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SEQUENCE STRATIGRAPHY BASED ON KAZHDUMI FORMATION LOGGING DATA, SOUTHWEST OF IRAN

The Albian to Campanian sequences (Kazhdumi, Sarvak, Surgah and Ilam Formations) in Zagros basin belong to the Bangestan Group. Kazhdumi Formation with the Albian age in this basin has a particular importance due to its hydrocarbon generation potential in most of Iran's oil fields.

In this research, we calculated the shale volume based on two methods: linear method and neutron porosity cross-plots. From these two results, we choose the minimum value due to: Fundamentals of Log Interpretation. The shale volume in two wells 1 and 2 in the Azadegan oil field in the north of the Dezful structural zone has been calculated using gamma ray log and neutron-density and neutron-porosity cross plot. The sequence stratigraphic analysis by the Pruned Exact Linear Time algorithm of the studied sedimentary rocks in two wells shows that the Kazhdumi Formation in wells 1 and 2 consists of 69 and 76 sedimentary sequences of the 5th order, respectively. This sedimentary sequence includes transgressive sequence systems tracts, highstand systems tract and low stand systems tract.

Keywords: *Kazhdumi Formation, Azadegan oil field, Pruned Exact Linear Time algorithm, sequence stratigraphy, transgressive sequence systems tracts, highstand systems tract, low stand systems tract, Southwest of Iran.*

Introduction

The Dezful embayment, located at the Zagros Fold-Thrust Belt, in the southwest of Iran is part of the Zagros Sedimentary Basin, in the northern Persian Gulf and one of the most oil-rich regions in the world [Sharland et al., 2001] (Fig. 1). The Dezful embayment which is part of the folded Zagros includes about 7 to 12 km thickness of sedimentary rocks and is from the Precambrian basement to the present [Colman-Saad, 1978].

As a part of Zagros area, this embayment is divided into two northern and southern parts by the Hendijan–Bahregansar fault (Fig. 1). In the formation of this embayment, the combined action of the Qatar-Kazerun fault and the Balaroud fault have played a major role. The tectonic activities in the Zagros region caused frequent fractures in the petroleum system [Bordenav, Hegre, 2010]. The resistance of this region to three important structural pressures and its subduction caused the formation of a powerful sedimentary sequence from the Mesozoic to the Cenozoic, which contributed to the formation of the oil systems in the Zagros Basin.

