

# The Impact of Pore Geometry and Microporosity on Velocity-Porosity Relationship in Carbonates of Central Luconia, Sarawak\*

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## Abstract

Carbonate rocks frequently exhibit velocity-porosity relationships less predictable than those found in siliciclastics because of complex and heterogeneous pore structures. Pore structures are constructed by macropores and micropores. In this study, macropores are the pores that can be detected in thin section images, while microporosity includes the pores that cannot be detected in the thin section images (diameter of the pores are <30  $\mu\text{m}$ ).

In this preliminary research, velocity measurements of 20 core plugs of a Miocene carbonate platform in Central Luconia, Sarawak were made under dry-saturated conditions at variable confining pressures and at effective pressures of 20 MPa. The cross plot of measured velocity and porosity shows scattering along the Wyllie's time average equation. The large scattering in most cases will result in large uncertainties in seismic inversion and calculations of porosity volumes.

Digital image analysis (DIA) of thin section images were used to identify the cause of the scattering and improve the velocity-porosity relationship. The amount of microporosity is calculated as the difference between the observed porosity in digital image analysis and the measured porosity from the core plug. The correlation coefficient ( $R^2$ ) between total porosity and velocity is 0.722.

The advantage of DIA is that it derives quantitative description of the pore structures. Four DIA parameters proved to best describe several aspects of the pore system: dominant size (DOMsize), perimeter over area (PoA), gamma ( $\gamma$ ), and aspect ratio (AR). PoA and DOMsize, in words, tortuosity of the pore system and the pore size, show good correlation with velocity. The addition of these macropores geometric parameters increase the  $R^2$  by 0.17. Combining microporosity data and geometric parameters in the velocity-porosity relationship increases

the R<sup>2</sup> by 0.18 to 0.896. In conclusion, four main factors, namely pore size (DOMsize), pore system tortuosity (PoA), pore circularity ( $\gamma$ ) and percentage of microporosity are the cause of scattering along the velocity-porosity relationship for Miocene carbonates of Central Luconia, Sarawak.

## **Introduction**

Lack of correlation between porosity and other physical properties in carbonate rocks causes uncertainty in porosity prediction and seismic inversion. The high diagenetic potential of carbonates results in intense alteration of pore structure, which can lead to a decrease of effective porosity for flow and wave propagation (Baechle, 2004).

In 1958, Wyllie et al. proposed a theory that linked velocity and porosity, although they proposed the theory for siliclastic rock, their theory has been widely used to predict porosity in carbonate rocks. Velocity-porosity relationships in carbonate rock studies have entered the stage where a consensus exists that pore types and the internal geometry of rocks influence acoustic velocity in some way. Nevertheless, the details of how the internal geometry of rocks affects acoustic velocity is not entirely understood because the approach used remains qualitative or semi-quantitative (Weger, 2006).

The hypothesis made is that separating the effects of pore structure on acoustic velocity from porosity will improve the porosity prediction from velocity. The objectives of this research are:

- 1) To investigate how valid it is to use Wyllie's time-average equation to predict porosity in carbonates.
- 2) To quantify geometric parameters and find out which aspects of pore geometry influence acoustic velocity.
- 3) To explore the link between carbonate porosity, acoustic velocity and pore geometry information.

## **Methodology**

Twenty core plugs of a Miocene carbonate reservoir from a well in one of the carbonate platforms of Central Luconia, Sarawak, were used for this preliminary verification. Acoustic velocities of core plugs from Miocene carbonates of Sarawak were measured using a pulse transmitter technique at different pressures to simulate the real reservoir conditions. Porosity of the samples was measured using a helium pycnometer.

Weger et al. (2004) introduced digital image analysis (DIA) to produce quantitative pore geometric parameters, which can be linked to physical properties in carbonates. The methods of Weger et al. (2004) are used to analyze thin sections to quantitatively evaluate the influence of pore geometry on acoustic velocity. This study explores the possibility that the reasons for scattering in the velocity-porosity space could be caused by the pore geometry and microporosity. If this can be proven, they can be used to improve porosity prediction from velocity.

## Parameters Calculated from Image Macroporosity

Four geometric parameters proved to be best to describe several aspects of the pore system. The explanations of the four geometric parameters given by Weger (2006) are as follows:

### **Dominant size**

Dominant pore size (DOMSize) is defined as the upper boundary of pore sizes of which 50% of the porosity in a thin section is composed. This parameter provides an indication of the pore-size range that dominates the sample. In our data, DOMSize ranges from 100 to 350  $\mu\text{m}$  (units given in length as equivalent diameter).

