Biogenic Gas Systems in the Qaidam Basin, NW China*

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Abstract

Large quantities of biogenic gas were accumulated in the Quaternary section of the Qaidam Basin, NW China, with proven gas reserves of 7.9 Tcf. The gases are dominated by methane (>95%), with $\delta^{13}C1$ values in the range from -65 to -68‰. Major source rocks are lean lacustrine shales with average TOCs of around 0.5%. Gas reservoirs, with burial depths generally less than 1900m, are Lower Pleistocene unconsolidated siltstones and muddy siltstones which form carrier beds within the petroleum system. Formation water circulation and early formed syn-depositional anticlines play an important role in the maintenance of the dynamic charge-leak biogenic gas accumulations. Although considerable work has been done, little is understood about the biogenic gas origin and accumulations. Gas compositions, microorganism community, source rock geochemistry, and petrophysical mudstone permeability assessments were thoroughly investigated to identify source rocks and to assess the rate of gas charge and leaking.

Headspace gas profiles suggest that both CO_2 reduction and acetate fermentation occur in the studied area with CO_2 reduction dominating. Microbial community analysis shows that both bacteria and archaea are abundant and viable. Specific biomarkers used to diagnose methanogenesis activity from archaea are well correlated to laboratory simulated gas yields and indicates biogenic gas is mainly derived from processing of lacustrine material rather than land plant detritus. Rock-Eval S1/S2 ratios from a specially designed heating program provide reliable proxies for kerogen reactivity assessment. TOC levels as low as 0.3% in large volumes of mudstone support significant methanogenic activity in the studied area at optimal microbial activity temperature while siltstone carrier beds focus gas to commercial quantities. Gas column heights are controlled by the competence of overlying local seals which are poor seals holding <2 m column of gas before capillary failure. Gas accumulation is a dynamic process, suggesting both charge and leaking are actively going on. Some gas chimneys found on the high-resolution seismic images provide supplemental evidence of dynamic migration and accumulation. The study indicates that with appropriate internal migration routes even lean shale packages can be commercial gas prospects.

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Study area

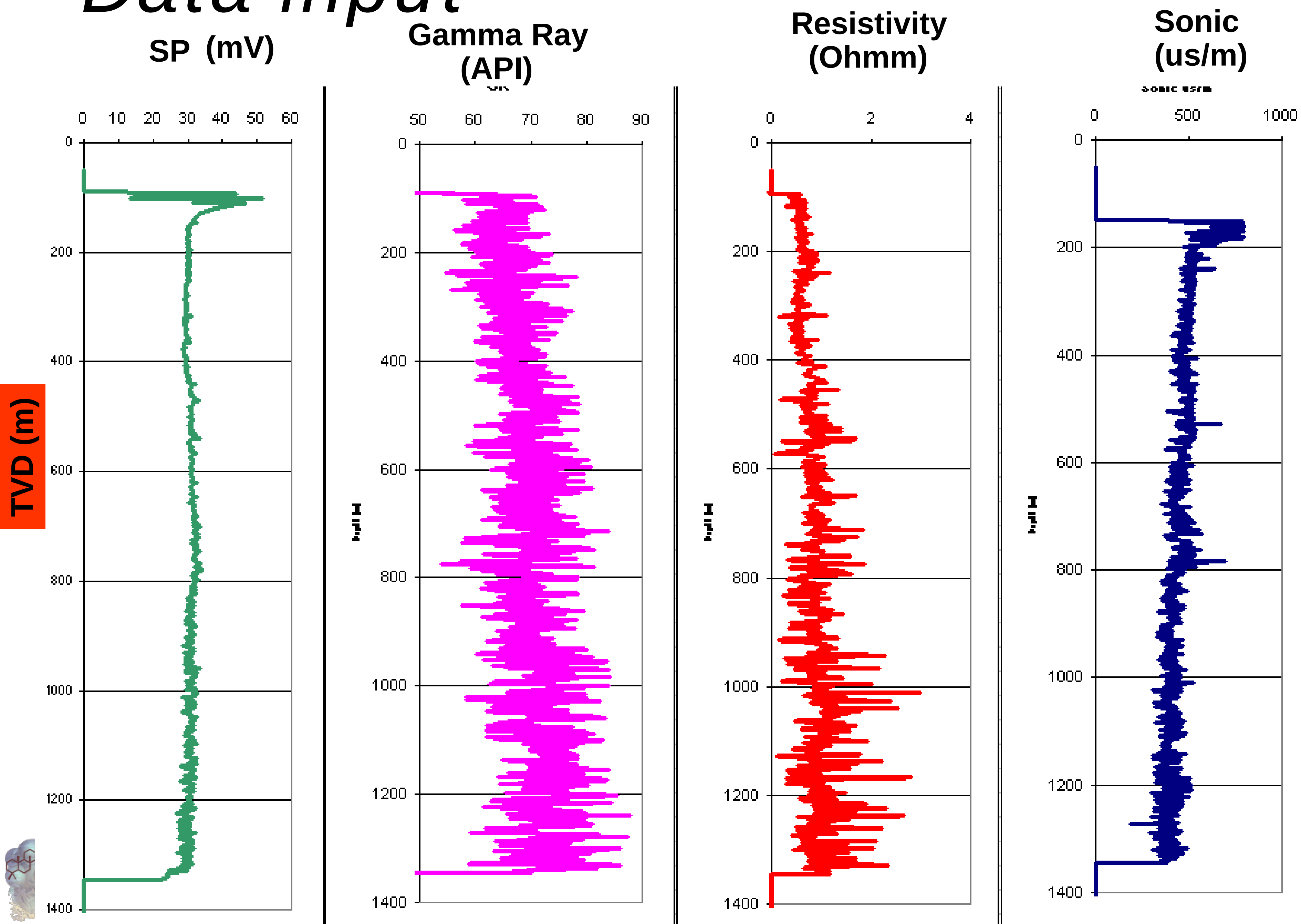

Study Area
Mongolia
Urumqi
乌鲁木齐
Kyrgyzstan
Harbin
哈尔滨
Changchun
长春
Shenyang
沈阳
Beijing
北京
Hohhot
呼和浩特
Yinchuan
银川
Xining
西宁
Lanzhou
兰州
Taiyuan
太原
Shijiazhuang
石家庄
Jinan
济南
Xi'an
西安
中国
China
Zhengzhou
郑州
Nanjing
南京
Wuhan
武汉
Hefei
合肥
Hangzhou
杭州
Chengdu
成都
Lhasa
拉萨
Chongqing
重庆
Kunming
昆明
Guiyang
贵阳
Changsha
长沙
Fuzhou
福州
Nanning
南宁
Guangzhou
广州
Haikou
海口
香港
Hong Kong
澳门
Macau
台灣
Taiwan
North Korea
Seoul
서울
대한민국
South Korea
Daejeon
대전
Gwangju
광주
Busan
부산
日本
Japan
Osaka
大阪
Fukuoka
福冈
East China Sea
Naha
那覇
Philippine Sea
Luzon
South
Lahore
Faisalabad
Baitadi
New Delhi
Nepal
Jaipur
Malangawa
Bhutan
Ilam
Bangladesh
Khulna
India
Chittagong
Myanmar (Burma)
Ha Noi
Laos
Pune
Visakhapatnam
Hyderabad
Yangon
ประเทศไทย

Overview of Qaidam Basin biogenic gas system

- It is the largest biogenic gas accumulation in China
- The proven reserve is about 10 Tcf
- The Sanhu Sag covers an area of about 37,000 km^2, with a maximum thickness of Quaternary sediments of 3,400 m.
- The gases are methane-rich (95.17-99.41%), with $\delta^{13}C1$ values ranging from -65 to -68.54‰.
- Source rocks consist of Quaternary lacustrine mudstones with an average TOC value of about 0.5%.
- Reservoirs consist of Lower Pleistocene siltstones and muddy siltstones with high porosity and permeability.
- Regional seals are Quaternary gypsiferous mudstones with a thickness of 400-1,000 m.
- Traps are typically syn-depositional anticlines with gently dipping limbs (< 5˚).

Geological characterization of Qaidam Basin biogenic gas system

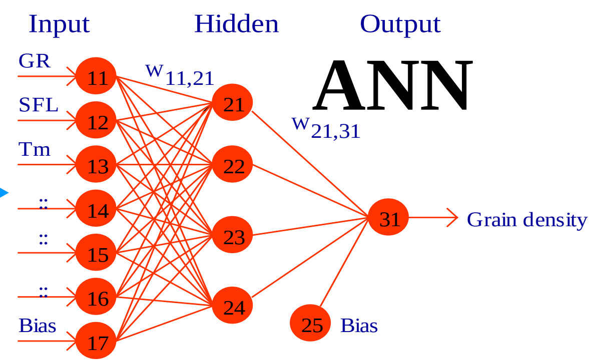
Data input



SP (mV)
0 10 20 30 40 50 60
Gamma Ray (API)
50 60 70 80 90
Resistivity (Ohmm)
0 2 4
Sonic (us/m)
0 500 1000
TVD (m)
0 200 400 600 800 1000 1200 1400

Shaequant Rapid analysis from wireline

- Sonic
- Gamma
- Density
- (Neutron)
- Resistivity
- Caliper



Useful Data

Inputs

Clay fraction

Porosity

Permeability

Effective stress/
Pore pressure

Aplin et al(2000)

