# Decapod crustaceans from the lower Miocene Qom Formation of the Isfahan area, Central Iran

## *Crustáceos decápodos de la Formación Qom del Mioceno inferior en el área de Isfahan, Irán central*

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## ABSTRACT

From the lower Miocene (Burdigalian) of the Qom Formation, exposed in three sections (Kuh-e-Donbeh, Bagher-Abad, and Vartun) in Central Iran, a decapod crustacean assemblage is described. The specimens exhibit two modes of preservation: carapaces (either isolated or with attached appendages) and isolated cheliped elements. All studied specimens are fractured and/or eroded. Based on this moderately preserved material, three brachyuran crab taxa are identified, including *Mursia* cf. *lienharti* (Bachmayer, 1962), *Palaeocarpilius rugifer* Stoliczka, 1871, and *Necronectes* sp. The occurrence of *P. rugifer* represents the youngest confirmed occurrence of the species, whereas other two taxa represent the first confirmed Iranian occurrences of respective genera. This report enriches our knowledge on Miocene decapod assemblages of Iran, and thus helping to better understand the decapod migratory patterns along the Tethyan Seaway.

**Keywords: Brachyura, early Miocene, Qom Formation, Isfahan, Central Iran.**

## *RESUMEN*

*Se describe un conjunto de crustáceos decápodos correspondientes a la Formación Quom del Mioceno inferior (Burdigaliano) en tres regiones de Irán central (Kuh-e-Donbeh, Bagher-Abad y Vartun). Los especímenes exponen dos modos de preservación: caparazones (ya sea aislados o con apéndices adheridos) y elementos aislados quelípedos. Todos los ejemplares aquí estudiados están fracturados o erosionados. Con base en este material moderadamente conservado, se identificaron tres taxones de cangrejos braquiuros incluyendo Mursia cf. lienharti (Bachmayer, 1962), Palaeocarpilius rugifer Stoliczka, 1871 y Necronectes sp. Además, P. rugifer es el indicio confirmado más reciente de esta especie, mientras que los otros dos taxones son las primeras muestras iranías en estos respectivos géneros. Este informe enriquece nuestro conocimiento sobre los conjuntos de decápodos del Mioceno en Irán, lo que contribuye a una mejor comprensión sobre los patrones migratorios de decápodos a lo largo de la vía marítima de Tetis.*

***Palabras clave: Brachyura, Mioceno temprano, Formación Qom, Isfahan, Irán central.***

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## 1. Introduction

Number of studies on fossil decapod crustaceans of Iran were published in the last fifteen years. For such a geologically diverse country, this is, however, still insufficient and the knowledge on the decapod fossil record of Iran remains poor. The first report of fossil decapods was that by Förster and Seyed-Emami (1982) on an erymid lobster from the Middle Jurassic of northern Iran. Cretaceous decapods were discussed by McCobb and Hairapetian (2009), Yazdi *et al.*, (2009, 2010), Jagt *et al.*, (2014), and Bahrami *et al.*, (2020); the alleged lobster of uncertain affinities described by Feldmann *et al.*, (2007) was later reinterpreted to be an isopod (Hyžný and Zorn, 2020). Cenozoic decapod occurrences from Iran include those from Eocene and Miocene strata. Eocene decapods were reported by Garassino *et al.*, (2014) and Khodaverdi Hassan-vand *et al.* (2016). The first report on Miocene decapod crustaceans of Iran was an abstract by Torabi and Yazdi (2002), presenting a portunid crab from the Isfahan area. Much more attention was dedicated to Miocene decapod assemblages from the Mishan Formation (Vega *et al.*, 2010a, 2012; Heidari *et al.*, 2012; Hyžný *et al.*, 2013; Yazdi *et al.*, 2013; Key *et al.*, 2017). The present study focuses on description of decapods from the lower Miocene of the Qom Formation exposed in the Isfahan area.

## 2. Geological setting

Oligo-Miocene deposits of the Qom Formation are located in the Sanandaj–Sirjan fore-arc basin, Urumieh-Dokhtar magmatic arc (UDMA) (intra-arc basin) and Central Iran back-arc basin. Deposition occurred during the final sea transgression of the Iranian Plate. The extensive shallow to open marine succession of the Qom Formation includes shallow-marine limestones and fossiliferous marl, with subordinate evaporites, and extends throughout Central Iran (Rahimpour-Bonab and Kalantarzadeh, 2005). The thickness of the Qom Formation varies from area to area. Active tectonics led to the formation of complicated local tectonic movements with erosional faces which influenced the lateral thickness in the Qom Formation and produced facies variations (Poroohan *et al.*, 2009; Jalali and Feizi, 2010). Because of the major facies changes of the Qom Formation, no stratotype section has been introduced for it, but the Qom area (located approximately 100 km south of Teheran) is proposed as its type area (Rahimzadeh, 1994; Aghanabati, 2006; Mohammadi *et al.*, 2011, 2013). The studied sections (Kuh-e-Donbeh, Bagher-Abad, and Vartun) are situated in the Isfahan area (Figure 1A) in the Isfahan-Sirjan fore-arc Basin.

