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GIRASSOL FIELD OPTIMIZED DEVELOPMENT

The GIRASSOL field is located in Block 17, offshore Angola. It is a deep offshore field with water depths ranging from 1250 to 1400 m. The Girassol field was discovered in May 1996 with the GIR-1 well and was appraised later with three additional wells.

The Girassol system consists of three main turbiditic faulted channel complexes eroding underlying complexes and thinner sheet-like deposits (see cross sections). Sand juxtaposition also exists across the faults (Figure 1).

The development of Girassol was decided in 1998. It took place in three phases with data acquisition and drilling rig activity adapted to each phase. A high resolution 3D seismic (3DHR) was carried out in 1999 and a repeat 3DHR (4D 2002) was carried out one year after first oil in order to mainly monitor gas injection.

The sealine layout consists of a two-well manifold system linked by insulated flowline bundles. The layout lends flexibility in well planning, integration of acquired data and new technologies. The manifold concept allows trajectory optimisation for multi-target high-angle wells for the relatively shallow Girassol reservoirs.

Excellent reservoir properties and good communication has been established through DST, MDT and interference testing. Water injection and produced gas re-injection started several months after first oil. The reservoir pressure reacted efficiently to injection. Well performance and reservoir performance, in general, have been better than expected.

Produced gas is re-injected into the main complex in two gas injectors drilled in the central area. Desulfated seawater injection started in May 2002 for reservoir pressure maintenance and sweep efficiency. Water breakthrough as well as injected gas breakthrough have occurred in several wells.

Data acquired both before and after first oil have been used to mitigate reservoir risk by building better reservoir models. The well placement has evolved with the availability of qualified improved technology and integration of acquired data. The well count for the initial development has been reduced by eight with respect to the 1998 development plan.

In order to optimise reserves, identify, locate and optimise infill targets, the data acquisition program has been adapted to the production phase.

Initial development

The development of Girassol was approved based on the data available in 1998: the 3D seismic shot in 1996, one exploration well and three appraisal wells. The oil in place was estimated at about 1.5 Gbo. The oil quality of 32°API is close to Brent specifications. Initial plans called for 40 subsea wells: 23 producers, 14 water injectors and 3 gas injectors (to be converted to water injection at a later stage).

Consistent with TOTAL's environmental policy and in line with the Angolan authorities regulation, all associated gas is reinjected in the main reservoir, except internal consumption for fuel and safety flaring. Gas re-injection will continue until a pipeline is built for gas export to the Angola LNG.

A fast-track approach was decided for this ambitious deep offshore project. Girassol, one of the largest deep offshore fields, was put on stream in December 2001 less than 5½ years after discovery. This was followed by ramp-up to production plateau oil rate of 200 kbopd reached by February 2002 well ahead of schedule. Well performance has been better than expected. Production in 2003 averaged nearly 215 kbopd.

As a result of the fast track approach and the limited available data, some significant uncertainties still remained and needed to be addressed during development.

The less risky and most prolific wells were drilled in 2001. The plan was to put the B3 complex on production first, then to develop the B1 with a program to mitigate major B1 uncertainties (presence or not of a channel skin like levee / channel communications) and to appraise the B2 to the East. Communication between complexes was not considered in reservoir models at that time.

Data acquisition

Interference tests: The sealing potential of the faults was one of the essential factors to consider when defining the well pattern. It was evaluated with different techniques using 3DHR data and seismic attributes, but the different results remained qualitative with insufficient confidence to predict the sealing potential of the main faults. It was decided to make a dynamic acquisition by performing interference testing in the B3 complex during the first development phase (before first oil), between wells separated by one or two major faults. Six tests were performed between an observation well and an active well (oil production or water injection). The observation well was equipped with the SAMS (Subsea Acoustic Monitoring System) designed to transmit the down hole pressure records to the surface. Five tests were positive showing that most of the faults were non-sealing (Figure 2).

MDT: During the first year of production (with only the B3 complex producers being on stream), MDTs have been acquired in most of the newly drilled wells. The pressure measurements showed that all the other complexes and sheets were affected by the production start-up in B3, which meant that all the complexes are in communication through either erosion surface or faults (Figure 3). The level of depletion from one complex to another also gave information on the heterogeneity between the sand bodies.

