DETERMINATION OF PRESSURE, CRACKING AND TEMPERATURE GRADIENTS IN THE CENTRAL-NORTHERN PART OF THE MOESIAN PLATFORM

DETERMINAREA GRADIENȚILOR DE PRESIUNE, FISURARE ȘI TEMPERATURĂ DIN PARTEA CENTRAL-NORDICĂ A PLATFORMEI MOESICE

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DOI: 10.37410/EMERG.2026.1.01

Abstract: *Currently, globally, the need for energy resources (especially natural gas) is becoming more and more evident, as a result of the current geopolitical context. Romania, one of the oldest oil-producing countries, still possesses areas with important prospects in terms of natural gas resources located both onshore and in the Romanian sector of the Black Sea. It is obvious that at the "onshore" level, most of the gas fields with important resources/reserves have already been discovered, the first commercial production reported in 1910 and are in an advanced stage of exploitation. The Moesian Platform is present on the territory of Romania between the Danube Carpathian Orogen and the Black Sea. In relation to the Carpathian Orogen, it subsoils, sinks under the deposits of the Carpathian foredeep, reaching even under the flysch sheets of the Curvature Carpathians. Also, since the commissioning of the first deposits on the platform until now, a large part of the hydrocarbon resources has already been highlighted, so it is natural to consider the areas that have been less researched to date and which, implicitly, will lead to the highlighting of new promising areas and new hydrocarbon resources. The researched area is positioned from a physical-geographical point of view in the NE part of the Romanian Plain in the proximity of the Subcarpathian Hills. From an administrative point of view, the study area is positioned at the border between the counties of Buzau, Braila and Ialomița. The well will be located in the administrative perimeter of commune A, Brăila* county *and is located 170 m N of well 1X.*

***Keywords**:* Moesian Platform, wells, drill, simulation, depth.

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Rezumat: *În prezent, la nivel global, nevoia de resurse energetice (în special gaze naturale) devine tot mai evidentă, ca urmare a contextului geopolitic actual. Romania una dintre cele mai vechi țări producătoare de petrol posedă și în prezent zone cu perspective importante în ceea ce privește resursele de gaze naturale aflate atât pe uscat cât și în acvatorialul sectorului românesc al Mării Negre. Este evident că la nivelul uscatului "onshore" majoritatea zăcămintelor de gaze cu resurse/rezerve importante au fost deja descoperite, prima producție comercială raportată în anul 1910 și se află într-un stadiu avansat de exploatare. Platforma Moesică este prezentă pe teritoriul Romaniei între Orogenul Carpatic Dunăre şi Marea Neagră. În raport cu Orogenul Carpatic aceasta subşariază, se afundă sub depozitele avanfosei carpatice ajungâng chiar şi sub pânzele flişului din Carpaţii de Curbură. De asemenea de la punerea în exploatare a primelor zăcăminte din platformă până în present, o mare parte dintre resursele de hidrocarburi au fost deja evidenţiate astfel că este firesc să fie luate în consideraţie domeniile (zonele) mai puţin cercetate până în prezent şi care, implicit vor duce la evidenţierea unor noi suprafeţe de perspectivă şi a noi resurse de hidrocarburi. Zona cercetată este poziționată din punct de vedere fizico-geofrafic în partea de NE a Câmpiei Romane în proximitatea Dealurilor Subcarpatice. Din punct de vedre adminstrativ zona de studiu se poziționează la limita dintre județele Buzau, Braila și Ialomița. Sonda se va situa în perimetrul administrativ al comunei A, judeţul Brăila și se amplasată la 170 m N de sonda 1X.*

Cuvinte cheie: Platforma Moesică, sonde, foraj, simulare, adâncime.

1. Introduction

Currently, at a global level, the need for energy resources (especially natural gas) is increasingly felt, which, due to the current geopolitical situation, can no longer be procured from "historical" sources (Russia, a country that possesses over 65 % of the world's natural gas resources). Romania, one of the oldest oil-producing countries, still possesses areas with important prospects in terms of natural gas resources located both on land and in the Romanian sector of the Black Sea.

It is obvious that at the "onshore" level, most gas fields with significant resources/reserves have already been discovered, with the first commercial production reported in 1910 and are in an advanced stage of exploitation.

The continuation of the research/discovery of new gas fields naturally required the approach of new areas, namely the highlighting of contingent resources, subtle traps and especially on land, the research of potentially productive formations located at increasingly greater depths. Thus, at the level of the Transylvanian Basin [5], exploration wells were drilled for Mesozoic formations (e.g. the Deleni, Boian structures, etc.) but which have not yet confirmed the existence of commercial gas accumulations. Research carried out by drilling in the external area of the Carpathian arc in folded areas (e.g. the Frasin structure) had punctual results and are hampered by the existence of very complicated tectonics which make drilling work difficult.

2. General data

2.1. Location

The Moesian Platform is present on the territory of Romania between the Danube Carpathian Orogen and the Black Sea. In relation to the Carpathian Orogen, it subducts, sinks under the deposits of the Carpathian foredeep, reaching even under the flysch sheets of the Curvature Carpathians. However, it can be considered that the boundary between the two domains is the Pericarpathian Fault, which represents the maximum extension limit of the Carpathian foredeep over the subducted platform.

The geological evolution of the Moesian Platform (the existence of several distinct sedimentary cycles, with deposits thousands of meters thick, the variety of lithofacies and structural and stratigraphic arrangements of the geological formations) has favored the generation and accumulation of oil, so that currently it constitutes an area of maximum interest for the exploitation of hydrocarbons. Several sedimentary cycles are present at the level of the Moesian Platform, so it is necessary to present the conditions of formation of oil deposits in accordance with them.

Also, since the exploitation of the first deposits in the platform until now, a large part of the hydrocarbon resources has already been highlighted, so it is natural to consider the areas (zones) less researched so far and which, implicitly, will lead to the highlighting of new prospective areas and new hydrocarbon resources. So far, petroleum structures and hydrocarbon reservoirs have been highlighted especially in the northern part of the Moesian Platform, more precisely north of the inflection zone of the foundation (in the eastern part) and respectively adjacent to the Oltean Uplift (in the western part) [7]. The other major structures belonging to the Moesian Platform: the Băileşti Depression, the Roşiori Alexandria Depression and the Călăraşi Depression (figure 1) have remained less researched and although they meet the conditions for the existence of important oil accumulations, they have not yet been sufficiently valued.

