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# NEOGENE AND QUATERNARY CONTINENTAL BIOSTRATIGRAPHY OF GREECE BASED ON MAMMALS

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### Abstract

*Most basins of Greece were filled with thick Neogene-Quaternary continental deposits, which include a large number of mammal fossiliferous sites. The investigations of the last 40 years in the various basins of Greece led to the discovery of many new fossiliferous sites. The extensive, long time and continuous excavations in the new fossiliferous sites as well as in the previously known ones - like the classical localities of Axios Valley, Pikermi and Samos Island - provided numerous fossils enriching remarkably the Greek fossil mammal record. The systematic study of these collections provided numerous data for their biochronology. Further magnetostratigraphic, radiometric or other methods of absolute chronology provided additional chronological data for the mammal faunas and the corresponding deposits. The correlation of all these data allowed the biostratigraphic classification of the continental Neogene-Quaternary deposits of Greece which is given in the biostratigraphic tables of the present article. From these tables it is clear that for some time-intervals (Late Miocene, Early Pleistocene) the data are abundant allowing a detailed biostratigraphy, but for some others (Early- Middle Miocene, Pliocene, and for some time-spans of Early Pleistocene) the data are limited or missing and cannot allow an accurate and complete biostratigraphy.*

***Keywords:*** *Miocene-Pleistocene, mammal biostratigraphy, terrestrial deposits.*

### Περίληψη

*Οι περισσότερες λεκάνες του ελλαδικού χώρου έχουν πληρωθεί από μεγάλου πάχους Νεογενείς-Τεταρτογενείς χερσαίες αποθέσεις, που περικλείουν μεγάλο αριθμό απολιθωματοφόρων θέσεων θηλαστικών. Οι έρευνες των τελευταίων 40 χρόνων οδήγησαν στην εύρεση πολλών νέων απολιθωματοφόρων θέσεων. Οι εκτεταμένες, πολύχρονες και συνεχιζόμενες ανασκαφές στις νέες αυτές θέσεις καθώς και σε παλαιότερες, όπως οι κλασσικές θέσεις της κοιλάδας του Αξιού ποταμού, του Πικερμίου και της Σάμου, έφεραν στο φως μεγάλο αριθμό απολιθωμάτων και εμπλούτισαν σημαντικά το ελληνικό αρχείο απολιθωμένων θηλαστικών. Η συστηματική μελέτη του αρχείου αυτού έδωσε πολλά και σημαντικά στοιχεία για τη βιοχρονολόγηση των θέσεων αυτών. Επιπλέον έρευνες, κυρίως μαγνητοστρωματογραφικές, αλλά και ραδιοχρονολογήσεις ή άλλες μέθοδοι απόλυτης χρονολόγησης προσέφεραν πρόσθετα δεδομένα σχετικά με την ηλικία των θέσεων αυτών. Η συσχέτιση όλων αυτών των δεδομένων επέτρεψε την βιοστρωματογραφική ταξινόμηση των χερσαίων αποθέσεων του Νεογενούς-Τεταρτογενούς της Ελλάδος που δίνεται στους βιοστρωματογραφικούς πίνακες της παρούσας εργασίας. Από τους πίνακες αυτούς γίνεται φανερό ότι για ορισμένα χρονικά διαστήματα (Αν. Μειόκαινο, Κατ. Πλειστόκαινο) υπάρχουν πολλά δεδομένα που επιτρέπουν μια πλήρη βιοστρωματογραφία, ενώ για άλλα χρονικά*

*διαστήματα (Κατώτερο-Μέσο Μειόκαινο, Πλειόκαινο, αλλά και ορισμένα τμήματα του Κατώτερου Πλειστόκαινου) τα στοιχεία είναι λίγα ή λείπουν κα δεν επιτρέπουν μια ακριβή και ολοκληρωμένη βιοστρωματογραφική ταξινόμηση.*
***Λέξεις κλειδιά:*** *Μειόκαινο-Πλειστόκαινο, βιοστρωματογραφία, χερσαίες αποθέσεις.*

## 1. Introduction

The biostratigraphy of the Greek continental deposits started at the end of the 1970's, when Mein (1975) included some known Greek mammal localities in the European mammal biozones; later on sporadic or limited biostratigraphic tables, based on mammals were given in various articles or some Greek localities were included in biostratigraphic tables for the wider Eastern Mediterranean region (de Bruijn *et al.*, 1979; Benda and Meulenkamp, 1979). During the last 40 years extensive field work in the Neogene-Quaternary deposits led to the discovery of several new localities which excavated (in some of them the excavations are still continued) and the unearthed material enriched remarkably the Greek fossil mammal record. The study of the mammal faunas provided an important basis for the biostratigraphy of the Greek continental deposits, as it includes numerous biochronological data for precise age determinations. The application of other chronological methods, such as magnetostratigraphy, radiochronology, provided numerical ages helping the correlations. At the same time, several new data for the mammal faunas and their age came from the neighboring countries, enriching remarkably our knowledge and provided new data for better faunal comparisons and biostratigraphic correlations.

