Porosity and density from Sonic Logs in Camamu, Almada, Cumuruxatiba and Recôncavo Basins (Brazil)

José Adauto de Souza

Petrobras SA

Abstract

The derivation of mathematical analytical solutions to questions that involve the response of rock properties is no far a hard job. In many situations, good empirical equations are derived based on observed or measured data. Wyllie *et al.*(1956) found an empirical equation relating porosity and velocity of compressional waves of rocks. Similarly, Gardner *et al.*(1974) proposed another equation relating rock density and velocity of compressional waves. In the oil industry, the equation of Wyllie *et al.*(1956) was further applied to estimate porosity of rocks based on well sonic logs (Sclumberger, 1972). Historically was registered that these kind of estimations return values higher than the real ones (around 15% higher). Here, I discuss the method that combines the relationship obtained by Wyllie *et al.*(1956) and Gardner *et al.*(1974) to solve for density and porosity of rocks. The lithology has been taken into account, making possible a better tuning in the results. As a consequence, the estimated values are closest to the real ones.

INTRODUCTION

The **Poroden** application was developed by the author in Fortran PowerStation language(for personal computers Pc), which estimates porosity and density values starting from the sonic profile and considering the present lithologies in the well. In the development of this work it was evidenced that empiric general equations on the properties of the rocks can be better tuned if the geological responses of a certain area are taken into account. Generic constants of the equations can be altered in function of the regional geology and they can even be modified as a function of the lithology of local layers. The obtaining of density values also is configured as important, once the readings of the profile RHOB(Sclumberger density Log) sometimes are not good enough: the applied technique is sensible to the rock rugosities in the well. It is common to discard 20% of the RHOB density readings. The obtained porosity values showed good fit with data measured in the laboratory or observed in practice.

DENSITY

Gardner *et al*. (1974) found an empiric equation which relates density and velocity of rocks. In Duarte(1997) this equation is written as (converted from us/feet to m/s):

$$\rho = 0{,}3365\, V^{1/4}\ , \qquad (1)$$

where ρ = estimated density of the rock.
V = velocity of the rock.

This equation was tested in several wells of Camamu, Almada, Cumuruxatiba and Recôncavo basins (Brazil). On average, the tests showed that the value 0,31 (equation (2)) is the one that better adjusts in the equation of Gardner *et al*. (op.cit) for sandstones, shales and limestones and the value 0,33 (equation (3)) for marls, that is to say:

$$\rho = 0{,}31\, V^{1/4}, \qquad (2)$$

$$\rho = 0{,}33\, V^{1/4}. \qquad (3)$$

These changes in equation (1) may be associate with age and compaction of the local sedimentary layers. Some results of these tests can be verified in **figure 1**. The adjustment among the curves of the RHOB profile (density) and the one obtained with equations (2) and (3) is very good. The observed discrepancies are due to bad readings of the RHOB profile, since this technique is very sensitive to the well wall irregularities. The magenta curve on the left shows the CALIPER (well diameter): there is a immediate relation between well wall irregularities and RHOB bad readings. The RHOB log sometimes returns those bad values and when it happens you can't use it in a reliable way in techniques that need continuous data along the well (for example, the synthetic seismogram). In the other hand, the Sonic survey in general extracts good velocity values, giving us a nice chance to compute densities. One important thing to mention is that it allows the recovery of a passive: most of the old exploratory wells don't have RHOB log but have the sonic profile. In most of the figures showed in this work the high frequency data present punctual sampled data (1 m) and the one of low frequency shows smoothing of these punctual data (mixing with moving average).

