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Successful Applications of the Latest Technology for Improved Oil Recovery in Saudi Arabia

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Abstract

Case studies of the applications of three new technologies – 3-D Seismic, Horizontal Drilling and Multi-lateral Drilling – in Saudi Arabian Oil fields are described. Results demonstrate that: (1) 3-D Seismic surveys are resulting in better field delineation and more accurate reservoir characterization. Better volumetric estimates result in setting realistic field development and production targets. Better reservoir characterization – facies distributions and saturation domains – aids in cost-effective field development plans and efficient reservoir management programs. (2) Horizontal and high-angle wells are aiding in producing: (a) relatively low permeability tight reservoirs where vertical wells cannot produce at economic rates, (b) oil pockets trapped within the random tar-filled areas of the reservoir as well as in the attic area, (c) water-free oil from water-underlain, seemingly stagnant thin oil columns, and (d) oil zones underlying large gas caps without excessive gas production. (3) Multi-lateral wells are providing means to produce: (a) low permeability tight reservoirs with each lateral draining a separate area, and (b) high flow-capacity contrast multi-layered reservoirs promoting simultaneous production from various layers.

Implementation of these technologies has had a pronounced effect on reducing capital and operating costs. Development planning has become more cost-effective, oil production rate declines are being arrested, plateau oil rates are being sustained over longer duration, and oil recoveries are being improved.

Introduction

Saudi Aramco, a technology-based operator of oil and gas resources in the Kingdom of Saudi Arabia, continues to utilize state-of-the-art technology in its exploration and production operations.

Proven technology is imported whenever it is readily available and is considered cost-effective and capable of producing the desired results of improving productivity and enhancing reserves. The emerging technology having potential application in Saudi Arabia is sponsored, both internationally and within the Kingdom. In addition, a major in-house effort is dedicated to wide-range research and development programs.

Technology Applications

This paper presents case studies of the applications of three major new technologies in Saudi Arabian oil fields.

1. 3-D Seismic Surveys
2. Horizontal Drilling
3. Multi-lateral Drilling

1. 3-D Seismic Surveys Are Providing Better Reservoir Characterization.

3-D Seismic surveys are providing detailed information on reservoir configuration, hydrocarbon limits and reservoir attributes. Their applications are now almost routine in exploiting maturing fields as well as in characterizing the newly discovered and partially developed fields. Examples described below show their various uses in Saudi Arabian fields.

Example No. 1. This example comes from a partially delineated sandstone reservoir within a highly complex depositional setting – a composite of braided stream-alluvial fan system and eolian-braid plain complex. **Fig. 1** on the left shows the outer limit of the oil accumulation as interpreted from the 2-D seismic data on a 5-km spacing and limited well control. A 3-D seismic survey on 25-meter line spacing was conducted; the revised interpretation shown in **Fig. 1** on the right shows a significant extension of the areal limits of the accumulation. Subsequent evaluation drilling has confirmed this extension, resulting in a four-fold increase in the estimated original oil-in-place. This has resulted in doubling the development target from this reservoir.

Example No. 2. This example comes from a fairly well delineated sandstone reservoir, in the same depositional setting as in Example No. 1, with a 5-km line spacing 2-D seismic survey and extensive well control. The initial external limit, shown on the left in **Fig. 2**, is significantly revised after a 25-meter line spacing 3-D seismic survey. A stratigraphic extension is identified in the northwest area and a structural high is located in the northeast. Subsequent evaluation drilling has confirmed these extensions. The original oil-in-place estimates have been revised upward by 20%, allowing room for incremental development.

Example No. 3. This example, dealing with the reservoir described in Example No. 1, shows that a successful 3-D seismic survey has immense value in providing detailed information on reservoir quality and spatial continuity. This reservoir was being developed on a conventional regular grid, an age-old successful practice in the giant-size oil fields of Saudi Arabia. Drilling encountered many unexpected surprises in this field – shaling out of sands over the crestal highs, random distribution of sands and silts, thickening and thinning of sands, and multi-stacking of sand bodies. Interpretation of the 3-D seismic results utilizing impedance (velocity x density) analysis resulted in identifying reservoir-quality sandstones and non-productive tight siltstones.

