

SIRENIA FOSSILS FROM QOM FORMATION (BURDIGALIAN) OF THE KABUDAR AHANG AREA, NORTHWEST IRAN

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Abstract. Fossil remains of sirenians (Mammalia; Dugongidae) are reported from the late early Miocene (Burdigalian) Qom Formation near the town of Shirin Su, northwest Kabudar Ahang region, west of Tehran, Iran. The fossils consist of partial postcranial skeletons preserved mostly as natural molds in limestone. In the absence of skulls or other diagnostic elements, it is not evident which dugongid subfamily these specimens represent: Halitheriinae or Dugonginae. Both subfamilies were present in contemporaneous Western Tethys (Mediterranean) deposits, but so far only dugongines have been found in Neogene rocks of Eastern Tethys. Since the Iranian deposits are located between these two parts of the former Tethys seaway, it will be interesting to see which group(s) the Iranian sirenians prove to represent, once their taxonomic identity has been determined through future discoveries.

INTRODUCTION

Reconnaissance and discovery of mammal fossils from unknown areas is important for paleontologists, because new data are useful to reconstruct and/or improve our knowledge about the paleobiogeographic ranges of organisms. The Iranian plateau was located in the central part of Tethys, which acted as a seaway and/or bridge for the migration of either marine or terrestrial mammals during the Cenozoic Era. Thus collecting of mammal fossils from Iran and adjacent areas will improve knowledge of mammal distributions before and after the Eurasian-Afroarabian closure. The Late Miocene Maragheh bone beds are a famous site for vertebrate paleontology in Iran, which has been investigated for 150 years (Khanikoff 1858; Rodler & Weithofer 1890; Mecquenem 1925; Campbell et al. 1980). There are, however, few reports about mammal fossils from other parts of Iran (e.g. Najafi & Bazarghani Gilani 2006). Initially, Reuter et al. (2007) reported Miocene marine mammals (Sirenia) from the Qom Formation of the Zefreh area, Central Iran. Recently, sirenian fossils have also been collected and

preliminarily studied from the Asmari Formation of the Zagros Mountains (Dezful and Bastak areas) and the Qom Formation of Central Iran (Zefreh-Chahriseh, Malayer and Kabudar Ahang areas; Mirzaie Ataabadi et al. 2014). Additional occurrences of mammal fossils have been reported from the abandoned decorative-stone quarry of Shirin Su in northwest Kabudar Ahang, Central Iran. Based on local reports, the Iranian authors visited and studied marine mammal fossils of Shirin Su in March and September 2014. The main purpose of this paper is to add to data on mammal paleontology from the Iranian plateau.

GEOLOGICAL SETTING

The Qom Formation is the main Oligo-Miocene lithostratigraphic unit in Central Iran. It crops out from east of Semnan and north of Nain to Mount Ararat in eastern Turkey (Fig. 1). Lithostratigraphic units equivalent to the Qom Formation are known as the Asmari Formation (Oligo-Miocene) and Guri Member (lower Miocene) of the Mishan Formation in the Zagros Mountains. Oligo-Miocene limestone of the Esfahan-Sirjan basin with local

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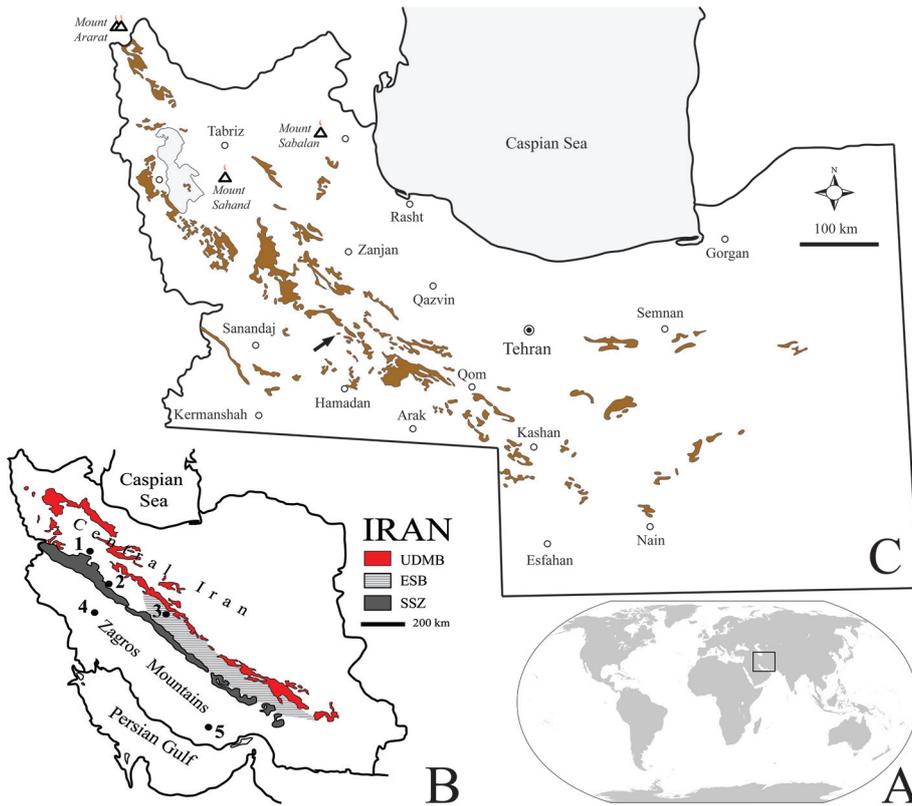