Outputs

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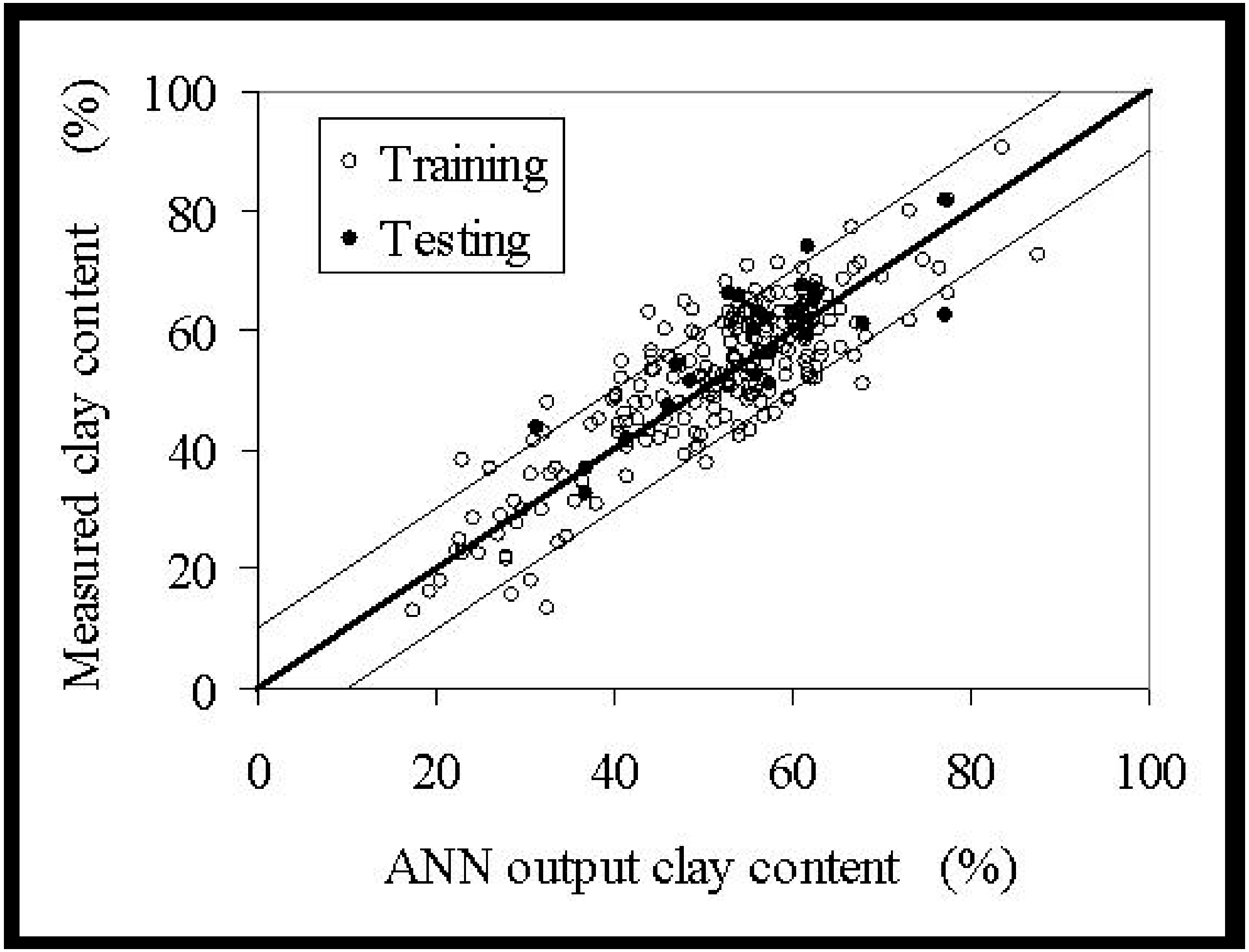
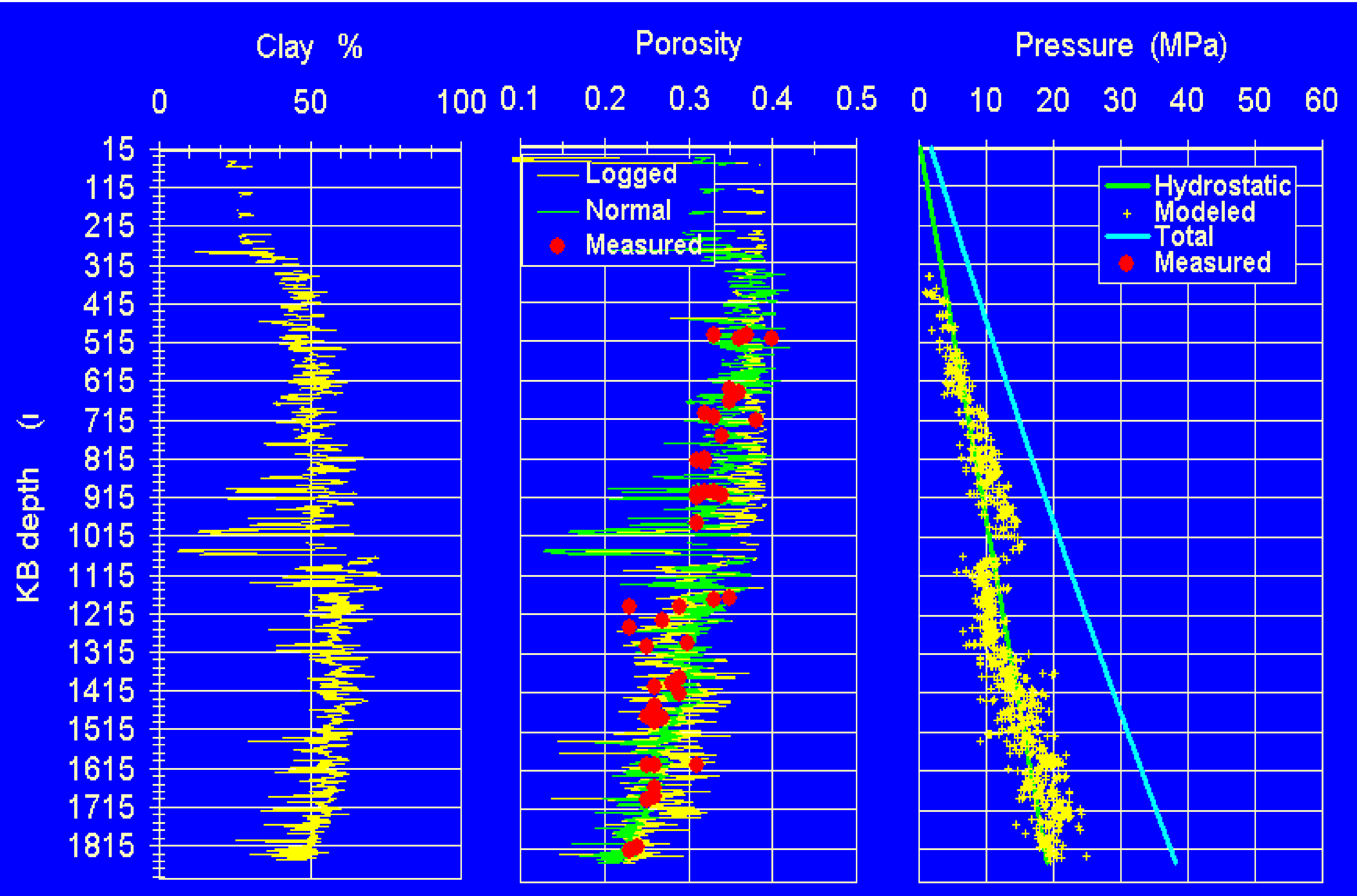
Measured vs. ANN Output: Clay Content

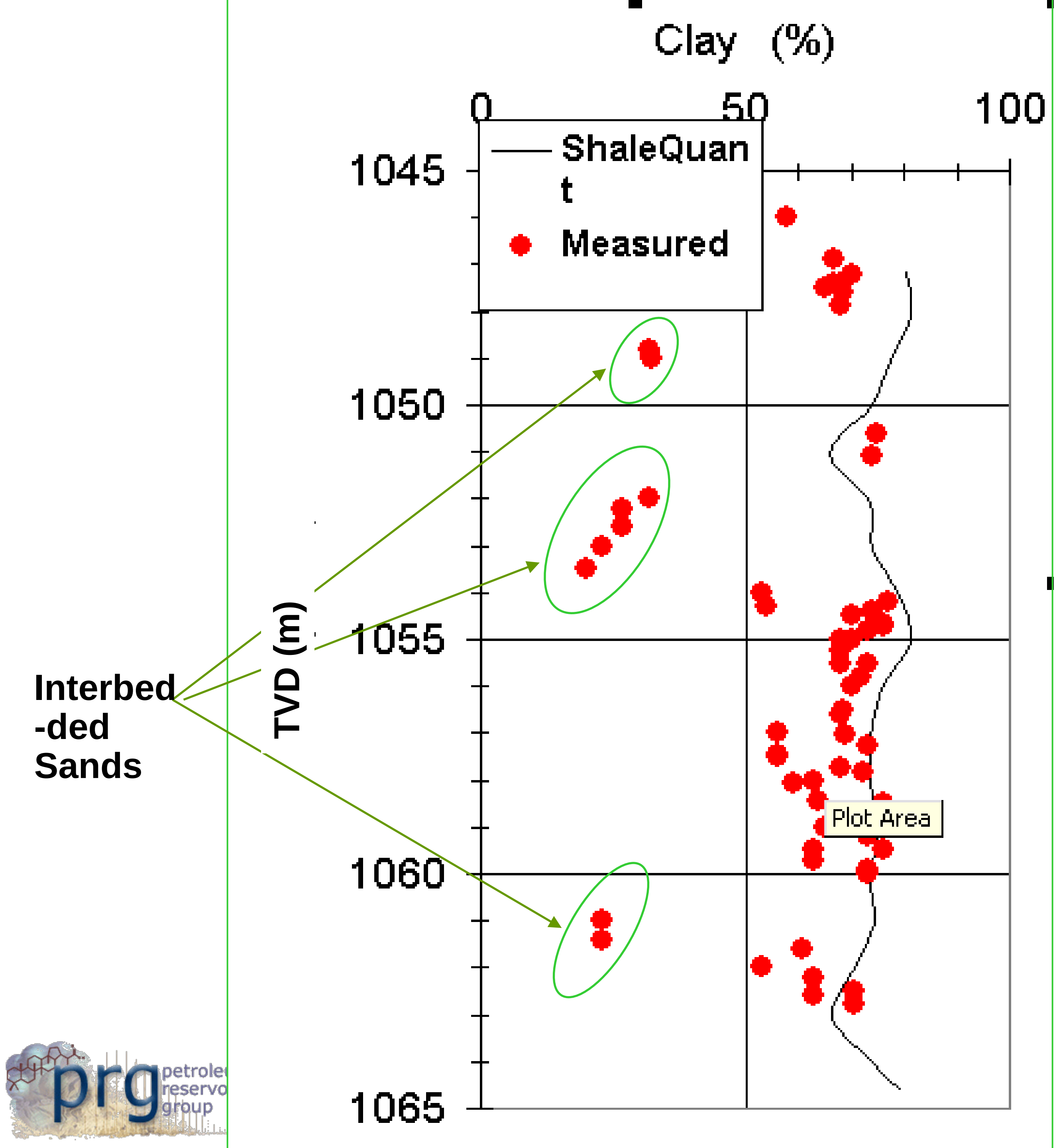


Representative well profile

Well A



Well A



Measured and Modelled clay content in the Tainan field.

Note some sandy sections with low clay content. Shalequant is trained only to predict shale properties

