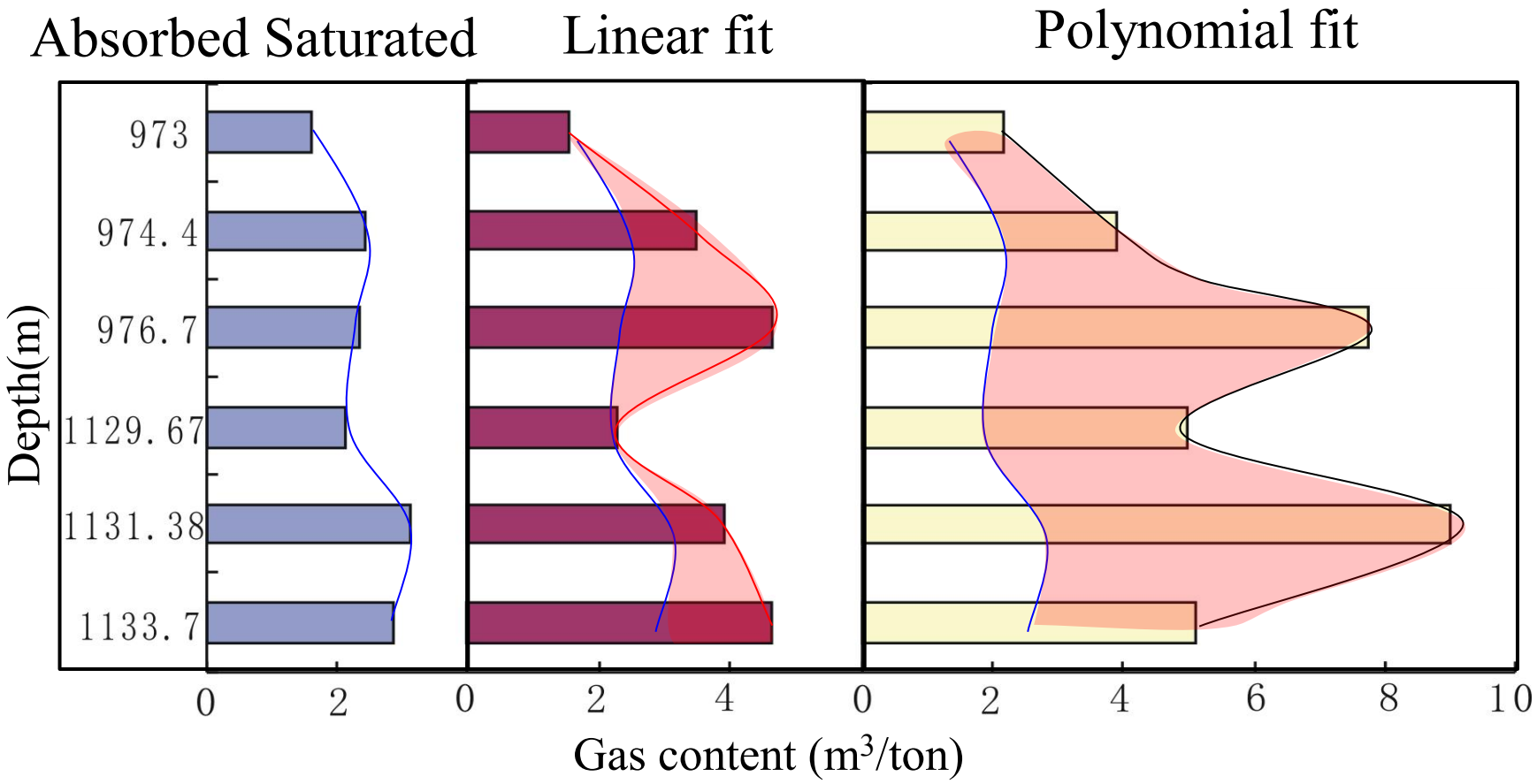
Canister Gas desorption

Well Wan 169

Strata	depth(m)	linear fit (m^3/t)	polynomial fit (m^3/t)
C7	973	1.548	2.143
C7	974.4	3.4832	3.876
C7	976.7	4.646	7.714
C9	1129.67	2.28	4.978
C9	1131.38	3.9514	8.986
C9	1133.7	4.614	5.098

