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THE ROLE OF STRATIGRAPHY IN GROWTH STRATA STUDIES: A CASE STUDY FROM THE MIDDLE-LATE CRETACEOUS DEPOSITS IN PERSIAN GULF, SW IRAN

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ABSTRACT
The growth strata in the Middle-Late Cretaceous deposits including Kazhdumi, Sarvak and Ilam formations and Lafan Shale in the Well 1 located between Qatar-Iran height and Hormuz Strait in Persian Gulf was studied. The present work is based on the lithostratigraphic analysis and distribution of microfossils. Based on the microfossils content, the age of studied successions is Albian to Campanian. Comparison of seismic points, lithostratigraphic analysis and distribution of microfossils show that growth and generation of anticlines are occurred in the Middle-Late Cretaceous. As of results, the Kazhdumi, Sarvak and Ilam formations and Lafan Shale have potential reservoir and oil trap.

Keywords: Growth strata, Stratigraphy, Middle-late cretaceous, Persian gulf.

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Contribution/ Originality

This study is one of very few studies which have investigated the growth strata in the Middle-Late Cretaceous deposits in Persian Gulf, south west of Iran with using the lithostratigraphic and biostratigraphic analysis and seismic interpretation. The basic information of this manuscript are provided by National Iranian Oil Company.

1. INTRODUCTION

The Middle-Late Cretaceous deposits in south west of Iran have been divided into several rock units including Kazhdumi, Sarvak and Ilam formations and Lafan Shale (James and Wynd, 1965; Wynd, 1965; Motiei, 1993) (Fig. 1). The lithological diversity of the deposits show unstable environmental conditions and active tectonic resulting from subduction of Arabian Plate beneath Iranian Plate (Takin, 1972; Berberian and King, 1981; Alavi, 1994). To reconstruct tectonic process and paleogeographic map of the Middle-Late Cretaceous deposits succession, the lithostratigraphic and biostratigraphic analysis have been performed. Investigation of lithostratigraphic characteristics is more effective in order to recognize source and reservoir rocks (Khodadust, 2012). The present study has been focused on the growth strata in the Middle-Late Cretaceous deposits based on the lithostratigraphic characteristics, biostratigraphic analysis and seismic interpretations. The growth strata is deposited along with tectonic activities such as folding and have an important status in generation of oil traps. In other words, folds can be a place for accumulating oil and gas. The results of this study can be helpful in identifying oil traps and their evolution along geological periods (Soleimany, 2010).

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2. GEOLOGICAL SETTING

The Zagros mountains in south west of Iran is considered as part of the Alpine-Himalaya mountains (Alavi, 1994; Alavi, 2004; Alavi, 2007). The Zagros mountains is located in northwestern of the Persian Gulf and is affected by the Middle-Late Cretaceous to present Zagros orogeny. From the Middle Eocene to Late Miocene, the Arabian Plate began to impact with Central Iran and the Zagros belt orogeny is generated. The collision of Arabian Plate and Zagros mountains is created the topography of Persian Gulf (Alavi, 1994; Alavi, 2004; Alavi, 2007). Persian Gulf is a marginal sea situated on continental shelf and its downhill is towards Oman Sea. Persian Gulf is 200-300 km wide and covered an area about 226000 km². Morphologically, Persian Gulf have has asymmetrical form and the its slope is toward Arabian coast (Stoklin, 1968; Alavi, 1994; Alavi, 2004; Alavi, 2007). The southern shore of Persian Gulf consists of evaporation and tidal flat environments, while the northern shore comprises of hard and high rock units. The low-slope southern shore of Persian Gulf and its shallow sea was formed anticlines with northern-southern trend like Saudi Arabia basement trend (Berberian and King, 1981; Alavi, 1994; Alavi, 2004; Alavi, 2007).