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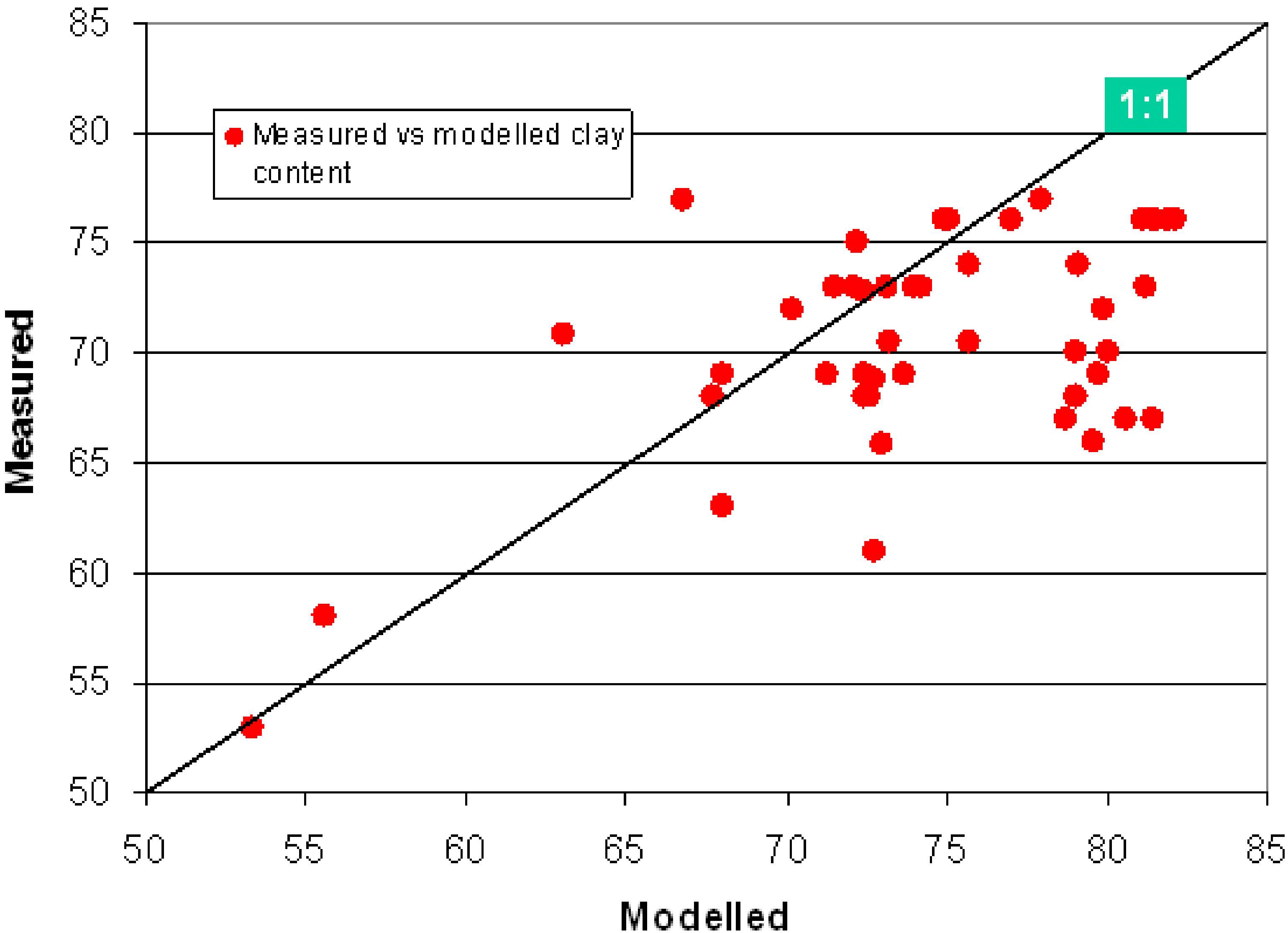
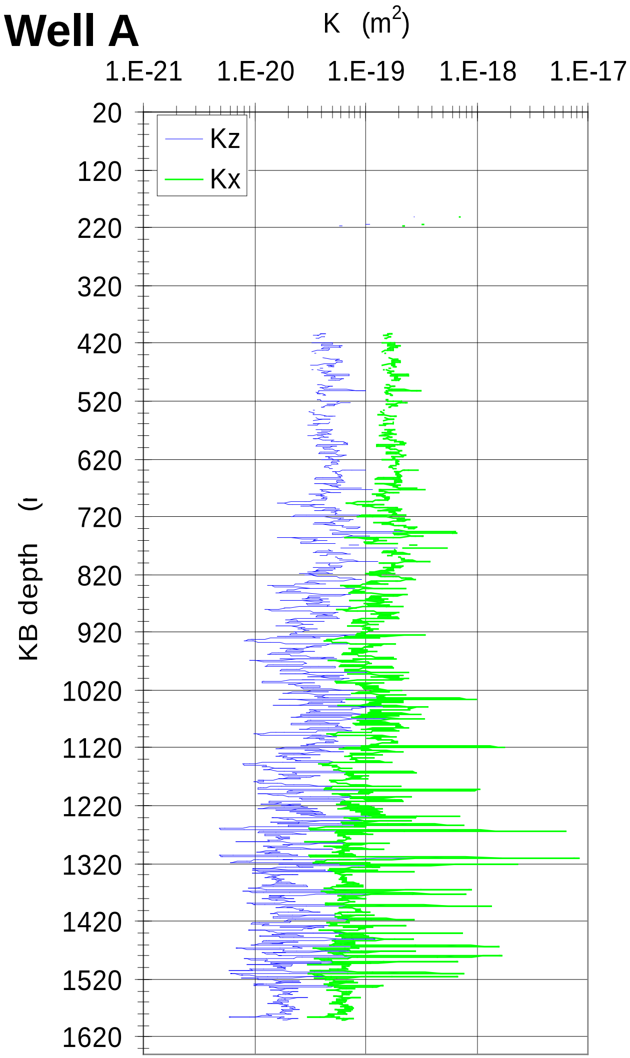
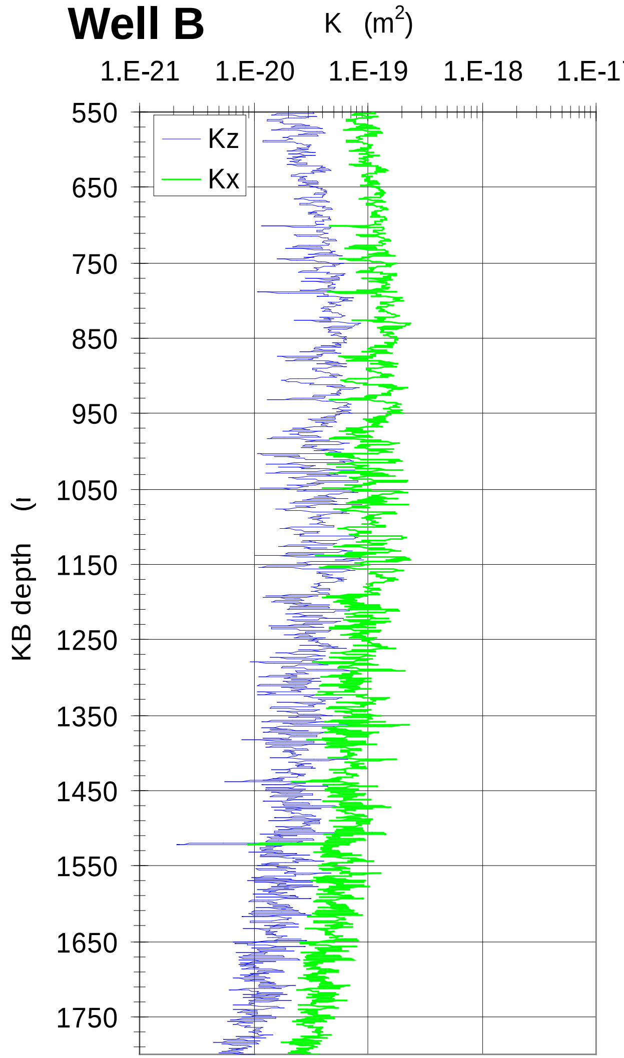

85
80
75
70
65
60
55
50
Measured
Measured vs modelled clay content
1:1
50
55
60
65
70
75
80
85
Modelled

Modelled Permeability

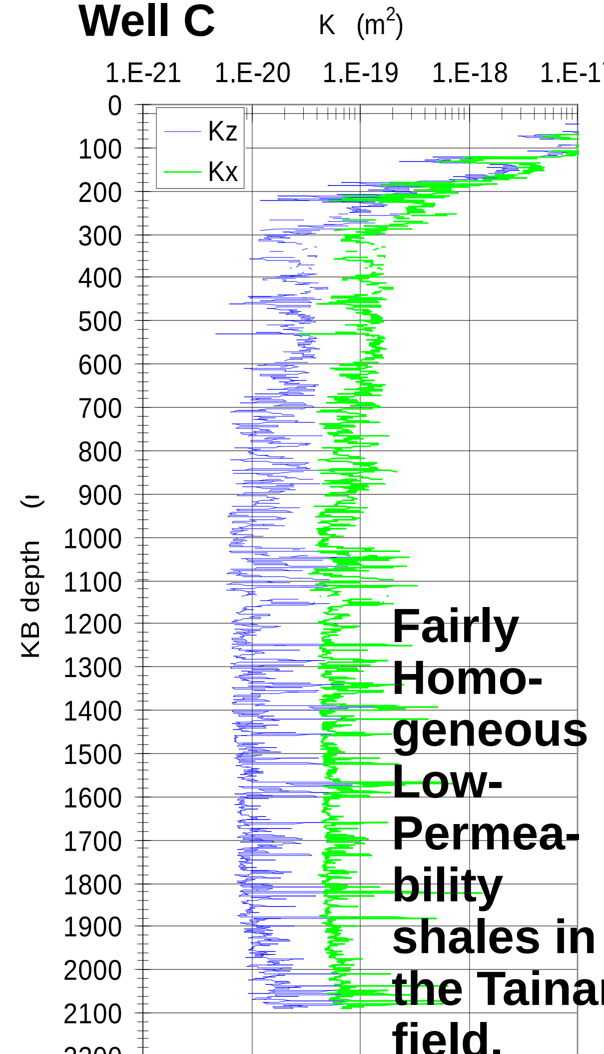
Well A



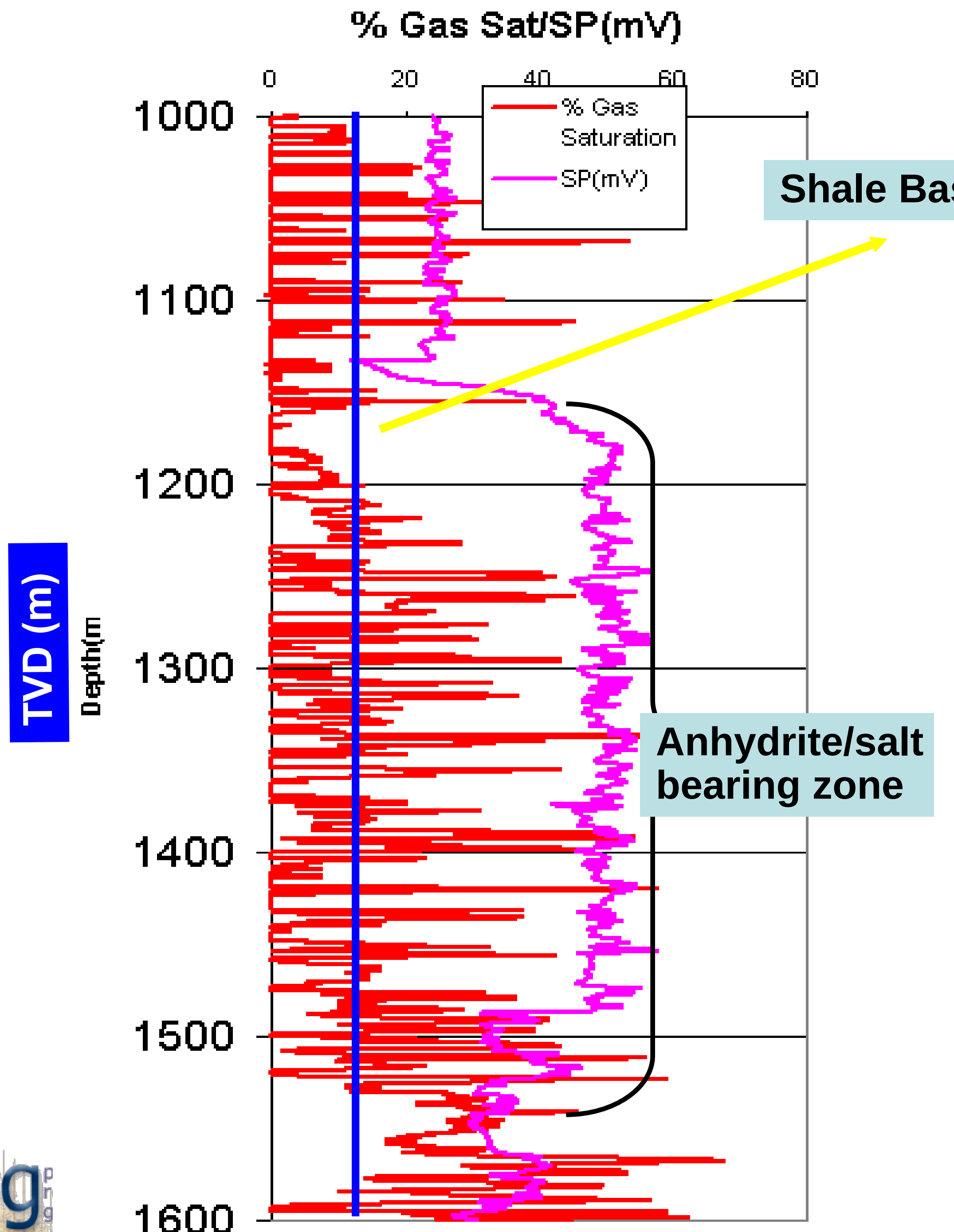
Well B



Well C



Fairly Homo-geneous Low-Permea-bility shales in the Tainan field.