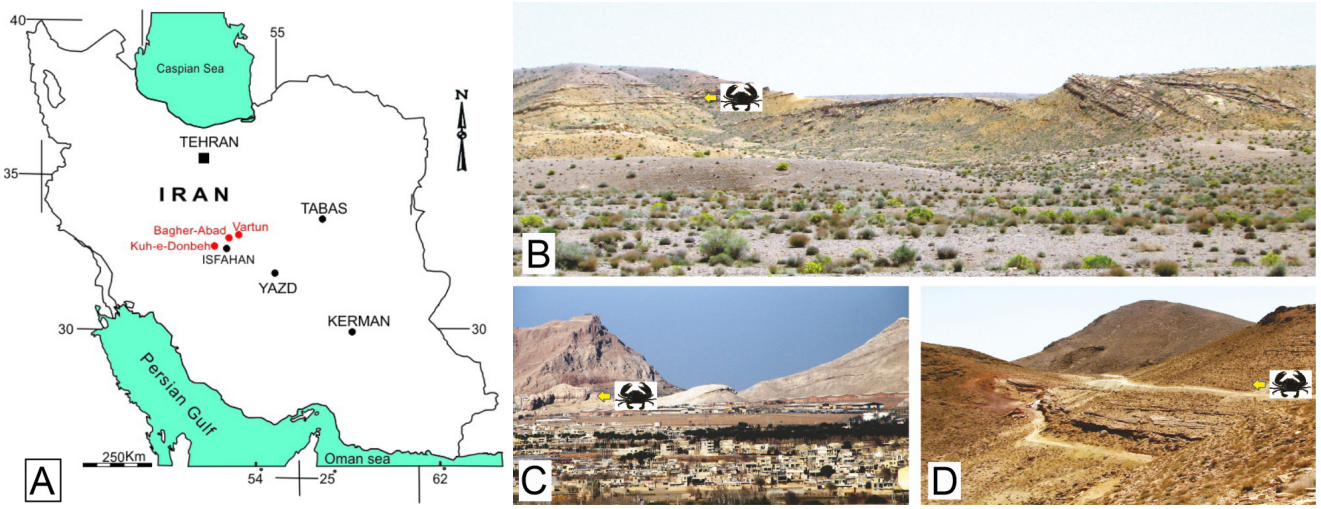


**Figure 1** Study area with indication of decapod-bearing levels (indicated with icons and arrows). A. Geographical map of Iran with the position of the studied sections in Isfahan area. B. Vartun section, C. Kuh-e-Donbeh section, D. Bagher-Abad section.

