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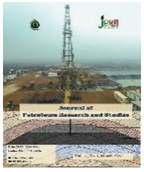

Importance of Dynamic Data in Detecting Reservoir Anomalies, A Case Study

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Abstract

The exploitation of oil reservoirs is a critical activity in the energy industry, contributing significantly to global energy needs. Accurate assessment of reservoir properties and fluid characteristics is vital for effective operations in oil and gas reservoirs. In order to reach this principle, static and dynamic data are integrated to provide a comprehensive understanding of reservoir behavior. However, it is possible for these data not to yield the same results; in which scenario selecting correct and accurate data is essential. This study tries to reveal the importance and essentiality of dynamic data. A case study alongside its numerous data is referenced to support the importance of data integration, demonstrating its effectiveness in improving reservoir understanding, fluid typing, and reservoir connectivity assessment. By analyzing the real case study, studying the results of static and dynamic data, and investigating their impact on the well's development path, the undeniable need for dynamic data and their priority is demonstrated. More importantly, this study presents a comprehensive diagnostic workflow for reconciling conflicts between static and dynamic data in highly heterogeneous reservoirs. The workflow consists of systematic data quality control, cross-validation of independent measurements, and extended fluid analysis (LFA) to resolve discrepancies. The novelty of this work lies in documenting the step-by-step approach for diagnosing and resolving data conflicts, rather than only reiterating the established principle of dynamic data priority.

Keywords: Static data, Dynamic data, Fluid typing, Fluid profiling, Fluid saturation, Well development plan, Core data, Well logging, Well testing.

أهمية البيانات الديناميكية في كشف الشذوذات المكمنية: دراسة حالة

الخلاصة:

يُعدّ استغلال مكامن النفط نشاطًا بالغ الأهمية في قطاع الطاقة، إذ يُسهم بشكل كبير في تلبية احتياجات الطاقة العالمية. ويُعدّ التقييم الدقيق لخصائص المكامن وخصائص السوائل أمرًا بالغ الأهمية لضمان فعالية العمليات في مكامن النفط والغاز. ولتحقيق هذا المبدأ، تُدمج البيانات الثابتة والديناميكية لتوفير فهم شامل لسلوك المكامن. ومع ذلك، من الممكن ألا تُعطي هذه البيانات النتائج نفسها؛ وفي هذه الحالة، يُعدّ اختيار بيانات صحيحة ودقيقة أمرًا بالغ الأهمية. تسعى هذه الدراسة إلى إبراز أهمية البيانات الديناميكية وضرورتها. وقد تم الاستناد إلى دراسة حالة، إلى جانب بياناتها العديدة، لدعم أهمية تكامل البيانات، مُبيّنةً فعاليتها في تحسين فهم المكامن، وتحديد أنواع السوائل، وتقييم مدى ترابط المكامن. من خلال تحليل دراسة الحالة الواقعية، ودراسة نتائج البيانات الثابتة والديناميكية، والتحقيق في تأثيرها على مسار تطوير البئر، تُظهر هذه الدراسة الحاجة المُلحّة للبيانات الديناميكية وأولويتها. تُقدّم هذه الورقة منهجيةً لمقارنة الاختلافات بين البيانات الثابتة والديناميكية والتوفيق بينها، مُقترحةً حلاً لإعطاء الأولوية للبيانات الديناميكية في حال وجود أي اختلافات. وعلاوة على ذلك، فإنه يظهر أن الاعتماد فقط على البيانات الثابتة يمكن أن يؤدي إلى سوء تفسير خصائص الخزان، وقد يترتب على ذلك آثار سلبية في دورة حياة البئر والحقل.

1. Introduction

Exploitation of oil resources is one of the most critical activities in the energy industry, that contributes to the global energy needs [1; 2]. This activity encompasses the extraction, separation, transportation, processing, and distribution of hydrocarbon fluids from oil and gas reservoirs [3; 4]. To execute these operations effectively, it is essential to accurately identify and evaluate the reservoir rock properties and fluid characteristics [5]. This is accomplished through the utilization of static and dynamic data obtained from various methods such as core analysis, well logging, and pressure testing [6]. The importance of exploitation and determination of the quality, quantity, and type of stored fluids in oil and gas reservoirs can be examined from several perspectives:

Economic Perspective: From an economic standpoint, assessing the characteristics of hydrocarbon reserves in oil and gas reservoirs holds a pivotal role in determining the economic value of these resources [7; 8]. Additionally, optimizing extraction and fluid separation processes leads to cost reductions and increased revenue.

Technical Perspective: Evaluating the production and characterization of fluids within oil and gas reservoirs actively contributes to the development and execution of suitable approaches for the production, transportation, processing, and distribution of hydrocarbon fluids [9; 10]. Additionally, by identifying fluid properties, risk is minimized in reservoir assessment.

Static and Dynamic Data Analysis: Reservoir evaluation through static data is a method that determines the properties of the reservoir formation, by using information obtained from core data, well logging, and geophysical interpretation [11]. The static data used in this paper include petrophysical logs, petrophysical-full set logs, image logs, and cement evaluation logs [12]. Table (1) classifies the calculated parameters from each log. Dynamic data, including wireline formation testers (WFT) data, well test data, and production logs; where their resulting parameters are listed in Table (2).

Table (1): Calculated parameters from static data

Log Type	Log Name	Parameters Calculated
Petrophysical	DSI	Dipole shear sonic imager, Shear wave velocity, Compressional wave velocity, Shear wave anisotropy, Stress orientation, Permeability [13]
	CMR (NMR)	Pore size distribution, Bound fluid, Free fluid, Permeability [14]
Petrophysical-full set	Resistivity	Formation resistivity, Water saturation, Hydrocarbon saturation, Resistivity index, Cementation factor [15]
	Neutron	Hydrogen index, Porosity, Fluid type, Lithology [16]
	Gamma ray	Natural radioactivity, Shale content, Clay content, Lithology [17]
	Density	Bulk density, Electron density, Porosity, Lithology, Photoelectric absorption cross section [18]
	Sonic	Travel time, Acoustic impedance, Porosity, Lithology, and Seismic correlation [19]
Image log	FMI	Formation micro-imager, Borehole image, Fracture identification, Dip analysis, Bedding orientation [20]
Cement evaluation	CBL-VDL	Cement bond log, Variable density log, Cement quality, Casing integrity, Acoustic amplitude [21]

Table (2): Calculated parameters from dynamic data

Log Type	Log Name	Parameters Calculated
Pressure testing data	Well test	Permeability, Skin, Reservoir pressure [22]
	MDT	Mobility, Permeability, Formation pressure, Fluid gradient [23]
	MDT coupled with LFA	Fluid type, Fluid saturation [24]
Production logs	PLT	Fluid type, Production rate [25]

