

Sedimentary Environments and Correlative Sequence Stratigraphy of Upper Cretaceous—Paleogene Succession in Shiraz Area, Fars, SW IRAN

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Received December 2, 2013; revised December 28, 2013; accepted January 5, 2014

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ABSTRACT

Sequence stratigraphic evidences have been used in this research to investigate the stratigraphic correlation of cretaceous paleogene succession in Shiraz area, Fars, SW Iran. For this purpose, 4 stratigraphic sections have been chosen and provided. According to petrographic study and field evidences, 4 depositional sequences were identified including the Tarbur, Sachun and Jahrum formations in the east and the Gurpi, Pabadeh and Asmari formations in the west of study area. After identifying the boundaries and systems tract facies, it has been found that the mentioned formations have been deposited among the continuous/discontinuous boundaries in an equivalent manner. In this case, the purple shale (between the Gurpi and Pabdeh formations) could be considered equivalent to the upper part of the Sachun formation. From the point of Paleogeography, the plat-form sedimentary environment covered almost the whole area during the Oligo-Miocene age, so that the Asmari formation would have been deposited, which is marked by sharp contact as disconformity on Jahrum formation in the east of the basin and with continuous contact (C.C) on the Pabdeh formation in the west and southwest.

KEYWORDS

Iran; Fars; Shiraz; Sedimentary Environment; Sequence Stratigraphy; Cretaceous-Tertiary Boundary

1. Introduction

Upper cretaceous sediments in study area cover two formations: Gurpi and Tarbur. Gurpi formation consists of shale and marl and Tarbur formation formed of reef massive limestone. Paleogene sediments in the Shiraz region cover four formations: Sachun, Jahrum, Pabdeh, and Asmari. The mentioned formations are expanded over the studied area with a petrological variety of marl, limestone, dolomite, dolomitic limestone and evaporate rock with different thicknesses [1]. The sequence stratigraphic evidences have been applied in this research to study the stratigraphic conformity and correlation of the formations in the upper cretaceous—paleogene time frame. Such studies would have application in paleogeography and the evolution of the Zagros sedimentary basin in this period.

2. Materials and Methods

The research method includes four general stages: 1) collecting data (from new references) and studying aerial photographs, initial field visits; 2) field survey, taking field photos, preparing thin sections and providing photos from thin sections; 3) data analysis and interpretation of the results; 4) presenting depositional environments models and the stratigraphic correlation of under study formations. For this purpose, after full field survey, 4 stratigraphic sections including 1) Sarvestan section; 2) Estahban section; 3) Mook section; and 4) Shahneshtin section, were selected and studied.

3. Geologic and Stratigraphic Setting

The study area is located SW of the Zagros Mountains,

which is a cretaceous—paleogene sediments in fold-thrust belt Zagros that located in Fars area. The Zagros is the result of a multi-phased collision between the Arabian plate, the Neo-Tethys ocean, and the central Iran microplate [2]. In study area Tarbur, Sachun, Jahrum, Gurpi, Pabdeh and Asmari formations are expanded all over the in the cretaceous-Tertiary boundary CTB and Paleogene period. The selected sections include one, two or three rock units based on the case. As such, the Estahban and Sarvestan sections includes four formations of Tarbur, Sachun, Jahrum and Asmari, the Mook and Shahneshin sections covers the Gurpi, Pabdeh and Asmari formations. **Figure 1** shows the geological setting and Geographical location of the studied sections.

4. Lithostratigraphy of the Studied Sections

The geographic coordinates of the base of the selected sections, together with their lithostratigraphical characteristics are summarized in **Table 1**. **Figure 2** shows lithostratigraphical relationship between formations in Fars area, SW of Iran and **Figures 3-5** show some field photos

of study area.

5. Microfacies & Depositional Environments Model Based on the Relative Sea Level Changes

A wide range of carbonate, clastic (Litofacies) and evaporite facies have been identified in petrographic and field studies of the studied formations. Type of skeletal and non-skeletal grains, grain size and their frequency percentage, Matrix and cement have been used to discriminate and identify carbonate facies from factors such as constituents of carbonate rocks including orthochem and allochem. Skeletal grains are mostly from *Miliolidae*, *Algae*, *Nummulitidae*, *Globigerinidae*, *Globorotruncanidae*, *Discocyclinidae*, *Lepidocyclinidae* and *Alveolinidae* families. For determination of carbonate microfacies use of Flugel 2004 [3].

Non-skeletal grains include pellet and intraclast, the frequency of which in some samples reaches to 50%. Nomenclature of the carbonate samples has been carried out by Dunham method [4]. In general, having precisely

Table 1. The geographic coordinates and lithostratigraphy of the studied sections.

No	Section Name	Formation	Lithology	Coordinate U.T.M	Lower Limit	Upper Limit	Thick (m)
1	Sarvestan	Tarbur, Sachun, Jahrum, Razak	Red and Green Marl, Evaporate (Jepsun & Anhydrite), Limestone, Dolomit, Dolomitic Limestone	53°30'45"E 29°7'50"N	Tarbur, CTB Boundary	Razak	570
2	Estahban	Tarbur, Sachun, Jahrum, Asmari	Limestone, Dolomite, Dolomitic Limestone	53°55'36"E 29°7'50"N	Tarbur, CTB Boundary	Razak	226
3	Mook	Gurpi, Pabdeh, Asmari	Dark, Pale Yellow, gray and slightly blue Shale and Marl, Calcareous Shale, Limestone and Calciturbidite Sediments	52°10'30"E 29°4'10"N	Purple Shale, SB2, CTB Boundary	Asmari, Gachsaran	400
4	Shahneshin	Gurpi, Pabdeh, Asmari	Dark, Pale Yellow, gray and slightly blue Shale and Marl, Calcareous Shale, Limestone and Calciturbidite Sediments	55°55'50"E 29°24'40"N	Purple Shale, SB2, CTB Boundary	Asmari, Gachsaran	500

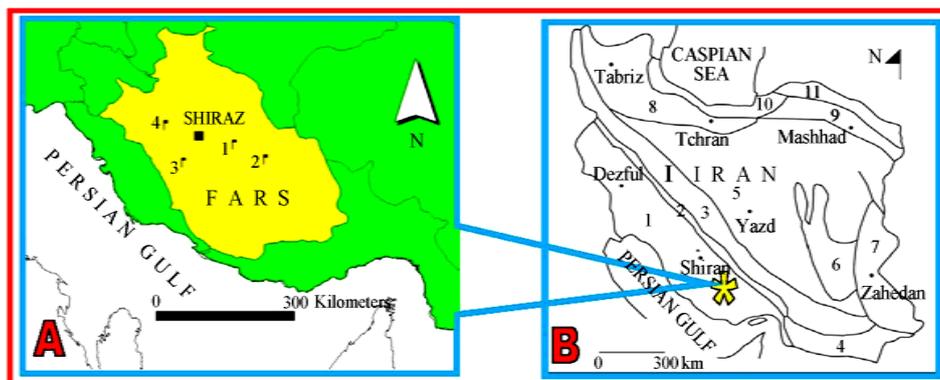


Figure 1. A: Geographical situation of the studied section in study area: 1—Sarvestan section; 2—Estahban section; 3—Mook section; 4—Shahneshin section. **B:** Tectono-sedimentary provinces of Iran and the location of the study area. 1—Folded Zagros; 2—High Zagros; 3—Esfandaghe-Marivan, 4—Makran; 5—Central Iran; 6—Lut Block; 7—Nehbandan-Khash, 8—Alborz-Azarbayegan, 9—Binalud, 10—Gorgan-Rasht, 11—Hezarmasjed-Kopedagh; *study area.

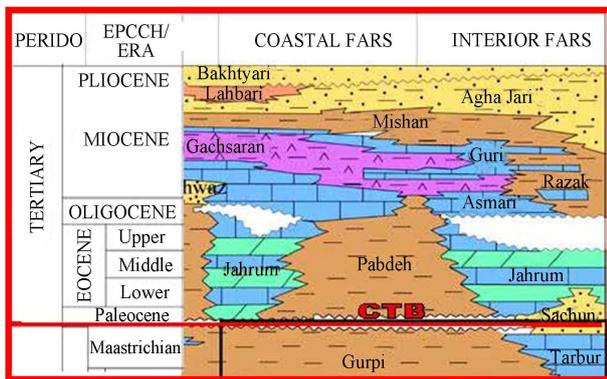


Figure 2. Lithostratigraphical relationship between formations in Fars area, SW of Iran (Modified of James & Wynd, 1975).

carried out the study and nomenclature of microfacies, the depositional model of each of the formations under study has been brought out according to the relative changes curve of the sea level based on their time.

