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Rock physics templates for integrated analysis of shales considering their mineralogy, organic matter and pore fluids

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ABSTRACT

Mudstones are characterized by considering their mineralogy, organic matter and pore fluids simultaneously by means of effective properties calculated using the self-consistent method. The self-consistent equations are solved in order to get the effective properties, Lame's parameters and bulk density. With them, the P- and S-wave velocities are calculated for all types of shale rocks. These results are in accordance with those reported by Pickett (1963), Leslie and Mons (1982) and Castagna et al. (1985) for their particular cases. In this work, the effect of pore fluid and organic matter is added and can be observed in the rock physics templates of the V_P–V_S and $\lambda\rho$–$\mu\rho$. These templates represent the straightforward integration of multi-data generated by the core and well-log analysis, reservoir studies and geosciences; namely, geophysics, petrology, petrophysics and geology. This integrated information is useful for fluid discrimination, well placement and stages of fracking in the unconventional reservoirs. Also, the modeling results are applicable to identify commercial shales like Barnett-1, Fort St. John and Haynesville-1.

1. Introduction

Ternary diagrams are the easiest formal tool for correlating three mineral constituents, and they are widely used because any complication is shattering during the process of rock mineral interpretation of sedimentary rocks. In this research, rock physics templates based on V_P–V_S and $\lambda\rho$–$\mu\rho$ ternary templates were developed applying the self-consistent method to obtain the effective properties. This mathematical model has the virtue of considering the full-coupled analysis of the elastic properties for heterogeneous composites (Sabina and Willis, 1988). The shale system is basically composed of mineral-solid frame and inclusions of organic matter and fluids. The classical ternary plot based on Clay (CL), Quartz (QR) and Carbonate (CA) is utilized for describing the solid frame of mudstones and the lithofacie variations in the unconventional reservoirs. Additionally to these three minerals, the elastic properties of rock systems composed by mudstones and kerogen (organic matter), dry gas, sea water and oil saturating the total porosity ϕ at values of 10%, 20%, and 25% are discussed. Therefore, the templates are a useful tool for the integrated analysis of the multidata generated by petrology, geophysical and geological modeling.

The mudstone mineralogy is very similar for shale because shale rock is considered as a laminated and fissile mudstone. So, we are using mudstone and shale in the same way according to the mineral classification of fine-grained sedimentary rocks. This practical assertion is valid because the effective rock elastic response is mainly caused by the volumetric fraction of their mineral content. Also, the literature is rich with many results based on core and log-well studies for discriminating lithotypes as a direct function of the mineral data location inside the CL–QR–CA ternary diagram (Wang and Carr, 2012; Gamero-Diaz et al., 2013). For instance, Eagle Ford, Marcellus, Haynesville and Barnett approximately cover the entire possible region for shale-gas and shale-oil resource plays, Fig. 1. However, there are at least nine well-defined lithotypes: clay dominated lithotype, silica-rich argillaceous mudstone, carbonate-rich argillaceous mudstone, silica dominated lithotype, clay-rich siliceous mudstone, carbonate-rich siliceous mudstone, carbonate dominated lithotype, clay-rich carbonate mudstone, and silica-rich carbonate mudstone, Table 1. All of them are associated with numerical ranges of mineral volumetric fractions.

The combinations of pure mineral and bulk densities are used for modeling the effective elastic properties of source rocks applying the self-consistent scheme. Recently, this method has been applied to characterize the complete set of dominated lithotypes of shale by means of dispersion and attenuation of P- and S-wave (Valdiviezo-Mijangos and Nicolás-López, 2014). In this work, this method is used to get the static case of the effective properties and all physical quantities V_p, V_s, etc. are calculated with them to generate the V_P–V_S

