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Crustacean microcoprolites from Lower Cretaceous and Oligo-Miocene deposits, Persian Gulf, Iran

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ABSTRACT: Biostratigraphical observations in different locations and horizons of carbonate strata from four oil wells drilled in the Persian Gulf Basin document three new ichnospecies of crustacean microcoprolites. *Favreina irannensis* n. sp. occurs in Valanginian–Hauterivian strata of the Buwaib Formation (Gadvan Formation), *Palaxius asmariensis* n. sp. in the Lower Miocene strata of the Asmari Formation, and *Palaxius minaensis* n. sp. in the Aptian strata of the Dariyan Formation.

KEYWORDS: *microcoprolites; Lower Cretaceous; Persian Gulf; Palaxius; Favreina*

INTRODUCTION

Records of crustacean microcoprolites from Iran, especially in the Persian Gulf are scarce. Brönnimann (1977) described *Favreina tabasensis* from the Upper Jurassic of the Tabas area of Iran. Around the world generally crustacean microcoprolites have been reported by several authors from the Palaeozoic to Cenozoic. For example, *Favreina carpatica* was described by Senowbari-Daryan *et al*. (2013) from the Middle Jurassic of the southern Carpathians. From Neocomian strata, Brönnimann (1976) revised *Favreina salevensis* Paréjas, 1948. In addition, faecal pellets have been reported from the Oligocene of Turkey by Altinli (1942), from the Jurassic of Switzerland by Joukowsky & Favre (1913), from the Mesozoic of France by Cuvillier & Sacal (1956), from the Upper Jurassic and Lower Cretaceous of Cuba by Paréjas (1948) and Brönnimann (1955), and from the Triassic to Miocene of the Middle East by Elliott (1962, 1963). A circular cross-section with tiny spherical, hook-shaped and crescentic canals that are regularly arranged are important characteristics of microcoprolites. Variety of arrangement, number and shape of internal longitudinal canals permit separation of forms such as *Favreina* Brönnimann, 1955, *Palaxius* Brönnimann & Norton, 1960 and *Parafavreina* Brönnimann, 1972. Among Decapoda crustaceans, four families are known that produce microcoprolites: Galatheidae, Thalassinidae, Upogebidae and Callianassidae (Moore, 1932, 1933; Blau *et al*., 1993). Recently, well-preserved microcoprolites produced by decapod crustaceans were identified (Senowbari-Daryan *et al*., 2009). The ichnogenus *Palaxius* embraces 22 ichnospecies, from the Permian to Tertiary, which were listed with their morphological characteristics in Senowbari-Daryan & Kube (2003). The genus is recognized for the first time from the Carboniferous, *Palaxius salataensis* (Masse & Vachard, 1996), and ranges up to the Miocene (Paganelli *et al*., 1986). This study is focused on the introduction and description of new crustacean microcoprolites that have not been reported previously from the Persian Gulf region.

GEOLOGICAL SETTING AND STUDIES

The Persian Gulf Basin is situated between the Arabian Shield in the west, Taurus Mountains in the north and the Zagros Orogenic Belt in the east and NE (Konyuhov & Maleki, 2006). The samples containing microcoprolite ichnofossils were collected from different stratigraphic locations and horizons of four oil fields from the Persian Gulf (Fahliyan Formation from the SR field, Dariyan Formation in the CR field, Buwaib Formation in the WI–W7 Field, and the Asmari Formation from the AB field; Fig. 1). The detailed lithologies of these formations are given below.

In the SR field, the microcoprolites were found only in the Fahliyan Formation, which consists of limestone interbedded with argillaceous limestone, marl, and thin layers of dolomite at approximately 53.20 m depth. The ichnogenus *Favreina* is associated with foraminifera: *Everticyclammina, Permocalculus, Actionoporella, Pseudolitunella, Charentia, Trocholina, Mayncina, Nautiliculina, Derventina, Glomospirella* and miliolids. The abundance of algal fragments in intervals of this limestone indicates the presence of an algal mound formed in the inner ramp region.