### **Perimeter Over Area**

Perimeter over area (PoA) is the ratio between the total pore-space area on a thin section and the total perimeter that encloses the pore space. The PoA can be regarded as a 2-D equivalent to a specific surface, the ratio between pore volume and pore surface. Generally, a small number indicates a simple pore system. The PoA values in our data range from 40  $\text{mm}^{-1}$  to more than 100  $\text{mm}^{-1}$ .

### **Gamma**

Gamma ( $\gamma$ ) was defined by Anselmetti et al. (1998) as the perimeter of an area of an individual pore normalized to a circle, i.e. a perfect round circle would have a gamma of 1. The  $\gamma$  parameter describes the roundness/edginess of the pore. In our data, the area-weighted mean of  $\gamma$  for the entire thin section ranges from 1.5 to 4.5.

### **Aspect Ratio**

Aspect ratio (AR) is defined here as the ratio between the major and the minor axis of an ellipse that encloses the pore. The AR describes the elongation of the pore-bounding ellipsoid. In our data, the arithmetic means of AR values for the entire thin section range from 0.53 to 0.57.

## Impact of Pore Geometry on Acoustic Velocity

PoA and AR show an inverse trend: low values of PoA and AR result in high velocity. DOMsize and  $\gamma$  show a proportional relationship on the velocity-porosity cross plot. High DOMsize and  $\gamma$  result in low velocity.

DOMsize and PoA show a strong correlation to velocity relative to other geometric parameters. A combination of DOMsize and PoA geometric parameters information contribute to a quantitative description of the thin section. For example, low velocity samples are the result of low DOMsize (which indicates the existence of small individual pores) and high PoA (complex pore network).

The DOMsize shows a trend of increasing velocity with increasing values of DOMsize at a given porosity ([Figure 2b](#)). The larger the dominant size of the pores, the faster the sound wave travels in the samples, relative to the samples that have smaller dominant pore sizes. At any given porosity, samples with a high value of PoA have low velocities; samples with low value of PoA have high velocities ([Figure 2c](#)).

Perimeter over area captures the overall tortuosity of the pore system, small value of PoA means the pore system of the sample appears to have simple pore geometry. The more complex the pore geometry, the more tortuous the sound path will be and the longer time it will take for the sonic wave to travel from one end of the sample to the other.

The trend for  $\gamma$  parameter is not that well developed for this set of data ([Figure 2d](#)). However, generally at any given porosity, low gamma values correlate with high velocities. This trend indicates that the rounder the individual pores, the slower the velocity. AR also shows a weak trend on the velocity-porosity crossplot ([Figure 2e](#)). In general, low AR results in high velocity. Most of the samples however, have relatively high AR, which means the individual pore shapes are less ellipsoid.

Low DOMsize and high PoA values result in low velocity of the sample. High velocity samples show high values of DOMsize and low values of PoA.

### **Impact of Microporosity on Acoustic Velocity**

Macropores are defined by pores, which are vertically connected through the thin section, resulting in a minimum pore diameter of approximately 30  $\mu\text{m}$  (the thickness of a thin section). The amount of microporosity is calculated as the difference between the observed porosity in DIA and the measured porosity from the core plug (Anselmetti et al., 1999). The geometry of the micropores is not assessed in this study, but the percentage of microporosity is included in the analysis.

Microporosity fraction shows a clear inverse trend, velocity decreases with an increase in microporosity ([Figure 2a](#)). Samples with a high amount of microporosity (20-25%) plot in the lower part of the velocity-porosity data cloud and tend to cluster around the Wyllie time-average equation.

### **Link Between Velocity, Porosity and Pore Geometric Parameters**

Anselmetti et al. (1999) introduced “velocity deviation log” which is the difference of the measured acoustic velocity to the velocity calculated from the porosity value estimated from time-average equation . Because deviations are the result of the variability of velocity at certain porosity, the deviation log reflects the different rock-physical signatures of the different pore types.

DIA parameters provide quantitative description for these pore types. Positive velocity deviations mark zones where velocity is higher than expected from the porosity values, such as zones where frame-forming pore types dominate. These samples show high DOMsize and low PoA value; which verbally means large pores and simple pore network. Negative deviations mark zones in which sonic velocities are unusually low ([Figure 1](#)). These samples show relatively low DOMsize and high PoA value. In other words, these samples are characterized by small pores and a complex pore network.

