First mammal fossil locality from the late Miocene of Zagros, Western Iran

Zahra Orak[1], Majid Mirzaie Ataabadi*[2], Ali Solgi[1], Mahmood Reza Majidifard[3], Dimitris S. Kostopoulos[4]
[1] *Department of Geology, Science and Research branch, Islamic Azad university, Tehran, Iran*
[2] *Department of Geology, Faculty of science, University of Zanjan, Zanjan 3879145371, Iran*
[3] *Research Institute for Earth Sciences, Geological Survey of Iran, Tehran, Iran*
[4] *Laboratory of Geology and Palaeontology, School of Geology, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece*
**Corresponding author, e–mail: majid.mirzaie@znu.ac.ir*
(*received: 01/12/2018 ; accepted: 10/04/2019*)

Abstract
A new and the first mammal fossil locality from the Zagros Basin of Iran is reported here. The fossil locality, known as Dimeh, is located in the Lorestan province, west of Iran. The fauna includes abundant bovid cranial remains, mostly representing boselaphines and palaeoryxoids, as well as gazelles and spiral horned antelopes. Hipparionine horses similar to *Hippotherium* group are also represented by many individuals and specimens. In addition, large giraffids are among the common elements. Rhinocerotidae, Proboscidea and hyaenids are also present. Based on the current assessment of this fauna, it is most similar to the Middle Maragheh biostratigraphic levels in northwest Iran. Hence, an age of 8-7 Ma (MN 11-12 equivalent) can be assigned for this assemblage. This new fauna is comparable to the Pikermian-type mammal palaeocommunities of the late Miocene and may indicate an extension of these faunas toward Zagros high lands in pursuit of seasonal precipitation and vegetation.

Keywords: *Neogene, Lahbari Member, Bovidae, Lorestan, Dimeh.*

Introduction

The late Miocene is the time of expansion of open-adapted mammalian faunas in Eurasia. These faunas, known as the Pikermian chronofaunas /faunas/ paleobiome (Solounias *et al.,* 1999; Eronen *et al.,* 2009; Kostopoulos 2009), include abundant representatives of families such as Equidae, Bovidae, Giraffidae, Hyaenidae and Felidae (Bernor, 1984, 1996; Solounias *et al.,* 1999). Pikermian-type mammalian faunas in Iran have been so far restricted to the Azarbaijan region. For more than one and a half century, the bone beds of Maragheh were the only source of information for the late Miocene mammals in Iran (Campbell *et al.,* 1980; Bernor, 1986; Mirzaie Ataabadi *et al.,* 2013). Recently, other fossil localities similar to Maragheh have been discovered and studied in eastern Azarbaijan province. These include the fossil locality of Ivand, north of Tabriz (Sen & Pourabrishemi, 2010; Mirzaie Ataabadi *et al.,* 2011a) and Abkhareh in Varzeghan (Mirzaie Ataabadi *et al.,* 2011b; Pickford & Pourabrishami, 2013).

In the Zagros region, southwest and west Iran, although terrestrial Neogene deposits are present and widespread, terrestrial mammals are barely reported. To date, only fragmentary mammalian teeth or bones are recorded (Stöcklin & Setudehnia, 1970; Motiei, 1993). Zagros Miocene mammals are best known from the Injana (Jabal/Jebel Hamrin) locality in Iraq (Thomas *et al.,* 1980). Here, we report the first Pikermian-type mammal palaeocommunity from the Zagros Basin of Iran, Lorestan province.

Geological setting

Zagros is a mountain range formed in the west and southwest of Iran. It has a northwest-southeast trend and a length of 1250 km. It is located in the middle of Alpine-Himalayan belt and is among the youngest orogenies of the Cenozoic. The Zagros region is connected to the Iranian block (Eurasian plate) from the northeast and it is part of the Arabian plate in the southwest (Fig. 1). Based on geomorphological aspects, Zagros is divided into three zones: Inner or High-Zagros, outer or Folded Zagros, and Khuzestan plain. According to the facies and structural viewpoints, Zagros is divided to Lorestan, Khuzestan, and Fars basins, and Bandar-Abbas Hinterland (Motiei, 1993). The studied area (Dimeh) is located in the High-Zagros (also known as the Zagros trust zone and Crushed Zone), which is a narrow belt forming the highest part of the Zagros Mountains (Fig. 1).

In the Paleogene, the Zagros region was covered by a transgressive sea resulting in Paleocene and

Eocene carbonate depositions. This was followed by the Asmari sedimentary cycle (Oligocene-Early Miocene), which marks the second important carbonate sedimentary cycle of the Cenozoic in the Zagros basin. Eventually, the Fars sedimentary cycle with reduced marine sedimentation was formed. Lagoonal and continental deposits constituting the bulk of this sedimentary cycle (Stöcklin & Setudehnia, 1970). Stratigraphic units of the upper parts of this sequence including continental deposits, show structural changes simultaneous with sedimentation (e.g. growth strata), thus indicating their deposition on the top of accretionary prisms (Homke *et al.,* 2004).

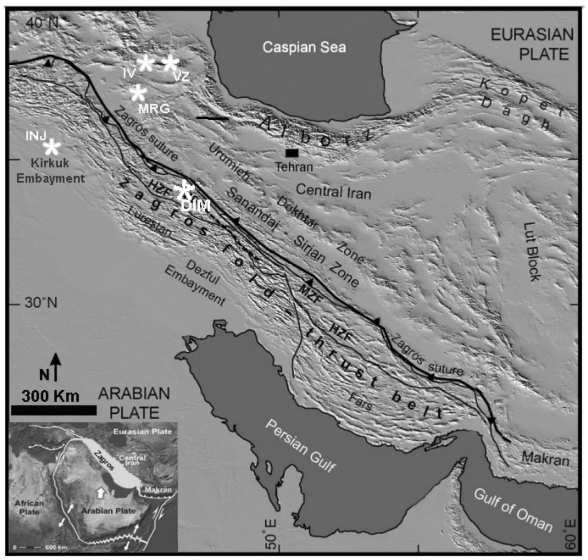

Figure 1. Location map of the mammal fossil faunas in northwest Iran and Zagros Basin (Iran and Iraq), and different subdivisions of Zagros (maps modified after Fakhari *et al.,* 2008, Etemad-Saeed *et al.,* 2018). MRG (Maragheh), IV (Ivand), VZ (Varzeghan), DIM (Dimeh), INJ (Injana), HZF (High Zagros Fault), MZF (Main Zagros Fault).

