Geopressure Calculations in Real-time to Calibrate Operation Windows*

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Search and Discovery Article #41931 (2016)
Posted November 21, 2016

*Adapted from extended abstract prepared for oral presentation given at AAPG/SEG International Conference & Exhibition, Exploring Frontiers in a Competitive Environment, Cancun, Mexico, September 6-9, 2016.

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Abstract

The drilling of oil wells requires big financial investments, hence the strategic importance of this activity for all worldwide operators. This condition requires the elaboration of drilling programs, in which potential risks and prevention plans should be included in order to avoid unwanted events. The monitoring of real-time parameters is presented as a preventive action that seeks to minimize the risks and uncertainties contemplated in the drilling of oil wells.

The calculation of geopressures in real-time is one of the several activities taking place within the real-time monitoring process. This is achieved by using the information from the Logging While Drilling (LWD) tools for its use in real-time calculations. The geopressure calculation in real-time permits validating and adjusting the operating window planned in order to predict the behavior of pressures during drilling.

This article proposes the development of a solution for the geopressure calculation and operating windows calibration in real-time using the resistivity and LWD logs and creating a sonic synthetic log to calculate the pore pressure, collapse and fracking gradients, in order to allow multidisciplinary teams assigned to projects to assess trends in the pressure gradients and thus facilitate decision making, establish operational procedures, and generate preventive actions.

This solution will allow for drilling optimization by making immediate engineering recommendations to prevent, minimize, or eliminate unwanted events, such as influx or kicks, lost circulation, stuck pipes, problems with the definition of the casing point or even the loss of the well, while maximizing the options to achieve an optimum cementing of the casing and ensure a safe operation even in overpressured zones.

Introduction

Monitoring parameters in real-time is presented as a preventive action that seeks to minimize the risks and uncertainties listed in the drilling of oil wells. Calculating geopressures validates or adjusts the planned operational window in order to predict the behavior of pressure while drilling.

Currently geopressures are calculated using Resistivity and Gamma Ray logs with LWD or tools after running of electrical cable, for which you must wait to receive them in an customary format and then to import them into diverse specialized applications, which take much time to get any response to the analysis. In addition, for reasons of time and costs, often the sonic logs are not available, even though they are better for analysis than resistivity logs.

Due to the above, we decided to perform a solution for the calculation of a sonic synthetic log from the resistivity logs taken with LWD tools, utilizing the González equation. This equation was tested with onshore well data from the Southern Region of Mexico, obtaining optimal results for planning, tracking, and forecasting of geopressures in deep wells in the presence of salt intrusion.

Developing

The geopressures in real-time solution is based on the Terzaghi equation (Figure 1) and was validated with the results obtained in different wells. The formulas implemented were as follows:

- Calculation of Sonic Synthetic log (DT) by González's equation.
- Calculation of Density Synthetic log (RHOB) by Gardner's equation.
- Determination Pressure Overload (OBG) through compressional transit time.
- Determination of Pore Pressure (PP) using Eaton's coefficient.
- Fracture Pressure Determination (FG) using Eaton's coefficient.

Sonic Synthetic Log

Modeling of sonic log is needed in the development of geomechanical models. These models are based on the information provided by porosity and sonic logs (DTC), which generally are outlined in the reservoir, leaving, therefore, some formations without log information.

Considering the above, the necessity arises from generating synthetic sonic log for calculating overburden pressure by using resistivity electric logs, which are available to all wells. The calculation of a sonic synthetic log from the resistivity log taken with LWD tools was compiled from the González equation (Figure 2); it was tested with onshore wells data from the Southern Region of Mexico, where optimal results were obtained for planning, tracking, and forecasting geopressures in deep wells in the presence of salt intrusion.

The second term of the equation is the solution for the calibration of pseudo-sonic registration salt and Cretaceous formation where equations of Faust and Smith did not fit. The coefficients of the equation are the product of the previous calibration logs and Sonic - Resistivity profile in correlation wells (Figure 3).

