碳酸盐岩缝洞型油藏开发关键技术

—以塔河油田为例

Key Petroleum Development Technologies in Fractured & Caverned Carbonate Reservoirs

— Illustrated by the Example of Tahe Oilfield

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中国.重庆. 2015年9月

Xinjiang, China. September, 2015

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一、引言　Introduction

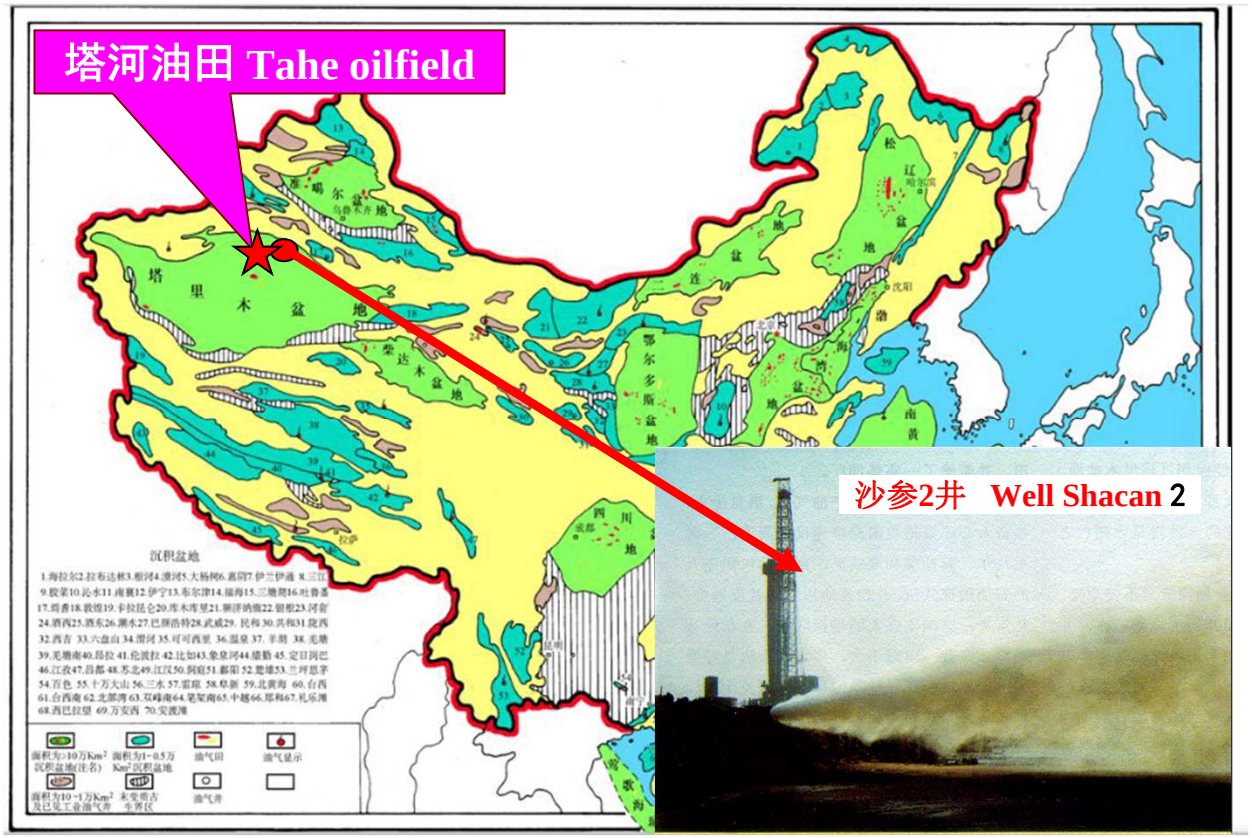
二、开发关键技术　Key development technologies

三、经济与社会效益　Economic and social benefits

四、结束语　Concluding remarks

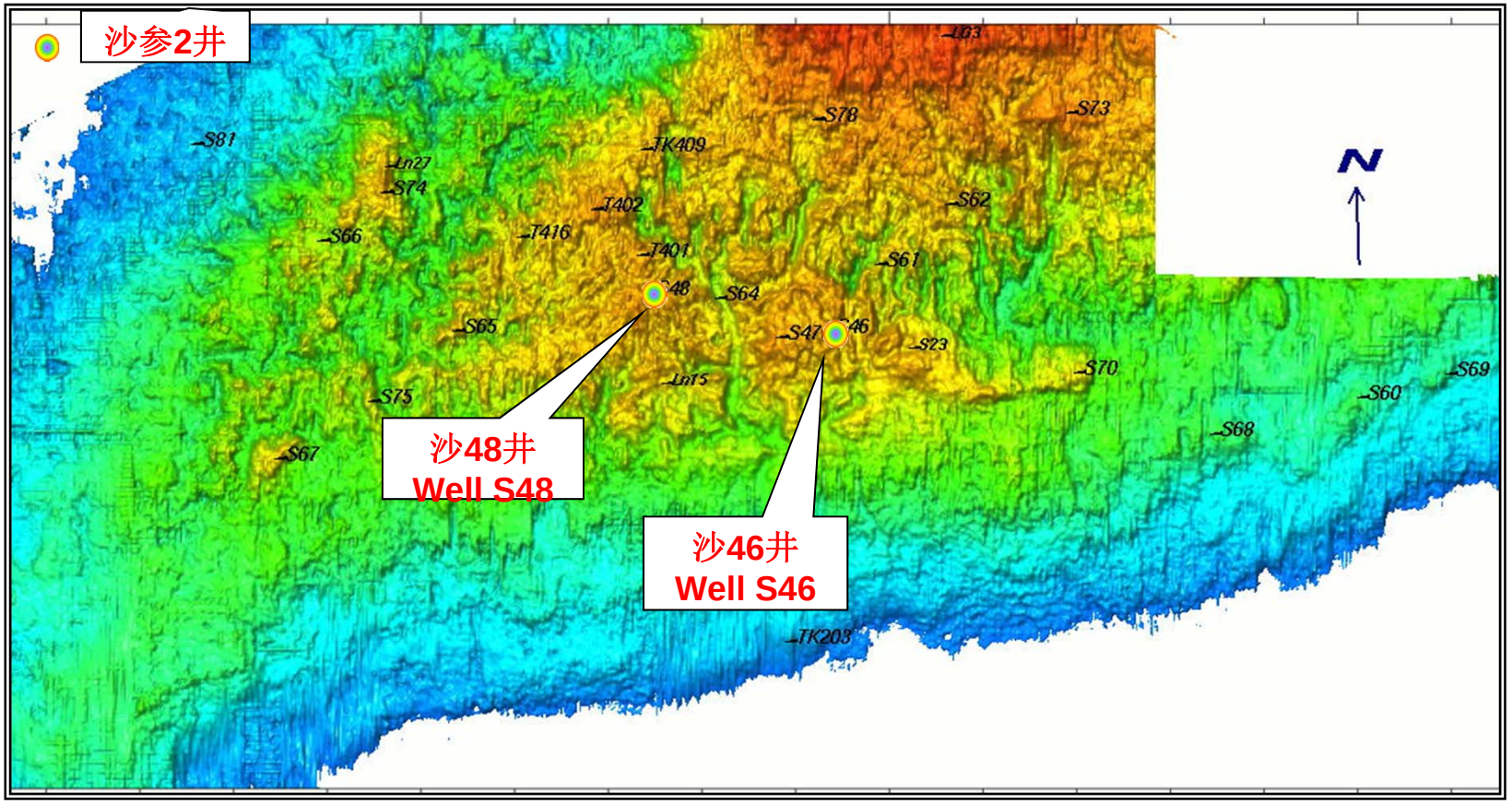
一、引言　Introduction

塔河特大型油气田位于中国新疆塔里木盆地北部，1984年沙参2井在奥陶系获日产油866吨，天然气200万方，拉开了塔里木盆地寻找海相油气的序幕。 Super sized Tahe oil & gas field is located in the north of Tarim basin in Xinjiang, China. Searching marine facies petroleum in Tarim Basin began with the discovery of well Shacan 2 which produced daily 866 tons of oil and 2 million m3 of gas.



一、引言 Introduction

1997年S46井、S48井在奥陶系分别获得日产油182吨、524吨，从而发现了塔河油田，实现了塔里木盆地海相地层寻找大油田的梦想，为国家能源战略西移奠定了基础。 Based on the daily oil production of 182t and 524t separately from well S46 and S48, Tahe oilfield was discovered, which realized the possibility of the dream looking for large marine fields in Tarim basin and laid the foundation of energy movement toward the west for China.



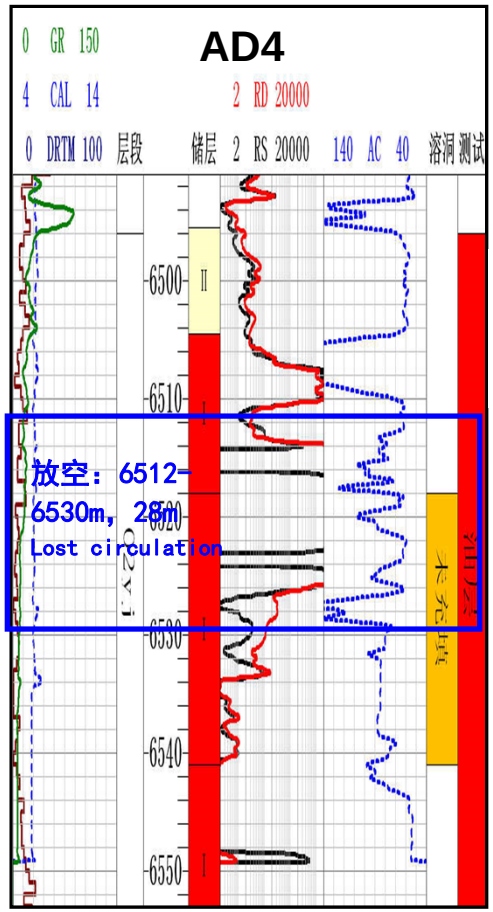
一、引言 Introduction

1. 塔河油田碳酸盐岩油藏以缝洞为主要储集空间，尺度差异大（几mm-百m），多期岩溶改造后储集空间分布复杂，储层预测、地质认识难度大

1. In Tahe carbonate reservoirs, fractures, caverns and pores consist main spaces that possess large range (several mm to hundred m).

