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ORIGINAL ARTICLE

Microfacies and depositional environment of Asmari formation in the Zeloi oil field, Zagros basin, south-west Iran

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Abstract

The Oligocene–Miocene Asmari Formation is well known as a major hydrocarbon reservoir in southwestern Iran. To study the microfacies and sedimentary environment of Asmari Formation in the Zagros basin (south-west Iran), No. 6 well and No. 11 well sections in Zeloi oil field were selected. 500 thin sections were studied for petrographic and facies analysis. Based on petrographic and sedimentology analysis of the Asmari Formation in these sections, 13 carbonate microfacies and 1 petrofacies can be identified into three main depositional environments consisting of: outer ramp, middle ramp and inner ramp. The outer ramp environment is characterized by the presence of abundant planktonic foraminifera and echinoid fragments. The middle ramp environment is represented by the presence of echinoids and planktonic foraminifera, red algae and perforate foraminifers. In the inner ramp, the most allochems are ostracoda, imperforate and perforate benthic foraminifera, algae ball, peloid and oncoid.

Keywords Asmari · Iran · Zagros · Zeloi · Ramp

Introduction

The Oligocene–Miocene Asmari Formation is a thick sequence of shallow-water carbonates of the Zagros Basin. The Asmari Formation was measured and defined as an Oligocene nummulitic limestone by Richardson (1924) and described by Thomas (1948) as an Oligocene–Miocene carbonate interval. James and Wynd (1965) summarized previous viewpoints and finally formally defined the Asmari Formation (Sahraeyan et al. 2014).

Due to significant oil reservoirs existing in Zagros Mountains, geology of this region has been investigated by enormous world geologists from past till now. Among them, studied microfaceis and sedimentary of the Asmari Formation by Kalantari (1986), (1992), Maghsodi Gharebalagh et al. (2005), Mohseni (2006), Vaziri-Moghaddam (2006), Ranjbaran (2007), Ehrenberg (2007), Amirshahkarami (2007a, b), Bahrami (2009), Taheri (2010), Sadeghi et al. (2010), Vaziri- Moghaddam (2010), Dehghanian (2011), Sooltanian et al. (2011), Yazdani (2014), Mirzaee Mahmoodabadi (2014), Sahraeyan et al. (2014), Avarjani et al. (2015), Kangazian and Pasandideh (2016), Mombani et al. (2017), Vafadar and Golestan (2016), Kakemem et al. (2017).

The Zeloi oil field is located in south west of Zagros basin about 70 km north of Ahvaz city, 15 km south of Lali oil field and 30 km north-west of Masjed Soleiman city. It is situated in the Dezful Embayment, which is structurally bounded by the Bala Rud, Mountain Front, and Kazerun faults (Bahadori et al. 2011). The Zeloi oil field is one of the over-pressurized oil fields in southwestern Iran and it extends along a disharmonic anticline of the Fars groups of Formations. The Asmari reservoir in Zeloi oil field, measuring about 40-km long and 6-km wide, is an asymmetric anticline.

Lithostratigraphic limits of the Asmari Formation in these sections are marked by marly and shaly sediment of Pabdeh Formation at the base and evaporite sediment of the Gachsaran Formation on the top.

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Microfossils below were distinguished in Asmari Formation in this section: *Meandropsina iranica*, *Dendritina rangi*, *Amphistegina* sp., *Discorbis* sp., *Elphidium* sp., *Rotalia* sp., *Miogypsina* sp., Bigerina sp., *Peneroplis* sp., *Pseudolithonella reicheli*, *Borelis melo curdica*, *Borelis* sp., *Globorotalia* sp., *Globigerina* sp., Austrotrillina sp., Miliolids and Valvulinid. Based on the recognized foraminifera, the section is comparable to *Miogypsina–Elphidium* sp.14 and *Borelis melo curdica–Meandropsina iranica* zones (Laursen et al. 2009). Micropaleontological studies suggest early Miocene age for Asmari Formation in Zeloi oil field.

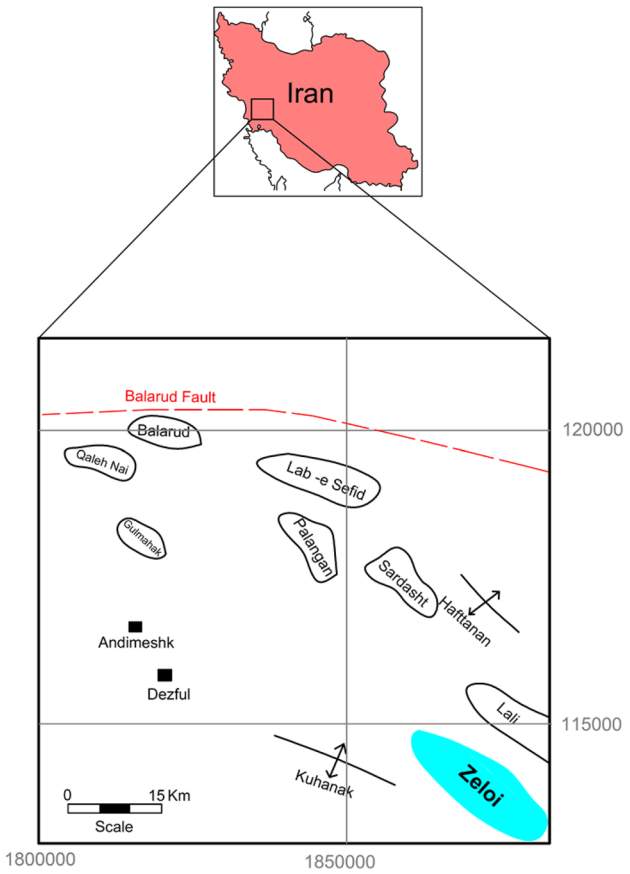

Fig. 1 Location map of the Zeloi oil field

Methodology

500 thin sections (402 thin sections from No. 6 well Zeloi and 98 thin sections from the No. 11 well Zeloi) were studied for petrographic and facies analysis (Figs. 1, 2, 3 and 4). Distinguishing Rock texture was done based on Dunham and Folk classifications (Dunham 1962; Folk 1962). Facies classification and suggestion of depositional model were done using (Wilson 1975; Lasemi and Carozzi 1981; Flugel 2004, 2010; Buxton and Pedley 1989).

