

A NEW ANALYTICAL METHOD FOR CHARACTERIZATION OF  
FRACTURED RESERVOIRS

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Specially dedicated to *my mother*

I really miss you

*Al-Fatihah*

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## ABSTRACT

Structural delineation is the main issue in the evaluation of carbonate reservoirs in structurally complex areas. Permeability is a critical reservoir parameter that influences well and/or reservoir performance and it is even more challenging when the reservoir is fractured. Oil Based Mud Micro Imager - resistivity of invading zone (OBMI-Rxo) is a high resolution curve that is sensitive to fluid mobility near the borehole wall and indicates invasion. However most operators are not using an accurate Rxo curve of OBMI for reservoir and petrophysical applications. After drilling it is important that the borehole stays in good shape, moreover, borehole instability will reduce the working life of the well. The main aim of this study is to design a workflow in order to establish an advanced formation evaluation in a carbonate fractured and clastic reservoirs. The entire workflow involved incorporating borehole images, petrophysical logs, Modular Formation Dynamics Tester tool (MDT), Xpress Pressure Tool (XPT) and cores in characterizing fractured and non-fractured reservoirs. Image log data are processed and interpreted in the computer using a Geoframe software. The bedding, deviation survey and image logs are imported into the Bortex software and the heterogeneity analysis of reservoirs from borehole images is computed based on the same resistivity contrast principle than the layer delineation. Respectively, the Formation Micro Imager (FMI) and OBMI images are used to examine permeability and index mobility in conjunction with open hole logs. As a result, the answers provided by the FMI tool helped in understanding the reservoir structure, identify and evaluate fractures, visualize the rock texture, and complement coring programs. Single-well permeability distribution was demonstrated by the use of advanced image analysis. OBMI-Rxo helped to identify zones of higher permeability when combined with conventional induction logs and porosity logs. In addition, working on advanced borehole shape analysis improved information about the well condition.

## ABSTRAK

Struktur delineasi menjadi isu yang utama untuk penilaian reservoir karbonat di kawasan berstruktur rencam. Ketertelapan merupakan parameter reservoir kritikal yang dapat mempengaruhi pelakuan telaga dan/atau reservoir dan ianya didapati lebih mencabar apabila reservoir mempunyai rekahan. Pengimbas Mikro Lumpur Dasar Minyak – kerintangan zon serbuan (OBMI-Rxo) adalah lengkuk beresolusi tinggi yang sensitif kepada pergerakan bendalir berhampiran dinding lubang telaga dan yang menunjukkan penyerbuan, kebanyakan operator didapati tidak menggunakan lengkuk OBMI-Rxo dengan betul pada reservoir dan bagi aplikasi petrofizik. Selepas penggerudian dijalankan, adalah penting untuk memastikan lubang telaga dalam bentuk yang baik. Tambahan pula, ketidakstabilan lubang telaga akan mengurangkan jangka hayat telaga tersebut. Tujuan utama kajian ini adalah untuk merekabentuk carta alir kerja tetap bagi penilaian formasi lanjutan untuk reservoir karbonat rekah dan juga klastik. Secara keseluruhannya, carta alir kerja ini untuk tujuan pencirian reservoir rekah dan bukan rekah adalah merangkupi imej lubang telaga, log petrofizik, ‘modular formation dynamics tester tool’, ‘Xpress pressure tool’ dan teras. Data log imej diproses dan diterjemah dengan menggunakan komputer dengan perisian ‘Geoframe’. Data dari lapisan, survei deviasi dan imej log diimport ke dalam perisian ‘Bortex’ dan kemudiannya pengiraan analisis keheterogenan reservoir daripada imej lubang telaga dilakukan berdasar kepada prinsip perbezaan kesamaan resistiviti berbanding deliniasi lapisan. Berkaitan log lubang telaga terbuka, pengimbas mikro formasi (FMI) diguna untuk menilai ketertelapan, manakala imej OBMI diguna untuk menilai indeks mobiliti. Sebagai kesimpulan, hasil yang diberi oleh alatan FMI didapati dapat membantu dalam penelitian struktur reservoir, mengecam dan menilai rekahan, memapar tekstur batuan, dan pelengkapan program penerasan. Taburan ketertelapan telaga tunggal telah dipapar dengan menggunakan analisis imej lanjutan. OBMI-Rxo membantu untuk mengenal zon ketertelapan tinggi apabila ianya digabungkan dengan log induksi konvensional dan log keliangan. Berkaitan kestabilan lubang telaga, kajian ini juga didapati dapat menambah baik maklumat tentang keadaan telaga apabila dijalankan analisis lanjutan bentuk lubang telaga.

