

# Stratigraphy of Oligocene–Miocene salt deposits in the SE Persian Gulf

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**Abstract** The purpose of this study is lithostratigraphic investigation of Oligocene–Miocene salt deposits in the SE Persian Gulf. This study is based on lithostratigraphy and biostratigraphy data, gamma ray and sonic logs of nine drilled wells along southeast Persian Gulf to Strait of Hormuz. As a result, the Oligocene–Miocene deposits of this region were subdivided into four formations (Fms) which include Pabdeh Fm (Rupelian– Chattian), Asmari Fm (Rupelian– Aquitanian), Gachsaran Fm (Aquitanian) and Mishan Fm (Burdigalian). The salt and evaporated deposits situated between the Pabdeh and Gachsaran Fms which are assigned to the Aquitanian age. Finally the stratigraphical setting and distribution of the salt deposits are cleared.

**Keywords** Lithostratigraphy · Oligocene · Miocene · Persian Gulf · Iran

## Introduction

The Paleogene Sea in Iran that is related to remnant of Neo-Tethys great sea is widespread in Zagros basin. The Zagros basin was part of the stable supercontinent of Gondwana in Paleozoic times, a passive margin in Mesozoic times, and became a convergent orogeny in Cenozoic times (Bahroudi and Koyi Hemin 2004) (Fig. 1). Orogeny activities accrued in late Eocene time caused by extensive regressive Paleogene Sea. Early Oligocene Sea has progressively drowned some areas such as in Southeast Lurestan, Khozestan and interior Fars province. So, pelagic sediments, corresponding to Pabdeh Fm are deposited. The Asmari carbonate succession was precipitating steadily throughout Oligocene to Miocene. Thus, Early Miocene sediments in Zagros basin mainly comprise Asmari limestone. During the Neogene period at the end of early Miocene with further regression of sea, shallow and lagoon environment dominated and accumulated 1000 m of evaporation, sandstone and claystone sediments in Khozestan and Lurestan regions. These deposits are called Fars Group which encompasses Gachsaran, Mishan and Aghajari Fms and lies continually in the Asmari Fm. This group is widespread throughout the Zagros basin. The Gachsaran Fm in interior Fars turns into shale and marl units that are called Razak Fm. The Mishan Fm broadens in Khozestan area as well as interior and coastal Fars which laterally turns into clastic deposits of Aghajari Fm in Fars and Khozestan Regions (Fig. 2). The area of this study is a part of the southeast extremity of Zagros basin. The eastern border is limited to Minab fault, in the southern border of rest of Zagros simple folds zone, that passes within into the Persian Gulf and northern border is coincidental to Razak fault (Aghanabati 2004) or Nakhilu–Finu fault (Fig. 3). As already mentioned, the Paleogene Sea is well developed in

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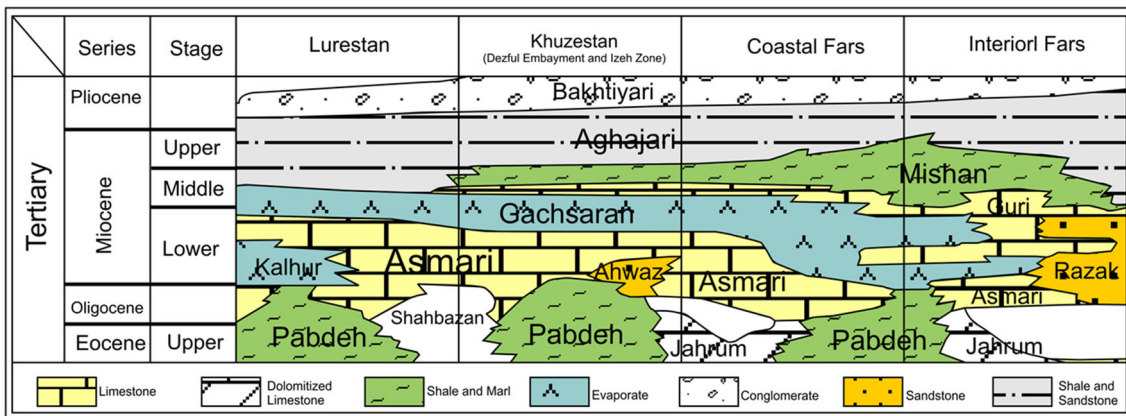
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**Fig. 1** Map of Middle East showing location of Zagros basin (Moghaddam et al. 2013)



