RockMat: A Comprehensive MATLAB Toolbox for Rock Physics Modeling

Abbasi, Mostafa[1]

[1]*Geophysicist, National Iranian Oil Company, Exploration Directorate, abbasi.mstfa@gmail.com*

ABSTRACT

In the past decade, a wide variety of rock-physics modeling publications for different reservoir rocks have been emerged as workflows and case studies. But these studies are generally very case-specific and limited to few rock-physics models. Besides, these literatures rarely describe the workflow details and codes and are specific to that reservoir. To address these limitations, I have developed a comprehensive and easy-to-use rock-physics modeling toolbox in MATLAB (RockMat) that cover a wide variety of models to define the rock properties. These models include theoretical models (such as inclusion, crack and contact models), bound models, experimental models and fluid effect models (including fluid substitutions and frequency-dependent attenuation models). RockMat is developed in a modular scheme where the models can easily be combined to define more sophisticated models. The models are validated with different industrial packages and/or the original literatures.

Keywords: Rock-Physics Modelling, Software, MATLAB, Reservoir Characterization

INTRODUCTION

Rock-physics is a multidisciplinary field of study that has long been used to characterize rock properties based on the behavior of seismic waves propagating through them. This requires consideration of how the composition of a rock dictates its stress-strain relationship and thus seismic response. Primarily, this knowledge was mostly using experimental models to study the Earth's interior properties (Birch, 1952) but later, more theoretical models were involved to study the elastic properties of rocks. The fundamental theoretical concepts of rock physics are coming from the science of metallurgy and mechanics of solid material where the primary target is the solid phase. But, in the hydrocarbon industry this objective is shifted to the fluid phase, due to the importance and variability of the pore fluids.

In a standard seismic interpretation workflow, rock physics is used to relate impedance and elastic parameters derived from seismic data to specific rock properties. However, rock physics has a wide range of applications in different studies, such as studying the effect of fluid extraction and injection on the reservoirs, quantitative interpretation of changes in seismic responses due to changes in rock and fluid properties, sequestration of CO2 into depleted reservoirs or exploration of geothermal energy.

One of the earliest open-source projects to develop rock physics models is the QSI toolbox from The Stanford SRB team that is a complement to Avseth et al's (2018) book, "Quantitative Seismic Interpretation". This library is very limited and covers just a few models. The Stanford SRB team has also developed another but much more extensive MATLAB toolbox (RPH tools) as a complementary resource to well-known Mavko et al's (2009) "Rock physics handbook". This library includes a great number of rock physics model along with a set of tools and utilities, but models are mainly limited to the book and must be applies in sample-by-sample scheme rather than a vector (matrix) scheme. Another effort to this subject is a Python package RockPhyPy (Yu et al, 2023) which is a recent and comprehensive set of many rock physics models that are stored into classes.

Comparing to the RPH toolbox, RockMat includes a greater number of effective medium models from different resources and literatures. Furthermore, functions and model presented in RockMat are coded using the matrix algebra such that they can be applied on the whole well-log or seismic trace at once. This makes the code much more efficient comparing to the SRB toolbox, where the codes are applied under a sample-by-sample scheme. This property makes the RockMat a fast and reliable tool for rock-physics inversion where, generally, a huge number of forward computations are required during the process.

Codes Breakdown

The codes presented in this toolbox are generally follow the formulation presented in the Mavko et al’s (2020) “The Rock Physics Handbook”. However, models are not limited to this book and many newer models and relations are also included in the package. Accordingly, MATLAB codes follow, more or less, the same classification as those given in this book as follows:

- **Constants**

This category includes some of the most common constant parameters relating to some of the empirical models and properties. This includes, Castagna's coefficients, Gardner's coefficients, Vernik's coefficients (of Vp-Vs relations) and the standard values of critical porosity for different rock types. Furthermore, this category also includes the standard values for elastic properties of different minerals.

- **Fluid Properties**

Fluid properties include a set of relations as proposed by Batzle and Wang (1992), for calculating the viscosity and elastic properties of different fluid types (including clean water, brine, gassy brine, dead and live oil and gas) under in-situ pressure and temperature conditions.

- **Empirical Models**

Empirical models are a set of relations between elastic and/or petrophysical properties that generally are estimated using regression on specified datasets. RockMat includes more the 30 well-known empirical relations for different rock properties.

- **Effective Medium**

Effective medium can be considered as the core of this toolbox. This category includes many functions based on different mixing law such as granular media, inclusion models, bound models crack models, and anisotropic models. Furthermore, two more specific models (i.e., Xu-White and Xu-Payne and Keys-Xu models) which are a combination of other models are also packaged into single m-files. Models presented in this category are very versatile and diverse such that they can be combine in different ways to produce more sophisticated model, specific to our desired reservoirs.