This calculation is innovative, because, it allows calculation of overburden in real-time, avoiding the use of correlation wells, obtaining synthetic curves that fit between 80 - 100% to real DTC logs per field, allowing the calculation of a Density (RHOB) log to determine the pressure overload (OBG); then the Pore and Fracture gradients are calculated.

Density Log (Rhob)

The density log of the rock is determined by use of the Gardner's sonic equation (Figure 4).

Overburden Calculation (OBG)

Calculating the synthetic overload density log through compressional transit time was performed (Figure 5).

Pore Pressure

The solution calculates Pore Pressure (PP) using Eaton´s resistivity method (Figure 6). It is based on the principle that normal compaction trend is altered in the area of abnormal pressure. Eaton used a large amount of data from geophysical logs and measurements of pore pressures of different geological to develop a series of equations, which directly relate pore pressure with the amount of deviation between the observed values and those obtained from extrapolation of the normal trend. The solution allows onr to calibrate the pore pressure, with the adjustment of Eaton´s coefficient.

Fracture pressure

The solution calculates the fracture pressure (*PF*) through the Eaton´s method (Figure 7). Eaton´s equation/coefficient for calculating the fracture pressure (*PF*) is a function of pore pressure (*PP*) and overload (*OBG*), previously calculated, as well as Poisson's ratio (v)

Poisson's ratio is a mechanical property of the rock. It is the ratio of the lateral and longitudinal deformation of a body when subjected to an axial tensile force or compression. This provided the stress state located within the elastic range of the material. This responds to the submission of a body at an axial tensile force, where it not only lengthens but also shrinks laterally. Similarly, a compressive stress acting on a body causes it to contract in the direction of that stress and to expand laterally. The solution allows the calculation of the Poisson ratio through empirical equation (Figure 8). Additionally values can be used of Poisson ratio determined by laboratory tests or by analysis of formation integrity tests.

The implemented solution also includes:

- Sampling intervals to filter and Gamma Ray / Resistivity values received in real-time, which aims to provide a curve of pore pressure and fracture gradient with better appreciation based on their tendency.
- Shale base line to identify shale section: This baseline must be taken to evaluate the description lithology in neighboring wells. Additionally, it is necessary to agree with the values from the geology team.
- Filtering shales establishes a mathematical method for calculating the dispersion of the data and calculating the best trend.
- Train normal compaction: All the properties of rock lithology measurements, sonic logs, density, temperature are directly related to measuring the porosity of the rock. The definition, train normal compaction trend, allows for reducing porosity with increasing depth. A deviation from this normal trend is indicative of abnormal pressure. This module allows the definition of standard linear compaction train. Compaction trains may vary by geological events such as reverse faults, intrusion of salt domes, etc. So this module allows one to define several trains of compaction and thus to calibrate the geopressures in the presence of a geological event that disrupts the normal basinal compaction train.

Tests and Results

Several wells with different characteristics were considered to perfom the tests in order to prove the reliability of the solution. Below you can see the characteristics of some wells we used and the results obtained during tests with the current model.

Well I

General Conditions of Well

Tests on a well which were not available in real-time. The logs used were available for testing in the standard WITSML.

Results

A similar trend to the planned values of the well is observed. The logs evaluated were for overload, pore pressure, and fracture gradient (Figure 9).

Well II

General Conditions of Well

Classification: development well that had data transmission in real-time.
Type: “slant”
Objective: Well re-entry, displacement of 668 m, maximum inclination of 23.55° and azimuth of 316.30° to test KS and KM formations.

Results

Logs and necessary information for calculating the geopressures were loaded for analysis. Engineering personnel calibrated values for setting the geopressures, in parallel with software normally used by the operator. The pore pressure curve obtained with our software presents a deviation of +/- 5 - 10% with respect of the calculated curve obtained with the software normally used by the operator; this variation is in magnitude by not in trend. In calculations of fracture pressure the curves are equal in magnitude and trend (Figure 10).

