Application of Elastic Parameters in the Basin Modeling of Unconventional Reservoirs*

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Search and Discovery Article #41935 (2016)**
Posted November 21, 2016

*Adapted from extended abstract based on oral presentation given at AAPG/SEG International Conference & Exhibition, Cancun, Mexico, September 6-9, 2016

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Abstract

Exploration appraisal for the unconventional reservoir has diverse and varied techniques and methodologies in order to define the sweet spot. These techniques and methodologies can contrast according with the type and amount of acquired information on an area. In this work we show a new application of a mathematical model that takes into account the effective elastic properties of rocks to generate new rock physics templates that can simultaneously characterize the mineralogy, organic matter and fluids for formation with characteristics of unconventional reservoirs. Lithology of geological formations obtained from the rock physics templates are loaded into basin modeling software, as lithological mixtures for different intervals of the geologic column. Considering a thermal model related to the particular evolutionary tectonic history of the geologic column and the geochemical characteristics of source rocks in the basin modeling; subsidence and burial history are calculated through geological time (Figure 6); and several properties like source rock maturity, hydrocarbon saturation, gas oil ratio (GOR), pressures, etc., are estimated. Based on these properties, the 1D, 2D and 3D locations with better conditions (sweet spot) for the exploration of unconventional reservoirs are defined.

Introduction

There are several parameters and variables used to define a geological model and loaded in the software to model an oil system, and even more when the basin model is applied to unconventional reservoirs. Lithology, petrophysics, TOC, elasticity and brittleness parameters are the most important data to characterize the higher-interest prospective zone. The rock physics templates designed by Nicolás-López and Valdiviezo-Mijangos (2016) can analyze all of these parameters together in one-step. These ternary diagrams allow us to select lithological mixtures and classify the interval 3D with higher TOC and presence of hydrocarbons.

The lithological mixtures are characterized by their mineral content and effective properties. To make this task easier, the templates are plotted based on Lambda-Rho versus Mu-Rho. A self-consistent scheme calculates the elastic mineral contribution given the elastic pure minerals, i.e. quartz, calcite and clay. Additionally, the presence of hydrocarbons shifts and resize the elastic templates of the lithological mixtures as a function of the fluid type content in the pore, as heavy oil or dry gas.

Therefore, the contribution of this work is supported by the new rocks templates, which are built from a micromechanics model developed by Sabina and Willis (1988). This model was originally made to describe the dispersion and attenuation in composite materials and Nicolás-López and Valdiviezo-Mijangos (2016) made improvements to model the heterogeneity of the shale rocks. The bulk, shear and density effective modulus are calculated with the self-consistent equations,

$$\kappa_0 = \kappa_{n+1} + \sum_{r=1}^{n} \frac{\alpha_r(\kappa_r - \kappa_{n+1})}{1+3(\kappa_r-\kappa_0)/(3\kappa_0+4\mu_0)} \quad (1)$$

$$\mu_0 = \mu_{n+1} + \sum_{r=1}^{n} \frac{\alpha_r(\mu_r - \mu_{n+1})}{1+2(\mu_r-\mu_0)[2\mu_0+(3\kappa_0+4\mu_0)]/[5\mu_0(3\kappa_0+4\mu_0)]} \quad (2)$$

$$\rho_0 = \rho_{n+1} + \sum_{r=1}^{n} \alpha_r(\rho_r - \rho_{n+1}) \quad (3)$$

where κ_0, μ_0 and ρ_0 are the bulk, shear and density effective properties, the subscript $n+1$ indicates the mechanical properties of the matrix, r to n are number of heterogeneities that are embedded in the matrix, these can be a mineral or a fluid; α_r, κ_r, μ_r and ρ_r are volumetric fraction, bulk, shear modulus and density for each inclusion, respectively. The Equations (1) and (2) are a non-linear equation systems that must be solved to find the effective properties which the rock physics templates are built. These equations were solved by the fixed point method. The $\lambda\rho$ $vs.$ $\mu\rho$ were made using the relation $\lambda_0 = \kappa_0 - 2/3\mu_0$. The rocks physics templates are showed in the Figure 1.

The rock physics template for the solid rock is depicted in the Figure 1a, Ov-Ni template. As was above mentioned, the presence of heavy oil shifts and resize this elastic template, Figure 1b; lower Figure 1c and Figure 1d describe the application of the new rock physics templates to estimate the elastic contribution of pure mineral for solid shale rocks; i.e. Eagle Ford, Fort St. John, Barnett, and Haynesville. Quartz, Clay and Carbonate as pure minerals are located in each vertex of the “pseudo triangle”. This elastic ternary diagram was constructed from the effective properties calculated by solving the Equations (1)-(3) for different mineral volumetric fraction α_r. Each mineral can be considered an inclusion embedded in a matrix composed by different minerals. For example, carbonate dominated lithotype means that the rock contains the 80% of carbonate, the resting 20% could be formed by any mineral combinations; i.e. 10% of Quartz, and 10% of Clay. Clearly, it is noticed that the triangle is not a “perfect” triangle because the Eqs. (1)-(2) are nonlinear equations. Herein the philosophy is “to establish a unique elastic response to each mineral combination and after that quantify the effect of the hydrocarbons for the unconventional lithology”. Several regions defining sedimentary rocks are easily delimited based on proportional lines drawn from one side to another side of the diagram. It is helpful to interpret and analyze the rock mineral quantification, lithological classification and stratigraphy units because the effective elastic properties include the heterogeneities of shale rocks. This templates were tested with data of formations of unconventional reservoirs like the Eagle Ford, Haynesville and Fort St. John.

