Characteristics and Hydrocarbon Sealing Capacity of the weathering mud layer in an unconformity

KONGYOU WU

CHINA UNIVERSITY OF PETROLEUM

School of Geoscience

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3. Identification of the Weathering Mud Layer
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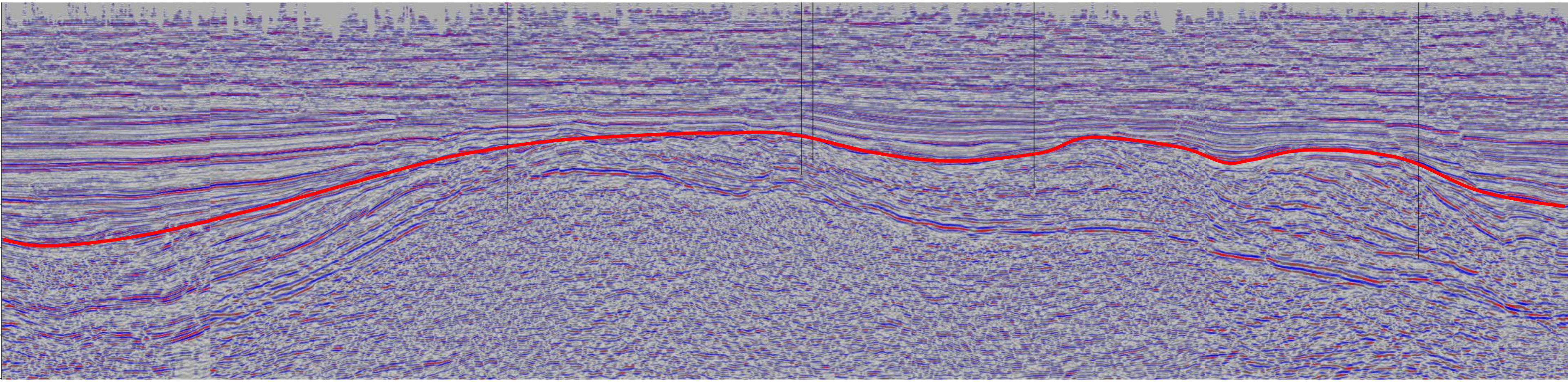
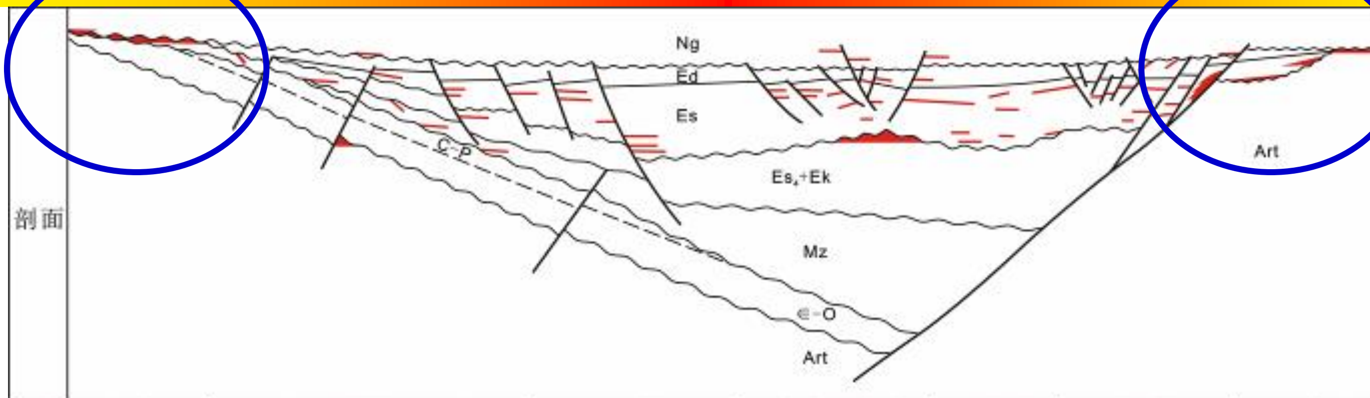
1.Introduction



As faults and folds, unconformity is also an important structure that plays important control on hydrocarbon migration and accumulation.

1.Introduction



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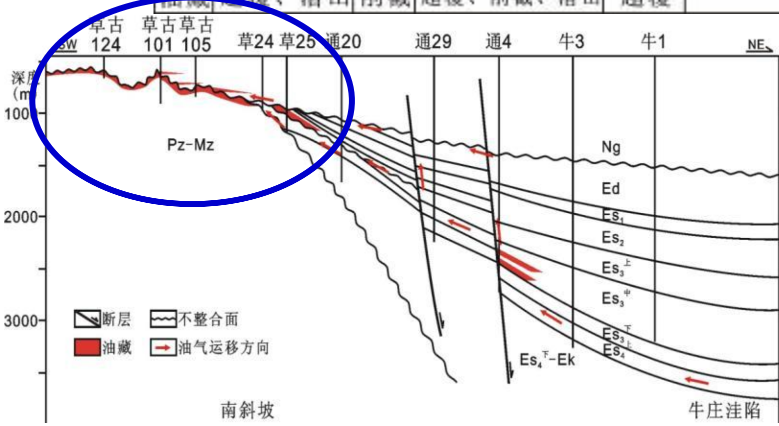
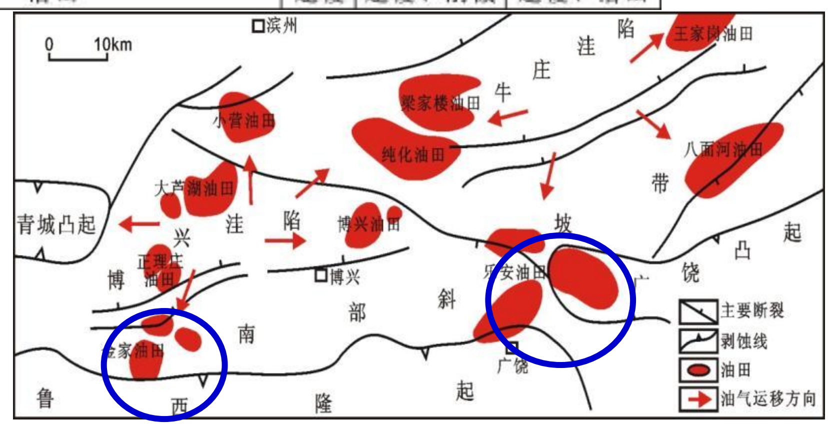
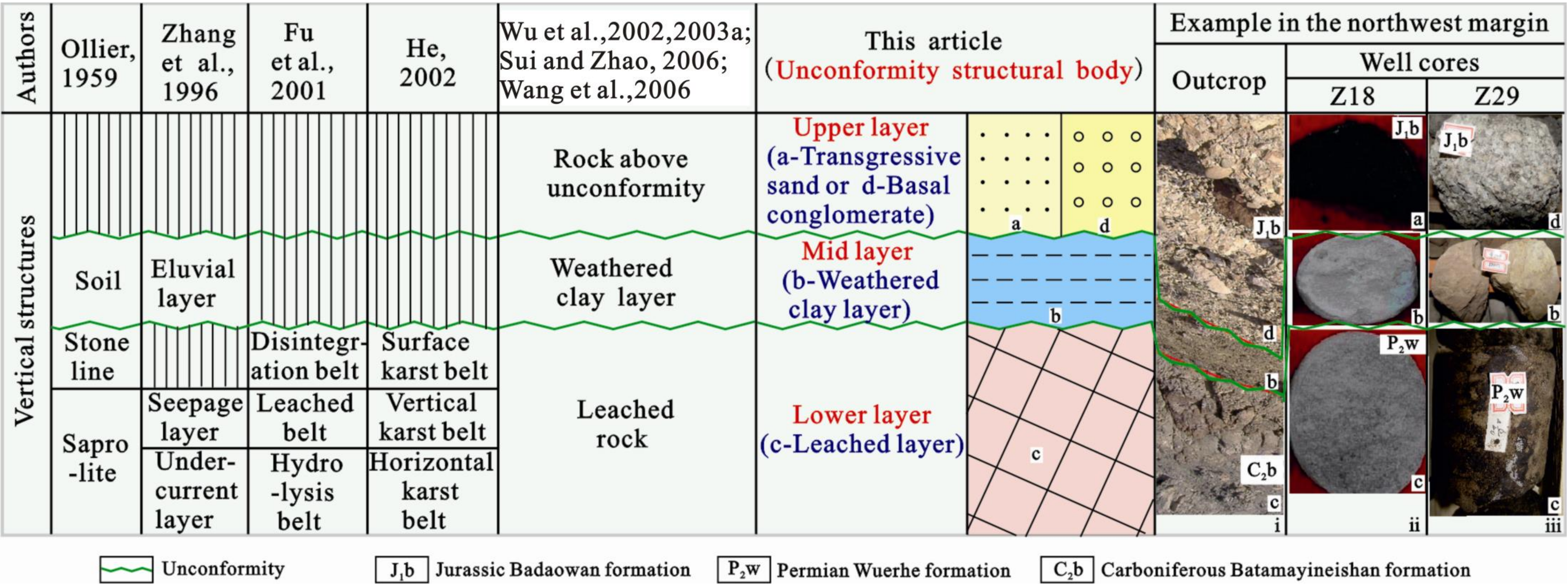




The unconformity-related reservoirs present high exploration potential because of its shallow burial depth and low exploration cost.