The Dariyan Formation in the CR Field consists of 44 m of shallow-water limestone formed on the inner to mid-ramp, with marl and argillaceous limestone from an open marine environment. The microcoprolites in this interval occur in two distinct types of microfacies: ‘bioclastic wackestone–mudstone’ which belongs to the outer ramp, and ‘boundstone’ and ‘bioclastic-Orbitolina wackestone–mudstone’ facies that have been referred to the inner ramp depositional environment. In the first microfacies, foraminifera of *Hedbergella* species, *Globigerinelloides, Neotrocholina, Mesorbitolina, Choffatella* and *Epistomina* are present. Most of the foraminifera present belong to the outer ramp environment. The second microfacies contains benthic foraminifera *Archaeoalveolina, Nezzazata, Pseudocrysalidina, Salpingoporella, Voloshinoides, Nezzazata, Nezzazatinella* and *Praechrysalidina* and algae such as *Lithocodium* and can be assigned to the inner ramp environment. It is noteworthy that according to Feldmann *et al*. (2007) the microcoprolites present in the Dariyan Formation belong to blind decapods (lack of eyes as in *Tricarina* sp.), adapted to an aphotic and open-marine deep-water environment that is represented by Barremian–Aptian strata of the Zagros area.

In WI–W7 Field, a 58 m thick sequence of Buwaib Formation of late Neocomian age is considered to be a shallow-water

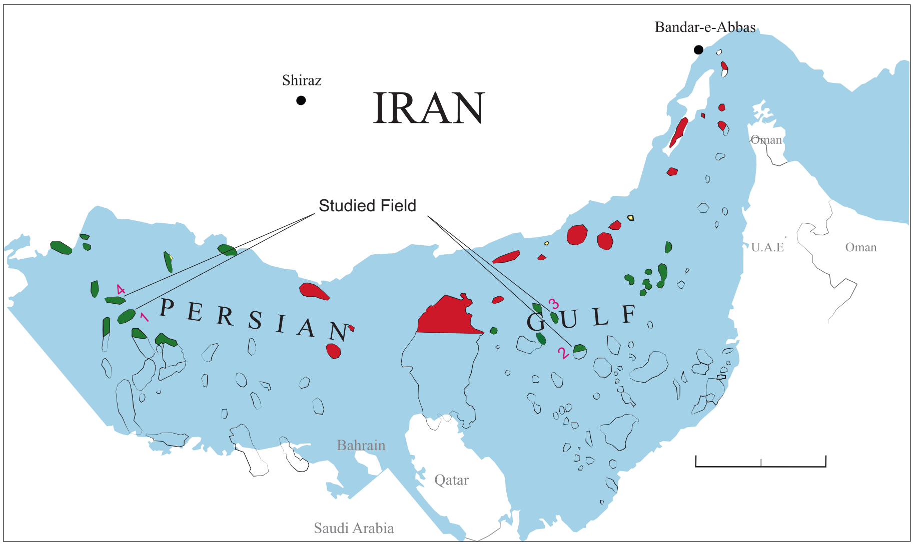


Fig. 1. Location map of the studied fields in the Persian Gulf: (1) SR, (2) CR, (3) WI–W7 and (4) AB.