All in all, about 800 thin sections have been provided from the 4 studied sections and after precise study of the samples, the facies of the Tarbur, Gurpi, Sachun, Jahrum, Pabdeh and Asmari formations were studied in detail, the abstract of which has been brought out in the following tables.

5.1. Microfacies of Tarbur Formation

Tarbur formation expanded in Sarvestan and Estahban sections. Tarbur Formation in study area is divided into two lithostratigraphic parts which are lower and upper parts. The lower part of the Tarbur Formation comprises medium-bedded limestones, which consists of Iron nodules, Gastropoda and Rudist debris whereas the upper part is including Rudist and Gastropoda massive limestone with bivalve fragments. Generally, based on the identified foraminifers, Tarbur Formation is assigned to Upper Maestrichtian. According to the microscopic investigations, the index microfacieses, consists of Framestone, Wackestone, Grainestone, Packestone, Floatestone, Rudestone, Buffelestone, *Omphalocyclos* bioclast packstone and *Loftosia* bioclast Packstone (Figure 6, photos 1-3). Moreover, occurrence of foraminifera with Hyaline wall reflects the seaward part of the Tarbur carbonate depositional system. Also appearance of the Agglutinated wall genera and species have supported reef marine sedimentary environment [5].

5.2. Microfacies of Gurpi Formation

Gurpi formation expanded in study area in Mook and Shahneshin sections. Gurpi Formation, that with a thickness of about 500 m at these sections and includes thin to

medium bedded bluish gray shale/marl associated with thin interlayer's of argillaceous cream limestones. Some microfacies in Gurpi formation are mudstone, pelagic foraminifera wackestone and pelagic foraminifera packestone (Figure 4, photo 1, Figure 5, photos 1 and 7 and Figure 7, photo 7).

5.3. Microfacies and Lithofacies of the CTB

5.3.1. Purple Shale

Purple shale is keyed and expanded in west of study area between Gurpi and Pabdeh formations. This layer is red and there is no conclusive evidences indicating that this time CTB exposed area. This layer is sequence boundary type 2, SB2 in sequence stratigraphy interpretation (Figure 5, photos 4 and 7). For geochemical study of purple shale 4 sample selected under to above of this layer and examined with XRF method, that results are in Table 2.

5.3.2. Interpretation

Sample 1 and 4 related to lower and upper part of purple shale. in Sample 1 value of Fe and Mn is high and indicated highstand systems tract HST of Gurpi formation, because in HST, value of Mn and Fe are increasing. Sample 2 and 3 related to purple shale, in these samples value of Fe (900 - 1070 ppm) and Mn (20 - 30 ppm) decreased and indicated sequence boundary type 2 SB2. Totally in sequence boundary value of Mn and Fe decreasing and in TST and MFS these values are increasing. Also in low PH of environment in deep marine shelf carbonate is soluble and silica is sediment. Changes of Si in samples indicated while the Purple Shale deposited depth is decrease and Ph is increased and finally amount of Si is decreased (Figure 8).

5.3.3. Lime Sandstone, Sandy Limestone and Microconglomerate

In East of study area CTB is SB1 and contact between Tarbur and Sachun is erosional and recognized with microconglomerate, sandstone, nodular iron oxides and Paleosol (Figure 9, photos 2-9).

5.3.4. Gamma Log Evidences

Changes of Gamma-Ray (GR) in subsurface sections can be used to detection and recognition disconformity, when condition of sedimentary environment are changed, for example region exposed area rate of sedimentation of radioactive elements such as Thorium and Potassium change and ratio of Th/K increasing that this change indicative disconformity [6]. Because in study area have been used of surface data there was no evidence of GR, but some example of subsurface geology in SW of Iran show in Figure 10 [7].



Figure 3. Field photo of Sarvestan section. Tarbur, Sachun, CTB, Jahrum and Asmari formations in East of study area.



Figure 4. Field photo of CTB and formations, 1—West of study area, Shahneshin section. 2—East of study area, Sarvestan section.

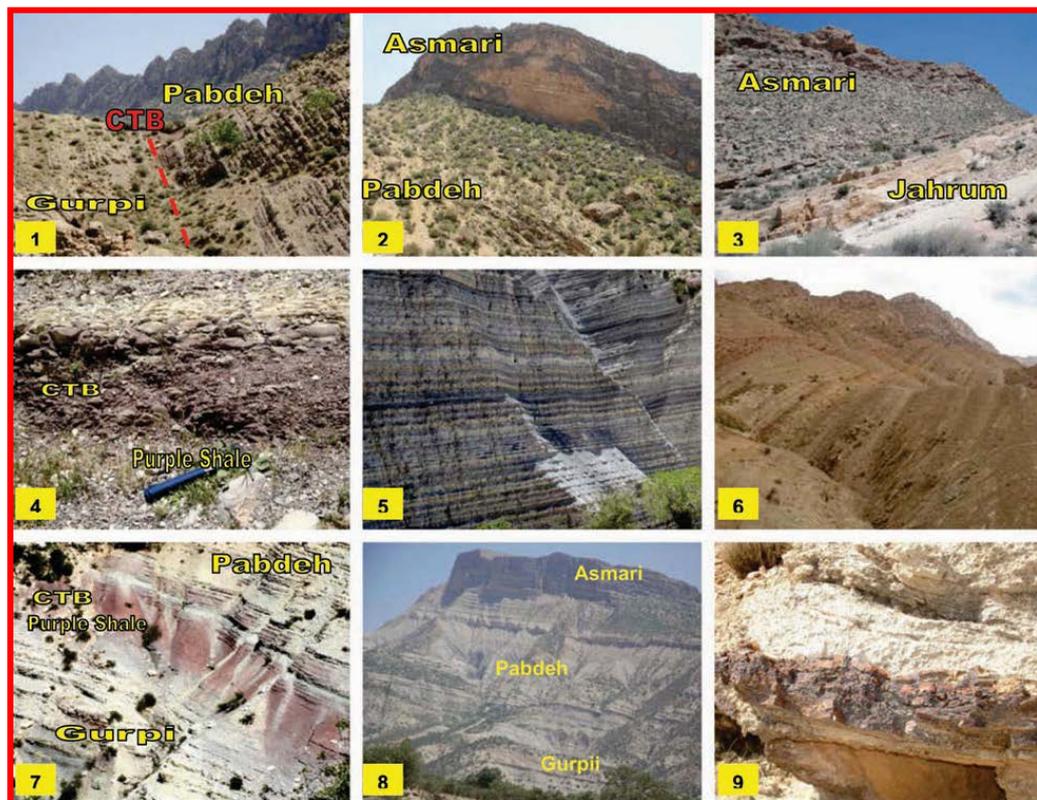


Figure 5. Some field photos of study area. 1—Purple Shale (CTB) between Gurpi and Pabdeh formations, Shahneshin section (Tang-e Abol-Hayat). 2—Pabdeh and Asmari formations, Mook section. 3—Jahrum and Asmari formation, Sarvestan section. 4—Purple shale in (CTB, SB2) base of Pabdeh formation, keyed between Gurpi and Pabdeh formations, Shahneshin section. 5—Alternative dark, blue and bright shale/marl in Pabdeh formation, Shahneshin section. 6—Alternative Evaporate layers and red shale/marl in Sachun formation, Sarvestan section. 7—Purple Shale (CTB) between Gurpi and Pabdeh formations, Shahneshin section (Sout ridge Shahneshin Anticline). 8—Gurpi, Pabdeh and Asmari formation in Shahneshin section. 9—Siliceous Nodule in calcareous shale, Pabdeh formation, Shahneshin section. Real diameter size is 12 cm.

Table 2. Geochemical data (XRF, ppm) of samples in purple shale, CTB SB2.

