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Neocomian Fahliyan formation carbonates in the oil well X2 (Dorood oil field, Persian Gulf): Biostratigraphic data from benthic foraminifera and algae

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Abstract

The Fahliyan Formation of the Khami Group is the most important oil and gas reservoir in southwestern Iran. The formation attains a thickness of 435.5 m in the oil well X2 in Dorood oil field, Persian Gulf. It is represented mainly by thin-bedded limestones. This formation unconformably overlies the evaporate late Jurassic Hith Formation and conformably underlies the Gadvan Formation. Integrated palaeontological and sedimentological studies supported by an analysis of 150 thin-sections led to the identification of 21 benthic foraminiferal genera dominated by agglutinated forms with an additional 8 algal genera. Two foraminiferal biozones of Berriasian through Hauterivian age include the *Pseudochrysalidina* (*Dokhania*) *arabica* acme zone and *Pseudocyclammina lituus-Coscinoconus* assemblage zone, and an algal zone includes the *Salpingoporella annulata* range zone have been recognized. The correlation of the lower Cretaceous petroleum source rock in the Persian Gulf with regions from Tethyan Realm is limited by the lack of the analog formation that can be used for comparison. In this way, the foraminiferal zones are correlated with coeval zones in south and southwest of Iran.

Keywords: *Fahliyan Formation, benthic foraminifera, algae, Berriasian-Hauterivian, Persian Gulf*

1. Introduction

Fahliyan Formation is a part of the Khami Group in Zagros Basin which is among the most important oil and gas reservoirs in southwestern Iran. The type section of the Fahliyan Formation is located on the southern flank of Kuh-e-Dal, in the vicinity of Fahliyan village, 90 km east-southeast of Gachsaran, in the Zagros Basin. The Zagros Basin is lying between the central Iranian plateau in the NE, the Arabian Shield to the SW and the Taurides of Turkey to the NW (Bahroudi and Talbot 2003). A great number of geological studies have been performed on the Zagros carbonate reservoir (e.g. Gollesstaneh 1965; Wynd 1965; Kheradpir 1975; Kalantari 1975; Shakib 1994; Moallemi 2000; Mohammad-Khani 2003; Afghah 2006; Lasemi and Feyzi 2007; Hosseini and Conrad 2008; Rastegar Lari 2009; Mosadegh and Shirazi 2009; Adabi et al. 2010; Jamalian et al. 2010; Feghhi 2010). Fahliyan Formation, one of the important oil and gas reservoir in Zagros Basin, unconformably overlies the evaporate Late Jurassic Hith Formation and conformably underlies the Hauterivian/Barremian Gadvan Formation. James and Wynd (1965) were among the first geologists to propose the Neocomian age for shallow marine platform carbonate succession. Recent studies in the last decade have provided more data on stratigraphy, sedimentology and depositional environments of the Fahliyan Formation. Both shallow and deep marine depositional environment of the Fahliyan Formation were suggested by Khosravi et al. (2009) and Adabi et al. (2010). Dasycladacean algae and benthic foraminifera were reported from Kuh-e-Surmeh by Hosseini and Conrad (2008) and Kuh-e Siah surface section by Jamalian et al. (2010); Abedpour et al. (2016) and Kuhe-e-Surmeh section (Abyat et al. 2012). Subsequently, sedimentary facies and diagenetic features were interpreted by Sahraeyan et al. (2013). Soleimani et al. (2017) carried out the investigations on the formation of pore pressure variation of the Fahliyan Formation. In this study we give new data on the biostratigraphy and age of the Lower Cretaceous source rock corresponding to Fahliyan Formation from oil well X2 in the Dorood oil field, Persian Gulf (coordinates 29°11′45.69″ longitude and 50°15′56.96″ latitude) (Fig 1a). Dorood oil field, which partly underlies the Kharg Island, is the largest Iranian offshore oil field discovered in 1961. It is 25 km long and 5 km wide, located offshore in the northern part of the Persian Gulf area. The Dorood structure is an elongated anticline plunging toward north and northeast (Chehrazi et al. 2011). It is considered that oil and gas probably generated in facies that are equivalent in age to the reservoir rock (Masters et al. 1982). Fahliyan Formation is represented by several carbonate intervals: The Manifa Member, corresponding to the best reservoir interval; middle Yamama Member, corresponding to the

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major reservoir interval; and upper Yamama Member corresponding to poor reservoir quality limestones (Chehrazi et al. 2011) (Fig 1b). Up to now the biostratigraphy of the Fahliyan Formation from oil wells has not been available. A preliminary report on the microbiostratigraphy and lithostratigraphy is given by Rostami et al. (2017). The aim of this study is to present new results on the biostratigraphy and to propose a zonal scheme on the basis of benthic foraminiferal and algal associations.

The correlation of the petroleum source rock in the Persian Gulf with regions from the Tethyan Realm is limited by the lack of the analog formation that can be used for comparison. In this way, the foraminiferal and algal zones are correlated with coeval zones from Iran regions.