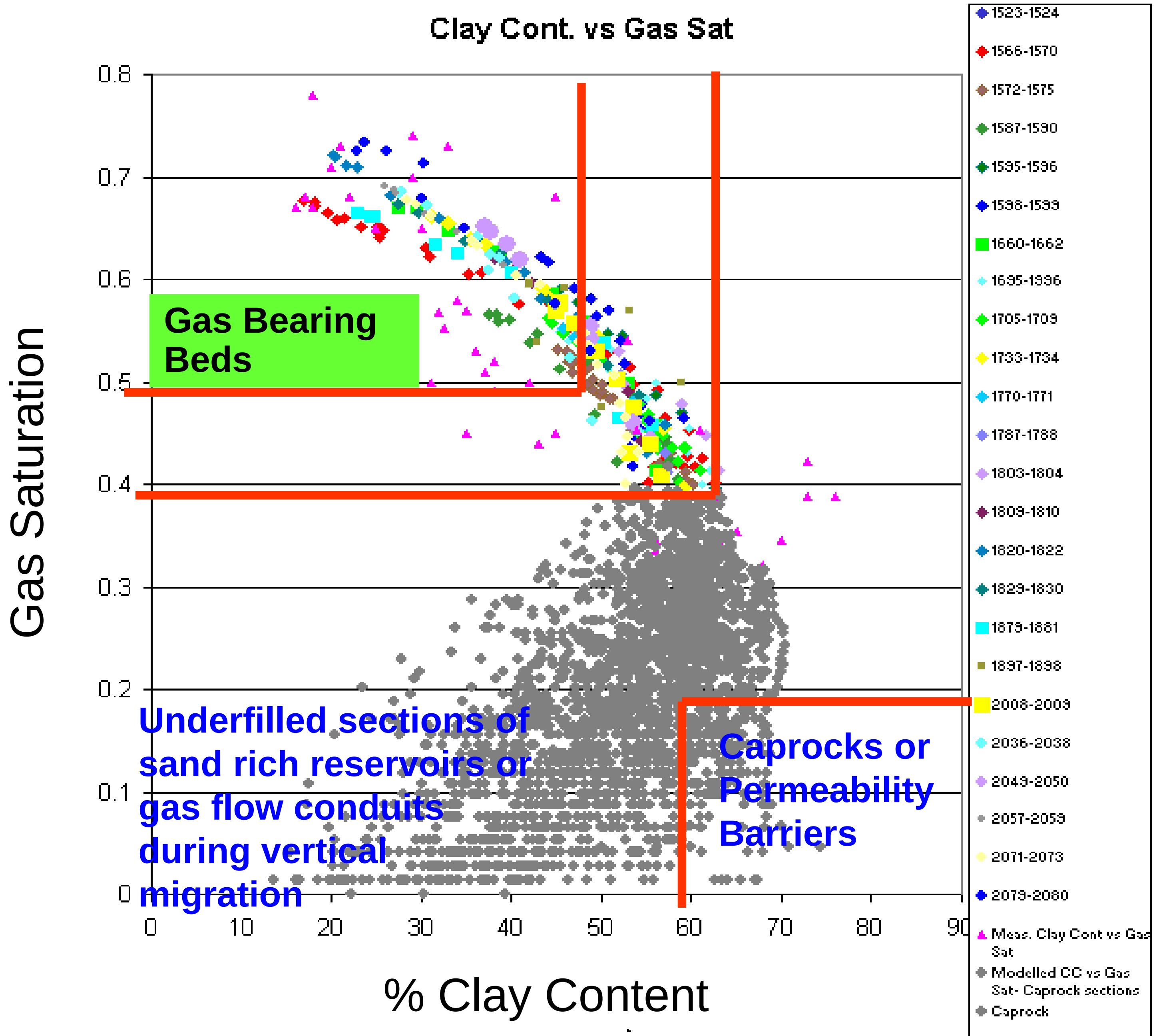


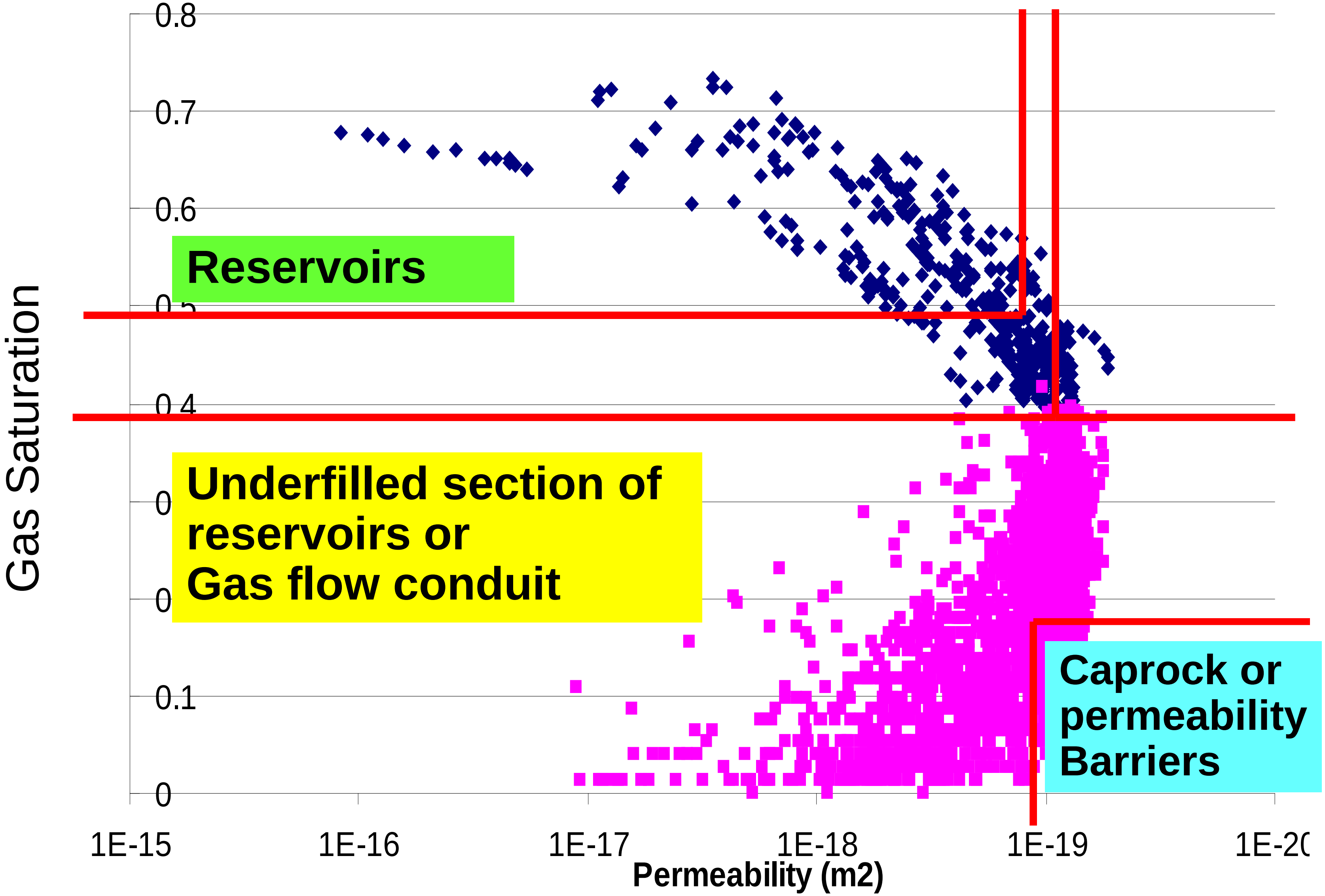
Gas Saturation is also found in within the salt-rich sections of the wells.

The salt bearing zones though associated with shales, can only act as permeability barriers but without the ability to hold higher gas column over a longer geological time period.

The entire system is dynamic.

Fits well into a charge-leak Model.


Clay Cont. vs Gas Sat
Gas Saturation
% Clay Content
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
70
80
90
Gas Bearing Beds
Underfilled sections of sand rich reservoirs or gas flow conduits during vertical migration
Caprocks or Permeability Barriers
1523-1524
1566-1570
1572-1575
1587-1590
1595-1596
1598-1599
1660-1662
1695-1996
1705-1709
1733-1734
1770-1771
1787-1788
1803-1804
1809-1810
1820-1822
1829-1830
1879-1881
1897-1898
2008-2009
2036-2038
2049-2050
2057-2059
2071-2073
2079-2080
Meas. Clay Cont vs Gas Sat
Modelled CC vs Gas Sat- Caprock sections
Caprock



Gas Saturation
0.8
0.7
0.6
0.4
0.1
0
1E-15
1E-16
1E-17
1E-18
1E-19
Permeability (m2)
Reservoirs
Underfilled section of reservoirs or Gas flow conduit
Caprock or permeability Barriers

Overview of Capillary failure in Mudstones

- **Since the rocks are normally compacted, capillary failure is probably the dominant mode of migration of the gases in this biogenic fields.**

For capillary flow to occur;

$$P_{Buoy} > P_{Cap}$$

P_{Buoy} **and** P_{Cap} **represents the buoyancy force from the migrating gas/oil and the capillary entry pressure respectively.**

$$P_{Cap} = \frac{2\sigma Cos\theta}{r_{Cap}}$$

r_{Cap} **is the critical capillary entry radius and inversely proportional to P cap**

