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First Turolian findings in the Neogene sequence of Denizli Basin (SW Anatolia) and its regional palaeobiogeographic significance

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ABSTRACT

The large fossil vertebrates obtained from the alluvial flood-plain deposits of the Kolankaya formation are determined as *Skoufotragus laticeps* (Andree, 1926) and *Hipparion brachypus* (Hensel, 1862), as representative elements of palaeomammal faunas spanning from the eastern Mediterranean to Iranian domains during the late Miocene (early-middle Turolian, MN11-12). These first Turolian records from the basin fill succession bear importance on reconstruction for the palaeobiogeographic diversity of relevant taxons as well as admit of interbasinal stratigraphic correlation for the Western Anatolian terrestrial Neogene basins.

1. Introduction

The Anatolian peninsula has a key position for migration and distribution of vertebrate groups due to its geographic location between Asia, Africa and Europe. Therefore, the rich fossil content of the terrestrial Neogene basins of Anatolia is of great importance in understanding inter-continental faunal changes and biodiversity (Sickenber and Tobien, 1971; Saraç, 2003; Alçiçek, 2010; Alçiçek et al., 2019; Krijsgman et al., 2019). Although there are already known vertebrate fossil records in the Neogene sequence of the Denizli Basin (Saraç, 2003), yet there is no record of Turolian time. On the other hand, the Turolian vertebrate fossil records are already known in many localities around the Denizli Basin such as Asarlık (Alçiçek et al., 2012, 2019; Alçiçek and Alçiçek, 2014), Mahmutgazi (Sickenberg et al., 1975; Pickford and Ertürk, 1979; Köhler, 1987; Saraç, 2003; Pickford, 2016; Geraads, 2017), Sazak (Saraç, 2003; Tuna, 1999), Elmalıyurt (Saraç, 2003; Alçiçek et al., 2005, 2006, 2019); Kemiklitepe (Şen et al., 1994; Saraç, 2003; Xafis et al., 2020), Karabeyli (Seyitoğlu et al., 2009), Karamusalar (Alçiçek, 2007; Alçiçek et al., 2019), Şerefköy (Saraç, 2003; Kaya et al., 2012; Mayda, 2014), Özlüce (Saraç, 2003; Alpagut et al., 2014; Mayda, 2014).

In this study, the presence of regional inter-basinal faunal connectivity and migration routes have been shown with support of the first Turolian vertebrates found in the Denizli Neogene sequence for the first time. These findings, which fill an important gap for a more detailed understanding of Turolian palaeobiogeography in Anatolia, also enable regional stratigraphic correlation among the basins.

2. Geological Setting

Since the Miocene, the western Anatolia has been consisted of horst-graben system driven by the

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regional crustal extension and associated normal faults. The metamorphics of the Precambrian-Paleozoic Menderes Massif and tectonically overlying the Mesozoic carbonates and ophiolites of the Lycian Nappes are the basement rock suits. The regional extension was resulted in the subsidence of the Denizli Basin from the beginning of the early Miocene and initiated alluvial, fluvial and lacustrine sedimentation (Şimşek, 1984; Okay, 1989; Sun, 1990; Westaway, 1993; Konak and Şenel, 2002; Koçyiğit, 2005; Kaymakçı, 2006; Alçiçek et al., 2007; figure 1). Westaway (1993) states the Denizli Basin as a graben that subsided continually by the extension of western Anatolia, while Koçyiğit (2005) proposes a short term of compression interrupted the extension. Based on micro-mammal fossils Saraç (2003) attributes an early Miocene age to the oldest basin-fill deposits.

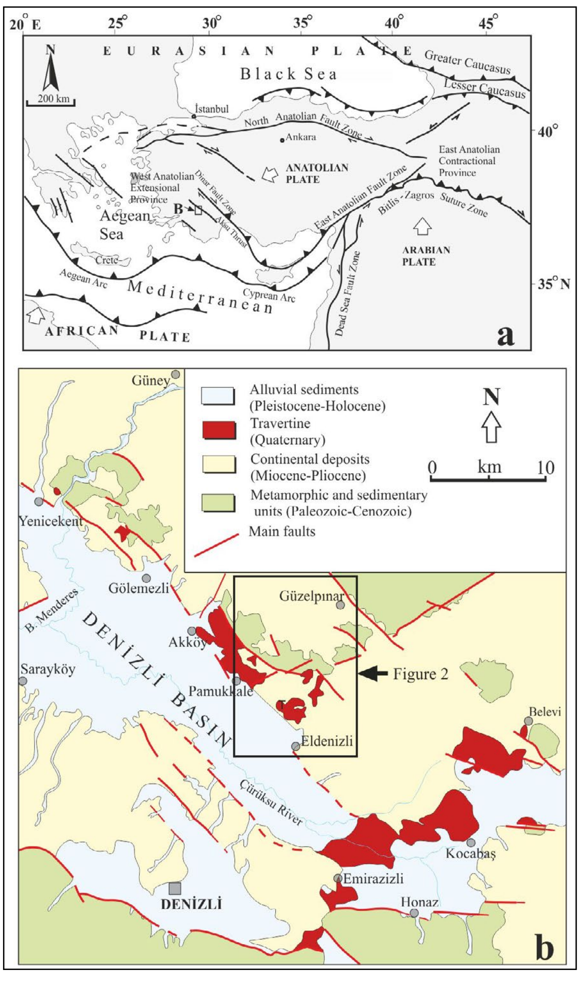

Figure 1- a) Regional tectonic setting of Anatolia (Bozkurt, 2003; Alçiçek et al., 2013; Kaymakçı et al., 2018) and b) geological map of the Denizli Basin (Sun, 1990).

Kaymakçı (2006) states that the extension in the basin was accompanied by transfer faults and documented a late Pliocene age of the basin based on micro-mammal fossils. According to Alçiçek et al. (2007) sedimentation in the basin has been constant until present in control of NW trending faults that limit the basin and accompanied by the climatic and lake-level changes.

In this study, a detailed geological map of the study area to the northeast of Denizli Basin framed in the Denizli M22-a2 sheet has been produced in 1/25.000 scale (Figure 2). The stratigraphy of the basin was elaborated by correlating the findings of the new Turolian fauna in the study area with the previously founded fossils in surrounding basins. The new fossils were found at Gölyeri (UTM 693655/4200295) within the Güzelpınar member of Kolankaya formation which consists of alluvial-fan deposits, tectonically elevated at the northeast margin of the basin.

3. Neogene Stratigraphy of the Denizli Basin

The Neogene units that unconformably overlie the basement in the study area were first described by Şimşek (1984) as the Denizli Group (Figure 3).