Static and dynamic data are used together to provide an accurate simulation of reservoir properties and the fluid within. This simulation serves as the foundation for the reservoir's future and well operations. Many researchers have emphasized the significance of integrating these data. Elshahawi et al. [26] presents a case study exploring the compositional gradient of fluids in a reservoir and improves understanding of reservoir architecture by combining continuous fluid typing, wireline formation testers, and geochemical measurements. Simulations of Anderson et al. [27] showed gas production rates increasing over time, with unique features analyzed from MDT results. The dynamic data obtained from the MDT provides crucial insights into the changing reservoir conditions during fluid flow, aiding in understanding the behavior of the formation over time. By incorporating dynamic data into the design process, engineers can make more informed decisions regarding well and fluid flow dynamics, leading to a more effective and optimized master development plan (MDP) for reservoir development and production. Tsiklakov et al. [28] highlighted the challenges and methods for assessing reservoir connectivity using fluid composition, including the use of wireline formation testers. Aguilera et al. [29] discussed the success of production estimation in a high-profile deep-water well using dynamic formation testers. They outlined a methodology, which involves identifying zones of interest with the help of petrophysical and geological logs, and the use of open hole formation testers for fluid characterization and reservoir productivity estimation. Ramaswami et al. [30] affirmed the importance of integrating advanced petrophysical logs and formation testing in a Middle East case study to describe fluid distribution within a complex carbonate reservoir. The main challenge was the heterogeneity of formation properties, particularly permeability. Formation testing plays a crucial role in identifying the flowing phase. The paper emphasized that integrating various technologies in real-time guidance was essential for conclusive results. Ma et al. [31] offered a methodology for reservoir characterization, geological modeling, and well performance prediction. The methodology integrates various data sources, including cores, open hole logs, WFT pretests, and vertical interference tests (VIT). The study demonstrates the effectiveness of VIT in characterizing reservoir heterogeneity. Noah [32] utilized dynamic data from tools like the Repeat Formation Tester (RFT), which is crucial for verifying reservoir pressure estimates, determining pressure gradients, and identifying fluid characteristics such as oil and water gradients in the Kareem Formation at Amal Field, Gulf of Suez, Egypt. This real-time data allows for accurate localization of oil-water contact depths and provides valuable insights into reservoir behavior, essential for designing a successful MDP. Without dynamic data from tools like RFT, the planning process may lack critical information needed for optimal reservoir management and production strategies. Blinov et al. [33] determined fluid contact, fluid typing, and deliverability estimation in North Caspian appraisal wells, and presents the comparison between WFT and Drillstem Tester (DST) technologies to reveal their effectiveness in reservoir evaluation and fluid sampling. WFT is suitable for high mobility formations, while DST is more versatile for various reservoir types. WFT provides valuable data for determining reservoir connectivity and compartmentalization, especially in shale sands. It helps in clarifying gas/oil contact determination, which can be challenging in the presence of clay. On the other hand, DST offers insights into permeability and fluid characteristics, such as salinity and hydrocarbon detection.

Both technologies contribute to obtaining high-quality samples and accurate reservoir analysis. Vij et al. [34] combined Logging-While-Drilling (LWD) and NMR with other measurements like elemental capture spectroscopy (ECS), density, neutron, and resistivity to enhance insights into reservoir fluids and lithology. The technique was successfully applied in Angola, addressing challenges in identifying gas, oil, and condensate layers. The paper presents an easy-to-use fluid identification cross-plot. Wu et al. [35] focused on reservoir connectivity in a super-deep-water carbonate oil field in Brazil characterized by thick dissolved pore reservoirs and strong heterogeneity. Multiple oil-water contacts have been drilled by exploration wells, emphasizing the significance of the reservoir model and connectivity for development planning. Due to the complex reservoir and fluid distribution in the area, the study proposes a method that combines dynamic and static information for connectivity analysis. Belhouchet et al. [36] presented a method that involves using MDT to analyze pressure gradients and fluid characteristics in reservoirs. The results include the identification of reservoir compartments, determination of initial conditions, and setting the Free Water Level (F.W.L.) for each zone. This analysis was conducted in an oilfield located in the Saharan platform in Algeria to study reservoir heterogeneity and fluid behavior that helps field development plan.

However, it is essential to keep in mind that static and dynamic data may not always align in predicting certain reservoir properties. Erroneous identification of the type and amount of fluid in-place causes significant economic consequences for field development. The contribution of this study is not merely to restate the known importance of dynamic data, but to provide a structured workflow that demonstrates how conflicting datasets were systematically evaluated and resolved in a real case. By explicitly documenting the steps of data QC, cross-validation, and the use of extended dynamic tests such as long-duration LFA, this work offers a practical diagnostic framework for reservoir engineers dealing with similar heterogeneities (Fig. **(1**).

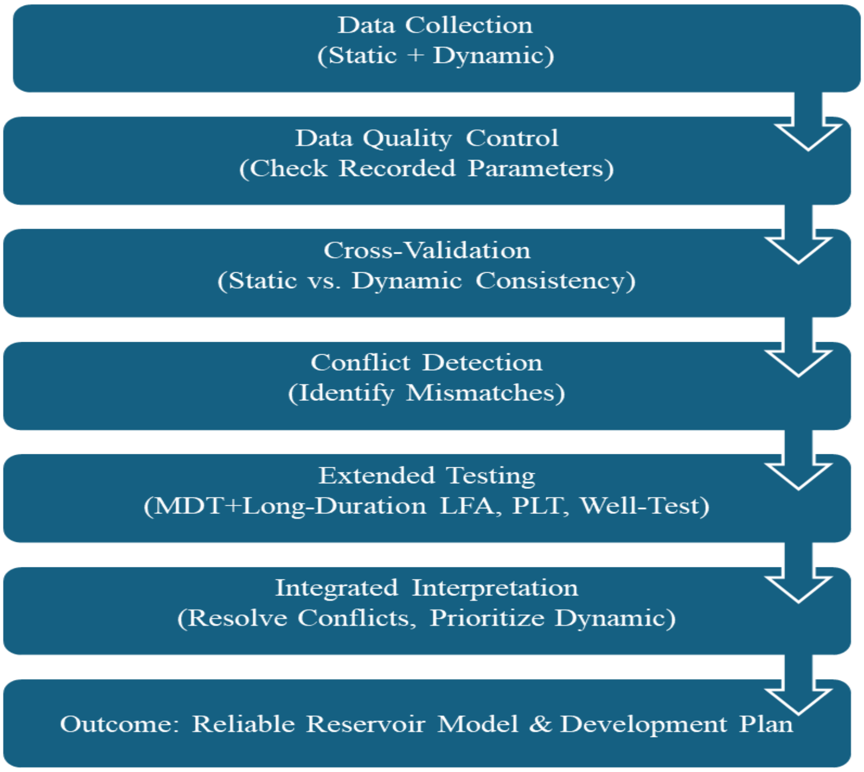

Fig. (1): Proposed Diagnostic Workflow for Reconciling Static and Dynamic Data

2. Result and Reservoir Background

Well A is located in one of the Iranian gas fields and is drilled into layer I and layer II. Fullset data shows that layer I consists of mainly limestone and dolomite with a low amount of anhydrite in some parts, and layer II is mostly limestone and dolomite (Fig. **(2**). The well is completed using a 7-inch liner in both layers. The typical properties of both layers are shown in Table (3**)**.