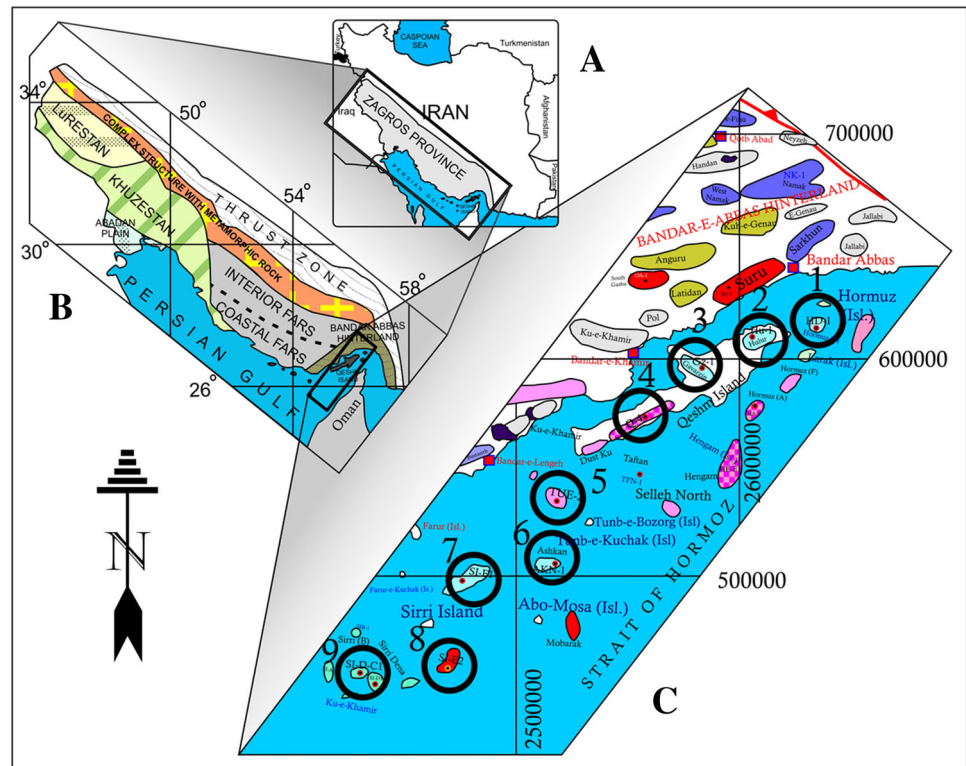
**Fig. 2** Cenozoic stratigraphic correlation chart of the Iranian sector of the Zagros basin, adopted from (James and Wynd 1965)

the Zagros Basin that is the result of the opening and closure of the Neo-Tethys Ocean along the northeastern border of the Arabian plate. The Oligocene–early Miocene (Rupelian to Burdigalian) age has been determined for the unit based mainly on foraminiferal zones and strontium isotope stratigraphy (Lees 1933; Thomas 1950; Wynd 1965; James and Wynd 1965; Adams and Bourgeois 1967; Ehrenberg et al. 2007). Despite of many geological studies in and around hydrocarbon fields in the Zagros basin and this region, there are few detail reports of the lithostratigraphy of Oligocene to Miocene times in the study area and have not been separated and denominated.

**Materials and methods**

This research is based on results derived from nine hydrocarbon fields at southern Bandar Abbas Hinterland, eastern Persian Gulf close to the Hormuz, Qeshm and Sirri islands. Each interval is measured and logged. A total of 2860 thin sections of the cores and cuttings are analysed and studied for description of lithostratigraphy characteristics. Based on the distribution of the foraminifera, the samples range consists of uppermost part of the Pabdeh Fm, Asmari Fm, Gachsaran Fm and the lowest part of the Mishan Fm. Most samples contain well-preserved and

**Fig. 3** a General map of Iran showing the Zagros zone b Structural of Zagros basin (Aghanabati 2004) c Location map of the studied transect modified after (Report of 1/100000 Bandar Abbas map, 2006)



abundant planktonic and larger benthic foraminifera. Biostratigraphy are determined by (2014) which are based on the well-known benthic and planktonic biozonation of foraminifera.

### Geological setting

Hormozgan province is located in southern Iran and is part of Zagros Folded belt (Fig. 1). This region is accompanied by NW–SE, W–E and N–S trending simple anticlines and synclines with very great thickness of Fars Group deposits (Gachsaran, Mishan, Aghajari and Bakhtiari Fms) and presence of 118 salt plugs. So, for these specific features, Motiei (1993) called this area as the “Bandar Abbas Hinterland”. The studied area is in Southern Bandar Abbas Hinterland where the Strait of Hormuz is located (Fig. 3). As there is not any complete outcrop of Fars group in this region, most of study is subsurface. To study the lithostratigraphy, a transection has been selected along a line NE to SW of Persian Gulf length 293.6 km (Fig. 6). There are nine wells along the selected section which are from east to west, respectively consisting of Hormuz, Qeshm and Sirri islands fields.

