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REAL-TIME DETERMINATION OF FLUID CONTACTS DURING HORIZONTAL WELL DRILLING USING MUD GAS LOGGING

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ABSTRACT

The article analyzes real-time detection of gas-oil (GOC) and oil-water (OWC) contacts during horizontal drilling in clastic reservoirs. Timely localization ensures high-quality geosteering, keeping the wellbore within the pay zone and preventing undesirable fluid intersections. Relying solely on conventional logging-while-drilling (LWD) is often insufficient. Limitations arise from electrical macroanisotropy distorting resistivity data, the clay electrical double layer masking responses, and tool «blind zones» causing delayed observations, which poses a critical risk in horizontal drilling. To address this, advanced mud gas logging is proposed. Instead of indirect electrophysical features, this method captures actual reservoir fluid dynamics. By using chromatographic analysis of C_1–C_5 fractions and calculating Wetness, Balance, and Pixler ratios, characteristic fluid signatures and transition zones are identified. Crucially, reliable interpretation requires mathematical normalization of gas data. Without it, operational artifacts from rate of penetration (ROP) and mud flow rate fluctuations create false anomalies or obscure actual boundaries. An Eastern Siberian field case study demonstrates that normalized mud gas logging achieved real-time GOC localization with sub-meter accuracy in a low-contrast reservoir. Validated by pulsed neutron logging (PNL), this method proves to be an effective geosteering and risk management tool.

Keywords: mud gas logging; horizontal wells; gas-oil contact (GOC); oil-water contact (OWC); geosteering; mud logging; gas chromatography; gas data normalization.

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Introduction

Traditionally, determining the depth of the gas-oil (GOC) and oil-water (OWC) contacts is considered a static problem, solved during the exploration phase to calculate initial hydrocarbon reserves. However, in reality, during the active development of oil and gas pools in clastic reservoirs, the position of fluid contacts is not stationary. Due to the withdrawal of reservoir fluids, a continuous redistribution of reservoir pressure occurs. A pressure drop below the bubble-point pressure leads to the liberation of dissolved gas and the volumetric expansion of the primary gas cap, which causes the downward movement of the GOC [1]. Simultaneously, driven by an elastic water-drive regime or a reservoir pressure maintenance system, the advancement of bottom, edge, and injected waters occurs, resulting in the continuous and unstable upward movement of the OWC [2]. Consequently, the real-time determination of the current contact positions during the drilling of new production wells or sidetracking becomes a critical operational task.

Errors in localizing the current positions of the GOC and OWC carry direct risks for the well design and the field development economics. From an engineering perspective, the gas cap must be reliably isolated by an intermediate or production casing, followed by high-quality cementing of the annulus. If a well penetrates the reservoir without precise localization of the lowered GOC, there is a high risk of perforating the transition zone. The high mobility of gas compared to oil leads to its rapid breakthrough into the wellbore. In porous clastic media, this causes a sharp decrease in the relative permeability of the rock to liquid hydrocarbons (the «gas blocking» effect), a decline in oil production rates, and the inefficient depletion of natural reservoir energy [3].

Similarly, accurate OWC localization is critically necessary to calculate a safe distance from the producing wellbore to the aquifer. Incorrectly placing the wellbore too close to the current OWC inevitably triggers water coning in vertical wells or water cresting in horizontal wells.

For clarity, let us consider the initial conditions when the phase velocities are zero, the reservoir is in a state of static equilibrium, and pressure is a function solely of the vertical coordinate *h* (fig. 1).

The fact that a phase is immobile in a given region does not necessarily imply that the forces are in equilibrium; rather, these very forces act as precursors to fluctuations and instability during fluid movement within the contact zone or

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the transition zone during waterflooding. Considering the dependence of capillary pressure on connate water saturation, the water distribution above the OWC zone is dictated by a gradient corresponding to the oil density. Conversely, when water saturation reaches its maximum value and the relative permeability to oil becomes zero, the pressure gradient within the oil corresponds to the gradient determined by the water density. Evidently, within transition zones, even the static equilibrium assumed at zero phase velocity is disrupted by the gradient of forces generated by the fluid density difference.