The Fars group comprises the Gachsaran, Mishan, and Aghajari formations. The Gachsaran Fm is mainly composed of evaporates. The overlying Mishan Fm consists of calcareous and marly deposits implying a limited marine transgression in the southern parts of the Zagros. The Aghajari Fm is made up of gray /brown calcareous sandstones, gypsum interlayers, red marls and siltstone. Its contact with the underlying Mishan Fm is gradual whilst, in the Lorestan area, the Aghajari Fm directly overlies the Gachsaran Fm due to absence of the Mishan Fm. The upper parts of the Aghajari Fm are known as the Lahbari Member. This includes siltstones, marly silts, calcareous sandstones, gypsum interlayers and conglomerates. It has a characteristic pale yellow/khaki color and conformably lies on sandstones and red marls of the Aghajari Fm. This member was previously known as the lower Bakhtiari. Generally, the age of the Aghajari Fm is known as middle to late Miocene (Motiei, 1993; Homke *et al.,* 2004).

The Bakhtiari Fm is the topmost and the youngest unit in the Zagros Basin. It overlies the Aghajari Fm with an angular unconformity (Stöcklin & Setudehnia, 1970). The Bakhtiari Fm is mainly composed of conglomerates with minor sandstone lenses, interpreted as representing alluvial deposits formed from mountain erosion. The thickness of the Bakhtiari Fm in the Folded Zagros zone is 300-500 m. It increases northwards, reaching more than 2400 m of thickness in the Aleshtar area, close to the Dimeh site (Fakhari *et al.,* 2008). Due to the age of Aghajari Fm, which is middle Miocene, the Bakhtiari Fm in the Folded Zagros can be attributed to the uppermost part of the Miocene and Pliocene (Motiei, 1993). Magnetostratigraphy in the Lorestan and Ilam basins indicates a late Miocene age for the Aghajari Fm, and around 3 Ma for the Bakhtiari Fm (Homke *et al.,* 2004). The results of new investigations show an older age (early Miocene and probably Oligocene) for the Bakhtiari Fm in the High Zagros. This indicates that the age of primary expansion of foreland basin and the Bakhtiari Fm proximal deposits in the High-Zagros are older than previously thought (Fakhari *et al.,* 2008).

Geographic location and the fossil collection

The fossil site is located at N 33.97812, E 48.07429 in the high-Zagros belt in west of Iran. The elevation of the site is ca 1900 m. It occurs at the road cut of the main highway from Khorram-Abad to Noor-Abad and Kermanshah. It is about 15 km from Noor-Abad, the center of Delfan district of Lorestan Province, and 60 km from Khorram-Abad, the capital city of Lorestan province (Fig. 2). The locality is placed in Dare-Dimeh near Gavkosh village; hence, its name (Dimeh/Gavkosh).

Vertebrate fossils in the continental sediments of the Noor-Abad region, within the Zagros Basin, were discovered as a result of local road extension operations. After this discovery, several groups from Geological Survey of Iran, Cultural Heritage Organization, and Department of Environment visited this area and undertook prospecting and minor excavations of fossil vertebrates. Due to the official responsibility of the Department of Environment (DOE) in the protection of vertebrate fossils in Iran, and supervision of vertebrate paleontology studies, this department (office of natural history museum/MMTT) carried out several major excavations in this region (Fig. 3).

This paper is the first to report the abundant vertebrate fossils unearthed during these excavations. The fossil collections are stored in the National Museum of Natural History (MMTT) of the Environmental Protection Agency (or DOE), located in the Pardisan Park, Tehran. Similar to other late Miocene fossil mammal localities, equid remains are dominant in the collection. Bovids are also very common, represented by numerous complete skulls and horn cores. This is one of the characteristics of this site. The presence of large skeletal remains of giraffes and other herbivorous mammals is also noteworthy.

Stratigraphy and Sedimentology

In addition to the continental deposits of the Aghajari and Bakhtiari formations, the other outcropping stratigraphic units in the study area consist dominantly of the Mesozoic formations of the Bangestan group (Cretaceous), as well as of the Oligo-Miocene Asmari limestone and the late Eocene carbonates of the Shahbazan Fm. Based on the geological map of the region (National Iranian Oil Company, Aleshtar sheet, No. 20809W, scale 1:100,000), fossiliferous sediments at Dimeh are referred to the Bakhtiari Formation (Fig. 2). According to the surveys conducted in this area, the lower boundary of these deposits is undistinguishable, and covered with the recent sediments and agricultural soils. Unlike the typical Bakhtiari Fm, consisting mainly of massive and coarse, clast supported, conglomerates and minor sandstone lenses, the fossiliferous deposits in this area include a considerable amount of marl/clay deposits. Indeed, fossils occur in the light brownish/ reddish clay sediments, indicative of flood plain deposits and even small marginal lakes (Fig. 3). Sand and gravels are also seen locally interbedded with the clays. In a handful of cases, fossil remnants are preserved on top or within sandstones, which is evidence of their transportation and deposition by river flows.

According to this evidence, assignment of fossiliferous sediments to the Bakhtiari Fm is questionable. The sedimentary sequence in the Dimeh valley is similar to the general lithology seen in the Lahbari Member of the Aghajari Fm (Fig. 4). Fossils from the other well-known locality in Zagros Basin (Injana, Iraq) also occur in the same member (Thomas *et al.,* 1980). This member includes several cycles of fining upward sequences. Each cycle starts with a laterally extensive, thick conglomerate bed.

The basal conglomerate is overlain by a thick, pebbly coarse sandstone, that fines upwards into fine sand, silt and thinly laminated clay with hydraulic sedimentary structures like cross beddings and ripple cross-laminations.

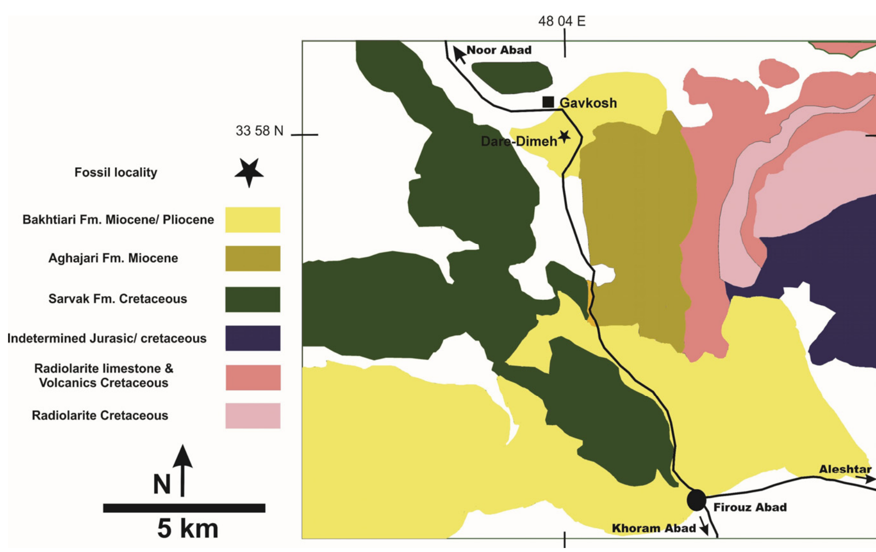

Figure 2. Geological map of the study area and the position of the Dimeh fossil site in the stratigraphical units of the area (map after NIOC sheet No. 20809W).