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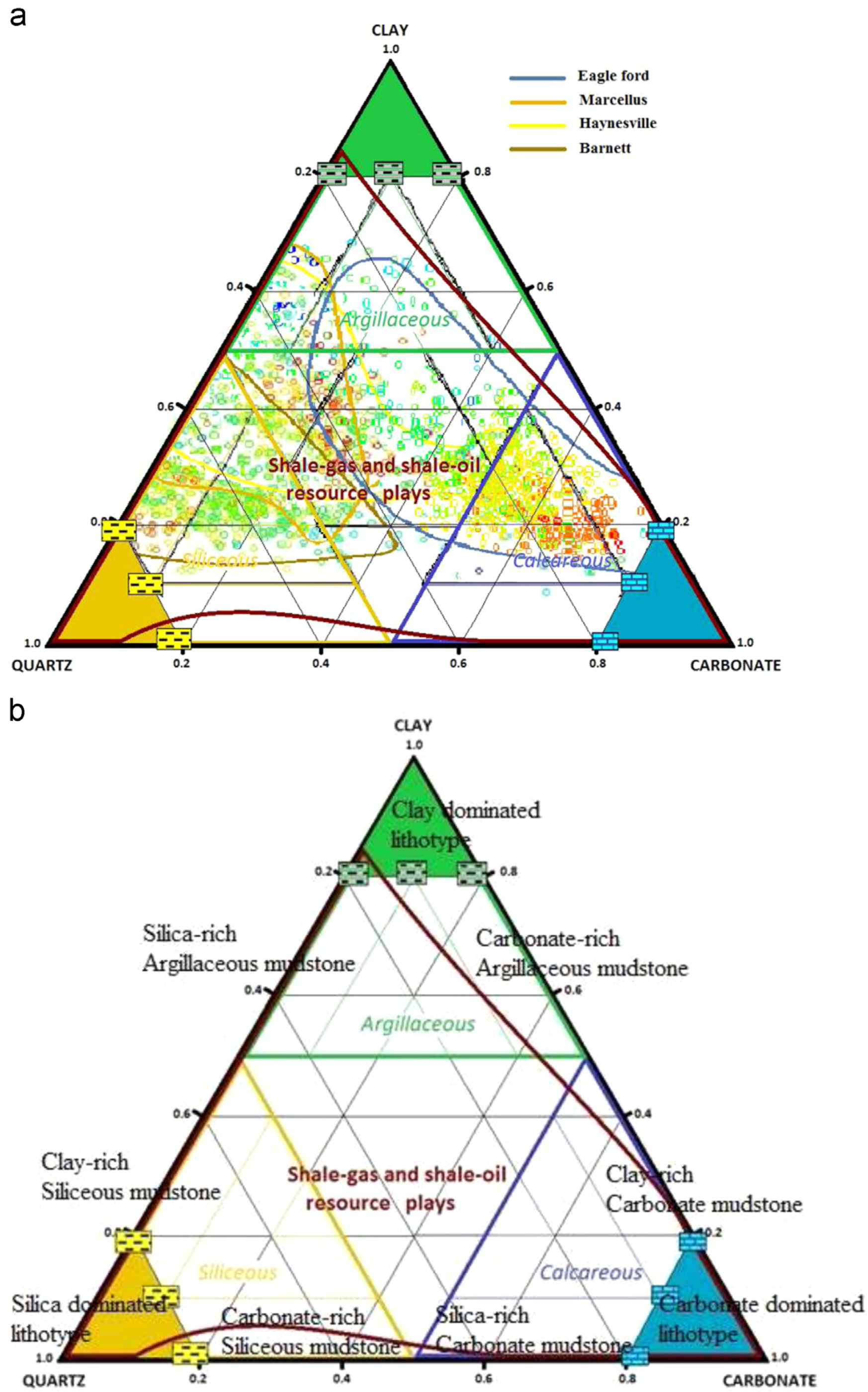

Fig. 1. (a) Ternary diagram from mineral laboratory data, (b) general classification of mudstones. Modified from Wang and Carr (2012), Gamero-Diaz et al. (2013), and Valdiviezo-Mijangos and Nicolás-López (2014).

and $\lambda\rho-\mu\rho$ ternary templates, Figs. 2–6. After solving the self-consistent equations (Eqs. (10b–12b)) and calculating ($\frac{V_P}{V_S}$), excellent agreement and consistency with widely accepted values for this ratio (Pickett., 1963; Leslie and Mons, 1982; Castagna et al., 1985), for quartz (1.5), clean sand (1.6), very limy sand (1.7), dolomite (1.8), limestone (1.9), calcite and clay (2.0), Fig. 2 is observed. It is well known that shales could exhibit different geometries defined by the aspect ratio (ar); i.e., ar $\leq$ 0.05 denotes layers, 0.05 $<$ ar $\leq$ 0.5 to lenses and 0.5 $<$ ar $\leq$ 1 is for patches (Sone and Zoback, 2013), herein as an approximation to model mudstones and shale rocks, the patches are chosen with aspect ratio equal to 1. In addition, the argillaceous, siliceous and calcareous lithofacies are placed in both ternary diagrams for qualitative and quantitative description of true mineral data from Barnett-1, Fort St. John, Haynesville-1 and Eagle Ford-1, Figs. 3 and 4.

At this point, the above mentioned describes how geoscientists can obtain the mineralogy input data for applying the self-consistent method. At the same time, the potential applications of V_P-V_S and $\lambda\rho-\mu\rho$ ternary templates for discriminating lithofacies and elastic responses of commercial shales are demonstrated. Now, another contribution, which deals with the effects of kerogen, dry gas, sea water and heavy oil saturating the total porosity (ϕ=0%, 10%, 20%, and 25%) shall be exposed. The total porosity is based on conventional log interpretation. The ϕ=0% identifies solid frame composed by any mineral combination of CL, QR, and