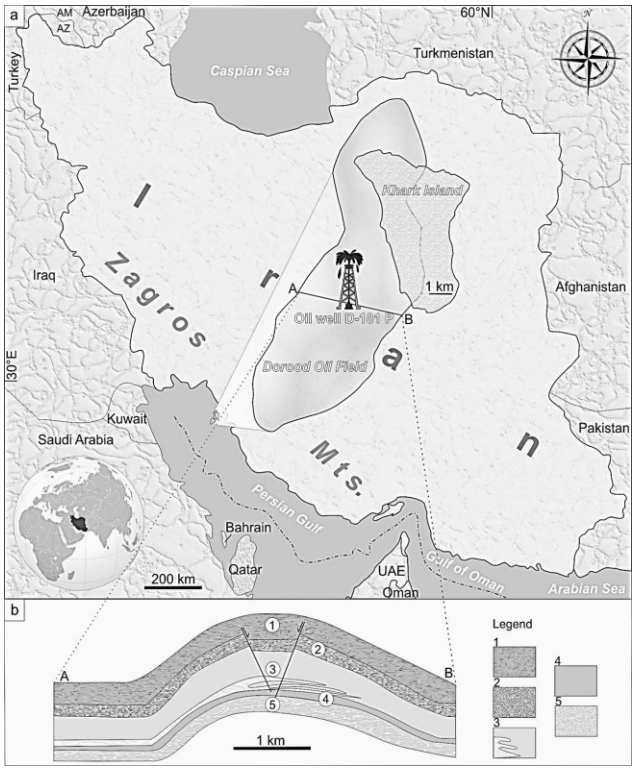

Fig 1. a, Location of the oil well X2 in the Dorood oil field, Persian Gulf, SW Iran. b, Simplified geologic cross-section of the Dorood Oil Field showing the members of the studied Fahliyan Formation. 1, Khami Member overlain by Gadvan Formation. 2, Upper Yamama Member. 3, Middle Yamama Member. 4, Manifa Member. 5, Hith Formation (Renaud and Gildas 2000).

2. Material and Methods

Iranian Offshore Oil Company (IOOC) provided 150 thin-sections from the oil well X2 for biostratigraphic study. The sampled intervals of the Fahliyan Formation range from 3736 m to 4171.5 m depth in oil well X2. The thickness is 435.5 m.

Taxonomic interpretations include generic attributions of the benthic foraminiferal taxa based on Loeblich and Tappan's (1987) classification; the latest classification of agglutinated foraminifera by Kaminski (2004) and the taxonomy of larger benthic foraminifera by Bou Dagher-Fadel (2008) supplemented by the algae publications (e.g. James and Wynd 1965; Gollesstaneh 1965; Kalantari 1975; Deini and Radoičić 1999; Husinec and Sokač 2006; Hosseini and Conrad 2008). Investigation of foraminifer and calcareous algal stratigraphic distribution led us to establish biozones and age determination of the Fahliyan Formation in the oil well X2, Dorood oil field in the Persian Gulf. Vertical distribution of determined taxa allowed identification of two foraminiferal and one algal biozones include the Pseudochrysalidina (Dokhania) arabica Acme Zone, Pseudocyclammina lituus-Coscinoconus Assemblage Zone, Salpingoporella annulata Range Zone.

3. Lithostratigraphy

In the oil well X2, the formation consists of a 435.5 m thick succession dominated by limestones with intercalated layers of clay stones deposited through Berriasian to Hauterivian. The Fahliyan Formation in the oil well consists of four members: Manifa, Middle Yamama, Upper Yamama, and Khami Member assigned to massive and thin-bedded limestone (Fig 2). The Lower Fahliyan/Yamama reservoir consists of carbonate with low clay content deposited in a ramp-type platform through Berriasian/Valangainian, whereas, the Upper Fahliyan consists of an alternation of claystone and limestone deposited during Hauterivian when abundant clastic influx invades the carbonate ramp (Hassani-Giv et al. 2016; Soleimani et al. 2017).

3.1. Manifa Member

The Manifa Member unconformably overlies anhydrite of the Late Jurassic Hith Formation. James and Wynd (1965) were among the first geologists to mention the presence of grey to brown, massive, oolitic to pellety limestone with minor brecciation in the basal portion of the Fahliyan formation. The member thickness in the oil well X2 is inferred as 55.5 m. It consists of a rhythmic pattern of brownish packstones and grainstones with recrystallized bioclasts, oolites and vuggy porosity. Vugs are usually completely filled with calcite. Vuggy porosity suggests reservoir -grade secondary porosity in the area (Rollinston et al. 2014).

3.2. Middle Yamama Member

This member directly overlies the Manifa Member. It consists of a 197.5 m thick succession dominated by brownish massive packstone/grainstone interbedded with chalky and argillaceous limestones with common ooids and bioclasts.

3.3. Upper Yamama Member

Upper Yamama Member attains a thickness of 101 m. It is composed of a rhythmic alternation of brownish and light beige lithoclastic mudstone/wackestone with sparry calcite matrix. Stylolites are noticeable. Styloacumulates marked by oil are rare.