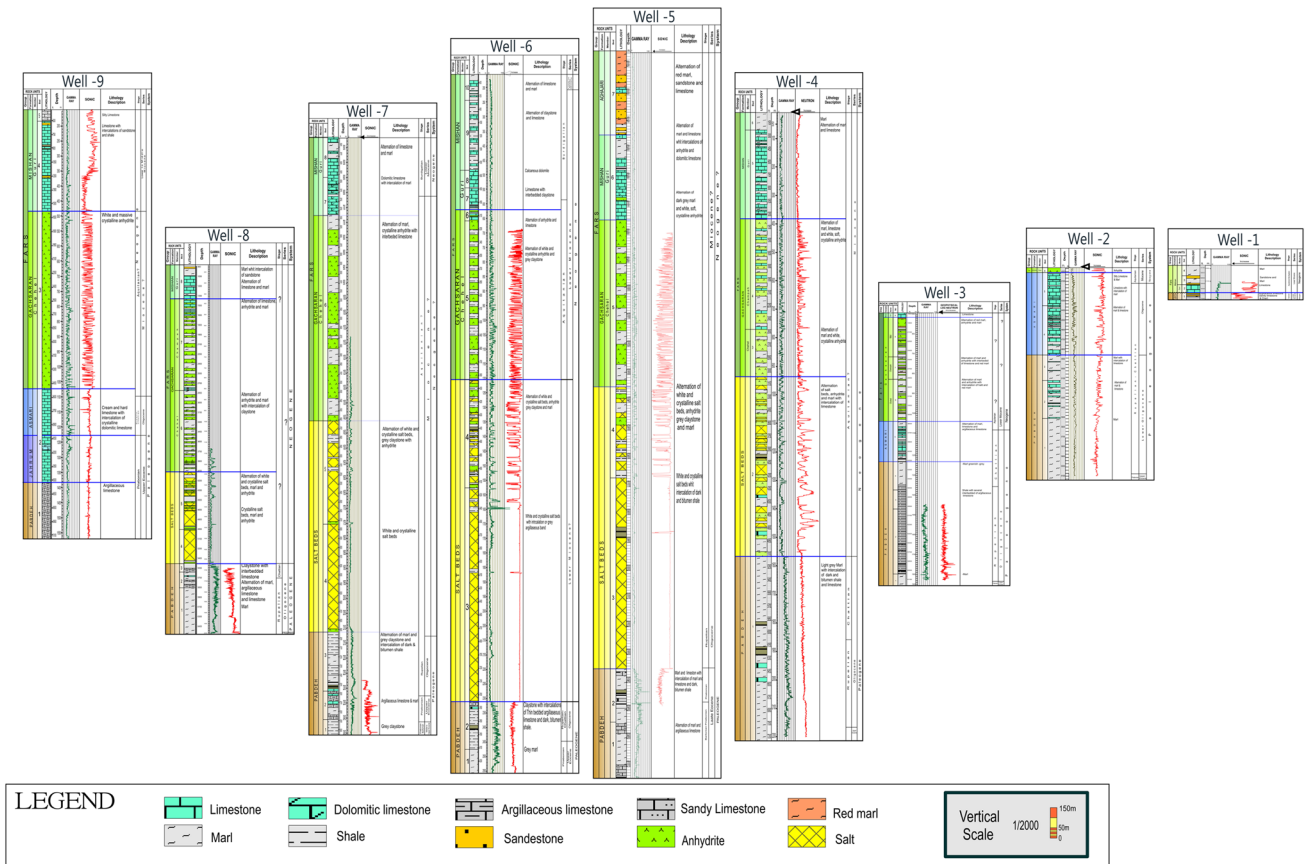
### Results

The focus of this study is the analysis of stratigraphy of Oligocene–Miocene deposits in the study area, so the Oligocene–Miocene biostratigraphy is only discussed in brief here. According to newest and the most well-known biozonation of foraminifera, 10 biozones have been recognized by studying of thin sections of the wells. The results of this comparison are as follows: two biozones were equivalent to Iaccarino and Premoli Silva (2005), two biozones were equivalent to Bolli (1957), four biozones were adapted to Wynd (1965), two biozones were adapted to Adamz and Bourgeois (1967). Based on the biostratigraphical data and biozonation, the boundaries of Oligocene–Miocene and age of deposits were identified. These biozones are in the ascending stratigraphic order as below and help separate the Fms (Fig. 4).

### Biozonation

*Cassigerina chiploensis*–*Pseudohastigerina micra*  
concurrent range zone

Estimated age: Rupelian (based on Iaccarino SM Premoli Silva 2005)



**Fig. 4** Lithostratigraphy columns of nine wells, lithology description, gamma ray, sonic logs and biozonation

*Turborotalia ampliapertura interval zone*

Estimated age: Rupelian (based on Bolli 1957)

*Paragloborotalia opima opima taxon range zone*

Estimated age: Rupelian (based on Bolli 1957)

*Globoturborotalia ciproensis Interval Range Zone*

Estimated age: Chattian (based on Iaccarino SM Premoli Silva 2005)

*Eulepidina-Nephrolepidina-Nummulites assemblage zone*

Estimated age: Oligocene (based on Adams and Bourgeois 1967)

*Miogypsinoides-Archaias-Valvulinid sp. 1 assemblage zone*

Estimated age: Early Miocene (based on Adams and Bourgeois 1967)

*Globigerina spp. assemblage zone*

Estimated age: Oligocene (based on Wynd 1965)

*Nummulites intermedius-Nummulites vascus assemblage zone*

Estimated age: Oligocene (based on Wynd 1965)

*Borelis melo curdica zone*

Estimated age: Early Miocene (based on Wynd 1965)

*Mishan formation biofacies*

Estimated age: Early Miocene (based on Wynd 1965)

**Stratigraphy and lithology description**

In this part, based on gamma ray and sonic logs as well as the study of thin sections of cores and cuttings, lithology columns of nine wells are described. Based on biostratigraphy and lithological evidence, there are four Fms in Oligocene–



**Table 1** Results of stratigraphical description of nine wells in Pabdeh Fm and age determination based on this study

Oligocene deposits	Intervals	Lithology description	Upper contact	Lower contact	Total thickness	Age
Pabdeh formation	Well 1	Pabdeh formation consists of cherty and sandy limestone	Asmari Fm to a depth of 2130 m with unconformity	It is studied to a depth of 2152 m	22 m	Lower Eocene (Ypresian)
	Well 2	Consists of marl, limestone and alternation of marl and argillaceous limestone	Overlies by Asmari Fm gradually	Lies on the Pabdeh Fm gradational	404.86 m	Oligocene
	Well 3	Contains of 72.5 m marl, 445 m shale with thin layers of limestone and 165 m marl	Overlies by Asmari Fm gradually	Lies on the Pabdeh Fm gradational	682.5 m	Oligocene
	Well 4	Mainly comprises marl, with thin layers of black and bitumen shale which can be followed across transect	Overlies by salty beds gradually	Lies on the Pabdeh Fm gradational	493 m	Oligocene
	Well 5	Mainly comprises grey to brown marl, grey shale, soft limestone and chalk with thin layers of black and bitumen shale which can be followed along transect	Overlies by salty beds gradually	Lies on the Pabdeh Fm gradational	192 m	Oligocene
	Well 6	Mainly comprises grey shale with thin layers of limestone and argillaceous limestone. There is black and bitumen shale band which can be followed along transect	Overlies by salty beds gradually	Lies on the Pabdeh Fm gradational	143.5 m	Oligocene
	Well 7	8 m marl, 60 argillaceous limestone and limestone, 15 m with black and bitumen shale, 100 m alternation of marl and shale and 80 m grey shale	Overlies by salty beds gradually	Lies on the Pabdeh Fm gradational	256.4 m	Oligocene
	Well 8	15-m argillaceous limestone, 52 m alternation of marl and grey argillaceous limestone, a thin layer of limestone, 29.5 m alternation of light shale and argillaceous limestone	Overlies by salty beds gradually	Lies on the Eocene deposits of Pabdeh Fm gradational	102 m	Oligocene