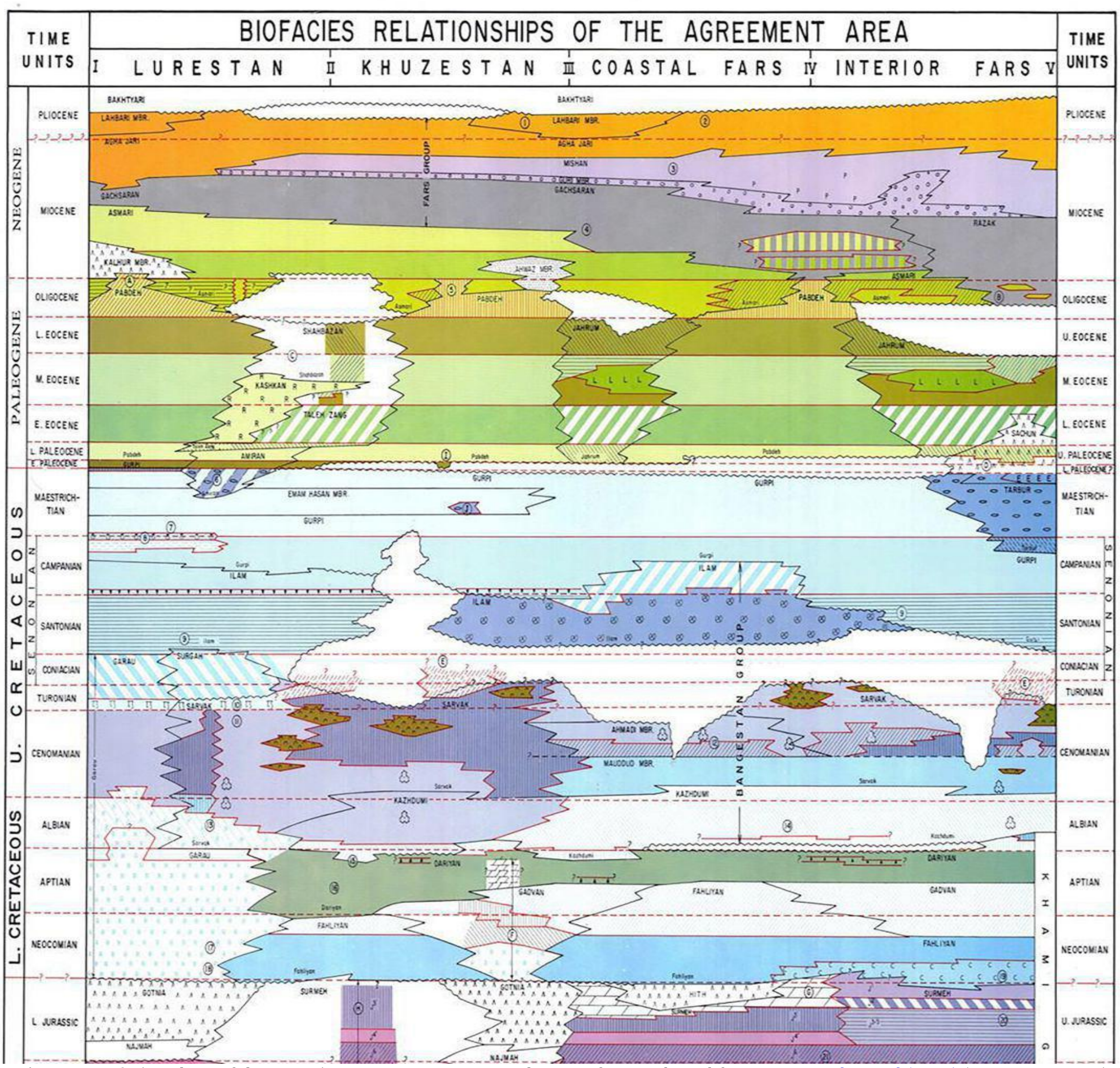


Fig-1. Correlation chart of the Jurassic to Neogene strata, south west of Iran, adapted from James and Wynd (1965) (NIOC Company)

The anticlines of Qatar, Roodkhan, and Bahrain have often constituted low-slope topography view controlled by fault systems. The northern shore of Persian Gulf is clift shore with a north west trend and height of anticline reach to 1500m. Therefore, the northern shore structures of Persian Gulf are different with southern shore structures, geometrically. Generally, the present deposits of Persian Gulf become more fine-grained from the shore towards the depths. Currently, the deepest facies of Persian Gulf is argillaceous limestone (Wanger and Van, 1973). Geologically, Persian Gulf is a shallow subduction formed during Neogene period in the southern margin of Zagros mountains. The northern shore of Persian Gulf has been folded by foldings of Pliocene-Pleistocene period. The main trend of Persian Gulf is one of the geological consequence of Zagros folding event formed during Pliocene-Pleistocene period (Stoklin, 1968). The studied well is located in Persian Gulf between the heights of Qatar-Iran and Hormuz Strait (Fig.2).