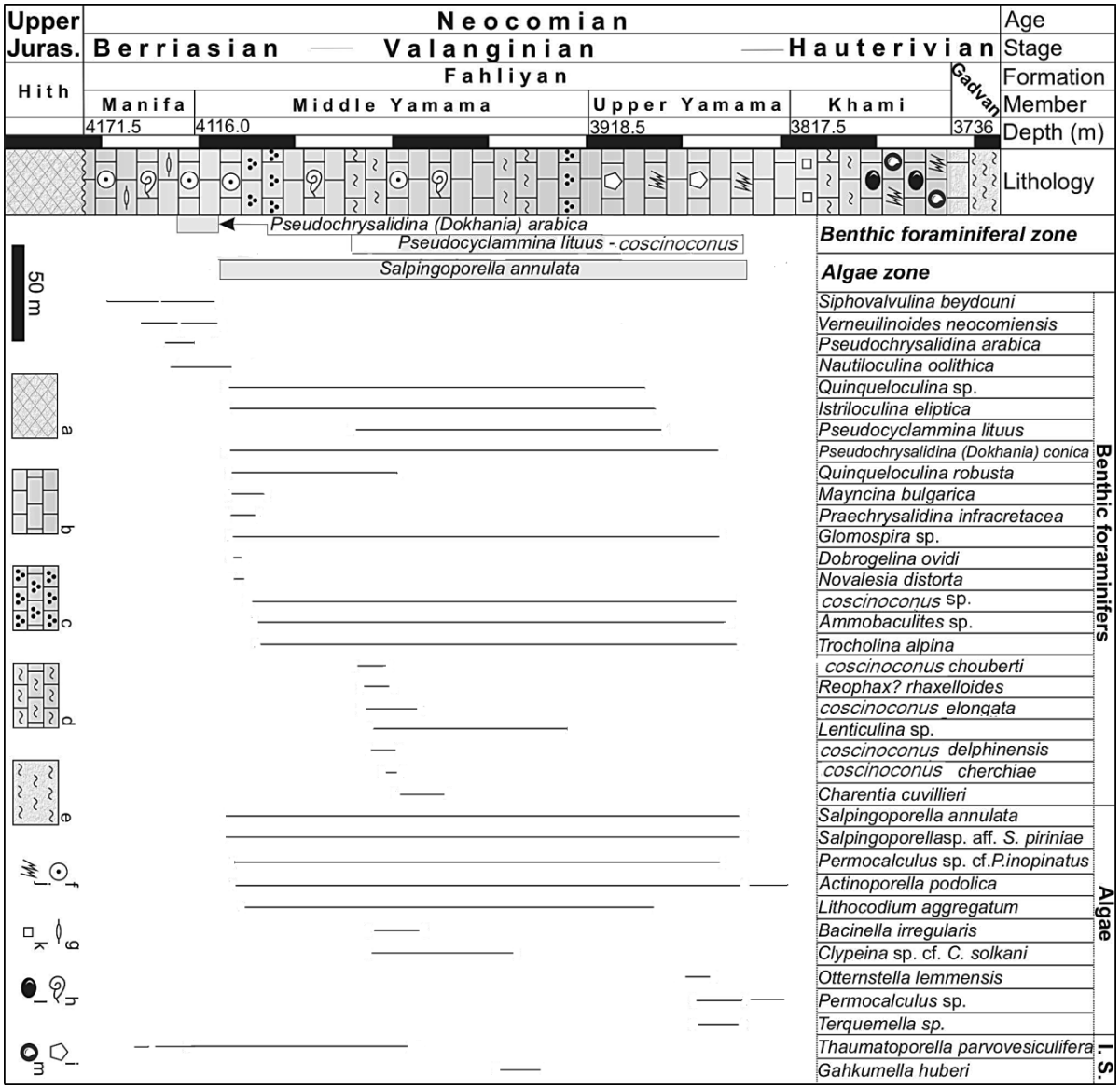

Fig. 2. Lithological column and biostratigraphy of the Neocomian deposits in the oil well X2, Dorood oil field, Persian Gulf, SW Iran. a anhydrite. b, limestones. c, chalky limestones. d, argillaceous limestones. e, marls. f, ooids. g, vugs. h, bioclasts. I, lithoclast. j, stylolite. k, pyrite. l, peloids. m, oil.

3.4. Khami Member

The Khami Member overlies the Upper Yamama limestones. At the base, there are pyritic and argillaceous limestones overlain by light grey and brownish wackestones and packstones with pelletoidal grains and pyrite laminae. The styloacumulates consist of oil. The thickness is 81.5 m. It is topped by brownish limestones and marls of the Gadvan formation. General sea-level rise allowed the establishment of a regional carbonate platform during the Neocomian (Jamalian et al. 2011). This was followed by progradation of the Fahliyan carbonate platform and finally deposition of the deeper marine Gadvan Formation (Adabi et al. 2010).