Table (3): Layers properties

	Layer I	**Layer II**
Top (m)	5104	5223
Thickness (m)	119	50
Average porosity (%)	5.2	5.4
Initial pressure (psi)	5028.0	4799.9

Both static and dynamic data have been recorded in each layer, including Fullset logs (a standard suite of petrophysical logs such as gamma ray, resistivity, density, neutron porosity, and sonic), DSI, CMR, and FMI logs for static surveys, and Well-Test, PLT, and MDT coupled with LFA for dynamic surveys.

Although core samples were taken from all layers of Well A, gas saturation measurements were not performed at that stage in order to reduce operational costs. Instead, reliance was placed on static log interpretations and analog well data. As discussed later, this early decision contributed to subsequent uncertainties and the need for extensive dynamic testing.

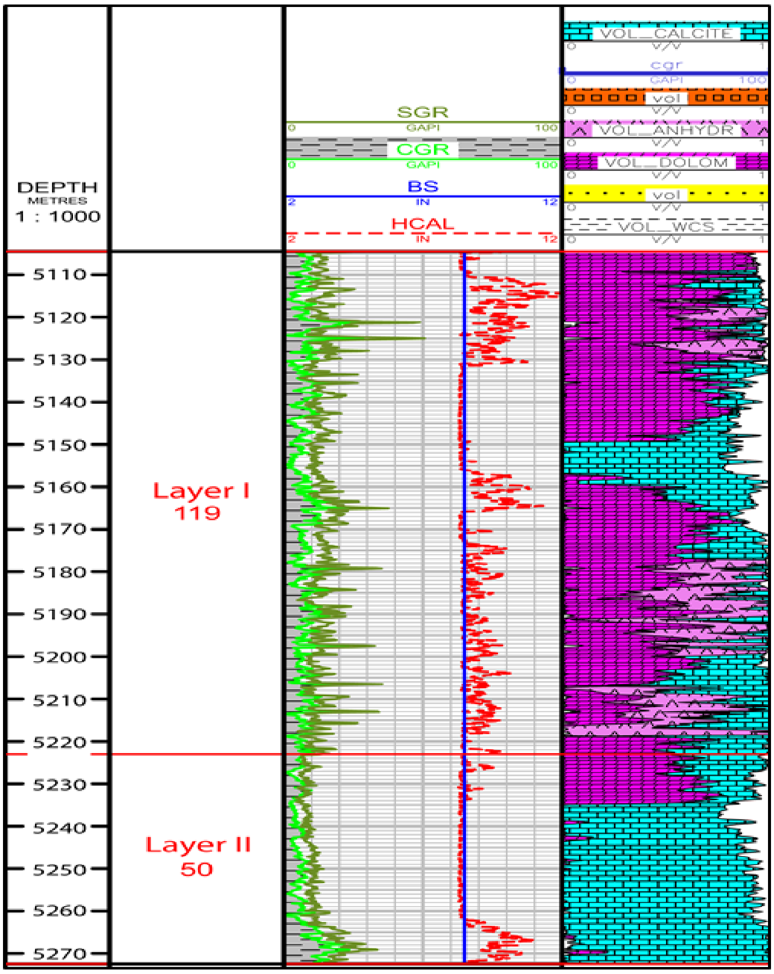

Fig. (2): Layer I and Layer II Lithology

2.1. Data Evaluation

First, the quality of all data should be evaluated to ensure that they are recorded correctly and can be relied on. For this purpose, the CBL/VDL log is used to check well integrity in the logging interval. As Fig. (**3**) shows, well A has good integrity, and the cementing job has been able to completely isolate layer I from layer II, and layer II from layer III. On top of that, according to FMI logs, there is no evidence of fracturing between layer I and layer II, nor between layer II and layer III. Additionally, the dip angle changes notably across these layers: in layer I, the dip increases from 50° to 65-70°, while in layer II, it decreases from 70° to approximately 55°, Fig. (**4**). As a result, channeling behind casing and crossflow are prevented, and the data recorded in each layer is specific to itself and is not affected by adjacent layers, making them reliable.

