The Application of Horizontal Wells in Effectively Developing Thinly-Bedded Carbonate Reservoirs of Block 5, Oman*

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Abstract

Located between the Eastern Platform and Bab Basin, Oman, Block 5 includes the DL, MZ, BSH and SD fields. Reservoirs are dominated by Cretaceous thinly bedded bioclastic packstones and wackstones, which are buried at depths of 1,500 to 1,700 m. As of the end of 2010, 195 horizontal wells containing 273 laterals with an average horizontal section of 1,000 m had been drilled in Block 5, which has significantly improved field development and production.

From 2002 to the end of 2004, based on reservoir characterization, horizontal wells were used to find and develop new oil-bearing blocks and zones, which tripled production rate from 4,500 to 15,000 bo/d in three years.

Thinner reservoirs with net pays of 3-5 m have been effectively developed using geological steering technology. Four geological steering scenarios of horizontal wells have been summarized based on practical drilling experiences. In practice, 1,500 Mbbl oil has been recovered by eight horizontal wells from the MZ field, which was considered sub-commercial before.

Water flooding has been implemented based on an alternating pattern of horizontal water injectors and oil producers, with approximately 1 km horizontal section, spaced 100 m apart. For Fault Block B of the DL field, the production has rapidly increased from 1,500 to 9,000 bo/d after water flooding in horizontal wells.

In response to thinly-bedded carbonate reservoirs with higher porosity and lower permeability of the DL field and rapid water cut rise during water flooding in horizontal wells, horizontal well correlation under depositional model, small fault interpretation, refined geo-modeling have been thoroughly studied. In the framework of depositional model, data from

horizontal wells has been fully used and pseudo-wells have been designed to build refined geo-models, which have accurately delineated small fault, inter-well subtle structure and reservoir pinch-out. The results provided a reliable geological base for water flooding adjustment in horizontal wells.

In summary, horizontal wells with long horizontal sections are helpful to discover new hydrocarbon-bearing potentials and to effectively develop thin and low permeability reservoirs. Water flooding in horizontal wells can markedly increase recovery factor of high porosity and low permeability reservoirs.

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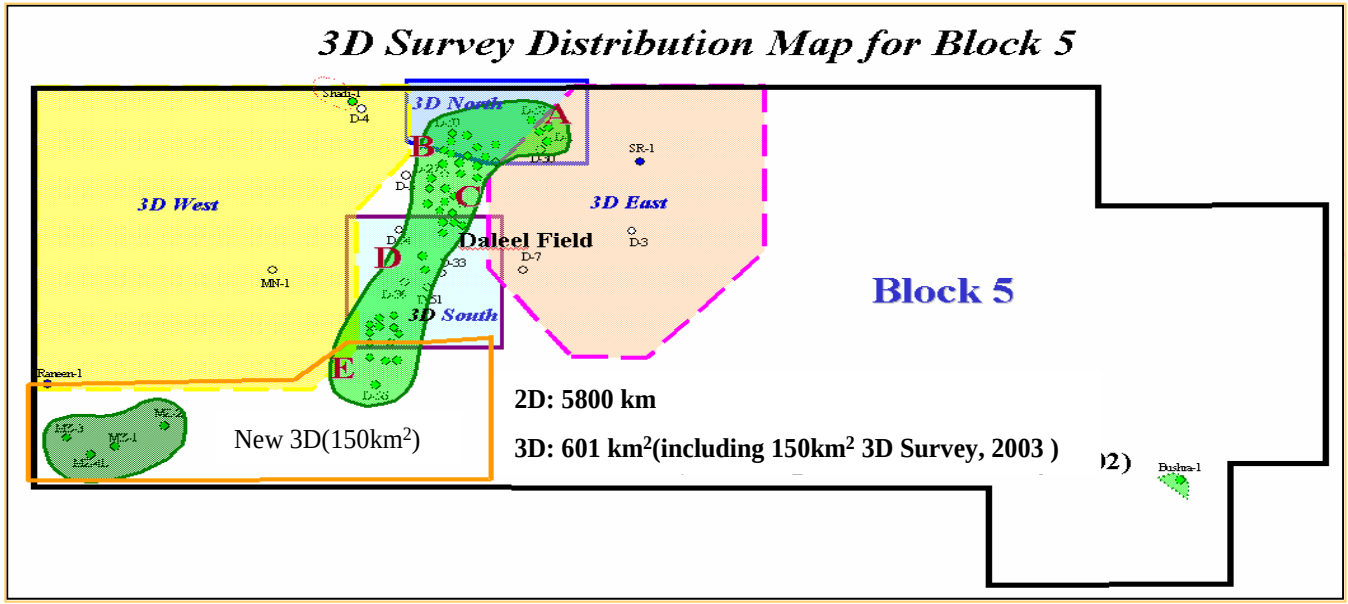
Outline

- ✓ The Overview of Oil Fields
- ✓ Contribute to discover new blocks and zones
- ✓ Effectively develop thin reservoirs
- ✓ Water flooding in horizontal wells

The Overview of Block 5, Oman



- Location: NW, Oman, 450km to Muscat Area: 992km2
- Contract: acquired in July 2002.
- Discovered fields: Daleel(Main), Mezoon, Shadi, Bushra
- Reservoir: Shuaiba, Natih
- OOIP: 1148MMBBL(P1: 499, P2:226, P3:423)
- Production as of 2011: 92 MMBBL
- Daily production: 32,000BOPD in 2011
- Producing in depletion and water injection