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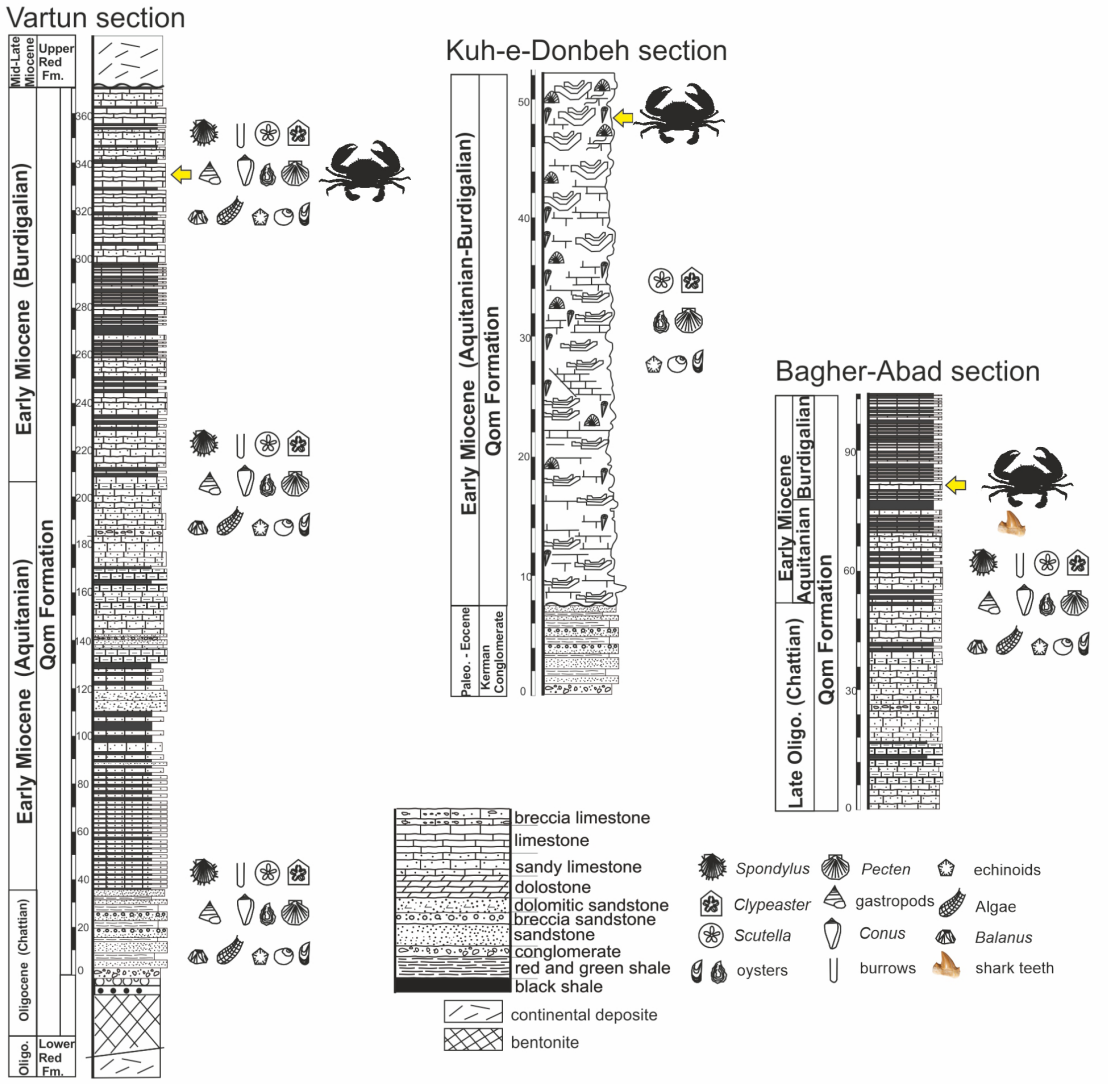


**Figure 2** **Lithostratigraphic columns of the studied sections with indication of decapod-bearing levels (indicated with icons and arrows).**

The Kuh-e-Donbeh section (Figure 1C; GPS co-ordinates: 32° 35′ 36″ N; 51° 34′57″ E) is located in the residential part of the Isfahan city, along the Soffeh Mountain close to the Dorcheh district. The section exposes 50 m of reefal limestone with marl interbeds, and locally with colonial and solitary corals (Figure 2). Foraminifers *Lepidocyclina* sp., *Amphistegina* sp., *Neoalveolina melocurdica, Peneroplis evolutus, Dentritina rangi, Meandropsina anahensis, Acervulina* sp., and *Archaias* sp. indicate Aquitanian-Burdigalian age.

The Bagher-Abad section (Figure 1D; GPS co-ordinates: 32° 59′50″ N; 52° 02′47″ E) is located ca. 55 km north of Isfahan, along the Isfahan-Ardestan road. The section was studied by Yazdi *et al*., (2012) and Nouradini *et al*., (2015). In the section, grey-yellow to yellow-white highly fossiliferous marls and fossiliferous argillaceous to sandy limestones are exposed (Figure 2). The fossils, among others, include coralline red algae (*Lithophyllum* sp., *Lithothamnium* sp.), molluscs (*Spondylus* sp., *Turritella* sp.), and echinoderms (*Eucidaris* sp., *Clypeaster* sp., scutellid echinoids). The fauna suggests a shallow, warm, marine environment of the inner neritic zone (Nouradini *et al*., 2015).

