Exploitation of Untapped Oil Through Conventional Inclined Wells in a Multilayered Giant Offshore Carbonate Field - A Case Study*

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Abstract

The carbonate formations of Mumbai High Field are the most prolific oil reservoirs in India. These Miocene carbonates are very complex in nature in terms of reservoir heterogeneity. The Mumbai High South (MHS) Field was put on production in October 1980 and, by September 2010, has produced 263.8 MMt of oil, which is about 26.6% of the in-place oil. The main pay zone L-III is a multi-layered limestone reservoir with a large gas cap and partial water drive. The field has been under water injection for the last 25 years for reservoir pressure maintenance. Presently, some of the layers are producing with high water cut and high GOR, leading to decline in oil production.

A philosophy of phase-wise efforts is being followed to improve recovery of the hydrocarbon reserves of MHS Field. During the Phase-I redevelopment plan, which commenced in 2001, the oil production decline was arrested and the production increased from a level of 131,000 bopd on June 1 to 173,000 bopd by the beginning of 2007. The recovery improvement strategy incorporated reduction of inter-well spacing through infill drilling and improvement in water injection to enhance areal sweep.

Adopting a similar approach, the Phase-II redevelopment input plan was put into action in MHS in April 2007. Targeting the zones and patches of untapped oil, infill wells were planned through four new platforms. This paper focuses on inclined conventional wells planned through one of the new platforms, named here as ‘A’. The platform was installed with 12 slots, but initially only five wells were planned and drilled to generate the data for the new locales for better placement of wells through the remaining seven slots. All five locations were drilled in 2009 and the wells are producing 2500 bopd against the planned rate of 2300 bopd.

The present study has shown that placement of the wells based on detailed analysis of available geoscientific data of the nearby area can yield encouraging results, as confirmed by the performance of the conventional inclined wells drilled. The data generated from these wells would help in selecting appropriate layers for drilling and completion of the remaining wells on the platform and help in further enhancing the production of MHS.

Introduction

Mumbai High is a giant offshore oil field discovered in 1974 and located about 160 km west-northwest of Mumbai city in India (Figure 1). On the basis of an E-W trending shale channel in L-III reservoir, the field is divided into two blocks: Mumbai High North (MHN) and Mumbai High South (MHS). Oil and gas have been discovered in a number of reservoirs, viz., L-I, L-II, L-III, L-IV, L-V, basal classics and fractured basement. Out of these, LII and LIII are the two main limestone oil reservoirs of Miocene age. L-III reservoir is a multilayered limestone reservoir with a gas cap and partial water drive and holds about 94% of the total initial oil in place of the field. Mumbai High is one of the most complex fields in terms of reservoir heterogeneity. The major reservoir (L-III) is multi-layered with 10 limestone sub-layers designated as A1, A2-I to A2-VII, B & C of 2-5 m thick each, separated by 1-5 m shale layers. The multilayered heterogeneous carbonate reservoir has a complex mixed drive mechanism of depletion with expansion of the gas cap. Development of L-III layer has been carried out since 1976 in phases. In Mumbai High Field, a water injection facility with rows of injectors was started from April 1987 and gas lift facilities were created in March 1992. The MHS Field is developed with about 637 wells (706 strings), both producers and injectors.

Production History

The MHS Field was put on production in October 1980 and by September 2010, had produced 263.8 MMt of oil from the reservoir, which amounts to about 26.96% of in place oil. The average daily rate of production during 1980-1981 was about 33,000 bopd. In the next few years, the field production increased gradually on account of drilling and completion of development wells. The field produced between 243,000 bopd and 300,000 bopd for 7 years from 1984-1985 to 1989-1990 and thereafter production started declining. Oil production peaked at 308,097 bopd during 1989-1990 with GOR of 360 v/v and water cut of 7.4%. Present production rate from the field is 138,352 bopd (during September 2010) with GOR of 337 v/v and water cut of 72%. The field has passed the mature stage of its producing life and has entered into the decline phase. During 1998-2000 continuous decline in the oil rate and increase in water-cut occurred alarmingly in spite of drilling inputs. The main concern was cumulative voidage compensation which was 50% and steep decline in water injection rate. The decline in oil production is attributed to decline in reservoir pressure as a consequence of less than full voidage compensation, due to high GOR, drop in productivity of oil with increase in water cut and conversion of producers into injectors.

Development Strategy

The large size and complex reservoir characteristics of the field have necessitated the acquisition of information, initially on a strategy to drill widely spaced wells for determining the geological and reservoir heterogeneities, areal extent, fluid properties, the initial oil and gas volumes and drive mechanism. In the development/ redevelopment scenarios, knowledge of these parameters is utilized in the placement of infill wells. Drilling of infill and sidetrack wells is a proven incremental recovery option and to recover more of bypassed mobile oil in complex carbonate reservoirs after water flooding. This has increased the amount of recoverable reserves and the effort is continuing.

A major redevelopment programme in two phases has occurred during the last nine years to enhance production and recovery from the field. Induction of various techniques and technologies put the field production on an ascending trend. Under the redevelopment plan Phase-I and Phase-II for this field, infill drilling through available spare platform slots/new platforms through which about 190 side-tracking/redrilling of the existing wells and drilling of about 233 horizontal wells, drainholes, 38 conventional wells and five Extended Reach Wells have been taken up to maximize oil production with minimum water cut. A number of sub-optimal producers were also converted as horizontal sidetracks under brown-field development.

IOR Project Phase-I was implemented with a fresh geological model and fine-scale reservoir simulation using ECLIPSE Software with input of 14 additional platforms, drilling of about 200 infill wells with the recovery of up to 32% by 2030. Induction of new technology in drilling and completion yielded encouraging results in targeting the potential locales of bypassed/unswept oil zones and reversed the production decline trend while stabilizing the water cut. Significant oil gain achieved in Phase-I has been a learning curve to continue with the similar philosophy for IOR Phase-II (Figure 2). Inputs envisaged in Phase-II aim at further reduction in inter-well spacing, improvement in voidage compensation through water injection to take the VRR closer to 100%, higher withdrawals through submersible pumps in high productivity wells and development of the crestal area below the GOC. Installation of four additional platforms, drilling of 86 horizontal and conventional locations, and other surface facilities like a bridge-connected process platform, laying of well fluid lines, etc. are planned in Phase-II with an envisaged incremental oil production of 22.02 MMt. Three new platforms of 12 slots each have been installed as part implementation of Phase-II in 2008-2009.

The platform ‘A’ mentioned in the abstract is one of the platforms installed recently for exploitation of lower sub-layers of L-III reservoir in the crestal part of the Mumbai High South Field. The platform was installed with 12 slots, but initially only five wells, namely A1, A2, A3, A4 and A5, were planned and drilled to generate the data for identifying the unswept oil locales for better placement of the new wells through the remaining seven slots. Structure map and location map of platform 'A' are shown in Figure 3 and Figure 4, respectively.