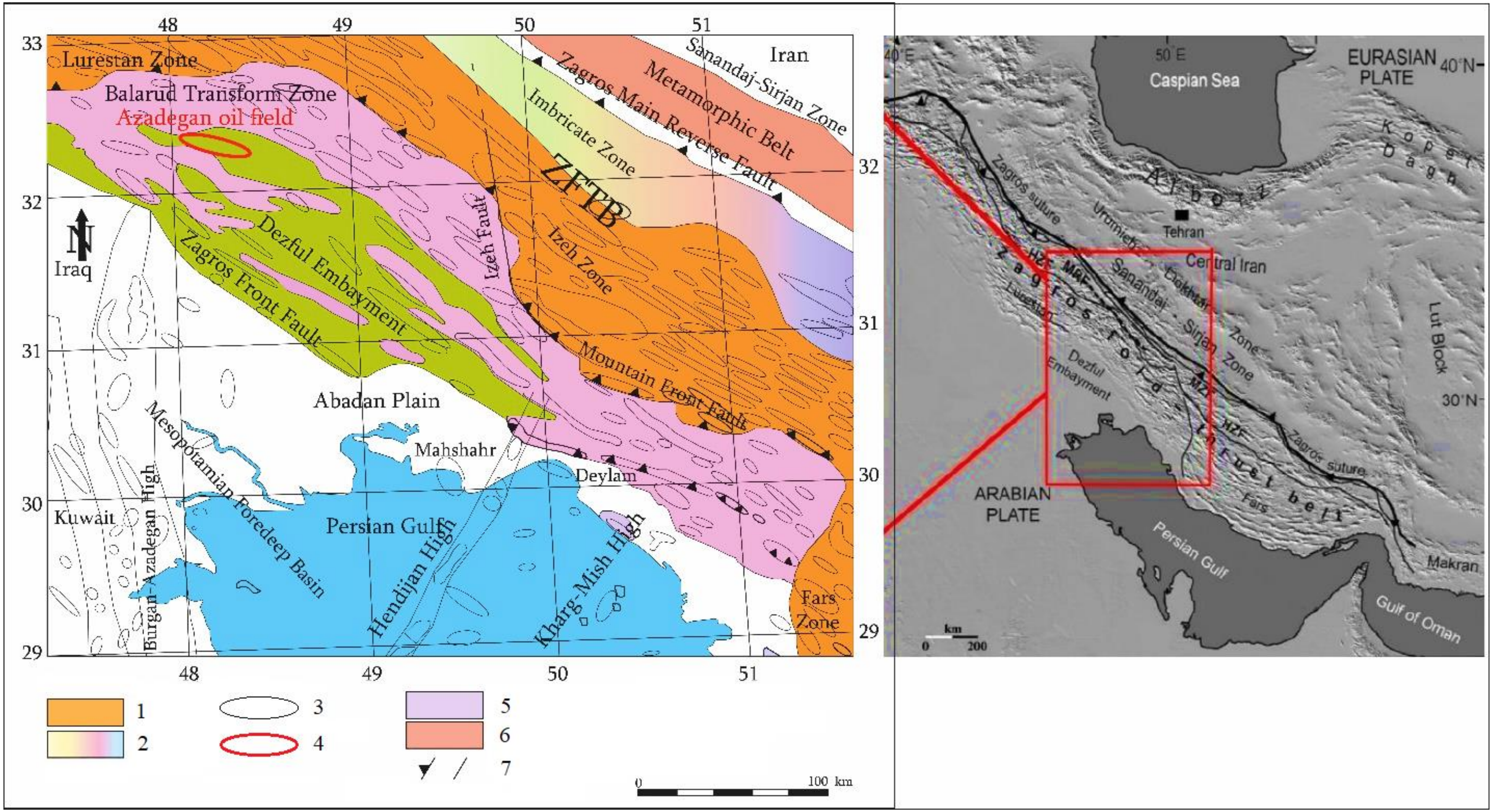

Fig. 1. Location of the Dezful structural zone in Zagros Fold-Thrust Belt [Sharland et al., 2001]

1 - outcrops of mainly Cretaceous-Miocene sediments; 2 - Imbricate zone (pile of thrust sheers); 3 - anticlines; 4 - Azadegan oil field; 5 - outcrops of mainly Mid Miocene Pliocene sediments; 6 - transported nappes of metamorphosed Phanerozoic rocs; 7 - faults and trust fault. ZFTB - Zagros Fold-Thrust Belt.

The late Lower Cretaceous sedimentation started with rising sea level which resulted in deposition of Kazhdumi Formation throughout Albian [Alsharhan, Kendall, 1991]. In the fields near the coast of Iran, the Kazhdumi Formation consists of a sequence of black shales with clayey limestones, dark bitumen and shaly limestone. At the time of Albin there was a gentle slope at Dezful area and north of the Persian Gulf. Reducing conditions have led to the deposition of bituminous marls in the center of this embayment. In general, the Kazhdumi Formation in the Dezful area is mainly composed of deep clay facies, while in the Fars area it is mostly shallow carbonate facies. The Kazhdumi Formation is visible in entire Khuzestan and Fars basins (sub-basins of the main Zagros structural sedimentary basin) and gradually turns into carbonate sequences from the northern areas of the Dezful embayment towards the northeast of Lorestan. However, in the center and southwest of Lorestan, it turns into limestone and black shales of the Garu Formation (Upper Barremian - Middle Aptian). This formation changes its facies from Dezful embayment to the southwest to Burgan sandstone Formation with tongue overlap (basal sandstone of the Kazhdumi Formation in Kuwait, neighboring Arab countries and Nahr-e-Omar in southwestern Iraq). Late Lower Cretaceous sedimentation began with sea level rise, which led to the deposition of the Kazhdumi Formation throughout the Albian. In strata off the coast of Iran, the Kazhdumi Formation consists of a black shale sequence with argillaceous limestones and dark bitumen. In the type section, the Kazhdumi Formation has a thickness of about 210 meters at Tang-e Gurguda, located on the northern edge of Mount Mish, 7 km northeast of Dogonbadan. In the studied area the thickness of the first well was 550 m, the second - 650 m. Based on the stratigraphic repartition of various types of ammonites, 11 biozones were identified, which indicate the Early Aptian of the upper part of the Daryan Formation (Aptian). Thus, it appears that there is a stratigraphic gap between the Daryan and Kazhdumi Formations overlying the Middle Aptian [Ghorbani, 2013]. This gap is a result of the Austrian orogenic phase and confirms the epeirogeny between the two formations. During Albian, there was a gentle slope in Dezful area and north of the Persian Gulf. Reducing conditions have led to the deposition of bituminous marls at the center of this embayment [Bordenave, Burwood, 1990]. In general, the Kazhdumi Formation in Dezful region is mainly composed of deep shaly facies and in Fars region of shallow carbonate facies.

