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# Mathematical modeling of the geothermal gradient of oil and gas deposits

Seyed Mehdi Tabatabai*, Cristina Jugastreanu**, Timur Chis***
**(Ph. D. School, Oil-Gas University Ploiesti, Ploiesti, Prahova, Romania*
***(Ph. D. School, Oil-Gas University Ploiesti, Ploiesti, Prahova, Romania*
****(Applied Science and Engineering Faculty, Ovidius University, Constanta, Romania*

**ABSTRACT**
The geothermal gradient of the oil and gas fields can be determined by measuring the geological layers at different temperatures and at different depths of the oil and gas well. If in the vast majority of geological layers the gradient variation is linear and can be described by a first degree equation, in the case of oil and gas deposits, geothermal anomalies appear. These anomalies can lead to the determination of the type of oil exploitation and especially to the presence of the water flood front of the field. The article describes the types of geothermal anomalies discovered in the oil and gas fields and especially ensures the numerical modeling of the response of the geological layers to the electrical and thermal logging

***Keywords* – geothermal gradient**, **oil and gas deposits**, mathematical modeling, electric coring,

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## I. INTRODUCTION

The analysis of the temperature of the geological structures indicated its increase with depth.

In principle, the temperature variation with depth can be calculated with a first-order mathematical regression relation, the temperature increasing by 1ºC, every 10 m [1].

But in the case of rocks with high conductivity, it is possible to change the temperature by 11 ºC to 10 m [2].

The increase in the temperature of geological layers may be due to the presence in the area of eruptive (volcanic) geological structures, or of fluids circulating in areas with higher temperatures, or which have high flow rates.

## II. ANALYSIS OF TEMPERATURE VARIATION IN OIL AND GAS DEPOSITS

Knowing the temperature of an oil or gas field gives us data on the possibility of discovering gas, water deposits or determining the height to which the drilling column has been cemented.

In the case of oil and gas field drilling, temperature variation may indicate the presence of a gas-rich area (in which case there is a decrease in temperature), or an oil field (with a slight increase in temperature).

The determination of gas deposits can be done with the help of thermal anomalies, in their area the temperature being lower.

In the presence of a gas field, a decrease in the temperature of the geological layer was observed by up to 10ºC.

Analyzing the oil and gas field from Băicoi, Romania, shows a decrease in temperature in the perforated ranges 2577-2586 m and 2588-2591 m (figure 1).

The first production range produces gas and the second production range produces oil and gas, the well having a production capacity of 17 tons/day oil with a gas-oil ratio of 1500 $Nm^3/m^3$.

In order to determine the level of cement existing behind the well column, a geothermal profile of the wellbore is made in the first 72 hours after the operation.

After performing the operation, the area where the cement is located will be determined with sufficient precision, because after the cementation a heat transfer process takes place (exothermic reactions).

The determination of the thermal gradient will show us the level of cementation, in figure 2 being presented the operation of cementing an oil well in the Băicoi area, for the interval of 750-760 m.

It is observed that no sewers were produced during the cementing operation.

Another use of geothermal profiles is the determination of water layers, where there is an increase in temperature in their area.

The temperature anomaly is proportional to the amount of water produced, in figure 3 being presented three curves, depending on the water flow formed in the productive layers.

In curve 1 the water flow is very small, curves 2 and 3 being determined during the operation to stimulate the productivity of the well.

At the same time, for the analysis of the receptivity of the open layers in the injection wells, a geothermal profile is made, which will have the role of determining the layers with higher permeability, which have a lower temperature (close to the injection water temperature).

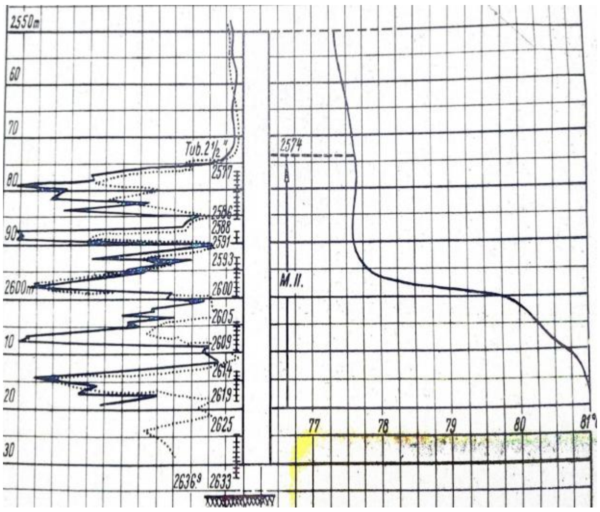


Figure 1. Geothermal gradient of oil and gas deposit (Baicoi, Romania)