Fig-2. The geographical position of the studied well in Persian Gulf, south west of Iran, (NIOC Company)

3. MATERIALS AND METHODS

The Middle-Late Cretaceous deposits in the Well 1 in Persian Gulf was investigated. This well has been drilled and sampled by National Iranian Oil Company (NIOC). A total of 46 thin section were prepared and analyzed in order to determine lithostratigraphy, biostratigraphy and growth strata analysis. Thin sections were stained by potassium ferricyanide and alizarin-red S solution (Dickson, 1965). Biostratigraphic analysis are based on studies of (Raymond and Douglass, 1960; Wynd, 1965; Kalantari, 1976; Loeblich and Tappan, 1988; Razin *et al.*, 2010; Schroeder *et al.*, 2010; Ghanem and Kuss, 2013; Felix, 2015; Schlagintweit, 2015). Also, the frequency of the benthic microfossils were determined. The boundary between formations were determined by lithostratigraphic characteristics and distribution of microfossils, and then growth strata of deposites were investigated. The study method of growth strata is based on In-line study and also flatted of headformations by Karizma software. The growth strata of the Middle-Late Cretaceous deposits were recognized by the determination of thickness difference of headformations.

4. LITHOSTRATIGRAPHY

The drilled thickness in the Well 1 is 3066m and consists of Kangan to Mishan formations. Tle Middle-Late Cretaceous deposits with 230m in studied well consists of Kazhdumi, Sarvak, Lafan and Ilam rock units. The thickness of the Kazhdumi Formation is 50m and lithostratigraphically consists of sandstone, shale, argillaceous limestone and limestone. The thickness of the Sarvak Formation is 85m and lithostratigraphically consists of limestone, argillaceous limestone, shale and dolomite with chert nodules. The thickness of the Lafan Shale is

50m and lithostratigraphically consists of shale, argillaceous limestone and dolomite. Also, the thickness of the Ilam Formation is 45m and lithostratigraphically consists of limestone and dolomite.

5. BIOSTRATIGRAPHY

The biostratigraphic scheme of the Middle-Late Cretaceous deposits in south west of Iran studied by Wynd (1965) and summarized in the Tables1 and 2. Biostratigraphic studies led to recognition of 7 species belonging to 15 genera benthic foraminifera Considering the studied microscopic samples, as the mentioned formations were of dolomite, the identified microfossils did not have a good preservation and for this reason the number of identified genera is low and the determination of species is mainly very difficult. However, based on the recognized microfossils in the Middle-Late Cretaceous deposits, three biozones are identified and these biozones are adaptable with biozone 19, 25 and 30 indicated by Wynd (1965). The distribution of benthic foraminifera has been plotted on the biostratigraphic column (Fig. 3). Examples of the genera and species of benthic foraminifera are shown in Fig 4 The following assemblages were identified for this study.

5.1. *Hemicyclammina-Orbitolina* Assemblage Zone (No .19)

This assemblage zone is identified in the Kazhdumi Formation and is marked by the presence of benthic foraminifera such as *Hemicyclammina sigali*, *Hemicyclammina* sp., *Orbitolina* sp., *Marssonella trochus*, *Nezzazata* sp., Cyclamminids, textulariids and miliolids. This assemblage indicates the *Hemicyclammina*-*Orbitolina* assemblage zone of Wynd (1965). The thickness of this assemblage zone is 20m (From 1080 to 1100m) and its age is assigned to Albian-Cenomanian.

5.2. Equivalent to *Nezzazata-Alveolinids* Assemblage Zone (No .25)

This assemblage zone is recognized in the Sarvak Formation and is marked by the presence of benthic foraminifera such as *Nezzazata* sp., alveolinids, *Dicyclina schlumbergeri*, *Cuneolina pavonia*, *Orbitolina* sp., *Dictyoconus* sp., *Cuneolina* sp., *Dicyclina* sp., *Orbitolina* sp., *Orbitolinella* sp., *Dukhania* sp. and *Trocholina* sp. This assemblage indicates the *Nezzazata-alveolinids* assemblage zone assemblage zone of Wynd (1965). The thickness of this assemblage zone is 40m (From 990 to 1030m) and its age is assigned to Cenomanian.

5.3.1. Equivalent to *Rotalia* Sp. 22 – *Algae* Assemblage Zone (No.30)

This zone is indicated in the Lafan Shale and is marked by the presence of benthic foraminifera such as *Rotalia* sp. 22 (*Rotalia* cf. *skourensis*), *Nezzazatinella picardi*, *Biconcava bentori*, *Cuneolina pavonia*, *Dicyclina schlumbergeri*, *Glomospir*a sp., *Pseudonummoloculina* sp., *Spiroloculina* sp., *Marssonella* sp., *Spiroculina cretacea*, *Pseudolitunella* sp., *Nezzazata* sp., *Quinqueloculina* sp., *Ammobaculites* sp., *Rotalia* sp., *Dicyclina* sp., *Cuneolina* sp., *Valvulammina* sp., miliolids and textulariids. This assemblage can be correlatable with the to *Rotalia* sp. 22-*algae*zone assemblage zone of Wynd (1965). The thickness of this assemblage zone is 50m (From 915 to 965m) and its age is assigned to Coniacian and Santonian.