Fig 1 - Outcrops of the Qom Formation in Central Iran. A) Location map of Iran on the world map. B) Location of Central Iran, Esfahan-Sirjan basin and Zagros Mountains in Iran; areas where sirenians found include: 1 - Kabudar Ahang, 2 - Malayer, 3 - Zefreh-Chahriseh, 4 - Dezful, 5 - Bastak. Abbreviations: UDMB, Urumieh-Dokhtar Magmatic Belt; ESB, Esfahan-Sirjan basin; SSZ, Sanandaj-Sirjan Zone (base map modified by Nogole Sadat & Almasian 1993). C) Outcrops of the Qom Formation in Central Iran (modified from Rahimzadeh 1994); arrow indicates the Shirin Su section.

units (e.g. the Chahar Gonbad Formation) are correlative with the Qom Formation.

The Qom Formation has extensive outcrops in the Kabudar Ahang area, in Hamadan Province (Fig. 2). The Qom Formation was deposited in a fault-controlled marine basin with different lithofacies in the Ab-e garm, Avaj, Razan, and Sanandaj-Sirjan zones (Bolourchi 1979). The major faults of this area, all of them with NW-SE strike, include the Hassan Abad, Ahmad Abad-Avaj, and Aznove-Morgh Abad faults (Fig. 2).

The northern part of the Ab-e garm zone

includes the southeastern parts of the Soltanieh Mountains. The Soltanieh zone was uplifted in a horst after the Eocene. Thus, the Qom Formation has exposures on the southern flanks of the Soltanieh Mountains.

The Ab-e garm zone is located in the southern range of the Hassan Abad fault. The Qom Formation in this zone includes light-colored limestone with green marlstone and detrital beds of sandy limestone intercalations. The formation is 440 m thick, with Burdigalian foraminifers (Bolourchi 1979).

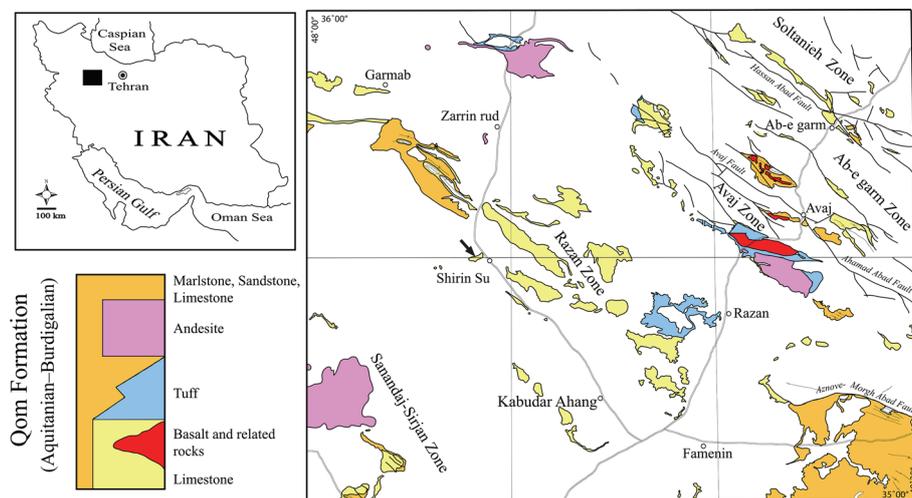


Fig 2 - Qom Formation lithofacies in the Kabudar Ahang area with main local geological zones. The studied section (arrow) is located west of Shirin Su.