Downhole measurements: All the producers are equipped with permanent downhole gauges. This allows gathering pressure measurements during well testing (build-ups), for static reservoir pressure monitoring and reservoir characterisation. Transient behaviours are matched in fine gridded reservoir models. Prior to well connection, the SAMS is used to monitor static pressure and interference between wells (Figure 2). Temperature data permits the detection of breakthrough events. Intelligent completions (with adjustable downhole chokes) are installed on wells in the Jasmim field (Jasmim reservoirs are in communication with Girassol and are producing through the Girassol FPSO).

4D seismic: One year after first oil and eight months after water and gas injection start-up, a 4D seismic was acquired. The objective was the monitoring of the extension of the injected gas bubble. The analysis of the discrepancies with the first 3D shot three years before allowed observation of the expansion of the gas bubble resulting from gas injection at the top of the B3, the rise of the water oil contact in the different complexes and sheets, and some heterogeneities not taken into account by the geological model (Figure 4).

PLT: Two types of PLT acquisition have been performed, namely initial and monitoring. Initial PLT are performed on multi-reservoir completed wells. In injectors, PLT are mostly performed several months after start of injection. Monitoring PLTs are acquired to answer specific development issue and/or for well behaviour prognoses.

Tracer Injection: Interference testing before and after Girassol first oil has proved communication across faults. MDT measurements have proved communication between complexes. Water breakthrough has been observed but produced water chemistry has not been completely conclusive on the origin of produced water on wells. Injection of inert tracers is being implemented in a comprehensive effort to optimise injected water flow pattern, reservoir connectivity and locate in-fill wells.

Reservoir model updates (Figure 5)

Reservoir models 1 to 3 were based on exploration wells, the 1996 3D seismic and its successive processings. Reservoir model 4 was based on the 1999 3DHR that allowed a better stratigraphic reservoir description, as well as better architectural element characterisation. In reservoir model 4, data acquired from the first eight initial B3 development wells was integrated. It became increasingly evident early in the development process that inter-complex communication was playing an important role on Girassol. It became necessary to model inter-complex communications to minimise adverse effects on offset wells. Initial reservoir models built for each complex were connected in an attempt to model inter-complex communication.

The appraisal of the B2 had shown the latter was a much better and larger reservoir than initially mapped. The well pattern was adjusted thanks to flexibility inherent in the initial well pattern. A new version of model 4 was built and used to develop the B2 reservoir. The model was history matched with production data available at that time.

This model showed that, out of the initially planned 40 wells, only 32 were required for the initial development (Figure 6). The intensive use of horizontal wells was implemented along the data acquisition establishing good vertical communications.

Today a new reservoir model 5 integrates both improved static data (seismic inversion from 1999 3DHR, results of 25 development wells) as well as 2 years of production history.

In this new model all Girassol complexes have been included in the same grid and inter-complexes communication modelled explicitly. Smaller sheet like deposits are also included as result from the higher seismic resolution. This model confirms the plans for the initial development and provides a better understanding of the flow pattern. This model is being used to study gas management, waterflood optimisation, optimise location of the few wells left before initial development closeout.

A newer reservoir model 6, including Girassol and Jasmim reservoirs is being constructed. It will take into account all learnings from the 2002 4D seismic. Another 4D acquisition is planned to monitor water movements as well as identify and optimise in-fill well targets.

<u>Ullage Optimisation</u>

After Jasmim reservoirs were put on stream in November 2003, it is planned to tie in Rosa, Cravo and Lirio fields to the Girassol FPSO for ullage filling. Optimising the timing of these developments and remaining expenditures on Girassol / Jasmim is a major challenge for the reservoir models.