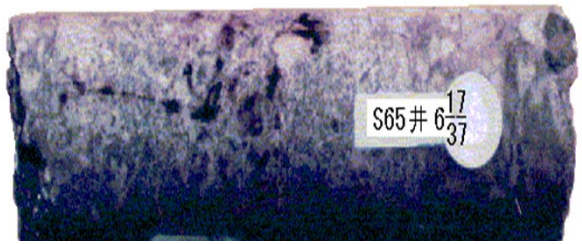
溶洞型

Solution caverned type



裂缝—孔洞型

Fractured-porous type



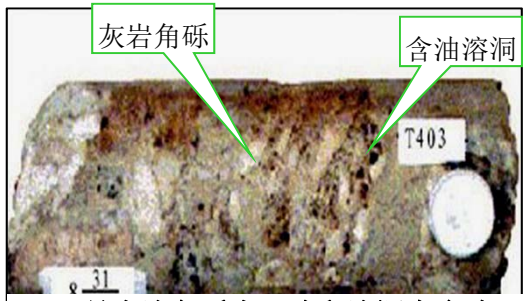
S65井具微裂缝-溶蚀孔洞型储层充满了褐色原油

Well S65, fractured-porous reservoir filled with brown crude

裂缝型 **Fractured type**

T453井溶蚀扩大缝和溶蚀孔、洞发育，充满原油

Well T453, solution expanded fractures and pores filling with crude



T403晶岩溶角砾岩，残留溶洞中含油

Well T403, karst breccia, residual karst holes are filled with crude

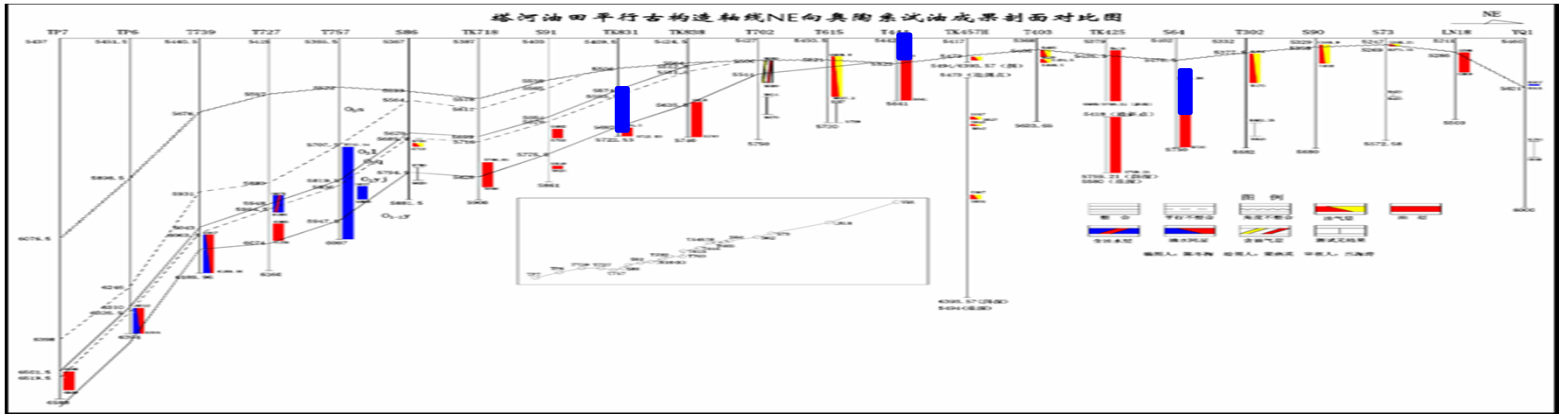
中国Karst岩溶

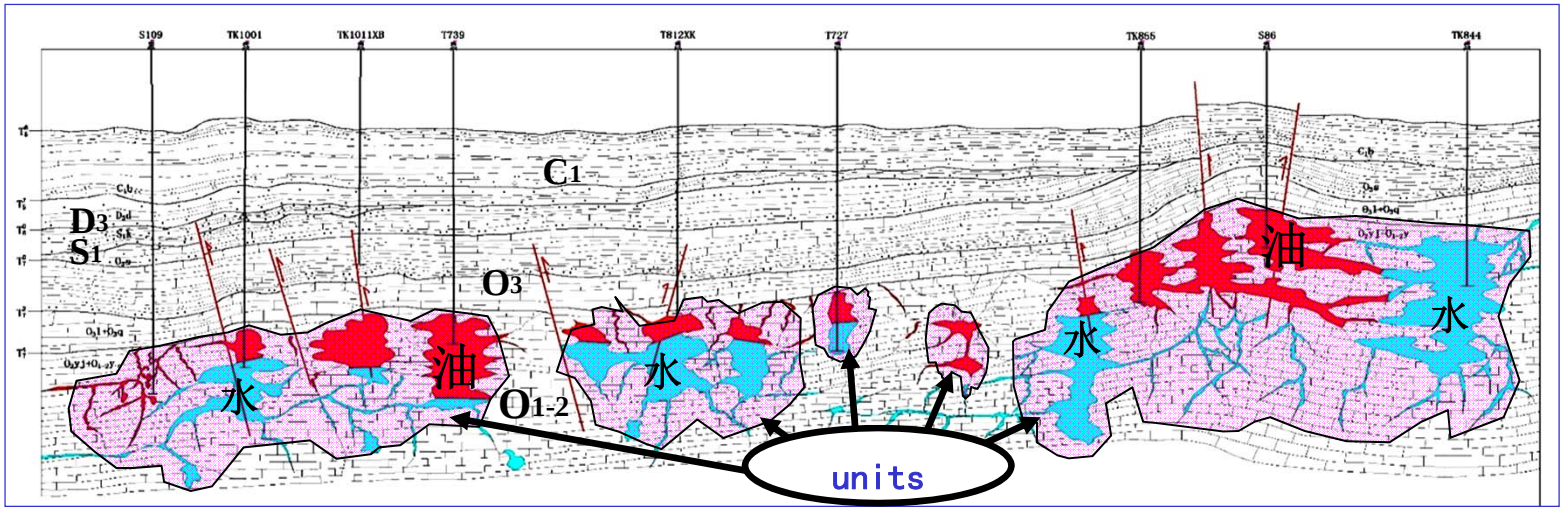
Karst caves in China

一、引言 Introduction

2. 流体平面纵向分布复杂，每个缝洞单元都有独立的油水关系和能量特征，经济开发风险大

2. Fluid shows complex distribution laterally and vertically. Each fractured-caverned unit has independent oil and gas system and energy characteristics, which causes high economic risk in development.

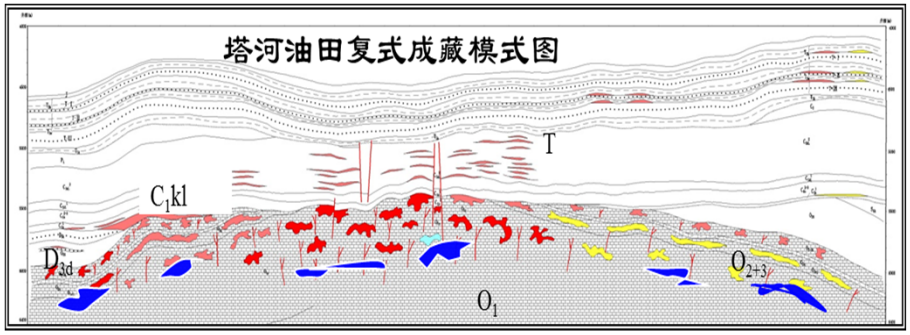




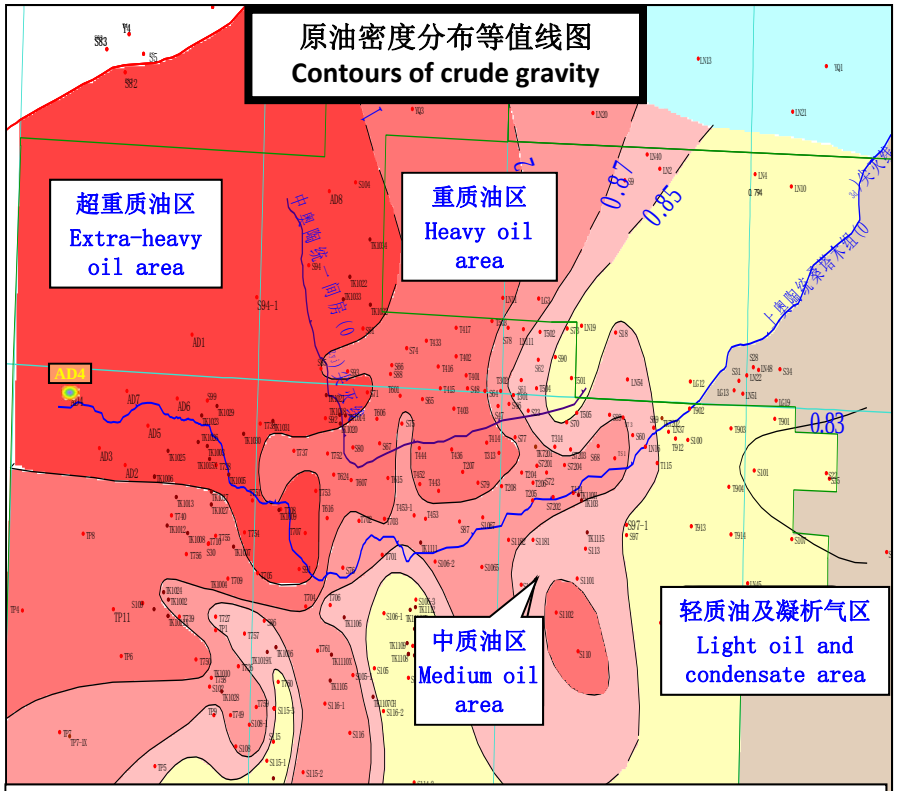
一、引言 Introduction

3. 油藏埋藏深（5300-7500米），温度高（120-160℃）、矿化度高；油气经过多期充注改造，重质、超重质原油储量大，对钻、完、采技术提出更高要求，开发成本高

3. Reservoirs are buried deeply (5300-7500m) with high temperature (120-160℃) and high salinity; oil and gas experienced multi-stage filling reforms; there are considerable reserves of heavy and extra-heavy oil that require higher leveled technologies on drilling, complement and production, so the cost is very high.