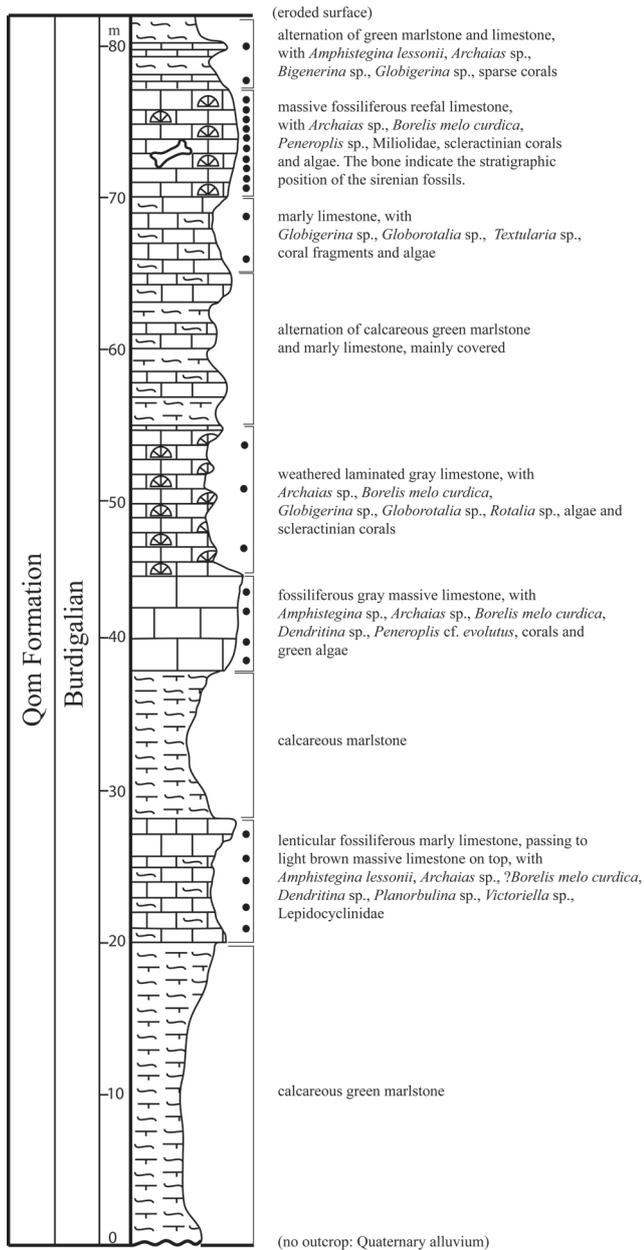


Fig. 3 - Stratigraphical column of surveyed section of the Qom Formation west of Shirin Su. Mammal fossils have been found in the upper massive fossiliferous reefal limestone. Black points indicate the locations of collected micropaleontology samples.

The Avaj zone is located around the Avaj-Ahmad Abad faults. The Qom Formation in the north Avaj fault zone predominantly contains marly limestone with detrital limestone intercalations. It is locally interbedded with tuff beds and accompanied by basalt, olivine basalt, and basaltic andesite. The thickness of the formation here exceeds 1100 m. The microfauna collected from the lower part of the formation represents the Aquitanian Stage while fossils from the upper part include Burdigalian

microfauna (Bolourchi 1979).

In the southern part of the Avaj fault, the Qom Formation is 2400 m thick, and includes huge volcanic rocks and tuffaceous sediments reactivated with the Avaj fault. The formation is divided here into 6 units, including limestone, tuff, andesite, hornblende andesite, dacitic andesite, basaltic andesite, basalt, and diabase. The microfaunas indicate an Aquitanian age for the lower limestone and tuff, and Burdigalian for the upper tuff and limestone (Bolourchi 1979).

The Qom Formation is well developed in the Razan zone in southern parts of the Aznove-Morgh Abad fault zone. The formation consists of green-gray, well-stratified, marly limestone intercalated with sandstone and lenses of reefal limestone. The lower part of the formation (2700 m) is Aquitanian, and the upper part (700 m) is Burdigalian (Bolourchi 1979).

The Qom Formation cropping out in the most southwestern areas of the Kabudar Ahang is a part of the Sanandaj-Sirjan zone, where the formation includes andesite rock.

The studied section of the Qom Formation, where the sirenian fossils have been found, crops out in a hill west of the town of Shirin Su, northwest Kabudar Ahang. The Qom Formation is 82 m thick in this outcrop, and includes alternating marlstone, bioclastic reefal limestone, marly limestone, massive bioclastic (mainly coral) limestone, and calcareous marlstone (Fig. 3). The mammal fossils were found in the upper massive fossiliferous reefal limestone. Samples from limestone layers contain the following foraminifera: *Amphistegina lessonii*, *Amphistegina* sp., *Archaia* sp., *Bigenerina* sp., *Borelis melo curdica*, *Dendritina* sp., *Globigerina* sp., *Globorotalia* sp., *Peneroplis* cf. *evolutus*, *Peneroplis* sp., *Planorbulina* sp., *Rotalia* sp., *Textularia* sp., *Triloculina* sp., *Victoriella* sp., *Lepidocyclinidae*, Miliolidae.