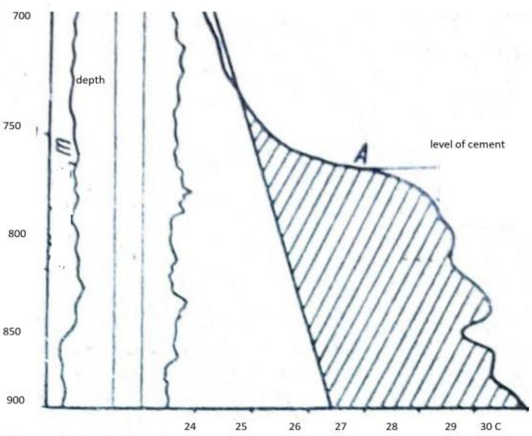


Figure 2. Geothermal gradient of a cemented oil geological layer

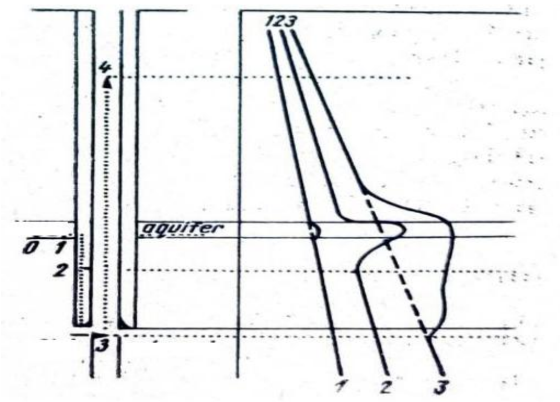


Figure 3. Geothermal gradient of geological layer whit spiled water

## III. TEMPERATURE VARIATION IN NEW GAS LAYER DEPOSIT

Following the geophysical research of the Slobozia geological platform, several geological research drillings were carried out.

The following oil operations were also carried out during the drilling:

a. Determination of the granulometry of geological layer and their age,

b. Determining the temperature of geological layer,

c. Carrying out a geophysical logging,

d. Determining the productive area,

e. Determination of reservoir pressure and fluid temperature in the productive geological structure.

Following the analysis of the collected data, it was succeeded:

a. Determining the thermal gradient,

b. Numerical modeling of the variation of the thermal guard in the non-productive and productive areas,

c. Determining the ratio of variation of the electric gradient according to the depth of the probe,

d. Correlation of temperature data with those resulting from the determination of the electrical resistivity of the layers.

## IV. GEOLOGY OF THE ANALYSED AREA

The investigated area is part of the Central Baragan Plain.

From a geological point of view, this represents the crater surface made up of the foundation and the sedimentary cover formed in several stages of sedimentation.

The foundation of the Central Baragan Plain includes parts of the South-Dobrogean platform, to which are added, in the eastern extremity, sunken Cadomian structures.

The Bărăgan Central Plain, also called Călmăţuiului Plain or Bărăganul Ialomiţei, is an integral part of the Bărăgan Plain, considered in the geographical literature the most typical tabular plain, of lacustrine or lacustro-fluvial origin.

The Central Bărăgan Plain is located in the southeast of the country, in the eastern part of the Eastern Romanian Plain and overlaps the Ialomiţa-Călmăţui interfluve.

The meadows of the two rivers represent the southern and, respectively, the northern limits of the plain, which separates it from the Southern Bărăgan, respectively from the Northern Bărăgan (Brăilei Plain).

The other two limits are the Săratei Valley, in the west, which separates the Central Bărăgan from the Săratei Plain, and the Danube meadow, in the east (figure 4).

It has an area of about 3370 km² and a slightly rectangular shape, with a length of about 90 km and an average width of about 40 km.

