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The Utilization of Borehole Images for Sampling Optimization in Heterogeneous Carbonate Reservoirs of South Iraq

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SUMMARY

Wireline Formation Testers have been used in the petroleum industry for decades to provide accurate formation pressure measurements and fluids properties with wide range of applications through all the stages of in the life of a reservoir; exploration,appraisal,development,production and injection. Wireline formation testing done mostly using cable-operated tester and sampling tool anchored at depth while reservoir communication is established through one or more pressure and sampling probes .Traditionally, the selection of the formation pressure and sampling points rely on conventional resistivity and porosity logs. These logs often fail to produce optimal results because of the complex nature of the dual-porosity carbonates in South Iraq. The work illustrated in this paper tried to optimize the selection of formation pressure and sampling points by the utilization of high-resolution azimuthal log measurements such as borehole images. The use of a high-resolution electrical borehole image log helps place the tool probes at optimum depth locations and pinpoint the “sweet spots” suitable to achieve the best results of formation pressure and sampling measurements.

Introduction

Carbonate sequences of South Iraq are known for highly varying reservoir properties (e.g., porosity, permeability, flow mechanisms) within small sections of the reservoir; mostly as a result of later diagenesis that makes the flow behavior through them pretty erratic at times. There are loads of examples available in public domain where not understanding the formation heterogeneity has caused a lot of production surprises; especially in Mishrif.

Formation sampling provides an important, direct and first means to understand the fluid properties and flow capacity from the sub-surface units. Often, these results are used to further decide the course of development of the reservoirs. Therefore, it is imperative that formation sampling strategy is free of statistical sampling bias; and provides the results that could be representative enough of the sub-surface. In heterogeneous formations like Mishrif, often the sampling strategy could be skewed by good permeability zones that might not be accounting for the heterogeneity inherent of this formation.

Electrical borehole image logs provide both the small-scale resolution and azimuthal coverage to quantitatively resolve the heterogeneous nature and are used routinely to determine sub-seismic structural or stratigraphic events, as well as to optimize the selection of formation pressure and sampling points. The use of a high-resolution electrical borehole image log helps place the tool probes at optimum formation and depth locations, thereby reducing risk and operating time. Analysis of dynamic pressure data can confirm sub-seismic reservoir barriers that had been earlier interpreted as structural or stratigraphic breaks.

In carbonate reservoirs of South Iraq, it is always a challenge to pinpoint the “sweet spots” suitable to achieving the best selection of formation pressure and sampling points. Mishrif formation for instance has dual porosity systems with widely varying proportions of primary and secondary porosity. The secondary porosity is largely dominated by vugs and molds. The rock matrix is further altered by cementation which reduce the porosity dramatically. All these textural variations in small scale has big impact on the results of formation sampling operations. Traditionally, the selection of the formation pressure and sampling points rely on traditional resistivity and porosity logs. These often fail to produce optimal results because of the complex nature of the dual-porosity carbonates and the lack of high vertical resolution. Borehole electrical images provide both the small-scale resolution and azimuthal borehole coverage to capture the textural and porosity variations. The information acquired by borehole images can be utilized effectively in the formation sampling operations by optimizing the selection of the sampling points.

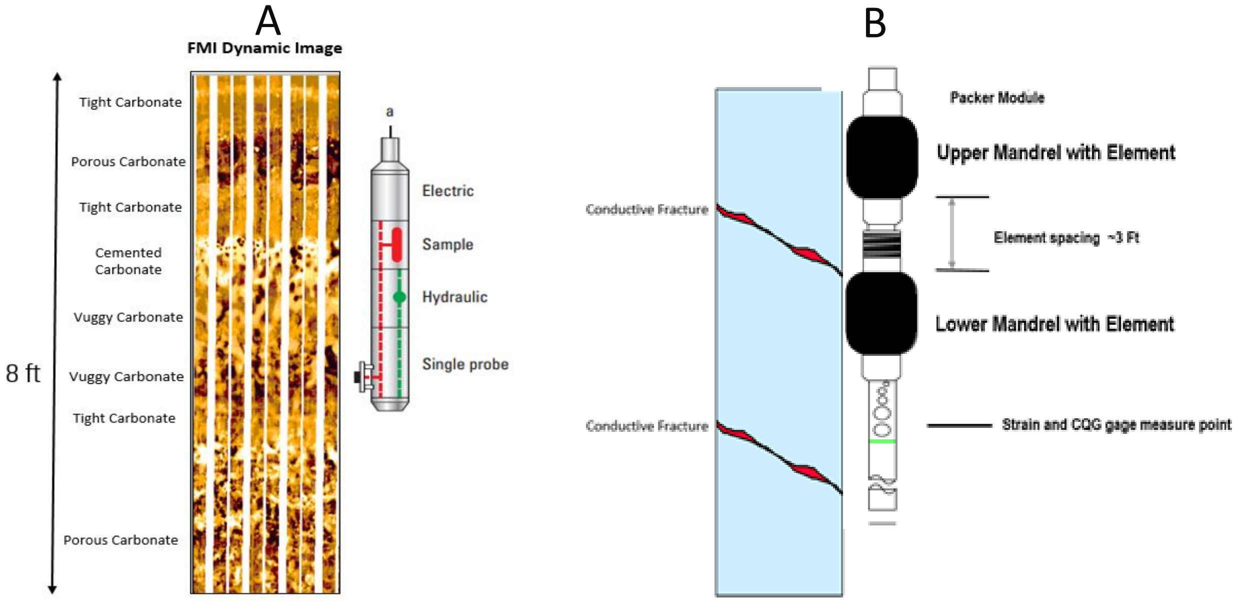

Figure 1: A-Example of FMI images in heterogeneous carbonate formation with MDT probe placed opposite to the sweet spot which contain connected vuggy porosity (conductive spots), B- Dual Packer setting opposite to conductive fracture to maintain the seal.