In exploring the link between velocity, porosity and pore geometric parameters, multivariate regression analysis was used to calculate the correlation of determination between these variables. Porosity alone used as velocity estimator for Miocene carbonates of Central Luconia, Sarawak resulted in a correlation coefficient (R<sup>2</sup>) of 0.722 ([Table 1](#)).

To find out which parameter(s) gives a coefficient of determination nearest to 1, a single DIA parameter (AR,  $\gamma$ , % microporosity, PoA or DOMsize) is added to porosity in a linear combination. Combination of porosity and PoA results in the highest R<sup>2</sup> among the DIA parameters; with R<sup>2</sup> of 0.873. DOMsize and PoA have a strong correlation coefficient (R<sup>2</sup>) of 0.893. Velocity prediction will be more accurate using a combination of porosity with  $\gamma$ , PoA and DOMsize with a correlation coefficient (R<sup>2</sup>) of 0.898.

### **Conclusions**

The weak relationship between porosity and velocity in carbonates can be related to pore geometry and microporosity. A combination of porosity and digital image parameters is able to explain more than 89% of the variation in velocity. DIA parameters that have the greatest impact on velocity in Miocene carbonates of Sarawak are PoA, DOMsize and  $\gamma$ . This indicates that pore sizes, tortuosity and edginess of the pore are more important in affecting the rock stiffness, and thus the acoustic behavior of carbonates.

The aspect ratio, which is commonly used in theoretical models to explain rock stiffness relationship with velocity, does not significantly improve the ability to estimate velocity in carbonates. A more comprehensive study that includes more samples with various pore types and similar porosity values needs to be carried out to improve these findings. A new pore type classification, specifically for Central Luconia carbonates could also be introduced.

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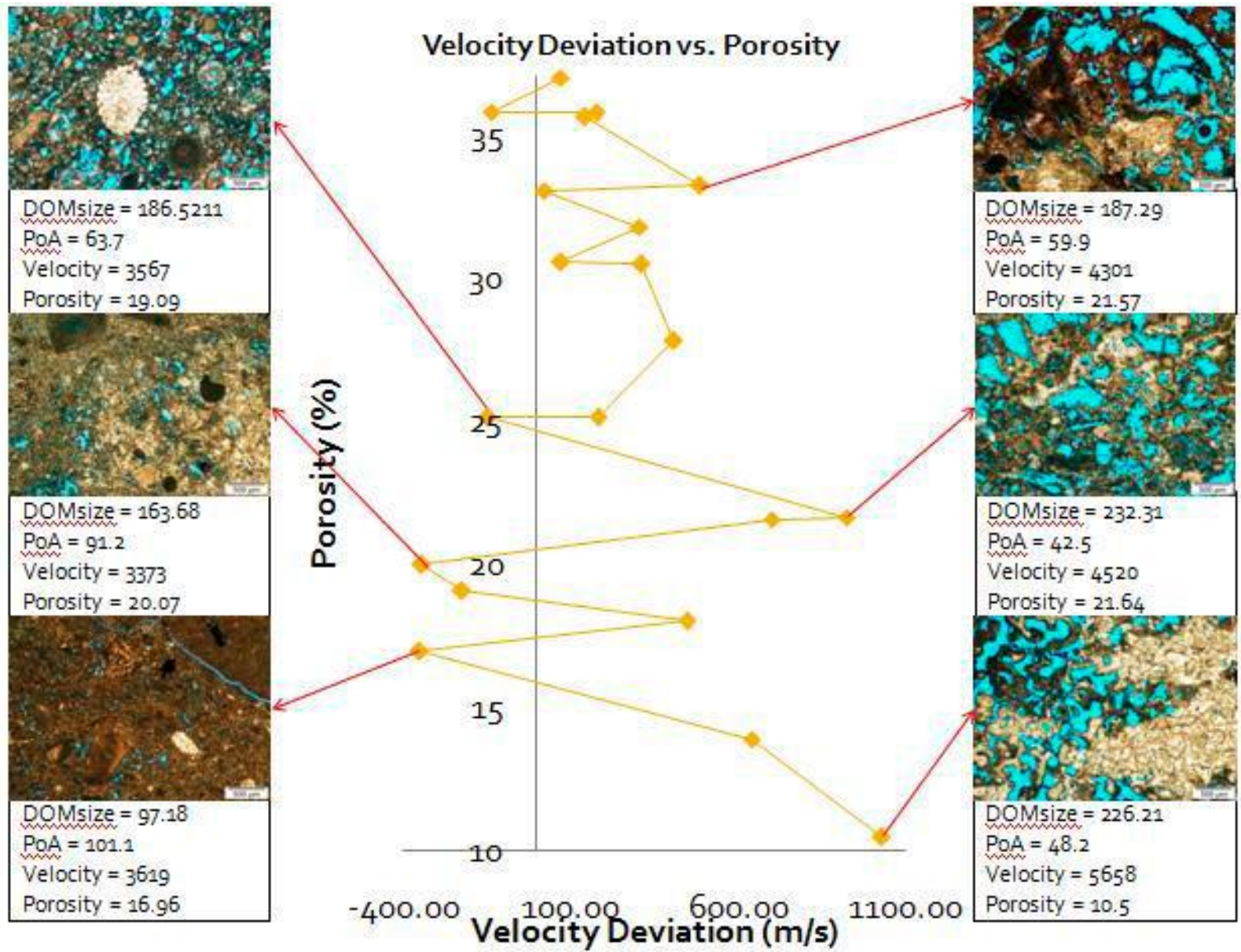