3.1. Kızılburun Formation

The unit forming the base of Denizli Neogene succession overlies unconformably the basement rocks. It is consisted of conglomerate at the base and sandstone, siltstone and mudstone alternations towards the top. The upper levels include clayey limestones, siltstones, mudstones and coal lenses. The unit is conformably overlain by lacustrine Sazak formation. The age of the unit was determined as early Miocene by Saraç (2003) according to the micro-mammalian remains (MN5-6).

3.2. Sazak Formation

The unit is mainly composed of lacustrine sediments, consists of limestones, marls, siltstones, claystones and organic mudstones, cherty limestones which contain gypsum, gypsum arenite and organic levels. The unit conformably overlies the Kızılburun formation as well as onlaps the basement units, and overlains by the Kolankaya formation. Saraç (2003) suggests a middle Miocene age for the unit according to the micro-mammalian associations (MN6-8).

3.3. Kolankaya Formation

The dominant lithology of the unit is yellowish-brown, gray coloured sandstones with alterated sandstones, marls and limestones at the base. Thin-medium to thick bedded sandstones are loosely cemented, dispersed and bright mica flakes within them are among the characteristics features in the field. Interlayers of clayey limestone are common in the unit and gypsum layers developed in the marshy environment towards the top. Fluvial deposits reaching

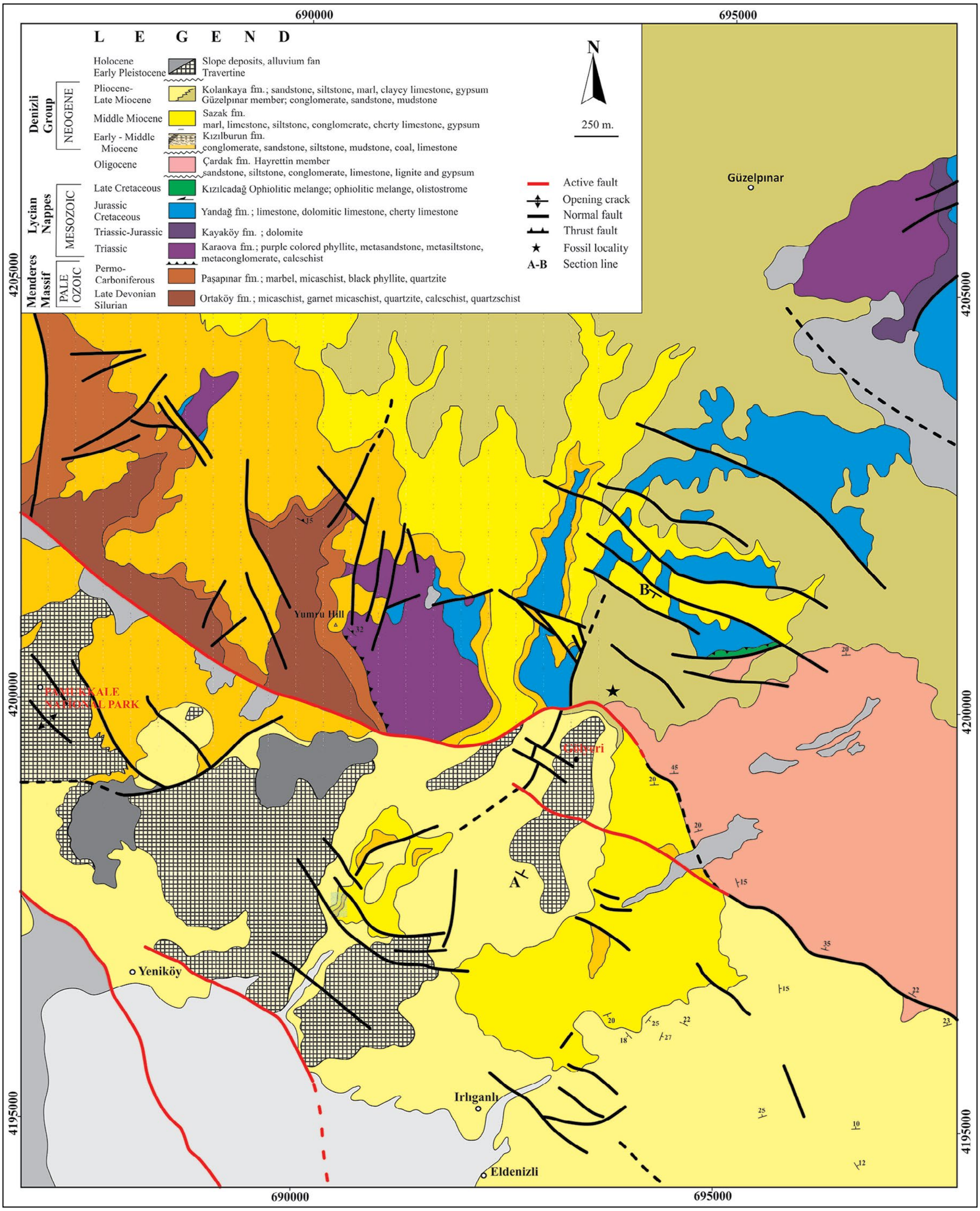

Figure 2- Detailed geological map of the study area (Denizli M22-a2). Based on the unpublished geological map of MTA in 1/25.000 scale compiled by N. Konak, and the active tectonic map of MTA (Emre et al., 2013).