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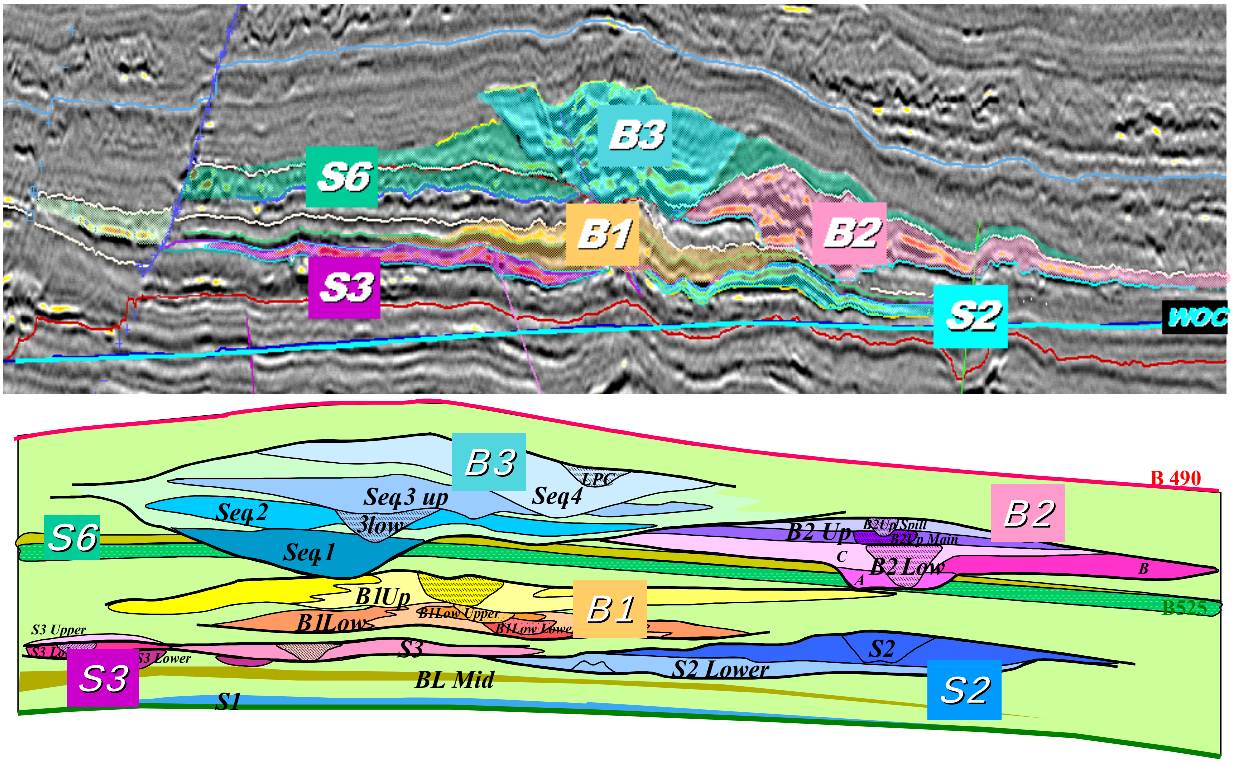

Figure 1 - Girassol cross section

- **Interference test before first oil :** ⟷
  - *5 tests showed a communication through faults:*
    - *H with I*
    - *A with B*
    - *C with D*
    - *C with E*
    - *E with G*
  - *1 test did not show communication: E with J*
- **Interference tests @ 1st oil :** ⟷
  - *A & B with D : positive*
  - *E with D : positive*
  - *C with D : positive*
  - *H & I with E : negative*