Elastic Parameters Analysis of Shale Rocks

To analyze oil systems based on the elastic parameters, it is first necessary to obtain the values of the constants of Lamé at different depths. Then they are multiplied by the corresponding bulk density to get Lambda*Rho and Mu*Rho; also the values of these elastic parameters can be obtained from geophysical logs V_p, V_s and density applying the following equations:

$$\mu\rho = \rho \cdot \rho V_s^2 \qquad (4)$$

$$\lambda\rho = \rho \cdot \rho\left(V_p^2 - V_s^2\right) \qquad (5)$$

After the values of Lambda-Mu-Rho and Rho are obtained (Table 1), they are plotted in a cross plot diagram. The generated diagram overlaps a distribution template with mineralogical and sedimentological classification (Figure 2), where different values obtained in the cross diagram are discriminated; or to take readings of the percentages of major mineralogical components to associate to a percentage of lithological mixtures. It is advisable to cross-graph intervals of units or sub-stratigraphic units in order to further detail the application as well as reading templates depending on the detail of the vertical lithological characterization want to perform. Built templates considering the presence of fluids (Figure 1b) are used when the values of the elastic parameters are out cross plot template Figure 3.

Input to Basin Modeling of Unconventional Reservoirs

The modeling of basin and petroleum systems mainly involves three areas of geological knowledge: stratigraphy, tectonics and geochemistry. The study and analysis of each of these areas and related sciences, provide the earth elements to introduce into the model. Sedimentologic and stratigraphic analysis define the framework chrono-stratigraphic and lithologic model (Figure 4 and Figure 5); tectonics and structural geology help to establish models of thermal evolution and structural evolution, respectively, and geochemistry provides the elements related to the characteristics of the source rock, mainly organic richness and maturity, among others. In a shale gas/oil reservoir the source rock functions as reservoir and seal because of their geochemistry and lithological characteristics. The ternary diagrams provide lithology information based mineralogical composition, in addition to quantifying the presence of fluids. This information can be used in a basin model.

Modeling Results

The basin modeling applied to unconventional reservoirs (shale/oil gas) allows us to calculate basic elements to define areas of sweet spots, such as areas with optimal maturity of organic matter and areas with higher hydrocarbon saturation (Figure 6 and Figure 7), among other important elements, such as geopressures, the gas-oil ratio, oil volumes, etc.

Applications

The obtained results through the analysis of elastic parameters may be used in the development of two and three dimension modeling basins. Templates can also be used similarly to the geophysical logs, for analysis of sections and volumes of seismic inversion properties. Also to determine the horizons of interest and the definition of sedimentological facies.

Conclusions

The implementation of the lithological characterization through the use of templates of elastic parameters is a viable and expeditious alternative that can be applied pragmatically rather than a conventional petrophysical analysis. With detailed lithological characterization it is possible to generate input data for modeling unconventional reservoirs.

Acknowledgements

Thanks to the Mexican Petroleum Institute (Instituto Mexicano del Petróleo) for providing the facilities to develop this work and giving permission divulge this study.

References Cited

Nicolás-López, R., and O. Valdiviezo-Mijangos, 2016, Rock physics templates for integrated analysis of shales considering their mineralogy, organic matter and pore fluids; Journal of Petroleum Science and Engineering, v. 137, p. 33-41.

Sabina, F.J., and J.R. Willis, 1988, A simple self-consistent analysis of wave propagation in particulate composites: Wave motion, v. 10, p. 127-142.

Valdiviezo-Mijangos, O., and R. Nicolás-López, 2014, Dynamic characterization of shale systems by dispersion and attenuation of P- and S-waves considering their mineral composition and maturity: Journal of Petroleum Science and Engineering, v. 122, p. 420-427.

Nicolás-López, R., and O. Valdiviezo-Mijangos, 2015, Modelado de la fragilidad de las lutitas considerando su mineralogía, fluidos en los poros y materia orgánica utilizando un esquema auto-consistente: Independent rights in Instituto Nacional de Derecho de Autos (National Institute of Independent Rights): 03-2015-081310413700-01.

