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Three-Dimensional Modeling of Geomechanical Units Using Seismic Data in One of the Southern Iran Gas Fields

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Abstract

The current study employs an efficient approach in construction of 3D reservoir geomechanical models based on the concept of GMUs. Rock strength estimation using indirect methods plays an important role in reservoir characterization. Indirect methods are more cost-effective and efficient than direct methods. The elastic-dynamic moduli can be used to obtain rock strength data. In this study, the amount of data was reduced through using multiresolution graph-based clustering and geomechanical units (GMUs) were established based on MRGC-derived clusters. Construction of a 3D geomechanical model using these GMU's is a reliable approximation of reservoir characteristics from the rock strength point of view. The elastic-dynamic moduli such as Young's modulus, bulk modulus, shear modulus, Poisson's ratio and UCS of the formation were calculated using compressive and shear wave velocities which are provided by DSI logging tools in eight wells. In some of the wells, shear wave velocities are predicted through multivariable regressions. Results show that the correlation coefficient between measured and estimated shear velocity is approximately 90 percent. Afterward, the calculated dynamic moduli were calibrated to static values using empirical equations extracted from a neighboring field. All calculated static moduli were clustered by using multiresolution graph-based clustering (MRGC) method for all eight wells. Finally, a 3D geomechanical model of the reservoir was generated based on these geomechanical units and the reservoir acoustic impedance model as a secondary parameter of co-kriging. The reservoir acoustic impedance model was built by using a genetic algorithm and model based inversion. After establishing the GMUs by MRGC, the GMUs evaluated through correlating with the caliper, gamma ray and NPHI logs. There is a good correlation between the clusters and the log-derived properties in all wells. GMUs can be compared with lithology logs and core data as an alternative verification method. Results of this study show that the mechanical properties of GMUs are strongly affected by the clay content and porosity of rocks. Also, the 3D geomechanical model has been generated from GMUs, and the reservoir acoustic impedance model shows a good degree of correlation confirming further confidence on the results of this study.

Keywords: Geomechanical Units, Multi-Resolution Graph-Based Clustering, Elastic Modulus, Static Data, Acoustic Impedance, Genetic Algorithm

Introduction

Despite a growing propensity to use 3D geomechanical models in petroleum engineering practices, there needs further understanding of the underlying concepts and data handling procedures. This study employs an efficient approach to construct a 3D reservoir geomechanical models based on the concept of Geomechanical Units (GMUs).

Rock strength estimation using indirect methods plays an important role in reservoir characterization. Indirect methods are more affordable and efficient than direct methods. Elastic-dynamic moduli can be used to obtain rock strength data. Mechanical properties of rocks are used for hydraulic fracture design, for seismic modelling and interpretation, and for stress calculations in geological studies.

In this study, we have reduced the amount of these data using multiresolution graph-based clustering and through the establishment of geomechanical units (GMUs) with these clusters. Construction of a 3D geomechanical model using these GMUs is a reliable approximation of reservoir characteristics from the rock strength point of view.

Methodology

Compressive and shear wave velocities are provided by DSI logging tools in eight wells. Shear wave velocity (Vs) associated with compressional wave velocity (Vp) can provide accurate data for the geophysical study of a reservoir. In five wells that the shear wave velocities were not present, the results from sonic measurement of compressional and shear wave velocities in neighboring Salman field were used to establish an empirical equation for estimating shear wave velocities. This equation made a correlation coefficient of about 0.9 between estimated shear wave velocities and present Vs in three wells.

Appropriate equations were used for calculating elastic-dynamic moduli such as Young's modulus, bulk modulus, shear modulus, and Poisson's ratio. Because of carbonate lithology of the Kangan and Dalan formations, Militzer equation was used for calculating the dynamic UCS.