Production Performance of Infill Wells – Case Studies

Case 1

Well "A1" in 'A' platform was originally proposed for drilling of a drainhole in 'C' layer with a drift of 1768 m in N 82°. After detailed analysis of the geoscientific data of the nearby wells of adjoining area it was concluded that the lower sub-layers 'A2-VII, B & C' have good development and that though the C layer is oil bearing, it has high water saturation and hence relatively less potential than the overlying oil bearing layers. Therefore, it was decided that the better option was to drill an inclined well targeting more layers than one to exploit the maximum oil. The well was finally planned in May 2009 as a conventional well with target layers A2-VII, B & C with a drift of 1650 m and azimuth of N 82 degrees. In November 2009 well 'A1' was completed in layers A2-VII & B. The well was completed with 3½" completion string with gas-lift valves. The log motifs and production performance of the well A1 are shown in Figure 5. As per simulation model, the expected oil rate was 454 bopd with 65% water cut. The well, on activation, produced 521 bopd with a water cut of 50% and GOR of 182 v/v. The oil rate and water cut are consistent even after almost a year of continuous production. The present oil rate is 497 bpd with 54% water cut.

Case 2

Well "A2" in 'A' platform was initially conceptualized as a drainhole in 'C' layer with a drift of 1200 m in N 5°. Detailed analysis of the geoscientific data of the nearby wells of adjoining area suggested that lower sub-layers 'A2-VII, B & C' have better development, with the C layer also oil bearing, but having high water saturation. PLT data of a nearby injector indicated that greater quantum of injected water has gone into the layer A2-VII layer. Hence, the B layer should logically be expected to have better prospects for undrained oil and, therefore, the better option appeared to be to drill the well as a horizontal drainhole targeting B layer. However, after detailed deliberation, it was decided to plan the well with a drift of 970 m and azimuth of N 10 degree as conventional well targeting layers A2-VII, B & C. In September 2009 the well A2 was drilled and completed in layers A2-IV, V, VII, B & C as per petrophysical parameters with 3½" completion string with gas-lift valves. Well log motifs and production performance graphs of the well are shown in Figure 6. As per simulation model the well was expected to produce at an oil rate of 550 bopd with 60% water cut. The well, on activation, produced 440 bopd with a water cut of 77% and GOR of 227 v/v. The variation in oil rate is mainly due to increase in water cut from 60% (expected) to 77% (actual). Both the oil rate and water cut are consistent even after a year of production. The present oil rate is 387 bpd with 76% water cut.

Case 3

Well “A3” in ‘A’ platform, was originally thought of as a drainhole in ‘B’ layer with a drift of 1118 m in N 63°. On analyzing the geoscientific data of the nearby wells, this well was planned to be drilled as a vertical well to generate the maximum possible petrophysical, geological and other data. The planned target layers were A2-VII, B & C. In July 2009 the well A3 was drilled and completed, with 3½” tubing string fitted with gas-lift valves, for production from layers A2-V, VI, VII & B. The well log traces and production performance graphs of the well A3 are shown in Figure 7. As per simulation model, the expected oil rate was 400 bopd with 68% water cut. The well initially produced @ 411 bopd with a water cut of 65% and GOR of 307 v/v. The water cut remains constant even after the completion of a year. The present oil rate is 361 bpd with 67% water cut.

Case 4

The well ‘A4’ was at first thought to be drilled as a drainhole in ‘A2-VII’ layer with a drift of 1768 m in N 278°. Analysis of geoscientific data of nearby wells showed that the wells to the southwest are completed as drainholes in layer A2-VII layer with the reservoir pressure expected to be in the range of 1100 to 1300 psi for the layer. The other nearby wells in the northwest direction are completed in multilayer from A2-III to N / B; hence, it was considered a better option to drill it as an inclined dual-string well targeting A2-III to VII layers. Expecting a large differential pressure between the layers targeted, this well was planned to be completed dually with the short string in A2-III & IV and long string in A2-V, VI & VII.

Well “A4” in ‘A’ platform, was then designed as a conventional dual producer with the target layer of short string in A2-III, IV & long string LS in A2-V, VI, VII with the drift of 1200 m and azimuth of N 275 degrees. In September 2009 the well was drilled and the MDT pressure recorded in these layers was in the range of 1567 to 1702 psi. In view of the data obtained on drilling the well, the well was completed with 3½” tubing and gas-lift valves for commingled production from layers A2-IV, V, VI, VII, B & C. The well log extracts and production performance graphs of the well are shown in Figure 8. As per simulation model the expected oil rate to be 450 bopd with 71% water cut. The well produced 807 bopd with a water cut of 51% and GOR of 215 v/v. The oil rate and water cut subsequently increased to 1105 bpd and 61% water cut. The present oil rate is 987 bpd with 62% water cut.

Case 5

The well 'A5' in 'A' platform was originally planned as a drainhole in 'B' layer with a drift of 707 m in the direction of N 225°. Analysis of the geoscientific data of the nearby wells west of the planned location for the well A5 showed that they were initially completed in layers A2-VII & B and producing with high water cut. Subsequently some of the wells had been sidetracked to different locales in layer A2-VII and are presently producing with high water cut. The wells to the southwest of well A5 are completed in layers A2-V to VII / B. The better option appeared to be to drill an inclined well targeting layer A2-V to B layers.

Well 'A5' was then designed in May 2009 as a conventional well, targeting layers A2-V, VI, VII & B, with a drift of 1500 m in the direction of N 210°. In November 2009 the well was drilled and completed with 3½" completion string and gas-lift valves for production from layers A2-VII, N & B. The log motifs and production performance graphs of the well are shown in Figure 9. As per simulation model the expected initial oil rate was 450 bopd with 69% water cut. The well initially produced 124 bopd with a water cut of 93% and GOR of 422 v/v. The present oil rate is 148 bpd with 93% water cut.

The improved understanding of reservoir complexity through completion of the five wells on the basis of integration of geo-scientific data, refined geological and reservoir simulation models has provided a higher degree of confidence to assess the potential reserves of by-passed oil. The inter- and intraplatform locales of the unswept /undrained oil in the various sub-layers of the reservoir can be targeted with infill wells for the remaining slots on platform 'A'. The main strategy for the exploitation of by-passed oil has been locating undrained oil and targeting it with suitably placed wells. Further, planning on the basis of production performance of all the five wells and layer-wise PLT survey data will help in exploitation of untapped oil through a mix of conventional and horizontal wells and increase oil production from the area. Also, it may help to locate the presence of major and minor faults in the vicinity of the producing area which may act as conduits for injection water, thereby affecting the oil production. The highly heterogeneous character of the carbonate sub-layers has led to differential flooding leading to early water-breakthrough as well as bypassed oil locales. Faults have also affected the flow of injection water in terms of injector-producer connectivity and communication.