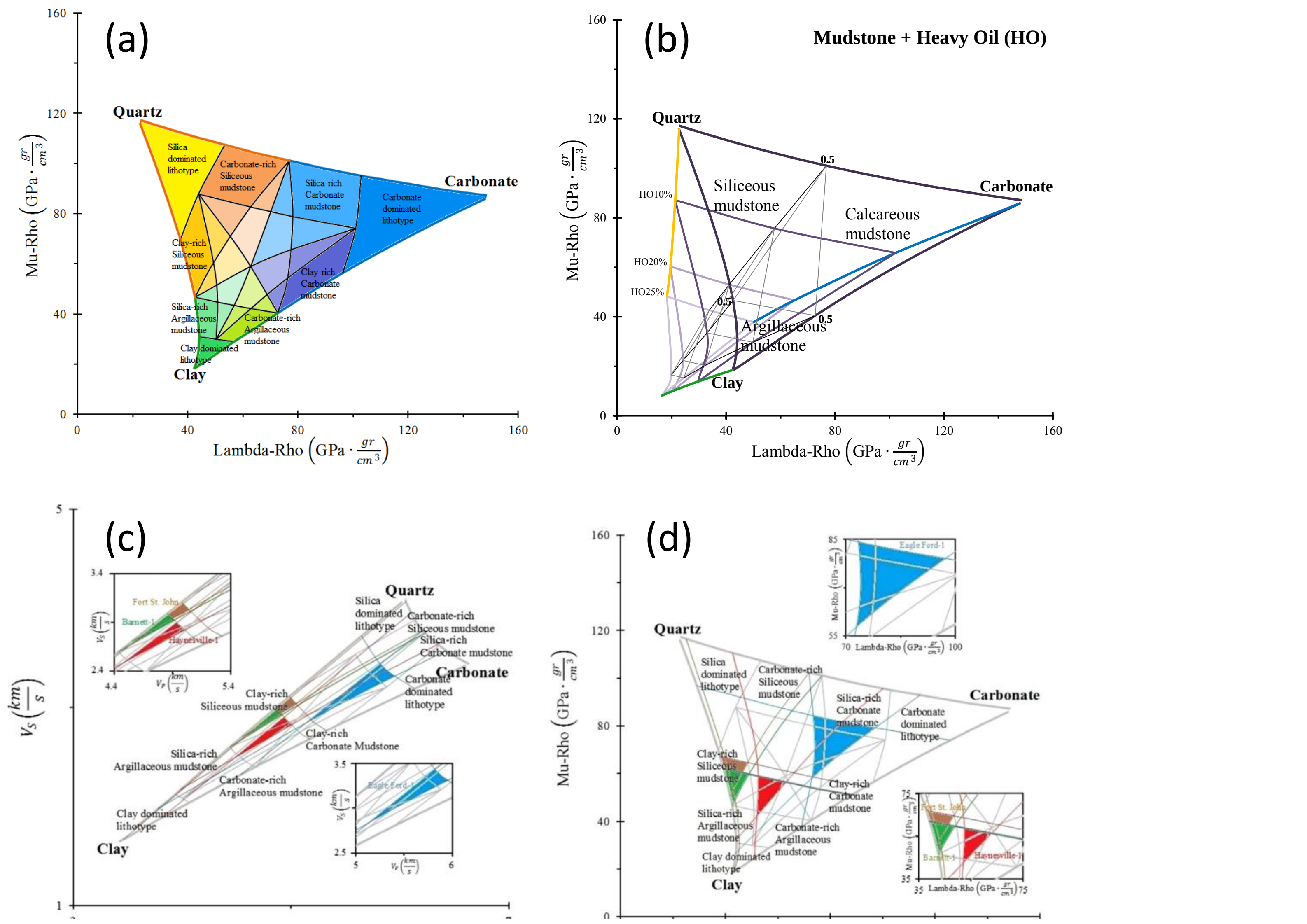

Figure 1. Rock physics templates to characterize the elastic response of mixed sedimentary lithologies based on Quartz-Clay-Carbonate mineral classification. (a) Elastic-property contribution of the myriad of pure mineral combinations, Ov-Ni template, (b) elastic effect of the fluid content in the pores, (c) application of shale based on Vp and Vs, and (d) the same application based on Lambda-Rho Mu-Rho. Figures (b), (c), and (d) after Nicolás-López and Valdiviezo-Mijangos (2016).

