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EDITORIAL

Introduction to the special issue "The late Miocene Maragheh mammal fauna; results of recent multidisciplinary research"

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Maragheh is located at the foothills of Mount Sahand (Fig. 1a) in the East Azarbaijan province of northwest Iran. Besides its historic importance as the capital of the Ilkhanid dynasty (Genghis Khan's successors, thirteenth century), this area was for a century and a half the sole location in Iran known to contain fossil mammals. Maragheh is a true "Lagerstätte", thanks to the sheer abundance and diversity of its fauna (Table 1) which, along with Samos and Pikermi in Greece, has long been considered as one of the three most preeminent western Eurasian late Miocene Pikermian faunas, often referred to as Pontian in the older literature (Bernor et al. 1996; Mirzaie Ataabadi et al. 2013). Indeed, Maragheh fossils figured importantly in the early thinking about a 'Pontian savanna' (Tobien 1967). A great diversity of horses, rhinoceroses, antelopes, giraffes, and distant relatives of elephants combined with a relative scarcity of deer and pigs is typical for this open woodland paleobiome. The Pikermian paleobiome climaxed around 8–7 Ma, covering at that time most of the middle latitudes of Eurasia (Kurtén 1952, Eronen et al. 2009).

The fossil localities of Maragheh are mainly located ca. 10–15 km to the east of Maragheh. However, fossil sites can be found between 37° 20′–37° 25′ N latitude and 46° 16′–46° 37′ E longitude, even within the present extension of Maragheh city. Although fossil bones of Maragheh have been likely known by local villagers for a long time, the Russian explorer Khanikoff is credited with first finding the Maragheh site in 1840. The main early classic fossil excavations in Maragheh were carried out by Austrian and French delegations in late nineteenth and early twentieth centuries (Table 2 and Bernor et al. 2016, this issue). While the second generation 'classics' and the most important studies were conducted during the 1970s by three scientific groups: a combined Dutch-German group led by Erdbrink and assisted by University of Tehran staff (Erdbrink et al. 1976), a joint University of Kyoto-Geological Survey of Iran led by Kamei (Kamei et al. 1977) and the Lake Rezaiyeh Expedition (LRE) led by Professor Campbell and supported by Iranian National Museum of Natural History (MMTT), Tehran and the LSB Leakey Foundation, Berkeley, California (Campbell et al. 1980; Bernor 1986). These expeditions had several important outcomes including the following: (a) collection of fossils with attention to their stratigraphic provenance which was usually neglected by old collectors and (b) application of various geochronologic tools to obtain well resolved ages for the Maragheh section and its faunas.

The late 1970s revolution in Iran brought a long break in the international involvement and scientific excavations in Maragheh for nearly three decades. Nonetheless, by start of the new century the attention to this site was raised among Iranian scientists, leading eventually to a new excavation project in Maragheh in 2004 under the auspices of MMTT. During this project, two sites were initially excavated at

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Fig. 1 **a** Mount Sahand (*centre*) and Maragheh Formation as seen at the top of Dareh Gorg and Karajabad village in Maragheh area. **b** A general view of late Miocene Maragheh Fm. as seen near Shalilvand village in Maragheh area. Photos: M. Mirzaie Ataabadi

middle levels of the Maragheh Formation (Bernor 1986) in Dareh Gorg (Gurt Dareseh) area near Mordagh in the summer of 2004. One of these sites (Site II) revealed a very rich fossiliferous layer that caused the extension of excavations. The northern extension of this site proved to be quite successful and more fossils were revealed. In late 2004, quite unexpectedly remains of fossil primates, including an ape as well as a monkey, were also discovered at this site. Therefore, although some previous excavations (e.g. Japanese and American) which aimed at finding fossil hominoids in Maragheh were unsuccessful, this late activity by Iranians surprisingly resulted in the discovery of the first fossil hominoid from Maragheh Formation. At the time of this discovery the record of hominoids from the Pikermian paleobiome was restricted to the Vallesian of Greece and Turkey. However, a few years later, hominoids were also reported from the Turolian of Turkey and Bulgaria. The conclusion of Campbell et al. (1980) "that the absence of hominoid primates from this site and other late Miocene sites with similar savannah-like faunas strongly suggests their adaptation at this time to more forested environments which existed in Eurasia and Africa before and during the Maragheh interval", unchallenged for a long time, is now being thoroughly revised.

