Porosity and Heterogeneity Effect on V_p/V_s Ratio in Carbonate Rocks from a Reservoir in the Middle East*

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Abstract

Acoustic velocity measurements on carbonate rocks are often influenced by the level of heterogeneity, particularly in texture and pore type. This phenomenon, in return, affects the relationship between P- and S-wave velocity ratio (V_p/V_s) and porosity. Our objective in this study is to improve our understanding of how heterogeneity affects these relations. For this purpose, we analyzed 78 core plug samples at dry and ambient conditions. These samples were taken from a producing reservoir in the Middle East. We conducted measurements of porosity and acoustic velocities (V_p and V_s) in dry samples. In addition, we used Dunham's carbonate rock classification to sort the core samples into smaller groups that are less heterogeneous and have distinguishable rock types. Vp and Vs cross plots were generated to investigate the general trends of acoustic velocities ratio to porosity and rock class.

Our preliminary results confirm that the V_p and V_s relation is generally linear, with an average V_p/V_s ratio of 1.74. Our findings also show that dense limestones with relatively low porosities tend to have the highest average V_p/V_s ratio (1.89), while skeletal peloidal packstones and wackestones tend to have the lowest average V_p/V_s ratio (1.68 and 1.70, respectively). In addition, the cross plot between V_p/V_s ratio and porosity suggest that the V_p/V_s ratio decreases as porosity increases. Moreover, when taking into consideration the rock classification, we found that dense limestones and grainstones show the sharpest decline in V_p/V_s value as porosity increases. On the other hand, wackestones V_p/V_s values proved to be the least affected by the increase in porosity. In conclusion, the V_p/V_s ratio correlation with porosity confirms an inversely proportional relation that slightly varies between the different carbonate rock classes; this is probably caused by their level of heterogeneity. These correlations have the potential of identifying different carbonate rock types from V_p/V_s ratio and porosity cross plots.

Introduction

When acoustic velocity laboratory measurements are conducted, correlating the acoustic compressional velocity (V_p) to acoustic shear velocity (V_s) in carbonates is often overlooked. However, it is a known fact that the V_p/V_s values can aid in identifying different lithologies. For instance, V_p/V_s values for limestone are in the order of 1.9 while dolomite display a V_p/V_s ratio of about 1.8 and sandstones show a

V_p/V_s ratio of around 1.6 as shown by (Pickett, 1963). These observations are supported by several laboratory and well-log studies (Nations, 1974; Kithas, 1976; Benzing, 1978). V_p/V_s ratios are also known to be very sensitive to saturating pore fluids and tend to have 10–20 % lower values when samples are measured in dry conditions (gas saturated), when compared to samples measure with water- or brine-saturated pores (Tatham and Stoffa, 1976; Tatham, 1982; King, 1966).

On the other hand, acoustic velocities of carbonate rocks seem to be highly influenced by heterogeneity, particularly by texture and porosity type (Eberli et al., 2003; Weger et al., 2009). This phenomenon, therefore, must affect the V_p/V_s ratio, and even more its relationship with porosity. These relationships can be of great importance and can help identify rock types and their connection with seismic. In this research, we intend to improve our understanding of how heterogeneity affects these correlations.

Methodology

Seventy eight core plug samples from an Upper Cretaceous carbonate reservoir in the Middle East were analyzed in this study. We performed the measurements of porosity, V_p and V_s at ambient and dry conditions.

An initial lithological description was performed on the analyzed set of core plug samples based on Dunham's carbonate rocks classification. Though not as accurate as a thin-section description, it gave us an initial idea about the lithology and texture of these Cretaceous carbonate samples. The description divided the analyzed set of core samples into seven rock classifications which are as follows: Dense Limestone, Mudstone, wackestone, Skeletal Peloidal Packstone, Grainstone, Rudstone and Coated Rudstone.

We used a gas expansion helium porosimeter at ambient conditions to measure porosity by applying the gas transfer method (Boyle's Law) to determine the grain volume and calculate the pore volume.