The 'seismic section' on the left in **Fig. 3** shows the vertical view of the reservoir with the sandstone-rich layers being the dark and the siltstone-rich layers being the light intervals. The 'time horizon' on the right shows an areal view of the reservoir with darker areas as sandstone-rich and the lighter areas as siltstone-rich. The productivity data from the wells drilled prior to the seismic survey – Wells 1 and 3 being high rate producers, Well 4 being a marginal producer, and Wells 2, 5 and 6 being sub-marginal – are in agreement with the interpreted results.

The 3-D seismic response identified spatial continuity of the reservoir-quality sands, as shown in **Fig. 4**. The black regions are the siltstone rich areas and the interconnected sandstones are shown by the network. Pre-survey development drilling resulted in most of the crestal wells and a good number of peripheral injectors being in the siltstone-rich areas with only marginal to sub-marginal utility. Post-survey wells were successfully drilled in the sandstone-rich area.

Visualization of the 3-D seismic data with the assistance of super computers and newer processing technology was utilized to image the reservoir in its sub-surface setting. The results of the conventional processing, shown on the left in Fig. 5, show large scale structural discontinuities such as faults and fractures and major stratigraphic changes. The results of special processing, such as Coherency Technique which identifies and correlates similarities, shown on the right in Fig. 5, show sub-seismic fractures, faults and lithological differences.

2. Horizontal Wells Are Enhancing Production Rates and Recovery.

Horizontal and high-angle drilling technology has been a major recent advancement in the oil industry. It is resulting in improved well productivity and injectivity, revitalizing many old oil and gas fields with marginal economics.

Saudi Aramco is applying this technology as well as its time-lapse version (4-D) in a variety of situations. The case studies described below are some examples.

Example No. 1. Fig. 6 shows that some semi-solid tar patches, present at the oil-water contact as well as at structurally higher unknown and unidentifiable locations, in a massive limestone reservoir creates an unusual situation: (1) oil pockets trapped in between the tar patches may not be contacted by the flood water, and (2) attic oil pockets are formed at locations updip of the highest producers due to peripheral water injection. Previously, vertical wells targeted these oil pockets; some being only marginal wells, others being wasted.

Horizontal wells have proven very successful in locating and draining these somewhat isolated pockets of oil. An innovative approach, Pyrotechnic analysis of drill cuttings at wellsite, greatly assisted this application. The difference in the hydrocarbon residue between the oil bearing and the tar-bearing cuttings provided a simple and inexpensive method of deciding on the steering of the horizontal well in the desired direction.

Example No. 2. This example shows the application of horizontal wells in a situation that has developed in our maturing high permeability multi-layered limestone reservoirs under gravity-dominated peripheral waterfloods in areas where wells currently produce at increasing water-cuts exceeding 50 percent.

Figure No. 7 shows porosity profile, current oil and water saturation, and flow profile for an openhole vertical producer at 60 percent water-cut. Here, the middle Zone 2-b is essentially watered out while the upper 25-ft of Zone 2-a is still producing dry oil with the remainder producing both oil and water. This well is expected to stop flowing, when water-cut exceeds 70 percent, within a short time due to the increasing bottomhole back pressure. Many such wells are now standing dead due to the non-availability of artificial lift.

The short-radius horizontal drilling has salvaged such wells. The lower watered-out zones are being abandoned and wells are being re-completed horizontally with the maximum possible standoff between the well trajectory and the bottom water. The horizontal well is produced at a restricted rate to avoid water coning due to excessive pressure drawdown. This example well has during the first 15 months produced over one million barrels of oil at lower water-cuts.

3. Multi-lateral Wells Are Enhancing Production Rates and Improving Waterflood Sweep Efficiency.

Multi-lateral well drilling is gaining momentum in our operations. It offers the potential of searching for and producing the by-passed, the slow moving, and the stagnant oil pockets in many mature reservoirs under waterflood. Two examples are described below:

Example No. 1. A high angle slanted well, drilled in an offshore highly complex heterogeneous limestone reservoir, encountered only the poor quality facies and was tested non-productive (left-hand side in **Fig. 8**). Multi-lateral drilling saved the well. Two laterals, spaced 1,700 ft. apart, were drilled from the mother hole in two prospective directions. They both encountered reservoir-quality rock and the well tested at rates exceeding 10,000 STB/D. This well has long been on production at the restricted rate of 3,000 STB/D to avoid water coning from the water leg below.

Example No. 2. The left-hand side of **Fig. 9** shows the porosity and flow profiles of a vertical well completed openhole in a massive multi-zone limestone reservoir. It has an unusual problem of flow domination by a very thin layer of high permeability – the 5-ft layer contributes well over 60 percent. A major potential problem is associated with this layer; it is very conducive to premature water breakthrough, rapid rise in water production, well drowning, and the resulting uneven vertical sweep from this area.