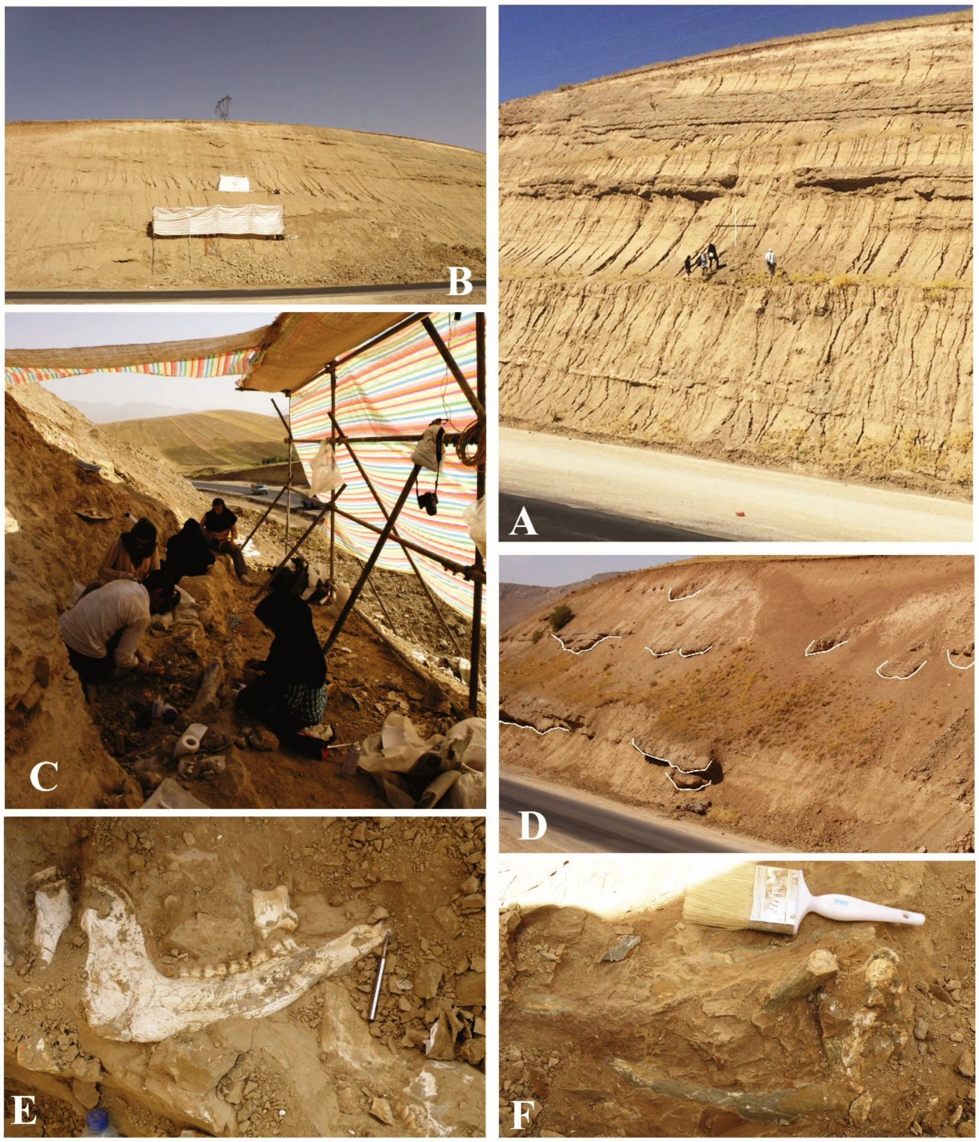

Figure 3. General view of the fossil site, and excavations. A: The outcrop of the Neogene terrestrial sediments at the road cut along the Khoram-Abad/Noor-Abad highway. The total thickness is ca. 30 m. People in the photo are standing about 5 meters above the fossiliferous level; note the predominance of conglomerate horizons toward the top. B: Fossil bearing level (sheltered area) on the outcrop at the road cut. The white tent is the level of standing point in A. C: A view from the excavation site in 2016, D: Chanel deposits present in the study area, E-F: close view of some in situ fossils; large giraffid mandible (E) and bovid skull with long horn cores (F).

Conglomerates of this member get thicker toward the top and eventually turn into the Bakhtiari Fm (Fig. 4). Sedimentary cycles of the Aghajari Fm are generally fining upward. This is indicative of fluvial deposits. Sandstones show lateral accretion surfaces (point bars) and change laterally into floodplain deposits. Interbedded thin evaporates and thinly laminated siltstones and occasional sandstones are indicative of ephemeral lakes and ponds. The Lahbari Member indicates an intermediate depositional environment from meandering rivers of the Aghajari Fm to braided rivers and alluvial systems of the Bakhtiari Fm (Elmore & Farrand, 1981; Motiei, 1993; Etemad-Saeed *et al.,* 2018).

Geomorphologically, the study area contains several hills of the Lahbari/Bakhtiari sediments which are cut off by the road, creating appropriate outcrops for study. The thickness of the stratigraphic section at the Dimeh site is about 30

m. Most of this road cut section is a vertical cliff which makes it difficult to access and study (Fig. 3). However, during the excavation, the first 10 meters of this sequence in which the fossils occur was available for study (Fig. 4). As mentioned, the entire sequence is composed of clay, sandstone and conglomerate intervals. Thick conglomerate and sandstone lenses and channel deposits form large parts of this sequence, which laterally change into sandy and clayey facies.

Taphonomy

Fossil skeletal elements are usually disarticulated and mostly fragmentary. However, a few partial articulated limbs have been found in the Dimeh site. Breakage in fossils is relatively low and there are a lot of complete bones in the collection.