The Vartun section (Figure 1A; GPS co-ordinates: 32° 55′51″ N; 52° 09′59″ E) is located further along the Isfahan-Ardestan road. Here,

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thick prominent limestones (Figure 2), with minor intercalation of marly limestones with the occurrence of foraminifers *Neoalveolina melocurdica, Peneroplis evolutus, Dentritina rangi, Meandropsina anahensis, Acervulina* sp., and *Archaias* sp. are exposed. Faunal elements include also oyster shells, algal fragments, and other macrofossils. The foraminifers indicate Aquitanian-Burdigalian age (Pedramara *et al*., 2019).

## 3. Material and methods

From Burdigalian strata of studied sections, altogether seven fossil brachyuran crabs were examined (Figure 2): Kuh-e-Donbeh (1 specimen), Bagher-Abad (4 specimens), and Vartun Section (2 specimens). The specimens exhibit two modes of preservation: carapaces (either isolated or with attached appendages) and isolated cheliped elements. All studied specimens are fractured and/or eroded. Material was documented photographically. The specimens are deposited at Department of Geology, Faculty of Sciences, University of Isfahan, Iran (EUIC).

## 4. Systematic palaeontology

Order Decapoda Latreille, 1802
Section Eubrachyura de Saint Laurent, 1980
Subsection Heterotremata Guinot, 1977
Superfamily Carpilioidea Ortmann, 1893
Family Carpiliidae Ortmann, 1893
Genus *Palaeocarpilius* A. Milne-Edwards, 1862
Type species: *Cancer macrochelus* Desmarest, 1822, by original designation.

*Palaeocarpilius rugifer* Stoliczka, 1871
Figures 3A–3E

1871 *Palaeocarpilius rugifer* – Stoliczka, p. 8, pl. 4, figs. 1–6, pl. 5, figs. 1–5.
?2009 *Palaeocarpilius rugifer* Stoliczka – Ralte, Lalchawimawii, Malsawma, Tiwari, p. 205, pl.1 fig. 12.
2010 *Palaeocarpilius rugifer* Stoliczka – Vega, Tiwari, Bajpai, p. 46, pl. 1, figs. 1–12.

**Material:** Female individual with preserved carapace, sternum, right (crusher) cheliped and portions of pereiopods 2 and 3 (EUIC 100) from the Kuh-e-Dondeh section; female individual with preserved carapace, pleon, and portions of both chelipeds, including left (cutter) claw (EUIC 101) from the Vartun section; female individual with preserved carapace, pleon, and portions of both chelipeds, including left (cutter), claw (EUIC 102) from the Vartun section; left (presumably cutter) cheliped propodus without fixed finger and with articulated (and broken) dactylus (EUIC 103) from the Bagher-Abad section; isolated crusher claw dactylus (EUIC 104) from the Bagher-Abad section.

**Description:** Carapace suboval transversely, widest at lower third, vaulted in both directions; front deflexed, poorly preserved; orbits presumably circular; anterolateral margins rounded, with seven blunt equally sized teeth; posterolateral margin slightly concave; posterior margin straight, approximately as wide as front. Carapace regions undefined, with short transverse ridges extending from last anterolateral tooth. Sternum subtriangular, sutures between respective sternites well-developed. Female pleon longitudinally ovate, somite 6 longest. Chelipeds robust, heterochelous, right claw (crusher) more robust, left claw (cutter) slenderer; merus and carpus of both chelae robust, propodus with at least four large blunt spines on its upper margin; right propodus subtriangular in outline, highest distally, fixed finger short; right dactylus strongly curved with large molariform teeth on occlusal surface; left propodus broadly elongate, fixed finger subtriangular, slender; right dactylus elongate, slender.

**Remarks**: The material, although incomplete and imperfectly preserved, clearly can be assigned to *Palaeocarpilius* A. Milne-Edwards, 1862 based on these characteristics: the carapace is suboval in outline, vaulted in both directions, and with undefined regions; anterolateral margins are adorned

