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Mumbai High Redevelopment – Geo-Scientific Challenges and Technological Opportunities

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ABSTRACT : Mumbai High, a giant oil field located in western offshore, is considered in the world oil industry as one of the most complex field , especially from geological and geophysical (G&G) point of view. In view of this, optimising oil production from this field, has been a challenging task to geoscientists over the years. In recent times the industry has witnessed significant advances in geo-scientific areas such as 3D seismic, Logging While Drilling (LWD), reservoir simulation etc. Of late, some of these high end technologies have successfully been attempted for micro level understanding of Mumbai High reservoirs. The results, though encouraging, still fall short of requirement. However, advances made in drilling and completion technologies, to a great extent are helping in achieving higher per well production rates, G&G complexities notwithstanding. This paper addresses, in brief, the results of geo-scientific understanding of this matured multi-layered carbonate reservoir and technological achievements towards optimising oil production from Mumbai High field.

INTRODUCTION

Mumbai High is an offshore oil field in water depth of 80m in the Arabian sea and 160Km west–north-west of Mumbai city . Discovered in 1974 and put on production in 1976 Mumbai high oil field is the main center of activity of Oil and Natural Gas Corporation Ltd. (ONGC). This giant field holds nearly 1600 MMt of oil (~12billion barrels) and till date ~300MMt (~2.3 billion barrels) have been produced. The field has the largest number of wells and production platforms. The monsoon environmental conditions further complicates the situation. Thus development of Mumbai High and operations represents a challenge by any measure in the international oil and gas arena.

Having reached to a peak production level of ~400,000 barrels of oil per day during 1989-90, the field in subsequent years experienced steep decline in the output. Increase in gas oil ratio (GOR) levels, reduction in reservoir pressures and undesirable flow of water were some of the reasons for decline in the field output. Since 1990, a number of s teps were taken up in the field to arrest the rate of decline of oil production[1]. To augment the field production levels to achieve higher recovery two ambitious redevelopment plans, viz., Mumbai High North (MHN) and Mumbai High South (MHS) plans were drawn in 2000-01. The plans envisage massive investments and drilling of more than 200 development wells through induction of innovative drilling and completion technologies. With the implementation of these projects successfully the declining trend was fully arrested and upward trend in production could be established. The field still holds enormous potential for additional oil production in the years to come.

GEOLOGY AND MODEL BUILDING

Mumbai High offshore field is divided into MHN and MHS due to the presence of geological low between the two sectors (Fig.1) . The development history and forecast projections of oil production from the field is shown in Fig. 2.

Figure 1: Mumbai High Field

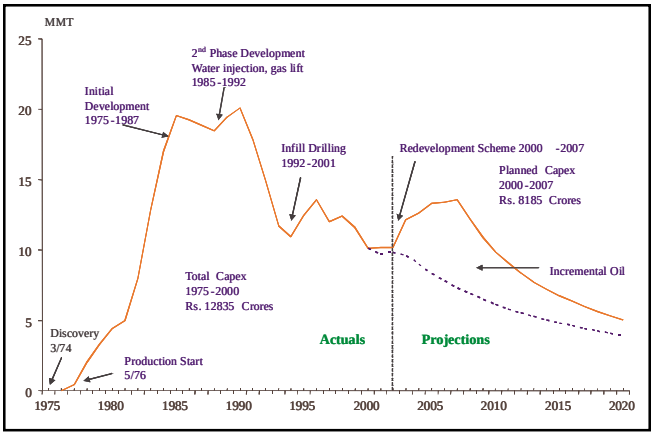

Figure 2: Development History and Forecast Projections in Mumbai High Field

Major oil production is from L-III pay consisting of thin limestone reservoirs inter-bedded with shale bands (Fig. 3). The very large geographical area of the field (1200 Km^2), complex geology and thin multi-layered nature of the oil and gas bearing reservoir have presented a singular and difficult challenge in the scientific study and optimal development of oil and gas production.

Between the period 1998 and 2000 an extremely ambitious reservoir analysis plan was undertaken, a prerequisite before a major investment plan. It required an exhaustive review of the static and dynamic data collected in the field since its discovery in 1974. The problem was addressed by a strong group of Multi-Disciplinary Team (MDT) of geoscientists of ONGC, with the help of internationally reputed oil field consultants Gaffney, Cline and Associates (GCA), UK. The task includes compilation, validation and transferring the data on electronic media, a vast amount geoscientific information available from ~ 700 exploratory and development wells drilled in the field over a period of nearly 25 years. A range of technologies were applied in order to quantify the complexity of the reservoir geology. The new findings have been incorporated into the geological model. The new geological model built formed the basis for carrying out reservoir simulation studies in order to forecast future production scenarios and estimate investments to infuse new life into the field.