Location	Sample	Si	Al	Fe	S	Na	K	Ca	Mg	Sr	Mn	P	Ti
Gurpi Fm. Lower part of Purple Shale	1	4990	1830	1230	70	70	290	50280	560	110	50	90	100
Purple Shale	2	3700	1490	900	200	50	250	51700	390	110	30	50	80
Purple Shale	3	59930	2710	1070	220	60	380	18270	1710	70	20	330	120
Pabdeh Fm. Upper part of Purple Shale	4	13040	2640	1670	110	100	510	43420	1270	90	60	280	160

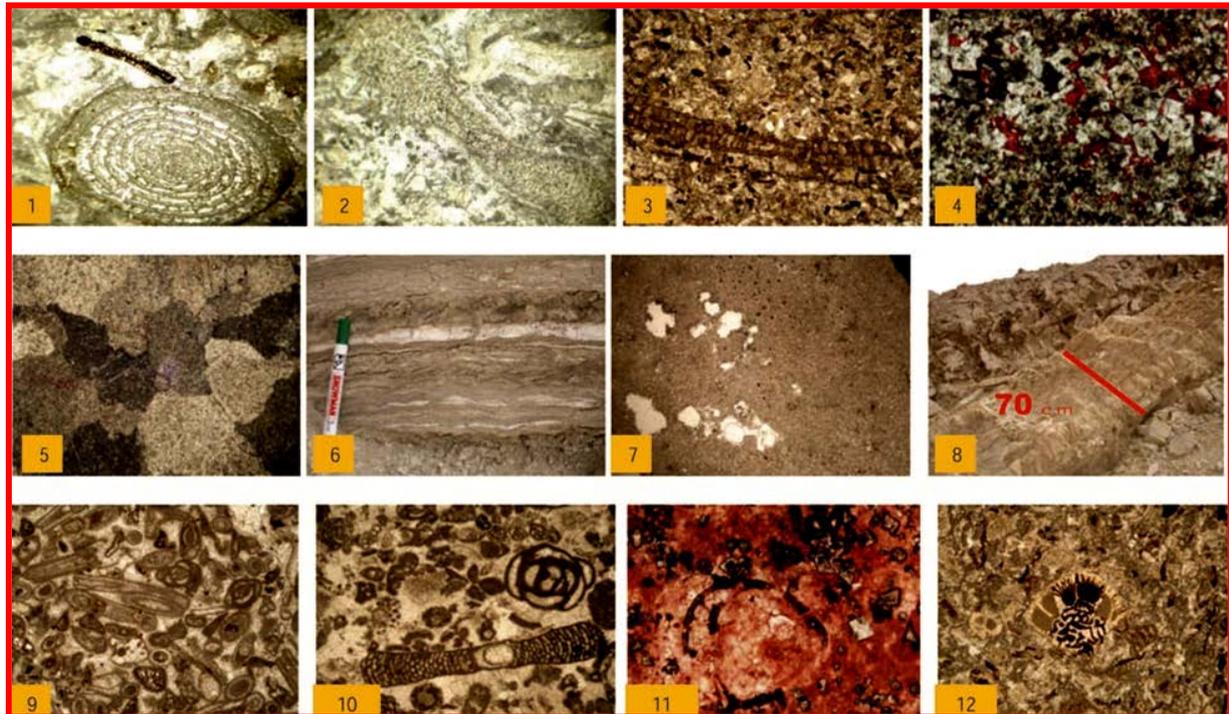


Figure 6. Some microfacies of study area. 1—*Loftusia*, *Omphalocyclus* bioclast packstone, Tarbur formation, Sarvestan section. Real size of *Loftusia persica* is 1 cm. 2 and 3—*Omphalocyclus* bioclast packstone, Tarbur formation, Sarvestan section. Real size of *Omphalocyclus macroporous* is 0.8 cm. 4—Dolomite wackestone, Jahrum formation, Sarvestan section, $\times 10$. 5—Saddle dolomite, Sachun formation, Sarvestan section, $\times 10$. 6—Laminated Jypsum and Dolomite, Sachun formation, Sarvestan section. 7—Dolomudstone with fenestral fabric, Sarvestan section, $\times 4$. 8—Thick bedded of laminated Jypsum, Sarvestan section. 9—Algae bioclast grainstone, Jahrum formation, Beyza section, $\times 10$. 10—*Orbitolites* bioclast grainstone, Jahrum formation, (*Orbitolites shirazienensis*, Upper paleocene), $\times 10$. 11—Dolomitized bioclast wackestone, Jahrum formation, Sarvestan section, $\times 10$. 12—*Rotalia* bioclast packstone Jahrum formation, $\times 10$.

6. Interpreting & Offering Depositional Model of Cretaceous-Tertiary (CTB) in Study Area

Based on microfacies study, sedimentary environments models and sequence stratigraphy evidences 3 depositional model based on relative sea level change is presented during CTB time in study area.

6.1. Model A

During cretaceous time in central and east of study area (Estahban and Sarvestan sections) carbonate Tarbur formation deposited and Equivalent to in west of study area

in pelagic marine environment Gurpi formation is deposited. During CTB time totally study area exposed of marine environment and LST systems tract deposited over on these formations (Figure 11, Model A).

6.2. Model B

After cretaceous period and start of Paleocene in west of study area (Mook and Shahneshin sections) purple shale equivalent to Sachun formation (in central and east of study area) is deposited (Figure 11, Model B). Purple shale is keyed for lithostratigraphical separation of Gurpi and Pabdeh formations. After transgressive sea level during Paleocene Eocene in west of study area

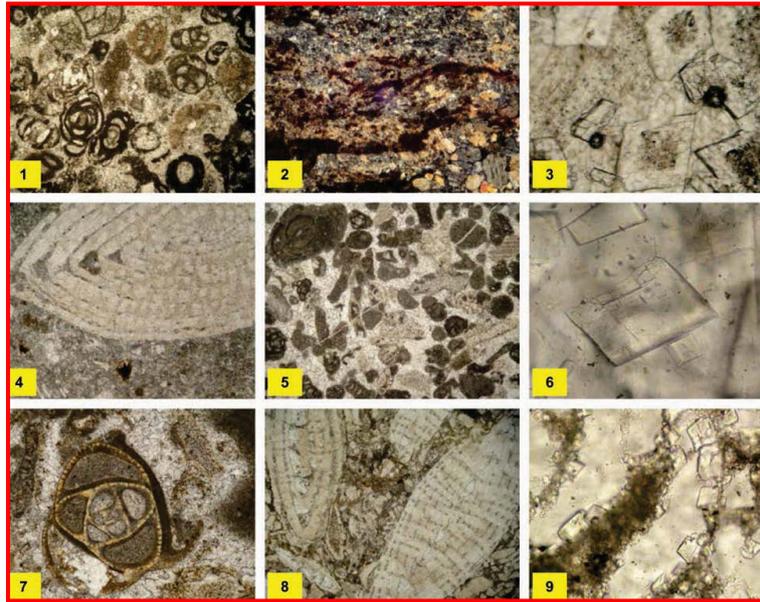


Figure 7. Some microfacies of study area. 1—*Miliolid* Bioclast Grainstone, Asmari formation, Sarvestan section, $\times 4$. 2—Gypsum/Anhydrite, Sachun formation, Sarvestan section, $\times 4$. 3—Dolograins, dolomite crystal with fuggy core and clear rim, Jahrum and Asmari formations, $\times 10$. 4—*Nummulites* bioclast Packstone, Asmari formation, Sarvestan section, $\times 10$. 5—*Algal Miliolid* bioclast Grainstone, Jahrum formation, Sarvestan section, $\times 4$. 6—Rhombohedral crystal of Dolomite, Jahrum formation, Sarvestan section, $\times 40$. 7—*Austrotrilina* bioclast Grainstone, Asmari formation, Sarvestan section, $\times 10$. 8—*Nummulites* bioclast Packstone, Asmari formation, Sarvestan section, (*Nummulites fichtelli*.) $\times 10$. 9—Rhombohedral crystal secondary dolomite in Gastropod chamber and fatal fabric of dolomitization, Jahrum and Asmari formation, Sarvestan section, $\times 10$.

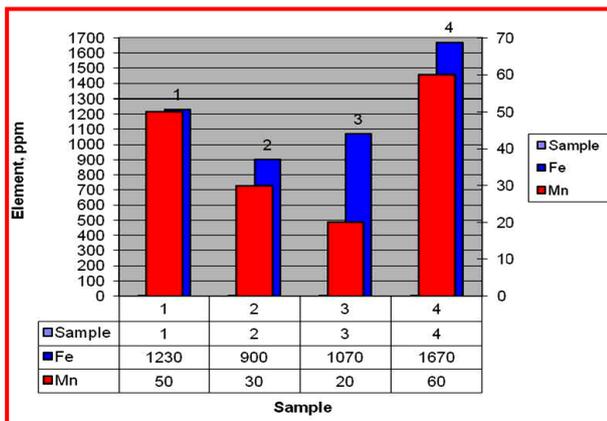


Figure 8. Distribution of Fe and Mn in samples 1 to 4 around Purple Shale, CTB, SB2.