Gas desorption range from 2.28-9$m^3/t\cdot$ Rock

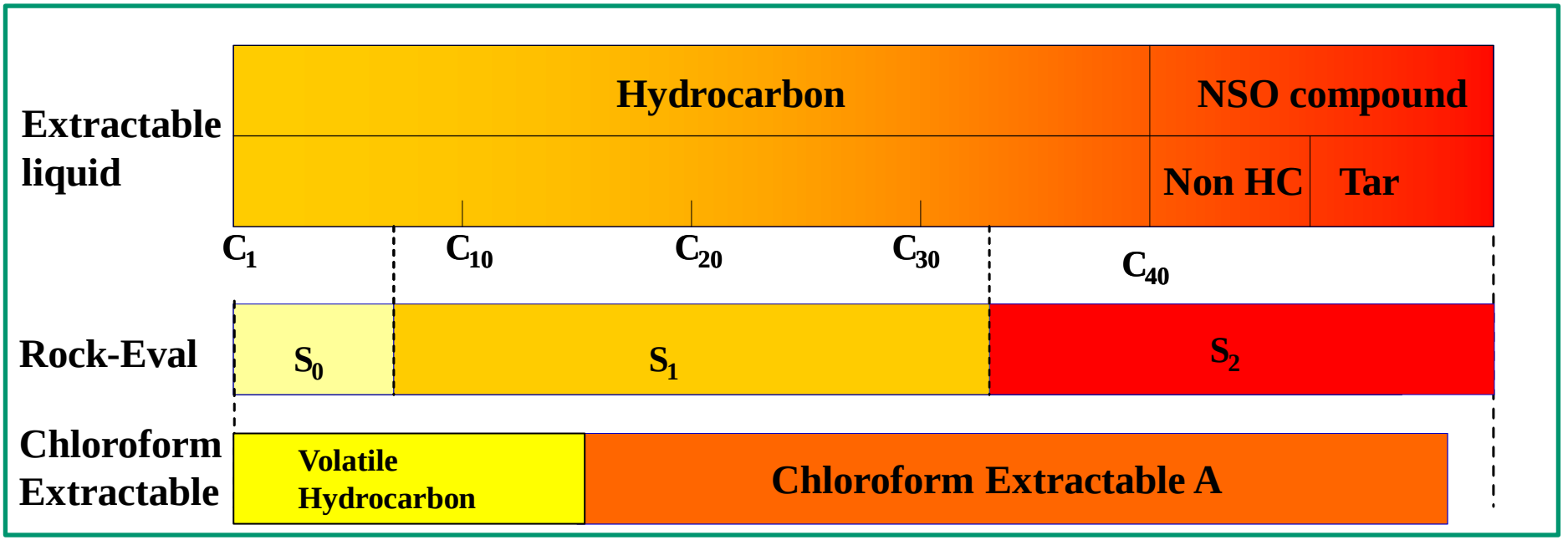
Adsorbed gas and dissolved gas proportion



Dissolved gas is equal or two times of saturated gas content absorbed

Oil content estimation

Modified from Bordenave, 1993



$Qr^o = k1 \times S1 + k2 \times S2$

Qr^o, recovered Oil retained within shale

k1,Light HC recovery coefficient of K1

k2,Solube HC of S2

（Sheng，1988；Pang，1995）

$Qr^o = Qr/(1-Bk)$

$Bk = 0.81 - 0.65*Ro + 0.18*Ro^2$

Qr^o, recovered Oil retained within shale

Qr, measured oil retainded within shale

Ro, Vitrinite reflectance(%)

Bk, Light HC recovery coef.