Different types of cross plots were generated to study V_p and V_s trends of behavior with respect to porosity and rock classification. Plots like V_p versus V_s and V_p/V_s ratios versus porosity, have been useful when comparing the acoustic responses from samples with different rock types.

Results and Discussion

The V_p/V_s values for the studied set of samples based on their carbonate rock classification range between 1.68 and 1.89, with an average V_p/V_s ratio of 1.74 for the whole set of samples (Figure 1). In addition, when we observe their V_p/V_s ratio with respect to their rock classes, we found that Dense Limestones tend to have the highest average V_p/V_s ratios while Skeletal Peloidal Packstones have the lowest V_p/V_s average ratios (Figure 2).

Porosities on the same set of samples range between 0.2% and 37.0%, with an average porosity of 23.8%. Plotting the V_p/V_s ratio versus porosity shows a very scattered relation, with no clear trend for all studied samples (Figure 3).

In spite of that, when taking into consideration the carbonate rock classifications of the analyzed set of samples, we found that V_p/V_s ratio decreases with porosity for each different group. In addition, the Dense Limestones that show the highest average V_p/V_s ratio value at 1.89 also have an average porosity of 2.2%, which is the lowest average porosity within the studied set of samples. This behavior can be attributed to the low amount of porosity found in Dense Limestones, which reduces the effect of the saturating pore fluid (gas in our case) on the V_p/V_s ratio. The steepest slope observed, from plotting V_p/V_s versus porosity, is for the Grainstones. On the other hand, wackestones show the smallest change in V_p/V_s ratio values with porosity. This result suggests that the V_p/V_s ratios in Grainstones are more sensitive to porosity changes than the rest of the samples, while the wackestones display the flattest slope in the examined set of samples and therefore show the least sensitivity to porosity changes (Figure 4).

Conclusions

Analyzing the V_p/V_s ratios of 78 carbonate samples from the Middle East shows that there is a proportional relation between V_p and V_s. Also, after including the rock classification, we observed that the dense limestones tend to have the lowest porosities and the highest V_p/V_s ratios. In addition, V_p/V_s decreases with porosity differently in each rock class. Grainstones samples, especially, have the highest drop in V_p/V_s ratio as porosity increases. Wackestones, on the other hand, exhibit the lowest drop in V_p/V_s ratio as porosity increases. These results indicate that there is a potential application to use V_p/V_s ratio to identify rock classes in carbonate rocks. Future studies will include the effect of fluid and potential applications using well logs.

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References

Benzing, W.M., 1978, V_p/V_s relationships in carbonates and sandstones, Laboratory data: 48th Annual International SEG Meeting, San Francisco.

Eberli, G.P., G.T. Baechle, F.S. Anselmetti, and M.L. Incze, 2003, Factors controlling elastic properties in carbonate sediments and rocks: The Leading Edge, v. 22, p. 654-660.

King, M.S., 1966, Wave velocities in rocks as a function of changes in overburden pressure and pore fluid saturants: Geophysics, v. 31, p. 50-73.

Kithas, B.A., 1976, Lithology, gas detection and rock properties from acoustic logging systems: Society of professional well log analysts

17th Annual Symposium.

Nations, J.F., 1974, Lithology and porosity from acoustic shear and compressional wave transit time relationships: Society of professional well log analysts 15th Annual Symposium.

Pickett, G.R., 1963, Acoustic character legs and their applications in formation evaluation: Journal Petroleum Technology, v. 15, p. 659-667.

Tatham, R.H., 1982, V_p/V_s and lithology: Geophysics, v. 47, p. 336-344.

Tatham R.H., and P.L. Stoffa, 1976, V_p/V_s – A potential hydrocarbon indicator: Geophysics, v. 41, p. 837-849.

Weger, R.J., G.P. Eberli, G.T. Baechle, J.L. Massaferro, and Y.-F. Sun, 2009, Quantification of pore structure and its effect on sonic velocity and permeability in carbonates: AAPG Bulletin, v. 93, no. 10, p. 1-21.