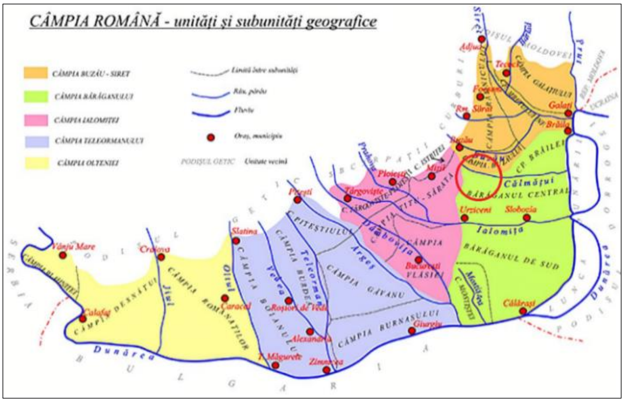

Figure 1 – Location of the study area at a regional geographic level [7]

2.2. Physical, geographical and administrative characterization

The researched area is positioned from a physical-geographical point of view in the NE part of the Roman Plain in the vicinity of the Subcarpathian Hills.

From an administrative point of view, the study area is positioned at the border between the counties of Buzau, Braila and Ialomița, the most important locality in the perimeter being the town of Faurei (figure 2). According to the usages of drilling design, the location of the well that constitutes the case study is reported as follows: the well will be located in the administrative perimeter of the commune of A, Brăila county and is located 170 m N of the well 1X. Access to the designed well is made from the county road, which connects the town of Faurei and the locality X and about 10 km N of the bed of the Buzău River.

Figure 2 – Administrative territorial location, case study

3. GEOLOGICAL – PHYSICAL CONDITIONS

3.1. Structural and lithostratigraphic considerations

From a geological point of view, the area to be investigated and the proposed case study, by well X, is located in the central-northern area of the eastern part of the Valahe Platform north of the Urziceni – Gârbovi – Brăgăreasa – Padina – Jugureanu structural alignment. Topographically it is located southeast of Buzau Municipality and north of Faurei town, Braila County (figure 3).

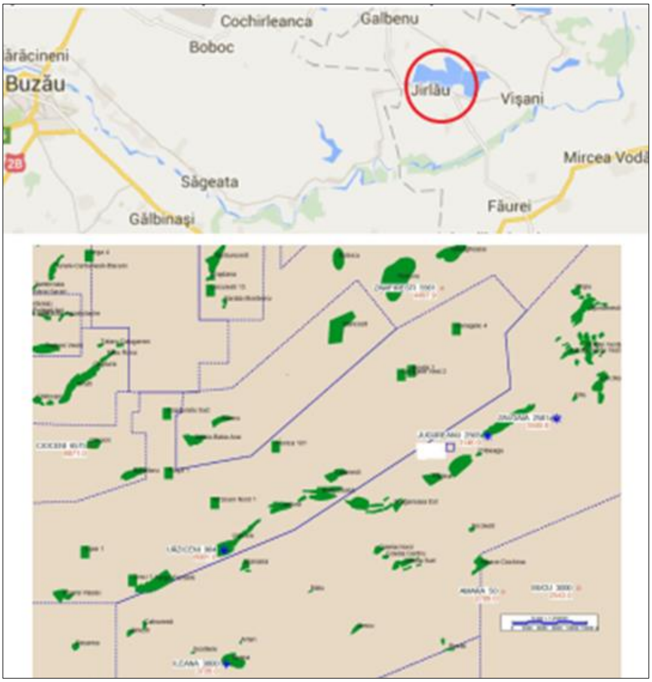

Figure 3 – Location of the area at a regional geological/structural level (Moesian Platform)

Geological research began in the 1960s by carrying out successive stages of seismic prospecting work, continued each time, with the execution of drillings including the following wells: E. C. A. Rosetti, N and N Surdila Greci, Y Nisipuri.

The sedimentological conditions in which the deposits that will be intercepted in the Caragele area were accumulated are directly related to the tectonic movements that affected the entire Wallachian Platform. Thus, in the stratigraphic succession of the Wallachian cover, four major sedimentation cycles were highlighted (Cambrian – Westphalian, Permian terminal – Triassic, Dogger – Cretaceous, Badenian – Pleistocene), formed as a result of repeated tilting movements (exundations/subsidences) during the last phases of the Hercynian orogeny, the Paleochimmerian phase and the Laramic phase [2].

4. Estimating pressure gradients and formation fracture

The study of the pressure values of the interstitial fluids that saturate the pores of the rocks crossed by the drilling works is an important field of geological research through drilling because, knowing them as accurately as possible, gives us both the possibility of creating a technological program appropriate to achieving the proposed objective (well drilling to the depth necessary to open the objective of interest), and through the geological significance of these values, the definition of the reservoir conditions and of some elements related to the evolution of the formations.

4.1. Geological basis of formation pressure formation

Abnormal pressure zone

After deposition, sediments are covered over time by other subsequent sediments so that they come to support an increasingly large lithostatic load corresponding to the weight of the overlying stack. We consider the rock formed by the mineral skeleton and the interstitial space (pores) saturated with fluid, the lithostatic load (S) will be taken over by the components of the system according to the relationship:

$$S = T + P_p \tag{1}$$

where:

S – represents the lithostatic load;
T – represents compressive stress in the pores;
P_p – represents pore fluid pressure.

Due to the lithostatic load, a compaction process of the initial sediment occurs, namely the reduction of its volume. The volume reduction occurs mainly based on the reduction of the pore volume. This is accompanied by the expulsion of an amount of fluid equivalent to the decrease in the pore volume. If the rate of fluid expulsion is consistent with the increase in lithostatic load, the pressure it bears will be equal to the pressure exerted by a column of fluid with a height equal to the depth at which the rock is located, called normal hydrostatic pressure (P_{hn}):

$$P_{hn} = H \cdot \gamma_{fl} \tag{2}$$

where:

H – represents the depth;
γ_{fl} –represents the specific gravity of the interstitial fluid.