Strata Sequence

Target Formation

- **Upper Shuaiba (Main reservoir)**

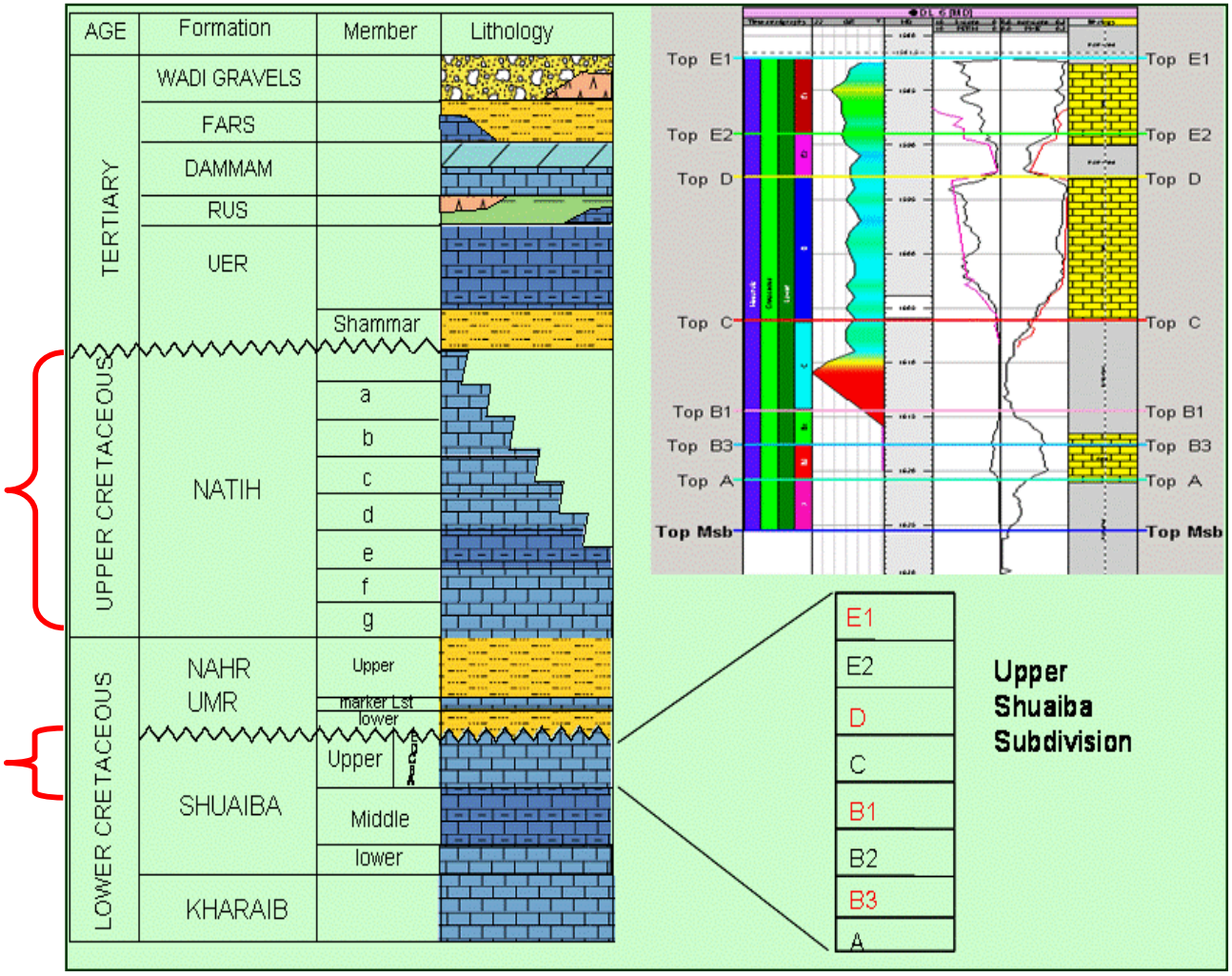
1500~1700m

8 units

Netpay: 18m

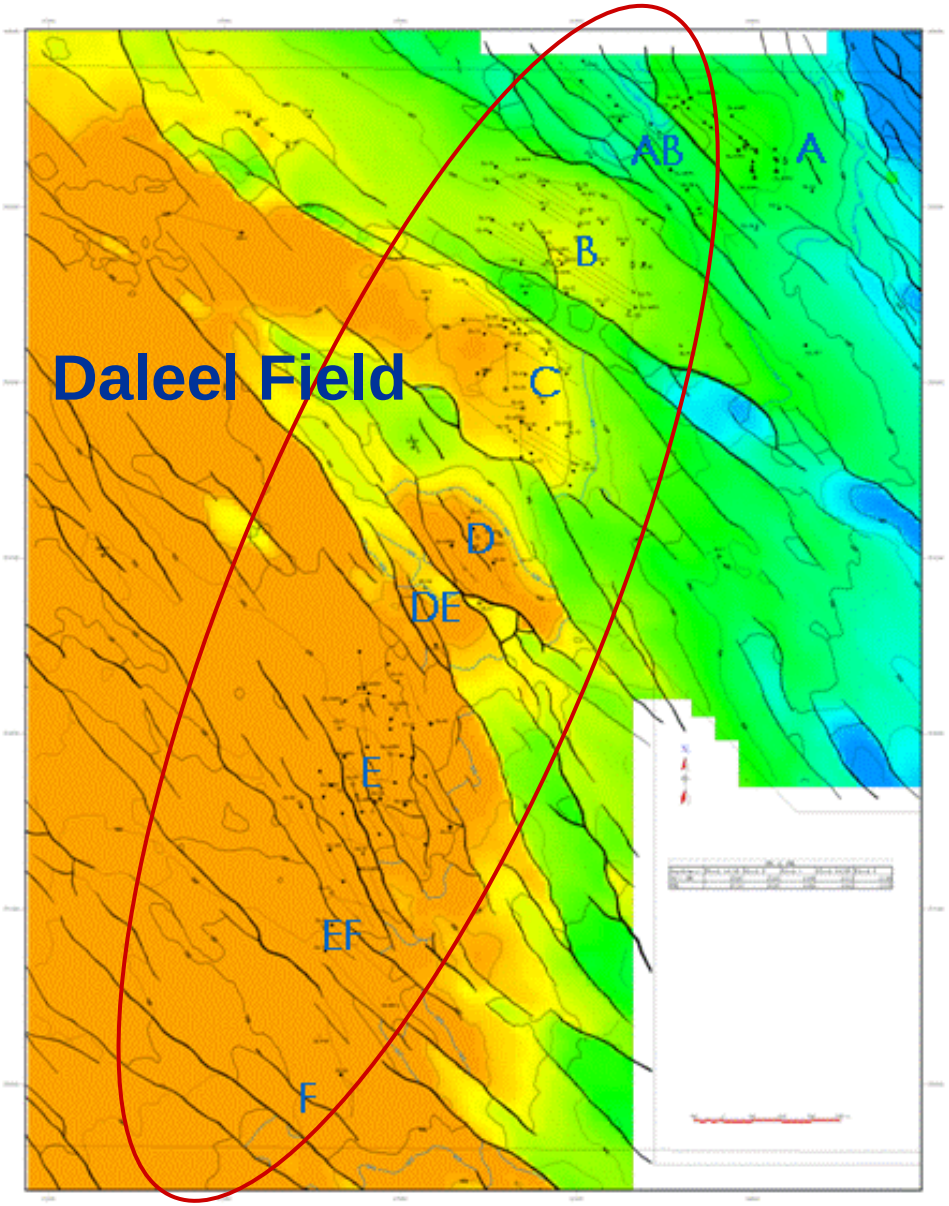
- **Natih**

1100~1300m



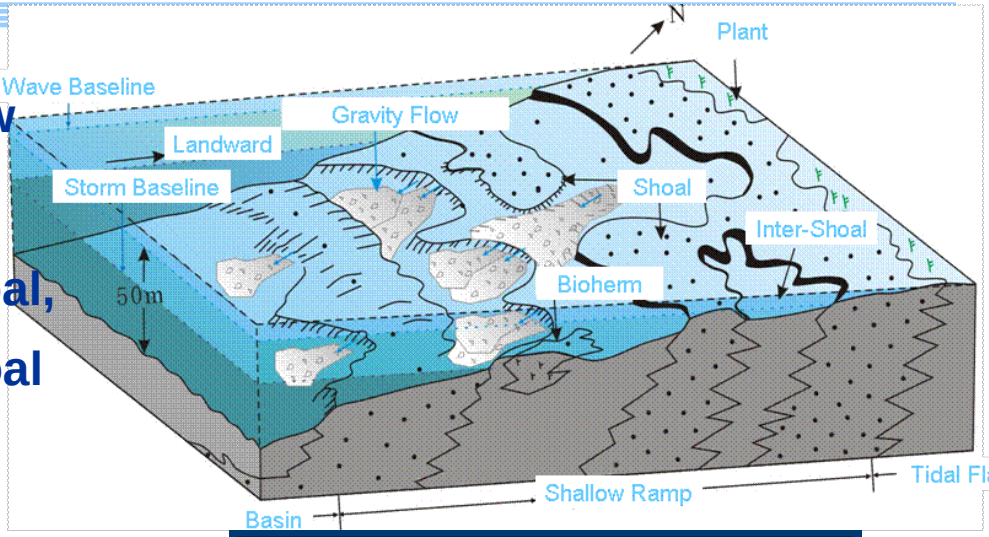
Structural Extension

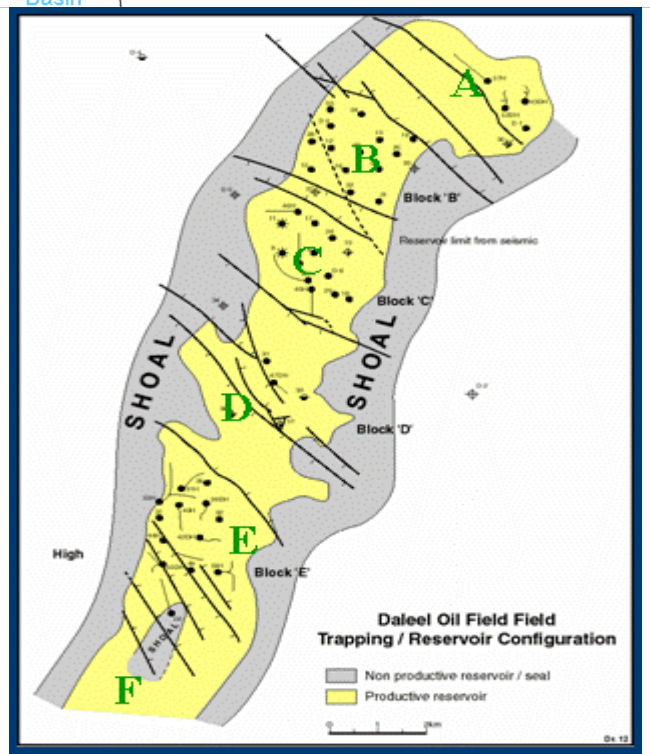
- Monoclinal structure
- Southwest – High & Northeast - low
- Dip angle of strata：2°～5°
- Horst alternating with graben
- 10 Blocks are partitioned by faults



Depositional Facies

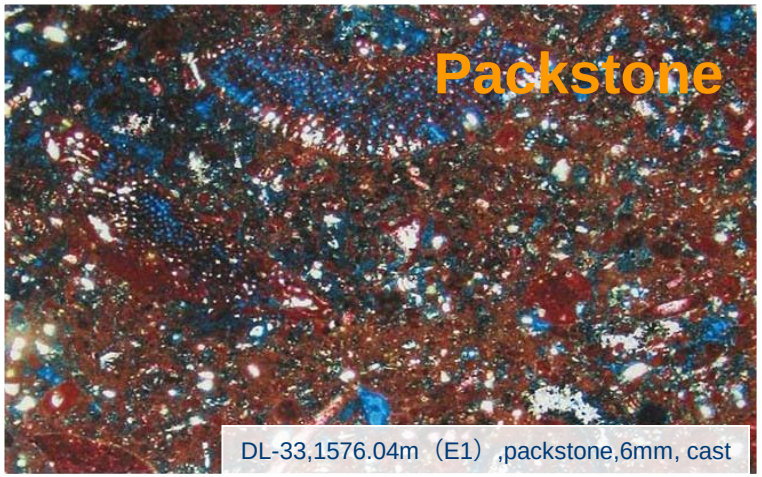
- USH of Daleel developed in shallow ramp environment.
- The main microfacies includes shoal, gravity flow, bioherm and inter-shoal lows.
- The favorable E1 and D reservoirs were mainly deposited in lower relief areas, such as inter-shoal and the lower energy environment in the bottom of local deeper ramps.
- In Daleel field, good reservoirs are controlled by fault blocks and pinchout.