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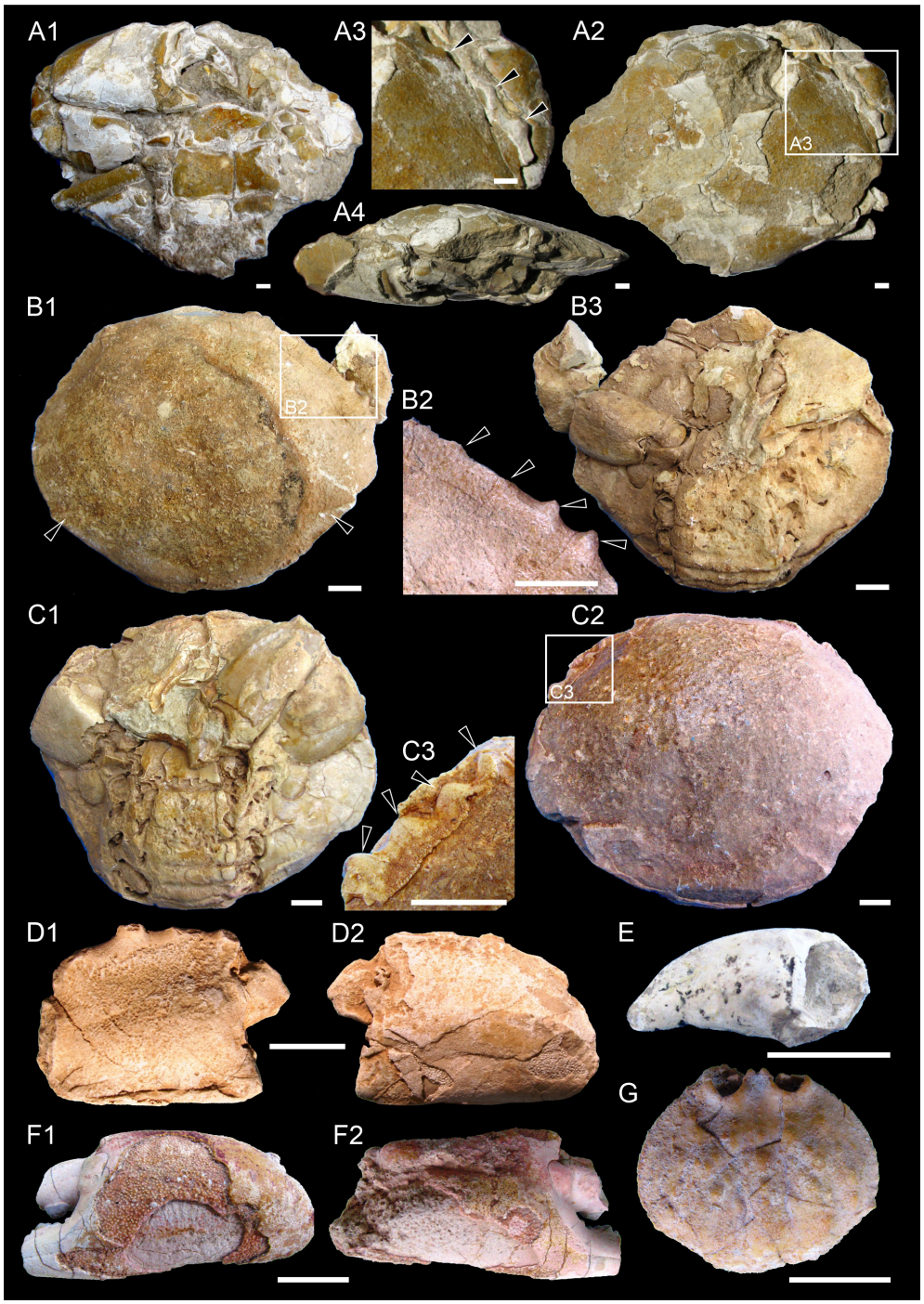


**Figure 3** Decapod assemblage from the Burdigalian of the Qom Formation; *Palaeocarpilius rugifer* Stoliczka, 1871 (A–E), *Necronectes* sp. (F), and *Mursia* cf. *lienharti* (Bachmayer, 1962) (G). A. Female individual with preserved carapace, sternum, right (crusher) cheliped and portions of pereiopods 2 and 3 (EUIC 100) in ventral (A1), dorsal (A2), and frontal (A4) views. Note preserved anterolateral teeth (A3). B. Female individual with preserved carapace, pleon, and portions of both chelipeds, including left (cutter) claw (EUIC 101) in dorsal (B1) and ventral (B3) views. Note preserved anterolateral teeth (B2). C. Female individual with preserved carapace, pleon, and portions of both chelipeds, including left (cutter) claw (EUIC 102) in ventral (C1) and dorsal (C2) views. Note preserved anterolateral teeth (C3). D. Left (presumably cutter) cheliped propodus without fixed finger and with articulated (and broken) dactylus (EUIC 103) in inner (D1) and outer (D2) lateral views. E. Isolated crusher claw dactylus (EUIC 104) in lateral view. F. Left (cutter) chela consisting of propodus and dactylus, with both fingers broken at their bases (EUIC 105) in outer (F1) and inner (F2) lateral views. G. Dorsal carapace (EUIC 106). Scale bars equal 10 mm.

