Global Deep Siliciclastic Reservoirs: Distribution Patterns and Geological Features*

Kaixun Zhang[1]

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[1]China University of Petroleum, Beijing, Beijing, China (zhangkaixun@126.com)

Abstract

In order to obtain new additional oil and gas reserves and improve energy security, it is of great significance to expand the petroleum exploration and development to deep siliciclastic rocks in petroliferous basins. Based on the latest data of deep siliciclastic reservoirs, this study aims at documenting the distribution patterns and geological features of the global siliciclastic reservoirs. Central and South America hosts 19358.5 million barrel oil equivalent, which are the largest share and amount to 27.31% of the total oil and gas proved and probable reserves in deep siliciclastic rocks. It is followed by North America (excluding the Lower 48 States). North America contains the bulk of oil reserves in deep siliciclastic rocks. Whereas Central and South America has the lion's share of gas and condensate reserves. Of the 74 deep petroliferous basins with siliciclastic reservoirs, the richest petroliferous basins are the Gulf of Mexico, East Venezuela Basin, Arabian, South Caspian, Tarim and Santa Cruz-Tarija Basins and they host 73.7% of the total oil and gas reserves in deep siliciclastic reservoirs. The maximum porosity of deep siliciclastic reservoirs significantly decreases with the buried depth. In contrast, the median value of porosity decreases at shallow and intermediate burial, then increases, and finally decreases again with the burial depth. The variation of porosity with depth implies that anomalously high porosities and permeabilities have developed in deep siliciclastics reservoirs. Their development is associated with the presence of grain coatings, hydrocarbon emplacement, fluid overpressure and formation of secondary pores. In China, deep petroleum exploration should focus on the fairways where oil and gas discoveries have been made at the intermediate and shallow reservoirs. To a large extent, the success of deep petroleum exploration depends upon the delineation of "Sweet Spots" in deep layers where grain coatings, fluid overpressure and well-developed salts might have preserved original primary porosity. Integrated application of diagenetic model, depositional model and 3-D basin modeling will play an important role in accurately forecasting the quality of deep siliciclastic reservoir rocks.

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Global Deep Siliciclastic Reservoirs: Distribution Patterns and Geological Features

Presenter: Kaixun Zhang
Email: zhangkaixun@126.com
China University of Petroleum (Beijing)

Outline

- Introduction
- Distribution pattern and geological features of the deep siliciclastic reservoirs
- The main mechanisms of high quality reservoirs' development in the world
- Case study: Jizhong Depression Raoyang Sag of Bohai Bay Basin
- Conclusion

Introduction

Definition:

The oil or the gas occurring in reservoirs at burial depths of no less than 15,000 ft(Dyman et all., 2002)

Chinese researchers defined deep petroleum burial depths no less than 10,000 ft(Tuo, 2002; Zhang, 2005; Zhu, et., 2009;)

Differences:

In China the researchers believe that the deep level physical properties of the reservoir, specifically. the porosity and permeability need to be considered together.

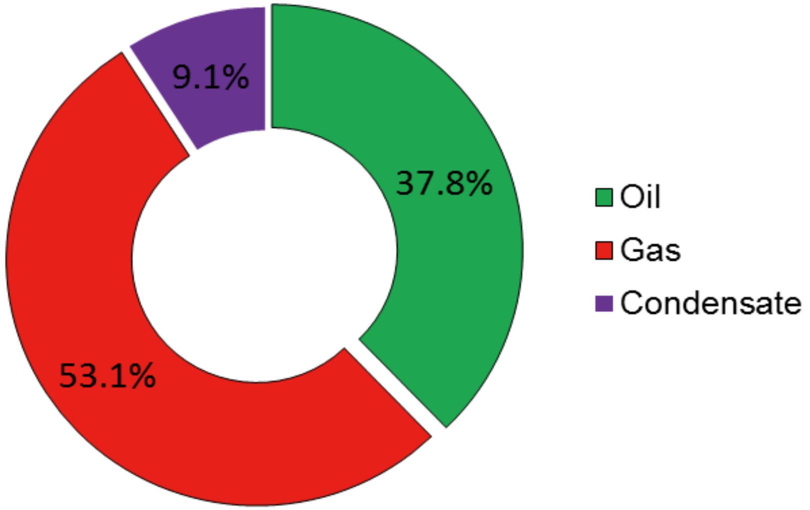
Introduction

The current composition of deep oil and gas resources

Deep oil: 42 BBO (Making up 1.9% of the world total oil supply)

Deep gas: 356 TCF (Making up 3.6% of the world's total oil supply)

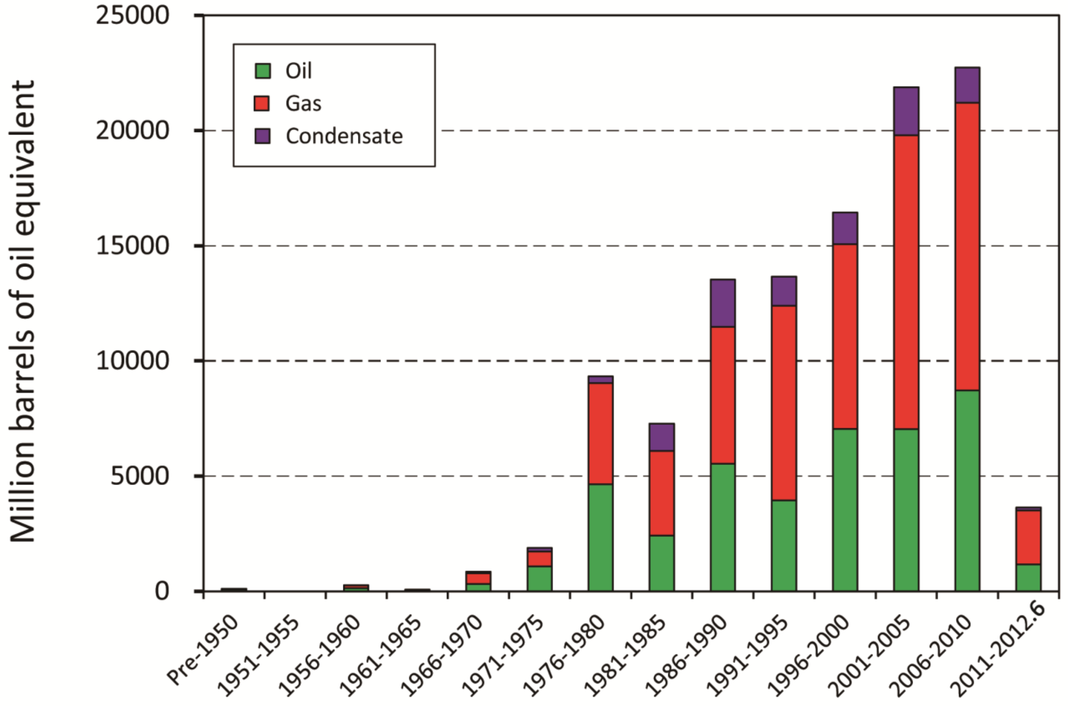
Deep condensate: 10 BBC (2.1%)