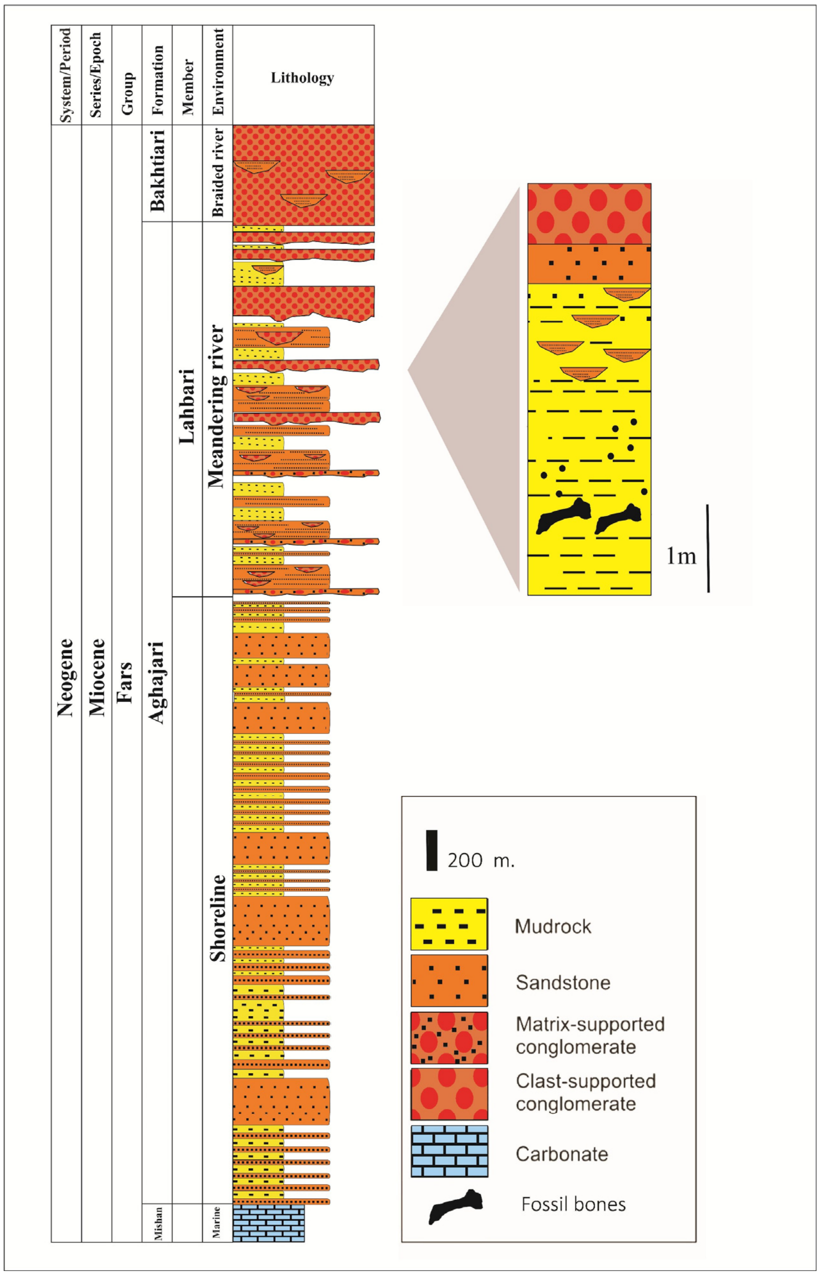

Figure 4. General stratigraphic column of the Fars group and Bakhtiari deposits in the Zagros Basin as recorded north of Dezful embayment (modified after Etemad-Saeed *et al.,* 2018). The enlarged part show details of the fossiliferous interval in the Dimeh site, Lorestan, and its approximate position in the Lahbari stratigraphic sequence.

Therefore, it can be assumed that fossils were not transported over long distances. Lack of cracking and weathering on bone surfaces also indicate relative rapid burial. Though, a few scavenged bones are present. These, together with disarticulated skeletons, show surface exposition of carcasses. Presence of many complete bovid skulls with long and spiral horn cores is one of the interesting evidences at the Dimeh site. This possibly indicates a mass mortality event. It could happen as a result of drowning, in which animals die while trying to pass rivers during migration seasons or other circumstances. Similar cases have been observed in present day Africa. Thousands of wildebeests drown annually while crossing the Mara River during their annual migration through the Serengeti Mara ecosystem (Subalusky *et al.,* 2017).

There are signs of orientation of the elongated bones in this locality, which is indicative of transportation by streams. In addition to the direction of the fossils, another phenomenon caused by transportation is the posture of the fossils relative to each other and their sorting. Some bones are mixed together during transportation and deposition. Such evidences can be helpful especially in interpreting the sedimentary environments. For example, the oblique placement of the long bones in sediments, is indicative of debris flow deposits (Sakai *et al.,* 2016). In Dimeh, the bones do not show good sorting either. Although sorting may be seen in some places at surface, closer examination suggests that there are smaller pieces along and around large bones. Bones of different animals and different sizes are seen in the site.

One of the non-diagenetic taphonomic processes seen in the post-burial stages is bone deformation. This happen as a result of tectonic processes or overlying sediment load. At Dimeh, gentle synsedimentary tectonic forces caused bending and deformations of some long bones and crania. Due to the active and dynamic tectonic of the Zagros, observation of such phenomena is not extraordinary.

Fossil bones of Dimeh are remarkably white colored and lack usual inclusions and impurities. Another unique phenomenon seen around the fossil bones of Dimeh is a green halo around the bones. This halo is apparently due to the concentration of chemical components originating or seeping from the bones. Crystallization is also observed in the empty bone cavities. In some cases the large space inside the bones is totally filled with calcite. Due to the high percentage of calcium content of the bones, origin of this calcite is likely from this source.

Material and methods

More than two hundred fossil specimens are recovered and identified so far from the Dimeh site. The identified taxa and the number of bones are listed in Table 1. The fossils were collected during four excavation seasons. All specimens were prepared and are coded as MMTT (Muze Melli Tarikh Tabiei or national museum of natural history in Persian)-Lor (Lorestan). We used methods and measurements by Kostopoulos & Saraç, 2005; Kostopoulos & Bernor, 2011; and Bernor *et al.,* 2016 for this study.

Table 1. Number of currently excavated and identified bones from the Dimeh site, Lorestan province, Iran.