- **Fluid Effect**

Fluid effect is one of the most important but less investigate topics in the rock physics studies. In most studies this topic is limited into Gassmann’s relation and fluid substitution, while it can provide very useful information regarding the scale and frequency calibration of different elastic measurements (e.g., well-log vs. seismic or core vs. well-logs). Furthermore, RockMat includes some relations for anisotropic fluid substitution and squirt-flow. Some of the relations in this category also provide some measures of compressional and shear rock quality factor.

- **Pressure**

Functions in this category relate the elastic properties of rock to pore-pressure variations. However, codes are no more than few best-known models including Bower, Eaton, modified Eaton Hottman-Johnson models.

- **Math**

Math functions includes a variety of mathematical relations to convert different elastic properties to each other, Mathematic operations, unit conversions, tensor operations, etc.

- **Utilities**

Utility functions consists of a diverse list of simple relations to estimate various rock features such as coordination number, contact ratio, crack density, tortuosity, pore stiffness, Biot coefficient, characteristic frequency, etc. These features are mainly used as primary model parameter in other functions. It also includes some more complex models such as Thomas-Stieber fitting plot, Marion-Bam pore stiffness factor and saturated and dry modulus vs critical porosity and pore stiffness.

RockMat Key Features

RockMat includes some specific features that distinguish it from similar code packages in Rock physic. First, all the codes in the RockMat are well documented not only in terms of description and form of input/output parameters, but also regarding to description of the special considerations about the methodologies, notes and references. I have tried, as much as possible, to provide the exact address to the formulations in the literature according to which codes are implemented.

Another feature of this toolbox is that they follow the same strategies for notations, documentations, inputs and outputs, etc. This makes codes very readable and comparable and easy to understand. Besides, Similar models can easily be substituted with each other to try out various functions during the modeling.
I have tried to write the codes with maximum flexibility and Generality. For example, all inclusion models are implemented such that they can insert the different inclusions either simultaneously or sequentially.
As noted earlier, this toolbox tries to use the matrix computation capabilities of MATLAB, as much as possible to be as efficient and fast as possible. Almost all the codes can be applied to a whole column vector (such as well-logs or seismic traces) at the same time, while yet loops and if-statements are avoided. This feature makes the functions very appropriate and efficient for the rock physics inversion process.
Another feature of RockMat is that it follows a modular scheme for coding, where each specific model, feature, property or relation is packaged into a single function. These functions can then be combined to setup more complex models in few numbers of code lines. For example, Xu-White model with all of its detail in Xu and White (1996) paper, can be written as follows

```
% Partition total porosity
phisand = phit.*(1-Vsh);
phiclay = phit.*Vsh;

% Calculate matrix and fluid properties
Km = voigtreusshill([Ksh, Kqz], [Vsh, 1-Vsh]);
Gm = voigtreusshill([Gsh, Gqz], [Vsh, 1-Vsh]);
rhom = voigt([rhosh, rhoqz], [Vsh, 1-Vsh]);
Kf = reuss([Kw, Ko], [sw, 1-sw]);

% Calculate dry rock properties
[Kmbw, Gmbw] = dem(Km, Gm, Kw, 0, phiclay, 'spheroidal', aspects(1));
[Kdry, Gdry] = demdry(Kmbw, Gmbw, phisand, 'spheroidal', aspects(2));

% Saturate sand pores with fluid
Ksat = gassmann( Kdry, Kmbw, phisand, Kf );
Gsat = Gdry;

% Convert elastic properties into P- and S-velocities
rhob = bulkdensity(sw, phit, rhom, rhow, rhoo )
[Vp, Vs] = mod2vel(Ksat, Gsat, rhob)
```

Code 1. Implementation of Xu-White model. Subscripts sh, qz, w, o corresponds to shale, quartz, water and oil respectively, Vsh is volume of shale and sw is water saturation.

Almost, all the codes are verified either with the literature results or available industrial packages (e.g., RokDoc). RockMat proved to exactly reproduced the same results as these references. Figure 1 shows an example of these results for Xu-Payne model in a shaly carbonate oil reservoir. As shown, the results from RockMat toolbox can exactly reproduce the RokDoc plots, where both have a reliable correlation with original measured logs.

CONCLUSION

In this paper we introduced a new comprehensive MATLAB toolbox (RockMat) for rock physics modeling which includes a wide variety of rock physical model. This toolbox has some features that makes it preferable to available academic and industrial packages, 1) It include almost all the proven rock physical models, 2) Its results are reliable for any type of reservoirs, 3) Its modular scheme makes it a flexible tool to easily generate more sophisticated models specific to our reservoirs, 4) A detailed documentation is included in the codes, 5) Its fast and easy-to-use. These features, makes RockMat a great choice for both academic studies and industrial applications.