θ **is the contact angle between the two phases (wetting angle).**

σ **is the interfacial tension between the two non wetting phases**

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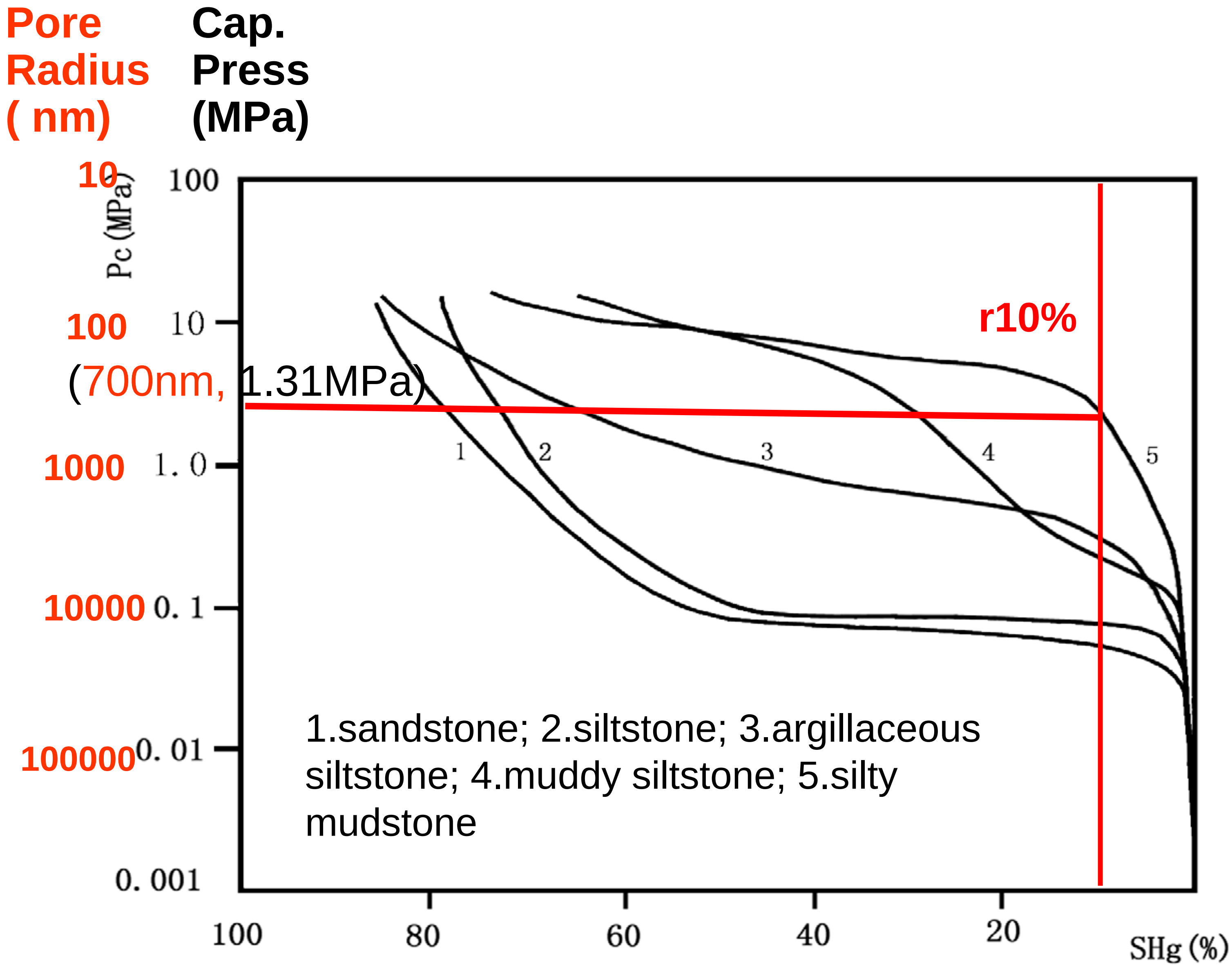
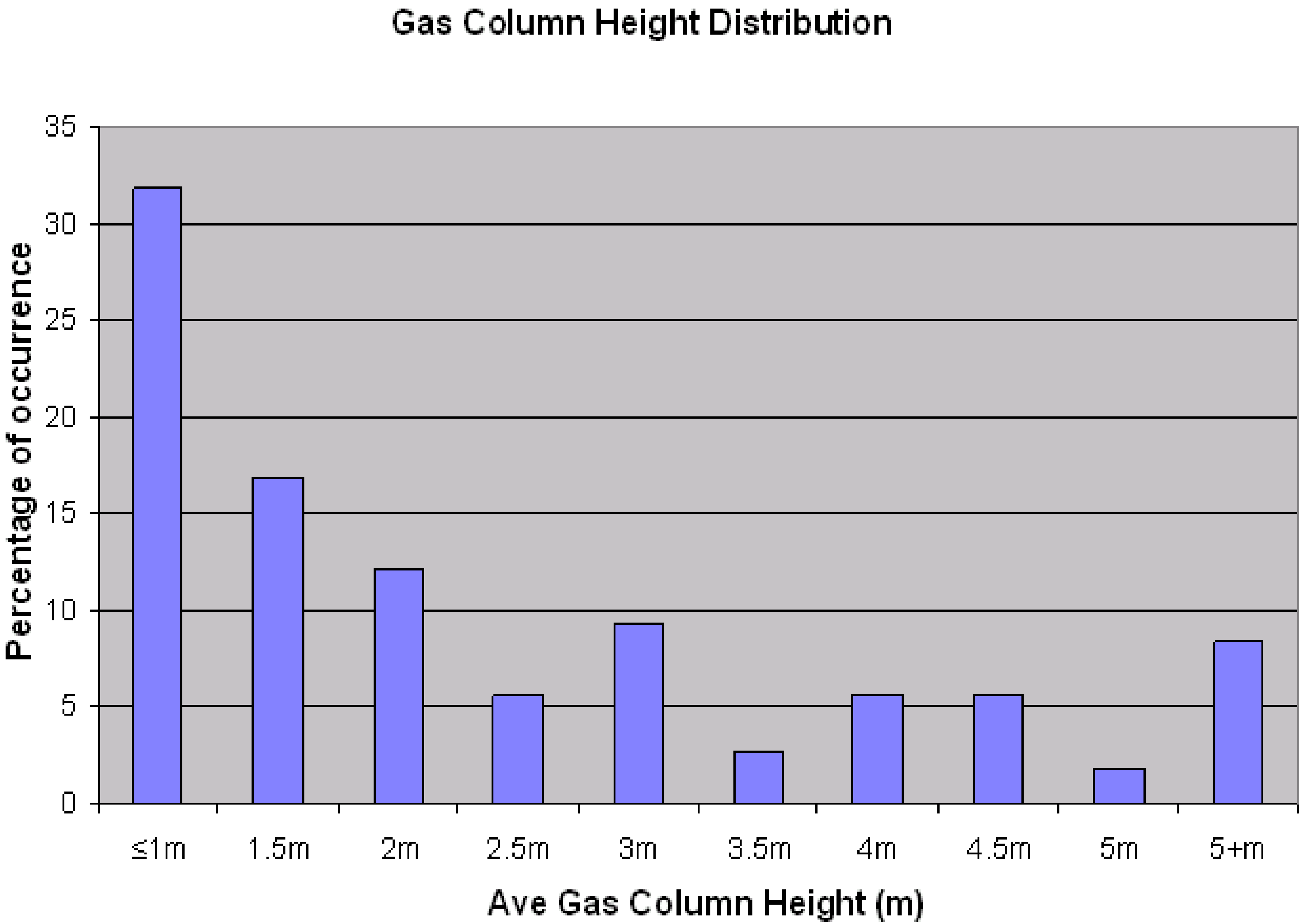


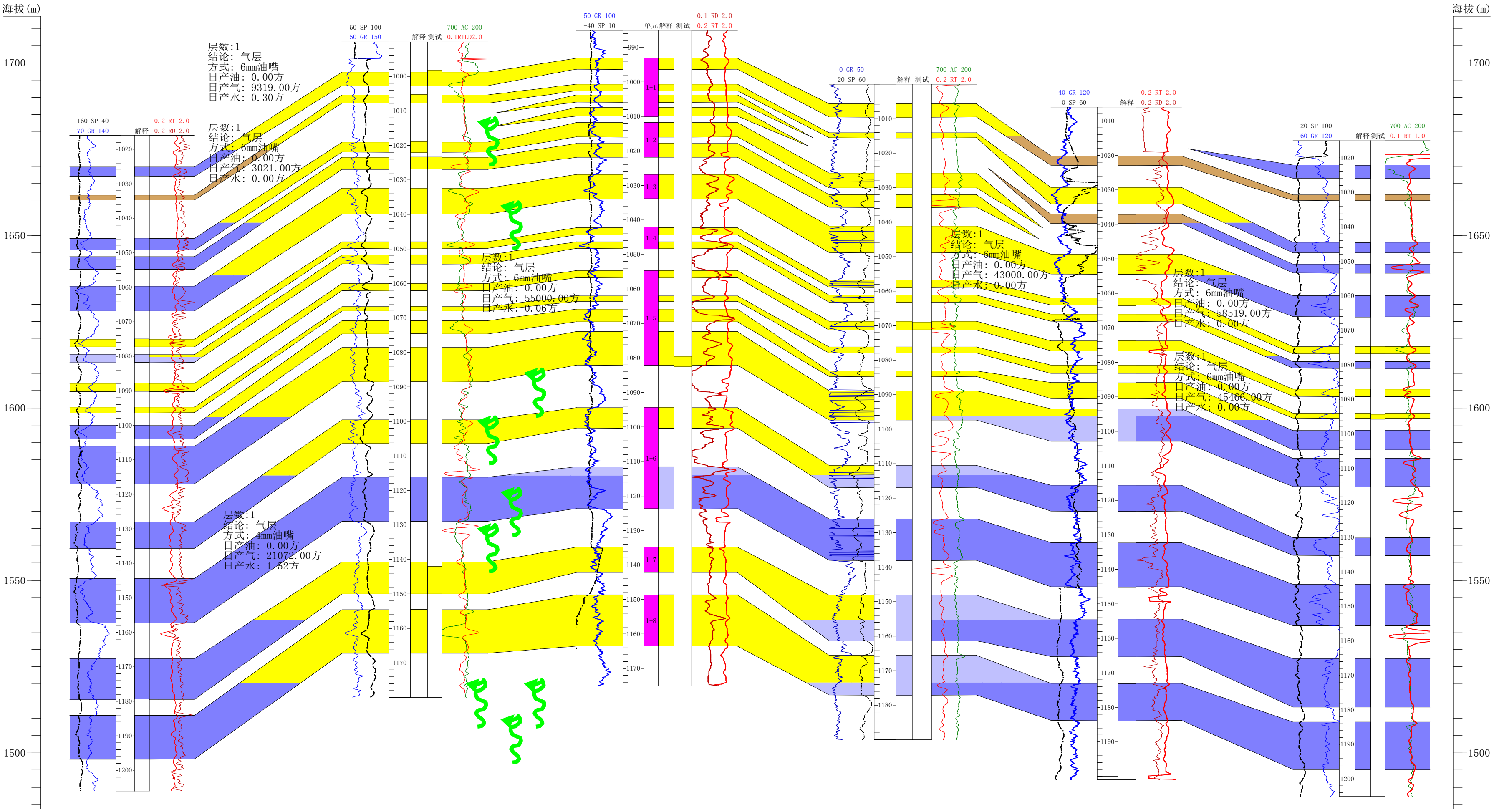
Mercury injection derived curves of the Quaternary rocks in the basin

Radius	Pressure		Vol of Hg Intruded					
nm	MPa	psi	Slty Mudst (5)	Muddy Sltstn (4)	Sltsn (3)		Sltsn (2)	Sstn (1)
176198.20	0.001	0.145	100	100	100		100	100
17619.82	0.01	1.4504	99.5	99	99		99	99
8090.75	0.1	14.504	98	98	95.5		50	44
704.8	1	145.04	92	76	52		32	28
70.5	10	1450	37	47	18		22	15
r 10%			700	3500	5000		10500	10900
Gas Column Height (m)			15.4	1.5	1.3		0.8	0.7
CP 10% (psi)			19.1	1.9	1.7		1.0	0.9
CP 10% MPa)			1.31	0.13	0.12		0.07	0.06

The higher the silt input, the lower the predicted Gas column height. Most samples are poor seals especially the silty ones capable of holding <2m column of gas before capillary failure.


Gas Column Height Distribution
35
30
25
20
15
10
5
0
Percentage of occurrence
≤1m
1.5m
2m
2.5m
3m
3.5m
4m
4.5m
5m
5+m
Ave Gas Column Height (m)

Cross section of the Tainan Field with gas distributions



(From Qinhai Oilfield)