1.Introduction



Rocks exposed on the earth’s surface will be damaged by physical, chemical, or biologic weathering.

Thus, the unconformity formed the vertical structures. So an unconformity is not only a homogenous surface, but also a complex structural body。

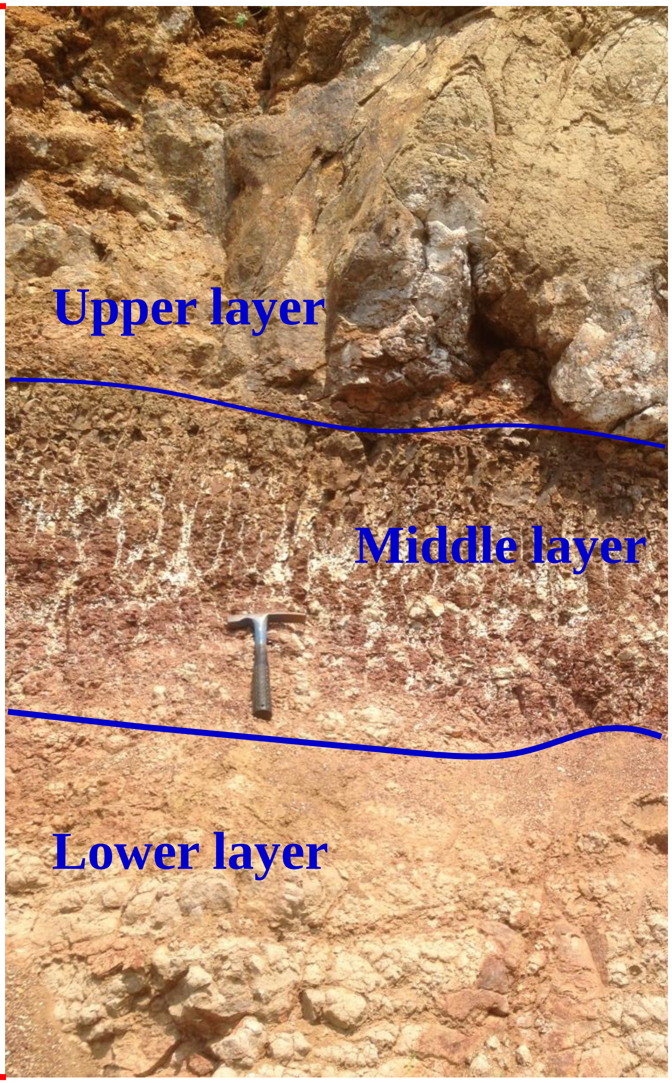
An unconformity can be vertically divided into upper, middle and lower layers.

1.Introduction

However, previous studies have primarily focused on the hydrocarbon migration and accumulation of the upper and lower layers（Peter J.J. Kamp,et al,1990; C.D. Oilier,et al,1990; Nicholas C.B,1990; J. San Romfin，et al,1992; Tom Dreyer,1994; D. A. Budd,et al,1996; A . Bosellini,et al, 1997; C.D. Ollier,et al,1997; G.M. Young,et al, 2009;Claudio M. F,et al,2011; Zhengle Chen, et al, 2011; Kari Strand,2012）, neglecting the importance of sealing capacity of the middle layer.

2.Characteristics of the Weathering Mud Layer

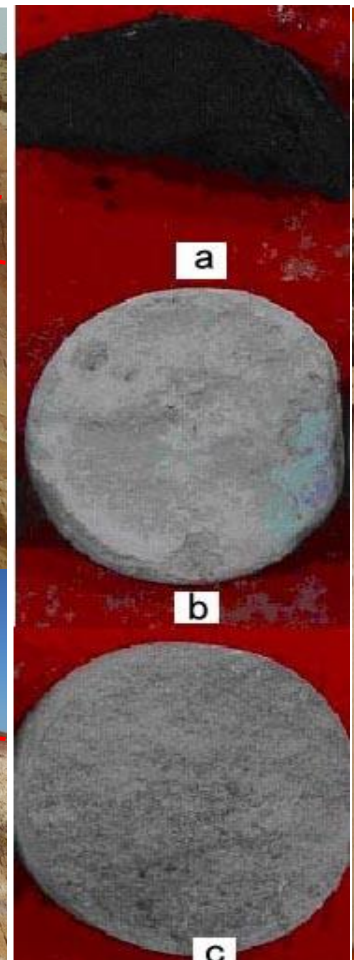
Unconformity structural body



The middle layer of an unconformity is weathering mud layer deposited due to the long term weathering.

2.Characteristics of the Weathering Mud Layer

A series of outcrop and core observations demonstrate that the weathering mud layer is usually red or grey because it contains ferrum or aluminium.



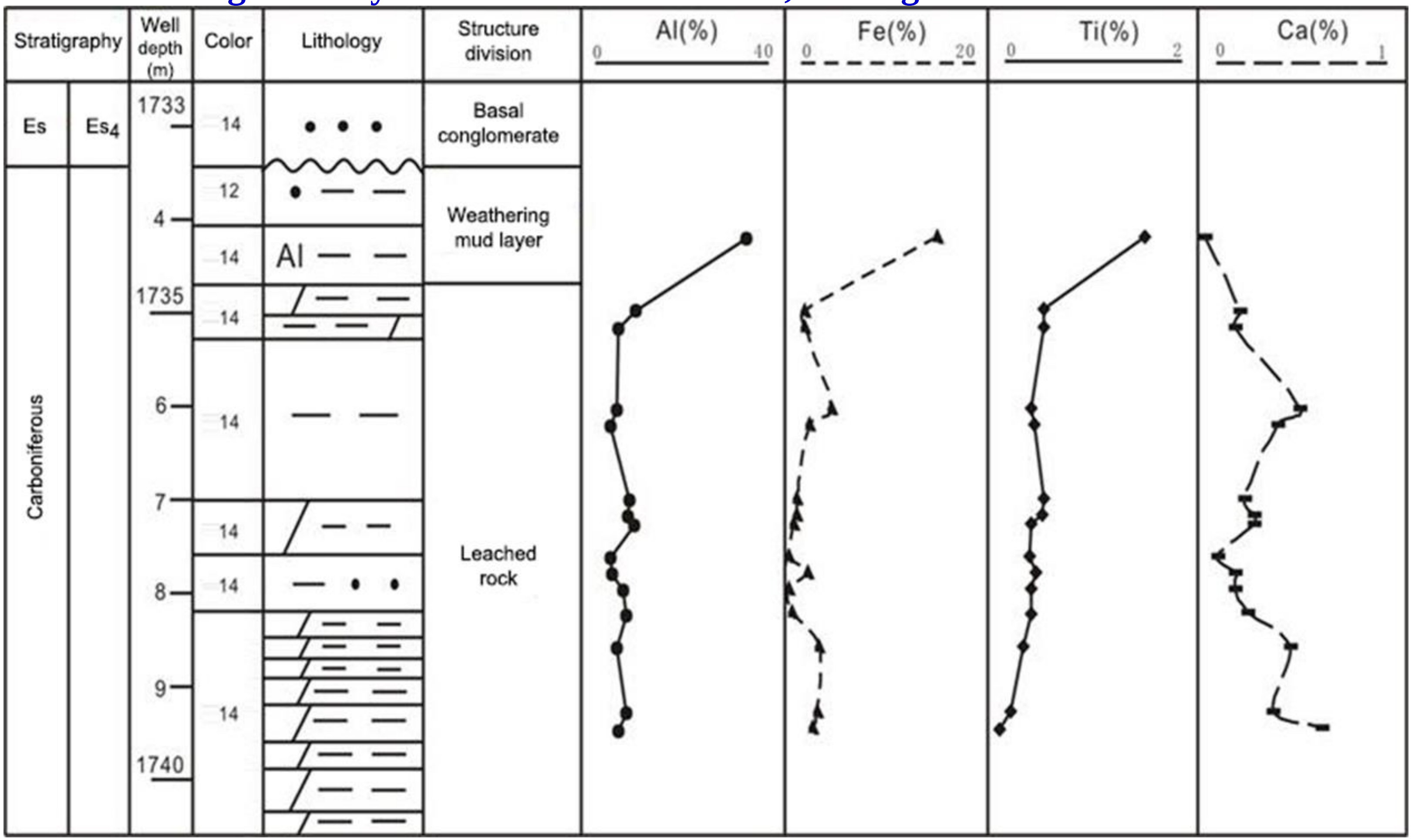
2.Characteristics of the Weathering Mud Layer

The middle layer is developed above water and does not present distinct sedimentary structures, so this layer presents no apparent bedding, no fossils. the middle layer is not easy to be recognized.

3.Identification of the Weathering Mud Layer

Due to the influence of weathering leaching and diagenesis , compared with normal mudstone, the content of O, Al, Fe, Ti and other elements which have strong resistance to weathering in the weathering mud layer are higher, and the content of Na, Mg, K are lower because of their weak resistance. The weathering mud layer contains no or less Ca, but high Ca is often found in normal mudstone.