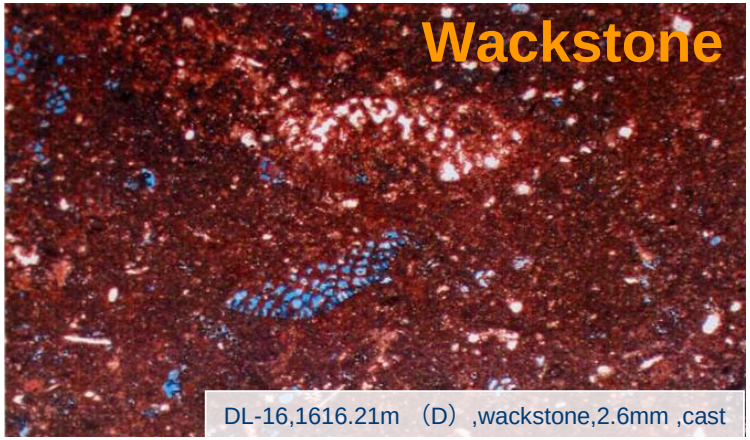


Reservoir Properties

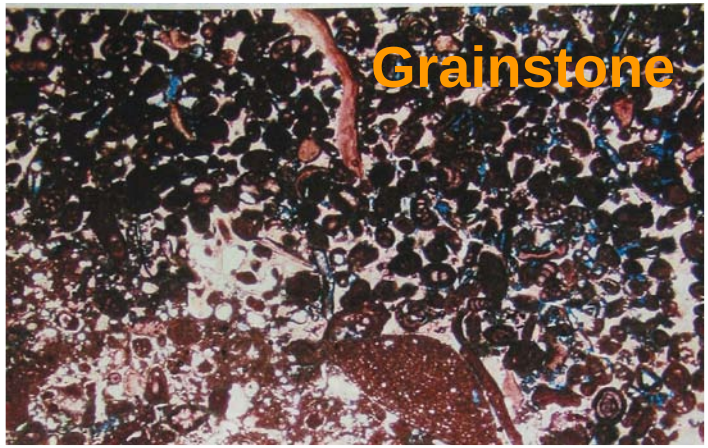
- The lithology of Unit D and E1 is dominated by bioclastic wackstone and packstone with high porosity and low permeability.
- Reservoir space is mainly primary pore dominated by micrite intercrystal pore and intergranular pore.
- Shoal is mainly composed of grainstone, floatstone with low porosity due to strong cementation.



DL-33,1576.04m（E1）,packstone,6mm, cast



DL-16,1616.21m （D）,wackstone,2.6mm ,cast

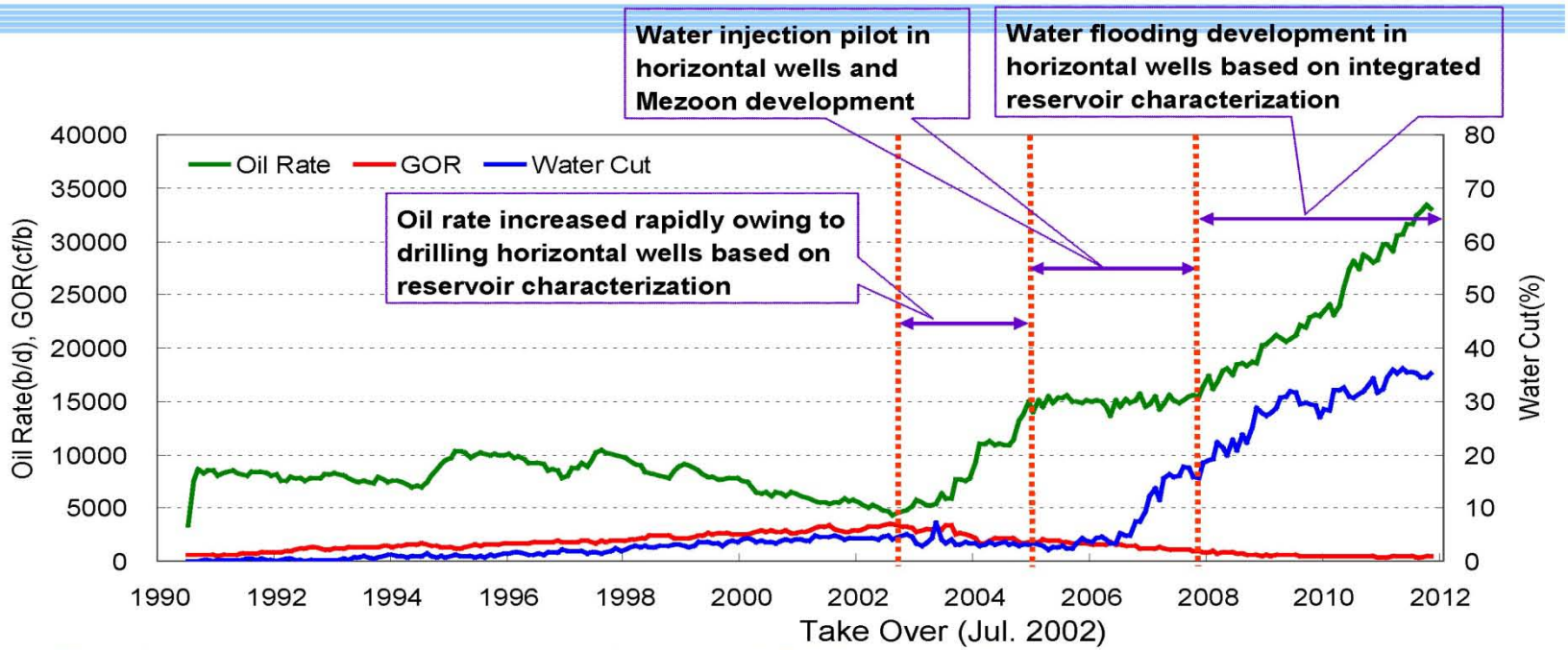


DL-33,1590.09m,1.3mm,
Ooide Peloid Orbitolina Grainstone
Porosity with low micrite

Reservoir Properties

➢ API of oil	39
➢ Viscosity(Cp)	0.75
➢ Pb(Psia)	1600
➢ Pi （ Psi @ 1475m)	2466
➢ Pressure Coefficient	1.06-1.20
➢ Formation Volume Factor	1.21—1.36
➢ GOR(Scf/bbl)	280—560
➢ Reservoir Temperature(°C)	90 （ 194°F ）
➢ Salinity of Formation Water(ppm)	170,000~190,000
➢ Water Type:	Nacl