Total: 111， 670 MMBOE

Introduction

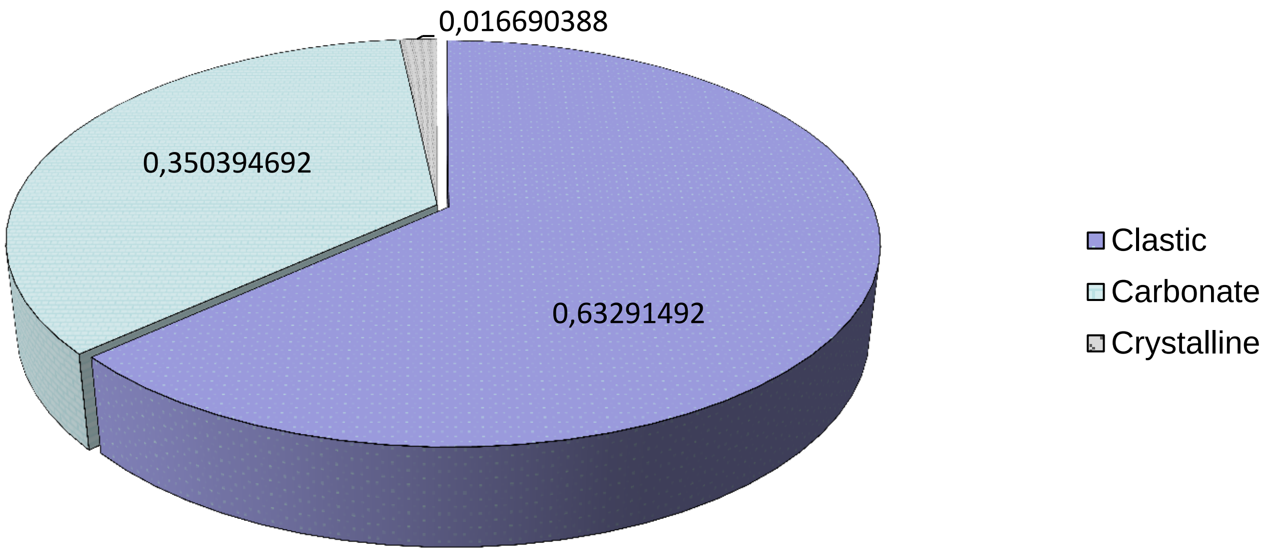
Discovery history of worldwide deep petroleum



(excludes onshore Lower 48 States and unconventional resources are not counted)

Introduction

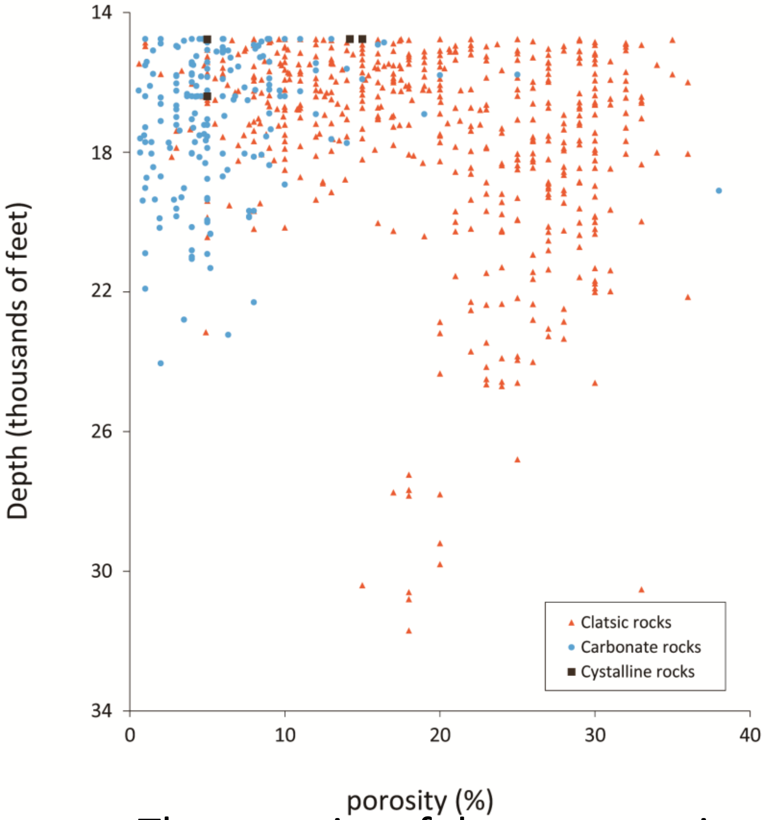
Clastic rock contains majority of all reservoirs