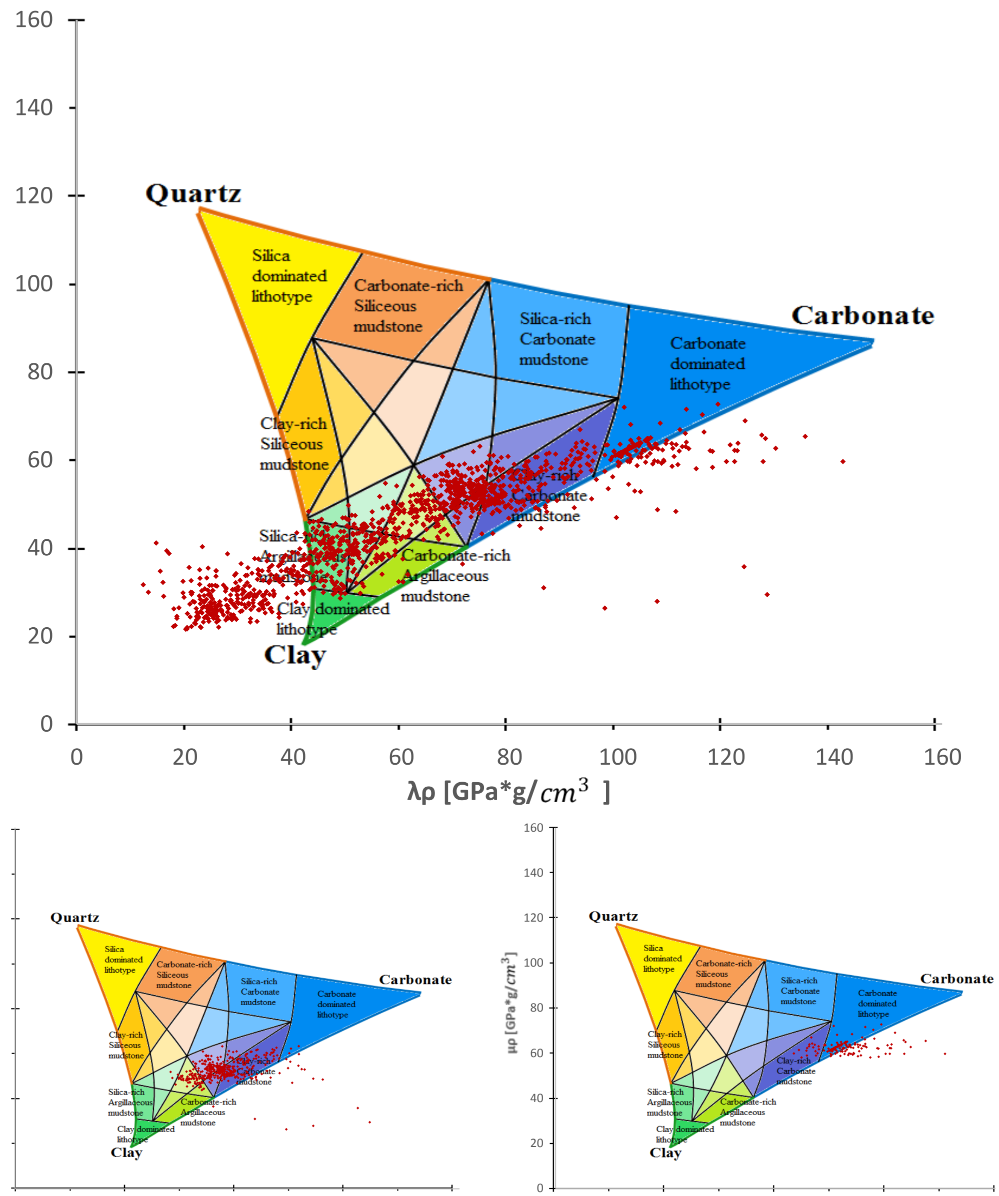

Figure 2. Different values obtained in the cross plot are discriminated in the templates, and readings of the percentages of the main mineralogical components are taken to associate to a percentage of lithological mixtures. (a) Values for all of Eagle Ford Formation, (b) top of the Eagle Ford, and (c) bottom of the Eagle Ford.