This assemblage is equivalent to the *Borelis melo curdica* assemblage zone of Wynd (1965), the *Borelis melo* group-*Meandropsina iranica* assemblage zone of Adams and Bourgeois (1967) and Daneshian and Ramezani Dana (2007), and the *Borelis melo curdica*-*Borelis melo* assemblage zone (Laurson et al. 2009) of the Asmari Formation in the Zagros Mountains, indicating a Burdigalian age for this section.

Neither the lower nor the upper boundaries of the exposed section are known (Fig. 3), but ba-

sed on paleontological data these sediments belong to upper parts of the Qom Formation in the Kabudar Ahang area and are equivalent to the (f) member of the Qom Formation at the type locality, east of Qom (Furrer & Soder 1955; Bozorgnia 1966).

MATERIALS AND METHODS

The sirenian fossils from Shirin Su comprise postcranial remains of at least three individuals. Specimen 1 (ICHTO 12) is an articulated partial skeleton preserved in two loose blocks. Block 1 (ICHTO 12/1, 1.6 x 1.2 x 1m) and block 2 (ICHTO 12/2, 3 x 2.5 x 1.2m) contain relatively complete natural molds of the articulated vertebrae and ribs, displaying the dorsal and ventral sides, respectively, of one individual. Impressions of vertebrae and ribs in these blocks are numbered in the figures according to their estimated anatomical positions. These blocks have been transported to the municipal office of Shirin Su town for preservation and geo-tourism. Specimen 2 (1 x 0.5 x 0.3 m) is also a loose block, containing natural molds of ribs, which remains in the quarry. Specimen 3 is a group of exposed ribs that remain in situ.

The stratigraphical position of the mammal fossils was determined by sampling and surveying bed by bed. Twenty-eight thin sections were prepared for micropaleontology. Dr. Abdoreza Moghadasi, a micropaleontology specialist in the paleontology laboratories of the National Iranian Oil Company, studied these thin sections and determined its foraminifera and the age of the studied section.

SYSTEMATIC PALEONTOLOGY

Class **MAMMALIA** Linnaeus, 1758

Order **Sirenia** Illiger, 1811

Family **Dugongidae** Gray, 1821

Dugongidae indeterminate

Figs 4-5

Referred specimens: Three sets of associated postcranial bones (ribs and, in two cases, vertebrae), preserved as natural molds in part. The most complete specimen is presently housed in the municipal office of Shirin Su town, bearing the numbers 12/1 and 12/2 in the catalog of the Iranian Cultural, Handicraft and Tourism Organization (ICHTO) of Kabudar Ahang Township, Hamadan Province; the other two specimens remain in the quarry.

Locality: Abandoned decorative-stone quarry near the town of Shirin Su, northwest Kabudar Ahang region, Central Iran. GPS coordinates are 35° 29' 50.4" N and 48° 25' 23.6" E.

Formation: Qom Formation.

Age: Late early Miocene (Burdigalian).

Description. The two specimens in loose blocks are preserved mainly as natural molds with some bone fragments, and include thoracic, lumbar, sacral, and caudal vertebrae and ribs. The third specimen comprises some ribs exposed in situ. Detailed descriptions of these specimens are as follows:

ICHTO 12/1 (block 1): This block contains molds of the dorsal sides of thoracic, lumbar, sacral, and parts of caudal vertebrae (neural arches) and ribs (Fig. 4A). Sixteen thoracic vertebrae are visible; these are numbered T3-T18 based on the conservative assumption that this animal had 18 thoracics and 18 pairs of ribs, which is the minimum number observed in other dugongids. Only molds of pleurapophyses of the lumbar and sacral vertebrae and partial transverse processes of caudal vertebrae are preserved. The spinous processes of the vertebrae are preserved as deep hollows (5 cm in depth) that are heart-shaped in cross section (Fig. 4C). Prezygapophyses form elongate hollows in T7 to T9, and postzygapophyses form round hollows with mild curvature. Seventeen casts of thoracic vertebrae are distinguishable. Only molds of the pleurapophyses of the right side of the lumbar and sacral vertebrae are visible. Similarly, only one transverse process of the first caudal vertebra remains. A mold of a small piece of bone is visible that may be a chevron bone. Some parts of articular areas of ribs and vertebrae are distinguishable, including tubercula on flattened parts of ribs. Other parts are shown in detail in Fig. 4C.