Once movement initiates, the transition zone loses stability due to an abrupt change in phase behavior under the new thermobaric conditions. Because of this instability and irreversibility, the process parameters change in an unbounded growth regime over a short time, akin to a blow-up regime. As a prototype for the mechanism of an abrupt change in water saturation, one can cite the discontinuous saturation shifts that occur during oil displacement by water, gas breakthrough into producing wells, or changes in fluid density in a supercritical state. This situation is further exacerbated because, during field development, the waterflooding system triggers instability of the displacement front within the transition zone of multiphase flow due to capillary, viscous, inertial, and other forces [4, 5].

Consequently, forecasting the exact timing of water or gas breakthrough into producing wells becomes a complex dynamic problem that cannot be resolved solely within the framework of the Buckley-Leverett theory combined with geological and hydrodynamic modeling. Attempts to solve such predictive tasks have been presented in studies [6–9] using discriminant criteria of growth models.

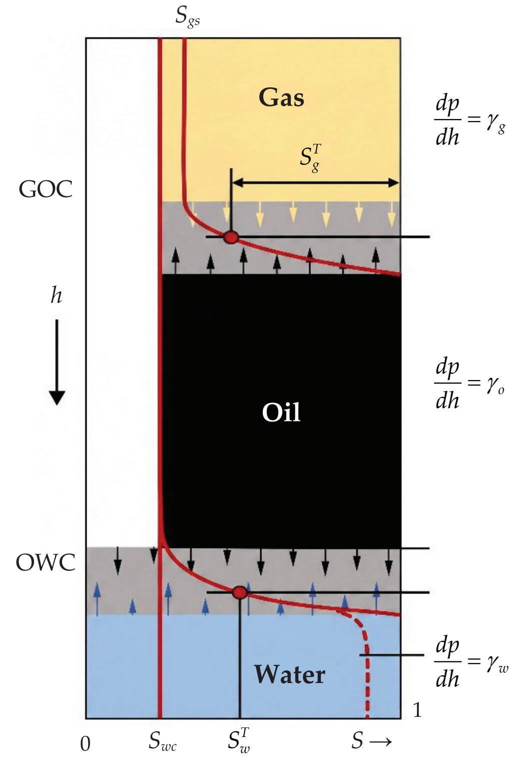
Therefore, premature breakthrough of reservoir fluids (gas or water) into producing wells leads to an exponential increase in water cut, a manifold rise in the costs associated with artificial lift and separation, and the necessity of early, though not always effective, water shut-off (WSO) operations [10, 11].

Specifics of determining GOC and OWC in horizontal wells

The problem of accurately delineating contacts becomes exponentially more complex when drilling horizontal wells (HW). Unlike vertical wellbores, where the intersection of gas-oil or oil-water contacts occurs orthogonally and appears as a distinct boundary on logging curves, the trajectory of a horizontal wellbore runs subparallel to the bedding. Under conditions of complex lateral heterogeneity in clastic deposits, the wellbore can remain within the capillary transition zone for hundreds of meters. In such intervals, there is no distinct free-water or free-gas level; instead, the fluid saturation changes gradually, forming a gradient (smeared) pattern of fluid distribution [12, 13].

The conventional suite of wireline logging and logging-while-drilling (LWD) exhibits critically high error margins under these conditions. This problem can be divided into three main groups of limitations: petrophysical, physical-mathematical (electromagnetic), and technological.

First, clastic reservoirs are often characterized by a high content of clay minerals, which possess a high cation exchange capacity (CEC) and form an electrical double layer on their surface that retains bound water. This clay surface conductivity, along with the presence of electrically conductive mineral inclusions (pyrite, glauconite) or initially fresh formation waters, radically reduces the overall bulk resistivity of the rock. As a result, the electrical resistivity of the oil-saturated section of the reservoir may be practically indistinguishable from the background resistivity of the water-saturated interval [14].



γ_w, γ_o, γ_g – are the pressure gradients in the water, oil, and gas zones, respectively

S_w^T, S_g^T – are the water and gas saturations in the OWC and GOC transition zones, respectively

S_{ws}, S_{gs} – are the connate water and irreducible gas saturations

Fig. 1. State of static equilibrium under initial reservoir conditions

Second, in horizontal wellbores, the physics of field propagation for induction and electromagnetic LWD tools differs fundamentally from that in vertical wells. In thinly bedded clastic sections, the effect of electrical macroanisotropy occurs: the tool simultaneously reads the horizontal and vertical resistivities of the layers, leading to an overestimation or underestimation of the true formation resistivity. Furthermore, when crossing boundaries of beds with contrasting resistivities at low angles (which is typical for geosteering), artifacts form on the logging curves—so-called «polarization horns.» These are non-physical, sharp resistivity spikes at the interface between media, which an inexperienced interpreter might mistake for the appearance of a tight streak or a gas-oil contact [15].