Family	Elements	Qnt.
Bovidae	Horncores	18
	Mandible	21
	Maxilla	15
	Phalanx/Talus	15
	Skull	10
	Metapodials	7
	Teeth	12
Equidae	Skull	2
	Mandible	13
	Maxilla	6
	Phalanx/Talus	28
	Teeth	20
	Metatarsals	14
	Metacarpals	10
Giraffidae	Mandible	2
	Maxilla	2
	Phalanx	4
	Metapodials	4
Rhinocerotidae	Metapodials	1
Hyaenidae	Teeth	2
	mandible	1
	Talus	1
Proboscidea	Teeth	1
	mandible	1

Systematic paleontology

Order Perissodactyla Owen, 1848

Family Equidae Gray, 1821

aff. *Hippotherium brachypus* Hensel. 1862

Equids are a main component of the Pikermian faunas and are therefore abundant in the studied material. They account for almost 30% of the material recovered from the fossil site. However, the diversity of equids at Dimeh is limited. Based on the morphological analyses of the skull and preliminary statistical study of metapodials, the equid remains of Dimeh are most likely similar to aff. *Hippotherium brachypus* (*sensu* Bernor *et al.,* 2016).

Similar to specimens from Maragheh, the skull from Dimeh (Fig. 5A, D, MMTT- LOR/3555) has a shallow, egg-shaped preorbital fossa (POF). The POF is fairly long, extending anteriorly to a level above the P4 mesostyle. It also has moderate dorsoventral dimensions and shallow medial depth. The peripheral rim morphology of POF is well expressed, including a posterior rim with no posterior pocketing. The nasal notch is placed to the anterior margin of the P2 (Fig. 5A). The P2-M3 is present. Premolars and M1 are worn but M2-M3 reveal the apparent occlusal morphology typical of the middle stage of wear (Fig. 5D). As a result, the plications are moderately complex, protocone is elongate, triangularly shaped and lingually flattened.

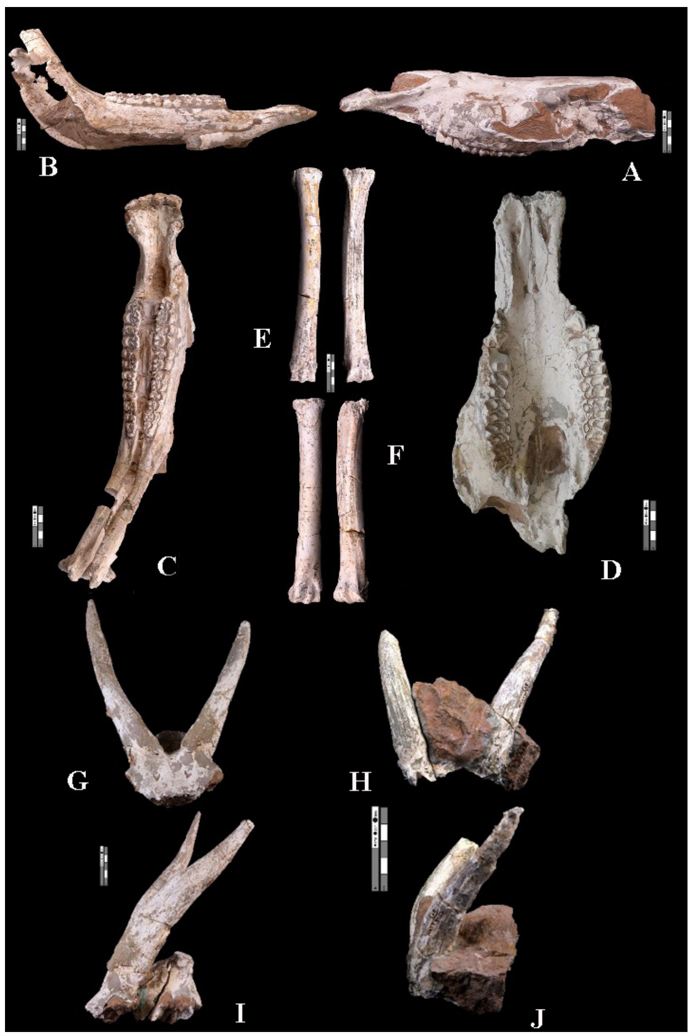

Figure 5. Equid (aff. *Hippotherium brachypus)* cranial and metapodials from the Dimeh site, Lorestan: A, D: skull, MMTT-LOR/3557, lateral (A), ventral (D), Scale bar: 5 cm, B, C: mandible, MMTT- LOR/3555, lateral (B), ventral (C), Scale bar: 5 cm, E: metatarsal, MMTT- LOR/3572, anterior and posterior view (C), Scale bar: 5 cm, F: metacarpal, MMTT- LOR/3580, anterior and posterior view (F), Scale bar: 5 cm, G, I: *Tragoportax* sp. A skull, MMTT- LOR/3483, frontal (G), lateral (I), Scale bar: 5 cm, H, J: *Gazella* cf. *capricornis*, skull, MMTT- LOR/3467, frontal (H), lateral (J), Scale bar: 5 cm

The mandible is elongated with a broad snout and cup. The symphysis is short. The condyle, coronoid processes, and the ascending ramus are partialy preserved (Fig. 5B, C, MMTT- LOR/3555). Horizontal alignment of incisors suggests it was a low grass feeder. Metapodials are relatively long and robust (Figs. 5E, F).

These forms were previously referred to *Hipparion prostylum* (s.l.) based on the derived, shallow POF (Bernor, 1985). Recently, due to new analyses of metapodials and great similarity of Maragheh material to those of *Hippotherium* clade, they are recognized as aff. *Hippotherium brachypus* (Bernor *et al.,* 2016).

Family Rhinocerotidae Owen, 1845

Rhinocerotidae indet.

A single metapodial is currently the only remain of Rhinocerotidae from the Dimeh fossil site. It is possible that some of the unidentified large postcranials belong to these animals. The metapodial is rather small and slender, similar in shape and size to *Chilotherium* (Fortelius *et al.,* 2003). This is a common genus in the late Miocene Pikermian faunas.

Order Artiodactyla Owen, 1848

Family Bovidae Gray, 1821

Tragoportax sp. A

Horn cores approach each other anteriorly, but they rest wide apart medially. The insertion angle of the horn cores with the dorsal surface of skull is high (60-70^{o}). They diverge toward the tip. The frontal between horn cores is strongly elevated forming a wide (medio-laterally) and deep (antero-posteriorly) hump (Fig. 5G, I, MMTT- LOR/ 3483). A strong anterior keel and weak heteronymous torsion occur. All horn cores show a strong distal demarcation. The horn core cross section is triangular at the base and oval to round at the apical part.