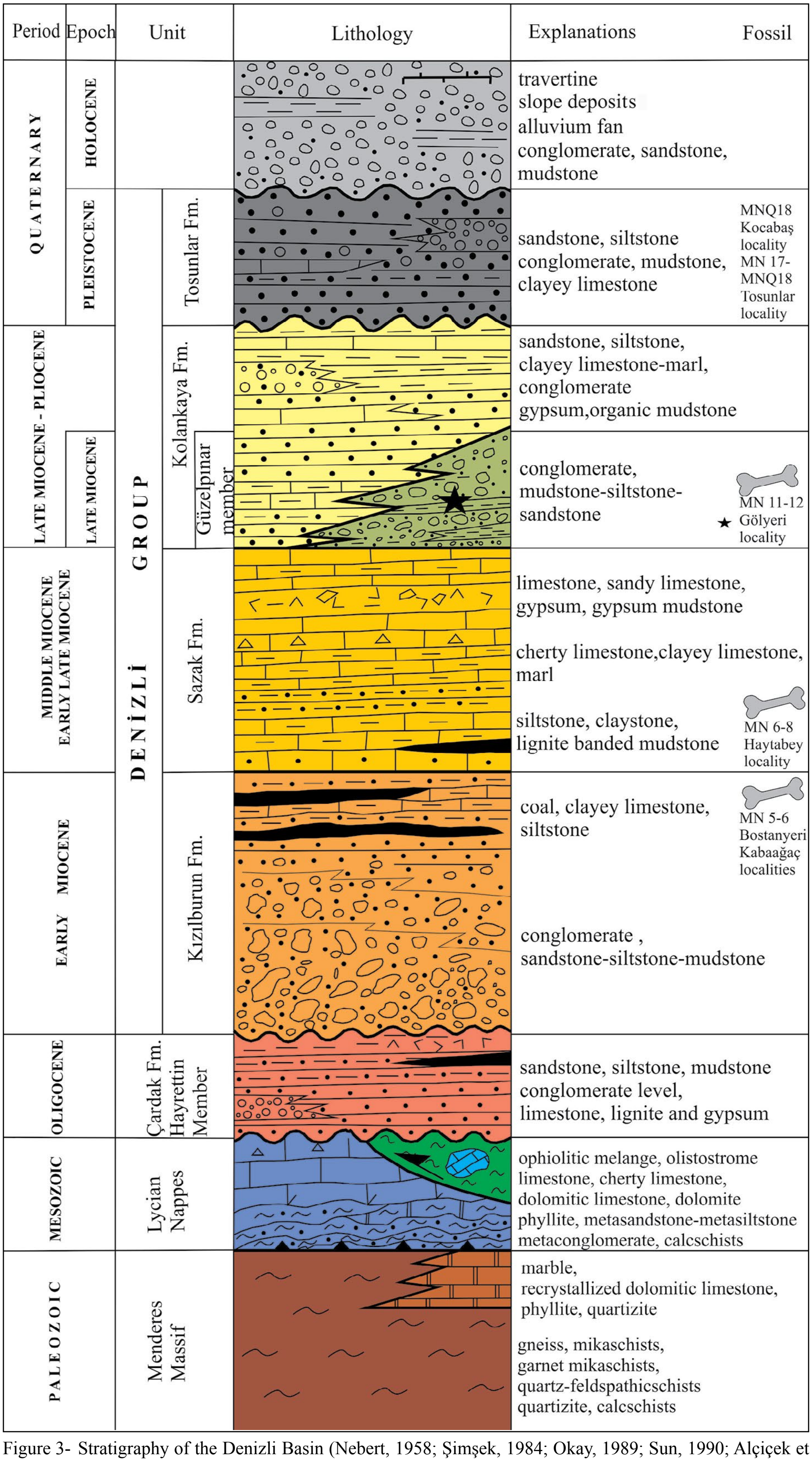

Figure 3- Stratigraphy of the Denizli Basin (Nebert, 1958; Şimşek, 1984; Okay, 1989; Sun, 1990; Alçiçek et al., 2007; Kaymakçı, 2006; Saraç, 2003; Lebatard et al., 2014*a, b*; Boulbes et al., 2014; Alçiçek et al., 2015, Rausch et al., 2019).

into the lacustrine part of the unit from the basin margins form shallow water deltaic successions. Saraç (2003) attributes a late Miocene-late Pliocene age to the unit based on the micro-mammal associations.

3.3.1. Güzelpınar Member

The fossil bearing unit presented in this study is defined as Güzelpınar member within the Kolankaya formation. The unit dominated by red, reddish brown coloured irregular alternation of conglomerate, sandstone, siltstone and mudstone. The pebbles are polygenic and rounded; angular to semi-angular pebbles are also observed. Sandstone-siltstone levels commonly contain caliches. The poorly-sorted, mass-transport dominated unit is mainly composed of alluvial flood deposits (Figure 4). The age of the unit is assigned to late Miocene (early-middle Turolian, MN11-12) according to the vertebrate fossils introduced in this study.

3.4. Tosunlar Formation

The dominant lithology of the unit is composed of yellowish-brownish sandstone and siltstones, conglomerate, mudstone and clayey limestones. It constitutes the uppermost reach of the Neogene sequence of the basin. The age of the unit has been determined as late Pleistocene based on the micro-mammal content of (MN17) by Kaymakçı (2006).