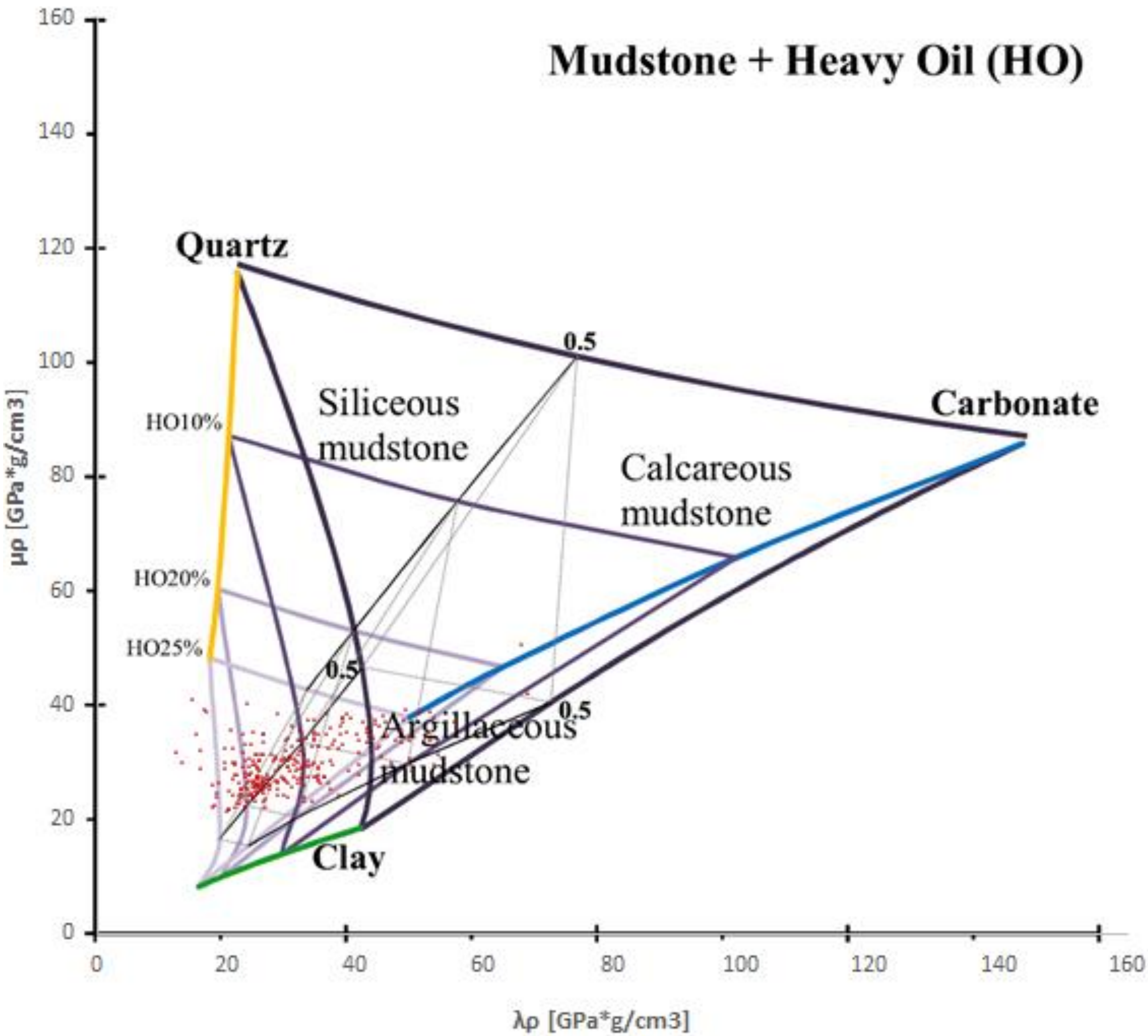

Figure 3. An interval cross plot with presence of fluid (40 m) of the Eagle Ford Formation.

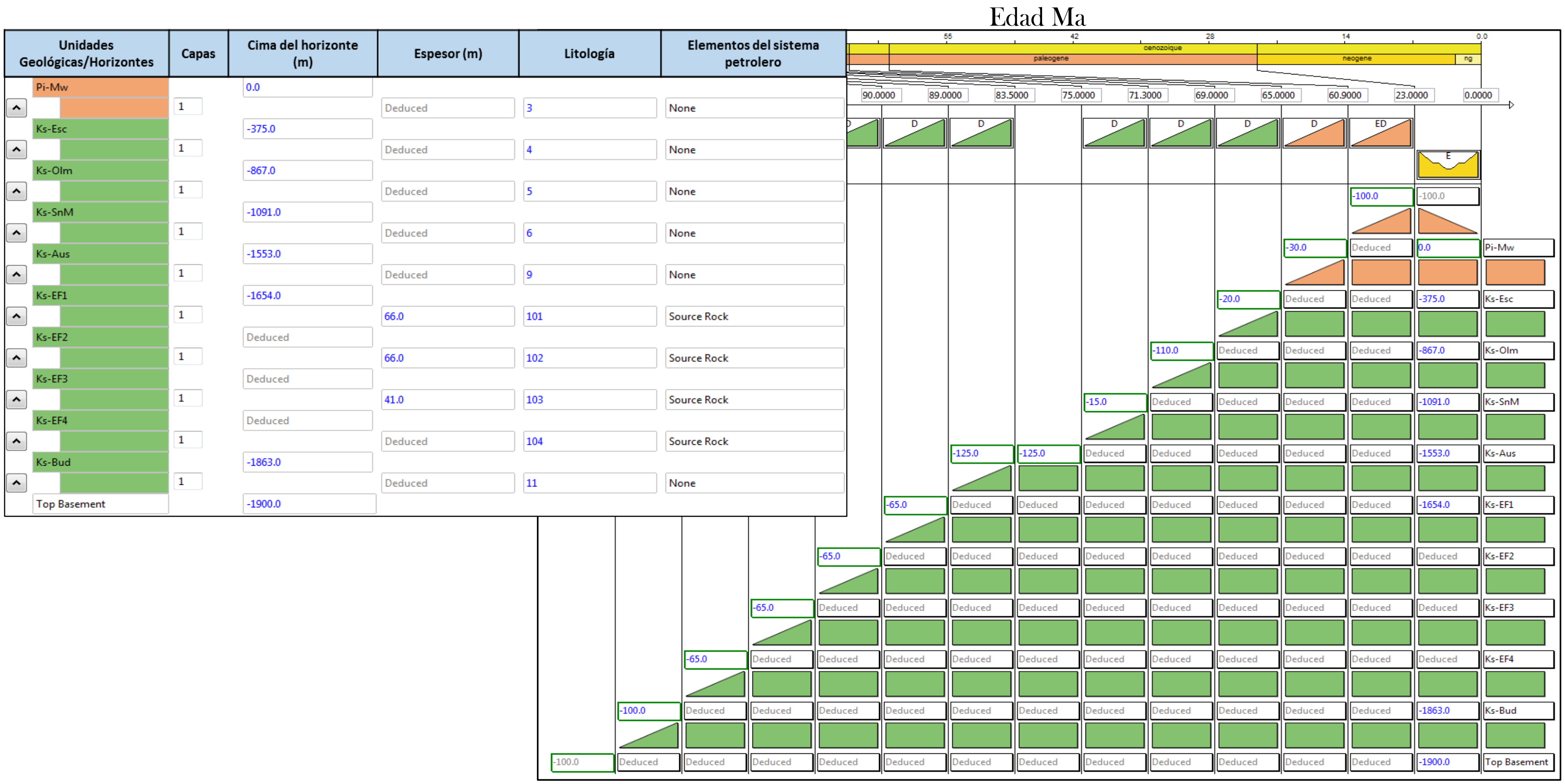

Figure 4. Here is an example chrono-stratigraphic data entry required by the modeling software.