The first effort for a biostratigraphic classification of the Greek mammal localities was the mammal faunal lists of the Greek Miocene localities prepared by the author for the Neogene Old World (NOW) database and it is continued until now (see Koufos, 2006, 2013 and ref. therein; Koufos and Kostopoulos, in press). In the present article a revised version for the Greek Neogene/Quaternary biostratigraphy is given. New data coming from the studies of the Greek and foreign researchers, working in the area are included and an updated version is presented. Even this new version is not the final one, as several colleagues and young students are working on the new material from the various localities and new data are published every year improving the known biostratigraphy of the Neogene-Quaternary deposits of Greece.

**Abbreviations**: FLA=first local appearance; GPTS= geomagnetic polarity time scale; LGPUT= Laboratory of Geology and Paleontology, University of Thessaloniki.

## 2. Early-Middle Miocene

The pre-Neogene mammal fossil record of Greece is very poor. The single known evidence originates from the lignites of Orestias Basin (Thrace, Greece) and is a maxilla of the anthracothere *Elomeryx crispus* dated to Late Oligocene (Lüttig and Thenius, 1961; Kopp, 1965). Likely the early Miocene mammal faunas of Greece are limited and the known material poor; excluding the relatively rich Aliveri fauna, the material from the other known localities is poor. The oldest known localities are Gavathas and Lapsarna, Lesvos Island (Figure 1) both dated to the early Orleanian, MN 3 (Figure 2); their stratigraphic position below the volcanic deposits of the area, dated at <18.5 Ma suggests an age slightly older than 18.5 Ma. This age corresponds to the first conection of Africa with Eurasia and the first faunal exchanges between the two continents (Koufos *et al*., 2003 and ref. therein; Vasileiadou and Zouros, 2012). The locality Aliveri, Evia Island (Figure 1) provided a rich micromammalian fauna together with a few large mammals; its age discussed a lot since its discovery but a middle Orleanian age (lower part of MN 4), (Figure 2) is the most possible (Koufos 2006, 2013 and ref. therein; van Hoek Ostende *et al.*, 2015 and ref. therein). It is noteworthy to mention the presence of the anthracothere *Brachyodus onoideus* in the locality Kalimeriani, Evia Island (Figure 1), (Melentis, 1966); the age of the taxon is early to middle Orleanian, MN 3-4. Two localities with micromammals are known from Western Thrace, Karydia I and II (Figure 1); the cricetids from these localities suggested a late middle Orleanian age, late MN 4 (Theocharopoulos *et al*., 2000).