Elements



3.Identification of the Weathering Mud Layer

A contrast of major elements between the weathering mud layer and normal mudstone

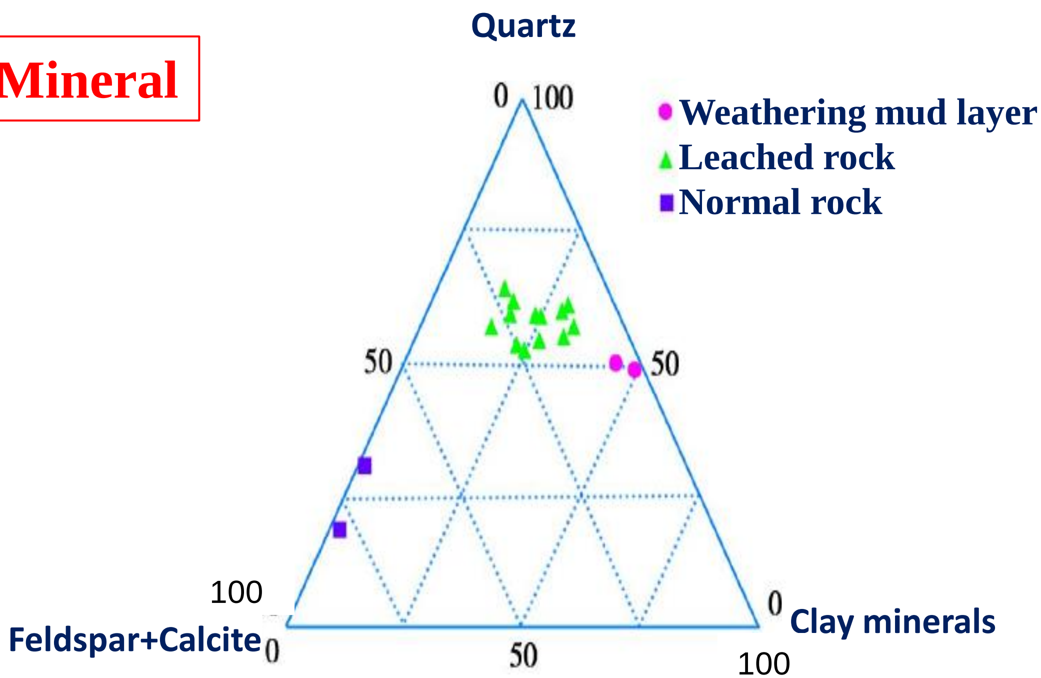
***Sample1：The weathering mud layer，gray，cementing loosely**
***Sample2：Normal mudstone，gray-black，cementing tightly**

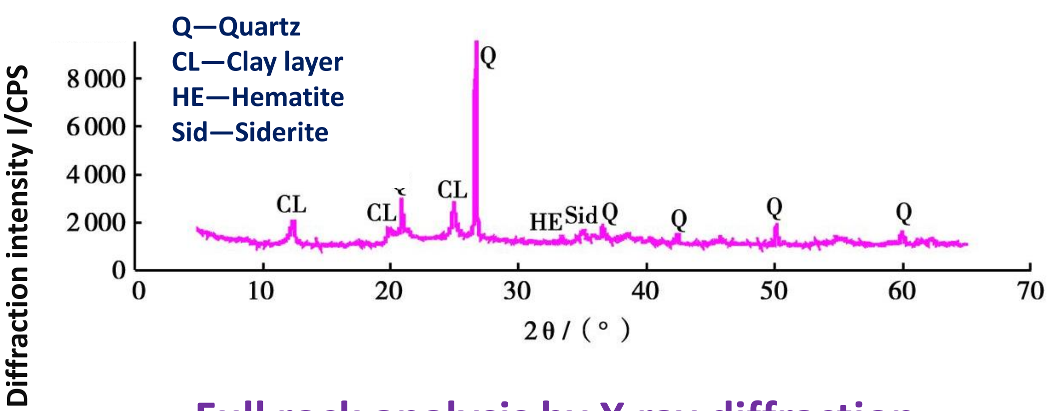
Elements

Stratigraphy	Lithology	Sample depth (m)	The percentage of major elements(%) O	Al	Si	K	Ca	Fe	Ti	Notes
($T_1 j$)		1978 (Sample 1)	60.36	10.10	23.58	0.64		4.87	0.45	The system resolution of sample analysis equipment is 60(eV)
($P_3 wt$)		2086 (Sample 2)	55.17	7.05	31.20	1.36	2.70	2.52		