Areas characterized by formation fluid pressures different from normal (equation 2) are called **abnormal pressure zones** [3].

Negative anomalies ($P < Phn$) are mainly related to "mature" hydrocarbon deposits where, due to the advanced stage of hydrocarbon extraction, the fluid pressure values are lower than normal. Since in most cases, areas with subnormal pressures do not appear as a result of natural processes, their study in the present work is not appropriate. In general, under natural conditions, pressure anomalies are positive ($P < Phn$) and characterize overpressured formations. The main causes of the generation of overpressures are:

– undercompaction of clays;
– diagenesis of montmorillonite-illite;
– gravitational slip phenomena;
– tectonic uplift of hydrodynamically impermeable blocks;
– the existence of relatively extensive impermeable evaporite deposits;
– the presence of fluids with different densities in closed structures;
– hydrodynamic (artesian) phenomena.

4.2. Basics of Formation Pressure Estimation

Starting from the existing interdependence between formation pressure and the rock compaction process (equation 1), Hubbert and Rubby define a porosity variation function with formation depth:

$$\varphi = \varphi_0 - e^{k\tau} \tag{3}$$

where:

φ – represents the porosity of the rock;
φ_o – represents the initial porosity (at the time of sediment deposition);
k – reprezintă constanta pentru un bazin sedimentar;
τ – represents the effective compressive stress: $\tau = S - P$.

The porosity of an undercompacted clay is:

$$\phi_{aH} = \phi_0 \cdot e^{-k(\Gamma_{lit} - \Gamma_{po})H} \tag{4}$$

$$\Gamma_{lit} = \frac{S_H}{H} \text{ – lithostatic gradient} \tag{5}$$

$$\Gamma_p = \frac{P_n}{H} \text{ – normal hydrostatic gradient} \tag{6}$$

$$\Gamma_p = \frac{P_a}{H} \text{ – formation pressure gradient} \tag{7}$$

where:

n – represents the normal compaction state;
a – represents the state of undercompaction (overpressure).

Thus, if a relationship can be established between the porosity of clays and the depth at which they are found (for a borehole, a structure, a sedimentary basin) then we will also be able to determine the pressure of the fluids in the pores of these formations. According to equations (3 and 4) if we present in a graph the logarithm of porosity or any geological-geophysical parameter dependent on porosity, then, for normally compacted clay formations, these values will be placed on a straight line representing the "normal trend" and the values for overpressured formations will be placed at a greater or lesser distance (depending on the size of the anomaly) from the straight line of the normal trend (figure 4).

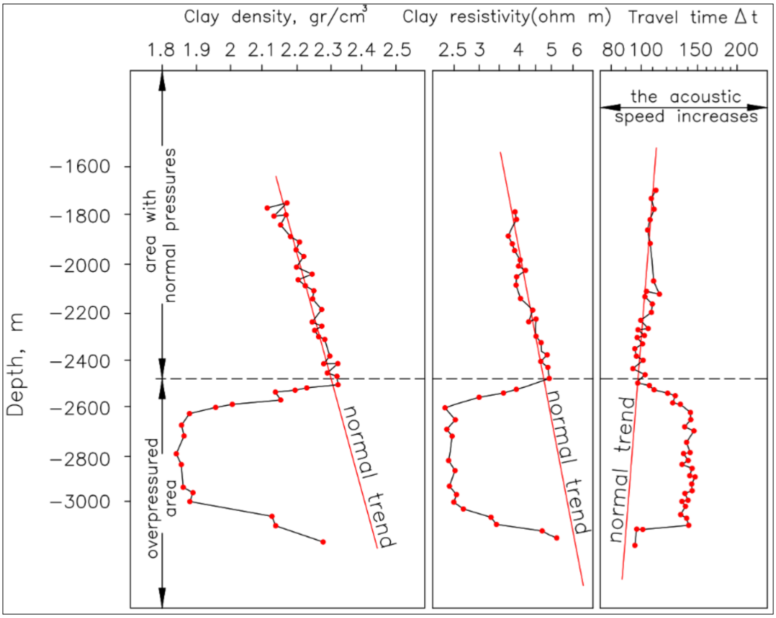

Figure 4 – Variation of clay porosity-dependent parameters as a function of depth (in normally and abnormally pressurized formations) [3]

The porosity-dependent physical parameters that can be used to estimate the degree of compaction of clays and implicitly the formation pressures are:

- density (from rock samples and/or CD);
- longitudinal acoustic wave velocity;
- resistivity;
- electrical conductivity;
- hydrogen index from neutron core (less commonly used).

Also, the variation in clay porosity induces the variation in the drill bit advancement regime (mechanical speed, exponent d, exponent dc).

In (figure 5) the variation with depth of a parameter “X” (which can be any of those mentioned previously) measurable in a borehole is present.

As the depth increases, a progressive increase in the parameter values is observed, marked by the MN level located on the normal trend line.

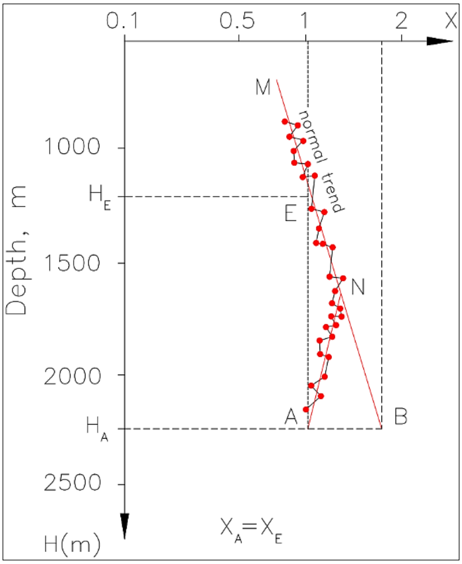

Figure 5 – Deviation of parameter “X” from the normal value (trend) in the overpressured area

5. Significance of pressure gradient and fracture values of formations

The estimation of the formation pressure values and implicitly of the pressure and fracturing gradients from the drills carried out on a certain area allows the highlighting (at the level of the different stratigraphic levels) of some areas characterized by a unity of the values. Considering that the formation pressure regimes reflect the history of the evolution of the respective formations, from the moment of the initial sediment deposition to the present, it can be hypothesized that the regions characterized by the similarity of the values had a unitary evolution. Also, by studying the pressure gradients, under certain conditions, depending on the cause that generated the formation of overpressured rock packages, the maximum burial depth can be defined and the burial history of the formations suggested, an important element in modeling the evolution of the basin.