4. Biostratigraphy

Many palaeontological studies involving biostratigraphy of Neocomian shallow-water benthic foraminifera and algae were published during the last few decades (e.g. Gollesstaneh 1965; Conrad 1977, Jaffrezo and Renard 1979; Jaffrezo 1980; Bucur 1995; Ziegler 2001; Bucur et al. 2004; Ivanova and Kolodziej 2004; Bucur and Săsăran 2005; Dragastan et al. 2005; Husinec and Sokač 2006; Kobayashi and Vuks 2006; Krajewski and Olszewska 2007; Bruni et al. 2007; Hosseini and Conrad 2008; Parvaneh Nejad Shirazi 2008; Bou Dhager-Fadel 2008; Mosadegh and Shirazi 2009; Ivanova and Kolodziej 2010; Jamalian et al. 2011). All determined foraminifera in the oil well X2 are benthic, with a general dominance of agglutinated taxa (Fig 3): *Ammobaculites* sp., *Charentia*

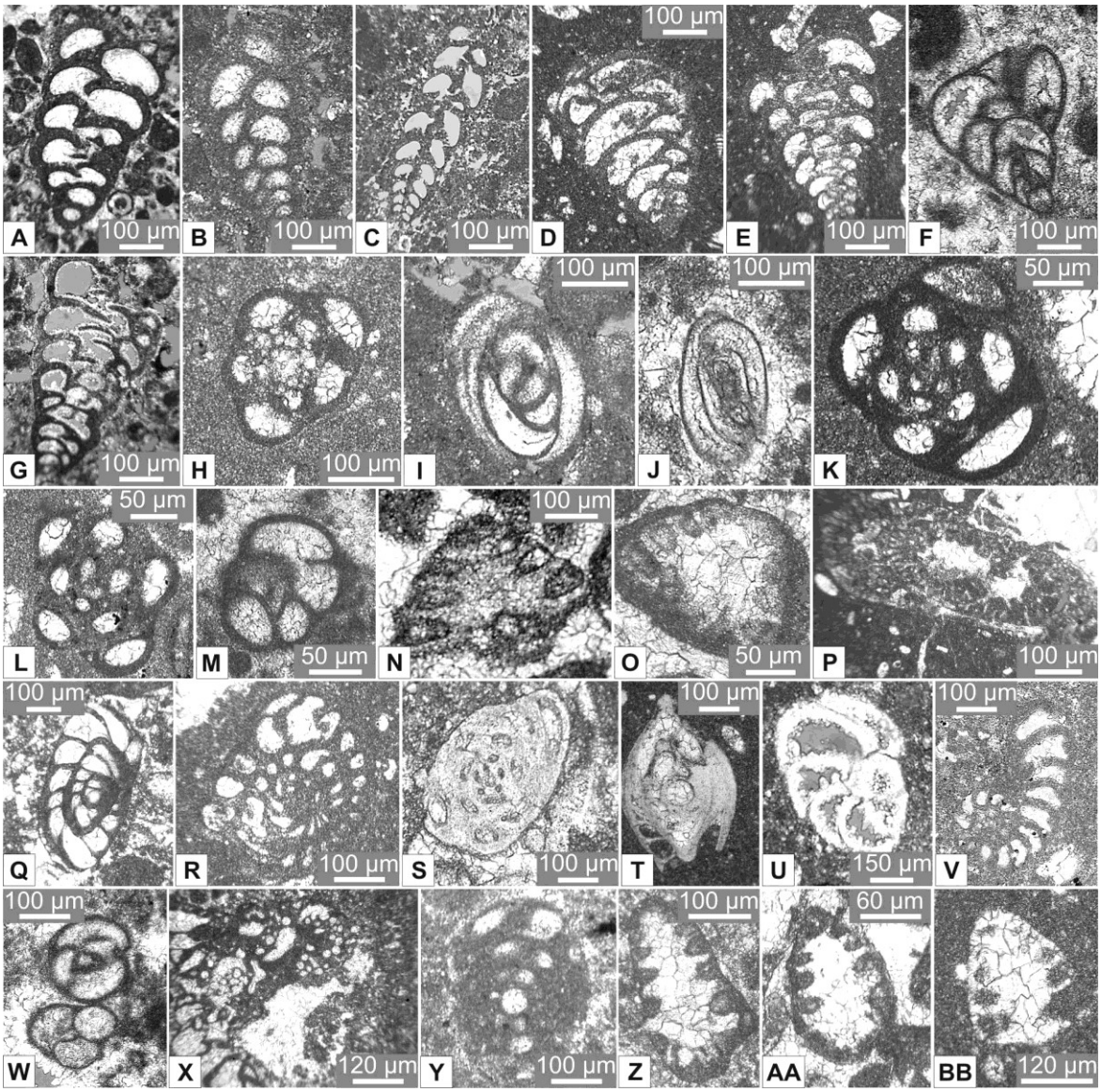

Fig 3. Thin-section photomicrographs of the determined benthic foraminifera from the Fahliyan Formation in the oil well X2, Dorood oil field, Persian Gulf, SW Iran. A, *Praechrysalidina* (*Dokhania*) *infracretacea*, sample 4112.40. B, *Pseudochrysalidina* (*Dokhania*) sp., sample 4110.80. C, *Siphovalvulina* sp., sample 4110.90. D, E, *Pseudochrysalidina* (*Dokhania*) sp. sample 4110.80. F, *Siphovalvulina beydouni*, sample 4114.50. G, *Pseudochrysalidina* (*Dokhania*) *arabica*, sample 4117.20. H, *Quinqueloculina robusta*, sample 4110.90. I, J, *Istriloculina elliptica*, I, sample 4111.54; J, sample 4109.40. K, L, Miliolids, sample 4108.84. M, *Dobrogelina ovidi*, sample 4109.40. N, *Coscinoconus* sp., sample 4105.20. O, *Coscinoconus* sp, sample 4105.20. P, *Pseudocyclammina lituus*, sample 3849.38. Q, R, *Mayncina* sp. cf. *M. bulgarica*, sample 4107.30. S, Unknown benthic foraminifer, sample 4112.40. T, U, *Lenticulina* sp., sample 4107.30. V, *Ammobaculites* sp., sample 3851.82. W, *Dobrogelina ovidi*, sample 4109.40. X, *Reophax*? *rhaxelloides*, sample 4108.84. Y, *Nautiloculina broennimanni*, sample 4105.20. Z, *Coscinoconus delphinensis*, sample 4004.50. AA, BB, *Coscinoconus elongata*, sample 4004.50.

cuvillieri Neumann, *Charentia evoluta* (Gorbatchik), *Dobrogelina ovidi* Neagu, *Eomarssonella paraconica* Levina, *Glomospira* sp., *Haplophragmoides joukowskyi* Charollais, Brönnimann & Zaninetti, *Haplophragmoides* sp., *Istriloculina elliptica* (Iovcheva), *Lenticulina* sp., *Mayncina bulgarica* Laug, Peybernès & Rey, *Nautiloculina broennimanni* Arnaud-Vanneau & Peybernès, *Nautiloculina cretacea* Arnaud-Vanneau & Peybernès, *Nautiloculina oolithica* Mohler, *Nautiloculina* sp., *Neotrocholina aptiensis* (Iovcheva), *Novalesia distorta* Arnaud-Vanneau, *Praechrysalidina* (*Dokhania*) *infracretcea* Luperto Sinni, *Praechrysalidina* sp., *Pseudocyclammina lituus* Yokoyama, *Pseudocyclammina* sp., *Pseudochrysalidina* (*Dokhania*) *arabica* Henson, *Pseudochrysalidina* (*Dokhania*) *conica* Henson, *Pseudochrysalidina*