3.Identification of the Weathering Mud Layer

Mineral

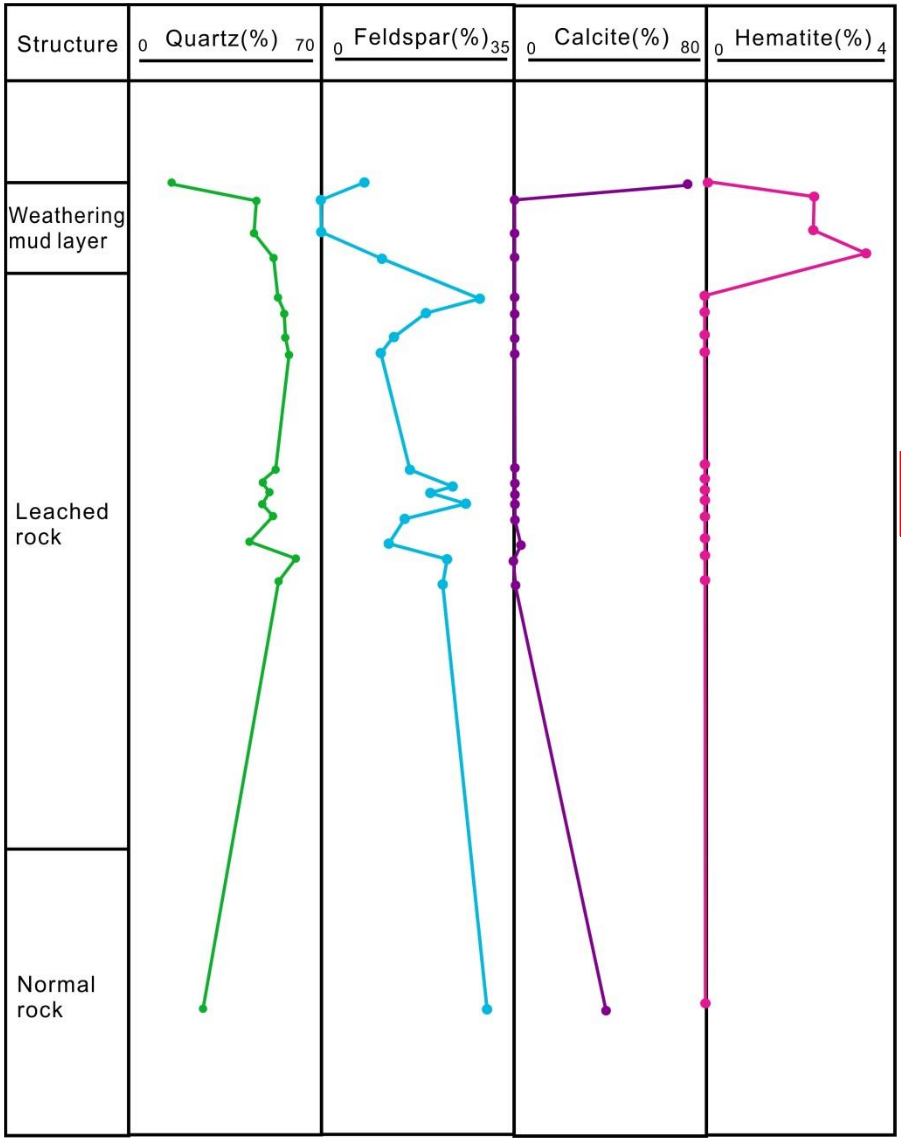




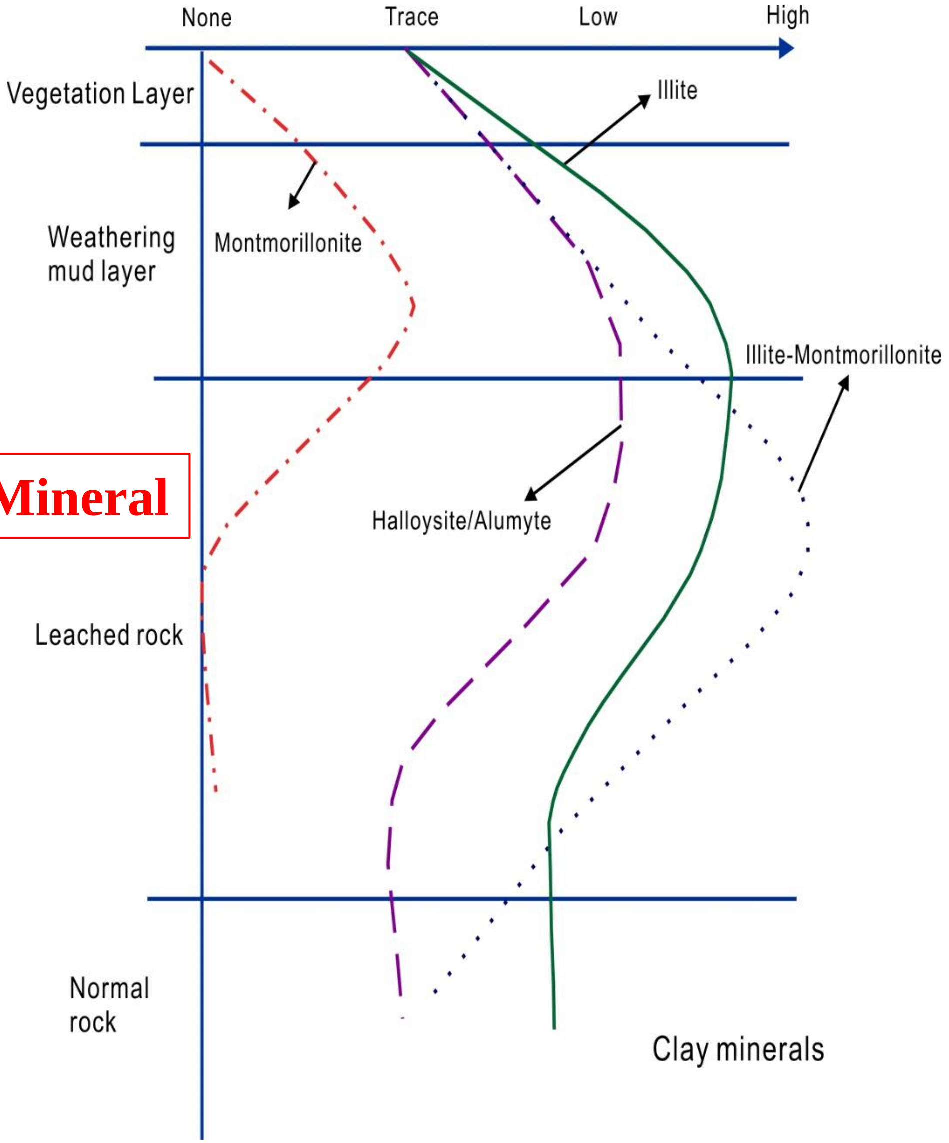
Full rock analysis by X ray diffraction

The mineral components are mainly quartz and clay minerals , which account for more than 90% of the total mineral content, and are basically free of feldspar, calcite. Ferric oxides—hematite、goethite are enriched.

3.Identification of the Weathering Mud Layer

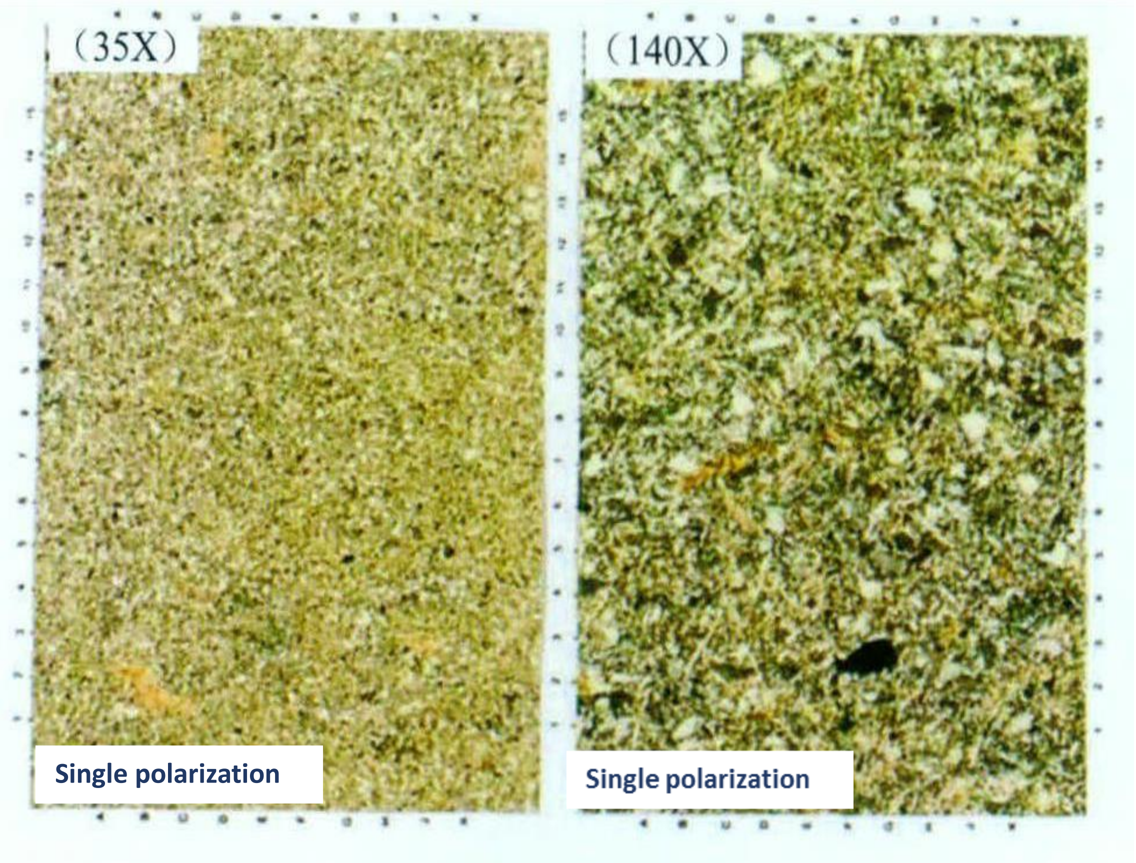


Mineral



3.Identification of the Weathering Mud Layer

Microscopic identification： **Mineral components are mainly clay minerals which are recrystallized and fibrotic, and contain quartz, feldspar silt particles, part of mudstone has chloritization.**



3.Identification of the Weathering Mud Layer

Weathering index: The degree of leaching and enrichment of elements in weathering process is different.

Index	Computational Formula	Unweathered	Weathered	Data Source
R	$w(SiO_2)/w(Al_2O_3)$	>10	0	Ruxton(1968)
I_{WP}	$100\times[(2w(Na_2O)/0.35)+(w(MgO)/0.90)+(2w(K_2O)/0.25)+(w(CaO)/0.70)]$	>100	0	Parker(1970)
V	$(w(Al_2O_3)+w(K_2O))/(w(MgO)+w(CaO)+w(Na_2O))$	<1	∞	Roaldset(1972)
I_{CA}	$100\times[w(Al_2O_3)/(w(Al_2O_3)+w(CaO)+w(Na_2O)+w(K_2O))]$	$\leqslant 50$	100	Nesbitt(1982)
I_{CW}	$100\times[w(Al_2O_3)/(w(Al_2O_3)+w(CaO)+w(Na_2O))]$	$\leqslant 50$	100	Hamois(1988)
I_{PA}	$100\times[(w(Al_2O_3)-w(K_2O))/(w(Al_2O_3)+w(CaO)+w(Na_2O)-w(K_2O))]$	$\leqslant 50$	100	Fedo(1995)
I_{ST}	$100\times[(w(SiO_2)/w(TiO_2))/((w(SiO_2)/w(TiO_2))+(w(SiO_2)/w(Al_2O_3))+(w(Al_2O_3)/w(TiO_2)))]$	>90	0	Jayawardena(1994)

3.Identification of the Weathering Mud Layer

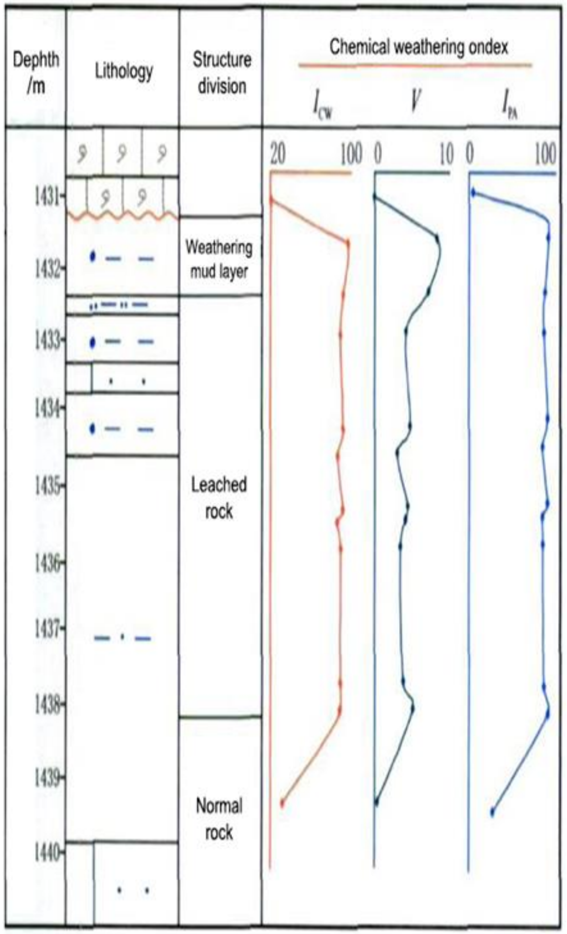
Compared to normal mudstone, the weathering mud layer has higher I_{CA}, I_{CW}, and I_{PA}, lower I_{WP}

