Revisiting the Wyllie time average equation in the case of near-spherical pores

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ABSTRACT

We suggest a generalized form of the Wyllie equation to better describe acoustic velocity variation with porosity in rocks with a mixture of intercrystalline and near-spherical pores. Introducing a pore shape factor in the Wyllie equation allows different weights to be applied to the solid-phase P-wave velocity to account for rock frame stiffness. This is demonstrated in carbonate and igneous rocks having variable amounts of spherical porosity, ranging from 0% to 80% of the bulk porosity.

The generalized equation describes a velocity–porosity envelope instead of the simple line given by the Wyllie equation. The lower limit of the velocity envelope is for rocks that have only interparticle or intercrystalline porosity (Wyllie equation behavior), and the upper limit is when all pores are spherical or near spherical. This upper limit corresponds to the Hashin-Shtrikman upper bound for porosities up to 30%. The realization portrays Wyllie's velocity–porosity relationship as one particular case in which all pores are intercrystalline or interparticle with a pore shape factor equal to unity. An increase in the amount of high-aspect-ratio pores leads to higher pore shape factor. We suspect that this factor may be generalized to include fracture porosity with values less than unity. We suggest that this factor represents the acoustic equivalent of the cementation factor in Archie's law for resistivity measurements.

The velocity calculated by the modified model correlates well with both the measured velocity and the calculated velocity using the Kuster-Toksöz theoretical model. Various factors controlling acoustic velocity in carbonates can be quantified, based on this modification.

INTRODUCTION

Rocks with intercrystalline or interparticle porosity have an ideal fabric to be described by the Wyllie time average equation (Anselmetti and Eberli, 1999). On the other hand, this equation underestimates the bulk rock velocity in the presence of high aspect ratio or near-spherical porosity and overestimates the velocity in poorly lithified rocks. The basic assumption in the Wyllie model is that the total traveltime is a volume weighted average of the pore phase, represented by pore fluid velocity, and the solid phase, represented only by a matrix velocity. This assumption does not consider that a change in pore type would affect the effective solid phase properties resulting from changes in pore shape, size, and distribution in the host rock.

The simple time average equation represents the most commonly used relationship to derive porosity from formation acoustic velocity. The validity of this model can be established by its ability to predict bulk rock velocity. This requires accurate determination of matrix and fluid velocities, porosity, and the recognition of the range of applicability of this relationship. The Wyllie equation overestimates rock velocity when rock porosity exceeds 40% (Paillet and Cheng, 1991). Also, it is well known that this equation does not work well when the pores contain gas, when the rock is not completely lithified, when the rock is fractured, and when the pore space has spherical or near-spherical pore shapes. This work deals with the application of the Wyllie equation for the latter case. We utilize well-log data for carbonate and igneous rocks that contain substantial amounts of vugs, moldic, and vesicular porosity.

Several classifications have been established for pore types. In most classifications, high-aspect-ratio pores or near-spherical porosity stand as a clear and distinguishable category. Archie (1952) classifies pore space in carbonate rocks, based on size, to matrix and visible porosity that mainly includes both vugs and moldic pores. Choquette and Pray (1970) emphasize the genetic and geometric complexity of vuggy pore space. They divide carbonate pore space into fabric selective and nonfabric selective. Two factors are involved in establishing...
fabric selectivity: the configuration of the pore boundary and the position of the pore relative to fabric elements or solid constituents. Lucia (1983) divides porosity into interparticle and vuggy porosity. He defines the latter as that pore space larger than or within the particles of the rock.

Many relationships have been developed to estimate the amount of near-spherical pores that constitute a part of the pore network in a rock. Most of these relationships are empirical and rely on the use of acoustic and resistivity logs to quantify this pore type. The basic concept in these models is that the deviation of Wyllie’s calculated velocity or porosity from either the measured velocity or porosity is an indicator for pore-type change from nonspherical to spherical. These models include the secondary porosity indicator (SPI) (Schlumberger, 1974), pseudofluid transit time (Meese and Walter, 1967), spherical porosity model (Brie et al., 1985), Lucia Model (Lucia and Conti, 1987), and velocity-deviation log (Anselmetti and Eberli, 1999). Other theoretical models, such as Kuster and Toksöz (1974) and O’Connell and Budiansky (1974), compute the effective elastic moduli of rocks and ultimately the bulk rock velocity. The rocks may have embedded inclusions of known concentrations (porosity) with different pore aspect ratios (from micropores to spherical pores).