Figure 1. Illustration shows velocity deviation versus porosity graph. Samples on right side of the zero deviation line shows high DOMsize and low PoA values compared to samples that deviates negatively.



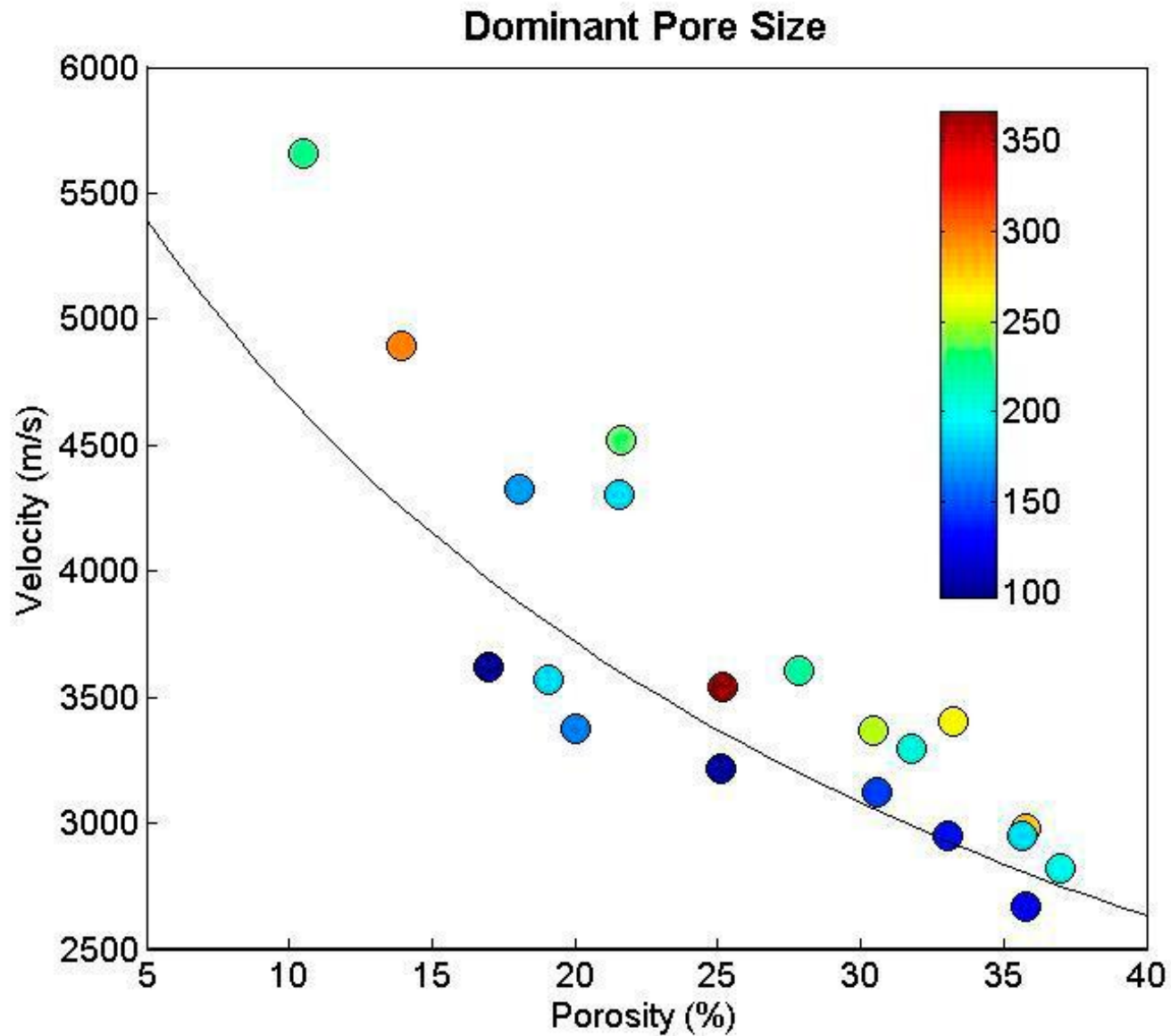


Figure 2a. Crossplot of velocity-porosity with color-coded data representing microporosity fraction. Color-coded indicates velocity values with blue color for lowest velocity and