Oil content estimation

sample	strata	depth	TOC（%）	chloroform extract “A” (%)	S_1（mg/g）	Ro (%)	Oil content（mg/g）
Wan 169	C 9	976.5	2.53	0.408	0.056	0.97	6.263
Wan 169	C 9	981.46	0.42	0.028	0.114	0.92	0.444
Wan 169	C 9	1107.3	1.86	0.052	1.796	1.05	0.776
Wan 169	C 9	1110.7	2.56	0.667	2.886	1.05	9.892

Oil retained within the shale :6.2-9.8 mg/g· Rock or kg/T· Rock

Gas Oil Ratio (GOR)

Isothermal simulation:
Saturated adsorption gas content: 1.5-2.5 m^3/t

Canister adsorption gas: 2-9 m^3/t

Dissolved gas: 0.5-5.5$m^3/t\cdot$ Rock

Oil retained within the shale:
6.2-9.8 kg/t· Rock

} GOR 50-1100$m^3/t\cdot$ Oil

Gas Oil Ratio (GOR) prediction

Hydrous pyrolysis experiments

Sample preparation: low mature Outcrop shale sample was crushed and sieved to a size range from 2.5 to10 mm and fully mixed up, and then divided into parts with 200 g weight.
Experiments design: The sample is designed to heat up to 250℃, 275℃, 300℃, 325℃, 350℃, 375℃, 400℃, 450℃, 500℃ and 550℃ respectively in High pressure Experimental Oven.
Closed system and water join: Before the hydrous pyrolysis experiment start, 10ml non-ion water was added and increase temperature by 2 ℃/hr, then keep the temperature as designed for 72hrs and then terminate the experiment.
Parameters studied: The original shale sample and solid remnant after hydrous Pyrolysis were tested for Total organic carbon (TOC), Rock-Eval Pyrolysis and methane isotherm examination

Hydrous pyrolysis experiments

Sample number	Experimental Temperature (℃)	Counting Number	Vitrinite reflectance	S_0	S_1	S_2	Tmax	Pg	I_P	TOC	S
			%	mg/g	mg/g	mg/g	℃	mg/g		(%)	(%)
1	room temperature	21	0.52	0.02	0.47	1.01	447	1.50	0.31	1.50	0.01
2	250	14	0.79	0.01	0.09	0.82	444	0.91	0.10	1.42	0.05
3	275	12	0.85	0.01	0.04	0.68	447	0.73	0.06	1.29	0.01
4	300	13	1.21	0.01	0.04	0.67	452	0.71	0.05	1.36	0.01
5	325	10	1.35	0.01	0.04	0.49	451	0.54	0.07	1.33	0.08
6	350	16	1.46	0.01	0.04	0.40	455	0.44	0.08	1.37	0.03
7	375	8	1.59	0.01	0.03	0.11	576	0.14	0.20	1.36	0.01
8	400	9	1.67	0.01	0.02	0.07	575	0.10	0.22	1.37	0.01
9	450	6	1.91	0.01	0.03	0.03	575	0.07	0.46	1.32	0.01
10	500	3	2.5	0.01	0.05	0.02	427	0.08	0.64	1.24	0.01
11	550	/	3.13	0.01	0.05	0.03	344	0.09	0.61	1.13	0.01