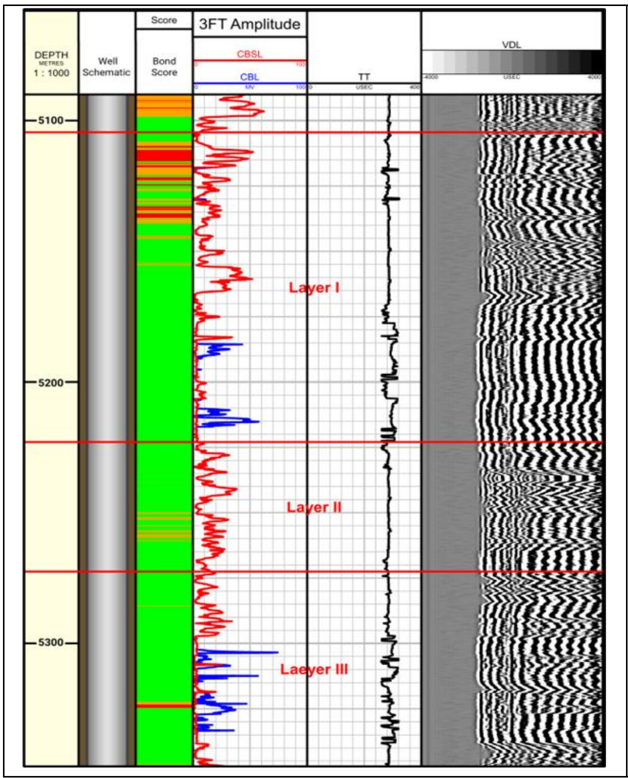

Fig. (3): CBL/VDL log for well A in layers I, II, and III

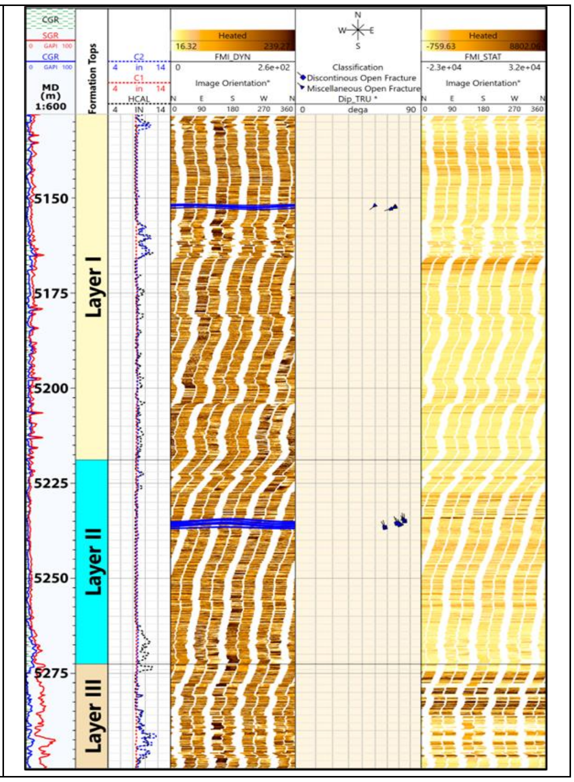

Fig. (4): FMI log for layers I, II, and III

By analyzing FMI log and PLT logs together, miscellaneous and open fractures in layer I and layer II and discontinuous and open fractures in layer II do not participate in fluid production, Fig. (**5**) and Fig. (**6**); in addition, most of them have minor discontinuous traces on the image. Consequently, fracture analysis has not been evaluated in this dataset, and FMI logs will not be used any further.

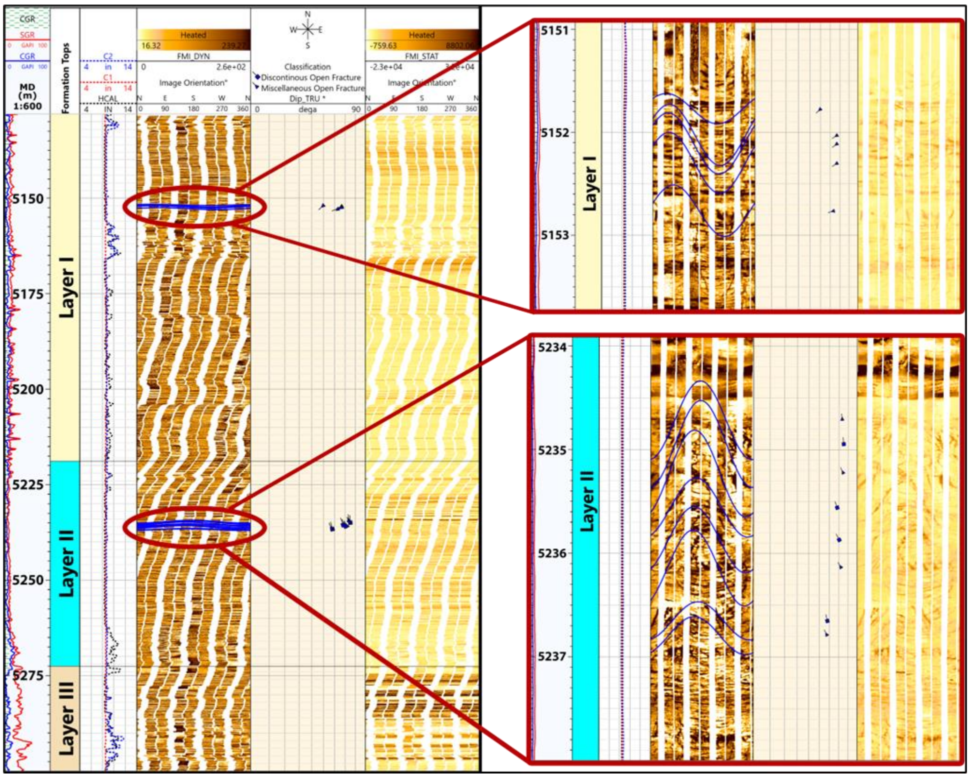

Fig. (5): Miscellaneous and discontinuous fractures in layers I and II

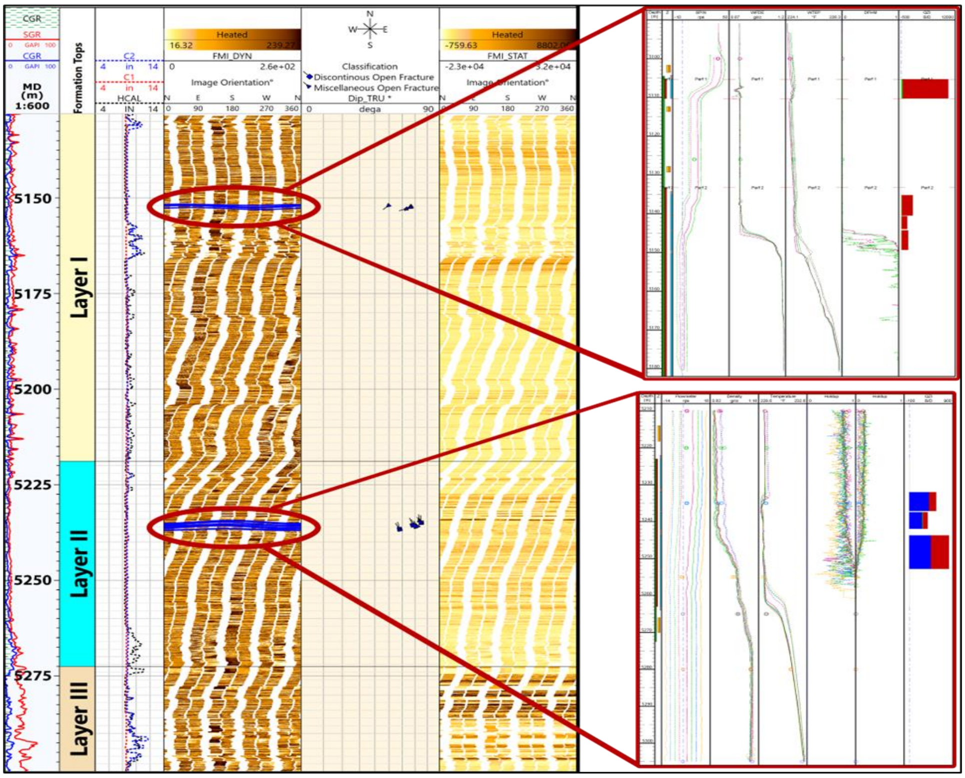

Fig. (6): Open fractures not participating in fluid production

Secondly, in the case of recording the data correctly, where tools are correlated precisely and recorded data has good quality, static and dynamic data will validate each other by representing almost the same properties for conventional reservoirs and wells. To check this, the recorded data in layer I has been used.