red for highest velocity. The black line represents Wyllie's time average equation velocity estimation.



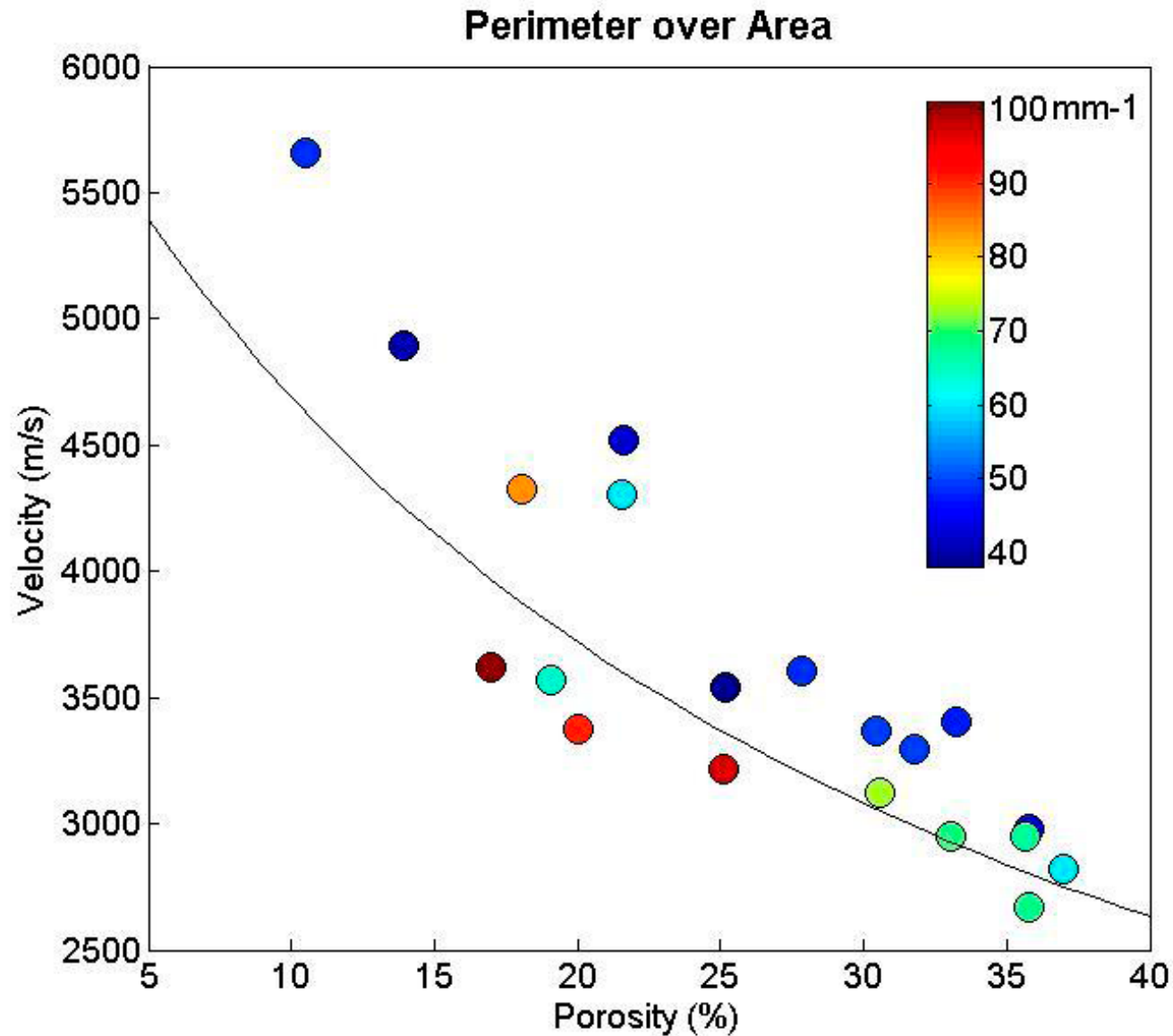


Figure 2b. Crossplot of velocity-porosity with color-coded data representing dominant pore size. Color-coded indicates velocity values with blue color for lowest velocity and red for highest velocity. The black line represents Wyllie's time average equation velocity estimation.

