Clustering Analysis of a Geophysical Database for delineating regions of higher potential for hydrocarbon reservoirs

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Summary

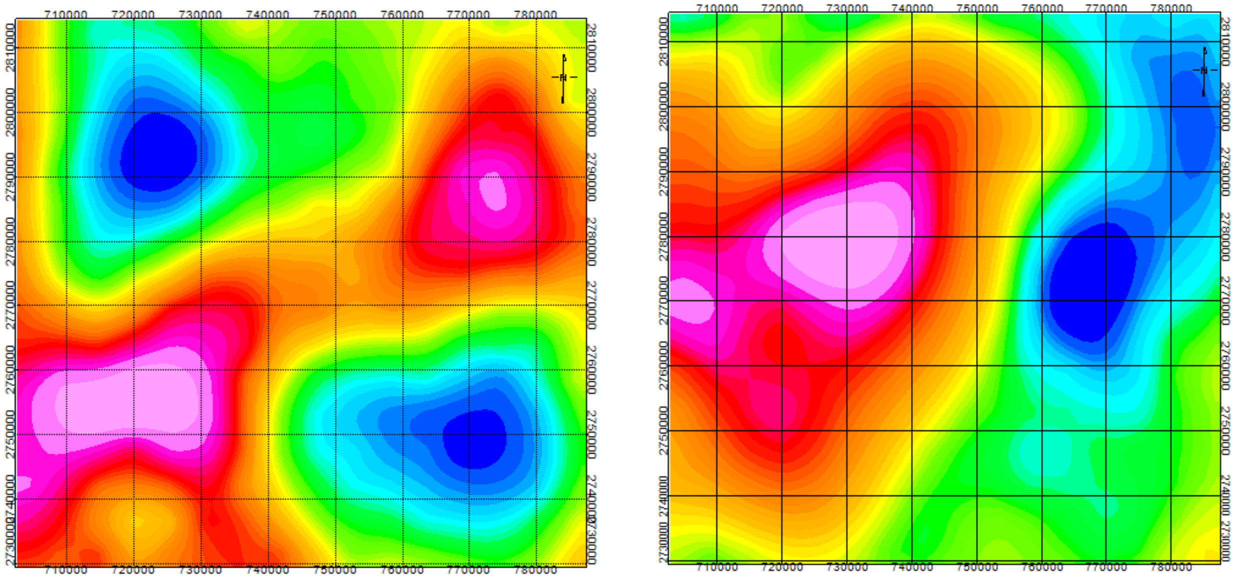
One of the most challenging problems in geophysics is the interpretation of geophysical models which demands the experience of the interpreter on the subject. However, the growing improvement of machine learning techniques has introduced powerful automated tools in geophysical studies. Unsupervised learning techniques for instance, are useful in extracting patterns from geophysical models whose class labels are unknown. One of the most well-known unsupervised learning algorithms is the k-means clustering technique (MacQueen 1967). The k-means cluster analysis in geophysics has been used by several researchers. Di et al. (2018) applied k-mean clustering for delineating the surface of salt bodies from several seismic attributes extracted from 3-D seismic surveying. This method is also used for interpreting geophysical models of a volcanic caldera, by integrating CSAMT-MT resistivity, P-wave velocity, and density models (Di Giuseppe et al. 2017).
We applied a clustering technique on a geophysical database to delineate locations of potential hydrocarbon reservoirs at offshore Abu Dhabi, U.A.E. Our database comprises gravity and magnetic field data and salt structure thickness derived from nonlinear inversion of gravity and magnetic data. Applying k-means clustering technique on the preprocessed data of the Budana oil field, the areas with higher probability of hydrocarbon reservoirs are distinguished. According to the results, the region is divided into two regions comprising smaller and larger hydrocarbon reservoirs and one with less possibility for hydrocarbon reservoirs.