ICHTO 12/2 (block 2): This block preserves natural molds of ventral parts of thoracic and lumbar vertebrae and ribs; 14 thoracic (numbered 5 to 18), 3 lumbar, 1 sacral, and 1 caudal vertebrae are visible (Fig. 4B). Ventral processes and epiphyses of the vertebral bodies are distinguishable (Fig. 4D). Thickness of epiphyses varies from 0.5 to 1 cm, decreasing toward the rear. The vertebrae after vertebra number 15 are partly covered by sediments (Fig. 4E). Each thoracic vertebra contacts its ribs with flat facets. The details of neural arches are visible on the posterior vertebrae (Fig. 4E), where the canal is elliptical, and 3 cm in diameter. What appears to be a foramen 1 cm in diameter is visible on the anterodorsal part of T15, but this may not be a part of this vertebra. There are molds of canals that may be related to neural canals (?IVF in Fig. 4E). Prezygapophyses and postzygapophyses are distinct as anterior and posterior impressions in the rock. Most of the lumbar, sacral, and caudal vertebrae are covered by sediment and only their left transverse processes are visible. Molds of other bones are also present; some of them are V-shaped, possibly attributable to chevron bones. A triangular flat mold may represent a blade-shaped bone (?B in Fig. 4B).

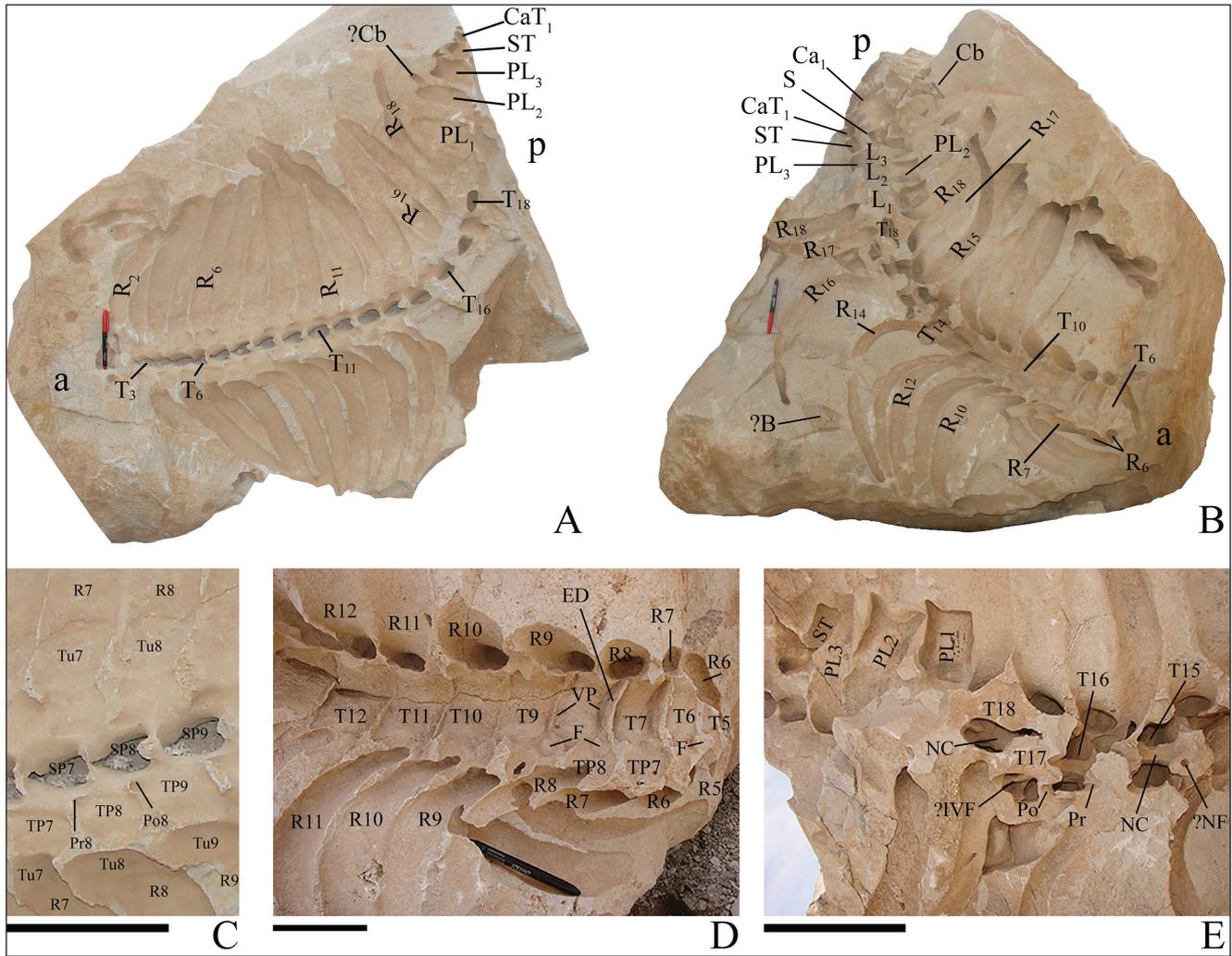


Fig. 4 - Specimen ICHTO 12 of *Sirenia* fossils from Kabudar Ahang. A) Block 1 (ICHTO12/1) with molds of dorsal sides of thoracic, lumbar, sacral, and caudal vertebrae and ribs. Dark-colored tips of spinous processes and other fragments of the vertebrae are still present in the cavities of the mold. B) Block 2 (ICHTO 12/2) with molds of ventral sides of thoracic, lumbar, sacral, and caudal vertebrae and ribs. C) Close-up of vertebrae no. 7 to 9 and details of mold preservation in block 1. D) Close-up of anterior vertebrae and adjacent ribs in block 2. E) Details of posterior vertebrae and adjacent ribs of block 2. Abbreviations: a, anterior; ?B, unidentified blade like bone; Ca, caudal vertebra; CaT, caudal