Based on Fullset data, layer I is mostly saturated by gas, Fig. **(7)**, which is confirmed by Well-test, PLT, fluid gradient by MDT, and LFA data showing gas production through perforations, Fig. (**8**). Moreover, Fig. (**9**) illustrates that the permeability obtained by Fullset and DSI are consistent with the permeability calculated from MDT, validating each other.

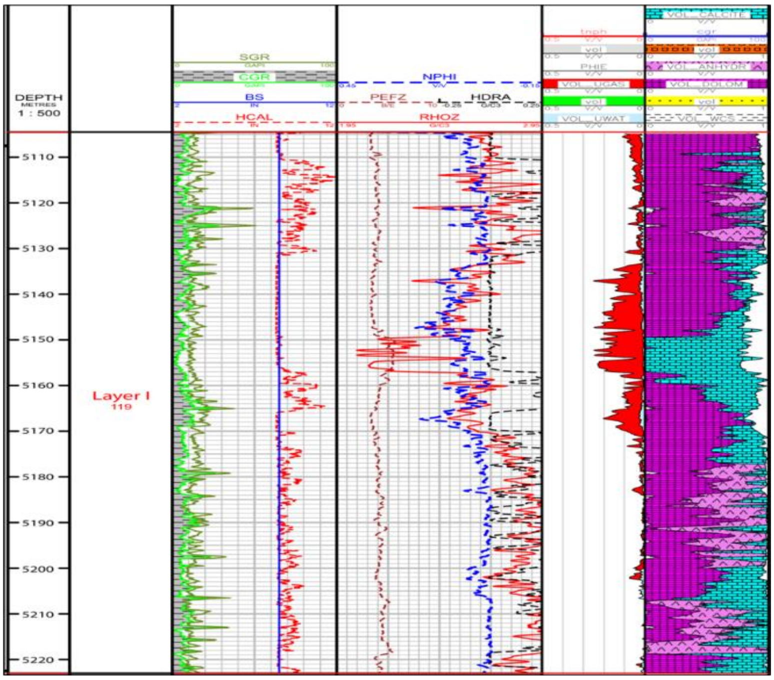

Fig. (7): Fullset Log for Layer I

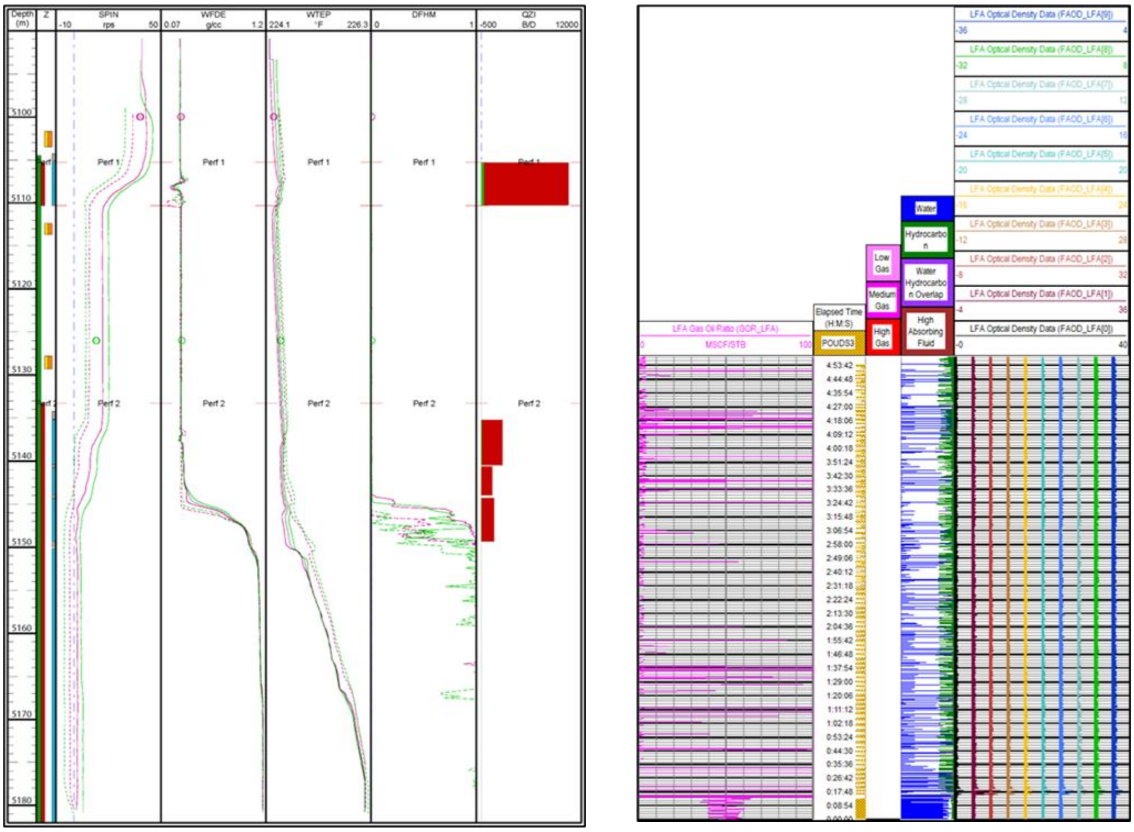

Fig. (8): PLT log (left figure) and LFA log (right figure) for Layer I

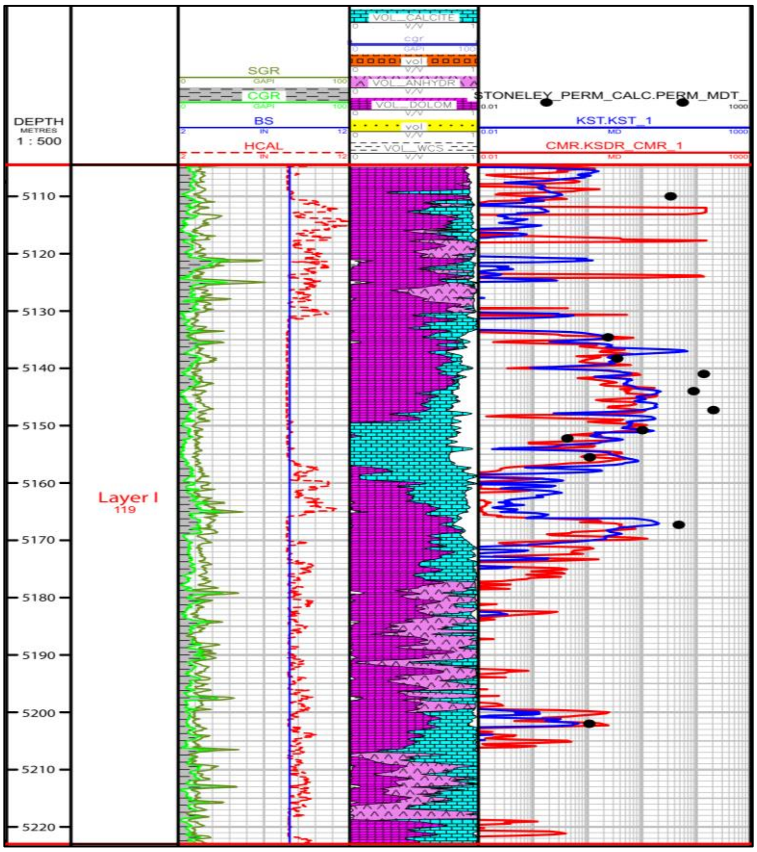

Fig. (9): Permeability overlap obtained from static and dynamic data

Unlike Fullset and DSI static data, saturation obtained from CMR data using MRF in layer I is very different from the saturation presented by other data; thus, CMR does not pass data evaluation and quality check. Hence, it is considered unreliable and will not be used any further. The reason behind this disparity could be the CMR tools' radius of investigation which usually records flushed zone data, which is severely affected by drilling fluid. The average gas saturation obtained by MRF along with other methods are shown in Table (4). Taking the above mentioned into account, static and dynamic data recorded in layer I, except CMR, are correct and reliable.

Table (4): Gas saturation obtained from every data

	Fullset	**PLT**	**Well-test**	**LFA**	**CMR**
Average saturations in Layer I	95% Gas 0% Condensate gas 5% Water	96% Gas 4% Condensate gas 0% Water	99% Gas 0% Condensate gas 1% Water	83% Gas 12% Condensate gas 5% Water	**36% Gas 0% Condensate gas 64% Water**