The plain of Bărăgan Central makes the transition between Bărăganul Sudic, higher, and Bărăganul Nordic, both by geographical and lithological position, by the lower thickness of the loess and the more clayey substrate (figure 4).

These characteristics are determined by the different paleogeographic evolution of the three plains, in the Central Bărăgan the subsidence being stronger than in the Southern Bărăgan, according to the geological drillings.

Morphologically, it is characterized by the obvious asymmetry through the steep or convex northern slope, generated by the climato-wind action, and the southern one, longer and lower, with the appearance of steps; predominance of flat surfaces, with N-S and E-V inclination; weak fragmentation, with shallow valleys; poor drainage, with many deep depressions without runoff, some with salt lakes, with a pronounced endorheic character.

The pre-Quaternary evolution of the Central Bărăgan Plain.

As part of the Romanian Plain, the Central Bărăgan Plain represents, from a geological point of view, a craton surface made up of foundation and sedimentary cover formed in several stages (sedimentation cycles).

The foundation of the Central Bărăgan Plain includes parts of the South-Dobrogean platform, to which are added, in the eastern extremity, sunken Cadomian structures (figure 5).

The South-Dobrogean Platform represents the eastern compartment of the Moesic Platform, separated from the western compartment, respectively the Wallachian Platform, through the intramosic fault.

It has an eoproterozoic base, made up of granitic gneisses and mesometamorphic crystalline schists and a cover made in several sedimentation cycles, from the Paleozoic to the end of the Pliocene and made up of an alternation of sedimentary rocks: conglomerates, sandstones, clays, limestones.

The last sedimentation cycle (Miocene-Pliocene) ends with arenito-pelitic deposits which were subsequently covered by Quaternary deposits.

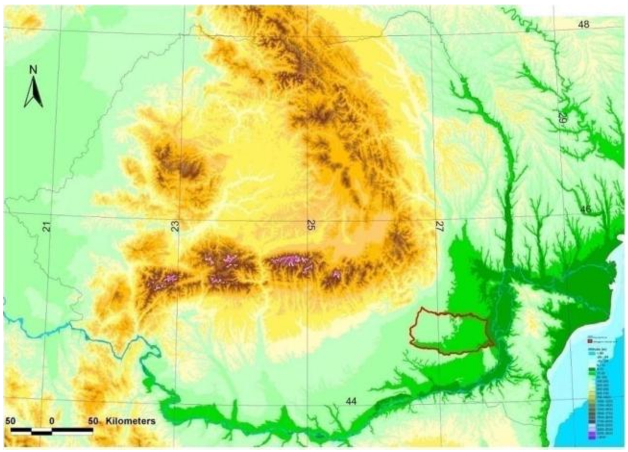


Figure 4. The location of Central Baragan Plain within the Romania

The Bărăgan compartment descended, at the beginning of the Quaternary, by 1000-1500 m, along a fault that follows the course of the Danube, between Galaţi and Ostrov.

The sunken Cadomian structures represent the continuation, west of the Danube, of the Central Dobrogean Massif and are separated from the South-Dobrogean platform by the Capidava-Ovidiu fault. The base, made of green shale, was found in boreholes below 2000 m depth.

The cover is made up of successions of pelitic and detrital deposits, the last being Mi-Pliocene.

In the Neogene the subsidence of the Moessice Platform began, which reached its highest values in the Focsani basin (Vrancea area), and the surface of the Romanian Plain became a lake, which gradually retreated to the northeast, the entire surface of the plain exonding at the end of the Upper Pleistocene.

Paraschiv framed the Badenian – Pleistocene formations as the result of the last sedimentation cycle, represented by molasses detrital deposits.

In the eastern sector, the subsidence movement continued from Romanian in the Pleistocene and Holocene, but only in the syncline axis, gradually moving from south to north, at the tectonic contact between the Romanian Plain and the Subcarpathians, along the sub-Carpathian fault.

On the eastern side of Bărăgan, the marginal fault of Dobrogea created an area of Danube subsidence and caused the Danube terraces to sink under the alluvium).