transverse process; Cb, chevron bone; F, articular facet; ED, epiphysis of body; ?IVF, unidentified intervertebral foramen; L, lumbar vertebra; NC, neural canal; ?NF, presumably neural foramina; p, posterior; PL, pleurapophysis; Po, postzygapophysis; Pr, prezygapophysis; R, rib; S, sacral vertebra; SP, spinous process; ST, sacral vertebra transverse processes; T, thoracic vertebra; TP, transverse process; Tu, tubercle of rib; VP, ventral process of vertebra. Numbers show estimated anatomical positions. Pen for scale in A and B is 14 cm long, scale bars equal 10 cm.

Specimens 2 and 3: These fossils include only ribs. Specimen 2 is a mold of five wide and close-set ribs (Fig. 5A). Specimen 3 comprises thick and round sections of ribs (Fig. 5B).

Discussion. Ancestors of sea cows (*Sirenia*; manatees and dugongs) and whales (Cetacea), the first marine mammals, appeared about 50 million years ago in the early Eocene (Berta et al. 2006). These mammals today are exclusively aquatic throughout their lives. However, the sirenian Family Prorastomidae (early-middle Eocene), the earliest sea cows, had both fore and hind legs, and some were able to walk on land, like the earliest cetaceans (Domning

2000, 2001; Springer et al. 2015).

The Protosirenidae, also known only from the Eocene, were the next sirenian family to appear after the prorastomids (Domning 1994). They still had four legs, but probably spent little if any time on land (Domning and Gingerich 1994; Domning 2000). They were followed in turn by the fully-aquatic families Dugongidae (which first appeared in the middle Eocene, and are represented today only by the dugong, *Dugong dugon*) and the Trichechidae (which first appeared in the late Oligocene, and include the modern manatees, *Trichechus* spp.) (Domning 2009).

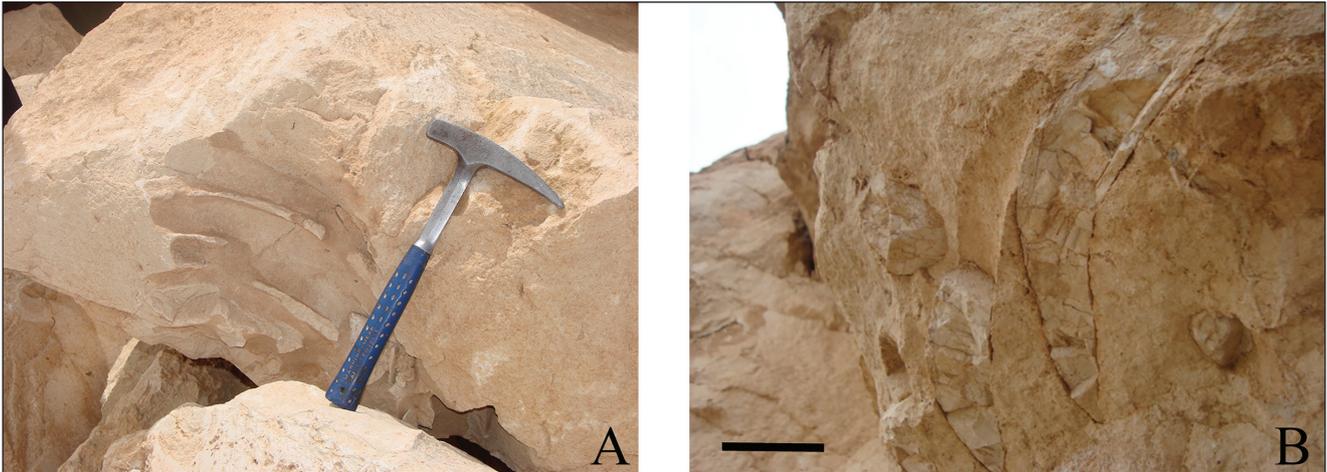


Fig. 5 - Specimens 3 and 4 of *Sirenia* fossils from Kabudar Ahang. A) Specimen 3 includes external molds of five ribs. Length of hammer 30 cm. B) Specimen 4 includes fragmentary ribs. Scale bar 5 cm.