At the request of MMTT one of us (MMA, PhD student at University of Helsinki at that time) visited the hominoid discovery site in Maragheh in summer 2005 in order to inspect and evaluate the excavations. Unfortunately it turned out that the work had been done hastily and many fossils had been damaged (probably including the fossil primates), while smaller fossils had been mostly neglected. However, since most of the work was by then completed, MMA, in his report to MMTT, proposed preservation and careful preparation of fossils by using proper materials and methods. He also suggested a detailed study of the fossils because of the importance of fossil hominoid discovery. The possibility of publishing a special issue about Maragheh was also raised at this time in the same report.

Based on the decision of MMTT, fossils at the hominoid site were preserved in situ in order to establish a field museum.

Table 1 Mammalian species of the late Miocene Maragheh Formation, northwest Iran (modified after Mirzaie Ataabadi et al. 2013)

Order Primates Linnaeus, 1758
Superfamily Hominoidea Gray, 1825
Hominoidea large, gen. et sp. indet.
Family Cercopithecidae Gray, 1821
Mesopithecus pentelici Wagner, 1839

Order Carnivora Bowdich, 1821
Family Ursidae Gray, 1825
Indarctos maraghanus Mecquenum, 1924
Family Mustelidae Swainson, 1835
Promeles palaeattica Zittel
Melodon maraghanus Kittl, 1887
Parataxidea polaki Kittl, 1887
Martes sp.
Family Hyaenidae Gray, 1869
Ictitheriinae gen. and sp. indet.
Ictitherium viverrinum Roth and Wagner, 1854
Thalassictis wongii (Zdansky, 1924)
Adcrocuta eximia (Kaup, 1828)
Family Felidae Gray, 1821
Metailurus orientalis Zdansky, 1924
Felis attica Wagner, 1857
Amphimachairodus aphanistus (Kaup, 1832)

Order Tubulidentata Huxley, 1872
Family Orycteropodidae Bonaparte, 1850
Orycteropus sp.

Order Proboscidea Illiger, 1811
Family Gomphotheriidae Cabrera, 1929
Choerolophodon pentelici Gaudry, 1862
Gomphotheriidae gen. and sp. indet.
Family Deinotheriidae Bonaparte, 1845
Deinotherium cf. *gigantissimum* Stefanescu, 1892

Order Perissodactyla Owen, 1848
Family Equidae Gray, 1821
"*Hipparion*" *gettyi* Bernor, 1985
aff. *Hippotherium brachypus* Hensel, 1862
Hipparion campbelli Bernor, 1985
Cremohipparion aff. *moldavicum* Gromova, 1952
Cremohipparion. matthewi Kormos, 1911
Family Chalicotheriidae Gill, 1872
Ancylotherium pentelici (*Gaudry, 1862*)
Family Rhinocerotidae owen, 1845
Diceros neumayri Mecquenem, 1905
Chilotherium persiae Pohlig, 1887
Iranotherium morgani (Mecquenem, 1908)
Persiatherium rodleri Pandolfi, 2016

Order Artiodactyla Owen, 1848
Family Suidae Gray, 1821
Microstonyx major (Gervais, 1848)
Family Cervidae Gray, 1821
Cervidae gen. and sp. indet.
Family Giraffidae Gray, 1821
Bohlinia attica Matthew, 1929
Palaeotragus coelophrys Rodler and Weithofer, 1890
Alcicephalus neumayri Rodler and Weithofer, 1890
Samotherium boissieri Major, 1888
Samotherium major (Bohlin, 1926)
Helladotherium duvernoyi Gaudry, 1860
Honanotherium bernori Solounias and Danowitz 2016
Family Bovidae Gray, 1821
Miotragocerus cf. *M. maius* (Meladze, 1967)
Miotragocerus sp.
Gazella capricornis (Wagner, 1848)
Gazella cf. *G. ancyrensis* Tekkaya, 1980
Demecquenemia rodleri (Pilgrim and Hopwood, 1928)
Prostrepsiceros cf. *P. rotundicornis* Weithofer, 1888
Prostrepsiceros houtumschindleri (Rodler and Weithofer, 1890)
Prostrepsiceros fraasi (Andree, 1926)
Prostrepsiceros cf. *P. vinayaki* (Pilgrim, 1939)
Protragelaphus skouzesi Dames, 1883
Skoufotragus laticeps (Andree, 1926)
Prostrepsiceros cf. *P. vinayaki* (Pilgrim, 1939)
Protragelaphus skouzesi Dames, 1883
Skoufotragus laticeps (Andree, 1926)
Tragoportax cf. *T. amalthea* (Roth and Wagner, 1854)
Urmiatherium polaki Rodler, 1889
Oioceros atropatenes Rodler and Weithofer, 1890
Oioceros rothii Wagner, 1857
Samokeros minotaurus Solounias, 1981
Palaeoryx sp.
Nisidorcas sp.
cf. *Palaeoreas* sp.