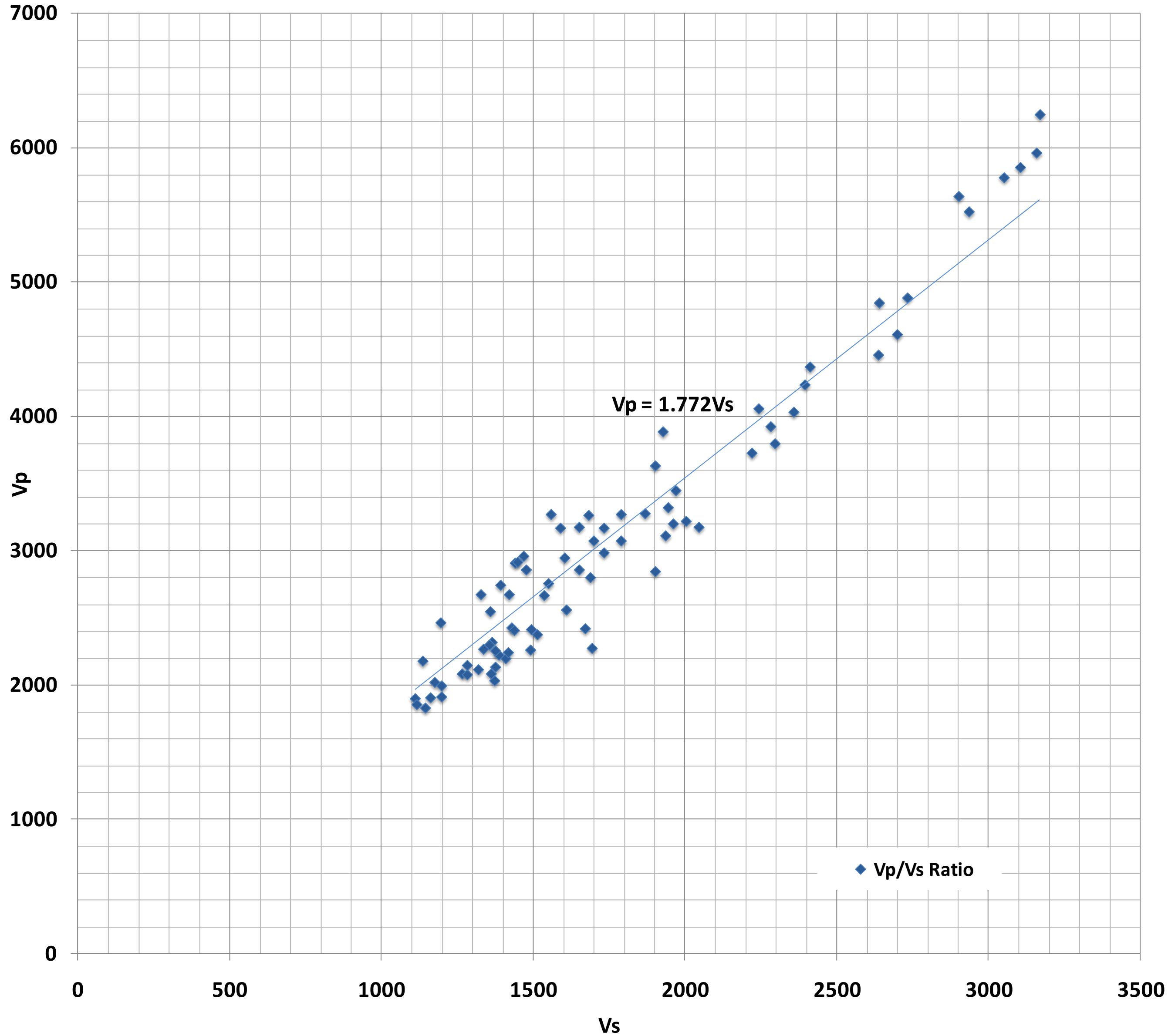

Figure 1. V_p Versus V_s for all studied samples. This plot shows the proportional relation between V_p and V_s, with an average general V_p/V_s trend of 1.78.