5.3.2. *Rotalia* Sp. 22 – *Algae* Assemblage Zone (No. 30)

This zone is extended from Lafan Shale to the Ilam Formation and is marked by the presence of benthic foraminifera such as *Nezzazatinella picardi*, *Dicyclina schlumbergeri*, *Rotalia* sp., *Cuneolina pavonia*, *Marssonella* sp., *Nezzazata* sp., *Pseudonummoloculina* sp. and *Quinqueloculina* sp. This assemblage can be correlatable with the to *Rotalia* sp. 22-*algaes* zone assemblage zone of Wynd (1965). The thickness of this assemblage zone is 37m (From 878 to 915m) and its age is assigned to Santonian-Campanian. Note that the age of the biozone 30 ranges between Coniacian to Campanian ages.

Table-1. Biostratigraphy scheme of the Middle-Late Cretaceous deposits in south west of Iran identified by Wynd (1965) (NIOC Company)

Age	Geographical extension	Stratigraphic position	The name of biozone
Aptian-Albian	Khuzestan and Fars Internal Fars regions	The base of the Kazhdumi Formation	*Globigerina* assemblage zone (No.17)
Albian	Fars region	Kazhdumi Formation	*Hemicyclammina–Orbitolina* assemblage zone No.19)
Late Albian-Cenomanian	Kermanshah region	Sarvak Formation	*Rotalipora–Radiolaria* assemblage zone(No.20)
?Albian-Cenomanian	Coastal Fars region	Maddud member	Trocholina – Orbitolina assemblage zone(no.21)
Cenomanian	Internal and Coastal Fars regions	The middle part of the Sarvak Formation	*Praealveolina–algae* assemblage zone(No.22)
Albian- Cenomanian	Dezful embayment zone	Kazhdumi Formation and the base of the Sarvak Formation	*Globigerina washitensis* (No.23)
Aptian-Maastrichtian	—	—	*Rudist debris* zone (No.24)
Cenomanian-Turonian	Dezful embayment zone	Sarvak Formation	*Nezzazata–alveolinids* assemblage zone(No.25)
Albian-Turonian	Lorestan, Khuzestan, and Fars regions	Kazhdumi Formation	*Oligostegina*(No.26)
Turonian	Lorestan region	The most upper part of the Sarvak and Garu Formations	*Globotrouncana halvetica–ClAvihedbergella–Hedbergella* assemblage zone(No.27)
Coniacian	Lorestan region	The base of the Surgah and Ilam formations	*Globotruncana schneegansi–Globotruncana sigali*assemblage zone(No.28)
Turonian	Lorestan, Khuzestan, and Fars regions	Sarvak Formation	*Valvulammina–Dicyclina* assemblage zone(No.29)

Table-2. Biostratigraphy scheme of the Late Cretaceous deposits in south west of Iran identified by Wynd (1965) (NIOC Company)

Age	Geographical extension	Stratigraphic position	The name of biozone
Coniacian-Campanian	Fars and Khuzestan regions	Ilam Formation	*Rotalia sp. 22–algae* assemblage zone(No.30)
Coniacian-Early Santonian	—	Between the topof zone 19 and the base of zone 30	*Chara-Ostracods* (No.30)
Santonian-Campanian	Coastal Fars and Persian Gulf regions	The upper pert of the Ilam Formation	*Archaecyclus midorientalis–Pseudomia (fabularia)*assemblage zone(No.31)
Santonian	Khuzestan and Fars regions	Gurpi Formation	*Globotruncana concavata-ventricosa carinata* assemblage zone(No.32)
Campanian	Khuzestan, Lorestan, and Fars regions	Ilam to Gurpi formations	*Globotruncana elevata* zone(No.33)
Campanian	Lorestan and Khuzestan regions	Ilam and Gurpi formations	*Ventilabrella (Planoglobulina)* subzone (No.33)
Campanian	Lorestan region	Gurpi Formation	*Ostracod*assemblage subzone(No.34)
Campanian	Internal Fars region	Tarbur Formation	*Monolepidorbis–Orbitolina* assemblage zone(No.36)
Maastrichtian	Fars, Lorestan and Khuzestan regions	Tarbur, Amiran and Gurpi formations	*Omphalocyclus–Loftusia* assemblage zone(No.37)
Maastrichtian	In Darab-Fasa regions	Sachun Formation	*Elphidiella multiscissurata* subzone (No.38)
Maastrichtian	Fars, Lorestan and Khuzestan regions	GurpiFormation	*Globotruncana stuartia–pseudotextularia varians*assemblage zone (No.39)
Cretaceous-Tertiary	Lorestan region	Gurpi and Pabdeh formations	*Abathomphalus mayaroensis* zone (No.40)