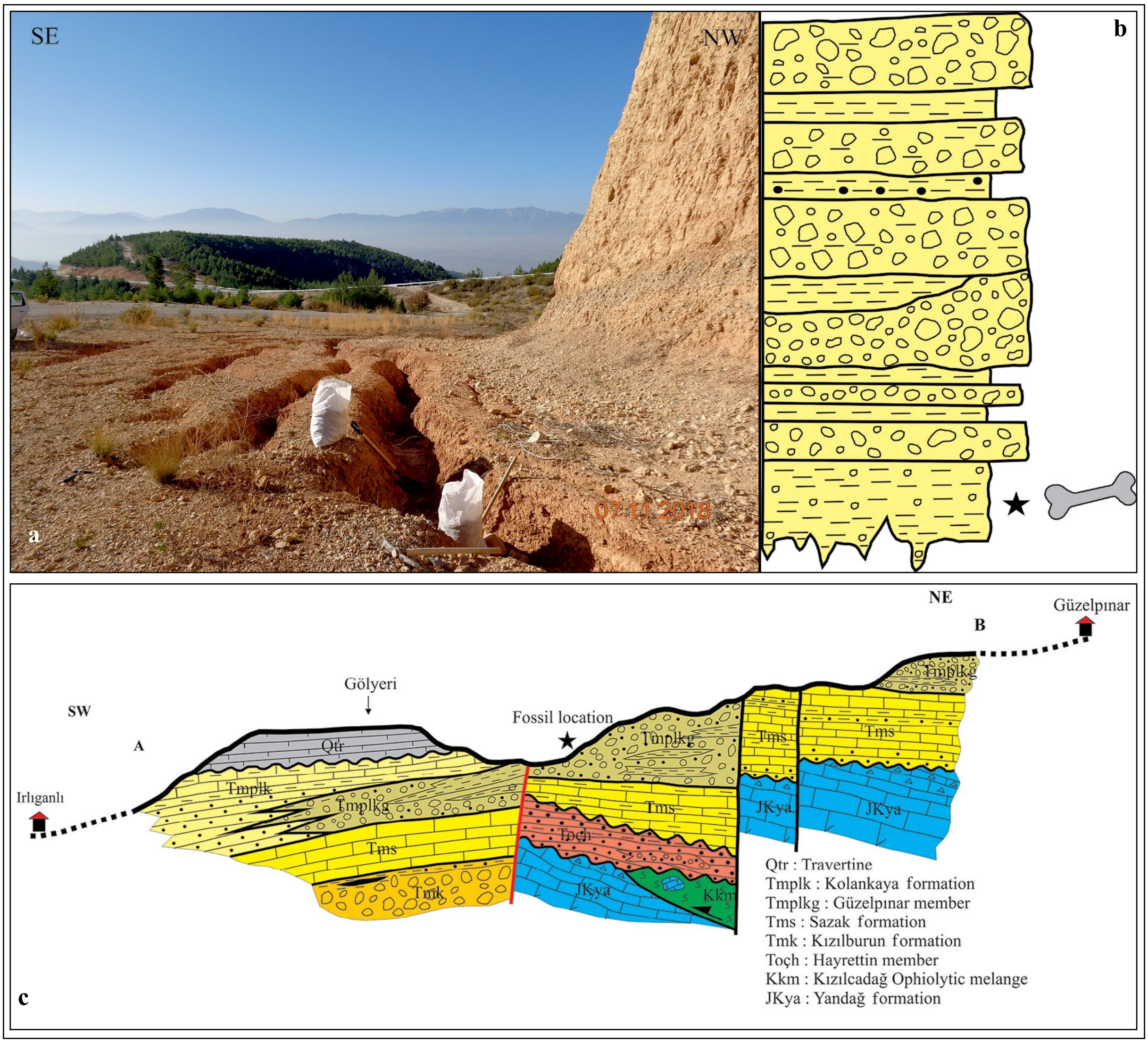

Figure 4- a) Field view of the Turolian fossil locality at Gölyeri, b) stratigraphic section of the fossil bearing unit and c) geological cross section through the fossil locality (not to scale).

The youngest units in the study area are the undifferentiated Quaternary alluvial-fan and scree and travertine deposits.

4. Material and Method

The fossil materials in this study (Figure 5) were found in situ and recorded in the inventory of Ege University Natural History Museum (EUNHM). The odontological study is based on a description of the structural elements of the tooth and comparison with the definitions in the previous studies. In this respect, for the dental terminology of the Bovidae, Gentry et al. (1999) has been followed. The upper teeth are indicated with M (upper case) and the measurements are obtained by measuring the maximum length and perpendicular width with a 0.1 mm precision calliper. All measurements are given in millimeters (mm). For the method and terminology of *Hipparion* metacarpal measurement, Eisenmann et al. (1988) has been followed. Measurements: M10 (maximum distal supra-articular diameter), M11 (maximum distal articular diameter), M12 (maximum diameter of the distal keel), M13 (minimum diameter of the distal lateral conduit), M14 (maximum diameter of the distal medial conduit) have been calculated and the values are depicted graphically in figure 6 and figure 7. Şen et al. (1978) suggested that the sagittal keel development observed in the distal third metapodials of Equidae family is an important morphological character to distinguish between the Vallesian and Turolian *Hipparion* forms, and they first revealed the index which was defined as the keel index. This index is obtained by (M12x100/M13) operation and this value increases from the Vallesian to Turolian. The development of the sagittal keel is directly related to the lateral mobility of horses, and it can be said that horses with larger keel values are runner forms that adapt to more open environments (Eisennmann, 1995; Koufos, 2016).

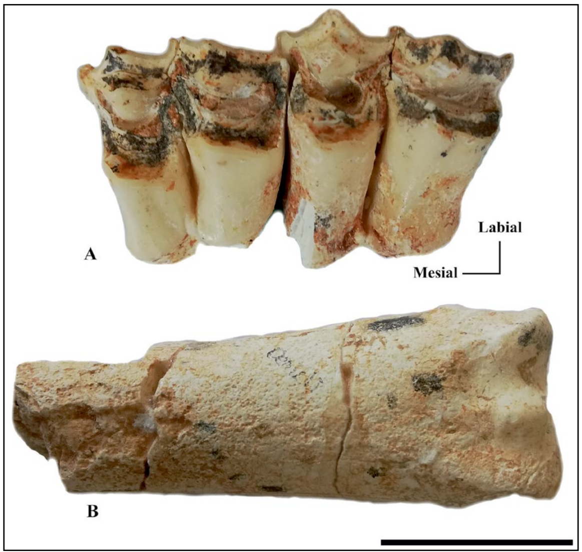

Figure 5- Fossil specimens of Denizli-Gölyeri fauna:
A. *Skoufotragus laticeps* upper letf M^{1-2} (EUNHM-PV-8000)
B. *Hipparion brachypus*: left distal MC3 (EUNHM-PV-8001) (Scale: 5a: 4 cm, 5b: 2 cm)

5. Systematic Paleontology

Ordo : ARTIODACTYLA Owen, 1848

Family : BOVIDAE Gray, 1821

Genus : *Skoufotragus* Kostopoulos, 2009

Type species : *Skoufotragus schlosseri* (Andrée, 1926)
Skoufotragus laticeps (Andrée, 1926)

Age: early-middle Turolian (MN12) (late Miocene**)**

Material: Upper left M^{1-2} (EUNHM-PV-8000) (Figure 5A)

Description: The specimen represents an upper left molar series of a semi-adult individual (length x width (mm): M1:20.3x19.2; M2:23.5x20.1). In both molars, entostyle is not observed with junction of the anterior and posterior medial lobes on the chewing surface. The protocon is angular and pointed, while the hypocon is larger and rounded. The basal pillar is not observed in the middle of the chewing surface of the tooth. Metastyle is the weakest and parastyle is the most developed style. M2 is larger than M1 and the proximal of the tooth is wider than its distal. Parastyle and mesostyle are equally developed.