This is the first major step ever undertaken by ONGC. About 600 openhole well logs of L-III reservoir were reprocessed using the state of art of software. Petrophysical properties of thin carbonate reservoirs of L-III were evaluated at as low as 15cm interval. Structural elements of the reservoirs

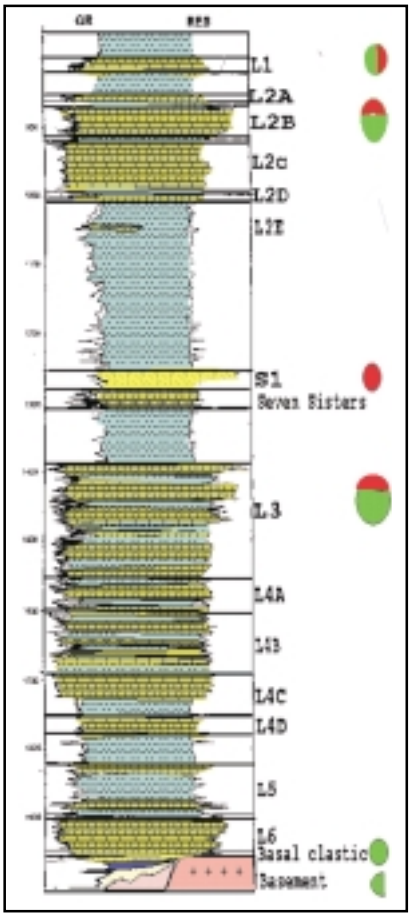

Figure 3(a) : Strategraphic Sequence in Mumbai High Field

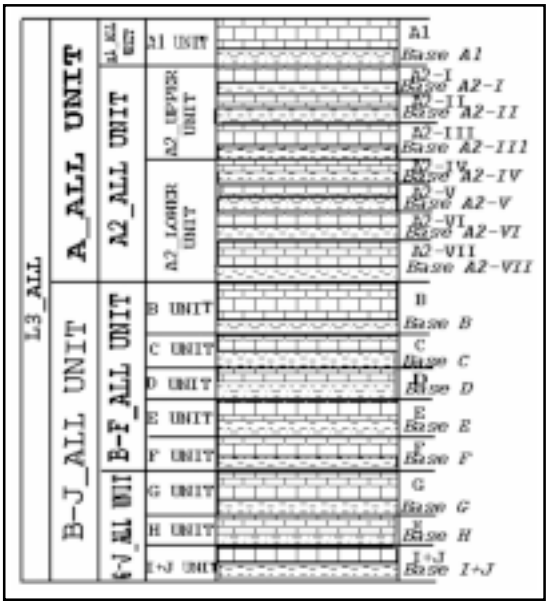

Figure 3 (b) : Sub-Layers of L-III Reservoir

picked from 3D seismic data were integrated in the geological model building (Fig. 4). During this process and subsequent reservoir simulation, however, the following aspects could not be resolved satisfactorily.

- Structural understanding of the field at L-III top and reservoir properties at thin L-III sub-layer level from 3D seismic data, input parameters for robust geological model building and reservoir simulation.
- Discontinuous nature of shales aerially and vertically within L-III carbonate, an understanding of which is critical for tracking down undesirable flow of fluids such as water and gas.
- Reliable permeability estimate, a key parameter for evaluating flow of fluids in porous media.

3-D SEISMIC SURVEY

The initial processed 3D seismic data shows varying degree of signal to noise ration (S/N ratio) at the primary reservoir level L-III. The poor data area can be attributed due to the presence of gas cap and the latest study on optical stacking has brought out that the data can be very meaningful in describing the reservoir in some areas. The inadequate velocity control from VSP and good sonic data is another constrain in preparing a more realistic structure maps at different reservoir levels. In order to address these issues, amplitude preserved , depth imaging and enhancement of S/N ratio through advanced algorithms has been planned. Acquisition of VSP and shear sonic data has already been initiated to have a better control. The proposed special processing would help us in building the complex framework of structure and estimate the rock property from seismic and log/core data.

