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Prediction of shear wave velocity using empirical correlations and artificial intelligence methods

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Abstract Good understanding of mechanical properties of rock formations is essential during the development and production phases of a hydrocarbon reservoir. Conventionally, these properties are estimated from the petrophysical logs with compression and shear sonic data being the main input to the correlations. This is while in many cases the shear sonic data are not acquired during well logging, which may be for cost saving purposes. In this case, shear wave velocity is estimated using available empirical correlations or artificial intelligent methods proposed during the last few decades. In this paper, petrophysical logs corresponding to a well drilled in southern part of Iran were used to estimate the shear wave velocity using empirical correlations as well as two robust artificial intelligence methods knows as Support Vector Regression (SVR) and Back-Propagation Neural Network (BPNN). Although the results obtained by SVR seem to be reliable, the estimated values are not very precise and considering the importance of shear sonic data as the input into different models, this study suggests acquiring shear sonic data during well logging. It is important to note that the benefits of having reliable shear sonic data for estimation of rock formation mechanical properties will compensate the possible additional costs for acquiring a shear log.

1. Introduction

In rock engineering, methodologies based on wave velocity are increasingly used to determine the dynamic properties of rocks (Singh et al., 2012). In Petroleum engineering context, this is mainly due to very sparse or no borehole-based rock mechanical data being acquired during drilling phase. This is while having this information is essential for reservoir development,

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management, and prospect evaluation in exploration areas (Ameen et al., 2009). The direct measurements of the geomechanical properties of formations need testing core samples in the lab. However, limited number of samples can be taken from the whole wellbore interval (of few thousands meter) due to cost and technical issues. In addition to the fact that lab experiments are time consuming and also expensive to be conducted, the results obtained from testing only few number of samples cannot provide a good estimation of mechanical properties of formations crossed by the wellbore. Indeed, it would be ideal to have continuous logs, similar to petrophysical logs, representing elastic and strength properties of different formations.

According to the studies carried out to estimate mechanical properties of subsurface layer, having shear velocity data is necessary to make reliable calculations (Ameen et al., 2009; Boonen et al., 1998; Eissa and Kazi, 1988; Rasouli et al., 2011; Zoback, 2007). However, in practice the shear sonic is not included in the set of acquired logs but only compressional sonic is available. In such occasions, several methodologies have been proposed to make an estimation of shear sonic data from other available data. For example, Wantland (1964) assumed Poisson's ratio for reservoir rocks and estimated shear wave velocities. However, Poisson's ratio is changing in a wide range in practice; hence the accuracy of estimated shear sonic data is questionable (Carroll, 1969). Another approach is to measure elastic properties of rocks through acoustic measurements of Vp and Vs using pulse transmission techniques in laboratory (Birch, 1960; Christensen, 1974; Kern, 1982; Burlini and Fountain, 1993; Ji and Salisbury, 1993; Watanabe et al., 2007). However, few lab data are available for V_s measurements compared to those of V_p (Ji et al., 2002). This is mainly due to the difficulties of V_s measurements at low pressures, as the transmission of shear wave through the sample requires a firm contact between the transducers and the end surfaces of the specimen. Since variations of shear wave velocity are related to the rock type, mechanical properties and loading conditions, the laboratory measurements cannot ideally simulate downhole field conditions (e.g. in situ stresses and fluid content). The use of a large range of empirical correlations has been reported during the last decades to estimate shear wave velocity from rock physical parameters (Castagna et al., 1993; Brocher, 2005, 2008; Ameen et al., 2009; Yasar and Erdogan, 2004). However, these correlations have been developed for a specific area and their use in other fields is subjected to uncertainties.

In recent years, artificial intelligence (AI) methods have been used widely for prediction purposes (Feng, 1995; Mohammadi and Rahmannejad, 2009; Zhang et al., 2009). Once the network has been trained, it can make prediction, based on its previous learning, about the output related to new input data set of similar pattern. Support Vector Regression (SVR) is usually used as an efficient machine learning methodology for prediction of rock properties (Annan and Chunan, 2008; Kang and Wang, 2010; Niu and Li, 2010; Rechlin et al., 2011; Wenlin et al., 2011). The SVR relies on the statistical learning theory enabling learning machines to generalize the unseen data. This technique has proven to have superior performances in a variety of problems due to its generalization abilities and robustness against noise and interferences (Steinwart, 2008). SVM is a device for finding a solution which uses the minimum possible energy of the data (Martinez-Ramon and Cristodoulou, 2006; Cristianini and Shawe-Taylor, 2000). In general, there are at least three reasons for the success of SVM: its ability to learn well with only a very small number of parameters, robustness against the error of the model, and its computational efficiency compared with several other methods such as neural network and fuzzy network (Martinez-Ramon and Cristodoulou, 2006).

In this paper, petrophysical logs corresponding to a well drilled in the southern part of Iran are used to estimate the shear wave velocity using empirical correlations as well as novel AI techniques.

2. Geology of field

This study uses the data belonging to an oilfield located in the Iranian Province of Khuzestan, onshore of the Ahwaz region, near the Iran-Iraq frontier (see Fig. 1). The field is a North–South oriented gentle anticline, located in the Dezful Embayment, which is a sector associated with the closing of the Neo-Tethys sea and the Tertiary formation of the Zagros-Taurus Mountains. The oilfield is close the Basrah area in the west. The structures in the Basrah area consist of gentle anticlines showing a North–South general trend which is the same to this field. The trend of these anticlines follows the old North–South oriented basement lines. The presence of Precambrian and Early Cambrian salt in Northern Persian Gulf area and Saudi Arabia is considered as a reason to explain the possible origin of these structures. However the development of these anticlines seems related to the reactivation of basement faults which can be responsible for their structural evolution. The structural growth of the field area may be already started during the Mesozoic or earlier and continued through the time.

The Fahliyan Formation is well exposed in the Zagros Mountains, in Fars province (James and Wynd, 1965). At the same time of the sedimentation of the Fahliyan, in the area located between the oilfield and the Khuzestan province, the intra-shelf basin of the Garau Formation takes place. The current oilfield area at the time of the Fahliyan sedimentation must have belonged to an articulate carbonate ramp complex, partly controlled by local tectonics, partly by sea level changes, probably limited Eastward by a more subsiding area underwent a deeper sedimentation. Argillaceous limestones and shales of deep environment also develop in Offshore Kuwait, suggesting that this area belonged to the same intra-shelf basin. The sedimentation of these units is related to the significant sea level rise started during the late Tithonian and continued into the early Berriasian (Sadooni, 1993). The shallow water sequences of Fahliyan and equivalent units of northern Persian Gulf underlay the shale and bioclastic limestone of the Ratawi Formation. Fig. 1 shows the approximate geographical location of the oil field in Iran.

The middle and upper Cretaceous sediments of the Dezful Embayment form one of the richest petroleum systems in the Middle East, with the presence of the Gurpi, Khazdumi and Gadvan source rocks and the Lurestan, Asmari, Khuzestan and Khami/Bangestan reservoirs (see Fig. 2).

3. Well A

The available well log data of the current study are belonging to a vertical wellbore drilled into a carbonate reservoir in southern part of Iran. The digitized well logs consist of dipole shear sonic imager (DSI), compressional wave sonic log