Sequence detection parameters

The rate of accommodation development (dA) with respect to the rate of sediment supply (dS) at the time of deposition (dA/dS) controls the stratal stacking patterns in shallow marine systems. These two parameters have a first-order role in determining both the thickness (T) and the sandstone fraction (SF) of the para sequence [Ainsworth, 2010]. This therefore suggests that there should be a numerical relationship between the products of these two parameters (dA and dS). The key problem is that deriving absolute rates of change of parameters such as accommodation development or sediment supply rates from the ancient at this para sequence scale of stratigraphy (fifth order; 10^4–10^5 yr) is not a trivial matter because of the effects of compaction, erosion, and poor absolute age dating at this scale [Ainsworth, Vakarelov, Nanson, 2011]. However, if it is assumed that para sequence thickness can be used as a proxy or the rate of accommodation at the time of deposition and that para sequence sandstone fraction can be used as a proxy for the rate of sediment supply then approximate quantitative proxies of rates of para sequence accommodation development and rates of sediment supply can be measured from lithological data acquired from wire-line logs, cores, or outcrop sedimentary logs. Vertical trends in these para sequence data can then be analyzed and compared with vertical sequence stratigraphic trends to determine if there is a relationship between the discrete quantitative para sequence thickness and sandstone fraction measurements and the stratigraphic patterns observed.

Methodology

The best stratigraphic models of sediment-filled basins are provided by a combination of seismic data, well logs, core and outcrop surveys combined with biostratigraphy. Cores, well logs, and outcrop surveys provide access to accurate vertical resolution of sedimentary sections, while seismic and outcrop surveys provide lateral continuity of the stratigraphic structure of the sequence, and biostratigraphy provides temporal constraints. All of these different sequence stratigraphy methods can be used independently to obtain accurate interpretations of the sedimentary history of the sediment-filled basins, but the best models are obtained by combining all three. In this research, Pruned Exact Linear Time (PELT) method and gamma ray data related to porosity and neuron density logs using sudden changes in shale volume values were used to determine the boundary of facies systems. The PELT method is used to detect maximum sudden changes in signals over time. The intuition behind PELT method is that for a time step to be identified as a change point, it must reduce the segmentation cost by more than the amount of the added penalty. If the cost reduction is less than the additional penalty, the penalty cost is increased and the time step is not identified as a change point. The use of the PELT method requires the maximum number of drops and rises, so an algorithm should be introduced that can be used in mathematically defined conditions and its results are consistent with the geological nature of the area. The optimal number of clusters was identified using the Elbow method. The Elbow method considers the percentage of explained variance as a function of the number of clusters.

Mathematical manipulation

The specified models are ideal models that are rarely seen on raw data. Therefore, in order to use the introduced patterns, it is necessary to make the available real data as close as possible to these patterns. In this regard, different statistical methods can be used. The first step is to identify the ups and downs of the shale chart. To calculate the volume of the shale, you can use the data of the gamma plot or cross plot of neutron porosity and density porosity. In the upcoming research, neutron porosity and density porosity cross plots are used to calculate shale volume. Identifying the boundaries of shale volume values is calculated using the PELT method, which was first introduced by Kilik R. et al. in 2012 [Killick, Fearnhead, Eckley, 2012] to detect the abrupt changes in signals over time. The PELT method aims to minimize the following relation:

$$\sum_{i=1}^{m+1}\left[C\left(y_{(\tau_{i-1}+1):\tau_i}\right)+\beta\right] \qquad (1)$$

Under the following conditions [Killick, Fearnhead, Eckley, 2012], there is a constant K such that for all $t < s < T$:

$$C\left(y_{(t+1):s}\right)+C\left(y_{(s+1):T}\right)+K\leq C\left(y_{(t+1):T}\right) \qquad (2)$$

Then, if

$$F(t)+C\left(y_{(t+1):s}\right)+K\leq F(s) \qquad (3)$$

Holds, at a future time $T > s$, t can never be the optimal last change point prior to T.