Third, a major limitation of LWD tools is the «blind zone» (sensor offset). Gamma ray and resistivity sensors are physically located in the bottom-hole assembly (BHA) at a distance of 10 to 20 meters behind the bit. At an average rate of penetration (ROP) of 30 m/h, the interpretation of geophysical data lags 30–40 minutes behind the bit. If the wellbore unintentionally crosses the OWC or GOC, the drilling crew will only become aware of it after the bit has already drilled

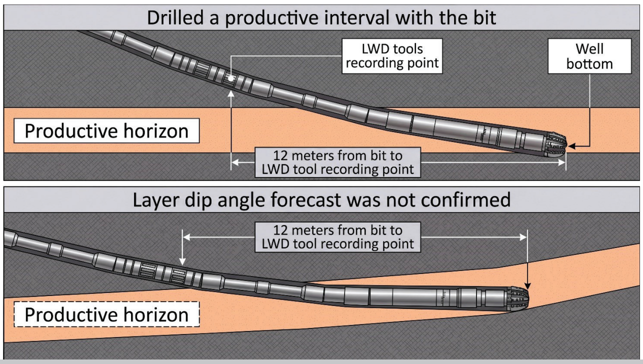


Fig. 2. Example of exiting the pay zone during reservoir penetration

15 meters into the water-bearing or gas-bearing formation, making real-time trajectory correction impossible (fig. 2). Additionally, nuclear LWD methods (neutron and density logging), which are capable of distinguishing gas from liquid, have a very shallow depth of investigation (up to 20–30 cm) and are severely distorted by wellbore washouts and heavy drilling mud [16].

Theoretical foundations of mud gas logging

Mud gas logging has undergone a significant evolutionary path since its first commercial application in the late 1930s. In the early stages, the equipment was limited to catalytic combustion detectors, which recorded only the total combustible gas content. This allowed for the identification of pay zones but did not provide the capability to determine the fluid type.

A qualitative leap occurred in the 1960s and 1970s with the introduction of field gas chromatographs equipped with flame ionization detectors (FID) and thermocatalytic detectors (TCD). This enabled real-time separation of the hydrocarbon mixture into components ranging from methane (C_1) to pentane (C_5). It was during this period that the foundations of geochemical interpretation based on component composition were established (Pixler and Haworth methods) [17–19].

Starting in the 2000s, with the development of horizontal drilling technologies, «advanced mud gas logging» became the standard, incorporating constant volume/temperature gas traps, mass spectrometry, and mathematical gas normalization algorithms [20].

Mud gas logging while drilling is the only method that provides a direct, rather than indirect (as in the case of electrical logging), analysis of the formation fluid directly during wellbore penetration [21]. To reliably localize the gas-oil (GOC) and oil-water (OWC) contacts in horizontal wells, a clear understanding of the genesis of the gas reaching the surface is necessary. During drilling, the registered gas signal is formed from three main sources:

Drilled (liberated) gas: Fluid that is mechanically released from the rock's pore space when it is destroyed by the bit. The volume of this gas is strictly proportional to the rock porosity, fluid saturation, and the volume of the drilled rock. It is the drilled gas that serves as the true indicator of crossing the GOC and OWC.

Produced gas: Fluid entering the wellbore from the walls of the already drilled interval due to an underbalance.

Background (recycled) gas: Gas that remains in the drilling mud after incomplete surface degassing and has completed another circulation cycle.

Thus, the interpreter's main task is to isolate the specific signal of the drilled gas from the total flow. In turn, the complexity of interpreting mud gas logging data is driven by the processes that occur during gas transportation from the bottom hole to the surface. The solubility of hydrocarbon gases (C_1–C_5) critically depends on the type of drilling fluid used.