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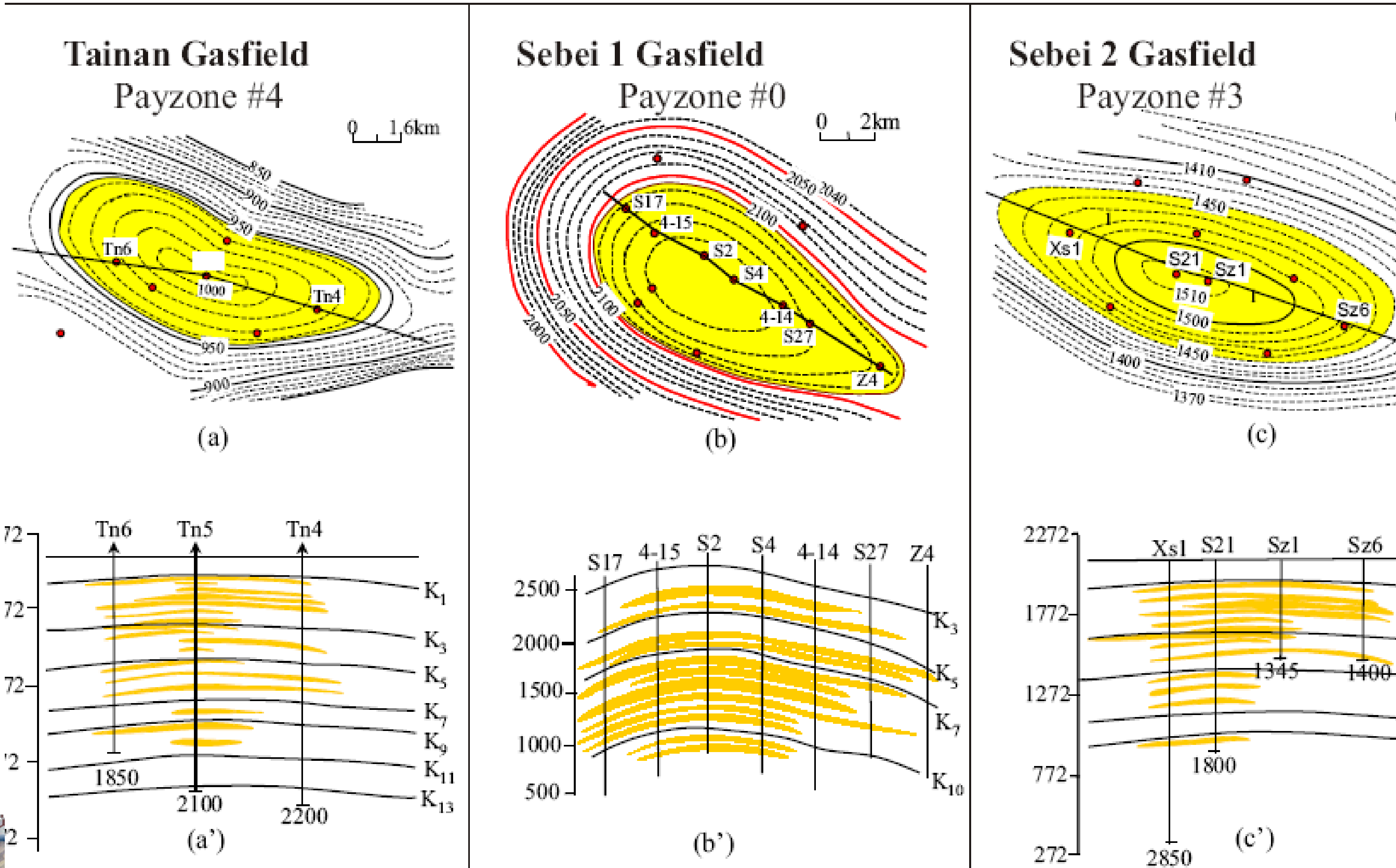
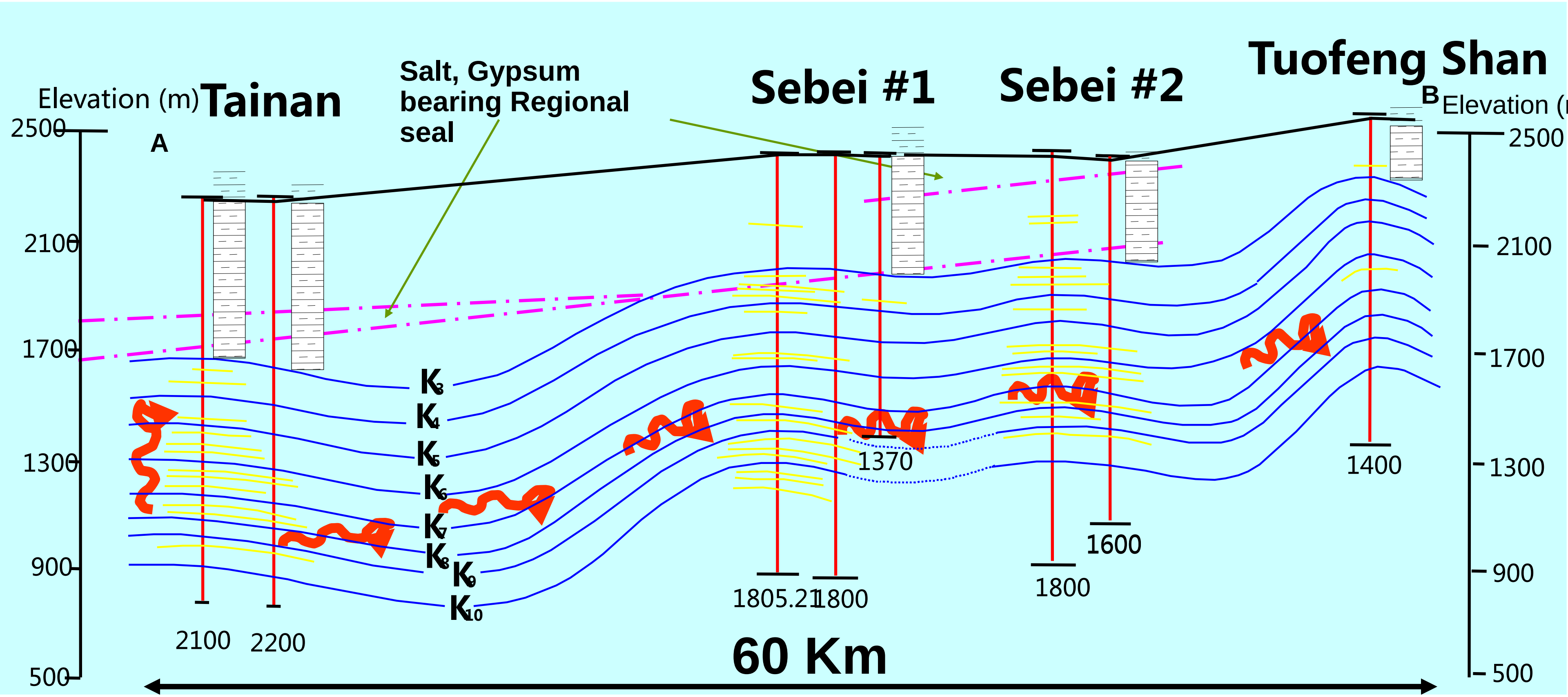
Structural maps and cross sections of the three largest biogenic gas fields



(From Qinhai Oilfield)

Generalized section showing the controls on gas migration and accumulations



The considerable accumulation and pool-formation of biogenic gas not only benefit from syndepositional structures but also, maybe more important, good preserve conditions. Large gas fields, such as Tainan, Sebei 1, Sebei 2, were formed because they had complete structures, high quality caprocks and good preserve condition. Only small gas fields were discovered from the Yanhu, taijinaier, and Tuofengshan structures due to strong tectonic movements and fault activity.

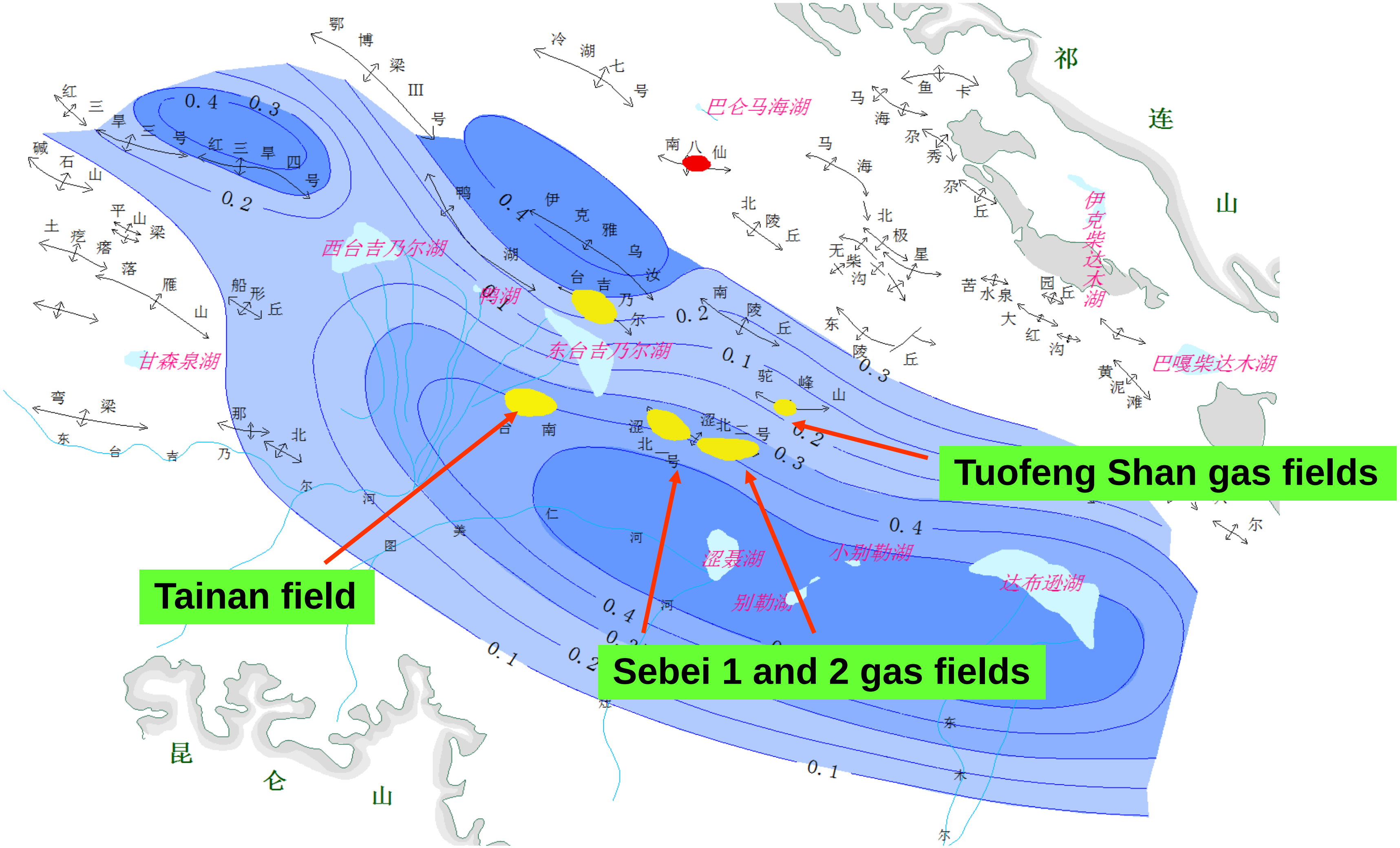
Summary of geological study

- Porosity and reservoir permeability appear not to control gas accumulations.
- Accumulations is also not a function of the thickness of the sand beds.
- Gas accumulation and gas column height at the different zones is controlled by the competence of the directly overlying local seals.
- If the local seal can only hold ~2m gas column, then accumulations at any given point in time would be limited to that amount and once that is exceeded as a result of charging, then vertical migration via capillary flow would occur.
- Most of the Local seals only acts as “bottle-necks” or “permeability barriers” (meaning migration conduits where flow is just retarded or slowed down for a while) as the system is very dynamic.

Geochemical characterization of Qaidam Basin biogenic gas system

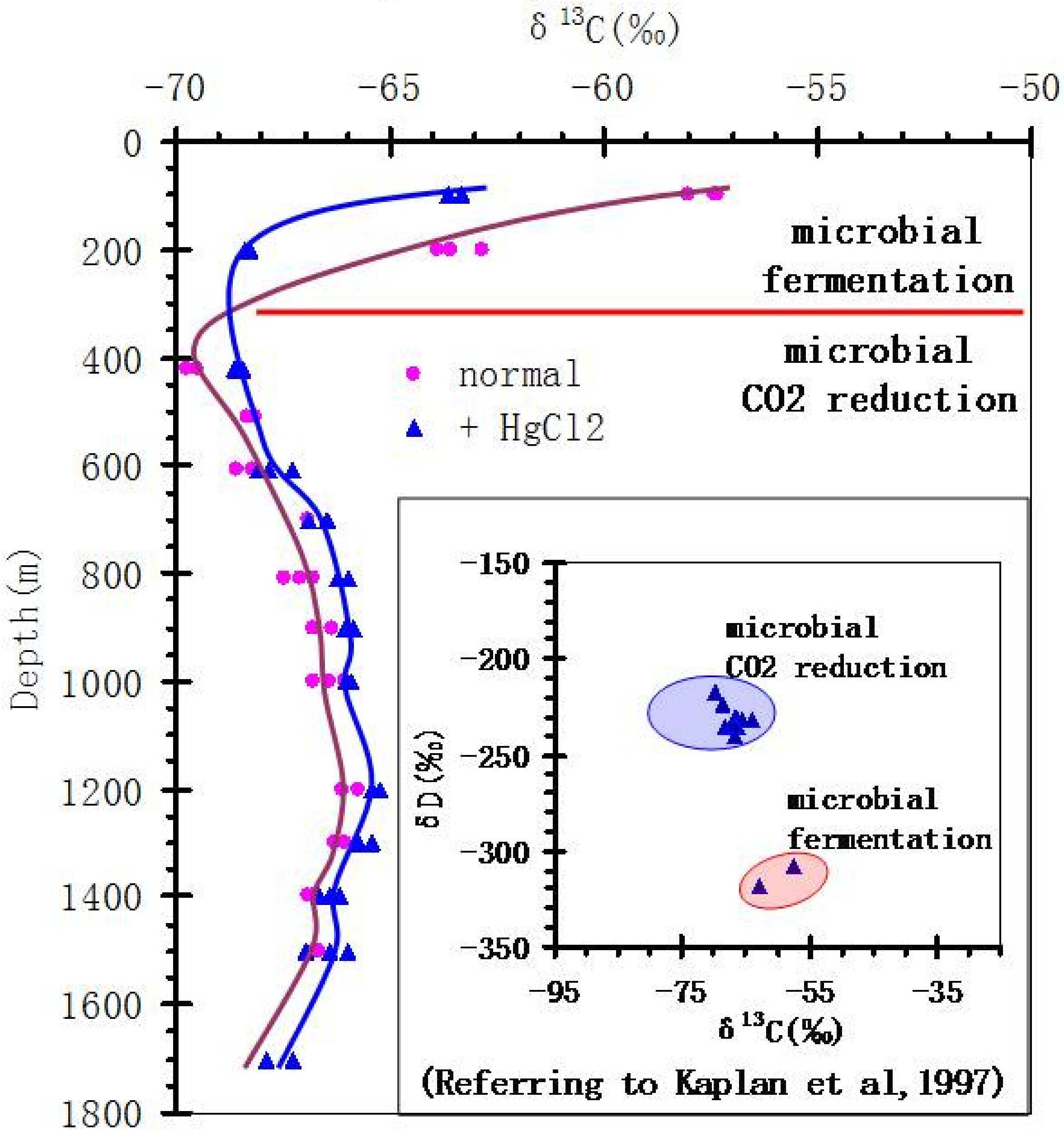
Source Rock

Contour of the TOC (%) of Q_{1+2} dark mudstone in the Sanhu area of the Qaidam basin