Where C is a cost function for the segment and β is a penalty to guard against over fitting. F(s) is the optimal segmentation and can be obtained recursively by the following formula:

$$F(s)=\min_t\left\{F(t)+C\left(y_{(t+1):n}\right)+\beta\right\} \qquad (4)$$

We start by calculating F (1) and then recursively calculate F (2), …, F(n). At each step we store the optimal segmentation up to t_{m+1}. When we reach F(n) the optimal segmentation for the entire data has been identified and the number and location of change-points have been recorded.

For the PELT method, the maximum number of abrupt changes should be provided. To omit this necessity, we suggest the following procedure: first, we consider minimum three points for each linear segment. It is a statistical consideration to fit a linear line to points. Therefore, divide the data number by three and consider the obtained value as the maximum number of segments (this is equivalent to maximum number of change points plus 1). Since the maximum number of drop and rise, points are required to use the PELT method, an algorithm should be introduced that is able to apply in mathematically defined conditions, and its results are consistent with the geological nature of the region.

To identify the optimum number of clusters there exist several methods among them the following methods are most popular: the Elbow method [Thorndike, 1953], the CH index [Caliński, Harabasz, 1974], the Silhouette Index [Rousseeuw, 1987], the KL index [Krzanowski, Lai, 1988] and the Gap statistics [Tibshirani, Walther, Hastie, 2001]. Discussion about efficient application of the mentioned methods and when to use which method is beyond the scope of the current paper.

For sake of simplicity the optimum number of clusters was identified using the elbow method [Thorndike, 1953]. The elbow method considers the percentage of variance explained as a function of the number of clusters: the number of clusters should be chosen so that adding another cluster does not give better data modeling. More precisely, if you plot the dependence of the percentage of variance explained by the clusters on the number of clusters, the first clusters will add a lot of information (explain the large variance), but at some point, the marginal gain will fall, giving an angle to the graph. At this stage, the number of clusters is selected. Percentage of variance explained is the ratio of variance between groups to total variance, also known as the F-test. The marginal variance percentage for our purpose is selected to be 0.95 which is equivalent to the critical α-value of 0.05.

Results and discussion

Seismic and outcrop data are not available for the current study. Therefore, gamma ray data was used in conjunction with porosity and neuron density logs. The PELT algorithm was originally used to detect abrupt changes in shale volume values. The optimal number of abrupt changes was estimated by the Elbow algorithm. Figure 2 illustrates the operation of the Elbow algorithm for the two studied wells. Optimal segments by the number of boundaries in well 1 and well 2. The optimal segments for well 1 are 69, for well 2 - 76 (it means the total number of sequence barriers for well 1 and 2) (Fig. 2).