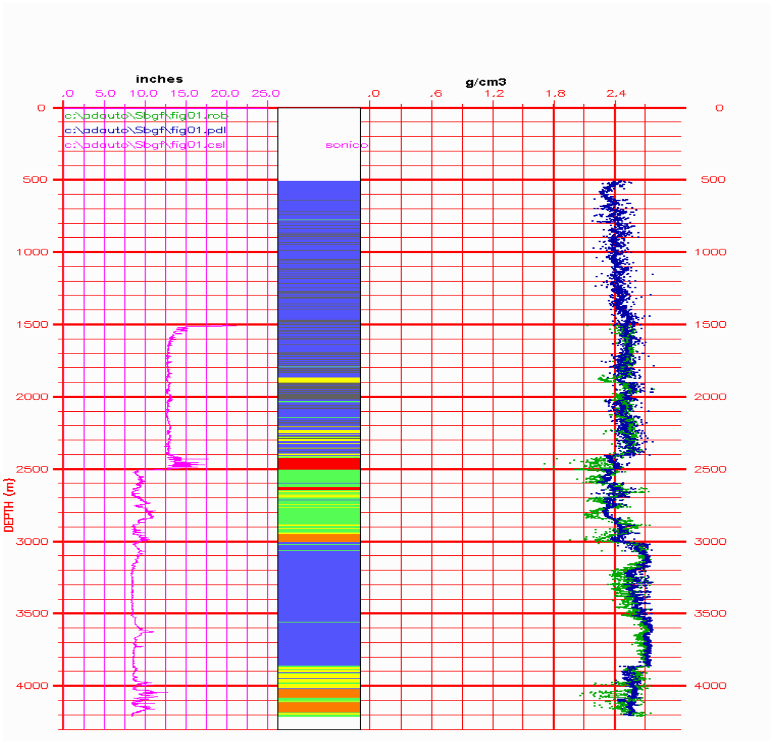

FIGURE 1 – Comparison between RHOB readings (green) and densities obtained with equations (2) and (3) (blue). The discrepancies are due to bad readings of RHOB tool.

Figure 2 presents estimated densities for one wildcat in Almada Basin. The blue curve presents densities obtained with the equation (2) only and the green curve shows data obtained with equations (2) and (3): equation (3) was just used in the intervals where the lithology is represented by marls (gray color). It can be observed that these two curves are the same (the blue curve overwrites the green one) unless in the interval where the lithology is marl. The green values have a better fit with the magenta ones (close to 2.4), which t are data acquired as a RHOB profile. This proves that a general equation just as (1) can be adapted if specific lithologies are taken into account. The change in the constant 0,3365 of the general equation (1) for 0,31 in equation (2) indicates that this last value better estimates the density of a specific lithology.