(From Qinhai Oilfield)

Carbon isotopic profile of Well X



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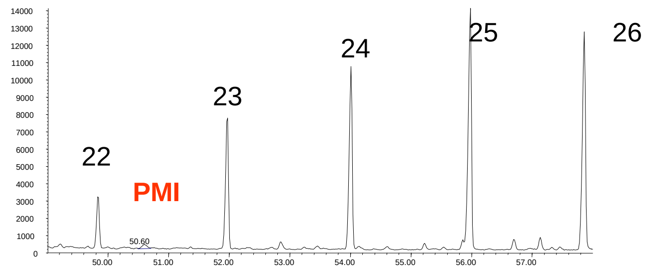
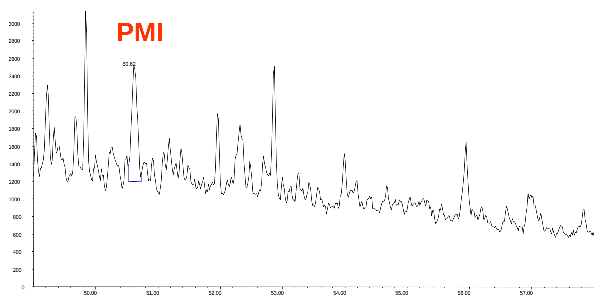
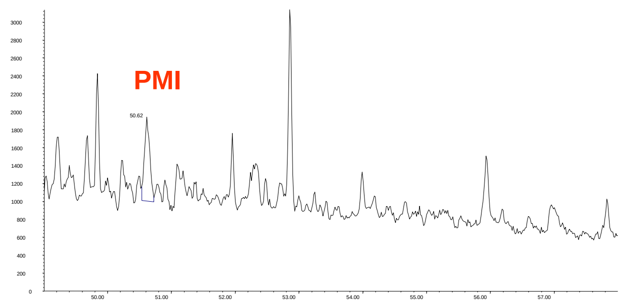
Geochemical Composition of kerogen

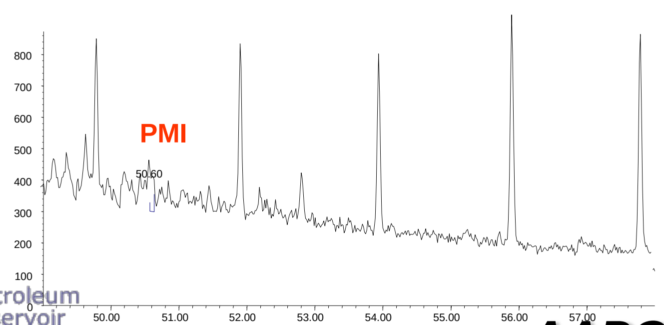
Interval	Age (Ma)	Well	Depth (m)	H/C	O/C	I_H	I_O	$\delta^{13}C_k$ (‰)	R_O (%)
K0-K3	0.8 | 1.7		114.5	0.49	0.20	48	97	-22.98	0.35
			315.1	0.61	0.19	18	76	-23.21	0.45
			205.0	0.66	0.23	38	60	-22.44	
			350.0	0.59	0.25	22	75	-20.98	
			520.0	0.95	0.16	46	149	-24.48	
			717.0	0.78	0.30	55	60	-22.60	0.41
K4-K10	1.8 | 2.5		973.0	1.06	0.25	151	68	-25.79	0.36
			1206.0	1.13	0.27	178	74	-27.35	0.33
			1422.0	0.98	0.24	129	60	-26.17	0.27
			1537.0	0.93	0.27	69	64	-25.95	0.47

PMI profile at Well L



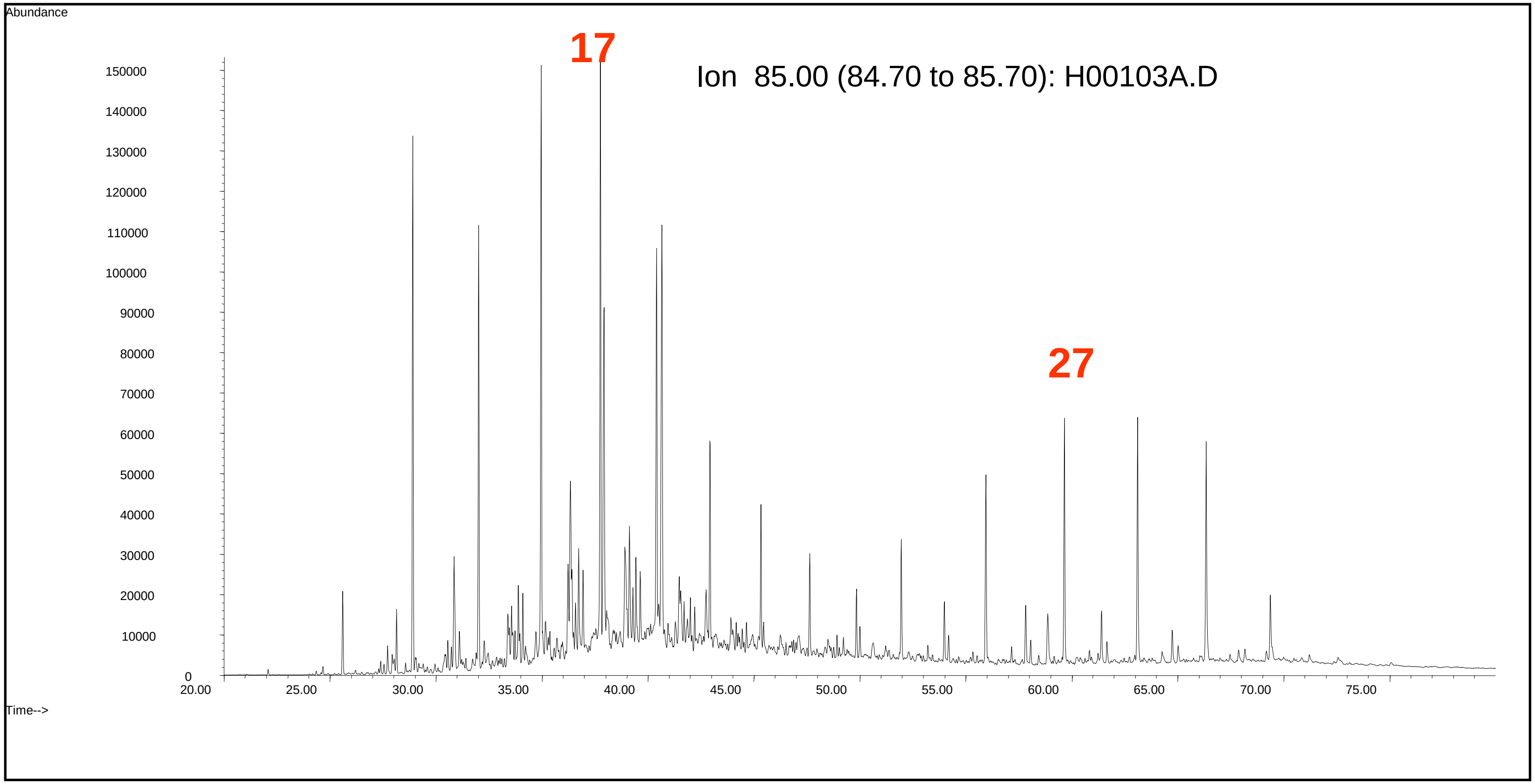






- 2,6,10,15,19-pentamethylicosane (PMI) is a specific biomarker for methanogen which has an origin from archaeal lipids.
- The abundance of these compounds indicates the intensity of methanogenesis

High concentration of LMW n-alkanes and strong odd over even predominance in HMW range