The existence of variations in the values of the fracturing gradients of the formations can be correlated with the temporal positioning and intensity of the tectonic events that generated these variations. Regarding the regime of interstitial fluids, correlations can be made regarding the degree of maturation of organic matter, the migration conditions of hydrocarbons, and the reservoir conditions of exploitable hydrocarbon accumulations.

A last aspect, but not the least important, is the need to know the values of the pressure and fracturing gradients of the formations as the main parameters in the development of a drilling technology that ensures the interception and investigation of deep geological formations in the best possible conditions.

6. Temperature gradients

In physics, the temperature gradient is a physical quantity used to describe the direction and intensity of temperature changes. Formally, it is a vector field defined as the gradient field of a scalar field, which is precisely the “temperature field” [3].

Assuming that we can associate a temperature value to each point in space, we will have a law of the type:

$$T: R^3 \to R \tag{8}$$

If this function is sufficiently regular, it will be possible to calculate its gradient:

$$grad\ T = \nabla T = \left(\frac{\partial T}{\partial x}, \frac{\partial T}{\partial y}, \frac{\partial T}{\partial z}\right) \tag{9}$$

The physical meaning of this vector quantity is the general one of the gradient of a function of several variables: the direction of the vector indicates the direction of the greatest increase in temperature, while its modulus indicates the intensity of this increase.

$$T(x,y,z) = T_0 \tag{10}$$

Equation (10) determines a manifold (generally three-dimensional), on which the temperature remains constantly equal to the value. Given that the temperature does not vary on the tangent plane to this soil, the thermal gradient will have zero projection, therefore, it will be perpendicular to it. In fact, such a surface is also called (in the context of functions of several variables), a contour line, which satisfies the orthogonality property just stated [4].

In the international system (SI) the unit of measurement is K/m (Kelvin per meter). For drilling and exploitation of oil wells it is necessary to know the variation of temperature with depth and the temperature gradient. In existing wells, the temperature is measured at the bottom of the well (figure 6).

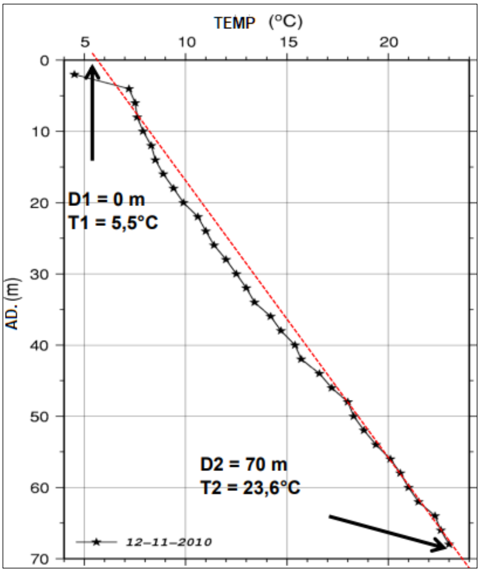

Figure 6 – Simulating the temperature gradient based on the available values

Thus, the temperature values at the desired depth can be calculated:

$$T_{emp.H} = (H - H_{ct.})\, \Gamma_t + TMA \tag{11}$$

where:

$T_{emp.H}$ – represents the temperature at depth H;

H – represents the depth;

$H_{ct.}$ – represents the depth of constant temperature (for Romania about 15 – 25 m);

Γ_t – represents the temperature gradient;

TMA – represents the average annual temperature.

$$\Delta T/\Delta Z = (T_2 - T_1) / (D_2 - D_1) = (23{,}6 - 5{,}5) / (70 - 0) = \\ = 0{,}258\ °C/m \times 1000 = 258°C/km \qquad (12)$$

Given that during drilling, the formations adjacent to the wellbore widen due to the circulation of the drilling fluid, it is necessary to correct them for the time elapsed since the circulation stopped.

7. Characteristics of the researched area

Based on the corroboration of data from wells drilled at the level of petroleum structures in the central northern area of the Moesian Platform, several specific characteristics could be highlighted in terms of pore fluid pressure gradients, formation fracturing and temperature gradient values.

7.1. Structural stratigraphic conditions

As previously shown, the Moesian Platform has experienced several tectono-sedimentary cycles that generated a specific arrangement, namely very different thicknesses of the formations, as well as a tendency for the Platform to sink northward, under the Carpathian Orogen (figure 7).

For the sake of brevity of the description, these characters are shown in figures (8,9).

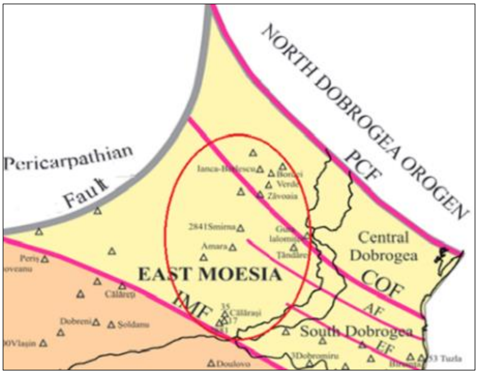

Figure 7 – Tectonic map of the area (after Seghedi, 2006)