(*Dokhania*) sp., *Quinqueloculina robusta* Neagu, *Quinqueloculina semisphaeroidalis* Danitsch, *Quinqueloculina* sp., *Reophax*? *rhaxelloides* Schlagintweit, Auer & Gawlick, *Siphovalvulina beydouni* BouDagher-Fadel & Noujaim-Clark, *Siphovalvulina* sp., *Textularia depravatiformis* Bielecka & Kuznetsova, *Textularia* sp., *Trocholina alpina* (Leupold), *Coscinoconus altispira* Henson, *Coscinoconus cherchiae* (Arnaud-Vanneau, Boisseau & Darsac), *Coscinoconus chouberti* Hottinger, *Coscinoconus campanella* Arnaud-Vanneau, Boisseau & Darsac, *Coscinoconus delphinensis* Arnaud-Vanneau, Boisseau & Darsac, *Coscinoconus elongata* (Leupold), *Coscinoconus histeri* Neagu, *Coscinoconus* sp., *Verneuilinoides neocomiensis* (Mjatliuk).

A total of 21 genera representing the suborders Ammodisina, Hormosinina, Lituolina, Spiroplectammina, Verneuilinina, Biokovinina, Nezzazatina, Orbitolinina, Textulariina, Involutinina, Miliolina and Lagenina were recognized in the benthic foraminiferal association.

The agglutinated benthic foraminifera are most frequent: the suborder Ammodiscina by the family Ammodiscidae (Glomospira); the suborder Hormosinina by the family Reophacidae (Reophax); the suborder Lituolina by the families Haplophragmoididae (Haplophragmoides) and Lituolidae (Ammobaculites); the suborder Spiroplectammina by the family Spiroplectamminidae (Novalesia); the suborder Verneuilinina by the family Prolixoplectidae (Eomarssonella) and Verneuilinidae (Verneuilinoides); the suborder Biokovinina by the family Charentidae (Charentia); the suborder Nezzazatina by essentially by two families: Mayncinidae (Mayncina), and Nautiloculinidae (Nautiloculina); the suborder Orbitolinina by two families: Pfenderinidae (Siphovalvulina, Dobrogelina) and Hauraniidae (Pseudocyclammina); the suborder Textulariina by the families Textularidae (Textularia) and Chrysalidinidae (Praechrysalidina, Pseudochrysalidina).

The calcareous group consists of aragonitic forms represented by the suborder Involutinina with the family Involutinidae (*Neotrocholina*, *Trocholina*) and porcellaneous forms that belong to the suborder Miliolina represented by the family Hauerinidae (*Istriloculina*, *Quinqueloculina*). The hyaline forms are scarce and belong to the suborder Lagenina, family Vaginulinidae (*Lenticulina*).