2.2. Main Challenge

Data interpretation becomes extremely complicated and difficult when entering layer II. As can be seen in Fig. (**10**), static data introduces layer II as a gas dominated layer with a very high gas saturation. Depending on static data results, layer II is capable of producing a massive amount of gas; hence, all the related operations and plans such as drilling, well completion profile, basic reservoir engineering studies, workover and stimulation, surface facilities design, prediction reservoir performance, and economical evaluation, which are incorporated in the master development plan (MDP), should be designed according to gas condition.

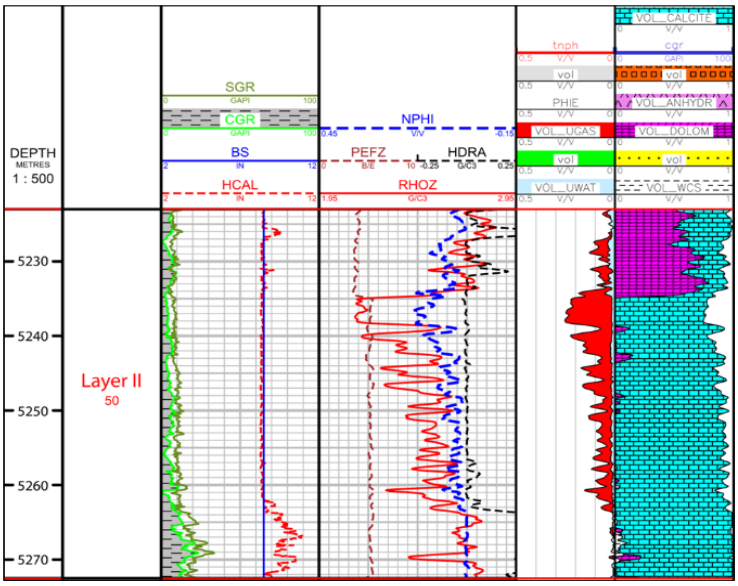

Fig. (10): Fullset saturation for Layer II

In spite of static data, dynamic data including PLT, MDT, and Well-test shows that a different type of fluid is occupying layer II. PLT indicates that layer II produces water twice as much as gas, as shown in

Table (5**)** and Fig. (**11**); as a matter of fact, the gas production amount in layer II is much lower than what is expected for a gas dominant layer. The well test claims that the water saturation in this layer is equal to 98%. In addition, the Live Fluid Analysis (LFA) module, the dynamic data recording reservoir fluid saturation with the most certainty, has been run in this layer for 13.5 hours with a pumped-out volume of more than 500 liters; resulting in 73% water saturation and 27% hydrocarbon saturation, Fig. (**12**).