When using water-based muds (WBM), hydrocarbon gases exhibit extremely low solubility. They are transported primarily as microbubbles, which allows for the extraction of up to 80–90 % of the gas. However, oil-based muds (OBM) are increasingly being used in horizontal wells. In OBM, heavy hydrocarbons (C_3, C_4, C_5) possess almost complete mutual solubility with the mud's base oil. As the mud rises to the surface, gas breakout occurs; however, heavy fractions often remain in a dissolved state. This «masking» effect of heavy gases requires the introduction of correction factors [22].

Determining GOC and OWC using mud gas logging

Crossing the GOC is identified by a change in saturation character, based on the ratio of heavy to light hydrocarbons in the extracted gas mixture using the following indices:

Wetness ratio (Wh) method:

$$W_h=\frac{\left(C_{2abs}+C_{3abs}+C_{4abs}+C_{5abs}+iC_{4abs}+iC_{5abs}\right)}{C_{1abs}+\left(C_{2abs}+C_{3abs}+C_{4abs}+C_{5abs}+iC_{4abs}+iC_{5abs}\right)}\times$$
$$\times 100 \tag{1}$$

where W_h is the fluid index characterizing the proportion of heavy alkanes (wetness ratio); C_{iabs} is the absolute concentration of the *i*-th component in the extracted gas mixture.

In a dry gas cap, W_h<1%. In a gas-condensate zone, Whranges from 1 to 17.5 %. At the moment of crossing the GOC and entering the oil rim, the Whvalue abruptly exceeds 17.5%.

Balance ratio (B_h):

$$B_h=\frac{C_{1abs}+C_{2abs}}{C_{3abs}+C_{4abs}+C_{5abs}+iC_{4abs}+iC_{5abs}} \tag{2}$$

where B_h is the fluid index characterizing the quantitative ratio of light to heavy alkanes (balance ratio); C_{iabs} is the absolute concentration of the *i*-th component in the extracted gas mixture.

If $B_h>W_h$, the well is in a gas zone. The crossover of the B_h and W_h curves is a classic indicator of the GOC.

Character ratio (C_h);

$$C_h=\frac{C_{4abs}+C_{5abs}+iC_{4abs}+iC_{5abs}}{C_{3abs}} \tag{3}$$

where C_h is the fluid index characterizing the quantitative ratio of heavy alkanes (character ratio); C_{iabs} is the absolute concentration of the *i*-th component in the extracted gas mixture.

It allows distinguishing light oil from heavy oil [23].

Pixler Ratios (C_{1abs}/C_{iabs})

Pixler proposed using the following ratios: C_1/C_2, C_1/C_3, C_1/C_4, and C_1/C_5. When drilling in a gas cap, the C_1/C_2 ratio is extremely high (ranging from 15 to 65). A sharp drop in the C_1/C_2 ratio below 15 and the C_1/C_4 ratio below 50 unambiguously indicates a transition from the gas phase to the oil phase [24].

The determination of the current OWC is based on Henry's law. Heavy hydrocarbons (C_3, C_4, C_5) have zero solubility in saline formation water. Methane (C_1) has slight solubility in water [25].

The approach of a horizontal wellbore to a risen OWC is accompanied by gas anomalies:

1. A general decrease in the total gas level.
2. The «tail-cutting» effect: the complete disappearance of components from C_3 to C_5.
3. False fluid «dryness»: the W_h index drops to zero. Gas from the aquifer consists of 95-99 % methane, which can be mistakenly interpreted as re-entering the gas cap.

When directly analyzing mud gas logging data, it is necessary to consider that the absolute (measured) gas concentrations at the surface are not a direct function of the rock's fluid saturation. They are subject to a strong distorting influence from current drilling operational parameters.

The dynamics of the gas signal are determined by the ratio of the volume of rock destroyed to the volume of drilling fluid. Within this process, two key operational artifacts are typically identified, which can significantly distort data interpretation:

Concentration effect and the influence of Rate of Penetration (ROP): when the ROP increases, a larger volume of rock is destroyed per unit of time. Consequently, more drilled gas enters the same, essentially unchanged, volume of drilling mud, creating an apparent gas anomaly. In practical interpretation, such a spike often looks plausible and therefore can be mistakenly interpreted as the manifestation of a gas cap or an indicator of a highly porous reservoir.