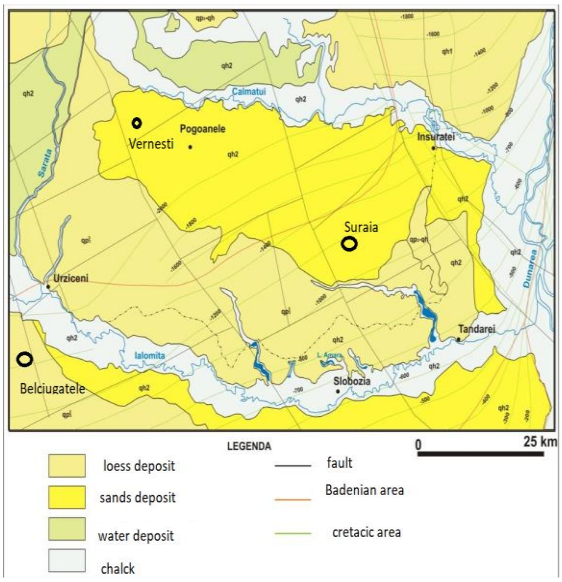


Figure 5. Geological map (after the Geological Map of Romania, scale 1: 200,000, sheets Bucharest, Ploieşti, Brăila, Călăraşi and Simplified structural map of the autochthonous units outside the Carpathians and the outline of the pre-Miocene foundation)

Deep drilling in the region, as well as geophysical research, have shown the existence of several tectonic compartments, separated by large faults, mostly NW-SE oriented, some limited to Paleozoic-Mesozoic cover, others reflected to the Neogene cover.

The Quaternary evolution of the Central Bărăgan Plain

At the beginning of the Quaternary, most of the Central Bărăgan Plain was characterized by a facies of swamps and ponds, in which fine materials were deposited.

According to Liteanu, the Upper Holocene-Neogene interval is characterized by fine deposits, clays and aleuritic sands, deposited continuously by sedimentation in the Pliocene and Pleistocene.

For the Romanian-Cuatemar period, Posea identified seven phases of the evolution of the plain:

1. Lower and middle Romanian: the territory of the Central Bărăgan Plain, as well as the east of the Romanian Plain, consisted of a low plain in which fluvial and lake environments alternated (in some places, of swamp).

2. Lower Pleistocene. The succession of Quaternary deposits begins with a horizon of fine clays and sands of Villafranca, corresponding to the pebbles of Cândeşti, covered by the layer of Frăteşti, st. prestiene, in the south and east of the plain (the area Nasul Mare-Nasul Mic), which represents, after Coteţ, fluvio-lacustrine deposits transported and deposited by the Danube by eroding the gorge at the Iron Gates.

3. Middle Pleistocene. Against the background of the expansion of the lake domain, the deposition of the "clay-marly" complex began. It sinks in a north-south and east-west direction, due to the subsidence, reaching thicknesses of up to 10-80 m. The Hagieni-Nasu Mare area (which had extensions, probably to Burnas) was dry, where loess and formations proluvio-colluvial from the south and southeast;

Upper Pleistocene.

4. The plain of Mostiştea sands (with an almost horizontal disposition, due to the reduction of subsidence), follows discordantly over the marly complex. These deposits, made up of fine sands, which pass into clayey sands in the east and northeast, were found in boreholes in the southern part of the Ialomiţa-Călmăţui interfluve, their thickness being 15-25 m.

5. During terraces 3 and 2, the Danube continued to form puddles above the middle, tabular level of Bărăgan (Câmpul Ciulnitei-Jegaliei, at about 35-40 m altitude), but it always moved to the right, also making arms passages on east of the Nasu Mare strip;

6. during terrace 1, the Danube moved, by lateral erosion and overflow, east of Borcea-Feteşti, invading an old section of local valley and permanently isolated the Hagieni Field from South Dobrogea, integrating it into the Romanian Plain;

7. during the Wiirmian regression (especially in W II and W III), all the courses deepened strongly, especially the Danube, and during the Neolithic transgression, the meadows from the east and the Danube are clogged to the level of the terrace 1. In the Upper Holocene, the riverbeds rose in alluvium, forming wide meadows, and small valleys with few alluvium were barred and their mouths turned into estuaries.

To these is added the Holocene period:

- Lower Holocene. During this interval, the alluvium of the Danube and Ialomiţa terraces is deposited, made up of sands and weakly clayey sands, 5-10 m thick.
- Upper Holocene. Loess deposits on terraces, meadow alluvium and wind sands belong to this range.