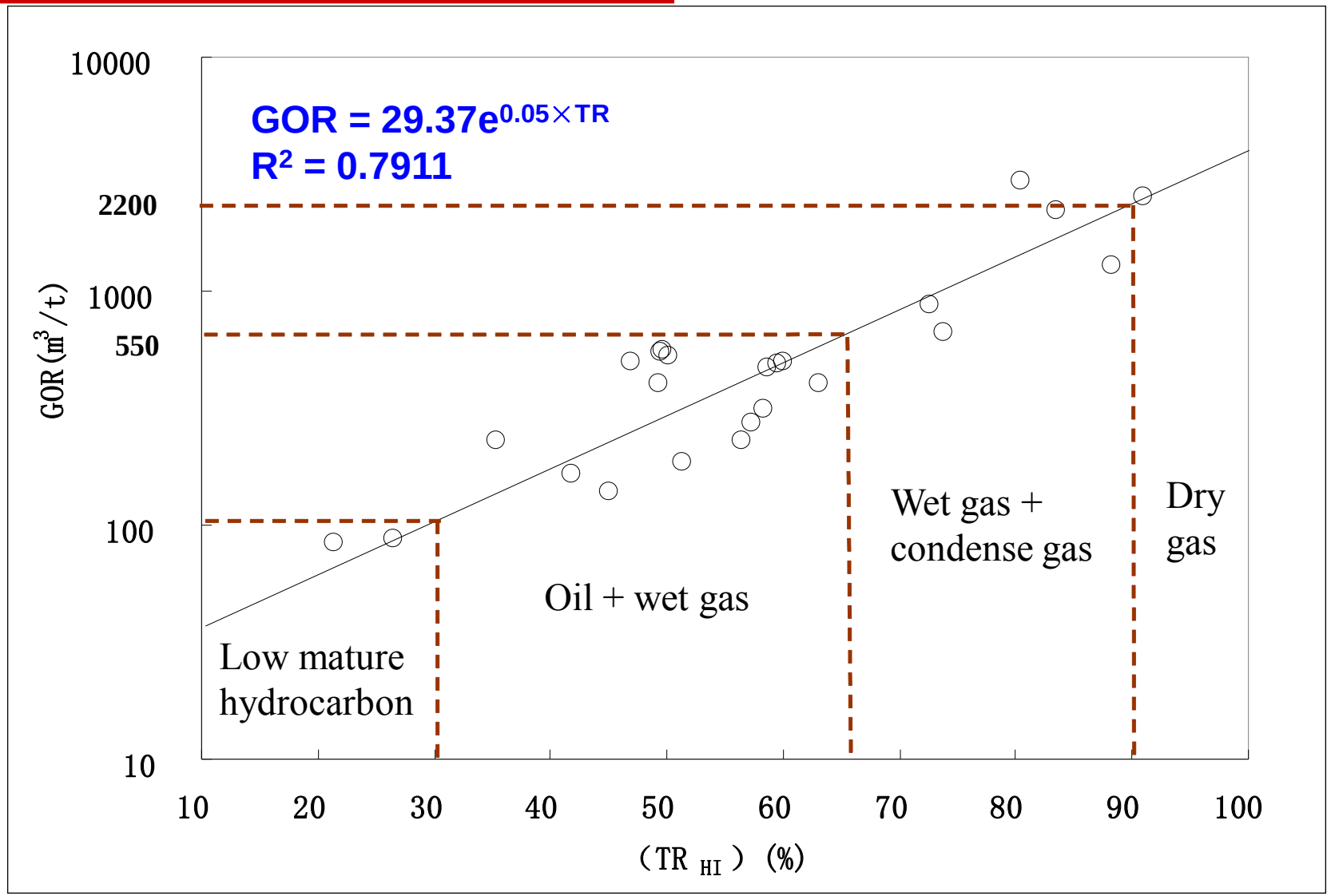
GOR prediction methods-Hydrocarbon transformation ratio

$$TR_{HI} = 1 - \frac{HI_{PD}\,[1200 - HI_O\,(1 - PI_o)]}{HI_0[1200 - HI_{\mathrm{pd}}(1 - PI_{pd})]}$$

$$PI = S_1/(S_1+S_2)$$

$$HI_0 = \left(\frac{\%typeI}{100} \times 750\right) + \left(\frac{\%typeII}{100} \times 450\right) + \left(\frac{\%typeIII}{100} \times 125\right) + \left(\frac{\%typeIV}{100} \times 50\right)$$

(from Peter, 2006)


GOR = 29.37e0.05×TR
R2 = 0.7911
10000
2200
1000
550
100
10
GOR (m3/t)
10
20
30
40
50
60
70
80
90
100
(TR HI) (%)
Low mature hydrocarbon
Oil + wet gas
Wet gas + condense gas
Dry gas

Summary

(1) Continental shale in Triassic yanchang formation possess Vitrinite reflectance value ranging from 0.8% to 1.5%, Kerogen predominantly Type I-II, and an organic abundance (TOC value) average 1.5% -4%.

(2)Isotope data shows the gas in the C -7 and C -9 member is thermogenic in origin and appears to be cogenerated with oil.

(3)Gas dissolved is significant proportion of total gas content, more than absorbed gas content

(4)Oil volume retained in the shale range from 6.2-9.8kg/t.

(5)TRHI are good tools for predict the GOR

(6)Shale gas is major targets for Yanchang oil company currently, oil would be the next promising interests.