Unconformity structural body	Chemical weathering index				
	I_{CA}	V	I_{CW}	I_{PA}	I_{WP}
Leached rock	80.30	2.36	84.10	75.70	17.65
Leached rock	84.52	2.61	89.16	79.33	14.44
Leached rock	80.03	2.58	84.49	74.76	13.22
Leached rock	80.86	2.60	85.61	75.31	12.91
Normal rock	3.25	0.04	3.26	3.02	132.06
Normal rock	6.34	0.07	6.38	5.66	113.72
Weathering mud layer	97.12	50.96	98.27	98.25	12.92
Leached rock	88.81	4.84	93.98	93.61	18.30
Leached rock	80.64	3.95	91.21	89.89	23.55
Leached rock	87.28	5.15	90.66	90.28	15.52
Leached rock	87.14	6.11	91.67	91.22	15.27
Leached rock	86.21	4.95	88.90	88.54	17.89
Leached rock	77.58	3.64	91.96	90.13	24.22
Leached rock	87.54	6.54	90.79	90.44	13.19
Leached rock	77.79	5.75	88.94	87.09	29.66

Carbonate rock

Unconformity structural body	Chemical weathering index				
	I_{CA}	V	I_{CW}	I_{PA}	I_{WP}
Weathering mud layer	76.86	8.21	92.53	90.62	34.98
Weathering mud layer	72.83	7.14	91.22	88.26	35.60
Leached rock	73.92	4.16	88.18	85.36	28.20
Leached rock	78.03	3.01	85.73	84.16	19.33
Leached rock	84.13	4.37	90.45	89.67	14.32
Leached rock	79.88	4.09	85.14	84.09	23.95
Leached rock	69.82	3.43	88.81	84.63	49.15
Leached rock	75.24	3.76	88.23	85.78	39.86
Leached rock	71.47	3.11	83.65	82.49	22.03
Leached rock	70.80	3.53	84.45	83.00	21.22
Normal rock	29.84	0.34	31.72	27.12	100.00

Clastic rock

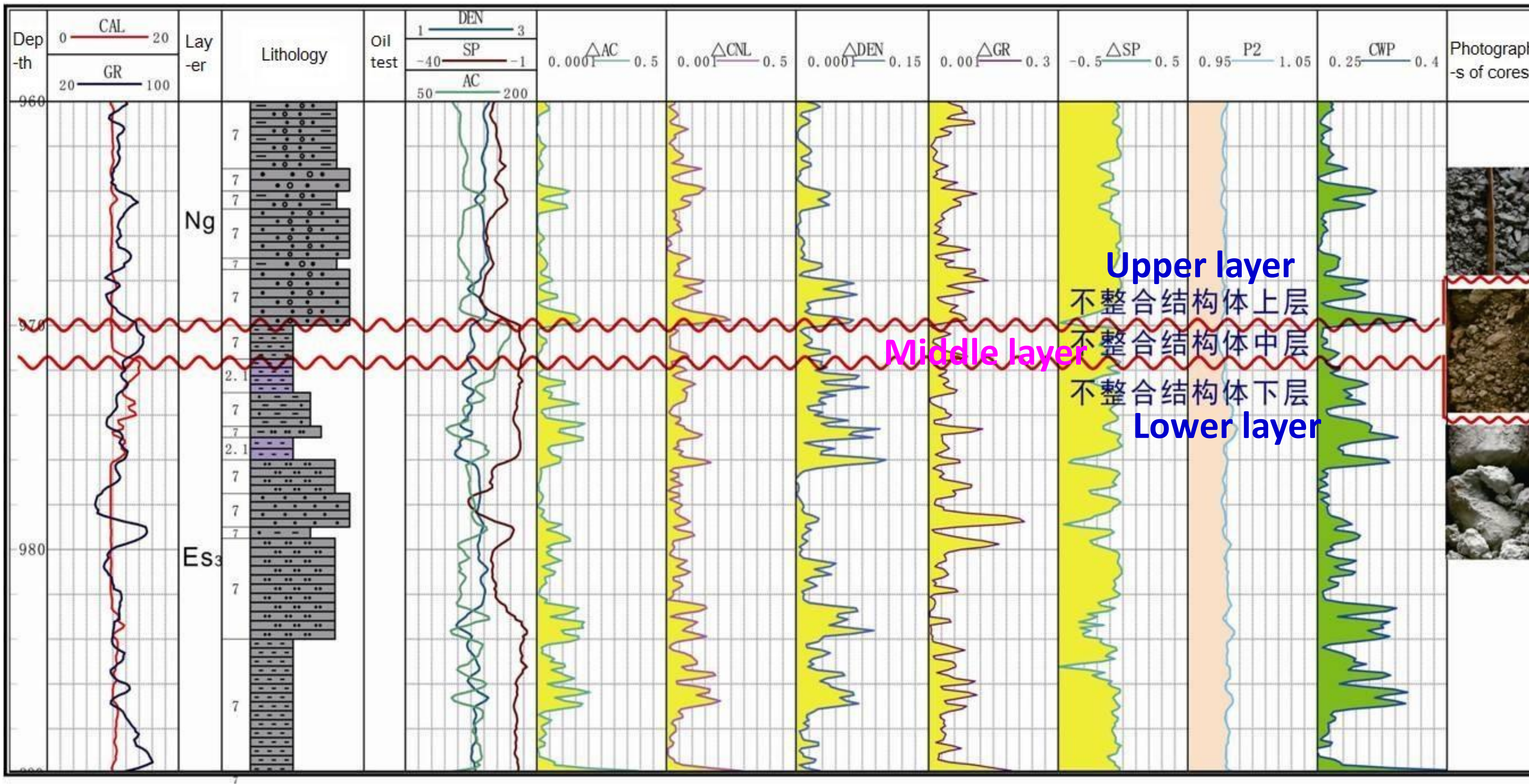


3.Identification of the Weathering Mud Layer

well log

Compared to normal mudstone, it has lower GR response.

GR is lower than normal mudstone； SP is low amplitude positive anomaly; CAL appears expanding; AC is median value; Low R and low DEN; LLD and LLS curves are near "box", and there is no amplitude difference between them.



4.Development Model of the Weathering Mud Layer

The main controlling factors of development

1.Time: Generally speaking, the longer the weathering takes place, the deeper the rock layers transform; the higher the weathering degree is, the more favorable it is to the formation of the weathering mud layer.

2. Lithology of parent rocks: The carbonate rock, mudstone and magmatic rock are easy to weathering and form the weathering mud layer. The weathering resistance of sandstone and metamorphic rock are strong and it is difficult to form the weathering mud layer.

3. Paleogeomorphology: Due to the erosion and scouring effect of uplift belt and steep slope belt are strong, the weathering crust rocks, especially the weathering mud layers, are difficult to preserve. It is easy to form the weathering mud layer in gentle slope belt because of its flat terrain and good preservation condition.

4.Development Model of the Weathering Mud Layer

The main controlling factors of development

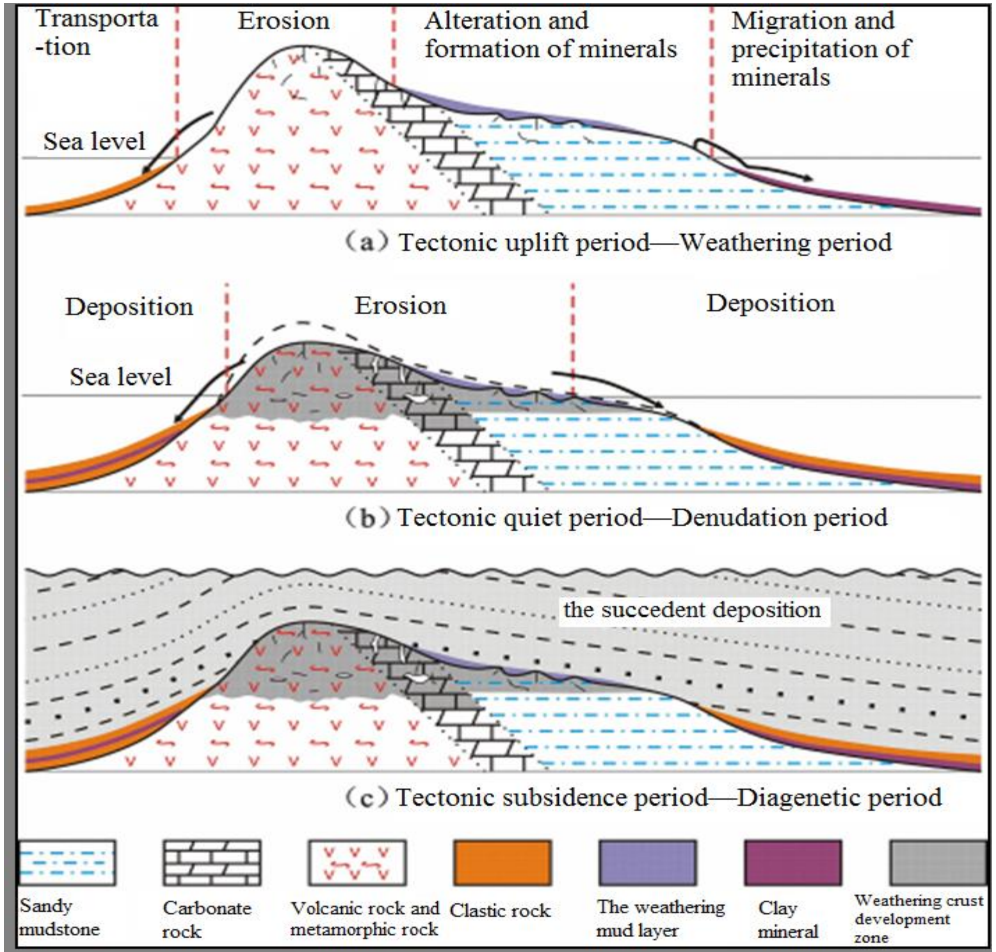
4. Paleohydrodynamic: It is good for the preservation of the weathering mud layer in the weak hydrodynamic conditions. Most of the weathering mud layers are eroded in the strong hydrodynamic conditions.