Our purpose is not to establish a different relationship that links the disparity in Wyllie model to a specific pore type but rather to present a more generalized form of the Wyllie equation that works in complex pore systems composed of both interparticle and spherical pores. We introduce a new realization of the Wyllie equation that accurately predicts velocity in the presence of spherical porosity. Also, we quantify the controlling factors on acoustic velocities based on this modified model.

**APPLICATION OF WYLLIE EQUATION AND PROBLEM DEFINITION**

The Wyllie model (Wyllie et al., 1956) assumes that the bulk rock velocity is given by equation (1), in the case of monomineralic rock, or equation (2) in the case of mixed lithologies (Castagna et al., 1993):

\[
\frac{1}{V_{P,\text{rock}}} = \frac{1 - \phi}{V_{P,\text{matrix}}} + \frac{\phi}{V_{P,\text{fluid}}} \tag{1}
\]

and

\[
\frac{1}{V_{P,\text{rock}}} = \sum_{i=1}^{N} \frac{X_i}{V_{P,\text{matrix},i}} + \frac{\phi}{V_{P,\text{fluid}}} \tag{2}
\]

where \(\phi\) is bulk porosity, \(V_{P,\text{rock}}\) is bulk rock velocity, \(V_{P,\text{matrix}}\) is matrix (solid grain) velocity, \(V_{P,\text{fluid}}\) is fluid velocity, and \(X\) is the fractional volume of a mineralogical component in the rock.

This empirical model, which does not have a theoretical basis, states that the traveltime of an acoustic signal through the rock is the sum of the traveltimes through the fluid and the matrix portions of the rock (Anselmetti and Eberli, 1999). The application of the Wyllie equation to obtain bulk rock velocity requires accurate determination of matrix and fluid velocities and porosity.

We selected well-log data for two completely different rock types, the Xan dolomite (Guatemala) and the Los Cavaos anodolite sill (Argentina), to avoid any bias caused by error in determining the matrix acoustic properties. Both rocks are clean, as the presence of clay minerals would complicate the interpretation because of their effect on the sonic log. The process of porosity development in each rock type is completely different, yet both rocks contain substantial amounts of spherical and near-spherical pores.

The matrix composition for each rock was carefully determined (Forgotson et al., 1998, 1999). Petrographic thin sections and core analysis showed that the Xan dolomite is composed of dolomite with variable amounts of calcite. The variations in the fractional volume of dolomite and calcite were calculated based on the photoelectric factor (PEF) and density logs. Anodesite is an intermediate volcanic rock composed of feldspars, pyroxene, and sporadic olivine (Hyndman, 1985). We relied on the description of petrographic thin sections to obtain the exact percentage of each of these minerals, which were 60% feldspar, 35% pyroxene, and 5% olivine. The matrix P-wave velocity for each of the minerals in the studied rocks was obtained from Ahrens (1995) and Mavko et al. (1998).

The studied rocks are not gas bearing. Sonic logs typically have a radius of investigation of about 6 inches (Morton-Thompson and Woods, 1993). This led us to use fluid velocity of the mud filtrate in the invaded zone of the studied rocks (Table 1). Both density and neutron logs measure pore volume and are not affected by pore shape. The bulk porosity was estimated by averaging porosities derived from both logs. The calculated porosity correlated well with the measured porosity for cored intervals.

The bulk rock velocity was calculated using the Wyllie equation for the studied rocks in two wells. Figure 1 clearly demonstrates that the velocity predicted by the Wyllie equation is slower than the measured velocity from the sonic logs, as most of the points are scattered below the line of \((V_{P,\text{log}} = V_{P,\text{rock}})\). Since we ensured accurate determination of the components required to predict the velocity from the Wyllie model, the only factor left that needs to be accounted for is the presence of substantial amounts of spherical and near-spherical pores.