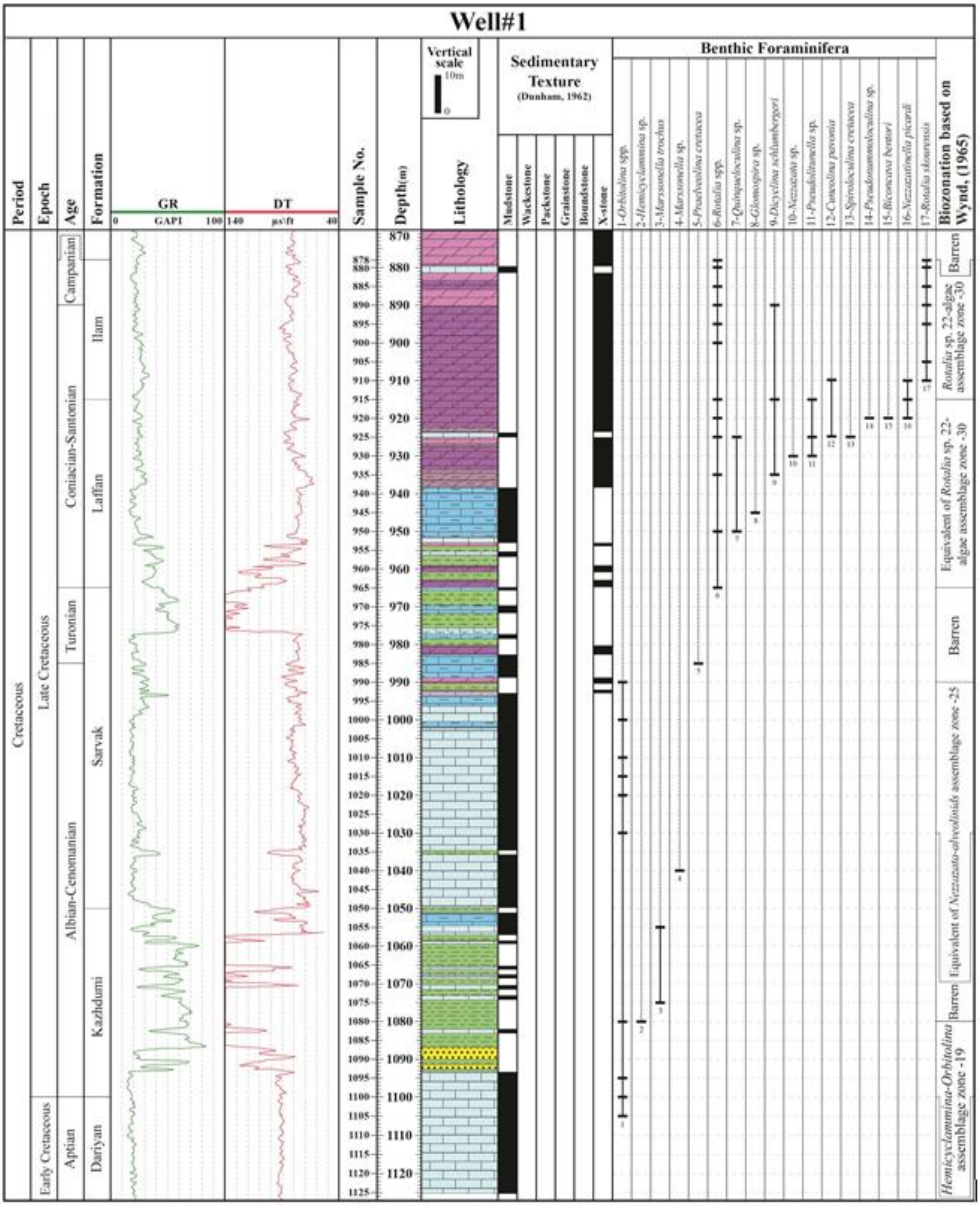