Geological Setting

The evolvement of Arabian plate includes several complicated geological events from ca. 715 to 610 Ma. During Neoproterozoic to late Devonian Arabian plate separated from Eurasia by Paleo-Tethys Ocean and constituted northeastern margin of Gondwana (Al-Husseini 2000). In the early Permian, evolution of Neo-Tethys Ocean initiated, proceeding by emplacement of Iranian microcontinent over Eurasia. By the latest Jurassic–Early Cretaceous, closure of Neo-Tethys Ocean was started following northeastward subduction of Arabian continent beneath Iranian plate. Finally, the collision of Arabia with Eurasia plates occurred during Cenozoic which has continued until present time (B. Ashena et al. 2018).
The approximate 8-10 km crystalline sedimentary strata of U.A.E, as part of the Arabian plate, is detached from the underlying basement by the latest Neoproterozoic–Lower Cambrian Hormuz evaporates. Hormuz evaporates exposure as several salt domes offshore Abu Dhabi. The salt diapirs are either intruded into overlying sequences or are of multiple phase diapirs (Ali et al. 2017).

Method

The study area is located at the western Abu Dhabi offshore, U.A.E. (Fig. 1). The high-definition airborne gravity and magnetic field data cover a major portion of the offshore Abu Dhabi. The bouguer gravity and total magnetic differentially-reduced-to-the-pole (DRTP) maps over the study area are depicted in Fig. 1a and Fig. 1b.



(a) (b)

Fig. 1 (a) bouguer gravity anomaly map; (b) total magnetic DTRP map of the study region.

We estimated depth to basement and depth to salt structures by conducting nonlinear inversion of gravity and magnetic field data, respectively (Kabirzadeh et al. 2019). A 3D model is constructed from a series of rectangular prisms in two layers with adjustable heights (Fig. 2). The upper layer is assigned to the salt structure which is magnetically transparent and has a constant density. The lower layer represents the basement strata, whose magnetization intensity is assumed constant and its lower boundary is at a constant depth. Furthermore, its variable vector of magnetization is extracted from global models (e.g., IGRF).

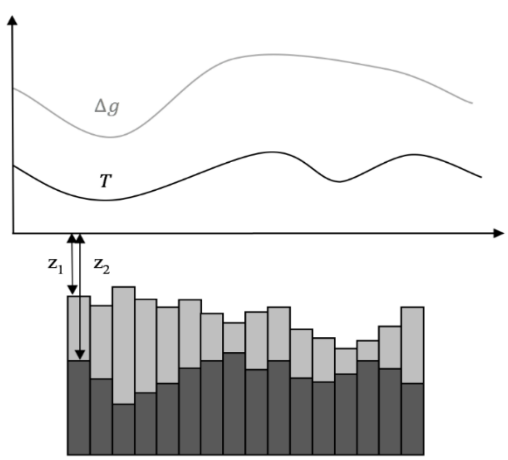


Fig. 2. Front view of a schematic 3D model from inversion of gravity and magnetic anomalies.

By adjusting the upper boundary of the rectangular prisms, we ended up with an estimated magnetized body with a magnetic effect that best fits the observed anomaly. After the thickness of lower layer is estimated, the upper boundary of the top layer will be estimated from the inversion of the basement reduced gravity data. This time, the lower boundary of upper layer is fixed at the estimated upper boundary of the basement, and the heights of all prisms in the upper layer are altered towards values that satisfy the gravity anomalies with an acceptable misfit.
These nonlinear systems of equations are iteratively solved with Levenberg-Marquardt technique to update the depth to the boundary until a solution is approached that satisfies the gravity or magnetic measurements with a reasonable accuracy. The salt thickness map is obtained from subtracting the depth to the salt from depth to the basement and is shown in Fig. 3.

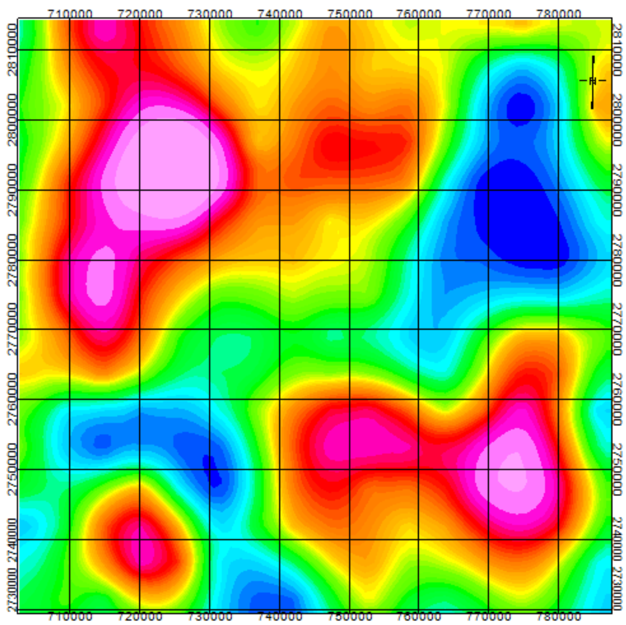


Fig. 3. Map of salt thickness of the study region.