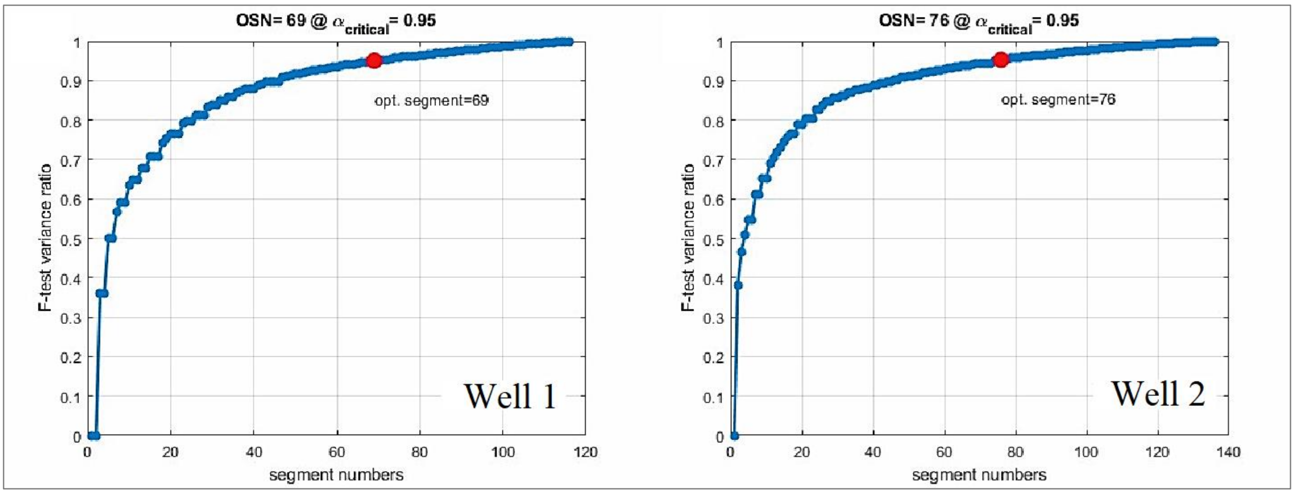

Fig. 2. Graph of sequence boundaries of Kazhdumi Formation using the Elbow method (Azadegan oil field, well 1 and 2)

Figure 3 shows how the PELT algorithm used distinguished statistically important abrupt changes. Based on the PELT algorithm used, the parameter T/Ts can be easily estimated. Figure 3 illustrates the vertical changes in the T/Ts parameters. Here and below, it is possible to identify the upward and downward trends in the T/Ts ratio and determine changes in sea level.