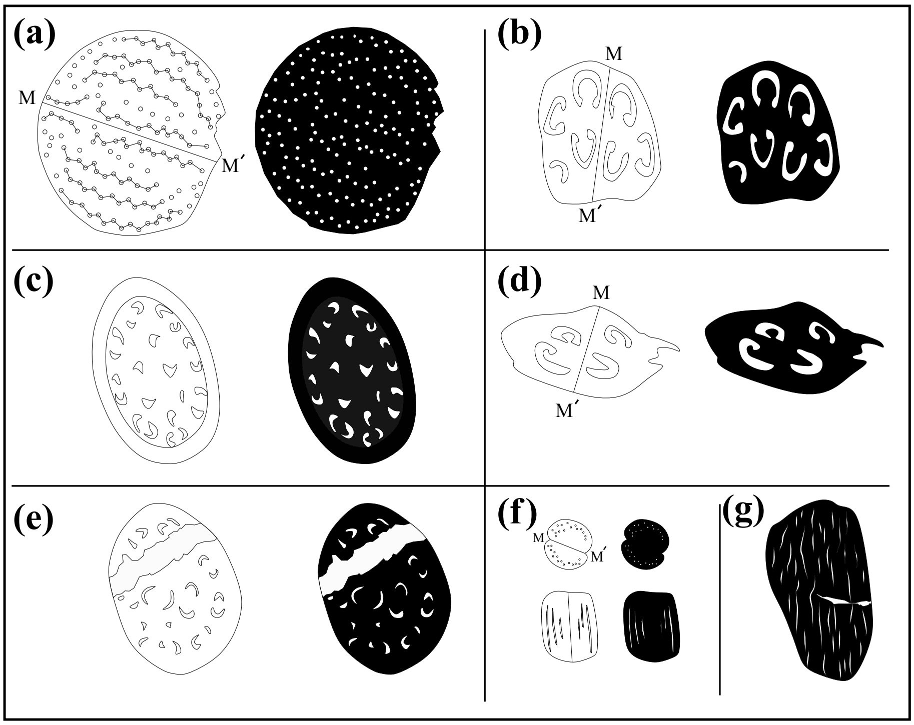
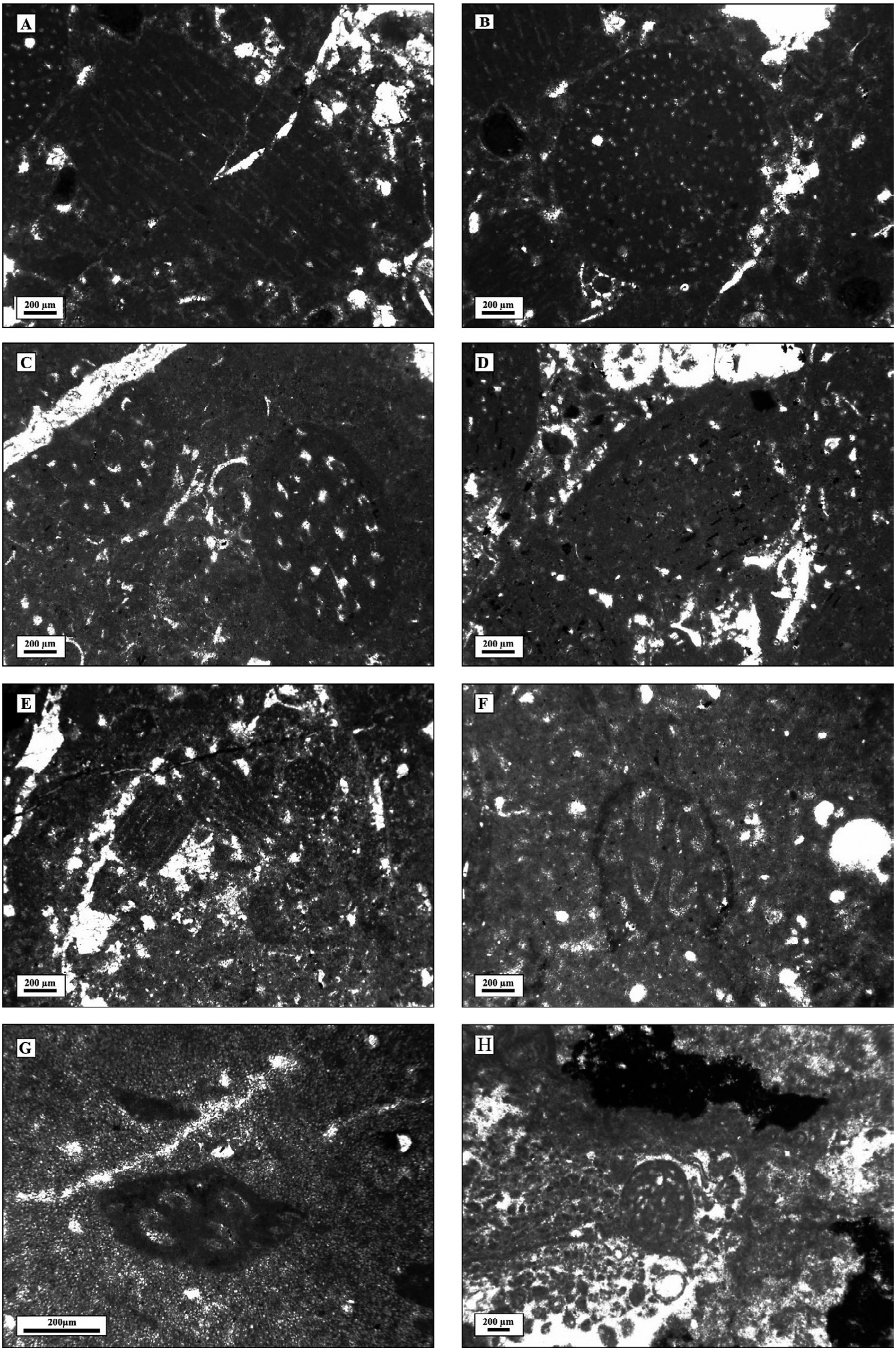