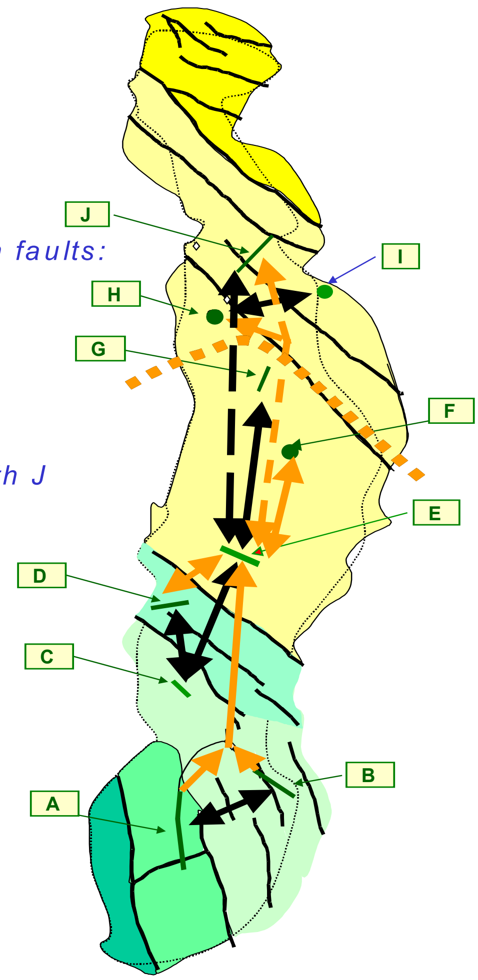

Figure 2 - Synthesis of interference tests performed on Girassol

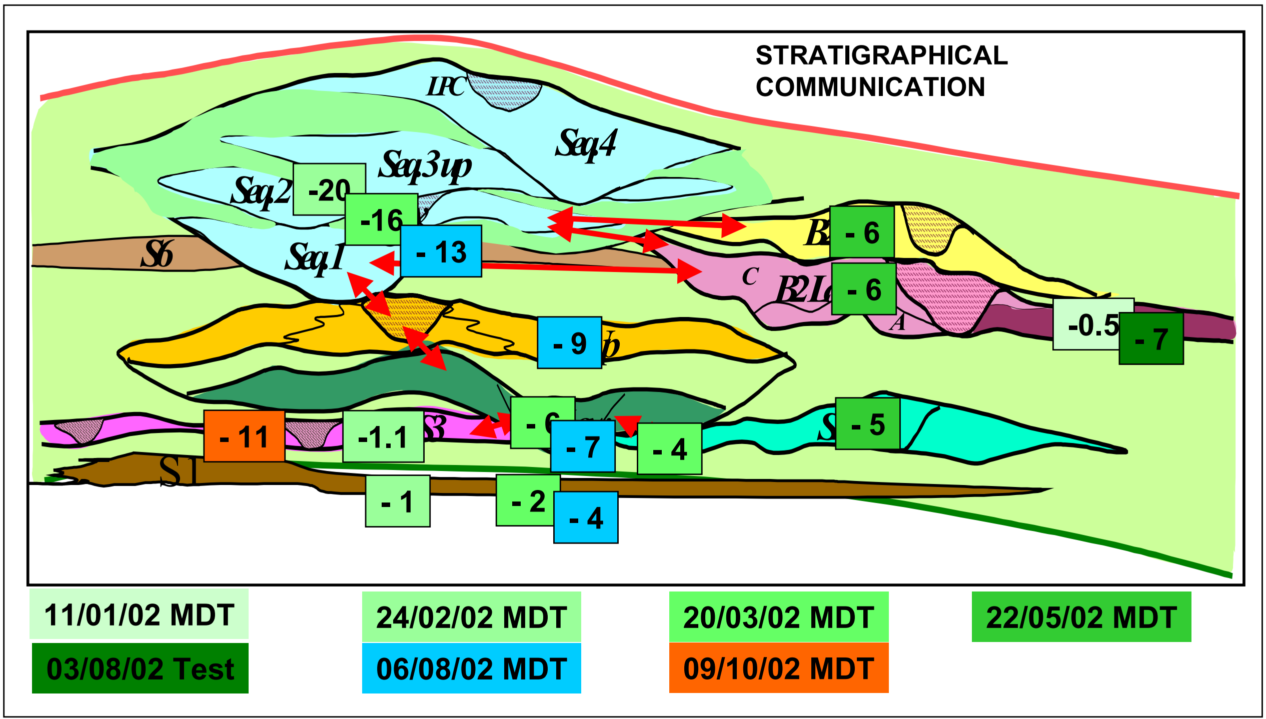

Figure 3 – Depletion (in bars) observed from MDT performed after first oil (Dec-2001)