Horizontal Well Application Summary

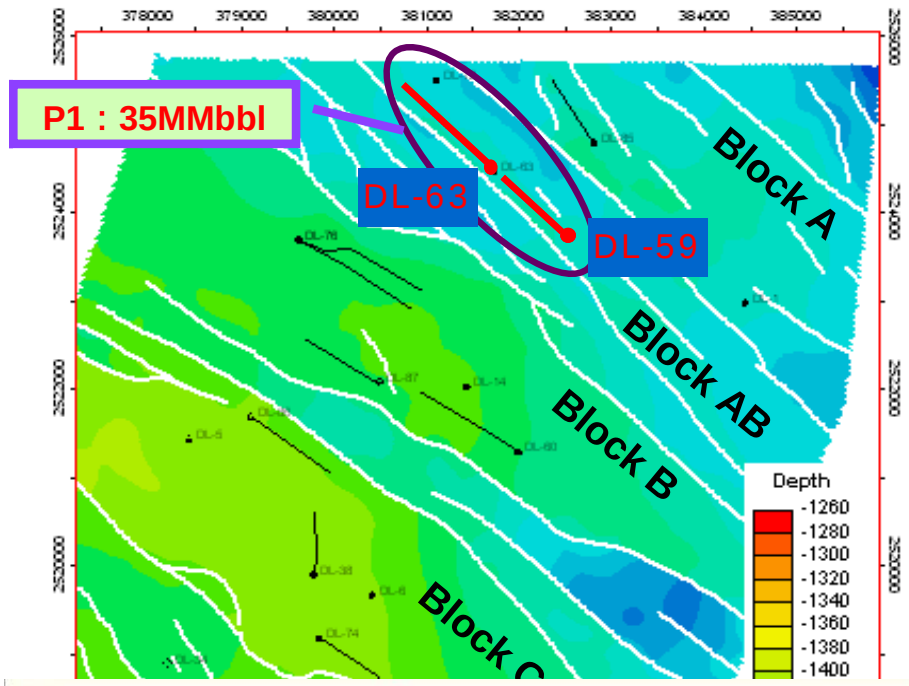


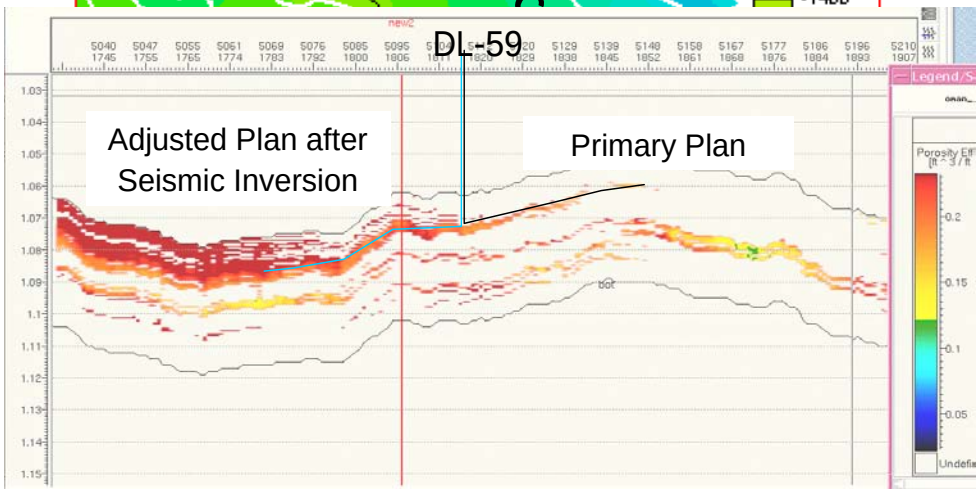
- The daily oil production was only 4500 BOPD When Petrochina took over the operatorship in July 2002. As of end-2010, 195 horizontal wells had been drilled.
- From 2002 to end-2004, based on reservoir characterization, horizontal wells were used to find and develop new oil bearing blocks and zones, which tripled production rate from 4,500 to 15,000 BOPD in 2.5 years.
- Thinner reservoirs have been effectively developed based on geological steering technology.
- Since Apr, 2005, Water flooding in horizontal wells in Daleel, the main oil field, has contributed to another rapid increase of oil production which has reached 33,000 BOPD in the end-2011.

Presenter's Notes: Daleel field had been producing by natural depletion from 1990 to 2005. Block B started depletion development in 1990 with 14 vertical wells. After 12 years' depletion, the reservoir pressure declined to only 0.36 of initial formation pressure.

Discovered New Oil Bearing Blocks and Zones

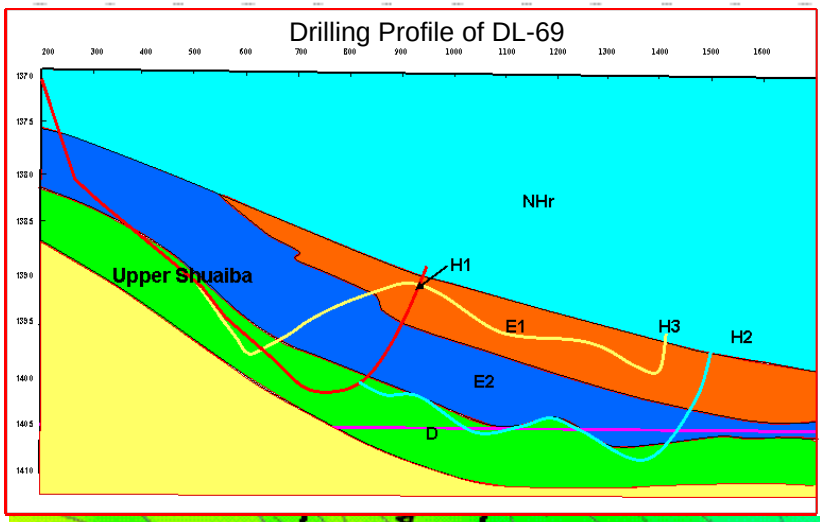
- The oil bearing graben block AB was found by well DL-59.
- According to primary plan, the horizontal section would be drilled towards structure high.
- After 3D seismic inversion, the horizontal section was adjusted to drill towards the favorable reservoir of NW.
- Daily oil production: 3000bbl/d
- Newly increased OOIP: 35MMbbl

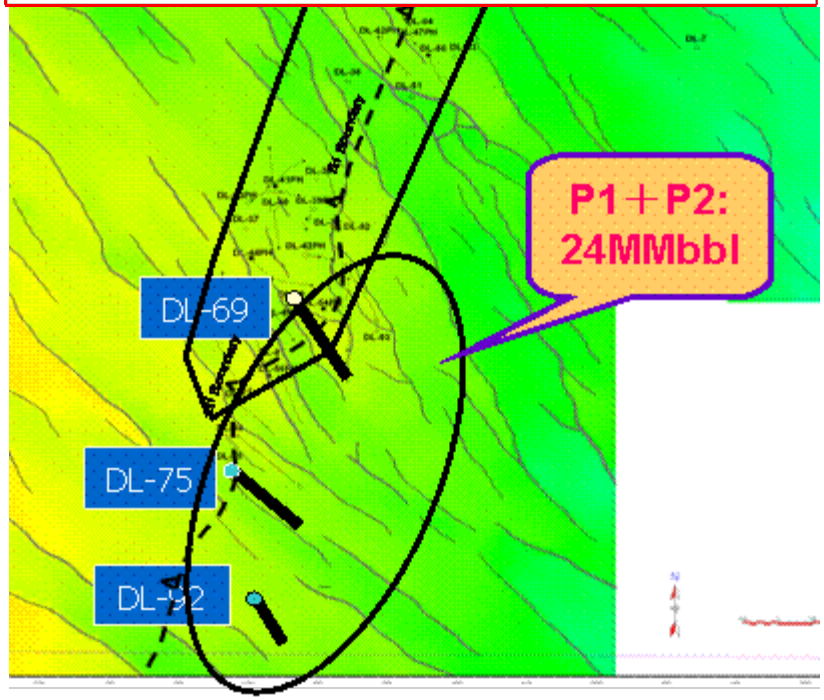




Discovered New Oil Bearing Blocks and Zones

- A new oil bearing zone E1 in Southeast of Daleel field was found by well DL-69 with 3 laterals based on reservoir characterization.
- The first lateral H1 for the primary purpose of exploiting unit D revealed that the reservoirs of unit D degraded because of lithology change. Then, it was decided to steer up and found the E1 reservoir unit exists in this area.
- The H2 leg was drilled for ascertaining the distribution of E1.
- Finally, the H3 leg was drilled to develop E1 reservoirs.
- Daily oil production: 1900bbl/d
- Newly increased 2P OOIP: 24MMbbl





Discovered New Oil Bearing Blocks and Zones

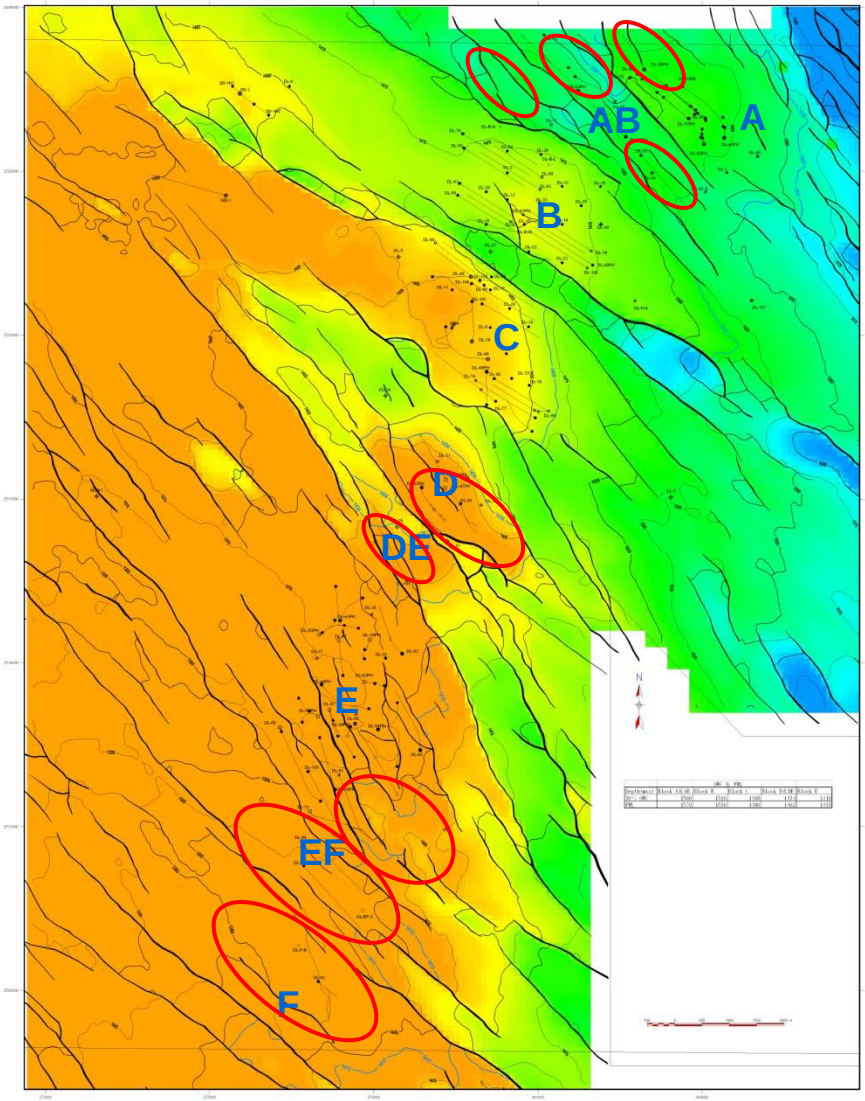
Based on reservoir characterization, horizontal wells are helpful to find new oil bearing blocks and zones. Newly increased P1 OOIP is 93.5MMBBL.