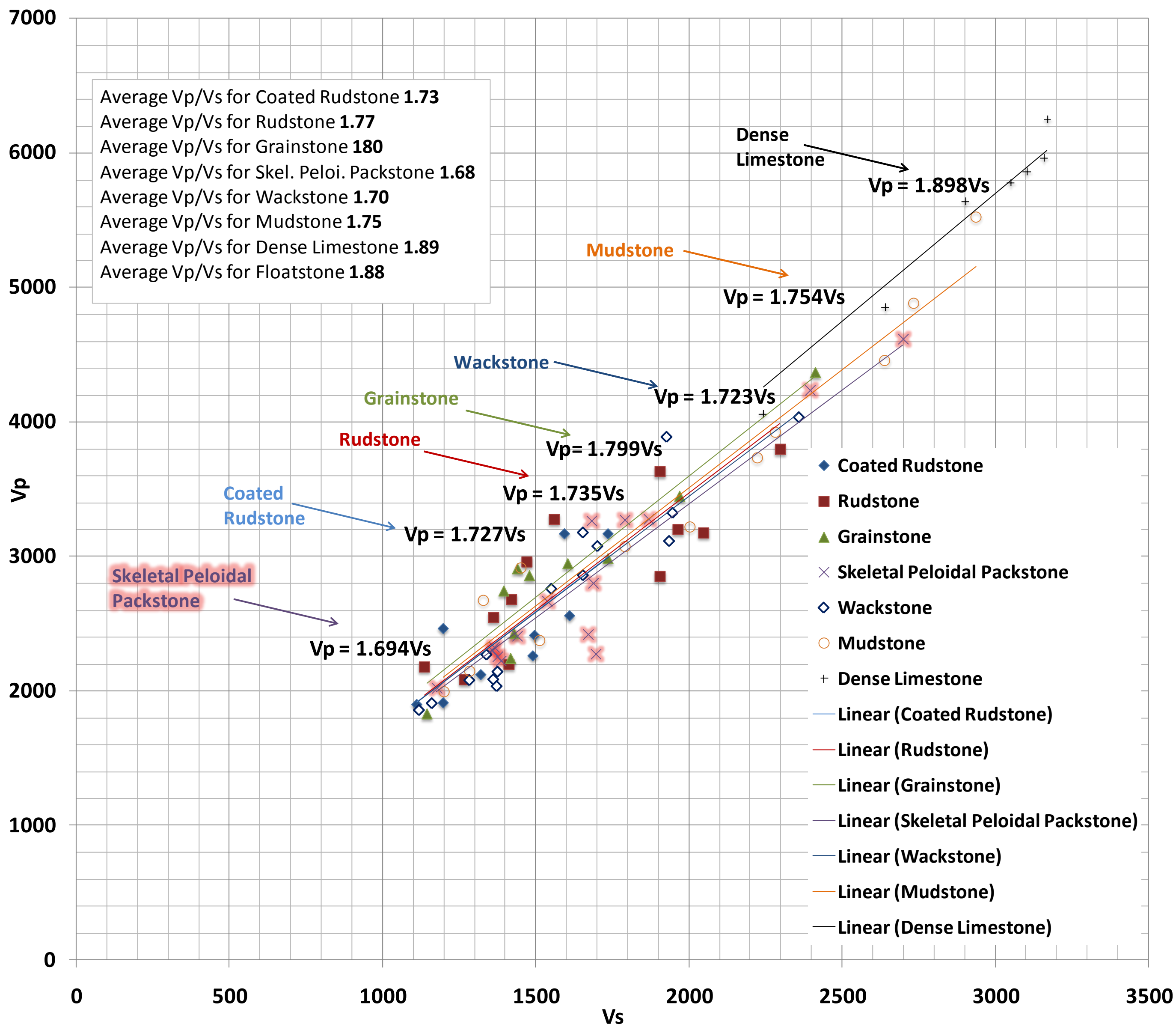

Figure 2. V_p versus V_s for Coated Rudstones, Rudstones, Grainstones, Skeletal Peloidal Wackestones, Mudstones, and Dense Limestones. This figure shows the proportional relation between V_p and V_s, and the average V_p/V_s ratios for each of the analyzed carbonate rock types.