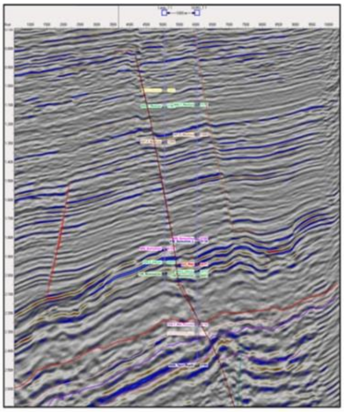

Figure 8 – Synthetic seismic Section for the researched area

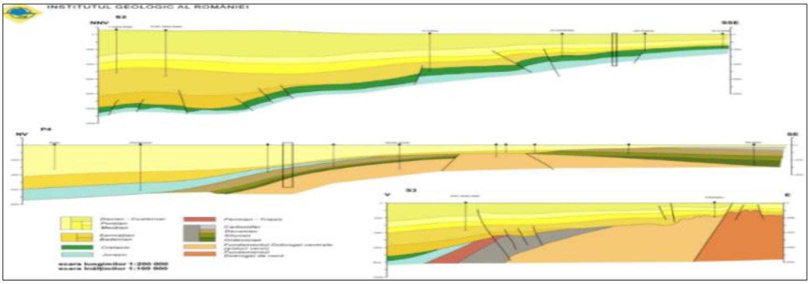

Figure 9 – Synthetic sections in the northeastern area of the Moesian Platform (after Geological Institute of Romania, 2007)

Thus, several areas with specific depth steps and thicknesses of the formations are highlighted depending on the sedimentation/erosion processes [8]. These have led to the emergence of different depths/formations, depending on the position in the regional geological framework of several areas (figures 10).

The thick Neogene deposits in the north determine important overpressures in the Middle Miocene – Badenian formations, up to 19 at/10 m, which requires construction programs of wells with columns to isolate this interval. In the East, where erosion was active, the post-Paleozoic formations are increasingly thinner to below 1000 m and do not present pressure anomalies. The central area, although characterized by large Neogene thicknesses, up to 3000 m, does not preserve overpressures although, like the northern area, it presents gas accumulations.

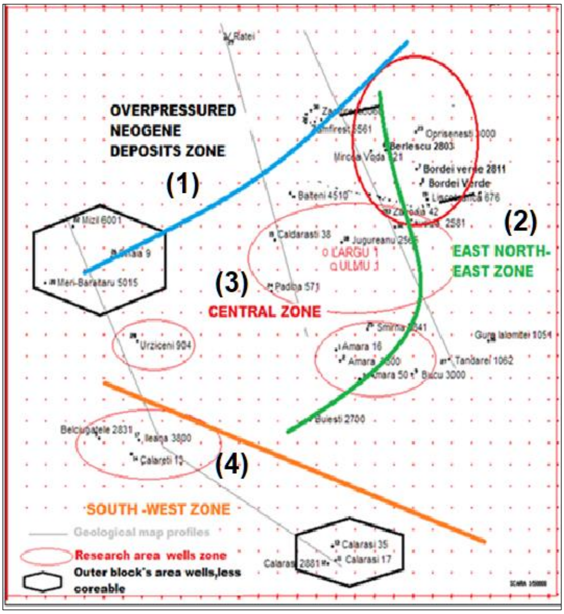

Figure 10 – Zoning of the researched area based on the values of pressure and cracking gradients

The southern area is also made up of much thickened formations at the upper stratigraphic levels without being overpressurized. It is important to note that, for the entire area under the Neogene formations, overpressurized or not, deposits of previous depositional cycles, Mesozoic, Paleozoic, where even at the Jurassic level very low values of the fracturing gradient are present, usually below 1.3 at/10 m, most of the wells crossing these intervals with massive circulation losses.

8. Case study – deep well

8.1. Stratigraphy and lithology

The lithostratigraphic column crossed by the above-mentioned wells belongs to the last sedimentation cycle, with the planned well to stop at the Meotian level. The exploration well – opening X aims to verify the structural image and specify the hydrocarbon content of the reservoirs belonging to the Neogene and Mesozoic sedimentary cycles [2].

The Dacian (0 – 1900 m) is made up of deposits developed in pelitic-psamitic facies (compact marls, sandy and fine sandy marls, marly sands, sands) with rare lenticular coal intercalations. The arenitic sequence is predominant in the lower half of the Dacian suite.

The Pontian (1900 – 2300 m) is a predominantly pelitic formation, having at the top a succession of marls, very fine mica-bearing slightly sandy marls, followed at the base by two psamitic complexes, represented by an alternation of sands, marly sands and marls. The Sarmatian (3000 - 3500m) is predominantly marly with subordinate intercalations of silty and arenitic sandstones.

The Badenian (3500 – 4300) consists of a predominantly pelitic series with subordinate intercalations of sandstones and marly sandstones. Due to rapid sedimentation, this interval is characterized by the existence of highly pressurized formations.

The Mesozoic (4300 – 5000 m) probably Cretaceous, with the Upper Jurassic also being intercepted, is developed in a carbonate facies forming a relatively monotonous stack of limestones with subordinate intercalations of marls, silty marls and carbonate sandstones.

When crossing the lithostratigraphic succession, during drilling, the phenomenon of contamination of the drilling fluid with foreign solids may occur, either due to the dispersion capacity of the marls or due to the fine grain size of the sands.

8.2. Simulation of pressure, cracking and temperature gradients

Following the analysis of the geophysical investigations, the information obtained from the drilling process and the production samples from the wells mentioned above, the pressure and fracturing gradients were evaluated depending on the lithological type and the depth at which the previously described formations are estimated to be encountered. Their values are presented in the simulation of the complex characterization of the stratigraphic column and the substantiation of the casing scheme and the drilling fluid program (figures 11).