5. Paleoclimate: Generally, high temperature and rainy climate conditions are beneficial to the rapid leaching of soluble and weathered components, and in favor of the infiltration of surface water, the weathering degree of rocks is high, it is easy to form the weathering mud layer.

Wells	Unconformity	Roof lithologic	Parent rock	Time of depositi-onal hiatus	Unconformity structure	Degree of weathering
Z362	Es_1/AnZ	Silty mudstone	Gneiss	533.3Ma	Undeveloped the weathering mud layer	Strong
Z606	Es3/AnZ	Sandstone	Gneiss	523Ma	Undeveloped the weathering mud layer	Medium
Z363	Es1/AnZ	Microconglomer-ate	Gneiss	533.3Ma	Undeveloped the weathering mud layer	Weak

4.Development Model of the Weathering Mud Layer

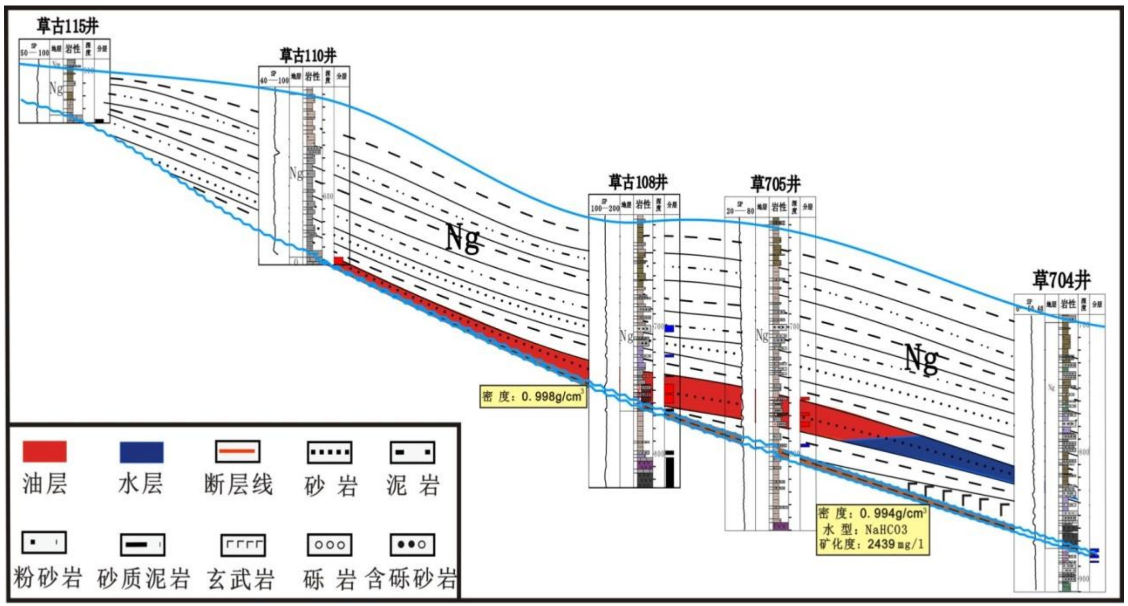
uplift belt → steep slope belt →depression belt, there is obvious difference in the weathering degree of rocks

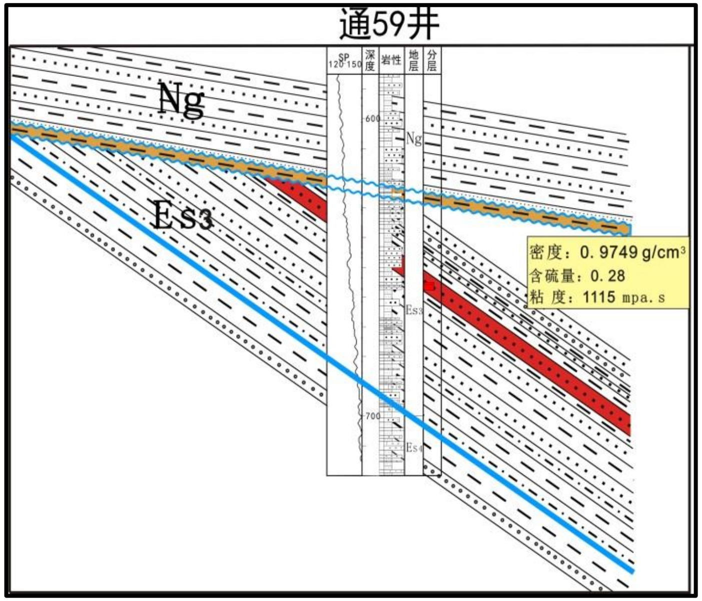


The formation process of unconformity structure

5.Sealing Action of the Weathering Mud Layer

The middle layer can present low porosity and permeability after the subsequent vertical compaction. Therefore, it can usually perform as base rock for its top reservoir or cap rock for its underlying reservoir, playing critical control on the development of unconformity-related reservoirs.





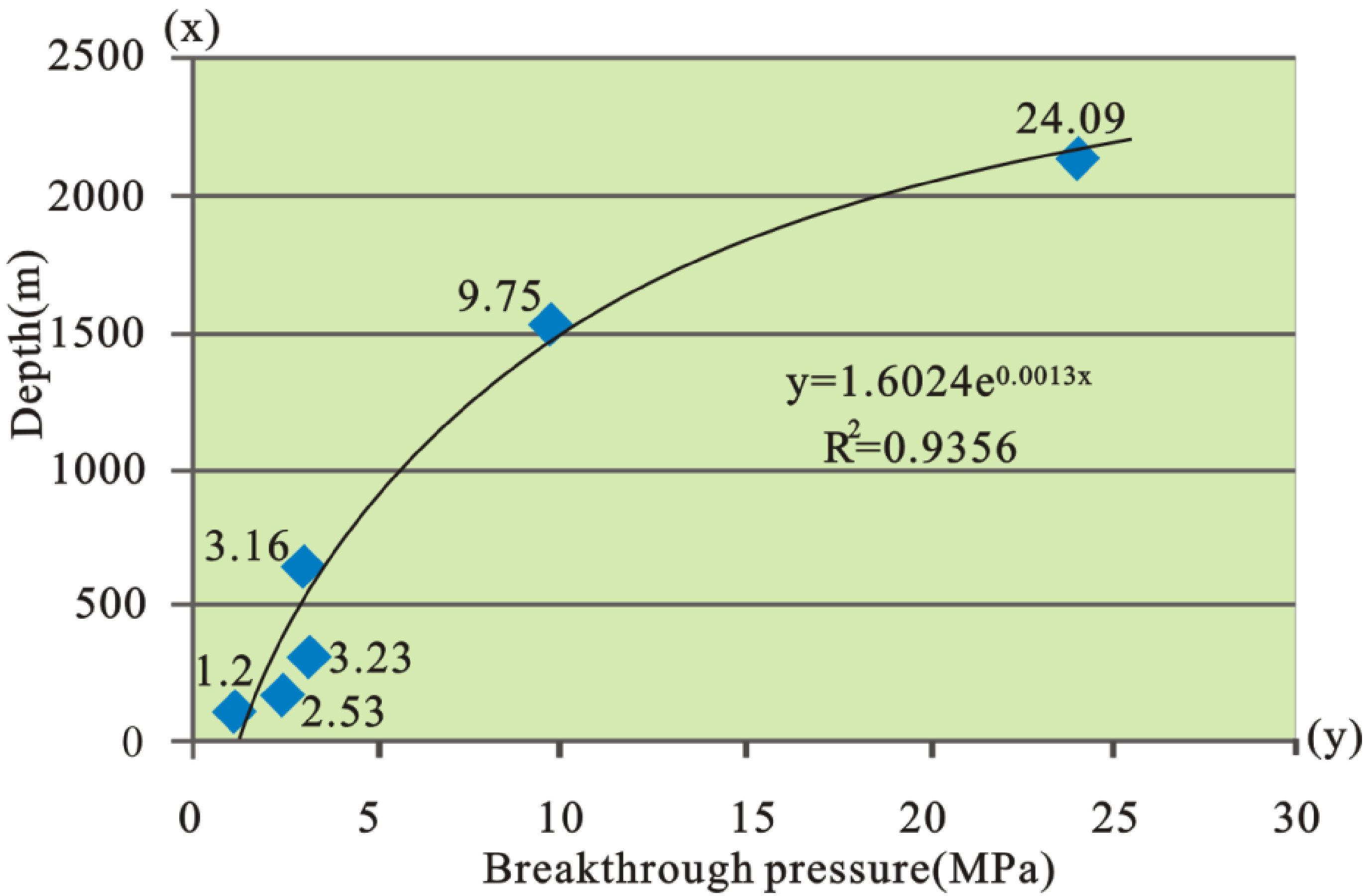
5.Sealing Action of the Weathering Mud Layer

The breakthrough pressure tests of sampled cores suggest that there is a positive correlation between the sealing capacity of wreathing mud layer and its burial depth.