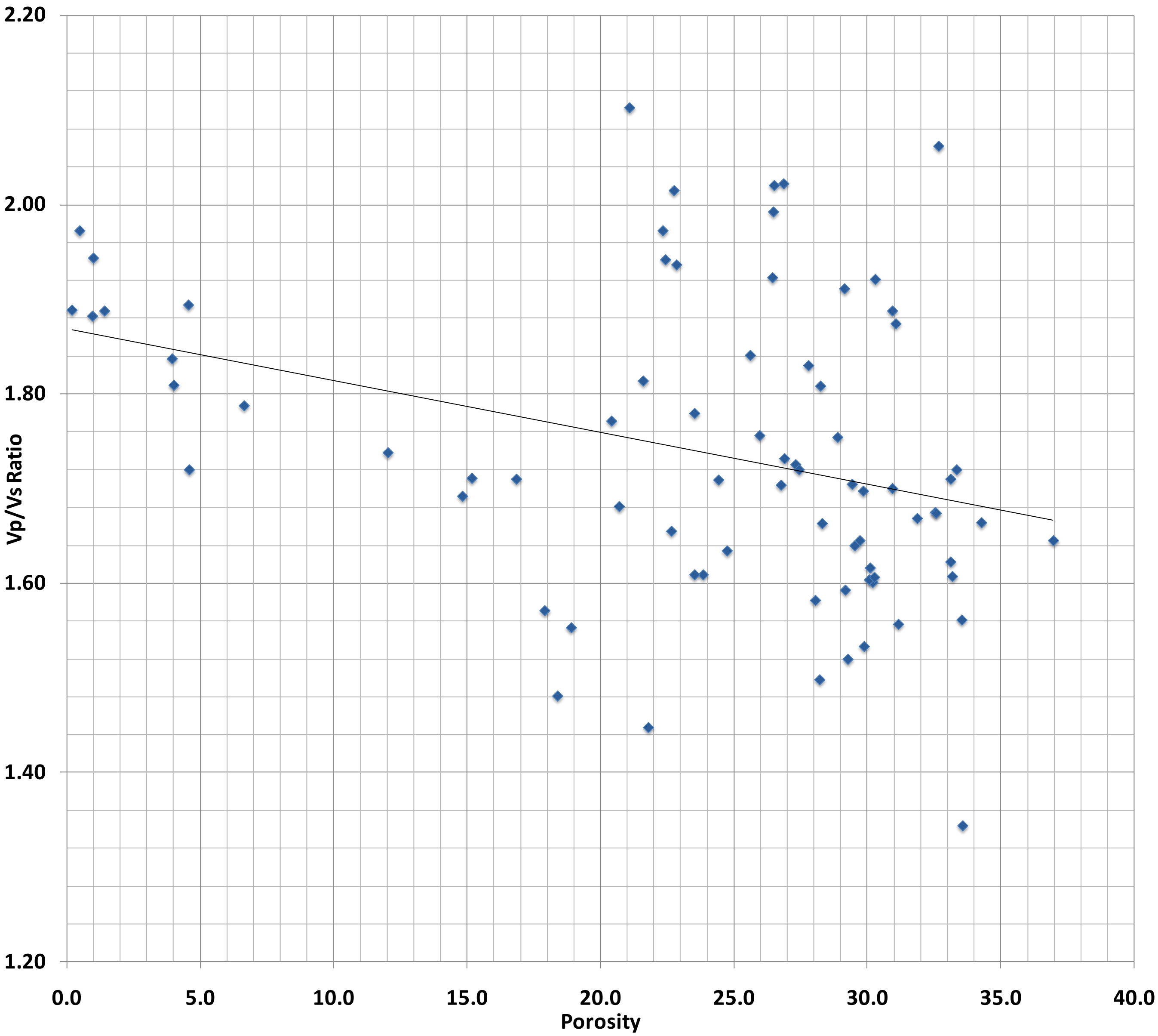

Figure 3. V_p/V_s ratio versus porosity for all studied samples.