Microfacies types of the Asmari formation

Based on the petrographic and sedimentology analysis of the Asmari Formation in these sections, 13 carbonate microfacies and 1 petrofacies can be identified into three facies groups. These comprise the outer ramp, middle ramp and inner ramp facies group.

Outer ramp microfacies

O1: Planktonic foraminifera wackestone–packstone (Plate 1a)

This microfacies indicated by abundant planktonic foraminifera (like *Globorotalia* sp. and *Globigerina* sp.), echinoid fragments, and rare benthic foraminifers, Ditrupa sp. and peloid. Planktonic foraminifera wackestone–packstone microfacies occurs at the Asmari–Pabdeh contact. The abundance of planktonic foraminifera and fine-grained matrix in O1 suggests an outer ramp environment with

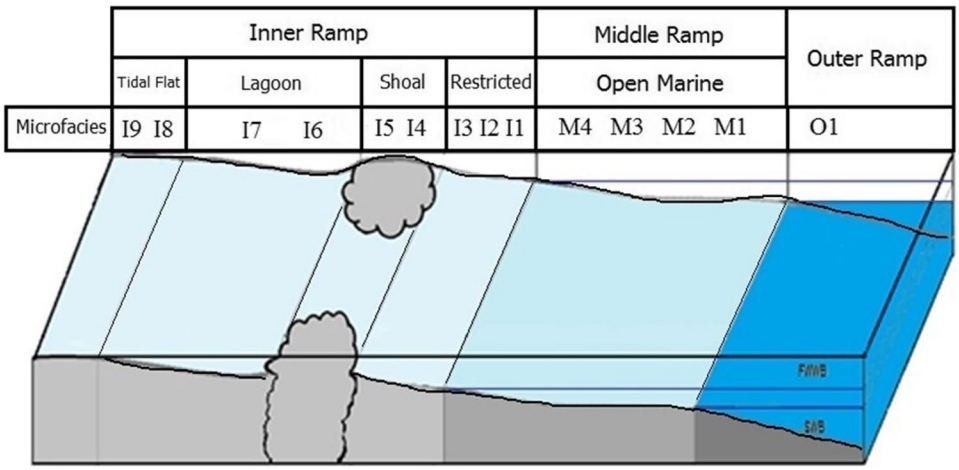

Fig. 2 Depositional model of the Asmari Formation in Zeloi oil field

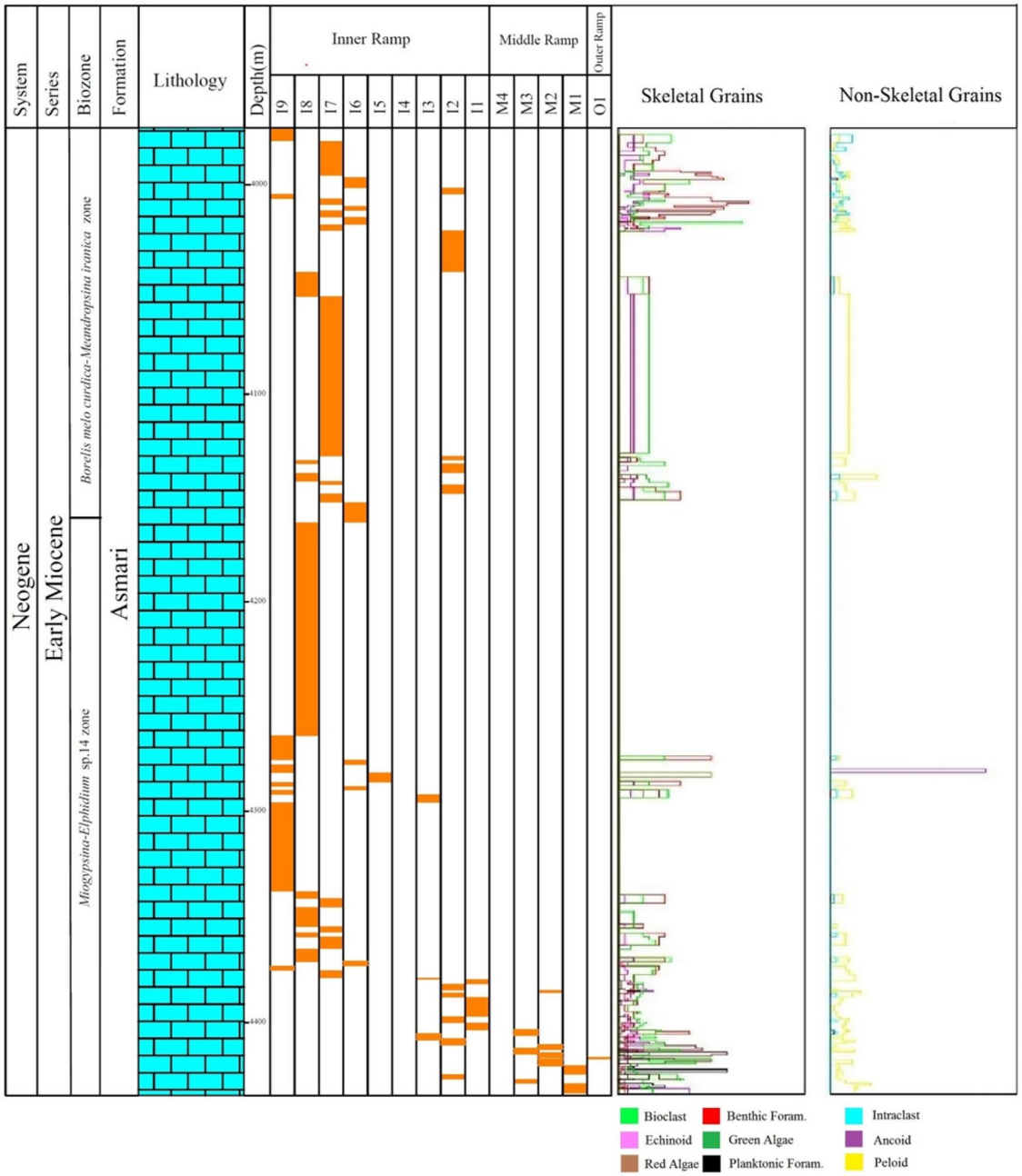

Fig. 3 Facies distribution of the Asmari Formation at No. 6 well Zeloi

low-energy hydrodynamic regime and normal marine salinity conditions (Wilson 1975; Buxton and Pedley 1989; Geel 2000; Cosovic et al. 2004; Flugel 2004, 2010). In O1, accompanying fauna is small and of low diversity (Buxton and Pedley 1989). In the absence of coeval larger foraminifers, water depth is assumed to have been more than 200 m (slope and basin facies). This microfacies is equivalent to RMF 5 of Flugel (2004) in outer ramp. Similar microfacies has also been reported from the base of the Asmari Formation in Zagros basin (Vaziri-moghaddam et al. 2006; Amirshahkarami et al. 2007a, b; Daniel et al. 2008; Mossadegh et al. 2009; Vaziri-moghaddam et al. 2010; Sadeghi et al. 2010; Sooltanian et al. 2011; Kakemem et al. 2017).

Middle ramp microfacies

M1: Echinoid planktonic foraminifera packstone (Plate 1b)

The major allochems of this facies are echinoid and planktonic foraminifers (like *Globigerina* sp.). Subordinate