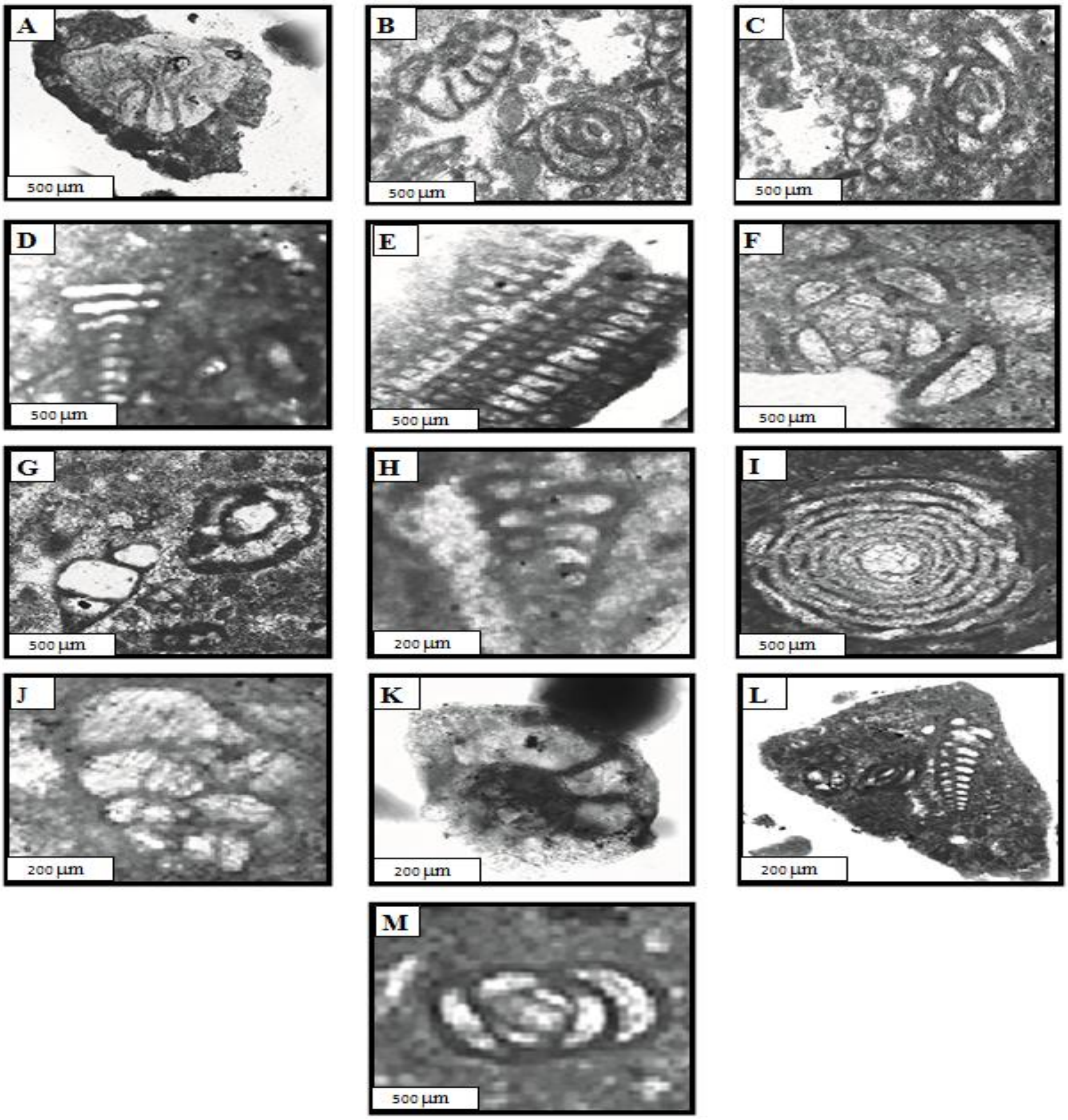