Discussion and Conclusions

Exploitation of untapped oil from the complex, developmentally matured multi-layered carbonate reservoir of Mumbai High is a real challenge. The most significant initiative to improve the reservoir performance of the field was the Redevelopment Phase-I from April 2001 to April 2007. Successful implementation and the significant oil production gained in Phase-I encouraged the launching of Redevelopment Phase-II, which is under implementation. A noticeable turnaround in field performance has been achieved by completing most of the infill and sidetrack wells as horizontal drainholes. Further, to improve the recovery factor of the field, Phase-II is planned with a change in strategy to drill a mix of conventional wells and horizontal drainholes. To date, around 22 horizontal drainholes and 17 conventional wells have been completed. The case studies of the above-mentioned five wells is also a part of implementation of Phase-II. All the five wells have been completed as conventional wells with the objective to exploit and understand flow behavior of sub-layers producing commingled together and to arrest the fast decline of oil rate in initial years. The **five wells** of platform "A" have been drilled and completed between July 2009 and December 2009. In January 2010, the oil production rate of all wells was 2650 bpd against the planned rate of 2304 bpd (Figure 10). The current oil production rate is 2380 bpd after nearly a year. From this case study, it emerges that:

1. Completion of conventional wells from the platform 'A' has yielded big success in terms of oil production.

2. The decline rate was arrested during the first year.

3. Conventional wells help in exploitation of a number of sub-layers together.

4. The petrophysical, production and pressure data of sub-layers generated from the initial five wells will lead to planning of successful trajectories/profiles for drilling wells from the remaining slots of the platform.

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References

Singh, K., A.K. Mittal, and S.K. Verma, 2005, Mumbai High Revitalization: The Technology Leverage, *in* Petrotech 2007, 7th International Petroleum Conference and Exhibition, 15-19 January 2007, New Delhi, India: Oil and Natural Gas Corporation Ltd.

(India), India Ministry of Petroleum & Natural Gas, 1 CD-Rom, #515, Web accessed 28 April 2011, http://www.petrotechsociety.org/elibrary/2005.php

Singh, Khark, J.L. Narasimham, S. Ramanan, R.D. Chourasia, 2003, Maximising Oil Production in Mumbai High *in* Petrotech 2003, 5th International Petroleum Conference and Exhibition, 9-12 January 2003, New Delhi, India: Oil and Natural Gas Corporation Ltd. (India), India Ministry of Petroleum & Natural Gas, Baker and Taylor (BTCP), volume 1-2.

Singh, U.B., Uma Goyal, and S.K. Verma, 2004, Effective layer management to enhance oil production in multi-layer reservoir: Presented in strategic meeting on well flowing-wells, in MH Asset, unpublished.

Verma, S.K., and R. Kumar, 2007, High Performance of Mumbai High - The Contribution of Emerging Technologies: 2nd Conference on Emerging Offshore Technologies, Oil and Natural Gas Corporation (ONGC), 18-19 June, 2007, Mumbai, India, unpublished.

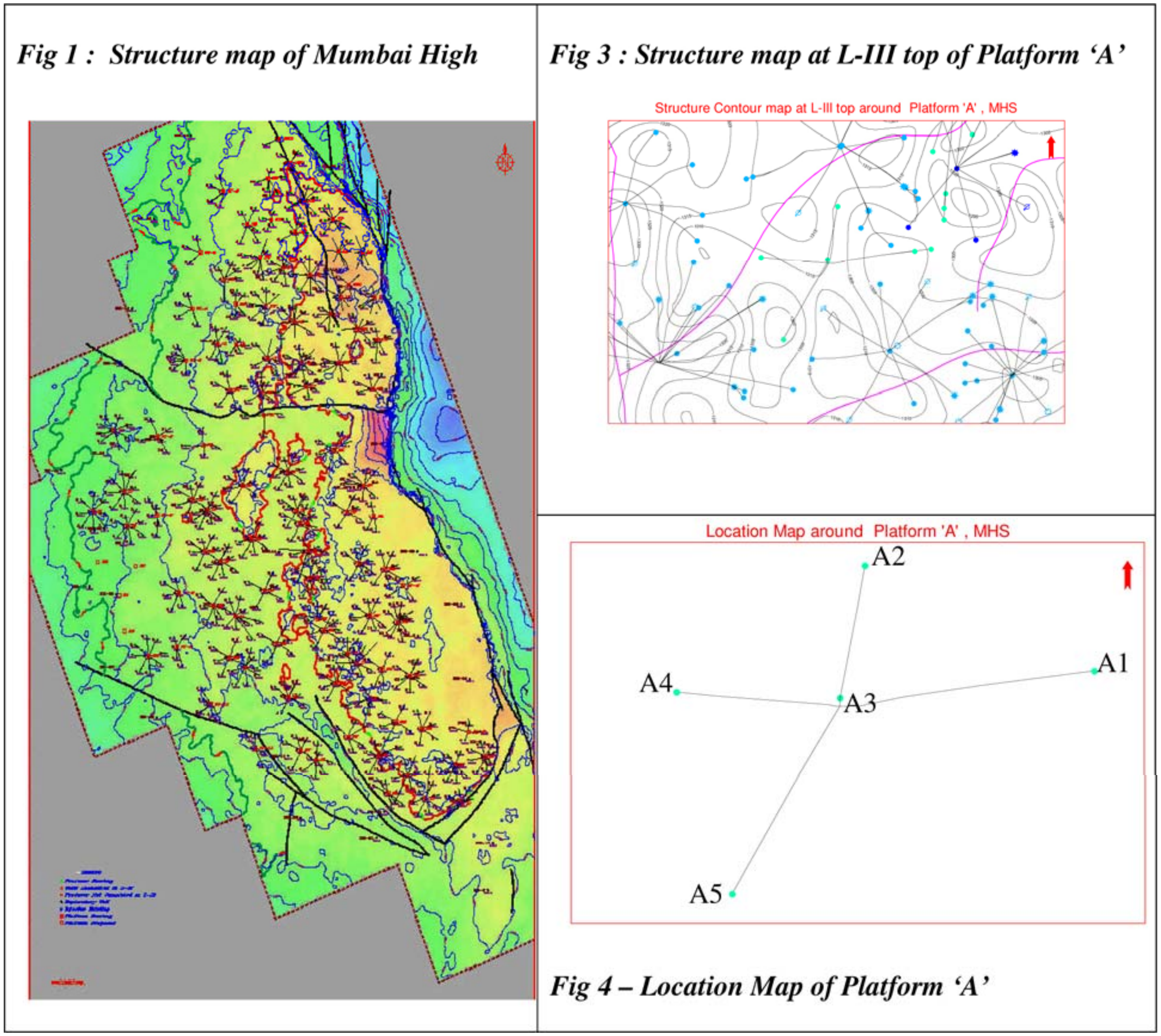


Figure 1. Structure map of Mumbai High.