Multi-lateral drilling technology rescued the situation: the super-perm layer in Zone 2-a was cased off, thereby eliminating the potential problems, and two high angle 700-900 foot long laterals separately targeted the lower flow capacity Zone 2-b and Zone-3. On a production test, the two laterals produced at 12,000 STB/D. These two zones together had contributed around 500 STB/D when produced commingled with Zone 2-a above.

Conclusions

1. 3-D seismic surveys are becoming routine in exploration programs, exploitation projects, and reservoir monitoring. They are resulting in better field delineation and more accurate reservoir characterization.
2. Horizontal and high-angle slanted wells are in increasing use to improve well productivity and injectivity, to recover by-passed oil and to produce thin oil columns underlain by water or overlain by gas.
3. Multi-lateral wells are being successfully introduced to search for and produce the by-passed, the slow moving, and the stagnant oil pockets in many mature oil reservoirs under peripheral waterflood.

Acknowledgment

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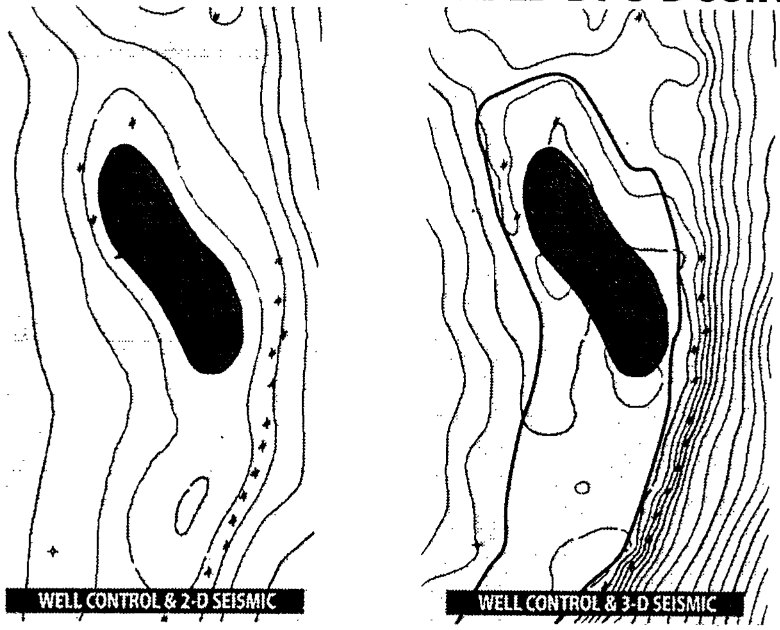
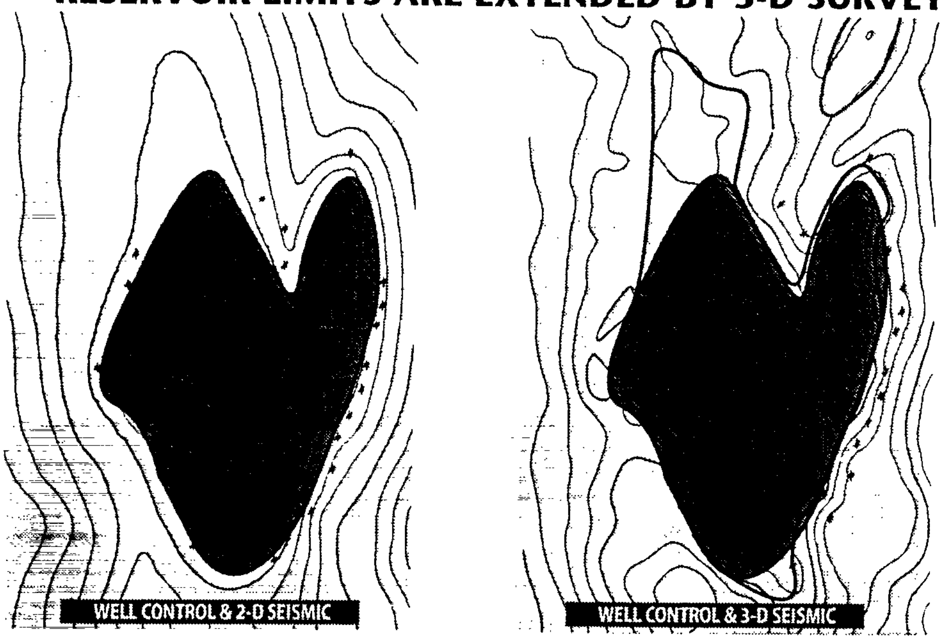
RESERVOIR LIMITS ARE EXTENDED BY 3-D SURVEYS