Dilution effect: with an increase in mud pump output, i.e., drilling fluid flow rate, the same volume of drilled gas is distributed over a larger amount of mud. As a result, gas readings are artificially lowered, which is also reflected in source [26].

To eliminate these operational distortions and bring the chromatographic data to a single standard, a mathematical gas normalization procedure is applied. The most widely used in international practice is the empirical normalization equation (often called the Weaver equation), which normalizes the volume of extracted gas to a standardized volume of drilled rock [26]:

$$Gas_n = \frac{Gas_{raw} \times Q}{ROP \times D^2)} \times K \qquad (4)$$

where Gas_n is the normalized gas value (dimensionless or arbitrary unit); Gas_{raw} is the total measured gas concentration at the gas analyzer (%); Q is the total measured gas concentration at the gas analyzer (%); ROP is the rate of penetration (m/h); D is the bit diameter (mm), which determines the bottom-hole area; K is a scaling factor (used to bring the values to a convenient scale for interpretation).

Operating with the normalized gas (Gas_n) curve instead of «raw» data is a mandatory requirement when localizing fluid contacts in horizontal wellbores. Only the transition to normalized values guarantees that a sharp drop in gas readings when approaching the oil-water contact (OWC) is caused by a true phase substitution of hydrocarbons by formation water, rather than a mere drop in the drilling rate when passing through a tight interbed [26].

Field experience in determining the GOC using mud gas logging data

Figure 3 presents a field case study of real-time GOC identification during the drilling of a horizontal well in an Eastern Siberian field. The geological conditions of this asset are characterized by a low-contrast reservoir: the applied basic LWD suite, which included gamma ray, electromagnetic, and litho-density logs, did not allow for unambiguous identification of the current GOC position due to the absence of pronounced anomalies on the resistivity and density curves.

Running an advanced open-hole wireline logging suite was technologically impossible due to the high deviation angle and sub-horizontal profile of the well. Tool delivery on drill pipes was deemed economically unviable and also carried high risks of wellbore complications due to additional tripping operations. Under these conditions, mud gas logging was the only reliable tool for making decisions regarding geosteering and well design.

Real-time analysis of the chromatographic data allowed for a clear separation of the fluid zones:

1. Gas cap interval: At a depth of 2205 m (Measured Depth) (interpretation No. 1, fig. 3), the gas signal was characterized by an extremely high fraction of methane (C_1) with an almost complete absence of heavy hydrocarbons. The calculated Pixler ratios and low values of the Wetness ratio (W_h) unambiguously indicated the penetration of a purely gas-bearing zone.
2. Crossing the GOC and entering the oil zone: With further deepening, at the 2213 m mark (interpretation No. 2, fig. 3), a sharp inversion of the gas composition was recorded. Against the background of an overall increase in total gas readings, an abrupt increase in the concentration of heavy hydrocarbons (from propane C_3 to pentane C_5) occurred. The crossover of the calculated indices (W_h and B_h) made it possible to determine with high precision the moment of crossing the gas-oil contact and the bit entering the oil zone.

Subsequently, the GOC depth determined from the mud gas logging data was fully confirmed by the results of Pulsed Neutron Logging (PNL), conducted in the cased hole. Timely localization of the contact allowed the gas cap to be successfully isolated with an intermediate casing and high-quality cementing to be performed, eliminating the risk of premature gas breakthrough during well operation.

Limitations of classical mud gas logging interpretation methods and the transition to machine learning algorithms

The practice of applying the aforementioned mud gas logging interpretation methods in complex reservoirs – low-permeability clastic and carbonate formations, horizontal wells with extended laterals, and multilayer targets – has revealed a number of fundamental limitations that reduce the reliability of interpretation [27]:

1. Gas lag time – the interval between rock destruction by the bit and the registration of the corresponding gas signal on the surface – is a fundamental parameter for correlating gas anomalies to depth. In vertical wells with a constant drilling fluid flow rate, this parameter is relatively stable and can be calculated

using standard formulas. However, in horizontal and directional wells, the situation is fundamentally different. The transport velocity of cuttings and gas in the annulus is determined by a combination of interdependent factors: wellbore profile geometry, instantaneous mud flow rate, its rheological properties (plastic viscosity, yield point), drilling parameters, and hole cleaning efficiency. As a result, lag time ceases to be a constant value and acquires a dynamic nature, varying over a wide range even within a single bit run. This leads to a systematic depth shift of gas anomalies and a significant deterioration in the correlation of mud logging data with logging-while-drilling (LWD) and wireline logging results.