Well III

General Conditions of Well

Classification: development well, which had data transmission in real-time.
Type: “slant”
Objective: Well re-entry, displacement of 267 m, maximum inclination of 34.88° and azimuth of 209° to test KS and KM formations.

Results

Logs and necessary information for calculating the geopressures were loaded for analysis. Engineering personnel calibrated values for adjusting the geopressures, in parallel with software normally used by the operator. The pore pressure curve obtained with our software presents a deviation of +/- 5 - 10% with respect of the calculated curve obtained with the software normally used by the operator; this variation is in magnitude but not in trend. In calculations of fracture pressure the curves are equal in magnitude and trend (Figure 11).

Conclusions

With the Synthetic sonic log we obtained the curve of density and overburden adjusted to the fields under study in Mexico. The final results (Curves of pore pressure and pore fracture) of this solution have a 10% deviation from the results obtained with the software normally used by the operator; this deviation is in magnitude is not in trending. Adjustments are required in Eaton coefficients for pore pressure curve at a percentage <= 5%. The equations used to calculate pore pressure work for intervals and interbedded of shales.

Applying this solution, the company reduced time and cost because it allowed to calculate the synthetic sonic log and thus prevent further running (in case of electric cable) or using an additional tool in LWD, additionally the solution allowed to maintain the calibration of the operation window while drilling, helping to make recommendations in Real-time.

Selected References

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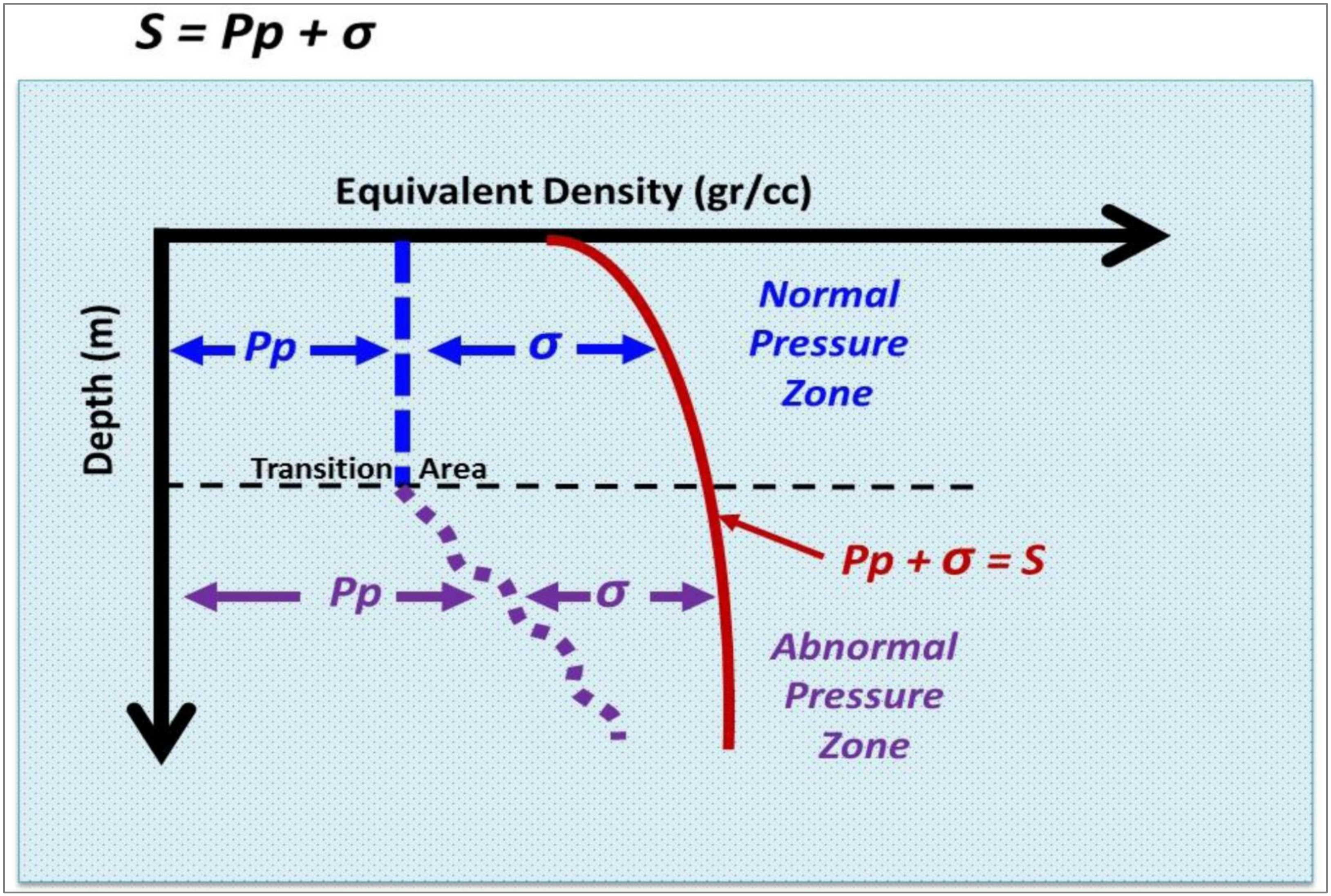