2003, Block AB was discovered and developed by DL-59H,-63H.

2007, Southern Block AB was discovered by DL-122H, DL-129H.

2006, Block DE was discovered by DL-105H.

As of present, 4 new blocks，AB, DE, EF and F have been put into production.



2005, favorable reservoirs in northwest of Block A were discovered by DL-85.

2005, fractured reservoirs of Unit B were discovered by DL-99H in southeast of Block AB.

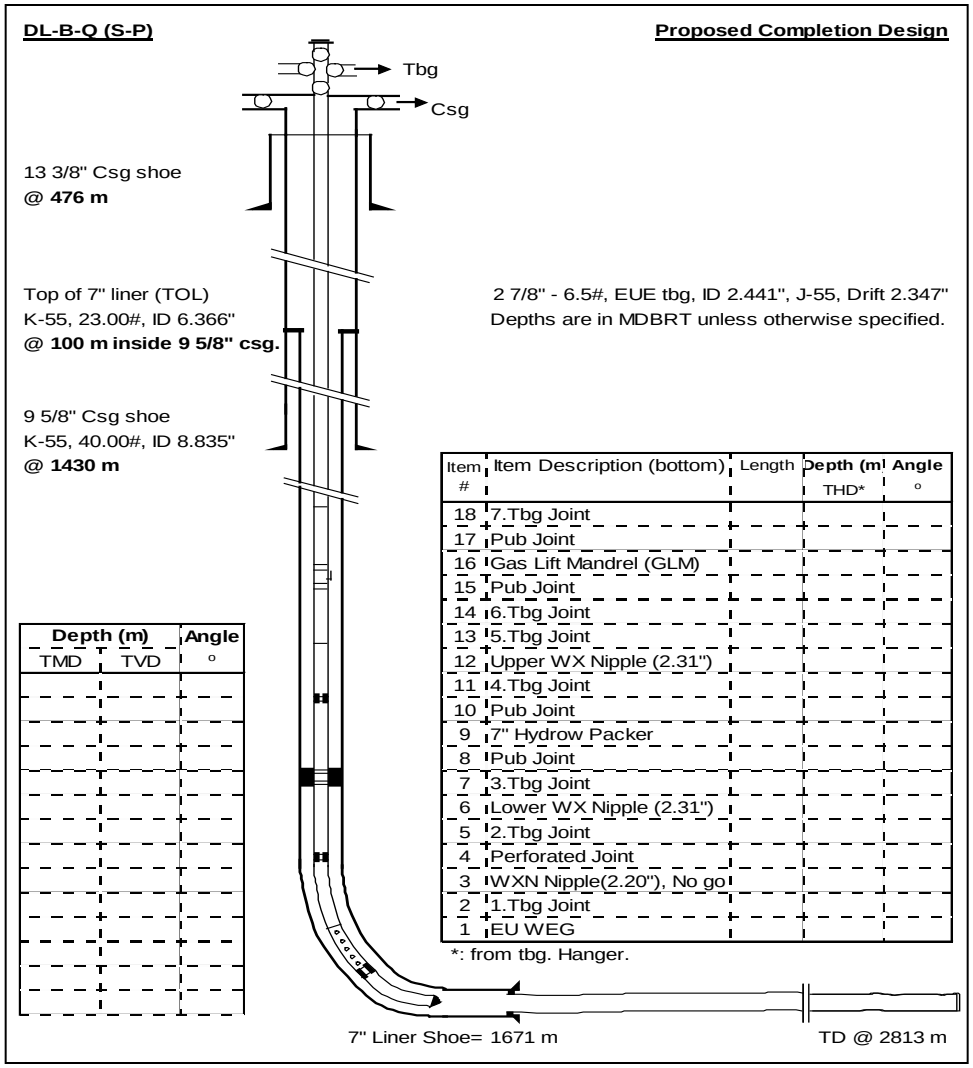
2003-2004, good E1 reservoirs in southeast of Block D were discovered by DL-62H, -64H, -66H.

2004-2005, good E1 reservoirs in southeast of Block E were discovered by DL-69H. E1 reservoirs in Block F were discovered by DL-92H.

Effectively Develop Thinner Reservoirs

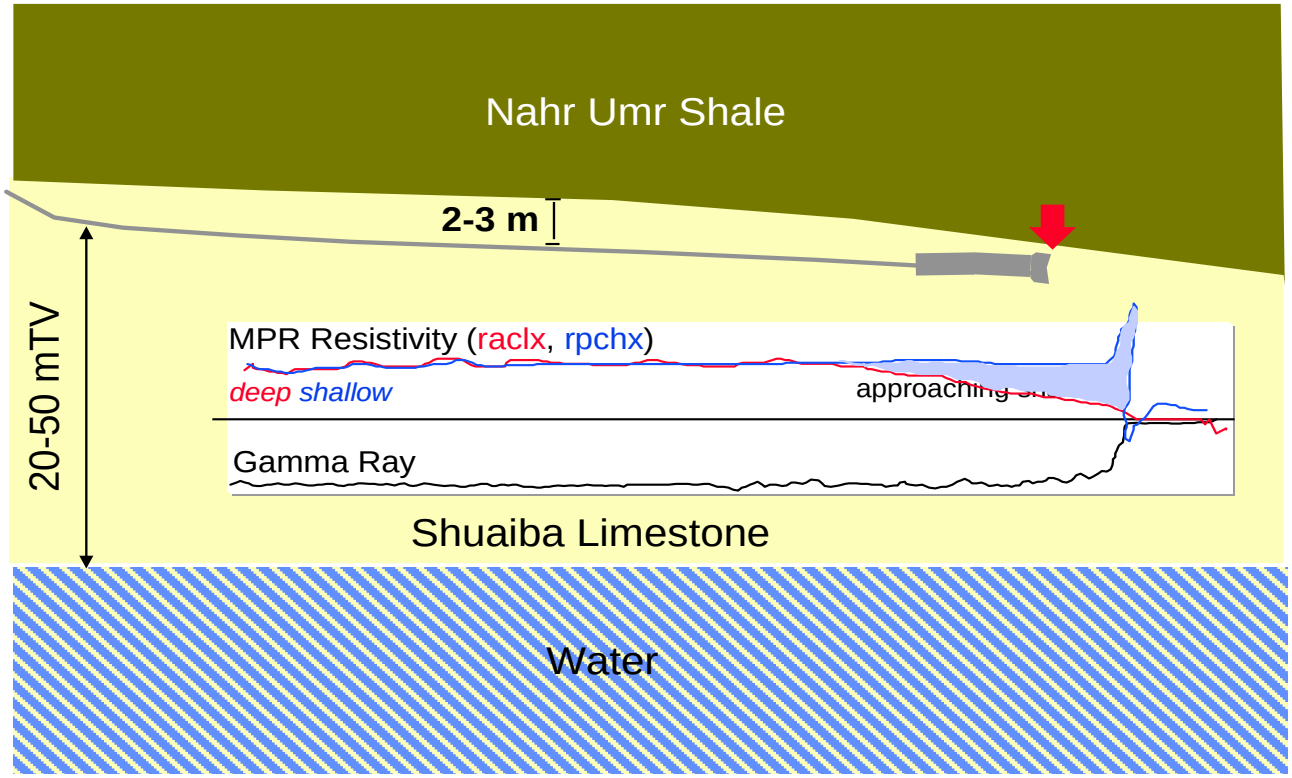
- 4 geological steering scenarios of horizontal well were summarized based on practical drilling experiences in block 5.
- The drilled pay zones of horizontal section reach 90%.