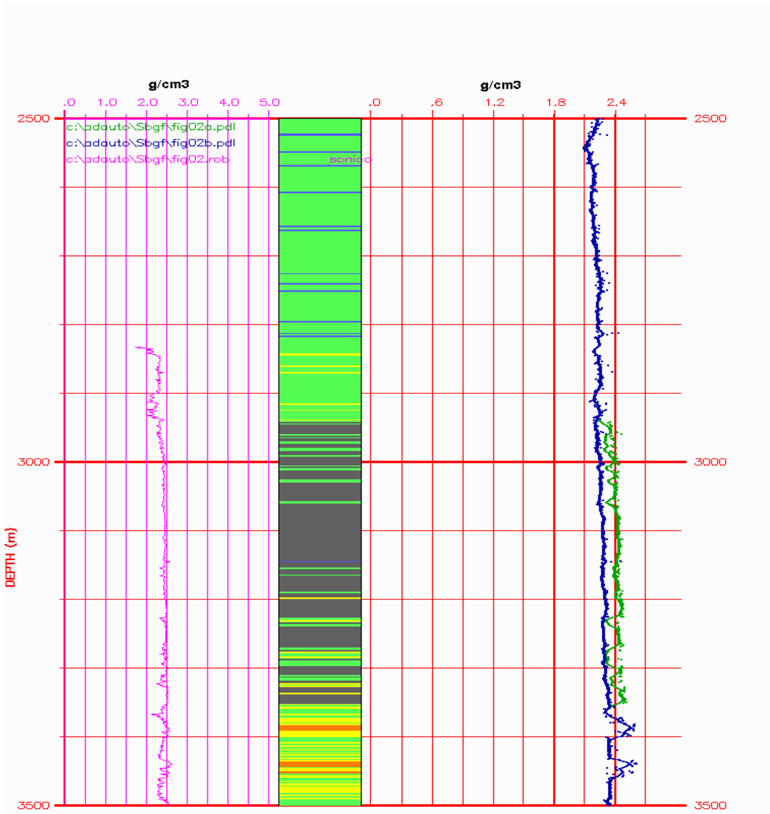

FIGURE 2 – densities obtained with equation (2) (blue curve) and with equation (3) (green curve). The green values are more close to RHOB readings (magenta curve, on the left)

POROSITY

Wyllie *et al.* (1956) established an empiric relationship between porosity and velocity of the rocks("time-average equation"):

$$\phi = (Vm - V) / (Vm - Vf), \qquad (4)$$

where ϕ = estimated rock porosity,
V = rock velocity,
Vm = matrix velocity,
Vf = fluid velocity

In practice the term V can be substituted by the actual value read in the sonic profile and Vm can be obtained from rock property tables. It is usually well known that the values of ϕ computed by this equation are higher then those found in practice.

THE GARDNER-WYLLIE METHOD

Rock porosity (ϕ) may be deduced from bulk density using the following relationship (Brigaud *et al*, 1990, equation (3), page 1461):

$$\phi = (\rho m - \rho b) / (\rho m - \rho f), \qquad (5)$$

where ϕ = rock porosity,
ρb = bulk density
ρm = matrix formation density,
ρf = fluid density

Equation (5) is similar to equation (4): in this case the velocity values are substituted by densities. The computation of densities with equations (2) and (3) and the use of these densities in equation (5) is a method: we will call this Gardner-Wyllie method. Many porosity estimations were performed using sonic data from different sedimentary basins and, as a general rule, we may confirm that: (a) the values obtained using Willie's equation (4) are higher than those observed in practice ; (b) values estimated with Gardner-Wyllie's method are close to those observed in practice.

Figure 3 illustrates the conclusions above. The blue curve (smoothed) presents porosities derived from a sonic log using Wyllie's equation (4). The green curve (also smoothed) is data estimated with equations (2), (3) and (5), or the Gardner-Wyllie method. Clearly the blue curve has values higher than green one, mainly where the lithology is shale. There is a gas zone pointed out in the graphic: the measured porosity there is 24%. The Gardner-Wyllie method returns values close to 25%, and the Wyllie's equation (4) shows values around 31%.

THE PORODEN APPLICATION

Figure 4 (next page) presents a graphic image generated by the PORODEN (Fortran Pc software) displaying a well profile including the sonic Log (punctual and smoothed), a colored representative column of the lithologies, the estimated densities (black curve) and the estimated porosities (punctual and smoothed). This software was built based on Gardner-Wyllie's