Order Rodentia Bowdich, 1821
Family Hystricidae Burnett, 1830
Hystrix sp.

The first stage of permanent cover over the fossil site was done in 2005 and was completed afterwards. Also, 10 km^2 of the Maragheh fossiliferous area (including the hominoid site and its surroundings) was nominated a national protected zone by Iran's department of environment.

Because of the importance of the hominoid discovery in Maragheh, we proposed to officials in the MMTT that the site and the area should be studied by an international team, an activity that did indeed begin later in 2006. Therefore, an initiative by MMTT-University of Helsinki-Japanese and other researchers known as the International Sahand Paleoenvironment Expedition (INSPE) was established (Mirzaie Ataabadi 2013 and papers in this issue). In September 2007, the first visit of the INSPE team to Maragheh was undertaken, during which the field museum (Site II, hominoid site) was also inspected and preliminary studied. The INSPE initiative later secured two field seasons in (May) 2008–2009, during which small (Fig. 2) and large (Fig. 3a–c) excavations were executed in the Dareh Gorg area.

Table 2 History of the excavations in the Maragheh fossil localities and the subsequent studies. (modified after Mirzaie Ataabadi 2010, for references see Mirzaie Ataabadi et al. 2013/Bernor et al. 2016, this issue)

Year	Excavators	Nationality	Fossil depository	Publications
1840	Khanikoff et al.	Russian	?	Abich 1858, Brandt 1870, Grewingk 1881
1884	Pohlig et al.	Austrian	Naturhistorisches Museum, Vienna?	Pohlig 1886
1885?	Damon?	British?	Natural History Museum, London	Lydekker 1886, Forsyth Major 1893
1885	Rodler and Kittl et al.	Austrian	Naturhistorisches Museum, Vienna	Kittl 1885, 1887 Rodler 1887, 1890, Rodler and Weithofer 1890, Bernor et al. and Solounias and Danowitz, this issue
1904	de Mecquenem et al.	French	Muséum National d'Histoire Naturelle, Paris	Mecquenem 1905, 1906, 1908, 1911, 1924–1925, Bernor et al. and Solounias and Danowitz, this issue
1956	Takai et al.	Japanese	?	Takai 1958
1958	Savage et al.	British	Natural History Museum, London	
1967	Tobien et al.	German	Bayerische Staatssammlung für Paläontologie/Geologie, Munich	Tobien 1968, Bernor et al. and Solounias and Danowitz, this issue
1973	Erdberink et al.	Dutch/German	Department of Earth Sciences, Utrecht University, Utrecht Bayerische Staatssammlung für Paläontologie/Geologie, Munich	Erdbrink et al. 1976; Erdbrink 1976a, b, 1977, 1978, 1982, 1988; Bernor et al. and Solounias and Danowitz, this issue
1973	Kamei et al.	Japanese	Department of Geology, Kyoto University, Kyoto	Kamei et al. 1977, Watabe 1990; Watabe and Nakaya 1991a, b, Yamada et al. this issue
1974 1975 1976	Campbell et al. (LRE project)	American	Department of the Environment (DOE), National Museum of Natural History (MMTT), Tehran, Iran	Campbell et al. 1980; Bernor et al. 1978, 1980, 1985, 1986, 1996; Morris 1997; Bernor et al. and Solounias and Danowitz, this issue
1987	Partoazar et al.	Iranian	Geological Survey of Iran	
2004	Pourabrishemi et al. (MMTT project)	Iranian	Department of the Environment (DOE), Maragheh	
2008 2009 2015 2016	Fortelius et al. Kaakinen et al. (INSPE project)	International-Iranian	Department of the Environment (DOE), Maragheh	Mirzaie Ataabadi et al. 2013 and this issue papers

These excavations aimed to give onsite instructions to MMTT staff in form of laboratory and field workshops (Fig. 3d–h). Although these new excavations did not produce new hominoid remains, the field seasons and their associated workshops did result in detailed study of stratigraphy, sedimentology and geochronology in the vicinity of Dareh Gorg and around the hominoid fossil site. In late May, 2009 the INSPE team could finally access the hominoid specimen in the MMTT office in Tehran and investigate and document the specimen for further studies.