Horizontal well program of Block 5



Effectively Develop Thinner Reservoirs

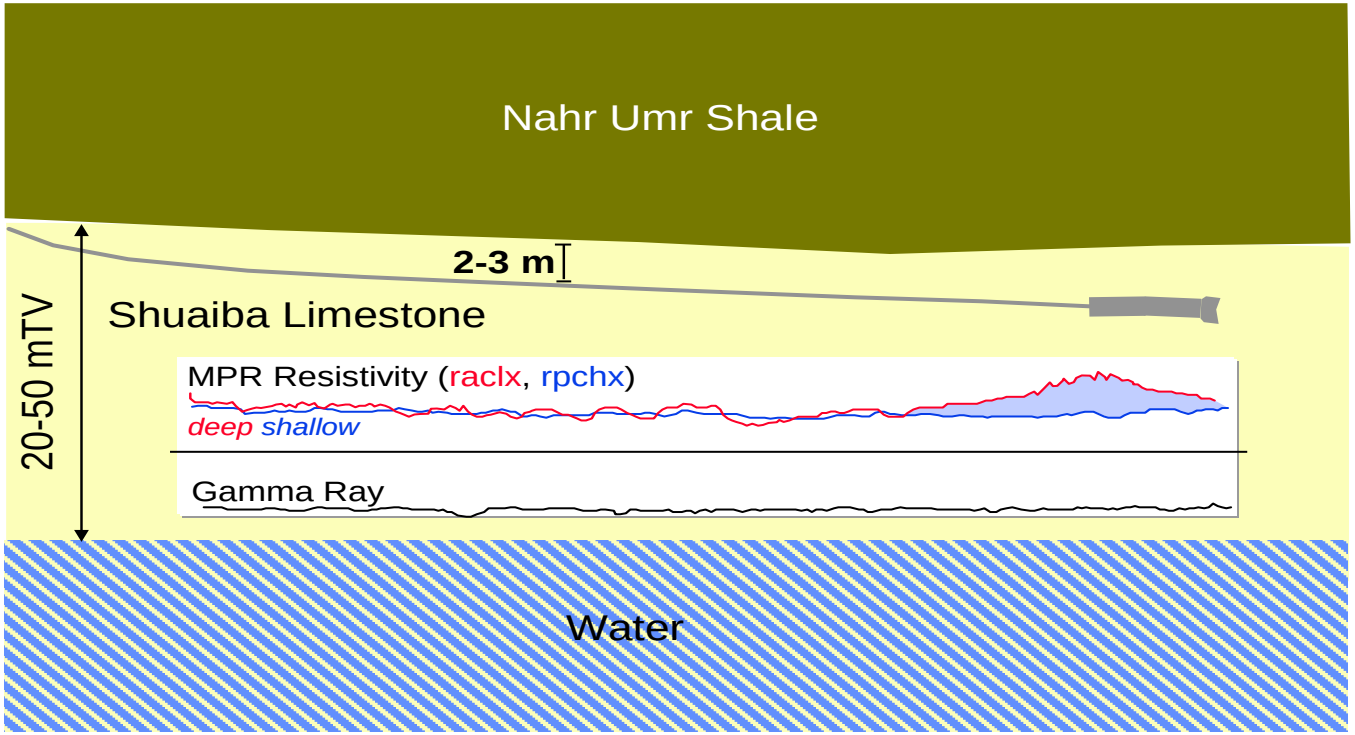
Scenario1 - Approaching the roof of reservoirs at a low angle



- **Under the influence of the overlain Nahr Umr shale, a distinct separation of deep and shallow resistivity will occur owing to deep resistivity decrease. Meanwhile, gamma ray will increase.**
- **Then the bit shall be steered down to ensure the horizontal trajectory in reservoirs.**

Effectively Develop Thinner Reservoirs

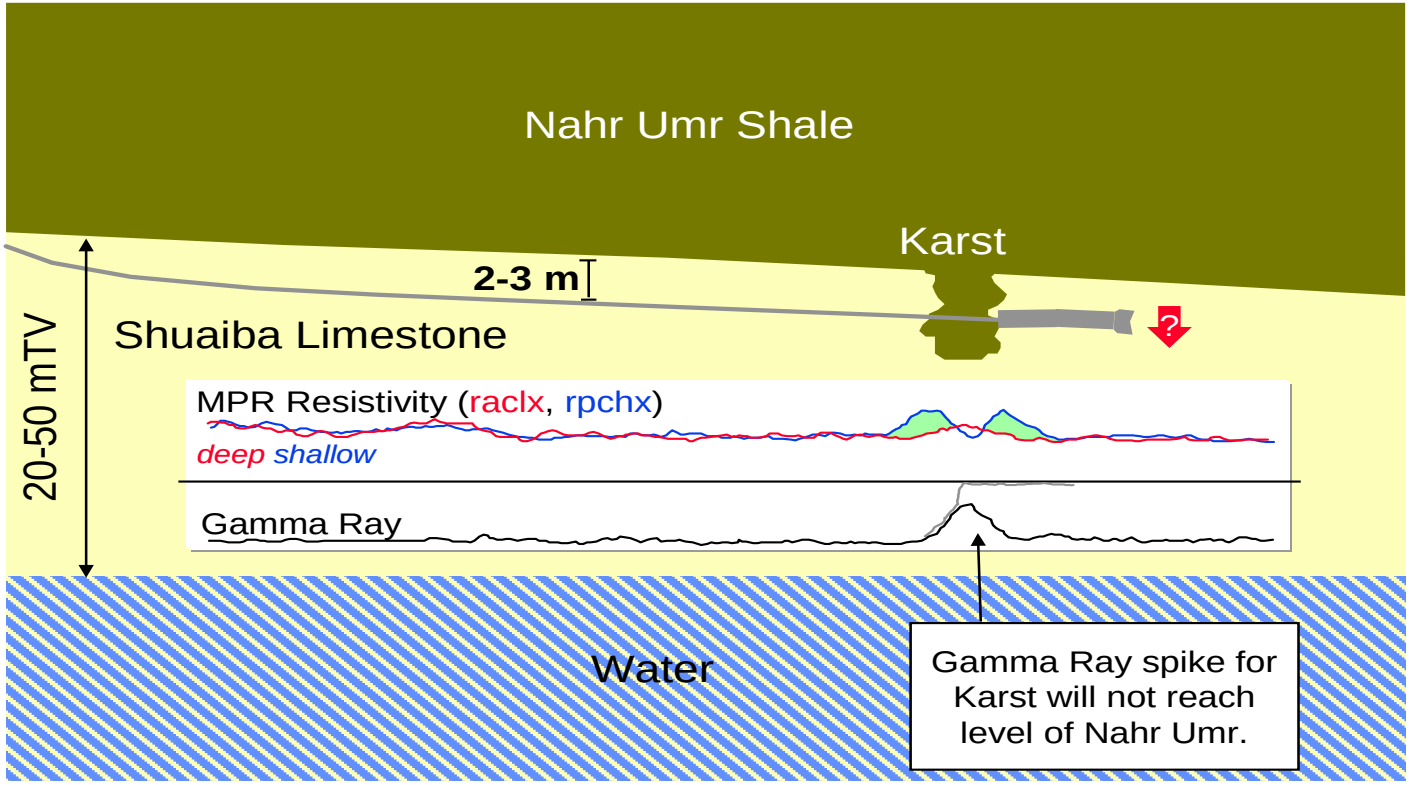
Scenario2 - Deviating roof of reservoir



- **Deep resistivity will increase and shallow resistivity and gamma ray will keep unchanged.**
- **Then the bit will be steered up to keep the horizontal trajectory of producers in the upper part of reservoirs.**