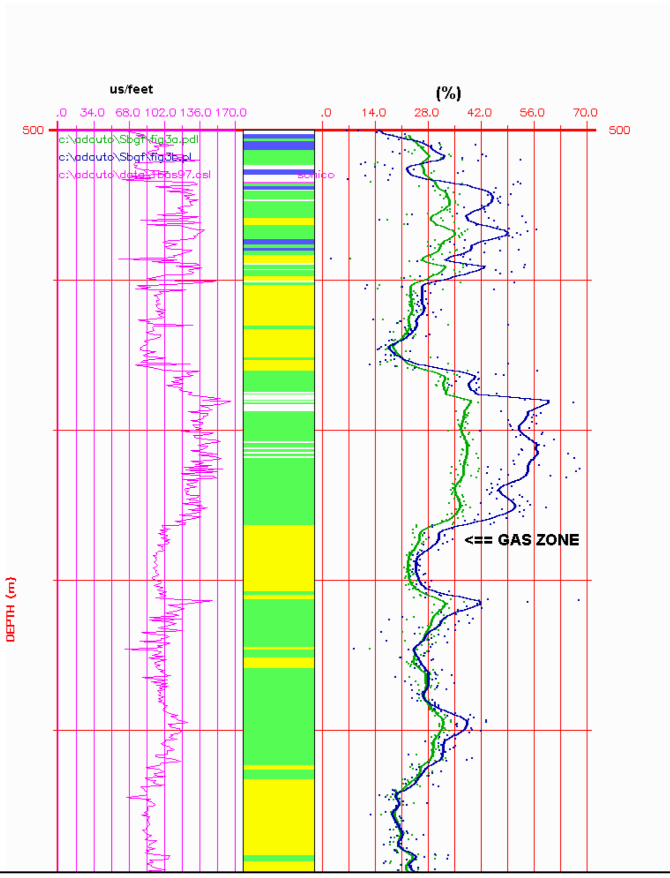

FIGURE 3 – Estimated porosity values using Wyllie equation (4) (blue curve) and the equations (2), (3) and (5) (green curve)

method. The input data should be a columnar ASCII file including depth, sonic readings and lithology. It generates a ASCII columnar file including porosity, density and lithology with depth. The graphic output image is a bitmap formatted file (BMP) that may be read by many graphic software. The user of this application may select depths in a target zone. Also he can make the option to select lithologies: all, only sandstones, only shales and no shales.

CONCLUSIONS

The present work demonstrates that starting from general equations as the one of Wyllie *et al*. (op.cit) and Gardner *et al*. (op.cit) satisfactory results can be obtained in the estimation of physical properties of the sedimentary rocks. Refinements of these results can be obtained taking into account the rock lithology. The computation of densities from sonic logs and the use of these values to estimate porosities demonstrate a valid technique, with more accurate results. One time these results are close to observed or measured data, they can be used in many situations: to build a continuous density log, to construct synthetic seismograms, to evaluate porosities in target zones, to build compaction curves and compute erosion, etc.

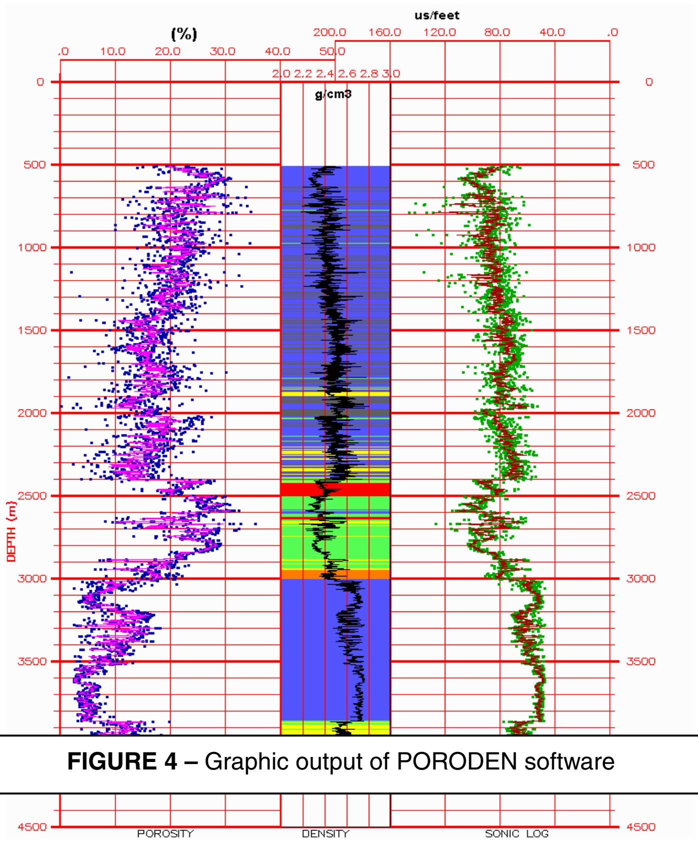

FIGURE 4 – Graphic output of PORODEN software

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