(Mook and Shahneshin sections) purple shale and Pabdeh formation is deposited over on Gurpi formation (SB2) (Figure 11, Model B).

6.3. Model C

During CTB time in central and east of study area sea level is transgressive and deposited TST and HST systems tract. In this time evaporate/marly Sachun formation deposited over on carbonate Tarbur formation. In west of study area in this time Purple shale and Pabdeh formation deposited over on Gurpi formation (Figure 11, Model C).



Figure 9. Some field and microfacies photos of study area. 1—Contact between Tarbur and Sachun SB1, Sarvestan section. 2—Sandy Limestone with Rework microfossils, *Omphalocyclus macroporus* (late maestrichtian), between Tarbur and Sachun formation, $\times 4$. 3—Lime sandstone with rounded sedimentary rocks fragments, between Tarbur and Sachun formations $\times 4$. 4—CTB, SB1 between Tarbur and Sachun formation, Paleosol with iron oxides debris, Sarvestan section. 5—Sandy limestone between Tarbur and Sachun formation, Estahban section, $\times 10$. 6—Lime microconglomerate, $\times 10$, XPL. 7—Sandy Limestone and Lime sandstone between Jahrum and Asmari formations, Estahban section. 8—Sandy Limestone and Microconglomerate between Jahrum and Asmari formations, Estahban section. 9—Lime microconglomerate, $\times 10$, PPL.

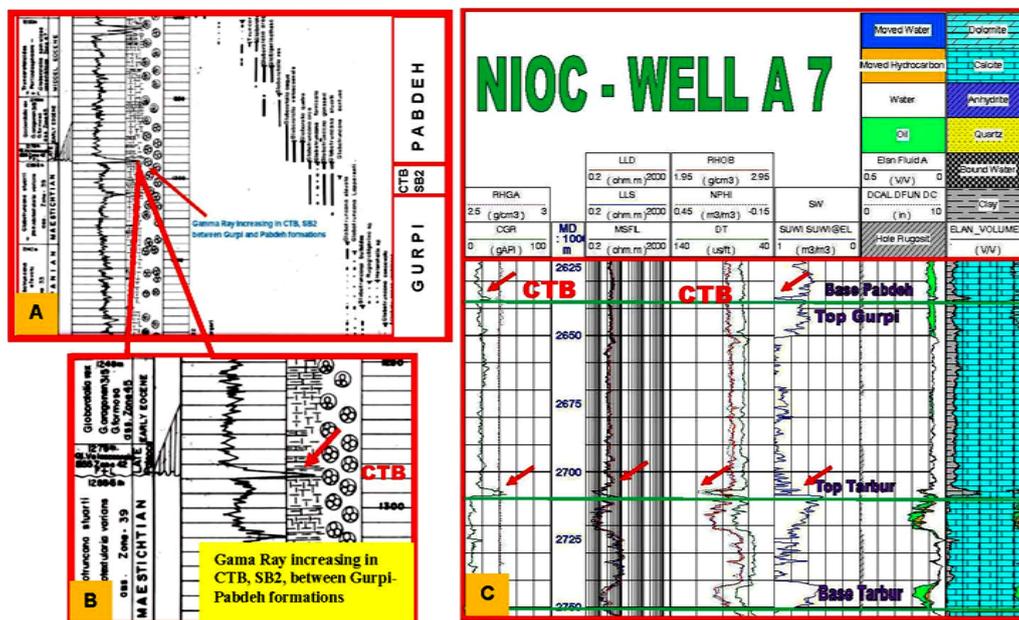


Figure 10. A and B: increasing API of GR in CTB, SB2 between Gurpi and Pabdeh formation, modified of NIOC. Persian Gulf of Iran. C: increasing API of GR in CTB, SB2 between Gurpi and Pabdeh formation, modified of NIOC. Khuzestan, SW of Iran.

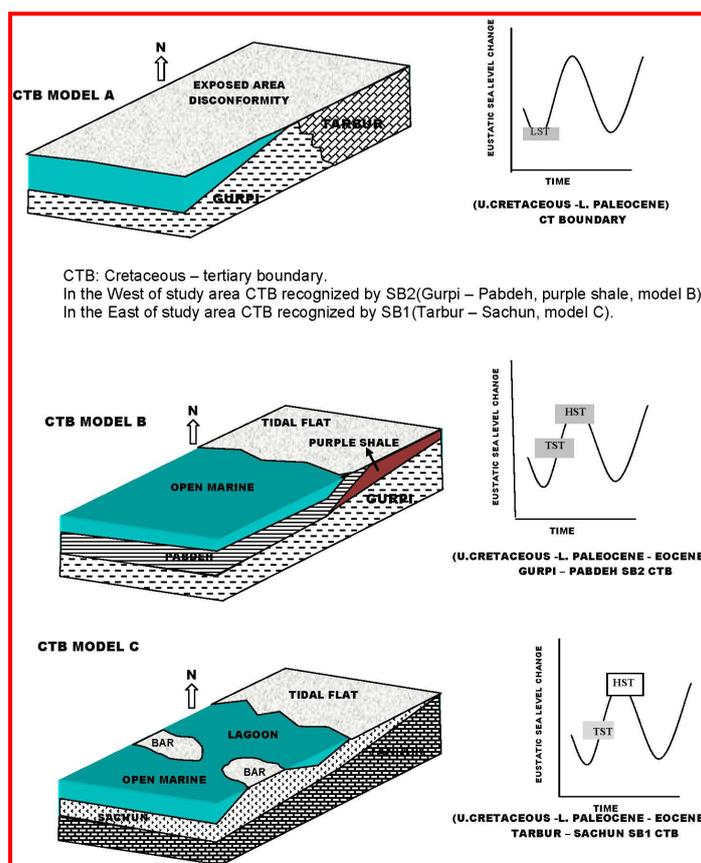


Figure 11. Depositional environment model based on sea level change during upper Cretaceous-Tertiary (CTB) in study area. A: Depositional environment model during CTB in east to west of study area. B: Depositional environment model during Upper Cretaceous—Lower Paleocene—Eocene between Gurpi and Pabdeh formations. C: Depositional environment model during Upper Cretaceous—Lower Paleocene—Eocene between Tarbur and Sachun formations.

7. Microfacies of Sachun Formation

Microfacies studies of the Sachun formation samples in Sarvestan section have shown that the Sachun formation has been made mostly from tidal flat and Lagoon facies. Some microfacies of Sachun formation summarized in **Table 3** (**Figure 6**, photos 5, 6 and 8 and **Figure 7**, photo 2).

Depositional Model of Sachun Formation

Field and microfacies studies indicate that sediments of the Sachun formation have been deposited in three facies belts of tidal flat, lagoon and barrier. In the proposed model, D, C, B & A facies are related, respectively, to supratidal, intertidal, shallow-lagoon, and back reef environment with moderate to high energy. The Sabkha environment is a salt bottom, sometimes temporarily covered by shallow water. Microfacies studies of the Sachun formation samples in the studied section indicate that in the initial parts of the Sachun formation, a carbonate platform was deposited, while the majority of its sedimentary environment coincides with the formation of tidal environment (**Figure 12**, photo A).

8. Microfacies of Jahrum Formation

In the studied zone, the Jahrum formation has an outcrop in the Estahban and Sarvestan sections. Microfacies studies of Jahrum formation samples in the sections under study have led to the identification of 13 microfacies, these microfacies summarized in **Table 3**. Some pictures of microfacies of Jahrum formation have been shown in **Figure 6**, photos 4, 5, 9-12 and **Figure 7**, photos 3, 5, 6 and 9.

9. Microfacies of Pabdeh Formation

Having carefully studied the field and microfacies samples, it was found that the identified facies in Pabdeh formation are all related to the deep marine zone, divided into two facies, plagic and re-sedimented calciturbidite limestones. The calciturbidite facies are seen on the ground as if interbedded with plagic facies. These microfacies summarized in **Table 3**. Some pictures of microfacies of Pabdeh formation have been shown in **Figure 13**, photos 1, 4 and 8.