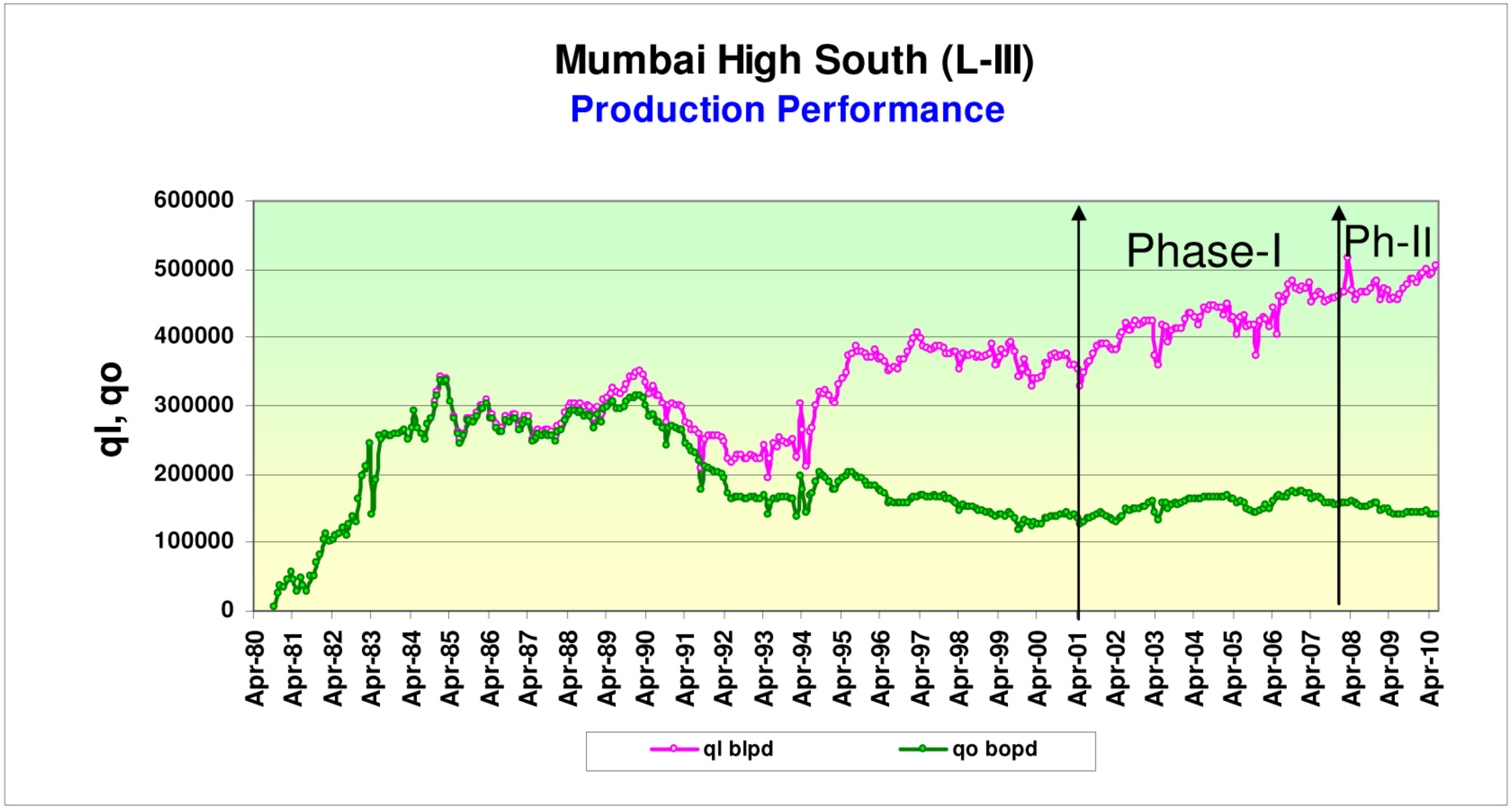


Figure 2. Production performance of Mumbai High South.

Fig 1 : Structure map of Mumbai High

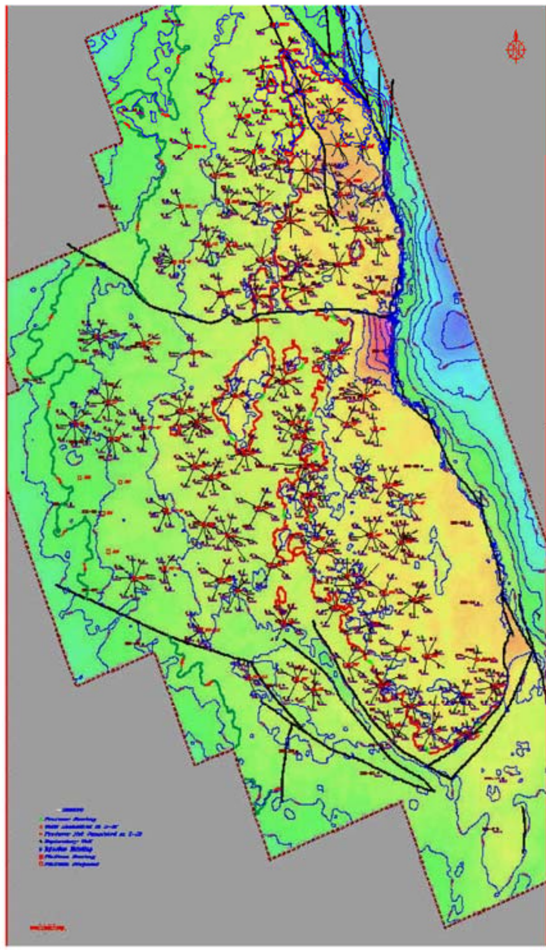
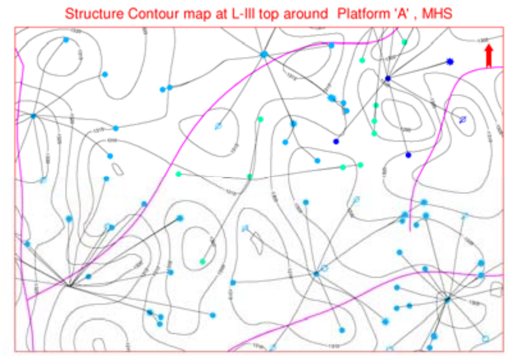


Fig 3 : Structure map at L-III top of Platform 'A'



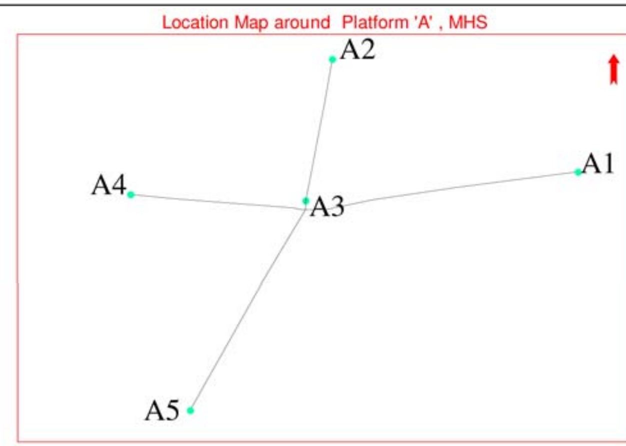


Fig 4 – Location Map of Platform 'A'

Figure 3. Structure map at L-III top of Platform 'A'.