Fig. 2. Schematic diagrams of microcoprolite and mirror plan of symmetry (M&M′): (**a**, **g**) *Favreina iranensis* n. sp.; (**b**) *Palaxius asmariensis* n. sp.; (**c**, **e**) *Palaxius minaensis* n. sp.; (**d**) *Palaxius* sp.; (**f**) *Favreina* sp.

Fig. 3. Photomicrographs of thin sections of studied crustacean microcoprolites. (**a**, **b**) *Favreina iranensis* n. sp.: (a) holotype, longitudinal section and (b) transverse section, WI–W7 field, depth 2475.05 m, Buwaib Formation. (**c**) *Palaxius minaensis* n. sp., holotype, CR field, depth 1552.30 m, Dariyan Formation. (**d**) *Favreina iranensis* n. sp., paratype, WI–W7 field, depth 2471.21 m, Buwaib Formation. (**e**) *Favreina* sp., SR field, depth 2759.77 m, Fahliyan Formation. (**f**) *Palaxius asmariensis* n. sp., holotype, AB field, depth 864.05 m, Asmari Formation. (**g**) *Palaxius* sp. AB field, depth 858.80 m, Asmari Formation. (**h**) *Palaxius minaensis* n. sp., paratype, CR field, depth 1575.90 m, Dariyan Formation.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bioclastic limestone and argillaceous limestone. Based on sedimentological and micropaleontological studies of the Buwaib Formation and the presence of foraminifera such as *Clypeina, Actinoporella* and *Trocholina*, calcareous sponge spicules, and dasyclad algal fragments, the 'foram algal debris wackestone' and 'peloid bioclastic packstone to grainstone' microfacies can be assigned to lagoonal and back shoal environments (that is the sections containing *Favreina*).

The Asmari Formation in the AB Field, about 39 m thick, is highly variable and consists of anhydritic dolomite, anhydrite, argillaceous limestone, dolomitic limestone, dolomite, limestone, limy dolomite, sandy dolomite and shale. The microfacies (of the interval containing *Palaxius*) includes two types: the 'Microbialite' and 'Coated grain Packstone–Grainstone' facies that can be referred to lagoonal and back shoal depositional settings, respectively. The microbialite facies is dominated by microbial structures that were produced by microbial processes in shallow-water environments. In this microfacies, lagoonal foraminifers such as *Dendritina, Elphidium, Rotalia* and *Archaias* are found. The second microfacies is a back shoal setting.

Thus, microcoprolite ichnofossils in these four different locations are generally located in lagoonal and back shoal environments. Only in the Aptian (Dariyan Formation) are microcoprolites observed in both lagoonal and open marine environments.

SYSTEMATIC PALAEONTOLOGY

Material is deposited in the collections of the National Iranian Oil Company, Tehran.

Class **Crustacea** Pennant, 1777
Order **Decapoda** Latreille, 1802
Infraorder **Thalassinidea** Latreille, 1831
Superfamily **Thalassinoidea** Latreille, 1831
Ichnofamily **Favreinidae** Vialov, 1978
Ichnogenus *Favreina* Brönnimann, 1955

Favreina iranensis n. sp.
(Figs 2a, g and 3a–b, d)

Origin of the name. From the occurrence of the coprolite in Iran.

Holotype. Thin section WI–W7/B 2475.05 (Fig. 3a–b).

Paratypes: Thin sections WI–W7/B 2475.05, WI/B 2471.21 (Fig. 3d).