Unfortunately, the unrests following the presidential elections in summer of 2009 in Iran temporarily prevented the INSPE team to continue its research afterwards. But recently (May/June 2015–2016), the palaeomagnetism and sedimentology teams visited Maragheh and the hominoid site, and conducted their studies (Fig. 4).

While it is difficult and indeed rather pointless to make predictions about the future, it is perhaps permitted here to express some hopes and wishes. For the future of international research, at Maragheh specifically and in Iran generally, the training of Iranian students and young scientists as part of collaborative research projects appears highly desirable. Such training works, we find, far better in the context of actual, hands-on research than in the form of general-purpose visits or education. Mutual exchange between actively collaborating Iranian and international institutions, involving students and researchers from both sides, should be strongly encouraged. Here it may be said that while Iran has been highly successful in recent decades in training young women for administrative tasks, including tasks at the highest levels of society, the number of female leaders in research is still low. There is a hidden resource here that should not be neglected.

When we look back to the fifteen years that have passed since our first meeting in Esfahan in the summer of 2001 we feel encouraged by the fact that while practical and political problems have occasionally loomed large, we have always found hospitality and willingness to overcome difficulties, equally among our Iranian hosts and our international collaborators. The acronym INSPE points to the Latin phrase *in spe*,

Fig. 2 **a** An overview of site DRG1 in Dareh Gorg, Maragheh (2008). **b**, **c** Excavation work in DRG 1. **d** Mikael Fortelius supervising excavation in DRG 1. Photos: M. Mirzaie Ataabadi and Mikael Fortelius

referring to a state of hopefulness regarding the future. This is the state in which the papers of this special issue were researched and written, and this is the spirit in which we hope that the work will continue and grow. The beloved lines[1] of Abu Sa'id (967–1049), often misattributed to Rumi, offer an open invitation across a millennium to multidisciplinary and multicultural collaboration in a spirit of love and trust:

> Come back, come back, whatever you are, come back, whether unbeliever, fire-worshipper, or idolater, come back!
> This Court of Ours is not a Court of despair:
> even though you may have broken your vow of repentance a hundred times, come back!

[0] Literal translation by Jaakko Hämeen-Anttila.

This special issue, which is also the first edited special issue on palaeontology in Iran, reports the multidisciplinary results of recent studies by the INSPE team in Maragheh, including vertebrate palaeontology, palaeoecology, sedimentology, stratigraphy, geochronology and magnetostratigraphy.

Mirzaie Ataabadi et al. summarised the studies by the INSPE team in the hominoid bearing area of the Maragheh Formation and revealed more details of the hominoid site and its fossils. A preliminary investigation of the palaeoecology based on the fossils present at the hominoid bearing level of Middle Maragheh interval is also presented. These analyses show the similarity of the Maragheh hominoid level with Turolian hominoid and *Mesopithecus* bearing localities in Turkey, Greece and Bulgaria. However, some environmental


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◀ **Fig. 3** **a** An overview of site AZM (Azim Dareh) near Aliabad and Dareh Gorg (2009). **b**, **c** Excavation work in AZM. **d** Workshop participants making a plaster jacket and **f** packing small specimens. **e** Mahito Watabe showing excavation and **h** preparation methods. **g** Hideo Nakaya lecturing in the workshop. Photos: M. Mirzaie Ataabadi and Mikael Fortelius

differences are present between these localities which are reflected in their faunal structure and taxa characters, as well as different masticatory adaptations present in their hominoids. (*Palaeobiodiversity and Palaeoenvironments 96*(3). Doi: 10.1007/s12549-016-0241-4)