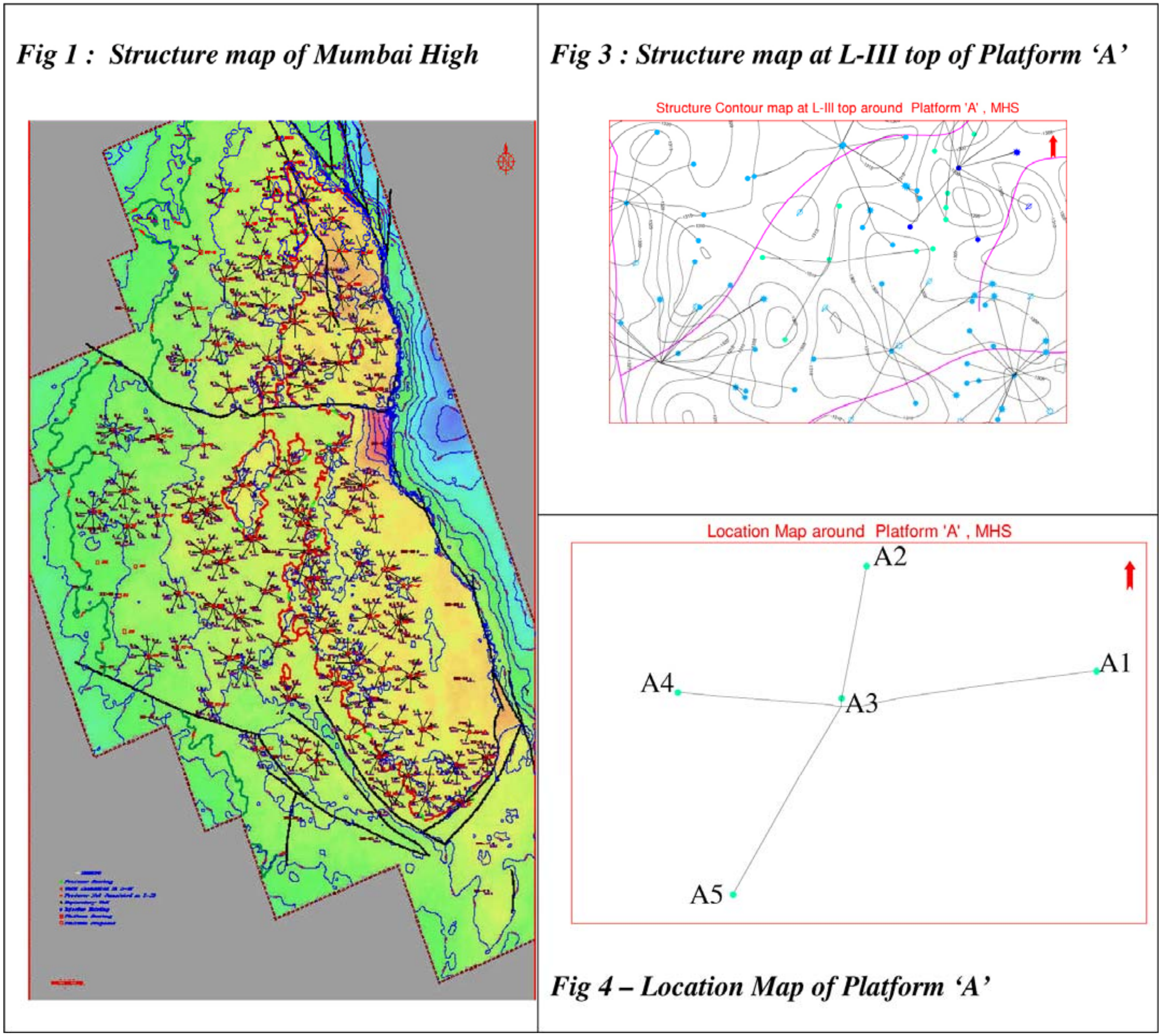


Figure 4. Layout of Platform 'A'.