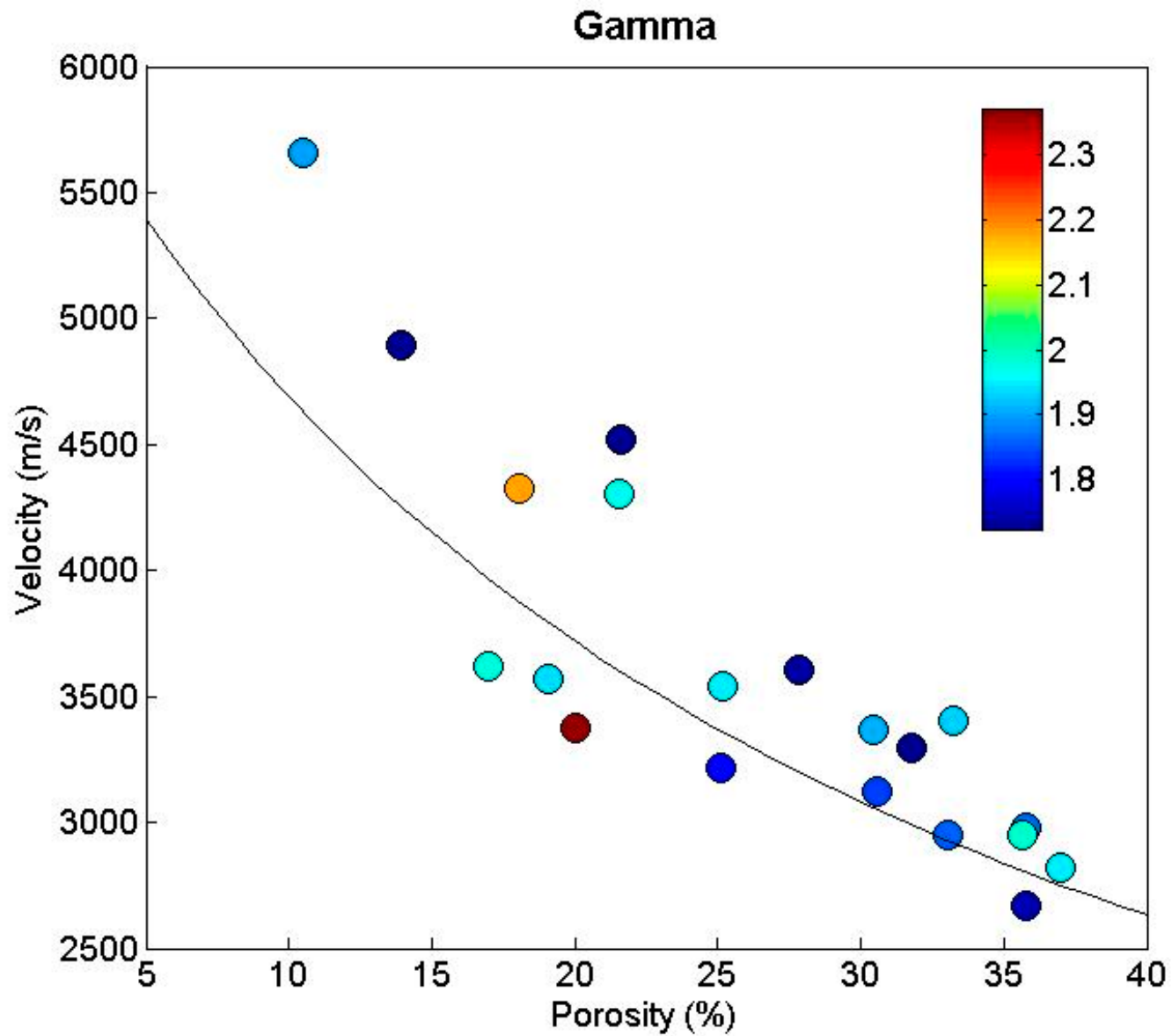


Figure 2c. Crossplot of velocity-porosity with color-coded data representing perimeter over area. Color-coded indicates velocity values with blue color for lowest velocity and red for highest velocity. The black line represents Wyllie's time average equation velocity estimation.

