Estimation of Consolidation Parameter of carbonate and sandstones rocks

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Abstract

The estimation of dry bulk modulus is determinant for the success of the application of Biot-Gassmann theory to forecast fluid changes within a reservoir. The Pride model is one of the various models described in literature for predicting the dry elastic moduli of rocks. However, that model depends on the consolidation parameter and its appropriate choice implies in the accuracy of that model. In this paper, one method for estimating the consolidation parameter are tested and compared in carbonate rocks and Berea sandstone. The observation of how this parameter changes with litology considering calcite and dolomite rock matrix.

Introduction

Carbonate rocks are characterized to be heterogeneous, fractured and to present a great textural variation, which lead to complex relationships between the rock physical properties and geophysical data. Nevertheless, the mapping of fluid distribution inside carbonate reservoirs through the seismic data is still one of the main issues for reservoir management. Rock physics models can be used to forecast fluid saturation changes inside the reservoirs through the analysis of the effect of those variations in the seismic properties such as velocities or elastic moduli. Biot-Gassmann theory (BGT) is the most used method to relate fluid saturation changes and seismic properties, although its efficiency to carbonate rocks is sometimes questioned (Rasolofosaon et al., 2008; de Paula et al., 2010). The success of the Biot-Gassmann theory depends on the accurate characterization of the dry rock bulk modulus. There are several theories described in the literature that aim to evaluate the dry rock bulk (Kdry) and shear moduli (Gdry) from mineralogy and porosity info, as Geertsma (1961), Krief et al. (1990) and Nur et al. (1995). Pride (2003) presented a model that related the dry bulk and shear moduli as a function of porosity and the consolidation parameter, which depends on differential pressure and the degree of consolidation between the grains. Lee (2005) derived a generalization of Pride's and applied that theory to consolidated and unconsolidated sandstones. Zhang et al. (2009) studied the accuracy of Pride model compared to Krief and Nur models and found that it provides the best results once such consolidation parameter could vary with different rocks while Krief model has no adjustable parameter and in Nur model, the critical porosity is usually constant for the same type of rocks.

In this work, Pride model is applied to carbonate and sandstones rocks and the consolidation parameter is estimated.

Method

The formation of carbonate sedimentary rocks is influenced by physical processes dominated by complex biological and diagenetic processes that do not occur in siliciclastic rocks. The generation of siliciclastic sediments is related to the intensity and type of physical energy, such as winds, waves, direction and intensity of currents, which affect sediment texture on the depositional site. On the other The formation of carbonate sedimentary rocks is influenced by physical processes dominated by complex biological and diagenetic processes that do not occur in siliciclastic rocks. The generation of siliciclastic sediments is related to the intensity and type of physical energy, such as winds, waves, direction and intensity of currents, which affect sediment texture on the depositional site. (Dunham 1962).

Pride model relates the dry rock moduli to porosity as described in Eqs. 1 and 2.

$$K_{dry} = \frac{K_{ma}(1-\phi)}{(1+c\phi)} \quad (1)$$

$$G_{dry} = \frac{G_{ma}(1-\phi)}{(1+1.5c\phi)} \quad (2)$$

Where:

K_{ma} = Mineral bulk modulus;
G_{ma} = Mineral bulk modulus;
ϕ = Porosity;
c = Consolidation Parameter.

According to Pride (2003), the consolidation parameter indicates the degree of consolidation of a rock and usually ranges from 2 to 20 in sandstones. Lee (2005) defined that in practical applications, such parameter can be viewed as a free parameter to fit the observation data if porosity, P- and S-wave velocities are known. In practice a broad range of values can be used to estimate K_{dry} within the Voigt and Reuss bounds.