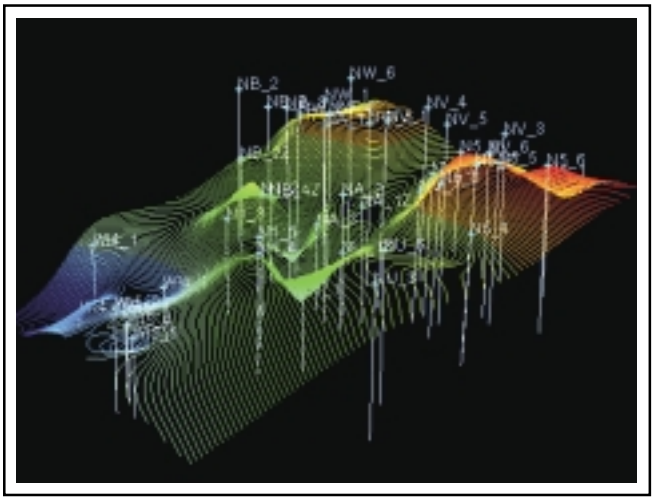

Figure 4: Structural Disposition in Mumbai High North

FORMATION EVALUATION

Historically Mumbai High field was developed through conventional well technology. In this approach wells were drilled as vertical wells or slightly deviated, penetrated through the bottom of the L-III reservoir, cased, cemented, selectively perforated and activated for oil and gas flow. This strategy has many advantages but in specific reference to thin L-III sub-layers (2 to 5 m thickness) the rock face exposure is small and therefore the production capacities of the wells are limited. Present reservoir conditions are not conducive for drilling conventional wells anymore for augmenting production from the field.

In order to understand and quantify the permeability values of thin carbonate layers of L-III reservoir a significant effort was expended in assembling core database which was depth matched to wire line logs. This process was complicated by the fact that no logs have been taken over the interval of the retrieved cores. It was concluded that geological based approach for Micro-facies identification could not be applied to the L-III reservoir. The only scope left for permeability description is solely based on wire line log responses. In view of the development of the secondary porosity in the carbonates there is no satisfactory solution for evaluating permeability from the wire line log data as well. Often it is found that there is a wide disparity between log derived permeability and well test permeability probably in view of secondary porosity development. The standard method of detecting the development of secondary porosity could not be applied as there was not enough sonic logs run in the field. It was concluded that Porosity-permeability is not facies dependent but controlled by different dia-genetic processes. Conventional poro-perm relations per L-III sub-layers were found to be inadequate. This experience led to using a field specific empirical (Timur Type) relationship between permeability and log derived porosity and saturation. However, this is at best an approximation to proceed further (Fig.-5).

Under the Mumbai High redevelopment projects a number of horizontal wells are being drilled through thin (2-5m) limestone reservoirs of L-III pay. These horizontal drain holes are logged using state-of-the art technology, i.e., Logging While Drilling (LWD). LWD is a powerful tool to provide on real time basis the nature of the reservoir, i.e., lime

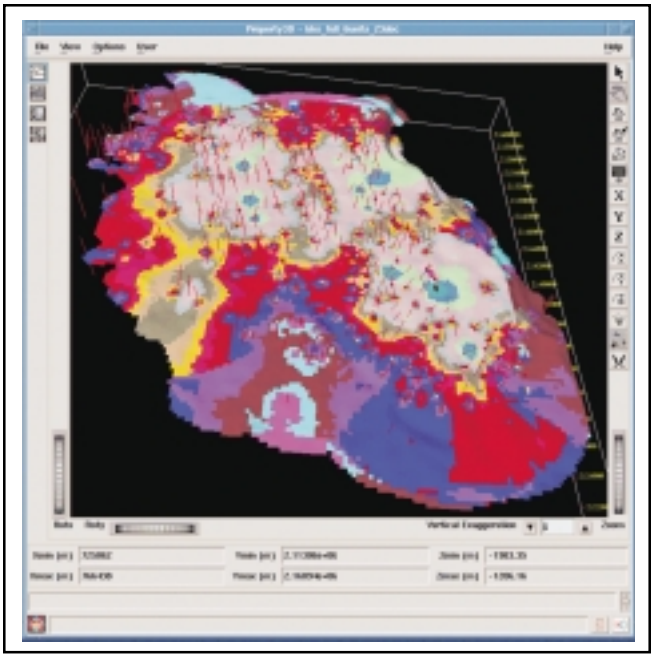

Figure 5: Permeability Modelling in Mumbai High South

stone or a shale and also a quick look evaluation of the presence of hydrocarbons/water and also the porosity of the limestone being drilled. Yet, as on date the industry has no solutions, unlike conventional logging, to quantify the pertrophysical properties of the limestone being logged using LWD technology.