Clastic rocks, carbonate, igneous and metamorphic rocks

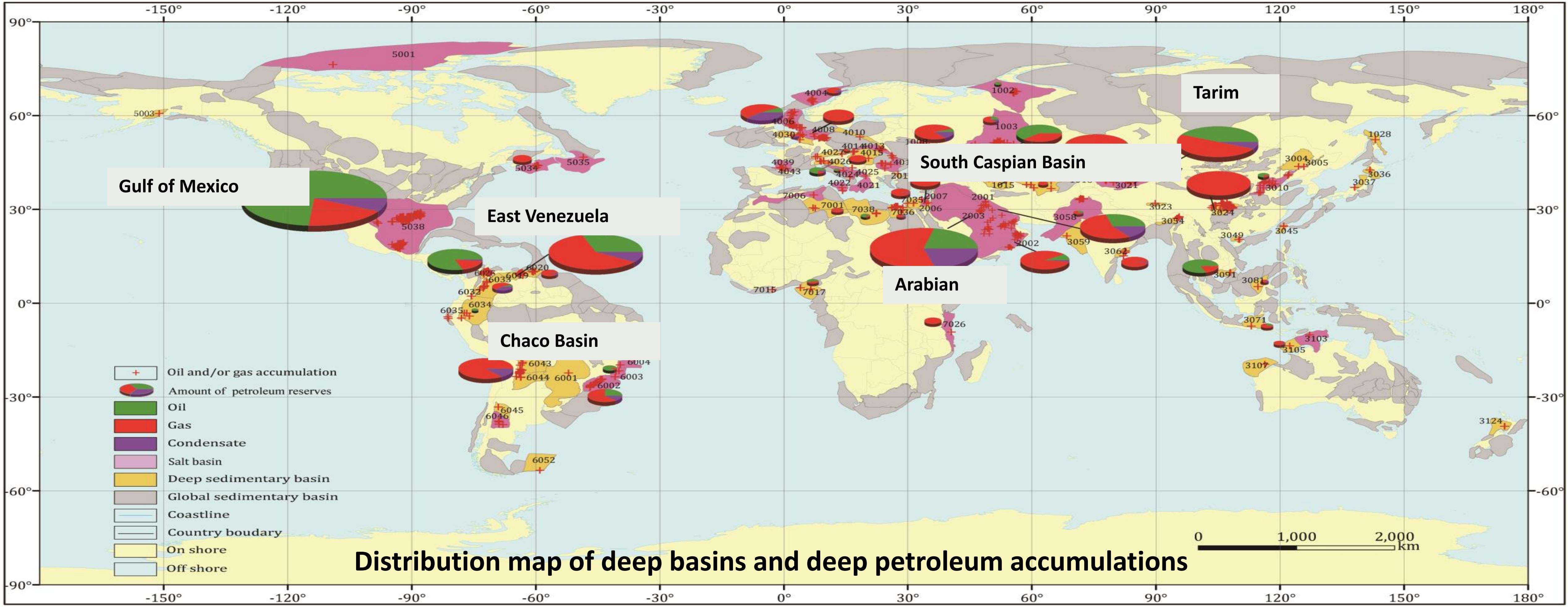
Introduction

Clastic reservoirs exhibit the highest porosities.



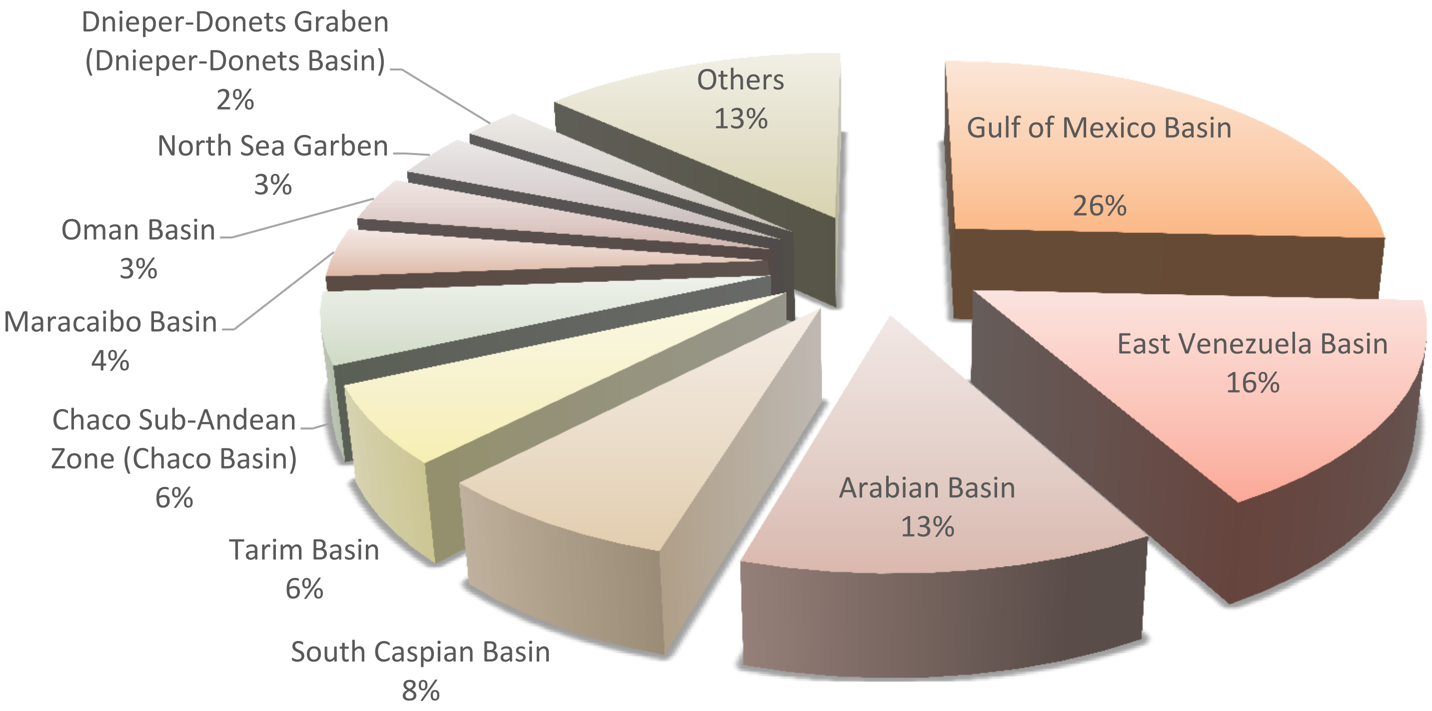
The porosity of deep reservoir

Distribution pattern and geological features of the deep siliciclastic reservoirs



Distribution map of deep basins and deep petroleum accumulations

Distribution pattern and geological features of the deep siliciclastic reservoirs



The top ten deep clastic rock oil and gas reservoirs compose 83% of the world total 2p （Proved Plus Probable）

Distribution pattern and geological features of the deep siliciclastic reservoirs