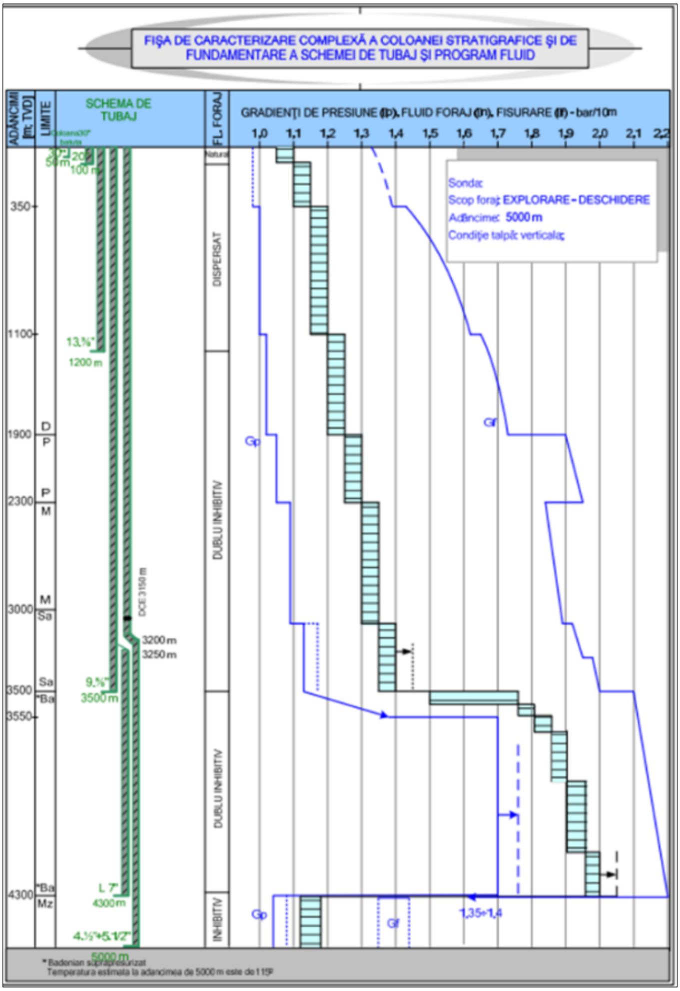

Figure 11 – Simulating complex characterization of drilling conditions

The temperature values are subnormal, so in (figure 12) the regional values of the geothermal gradient are represented. At the final depth a temperature of about 115 °C is estimated.

The temperature values are subnormal in (figure 12) represented the regional values of the geothermal gradient.

For the design of the well construction, drilling data and well logs from wells located in the proximity of the proposed drilling were used. These are located on the Caragele, Jirlău, Faurei, C.A. Roseti, Dămianca, Zamfirești structures.

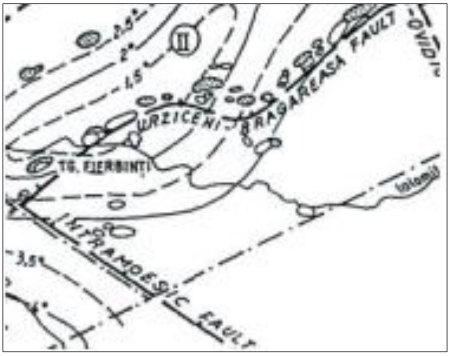

Figure 12 – Regional values of temperature gradient

8.3. Estimated drilling difficulties for well X

In the wells dug on the structure and on the bordering structures, a tendency for the drilling fluid to be lost in the surface formations can be observed, which motivated the fixing of the 30” protection column installed by Hammer at about 50 m [9]. Also, tendencies for gasification of the drilling fluid may appear when crossing the possible potential lenticular reservoirs in the Pontian and Meotian. In the Sarmatian and Badenian, there are tendencies for eruptive manifestations with gases and/or reservoir water. Starting with the depth of 4190 m, the appearance of salt water under pressure is very pronounced. When crossing the Neogene lithostratigraphic succession, during drilling, the phenomenon of contamination of the drilling fluid with foreign solids may occur, either due to the dispersion capacity of the marls or due to the fine grain size of the sands.

Mesozoic formations are characterized by the existence of a pronounced fracture system that favors the occurrence of drilling fluid losses even at low densities. From 4000 m to 5000 m, sieve samples will be collected every 2 m, and when carbonates are intercepted (specific to Cretaceous formations), drilling will be stopped.

From the point of view of the theoretical foundation of the well construction, it can be said that from the multitude and complexity of natural, geological and technological factors that condition the well design, this chapter will treat the most important elements that condition the well construction, namely the density (equivalent density) of the drilling fluid and the load regime in the well that condition the modeling of the well casing.

8.4. Equivalent traffic density

ECD (Equivalent Circulation Density – is the term given to the total pressure exerted on the walls of the well hole) is an important parameter to monitor in the drilling process of a well, its manifestation decisively affecting the well control process (figure 13). This achieves the golden rule of well drilling [1], namely:

$$\Gamma_p < \Upsilon_{ff} < \Gamma_{fis} \qquad (13)$$

where:

Γ_p – represents the fluid gradient in the pores of rocks;
Υ_{ff} – represents the specific gravity of the drilling fluid;
Γ_{fis} – represents the fracturing gradient of rocks.

There are several justified reasons to keep the Circulating Equivalent Density values under control. Let's list the important ones:

– reducing the risk of fracturing open geological formations and, respectively, of drilling fluid losses. Not to mention the increase in non-productive time and significant volumes of lost fluids, which can lead to problems related to well control.

– preventing ballooning phenomena, with overloading the resistance of geological formations;

– minimizing the instability of the well hole walls, due to pressure fluctuations;

– minimizing the risk of differential sticking of the tubular material;

– avoiding the increase in costs for problem wells.

Although ECD control is important in any drilling process, there are some types of wells where it becomes vital:

– ERD (Extended Reach Drilling)/horizontal holes, in which ECD increases with measured depth, but the fracturing gradient does not increase significantly due to relatively small changes in the vertical projection of the well trajectory (TVD);

– HPHT (High-Pressure High-Temperature) wells, where the drilling margin (the difference between pore pressure and fracturing pressure) is small;

– wells drilled in already exploited porous-permeable formations (mature reservoirs) in which the fracturing pressure has decreased over time, with the decrease in pore pressure, but the specific gravity of the drilling fluid cannot be reduced either due to the presence of a virgin isolated productive horizon (with higher pressure), or due to the need to stabilize shale intercalations. It is generally used to indicate the increase in pressure exerted during the circulation of fluids in the well, but also indicates the increase or decrease in pressure caused by the movement of the drilling string (surge and swab pressures).

It is expressed as density, in the same units as the density (measured at the surface) of the drilling fluid.