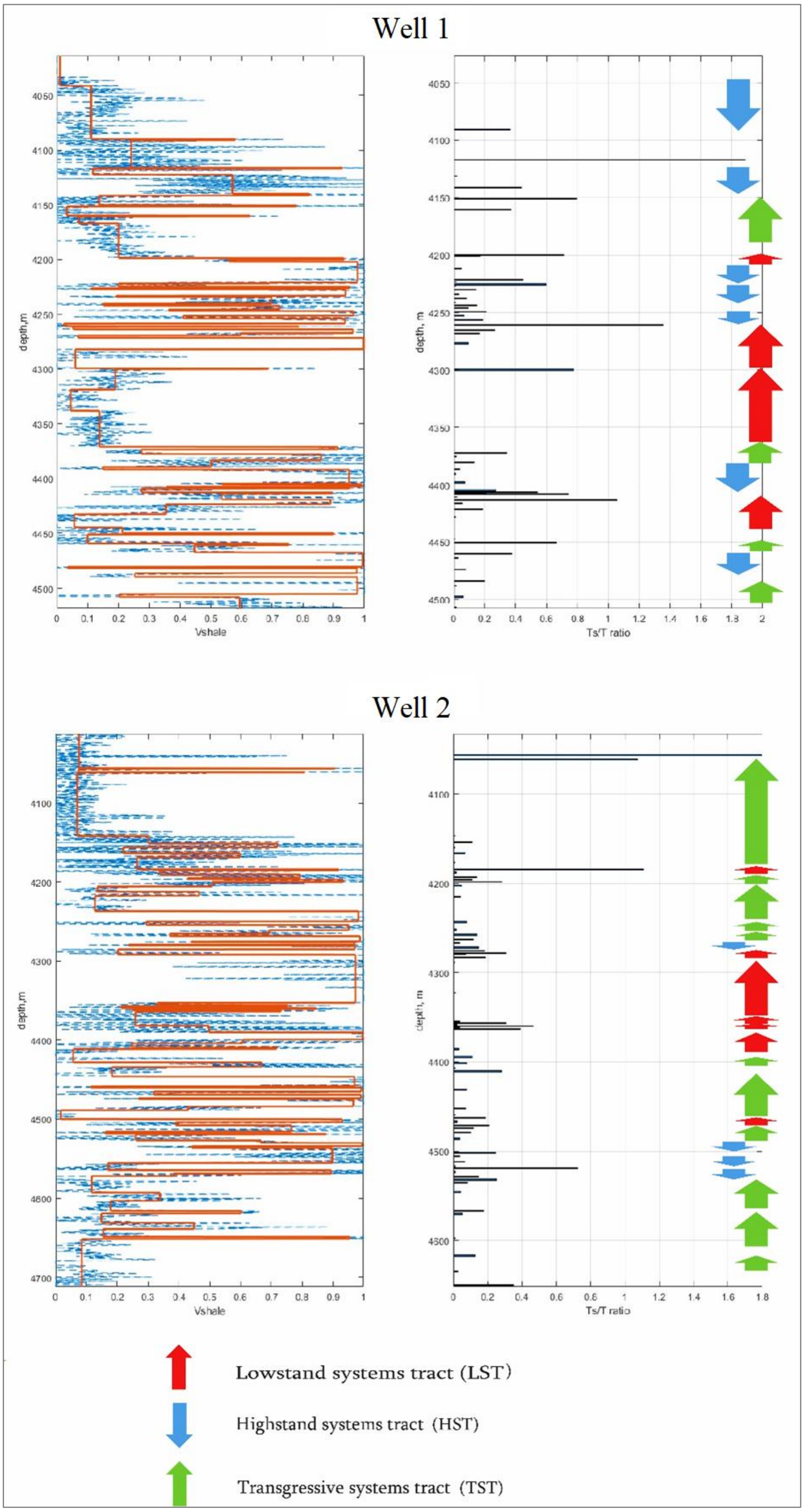

Fig. 3. Diagram of sequence stratigraphic analysis of Kazhdumi Formation (Azadegan oil field, well 1 and 2)

In the wells studied using the PELT algorithm, Kazhdumi Formation consists of 69 and 76 sedimentary strata of the fifth order in well 1 and well 2, respectively. This stratum in both wells 1 and 2 starts at the bottom with transgressive systems tract (TST), which are progressive facies showing sea level rise and are mostly composed of shale strata 20 meters thickness in well 1 and 100 meters in well 2. Then this sedimentary sequence continues in both wells with High stand systems tract (HST) facies, indicating maximum sea level rise and deposition of a large volume of shale 15 meters thickness in the first well and 40 meters in the second well. Further, in a repeating cycle, transgressive systems tract facies (TST) are traced 10 m thick in the first well and 15 m thick in the second well. In the next stage, a Low stand systems tract (LST) is followed by a thickness of 20 and 10 meters in wells 1 and 2, respectively. Finally, well 1 ends up with a maximum sea level rise with 40 m thickness as the High stand systems tract (HST) at a depth of 4055 m. Well 2 also ends up in a transgressive systems tract (TST) with a thickness of 130 meters, at a depth of 4150 m (Fig. 3).

Conclusion

The shale volume was estimated using the neutron density and neutron porosity cross-plot log data. Then, based on the calculated thickness and volume of shale, T/Ts values were calculated. To calculate this coefficient, which shows the trend of sea level change, the optimal number of line slope change points was calculated by an automated method based on the Elbow method, and they were used as input data in the PELT algorithm.

This method helps to ensure that the human decision does not interfere with the measurement activity, and all boundaries are identified with precise details and automatically. Based on the calculations, 69 sedimentary strata were identified in the first well, and 76 strata of the 5th order were identified in the second well with High stand systems tract, transgressive systems tract and Low stand systems tract.

Predicting the spatial and temporal distribution of source rocks within a stratigraphic interval is possible by sequence stratigraphy as a powerful tool at both exploration and reservoir scales.

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СЕКВЕНС-СТРАТИГРАФИЯ СВИТЫ КАЖДУМИ ПО КАРОТАЖНЫМ ДАННЫМ, ЮГО-ЗАПАД ИРАНА

Альбско-кампанские толщи (свиты каждуми, сарвак, сурга и илам) в бассейне Загрос представлены как Банжестанская группа. В этом бассейне свита каждуми альбского возраста имеет особое значение из-за ее потенциала генерации углеводородов на большинстве нефтяных месторождений Ирана.

В этом исследовании рассчитан объем сланца на основе двух методов: линейного и кросс-плотов нейтронной пористости. Из результатов выбрано минимальное значение из-за основ интерпретации каротажа. Объем сланца в двух скважинах 1 и 2 на нефтяном месторождении Азадеган на севере структурной зоны Дезфул рассчитан с использованием гамма-каротажа, кросс-плота нейтронной плотности и нейтронной пористости. Секвенс-стратиграфический анализ по алгоритму сокращенного точного линейного времени изученных осадочных пород показывает, что свита каждуми в скважинах 1 и 2 состоит из 69 и 76 осадочных секвенсов 5-го порядка, соответственно. Эта осадочная толща включает трансгрессивные системы секвенций, системы высокого и низкого уровня стояния моря.

Ключевые слова: *свита каждуми, нефтяное месторождение Азадеган, алгоритм сокращенного точного линейного времени, стратиграфия секвенций, тракт трансгрессивной системы, тракт высокого стояния моря, тракт низкого стояния моря, юго-запад Ирана.*

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