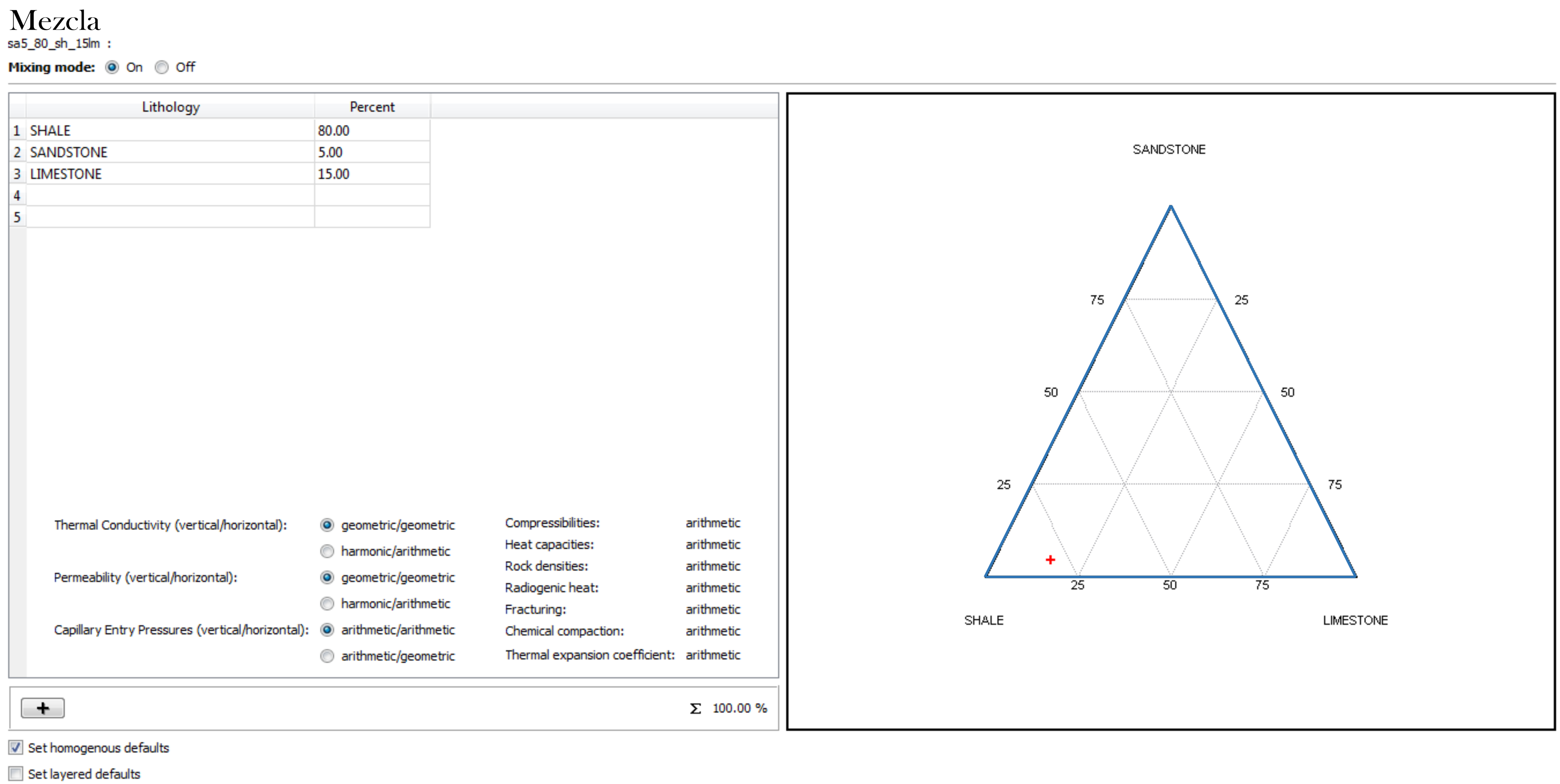

Figure 5. Example of editing mixture lithology in the modeling software.