Number of Sample	Unconformity	Depth	Breakthrough pressure	Breakthrough radius	Median pressure	Median radius	Gas column height	Sealing ratio
		(m)	(MPa)	(nm)	(MPa)	(nm)	(m)	(%)
T-001	K/J	247.0	0.337	422.910	0.950	150.208	33.75	67.49
T-002	J/P	110.0	1.198	119.145	2.832	50.401	119.79	239.57
T-003	K/J	134.0	0.861	165.828	2.484	57.458	86.06	172.13
T-004	J/P	167.5	2.528	56.462	6.912	20.649	252.77	505.53
T-005	K/J	304.2	3.230	44.185	7.270	19.630	323.00	646.01
T-007	J/T	1457.2	8.954	15.939	28.268	5.049	895.38	1790.75
T-008	K/J	374.0	1.214	117.555	3.140	45.446	121.41	242.81
T-009	J/C	495.0	0.960	148.733	6.121	23.316	95.96	191.91
T-010	J/T	2125.0	24.099	5.922	61.516	2.320	2409.86	4819.72

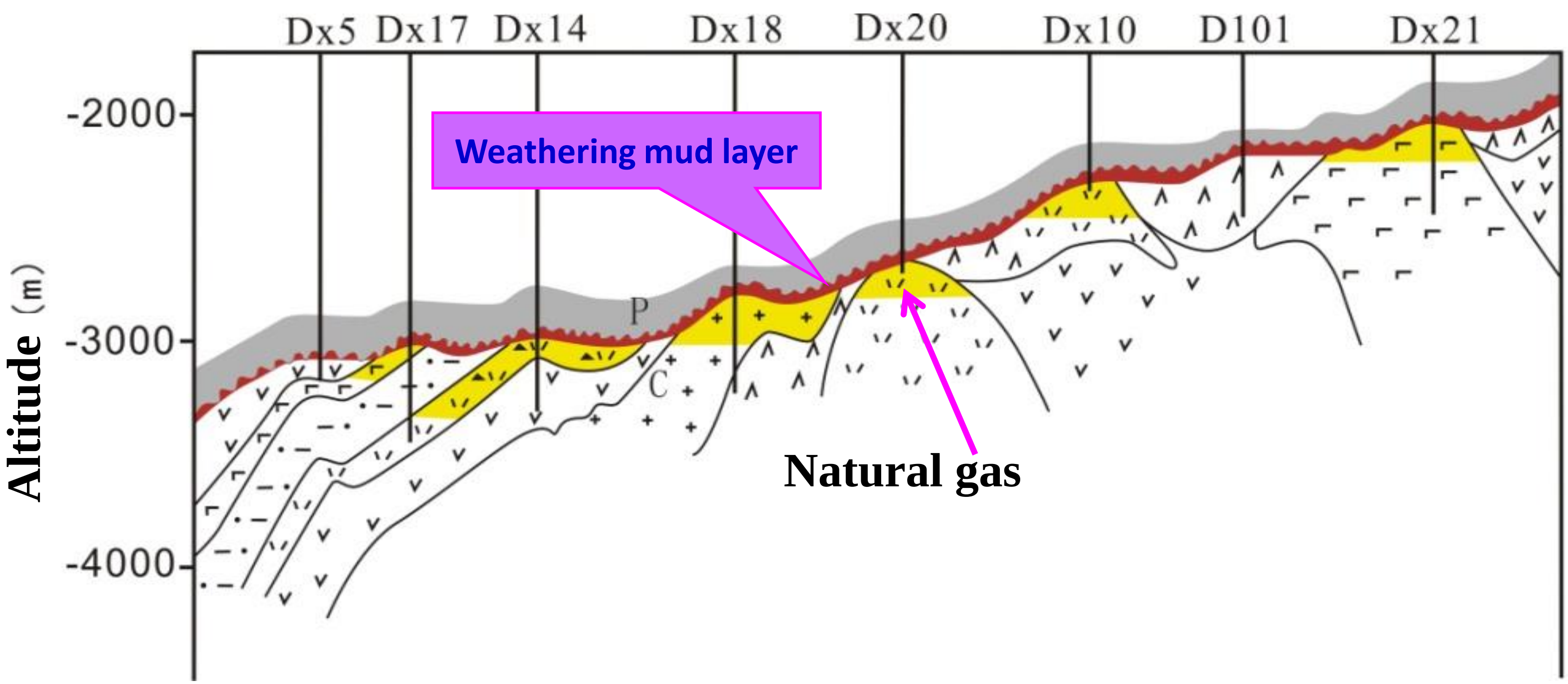
5.Sealing Action of the Weathering Mud Layer

The breakthrough pressure tests of sampled cores suggest that there is a positive correlation between the sealing capacity of wreathing mud layer and its burial depth.



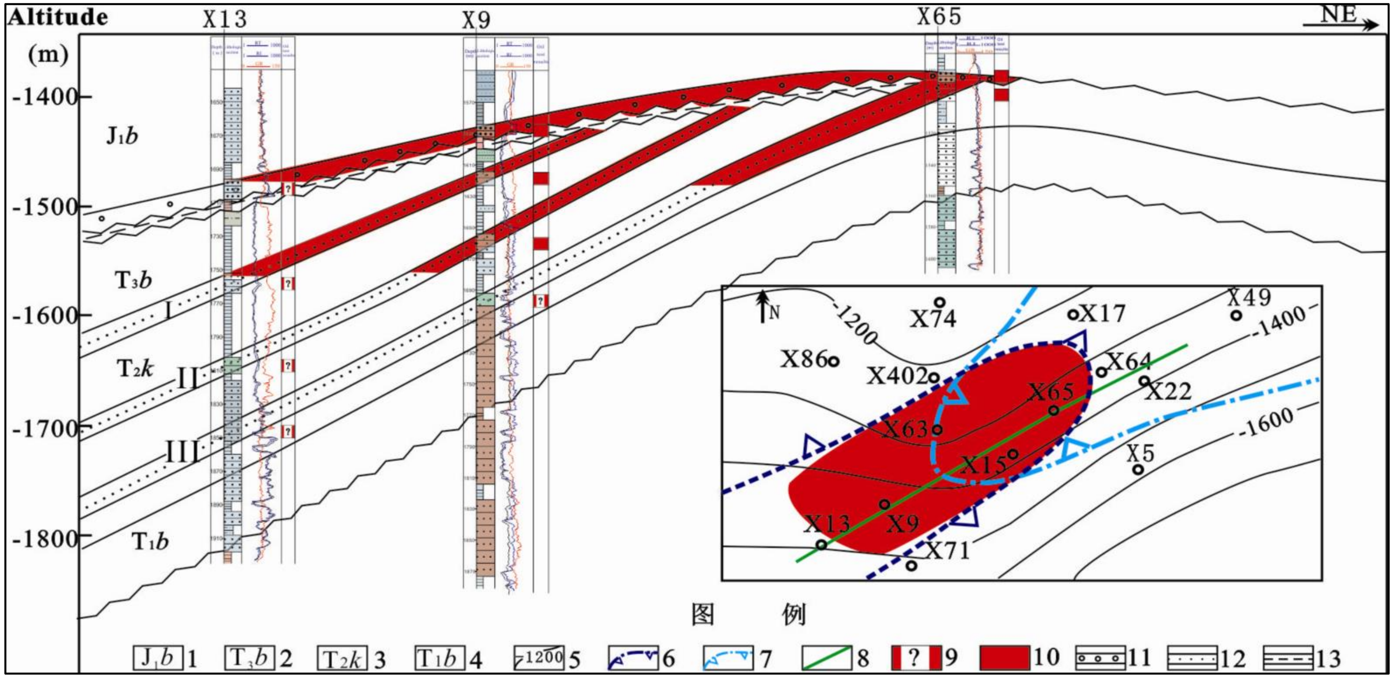
5.Sealing Action of the Weathering Mud Layer

The weathering mud layer can play the role of cap rock to hydrocarbon accumulation.
It's thickness is usually 0 to 10 meters, and the maximum thickness can be up to 30 meters.



