The main objective of this study is to provide a method to estimate pore aspect ratio from velocities. This approach uses a method proposed by Xu & White (1995) combined with a back-propagation neural network to derive elastic moduli in porous rock, and in turn to invert pore aspect ratio over the entire depth range based on log data. The approach provides a satisfactory connection between seismic data and well-log data.

INTRODUCTION

In order to predict P-wave and S-wave velocities in clay-sand mixture, various theoretical models have been proposed to study seismic wave propagation in porous rock. One recent study is that of Xu & White model (1995), which considered that the porosity can be divided into components attached to each clay and sand fraction separately, and that these fractions should possess different aspect ratios (the ratio of short axis to long axis). In their work, the aspect ratio remained fixed along the entire depth interval. In this paper, this restriction is relaxed by the construction of an inversion procedure using an artificial neural network. Firstly, the well-log and core data are used to derive porosity, shale and clay content. Secondly, the Xu & White model is used to estimate preliminary elastic moduli and properties, and then a back-propagation neural network inverts the pore aspect ratios directly for sand and clay. Finally, these new pore aspect ratios are inputted to the modified Xu and White model, and the elastic moduli are computed.

APPROACH

The Xu and White model [1995] is a practical model for simulating elastic wave velocities, which was based on the Kuster-Toksöz model [1974] and Gassmann [1951, 1965] model. According to this model, the total pore space consists of two parts, with one associated with sand grains and the other associated with clay. The pore space and pores are assumed to be spheroid, and their shape is characterised by the aspect ratio. The total effective pore space of the mixture ($\Phi$) is equal to the sum of the pore volumes related to sand grains ($\Phi_s$) and clay particles ($\Phi_c$):

$$\Phi = \Phi_s + \Phi_c,$$

and furthermore, the clay-related pore space can be approximately written as

$$\Phi_c = V_{sh} \frac{\Phi}{1 - \Phi}.$$  (2)

Kuster-Toksöz (1974) gives a series of equations to determine elastic moduli such as $K_d$, $K_m$, $K_f$, $\mu_d$, $\mu_m$, $\mu_f$, and the main relationship between the aspect ratio and elastic moduli is given by
\[ A = \frac{1}{3} \left( \frac{K_f - K_m}{3K_m + 4\mu_m} \right) \sum_{l=s,c}^{N} \Phi_l T_{iiij}(\alpha), \]  

\[ B = \frac{1}{25 \mu_m(3K_m + 4\mu_m)} \sum_{l=s,c}^{N} \Phi_l \left( T_{ijij}(\alpha) - \frac{T_{iiij}(\alpha)}{3} \right), \]  

where \( V_{sh} \) is the shale volume, \( K_f \) and \( \mu_f \) are the bulk moduli and shear moduli of fluid, both \( T_{iiij}(\alpha) \) and \( T_{ijij}(\alpha) \) are the functions of aspect ratio. But \( T_{iiij}(\alpha) \) and \( T_{ijij}(\alpha) \) cannot be directly measured from field data. In previous application of published papers, the aspect ratio for sand-related pores was often fixed at 0.1 for sand pores, and with 0.02 or 0.03 for clay-related pores, and these values are often used as best fits for large depth intervals up several hundred of meters. In reality, the pore aspect ratios in the real rock are not evenly distributed, and its value will change with lithology, fluid and pressure. As a result of this, the variation of aspect ratio will also affect velocity of seismic wave. From Figure 1(a) we can see that both aspect ratio and velocities have a very complicated relationship, the evidence from Nur & Simmons (1969), Gregory (1976) and Murphy (1982) shows that aspect ratio will be affected by many factors such as fluid, lithology, formation pressure and micro-cracks. Especially, when porosity is low and cracks are abundant, pressure often plays much more important role than others factors, Figure 1 (b) shows the aspect ratio variation with different experimental pressure (Nur & Simmons (1969) and Y.F.Sun & D.Goldberg (1997)).

![Figure 1: The relationship between velocity and aspect ratio, and pressure and aspect ratio](image)

Figure 1: The relationship between velocity and aspect ratio, and pressure and aspect ratio

Considering the effects of aspect ratio for velocity prediction, we suggest using a combined method of Xu and White (1995) and a back-propagation neural network (BPNN) to invert for depth variant aspect ratio. This approach includes three steps. Firstly, the Xu and White model is used to obtain preliminary elastic moduli, these include bulk and shear moduli for dry frame \( (K_d \text{ and } \mu_d) \), mixture \( (K_m \text{ and } \mu_m) \), fluid \( (K_f \text{ and } \mu_f) \), P- and S-wave velocity \( (V_p \text{ and } V_s) \). Secondly, the measured velocity will be used as a standard value to derive the functions of aspect ratio \( (T_{iiij}(\alpha) \text{ and } T_{ijij}(\alpha)) \) for sand and clay-related pores over the entire depth by means of Kuster-Toksöz model and a back-propagation neural network. In this neural network, the aspect ratio will be used as output layer, and four log curves will be used as input layers such as caliper log \((CAL)\), gamma-ray log \((GR)\), density log \((DEN)\) and self-potential log \((SP)\). Finally, the new aspect ratios from the
neural network will be used as the input of modified Xu and White model to replace fixed aspect ratio, and the new P-and S-wave velocities will then be predicted (Figure 2(a)).

![Diagram of the workflow](image)

**Figure 2**: Schematic diagram and results for aspect ratio

### RESULTS

The field data include log data, core analysis data and lithology data. Figure 2(b) show the result of the aspect ratio inversion which indicates that the values of aspect ratio related to sand are within 0.1 and 0.3, and the ranges of aspect ratio for the clay-related pores are within 0.01 and 0.02. Figure 3(a) is a comparison between the predicted and measured velocities using the result of depth invariant aspect ratio with our new approach. The new approach appears to be quite accurate. Figure 3(b) shows the results of error analysis for the predicted P-wave velocities, the left-hand plot is the result from the depth invariant aspect ratio model, and right-hand is the result of our new approach. We can find that our new approach has a good linear relationship and small scatter.

### CONCLUSIONS

The assumption of depth invariant aspect ratio has been used in velocity prediction, but it is only suitable for consolidated formations, and does not work well for the rocks containing fluids and rocks of low velocities. This is because aspect ratio may be affected by many factors. In this research, Xu-White model is used to obtain the preliminary elastic moduli and velocities, and a back-propagation neural network is used to invert the pore aspect ratios directly for the entire depth range. The validity of this approach is confirmed by real data and error analysis.

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REFERENCES


Figure 3: Comparison of results and error.