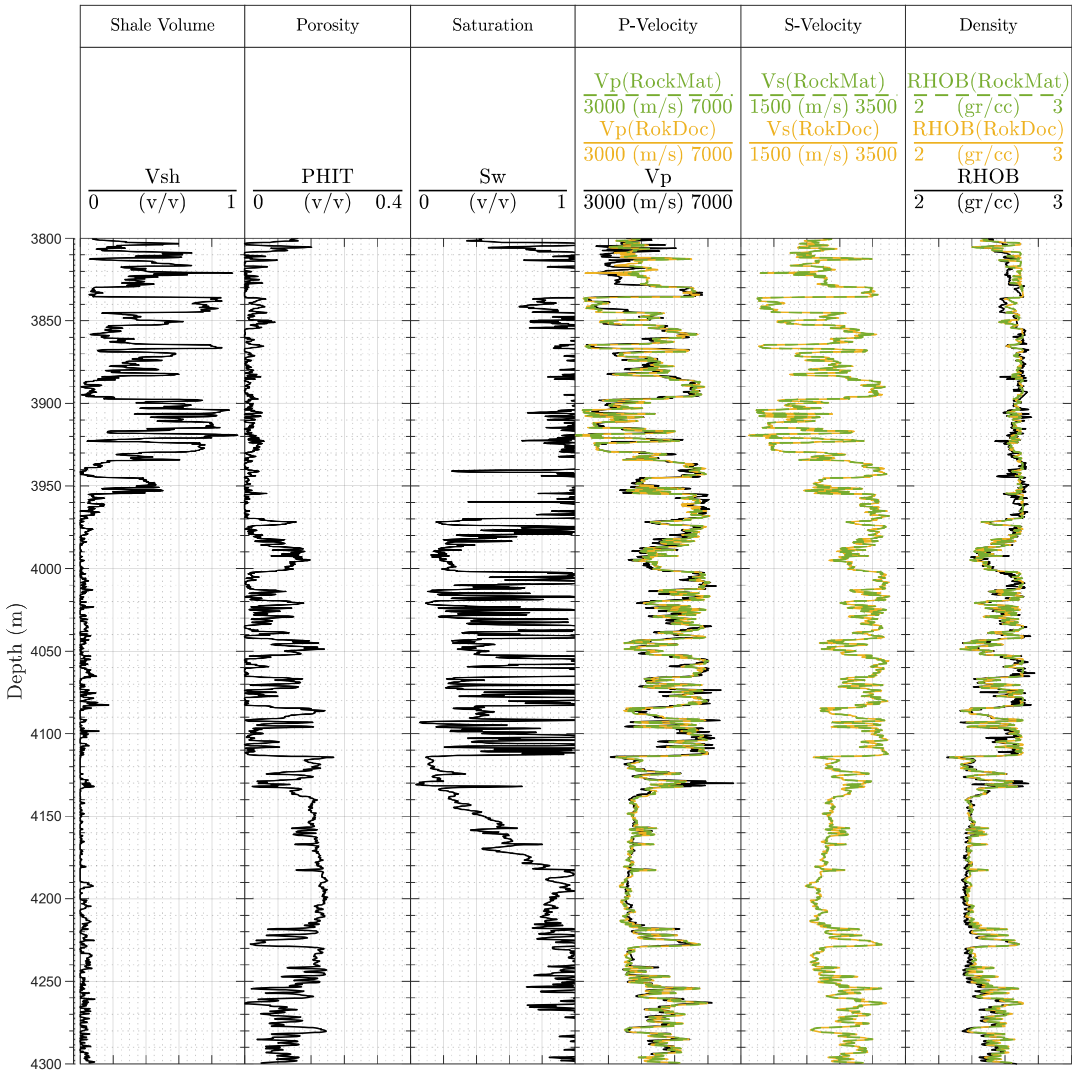

Figure 1. An example of Xu-Payne modeling results using RockMat (green) and its comparison to RokDoc results (Orange) and original measure logs (black). The first three tracks show the input petrophysical logs. As Shown, the results from the RockMat toolbox can exactly reproduce the RokDoc plots, and both have a reliable correlation with original measured logs.

REFERENCES

Birch, F., 1952. Elasticity and constitution of the Earth's interior. Elastic Properties and Equations of State, 26, pp.31-90.

Batzle, M. and Wang, Z., 1992. Seismic properties of pore fluids. Geophysics, 57(11), pp.1396-1408.

Xu, S. and White, R.E., 1996. A physical model for shear-wave velocity prediction1. Geophysical prospecting, 44(4), pp.687-717.

Avseth, P., Mukerji, T. and Mavko, G., 2005. Quantitative seismic interpretation: Applying rock physics tools to reduce interpretation risk. Cambridge university press.

Mavko, G., Mukerji, T. and Dvorkin, J., 2009. The rock physics handbook. Cambridge university press.

Avseth, P., Mukerji, T. and Mavko, G., 2020. Quantitative seismic interpretation: Applying rock physics tools to reduce interpretation risk. Cambridge university press.

Yu, J., Mukerji, T. and Avseth, P., 2023. rockphypy: An extensive Python library for rock physics modeling. SoftwareX, 24, p.101567.