To sum up, the limitations currently available of 3D seismic data, porosity-permeability understanding and inability to quantify LWD data as explained continue to constrain in describing L-III reservoir to an acceptable level, built robust geological/geophysical models, run reservoir simulation and forecast oil production scenarios with a high degree of confidence. At the same time the solutions for these problems are not likely to come over a short period of time and the field redevelopment cannot wait till perfect solutions are found to the geological/geophysical issues of L-III reservoir of the field. A way has to be found to redevelop the field with whatever geoscientific knowledge base currently available with ONGC.

DRILLING TECHNOLOGY

With significant advances in drilling related equipment, LWD technology and realization of higher per well productivity, currently drilling horizontal (Fig. 6) and multi-lateral wells (Fig. 7) are routinely being done by the operators

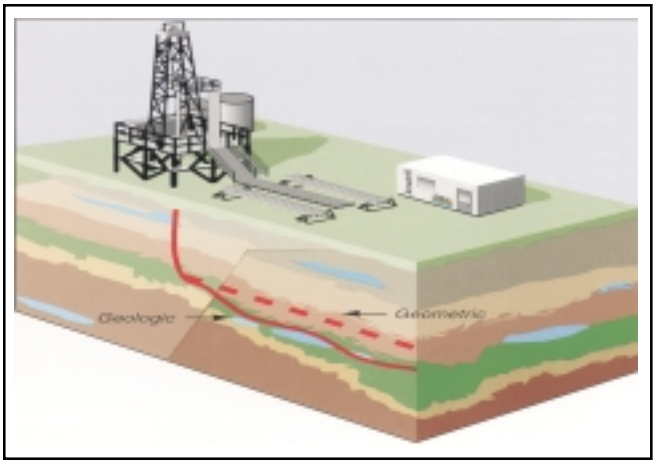

Figure 6: A Horizontal Drain Hole Well

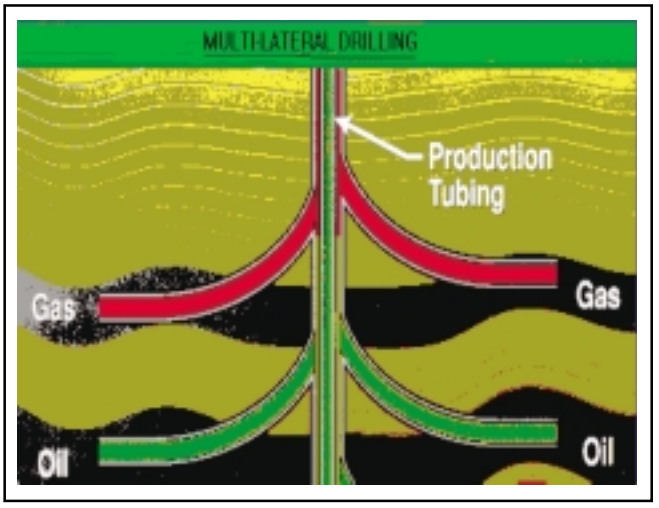

Figure 7: Drilling a Multi-lateral Well

all over the world. Not lagging behind, under a very ambitious plan of redevelopment of Mumbai High field, ONGC has embarked upon a strategy of drilling a large number of high technology wells beginning from January, 2001. Till date more than 60 horizontal/multi-lateral wells were drilled successfully and significantly high oil production rate could be established from the field.

Drilling horizontal/multi-lateral wells, application of LWD and pressure measurements have revealed that ,

- Openhole exposure of a large section of thin carbonate reservoirs yields higher well production rates
- Multi-laterals address larger drainable reservoir volume of each sub-layer of L-III reservoir

- The high technology wells through LWD tools, though qualitative, provides better insight into complex heterogeneity of carbonates
- Reservoir pressures recorded along the length of the drain holes provides additional and encouraging information about regional layerwise pressure distribution.

CONCLUSION

Based on the measures taken during the implementation of the redevelopment plans in Mumbai High Field, the following conclusions were made;

1. L-III reservoir is responding favorably to high technology wells.
2. Some of the relatively tight sub-layers are found to be far more productive on application of horizontal well technology.
3. The sub-surface G&G information, though cannot be quantified often, is found to be extremely useful in planning more and more high technology wells across the field.
4. Redevelopment of the field through application of high technology drilling and improved understanding of the reservoirs need to progress concurrently.

ACKNOWLEDGEMENTS

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