No.	Basin code	Basin Name	Basin Type	Original 2P Petroleum Reserves Class（MMTOE）	Original 2P Petroleum Reserves Class（MMBOE）	Main Reservoirs	Maximum Top depth （m）	Porosity（%）	Permeability（mD）	Significant Oil/Gas Field example：Primary reservoir(s)；Maximum top depth （m）
1	5038	Gulf of Mexico	Passive margins	2492	18263	Jr-K shallow clastc rocks, Pg and Ng deep marine slope sandstones	9999	4~36	9~3595	Mensa：U. Mio. sandstone； 4692
2	6019	East Venezuela Basin	Foreland	1564	11466	Oli-Mio marine delta and shallow marine sandstones	6228	5~21	3~1375	Santa Barbara：Oli-Mio sandstones；5840
3	2003	Arabian Basin	Passive margins	1224	8969	L. D shallow marine and fluvial sandstones, C-P glacio, and fluvial and eolian sandstones	5180	5.5~22		Ghawar：L. D sandstones, 5180
4	1015	South Caspian basn	Passive margins	739	5414	Pli lacustrine delta sandstones and siltstones	5950	5~19	0.9~461	Shah Deniz：Pli sandstones and siltstones；5900
5	3021	Tarim basin	Foreland	582	4267	C tidal and shallow clastics, K-Pg fluvial and lacustrine clastics	7057	3.4~22.6	0.2~1138	Tahe：C tidal and shallow clastics；5285
6	6043	Santa-Cruz-Tarija basin	Foreland	533	3905	L. D shallow marine sandstones,	6055			Incahuasi x-1 ST：L. D sandstones, 5973
7	6026	Maracaibo	Foreland	368	2700	K shelf clastic rocks, Eo. fluvial sandstones	5516	3~18.3	1~25	Ceuta：Eo. sandstones ；4550
8	2002	Oman Basin	Rift	332	2435	Cam-O shallow marine and eolian sandstones	5278	6~9	0.02~3.7	Saih Rawl：Cam sandstones；4972
9	4006	North Sea Graben	Rift	321	2351	Tr-Jr fluvial, shallow marine and deep marine slope clastics	5918	5~25	0.1~25	Elgin：Jr clastics；5212
10	1008	Dnieper-Donets basin	Foreland	239	1750	Miss shallow marine paralic sandstoens	6220			Yablunivske：Miss sandstoens；4568
11	4008	Northwest German basin	Foreland	167	1225	L. P fluvial, lacustrine and eolian clastics	5900	8~24	0.1~25	Soehlingen：L. P clastics；4943
12	2007	Levantine Basin	Passive margins	159	1167	Mio deep marine sandstones	5000			Aphrodite 1：Mio sandstones；5000
13	3062	Krishna	Passive margins	130	953	K, Pg and Ng deep marine sandstones	5250	25		UD-1：Oli. sandstone；5243
14	6033	Llanos-Barinas-Apure	Foreland	74	540	K fluvial and shallow marine sandstones, Eoc fluvial sandstones	5836	4~20	60~1000	Huron 1：U. Mio. sandstone；4832
15	7035	Nile delta	Passive margins	66	484	Oli-Mio shelf sandstones	4844	23~25	200	Satis 2：U. Oli-L. Mio sandstones；6000
16	5034	Scotian shelf	Passive margins	63	458	Jr-L. K marine delta and shelf clastics	5799	4.8~23.7		Venture：Jr-L. K clastics，5550
17	3019	Junggar basin	Foreland	60	441	L.-M. Jr and L. K fluvial-lacustrine sandstones, U. P lacustrine sandstones	6051	9.6~30	0.3~17.3	Liuhudi：L.-M. Jr and L. K sandstones；6051
18	4015	Pannonian Basin	Foreland	56	408	Mio fluvial and lacustrine conglomerates and sandstones	5500			Mako Trough：Mio conglomerates and sandstones；5500
19	7026	Tanzania basin	Passive margins	51	377	Pg deep marine sandstones	4500			Zafarani 1：Pg sandstones；4500
20	6020	Trinidad	Foreland	50	364	Ng marine delta and shelf sandstones	5090	18		Bounty 1：Ng sandstones；4600

Summary of deep siliciclastic reservoir data in the top 20 basins ranked by the proved plus probable (2P) original reserves of deep petroleum reservoired

Kaixun Zhang
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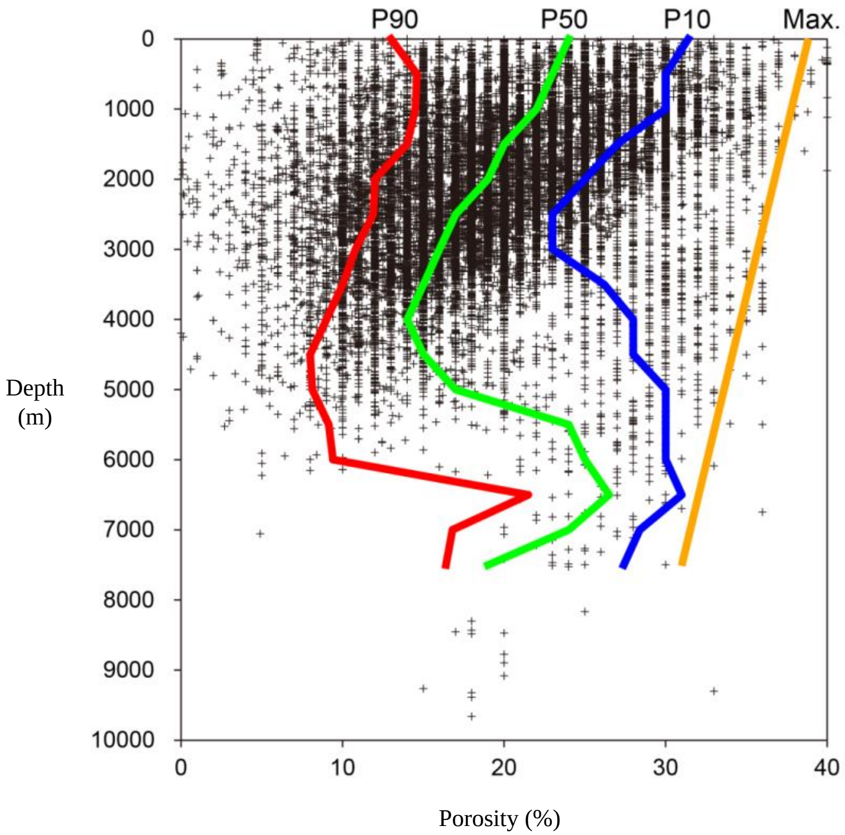
The main mechanisms of high quality reservoirs' development in the world

When the buried reservoir is below 4000m, there is an anomalously higher porosity in deeply buried reservoirs.