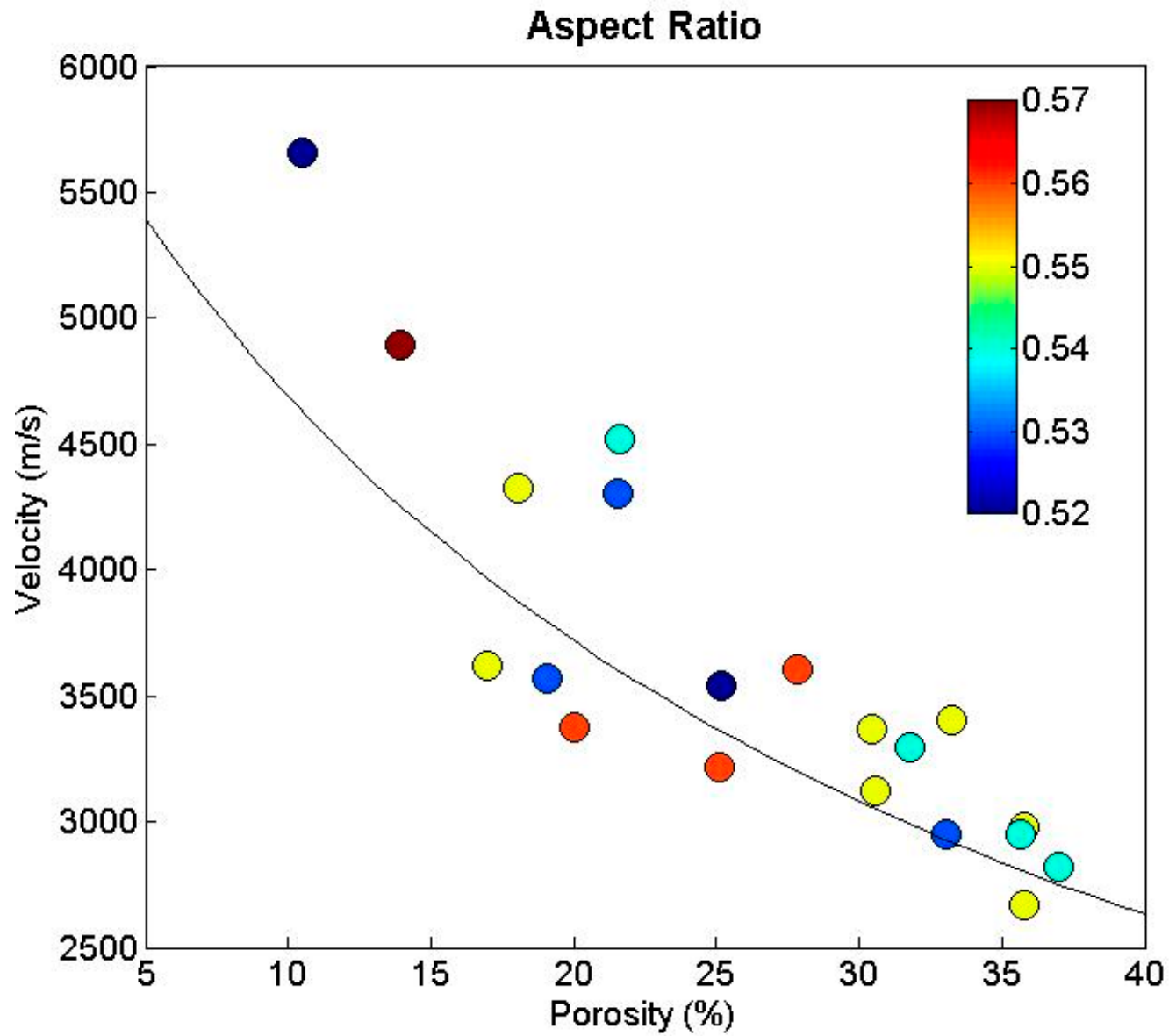


Figure 2d. Crossplot of velocity-porosity with color-coded data representing gamma. Color-coded indicates velocity values with blue color for lowest velocity and red for highest velocity. The black line represents Wyllie's time average equation velocity estimation.