- Reserves estimates are increased
- Higher production rates are made possible

Figure 1

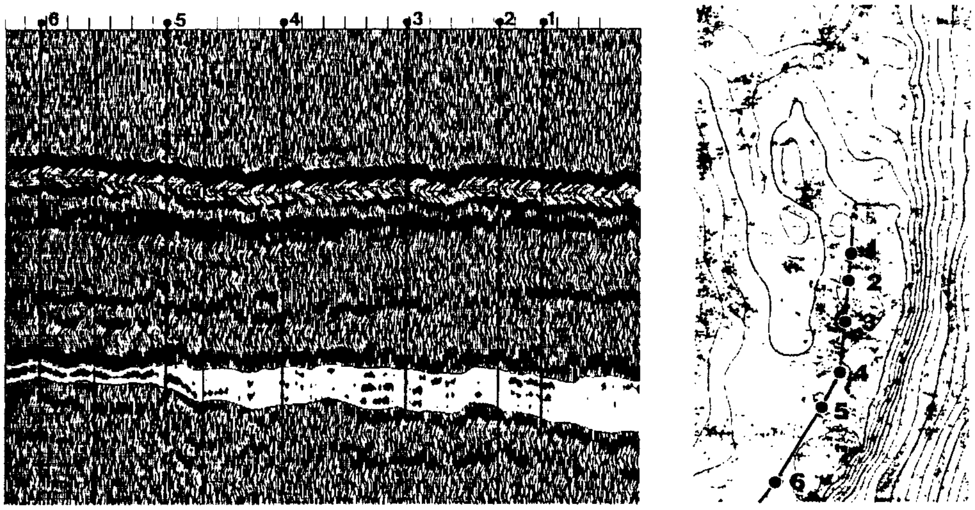
RESERVOIR LIMITS ARE EXTENDED BY 3-D SURVEYS



- Reserves estimates are increased
- Higher production rates are made possible

Figure 2

3-D SEISMIC ATTRIBUTES IDENTIFY RESERVOIR SANDS AND AND NON-RESERVOIR SILTS



■ Sandstone ■ Siltstone

- Wells target reservoir quality sandstones
- Minimize number of dry holes and low rate producers