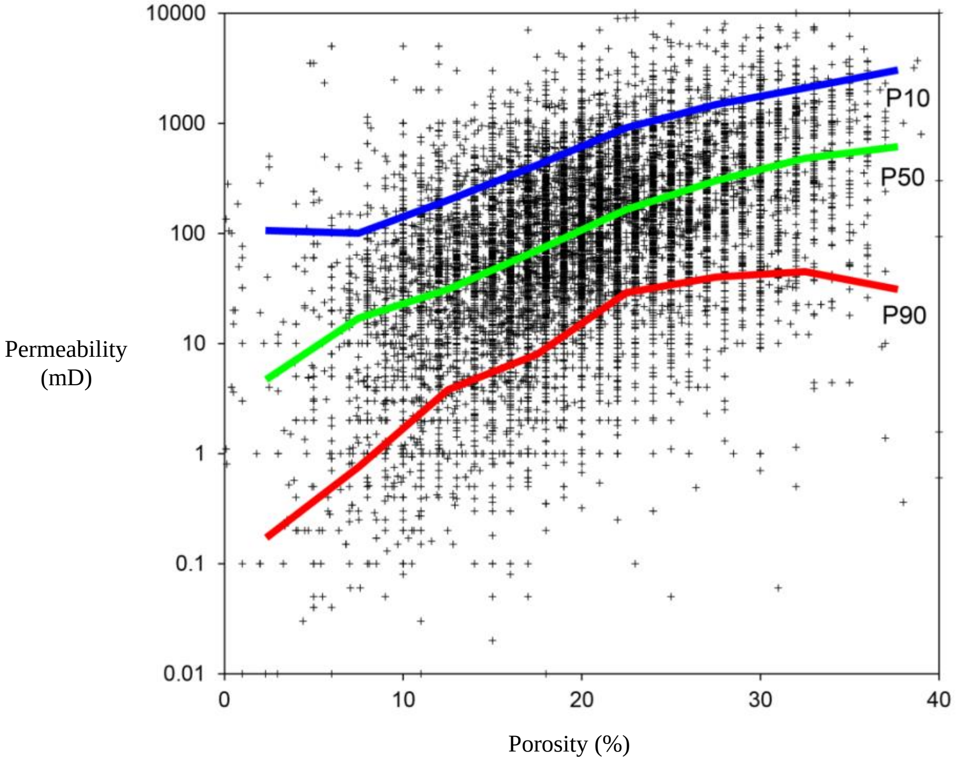
P90: 90% of data point is greater than the reference value
P50: 50% of the of data point is larger than the reference value (median)
P10: 10% of the data point is larger than the reference value
Max: all of the data point is larger than the reference value.



Porosity vs. top depth for global silicaclastic petroleum reservoirs

The main mechanisms of high quality reservoirs' development in the world

There is a positive correlation between permeability and porosity.



Permeability vs. porosity for global siliciclastic petroleum reservoirs

The main mechanisms of high quality reservoirs' development in the world

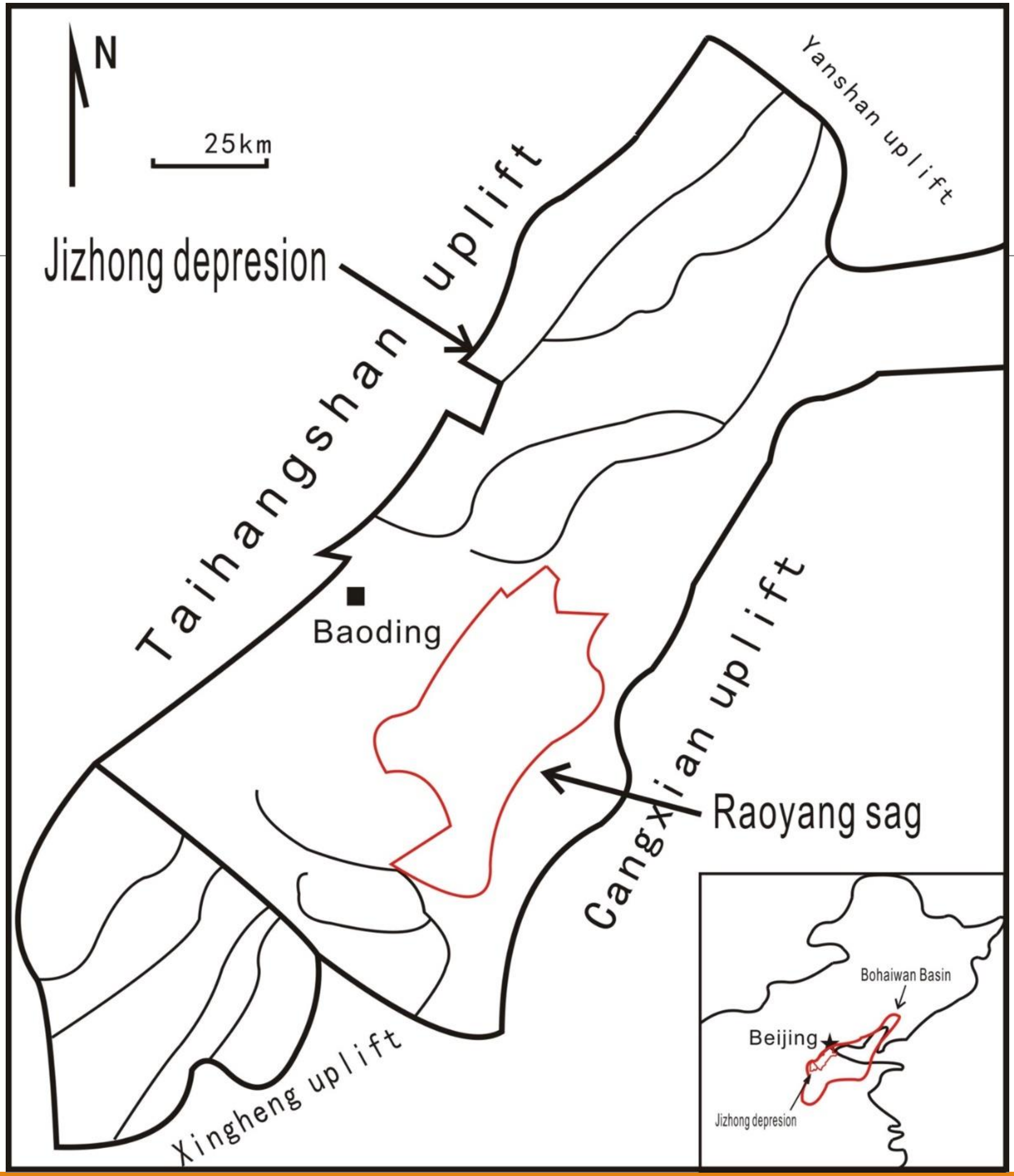
Reasons for this phenomenon

1. Grain coating and grain rims
2. Early emplacement of hydrocarbons
3. Shallow development of fluid overpressure.
4. Secondary porosity development
5. Salt development

(Schmidt， et al., 1979; Bjørlykkek, 1984, 1998,2012; Saigal, et al., 1992; Ehrenberg, 1993;Aase et al., 1996; Bloch et al., 2002; Tylor et al., 2010; Nguyen et al., 2013; Grant et al., 2014)