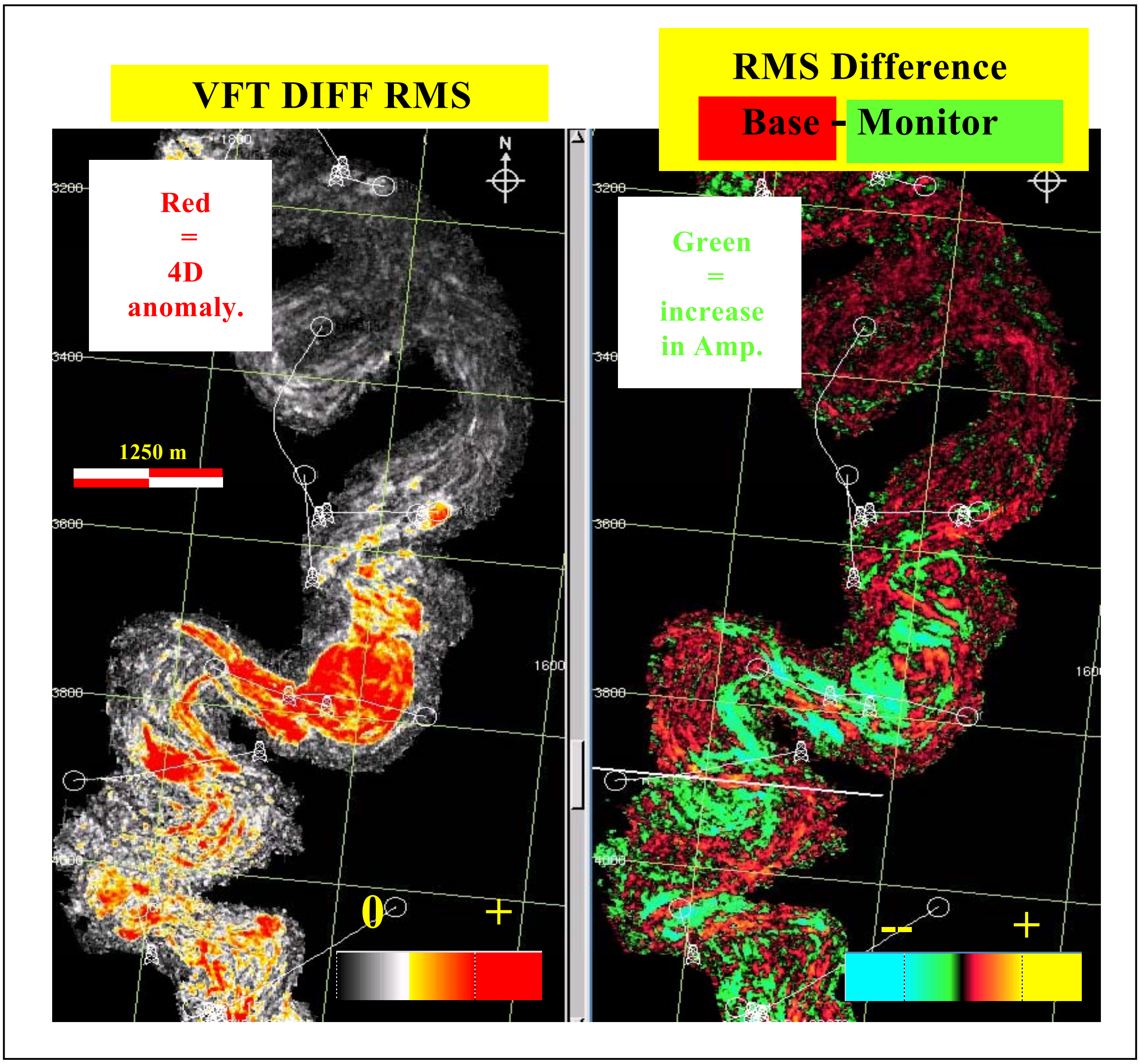

Figure 4 - Monitoring of gas injection expansion and depletion through seismic 4D interpretation