Interpreting & Offering Depositional Model of Jahrum & Pabdeh Formations

The Petrographic and field observation of the Pabdeh and Jahrum formations in the studied zone shows that its sedimentary environment is related to deep marine environment, and its facies includes shale, pelagic limestone and turbidity limestone (re-sedimented) facies group. The case that turbidity and pelagic facies are interbedded and

that the planktonic and benthonic fragments are mixed in turbidity limestones indicate a high rate of sedimentation, creation of turbidity currents, and carbonate slumping from a platform margin with a steep slope and its deposition in the sea depth (**Figure 12**, photos B and C).

Comparison of the microfacies sequences of the stratigraphic columns in the area under study as well as studying the facies of the Pabdeh and Asmari formations demonstrate that the Jahrum formation has been deposited in a carbonate platform of shelf type. Although, the carbonate platform of the Jahrum and Pabdeh shaly formations has been deposited similar in the open marine [8].

10. Microfacies of Asmari Formation

In the studied zone, the Asmari formation has an outcrop in the Estahban, Mook and Shahneshtin sections. Microfacies studies of Asmari formation samples in the sections under study have led to identification of 12 microfacies. Regarding their changes in the stratigraphical column, these facies have been deposited in a carbonate platform, and deposited in four belts of open marine (A), barrier (B), lagoon (C), and tidal flat, (D), some microfacies summarized in **Table 3**. Some pictures of microfacies of Asmari formation have been shown in **Figure 13**, photos 5, 6, 9-12 and **Figure 7**, photos 1, 3, 4, 7 and 8.

Depositional Model of Asmari Formation

According to vertical distribution of the foraminifera, physical sedimentary structures, and facies geometric relations, four depositional subenvironments have been identified for the Asmari formation in the study area in Oligo-Miocene. These four sub environments include tidal flat, lagoon, barrier and the deep open marine. Given the described belts, carbonate ramp sedimentary model is suggested for Asmari formation (**Figure 12**, D).

11. Sequence Stratigraphy of the Study Area

Sequence stratigraphy is the modern knowledge of dividing sediments of a basin to sequences which are between equivalent discontinuities and continuities. Depositional sequence (DS) is the main unit of sequence stratigraphy, the upper and lower limit of which have appeared during one of the main cycles of the rise and fall of the relative sea level. Chronologically, the sequence is equivalent to the third-order sedimentary cycle comprising a large number of small-scale shallowing upward cycles or parasequences.

In general, the discontinuity surface divides younger layers from older ones, which is made up of two types: type 1 discontinuity: when the degree of falling of the sea level is more than the basin subsidence in the continental margin, and type 2 discontinuity: when the rate of falling

Table 3. Summarized microfacies of study area.

Microfacies Analysis, Standard Microfacies, Facies Belt Zone, Flugle, 2004		East of study area										West of study area							
Sub Sedimentary Environment	No	Microfacies	SMF	FZ	Tarbur	CTB	SB1	Sachun	SB1	Jahrum	SB1	Asmari	Lateral Change	Gurpi	CTB	Pabdeh	SB2 (C.C)	Asmari	
																			East of study area
Open Marine	1)	Dark, blue shale/mudstone	1	FZ1						<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>			
	2)	Pelagic foraminifera mudstone	3	FZ1 FZ3						<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>			
	3)	Pelagic foraminifera Wackestone	3	FZ1 FZ3						<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>			
	4)	Pelagic foraminifera Packstone	10	FZ2						<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>			
	5)	Nummulites, Operculina, bioclast packstone	2	FZ2								<input checked="" type="checkbox"/>							
BAR (Reef)	6)	Gloconitic bioclast Packstone	3	FZ1 FZ3	<input checked="" type="checkbox"/>	Disconformity SB1 Microconglomerate/Sandstone/Iron Oxides	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	Correlative Conformity SB2									
	7)	Algal bioclast Grainstone	11	FZ6	<input checked="" type="checkbox"/>	Disconformity SB1	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	Purple Shale SB1									
	8)	Orbitolites bioclast Grainstone	11, 16	FZ6 FZ7 FZ8						<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>	
	9)	Miliolid bioclast Grainstone	11, 16	FZ6 FZ7 FZ8	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>									
	10)	Austrotrilina bioclast Grainstone	11, 16	FZ6 FZ7 FZ8								<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>	
	11)	Intraclast, bioclast Grainstone	11, 16	FZ6 FZ7 FZ8	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>										

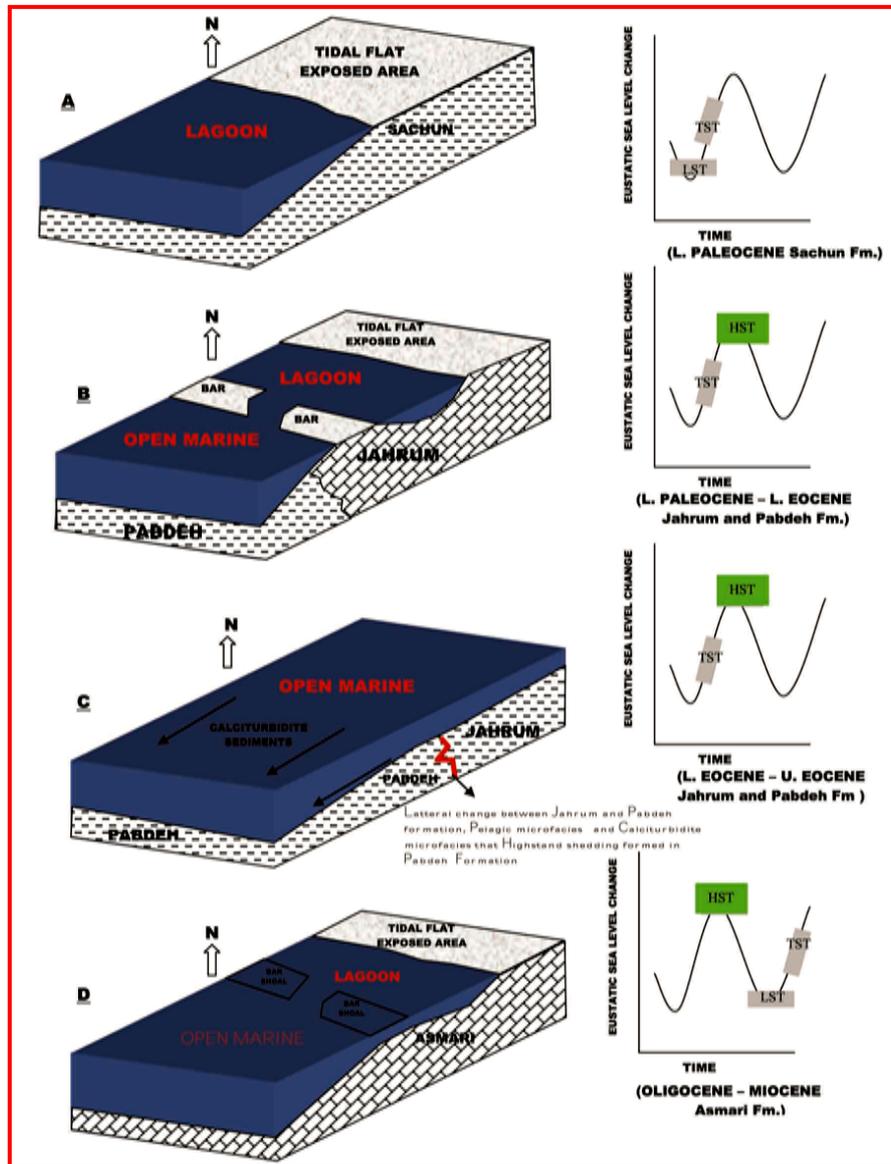


Figure 12. Depositional Model of the Studied Formations according to the Curve of Relative sea level change based on the time. A: Depositional model of Sachun formation during lower Paleocene. B: Depositional model of Jahrum and Pabdeh formation during Lower Paleocene—Lower Eocene. C: Depositional model of Jahrum and Pabdeh formation during Lower Eocene—Upper Eocene. D: Depositional model of Asmari formation during Oligocene.

of the sea level is slow, falling down to the middle part of the continental shelf. Each sedimentary sequence could be divided into the three systems tract, each associated with a specific part of the curve of sea level changes. The lower part of each sequence includes lowstand systems tract (LST), mainly consisting of epicontinental facies. The middle part of each sequence includes transgressive systems tract (TST) formed during seawater transgression, and the upper part of each sequence has also been formed with a systems tract related to the relative static state of seawater or the beginning of the seawater falling stage (Highstand systems tract) (HST). In sequence stratigraphic studies, references including Vail *et al.* (1977)

[9], Van Wagoner *et al.* (1988) [10], Nadjafi *et al.* (2004) [11], Emery and Myers (2005) [12], Schlager *et al.* (2005) [13], Zhang, X. *et al.* (2006) [14], Van Buchem *et al.* (2010) [15], Keller G. (2011) [16], Gang Li. *et al.* (2007, 2010) [17,18], Mirzaee Mahmoodabadi *et al.* (2013) [19, 20], have been used.