The elastic moduli calculated from the elastic wave velocities and density are the dynamic moduli. In contrast, the elastic moduli calculated from deformational experiments are the static moduli. Static values differ from dynamic values because wave propagation is a phenomenon of small strain with a large strain rate: rocks appear stiffer in response to an elastic wave, compared to a rock mechanics laboratory (triaxial) test, where larger strains are applied at lower strain rate. The weaker the rock, the larger the difference between elastic properties derived from acoustic measurements (dynamic) and those derived from triaxial measurements (static). This accounts for the marked difference between dynamic and static Young's moduli [2]. However, the difference between dynamic and static Poisson's ratio is very small and is generally not considered. By using static and dynamic data provided by sonic measurements and Schmidt hammer in Kangan and Dalan formations of Salman field, empirical correlations were developed for converting calculated dynamic data to static data. Afterward, multiresolution graph-based clustering (MRGC), ascendant hierarchical clustering (AHC), and self-organizing map (SOM) were used to cluster the static data.

MRGC method was a good procedure for this purpose as it made a descending average of geomechanical parameters from GMU number one to GMU number five. In addition, it made a thinner range of geomechanical parameters in each GMU. This property will enable the user to determine the value of geomechanical parameters more accurate [3]. Multi-resolution graph-based clustering is a multidimensional dot-pattern-recognition method based on non-parametric K-nearest-neighbor and graph data representation. The underlying structure of the data is analyzed and natural data groups are formed which may have different densities, sizes, shapes and relative separations. MRGC automatically determines the optimal number of clusters, and yet allows the geologist to control the level of detail actually needed for example to define an Electrofacies [4].

After establishing the Geomechanical units, the correctness of them must be evaluated. Caliper, Gamma ray, and NPHI logs were used for this purpose. Caliper log shows an increase in well diameter in GMU number five that has the minimum value of geomechanical parameters. NPHI log shows the maximum porosity for GMU number five, and gamma ray log shows the maximum volume of shale in this geomechanical unit. There is a good correlation between the clusters and the logs in all wells.

After this step, a genetic inversion was generated for 3D post-stack seismic data of the field of study. For this inversion, the values of acoustic impedance were calculated by multiplying density and compressional wave velocities in seven wells. The relation between the wavelet at the location of wells and this Acoustic impedance was made by genetic algorithm and expanded in the 3D seismic model. In other words, seismic data and well log analysis are combined to determine acoustic impedance. The vertical resolution of acoustic impedance model is far less than that of well logs, so some up-scaling issues addressed. This Acoustic impedance model was used as a secondary parameter of co-krigging to model the GMUs in the field of study «Figure 1».

Results and Discussion

Results of this study show that mechanical properties of GMUs are strongly affected by the clay content and porosity of rocks. Between the methods that have been used for clustering, the MRGC method made the best clusters. Also, the GMUs in 3D geomechanical model at the location of well number six which had not been used for modeling and GMUs in this well show a good degree of correlation of 77 percent, which provides further confidence for the results of this study.

The 3D geomechanical model of the field of study shows the least values of mechanical properties in K4 member of Dalan formation partially.

Conclusions

According to obtained results, modeling of geomechanical units in the field of study is a suitable method for estimating formation rock elastic parameters in the hole reservoir parts of K1 to K4.

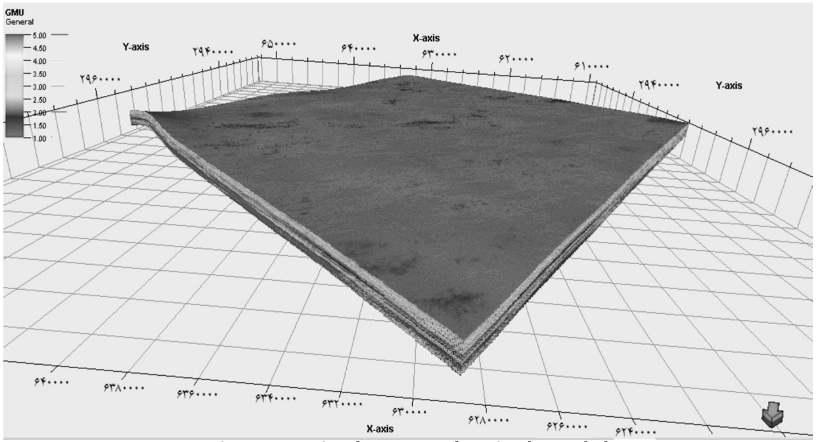

Figure 1: Final geomechanical model

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