2. Polygenic nature of gas anomalies – A fundamental interpretation problem is the ambiguity of the origin of recorded gas anomalies. An increase in total gas readings can be caused by fundamentally different reasons unrelated to the penetration of a productive horizon [28]:

a) changes in the rate of penetration (ROP): as ROP increases, the volume of rock destroyed per unit of time grows, which mechanically increases gas influx into the mud regardless of formation saturation;
b) changes in the mud degassing regime: fluctuations in temperature, pressure, and flow rate affect the completeness of gas extraction from the mud by the gas trap;
c) changes in the hydraulic regime of the well: pressure surges/swabs during tripping, reaming, and circulating can cause gas desorption from the wellbore walls and cuttings;
d) gas influx from previously drilled intervals when hydrostatic balance is disturbed. Classical compositional methods lack formalized criteria for differentiating these sources, forcing the interpreter to rely on subjective judgments [29].

Additionally, the raw mud logging dataset is characterized by a high noise level and systematic artifacts. The most significant of these is the so-called «connection gas» – an anomalous increase in gas readings recorded after circulation

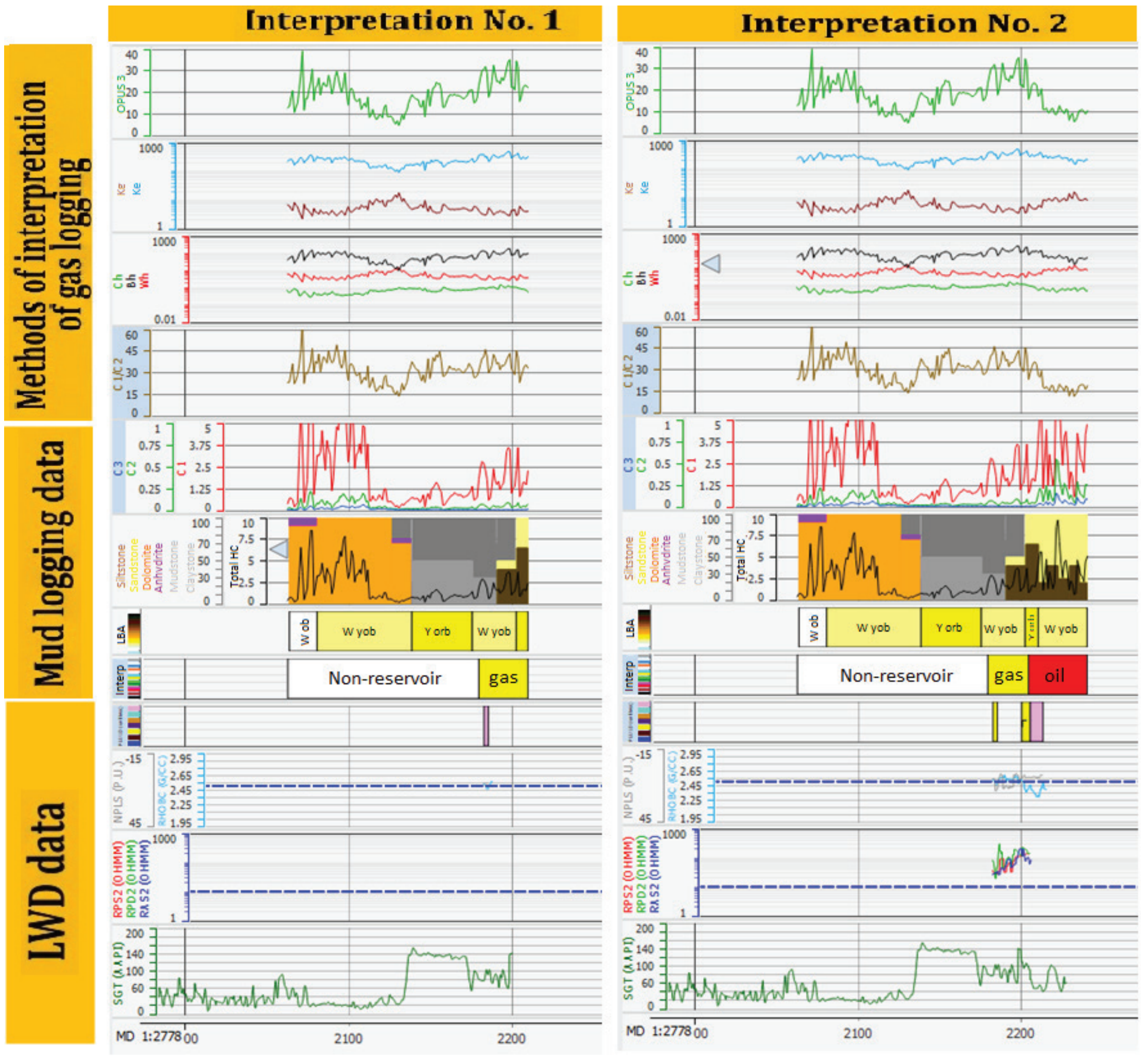


Fig. 3. Example of determining the GOC position using mud gas logging data

is restored following a technological break (drill string connection). During the circulation stop, gas entering from the formation accumulates in the annulus, and upon resuming circulation, it reaches the surface as a concentrated pulse, mimicking the penetration of a pay zone [30].

Furthermore, during circulation stops, gas recording is interrupted, creating gaps in the continuous time series of data. In manual interpretation, reconstructing missing values and distinguishing between drilling-induced and geological anomalies presents significant methodological complexity and is a source of systematic errors.

The application of oil-based muds (OBM) also creates a specific «background» signal that masks formation hydrocarbons. OBM components – diesel fuel, mineral oils, synthetic hydrocarbons – are recorded by the chromatograph alongside formation gas, which significantly distorts the compositional makeup and makes the application of standard ratio methods incorrect without special calibration.

Classical interpretation models calibrated using data from a specific field or an individual well pad typically lose significant accuracy when transferred to other assets. The reason lies not in a «model error» per se, but in the changing context: different formation fluid composition, varying mud types and formulations, different Bottom Hole Assembly (BHA) designs, varying geological structures of the section, while drilling parameters introduce additional shifts in the measured parameters. As a result, each new asset virtually forces a recalibration, which gradually diminishes the value of accumulated experience since it transfers poorly between sites.