The main objective in conducting this research was to study the Tarbur, Gurpi, Sachun, Jahrum, Pabdeh and the Asmari formations with regard to the vertical distribution of various of microfacies, so that sedimentary sequences in different parts of the sedimentary basin could be studied by determining sequences and facies association, and this evidence could be applied to the stratigraphic

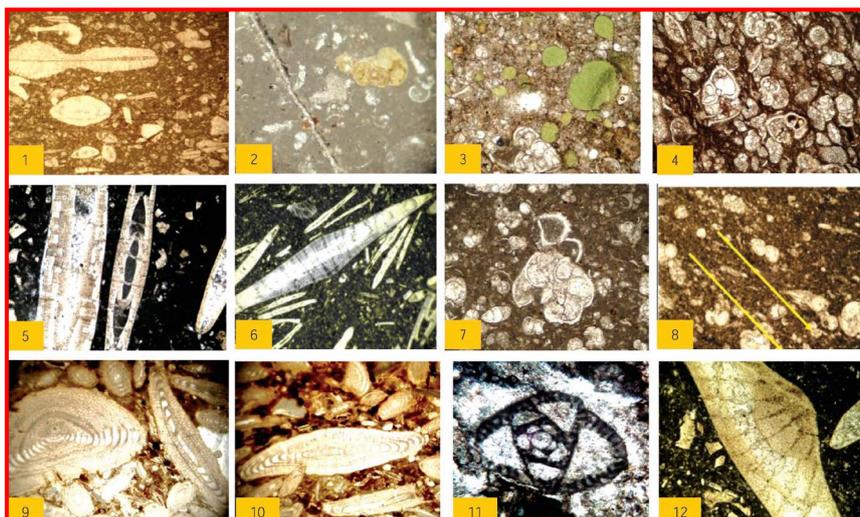


Figure 13. Some microfacies of study area. 1—*Loftusia*, *Omphalocyclos* bioclast packstone, Tarbur formation, Sarvestan section. Real size of *Loftusia persica* is 1 cm. 2 and 3—*Omphalocyclos* bioclast packstone, Tarbur formation, Sarvestan section. Real size of *Omphalocyclos macroporosus* is 0.8 cm. 4—Dolomite wackestone, Sarvestan section, $\times 10$. 5—Saddle dolomite, Sachun formation, Sarvestan section, $\times 10$. 6—Laminated Jypsum and Dolomite, Sachun formation, Sarvestan section. 7—Dolomudstone with fenestral fabric, Sarvestan section. $\times 4$. 8—Thick bedded of laminated Jypsum, Sarvestan section. 9—Algae bioclast grainstone, Jahrum formation, Beyza section, $\times 10$. 10—*Orbitolites* bioclast grainstone, Jahrum formation, (*Orbitolites shirazienensis*, Upper paleocene), $\times 10$. 11—Dolomitized bioclast wackestone, Jahrum formation, Sarvestan section, $\times 10$. 12—*Rotalia* bioclast packstone Jahrum formation, $\times 10$.

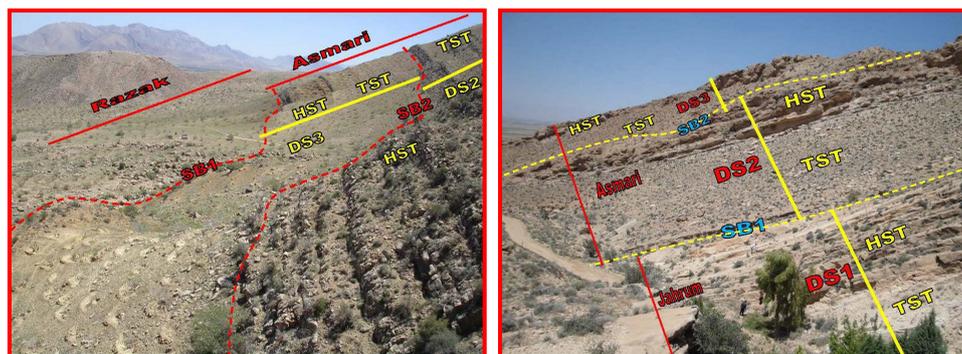


Figure 14. Sequence stratigraphy photo of Sarvestan and Estahban sections.

correlation investigation of the studied formations.

11.1. Sequence Stratigraphy of Estahban Section

The Estahban section with a thickness of 266 m comprises the Sachun, Jahrum and Asmari formations, and with regard to sequence stratigraphy, includes two third-order depositional sequences. As for the small outcrop of Sachun formation in this section, only the sequence stratigraphy of the Jahrum and Asmari formations are investigated. Jahrum formation in the studied section is consisted of a third-order depositional sequence (DS1). Its lower lithostratigraphic boundary is gradational and consistent with Sachun formation and its discontinuity is 2 type (SB2). The TST systems tract of this sequence, having a thickness of 75 m, is comprised of dolomite, dolomite limestones and thin-bedded limestone. HST

facies with a thickness of 105 m is composed of limestone and medium to thick-bedded dolomite limestones. Maximum flooding surface (MFS) is identified with plagic bioclastic wackestone. This systems tract is ended to the first type discontinuity (SB1) under depositional sequence of the Asmari formation. This boundary is distinctive on the land due to having paleosol and red beds. On this boundary the transgression of thin to medium-bedded carbonates of Asmari formations (TST facies) is started, and ends with HST facies of weathered medium to thick bedded ick-bedded limestones under Razak formation.

11.2. Sequence Stratigraphy of Sarvestan Section

The Sarvestan section, with a thickness of 570 m includes Tarbur, Sachun and Jahrum formations. This sec-

tion includes two third-order depositional sequences, of which the second depositional sequence is common between the Sachun and Jahrum formations. Sachun evaporite facies in the Sarvestan section has a thickness of 390 m, mainly consisting of green and red marls which have been interbedded with laminated gypsum, dolomite and dolomitic limestones. The study of vertical variation of microfacies, as well as the study of thin-bedded gypsum, dolomite, limestone, and marl facies in the field have led to the identification of a third-order depositional sequence. The identified sequence itself is comprised of several shallowing-upward sedimentary cycles. The thickness of this sequence is 350 m. (the upper 40 m of the Sachun formation is related to the depositional sequence of Jahrum formation DS2), and its lower boundary (sequence boundary type Two-SB2) is identified by contact with Tarbur formation and Sachun formation. Lowermost age of Sachun formation is determined by the last occurrences of Tarbur foraminifera which is assigned to Mid-Paleocene. TST facies of the concerning sequence is related to the deeper lagoon environment; having a thickness of 140 m, it is composed of dolomite, dolomite bioclastic wackestone, marl, stromatolite, and gypsum-anhydride, and is observed on the land as gray and green marls interbedded with light gray and green dolomite and dolomite limestones. Due to dolomitization, the maximum flooding surface is not recognizable; however, it is not further than the lagoon limit.

The HST facies of the Sachun formation with a thickness of 210 m is composed of red marls interbedded with gypsum, anhydride, dolomitized limestone, and dolomite layers. This sequence includes several shallowing upward parasequences (red and green marl alterations).

The Jahrum formation in the Sarvestan section includes a depositional sequence (DS2), consisting of a number of small-scale or shallowing upward parasequences. TST facies of the second type depositional sequence is marked on the land by gray and green marl facies of the upper part of the Sachun formation. HST facies is more than the systems tract of the lagoon sedimentary environment and is seen as light thin to medium-bedded dolomite and dolomitized limestone. The upper lithostratigraphic limit of the Jahrum sequence marked by erosional with Asmari formation (SB1) and the upper segment of this sequence is eroded or deleted (Figure 1).