Algae are represented by *Actinoporella podolica* (Alth), *Bacinella irregularis* (Radoičić), *Clypeina* sp. cf. *C. solkani* Conrad & Radoičić, Dasycladaceae, *Lithocodium aggregatum* Elliott, *Otternstella lemmensis* (Bernier), *Permocalculus* sp. cf. *P. inopinatus* Elliot, *Permocalculus* sp., *Salpingoporella annulata* Carozzi, *Salpingoporella* sp. aff. *S. piriniae* Carras & Radoičić and *Terquemella* sp (Fig 4). Another group is incertae sedis represented by *Thaumatoporella parvovesiculifera* (Raineri) and *Gahkumella huberi* Zaninetti. Calcareous dinocysts are represented by *Comittosphaera sublapidosa* (Vogler) and *Stomiosphaera wanneri* Borza. The micropaleontological associations include both foraminifera and algae composed mostly of taxa with stratigraphic ranges through the Berriasian/Hauterivian.

5. Biostratigraphic zonation of benthic foraminiferal and algal assemblages

Benthic foraminifera and algae represent the main components in microfossil associations in the oil well X2. Agglutinated, calcareous and hyaline forms are recognized, giving a total of 21 benthic foraminiferal identified genera with an additional 8 algal genera. The foraminiferal and algal succession that ranges from Berriasian to Hauterivian is divided into three zones. One foraminiferal zonal division is based on the abundances of taxa, whereas in the other, assemblage composition is the determining factor. Algal zonal divisions are based on the total range of species. The recognized biozones span the Berriasian to Hauterivian interval. The definitions of abundance of *Pseudochrysalidina* (*Dokhania*) *arabica* and its upper boundary is coincident with the last appearance of this foraminifer.

Remarks: The zone is recovered at depths of 4123.5-4102.3 m. It consists of 21.2 m thick layers of packstones and grainstones with recrystallized bioclasts, oolites and vuggy porosity, which passes upwards into chalky limestones. It should be noted that the biozone extends through the upper part of the Manifa Member, but it is also represented in the base of the Middle Yamama Member. This zone is characterized by the presence of *Nautiloculina oolithica*, *Praechrysalidina* sp., *Pseudochrysalidina* (*Dokhania*) *arabica*, *Siphovalvulina beydouni*, *Siphovalvulina* sp. and *Verneuilinoides neocomiensis*. The algal assemblage of this zone includes *Lithocodium aggregatum* and incertae sedis *Thaumatoporella parvovesiculifera*.

Age and correlation: This zone is identical with the Pseudochrysalidina (Dokhania) arabica Zone of Shakib (1994) and Abyat et al. (2012, 2014). It corresponds to the lower part of the *P. lituus-Trocholina* Assemblage Zone No.14 of Wynd (1965) and the lower part of the *P. lituus-P.* (*Dokhania*) *arabica* Zone No.11 of Gollesstaneh (1965) (Fig 5). The age of this zone is assigned to the Berriasian.

5.1. *Pseudocyclammina lituus- Coscinoconus* assemblage zone

Definition: Biostratigraphic interval represented by the abundance of *Pseudocyclammina lituus* and *Trocholina* species.

Remarks: The zone is recovered at depths of 4036.7.3-3833.9 m. It consists of 202.8 m massive packstones and grainstones interbedded with chalky and argillaceous limestones with common ooids and bioclasts. The upper part of the zone is represented by lithoclastic mudstones and wackestones.