The basic assumption in the Wyllie model is that both the pore phase, represented by pore fluid velocity, and the solid phase, represented only by a matrix velocity, are weighted based on their volumetric proportions. This assumption presumably is

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Density (g/cm³)</th>
<th>Bulk modulus (GPa)</th>
<th>Shear modulus (GPa)</th>
<th>Compressional velocity (km/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Augite</td>
<td>3.26</td>
<td>94.1</td>
<td>57</td>
<td>7.22</td>
</tr>
<tr>
<td>Olivine</td>
<td>3.32</td>
<td>130</td>
<td>80</td>
<td>8.45</td>
</tr>
<tr>
<td>Feldspar average</td>
<td>2.62</td>
<td>37.5</td>
<td>15</td>
<td>4.68</td>
</tr>
<tr>
<td>Dolomite</td>
<td>2.87</td>
<td>76.4</td>
<td>49.7</td>
<td>7.05</td>
</tr>
<tr>
<td>Calcite</td>
<td>2.71</td>
<td>76.8</td>
<td>32</td>
<td>6.64</td>
</tr>
<tr>
<td>Mud filtrate</td>
<td>1.1</td>
<td>3</td>
<td>0</td>
<td>1.65</td>
</tr>
</tbody>
</table>
incomplete. We believe this assumption fails to account for a change in pore type that would affect the representation of the effective solid phase in the Wyllie model resulting from the change in pore nature and distribution in the host rock.

**Spherical and Near-Spherical Pore Description**

A compound pore system in reservoir rocks is composed of two or more basic types of pores. Each type is somewhat physically discrete and distinguishable. The Wyllie model adequately describes the velocity–porosity relationship in the case of interparticle or intercrystalline pores. It fails once a dual pore system composed of spherical and intercrystalline (or interparticle) pores occurs. This would be caused by specific characteristics of the spherical pores. These characteristics were clearly demonstrated in the studied rocks. Each of these rocks contains compound pore systems: the Xan dolomite contains intercrystalline, vuggy, and moldic pore types, and the Los Cavaos igneous sill contains intercrystalline, alteration, and vesicular porosity (Figures 2 and 3). Based on thin-section description and pore classifications, vuggy, moldic, and vesicular pores are characterized by the following:

1) Somewhat spherical or not markedly elongate with high aspect ratio. Choquette and Pray (1970) mention that vugs may be not exactly equidimensional but do not go below a length–cross-sectional diameter ratio of 1/3.

2) Commonly larger in size than interparticle or intercrystalline pores, and sometimes visible to the unaided eye.

3) Do not specifically conform in position to particular fabric elements and are not uniformly distributed in the host rock. Figures 2b and 3a clearly demonstrate the occurrence of near-spherical pores as inclusions scattered in the groundmass of the host rock.

4) Formation of rims that surround many of these pores (Figures 2b and 3b). These rims may have developed during the dissolution and reprecipitation of the dissolved material in case of the vuggy and moldic porosity in the Xan dolomite and during the solidification of the andesitic magmatic melt.

**Quantifying Spherical and Near-Spherical Pores**

Examination of pore types in a rock is not only a matter of identification but it also involves quantifying their
The spherical porosity model was used to quantify high-aspect-ratio pores. This model is based on the hypothesis that these pores can be represented physically as ellipsoidal inclusions scattered in the host rock medium compared to the more uniformly distributed matrix porosity (Brie et al., 1985). This physical representation captures the essence of the classifications of both Choquette and Pray (1970) and Lucia (1983) in terms of pore geometry and distribution in rocks. Also, it provides a link to both Kuster-Toksoz and Maxwell-Garnett theoretical models to describe the acoustic and electric effects of including near-spherical pores in a host medium.

This model assumes a typical behavior for the primary host rock, like the Wyllie equation for acoustic velocities and Archie’s law for electric conductivity. The difference between these predictions and the actual measured values can be interpreted in terms of spherical porosity $s$:

$$
\phi_s = \frac{\phi_B - \phi_p}{1 - \phi_p},
$$

where $\phi_B$ is the bulk porosity calculated from density–neutron log combination and $\phi_p$ is the primary medium porosity calculated using the Wyllie time average equation. Additionally, this model establishes a correlation between Archie’s cementation factor $m$ and the ratio of spherical pores to bulk porosity:

$$
m = \frac{2 \log \phi_p'}{\log \phi_B} + \frac{\log \left[ 2 \phi_s (1 - \phi_p^2) + 1 + 2 \phi_s^2 \right]}{1 + 2 \phi_s^2 - \phi_s (1 - \phi_p^2)}.
$$