Suwa et al. described in detail the first hominoid fossil remains from Maragheh Formation, a maxillary fragment with well-preserved second and third molars. Molar morphology of the Maragheh hominoid makes it similar to several Eurasian Miocene genera but the authors cautiously suggest that it may be related more closely to either *Ankarapithecus* or *Sivapithecus* rather than to *Ouranopithecus*. Needless to say, the fragmentary nature of the fossil makes evaluations difficult. (*Palaeobiodiversity and Palaeoenvironments 96*(3). Doi: 10.1007/s12549-016-0234-3)

Sakai et al. presented preliminary results of depositional environment reconstruction from the Maragheh Formation. Their high-resolution facies analysis around the hominoid fossil site indicates that debris flow deposits and paleosols are dominant in the studied horizons. Fluvial channel fill and small pond facies are subordinate components in this interval. The internal architecture of fluvial channel deposits and structures of paleosols also imply the seasonal climate during the deposition of the studied interval. (*Palaeobiodiversity and Palaeoenvironments 96*(3). Doi: 10.1007/s12549-016-0238-z)

Sawada et al. provided new hornblende and plagioclase K-Ar ages for the key pumice and volcanic beds in Dareh Gorg area, sampled near the hominoid locality. The new dates indicate a time span of 8–7 Ma for the studied area. The Chemical composition of pumices shows adakitic features that fall in the dacite field of the total alkali-silica (TAS) classification diagram, similar to rocks from the Sahand volcano. It is inferred that the source materials of the adakitic dacite magma originated from the Neo-Thetys plate subducted beneath the Eurasia plate. (*Palaeobiodiversity and Palaeoenvironments 96*(3). Doi: 10.1007/s12549-016-0232-5)

Salminen et al. presented preliminary magnetostratigraphic results from the Maragheh Formation. This is the first high-resolution study of palaeomagnetism from Maragheh and it recognises three polarity intervals; a reversed polarity, bounded by normal polarities above and below. The shortness of the section makes inference challenging but three possible correlations to the geomagnetic polarity time scale are proposed, guided by palaeontological constraints and recent K-Ar age determinations. According to these correlations, the hominoid locality is correlated to C3Br.1n, C4n.1n, or C4n.2n,

Fig. 4 Field studies in Dareh Gorg near Mordagh tuff in late May 2016. Photo: M. Mirzaie Ataabadi

representing an age range of 8.1–7.3 Ma. (*Palaeobiodiversity and Palaeoenvironments 96*(3). Doi: 10.1007/s12549-016-0239-y)

Yamada et al. investigated the palaeoecology of the fossil hypsodont equids and bovids from Maragheh Formation by using mesowear analyses of sympatric ungulates. They show that the hipparionine horses were grazers whereas the bovids relied on broader range of plant foods. Their results represent dietary differentiations of the Maragheh ungulates, consistent with the concept of a mosaic vegetational habitat proposed by previous mesowear studies. (*Palaeobiodiversity and Palaeoenvironments 96*(3). Doi: 10.1007/s12549-016-0237-0)

Bernor et al. studied the hipparionine horses from Maragheh, including postcranial material in their new analysis. Together with previous studies on cranial and dental material, they characterise and define *Hipparion gettyi*, aff. *Hippotherium brachypus*, *Cremohipparion* aff. *moldavicum*, *Cremohipparion matthewi* and *Hipparion campbelli* in the Maragheh assemblage. This proposed taxonomic and biostratigraphic resolution is slightly different from previous studies especially in the recognition of *aff. Hippotherium brachypus* instead of *Hipparion prostylum*. (*Palaeobiodiversity and Palaeoenvironments 96*(3). Doi: 10.1007/s12549-016-0235-2)

Solounias and Danowitz reviewed the Giraffidae of Maragheh and provide detailed cranial and postcranial morphological descriptions of six Maragheh giraffids including *Helladotherium duvernoyi*, *Alcicephalus neumayri*, *Samotherium boissieri*, *Samotherium major*, *Palaeotragus coelophrys*, and *Bohlinia attica*, extending the geological range of several taxa. They also describe a new species of *Honanotherium* (*Honanotherium bernori*), representing the westernmost occurrence of *Honanotherium*. Using combined inner and outer mesowear analysis in a few adult Maragheh giraffids, they find individuals spanning the dietary continuum, but with a polarity towards browsing diets. (*Palaeobiodiversity and Palaeoenvironments 96*(3). Doi: 10.1007/s12549-016-0230-7)

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