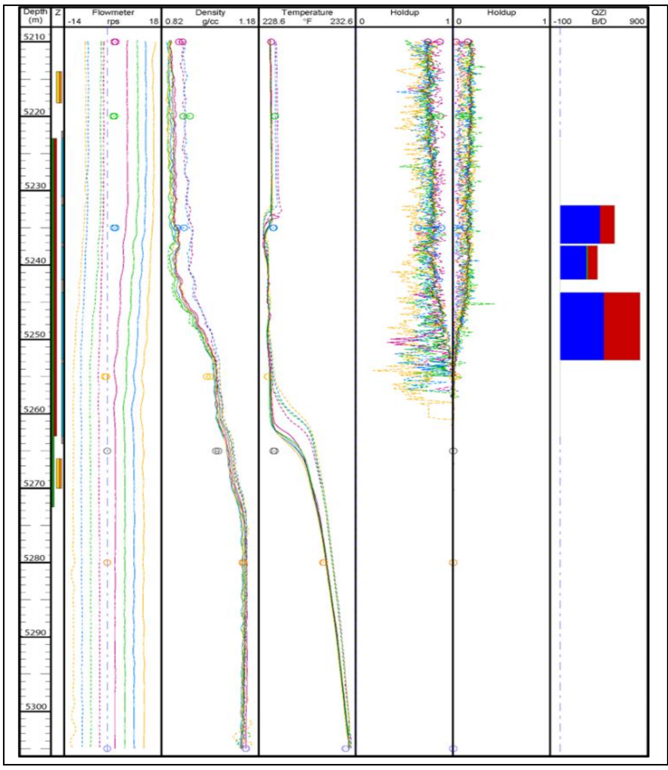

Fig. (11): PLT log for Layer II

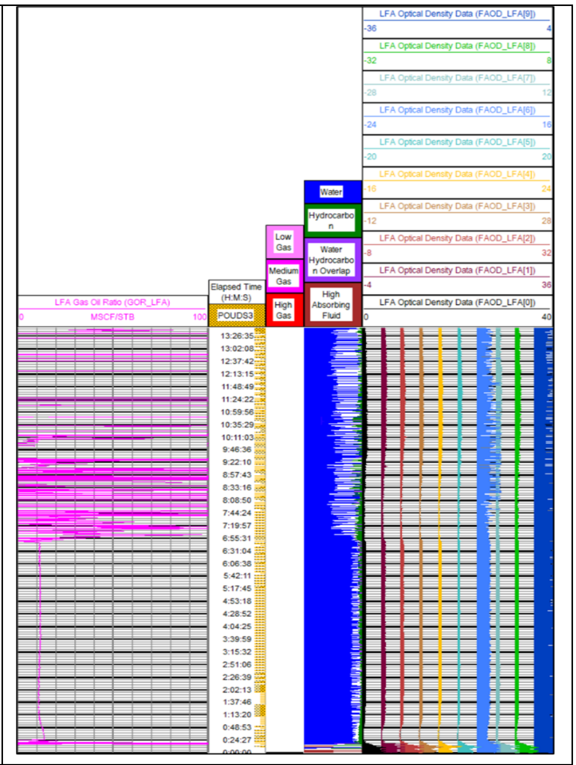

Fig. (12): LFA log for Layer II

Table (5): PLT fluid production contribution for Layer II

Total production rate	**1762 B/D**	**100%**
Water production rate	1130 B/D	**64%**
Gas production rate	620 B/D	**35%**
Condensate production rate	12 B/D	**1%**

Considering new results obtained from dynamic data, well completion with the aim of gas production would not be a good prediction; Because this layer is incapable producing of the expected or even economical amount of hydrocarbon. Not only drilling a well and its completion in this layer would cost massive expenses, but the produced fluid could damage the well and surface facilities. Thus, a new MDP should be designed for this well according to new conditions, or the well should be abandoned.

2. Speculation about the cause of this dispute

One simple reason that can mislead static data is the state of layer II in nearby wells, Fig. (**13**). Wells B, C, and D are drilled in the vicinity of well A and are perforated in layers I and II as well. According to static and dynamic data recorded from these wells, layer II is saturated with and producing only gas, Fig. (**14)**.

The disparity in fluid type occupying layer II between well A and wells B, C, and D can be related to this layer's depth at different parts of the field. Table (**6** describes the depth of layer II in the mentioned wells.

Table (6): Layer II depth in different wells

	Well A	Well B	Well C	Well D
Layer Top (m)	5225	5100	5134	5137
Layer Bottom (m)	5270	5142	5167	5185

Furthermore, layer II is extremely heterogeneous where the other reservoir properties like permeability differ so much from point to point that static and dynamic data do not agree on their value or their trend. Fig. (**15)** demonstrates this disagreement; As can be seen, neither permeability's value nor its trend is the same for static data and MDT.

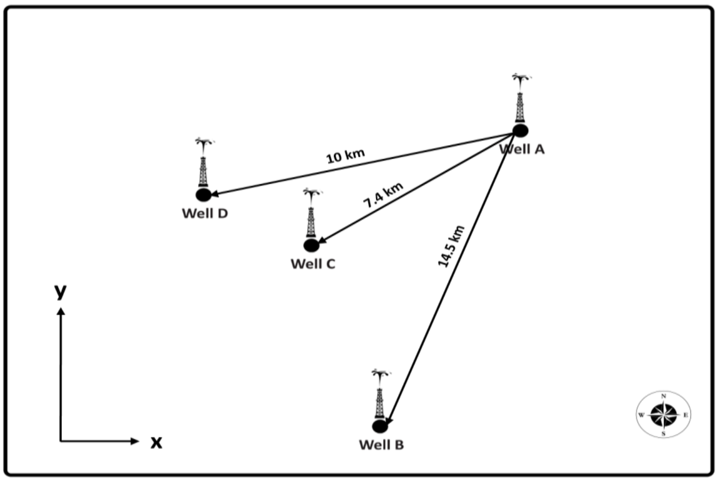

Fig. (13): Relative geographical location of wells A, B, C, and D

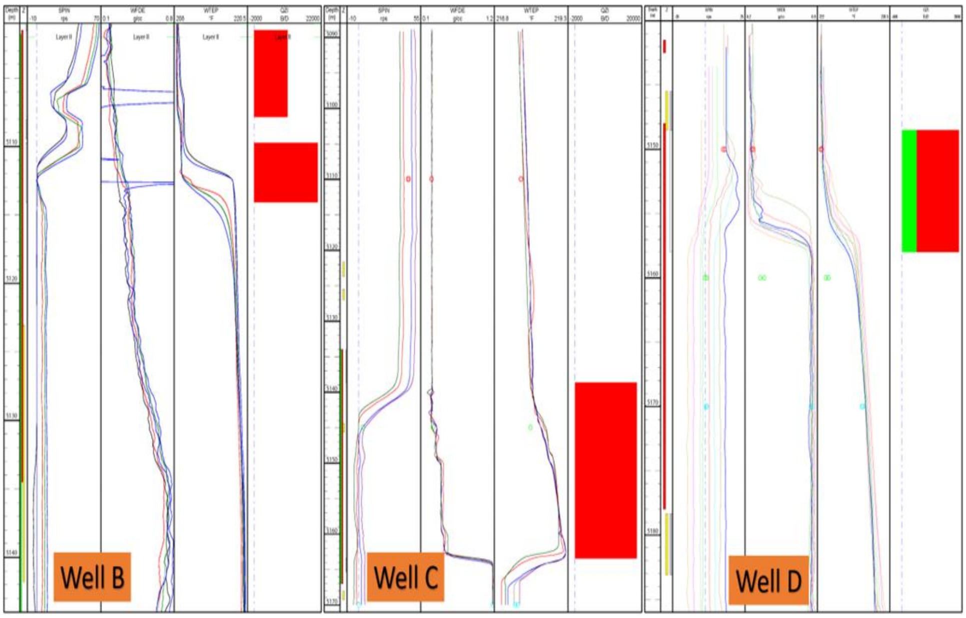

Fig. (14): PLT log of layer II in Wells B, C, and D

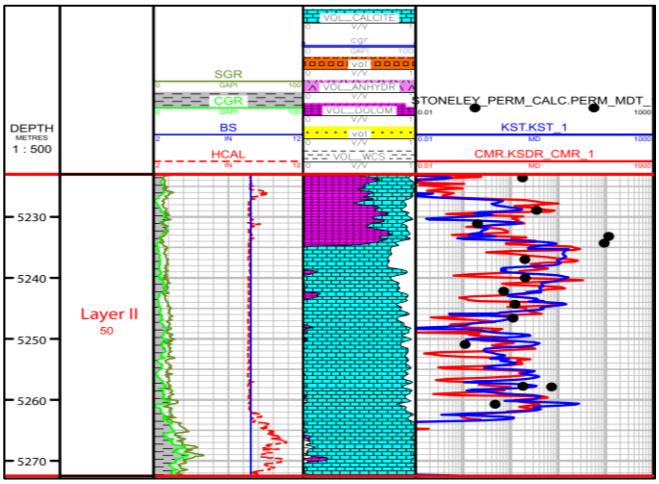

Fig. (15): Fullset and MDT permeability for Layer II in well A

The heterogeneity is so great that MDT was not able to find any fluid gradient for this layer (for clarity, MDT successfully found a fluid gradient for layer I and other layers in this field). Fig. (**16)** illustrates MDT points for layer I and layer II; Notice the gas gradient in layer I while there can be find no fluid gradient in layer II.