区块	面积 km²	地质储量/万吨	可采储量/万吨	采收率 %	地面粘度 万毫帕秒
6区	69.8	4703	632.1	13.4	4
7区	39.7	3547	561.9	15.8	1
8区	116.8	6714	763.9	11.4	3
10区	297.3	21534	2041.8	9.5	20
12区	421.5	23455	3131.2	13.3	50
YQ区西	5	108	17	15.7	100
合计	950.1	60060	7147.9		



原油密度0.83-1.08g/cm³，超重质原油粘度180×104mPa.s，硫化氢含量10000-40000mg/m³。

Crude gravity ranges 0.83-1.08g/cm³, viscosity of extra-heavy oil reaches 180×104mPa.s and H_2S content ranges 10000-40000mg/m³

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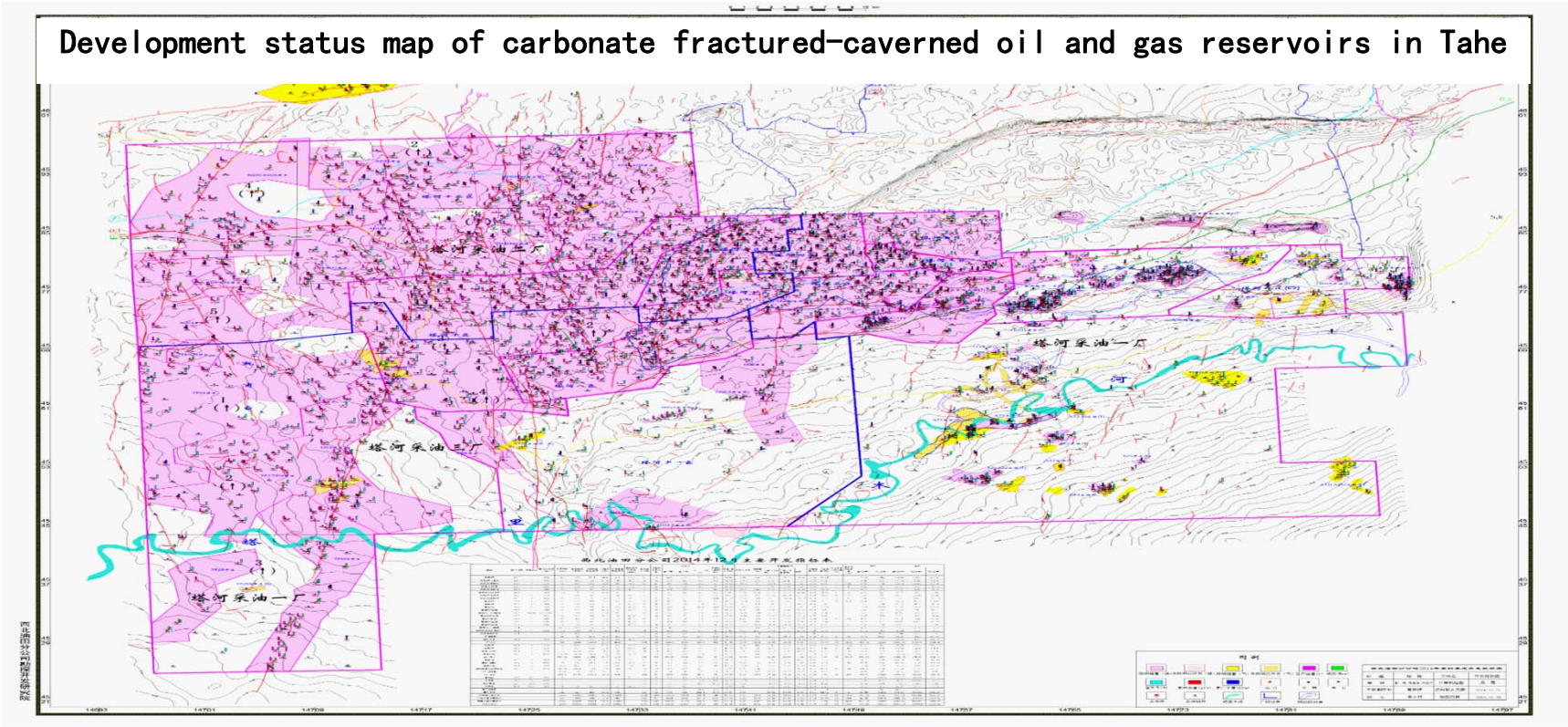
二、开发关键技术　Key development technologies

塔河油田碳酸盐岩缝洞型油藏储集体和流体分布的多样性，对油田开发技术提出更高的要求。塔河经过十几年的勘探开发，创新形成了一系列独具特色的开发关键技术

Because of the diversity of reservoirs and fluid in Tahe field, development requires higher leveled technologies. During decades of exploration and development in Tahe, our company establishses a series of key development technologies with specific features.

Development status map of carbonate fractured-caverned oil and gas reservoirs in Tahe



1. 三维地震采集、处理和储层预测技术

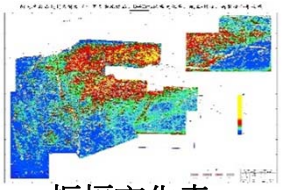
1. Technology on 3D seismic acquisition, process and reservoir prediction

针对油藏埋藏深，缝洞体识别难度大，发展了15m*15m高精度三维地震采集、叠前深度偏移和多地震属性分析技术，提高缝洞识别精度。

Focusing on problems of reservoir depth and identification of fractures, caverns and pores, our company developed the technology of 3D seismic acquisition with 15m*15 high resolution, pre-stack depth migration and multi-seismic attribute analysis to improve identification resolution for fractures, caverns and pores.