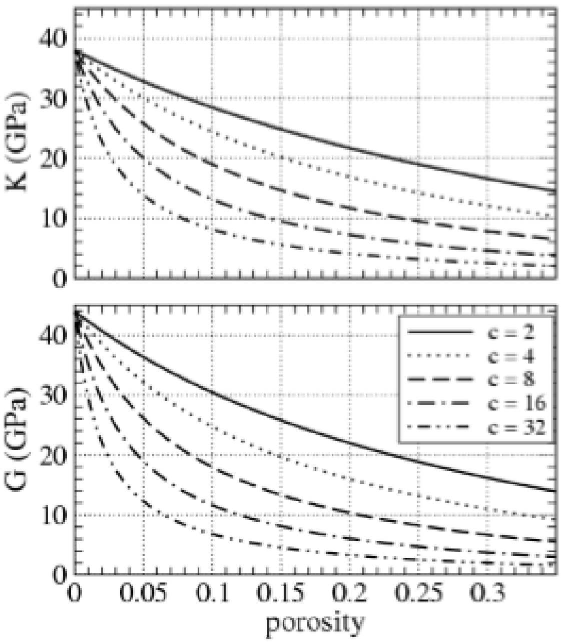

Figure 1: The frame formuli equation (1 and 2) and consolidation factors c and various porosities. The solid was taken to be quartz (Kma= 38 Gpa) and Gma=44 GPa (Pride, 2003)

The mineral bulk and shear modulus were estimated using Hill's average of the Voigt and Reuss bounds of the mineral content provided by XRD results.

$$M_{ma_V} = \sum_{i=1}^{n} M_{ma_i} f_{ma_i} \quad (3)$$

$$\frac{1}{M_{ma_R}} = \sum_{i=1}^{n} \frac{f_{ma_i}}{M_{ma_i}} \quad (4)$$

$$M_{ma_H} = \left(\frac{M_{ma_V}+M_{ma_R}}{2}\right) \quad (5)$$

Where:

Mma=Mineral modulus (bulk or shear);

fma=Fraction of each mineral phase (i);

n=number of mineral phases;

V=subscript to refer to Voigt bound;

R=subscript to refer to Reuss bound;

H=subscript to refer to Hill average.

Results

Using the mineral compressibility modulus as discussed in the paper by De Oliveira et al.(2013) from the X-ray diffraction test and using Hill's average of the Voigt and Reuss bounds of the mineral content it was possible to find the Berea 002 and Silurium Dolomite samples The values found were respectively 2,699562 and 3,893596 . The value obtained for Berea is inside the predicted range in the literature for sandstone rocks. This fact may be due to the use of Hill's average of the Voigt and Reuss bounds of the mineral content. The average value for the consolidation parameter is 8,958604 in carbonate rocks using Rogen *et al*. (2005).

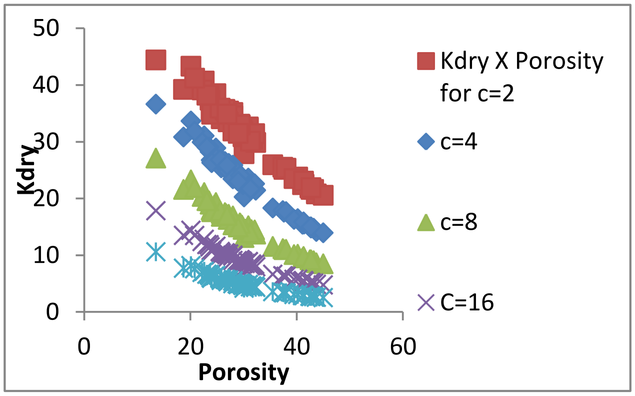

Figure 2: The frame formuli equation (1 and 2) and consolidation factors c and various porosities. The solid was taken to be calcite (Kma= 76,8 Gpa) using database from Rogen et al. (2005).

Conclusions

Differences in carbonic and siliciclastic lithologies lead todifferent consolidation parameter values. From the literature we know that for sandstones these values vary from 2 to 20 GPa. From the data Rogen et al. (2005) we reach an average value of around 8 GPa, for the Berea sandstone he value obtained is inside the predicted range in the literature for sandstone rocks. According to this study, the consolidation parameter indicates the degree of consolidation of a rock and usually ranges from 8 to 40 in carbonates using database from Rogen et al. (2005) and Fournier et al.(2014) .The value obtained for Silurium Dolomite is outside the predicted range made in this work.

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