Figure 1.Terzaghi equation for overburden. Where S = Overburden; Pp = Pore Pressure; σ = Interstitial strength rock matrix.

$$DT = \alpha * (Z * R_t * \gamma)^{-\beta} + (R_t * \delta)^{\theta}$$

$$(R_t * \delta)^{\theta}$$

Figure 2. Calculation of sonic synthetic log from the resistivity log taken with LWD tools, based on González equation. Where *Z* = Depth; *Rt* = resistivity; α, β, γ, δ, θ = coefficients adjusted according to the field under study.

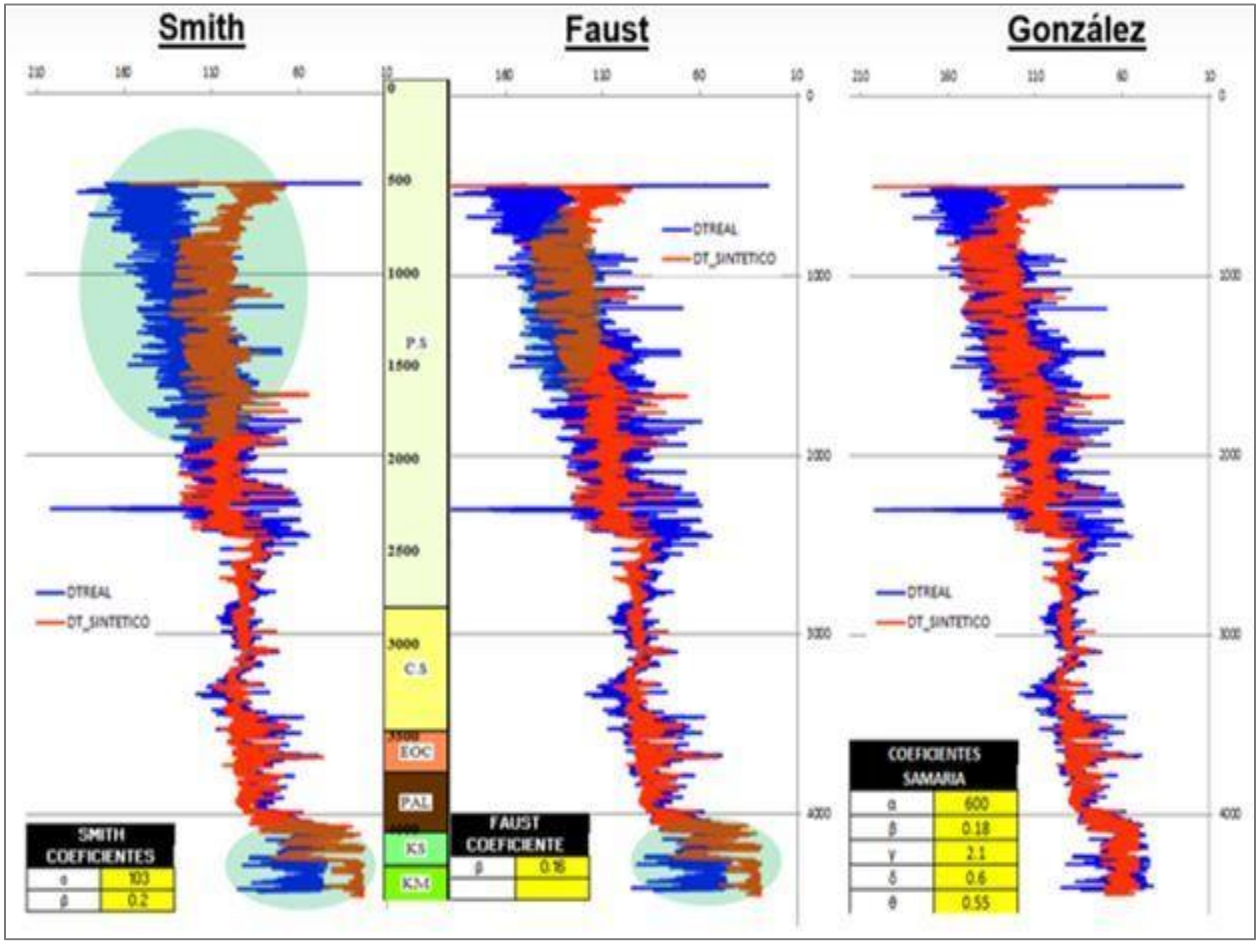

Figure 3. Sonic and resistivityprofiles in correlation wells used in calibration.

$$P_b = a\left(\frac{10^6}{\Delta t}\right)^b$$

Figure 4. Gardner Sonic equation. Where $\alpha = 0.23$; $b = 0.25$.

$$S = \frac{\sum_{n=1}^{n} \rho_{Fi}\left(D_i - D_{i-1}\right)}{10}$$

Figure 5. Equation for synthetic overload, using compressional transit time. Where ρ_{Fi} is the average density of formation (gm/cm^3), between D_i & D_{i-1} depths.

$$P_P = \left(OBG - PP_N\right)\left(\frac{Ro}{Rn}\right)^X$$

Figure 6. Pore pressure (P_P) through Eaton´s resistivity method. Where OBG = Overburden pressure gm/cc; PP_N = Normal pore pressure (1.03 – 1.06) gm/cc; Ro = Observed registration (µs/ft); Rn = Normal Registration (µs/ft).

$$PF = PP + (OBG - PP)\left(\frac{V}{1-V}\right)$$

Figure 7. Equation for calculation of fracture pressure, using the Eaton coefficient. Where *PP* = Pore pressure gm/cc; *OBG* = Overburden pressure gm/cc; *V* = Empirical or Sectional Poisson ratio.

$$v = 0.00000000017728 * D^2 + 0.0000094748424 * D + 0.372434086$$

Figure 8. Equation for empirical calculation of Poisson ratio. Where *v* = Poisson ratio; *D* = Depth (m).