Correlation/Comparison: 'Protoryxoid' bovids have been recorded in the SE Mediterranean region from the late-middle Miocene onwards (Gentry, 2000; Kostopoulos and Karakütük, 2015). During the late Miocene, especially in Anatolia, Greece and its environs, the group was widespread and many taxa co-exist in the same age. The taxonomy of the genera

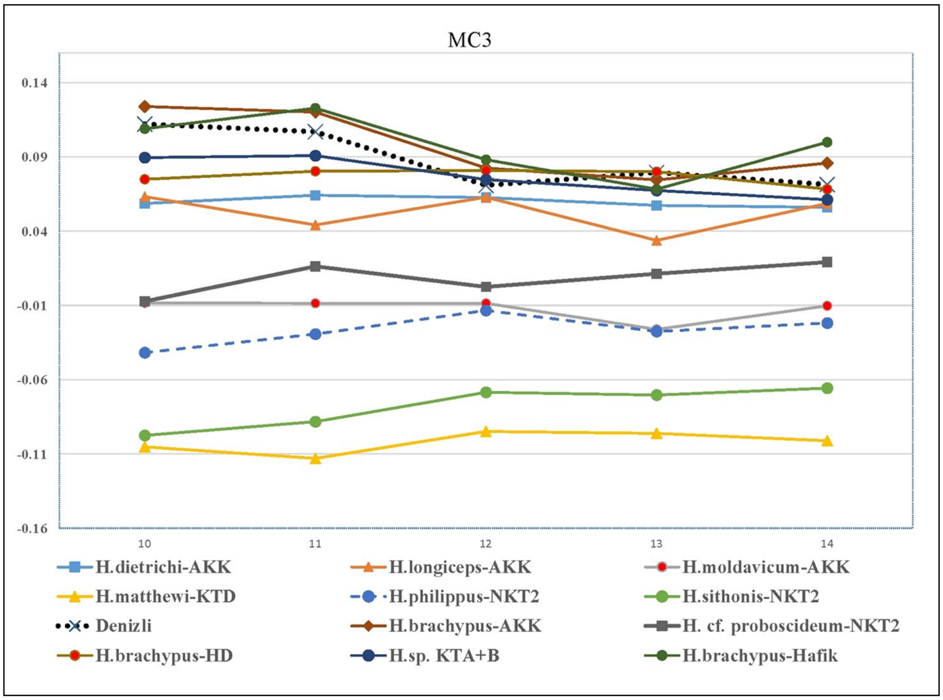

Figure 6- The logarithmic comparison diagram of the Denizli-Gölyeri fauna and various late Miocene *Hipparion* species presented by Hristova et al. (2003), Koufos and Kostopoulos (1994) and Koufos and Vlachou (2005) (Standard: *H. mediterraneum*, Pikermi-Greece, Koufos 1987). The M10-M14 measurements are compared with the findings by Hristova et al. (2003), Koufos and Kostopoulos (1994) and Koufos and Vlachou (2005).

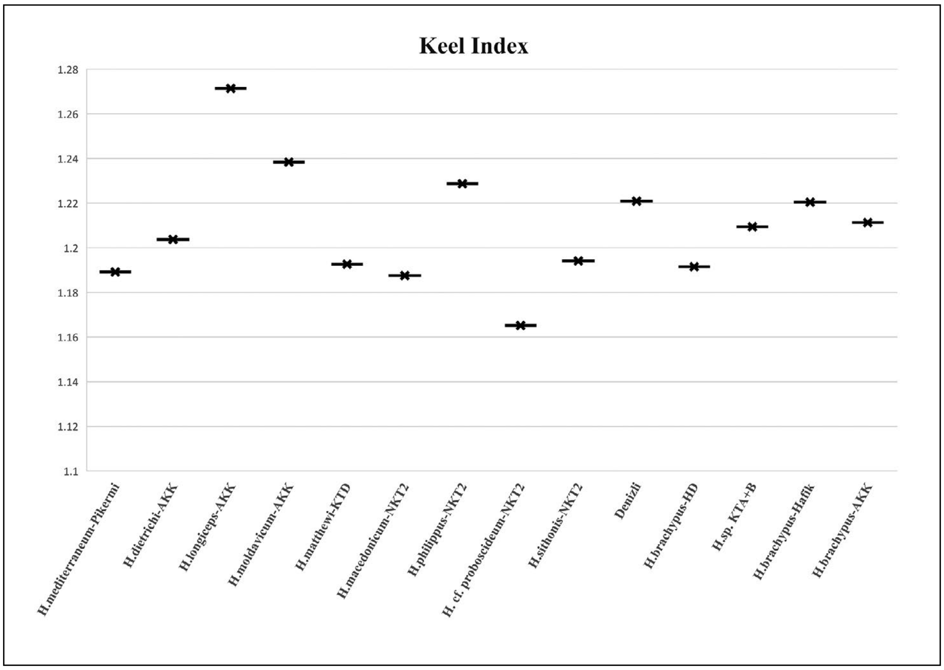

Figure 7- The MC3 keel index diagram including Denizli-Gölyeri fauna and various late Miocene Hipparion species presented by Hristova et al. (2003), Koufos and Kostopoulos (1994) and Koufos and Vlachou (2005).

involved was revised by Kostopoulos (2009), who suggested replacing the problematic *Pachytragus* by the new name *Skoufotragus*, keeping *Protoryx* only for *Protoryx carolinae* and *Pr. capricornis*. In Anatolia *Skoufotragus* is recorded in the localities of Kınık (*Skoufotragus sp.,* late Miocene, MN12) (Köhler, 1987), Kemiklitepe-A (*S. laticeps,* late Miocene, MN11) (Bouvrain, 1994), Akkaşdağı (*S. schlosseri,* late Miocene) MN12) (Kostopoulos, 2009) and Şerefköy-2 (*S.* cf. *schlosseri*, late Miocene, MN12) (Kostopoulos and Karakütük, 2015). In addition, this genus has been recorded in Greek (Samos, Kryopigi) (Kostopoulos, 2009; Lazaridis et al., 2018) and Iranian (Maragheh) localities (Kostopoulos and Bernor, 2011).

The Gölyeri specimen is similar to *S. laticeps* morphologically (absence of entostylid, narrow protocon in M1, relatively high hypsodonty (M1:102, M2:110 mm height/width) and biometrically, and larger than *S. schlosseri* and *S. zemalisorum* samples from neighbouring localities (Kostopoulos, 2009; Kostopoulos and Bernor, 2011).

Ordo : PERISSODACTYLA Owen, 1848

Family : EQUIDAE Gray, 1821

Genus : *Hipparion* de Christol, 1832

Hipparion brachypus Hensel, 1862

Age: early-middleTurolian (MN12) (late Miocene**)**

Material: Left distal metacarpal 3 (MC3) (EUNHM-PV-8001) (Figure 5B) (M10: 43.57, M11: 41.15; M12: 31.5; M13: 25.8; M14: 28.53

Description: The sample is a distal part of a large equid metacarpal. It is highly compatible with *H. brachypus* samples in size (Figure 6). In addition, the keel index (M12×100/M13) (Staesche and Sondaar, 1979; Şen et al., 1978, Eisenmann et al., 1988) value is compatible with *H. brachypus* values known from Anatolia and nearby regions (Akgün et al., 2000; Kaya et al., 2012) (Figure 7).