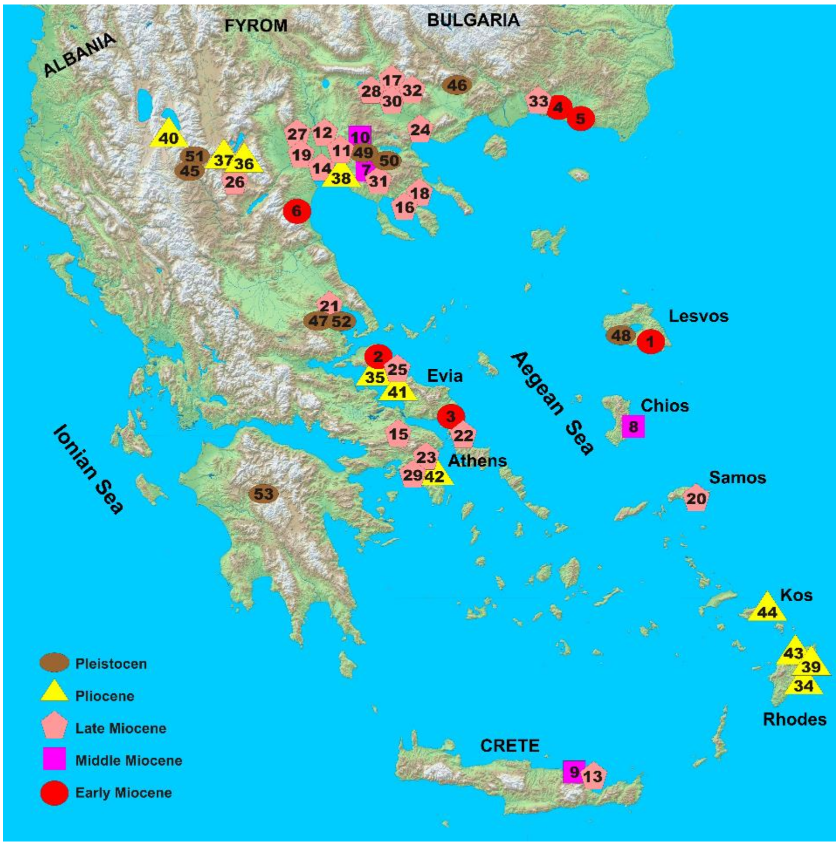


**Figure 1- Map of Greece indicating the position of the main Neogene-Quaternary mammal localities of Greece. 1. Gavathas; 2. Kalimeriani; 3. Aliveri; 4. Karydia I+II; 5. Komotini; 6. Moschopotamos; 7. Antonios; 8. Thymiana-A, B, C; 9. Melambes; 10. Chrysavgi; 11. Pentalophos-1; 12. Xirochori-1, 13. Kastelios, Plakias; 14. Ravin de la Pluie+Ravin des Zouaves-1; 15. Biodrak; 16. Nikiti-1; 17. Lefkon; 18. Nikiti-2; 19. Ravin des Zouaves-5; Vathylakkos localities; Prochoma-1; 20. Samos-Mytilinii localities; 21. Perivolaki; 22. Halmyropotamos; 23. Pikermi, Chomateres; 24. Rema Marmara; 25. Kerassia; 26. Lava-2; 27. Dytiko localities; 28. Ano Metochi 1, Monasteri; 29. Pyrgos Vassilissis; 30. Maramena; 31. Silata; 32. Ano Metochi 2-3, Spilia-0-4; 33. Kessani-1, 2; 34. Maritses; 35. Limni-3; 36. Kardia; 37. Ptolemais-1, 3, Komanos-1, Tomeas Eksi, Prosilion-Mercurion, Vorion-1; 38. Megalon Emvolon; 39. Apolakkia; 40. Kastoria-1; 41. Limni-6; 42. Tourkovounia-1-5; 43. Damatria; 44. Kardamena; 45. Dafnero; 46. Volax; 47. Sesklon; 48. Vatera; 49. Gerakarou, Vassiloudi; 50. Apollonia, Krimni, Kalamoto, Tsotra Vrissi, Ravin Voulgarakis, Platanochori; 51. Livakkos; 52. Alykes; 53. Megalopolis.**

The locality Komotini from the same area provided a small fauna of micromammals which should be similar to that of Karydia I+II (de Bruijn *et al*., 1992). Recently, some teeth of a small anthracothere were found in the LGPUT collections; their locality is unknown but the analysis and comparison of the associated lignitic remains found together suggested similarities with the lignites of Moschopotamos, Katerini Basin, Macedonia (Figure 1), dated to the early Miocene (Kostopoulos *et al*., 2012).

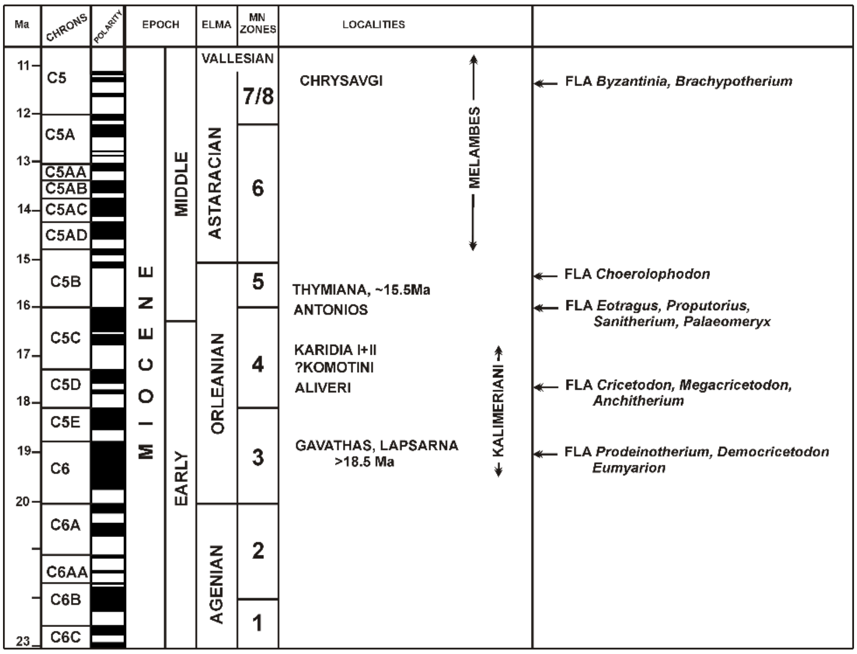


**Figure 2 - Biostratigraphy of the Early-Middle Miocene mammal localities of Greece with the first local appearance (FLA) of some important taxa. Data source: Koufos (2006, 2013); GPTS from Cande and Kent (1995) and MN zone boundaries from Steininger (1999).**