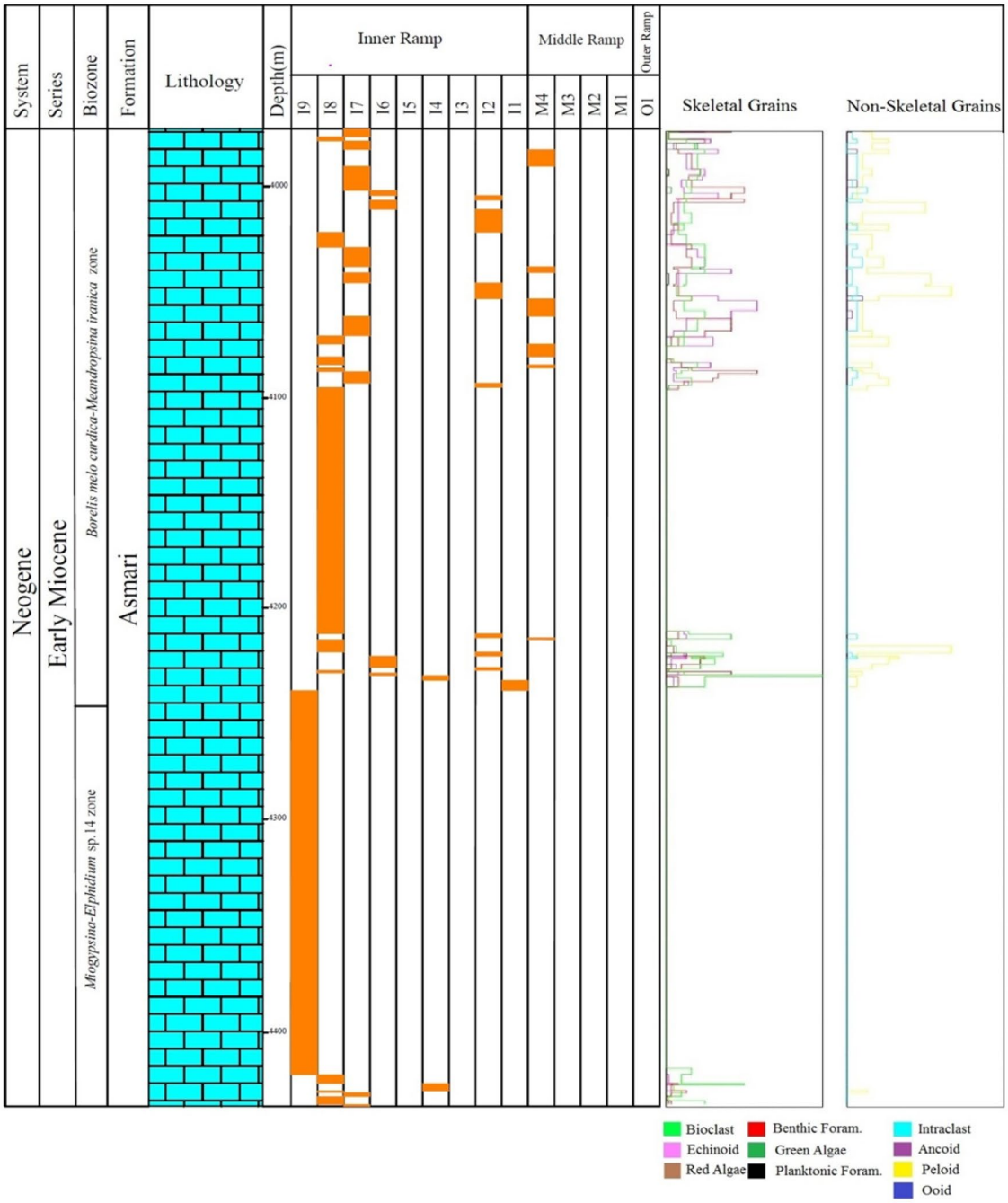

Fig. 4 Facies distribution of the Asmari Formation at No. 11 well Zeloi

components include benthic foraminifers, red algae, ostra, bryozoan, and ostracods. The non-skeletal components consist of peloids. The presence of open marine allochems such as echinoid and planktonic foraminifers and the absence of porcellaneous foraminifers points to open marine in middle ramp environment (Geel 2000; Beavington-Penney and Racey 2004; Nebelsick et al. 2005; Bassi et al. 2007; Barattolo et al. 2007; Brandano et al. 2009). This microfacies is correlated with RMF 7 of Flugel (2004). Amirshahkarami et al. (2007a, b), Daniel et al. (2008), Sadeghi et al. (2010), Vaziri-Moghaddam et al. (2010), Sooltanian et al. (2011), described similar facies from the Asmari formation, in the Zagros basin.

M2: Red algal rudstone–floatstone (Plate 1c)