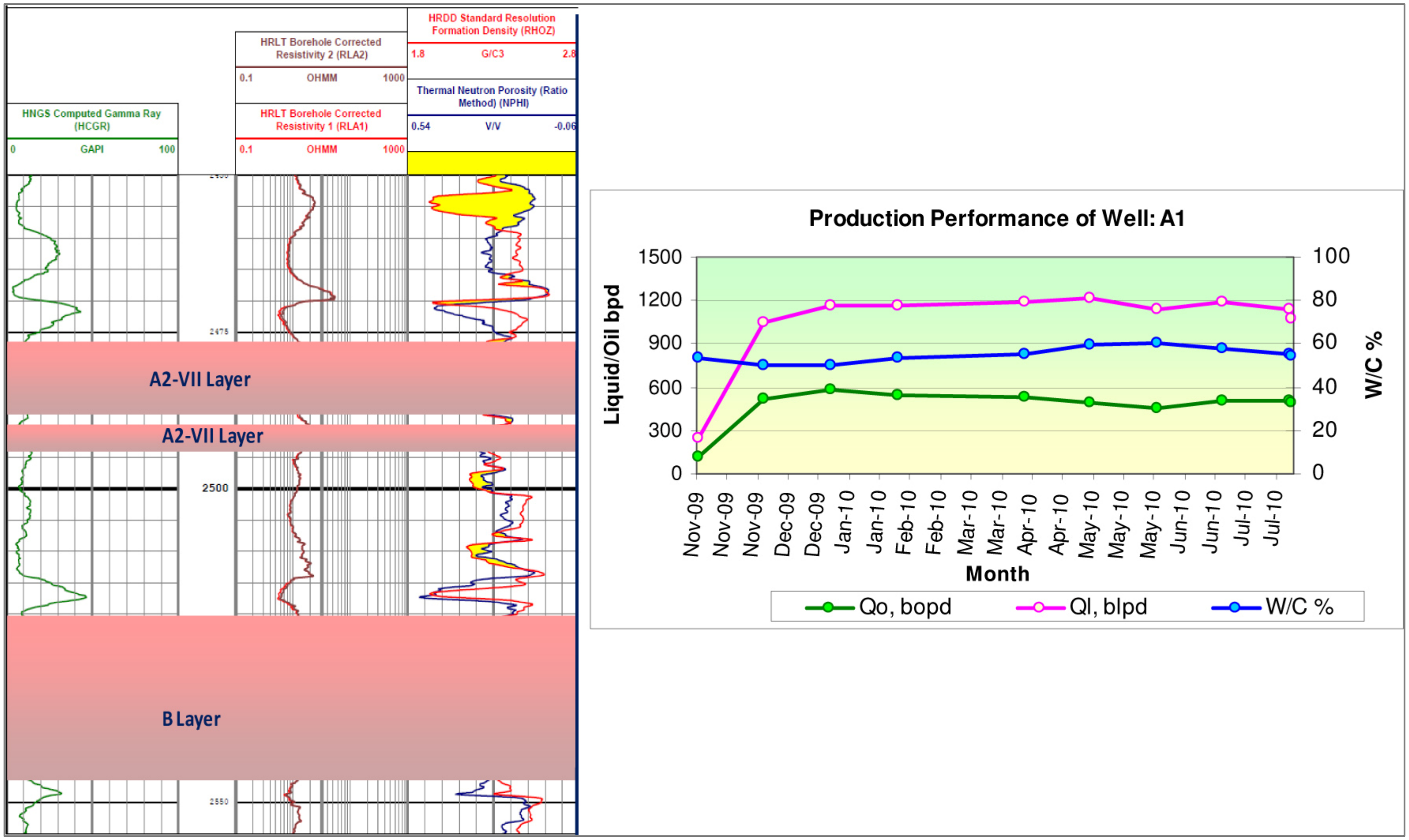


Figure 5. Well logs and production performance of Well ‘A1’.

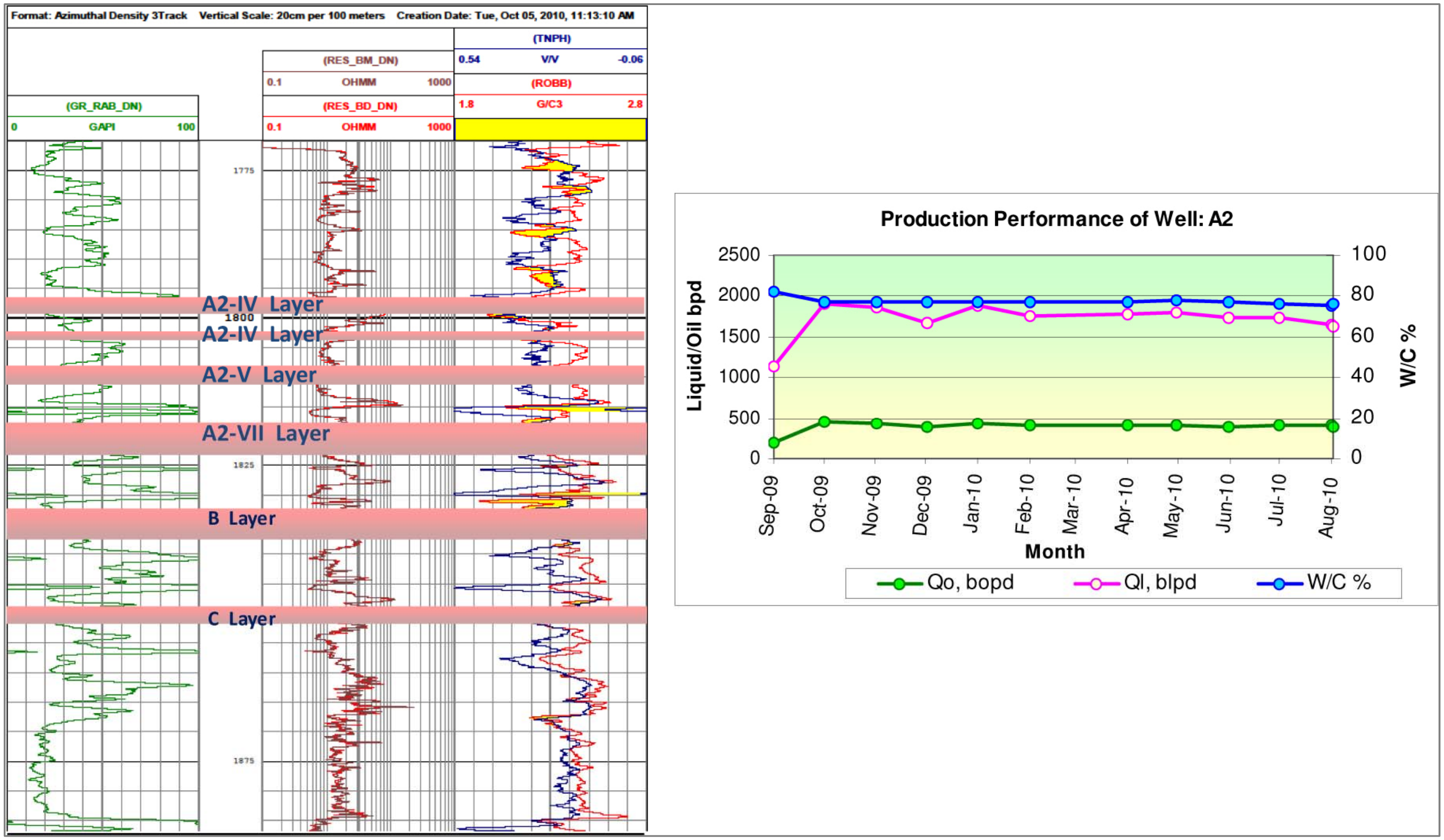


Figure 6. Well logs and production performance of Well ‘A2’.