Miocene deposits, which are divided by stratigraphic order into Pabdeh Fm, Asmari Fm, Gachsaran Fm and Mishan Fm. These Fms are studied separately in each well as shown in Fig. 4. Based on these observations, these intervals are described below and shown in Tables 1, 2, 3, 4.

## Discussion

### Description of Oligocene–Miocene type sections in the Zagros province

#### *Pabdeh formation*

The type section of this Fm is located at the Tang-e-Pabdeh on the southeastern end of Kuh-e-pabdeh. 2620 feet of low weathering grey shales and thin argillaceous limestones were measured. Two informal members are differentiated: the purple shale member at the base and grey shale with argillaceous limestone at the top. The age of this Fm in Fars and Khuzestan is from Paleocene to Oligocene and in Lurestan area is from the upper Paleocene to Miocene (James and Wynd 1965) (Fig. 2). In the present study, Pabdeh Fm encompasses abundant *Globigerina* deep-marine hemipelagic–pelagic calcareous shale, marl and lime-mudstone with subordinate argillaceous limestone which is turn into Jahrum carbonates in the southwestern section. The summary of this Fm is mentioned in each well (Table 1).

#### *Asmari formation*

The type section of the Asmari Fm was measured first in the Tang-e-Gele Torsh, Khuzestan province (Richardson 1924). It consists of 314 m of limestones, dolomitic limestones and argillaceous limestones at the type locality (Thomas 1950). Some anhydrite (Kalhur Member), lithic and limy sandstones (Ahwaz Member) also have occurred within the Asmari Fm (Motiei Motiei 1993) (Fig. 2). It lies conformably on the deeper facies of the Pabdeh Fm (Paleocene–Oligocene). The upper contact of the Asmari Fm is marked by a sharp boundary and unconformity with the Gachsaran Fm in most places. Based on biostratigraphy, this Fm is divided into three units: (1) lower Asmari (Oligocene age), (2) middle Asmari (Aquitanian age) and (3) upper Asmari (Burdigalian age) (Thomas 1948). Although recent reassessment of the age was suggested as Oligocene to lowermost Miocene (early Aquitanian) age for Asmari Fm (Laursen et al. 2006), new data in Khuzestan and Lurestan provinces is suggesting late Oligocene (Chattian) to early Miocene (Burdigalian) (Sahraeyan et al. 2013). Coralline red algae and large benthic foraminifera (*Nummulites*, *Operculina*, *Lepidocyclina*, *Archaias*, *Peneroplis* and *Dendritina*) are the most significant and dominant biota in the Asmari Fm

**Table 2** Results of stratigraphical description of nine wells in Asmari Fm and age determination based on this study

Asmari formation	Intervals	Lithology description	Upper contact	Lower contact	Total thickness	Age
Asmari formation	Well 1	Consists of limestone with intercalations of dolomitic limestone and argillaceous sandstone	It is studied to a depth of 2103	Lies on the Pabdeh/Jahrum Fm with angular unconformity (2130 m)	27 m	Lower Miocene (Aquitana–burdigalian)
	Well 2	Mainly comprise alternation of limestone, argillaceous limestone and marl	Overties by Gachsaran Fm gradually	Lies conformably on the deeper facies of the Pabdeh Fm	230.14 m	Oligocene to lower Miocene (Rupelian to Aquitanaian)
	Well 3	Mainly comprise alternation of limestone, argillaceous limestone and marl	Overties by Gachsaran Fm gradually	Lies conformably on the deeper facies of the Pabdeh Fm	149.5 m	
	Well 4	Asmari formation equivalent (Salt deposits) Mainly consists of crystalline white salt with alternation of marl and anhydrite	Overties by Gachsaran Fm gradually	Lies conformably on the deeper facies of the Pabdeh Fm	629 m	Upper Oligocene to lower Miocene (Chatian–Aquitanaian)
	Well 5	B Upper part comprises crystalline white salt with intercalations of grey calcareous claystone and white anhydrite	Overties by Gachsaran Fm gradually	Lies conformably on the deeper facies of the Pabdeh Fm	1006 m	
	Well 6		Overties by Gachsaran Fm gradually	Lies conformably on the deeper facies of the Pabdeh Fm	1041.5 m	
	Well 7	A Lower part mainly consists of massive, crystalline and white salt with thin band of black and bitumen shale at the top end	Overties by Gachsaran Fm gradually	Lies conformably on the deeper facies of the Pabdeh Fm	713 m	
	Well 8		Overties by Gachsaran Fm gradually	Lies conformably on the deeper facies of the Pabdeh Fm	421 m	
	Well 9	The sedimentary strata which encompasses this zone mainly consists of limestone with intercalation of crystalline dolomite	Overties by Gachsaran Fm gradually	Lies conformably on the Jahrum Fm	590.71 m	Oligocene