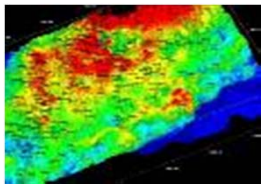
岩溶系统识别

Identification of karst system



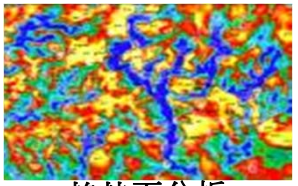
振幅变化率

Amplitude variation



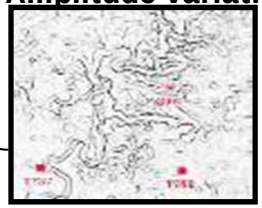
古地貌分析

Analysis of ancient landform



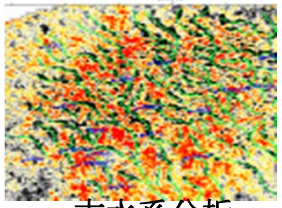
趋势面分析

Tendency plane analysis



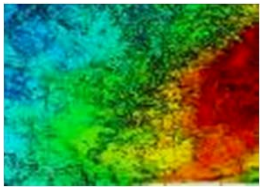
精细相干

Fine cohenrence



古水系分析

Analysis of ancient water system

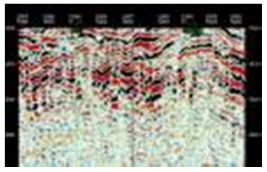


多属性叠合

Multi-attribute overlay

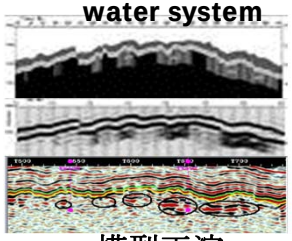
缝洞结构识别

Identification of fractures, caverns and pores



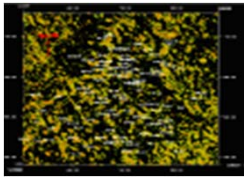
地震反射特征

Seismic reflection characteristics



模型正演

Forward model

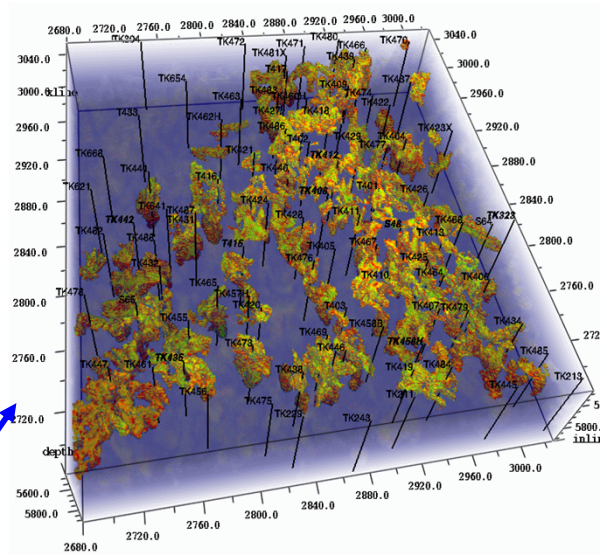


波形分析

Analysis of wave

塔河4区缝洞三维空间刻画

3D space depiction of Block 4 in Tahe

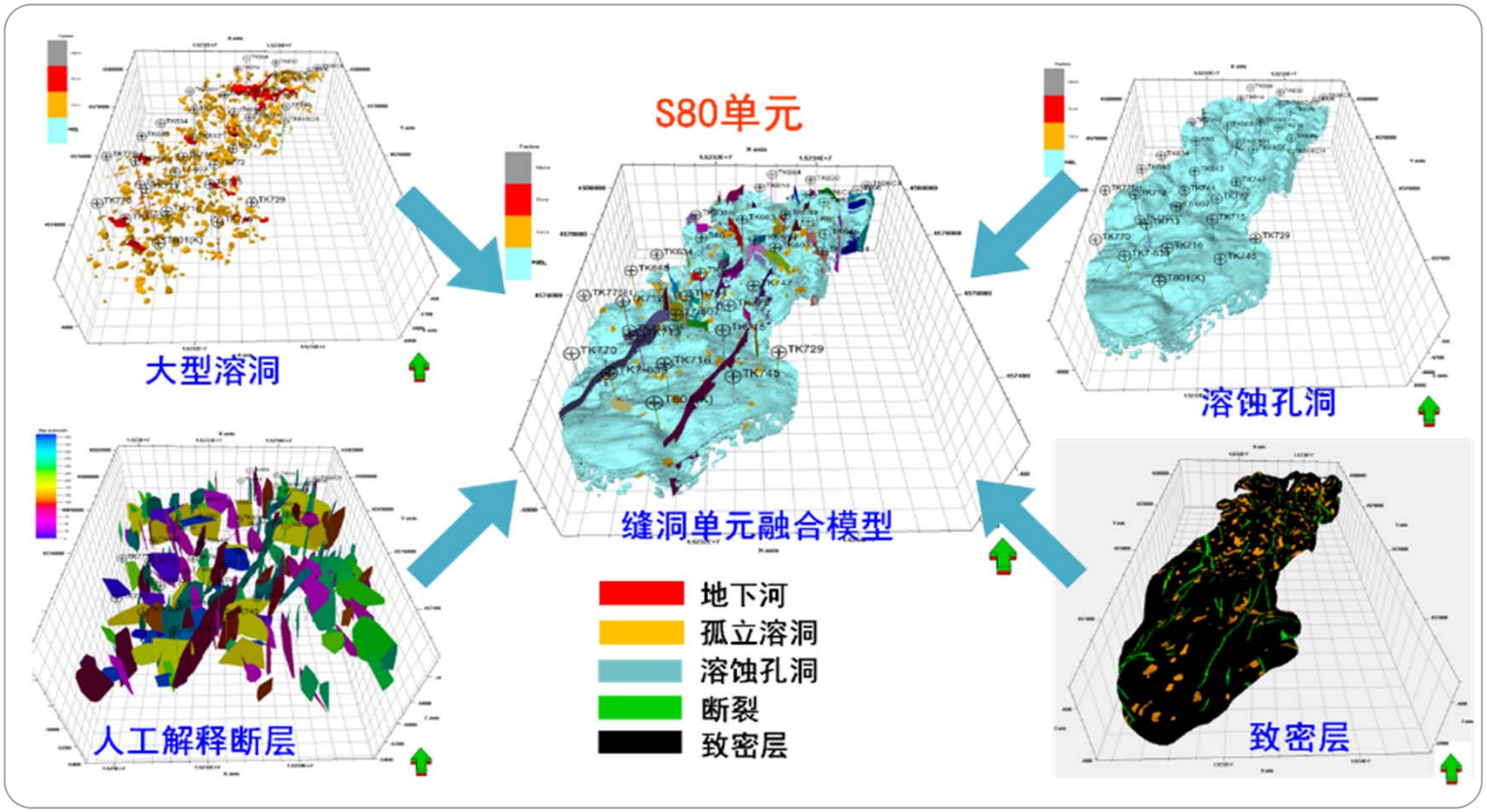


2. 缝洞型油藏三维地质建模技术

2. Technology on 3D geological modeling

缝洞空间分布随机，非均质强，创新了“不同岩溶相控制、分储集体类型融合”的三维地质建模技术

Spaces distributes randomly and possess strong heterogeneous, so our company created 3D geological modeling of “controlling different karst facies and combining different reservoir types”.



缝洞储集体分类建模技术

3. 缝洞型油藏数值模拟技术

3. Technology on reservoir numerical simulation

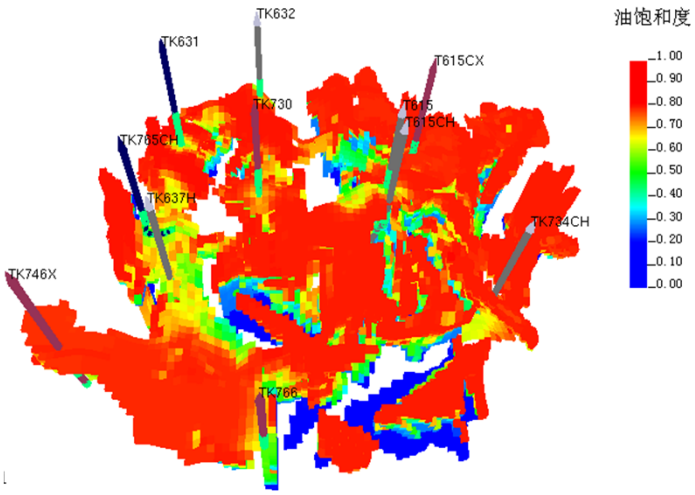
由于缝洞型油藏缝洞储集体的多尺度性，空腔流、非达西流、达西流共存，独创了“非达西流和达西流耦合”的数值模拟技术

Because of large range of reservoir spaces, cavity flow and co-exist of Darcy and non-Darcy flow, our company created the technology on reservoir numerical simulation that is “interconnection of Darcy and non-Darcy flow”

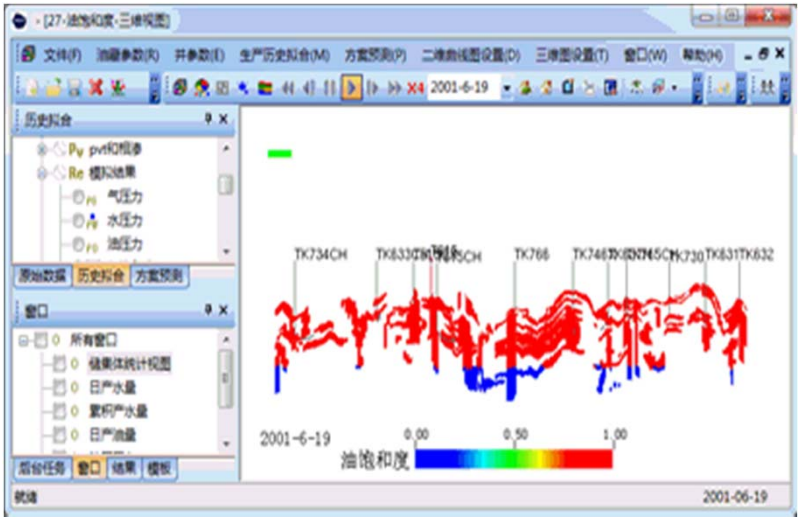
洞、缝、孔中油气水三相流的耦合运动方程

$$\frac{\partial(\rho_i v_i)}{\partial t}+\nabla\cdot(\rho_i v_i v_i)+\nabla p-\nabla\cdot\tau-\rho g+\sigma\nabla\cdot\left(\frac{\nabla S_i}{|\nabla S_i|}\right)\nabla S_i+\left(\frac{\mu}{K}+\frac{C_2\rho}{2}|v_i|\right)v_i=0$$

溶洞流体运动方程　　界面方程　孔缝流体运动方程



缝洞体含油饱和度分布



耦合型数值模拟软件平台

4. 开发方案优化设计技术

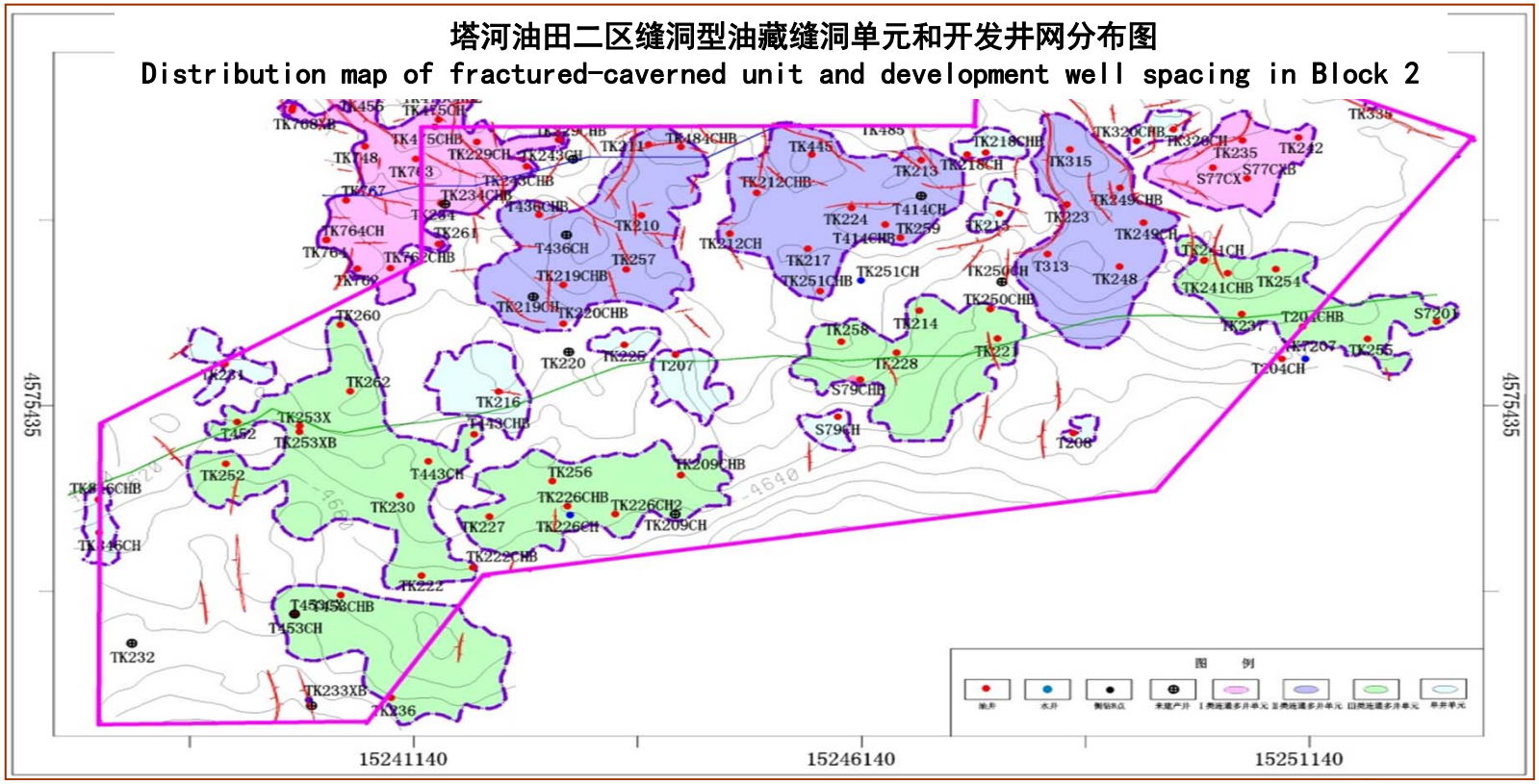
4. Technology on planning optimized development project