The M2 is characterized by an abundance of red algae coarse grains larger than 2 mm. in micritic matrix. Other

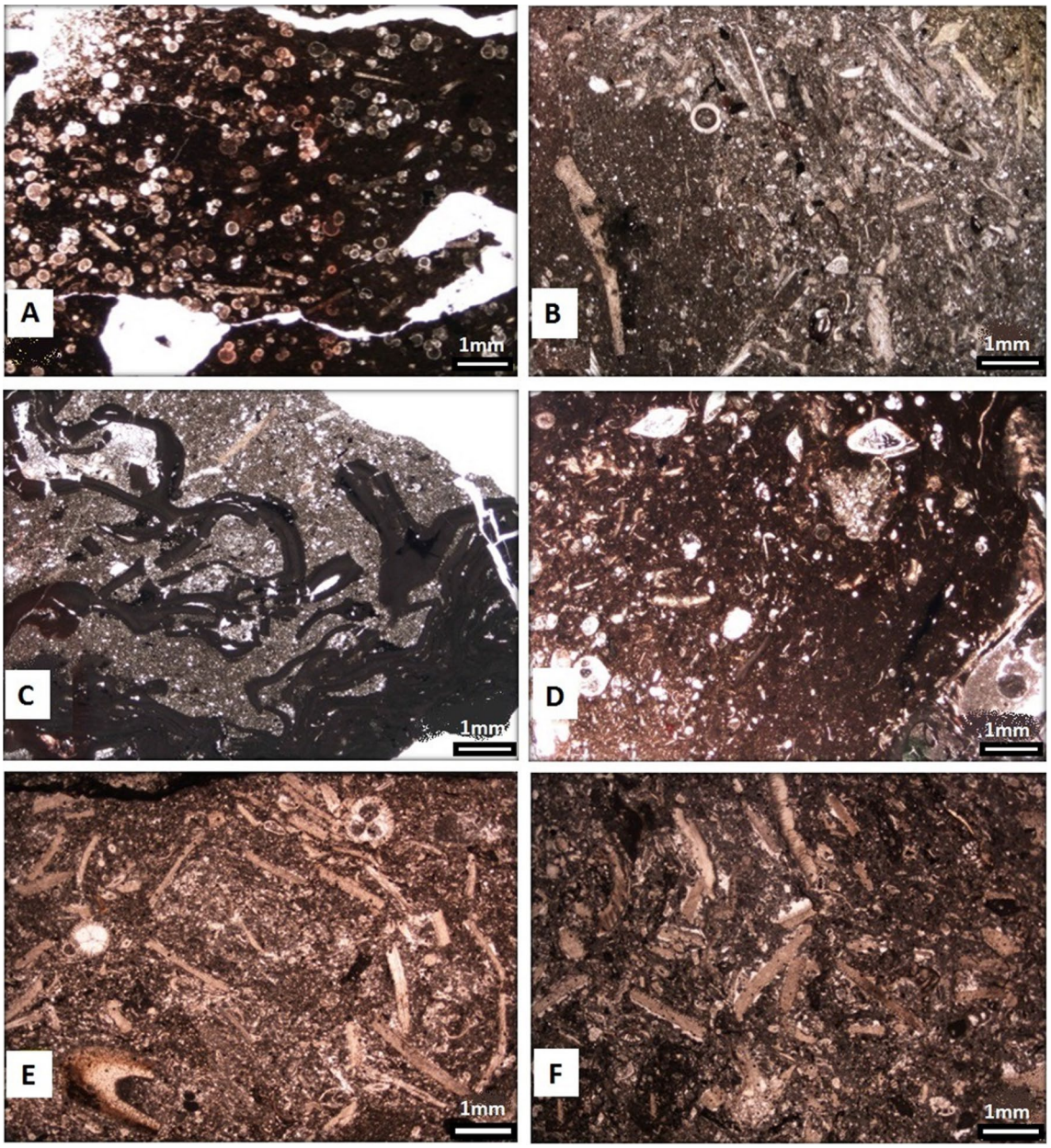

Plate 1 **a** O1: Planktonic foraminifera wackestone–packstone, Outer Ramp, Depth: 4424 m. Section: No. 6 well Zeloi, **b** M1: Echinoid planktonic foraminifera packstone, Middle Ramp, Depth: 4434 m. Section: No. 6 well Zeloi, **c** M2: Red algal rudstone–floatstone, Middle Ramp, Depth: 4486 m. Section: No. 6 well Zeloi, **d** M3: Hyaline foraminifers bioclastic packstone–wackestone, Middle Ramp, Depth: 4413 m. Section: No. 6 well Zeloi, **e** M4: Bioclastic echinoid wackestone–floatstone to rudstone, Middle Ramp, Depth: 3913 m. Section: No. 11 well Zeloi, **f** M4: Bioclastic echinoid wackestone–floatstone to rudstone, Middle Ramp, Depth: 3895 m. Section: no. 11 well Zeloi