**Table 3** Results of stratigraphical description of nine wells in Gachsaran Fm and age determination based on this study

Miocene deposits	Intervals	Lithology description	Upper contact	Lower contact	Total thickness	Age
Gachsaran formation	Well 2	The sedimentary strata which encompasses this zone mainly consists of anhydrite and gypsum	It is studied to a depth of 1210	Lies conformably on the Asmari Fm	The studied thickness is 18 m	Lower Miocene (Aquitanian)
	Well 3	The sedimentary strata which encompasses this zone mainly consists of anhydrite and gypsum	It is studied to a depth of 1070	Lies conformably on the Asmari Fm	The studied thickness is 22.9 m	Lower Miocene (Aquitanian)
	Well 4	Mainly comprises alternation of marl and crystalline, white anhydrite	Overlies conformably and sharp by Mishan carbonates	Lies conformably on the salt deposits	556 m	Lower Miocene (Aquitanian)
	Well 5	Mainly comprises alternation of marl and crystalline, white anhydrite	Overlies conformably and sharp by Mishan carbonates	Lies conformably on the salt deposits	598 m	Lower Miocene
	Well 6	Mainly comprises alternation of marl and crystalline, white anhydrite	Overlies conformably and sharp by Mishan carbonates	Lies conformably on the salt deposits	643 m	Lower Miocene
	Well 7	Mainly comprises alternation of marl and crystalline, white anhydrite	Overlies conformably and sharp by Mishan carbonates	Lies conformably on the salt deposits	688.17 m	Lower Miocene (Aquitanian)
	Well 8	Comprises alternation of marl and crystalline, white anhydrite with thin layer of shale	It is studied to a depth of 1150	Lies conformably on the salt deposits	The studied thickness is 100 m	Lower Miocene
	Well 9	Comprises white and massive crystalline anhydrite	Overlies conformably and sharp by Mishan carbonates	Lies on the Gachsaran Fm conformably and sharp	590.71 m	Lower Miocene

**Table 4** Results of stratigraphical description of nine wells in Mishan Fm and age determination based on this study

Miocene deposits	Intervals	Lithology description	Upper contact	Lower contact	Total Thickness	Age
Mishan formation	Well 4	B Upper part mainly comprises grey and green marl	Land level	Lies on the Guri member conformably	71 m	Lower Miocene (Burdigalian)
	Well 5	A Guri member: white to grey limestone with intercalations of grey claystone	Overlies conformably by Mishan marls	Lies on the Gs. Fm. conformably and sharp	106 m	Lower Miocene
		B Upper part mainly comprises grey and green marl	Overlies gradational by Aghajari Fm.	Lies on the Mishan Fm. gradational	70 m	
	Well 6	A Guri member: white to grey limestone and dolomitic limestone	Overlies conformably by Mishan marls	Lies on the Gachsaran Fm. conformably and sharp	219 m	Lower Miocene
		B Upper part mainly comprises grey claystone to argillaceous limestone and green marl	Overlies gradational by Aghajari Fm.	Lies on the Mishan Fm. gradational	310 m	
	Well 7	A Guri member: purulent white limestone and dolomitic limestone with intercalations of grey claystone	Overlies conformably by Mishan marls	Lies on the Gachsaran Fm. conformably and sharp	142 m	Lower Miocene (Burdigalian)
		Comprises limestone and dolomitic limestone with thin layer of claystone and evaporation	It is studied to a depth of 469.39 m	Lies on the Gachsaran Fm. conformably and sharp	250.61 m	
	Well 9	Mainly comprises limestone with intercalations of sandstone and shale	It is studied to a depth of 145 m	Lies on the Gs. Fm. conformably and sharp	338.41 m	Lower Miocene

at the study area. The summary of this Fm is mentioned in each well (Table 2).

#### *Gachsaran formation*

The type section is a composite of intervals compiled by Watson from wells of the Gachsaran oil field (Watson 1960). However, in the oil fields area the Gachsaran Fm has been divided into seven informal members (James and Wynd 1965) and in the Fars province is differentiated into three members: the Chehel (limestone and dolomite), Champeh (anhydrite) and Mol (red marl and anhydritic limestone) members (James and Wynd 1965; Motiei 1993). The base of the Fars group is diachronous along the foreland basin and becomes younger with evaporate increases northwestward (Gill and Ala 1972). This Fm conformably overlies the upper Oligocene–lower Miocene Asmari limestone and is underlain by the middle Miocene Mishan Fm (Fig. 2). Variation in thickness of these members has been attributed to the activity of many salt structures of Hormuz series in the Fars province. The proportion of salt and anhydrite generally increases northwestward along the foreland basin. The thickness of the Gachsaran Fm usually varies over short distances (Bahroudi and Koyi Hemin 2004) typically from several hundred up to 2000 in metres (Edgell 1996; James and Wynd 1965; Stöcklin 1968). This Fm is one of the most important seals for hydrocarbon reservoirs (especially in the Asmari limestone) in one of the richest habitats for hydrocarbon in the world (Bahroudi and Koyi Hemin 2004). Gachsaran Fm was deposited in very shallow lagoonal and subkha environments in arid conditions. The regional aspect of this Fm has been determined throughout the studied transect (Fig. 6) and based on the stratigraphic setting, is assigned to the Aquitanian age (Table 3).