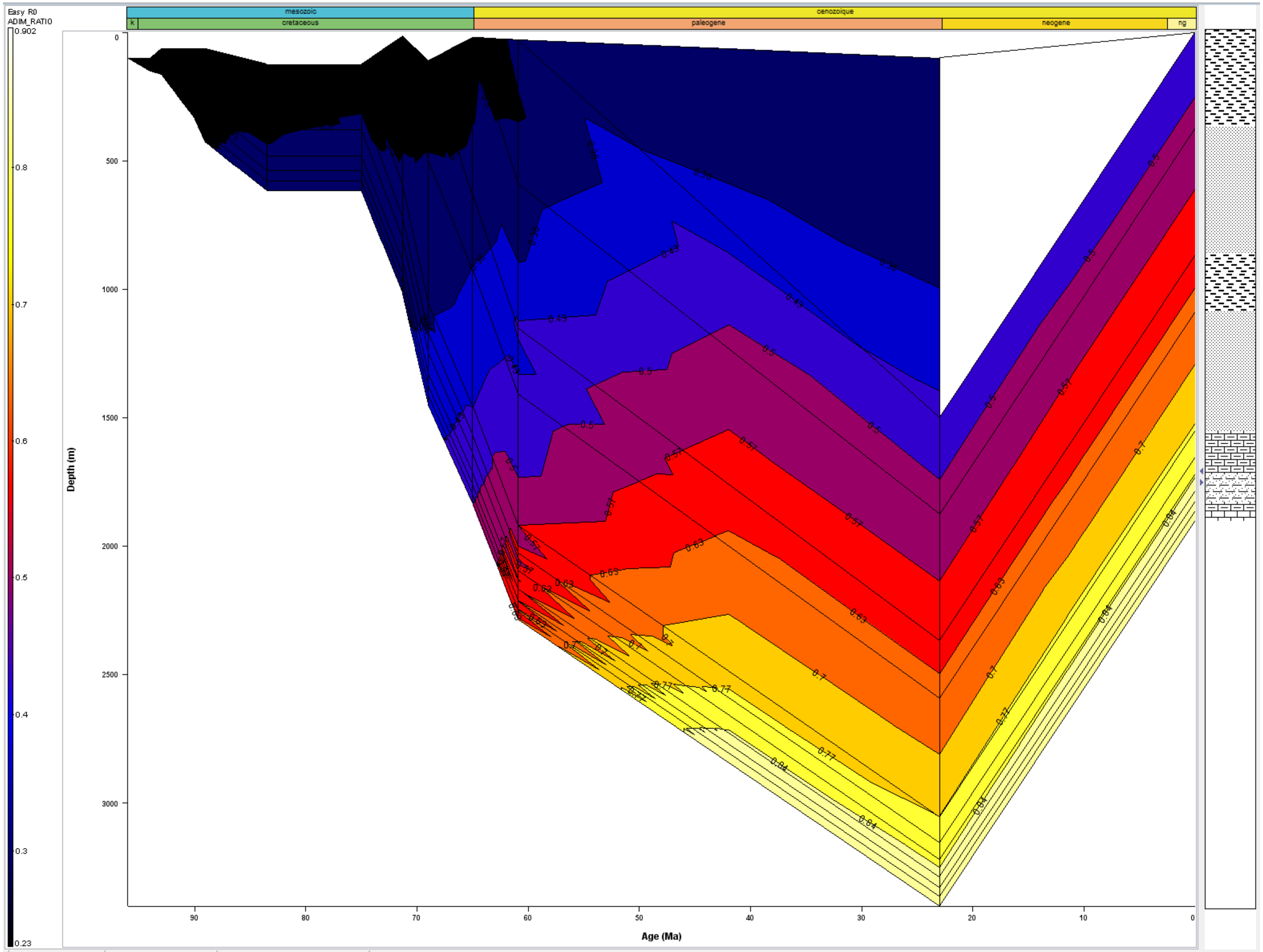

Figure 6. 1D modeling of burial analysis of maturity of organic matter.