components such as planktonic foraminifers, benthic foraminifers (*Miogypsina* sp., *Amphistegina* sp., *Discorbis* sp., *Rotalia* sp.), echinoids, bryozoan, ostra, brachiopods and peloids are subordinate. Also fine–medium-grained detrital quartz is recognized in this microfacies. This facies was deposited in an open marine environment with normal salinity and moderate energy as indicated by abundant of red algae and existence of planktonic foraminifers as well as stratigraphic position (Pedley 1996; Pomar 2001). Coralline red algae are common in Oligocene and Miocene marine shallow-water carbonate and siliciclastic rocks, as well as deep-water re-deposited sediments containing particles removed from platforms (Braga et al. 2010). This microfacies is equivalent to RMF 9 of Flugel (2004). Similar microfacies has also been reported from inner ramp of Zagros basin by Mombani et al. (2017) and Avarjani et al. (2015).

M3: Hyaline foraminifers bioclastic packstone–wackestone (Plate 1d)

This microfacies is mainly hyaline foraminifers (*Amphistegina* sp., *Discorbis* sp., *Rotalia* sp., *Elphidium* sp., *Dendritina rangi*, Austrotrillina sp., Miliolids and Valvulinid) with subordinate Ditrupa sp., gastropods, bryozoan, red algae, echinoids, ostracods. peloids, ooids, and quartz grains are rare. This facies was deposited in middle ramp environment with normal salinity and middle energy hydrodynamic, as indicated by imperforate foraminifera, red algae, echinoids and planktonic foraminifers. The overall characteristics suggest that deposition took place between normal wave base and storm wave base (Romero et al. 2002; Corda and Brandano 2003). This microfacies is correlated with RMF13 of Flugel (2004). Similar microfacies has also been reported from the Asmari Formation in Zagros basin by Vaziri-Moghaddam et al. (2006), Amirshahkarami et al. (2007b), Vaziri-Moghaddam et al. (2010), Mirzaee Mahmoodabadi (2014).

M4: Bioclastic echinoid wackestone–floatstone to rudstone (Plate 1e, f)

Echinoids are the main components in this microfacies. The M4 is indicated by abundant echinoids and shell fragments and rare brachiopods, bivalves, gastropods, peloids and red algae. Other components consist of *Rotalia* sp., *Elphidium* sp., *Discorbis* sp., Tubucellaria sp. and *Textularia* sp. Mainly texture of this microfacies is micritic matrix (wackestone) but in some part of thin sections, we can see allochems with more than 2 mm. size (floatstone to rudstone). This microfacies is equivalent to RMF 7 of Flugel (2004). Sahraeyan et al. (2014) described similar facies from Asmari Formation in Zagros basin.

Inner ramp microfacies

I1: Bioclastic ostracoda wackestone–packstone (Plate 2a)

Bioclasts and ostracoda are the main components in this microfacies. Other components such as echinoids, red algae, benthic foraminifers (*Rotalia* sp., *Elphidium* sp., *Discorbis* sp., and miliolids) and quartz are subordinate. The non-skeletal components consist of rare peloids. In this microfacies, the restricted sedimentary environment setting is suggested by abundance of micrite, low-energy conditions and poor biota. This restricted sedimentary environment can be lagoon with saline to hyper saline water or back reef environment (Daniel et al. 2008). The absence of porcellaneous foraminifera, existence of hyaline foraminifera like *Rotalia* sp. and red algae indicate the inner ramp environment for I1. This microfacies is correlated with RMF 18 of Flugel (2004). Similar microfacies has also been reported from inner ramp sediments of the Asmari Formation in Zagros basin by Mombani et al. (2017) and from Eocene of Egypt by Abu El Ghar (2007).

I2: Peloidal bioclastic wackestone (Plate 2b)

The principal allochems of I2 are bioclasts including echinoids, bivalves, brachiopods, shell fragments and rare red algae. The non-skeletal components consist of peloids and rare intraclasts. Subordinate components include hyaline benthic foraminifers such as rare *Discorbis* sp., *Rotalia* sp., Bigerina sp. and *Elphidium* sp. The texture of this microfacies is a micritic matrix. Micritic matrix is suggested low-energy condition. Sometimes bioclast breaking can be seen in thin sections of this microfacies. Bioclast breaking suggested high-energy condition in small part of this sequence. Peloidal bioclastic wackestone microfacies is equivalent to RMF 7 of Flugel (2004). Mirzaee Mahmoodabadi (2014), Taheri (2016), described similar facies from Asmari Formation in Zagros basin.