The Wyllie equation is an average of the acoustic travel-time of the solid and fluid phases. Pore shape and distribution affect the effective solid phase properties, and any mathematical representation for variations in pore type can be included in the solid-phase term $(1 - \phi_B)/V_{P_{\text{matrix}}}$. We empirically found that introducing an exponent to $V_{P_{\text{matrix}}}$ would account for such variations and allow reliable prediction of the measured velocity, as shown in Figure 6. The correlation coefficients ($R^2$) are 0.97 and 0.99 in the case of the Xan dolomite and andesitic sill, respectively. This exponent is termed the pore shape factor $S$ because it linearly relates to both the ratio of spherical–bulk porosity and bulk porosity by

$$
S = 1 + \left( \frac{\phi_s}{\phi_B} \right) \times \left( \frac{6.5/V_{P_{\text{matrix}}} - 3\phi_s + 2\phi_s^2}{\phi_s} \right)
= 1 + \frac{\phi_s}{6.5/V_{P_{\text{matrix}}} - 3\phi_s + 2\phi_s^2}.
$$

Figure 4 shows a wide distribution of spherical porosity that ranges from 0% to over 80% of the bulk porosity in the studied rocks. It also demonstrates that Archie’s cementation factor increases as a function of that ratio.

**MODIFICATION OF THE WYLLIE EQUATION**

This modification was initiated to develop a general form of Wyllie equation that can account for variations in pore types and consequently predicts the rock-measured velocities. This required that we examine the components of departure of Wyllie’s predicted velocities from the measured ones. The percentage of spherical to bulk porosity is one of these components, as illustrated in the velocity crossplot (Figure 5a). However, variations in this ratio cannot fully explain this departure because lines of equal ratios are not parallel to the line $(V_{P_{\text{matrix}}} = V_{P_{\text{bulk}}})$. Variations in amount of bulk porosity represent a less pronounced yet significant component, especially at high bulk porosity (Figure 5b).

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$$
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= 1 + \frac{\phi_s}{6.5/V_{P_{\text{matrix}}} - 3\phi_s + 2\phi_s^2}.
$$

---

**Fig. 3.** Some pore types in the andesitic igneous sill. (a) Core slab showing spherical vesicles up to 2 mm in diameter. (b) Thin section showing spherical vesicular pore. (c) Thin section showing network of intercrystalline pores connecting larger alteration of patchy and vesicular pores.
Hence, in the case of monomineralic rock, the Wyllie time average equation is modified to

$$\frac{1}{V_{P_{\text{rock}}}} = \frac{1 - \phi_B}{(V_{P_{\text{matrix}}})^3} + \frac{\phi_B}{V_{P_{\text{fluid}}}}. \quad (6)$$

In the case of rocks composed of mixed lithologies, it is modified to

$$\frac{1}{V_{P_{\text{rock}}}} = \sum_{i=1}^{N} \frac{X_i}{(V_{P_{\text{matrix}_i}})^3} + \frac{\phi_B}{V_{P_{\text{fluid}}}}. \quad (7)$$

We examined the accuracy of the modified model by comparing the model results with the Kuster-Toksöüz model. This theoretical model calculates the effective elastic moduli of a rock and, consequently acoustic velocity, given the elastic moduli of the individual components. The rock is represented as a medium that may have embedded inclusions of known pore concentrations with different aspect ratios (from micropores to spherical pores).

Calculation of the effective elastic moduli for each log measurement is a tedious process. For convenience, we included in the model calculations about 60% of the measurements covering the whole spectrum of the pore-type proportions. Since the studied rocks included a mixture of both intercrystalline and high-aspect-ratio pores, we assumed that these pores have aspect ratios of 0.1 and 0.9, respectively. We used the bulk porosity calculated from density and neutron logs. The spherical porosity, estimated from the spherical porosity model, was used as the high-aspect-ratio pore concentration. The elastic moduli

![Fig. 4. Crossplot showing the wide distribution of the spherical and near-spherical porosity represented as a percentage of bulk porosity. (a) Xan dolomite; (b) andesitic igneous sill.](image-url)
for the minerals and fluid were obtained from Ahrens (1995), Mavko et al. (1998), and Castagna et al. (1993) (Table 1).

Figure 7 illustrates the prediction accuracy of the modified model. It can predict both the measured velocities and the calculated velocities from the theoretical Kuster-Toksöz model within a very small margin of error. For the Xan dolomite, the rms error values were 0.099 and 0.156 km/s, respectively. For the andesitic sill, rms error values were 0.023 and 0.09 km/s, respectively. In contrast, the rms error values for the velocities predicted using the Wyllie equation and the measured velocities were 0.69 km/s for the Xan Dolomite and 0.566 km/s for the andesitic sill.