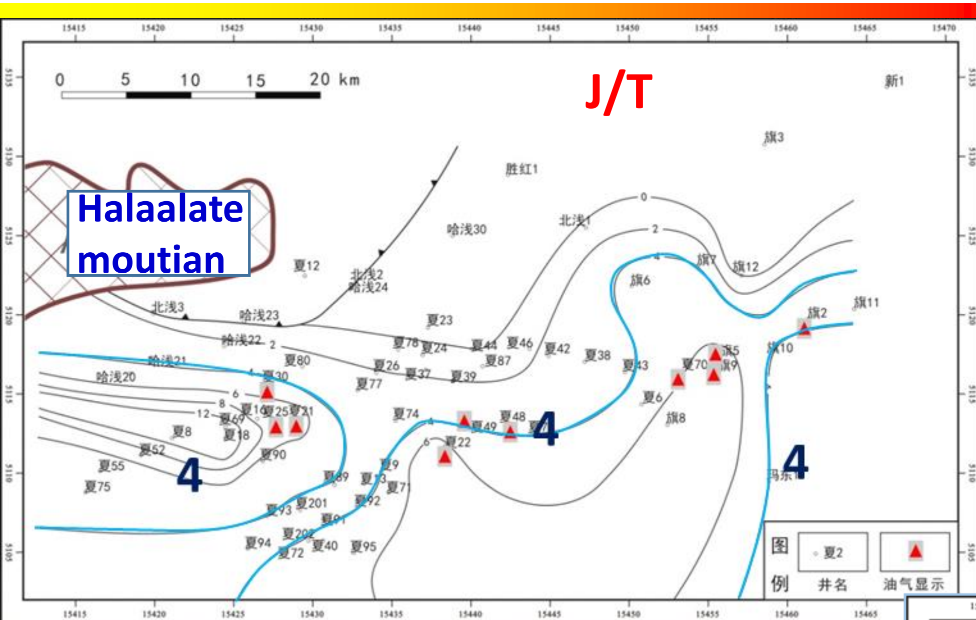
5.Sealing Action of the Weathering Mud Layer

Three sand bodies (I, II, III) in the Triassic system were filled with oil . The III sand body is consistent with the Jurassic Badaowan Formation. Drilling results showed that the thickness of the weathering mud layer in X13 well is 8 m, X9 well is 6.7 m, and X65 well is 0 m, so the Jurassic basal conglomerate directly connects with the Triassic III sand body . I and II sand bodies of the Triassic Karamay Formation have the low oil-water interfaces, and formed independent reservoirs because there is the weathered clay layer to cover.



1-Jurassic Badaowan Formation, 2-Triassic Baijiantan Formation, 3-Triassic Karamay Formation, 4-Triassic Baikouquan Formation, 5-Structural contours of Jurassic bottom, 6-Onlap pinchout line of Jurassic conglomerate, 7-Erosive pinchout line of Triassic Baijiantan Formation, 8-Location of the section line, 9-Possible oil-bearing layer, 10-Oil-bearing layer, 11-Conglomerate stone, 12-Sand stone, 13-Mud stone.

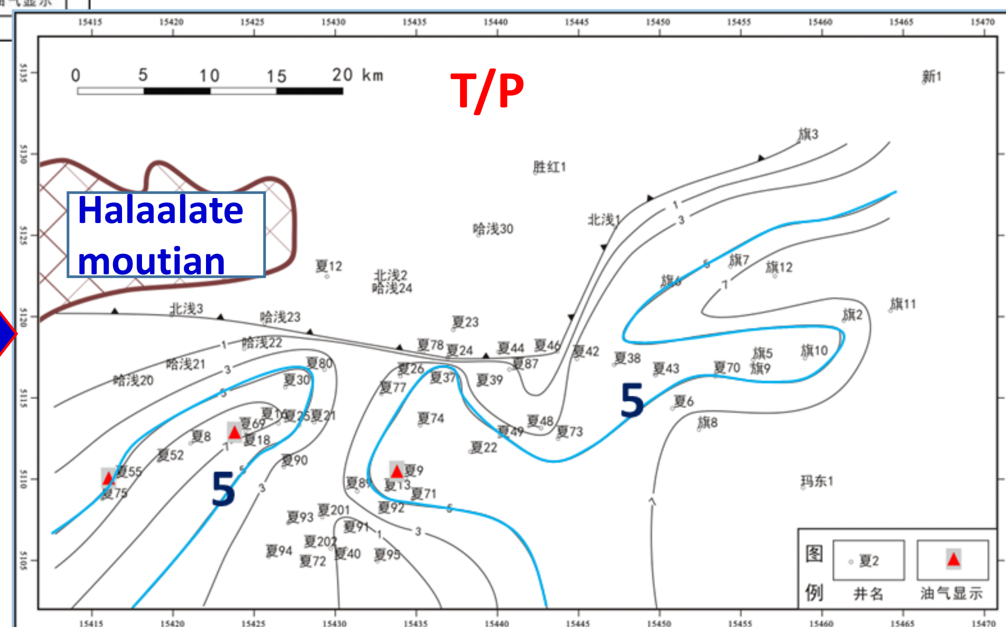
5.Sealing Action of the Weathering Mud Layer



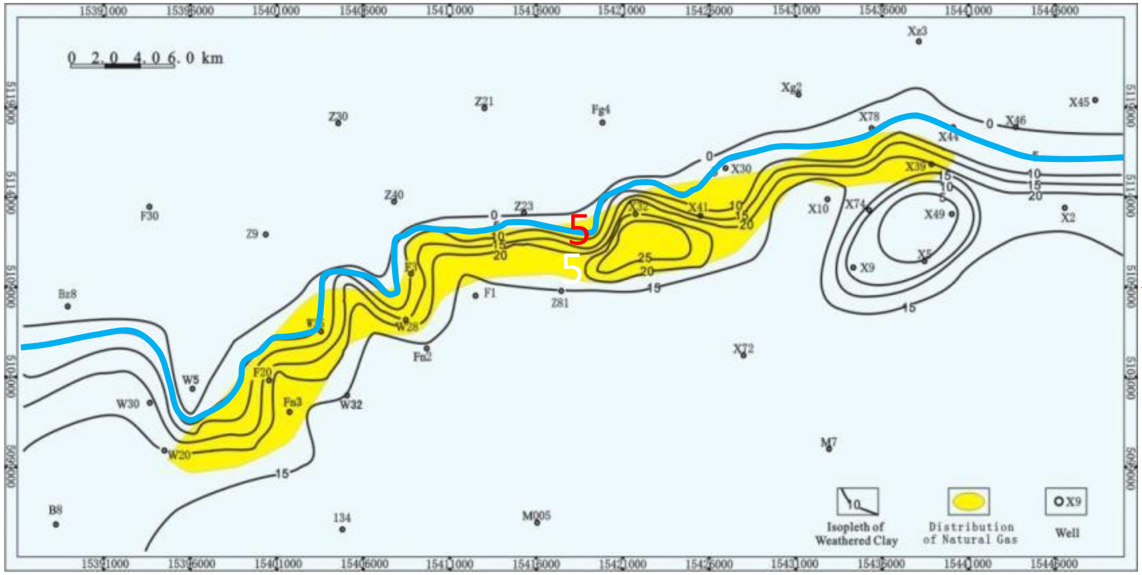
Xiazijie region in Junggar Basin

The thickness of weathering mud layer between Jurassic and Triassic system more than 4 meters can seal effectively the oil.

The thickness of weathering mud layer between Triassic and Permian system more than 4 meters can seal effectively the oil.

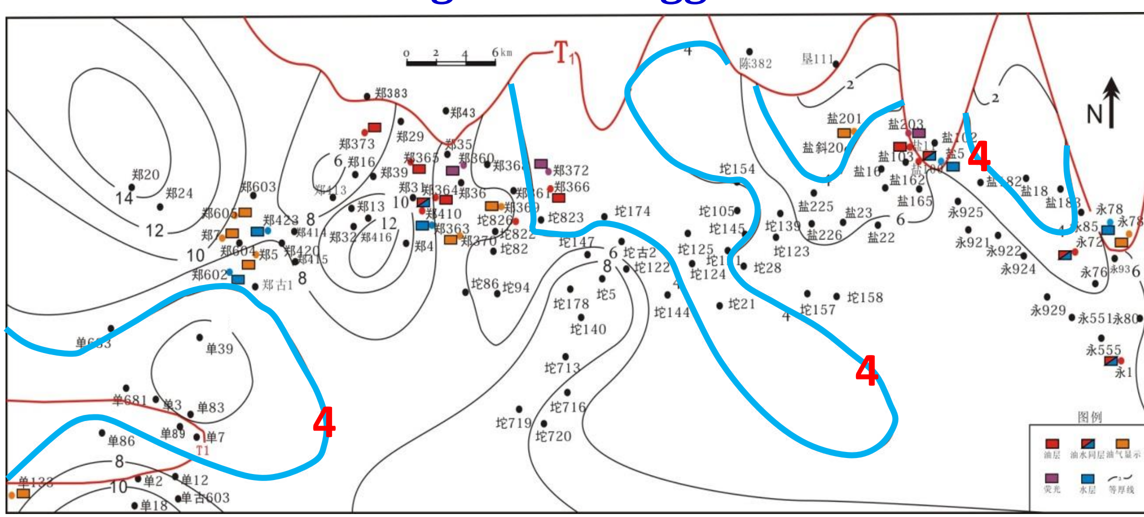


5.Sealing Action of the Weathering Mud Layer



Wuerhe region in Junggar Basin

The thickness of weathering mud layer between Triassic and Permian system more than 5 meters can seal effectively the gas.



Northern region of Dongying sag in Jiyang depression

The thickness of weathering mud layer between Neogene and Paleogene system more than 4 meters can seal effectively the oil and gas.

6. Discussion

1）How much can the available thickness of the Weathering Mud Layer seal the oil and gas?

2）How can we distinguish the Weathering Mud Layer by seismic data?

I think that these researches would need to strengthen!