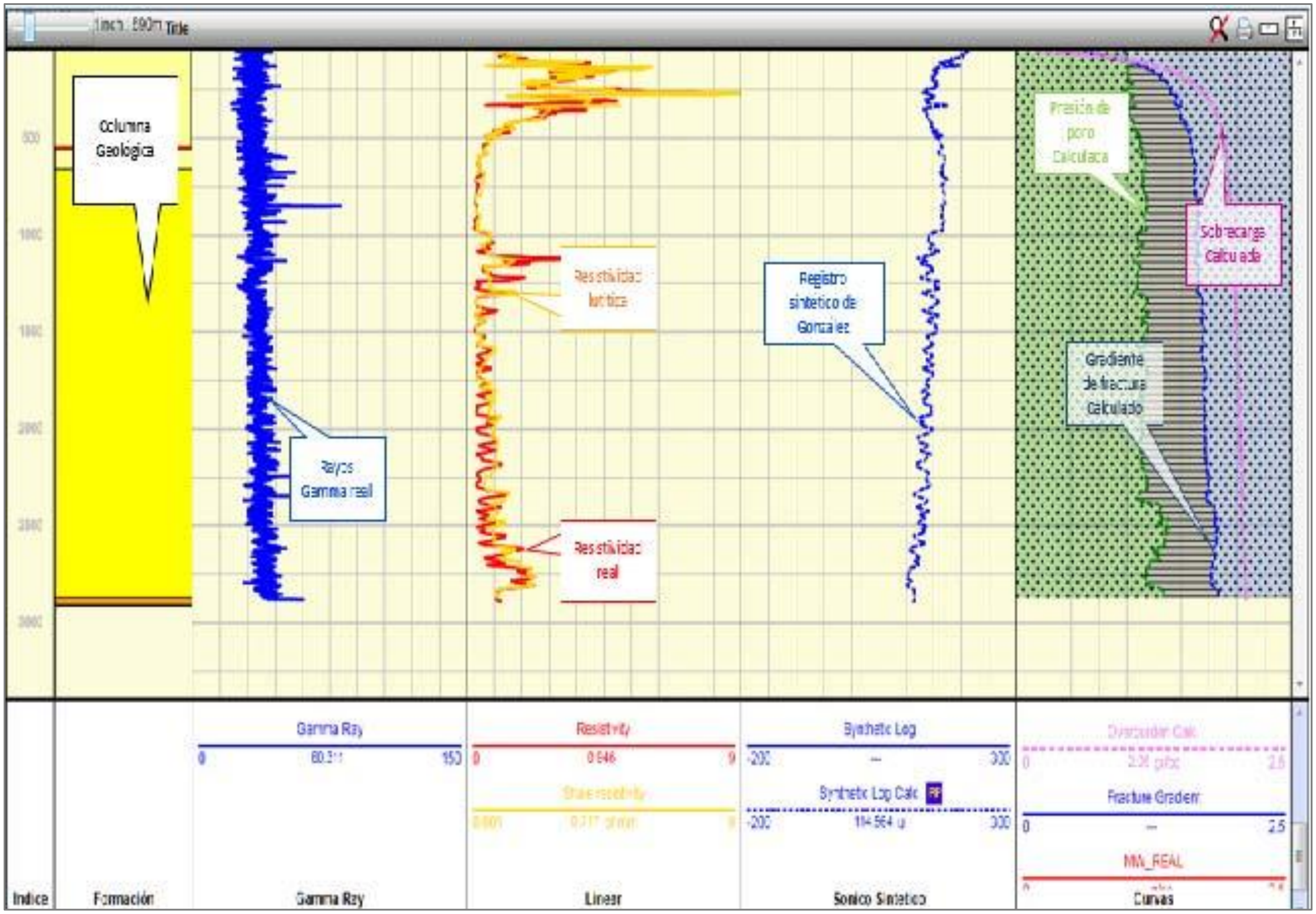

Figure 9. Logs of Well I, with evaluation of overload, pore pressure, and fracture gradient.