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## LIST OF ABBREVIATION

<i>BS</i>	-	Bit Size
<i>C1</i>	-	Caliper Pair 1-3
<i>C2</i>	-	Caliper Pair 2-4
<i>CGR</i>	-	Gamma Ray (Corrected)
<i>CKH</i>	-	Core Horizontal Permeability
<i>COND.CONNECTED.SP</i>	-	Conductive Connected Spots
<i>COND.PATCHES</i>	-	Conductive Patches
<i>COND.ISOLATED.SPOT</i>	-	Conductive Isolated Spots
<i>CPOR</i>	-	Core Porosity
<i>CS</i>	-	Cable Speed
<i>DEVI</i>	-	Borehole Deviation Angle (deg)
<i>DYNAMIC</i>	-	Sliding Window Normalization
<i>EMEX</i>	-	Measurement Control Voltage
<i>FMI</i>	-	Full bore Formation Micro Imager Tool
<i>FRACTURE APERTURE</i>	-	Aperture of Fractures
<i>FRACTURE DENSITY</i>	-	Number of Fractures Per Meter
<i>FRACTURE POROSITY</i>	-	Porosity of Fractures
<i>GEOLOG</i>	-	Geological Lithozones
<i>GPIT</i>	-	General Purpose Inclinometry Tool
<i>HAZI</i>	-	Borehole Deviation Azimuth (deg)
<i>HC BEDDING</i>	-	High Confidence Bedding
<i>HDRS</i>	-	Deep Resistivity
<i>HGR</i>	-	Gamma Ray
<i>HMRS</i>	-	Shallow Resistivity
<i>ILD</i>	-	Deep Resistivity (Deep Induction)
<i>ILM</i>	-	Shallow Resistivity (Shallow Induction)
<i>LQC</i>	-	Log Quality Control

<i>LC BEDDING</i>	- Low Confidence Bedding
<i>MDT</i>	- Modular Formation Dynamics Tester Tool
<i>NPHI</i>	- Neutron Porosity
<i>OBMI</i>	- Oil Base Mud Imager
<i>P1AZI</i>	- Pad 1 Azimuth (deg)
<i>PE</i>	- Photoelectric Factor
<i>PEFZ</i>	- Photoelectric Factor
<i>PERM</i>	- Permeability from FMS
<i>PERM.INDEX</i>	- Raw FMI Permeability Indicator (Mobility)
<i>PEX</i>	- Platform Express
<i>PHIS</i>	- Secondary Porosity
<i>PHIT_FMI</i>	- Average High-resolution Porosity from FMI
<i>PIGE</i>	- Shale Corrected Log Porosity
<i>POR_HIST</i>	- Porosity Histogram
<i>PP</i>	- Pad Pressure
<i>RES.SOPTS</i>	- Resistive Spots
<i>PES.PATCHES</i>	- Resistive Patches
<i>RHOZ</i>	- Formation Density
<i>RLA3</i>	- Shallow Resistivity
<i>RLA5</i>	- Deep Resistivity
<i>SPOR</i>	- Secondary Porosity from FMI
<i>STATIC</i>	- Fixed Window Normalization
<i>TENS</i>	- Tension
<i>TNPH</i>	- Porosity from Neutron Log
<i>UBI</i>	- Ultrasonic Borehole Imager tool
<i>WALL</i>	- Borehole Wall
<i>XPT</i>	- Xpress Pressure Tool

## LIST OF SYMBOLS

Symbol		Dip Classification
	-	High Confidence Bedding
	-	Low Confidence Bedding
	-	High Confidence OBMI Bedding
	-	Low Confidence OBMI Bedding
	-	High Confidence UBI Bedding
	-	Low Confidence UBI Bedding
	-	Minor Open fractures
	-	Major open fractures
	-	Medium open fractures
	-	Closed fracture
	-	Continuous open fractures
	-	Discontinuous open fractures
	-	Fault

## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 Introduction**

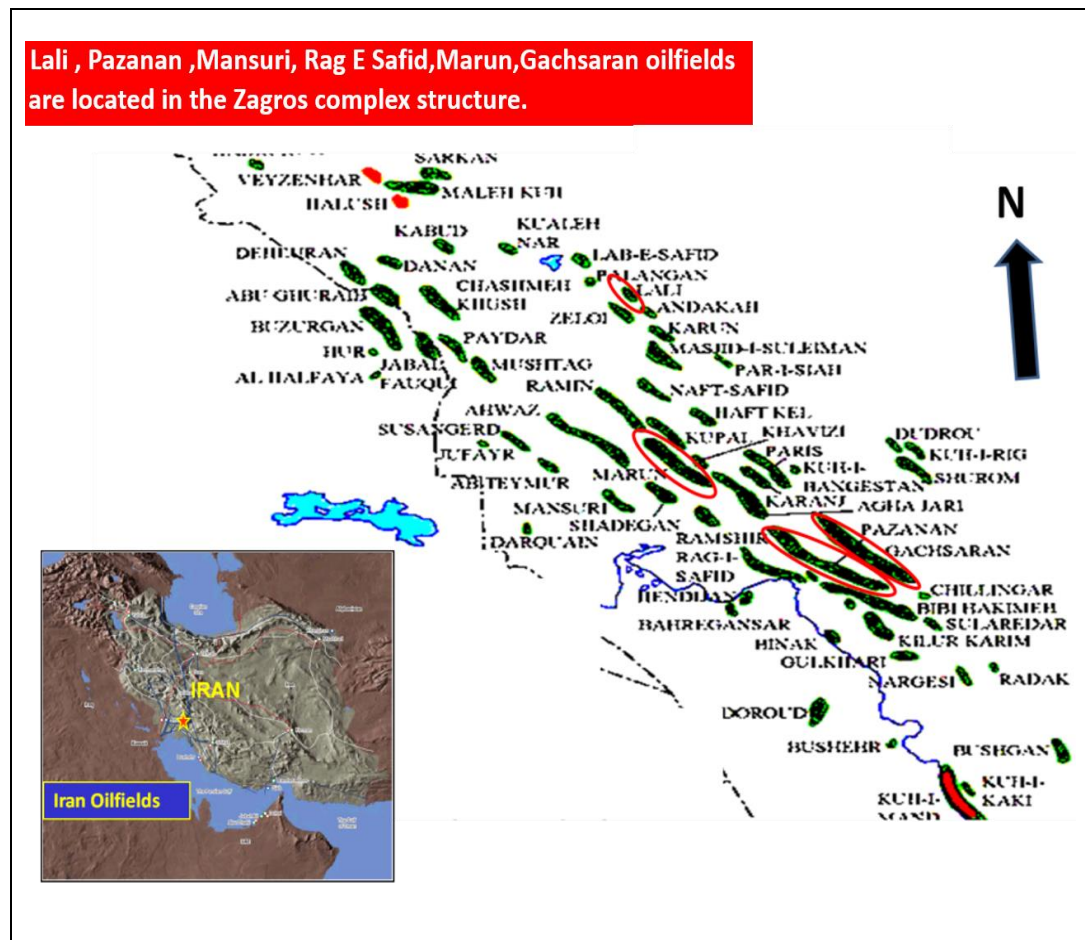
Outcrop study of the target formations/ reservoirs have a great importance to understand the possible geological (structural and sedimentological) and reservoir characteristics of the reservoir. These features are studied at different scales to determine their lateral and vertical extent and distribution. This is mainly achieved by various technologies, such as, Brunton compasses/Inclinometers, topographic maps, aerial photographs, and satellite images. A similar approach is needed for delineating and characterizing the reservoirs in the subsurface. The large scale subsurface features are delineated with the surface seismic (2D and 3D) techniques. However, the coarse resolution (generally greater than 10 m) of these techniques does not allow for feature identification of smaller scales (for instance, cross bedding, bedding, fractures, and vugs/moulds) that are very useful for detailed characterization of reservoir rocks.

Borehole images are very useful in cases where information on geological (structural and sedimentological) and reservoir features are required. Structural dip by definition is the present day formation dip used to build the structural cross section. It is also a record of the post-depositional structural alteration and may indicate the tectonic history of the sequence. It is not an average dip for all the bedding planes. Apart from structural analysis, the investigation of fractures is the main application for image logs in Dezful Embayment, Iran. Information on fractures is important to know because of their higher permeability, hence their



biggest influence on reservoir producibility. Schlumberger provides high quality borehole images in wells drilled with all types of mud; water based mud and oil based mud. These images can be acquired in wells of all geometries ranging in deviation from 0.0 degrees to more than 90 degrees. It is now possible to get resistivity of the invaded zone ( $R_{xo}$ ) in the wells drilled with oil-base mud using the state-of-the-art imaging tool called the Oil Base Mud Imager (OBMI) (Schlumberger, 2005). By using advanced interpretation, it can compute permeability from the borehole images in carbonates.