I3: Foraminifers peloidal packstone–grainstone (Plate 2c)

This microfacies is characterized by an abundance of bioclasts (echinoids and red algae), hyaline benthic foraminifers (*Discorbis* sp., *Rotalia* sp. and *Elphidium* sp.) and peloids. Low micritic matrix, high sparite, the absence of lagoonal imperforate foraminifers and abundance of red algae and echinoids, indicate that sedimentation took place in an open marine environment, towards the barrier (Pomar 2001). Based on Wilson (1975), in foraminifers peloidal packstone–grainstone microfacies, the inner ramp depositional with high-energy setting is suggested by sedimentary texture (grain-supported texture, well-rounded and well-sorted grains). Foraminifers peloidal bioclastic packstone–grainstone is correlated with RMF 26 of Flugel (2004). Similar microfacies has also been reported from inner ramp sediments of the Asmari Formation in Zagros basin by Daniel et al. (2008), Mossadegh et al. (2009), Vaziri-Moghaddam et al. (2010), Kakemem et al. (2017).

I4: Ostracoda bioclastic packstone–grainstone (Plate 2d)

Cemented bioclasts and ostracods are the main components in the MF9 microfacies. Other components such as echinoids, gastropods and benthic foraminifers (*Rotalia* sp., miliolids) are subordinate. The non-skeletal components consist of rare peloids. This facies was deposited in a restricted environment high energy, as indicated by abundance of sparite as well as abundance of lagoonal foraminifers. Ostracods are most valuable indicators of paleosalinities. They occur with facies-diagnostic

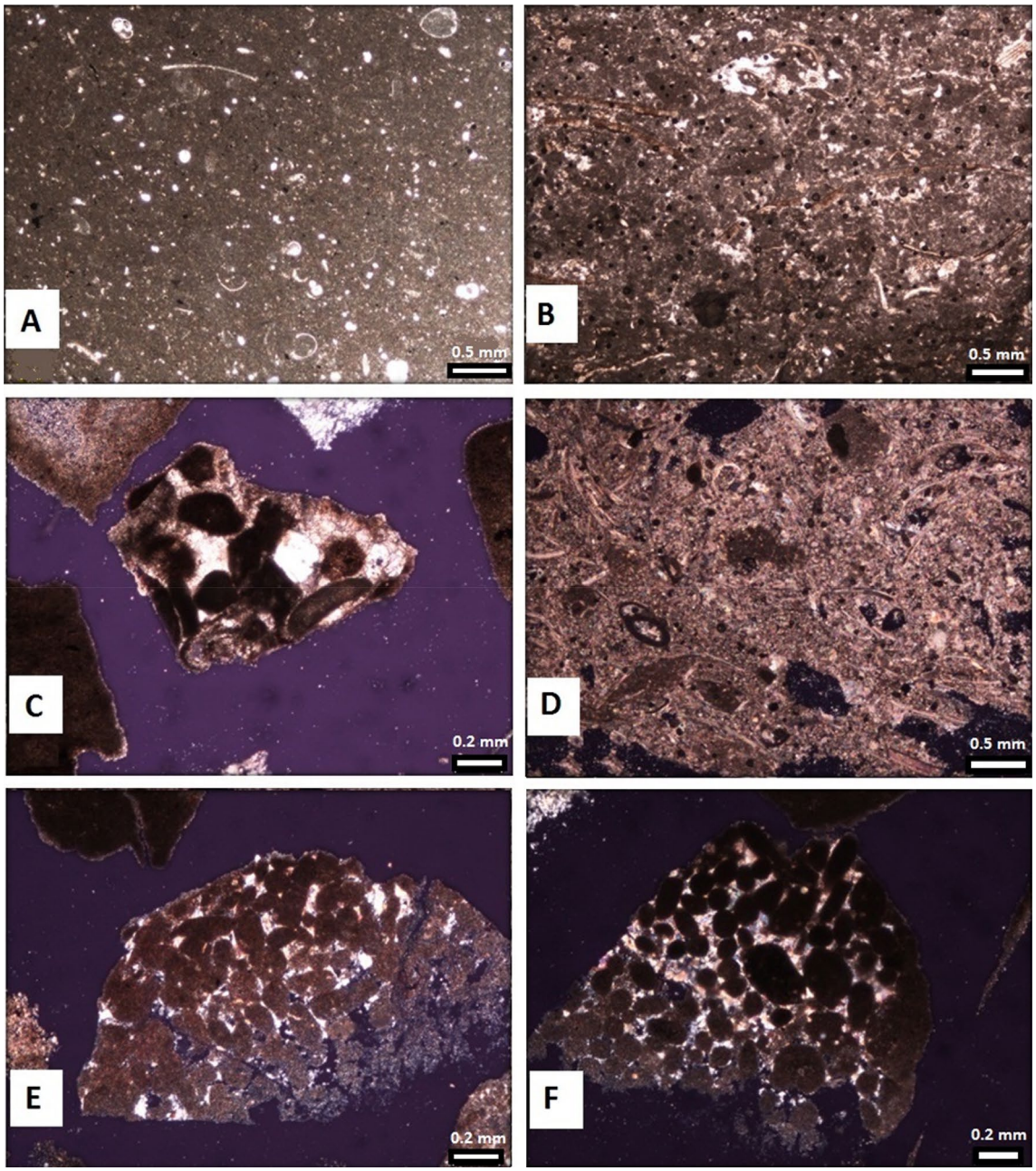

Plate 2 **a** I1: Bioclastic ostracoda wackestone–packstone, Inner Ramp, Depth: 4382 m. Section: No. 6 well Zeloi, **b** I2: Peloidal bioclastic wackestone, Inner Ramp, Depth: 3891 m. Section: No. 11 well Zeloi, **c** I3: Foraminifers peloidal packstone–grainstone, Inner Ramp, Depth: 4292 m. Section: No. 6 well Zeloi, **d** I4: Ostracoda bioclastic packstone–grainstone, Inner Ramp, Depth: 4108 m. Section: No. 11 well Zeloi, **e** I5: Oncoid grainstone, Inner Ramp, Depth: 4282 m. Section: No. 6 well Zeloi, **f** I5: Oncoid grainstone, Inner Ramp, Depth: 4296 m. Section: No. 6 well Zeloi

species and assemblages in freshwater, brackish water and marine environments (Flugel 2004, 2010). In this microfacies Ostracods assemblages with components such as echinoids, gastropods and benthic foraminifers, that shows a marine environment. Ostracoda bioclastic packstone–grainstone microfacies is equivalent to RMF 27 of Flugel (2004). Similar microfacies has also been reported by Abu El Ghar (2007) from inner ramp sediments of Eocene in Egypt.