#### *Mishan formation*

The Mishan Fm is previously called middle Fars. Its usage is also extended into Fars province, thus replacing the names argillaceous group and Anguru Marl. The type section was measured along the golden staircase road on the southwestern flank Gachsaran oil field approximately 710 m of Mishan is present (James and Wynd 1965). From the lithological point of view, it is differentiated into two parts. The lower part comprises Guri Limestone Member which previously has been called *Operculina* limestone and overlies conformably and sharp by deposits of Mishan grey marls in the upper part. The sharp basal contact with gypsum of the Gachsaran Fm is accompanied by minor amount of ferruginous staining and is underlain by the Aghajari Fm gradational (Fig. 2). Based on regional aspects, Mishan Fm is sandier from the type section

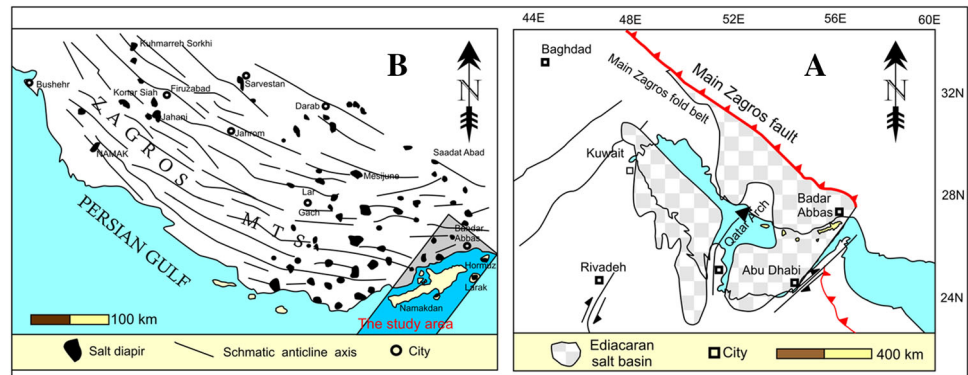
towards northeast Zagros basin, while the sedimentary strata which encompasses this zone mainly consists of silty facies in interior Fars and Bandar Abbas regions (Aghanabati 2004). Biostratigraphic zonation based on the larger foraminifera suggested the early to middle Miocene age for this rock unit (Wynd 1965) (Fig. 2). The summary of this Fm is mentioned in each well (Table 4).

#### **History, structure and distribution of Hormuz salt**

In addition to the rock salt, other salts such as gypsum, potassium and magnesium salts on evaporation can be converted into diapir with or without halite under certain conditions. Some sediments including shale and clays can form diapir under high pressure such as in Niger River delta in Africa (Arian 2011a, b). The Hormuz salt accumulated on crystalline Panafrican basement which was deposited during upper Precambrian (Vendian) to middle Cambrian times in extensive evaporation basins (Kent 1970). Talbot and Alavi (1996) used lithofacies to subdivide the Hormuz series into two sequences: (1) The Vendian Hormuz sequence, which is cyclic and consists of multicoloured alternating beds of carbonate, anhydrite and halite deposited in shallow brines that are controlled by NW–SE faults (Talbot et al. 2009). (2) By contrast, the Hormuz salt with middle Cambrian trilobites assemblages (Kent 1979) is comparatively clean and uniform over thicknesses of hundreds of metres, but includes both mafic and silicic volcanic rocks that were probably erupted along N–S faults (Talbot et al. 2009). The chemical compositions vary and consist of three members: evaporite minerals (gypsum and anhydrite), carbonates (dolomite and calcite) and silicates–oxides (mostly quartz, phyllosilicates and hematite). Halite is mostly leached out from surficial deposits even in arid climates (Bruthans et al. 2009). The rock salt consisted mainly of halite as well as secondary halite deposits in Hormuz Fm which are usually found in an evaporate rock salt environment. Some of these forms are evidence of the paleo-water surface level. According to Filippi et al. (2011) water level changes and determination the position of the paleo-water surface level used to distinguish by dating these forms of halite in geological deposits. Hormuz Fm is the most important source salt structure in Zagros basin and its geographical aspect is recognized in four regions with a north–south trend (i.e. Kazerun in west Fars, east Fars, southern Persian Gulf, Oman–Dhofar) (Arian 2011a, b) (Fig. 5). The extent of salt exposures is an important factor in the morphological evolution of salt diapirs as it can inhibit the further expansion of diapir (Bruthans et al. 2008). Halokinesis term is used to describe deformation of salt group under gravity force. Some islands in the Persian Gulf are discussed as an example of Halokinesis salt (Arian 2011a, b).



**Fig. 5** *a* Distribution of Hormuz salt basin as well as tectonical structure view *b* Generalized map of the study area and salt diapirs in Zagros basin, after geological map of (Haghipour and Aghanabati 1989)



Persian Gulf includes active salt tectonics. Mukherjee et al. (2010) pointed out the estimated range of viscosities calculated for the salts of the Hormuz diapirs is broader than that for Newtonian salts and higher than that for the average value of salt. The estimated range of diapirs viscosities can be useful for tectonic modelling (Mukherjee et al. 2010). The diameters of salt diapirs usually vary between about 1 and 15 km (Kent 1958). In some diapirs, the salt rises vertically with minimal spreading over the surrounding country rocks (such as in Hormuz island); however, in some others, the salt spreads horizontally up to several kilometers in the form of salt glaciers (i.e. Gach, Jahani, Mesijune, Namak) as shown in Fig. 5 (Talbot and Alavi, 1996; Talbot 1998; Bosák et al. 1998). Distribution of salt domes of the central Zagros (Fars) is mostly affected by basement right-slip faults (Arian 2011a, b). Many faults have been recognized in southern Zagros mountain ranges. Some of these faults could have an important role for salt uplifting (Such as in Hormuz, Larak, Hengam, Namakdan, etc. (Fig. 5)) (Rahnama Rad et al. 2009). Numerous salt plugs are associated with large fault structures, and these fault lines of the basement are important for the origin of salt diapirs. About 200 emergent Hormuz salt plugs are known in southwest Iran (Rahnama Rad et al. 2009).