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with blunt teeth; there is a well-developed ridge extending onto dorsal carapace from the last anterolateral tooth; chelipeds are strongly heterochelous, with the crusher claw having extremely high dactylus and short fixed finger; and the upper margin of the cheliped propodus is adorned with well-developed teeth (Schweitzer, 2003; Beschin and De Angeli, 2006). In *Palaeocarpilius*, the front is characteristically downturned and is bluntly triangular. One of the Iranian specimens indeed shows a downturned rostrum, although its morphology is not discernible due to poor preservation (Figures 3A and 4). Importantly, the isolated cheliped propodus exhibits a row of several massive spines on its upper margin (Figure 3D). In the type species, *P. macrochelus* (Desmarest, 1822), a widespread European taxon known from the Eocene and Oligocene strata (Beschin and De Angeli, 2006; Hyžný and Zorn, 2020), there are eight round tubercles adorning the upper margin of the cheliped propodus, quite unlike four or five large spines as exhibited by the Iranian material. Such chelae are present in Oligocene species, *P. aquitanicus* A. Milne-Edwards, 1862 and *P. rugifer* Stoliczka, 1871, as depicted by Beschin and De Angeli (2006, pl. 2, figs. 2b, 2c) and Stoliczka (1871, pl. 5, figs. 1–3), respectively. Both species share the same number (7, excl. outer orbital tooth) of similarly shaped and sized anterolateral teeth. The Iranian material is assigned to *P. rugifer* based on the presence of more rugose carapace tuberculation; in *P. aquitanicus*, the tuberculation is finer (Beschin and De Angeli, 2006). Also, *P. rugifer* has been reported from the Oligocene of northeast India (Stoliczka, 1871; Vega *et al.*, 2010b), which is rather close to studied Iranian localities.

*Palaeocarpilius rugifer* was previously reported from the Oligocene of India (Stoliczka, 1871; Vega *et al.*, 2010b). The Miocene occurrence presented by Ralte *et al.* (2009) is questionable, as already commented upon by Vega *et al.* (2010b). Nevertheless, the Iranian material represents the confirmation of the extension of stratigraphic range of the species to the early Miocene.

Superfamily Calappoidea De Haan, 1833 [in De Haan, 1833–1850]

Family Calappidae De Haan, 1833 [in De Haan, 1833–1850]

Genus *Mursia* Desmarest, 1823

Type species: *Mursia cristiata* H. Milne Edwards, 1837, by subsequent monotypy.

*Mursia* cf. *lienharti (*Bachmayer, 1962)

Figure 3G

?1962 *Calappa* (?) *lienharti* – Bachmayer, p. 41, pl. 2, fig. 2.

?1984 *Mursia lienharti* (Bachmayer) – Müller, p. 68, pl. 39, figs. 1–6, pl. 40, figs. 1–3, 5–6.

?2021 *Mursia lienharti* (Bachmayer) – Hyžný, Dulai, p. 153, figs. 56.1–9.

**Material:** Complete dorsal carapace (EUIC 106) from the Bagher-Abad section.

**Description:** Carapace circular, convex in both directions. Front presumably trilobed, median lobe broken. Orbits deep, circular; supraorbital margin with two fissures. Orbitofrontal margin half of carapace width. Anterolateral margins arcuate, crenulated with unknown number of blunt lobes and lateral spine of unknown length. Posterolateral margins slightly concave, rimmed. Posterior margin approximately as wide as front. Regions undefined. Carapace surface covered with variously sized tubercles arranged in five subparallel longitudinal ridges, one median and two on branchial and hepatic regions.

**Remarks:** A single carapace does not present sufficient details for confident attribution on the species level. Carapace tuberculation is similar to that of early Miocene *Mursia harnicari* Hyžný and Schlögl, 2011, and middle Miocene *M. lienharti* (Bachmayer, 1962), both known from the circum-Mediterranean region. Unfortunately, the carapace surface of the Iranian material is abraded and its crenulation on the anterolateral margin is not discernible. Also, lateral spines are eroded and it is not clear how large they were

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originally. Nevertheless, their bases appear to be relatively small and therefore we classify the material as being closer to *M. lienharti* (possessing moderately sized lateral spines), rather than to *M. harnicari* (with elongate lateral spines). More and better-preserved material is needed to resolve the systematic placement of Iranian taxon.