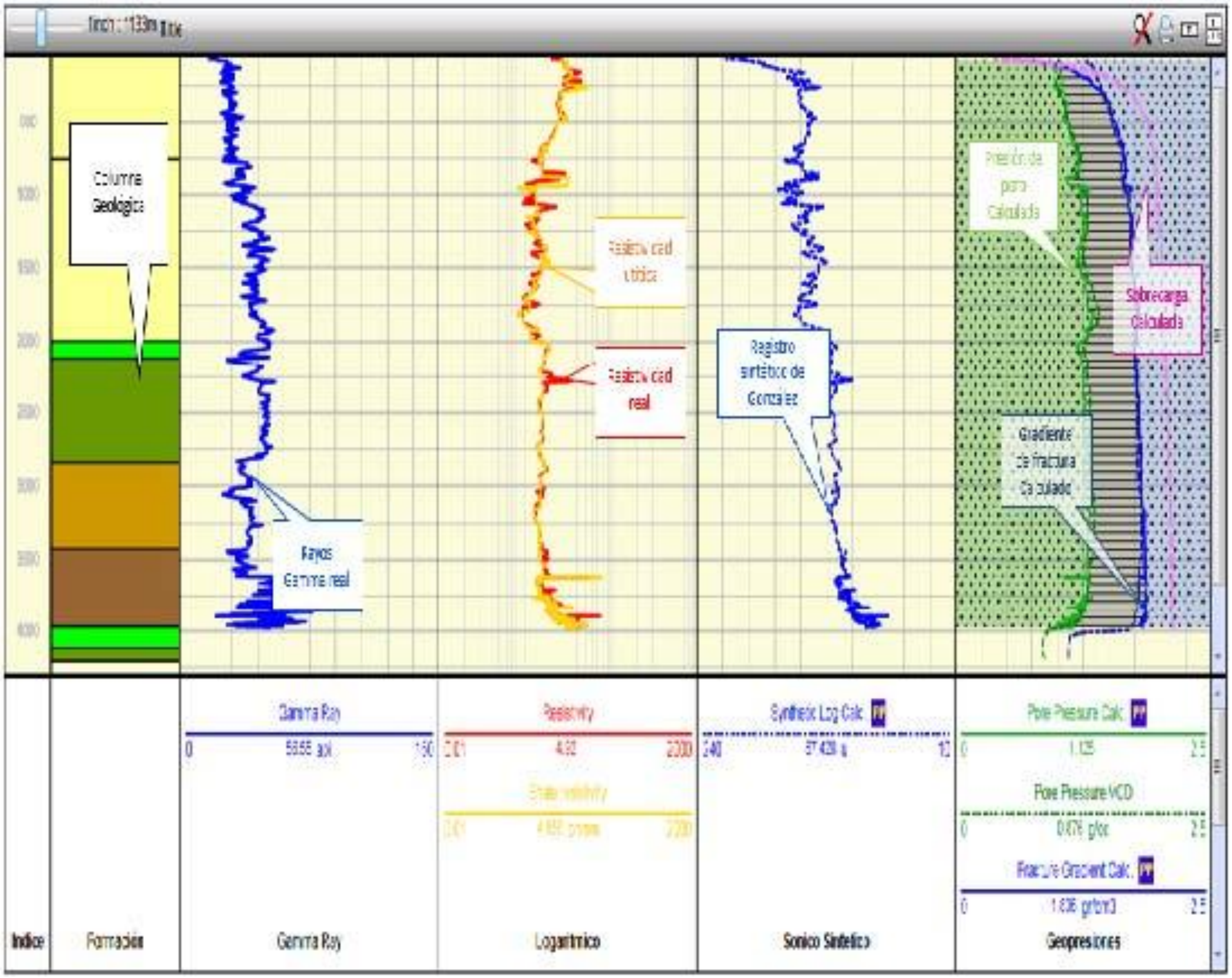

Figure 10. In calculations of fracture pressure in Well II, the curves are equal in magnitude and trend.