The cumulative effect of these limitations leads to the necessity of a different methodological approach to mud logging data interpretation. Relying on traditional mathematical models, where relationships between a small number of variables are defined linearly or only weakly non-linearly, makes it difficult to expect an accurate description of the multi-factor, highly non-linear «formation – wellbore – drilling mud – surface equipment» system [31]. Such a system behaves not as a sum of independent influences, but rather as an interconnected environment in which a change in one element often reconstructs the entire picture.

Machine learning (ML) methods possess features that directly address the identified problems:

1. Ability to model non-linear multidimensional dependencies. Approaches based on gradient boosting, neural networks, and ensemble methods allow for the extraction of hidden patterns within a space of dozens of simultaneously recorded parameters – gas, mechanical, hydraulic, and geological – without requiring a pre-defined specific functional form of the relationship [32].
2. Accounting for the temporal context of the signal. When considering tasks of classifying the current state of a system, it becomes obvious that without relying on the signal's history, the accuracy of conclusions is noticeably limited. That is why recurrent neural networks (RNN, LSTM) and transformer architectures are considered suitable tools: they allow incorporating the temporal structure of observations into the analysis. In drilling conditions, this is of fundamental importance, since differentiating between drilling-induced and geological anomalies in reality relies not on a single data «snapshot,» but on process dynamics and the sequence of changes.
3. Scalability and adaptability. Practice shows that models trained on extensive archives of well data collected from different fields are generally more transferable than deterministic analytical solutions strictly tied to a set of assumptions. Transfer learning methods provide additional flexibility: using them, a pre-trained model can be fine-tuned to the conditions of a new asset without needing a significant volume of new training data, which is especially important given the limited availability of labeled examples [33].

Based on a comparison of current publications and field developments, it is possible to outline a number of key areas where ML methods are gradually transitioning from experimental approaches into the practice of mud logging.