Effectively Develop Thinner Reservoirs

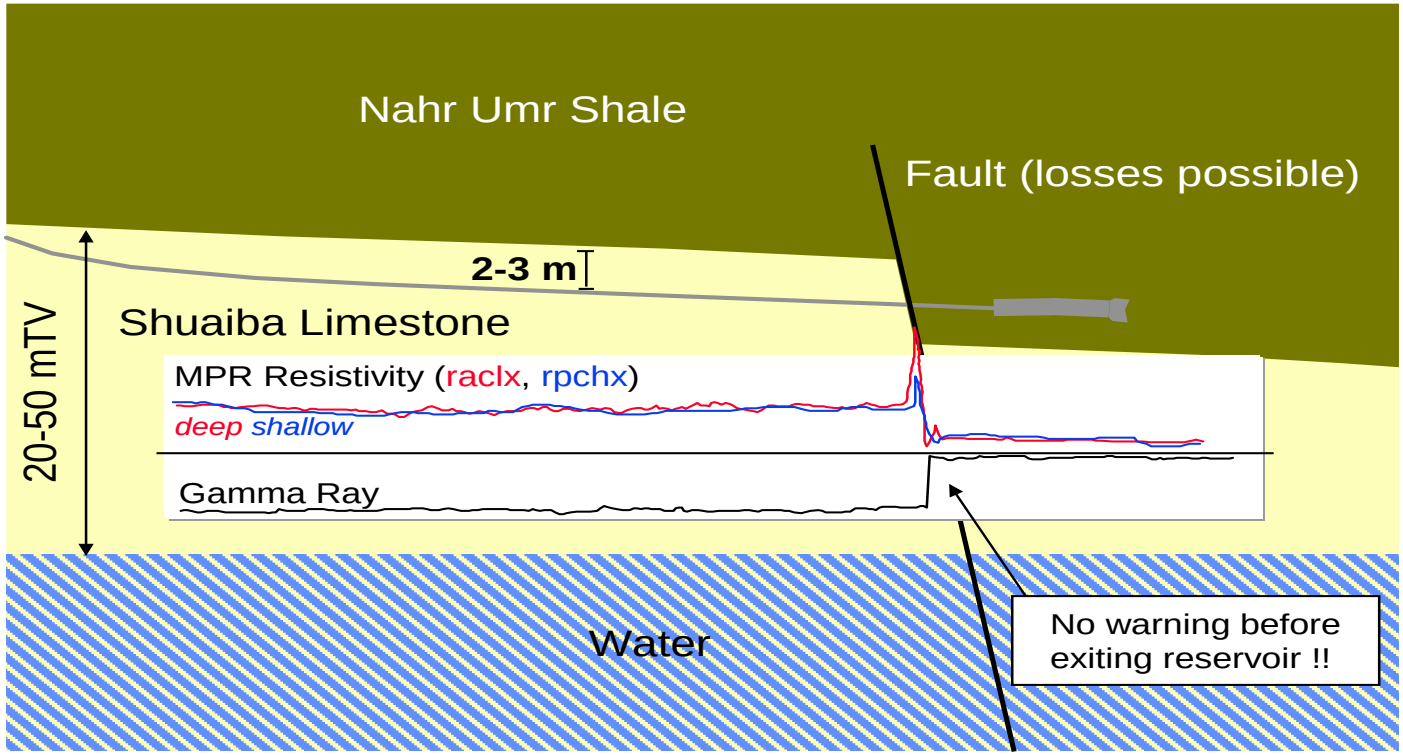
Scenario3 - Encountering Karst



- **A distinct separation of deep and shallow resistivity will occur and gamma ray will increase.**
- **Continue to drill 20 m ahead to confirm whether localized karst or Nahr Umr shale encountered.**

Effectively Develop Thinner Reservoirs

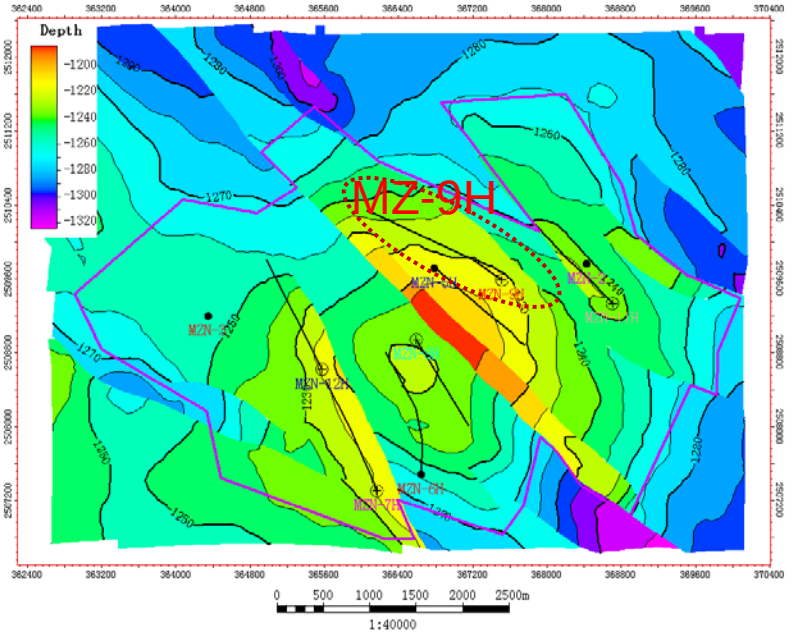
Scenario4 - Encountering faults



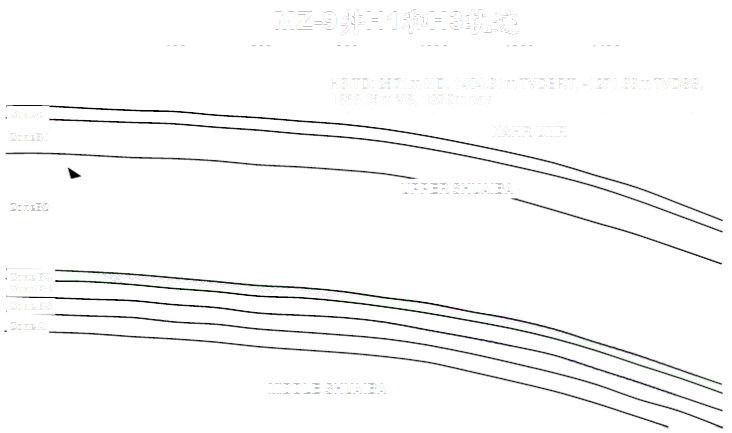
- A sudden change of resistivity and gamma ray will occur.
- Adjust bit to ensure the horizontal trajectory in reservoirs.

Effectively Develop Thinner Reservoirs

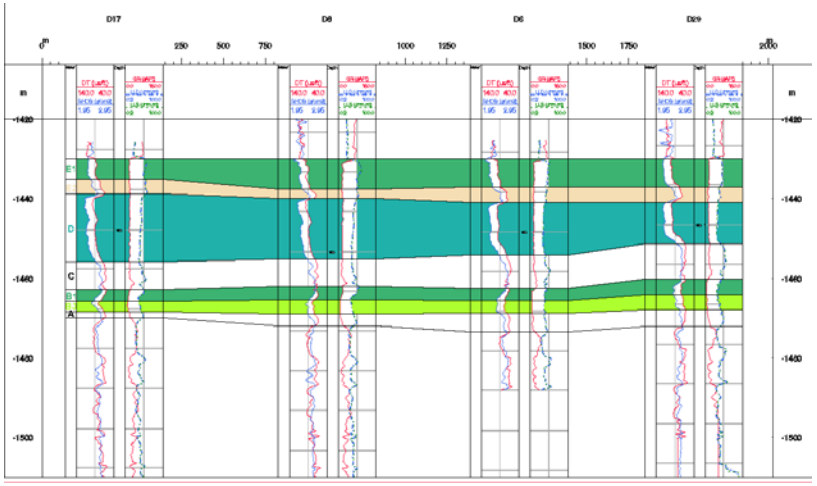
- Mezoon field is one of four fields in Block 5. the oil pay zones are dominated by thin carbonate reservoirs of Upper Shuaiba with a thickness of 3-5 meters.
- The reservoir properties are worse than those of the main Daleel field. The average porosity is 27%, but the average permeability is only 3 mD.
- Four drilled vertical wells had proven that it was difficult to develop this field with vertical wells.
- 8 multi-lateral horizontal wells have been drilled based on advanced geological steering technology from 2005.
- The initial daily production of single well reached more than 500 bbl/d.
- As of end-2011, 2055Mb crude oil has been recovered by 8 horizontal wells.



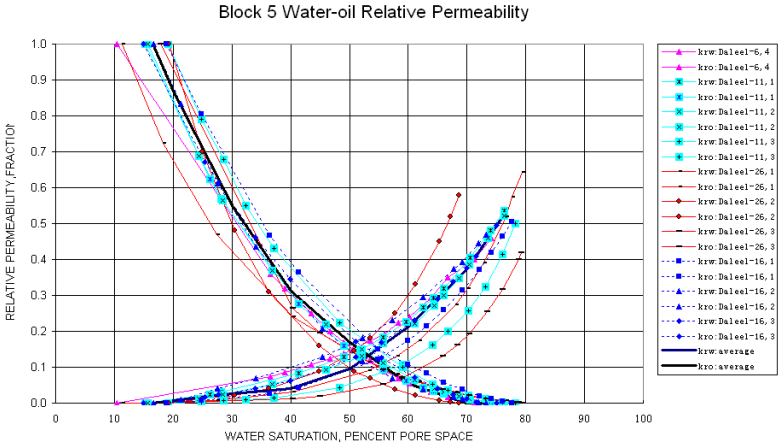
Drilling Profile of MZ-9



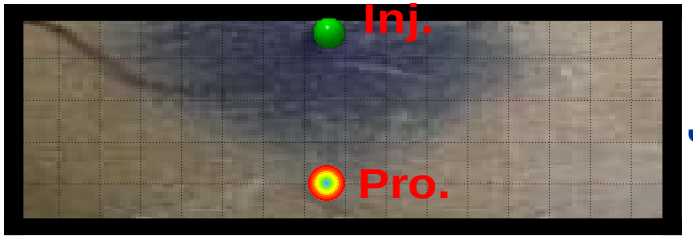
Water Flooding in Horizontal Wells



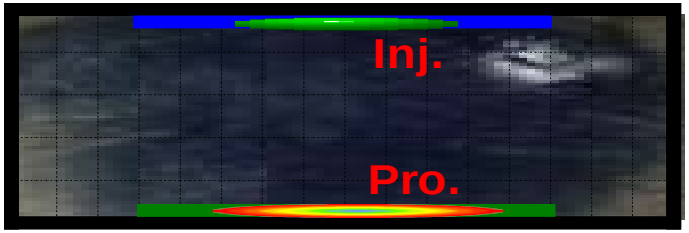
- Stratified reservoir with high Por and low Perm.