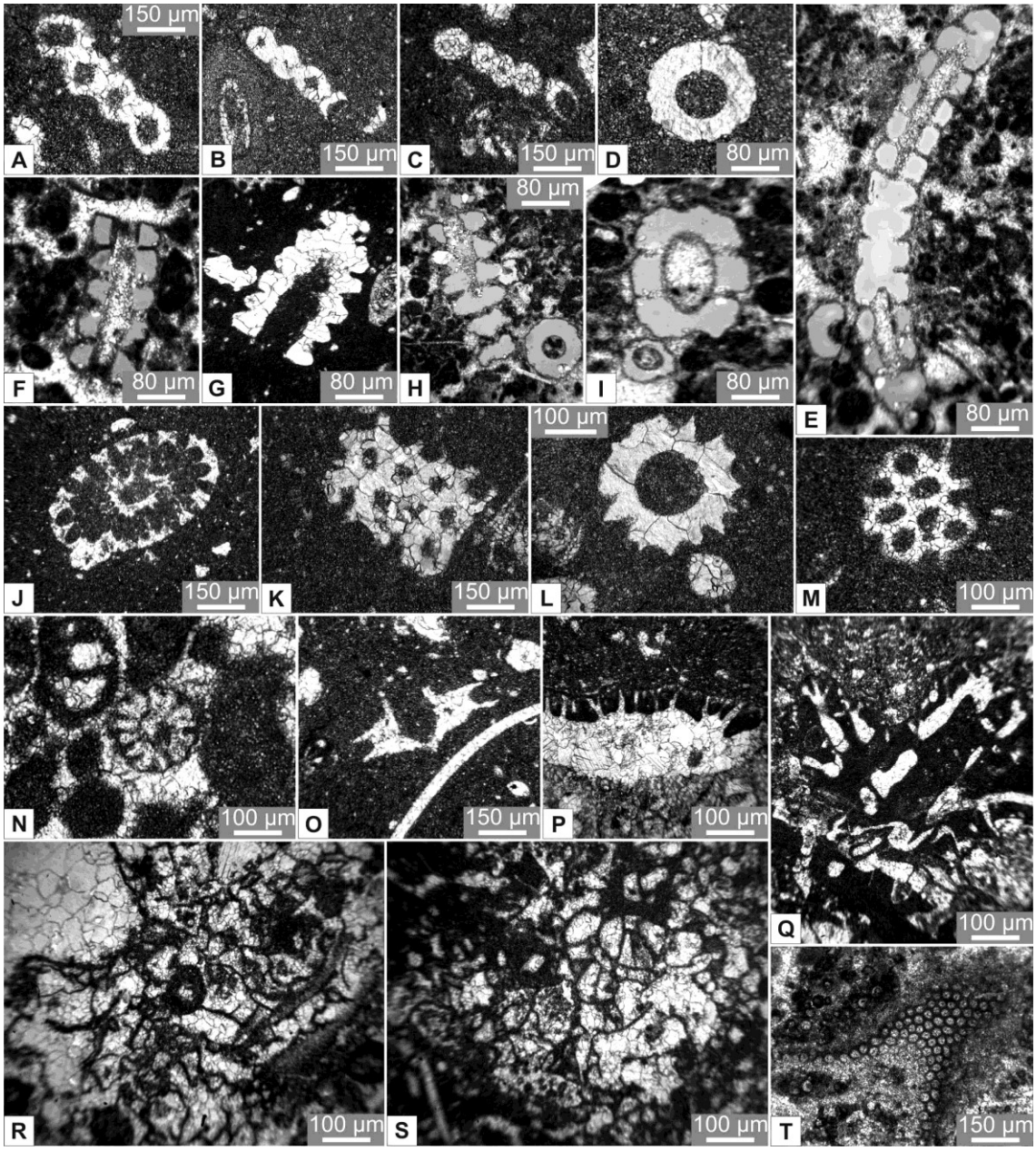

Fig 4.Thin-section photomicrographs of the determined algae and microproblematica from the Fahliyan Formation in the oil well X2, Dorood oil field, Persian Gulf, SW Iran. A-C, *Actinoporella podolica* (Alth), sample 3841.90. D-I, *Salpingoporella annulata* Carozzi, sample 4109.40. J, *Otternstella lemmensis* (Bernier), sample 3843. K, indet dasycladalean algae sample 3851.82. L, *Clypeina* sp. cf. *C. solkani* Conrad & Radoičić, 3841.90. M, Dasycladaceae, sample 4109.40. N, *Salpingoporella* sp. aff. *S. piriniae* Carras & Radoičić, sample 3841.90. O, *Actinoporella podolica* (Alth), sample 3841.90. P-Q, *Lithocodium aggregatum* Elliott, sample 3986.20. R-S, *Bacinella irregularis* (Radoičić), sample 4006.80. T, *Thaumatoporella parvovesiculifera* (Raineri), sample 4000.30.

The zone is widespread in both the Middle Yamama Member and the Upper Yamama Member. The assemblage of this zone is characterized by the abundant presence of *Pseudocyclammina lituus, Trocholina alpina, Trocholina altispira, Trocholina chouberti, Trocholina campanella, Trocholina delphinensis, Trocholina elongata,* and *Trocholina* sp. In addition to the species listed above, characteristic benthic foraminifers within this zone also include *Ammobaculites* sp., *Charentia cuvillieri*, *Glomospira* sp., *Istriloculina elliptica*, *Lenticulina* sp., *Mayncina bulgarica*, *Pseudochrysalidina* (*Dokhania*) *conica*, *Quinqueloculina robusta*, *Quinqueloculina* sp., *Reophax*? *rhaxelloides*. The algal assemblage of this zone contains *Actinoporella podolica*, *Bacinella irregularis*, *Clypeina* sp. cf. *C. solkani*, *Lithocodium aggregatum*, *Otternstella lemmensis* (Bernier), *Permocalculus* sp. cf. *P. inopinatus, Permocalculus* sp.,

Salpingoporella annulata, *Terqumella* sp. and incertae sedis Thaumatoporella *parvovesiculifera* and *Gahkumella huberi*.

Age and correlation: This zone is identical with the middle part of P. lituus-Trocholina Zone No.14 of Wynd (1965) and the middle part of *P. lituus* - *P.* (*Dokhania*) arabica Zone No.11 of Gollesstaneh (1965). It corresponds to the *P. lituus* Zone of Abyat et al. (2012, 2014) (Fig 5). The age of this zone is Valanginian-Lower Hauterivian.

5.2. Calcareous algal zone

4.1.2.1. *Salpingoporella annulata* range zone

Definition: Biostratigraphic interval represented by the total range of *Salpingoporella annulata*. Remarks: The zone is recovered at depths of 4103-3831.5 m. It consists of 271.5 m thick succession which extends through the Middle Yamama Member, but it is also represented in the Upper Yamama Member. Age and correlation: This zone corresponds to the S. annulata Zone by Yilmaz (1999). The age of this zone is assigned to the Berriasian-Lower Hauterivian.