Type locality. WI–W7 Oil Field, Persian Gulf, Iran (Fig. 1, location 3).

Type stratum: Upper Neocomian (Valanginian–Hauterivian) limestone of Buwaib Formation.

Description and dimensions. *Favreina* Brönnimann, 1955 is characterized by the numerous longitudinal canals arranged bilaterally in a symmetrical plane.

Favreina iranensis n. sp is represented by transverse and longitudinal sections (Figs 2a, g and 3a, b). The diameter of the transverse section is 600 µm and the length of the longitudinal section is about 900 µm. The ichnospecies is penetrated by 165 longitudinal canals with an average diameter of about 15 µm. Internally it has canals arranged in bilaterally symmetrical zigzag microstructures. Generally, four curved rows are visible in lateral cuts and some erratic pores are located among them. The length of the curved series increased from the centre of the microcoprolite towards the periphery. These zigzag lines are converted to straight lines towards the axis of symmetry (M, M′). Also, a pair of hook-shaped curved canal sets is seen (on the M axis). Each row consists of approximately 15–19 channels (Fig. 2a, g).

Comparisons. *Favreina tabasensis* Brönnimann, 1977 was described from the Upper Jurassic of the Tabas area, eastern Iran. There are some similarities and differences between this species and *F. iranensis* n. sp.: the number of curves and canals (4 curves and 113 canals in *F. tabasensis* and 5 curves and 165 canals in *F. iranensis* n. sp.), the diameter of the canals (25 µm in *F. tabasensis* and nearly 15 µm in our new species), the form of the curves (curves in *F. tabasensis* are completely zigzag form but in *F. iranensis* n. sp. the sides are smooth) are some of these differences. Also, *Favreina salevensis* Paréjas, 1948 differs with regard to the shape of the curves and diameters of the canals in cross-section (range from about 23 to 39 µm), that is larger than in the new species. Based upon the above-mentioned features and special characteristics we introduce *Favreina iranensis* n. sp.. In the Buwaib Formation the new ichnospecies is associated with foraminifers *Pseudocyclammina, Pseudochrysalidina* species, *Praechrysalidina, Trocholina* species and Neocomian index algae like *Salpingoporella* species and *Actinoporella*. A Valanginian–Hauterivian age is assigned to this assemblage.

Favreina sp.
(Figs 2f, 3e)

Remarks. The size of this species is smaller than in *Favreina iranensis* n. sp.. It is impossible to determine the original shape and number of canals of this form properly due to the poor preservation. It has a spherical shape with two depressions at the poles (Fig. 2f). The transverse section is about 200 µm in diameter and the length of the longitudinal section is nearly 400 µm. The general arrangement of the longitudinal canals as seen in the transverse section (Fig. 2f) is nearly zigzag, but the central part of the coprolite is not clear.

Ichnogenus *Palaxius* Brönnimann & Norton, 1960
Palaxius minaensis n. sp.
(Figs 2c, d and 3c, h)

Origin of the name. Fom the Iranian name of a black bird (Mina), after the occurrence of the coprolite.

Holotype. Thin section Cr/D 1552.30 (Fig. 3c).

Paratype. Thin section Cr/D 1575.90 (Fig. 3h).

Type locality. CR Oil Field. Persian Gulf, Iran (Fig. 1, location 2).

Type stratum. Aptian age medium- to thick-bedded limestone and argillaceous limestone of the Dariyan Formation.

Description and dimensions. This microcoprolite has an oval outline and a cross-section of 500 to 800 µm in diameter. Canals in this species are crescent-shaped and consist of 22 in number (e.g. eleven binary groups) (Fig. 2c, e). The lengths of the longitudinal canals are from 50 to 90 µm and widths approximately 25 µm. An axial imaginary plane divides these canal sets into two asymmetrical parts that may be due to depositional pressure. These longitudinal canals are arranged in 11 bilaterally symmetrical groups of 22 canals. The eight groups located at the periphery of the specimen and the rest are scattered in the centre. A characteristic feature of this species is a dark margin around canals in transverse section.