Fig-3. Lithostratigraphic and biostratigraphic column of the Middle-Late Cretaceous deposits in the Well 1, Persian Gulf, South West of Iran, (NIOC Company)



A -*Rotliaskourensis* Pfender, B-*Nezzazatinellapicardi* Henson, *Pseudonummoloculina* sp., C-*Biconcavabentori* Hamaoui, D-*Pseudolituonella* sp., E-*Dicyclinaschlumbergeri* Munier-Chalmas, F-*Quinqueloculina* sp, G-*Nezzazata* sp., H-*Marssonella* sp., I-*Praealveolinacreatacea* D'archiac, J-*Marssonellatrochus* d'Orbigny, K –*Hemicyclammina* sp., L- *Cuneolinapavonia* d'Orbigny

Fig-4. Examples of recognized benthic foraminifera in the Well 1, Persian Gulf, south west of Iran

6. DISCUSSION

The lithostratigraphic studies as well as distribution of microfossils allow to determine the position and thickness of formations. So far, numerous oilfields have been detected in Persian Gulf. Many of these fields are in the form of anticline. Anticlines are considered to belong to oil and gas traps and the majority of oil and gas stores are located in these oil traps (Wilson, 1975). Accordingly, identification of oil traps is crucial the growth strata analysis is effective in identifying these oil traps (Soleimany and Sabat, 2010). One of the different types of traps is folded type which has various subtypes. First subtype formed under the influence of compressional force and eventually folding. Second subtype developed in response to the difference between compressional deposits, and finally the third subtype is related to diapiric process (Rezaei, 2006). The first type or anticline traps are result of compressional forces and are formed in regions such as active margins of continents where the crust undergoes shortening (Rezaei, 2006). In Zagros Basin and Persian Gulf regions, different types of anticline traps are recognized. Tectonic activities are most important in making of oil traps and lead to folding of deposits. For this reason, the deposits are divided into three groups based on these activities (Poblet *et al.*, 2004). (I) Pertectonic: these deposits are same as initial deposition in deposit areas and are usually formed in response to factors such as weathering and erosion and then these deposits transferred to deposition areas such as seas and lakes. The most important characteristic of these deposits is their equal thickness. (II) Syntectonic: these deposits are usually deposited in an area concordant with tectonic transformations and greatly assist in interpretation of the tectonic activities of the area. These deposits are also crucial importance in dating the age of tectonic transformations. These deposits are known as growth strata if it is related to tectonic phenomena such as folding (Poblet *et al.*, 2004). The growth strata in anticlines are known to possess some characteristics including variable thickness, fanning state and alteration of the slope from edge to the head with a descending trend. (III) Posttectonic: these deposits are usually formed following tectonic activities in the deposition area. These deposits have absolutely equal thickness which does not change, and are deposited in the area following tension or pressure. Therefore, during the formation of an anticline in response to compressional forces in deposits, growth strata are deposited in the sides of anticline. The thickness of these deposits diminishes from the side or domain towards the head of the anticline. Reduction of thickness towards the head of the structure implies growth and formation of anticline (Poblet *et al.*, 2004). To investigate growth strata of Well 1, first the In-line study was performed (a horizontal line used in interpretation of seismic information of an anticline structure). Through In-line study on Middle-Late Cretaceous deposits the growth strata are identified the intervals between Dariyan and Sarvak formations.

As can be observed in Fig. 4, the In-line obtained from lithostratigraphic and biostratigraphic analysis, and then the difference in the thickness between the Dariyan and Sarvak formations were determined in the edges and head of the structure. This difference in thickness is from the side or domain towards the head of the structure. The deposited succession during the Middle-Late Cretaceous represent growth of the structure at this period. Therefore, the thickness of the studied formations at their edge parts show growth strata succession that deposited concurrent with generation of the structure. Following In-line investigation of the studied well, based on flatting of each horizon onto the headformations growth strata study was performed. Indeed through flatting on every horizon or headformation, variations in deposition are specified considering tectonic transformations at different geological periods on an anticline. In this method, by flatting on every horizon or headformation, the difference between the deposited thicknesses in other horizons becomes absolutely evident. Therefore, it is possible to investigate growth of the structure across distances in which we have difference thickness. Following the flattening on Kazhdumi horizon, the difference thickness between the Dariyan and Ilam formations is observed (Fig. 5). In these intervals, the difference in the thickness of deposits from the side towards the head of the structure suggests deposition of growth strata deposits during the Middle-Late Cretaceous period.

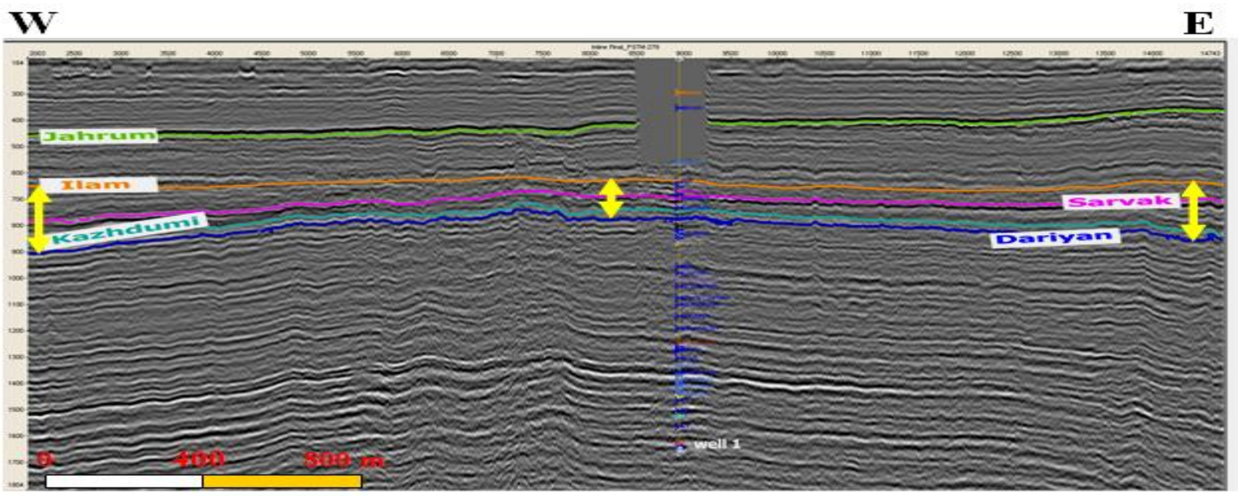


Fig-5. Seismic interpretation of Well 1 together with the information of studied headformations, (NIOC Company)