The solid phase of the rock is controlled by both the solid and frame moduli. The $V_{P_{\text{matrix}}}$ value in the Wyllie equation is a function of the solid moduli only. The introduction of the pore-shape factor renders the velocity–porosity relationship

![Diagram](image)

**Fig. 5.** Components of departure of Wyllie’s predicted velocity ($V_{P_{\text{Wyllie}}}$) from the measured velocity ($V_{P_{\text{log}}}$) represented by zones for (a) spherical–bulk porosity (%) and (b) bulk porosity (%). Note that zones width and position are different for the Xan dolomite and the andesitic sill.
sensitive to the change in the frame properties of the rock as a result of pore-type variations. This is demonstrated in Figure 8, in which we assumed that a carbonate rock, composed of calcite, has both spherical and nonspherical pores. We took into consideration the mathematical limitation of the Kuster-Toksöz model, that the concentration of pores having a particular aspect ratio should be less than that aspect ratio (Eastwood and Castagna, 1983). Figure 8a shows how the rock velocities predicted by the Wyllie model deviate from the Kuster-Toksöz model as the percentage of spherical porosity to bulk porosity increases. The maximum deviation occurs when all pores in Kuster-Toksöz model are spherical (Hashin-Shtrikman upper bound). Conversely, the rock velocities predicted by the modified model match that of the Kuster-Toksöz model, as demonstrated by merging lines at all percentages of spherical porosity up to a bulk porosity of 30% (Figure 8b). At a higher bulk porosity, assuming all pores are spherical, the rock velocity predicted by the modified model starts to deviate from the Hashin-Shtrikman upper bound. The realization of variable pore-shape factor portrays the Wyllie equation as only one solution for the velocity–porosity relationship, at which all pores are interparticle or intercrystalline and consequently $S$ is 1. An increase in the amount of high-aspect-ratio pores would lead to an increase in $S$. The maximum value of $S$ was 2.16 at a spherical porosity of 30%.

The Wyllie equation tends to overestimate bulk rock velocity in the presence of fracture porosity. If we view the pore type as a continuum that ranges from fracture pores on one end to spherical pores on the other end, then the pore shape factor as a function of the amount of specific pore type could perhaps

![Graph](image_url)

**Fig. 6.** A correlation of the velocity calculated using the modified Wyllie equation ($V_{\text{mod Wyllie}}$) after introduction of a pore shape factor and the measured velocity ($V_{\text{log}}$) for both rock types: (a) Xan dolomite and (b) andesitic igneous sill.
Fig. 7. The accuracy of the modified model in predicting (a) velocity calculated by the Kuster-Toksöz model and (b) measured velocity. (c) The accuracy of the Wyllie equation in predicting the measured velocity. Accuracy is measured in terms of root mean square error (RMSE) and absolute average error.
be generalized to account for fracture porosity. This generalization would require further investigation to determine the correlation between $S$ and the fracture porosity. Conceptually, since fracture porosity dramatically decreases the strength of the rock, $S$ would be less than unity.

**FACTORS CONTROLLING ACOUSTIC VELOCITY**

The generalization of the Wyllie equation is a four-parameter model. These parameters are bulk porosity, pore type, fluid type, and matrix composition. Figure 9 is a graphical presentation of this model, assuming that the pore fluid is mud filtrate and the matrix is either dolomite or limestone. A velocity envelope instead of a line, which describes the Wyllie equation, defines the inverse velocity–porosity relationship. The lower limit of the velocity envelope is for rocks that have only interparticle or intercrystalline porosity (Wyllie equation behavior); the upper limit is when all pores are spherical or near spherical.

Near-spherical pores cause little reduction in rock strength and acoustic velocities. In contrast, pores with low aspect ratios significantly decrease the bulk modulus and acoustic velocities (Brie et al., 1985). The introduction of the $S$ factor gives more weight to $V_{p,\text{matrix}}$ to retain the rock stiffness, depending on the amount of spherical porosity. When all pores in a rock are high aspect ratio pores, the rock follows the upper limit of the velocity–porosity relationship in Figure 9. Once intercrystalline or interparticle pores are introduced, a drop in the velocity occurs and the rock behaves in a Wyllie equation fashion depending on the amount of intercrystalline pores. This is illustrated in Figure 9 by lines of equal high-aspect-ratio pores. This representation allows direct estimate of pore-type proportions if porosity is known.