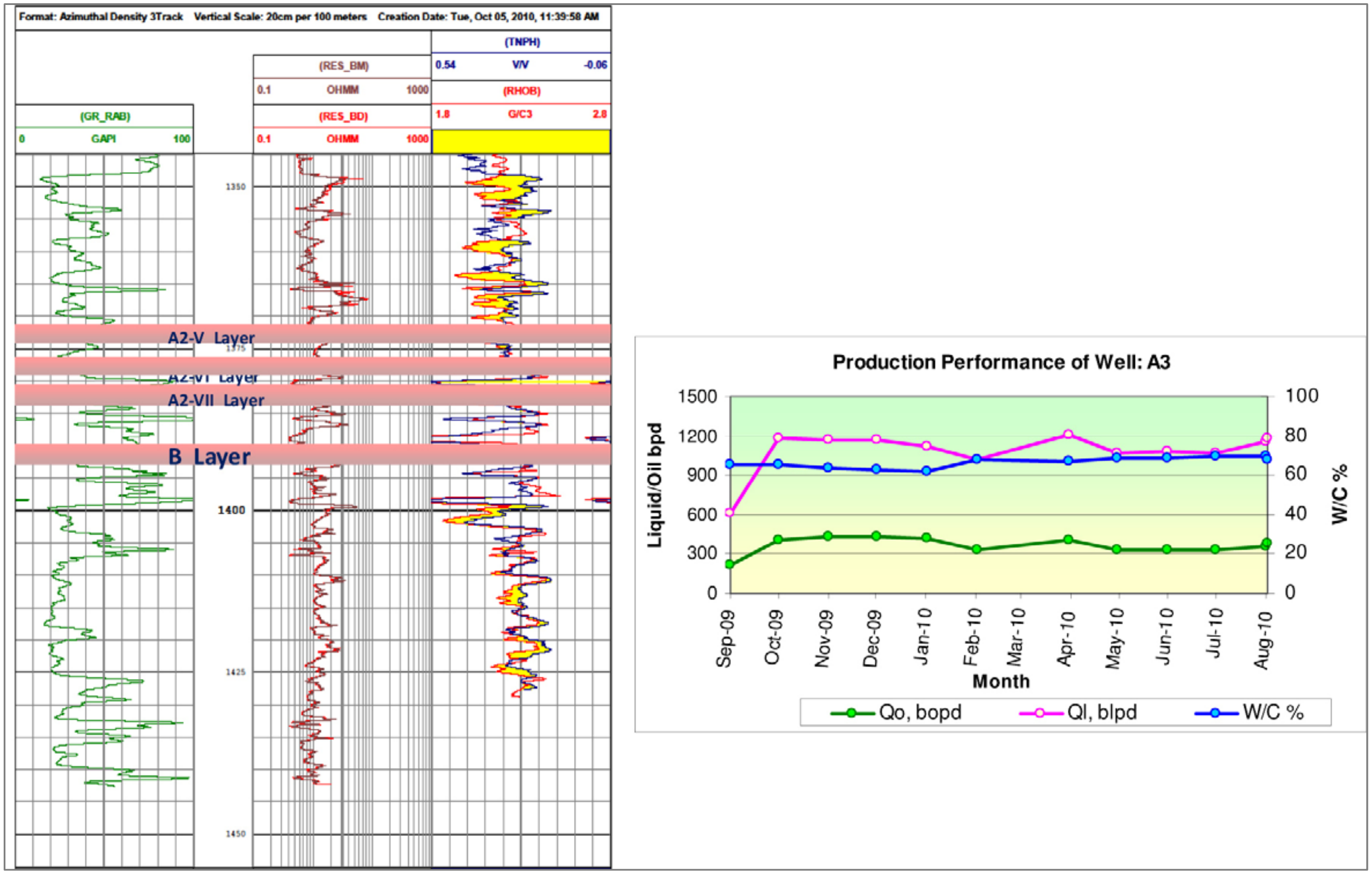


Figure 7. Well logs and production performance of Well ‘A3’.

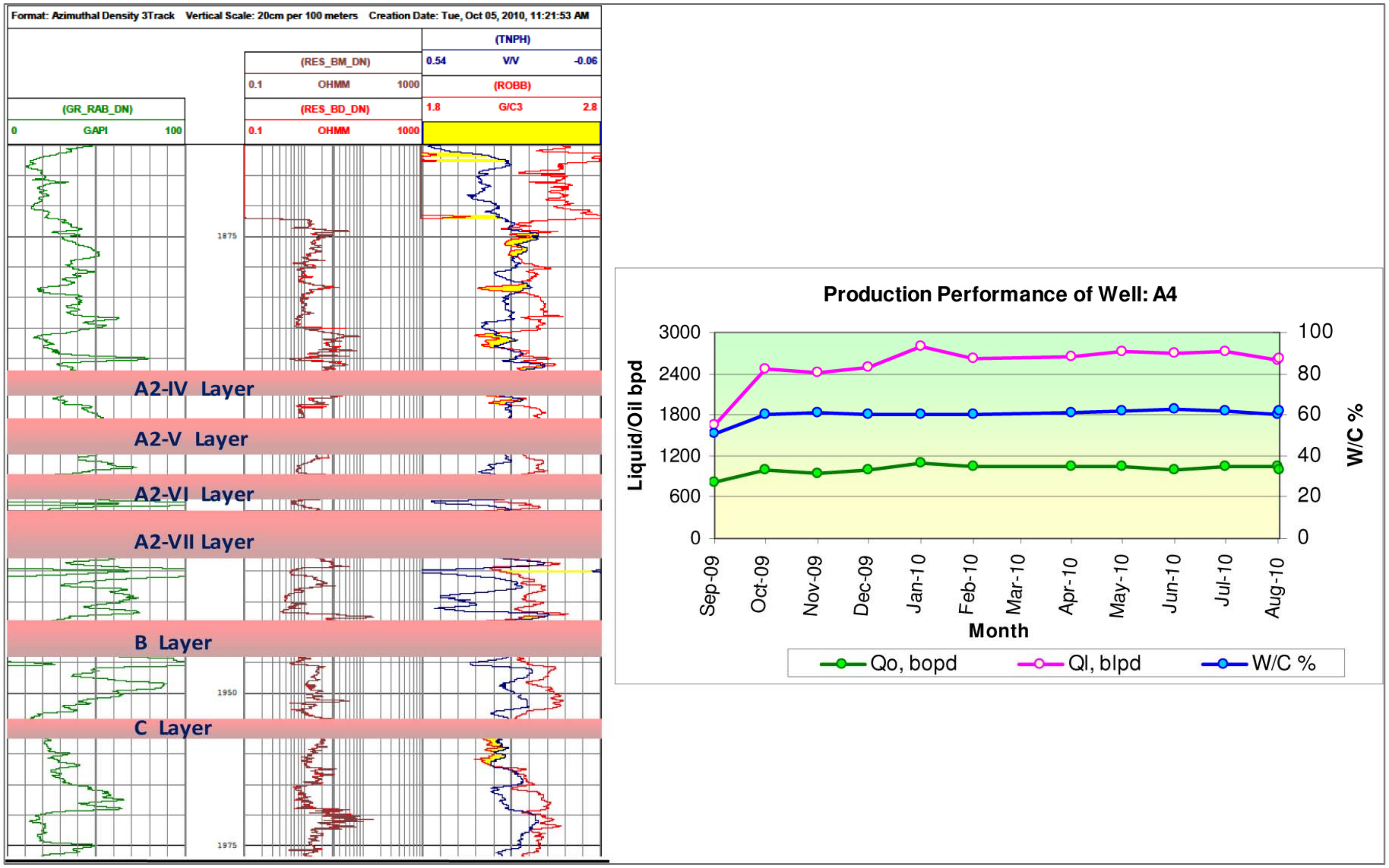


Figure 8. Well logs and production performance of Well ‘A4’.