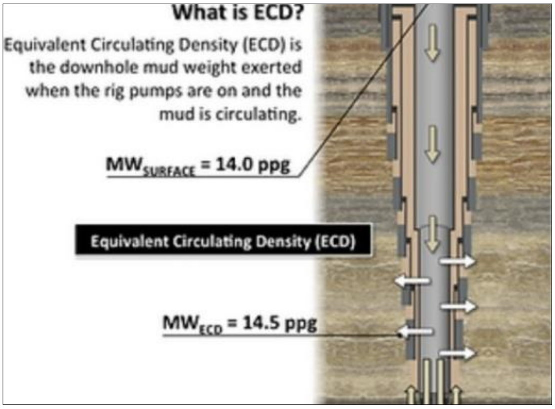

Figure 13 – Schematic representation of EDC

ECD is the combination of drilling fluid density and other influences affecting the pressure in the well annulus, so there are two components of ECD:

– static pressure component: the hydrostatic pressure of the loaded drilling fluid and debris;

– dynamic pressure component which includes:

- pressure losses in the annular space;
- speed of movement of the drill string;
- inertial pressures induced by acceleration/deceleration of drill string movements;
- pressure required to break the gel structure of the drilling fluid at the start of circulation.

Static pressure is the pressure exerted by a stationary fluid of a given density at a given vertical depth. It also includes any debris particles that may be suspended in the drilling fluid column.

A certain pressure is required for the circulation of the drilling fluid in the wellbore to overcome:

– internal friction forces in the fluid itself;
– backpressure as the fluid flows through a restrictive section;
– to drive the motor, turbine, and MWD tools.

The effort required to overcome the resistance to flow is called pressure loss. This pressure loss is measured by the loader manometer [6].

8.5. Case study sizing 12 $^{3/4}$ in anchor column at a depth of 500 m

– drilling fluid density in the range 0 – 500 m:

$$\rho_{n1} = 1250\ kg/m^3 \tag{14}$$

– drilling fluid density in the range 500 – 2225 m:

$$\rho_{n1} = 1300\ kg/m^3 \tag{15}$$

– inner diameter of the anchor column:

$$D_{sup} = (12 + 3/4)in = 323{,}85\ mm \tag{16}$$

– equivalent density at the anchor column level:

$$\rho_{fis} = 1500\ kg/m^3 \tag{17}$$

– 12 $^{3/4}$ in column tubing depth:

$$H = 2225\ m \tag{18}$$

– intermediate column tubing depth:

$$H_1 = 500\ m \tag{19}$$

The pore fluid pressure at the maximum open depth below the 12 $^{3/4}$ in column, at 2225 m, is considered equal to the mud column pressure:

$$P_p = \rho_{n1} \cdot g \cdot H_i = 283{,}65\ bar \tag{20}$$

The formation cracking pressure at the bottom of the 12 $^{3/4}$ in column, with an equivalent safety of 100 Kg/m^3:

$$P_{fis} = \left(\rho_{fis} + 100 \cdot kg/m^3\right) \cdot g \cdot H_a = 78{,}453\ bar \tag{21}$$

where:

P_p – represents the pressure of the fluids in the pores;

H_i – represents the height of the intermediate column;
ρ_n – represents the density of the mud;
ρ_g – represents the density of the gas;
H_a – represents the height of the anchor column.

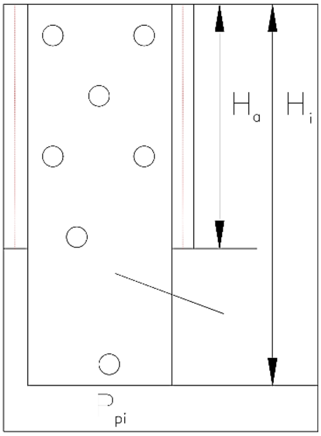

Figure 14 – Height of the intermediate column

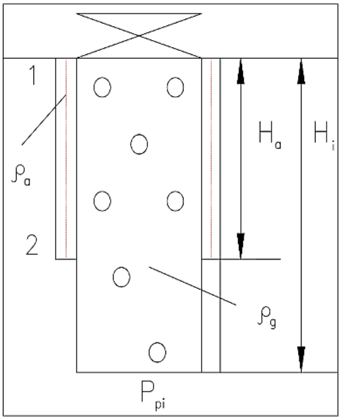

Figure 15 – Height of the anchor column

If we consider the pressure of the column full of gases, entering the well at 2250 m, their average density is $\rho_g = 200$ Kg/m^3 and behind the column the mineralized water with the density $\rho_a = 1050$ kg/m^3, then:

$$P_s = P_p - \rho_g \cdot g \cdot (H_i - H_a) = 249{,}824\ bar \qquad (22)$$

This value is higher than the cracking pressure, 78.45 bar, the maximum pressure possible at the 12 $^{3/4}$ in column.

Behind the column is considered mineralized water with a density of 1050 kg/m^3.

The internal pressure difference at the top of the column will be:

$$\Delta_{fis} = P_{fis} - \rho_{am} \cdot g \cdot H_a = 68{,}647\ bar \qquad (23)$$

At the surface, the internal pressure will be:

$$P_c = P_{fis} - \rho_g \cdot g \cdot H_a = 68{,}647\ bar \qquad (24)$$

Can be chosen casing columns, with a thickness of 9 mm, J-55 steel that have an allowable internal pressure of 147.2 bar higher than the pressure at the head of the column of 68,647 bar.

$$P_{ia} = P_{sp}/c_{sp};\ P_{ea} = P_t/c_t \cdot F_s = F_s/c_s \qquad (25)$$

where:

P_{sp} – represents the burst pressure;
c_{sp} – represents the coefficient of rupture, $c_{sp} = 1,25$;
P_t – represents the flattening pressure;
c_t – represents the flattening coefficient, $c_t = 1,05$;
F_s – represents the pulling force;
c_s – represents the pullout coefficient, $c_s = 1,75$.