Figure 10 demonstrates the applicability of the modified model on data published by Anselmetti and Eberli (1999). They measured the acoustic velocity for over 300 samples of carbonate rocks. Many pores in these samples are well embedded in the rock frame and include moidal, vuggy, and intrafossil pores. The velocity envelope of the modified model enclosed most of the measured velocity points to bulk porosity of up to 30%.

Carbonate rocks represent the most common reservoirs in which high-aspect-ratio pores may occur. Velocity–porosity transforms are commonly used to model and characterize such reservoir rocks. In many cases, assumptions are made with little certainty regarding the matrix composition, pore type, or amount of porosity in the modeled reservoir. The amount of error from uncertainty in pore types is much larger than that resulting from uncertainty in carbonate matrix composition as quantitatively evaluated using the modified model (Figure 11). This implies that using a velocity–porosity relationship that does not account for pore-type distribution, such as the Wyllie model, would lead to erroneous results—especially in good-quality reservoirs. Meanwhile, the pore shape factor as a function of measured rock velocity,

$$S = \log\left(\frac{(1 - \phi_B)V_{p,\text{fluid}}V_{p,\text{rock}}}{\phi_B V_{p,\text{matrix}} V_{p,\text{fluid}}}\right) - \log\left(V_{p,\text{fluid}} - \phi_B V_{p,\text{rock}}\right),$$

uses the sensitivity of velocity measurements to changes in pore types. Thus, this factor may serve as a quantitative indicator for pore-type distribution in such reservoirs.

**SUMMARY AND CONCLUSIONS**

The shape, size, and distribution of high-aspect-ratio pores provide more grain-to-grain-contacts in the host rocks than interparticle or intercrystalline pores at the same amount of porosity. This affects the frame properties of the rocks as they become stiffer. Our introduction of a pore shape factor into the Wyllie equation gives more weight to the $V_{p,\text{max}}$ value to retain the rock stiffness. Based on our modified model, there is no unique velocity–porosity curve but rather lines of equal high-aspect-ratio porosity. This realization recognizes Wyllie’s velocity–porosity relationship as one particular case in which all pores are intercrystalline or interparticle with a pore shape factor $S$ equal to unity. An increase in the amount of high-aspect-ratio pores leads to higher $S$. Further investigation is needed to determine the correlation between $S$ and the amount of fracture porosity. Conceptually, since fracture porosity dramatically decreases the strength of the rock, $S$ would be less than unity.

Although the rocks we studied have different lithologies and diagenesis, the predicted velocity of the modified model correlated very well with the measured velocity for both rocks: $R^2$
Fig. 9. Graphical presentation of the new realization of the Wyllie equation. A velocity envelope defines the inverse velocity–porosity relationship. When all pores in a rock are high-aspect-ratio pores, the rock follows the upper limit of the velocity–porosity relationship. Once intercrystalline or interparticle pores are introduced, a drop in the velocity occurs and the rock behaves in a Wyllie equation fashion, depending on the amount of intercrystalline pores (a) Limestone; (b) dolomite.

Porosity in carbonate rocks is characterized by diversity in pore shapes as a result of diagenetic factors. High-aspect-ratio pores such as vuggy and moldic are common in these rocks. The error in velocity–porosity conversion resulting from uncertainty in pore types is highest in good-quality reservoirs. Thus, it is crucial to identify such types in seismic modeling or well-log analysis of carbonate reservoir rocks. Our pore-shape factor represents a quantitative indicator for pore type distribution that may help in characterizing carbonate reservoir rocks.

Both sonic and resistivity measurements are texturally sensitive and are affected by changes in pore type. The Archie equation is the basic model that links both rock and fluid electric properties to resistivity measurements. The cementation exponent $m$ in the Archie model is the factor that captures pore-type changes (Doveton, 1994). On the other hand, the Wyllie equation is the basic model that links both rock and fluid acoustic properties to sonic measurements. However, it lacks any expression that can be related to changes in pore type.
The introduced pore shape factor $S$ can capture such changes. It may represent the acoustic equivalent to the cementation factor in Archie’s law.

REFERENCES