Figure 3

3-D SEISMIC RESPONSE IDENTIFIES SPATIAL CONTINUITY OF RESERVOIR QUALITY SANDS

Figure 4

3-D VISUALIZATION AND COHERENCY PROCESSING OF SEISMIC DATA ENHANCE SUB-SURFACE IMAGING

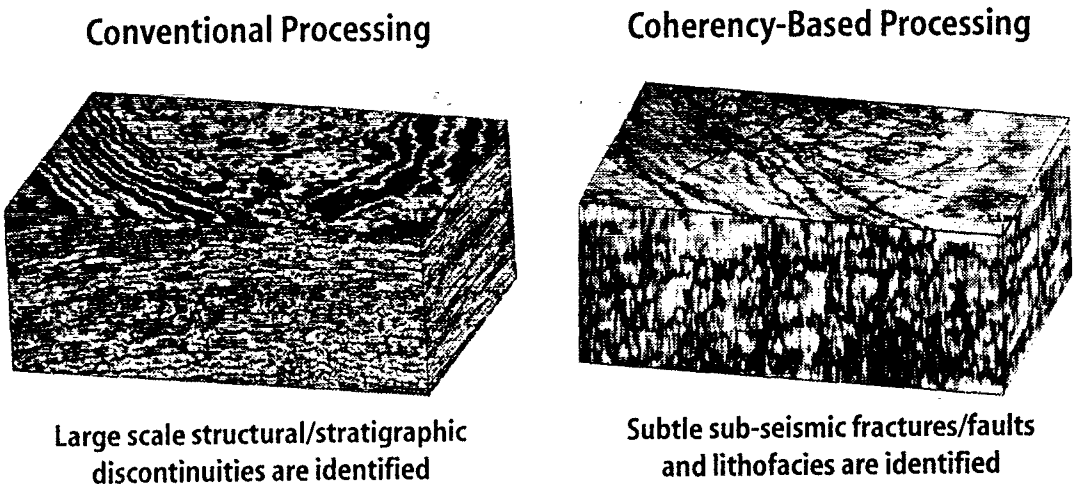


Figure 5

HORIZONTAL WELLS TARGET ATTIC OIL AND OIL POCKETS GHAWAR FIELD

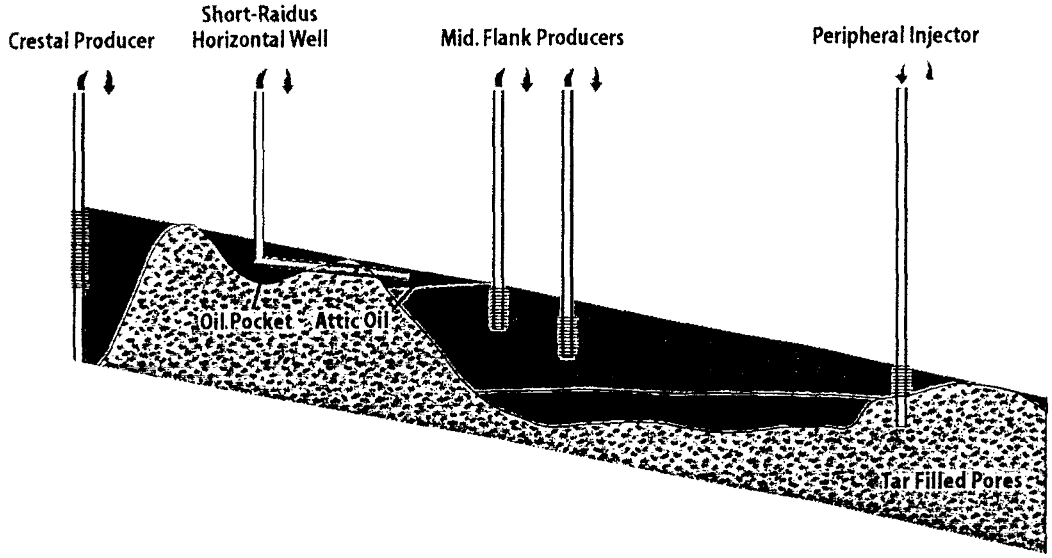


Figure 6

SHORT RADIUS HORIZONTAL WELLS TARGET WATER-UNDERLAIN THIN OIL COLUMNS