## V. ANALYSIS OF DRILLING

For the analysis of the gas structures in the Slobozia area, we analyzed three boreholes, namely:

a. Vernesti-3980 m depth,
b. Belciugatele-3313 m depth,
c. Suraia-4850 m depth.

For each of the three boreholes we analyzed the variation of the temperature and the resistivity of the layers.

Two productive layers were detected in the Vermesti drilling following the analysis of the electrical logs.

But as a result of the perforation, I find the following:

-the first layer between 2460 m and 2470 m did not show quantities of gas and crude oil,

- the second layer was perforated between 3132 m and 3146 m where a flow of 1.7 m3 of natural gas was found.

Analyzing the geothermal gradient and the resistivity of the geological layers, the following can be observed:

a. The equation of the geothermal gradient is

$y = 4E^{-18}x^6 - 7E^{-14}x^5 + 5E^{-10}x^4 - 2E^{-06}x^3 + 0.0029x^2 - 2.732x + 1085.9$

where y is the temperature of the geological layer and x is the depth.

The error rate $R^2$ is 0.9925.

b. The resistivity gradient equation is:

$z = 4E^{-18}x^6 - 7E^{-14}x^5 + 5E^{-10}x^4 - 2E^{-06}x^3 + 0.0029x^2 - 2.732x + 1085.9$, where z is the resistivity of the geological layer and x is the depth of measurement.The error rate $R^2$ is 0.8417.

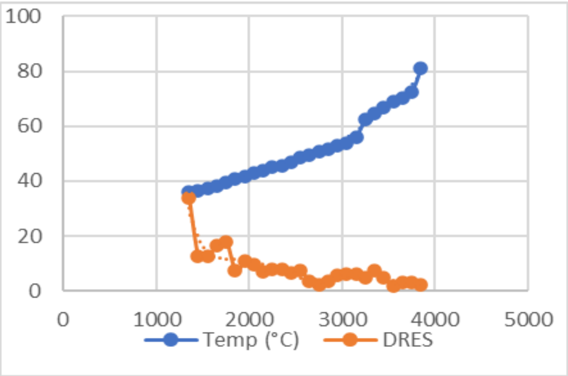


Figure 6. Thermal gradient and resistivity of layers at Vernesti drilling

In the case of the Belciugatele drilling, production tests were carried out in the layer located at the intervals:

-1100-1118, without oil product charges,

-1139-1146, without charges for petroleum products,

-1176-1190, without debts on petroleum products,

- 1240-1278, without debts for petroleum products,

-1530-1558 without charges for petroleum products,

-1700-1738, without charges for petroleum products,

-1870-1910, without debts of petroleum products,

-2160-2210, without charges for petroleum products,

-2293-2336, without charges for petroleum products,

-2472-2580, without charges for petroleum products,

-2720-2740, without charges for petroleum products,

- 2834-3359, without oil product debts.

And in this case, analyzing the geothermal gradient and the resistivity of the geological layers, the following can be observed:

a. The equation of the geothermal gradient is

$y = 5E^{-07}x^6 - 5E^{-05}x^5 + 0.002x^4 - 0.0369x^3 + 0.3131x^2 - 0.2178x + 28.586$

where y is the temperature of the geological layer and x is the depth.

The error rate $R^2$ is 0.9992.

b. The resistivity gradient equation is:

$z = -1E^{-05}x^6 + 0.001x^5 - 0.0183x^4 - 0.1123x^3 + 6.183x^2 - 44.544x + 81.162$ where z is the resistivity of the geological layer and x is the depth of measurement.

The error rate $R^2$ is 0.7544.

c. It is observed that the thermal gradient does not show variations so there are no viable oil and gas deposits.

In the case of the Suraia drilling, several horizons considered productive were analyzed following the analysis of the resistive gradient.

The following productive layers were perforated:

-2070-2070, without oil product flows,

-2154-2160, without oil product debts,

-2234-2274, without charges for petroleum products,

- 2588-2598, without oil product charges,

- 3505-3510, associated oil flow rate, 2 $m^3$/h,

-4055-4078, crude oil flow with associated gases, 7 $m^3$/day.