Tragoportax sp. B

Strong anterior and postero-lateral keel and stronger heteronymous torsion than in *T.* sp. A. The horn cores are much more compressed mediolaterally at the middle of their length and flattened. Posterior tilting is stronger than in *T.* sp. A, and horn cores are more widely apart anteriorly on the frontals. The intercoronal plateau is higher, deeper and wide (Fig. 6C, F, MMTT- LOR /3451).

Gazella cf. *capricornis* (Wagner, 1848)

Horn cores moderately long and compressed basally, with a cross section changing from oval at base to rounded at the top. They show a significant backward curvature. Grooving is more intense anteriorly/posteriorly than in the rest of the surface and twisting is weak (Fig. 5H, J, MMTT-LOR/3467 and Fig. 7E, MMTT-LOR/3761).

Gazella pilgrimi Bohlin, 1935

Horn cores are straighter and longer than in *G.* cf. *capricornis*. They are medio-laterally compressed, bearing strong grooving on their surfaces (Fig. 7D, MMTT LOR/3475).

Palaeoryx sp.

Horncores are above the orbits and almost vertical. They are laterally close to the orbital rims, long and moderately curved backwards. They moderately diverge toward ¾ lengths and then curve again weakly inwards. The cross section of horn cores is oval and become oval/round at top. They have no keel. Dorsal profile of cranial roof is slightly convex, braincase is moderately long, occipital crest is strong (Fig. 6A, D, MMTT- LOR/3450).

?Samokeros sp.

Horn cores are long, wide apart at the base, and above orbits. They are medio-laterally compressed, with compression increasing towards the tip. Surface of the horn cores has thin irregular grooves and a weak anterior keel. Supraorbital foramina are small and round without surrounding pits. Frontals are pneumatized (Fig. 6B, E, MMTT- LOR/3455).

?Skoufotragus sp.

Horn cores are very long and have elliptical cross section at the base and oval towards the tips. They are close to each other at the base, weakly diverging at the middle and they re-approach each other at the upper most part. Their insertion above the orbits is almost vertical (Fig. 6G-I, MMTT LOR/3458). The surface of the horn cores is smooth with some stronger posterior grooves. The braincase is high, narrow, relatively long, and convex in lateral view.

Prostrepsiceros cf. *rotundicornis* (Weithofer, 1888)

Spiral horn cores with heteronymous torsion (Fig. 7A-C, MMTT- LOR/3459). They are rather slender, not very long and normally tapering. The presence of posterior keel is moderately developed and is clear from base to top. There is no anterior keel in the basal half, but a weak keel is present in the upper half. The maximum basal axis forms a great

almost vertical angle with sagittal plane. Cross section of horn cores is oval at the base, tear shaped at 5 cm above the base, and elliptical to squarish at 10 cm. Horn cores curve backward at the middle and then turn upwards and inwards.
Family Giraffidae Gray, 1821

Genus *Helladotherium* sp.

A very large mandible (500 mm) with P2-M3 length of 199 mm (Fig. 7G, MMTT- LOR/3606) and several large/ very large postcranials including metapodials (Fig. 7F, MMTT- LOR/3712) are among the giraffid material recovered from Dimeh. Similar sized late Miocene forms are usually referred to the genera *Samotherium* (Palaeotraginae) and *Helladotherium* (Sivatheriinae). *Helladotherium* has larger premolar row relative to the molars than *Samotherium* and the limbs are also more massive (Kostopoulos & Sarac, 2005). Some of the metapodials from Dimeh are similar to *Samotherium*, but it needs further study to differentiate between these metapodials.

Order Proboscidea Illiger, 1811

A small mandible with a tooth is preserved. It apparently belongs to a juvenile. The tooth has characters typical of *Choerolophodon* (Konidaris & Koufos, 2013). It is trilophid and shows choerolophodonty and ptycodonty.

Figure 6. Bovid cranials from the Dimeh site, Lorestan: A, D: *Palaeoryx* sp. Skull, MMTT- LOR/3450, frontal (A), lateral (D), Scale bar: 5 cm, B, E: ?*Samokeros* sp. Skull, MMTT- LOR/3455, frontal (B), lateral (E), Scale bar: 5 cm, C, F: *Tragoportax* sp. B, skull, MMTT- LOR/3451, frontal (C), lateral (F), Scale bar: 5 cm, G, H, I: ?*Skouftragus* sp. skull, MMTT- LOR/3458, frontal (G), lateral (H), posterior (I), Scale bar: 5 cm

Figure 7. Bovid, giraffid and Carnivora from the Dimeh site, Lorestan: A, B, C: *Prostrepsiceros* cf. *rotundicornis*, left horn core, MMTT- LOR/3459, lateral (A), posterior (C), almost frontal (B), Scale bar: 5 cm, D: *Gazella pilgrimi*, right horn core, MMTT- LOR/3475, lateral (D), Scale bar: 5 cm, E: *Gazella* cf. *capricornis*, left horn corn, MMTT- LOR/3761, lateral (E), Scale bar: 5 cm, F:?*Helladotherium* sp., metacarpal, MMTT- LOR/3712, posterior (F), Scale bar: 5 cm, G: *Helladotherium* sp., mandible, MMTT- LOR/3606, lateral (G), Scale bar: 5 cm, H: Hyaenidae indet. , canine, MMTT- LOR/3762, lateral (H), Scale bar: 5 cm, I: Hyaenidae indet. , canine, MMTT- LOR/3763, lateral (I) Scale bar: 5 cm, J: Hyaenidae indet, premolar, MMTT- LOR/3764, lateral (J), Scale bar: 5 cm, K, L: Hyaenidae indet, canine and premolar, MMTT- LOR/3765, lateral (K), lingual (L), Scale bar: 5 cm

Order Carnivora Bowdich, 1821

Family Hyaenidae Gray, 1869

The carnivoran material from the studied fauna is limited. So far, a few mandibular and maxillary teeth (canine and premolars) and postcranials are recovered. Based on size, wear and characters of dentition they likely belong to small hyaenids (Fig. 7 H-L). A single calcaneum with typical characters of hyanids is also present. It is about 40 mm long and narrow. In addition, distal fragment of a matepodial is recovered. Very small sized carnivores are also present with a mandible fragment. More study is needed to reveal the carnivoran guild of the study area.

Discussion

Almost all the fossils present in the new fossil locality are also present in the famous Maragheh fossil sites (Table 2). This demonstrate high level of similarity despite the fact that bovids, specially the boselaphines and palaeoryxoid groups, are abundantly represented in the new locality. In Maragheh these taxa are not abundant. Paleoecological factors, taphonomical procedures or other reasons might have affected the fossilization of numerous bovids in Dimeh site. Table 2 shows the distribution of the mammalian taxa of Dimeh site in biostratigraphical levels of the Maragheh locality (Bernor, 1986, Mirzaie Ataabadi *et al.,* 2013). It is evident that the Dimeh fauna is more comparable with the Middle Maragheh, but some correlation with the Upper Maragheh is also apparent. More detail study and identification of fauna at the specific level will elucidate this relationship.