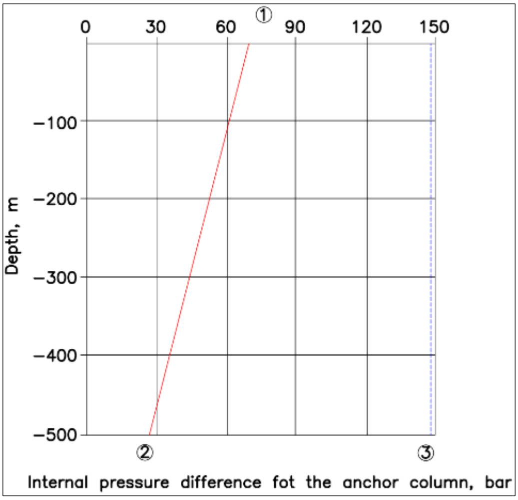

Figure 16 – Internal pressure difference for anchor column

where:
1 – The pressure inside the column $P_c = 68,647$bar;
2 – Internal pressure difference at the seat $Dp_{fis} = 26,968$ bar;
3 – Permissible internal pressure of casing columns 9 mm J-55, $P_{ia} = 147.2$ bar.

For external pressure sizing, the column is assumed to be completely empty, and outside it is considered the mud from the time of casing with a density of 1250 kg/m^3. The maximum external pressure difference is at:

$$\Delta_{es} = \rho_{n1} \cdot g \cdot H_a = 61{,}292\ bar \tag{26}$$

You can choose 9 mm thick casing columns made of J-55 steel with a pressure $P_{ea} = 69,52$bar.

The weight of the column in air having unit mass, $m_i = 72,3$ kg/m is:

$$G = m_1 \cdot g \cdot H_a = 354{,}51\ kN \tag{27}$$

The value is less than the permissible value of 1190.85 kN.

If the column is considered submerged in mud, the maximum tensile force is at the surface:

$$F_{t\,max} = G \cdot \left(1 - \frac{\rho_{n1}}{\rho_0}\right) = 298{,}060\ kN \tag{28}$$

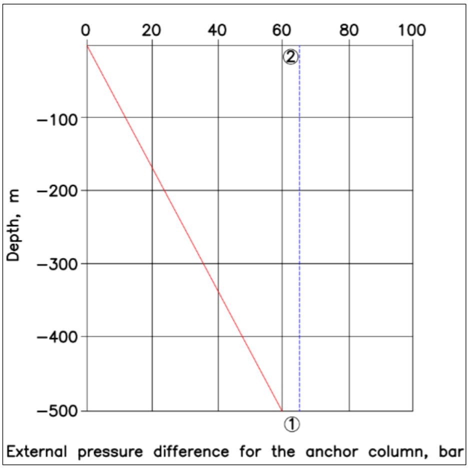

Figure 17 – External pressure difference for the anchor column

where:

1 – The pressure inside the column Pc = 357,845bar;

2 – Permissible external pressure of 9 mm J-55 casing columns, P_{ea}=69,52 bar.

In its presence, the allowable external pressure is:

$$R_{p\,02} = 397\ N/mm^2 \tag{29}$$

$$A = \pi \cdot t \cdot \left(D_{sup} - t\right) = 8902{,}174\ mm^2 \tag{30}$$

$$P_{cor} = P_{ea} \cdot \left[-\frac{F_{t\,max}}{2 \cdot A \cdot R_{p\,02}} + \sqrt{1 - 3 \cdot \left(\frac{F_{t\,max}}{2 \cdot A \cdot R_{p\,02}}\right)^2}\right] = 66{,}245\ bar \qquad 31)$$

This value does not exceed the external pressure of 61.29 bar so the entire column will be 12 3/4 in with a full thickness of 9 mm J-55 steel, with short thread. The profile of the anchor column is:

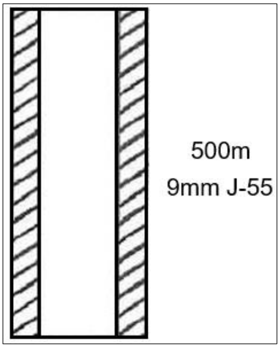

Figure 18 – Schematic presentation of the anchor column profile

9. Conclusions

The estimation/calculation of the pressure, fracturing and temperature gradient values of the formations traversed by a well are essential for the design of the well construction program and the drilling technology/technologies related to achieving the well objective.

The main methodologies for estimating pressure and fracturing gradients are based on the measurement and interpretation of the values of the drilling and geological-geophysical parameters of the formations.

The main drilling parameter, the advance rate, is closely correlated with the formation pressures, a factor that allows the calculation of the pressure gradient of the formations traversed or opened during drilling.

The method of the exponent “d” respectively the compensated “d” allows a correct estimation and based on it the rigorous design of the wells.

The researched area, the Moesian Platform (Northeastern part), is characterized by the existence of several tectono-sedimentary cycles that generated specific patterns of composition and properties specific to the formations. The existence of hydrocarbon deposits in this area made it necessary to dig exploration/exploitation wells for which it was necessary to characterize the associated pressure/temperature regimes.

From the study of the wells dug in the area, several perimeters with clearly different characteristics could be highlighted as well as the vertical succession of formations with distinct and sometimes antagonistic characters.

Thus, in the Northern area, the Badenian-age gas formations are characterized by large pressure anomalies, overpressures of up to 1.8 at/m of formation pressures. This leads to the need to cross the Badenian with very heavy drilling fluids and to casing columns with large casing thicknesses and superior steels capable of withstanding these pressures.

Also in this area, the underlying Cretaceous is characterized by very low values of the fracturing gradient, which requires very light drilling fluids. This antagonism has led in some cases to well failures, for example, the flattening of the column that had isolated the overpressured Miocene, to the shift of the drilling fluid density from very heavy to very light.

On the more southern alignments, a differentiated erosion process occurs so that formations of different ages appear under the Neogene sedimentary, most of which have very low fracturing gradients.

We can conclude that the area is extremely demanding in terms of drilling conditions, requiring a good knowledge of the values of the pressure, fracturing and temperature gradients. In the presented case study, precisely this shift of the values of the pressure/fracturing and temperature gradients with the construction related to them is achieved.

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Acknowledgments

I would like to thank all the people who helped me to prepare this work.

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