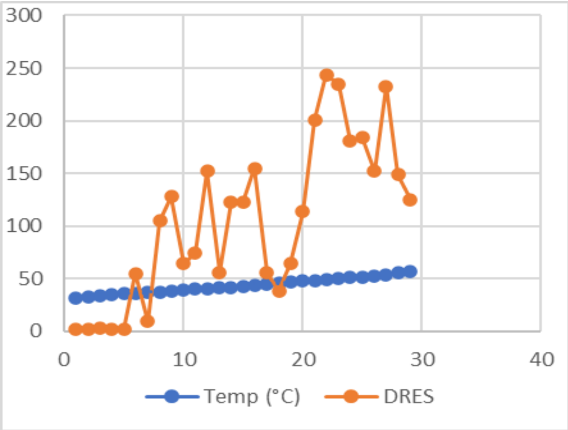


Figure 7. Thermal gradient and resistivity of layers at Vernesti drilling
Belciugatele

Analyzing the geothermal gradient and the resistivity of the geological layers, the following can be observed:

a. The equation of the geothermal gradient is

$y = 9E^{-19}x^6 - 2E^{-14}x^5 + 2E^{-10}x^4 - 6E^{-07}x^3 + 0.0013x^2 - 1.3415x + 586.4$

where y is the temperature of the geological layer and x is the depth.

The degree of error $R^2$ is 0.9841.

b. The resistivity gradient equation is:

$z = 9E^{-19}x^6 - 2E^{-14}x^5 + 2E^{-10}x^4 - 6E^{-07}x^3 + 0.0013x^2 - 1.3415x + 586.4$

where z is the resistivity of the geological layer and x is the depth of measurement.

The degree of error $R^2$ is 0.5292.

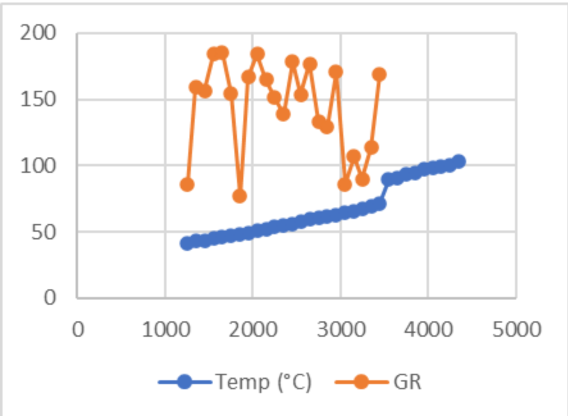


Figure 8. Thermal gradient and resistivity of layers at Suraia drilling

a. It is observed that in the area of crude oil deposits from a depth of 3505-3510, there is a sudden increase in temperature due to the increase in the flow rate of crude oil,

b. In the case of the deposit from horizon 4055-4078 the temperature increase is reduced due to the low flow 0.29 $m^3$/h.

## VI. CONCLUSION

The geological analysis of the Slobozia Depression shows the possibility of the existence of gas and oil deposits.

Following the geophysical analysis, 3 technical analysis wells were drilled.

During the drilling, the thermal testing of the geological layers and their geophysical testing were performed.

Following the analysis of the geophysical gradients (resistivity of the layers), several possible layers of the crude oil were tested.

But for the most part, these measurements did not indicate the presence of crude oil and gas deposits.

But analyzing the thermal gradient, it is found that in the area of its modification, there is the possibility to identify the presence of oil and gas deposits.

Also, following the temperature measurements, we were able to write a relationship of the form:

$y = A x^6 - B x^5 + C x^4 - D x^3 + E x^2 – F x + G$, where A, B, C, D, E, F, G are layer coefficients.

The error is over 0.999.

In the case of the geophysical gradient (resistivity) an equation of form can be written

$z = -A x^6 + B x^5 – C x^4 + D x^3 – E x^2 + F x - G$, the relationship error is very high, namely 0.82-0.52.

In the above relationships:

- y is the layer temperature ºC,
- x is the depth of the layer, m, -
z is the resistivity of the layer, ohm m,

In conclusion, we must not use for the determination of the productive layers of oil and gas, only the resistivity of the layers but especially the geothermal field.

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