Based on the facies analysis and the fractures, vugs distribution, MDT pressure test and sampling stations are selected, the value extracted from this to maximize the station value and minimize the rig time, probe depth selection is important in such environments to minimize rigs of getting lost seals (in case of fractures) and tight points in facies where secondary porosity is the main contributor, based on the FMI secondary porosity azimuthal distribution, pressure points selection can be dramatically more significant as the facies changes azimuthally and laterally.

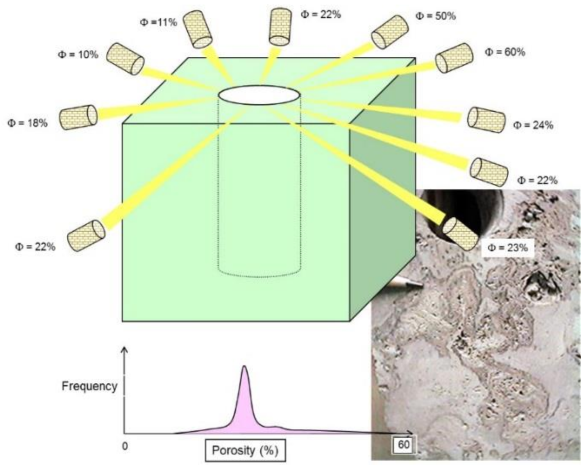

Figure 2: Example showing the azimuthal heterogeneity in Carbonate rock and effective porosity variation.

The efficiency of wireline formation tester operations can be greatly increased by accurate planning that include utilization of all the measurements that can address the textural and porosity variations of carbonate rocks to accurately placing the tester probes and packers in the borehole. A key element is the accurate understanding of subsurface lithological and textural variations, including reservoir internal baffles and barriers.

Wireline formation testers in its simplest configuration use a single probe which set in the wellbore. Formation pressure is generally obtained by withdrawing a small amount of fluid (Up to 20 cc) to generate a short transient test called a "pretest". The pressure response is then recorded during shut-in until it stabilizes .Both drawdown and build-up data are acquired for each pretest. In case of tight formations, the single probe can be replaced with "dual packer" that isolate a borehole interval for testing and sampling. The spacing between the packers is flexible (3-11.5 ft) so the entire borehole wall between that spacing is open to flow. The acquired information then used for wide range of applications. In virgin wells, the vertical pressure profiles can determine the in-situ fluid densities and fluid contact levels. In development wells, pressure profiles are used combined with production history, measurements from well testing, saturation monitoring to determine the hydraulic communication between wells, characterize the vertical and horizontal barriers and understand the permeability anisotropy. The accurate identification of flow barriers and reservoir compartments are critically important to reservoir management.

Permeability anisotropy (k_v/k_h) is of interest to all those concerned with production optimization since it affects crossflow, coning and horizontal well behaviour. Its quantification is currently undertaken using a combination of core log measurements, dynamic well testing and numerical upscaling. However, the modular configuration of modern wireline testers (MDT) allows to conduct one well testing technique called vertical interference test (VIT). VIT test can be used to determine the vertical permeability at reservoir length scale. It can also be conducted to determine the cross-flow between two layers separated by a low-permeability barrier, additionally, all these measurement can be acquired during sampling operations or fluid scanning to determine fluid properties with in-situ fluid analyzers, with the VIT technique or single probe/ packer drawdown operations, selectively from the build-up, flow capacity can be determined which has great impact on reservoir management and transmissibility mapping for water injection operations and pulse tests.

Summary

Electrical borehole images logs with its high resolution and azimuthal measurements help reservoir engineers to select formation pressure and sampling points accurately in the highly heterogeneous carbonate reservoirs in South Iraq such as Mishrif, thereby reducing risk and operating time. The carbonate facies containing open fractures and connected vugs interpreted on borehole images are highly recommended for taking pressure points and samples, which resulted in good-quality reservoir engineering data acquisition. The facies altered by cementation or containing tight spots and healed (closed) fractures were mostly avoided for taking pressure data points. The data measured by wireline formation tester can be further integrated with borehole image interpretation results for better understanding on reservoir compartmentalization. The structural or stratigraphic breaks interpreted from the dip data can be used with the discontinuities in pressures and pressure gradients to accurately define the compartments. In addition, vertical permeability barriers can be determined by dynamic pressure data and confirmed by the textural/structural/stratigraphic variations observed on borehole images.

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