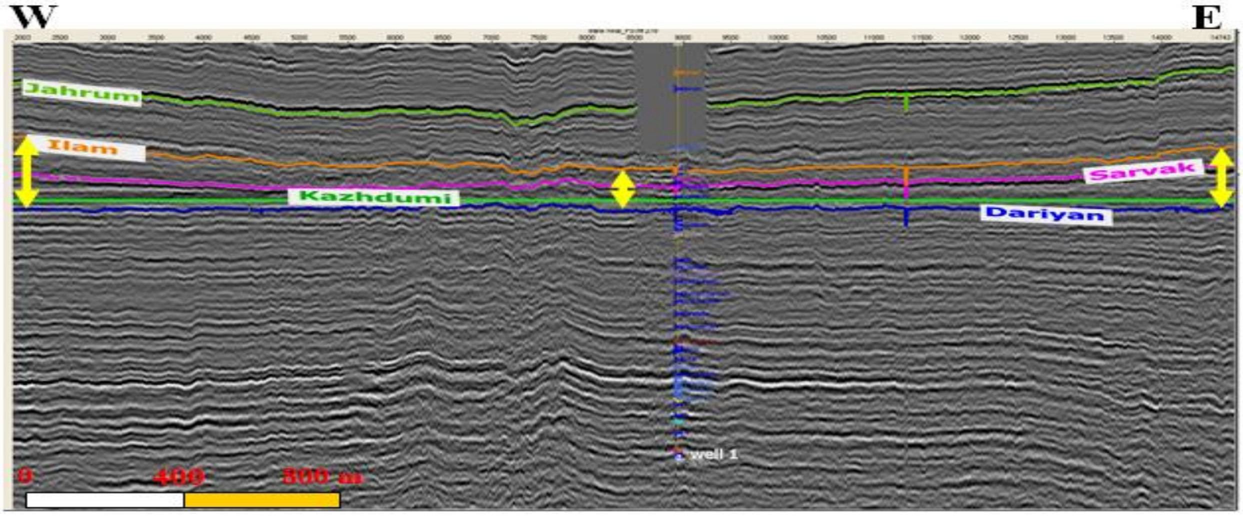


Fig-6. Flatting on Kazhdumi horizon in the studied well, (NIOC Company)

7. CONCLUSION

The first part of this research assigned to lithostratigraphy and microfossils distribution of the Middle-Late Cretaceous deposits including Kazhdumi, Sarvak, Lafan and Ilam rock units in Persian Gulf. The thickness of the Kazhdumi Formation have 50m and lithostratigraphically consists of sandstone, shale, argillaceous limestone and limestone. The thickness of the Sarvak Formation have 85m and lithostratigraphically consists of limestone, argillaceous limestone, shale and dolomite with chert nodules. The thickness of the Lafan Shale have 50m and lithostratigraphically consists of shale, argillaceous limestone and dolomite. Also, the thickness of the Ilam Formation have 45m and lithostratigraphically consists of limestone and dolomite. The biostratigraphic analysis based on benthic foraminifera led to recognition of three assemblage zone that are adaptable to biozones indicated by Wynd (1965). These biozones are *Hemicyclammina-Orbitolina* assemblage zone (No.19), *Nezzazata-alveolinids* assemblage zone (No.25) and *Rotalia* sp. *22-algae* assemblage zone (No.30). The age of studied formations based on identified biozones is assigned to Albian-Campanian. The headformations were placed in their accurate depths with considering the lithostratigraphic characteristics and stratigraphic distribution of microfossils. Also, the growth strata studies of the Middle-Late Cretaceous deposits were performed with the placement of headformations in their precise depths. The growth strata consists of concurrent deposition with tectonic activities and it can lead to recognize the age of formation and generation of an anticline. Anticlines are considered to belong to oil and gas traps, where the majority of oil and gas reserves have been located in these oil traps which have stratigraphic geological structure. By investigating growth strata deposits in the studied well, it is observed that generation of the structure has taken place within Middle-Late Cretaceous period and this generation has still been continuing until Eocene period, following which it has reached a stable state.

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Contributors/Acknowledgement: All authors contributed equally to the conception and design of the study.

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