I5: Oncoid grainstone (Plate 2e, f)

Principal grain of this micofacies is oncoid. Oncoid grainstone microfacies is indicated by abundance of rounded

and ovate micritic grains, and sparry calcite cement. These grains are well sorted, well rounded and cemented by anhydritic cement. The presence of oncoids, grain-supported texture and sparry calcite cement points to high-energy conditions (Geel 2000; Flugel 2004, 2010). The overall characteristics of this microfacies suggest a high-energy shoal in inner ramp environment. This microfacies is equivalent to RMF 27 of Flugel (2004).

I6: Bioclastic benthic foraminifers packstone–grainstone (Plate 3a)

This microfacies is indicated by abundant benthic foraminifera such as *Elphidium* sp., Meandropsina sp., *Borelis* sp., *Peneroplis* sp., *Dendritina rangi*, *Discorbis* sp., *Pyrgo* sp., miliolids and *Rotalia* sp. Other components consist of peloid, intraclasts, gastropods, red algae, echinoids and rare green algae and corals. The presence of allochems in sparry calcite cement and benthic foraminifers indicates that sedimentation took place in a lagoon environment towards the shoal. The presence of open marine components (perforate foraminifers and red algae) with imperforate foraminifers refers to the absence of effective shoal and suggests a lagoonal environment in inner ramp setting (Romero et al. 2002). This microfacies is equivalent to RMF 27 of Flugel (2004). Similar microfacies has also been reported from inner ramp sediments of the Asmari Formation in Zagros basin by Vaziri-Moghaddam et al. (2006), Amirshahkarami et al. (2007a, b), Daniel et al. (2008), Mossadegh et al. (2009), Allahkarampour Dill (2010), Sadeghi et al. (2010), Vaziri-Moghaddam et al. (2010), Sooltanian et al. (2011), Mirzaee Mahmoodabadi (2014), Yazdani (2014), Avarjani et al. (2015), Kakemem et al. (2017).

I7: Bioclastic benthic foraminifers wackestone–packstone (Plate 3b)

The principal allochems of the I7 are porcelaneous benthic foraminifers such as *Peneroplis* sp., Meandropsina sp., *Dendritina rangi*, *Borelis* sp. *Textularia* sp. and Miliolids. Subordinate components include foraminifers like *Discorbis* sp. and *Elphidium* sp., gastropods, echinoids, bivalves, green algae and rare ostracods. The non-skeletal components consist of peloids and rare intraclasts. The texture of