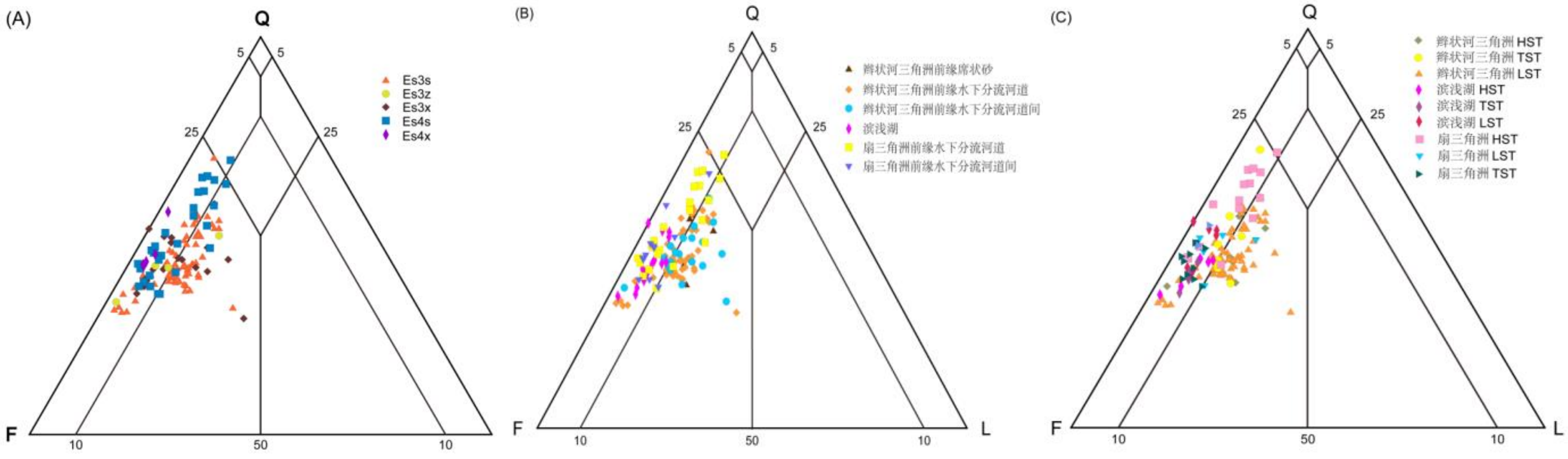
Case Study

Deep siliciclastic reservoir development characteristics in China:Jizhong Depression Raoyang Sag of Bohai Bay Basin



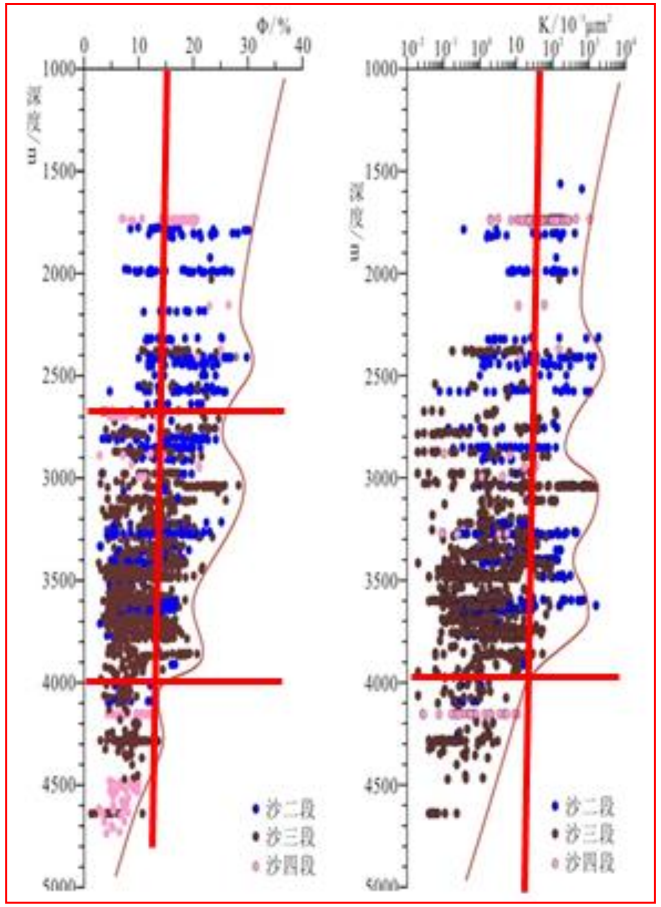
Case Study

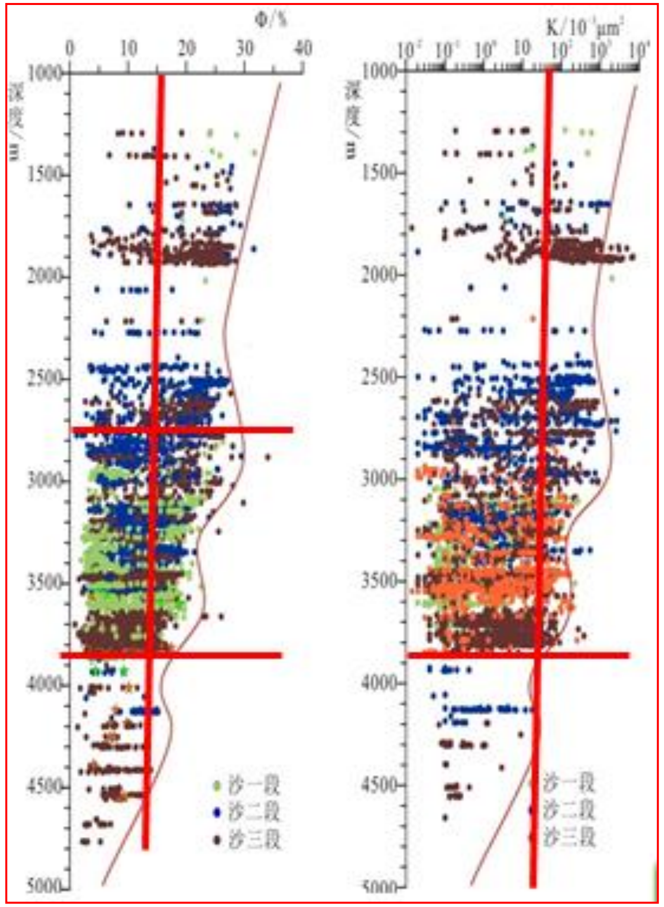
The main composition of Shahejie Formation is feldspar-quartz sandstone



Ternary diagram showing the framework-grain composition of Shahejie Formation sandstones in Raoyang Sag