11.3. Sequence Stratigraphy of Mook Section

Mook section, with a thickness of 520 m, stratigraphically includes 3 formations: Gurpi, Pabdeh and Asmari. The study of vertical variations of the facies of the Pabdeh and Asmari formations in Mook has resulted in the identification of 3 depositional sequences (third class cycle). The upper and lower boundary of each of these three sequences is continuous (SB2). The first and

second depositional sequence is related to Pabdeh formation and the third depositional sequence is common in the upper parts of the Pabdeh and Asmari formations. The thickness of the first depositional sequence (DS1) of Pabdeh formation is 95 m and its lower boundary is distinguished by the second class boundary in the lower part of purple shale (SB2).

TST facies of the first depositional sequence with a thickness of 35 m has been composed of mudstone/lichen and *Globigerina* and *Globorotalia* Bioclastic wackestone. The maximum flooding surface is identified by thin-bedded dark shale facies. The outcrop of these facies on the ground is shown by the alternation of yellow and gray shallowing upward shale and limy shale. At the relative rest condition of the sea level, HST facies with a thickness of 60m includes alternation of plagic facies and re-sedimented *Nummulites* limestone. The facies observed in this part includes *Globigerina* bioclastic wackestone, *Nummulites* and alveolunid bioclastic packstone, *Globigerina* and *Nummulites* wackestone, *Nummulites*, *Discocyclus* and *Globigerina* bioclastic packstone, algae bioclastic grainstone, intraclastic bioclastic packstone, and pallet and intraclastic bioclastic wackestone, which have been deposited on each other as shallowing upward cycles. Thickness of the second depositional sequence is 295 m, its lower boundary is of type two (SB2) and its upper boundary, which is correlative conformity ends in the lower part of the Asmari formation. The transgression surface is started with shale facies and the maximum flooding surface (MFS) is identified by bioclastic packstone facies with glauconitization in foraminiferal pores (Figure 13, photo 3).

TST facies having a thickness of 85 m have been composed of shale, globigerina bioclastic mudstone, *Globigerina* bioclastic wackestone, and *Globigerina* bioclastic packstone. The outcrop of this facies on the ground includes the alternation of shale and lime shale.

HST facies, the second sedimentary sequence (DS2) with a thickness of 210 m has been formed with an alternation of lime shale and re-deposited limestones. The microfacies of this systems tract includes shale, *Globigerina* bioclastic wackestone, *Nummulites* and *Milliolid* bioclastic wackestone, pellet, intraclastic wackestone, and *Nummulites* and *Discocyclus* bioclastic packstone, and while its outcrop on the ground includes alternation of medium to thick-bedded lime shale and re-sedimented limestones. This systems tract facies, which is correlative conformity, ends below the Asmari formation. Syndepositional fault operation causes different morphology in the carbonate platform and change in the manner and type of deposition. The final result of this process could cause different sequences in the Pabdeh formation.

The thickness of the third depositional sequence is 130 m; the upper limit of the Pabdeh formation with a thick-

ness of 70 m forms the TST facies. This systems tract facies has been composed of open sea facies including shale, marl, and lime shale. The maximum flooding surface is identified by *Globigerina* and *Globorotalia* bioclastic mudstone. HST facies having a thickness of 60 m include the Asmari formation and is composed of lime shale and medium to thick-bedded weathered limestones. The upper limits of the third sequence have been eliminated and ended by the erosive boundary with the Razak formation (Figure 15).

11.4. Sequence Stratigraphy of Shahneshin Section

The Shahneshin section, with a thickness of 600 m includes the 3 formations of Gurpi, Pabdeh and Asmari. With regards to sequence stratigraphy, it is comprised of a third-order depositional sequence. The boundary of all sequences is of type two, and the third depositional sequence is common in the upper sections of the Pabdeh and Asmari formations.

The thickness of the first sedimentary sequence in the Shahneshin section is 150 m, as in the Mook section, its lower boundary is identified by purple shale from the Gurpi formation. TST facies of this sequence with a thickness of 62 m is transgressive and includes mudstone/lichen and also *Globigerina* and *Globorotalia* bioclastic wackestone. In this systems tract, the maximum flooding surface is identified by glauconitic bioclastic packstone. This facies is seen as the alternation of yellow and gray shallowing upward shale and lime shale. In the relative static state of seawater, HST facies having a thickness of 78 m includes the alternation of plagic facies and *Nummulites* re-sedimented limestones. The facies observed in this section include pelagic bioclastic wackestone, benthic bioclastic packstone, benthic bioclastic wackestone, *Nummulites*, *Discocyclus*, and *Globigerina* bioclastic packstone, algae bioclastic grainstone, intraclastic bioclastic packstone, and the pellet and intraclastic bioclast wackestone have been deposited on each other as shallowing upward cycles.

The thickness of the second depositional sequence is 120 m, and its upper and lower boundaries are of type 2 (SB2). TST facies with a thickness of 50 m includes shale, *Globigerina* bioclastic mudstone, *Globigerina* bioclastic wackestone, and *Globigerina* bioclastic wackestone. The outcrop of this facies on the ground is as the alternation of shale and lime shale.

The transgression surface is begins with shale facies and the maximum flooding surface (MFS) is identified by bioclastic packstone facies with glauconitization in foraminiferal chambers.

HST facies, the second depositional sequence (DS2) with a thickness of 70 m includes the alternation of lime shale and re-sedimented limestones. The microfacies of

this systems tract includes shale, *Globigerina* bioclastic wackestone, milliolide *Nummulites* bioclastic wackestone, intraclastic and pallet bioclastic wackestone, and *Discocyclus* and *Nummulites* bioclastic packstone, and its outcrop on the field observation is in the alternation of medium to thick-bedded lime and re-sedimented limestones. This facies, which is correlative conformity, ends below the Asmari formation.

The thickness of the third depositional sequence is 330 m, and the upper part of the Pabdeh formation, having a thickness of 150 m includes the TST facies. This facies has been made from open sea facies including shale, marl and lime shale. The maximum flooding surface is identified by *Globorotalia* and *Globigerina* bioclastic mudstone. HST facies 180 m thick includes the Asmari formation and has been composed of lime shale and weathered medium to thick-bedded limestones. The high rate of carbonate production in the platform when the sea level was high, led to the transport of carbonate deposits from the shallow carbonate platform to the deep sea in both the Shahneshin and Mook sections.

The existence of benthonic bioclasts and the mixture of benthonic environment and platform facies indicate a highstand shedding and carbonate slumping from the platform margin with a steep slope and its deposition in the deep marine. The mentioned facies have been deposited in the deep basin and contact the carbonate platform of the Jahrum formation (Figure 15).

12. Investigating the Stratigraphic Correlation of the Studied Formations Based on Sequence Stratigraphic Evidences

In the Paleogene period in the southwest of the basin, 3 third-order depositional sequences including the Pabdeh and Asmari formations have been identified. The identified sequences have a gradual facies change as we move to the center and east of the basin and turn towards the latform facies of the Sachun, Jahrum and Asmari formations.

In order to investigate stratigraphic correlation of the studied formations, the continuous contact between the Gurpi and Pabdeh formations (sequence boundary of type 2-SB2) has been considered as the datum line for correlation.

As we proceed to the east of the studied sedimentary basin, this boundary is turned to the boundary of the second type between the Sachun and Jahrum formations. Also, the discontinuous boundary of type 1 (SB1) between the Jahrum and Asmari formations is turned to drowning discontinuous correlative conformity (C.C.) in the deep basin between the Pabdeh and Asmari formations as we approach the west and southwest of the basin.