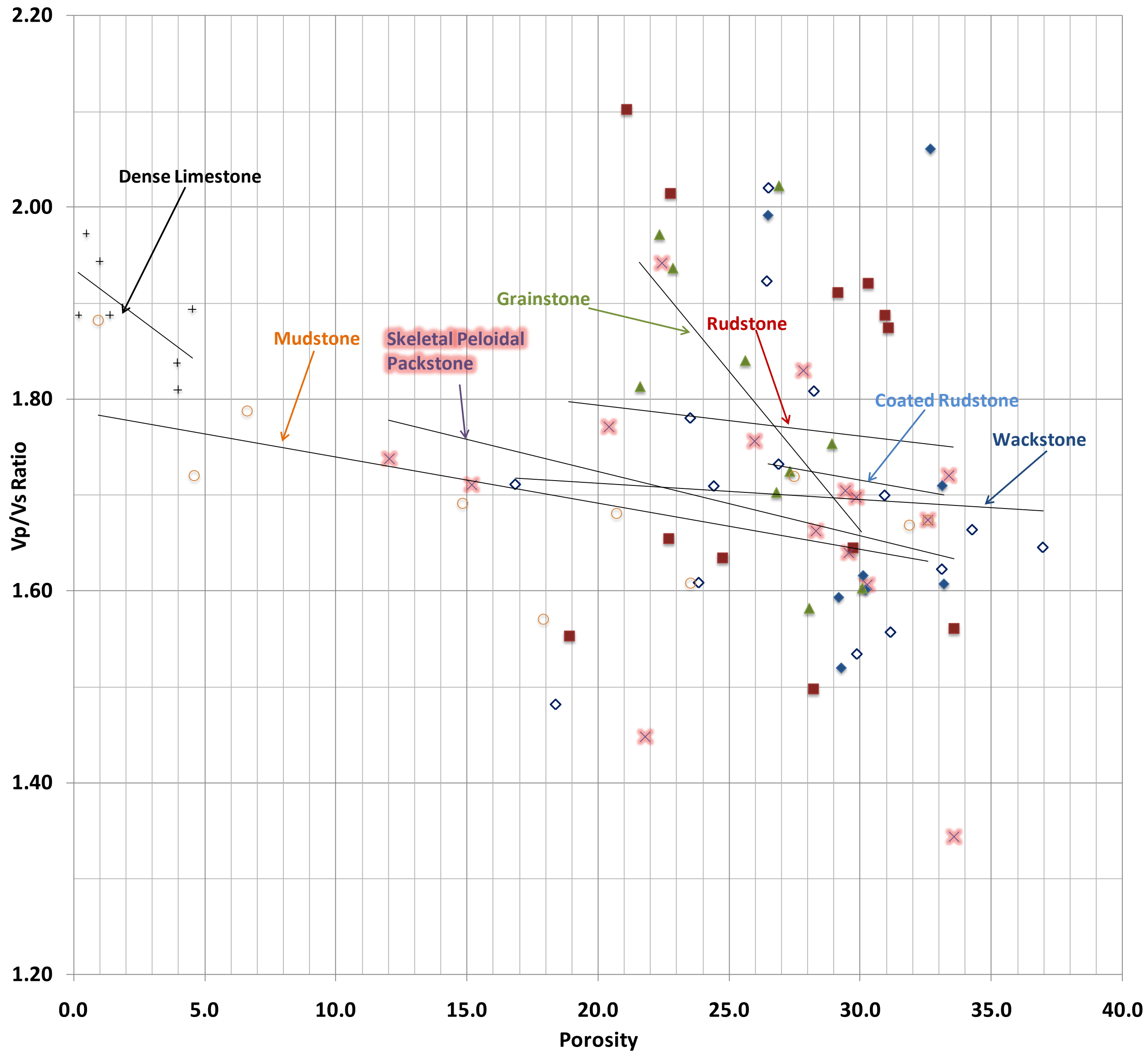

Figure 4. V_p/V_s ratio versus porosity for Coated Rudstones, Rudstones, Grainstones, Skeletal Peloidal Wackestones, Mudstones, and Dense Limestones. This plot shows the inversely proportional relation between V_p/V_s ratio and porosity and the varying degrees of sensitivity to porosity with respect to V_p/V_s ratio for the analyzed rock classes.