In Anatolia, large forms of late Miocene Equidae findings were grouped under *H. brachypus* species. To date, these findings are known in the localities of Kemiklitepe-A (late Miocene, MN11) (Koufos and Kostopoulos, 1994), Akkaşdağı (late Miocene, MN12) (Koufos and Vlachou, 2005), Şerefköy-2 (late Miocene, MN12) (Kaya et al., 2012) and Sivas-Hafik (late Miocene, MN12) (Akgün et al., 2000) (Figure 8). The species is also present in the late Miocene localities of Greece (Samos, Pikermi) (Koufos and Vlachou, 2005; Vlachou and Koufos, 2009), Bulgaria (Hadjidimovo, Kalimanci) (Hristova et al., 2003) and Iran (Maragha) (Bernor et al., 2016). The relatively short and coarse metapodials suggest that this species was adapted to living in more confined paleo-environments (Koufos and Vlachou, 2005; Vlachou and Koufos, 2009).

6. Discussion and Conclusions

The mammalian fossils known in the Neogene succession of the Denizli Basin have shown that the region is an important migration route for many terrestrial taxa during the Neogene period. In this study, the Turolian stage is defined for Denizli Basin for the first time in the regional paleobiogeographic context. These fossils are located in the Güzelpınar member which is composed of alluvial fan deposits and defined during this study within the Kolankaya formation which is tectonically uplifted on the northeastern margin of the basin. The Gölyeri vertebrate fossil fauna is composed of taxa within the Anatolia and Greco-Iranian bioprovince extending from Greece to Iran throughout the late Miocene (MN11-12, early-middle Turolian). Similar taxa are known in the context of Turolian faunas from Asarlik, Mahmutgazi, Sazak, Elmalıyurt (Pırnaz), Kemiklitepe and Karabeyli, Şerefköy, Özlüce and Karamusalar localities around Denizli Basin. Although the Gölyeri fauna contains a small number of specimens, it is of particular importance in terms of the stratigraphic correlation between the basins and the understanding of regional paleobiogeographic distributions as the first Turolian evidence in the Denizli Basin.

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Figure 8- Biostratigraphic distribution and correlation of Turolian localities known in western Anatolia. Karabeyli (Seyitoğlu et al., 2009), Kemiklitepe (Şen et al., 1994; Saraç, 2003; Xafis et al., 2020), Çal-Asarlık (Alçiçek et al., 2012, Alçiçek and Alçiçek, 2014, Alçiçek et al., 2019), Mahmutgazi (Sickenberg et al., 1975; Pickford and Ertürk, 1979; Köhler, 1987; Saraç, 2003; Pickford, 2016; Geraads, 2017), Şerefköy (Saraç, 2003; Kaya et al., 2012; Mayda, 2014), Özlüce (Saraç, 2003; Alpagut, et al. 2014; Mayda, 2014), Sazak (Saraç 2003, Oruç, 2009, Tuna, 1999, Kaya, 1993), Eşen-Karamusalar (Alçiçek, 2007; Alçiçek et al., 2019), Çameli-Elmalıyurt (Saraç, 2003; Alçiçek et al., 2005, 2006, 2019), Sazak (Saraç, 2003; Tuna, 1999), Gölyeri (in this study).

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References

Akgün, F., Kaya, T., Forsten, A., Atalay, Z. 2000. Biostratigraphic data (Mammalia and palynology) for the late Miocene Incesu Formation in Düzyayla (Hafik-Sivas). Turkish Journal of Earth Sciences 9, 57-67.

Alçiçek, H. 2010. Stratigraphic correlation of the Neogene basins in Southwestern Anatolia: regional palaeogeographical, palaeoclimatic and tectonic implications. Palaeogeography, Palaeoclimatology, Palaeoecology 291, 297-318.

Alçiçek, H., Alçiçek, M.C. 2014. Palustrine carbonates and pedogenic calcretes in the Çal basin of SW Anatolia: Implication on the Plio-Pleistocene regional climatic pattern in the Eastern Mediterranean. Catena 112, 48-55.

Alçiçek, H., Varol, B., Özkul, M. 2007. Sedimentary facies, depositional environments and palaeogeographic evolution of the Neogene Denizli Basin of SW Anatolia, Turkey. Sedimentary Geology 202, 596-637.

Alçiçek, H., Wesselingh, F.P., Alçiçek, M.C. 2015. Palaeoenvironmental evolution of the late Pliocene-early Pleistocene fluvio-deltaic sequence of the Denizli Basin (SW Turkey). Palaeogeograpy, Palaeoclimatology, Palaeoecology 437, 98-116.

Alçiçek, M.C. 2007. Tectonic development of an orogen-top rift recorded by its terrestrial sedimentation pattern: the Neogene Eşen Basin of Southwestern Anatolia, Turkey. Sedimentary Geology 200, 117-140.

Alçiçek, M.C., Kazancı, N., Özkul, M. 2005. Multiple rifting pulses and sedimentation pattern in the Çameli Basin, Southwestern Anatolia, Turkey. Sedimentary Geology 173, 409-431.

Alçiçek, M.C., Ten Veen, J.H., Özkul, M. 2006. Neotectonic development of the Çameli Basin, Southwestern Anatolia, Turkey. In: A. H. F. Robertson, D. Mountrakis (Eds.), Tectonic Development of the Eastern Mediterranean Region. Geological Society London Special Publication 260, 591-611.

Alçiçek, M.C., Mayda, S., Alçiçek., H. 2012. Faunal and palaeoenvironmental changes in the Çal Basin, SW Anatolia: Implications for regional stratigraphic correlation of late Cenozoic basins. Comptes Rendus Geoscience 344, 89-98.

Alçiçek, M. C., Brogi, A., Capezzuoli, E., Liotta, D., Meccheri, M. 2013. Superimposed basin formation during Neogene- Quaternary extension in SW-Anatolia (Turkey): insights from the kinematics of the Dinar fault zone. Tectonophysics 608, 713-727.

Alçiçek, M.C., Mayda, S., Ten Veen, J.H., Boulton, S.J., Alçiçek, H., Tesakov, A., Saraç, G., Hakyemez, Y., Göktaş, F., Murray, A., Wesselingh, F.P., Jimenez-Moreno, G., Büyükmeriç, Y., Bouchal, J.M., Demirel, F.A., Kaya, T.T., Halaçlar, K., Bilgin, M., Van den Hoek Ostende, L.W. 2019. Reconciling the stratigraphy and sedimentation history of the Lycian orogen-top basins, SW Anatolia. Palaeobiodiversity and Palaeoenvironments 99, 551-570

Alpagut, B., Mayda, S., Kaya, T., Göktaş, F., Halaçlar, K., Kesici, S.D. 2014. Overview of Recent Research on Muğla-Özlüce Mammalian Fossil Locality. 67th Geological Congress of Turkey.15-18 April 2014, Ankara, pp. 732-733.