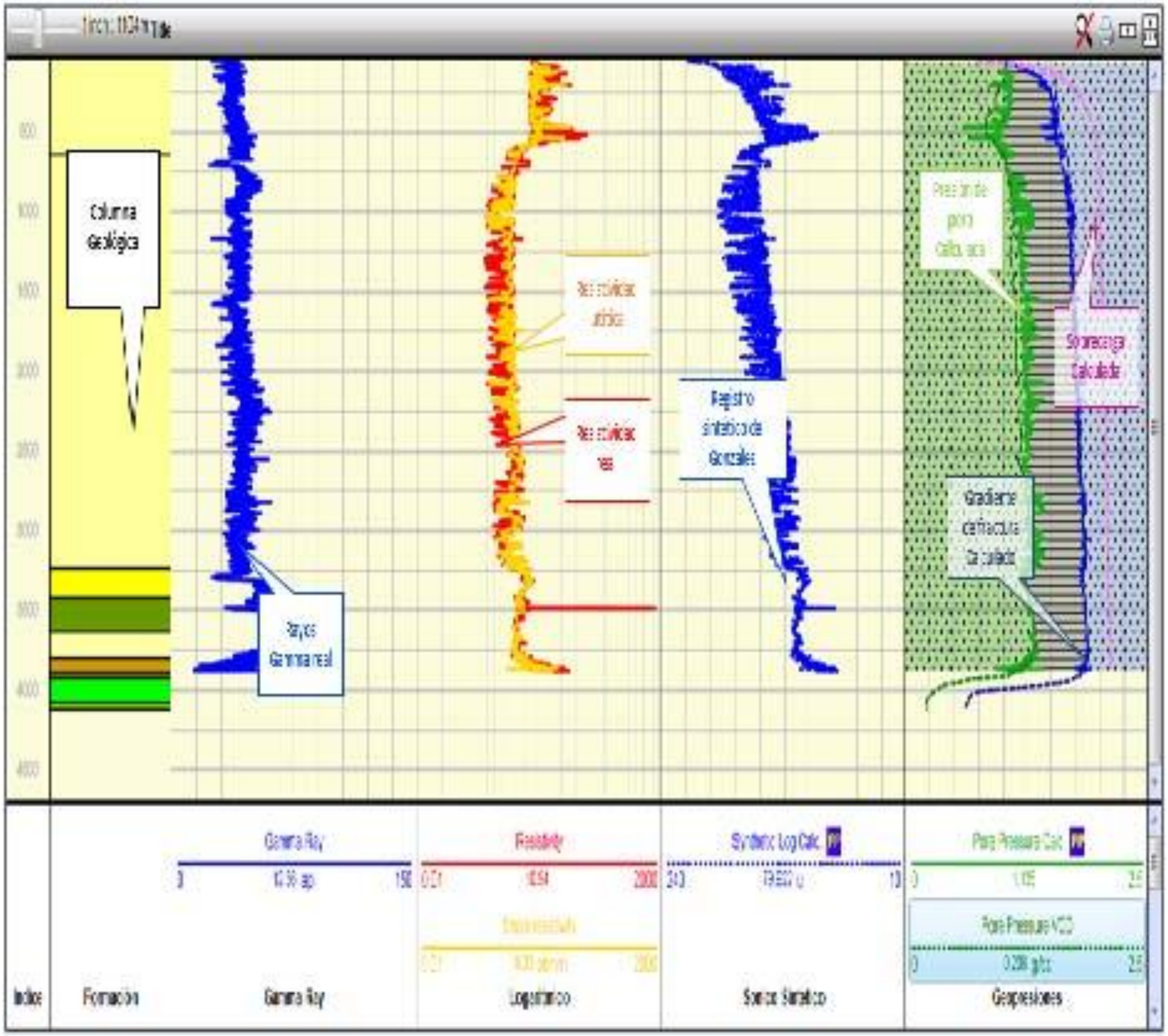

Figure 11. In calculations of fracture pressure in Well III, the curves are equal in magnitude and trend.