This study highlights the importance of data integration and borehole images in the domains of geology, petrophysics, geomechanics/drilling, reservoir and production engineering in different oil fields of National Iranian South Oil Company (NISOC). Borehole images logged in Asmari and Sarvak reservoirs from the NISOC fields like Lali, Gachsaran, Marun, Mansuri and Pazanan are discussed (Figure 1.1).



**Figure 1.1** Studied oilfields (red colored) in Dezful embayment.

The Asmari formation consists of limestones, dolomitic limestone, argillaceous limestone, and anhydrite and the lithology of Sarvak formation is limestone and it lies below Ilam reservoir (Motiei, 1993) (Figure 1.2). Our research establishes a technique to increase the reservoir explanation of the Asmari and Sarvak reservoir by using a new application of image logs.

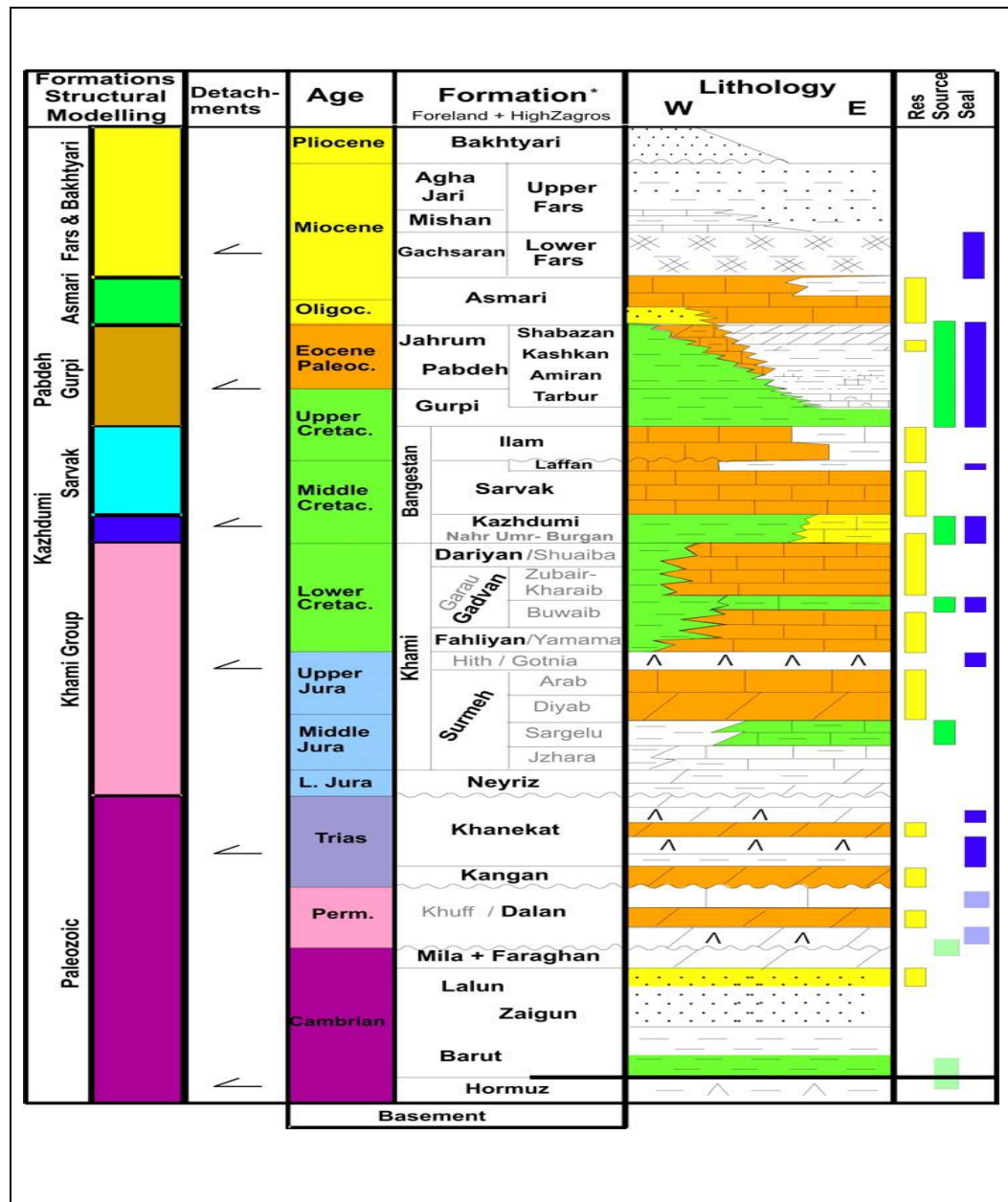


Figure 1.2 Asmari and Sarvak reservoirs in Iran (Bosold et al., 2005).