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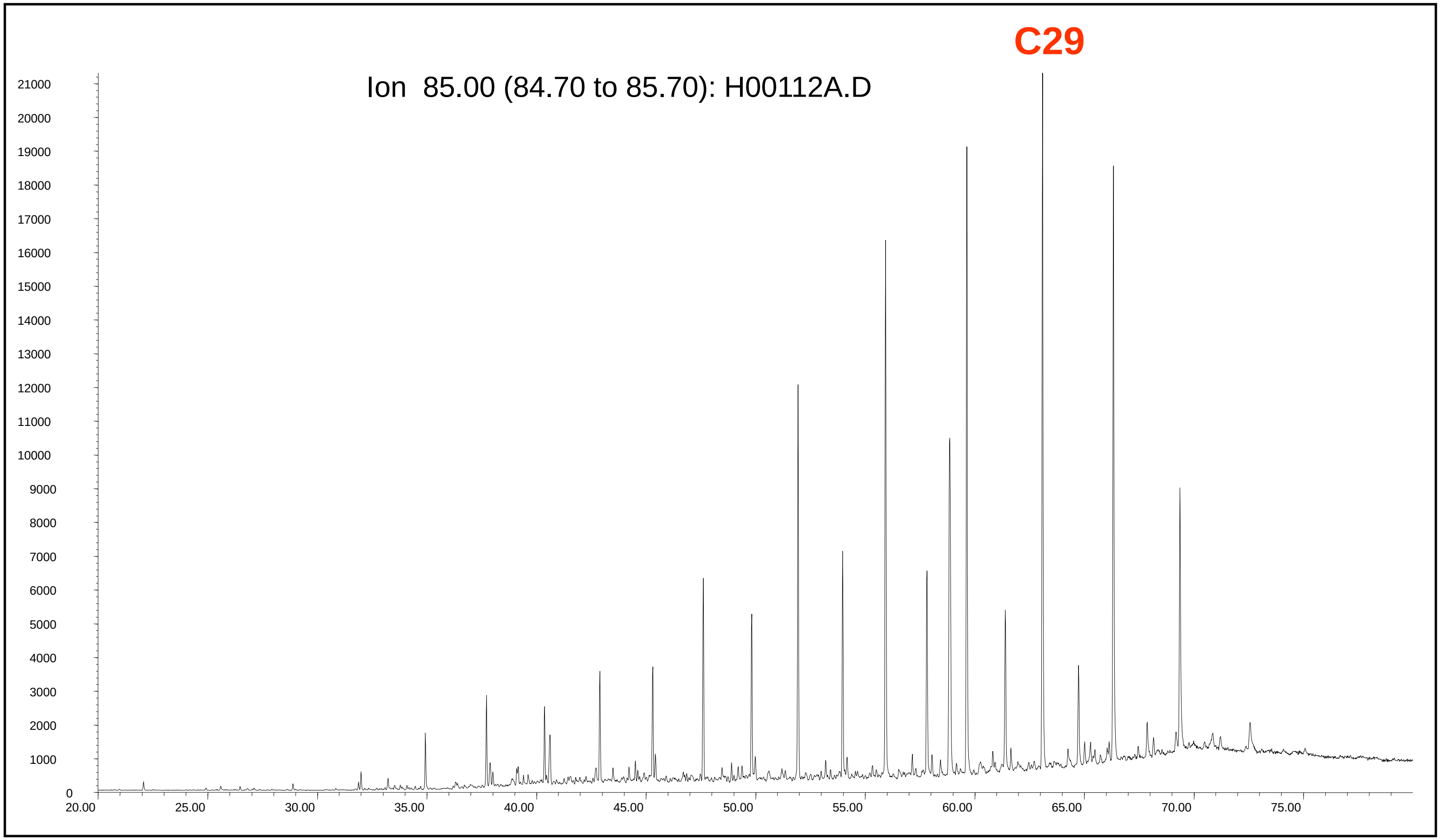
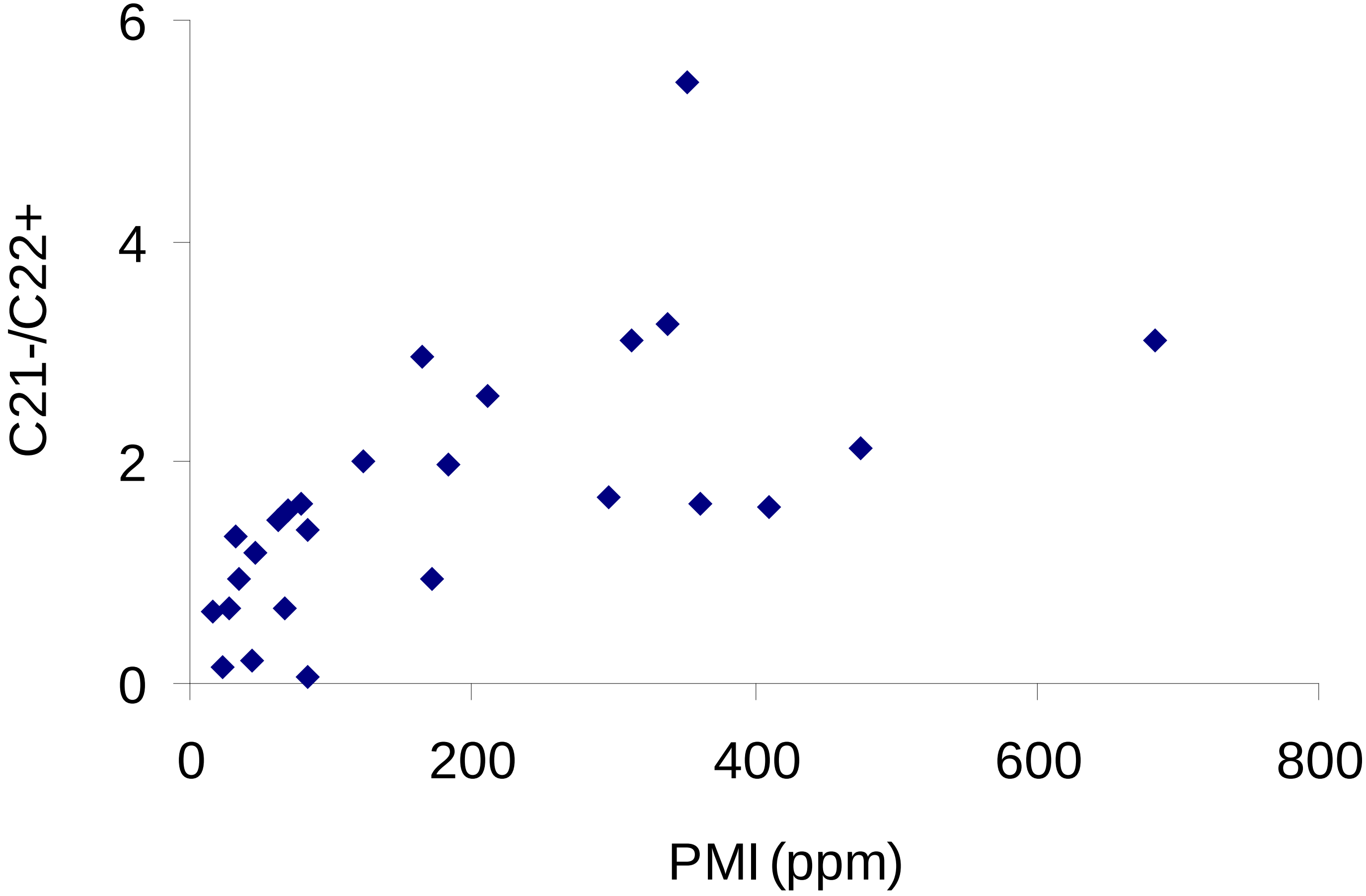
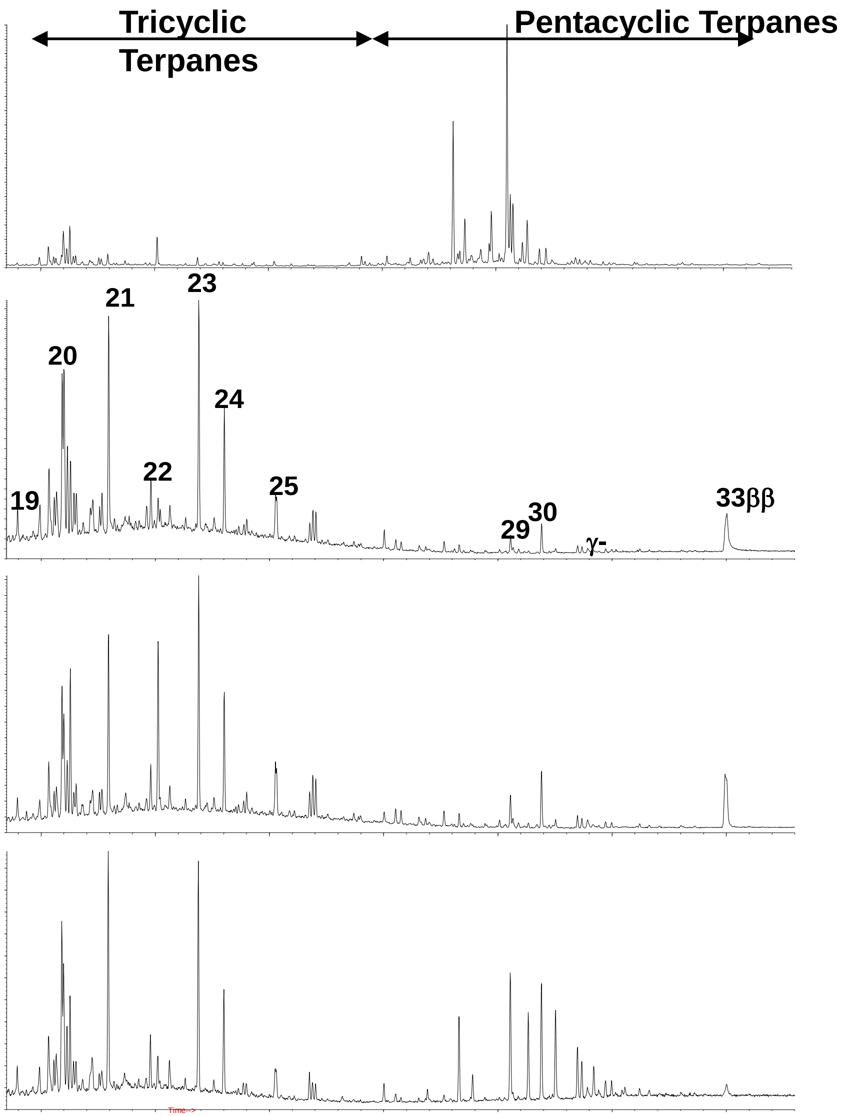
High plant dominated are non-source rock



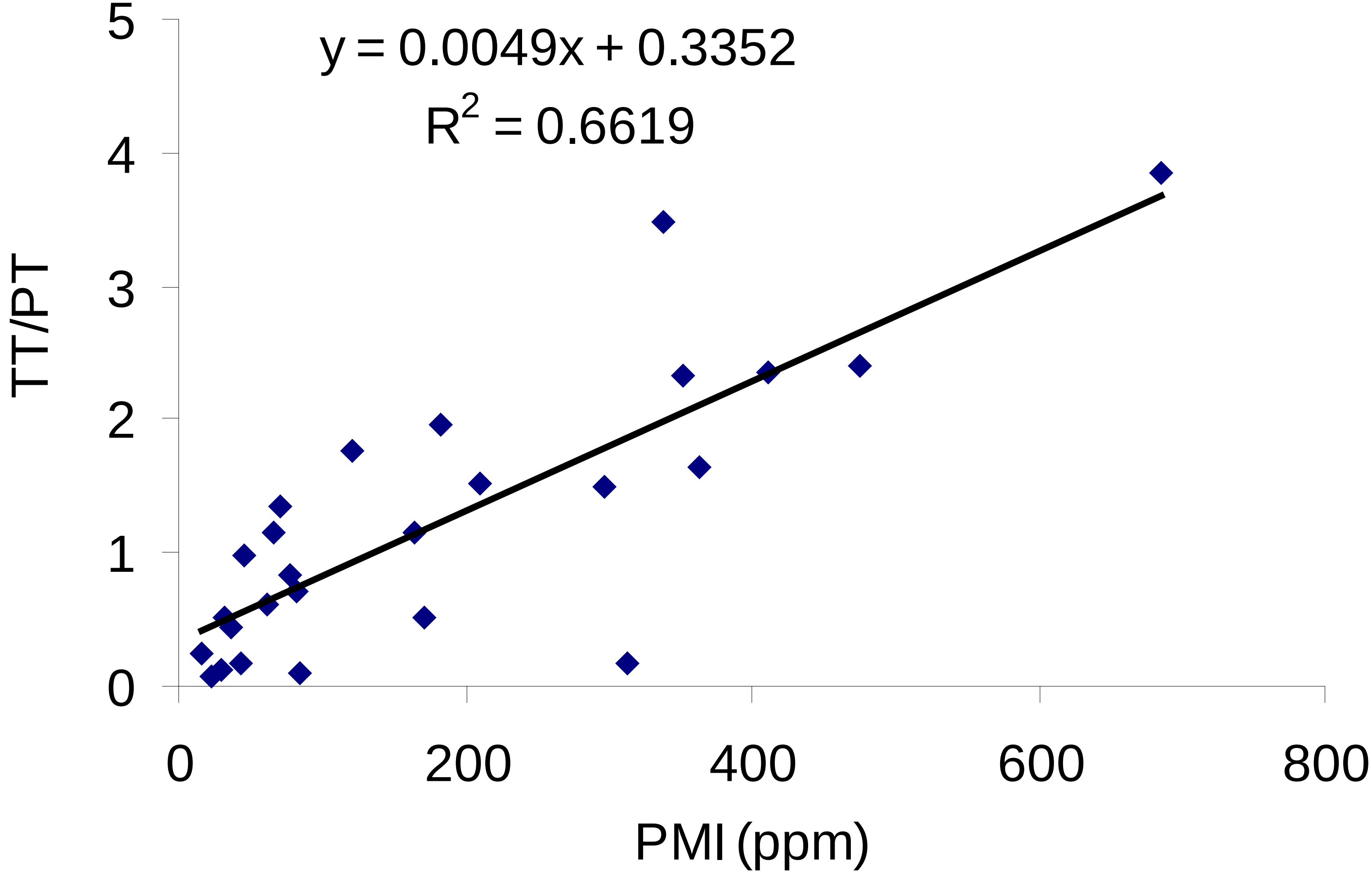
Correlation between PMI concentration and n-alkane distribution



Terpane distribution at Well L



Correlation between PMI concentration and terpane distribution



Summary of Geochemistry

- TOC levels as low as 0.3% in large volumes of mudstone support significant methanogenic activity in the studied area at optimal microbial activity temperature.
- Headspace gas profiles suggest that both CO2 reduction and acetate fermentation occur in the studied area with CO2 reduction dominating.
- Specific biomarkers used to diagnose methanogenesis activity from archaea indicate that biogenic gas is mainly derived from processing of lacustrine material rather than land plant detritus.

Conclusions

- Biogenic gas accumulation in the Qaidam Basin is a dynamic process, suggesting both charge and leaking are actively going on.
- The study indicates that with appropriate internal migration routes even lean shale packages can be commercial gas prospects.
- Biogenic source rock characterization is far more complicated than thermogeneic source rock system.

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