*Mursia lienharti* is a widespread species to date, reported from the Oligocene of Germany (Polkowsky, 2014), the lower Miocene (Burdigalian) of Belgium (Müller in Janssen and Müller, 1984) and Italy (Beschin and De Angeli, 2012), and the middle Miocene of Austria (Bachmayer, 1962) and Hungary (Müller, 1984; Hyžný and Dulai, 2021). If the Iranian material is confirmed to represent this species, it would represent a major geographic extension further to the East.

Superfamily Portunoidea Rafinesque, 1815
Family Portunidae Rafinesque, 1815
Subfamily Necronectinae Glaessner, 1928
Genus *Necronectes* A. Milne-Edwards, 1881
Type species: *Necronectes vidalianus* A. Milne-Edwards, 1881, by original designation.

*Necronectes* sp.
Figure 3F

**Material:** Left (cutter) chela consisting of propodus and dactylus, with both fingers broken at their bases (EUIC 105), from the Bagher-Abad section.

**Description:** Left cheliped manus suboval in outline; lateral surfaces of both fingers with two longitudinal furrows with setal pores; occlusal surface of fixed finger with serial conical teeth of two sizes; occlusal surface of dactylus with molariform tooth.

**Remarks:** There are two closely related genera with very similar cheliped morphology as that shown in the studied material, *Scylla* de Haan, 1833 and *Necronectes* A. Milne-Edwards, 1881. A main difference between them is the number of anterolateral spines on the carapace (Schweitzer *et al.*, 2006; Karasawa *et al.*, 2008), a character which cannot be observed in the Iranian material. As for chelipeds, no comparative study between the two genera has been performed to date. However, Keenan *et al.*, (1998) presented a revision of extant representatives of *Scylla* invariably showing spines in proximalmost and distalmost position of the propodal upper margin. These do not seem to be present in the chelipeds of *Necronectes* (Hyžný and Dulai, 2021, fig. 84). Because the Iranian material does not possess the respective spines, we assign it to *Necronectes*. The fragmentary nature of the specimen, however, prevents closer identification.

Torabi and Yazdi (2002) presented *Necronectes iranensis* as a new species from the Miocene of Central Iran. In the conference abstract, in which the taxon was presented, the authors failed to provide description or illustration of *N. iranensis*, and Schweitzer *et al.* (2010) considered the name as a nomen nudum. We concur. It is possible that the new material presented herein is conspecific with *N. iranensis*; unfortunately, without further data we are not able to compare both occurrences. Also, without a possibility of re-examination of *N. iranensis*, it is difficult to confirm the attribution of the material presented by Torabi and Yazdi (2002) to *Necronectes*. Therefore, *Necronectes* sp. from Bagher-Abad is considered the first confirmed occurrence of the respective genus from the Miocene of Iran.

## 5. Discussion

The subduction and final collision of the African-Arabian and Iranian-Eurasian plates during early Miocene was accompanied by closure of the Tethyan Seaway (Harzhauser *et al.*, 2007; Reuter *et al.*, 2009). Consequently, Central-Iranian palaeogeography changed dramatically with the development of a volcanic arc, which separated a forearc from a back-arc basin during the Miocene.

The Oligo-Miocene deposits of the Qom Formation developed in the south-eastern margin of the Western Tethys Region (Figure 4). The faunas of this region are important for the interpretation of palaeobiogeography of the circum-Mediterranean region, including the proto-Mediterranean

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and Paratethys seas, and its connection with the Indian Ocean, as have been discussed by various scholars since the 1990s (Stöcklin and Setudehnia, 1991; Rögl, 1999; Seyrafian and Torabi, 2005; Harzhauser *et al.*, 2007; Khaksar and Maghfori-Moghaddam, 2007; Daneshian and Ramezani Dana, 2007; Reuter *et al.*, 2009; Mohammadi *et al.*, 2011, 2013; Behforouzi and Safari, 2011; Yazdi *et al.*, 2012).

Marine sedimentation of the Qom Formation began during the Oligocene and continued to the end of the early Miocene in the Isfahan-Sirjan fore-arc and in the Qom back-arc basins (Schuster and Wielandt, 1999). The timing of opening and closure of the Tethyan Seaway (especially in the fore-arc and back-arc basins) is still being debated. Bozorgnia (1966) believed that the Qom Sea (Qom back-arc basin) persisted from the Rupelian (early Oligocene) to the Burdigalian (late early Miocene). Schuster and Wielandt (1999) also mentioned that in both foreland basins (Sanandaj-Sirjan and Central Iran), the marine sedimentation began during the early Oligocene and continued until the end of the early Miocene. However, Berning *et al.* (2009), suggested that during the late Oligocene, the narrowing Tethyan Seaway formed a connection between the Eastern Tethys and the Western Tethys regions.