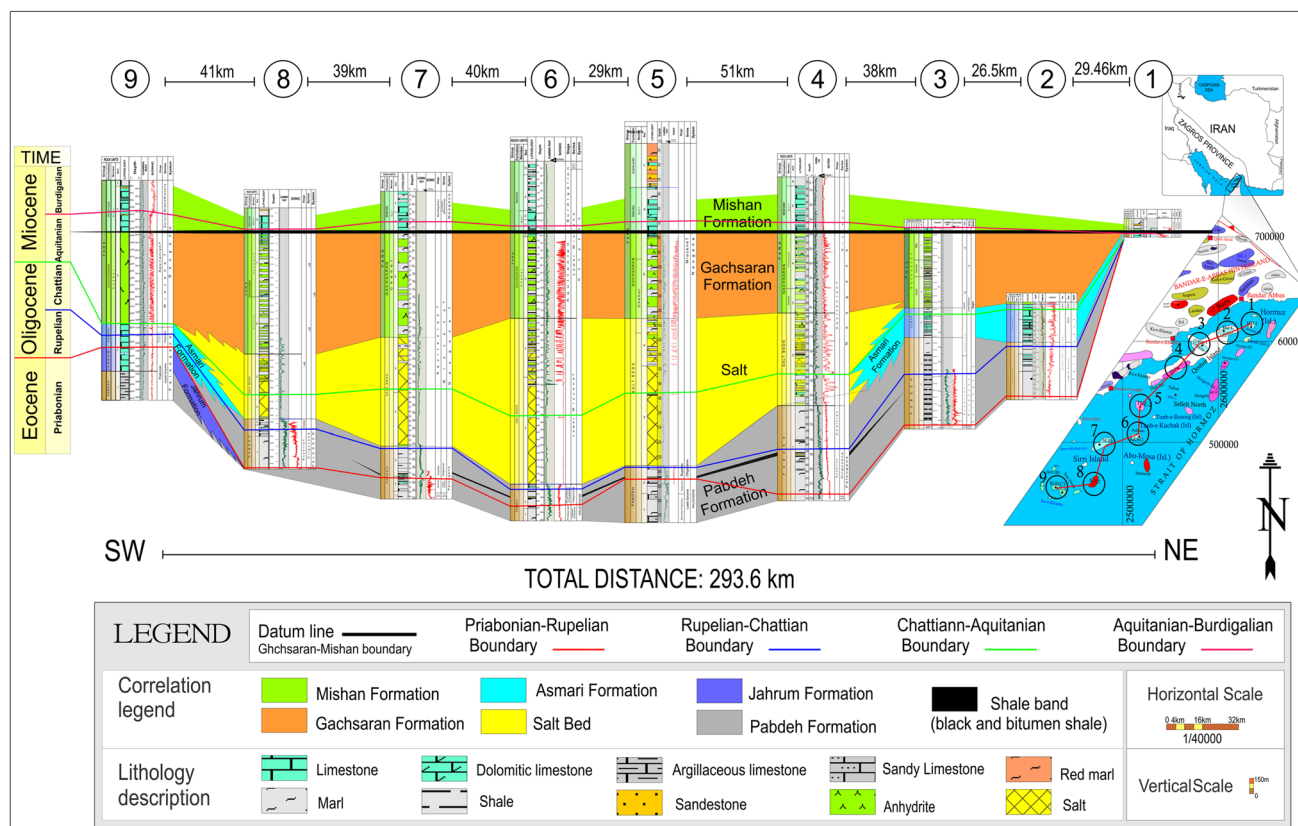
### Salt and evaporated deposits

The carbonate succession of the Asmari Fm and the presence of evaporation and salt deposits at high levels suggest that salinities ranged from normal marine to hypersaline during deposition of the Fm along the studied transect. Strontium dates are suggested that the anhydrite formed as an evaporate rather than as a later diagenetic product (Ehrenberg et al. 2007). Interpretation of depositional salinities and recognition of changes through the stratigraphic section may lead to a greater understanding of bathymetric changes and of restrictions in marine circulation during the late Oligocene (Chattian) to early Miocene (Aquitanian) in the study area. During deposition of the Asmari Fm in the basin, the most prolonged hypersaline

episodes probably occurred in the late Chattian and Aquitanian times, and changes from normal marine to hypersaline conditions may represent relative sea-level fall. Most marine organisms are sensitive to salinity changes. So, based on microfauna, the exact geological age cannot be specified for these intervals, but by means of the stratigraphical setting, these intervals belong to the late Oligocene (Chattian) to early Miocene (Aquitanian) age (Fig. 4). The Chattian to Aquitanian probably corresponds to the variable “shelly and miliolid (Thomas 1950). Thomas (1952) suggested that the microfauna were “very restricted” and the association with anhydrite nodules suggests a “highly saline environment”. Similar patterns of salinity change seem to be widespread in the Zagros basin such as in Lurestan and Khuzestan provinces. During most of the Chattian and Aquitanian, hypersaline conditions prevailed in Khuzestan province (Mossadegh et al. 2009). Over 200 structures of Hormuz salt varying in shape from salt pillows to extruding diapirs are known in the Zagros basin (Ala 1974; Jackson and Talbot 1986; Kent 1970, 1979) (Fig. 5). Movement of the Hormuz salt had significant influence on the facies and thickness of sediments deposited in the extreme southeastern part of the Zagros basin (Player 1969; Motiei 1993). It seems that the extrusion of large volumes of Hormuz salt into the southeastern part of Zagros basin, along the eastern Persian Gulf probably, supplied brines responsible for the thick salt in the late Oligocene to lower Miocene deposits. So, the lithological description of these deposits has been mentioned in each well (Fig. 4) and the regional aspects of salt deposits are determined and correlated in the studied transect (Fig. 6).