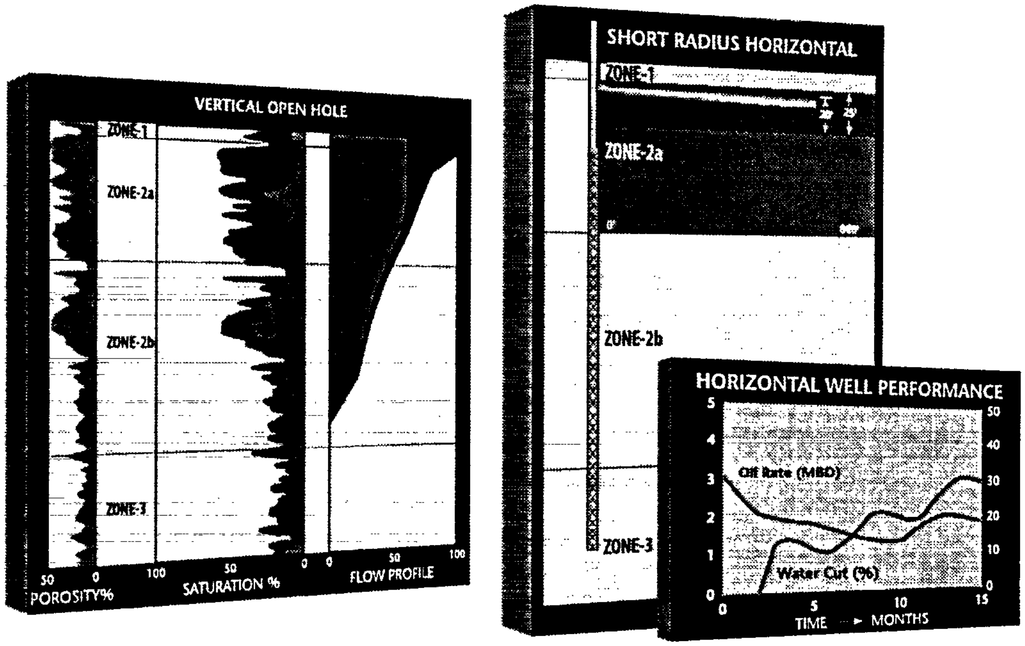
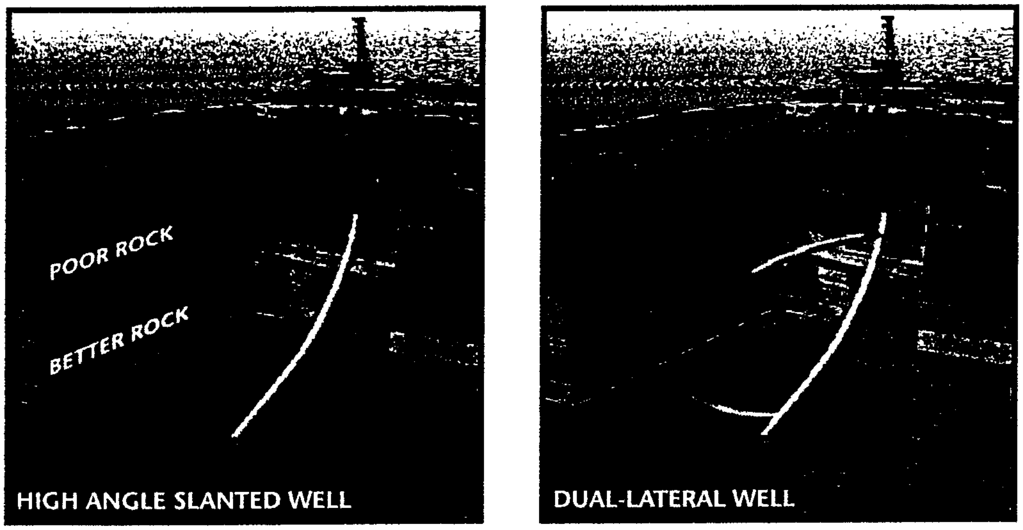


Figure 7

MULTI-LATERAL WELLS TARGET BETTER QUALITY ROCK IN A COMPLEX RESERVOIR

OFFSHORE SAUDI ARABIA



- A non-productive well is salvaged by two laterals

Figure 8

MULTI-LATERAL WELLS ENABLE

- CONTROL OF FLOOD FRONT
- PRODUCTION FROM TIGHTER ZONES

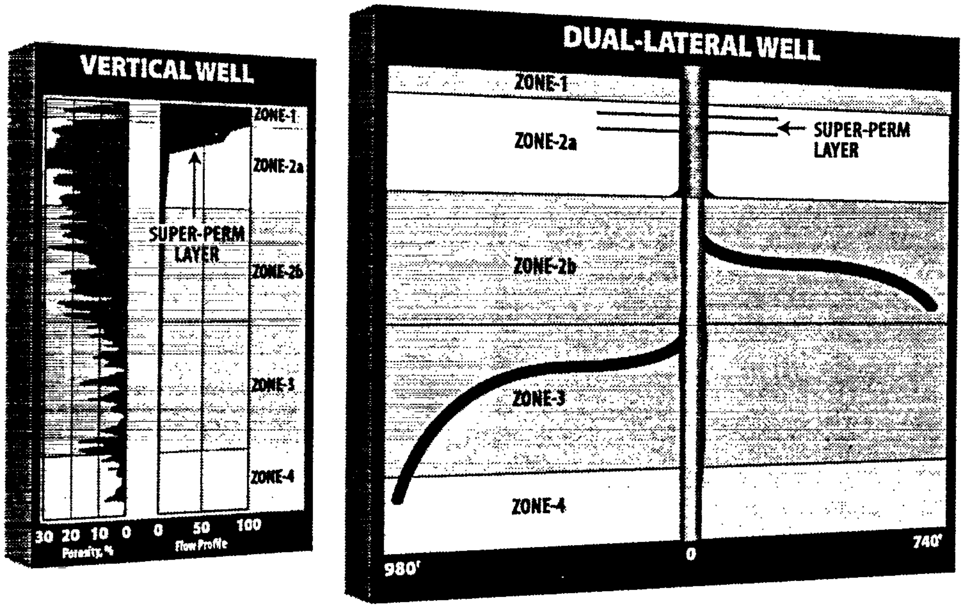


Figure 9