Applying the Pride model for estimating consolidation parameter of siliciclastic and carbonate rocks

Soares T., Ceia, M., Missagia, R., and Lima Neto, UENF/CCT/LENEP, Macaé – RJ, Brazil

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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, Pride model is used for estimating the consolidation parameter is tested and compared in carbonate rocks and Berea sandstone. The observation of how this parameter changes with litology.

Introduction

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).

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.

Ceia et al. (2015) used part of the database reported by Fournier & Borgomano (2009), which consists of measurements of the physical properties of microporous mixed carbonate-siliciclastic rocks obtained at two wells located within the South Provence Basin, in France.An empirical model was obtained from Ceia et al. (2015) through estimating a best fit surface that could describe the consolidation parameter as a function of those two properties for each pressure. A polynomial result that combines second order dependence to aspect ratio and third-order dependence to porosity.

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

Data set

Chalk Group

Part of the database was used from Rogen *et al.* (2005) was used which consists of 56 chalk samples from the Tor Formation of the Chalk Group from the Dan Field (25 oil zone samples),the South Arne Field (29 oil-zone samples) and the Gorm Field (two water-zone samples) in the Danish North Sea (The Tor Formation is of Maastrichtian age and is the main oil-producing formation in these fields. According to information from field operators, present effective stress on reservoir rocks is nearly equal for the three fields, because the present difference in burial depths of about 900 m is counteracted by differences in overpressure. The depositional texture from Rogen *et al*. (2005) according to Dunhan (1962) is mudstone and wackestone with 90% of microporo sity.

Urgonian limestone, Barremian–Aptian, SE France

The database of Fournier *et al.*(2014) is used partially. The data set consists of 214 limestone samples from Lower Cretaceous platform carbonates collected in various localities in Southeast France, displaying porosity values ranging from 0.1% to 23.1%. Additionally, the present work integrates the 85 microporous samplespublished. The Lower Cretaceous deposits from Provence consist of platform carbonates, with ages ranging from Valanginian to Early Aptian (Masse, 1993). In Provence, the Late Hauterivian–Early Aptian time interval represents the main growth phase of the so-called Urgonian platform that is bounded to the North by the Vocontian basin. The Provence Urgonian platform reached its largest extent during the Late Barremian–

Early Aptian. Urgonian limestones from Provence areregarded as excellent outcrop analogues of Middle East carbonate (Fournier *et al.* 2014).
The depositional texture from from Fournier et al.(2014) is grainstones and packstones.

Berea Sandstone

In this work , a sample of Berea Sandstone is used. Porosity and permeability in the Upper Berea sandstone samples studied range from 19.04 to 26.10 % and from 114 to 1168 mD respectively. The porosity appears to increase with increasing permeability. This increase appears to coincide with a similar increase in grain and pore body size. Although the petrographic properties controlling the permeability and porosity in these rocks are not precisely known, the trend towards an increase in the quartz content, pore body size, pore throat size, and a decrease in the feldspar and kaolinite content, may account for the observed trends in the permeability and porosity data. These petrographic properties also appear to be related to the observed trends in the specific surface area data Churcher, *et al* (1991)

Siluriam Dolomite

A sample of Siluriam Dolomite Is used which has porosity of 16.6%, mass of 197.4. Compressional and shear wave were measured 5585.6 m/s and 3024.76 m/s respectively. The bulk modulus of the sample is 44.5 GPa.

Theory

Pride model relates the dry rock moduli to porosity as described in Equation 1.

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

Where:

Kma = 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 (Figure 1). Lee (2005) defined that in practic 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 Kdry within the Voigt and Reuss bounds.

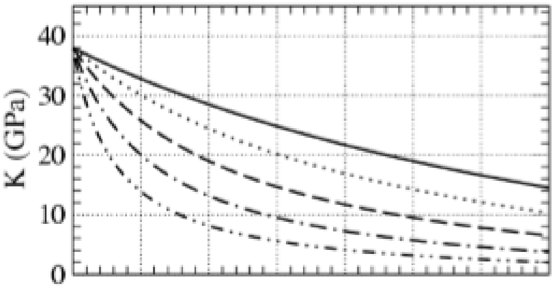

Figure 1: The frame formuli equation (1) and consolidation factors c and various porosities. The solid was taken to be quartz (Kma= 38 Gpa) (Pride, 2003)

Method

Estimation of Kma and Gma

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. according to Eqs. 2, 3 and 4.

$$M_{ma_V} = \sum_{i=1}^{n} M_{ma_i} f_{ma_i} \quad (2)$$

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

$$M_{ma_H} = \left(\frac{M_{ma_V} + M_{ma_R}}{2}\right) \quad (4)$$

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 avera

Discuss and 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 calculate the mineral modulus of these two samples (Berea 002 and Silurian Dolomite) The values of consolidation parameter obtained were respectively 2.7 and 3.9. 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.

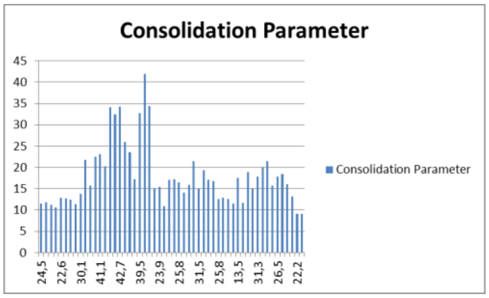

Figure 1: Histogram of the consolidation parameter X porosity for the data Rogen *et al*. (2005).

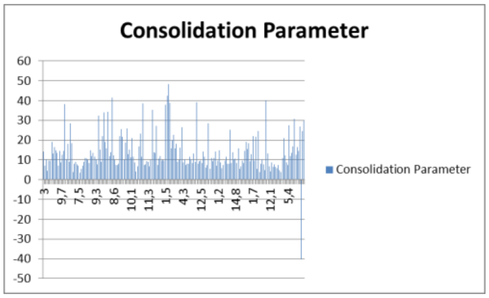

Figure 2: Histogram of the consolidation parameter X porosity for the data Fournier *et al*.2014

For database from Rogen *et al.* 2005, the values of the consolidation parameter range from 3.3 to 48 (Figure 1).

The calculation consolidation parameter of Fournier *et al*. 2014 range from 9 to 42 (Figure 2).

This difference in texture may explain the different behavior of the graphs.

The values obtained for the consolidation parameter for carbonate rocks for these datasets are higher than the values for siliciclastic rocks.

Conclusions

Differences in carbonate and siliciclastic lithologies lead to different consolidation parameter values. From the literature we know that for sandstones these values vary from 2 to 20. The value obtained for Berea 002 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 4 to 40 in carbonates using the carbonate database The value obtained for Siluriam Dolomite is inside the predicted range calculated in this study.

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