依据缝洞体空间分布复杂、分隔性强的特点，采用不规则面积井网、 “以洞布井、逐洞开发”的部署原则和滚动勘探、油藏评价、产能建设多期滚动的开发层序，进行方案优化设计。

Based on complex distribution of spaces and strong partitionment, plan optimized development project according to deployment principle of irregular well spacing, “deploying well in the area of caverns and developing cavern by cavern” and according to multi-stage rolling zone order of exploration, reservoir appraisal and productivity establishment.

塔河油田二区缝洞型油藏缝洞单元和开发井网分布图

Distribution map of fractured-caverned unit and development well spacing in Block 2



5.缝洞型油藏一井多靶点开发技术

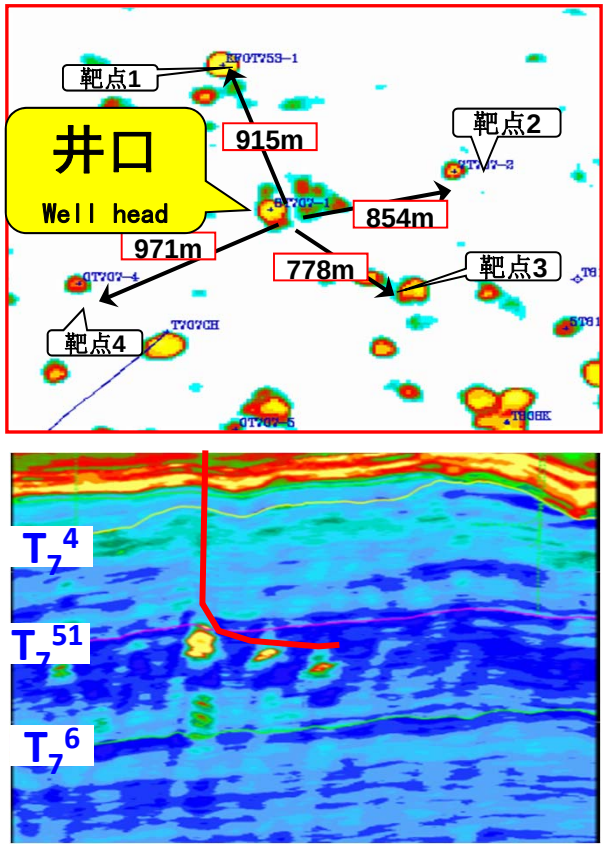
5. Technology on several objects from one well

针对缝洞空间分布不连续、分隔性强，如何进行经济开发，提出一井多靶点开发技术，实现开发效益最大化

Focusing on disconnected space distribution and strong partionment, and economic development, the technology was created to maximize development benefits.

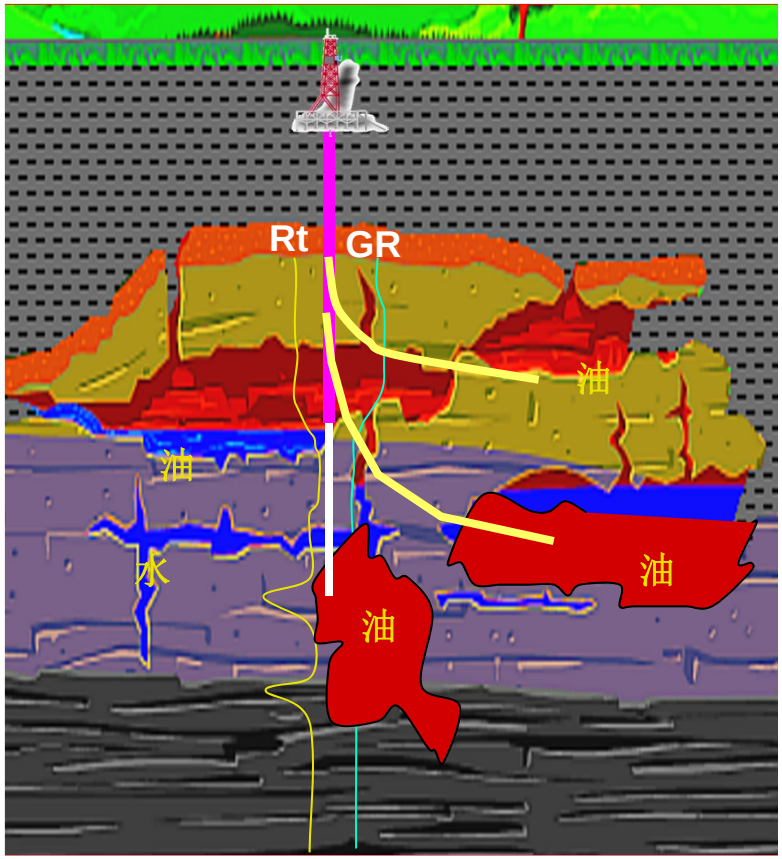
a. 一井多控（井工厂）

a. multi-controlling from one well (well factory)



b. 多方向侧钻

b. Side-track toward different directions

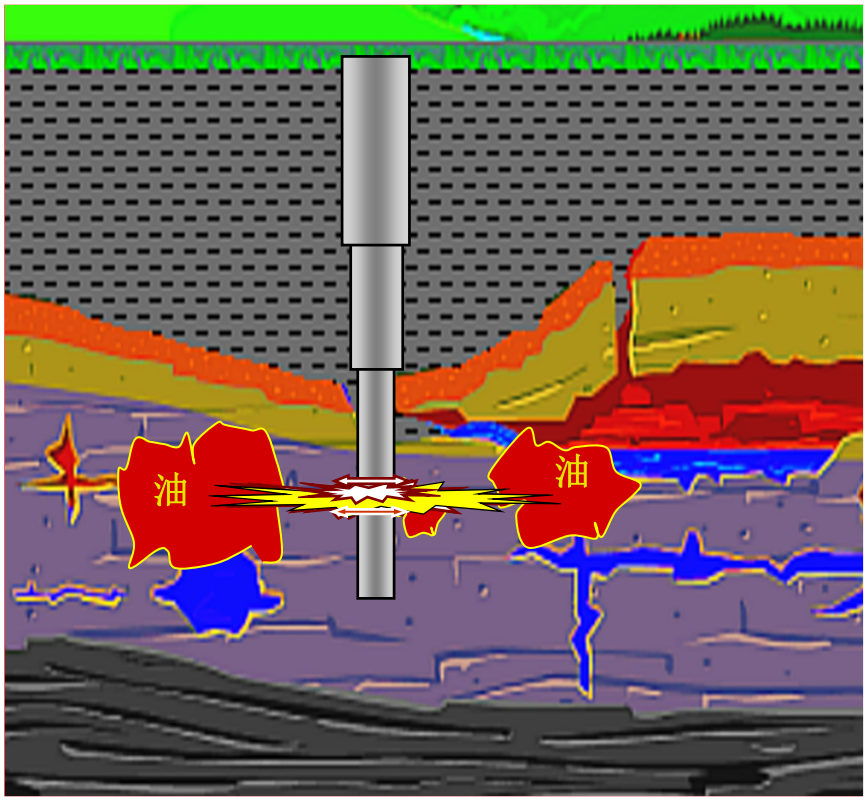


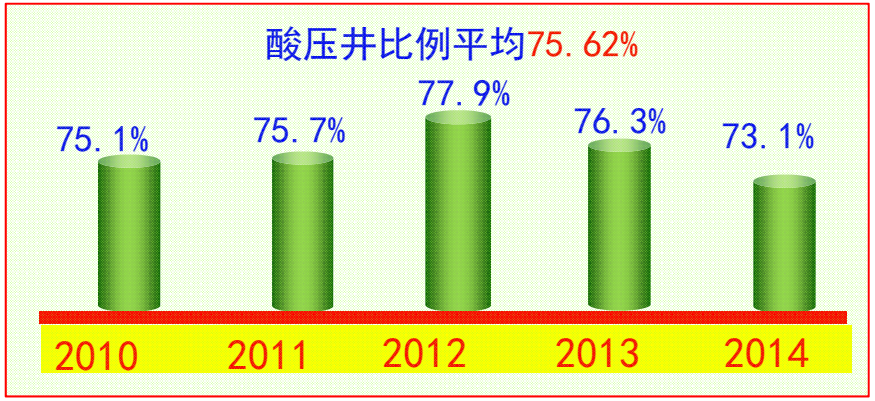
6. 缝洞型油藏裸眼酸压储层改造技术

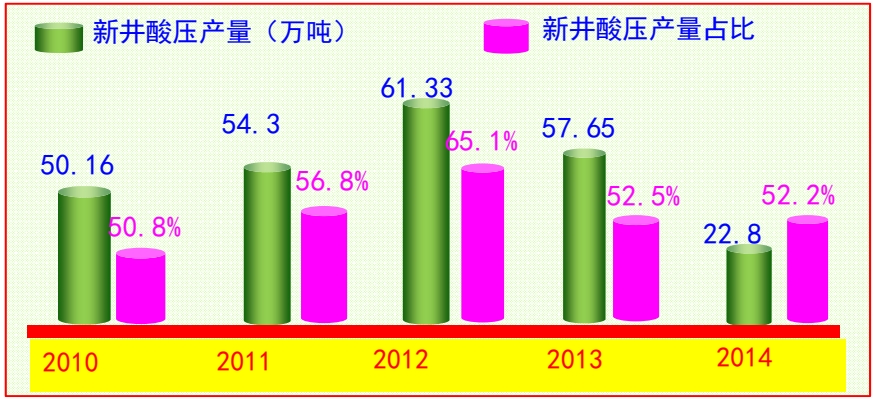
6. Technology on reservoir reformation by acid frac in open hole