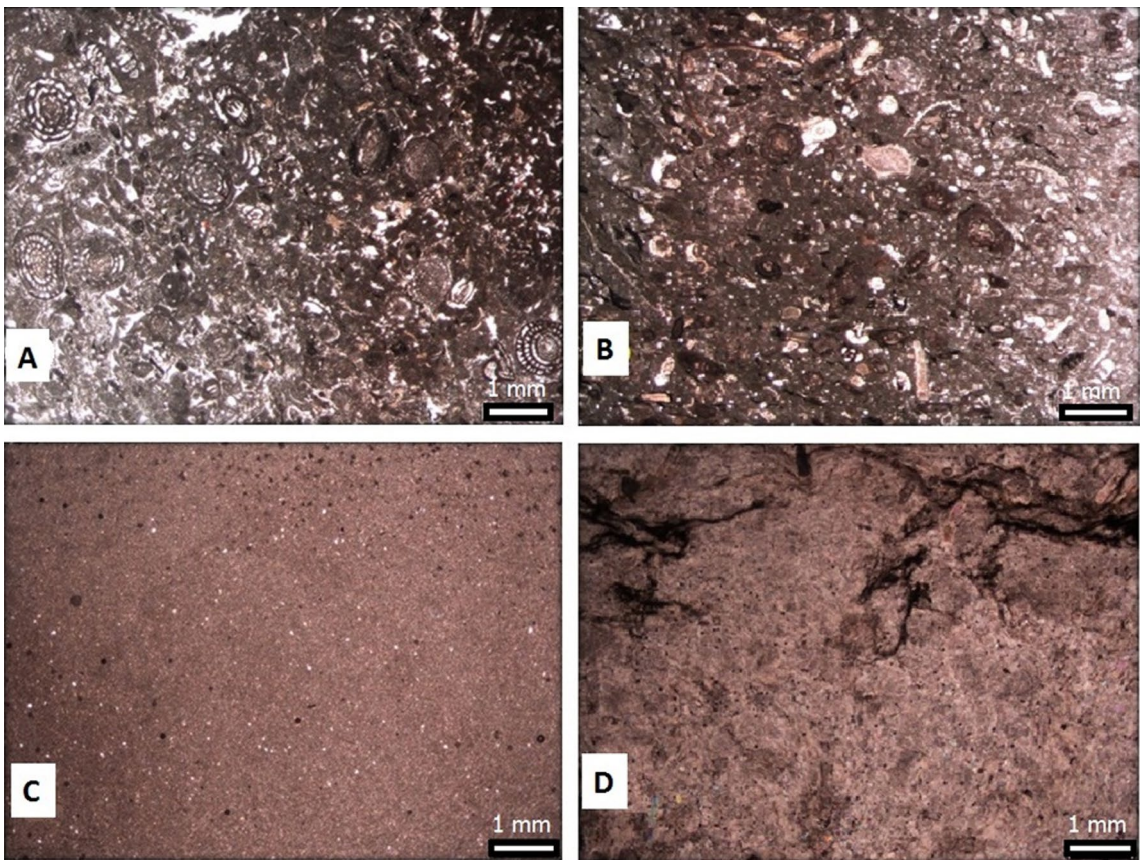

Plate 3 **a** I6: Bioclastic bentic foraminifers packstone–grainstone, Inner Ramp, Depth: 4114 m. Section: No. 6 well Zeloi, **b** I7: Bioclastic benthic foraminifers wackestone–packstone, Inner Ramp, Depth: 4013 m. Section: No. 6 well Zeloi, **c** I8: Mudstone, Inner Ramp, Depth: 3985 m. Section: No. 6 well Zeloi, **d** I9: Anhydrite, Inner Ramp, Depth: 4100 m. Section: No. 6 well Zeloi

this microfacies is a micritic matrix. This microfacies was deposited in a shallow lagoon with low energy, as indicated by micritic matrix, imperforate foraminifera such as miliolids and low taxonomic diversity of foraminifera (Wilson 1975, Flugel 1982; Geel 2000, Flugel 2004). The imperforate foraminifera indicates the restricted conditions (Hallock and Glenn 1986; Geel 2000; Romero et al. 2002) and hyper saline waters (Geel 2000). Bioclastic benthic foraminifers wackestone–packstone is correlated with RMF 20 of Flugel (2004). Daniel et al. (2008), Mossadegh et al. (2009), Allahkarampour Dill (2010), Mirzaee Mahmoodabadi (2014), Yazdani (2014), Avarjani et al. (2015), Kakemem et al. (2017), described similar facies from inner ramp sediments of the Asmari Formation in Zagros basin.

I8: Mudstone (Plate 3c)

This microfacies is composed of mudstone with rare bioclast (such as miliolids and ostracods), and silt-size quartz grains. The texture of this microfacies is a fine micritic matrix. The absence of fossils and the presence of silt-size quartz grains and mud matrix indicated that this microfacies formed in very shallow, low-energy conditions, most likely in a lagoon toward to tidal flat setting (Wilson 1975; Wilson and Evans 2002; Flugel Flügel 2004; Rasser et al. 2005). This microfacies is equivalent to RMF 19 of Flugel (2004). Similar microfacies were recorded in the Asmari Formation, in Zagros basin, by Amirshahkarami et al. (2007a, b); Allahkarampour Dill (2010); Sadeghi et al. (2010); Vaziri-Moghaddam et al. (2010); Sooltanian et al. (2011); Sahraeyan et al. (2014) and in Tarbur Foramation by Abyat et al. (2007a, 2007b, 2012, 2015), Khosrow Tehrani et al. (2008).

I9: Anhydrite (Plate 3d)

This microfacies occurs at the base of Asmari Formation. Anhydrite microfacies is without any skeletal or non-skeletal allochems. Considering the thickness of the anhydrite deposits, their vertical stacking and lateral continuity, it is assumed that they are submarine deposits formed in an isolated saline basin (Vaziri-Moghaddam et al. 2010). Similar facies described from of the Asmari Formation by Vaziri-Moghaddam et al. (2010), Amin-Rasouli (2012), Mombani et al. (2017).

Sedimentary model

According to facies distribution, energy condition, lack of reefal facies, lack of effective barrier and the absence of calciturbidite facies, homoclinal carbonate ramp environment was proposed for Asmari Formation in these sections. The outer ramp sediments in these sections are composed of abundance of planktonic foraminifera, echinoid fragments and rare benthic foraminifers (planktonic foraminifera wackestone–packstone). The middle ramp setting is characterized by echinoid, benthic and planktonic foraminifera, red algal and hyaline foraminifers in wackestone, packstone, rudstone and floatstone microfacies. The inner ramp sediments are composed of peloid, benthic foraminifers, ostracoda, oncoid in mudstone, wackestone, packstone, grainstone facies.

Conclusions

Based on the petrographic and sedimentology analysis, 13 carbonate microfacies and 1 petrofacies were identified in No. 6 well and No. 11 well sections in Zeloi oil field. In these sections, three distinct depositional settings can be recognized: outer ramp (O1:Planktonic foraminifera wackestone–packstone), middle ramp (MF1:Echinoid planktonic foraminifera packstone, M2:Red algal rudstone–floatstone, M3:Hyaline foraminifers bioclastic packstone–wackestone, M4:Bioclastic echinoid wackestone–floatstone to rudstone) and inner ramp (I1:Bioclastic ostracoda wackestone–packstone, I2:Peloidal bioclastic wackestone, I3:Foraminifers peloidal packstone–grainstone, I4:Ostracoda bioclastic packstone–grainstone, I5:Oncoid grainstone, I6: Bioclastic benthic foraminifers packstone–grainstone, I7:Bioclastic benthic foraminifers wackestone–packstone, I8:Mudstone, I9:Anhydrite). The outer ramp environment is characterized by planktonic foraminifera wackestone–packstone. The middle ramp environment is represented by the presence of wackestone, packstone, rudstone and floatstone with echinoids and planktonic foraminifera, red algae and perforate foraminifers. The inner ramp environment is characterized by mudstone, wackestone, packstone, grainstone with ostracoda, imperforate and perforate benthic foraminifera, peloid and oncoid.

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