Another "stratigraphically" similar fauna to Dimeh is the Injana (Jabal Hamrin/Jebel Hemrin) fauna of Iraq. This locality is situated in northern Iraq, 120 km north of Baghdad on the way to Kirkuk. The fossils in Injana also occur in the Aghajari Formation, previously known as the lower Bakhtiari (Thomas *et al.,* 1980).

Due to the older age of Injana fauna (MN11) compared to Maragheh (MN11-12) the level of similarity at the generic level between these two localities is not very high. Another major difference between these two areas is the higher number of close-adapted taxa in Injana (Mirzaie Ataabadi, 2010).

Table 2. Genera/species list of identified mammal fossils from the Dimeh site and their presence (*) in nearby localities (L: Lower, M: Middle, U: Upper Maragheh (MRG), northwest Iran and Injana (INJ), northeast Iraq). Double asterisks (**) indicate presence of the genus identified at the species level in those localities. Triple asterisks (***) show the genus is present but identified as different species. Data after Mirzaie Ataabadi *et al.,* 2013, and The NOW community 2018.

Genus/Species	LMRG	MMRG	UMRG	INJ
aff. *Hippotherium brachypus*		*		***
Palaeoryx sp.		*		
Samokeros sp.		**		
Skouftragus sp.		**	**	
Tragoportax sp.		**	**	
Gazella cf. *capricornis*		*	*	*
Gazella pilgrimi				
Prostrepsiceros cf. *rotundicornis*		*		***
Helladotherium sp.		**	**	

These are mammalian (e.g. *Merycopotamus, Dorcatherium*) and reptilian (crocodile) taxa that prefer closed vegetation habitats and wet environments under local ecological control. This fauna is thus believed to have close relationships with those of Siwaliks (Indo-Pakistan), Arabia and east Africa (Brunet & Heintz, 1983; Lihoreau *et al.,* 2007). The similarity between the faunas of Dimeh & Injana (Table 2) is very low, and only a few genera and species are shared. This indicates more relationships to Maragheh and Iran than to the west and Iraq. Geographic proximity within the Iranian plateau might explain this higher similarity with Maragheh. The slightly older age of Injana, its environmental differences, and Afro-Arabian affinities of some taxa at Injana (Brunet & Heintz, 1983; Mirzaie Ataabadi, 2010) may also explain the difference with the Dimeh fauna. Nevertheless, the Dimeh fauna may represent a mass mortality event that occured during seasonal migrations from seasonal dryer areas of the northwest and interior Iran to the wetter and higher regions of Zagros Mountains.

Regarding the age of the new fauna, based on the occurrence of aff. *Hippotherium brachypus* at Dimeh and comparison with the range of this taxon in the Maragheh fauna (Bernor *et al.,* 2016), an age of 8.1-7.9 Ma (MN 11 equivalent) can be proposed for the Dimeh fauna. The mentioned chronology of fossil localities in Maragheh is anchored in an interpolation method used to estimate the age of fossil localities and intervals (Mirzaie Ataabadi *et al.,* 2013). This is based on the distance of fossil localities from the dated marker tuff bed (7.9 Ma) at the base of the Upper Maragheh (Bernor, 1986). However, due to the presence of several Middle Maragheh taxa in the Dimeh site (Table 2) and the younger age of *H. brachypus* occurrence (middle Turolian) in eastern Mediterranean localities (Vlachou & Koufos, 2009), an MN12 equivalent age cannot be ruled out.

Conclusions

A new mammal fossil locality with the typical Pikermian elements is reported in this preliminary investigation. The fauna, which is the first for the Zagros region of Iran, includes many bovids, equids, and giraffids, together with a restricted number of rhinos, proboscideans and hyaenids. This assemblage is more comparable with the Middle biostratigraphical levels of the Maragheh fossil fauna. This can be due to geographic proximity of the two areas, or presence of a migratory root from Iranian plateau to the wetter areas of the Zagros in the west and southwest. The Dimeh fauna may thus partially indicate a mass mortality event that occurred during seasonal migrations. An approximate age of 8-7 Ma (MN 11-12 equivalent) can be currently proposed for this fauna.

Acknowledgements

We thank Department of Environment and MMTT for supporting the excavations at Dimeh and permission to study the fossils for this publication. We appreciate efforts by Geological Survey and Cultural Heritage Organization of Iran, as well as all the DOE/MMTT staff (Tehran and Lorestan) who helped with and participated in the excavations. DSK trip to Iran was supported by a grant to Anu Kaakinen (University of Helsinki) from the Finnish Cultural Foundation (Suomen Kulttuurirahasto). AK also kindly edited the language of this paper. Z. Davoudifard provided taphonomic data and prepared figures 2 and 4. We appreciate comments by S. Sen & R.L. Bernor which significantly improved the quality and language of this article.

References

Bernor, R.L., 1984. A zoogeographic theater and biochoronologic play: the time/biofacies phenomena of Eurasian and African Miocene mammal provinces. Paléobiologie Continentale, 14: 121–142.

Bernor, R.L., 1985. Systematic and evolutionary relationships of the hipparionine horses from Maragheh, Iran (late Miocene, Turolian age). Palaeovertebrata, 15: 173–269.

Bernor, R.L., 1986. Mammalian biostratigraphy, geochronology, and zoogeographic relationships of the late Miocene Maragheh fauna, Iran. Journal of Vertebrate Paleontology, 6: 76–95.

Bernor, R.L., Mirzaie Ataabadi, M., Meshida, K., Wolf, D., 2016. The Maragheh Hipparions; late Miocene of Azarbaijan, Iran. Palaeobiodiversity and Palaeoenvironments, 96: 453–488.

Brunet, M., Heintz, E., 1983. Interprétation paléoécologique et relations biogéographiques de la faune de vertébrés du Miocène supérieur d'Injana, Irak. Palaeogeography, Palaeoclimatology, Palaeoecology, 44: 283–293.

Campbell, B.G., Amini, M.H., Bernor, R.L., Dickenson, W., Drake, W., Morris, R., Van Couvering, J.A., Van Couvering, J.A.H., 1980. Maragheh: A classical late Miocene vertebrate locality in northwestern Iran. Nature, 287: 837–841.