缝洞型油藏埋藏深，攻关形成了超深碳酸盐岩深穿透酸压技术体系在5500-7000m深度下最大有效裂缝长度达到140m。

Facing deep buried reservoir, our company worked out acid frac technology with deep penetration in over deep carbonate. The longest fracture reaches 140m on the depth of 5500-7000m







7. 缝洞型油藏注水开发技术

7. Technology on water injection

利用缝洞体内油水的重力分异作用，注水建立人工底水，补充地层能量

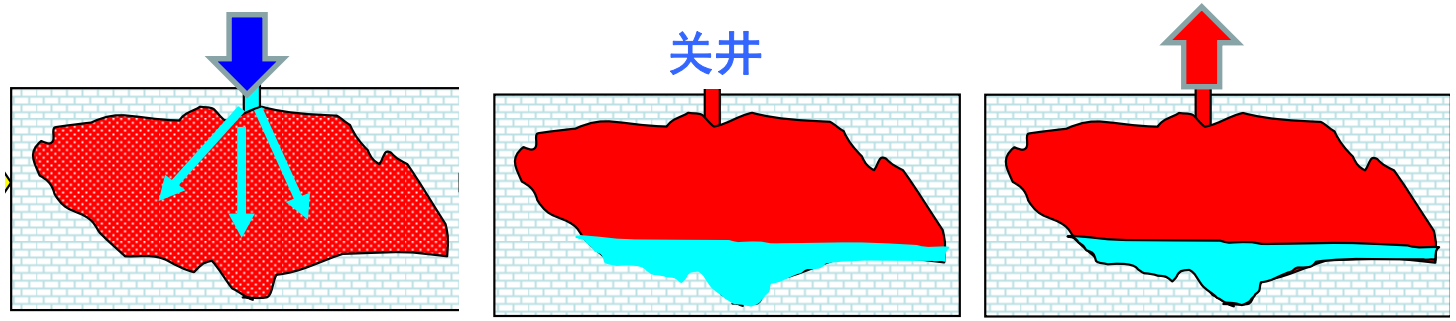
Use gravitational differentiation law of oil and water in fractured-caverned body to inject water building artificial bottom water and keep formation energy.

a. 单缝洞体注水替油技术

a. Water replacement technology for independent body

机理：利用重力分异原理补充能量

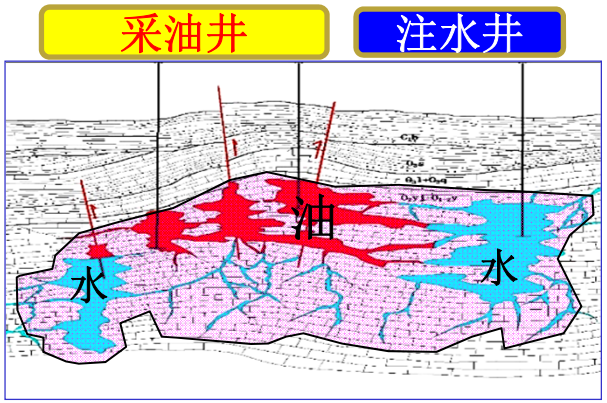
Mechanism: use gravitational differentiation law to keep formation energy

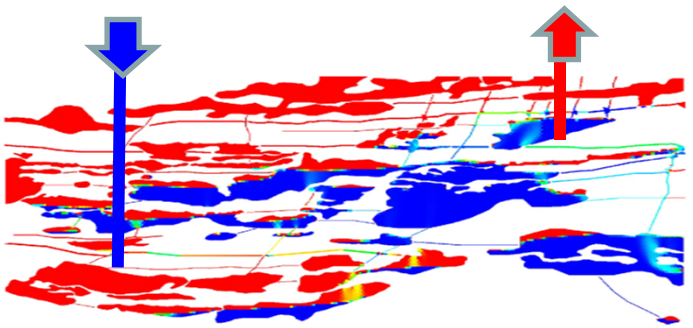


b. 多缝洞连通体注水驱油技术

机理：重力分异、扩大波及体积

b. Water driving technology for multi-connecting bodies





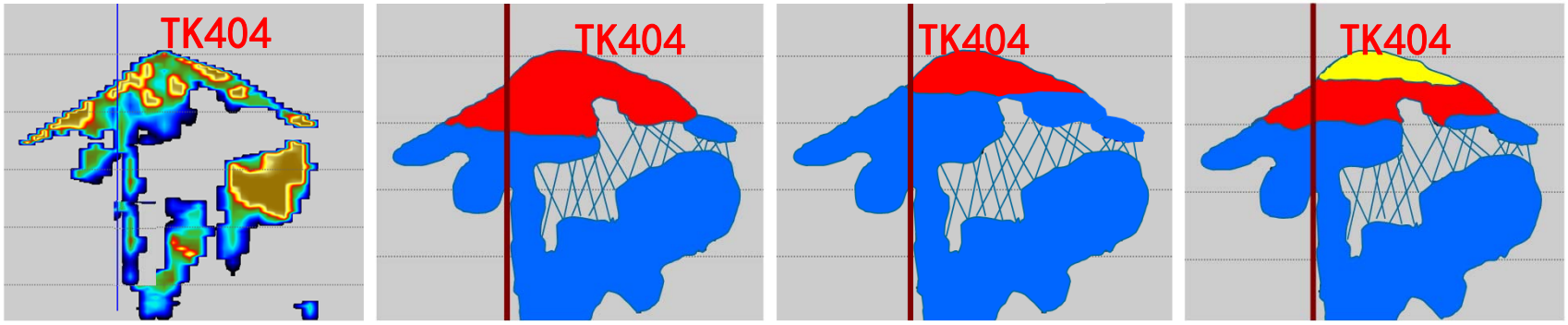
8.缝洞型油藏注气开发提高采收率技术

8. EOR technology of gas injection

利用缝洞体内油气的重力分异作用，注气建立人工气顶，补充地层能量，驱替洞顶剩余油

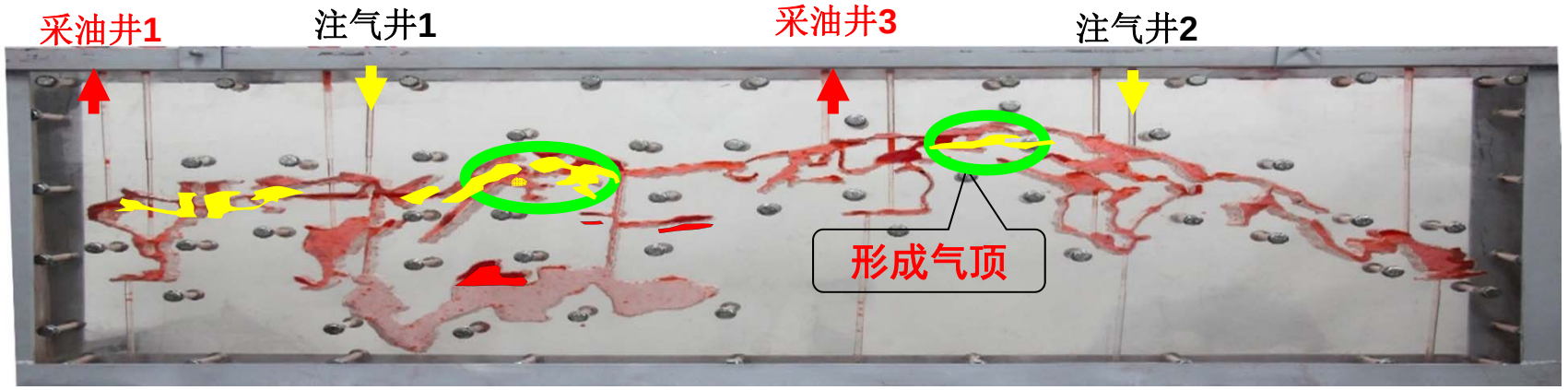
Use gravitational differentiation law to inject gas building gas top and keeping formation energy to drive residual oil