## 1.2 Problem Statement

The crossing Asmari reservoir is not so easy in some cases due to structural complexities, where there is a thick pile of evaporates of Gachsaran formation over the reservoir. In some wells, higher than the expected thickness of formations is found. Dip classification based on a geological log has the advantage of providing a direct representation of structural origin and identify Asmari fault and fracture systems and its influence on production and resolve structural complexity.

Fracture intensity and deep rooted fractures extensively increase risk of unexpected water production. So, it is vital to know, whether reservoir is fractured or not. If it is fractured then what is the kind of fractures (open or closed) and what is their intensity? Do they occur as a single set or multiple sets and what orientation is their dominant strike? Solutions to questions like these support geologists and reservoir engineers increase oil production (Movahed et al., 2014) and in this study the borehole imaging tools, like the Formation Micro Imager (FMI), Oil Base Mud Imager - Ultrasonic Borehole Imager (OBMI-UBI) are interpreted to find solutions for fracture systems and fracture attributes.

Permeability analysis of dual porosity systems with heterogeneous distribution of dissolution fabrics can evaluate by using the FMI, but NISOC is not using permeability from FMI in a case when there are no any formation testing data in the well for fracture and reservoir modeling. In this study, image logs provided the most representative measurements in geological and petrophysical heterogeneous formations and present a method to measure permeability from FMI in Asmari and Sarvak reservoirs.

OBMI-Rxo is a high resolution curve that is sensitive to fluid mobility near to the borehole wall and which indicates invasion and indirectly lithology, but NISOC is not using an accurate Rxo curve of OBMI for reservoir and petrophysical application. This method using resistivity classes is used to show how the high resolution OBMI curves can be used. The result of this research demonstrates the

new analytical method to evaluate a fractured carbonate and clastic reservoirs from Iran.

The most wells drilled in Iran suffer from geomechanical hazards owing to the high in-situ stress related to the proximity of the Zagros Mountain and it is not always possible to acquire wireline log data because of the borehole condition (Movahed et al., 2014). In this study, advanced borehole shape analysis by using FMI and UBI helped regarding borehole instability and improved information about the well condition.

### **1.3 Objectives of the Research**

The objectives of the research are given below:

1. To develop an accurate structural model for Asmari reservoir.
2. To characterize fractures in the borehole.
3. To compute reliable index mobility from OBMI and index permeability from FMI.
4. To evaluate the borehole condition in order to reduce drilling risk and avoid potential well bore damages.

### **1.4 Scopes of the Research**

Borehole images were integrated with other data (petrophysical, reservoir, and geophysical) to understand the various characteristics of the Asmari both in oil based mud and water based mud systems. In this study, borehole images are used to solve different issues in geology, petrophysics, reservoir engineering, production engineering, sedimentology, geomechanic and drilling in NISOC oil fields that is explained in the following:

1. Image log data are processed for a number of factors that may affect the quality of the images in Geoframe. Such factors include: variation in speed of the tool relative to the drill-pipes, or cable speed; sticking of the tool. Additionally, image logs are equalized and normalized to improve the information of features in it. Interpretation typically started with hand picking dips using sinusoid techniques on image log presented at 1:20 or 1:10 scale so that the geological features are easily visualized. Once dips have been picked they have to be classified into bed boundaries and fractures.
2. Interpreting structural dip resolved structural complexity, thus provided the exact location of the well in the Asmari reservoir, which could not reach the lower contact of Asmari by interpreting FMI images and petrophysical logs in wells LL-26.
3. The structural dip from PZ-126 was used as input for permeability analysis and it was imported into the Bortex module and computed reservoir heterogeneity from FMI used to extract heterogeneities and layer details from images. In addition to formation heterogeneities, the software also calculated index permeability of the reservoir. Fracture properties (open or closed), occurrence, orientation, spacing, and porosity were interpreted by using Image log and imported as indirect input for permeability analysis.
4. The OBMI structural dip data is imported into the Bortex software in the MN-322.OBMI tool was used to identify zones of higher permeability when combined with conventional induction logs and porosity logs. Separation between Rxo curves (one from each of four OBMI pads) and induction logs, due to invasion of oil in the mud, indicated higher permeability.
5. The borehole cross sections are interpreted to give a very detailed account of the in-situ stress conditions by using UBI.

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