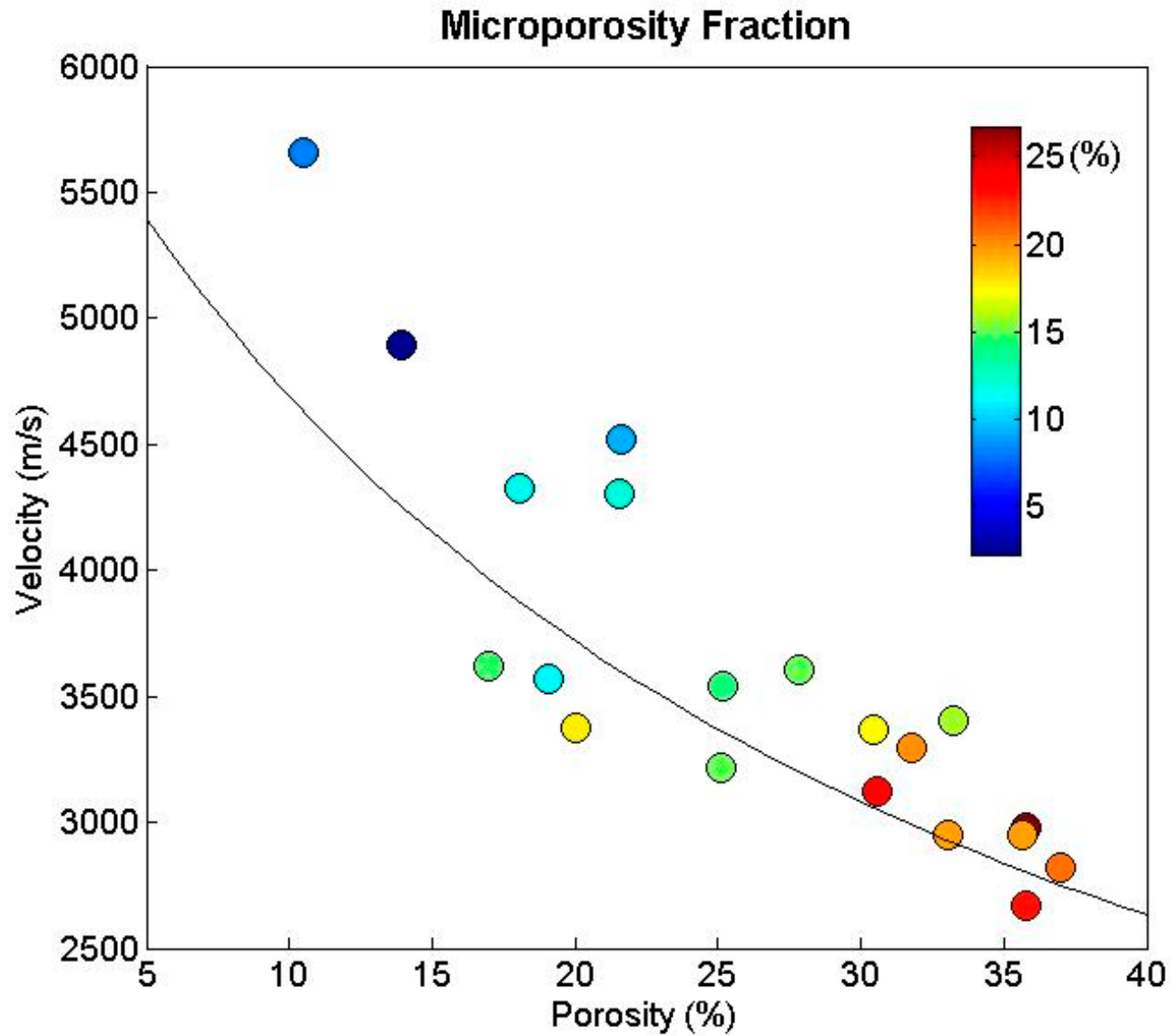


Figure 2e. Crossplot of velocity-porosity with color-coded data representing aspect ratio. Color-coded indicates velocity values with blue color for lowest velocity and red for highest velocity. The black line represents Wyllie's time average equation velocity estimation.

Variables	R <sup>2</sup>
Porosity	0.722
Porosity and AR	0.738
Porosity and % microporosity	0.738
Porosity and $\gamma$	0.768
Porosity and DOMsize	0.792
Porosity and PoA	0.873
Porosity and PoA and AR	0.873
Porosity and PoA and $\gamma$	0.874
Porosity and PoA and % microporosity	0.877
Porosity and PoA and DOMsize	0.893
Porosity and PoA and DOMsize and AR	0.893
Porosity and PoA and DOMsize and % microporosity	0.896
Porosity and PoA and DOMsize and $\gamma$	0.898

Table I. Coefficients of determination in ascending order – from the smallest to the highest R<sup>2</sup> value from the correlation between measured velocity and estimated velocity from the estimators, with DIA parameters as the input variables.