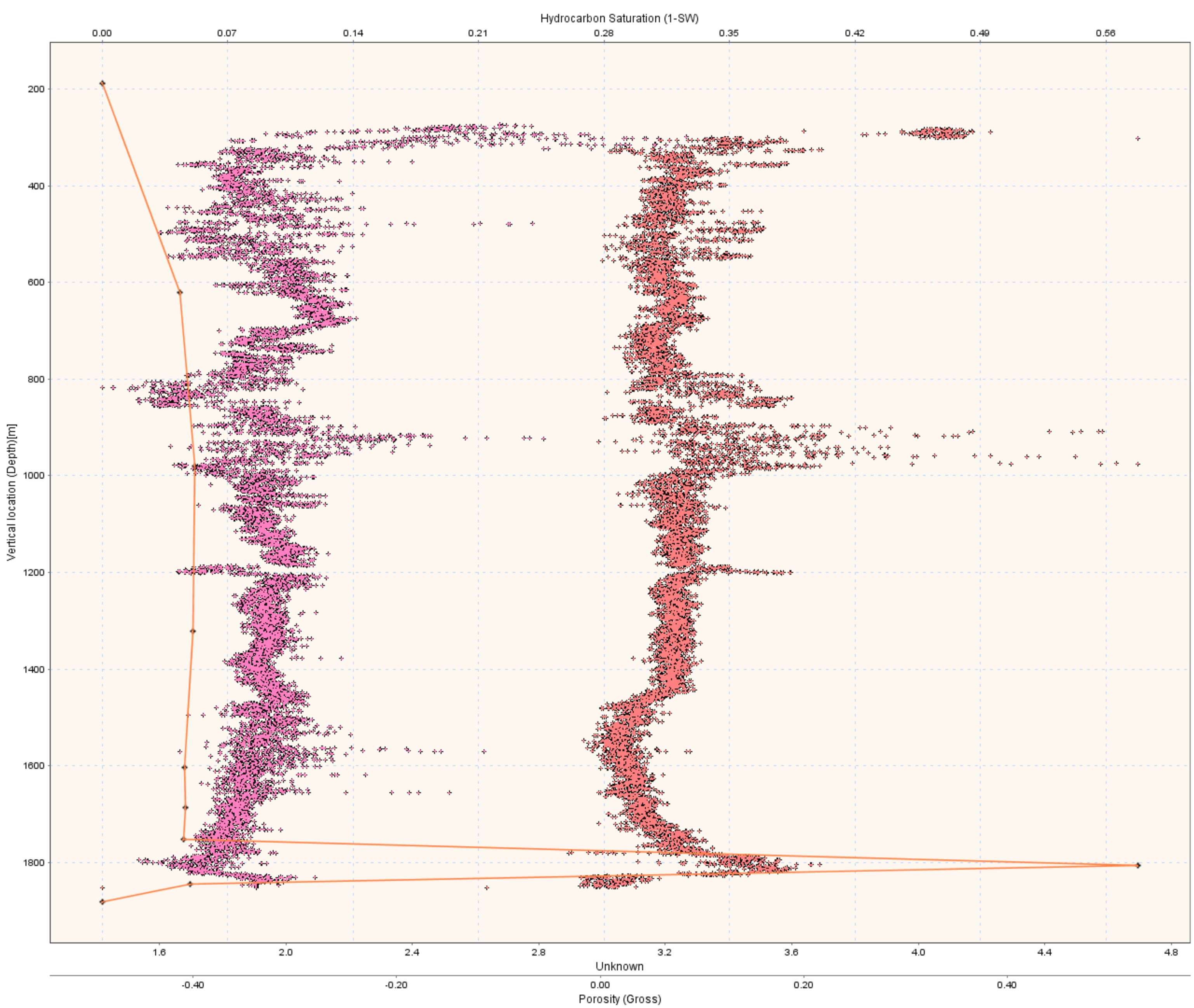

Figure 7. Well log V_p/V_s (pink), density log (orange) and the modeled curve of hydrocarbon saturation.

Prof	RHOB [Kg/m³]	Vp [m/s]	Vs [m/s]	RHOB [g/m³]	Vp [Km/s]	Vs [Km/s]	μ [Gpa]	λ [GPa]	μ [Pa]	λ [Pa]	λ*Rho [Gpa*g/cm³]	μ*Rho [Gpa*g/m³]
281.791	2160	4288.88632	1758.26204	2.16	4.28888632	1.75826204	6.67760849	26.3770022	6677608492	2.6377E+10	56.9743247	14.42363434
281.944	2160	4386.41937	1694.91525	2.16	4.38641937	1.69491525	6.20511347	29.1496308	6205113473	2.915E+10	62.96320253	13.4030451
282.096	2143.5	4196.38186	1658.17992	2.1435	4.19638186	1.65817992	5.89368324	25.9588555	5893683240	2.5959E+10	55.6428068	12.63311003
282.249	2131.3	4018.6853	1575.18566	2.1313	4.0186853	1.57518566	5.28820257	23.8437309	5288202568	2.3844E+10	50.81814367	11.27074613
282.401	2123.9	3934.16216	1565.33261	2.1239	3.93416216	1.56533261	5.20412032	22.4647017	5204120323	2.2465E+10	47.71277996	11.05303115
282.553	2142.6	3906.99105	1560.34033	2.1426	3.90699105	1.56034033	5.21650666	22.2728738	5216506659	2.2273E+10	47.72185948	11.17688717
282.706	2152.6	4002.87345	1601.0001	2.1526	4.00287345	1.6010001	5.51754716	23.4560066	5517547160	2.3456E+10	50.49139986	11.87707202
282.858	2164.4	4048.42705	1613.76572	2.1644	4.04842705	1.61376572	5.63661661	24.2007668	5636616608	2.4201E+10	52.38013957	12.19989299
283.011	2156.1	4105.06156	1644.85578	2.1561	4.10506156	1.64485578	5.8334375	24.6667098	5833437501	2.4667E+10	53.18389292	12.5774746
283.163	2147.3	4167.92584	1678.7284	2.1473	4.16792584	1.6787284	6.05136846	25.1993123	6051368463	2.5199E+10	54.1104832	12.9941035
283.315	2139.3	4127.31298	1666.9857	2.1393	4.12731298	1.6669857	5.94477523	24.5528099	5944775232	2.4553E+10	52.52582615	12.71765765
283.468	2144.4	4062.32632	1644.39433	2.1444	4.06232632	1.64439433	5.79852776	23.7908951	5798527755	2.3791E+10	51.0171954	12.43436292
283.62	2122.4	4055.13817	1651.69233	2.1224	4.05513817	1.65169233	5.79009305	23.3208685	5790093053	2.3321E+10	49.49621129	12.2888935

Table 1. Well log data measured V_p, V_s and RHOB and calculated data of the other elastic parameters.