As mentioned in part 1, in order to overcome the uncertainty about layer II fluid, LFA has run for 13.5 hours long (much longer than typical LFA for this field) which produced 500 liters of fluid from this layer (much more than typical LFA volume for this field). LFA was allowed to run in this magnitude so that the LFA suction radius passes invaded zone, which is affected by mud filtrate, and there was no contamination in the sucked fluid mixture, so there would be zero doubts about the reservoir fluid analyzed by LFA.

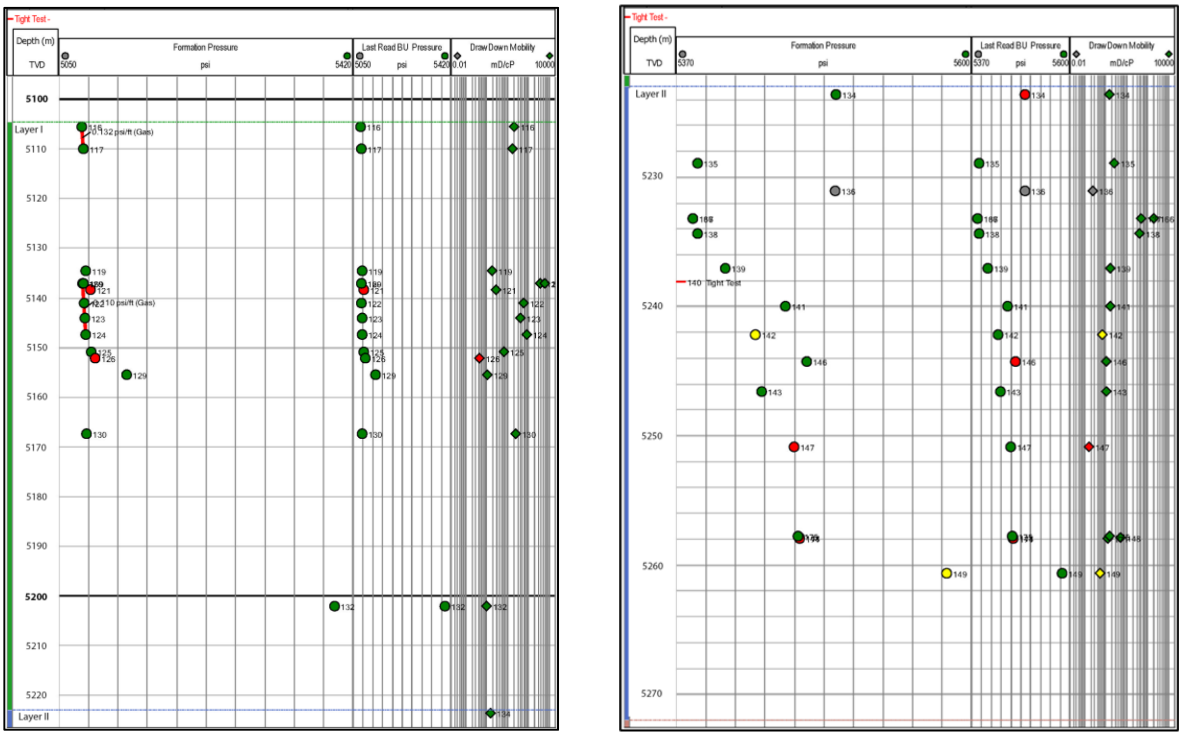

Fig. (16): MDT points for Layer I (Left figure) and Layer II (Right figure)

3. Discussion

After drilling a well, before completing the well and beginning the production, a master development plan (MDP) is designed and optimized based on laboratory and collected data from wells. Normally, the static and dynamic data collected from a well match and validate each other, which makes designing an optimum MDP a convenient task. However, in some cases such as those discussed well, where the results of static and dynamic data are contradictory, selecting incorrect data will be massively costly. Proceeding with a gas completion based solely on static interpretation would not only have resulted in an uneconomic well incapable of producing commercial gas rates, but it would also have required a costly workover to isolate the water-producing interval. Furthermore, designing surface facilities for gas, only to produce large volumes of water, represents a significant misallocation of capital and could cause serious operational challenges. Every parameter concerning field development, including completion type, surface facilities, wellhead pressure, and even plateau forecasts would be negatively affected by such a misinterpretation.

Core sampling have been performed in the all layers of Well A; nevertheless, gas saturation analyzing had not been carried out because they relied on acquired static data from this well and adjacent wells in order to optimize operational costs. Unfortunately, it was discovered that layer ll was mainly saturated with water later by MDT-LFA, PLT, and DST results, but by then, it was too late for gas saturation analysis from obtained cores.

Static data are indirect measurements of reservoir properties which are influenced by many parameters. Additionally, some static data recording tools have very shallow investigation radius, hence they are not able to represent reservoir properties accurately. On the contrary, dynamic data are recorded by allowing reservoir fluid to flow and record the reservoir response directly. When there is a difference between the recorded data, dynamic data should be prioritized and used as the basis of well development plan.

4. Conclusions

1- FMI Tools have a shallow radius of investigation due to their high resolution. Fractures seen by them may not be involved in fluid flow; therefore, their participation should be analyzed by PLT.

2- CMR data has high uncertainty due to its shallow radius of investigation and should be checked and validated with other data first.

3- The results obtained from static data may differ from dynamic data, in which case relying on incorrect data may lead to extensive costs. Core analysis, drilling, well completion, tubing type, surface facilities, and any other production parameter depend on the recorded data; Thus, leaning on a set of data that does not represent reservoir rock and fluid properties accurately will have a severe impact on the well development plan.

4- In case of disagreement between the results of static and dynamic data, priority should be on dynamic data results and any future planning concerning well development should be based on them. Dynamic data recording tools have a deep radius of investigation and are in direct contact with reservoir rock and fluid; therefore, they can simulate the reservoir with higher certainty and provide reliable information about the reservoir and fluid trapped inside pores.

5- Due to the unreliability of static data results when they differ from dynamic data results, it is essential to perform dynamic tests and record their data to ensure the future of the well and prevent financial and operational damages.

Author Contributions Statement: Keyvan Miladi contributed to the Conception, Methodology, Investigation/ Experiments; Data Analysis and Interpretation; Writing Original Draft, Writing – Review & Editing. Javad Mahdavi Kalatehno contributed to the Methodology; Data Curation and Analysis, Writing Original Draft, Writing – Review &

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