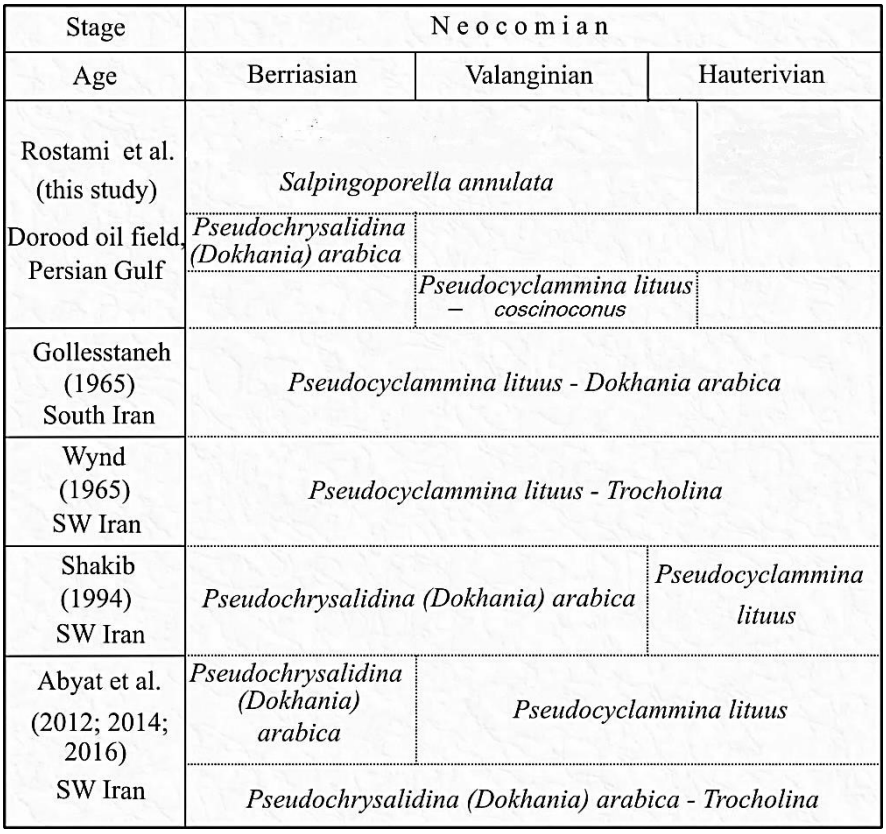

Fig 5. Proposed zonal scheme for the Neocomian Fahliyan Formation in the oil well X2, Dorood oil field, Persian Gulf, SW Iran compared with the coeval zones from South and SW Iran regions.

6. Conclusion

The Neocomian succession of the Fahliyan Formation in the oil well X2 includes four members from base to top: Manifa, Middle Yamama, Upper Yamama, and Khami. Detailed palaeontological investigations have yielded new data to establish the Neocomian benthic and algal biostratigraphy of the Persian Gulf in southwestern Iran.

The reservoir rock consists of mixed carbonate facies, including packstone, wackestone, and mudstone deposited under conditions between slope and carbonate platform edge localities (Masters et al., 1982). Forty-two species from 21 genera of benthic foraminifera and 10 species of calcareous algae from 8 genera were recovered from the oil well X2. Benthic foraminifera are especially abundant and along with calcareous algae are the most important fossils used for age determination of shallow-marine carbonate deposits. Agglutinated foraminifera are more typical and abundant than calcareous and hyaline forms in Neocomian deposits. Such trend continues through Barremian/Aptian (Carević et al. 2013).

The benthic foraminiferal assemblage belongs to the northern margin of the Alpine Tethys Ocean characterized by representatives of the genera *Ammobaculites*, *Charentia*, *Dobrogelina*, *Eomarssonella*, *Glomospira*, *Haplophragmoides*, *Istriloculina*, *Lenticulina*, *Mayncina*, *Nautiloculina, Neotrocholina*, *Novalesia*, *Praechrysalidina*,

Pseudocyclammina, *Pseudochrysalidina* (*Dokhania*), *Quinqueloculina*, *Reophax*, *Siphovalvulina*, *Textularia*, *Trocholina* and *Verneuilinoides*. Algae are represented by the genera *Actinoporella*, *Bacinella*, *Clypeina*, *Lithocodium*, *Otternstella*, *Permocalculus*, *Salpingoporella* and *Terqumella*. The stratigraphic range of foraminiferal and algal taxa had allowed recognition of three biozones covering the Berriasian/Hauterivian interval. These are the *Pseudochrysalidina* (*Dokhania*) arabica Acme Zone (Berriasian), *Pseudocyclammina lituus- Coscinoconus* assemblage zone (Valanginian-Lower Hauterivian), *Salpingoporella annulata* range zone (Berriasian-Valanginian).

Based on micropaleontological data from the oil well X2 the ages of the Fahliyan Formations have been determined Fahliyan Formation is of Berriasian and Valanginian age. The high-diversity benthic and algal foraminiferal assemblages from the Fahliyan Formation of Persian Gulf reveal a strong similarity to the Zagros Basin from the SW Iran. Particularly comparable with Hosseini and Conrad (2008) In Kuh-e-Surmeh.

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