Bernor, R.L., Ataabadi, M.M., Meshida, K., Wolf, D. 2016. The Maragheh hipparions, late Miocene of Azarbaijan, Iran. Palaeobiodiversity and Palaeoenvironments 96, 453-488.

Boulbes, N., Mayda, S., Titov, V.V., Alçiçek, M.C. 2014. Les grands mammifères pléistocènes des travertins du Bassin de Denizli, Sud-ouest de l'Anatolie, Turquie (The large Upper Villafranchian mammals from the Denizli Basin travertines, Southwest Anatolia, Turkey). Anthropologie 118, 44-73.

Bouvrain, G. 1994. Les gisements de mammifères du Miocène supérieur de Kemiklitepe, Turquie. 9. Bovidae. Bulletin du Muséum national d'Histoire naturelle 16, 175-209.

Bozkurt, E. 2003. Origin of NE-trending basins in Western Turkey. Geodinamica Acta 16, 6 -81

Eisenmann, V. 1995. What metapodial morphometry has to say about some Miocene hipparions. In: E.S. Vrba, G.H. Denton, T.C. Partridge, and L.H. Burckle (eds.), Palaeoclimate and Evolution with Emphasis on Human Origins, Yale University Press. New Haven, 48-162.

Eisenmann, V., Alberdi, M.T., Giuli, C. de., Staesche, U. 1988. Methodology.In: M. Woodburne and P.Y. Sondaar (eds.), Studying Fossil Horses, Brill press. Leiden, 1-71.

Emre, Ö., Duman.T.Y., Özalp, S., Elmacı, H., Olgun, Ş., Şaroğlu, F. 2013. Türkiye Diri Fay Haritası. Maden Tetkik ve Arama Genel Müdürlüğü Özel Yayın Serisi-30. Ankara-Türkiye.

Gentry, A.W. 2000. Caprinae and Hippotragini (Bovidae, Mammalia) in the Upper Miocene. In: Vrba, E. S.; Schaller, G. B. (ed.), Antelopes, Deer, and Relatives. Fossil Record, Behavioral Ecology, Systematics, and Conservation. New Haven, CT, USA: Yale University Press, 65–83.

Gentry, A. W., Rössner, G. E., Heizmann, E.P.J. 1999. Suborder Ruminantia in: Rössner, G. & Heissig, K. (eds.), The Miocene Land Mammals of Europe, Verlag Dr. F. Pfeil, s. 225-249.

Geraads, D. 2017. late Miocene large mammals from Mahmutgazi, Denizli province, Western Turkey. Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen 284, 241-257.

Hristova, L., Kovachev, D., Spassov, N. 2003. Hipparion brachypus Hensel, 1862 from Hadjidimovo, southwestern Bulgaria (late Miocene). Dokladi na Bulgarskata Akademiya na Naukite 56, 77-84.

Kaya, T. 1993. Late Miocene Perissodactyla from Sazak (Kale-Denizli). Bulletin of the Mineral Research and Exploration 115, 23-31.

Kaya, T., Mayda, S., Kostopoulos, D., Alçiçek, M. C., Merceron, G., Tan, A., Karakütük, S., Giesler, A. K., Scott, S. S. 2012. Şerefköy-2, a new late Miocene mammalian locality from the Yatağan formation, Muğla, SW Turkey. Comptes Rendus Palevol 11, 5-12.

Kaymakçı, N. 2006. Kinematic development and paleostress analysis of the Denizli Basin (Western Turkish): implications of spatial varition of relative paleostress magnitudes and orientations. Journal of Asian Earth Sciences 27, 207-222.

Kaymakçı, N., Langereis, C., Özkaptan, M., Özacar, A. A., Gülyüz, E., Uzel, B., Sözbilir, H., Koç, A. 2018. Paleomagnetic evidences for upper plate response to a STEP fault, SW Anatolia. Earth and Planetary Science Letters 498, 101-115.

Koçyiğit, A. 2005. The Denizli graben-horst system and the eastern limit of the Western Anatolian continental extension: basin fill, structure, deformational mode, throw amount and episodic evolutionary history, SW Turkey. Geodinamica Acta 18, 167-208.

Konak, N., Şenel, M. 2002. Geological map of Turkey in 1/500.000 scale: Denizli sheet. Maden Tetkik ve Arama Genel Müdürlüğü Ankara.

Kostopoulos, D.S. 2009. The late Miocene Mammal Faunas of the Mytilinii Basin, Samos Island, Greece: new collection. 13. Bovidae. Beiträge zur Paläontologie 31, 345-389.

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

Kostopoulos, D.S., Karakütük, S. 2015. late Miocene bovids from Şerefköy-2 (SW Turkey) and their position withinthe sub-Paratethyan biogeographic province. Acta Palaeontologica Polonica 60, 49–66.

Koufos, G.D. 1987. Study of the Pikermi hipparions. Part I: Generalities and taxonomy. Part II: Comparisons and odontograms. Bulletin Museum Nationale Histoire Naturelle Paris 4e ser. 9 sect. C 2: 197–252, 3: 327–363.

Koufos, G.D. 2016. Hipparion macedonicum revisited: New data on evolution of hipparionine horses from the late Miocene of Greece. Acta Palaeontologica Polonica 61, 519-536.

Koufos, G.D., Kostopoulos, D.S. 1994. The late Miocene mammal localities of Kemiklitepe (Turkey). 3. Equidae. Bulletin du Muséum National d'Histoire Naturelle Paris 4, 16C, 41-80.

Koufos, G.D., Vlachou, T.D. 2005. Equidae (Mammalia, Perissodactyla) from the late Miocene of Akkaşdağı. Geodiversitas 27, 633-705.

Köhler, M. 1987. Boviden des Türkischen Miozäns (Kanozoikum und Braunkohlen der Türkei). Paleontologia i evolució 28, 33–246.

Krijgsman, W., Tesakov, A., Yanina, T., Lazarev, S., Danukalova, G., Van Baak, G.C.G., Agustí, J., Alçiçek, M.C., Aliyeva, E., Bista, D., Bruch, A., Büyükmeriç, Y., Bukhsianidze, M., Flecker, R., Frolov, P., Hoyle, T.M., Jorissen, E.L., Kirscher, U., Koriche, S.A., Oms, O., Rausch, L., Singarayer, J., Stoica, M., Van de Velde, S.V., Titov, V.V., Wesselingh, F.P. 2019. Quaternary time scales for the Pontocaspian domain: interbasinal connectivity and faunal evolution. Earth-Science Reviews 188, 1-40.