a. 单缝洞体注气替油 Gas replacement for independent body



储集体空间分布　　原始油水分布　　水驱后油水分布　　注气后油水分布

b. 多缝洞连通体注气驱 Gas drive for multi-connecting bodies

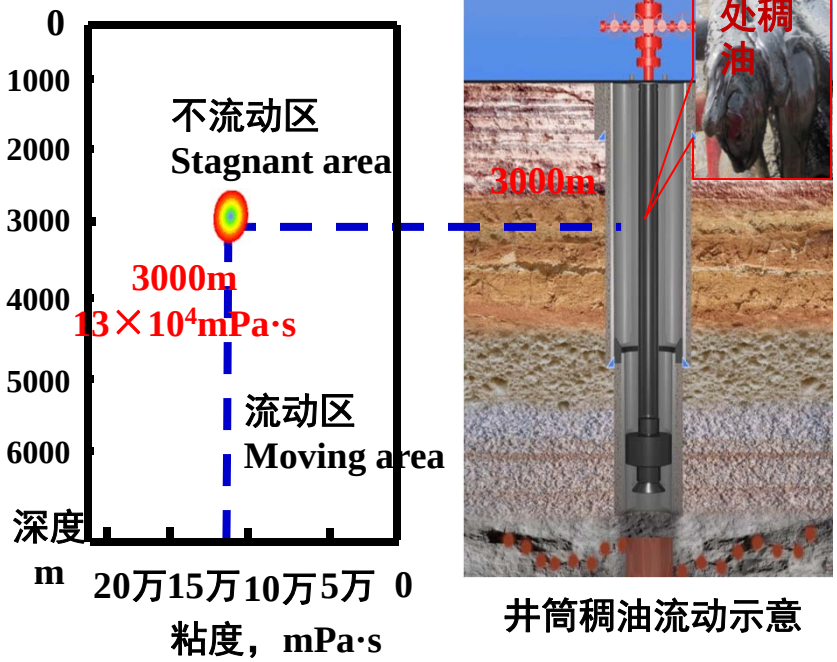


9. 超深缝洞型稠油油藏高效降粘和举升技术

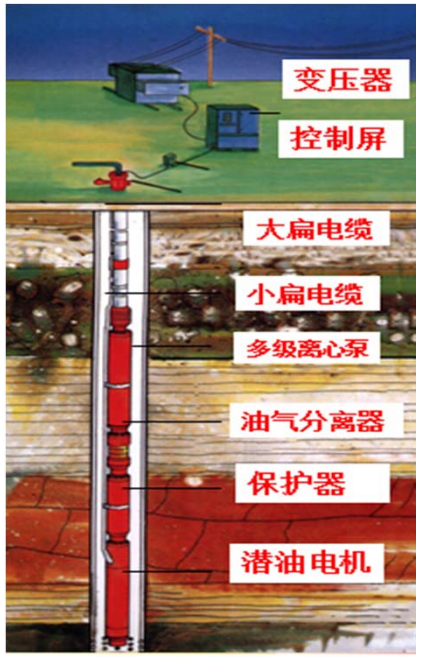
9. Technology on high efficient viscosity reduction and lifting fractured-caverned heavy oil reservoirs

油藏埋藏深度5700-7500m、超稠油(常温粘度数百万mpa·s)井筒不流动，利用中、轻质油掺稀相似相溶降粘原理，创新了掺稀降粘为主、化学降粘为辅的高效降粘技术，同时配套了深抽技术系列

In the depth of 5700-7500m, extra heavy oil (viscosity is several million mpa·s in normal temperature) in well is stagnant. Use medium or light oil to reduce viscosity based on rule of similarity, which is the technology of high efficient viscosity reduction, combining with chemical viscosity reduction and pumping technique in deep well.



井筒稠油流动示意



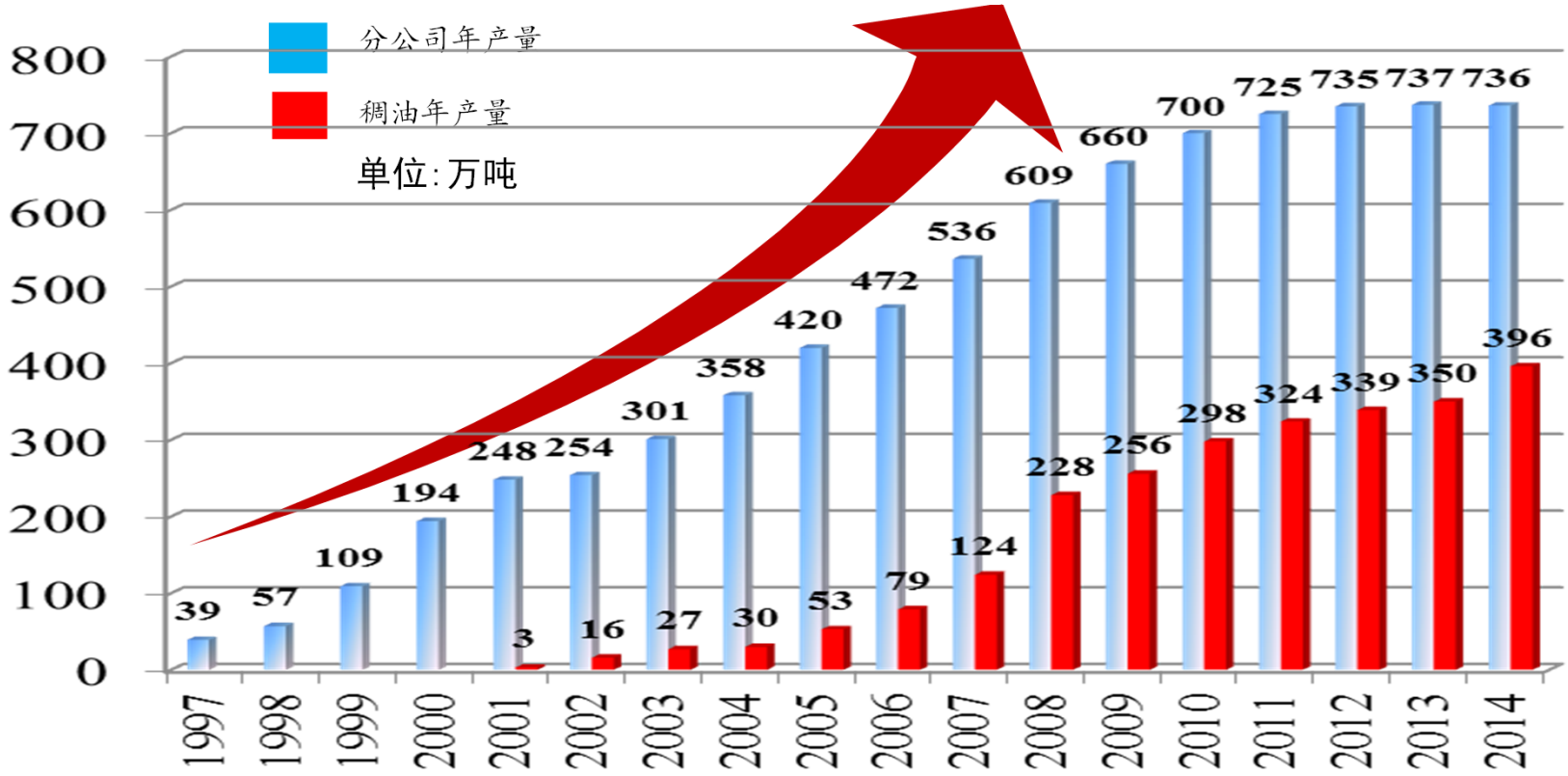
掺稀降粘、化学降粘改善流动性+高效深抽有效动用

9. 超深缝洞型稠油油藏高效降粘和举升技术

9. Technology on high efficient viscosity reduction and lifting fractured-caverned heavy oil reservoirs

该技术系列填补了世界超深井超稠油开采的技术空白，目前稠油产量比例已超过总产量的50%。

The technology filled in the blank of extra heavy oil production in over deep well. Production of heavy oil has been over 50% of the total.



塔河油田稠油产量趋势图

Trend of heavy oil production in Tahe field

题纲　Outline

一、引言　Introduction

二、开发关键技术　Key development technologies

三、经济与社会效益　Economic and social benefits

四、结束语　Concluding remarks

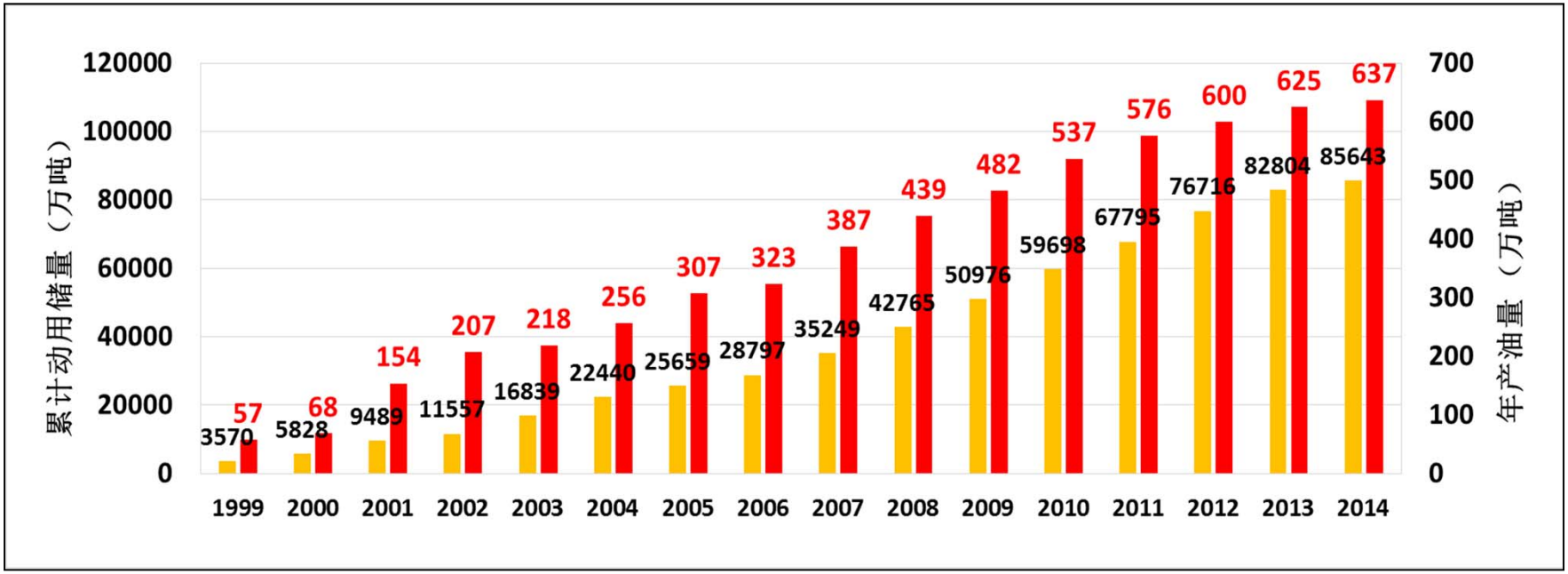
1. 经济效益 Economic benefit

塔河油田碳酸盐岩缝洞型油藏，自1997年以来，已累计探明原油地质储量12.7亿吨，累计动用地质储量8.56亿吨，目前年产油637万吨，有利支撑了中石化“稳定东部，发展西部”的发展战略。

Since 1997, fractured-caverned carbonate reservoirs in Tahe field has produced 1.27 billion tons of proved OOIP, that is 0.856 billion tons of OOIP. Annual production of oil is 6.37 million tons. The achievement support the SINOPEC development strategy of “stable in the east and development in the west”.