### Correlation-Interpretation

In this part, the Oligocene–Miocene deposits are correlated in nine wells. The well No. 1 is selected as a starting point of lithological study in the eastern transection, including a major gap. Consequently, middle to late Eocene and Oligocene deposits do not occur in this field. Thus, Mishan Fm overlies the Pabdeh Fm with unconformity. Except well-1,



**Fig. 6** Correlation chart of Oligocene–Miocene deposits of nine wells along northeast–southwest Persian Gulf

the Oligocene deposits occur throughout the selected transect. The Oligocene deposits consist of Pabdeh Fm, Asmari Fm and salt deposits. The thickness of Pabdeh Fm deposits is decreasing from the northeast to southwest of transection and finally turns into the Asmari carbonates in well No. 9 (Fig. 6). Depositional environment and sea-level changes at Oligocene time are the most important reasons for fauna change and sediments type in the Persian Gulf basin. So, in the northeastern point of the section, at Oligocene time, carbonate deposits with benthic fauna (Asmari Fm) conformably overlie the argillaceous limestone and marl facies with planktonic foraminifera (Pabdeh Fm) (Sajadi et al. 2014) which indicate change from low-energy to medium-energy environment (wells No. 2 and 3) (Fig. 6). But, across the middle of the study section, the salt deposits are extended to shape lens along the transection that has been shown by yellow colour (Fig. 6). This salt is as the same time as with late Oligocene to early Miocene of Asmari carbonates Fm and Miocene evaporates (Gachsaran Fm) in both side of transection. The Oligocene and Miocene boundary has been determined by fossil and correlated with gamma ray and sonic logs (Sajadi 2014) which is shown by green line (Fig. 6). Stöcklin (1968), Kashfi (1980) and Motiei (1993) pointed out that Kazerun–Qatar fault divides the Gachsaran basin into two different

segments: (1) the Qeshm salt sub-basin or Fars province in the southeast and (2) a northwestern sub-basin. The Qeshm salt sub-basin trended NE–SW across the eastern end of the Zagros foreland basin between the Dibba fault to east and the Arabian–Bastak fault to the west (Bahroudi and Koyi Hemin 2004). The Dibba fault along its eastern boundary controlled the influx of sea water into this sub-basin from the Oman Sea and Indian Ocean (Gill and Ala 1972). On a shallow-marine platform, changes from normal marine to hypersaline conditions occur when marine circulation is restricted and evaporation of seawater exceeds inflow of normal-marine waters. The restrictions may be due to closure basin and precipitation of high volume of evaporated deposits conformably overlies deep-marine deposits that occurred during the Chattian–Aquitanian age. The huge accumulation of salt in the Qeshm sub-basin was probably due not only to evaporation of seawater in an arid environment, but also from the re-precipitation of extruded Hormuz salt. The Gachsaran succession is extended throughout the studied transect. This Fm in the flanking parts of studied section conformably overlies the Asmari carbonate Fm (wells No. 2, 3 and 9) but, in the middle of transect it lies conformably on the salt and evaporated deposits (wells No. 4, 5, 6, 7 and 8). Also at the upper contact it is sharp and overlaid conformably by carbonate

deposits of Guri Member (Mishan Fm) throughout the section. Generally, across the western studied transect the thickness of Gachsaran successions is increasing. Progressive carbonate succession of Guri Member is extended throughout the Zagros basin especially in southern Bandar Abbas Hinterland and Zagros foreland (the studied area); thus, it is indicated as a datum line for intervals correlation. Mishan Fm is widespread in the studied transect. This Fm has sharp contact at the base and overlies different parts of Gachsaran Fm. This result represented sea-level falls at the top of Gachsaran, consequently shoaling basin and eroding upper parts of Gachsaran deposits.

## Conclusion

The important conclusions of this study can be summarized as follows:

Four Fms have been recognized including Pabdeh Fm, Asmari Fm, Gachsaran Fm and Mishan Fm. Biozonation and age determinations are based on planktic and benthic foraminifera and compared with well-known biozonation. Based on the biostratigraphy, correlation of gamma ray and sonic logs, the Oligocene and Miocene boundary has been determined. This boundary in the northeastern transect is located in Asmari Fm, the middle of transect is located in salt deposits and the southwestern transect is located between Asmari and Gachsaran Fms. Based on this result the Pabdeh Fm extended to Oligocene age and finally to southwestern transection the facies and fauna is changed laterally by Asmari Fm (well No. 9). Geography aspect, age and stratigraphic setting of salt have been determined in this research. By means of the stratigraphical setting and correlation, the Asmari Fm is equivalent to parts of the Pabdeh Fm and salt deposits. Following this episode, a change from normal marine to hypersaline conditions has occurred during the Chattian to Aquitanian in these intervals. In lower to middle parts of Fars group, Gachsaran and Mishan Fms are extended throughout the Zagros basin, especially in the area studied in this research that conformably overlies the oldest deposits.

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