According to the identified sequences in the studied

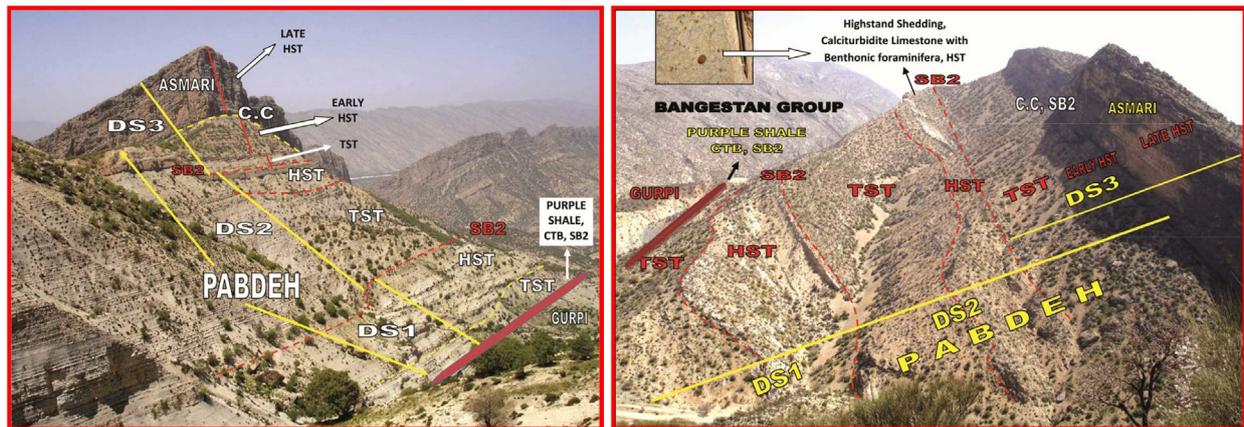


Figure 15. Sequence stratigraphy photo of Shahneshtin (left) and Mook (right) sections.

sections, the purple shale section could be equalized with the Sachun formation in the east of the basin, so that during sedimentation of the green shale and marls of the Sachun formation (TST facies) in the deep basin, the drowning discontinuous contact (C.C.) or the purple shale section has been deposited.

During Oligo-Miocene, the platform sedimentary environment included almost the entire area, so that the Asmari formation has been deposited with discontinuous contact on the Jahrum formation in the east of the basin and with correlative conformity (C.C.) on the Pabdeh formation in the west and southwest area. The sediments between these two boundaries include 3 depositional sequences in which the mentioned formations could be conformed according to the systems tract and boundaries as shown in Figure 16.

13. Conclusions

Field and laboratory study in 4 sections in study area recognized 25 facies such as carbonate, evaporate and clastic facies.

In the west of study area CTB recognized with purple shale (SB2) and in the east of study area this contact was investigated by clastic facies (SB1).

Based on microfacies study, sedimentary environments models and sequence stratigraphy evidences 3 depositional model based on relative sea level change are presented during CTB time in study area.

The sequence stratigraphy of study area on Tarbur, Gurpi, Sachun, Jahrum, Pabdeh and Asmari formations in 4 sections indicated 4 depositional sequences in the third order.

The sequence stratigraphic study of the Sachun formation in the Sarvestan section indicates that the major part of this formation is related to depositional sequence of type 1, the lower contact of which is SB1 with the Tarbur formation, but its upper contact is continuous with green marl of the mentioned formation (SB2). The TST facies

has been composed of green marl interbedded with dolomite and dolomite limestones, and the HST facies include shallowing upward parasequences comprised of red marl interbedded with gypsum.

The sequence stratigraphic study of the Sachun and Jahrum formations has resulted in the identification of 3 depositional sequences. The second depositional sequence is common between the Jahrum and Sachun formations. The TST facies of this sequence includes lagoon facies and the maximum flooding surface is identified by plagic bioclastic wackestone. The HST facies include the alternation of the lagoon environment, barrier, and tidal flat facies.

Sachun, Jahrum and Asmari formations in East of study area include 4 depositional sequences.

Pabdeh and Asmari formations in the Mook and Shahneshtin sections include 3 depositional sequences in which the third depositional sequence is common between the Pabdeh and Asmari formations. They only include TST, HST facies, which are composed of shallowing upward parasequences. TST facies mostly includes alternation of lichen and thin-bedded lime shale, while the HST facies is composed of lime shale, shale and re-sedimented limestones.

The continuous contact between the Gurpi and Pabdeh formations (the second type sequence basin, SB2) has been considered as the baseline for correlation. As we proceed to the east of the sedimentary basin, this boundary then becomes the boundary of the second type between the Sachun and Jahrum formations. Also, the discontinuous boundary of type 1 (SB1) between the Jahrum and Asmari formations is turned to drowning correlative conformity contact (C.C.) in the deep basin between the Pabdeh and Asmari formations as we approach the west and southwest of the basin.

The stratigraphic correlation studies indicate that the purple shale section has been deposited equivalently to the upper part of the Sachun formation.

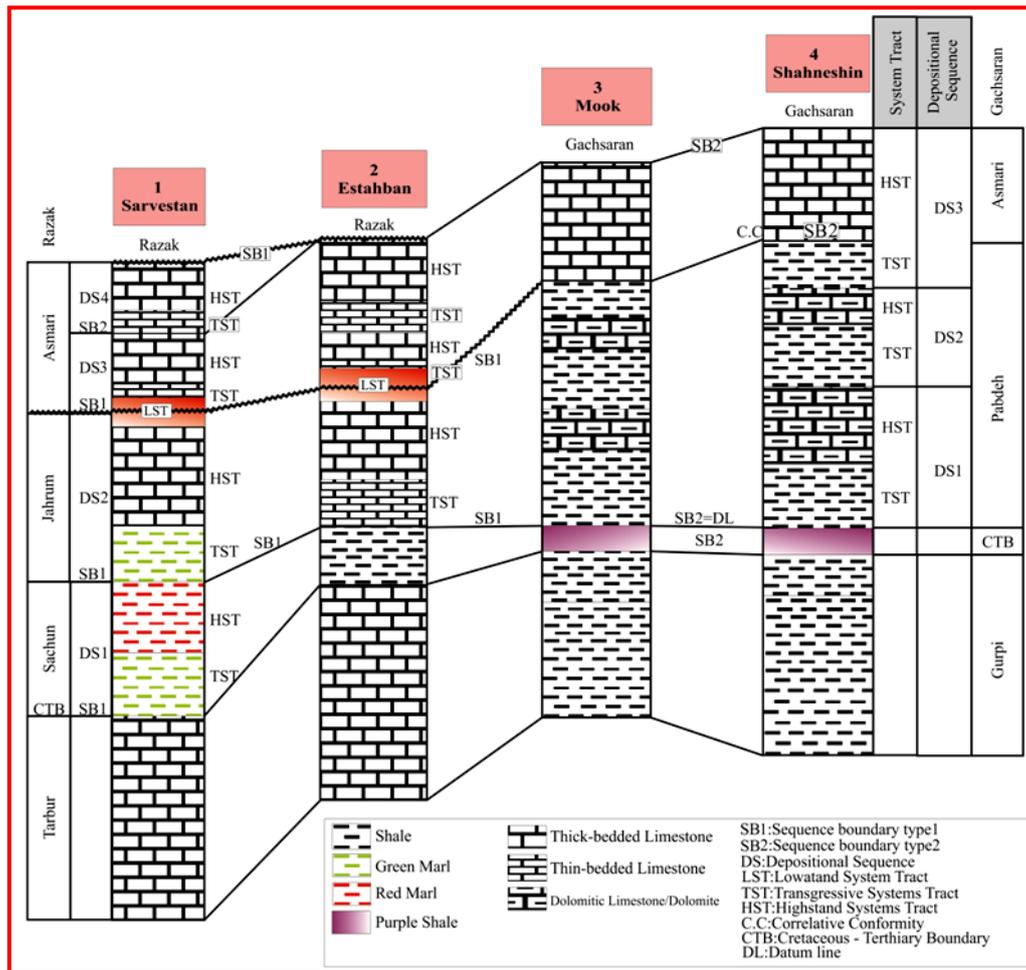


Figure 16. Stratigraphic correlation of the studied sections based on sequence stratigraphic evidences.

During Oligo-Miocene, the platform sedimentary environment included almost the entire area, so that the Asmari formation has been deposited with discontinuous contact on the Jahrum formation in the east of the basin (Estahban and Sarvestan sections) and with correlative conformity (C.C.) on the Pabdeh formation in the west and southwest area.

The conducted studies show that the facies of the Sachun formation in the zone that was studied has changed from evaporite-marl facies to marl, limestone, dolomite limestone, and purple shale in gradation manner as we go to the west.

Acknowledgements

This study is supported with research project of Islamic Azad University Estahban Branch, Estahban, Iran and the Author appreciates for providing the financial support.

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