- Big movable oil interval

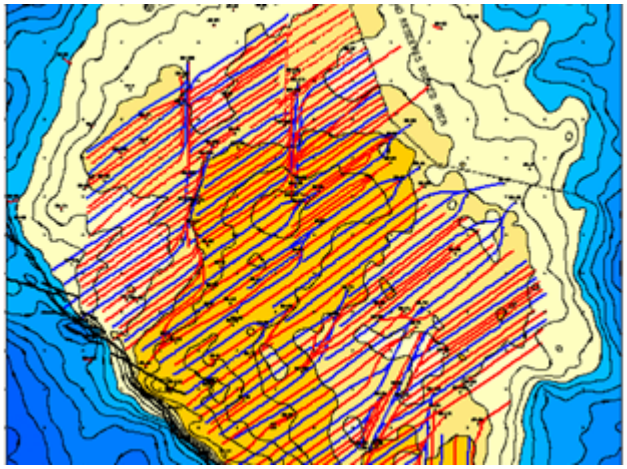


Radial flow with vertical Well



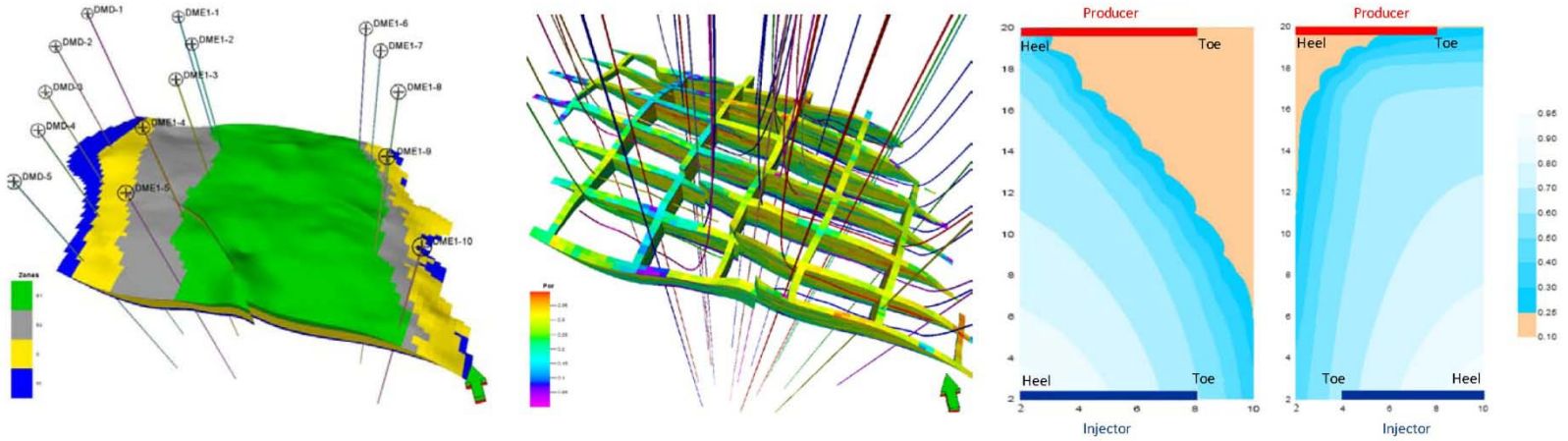
Linear flow with Horizontal Well

Physical model

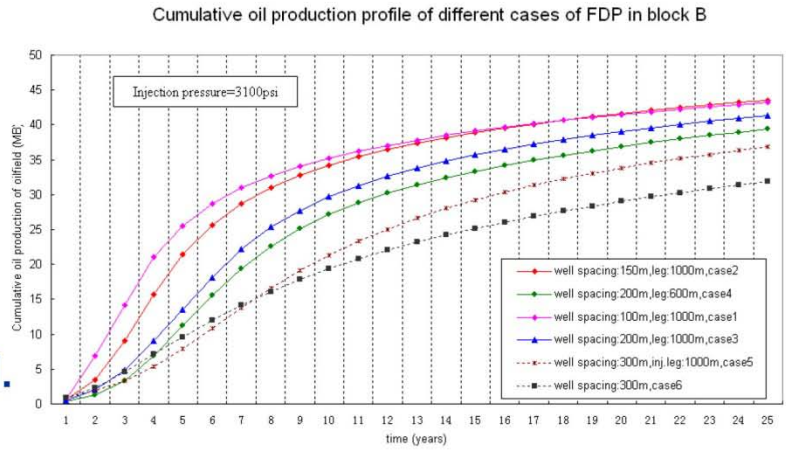


- Successful experience of WF with horizontal wells in adjacent fields

Water Flooding in Horizontal Wells

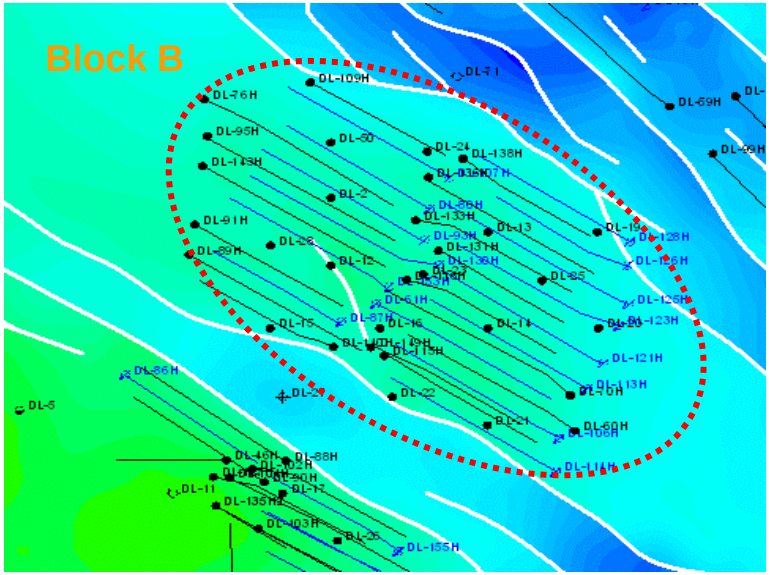


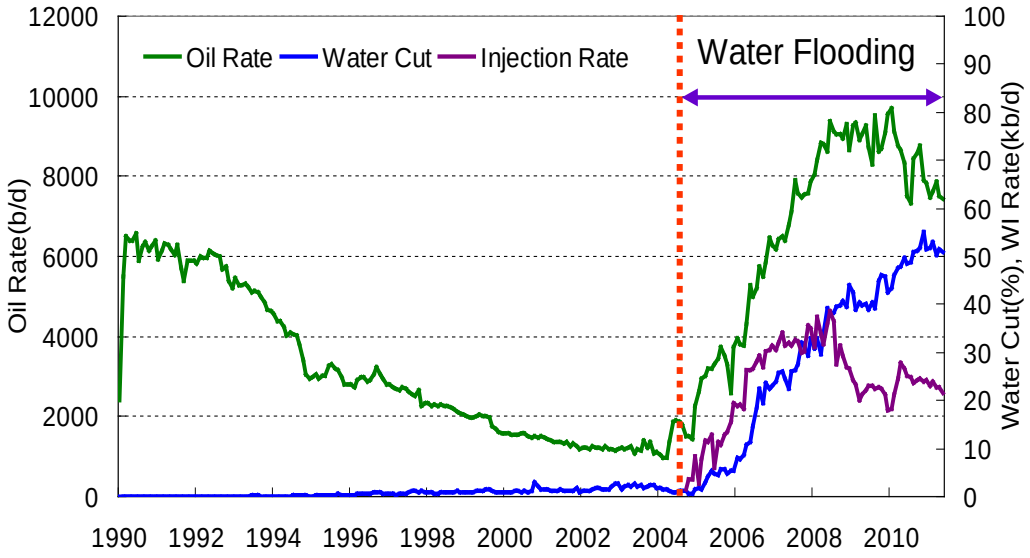
- **The toe to heel pattern can delay the water breakthrough and sweep more efficiently.**
- **An alternating horizontal injector/producer pattern with 1000 m horizontal section and 100 m inter-well space is adopted.**



Presenter's Notes: Two options, namely toe to heel and toe to toe, are available for corresponding horizontal legs of horizontal producers and injectors. While for the toe to heel pattern, the differential pressure of injection/production for the correspondent positions is relatively steady which can delay the water breakthrough.

Water Flooding in Horizontal Wells





- **As of 2008, Water flooding well pattern in Block B has been completed, including 14 producers and 16 injectors. And the daily oil production rapidly increased to 9000 bbls from 1500 bbls, which is six times as that before water flooding.**

Summary

- horizontal wells with long horizontal section are helpful to discover and confirm new hydrocarbon-bearing potentials.
- To effectively develop low permeability thin reservoirs.
- Water flooding in horizontal wells can markedly increase recovery factor of high porosity and low permeability reservoirs.


THANKS !
2012.4