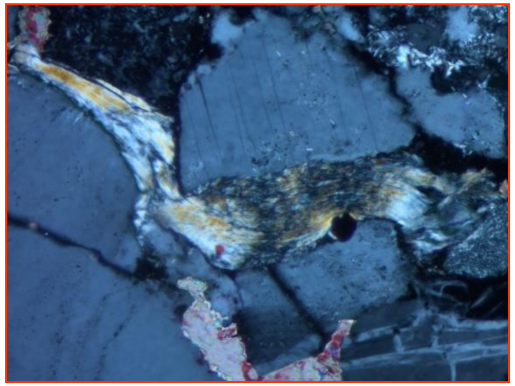
Case Study



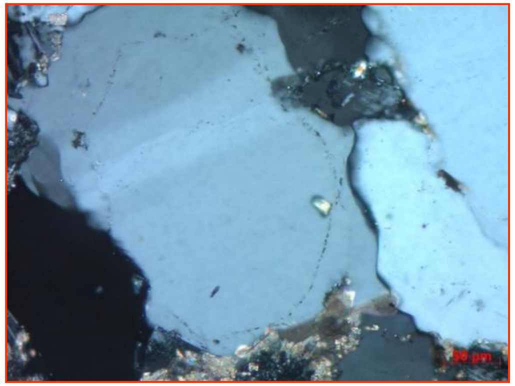


Cross plot of porosity vs. depth for Raoyang Sag

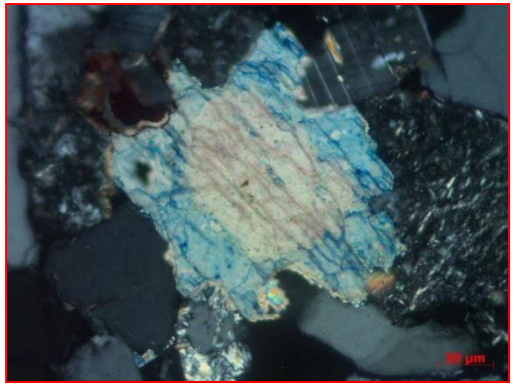
Case Study



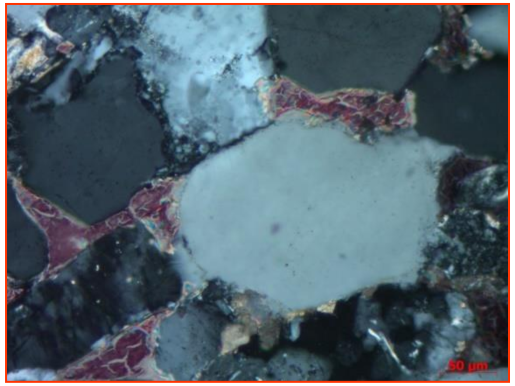
A well 3821.4m the compaction of mica



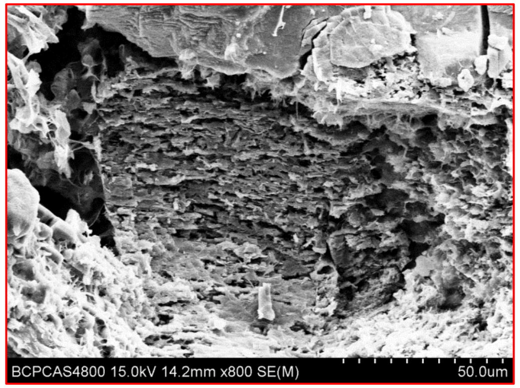
a well 4200.1m quartz cementation



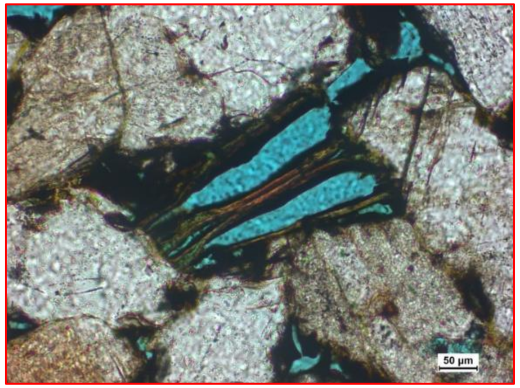
x well 3964.5m ankerite cementation



B well 3765.4m calcite cementation



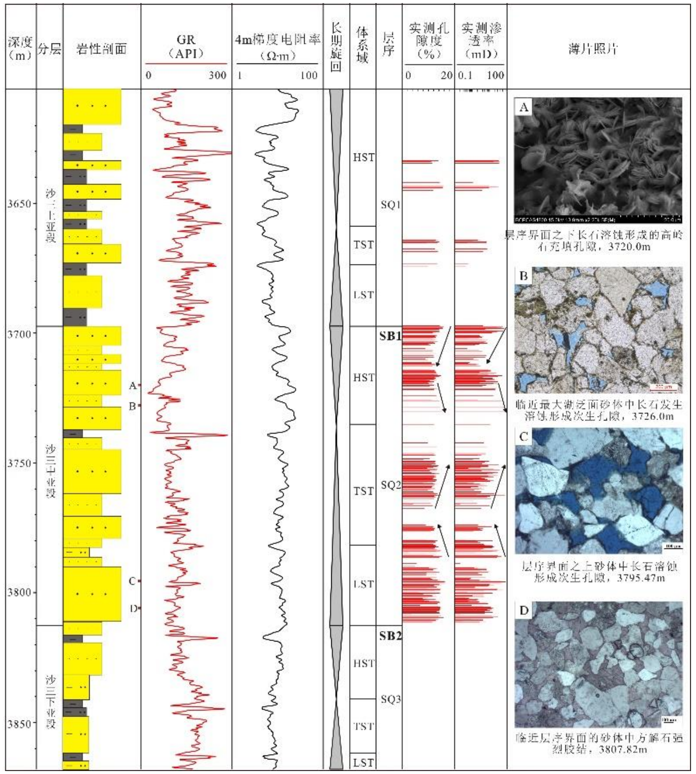
C well 4173.2m feldspar dissolution

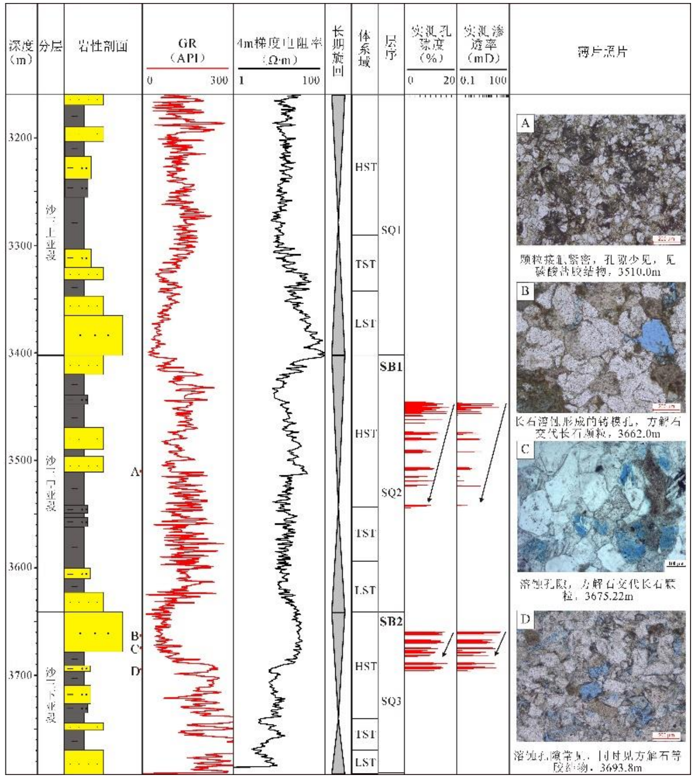


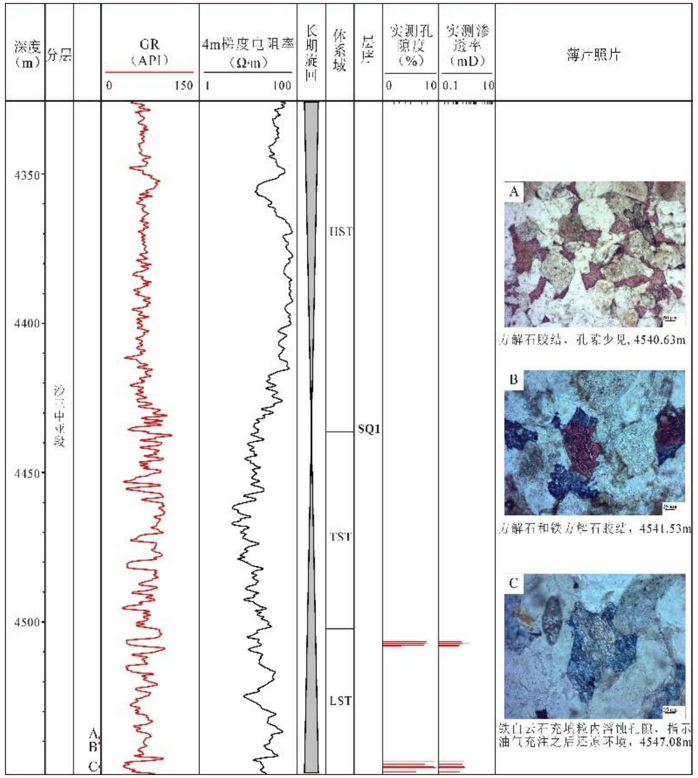
C well 4406.2m lithic fragment dissolution

Case Study

Diagenesis characteristics in sequence stratigraphic framework of Raoyang Sag







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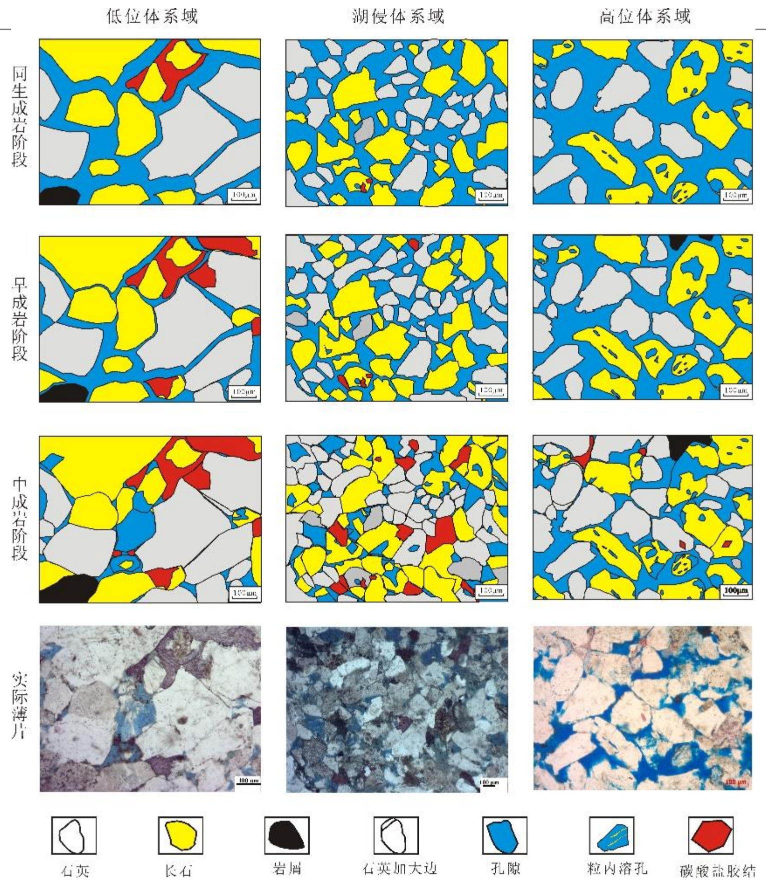
Case Study

If we want to obtain high porosity at the deep clastic reservoirs, better primary porosity are needed. This will help the development of early emplacement of hydrocarbons and secondary porosity



Diagenetic evolution models for sand bodies of various systems tracts in the sequence stratigraphic framework

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Conclusion:

- Central and South America and North America (excluding the Lower 48 States), which are the largest shares and amount to 57.3% of the total proved and probable oil and gas reserves in deep siliciclastic rocks.
- North America contains the bulk of oil reserves in deep siliciclastic rocks, whereas Central and South America has the lion's share of gas and condensate reserves.
- Of the 74 deep petroliferous basins with siliciclastic reservoirs, the richest petroliferous basins are the Gulf of Mexico, East Venezuela, Arabian, South Caspian, Tarim and Santa Cruz-Tarija Basins and they host 73.7% of the total reserves.
- The variation of porosity with depth implies that anomalously high porosity and permeability have developed in deep siliciclastic reservoirs. Their formation is most closely linked to the presence of grain coatings, early hydrocarbon charging, pore-fluid overpressure and secondary porosity.
- In China, deep petroleum exploration should focus on the fairways.The success of deep petroleum exploration depends upon the delineation of "Sweet Spots" in deep layers where grain coatings, fluid overpressure and/or well-developed salts might have preserved original primary porosity.

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Thank you for listening!

Any questions?