The sirenians known to have been present in Western Tethys during the Aquitanian and Burdigalian include members of two subfamilies of Dugongidae, the Halitheriinae (represented by the common genus *Metaxytherium*; e.g. Domning & Perverler 2001), and the Dugonginae (represented by the rare genus *Rytiodus*; e.g. Domning & Sorbi 2011). Still rarer are members of the trichechid subfamily Miosireninae, known only from western and northwestern Europe (e.g. *Miosiren*).



Fig. 6 - Late Oligocene-Early Miocene basins with carbonate deposition in Iran as straits between Western and Eastern Tethys (modified from Harzhauser & Piller 2007). Reported localities of *Sirenia* fossils include: 1 - Kabudar Ahang, 2 - Malayer, 3 - Zefreh-Chahrisheh, 4 - Dezful, 5 - Bastak. Abbreviations: UDMB: Urumieh-Dokhtar Magmatic Belt bridge; ESB: Esfahan-Sirjan Basin; SSZ: Sanandaj-Sirjan Zone bridge.

In Eastern Tethys, much less collecting of fossil sirenians has been done, but three species are already known from the Aquitanian of India: *Bharatisiren kachchbensis*, *Kutchisiren cylindrica*, and *Domningia sodhae* (Bajpai et al. 1987; Bajpai & Domning 1997; Bajpai et al. 2010; Thewissen & Bajpai 2009). Interestingly, all three of these are dugongines (Vélez-Juarbe et al. 2012). The halitheriines, which are so common in Miocene Europe (*Metaxytherium* spp.), have not been detected in the Indian Ocean, although halitheriines were represented there in the Eocene (Bajpai et al. 2006). A fourth Miocene specimen from the Indian Ocean (Madagascar), incorrectly identified by Collignon & Cottreau (1927) as “*Halitherium* sp.”, is probably also a dugongine. So the fossils from Iran are of special interest, as they represent a sample from the very seaway that connected Eastern and Western Tethys: are they dugongines, as the Indian Ocean record leads us to expect; or halitheriines, the most common sirenians in Europe; or both, or even something else?

Unfortunately, the specimens so far found in Iran are not diagnostic beyond the family level; identification to the subfamily level or below must await more complete specimens, ideally skulls. However, their morphology is consistent with that of the Dugongidae – specifically the heart-shaped cross sections of the thoracic neural spines, which have a pronounced median concavity on the posterior side (Fig. 4A, C). This morphology occurs in some Miocene dugongids (e.g. Simpson 1932: figs. 6, 7), but is not observed in the Miocene trichechid *Miosiren kocki* (Sickenberg 1934:315, pl. 11), which is

	Eocene	Oligocene	Miocene	Pliocene
Austria	-	-	1, 2	-
Croatia	-	-	3	-
Egypt	4, 5, 6, 7	8	-	-
France	9	10, 11	12, 13	14, 15
Hungary	16, 17, 18, 19	16, 19	16, 19, 20	-
India	21, 22	22	23, 24, 25	-
Iran	-	-	26, 27, 28	-
Israel	29	-	-	-
Italy	30	31	32, 33, 34	35, 36
Libya	37, 38, 39	40	41	15
Madagascar	42, 43	-	44	-
Malta	-	45	46	-
Morocco	47	-	-	48
Pakistan	49, 50	-	51	-
Portugal	-	-	52	52
Romania	53	54		-
Spain	55	-	56	-
Tunis	57	-	58	-
Turkey	-	-	59	-
Yemen	60	-	-	-