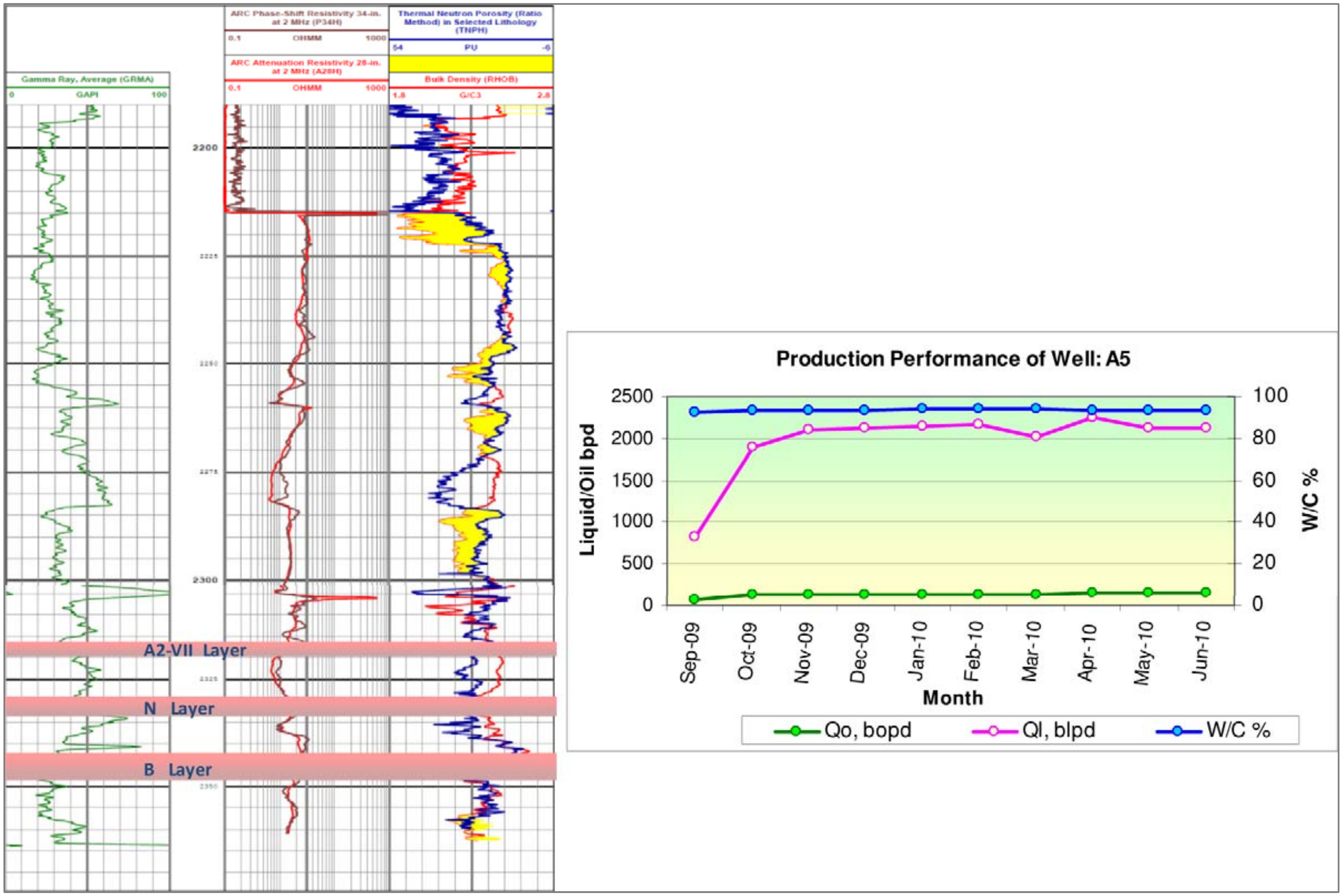


Figure 9. Well logs and production performance of Well ‘A5’.

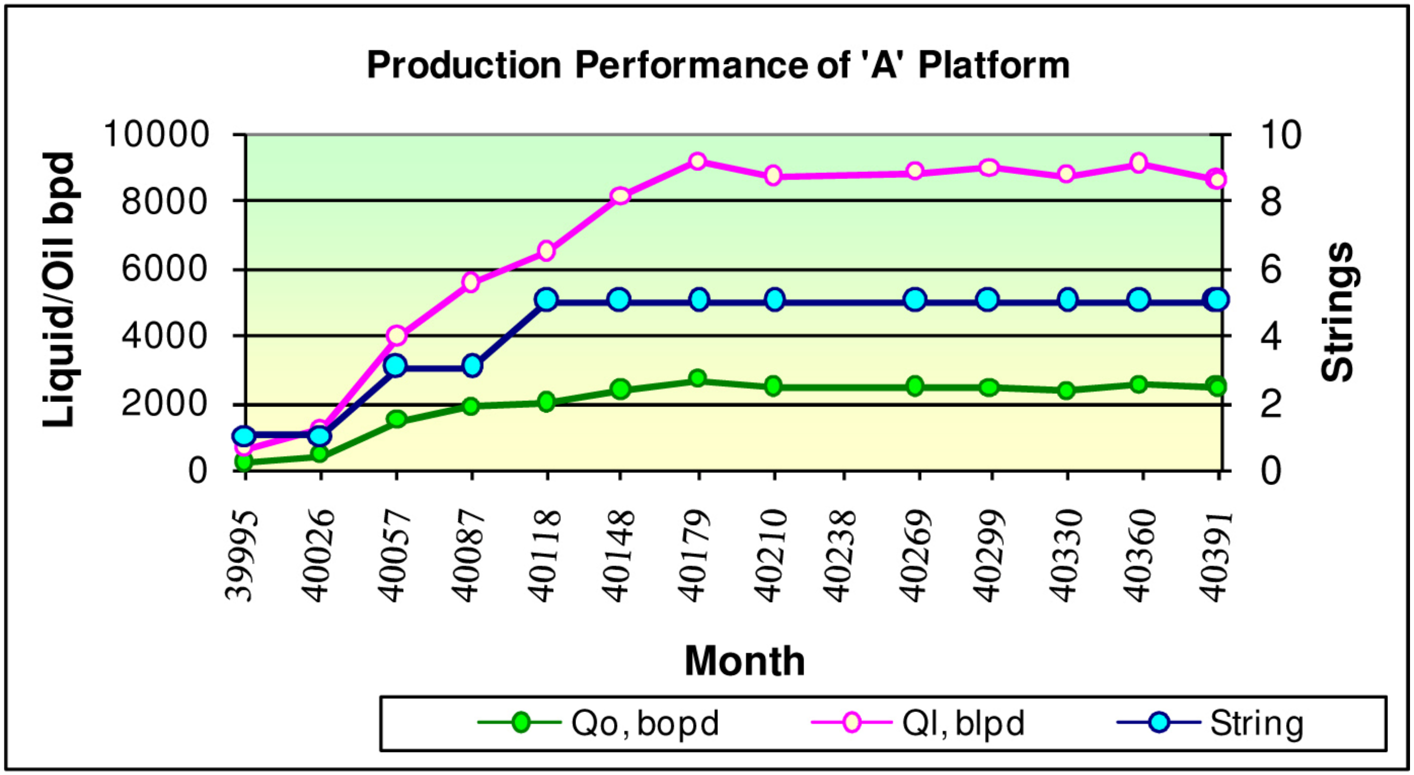


Figure 10. Production performance of Platform 'A'.