1. Automated data preprocessing and verification. In this area, the central task is preparing the measurement stream for subsequent interpretation: it requires filtering out drilling-induced noise (in particular, connection gas, tripping anomalies), as well as automatically refining the lag time considering current hydraulic parameters. A separate block involves the reconstruction of missing records – utilizing both interpolation procedures and generative models. Essentially, solving this task is a necessary prerequisite: without it, it is difficult to expect a steady improvement in the quality of all subsequent interpretation stages [34].
2. Real-time prediction of the lithological section. Joint analysis of gas readings, drilling mechanical parameters (ROP, Weight on Bit, Torque), and drilling fluid parameters allows for a continuous real-time lithology prediction. This provides geological support for drilling in intervals where coring is impossible or economically unviable [35].
3. Classification of reservoir saturation type. Differentiating between oil, gas, gas-condensate, and water saturation using mud logging data is one of the most in-demand and methodologically complex tasks. ML classifiers, trained on labeled data with confirmed well testing results, demonstrate accuracy exceeding the capabilities of traditional cross-plots and compositional ratios, especially in OBM environments and low-permeability reservoirs [36].
4. Early warning of drilling complications and kicks. Early kick detection systems, based on analyzing anomalies in the behavior of the multiparameter «formation – wellbore» system, help reduce response time to influx indicators and mitigate the risk of emergencies. The application of anomaly detection algorithms ensures the identification of kick precursors at early stages of their development [37].
5. Evaluation of productive potential and completion optimization. Indirect mud logging indicators – the nature of gas readings, rock mechanical properties from drilling data, cuttings parameters – can be used for preliminary ranking of horizontal wellbore intervals based on their productive potential. This allows for optimizing the placement of hydraulic fracturing ports and improving well completion efficiency without conducting additional costly surveys.

Conclusions

Based on the conducted theoretical analysis and field testing, the following conclusions can be drawn:

1. In the conditions of lateral heterogeneity of clastic reservoirs and sub-horizontal wellbore trajectories, traditional logging-while-drilling (LWD) methods have critical limitations. The effects of electrical macro-anisotropy, shale surface conductivity, and the distance of sensors from the bit (the «blind zone») do not always allow for the prompt and reliable identification of the current positions of the gas-oil and oil-water contacts (GOC and OWC).
2. Mud gas logging is the only available tool for continuous, direct, real-time analysis of formation fluids at the bottom hole. The method allows mitigating the technological delay of LWD systems and minimizing the risks of complications during well construction.
3. The use of geochemical criteria based on gas compositional makeup (C_1–C_5) typically provides distinct contrast in identifying inter-fluid boundaries in practice. Using this approach, the gas-oil contact (GOC) is quite reliably traced by the inversion of gas composition and the point where calculated wetness (W_h) and balance (B_h) ratios show a crossover, whereas the oil-water contact (OWC) logically manifests as a sharp depletion in heavy alkanes due to their poor solubility in formation water.
4. Field experience of applying this technology in East Siberian fields shows that mud gas logging results often correlate well with pulsed neutron logging (PNL) data. At the same time, timely refinement of the GOC position with sub-meter accuracy makes it possible to promptly revise the well design: appropriate technical solutions are implemented to achieve the required isolation of the gas cap, and the risks of premature gas breakthrough are reduced, which ultimately supports the economic viability of the asset’s further exploitation.
5. Reliably determining the initial positions of the GOC and OWC precisely at the drilling stage is considered a strategically important task, as it allows establishing phase boundaries before their production-induced displacement begins. Forming a correct database of initial oil-bearing contours becomes the foundation for a more justified estimation of current reserves, for designing the reservoir development system, and for selecting the spatial layout of injection wells for the reservoir pressure maintenance (RPM) system. Ultimately, this approach promotes more rational reserves recovery and helps maximize the delay of coning, as well as gas and formation water breakthrough into horizontal wells.
6. The accumulated limitations of classical mud gas logging interpretation methods – lag time variability, the polygenic nature of anomalies, and the influence of drilling-induced factors – significantly reduce the reliability of results in complex reservoirs and horizontal drilling. In this regard, machine learning methods are considered a promising addition to traditional tools, capable of improving the accuracy and reproducibility of interpretation through the analysis of multidimensional dependencies and adaptation to specific asset conditions.

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