Before applying clustering technique, we employed a few data preprocessing approaches including data cleaning and data normalization. Since attributes have different ranges, data need to be normalized. Accordingly, each attribute was brought to a set of normalized values with zero mean and identity covariance matrix.
The k-means clustering analysis was then applied on the data to detect and delineate geological features. The k-means clustering algorithm partitions the observed data into k clusters based on the shortest distance between the objects and their associated cluster centers. Initially, the centroids are placed randomly, and clusters are formed based on these centroids. The new centroids are calculated from the data in each cluster. The clusters are then reshaped. This procedure is updated iteratively until a convergence is reached.
The k-means method may not converge to the global optimum and end up at a local optimum since it depends on the first randomly selected centroids. One solution to this problem is to repeat the algorithm execution several times and select the smallest sum-of-squares-distance of the objects with centroids.

Results and Conclusions

We executed the clustering technique on our geophysical database, including gravity, magnetic and salt thickness. We assumed three clusters for our study region, one subregion with less probability for hydrocarbon reservoirs, and two including larger and smaller reservoirs. According to the results (Fig.4), most of the hydrocarbon reservoirs locate over the blue and green clusters. The blue cluster roughly encompasses the larger reservoirs while cyan cluster covers smaller reservoirs of the region. According to the properties of the cluster centroids (Table. 1), the green cluster shows in average thicker salt (with shallower salt and basement structures) while it has larger gravity anomaly compare to the blue cluster. This may arise from the shallower basement that obscures the negative gravity effect of the thicker salt that has lower density than background structures (including overlying sediments and basement rocks). Generally, anticline traps are connected to the undulation of basement structures which due to their higher density contrast increase gravity observation.

The gravity anomalies arise from several features, including depth of basement and salt structures, salt thickness, faulting, intruded ore bodies, etc. While the magnetic map simply shows the effect of the basement (considering insignificant magnetic effects of sedimentary rocks). It is not therefore trivial to make a direct relation between gravity map and location of hydrocarbon reservoirs.

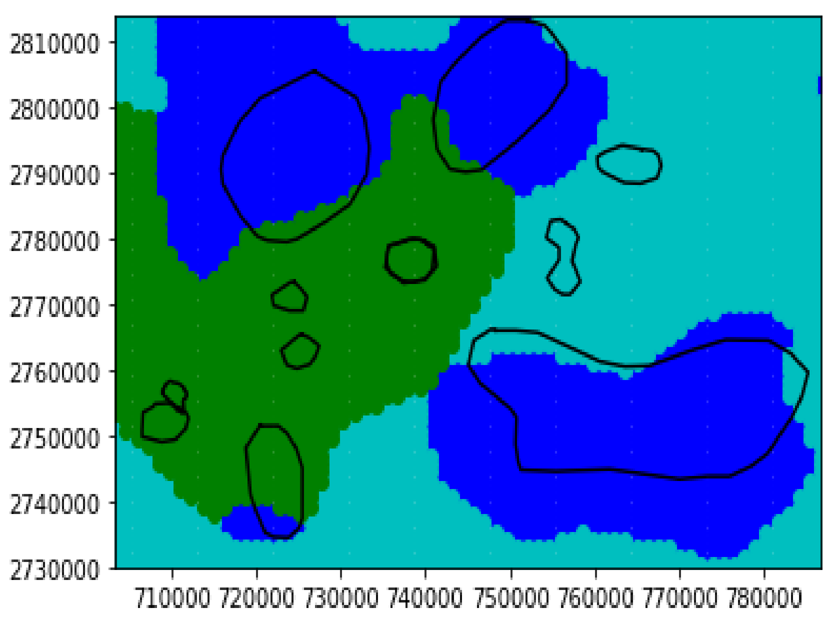


Fig. 4. Output from applying clustering technique considering 3 clusters.

	Gravity	DRTP	Salt Thickness
Cyan	0.71	-292	696
Blue	-4.10	-283	1534
Green	1.30	-250	1015

Table 1 - Location of cluster centroids.

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