Tab. 1 - Distribution of Tethyan Sirenian fossils, including representative localities and literature citations. 1 (Pervesler et al. 2000), 2 (Domning & Pervesler 2013), 3 (Šuklje 1938), 4 (Zalmout & Gingerich 2012), 5 (Domning & Gingerich 1994), 6 (Gingerich et al. 1994), 7 (Gingerich 1992), 8 (Domning et al. 1994), 9 (Sagne 2001), 10 (Bizzarini 1994), 11 (Patte 1963), 12 (Ginsburg et al. 1979), 13 (Sorbi 2008), 14 (Canocchi 1987), 15 (Domning & Thomas 1987), 16 (Kretzoi 1953), 17 (Kordos 1977), 18 (Kordos 1983), 19 (Kordos 1985), 20 (Kretzoi 1951), 21 (Bajpai et al. 2009), 22 (Bajpai et al. 2006), 23 (Thewissen & Bajpai 2009), 24 (Bajpai et al. 2010), 25 (Bajpai & Domning 1997), 26 (Reuter et al. 2007), 27 (Mirzaie Ataabadi et al. 2014), 28 (this report), 29 (Goodwin et al. 1998), 30 (Sickenberg 1934), 31 (Lydekker 1892), 32 (Guido et al. 2011), 33 (Carone & Domning 2007), 34 (Bianucci et al. 2003), 35 (Sorbi & Vaiani 2007), 36 (Tinelli et al. 2012), 37 (Savage & White 1965), 38 (Savage 1971), 39 (Savage 1975), 40 (Coster et al. 2015), 41 (Domning & Sorbi 2011), 42 (Samonds et al. 2009), 43 (Andrianavalona et al. 2015), 44 (Collignon & Cottreau 1927), 45 (Zammit-Maempel 1982), 46 (Adams 1866), 47 (Zouhri et al. 2014), 48 (Ennouchi 1954), 49 (Zalmout et al. 2003), 50 (Gingerich et al. 1998), 51 (Reza et al. 1984), 52 (Estevens 1998), 53 (Fuchs 1990), 54 (Fuchs 1971), 55 (Pilleri et al. 1989), 56 (Pilleri 1989), 57 (Benoit et al. 2013), 58 (Geraads 1989), 59 (Inan et al. 2008), 60 (As-Saruri et al. 1999).

the only non-dugongid sirenian known in the world that is contemporary with the Iranian fossils.

Most parts of Central Iran and the Zagros zones were occupied by early Miocene basins with carbonate deposition, which formed straits between

Eastern and Western Tethys. Migrations of marine organisms occurred by way of these passages (Harzhauser et al. 2007; Harzhauser & Piller 2007).

The Urumieh-Dokhtar and Sanandaj-Sirjan ridges divided this connection into three straits: the Qom basin in the north, the Esfahan-Sirjan basin in the middle part, and the Asmari basin in the south (Fig. 6).

The cool climate around the Oligocene-Miocene boundary was replaced by warmer conditions in the Miocene (Zachos et al. 2001). This was favorable for marine mammals of the Mediterranean-Iranian basins. The Iranian Miocene marine mammals so far discovered are found in the southern parts of the Urumieh-Dokhtar magmatic belt. The northern parts of the Miocene basin belonged to the Paratethyan realm, where so far we have no reports of marine mammal fossils from Iran. Miocene mammal biodiversity, however, shows essential changes after the Middle Miocene in the Paratethys (Rögl 1999). Uniformity between Eastern and Western Tethys marine mammal faunas could have been maintained by migration through the Iranian straits (Qom, Esfahan-Sirjan and Asmari basins), but this connection was terminated by the collision of the Arabian and Iranian plates. Thereafter, evolution of marine mammals in both parts of Tethys was independent and autonomous (Vélez-Juarbe 2014). On the other hand, new terrestrial passages were created, and migrations and connections of Eurasian-Arabian-African land mammals occurred by way of the *Gomphotherium* land bridge (Rögl 1999).

A high biodiversity of gastropods, bivalves and corals was found in the western parts of Tethys (Mediterranean area) prior to the formation of this land bridge. This high diversity became displaced towards the southeastern part of Tethys (Indian Ocean-Arabian Sea-eastern Africa [IAA]) after the Burdigalian and formation of the *Gomphotherium* land bridge. It seems that this disparity also involved marine mammals, so that sirenians are now absent from the Mediterranean although *Dugong dugon* is found in the IAA (Jefferson et al. 1994). Table 1 shows distribution of sea cow fossils around the Mediterranean and IAA. Certainly, our understanding of Tethyan sirenian paleobiogeography will improve through addition of Iranian data. The distribution of sirenian fossil records in Iran is considerable, but the lack of more diagnostic material

prevents their determination to species or genus.

Apart from biogeographic considerations, the occurrence of sirenians in marine deposits is one of the best indicators of the presence of seagrasses (marine angiosperms), on which sirenians in marine waters have fed throughout their history, but which are rarely fossilized themselves (Domning 1981; Vélez-Juarbe 2014; Reich et al. 2015). The carbonates and other early Miocene marine deposits of Iran surely represent depositional environments that supported diverse seagrasses along with the sirenians reported here. Consideration of this implication of sirenian presence, along with sedimentological, invertebrate, and other indications of seagrass presence, can add a further dimension to paleoecological reconstructions of this region of Tethys.

CONCLUSIONS

The Miocene marine sediments of the Qom Formation are good candidates for marine mammal investigations. Vertebrate fossils discovered in the Qom Formation of Shirin Su belong to the Sirenia, and probably represent the Family Dugongidae. Their identification to genus or species requires the discovery of skulls, which unfortunately have not yet been found in the studied section. The early Miocene basins with carbonate deposition of Iran developed as straits between western and eastern parts of Tethys and were channels of connection and migration for marine mammals.

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