Lazaridis, G., Tsoukala, E., Rae, T. C., Gómez-Olivencia, A., Nagel, D., Bartsiokas, A. 2018. Mesopithecus pentelicus from the Turolian locality of Kryopigi (Kassandra, Chalkidiki, Greece). Journal of Human Evolution 121, 128-146.

Lebatard, A.E., Bourlès, D.L., Alçiçek, M.C. 2014*a*. Datation des travertins de Kocabaş par la méthode des nucléides cosmogéniques 26Al/10Be (Dating of the Kocabaş travertines with the 26Al/10Be cosmogenic nuclide method). Anthropologie 118, 34-43.

Lebatard, A.E., Alçiçek, M.C., Rochette, P., Khatib, S., Vialet, A., Boulbes, N., Bourlès, D.L., Demory, F., Guipert, G., Mayda S., Titov, V.V., Vidal, L., de Lumley, H. 2014*b*. Dating the Homo erectus bearing travertine from Kocabaş (Denizli, Turkey) at at least 1.1 Ma. Earth and Planetary Science Letters 390, 8-18.

Mayda, S. 2014. The updated late Miocene mammalian faunas of Özlüce, Şerefköy and Salihpaşalar from Yatağan Basin, Muğla, SW Turkey. 8th International Symposium on Eastern Mediterranean Geology, 13-17 October 2014, Muğla, 176.

Nebert, K. 1958. Die Pliozanen Ablagerungen Von Denizli Und Ihre Bedeutung Fur Die Stratigraphie Des Westanatolischen Sosswasserneogens. Bulletin of the Mineral Research and Exploration 51, 7–20.

Okay, A.İ. 1989. Geology of the Menderes Massif and The Lycian Nappes South of Denizli, Western Taurides, Bulletin of the Mineral Research and Exploration 109, 45-58.

Oruç, S. 2009. The Fossils of Bovidae (Artiodactyla) From Denizli (Sazak) Neogene Mammalian Fauna and Their Biochronological, Paleobiogeographic and Paleoclimatologic Meanings. MSc Thesis. Ege University. İzmir. 154. (unpublished).

Pickford, M. 2016. Hippopotamodon erymanthius (Suidae, Mammalia), from Mahmutgazi, Denizli-Çal Basin, Turkey. Fossil Imprint 72, 183-201.

Pickford, M., Ertürk, Ç. 1979. Suidae and Tayassuidae from Turkey.Bulletin of the Geological Society of Turkey 22,141–154.

Rausch, L., Alçiçek, H., Vialet, A., Boulbes, N., Mayda, S., Titov, V.V., Stoica, M., Charbonier, S., Abels, H.A., Tesakov, A.S., Moigne, A-M., Andrieu-Ponel V., de Franceschi D., Wesselingh F.P., Alçiçek, M.C. 2019. An integrated reconstruction of the early Pleistocene palaeoenvironment of Homo erectus in Denizli Basin (Turkey). Geobios 57, 77-95.

Saraç, G. 2003. Türkiye omurgalı fosil yatakları. Maden Tetkik ve Arama Genel Müdürlüğü Rapor No:10609, 1-208, Ankara (unpublished).

Seyitoğlu, G., Alçiçek, M.C., Işık, V., Alçiçek, H., Mayda, S., Varol, B., Yılmaz, İ., Esat, K. 2009. The stratigraphical position of Kemiklitepe fossil locality (Eşme, Uşak) revised: Implications for the Late Cenozoic sedimentary basin development and extensional tectonics in Western Turkey. Neues Jahrbuch fur Geologie und Palaontologie-Abhandlungen 251, 1-15.

Sickenberg, O., Tobien, H. 1971. New Neogene and Lower Quaternary vertebrate faunas in Turkey. Newsletters on Stratigraphy 1, 51-61.

Sickenberg, O., Becker-Platen, J. D., Benda, L., Berg, D., Engesser, B., Gazlry, W., Heissig, K., Hünermann, K. A., Sondaar, P. Y., Schmidt-Kittler, N., Staesche, K., Staesche, U., Steffens, P., Tobien, H. 1975. Die Gliederung des höheren Jungtertiärs und Altquartärs in der Türkei nach Vertebraten und ihre Bedeutung für die internationale Neogen-Stratigraphie. Geologisches Jahrbuch, Reihe B, 15, 1-167.

Staesche, U., Sondaar, P.Y. 1979. Hipparion aus dem Vallesium und Turolium (Jungtertiar) der Türkei. Geologisches Jahrbuch B, 33, 35-79.

Sun, S. 1990. Denizli-Uşak arasının jeolojisi ve linyit olanakları. Maden Tetkik ve Arama Genel Müdürlüğü Rapor No 9985, 1-92, Ankara (unpublished).

Şen, S., Sondaar, P.Y., Staesche, U. 1978. The biostratigraphic application of the genus Hipparion with special references to the Turkish representatives. Proceedings of the Koninklijke Nederlandse Akademia van Wetenschappen Amsterdam B, 81, 370-385.

Şen, Ş, De Bonis, L., Dalfes, N., Geraads, D., Koufos, G. 1994. Les gisements de mammifères du Miocène supérieur de Kemiklitepe, Turquie: 1. Stratigraphie et magnétostratigraphie. Bulletin du Muséum national d'Histoire naturelle, Paris, 4e sér., section C, 16, 1, 5-17.

Şimşek, Ş. 1984. Denizli-Kızıldere-Tekkehamam-Tosunlar-Buldan-Yenice alanının jeolojisi ve jeotermal enerji olanakları. Maden Tetkik ve Arama Genel Müdürlüğü Rapor No: 7846, 85s, Ankara (unpublished).

Tuna, V. 1999. Late Miocene Artiodactylles (Mammalia) From Yukarısazak Village (Kale-Denizli). Bulletin of the Mineral Research and Exploration, 121, 73-82.

Xafis, A., Mayda, S., Alçiçek, M.C., Kaya, T., Halaçlar, K., Grimsson, F., Nagel, D. 2020. Large giraffid remains (Mammalia, Ruminantia) from the new late Miocene locality Kemiklitepe-E (Western Anatolia, Turkey) Palaeobiodiversity and Palaeoenvironments (https://doi.org/10.1007/s12549-020-00433-4).

Westaway, R. 1993. Neogene evolution of the Denizli region of Western Turkey. Journal of Structural Geology 15, 37-53.

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