Elmore, R.D., Farrand, W.R., 1981. Asphalt-bearing sediment in synorogenic Miocene–Pliocene molasses, Zagros mountains, Iran. American Association of Petroleum Geologists Bulletin, 65: 1160–1165.

Eronen, J.T., Mirzaie Ataabadi, M., Micheels, A., Karme, A., Bernor, R.L., Fortelius, M., 2009. Distribution history and climatic controls of the late Miocene Pikermian chronofauna. Proceedings of the National Academy of Sciences, 106: 11867–11871.

Etemad-Saeed, N., Najafi, M., Qavim, N., Ghods, A., 2018. Facies analysis and paleo-environmental reconstruction of the Neogene sediments in the Northern Dezful Embayment, Zagros. Geosciences, 27 (108): 3–12 (in Persian with English abstract).

Fakhari, M., Axen, G.J., Horton, B.K., Hassanzadeh, J., Amini, A., 2008. Revised age of proximal deposits in the Zagros foreland Basin and implications for Cenozoic evolution of the High Zagros. Tectonophysics, 451: 170–185.

Fortelius, M., Heissig, K., Sarac, G., Sen, S., 2003. Rhinocerotidae (Perissodactyla). In: Fortelius, M., Kappelman, J., Sen, S., Bernor, R.L. (Eds), Geology and Paleontology of the Miocene Sinap Formation, Turkey. Columbia University Press, New York; 282-307.

Homke, S., Verges, J., Graces, M., Emami, H., Karpuz, R., 2004. Magnetostratigraphy of Miocene–Pliocene Zagros foreland deposits in the front of the Pushe Kush Arc, (Lurestan Province, Iran). Earth and Planetary Science Letters, 225: 397–410.

Konidaris, G.E., Koufos., G.D., 2013. Late Miocene Proboscidea (Mammalia) from Macedonia and Samos Island, Greece: preliminary results. Palaeontologische Zeitschrift, 87: 121–140.

Kostopoulos, D.S. 2009. The Pikermian Event: temporal and spatial resolution of the Turolian large mammal fauna in SE Europe. Palaeogeography, Palaeoclimatology, Palaeoecology, 274: 82–95.

Kostopoulos, D.S., Saraç, G., 2005. Giraffidae (Mammalia, Artiodactyla) from the late Miocene of Akkašdaği, Turkey. In: Sen, S. (Ed.), Geology, mammals and environments at Akkašdaği, late Miocene of Central Anatolia. Geodiversitas, 27: 735-745.

Kostopoulos, D.S., Bernor, R.L., 2011. The Maragheh bovids (Mammalia Artiodactyla) systematic revision and biostratigraphic- zoogeographic interpretation. Geodiversitas, 33: 649–708.

Lihoreau, F., Barry, J., Blondel, C., Chaimanee, Y., Jaeger, J.J., Brunet, M., 2007. Anatomical revision of the genus *Merycopotamus* (Artiodactyla; Anthracotheriidae): its significance for late Miocene mammal dispersal in Asia. Palaeontology, 50: 503–524.

Mirzaie-Ataabadi, M., 2010. The Miocene of Western Asia; fossil mammals at the crossroads of faunal provinces and climate regimes. Ph.D. thesis, University of Helsinki.

Mirzaie-Ataabadi, M., Zaree, G., Orak, Z. 2011a. Large mammals from the new late Miocene fossil localities in Varzeghan area, northwest Iran. Vertebrata Palasiatica, 49: 311–321.

Mirzaie-Ataabadi, M., Mohammad-Alizadeh, J., Zhang, Z., Watabe, M., Kaakinen, A., Fortelius, M., 2011b. Late Miocene large mammals from Ivand (northwestern Iran). Geodiversitas, 33: 709–728.

Mirzaie-Ataabadi, M., Bernor, R.L., Kostopoulos, D.S., Wolf, D., Orak, Z., Zare, G., Nakaya, H., Watabe, M., Fortelius, M., 2013. Recent advances in paleobiological research of the late Miocene Maragheh fauna, northwest Iran. In: Wang, X., Flynn, L.J., Fortelius, M. (Eds.), Fossil Mammals of Asia Neogene Biostratigraphy and Chronology. Columbia University Press, New York; 546–565.

Motiei, H., 1993. Stratigraphy of Zagross. A Publication of the Geological Survey of Iran, 536 pp. (in Persian).

Pickford, M., Pourabrishami, Z., 2013. Deciphering Dinotheriensande deinotheriid diversity. Palaeobiology and Palaeoenvironment, 93: 121–150.

Sakai, T., Zaree, G.R., Sawada, Y., Mirzaie-Ataabadi, M., Fortelius, M., 2016. Depositional environment reconstruction of the Maragheh Formation, East Azarbaijan, Northwestern Iran. In: Mirzaie-Ataabadi, M., and Fortelius, M. (Eds), The late Miocene Maragheh mammal fauna; results of recent multidisciplinary research. Palaeobiodiversity and Palaeoenvironments, 96: 383–398.

Sen, S., Purabrishemi, Z., 2010. First porcupine fossils (Mammalia, Rodentia) from the late Miocene of NW Iran, with notes on late Miocene-Pliocene dispersal of porcupines. Paläontologische Zeitschrift, 84: 239–248.

Solounias, N., Plavcan, J.M., Quade, J., Witmer, L., 1999. The palaeoecology of the SubParatethyan province and the savanna myth. In: Agustí, J., Rook, L. and Andrews, P. (Eds), The Evolution of Neogene Terrestrial Ecosystems in Europe. Columbia University Press, New York; 436–453.

Stöcklin, J., Setudehnia, A., 1991. Stratigraphic lexicon of Iran. A Publication of the Geological Survey of Iran, 376 pp.

Subalusky, A., Dutton, C., Rosi, E., Post, D., 2017. Annual mass drownings of the Serengeti wildebeest migration influence nutrient cycling and storage in the Mara River. Proceedings of the National Academy of Sciences, 114: 7647–7652.

The NOW Community. 2018. New and Old Worlds Database of Fossil Mammals (NOW). Licensed under CC BY 4.0, http://www.helsinki.fi/science/now/.

Thomas, H., Sen, S., Ligabue, G. 1980. La faune Miocene de la formation Agha Jari du Jebel Hamrin (Irak). Proceedings of the Koninklijke Nederlandse Akademie van Wetenschappen B, 83: 269–287.

Vlachou, T. D. and Koufos, G.D., 2009. Equidae. In: Koufos, G.D. and Nagel D. (Eds), The late Miocene Mammal Faunas of the Mytilinii Basin, Samos Island, Greece: New Collection. Beiträge zur Paläontologie, 31: 207–281.