Comparisons. It is noteworthy that *Palaxius asmariensis* n. sp. is different from *Palaxius minaensis* n. sp. in the hook-shape of the longitudinal canals in transverse section and in their number. *P. minaensis* n. sp. is also different from *P. mendozaensis* Kietzmann, 2009 with 12 longitudinal hook-shaped canals. The new ichnospecies is associated with foraminifera *Hedbergella, Choffatella, Epistomina* and *Globigerinelloides* sp. of Aptian age.

Palaxius asmariensis n. sp.
(Figs 2b and 3f)

Origin of the name. After the occurrence of the new coprolite ichnospecies in the Asmari Formation.

Holotype. Thin section Ab/A 864.05 (Fig. 3f).

Paratype. Thin section Ab/A 864.05 (Fig. 2b).

Type locality. AB Field, Persian Gulf, Iran (Fig. 1, location 4).

Type stratum. Limestone and sandy limestone of the Asmari Formation, Lower Miocene.

Description and dimensions. The ichnospecies *Palaxius asmariensis* n. sp. is characterized by the presence of longitudinal canals with hook-shaped outline, arranged bilaterally to a symmetrical plane (Brönnimann, 1972). This species has a diameter of about 600 to 700 µm in transverse section.

P. asmariensis n. sp. has seven internal canals, six of them are symmetrical around the plane M, M′ (Fig. 2b). Probably half of these additional canals were lost due to pressure and depositional deformation. Thus, there is strong likelihood that this species had 8 canals. The length and width of the canals are 300 µm and 30–50 µm. They are orientated at 30° (a, a′) and 90° (b, b′) from the bilaterally symmetrical plane.

Comparisons. *P. asmariensis* n. sp. is differentiated from all other *Palaxius* (e.g. *P. caracuraensis* Kietzmann, 2009, *P. azulensis* Kietzmann, 2009, *P. decaochetarius* Palik, 1965) by the orientation and number of canals. Although the position of the canals in this species is approximately similar to *P. decemporatus* Senowbari-Daryan, 1979, their number and shape are different. Also, *P. hydranensis*, described by Senowbari-Daryan & Kube (2003) from the Triassic of Greece, is distinct in the number and shape of canals.

Palaxius sp.
(Figs 2e and 3g)

Remarks. The diameter of this species is about 250 to 350 µm. Although it is possible to observe four canals in the symmetrical plane, it seems that this species is similar to *Palaxius asmarensis* described above. Canals are 100 µm in length and 25–30 µm in width. Senowbari-Daryan *et al*. (2009) recognized *P. caucaensis* Blau *et al*., 1995 in the Upper Cretaceous of Egypt, which is similar to this species in the number and orientation of the canals (Fig. 2e). Due to poor preservation this species could not be referred to a specific form.

SUMMARY AND CONCLUSIONS

Records of crustacean fossils from Iran are extremely scarce, thus, assigning the ichnospecies introduced above to a genus of crustaceans is difficult. *Portunus withersi* (Glaessner, 1933) and *Cancer craniolaris* (Linnaeus, 1758) are two of the reported decapod crustacean species occurring only in the Middle Miocene of southern Iran (cited in Heidari *et al*., 2012 and Yazdi *et al*., 2013) so the ichnogenus *Palaxius* material described here from the Lower Miocene could not be referred to these decapods. At the present time, the ichnogenus *Palaxius* is thought to have been produced by *Callianassa* and *Protocallianassa* (Moore, 1939; Blau & Grün, 2000), while the ichnogenus *Favreina* belongs to the Thalassinidae family. Three ichnospecies that were described in this article, *Palaxius asmariensis* n. sp., *Palaxius minaensis* n. sp. and *Favreina iranensis* n. sp., are recorded for the first time from the Persian Gulf.

Using microcoprolites to determine the age and correlation of host sediments is doubtful and they cannot be considered good indices. However, Kietzmann *et al*. (2009) differentiated two microcoprolite assemblages in time, one from the Tithonian to early Valanginian and another from the early to late Valanginian. In this study, from detailed benthic foraminifera and other micropalaeontological analyses, the Early Miocene age for the Asmari Formation microcoprolites was determined. Also based upon foraminifera and algae a Neocomian (Berriasian–Valanginian age) for the Fahliyan Formation, a Valanginian–Hauterivian age for the Buwaib Formation, and an Aptian age for the Dariyan Formation were confirmed.

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