塔河油田历年碳酸盐岩油藏年动用储量、产量增长情况

History of OOIP recovery and increasing production in Carbonate reservoirs of Tahe field



1. 经济效益 Economic benefit

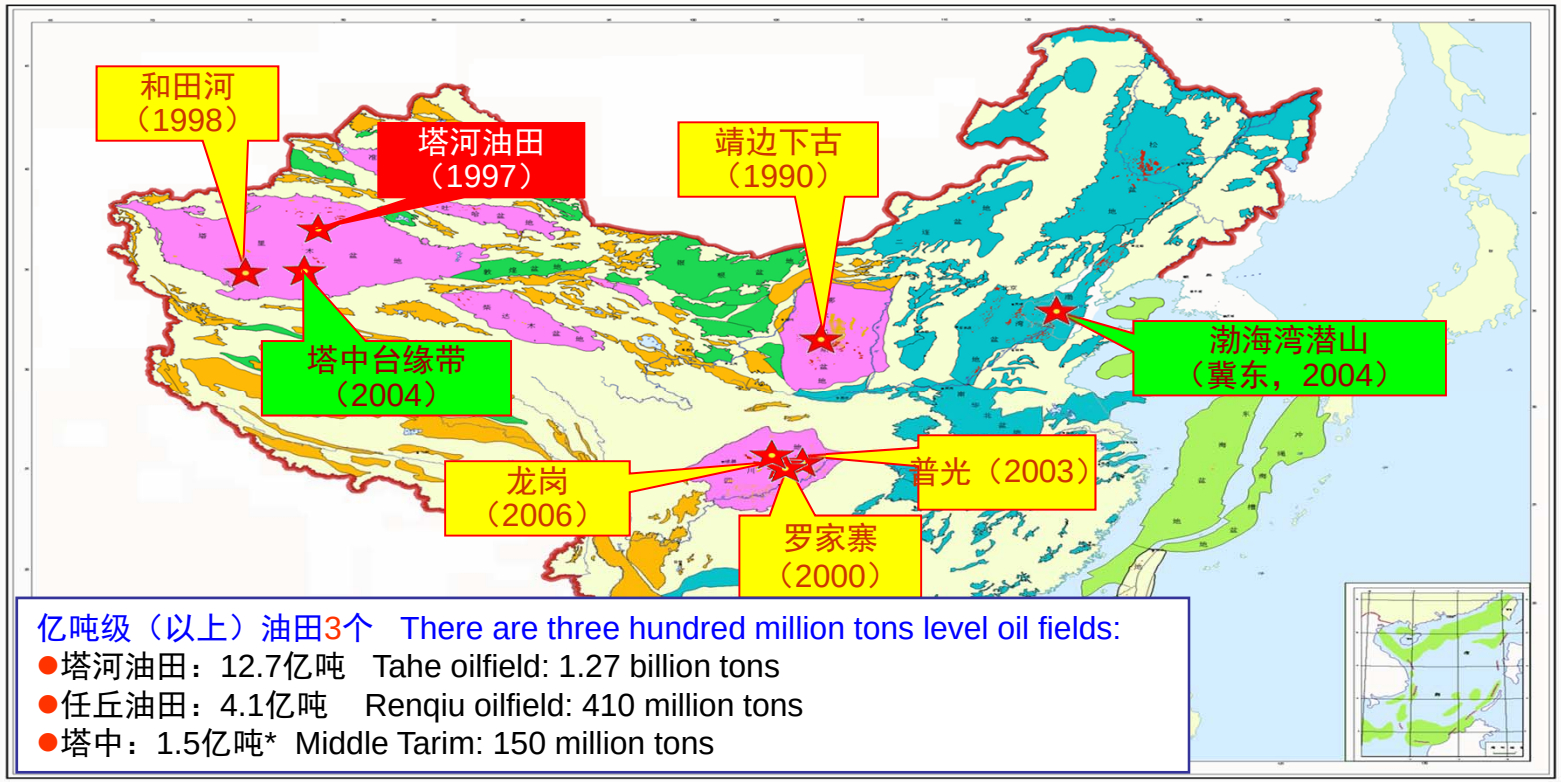
自2006年发现开始，已累计上缴国家税收**亿元，上缴地方税收**亿元，累计实现利润**亿元，有利支持了国家的西部大开发。

Since the discovery in 2006, ** billion RMB of national tax has been paid and ** billion RMB for local tax. Cumulative profits reached ** billion. All the contributes support China Western Development.

2. 社会效益　Social benefit

塔河油田缝洞型油藏的开发和建设，创新形成了勘探开发理论和高效开发技术，对同类油气藏具有广泛的推广应用价值

Reservoir development and establishment in Tahe oilfield makes creations on exploration and development theory and high efficient development technologies, which contributes great value for application in similar reservoirs.



亿吨级（以上）油田3个　There are three hundred million tons level oil fields:

- 塔河油田：12.7亿吨　Tahe oilfield: 1.27 billion tons
- 任丘油田：4.1亿吨　Renqiu oilfield: 410 million tons
- 塔中：1.5亿吨*　Middle Tarim: 150 million tons

2. 社会效益　Social benefit

建成了中国最大的第一个古生界海相碳酸盐岩缝洞型油田，世界前寒武纪--下古生界特大油田排名第七，已累产原油6148万吨，开创了大型缝洞型油田开发的先河；

Tahe oilfield is the first largest Paleozoic marine carbonate with fractures and caverns in China, ranking the seventh place of Precambrian-lower Paleozoic over-large sized field. It has produced 61.48 million tons of crude oil, which is a first on developing large fractured-caverned field.

世界前寒武系—下古生界油气田规模排序
Order in size of Precambrian-lower Paleozoic petroleum fields

油气田（国家，层系）	石油2P可采储量 (MMbbl)	天然气2P可采储量 (Mmboe)	凝析油2P可采储量 (MMbbl)	总油气2P可采储量 (MMbbl)
Hassi Messaoud（阿尔及利亚,∈2-3,O）	10335.0	1333.3		11668.3
Kovyktinskoye（俄罗斯,Vd）		8150.0	546.0	8696.0
Amal（012-B/E/N/R）（利比亚,Pre∈）	4250.0	666.7		4916.7
Chayandinskoye（俄罗斯,Vd）	366.5	3644.5	45.9	4056.9
Saih Rawl（阿曼,∈2-3—O1）	550.0	2678.5	300.0	3528.5
Tin Fouye-Tabankort（阿尔及利亚，O3-D）	1100.0	1333.3	270.0	2703.3
塔河（中_塔里木，∈,O）	2415.0	206.0	25.3	2646.3
Yurubcheno-Tokhomskoye（俄罗斯，R3）	894.0	947.2	90.0	1931.2
Zarzaitine（阿尔及利亚，D3-C）	1318.5	490.0	24.9	1833.4
Moxi（中国四川）	2.0	1814.2	0.7	1816.9
靖边-横山（中国）	2.3	1796.0	1.1	1799.4
Srednebotuobinskoye（俄罗斯,Vd.）	605.1	1138.8	28.5	1772.4
南堡（中国）	1040.0	708.3		1748.3
Saih Nihayda（阿曼，∈-O,C,P）	326.3	1089.7	28.8	1444.8
Rhourde El Baguel（阿尔及利亚,∈）	1200.0	200.0		1400.0
Verkhnechonskoye（俄罗斯,Vd）	1158.0	184.2	3.3	1345.5
Khazzan（阿曼,∈2-3）		1166.7	175.0	1341.7
Tiguentourine（阿尔及利亚,O1,D1）	90.0	908.2	266.0	1264.2
Akkas 1（伊拉克,O-S1）	10.0	1050.0	189.0	1249.0
Rhourde Nouss（阿尔及利亚,O-D）	50.0	796.0	304.0	1150.0
孤岛（中国 胜利）	1062.0	44.4		1106.4
Tinat（沙特阿拉伯,O3-P1）	300.0	550.0	202.0	1052.0
Talakanskoye（俄罗斯,Vd,∈1）	776.1	224.5	3.0	1003.6
Hamra（阿尔及利亚,O）		759.5	210.0	969.5
Kuyumbinskoye（俄罗斯,Rh3,）	731.7	219.6	17.1	968.4

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塔河油田碳酸盐岩缝洞型油藏的勘探开发理论和开发关键技术，支撑了同类油气田的储量规模动用和快速开发，目前面临提高采收率的技术挑战，我们希望和国际同仁技术共享，共同攻关，为提高该类油气藏的开发水平和人类发展，做出更大的贡献。

Exploration and development theory and high efficient development technologies on fractured-caverned carbonate reservoirs in Tahe oilfield support production improvement and rapid development for other similar reservoirs. Nowadays, we are facing challenges of EOR technologies. We expect to share technologies with international counterparts, work together to conquer difficulties and contribute much more for reservoir development and for all people.


汇报结束
请各位专家多多指教
谢谢！！！
Thanks for your comments!