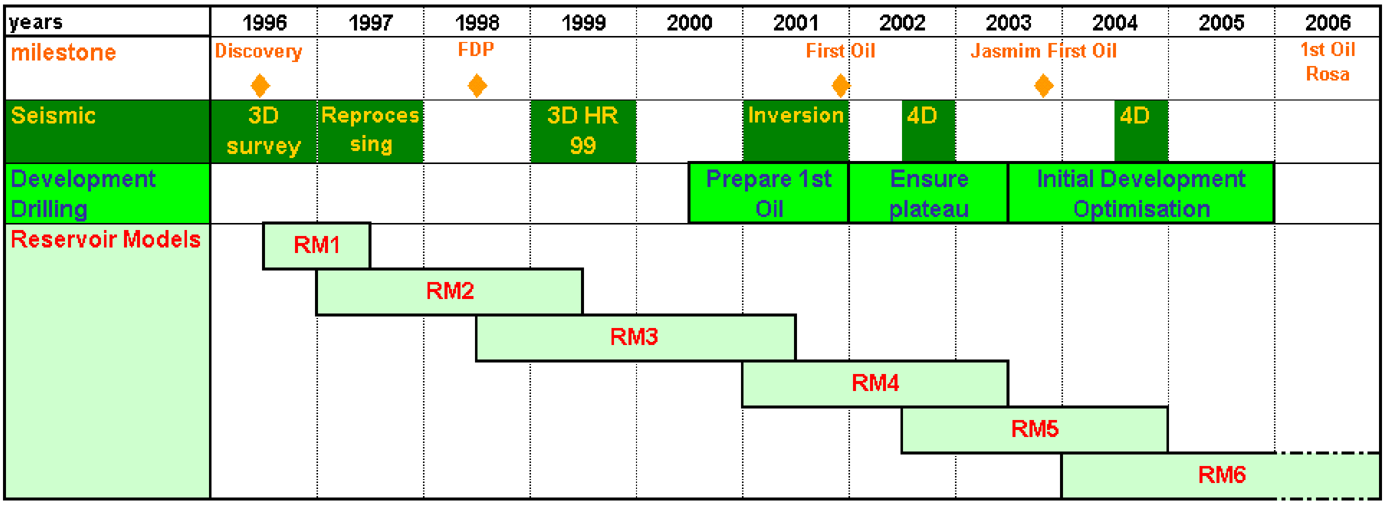

Figure 5 - Progress of Girassol Reservoir Models

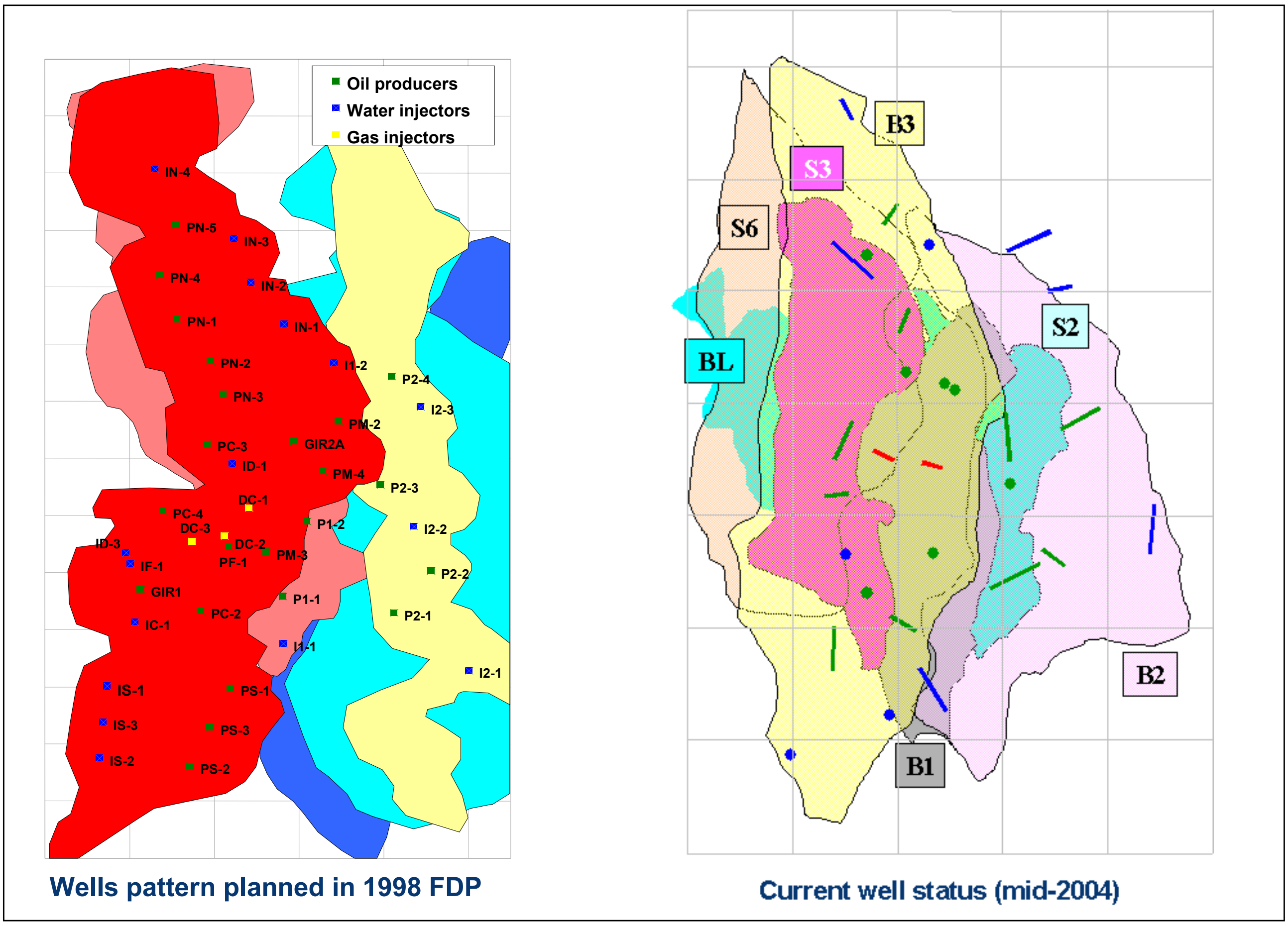

Figure 6 - Comparison between planned and realised well pattern