There are close faunal similarities between the Qom Basin and the proto-Mediterranean and the Paratethys. As for decapod crustaceans, genera reported herein are well-known from Cenozoic strata in the entire circum-Mediterranean region. Both *Mursia* and *Necronectes* were reported from the Oligo-Miocene of proto-Mediterranean (Müller, 1993; De Angeli and Garassino, 2006; De Angeli *et al.*, 2019) and Paratethys (Müller, 1984; Hyžný, 2016; Hyžný and Dulai, 2021), whereas *Palaeocarpilius aquitanicus*, a morphologically close relative of *P. rugifer*, is known from the Oligocene of Italy and France (De Angeli and Garassino, 2006; De Angeli *et al.*, 2019). *Palaeocarpilius rugifer* was reported also from the Oligocene of northeast India (Stoliczka, 1871; Vega *et al.*, 2010b), an area occurring further eastward on the Tethyan Seaway back in the late Cenozoic. In a wider view, it is good to note that it is difficult to state whether any of these areas served as a place of origin of discussed taxa, which then spread to other regions. Representatives of *Palaeocarpilius* were widespread in the Western Tethys during the Eocene (Lőrenthey and Beurlen, 1929; Vía Boada, 1969; Beschin and De Angeli, 2006), whereas the occurrences from Iran and India are younger (Oligocene). Similarly, Khodaverdi Hassan-vand *et al.* (2016) reported the co-occurrence of *Retrocypoda almelai* Vía Boada, 1959, from the middle Eocene of Catalonia and Iran, whereas the oldest occurrence of the species is known from the lower Eocene of France. Nevertheless, reports of other decapod taxa tell a different story: the oldest occurrences of ghost shrimps of the "*karumba* group", matching the lately erected genus *Karumballichirus* Poore, Dworschak, Robles, Mantelatto, and Felder, 2019, come from the Paleocene of Pakistan (Hyžný *et al.*, 2016). As noted by Hyžný *et al.* (2016, p. 351), if the Pakistani occurrences were not known, the oldest occurrence of the group would be in the circum-Mediterranean area and would match the "Go East!" scenario of Harzhauser *et al.*, (2007) or the concept of hoping biodiversity hotspots of Renema *et al.*, (2008). However, Cenozoic decapod assemblages of Eastern and Western Tethyan regions show a relative homogeneity at the genus level, as already suggested by Merle *et al.*, (2014) for gastropods. More research is needed

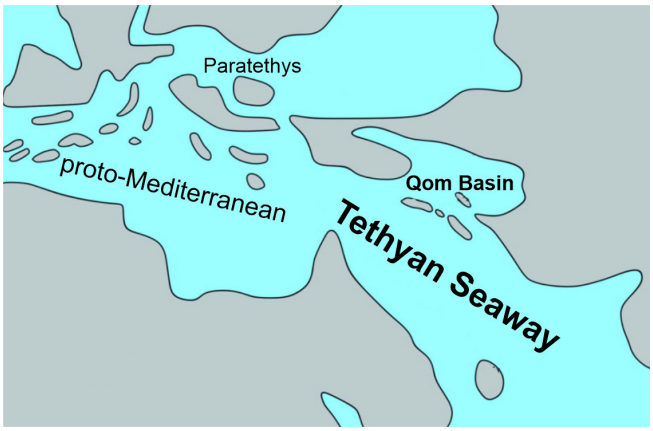


**Figure 4** **Palaeogeographic map of the Tethyan Seaway with indication of the Qom Basin (after Harzhauser and Piller, 2007; Reuter *et al.*, 2009).**

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to resolve the migratory routes of decapod crustaceans along the Tethyan Seaway, which might change throughout several tens of million years. Fossils from the Qom Basin, being positioned in the middle between Eastern and Western Tethyan regions, are of great importance in this research.

## 6. Conclusions

From the lower Miocene (Burdigalian) of the Qom Formation, exposed in three sections in Central Iran, a decapod crustacean assemblage is described. Based on moderately-well preserved specimens, three taxa were identified, including Mursia cf. lienharti, *Palaeocarpilius rugifer*, and Necronectes sp. The occurrence of *P. rugifer* represents the youngest confirmed occurrence of the species, whereas other two taxa represent the first Iranian occurrences of the respective genera. This report enriches our knowledge on Miocene decapod assemblages of Iran, helping to better understand the migratory patterns along the Tethyan Seaway.

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