The Middle Miocene fossiliferous sites of Greece, though they are more numerous than those of the early Miocene, they are still scarce and their mammal fauna limited known. The oldest locality is Antonios, Chalkidiki Peninsula, Macedonia (Figure 1) provided both large and small mammals dated to the middle/late Orleanian boundary, MN 4/5 (Figure 2), (Koufos, 2013 and ref. therein). One of the well-known Middle Miocene mammal fossiliferous sites is Thymiana, Chios Island (Fig. 1). The Thymiana fauna originates from three stratigraphic horizons and includes both macro- and micro-mammals dated to late Orleanian, MN 5 (Figure 2); the magnetostratigraphy of the Thymiana section suggested an estimated age of ~15.5 Ma (Koufos, 2013 and ref. therein). The locality Chryssavgi is known from Mygdonia Basin, Macedonia, Greece (Figure 1) and the micromammal fauna found after its re-discovery at the end of the 1980's suggests an age at the end of Astaracian, MN 7/8 (Koliadimou and Koufos, 1998). Besides the micromammals, some rhino dental remains from Chrysavgi attributed to *Brachypotherium brachypus*, confirm the age of the locality (Koufos and Kostopoulos, 2013). The hyracoid cf. *Prohyrax hedneyi* and the tragulid *Dorcatherium naui* were discovered in the locality Melambes, Crete Island (Figure 1) and a Vallesian (MN 9-10) age has been proposed. Later, the locality correlated to late Astaracian, MN 7/8 and recently to early Astaracian, MN 6 (Figure 2), (Koufos, 2013 and ref. therein). The locality of Plakias, Crete Island (Fig. 1) was known by a limited micromammalian fauna dated to late Astaracian MN 7/8 (de Bruijn and Meulenkamp, 1972) and for this reason it was referred in the Middle Miocene faunas of Greece (Koufos, 2013). Recently the study of a new collection suggested an early Vallesian (MN 9) age for Plakias (de Bruijn *et al*., 2012).

## 3. Late Miocene

The Late Miocene mammal fossiliferous sites of Greece are numerous (Figure 3) and only the most important and those with more precise age data will be referred. The numerous collections enriched remarkably during the last decades providing abundant data for the faunas, their relationships each other and with the known Eurasian ones, as well as for the biostratigraphy of the associated deposits.

The classical site of Pikermi, Attica, Greece (Figure 1) is the first found mammal fossiliferous site of Greece provided numerous fossils, housed in various European museums and institutes. However, as it always happened, all the old collections lack or have limited stratigraphic control and the fossils from the different spots and horizons are mixed providing difficulties and doubts in the age determinations. Based on the available data of the old collections different ages have been proposed for Pikermi (Mein, 1990; de Bruijn *et al*., 1992; Bernor *et al*., 1996; Koufos 2006, 2013). The most accepted age correlation for Pikermi is at the end of middle Turolian, MN 12, about 7.0 Ma (Figure 3). Recently a new field work started in Pikermi by the University of Athens which will provide more accurate data for the fauna and age.

The Late Miocene mammal localities of Axios Valley, Macedonia, Greece (Figure 1), known from the beginning of the 20$^{th}$ Century, are excavated since 1973 and a great amount of fossils has been unearthed. The collection is housed in LGPUT and is one of the best known in Eastern Mediterranean region with certain stratigraphic control and age; more details about the stratigraphy, localities, fauna and age are given in Koufos (2006, 2013 and ref. therein). The late Miocene continental deposits of Axios Valley are divided in three formations: Nea Messimvria Fm, Vathyalkkos Fm and Dytiko Fm. The Nea Messimvria Fm includes four fossiliferous sites (Pentalophos 1, Xirochori 1, Ravin de la Pluie, Ravin des Zouaves 1) dated to late Vallesian, MN 10 (Fig. 3) except the previous one which was recently correlated to the early Vallesian, MN 9 (Konidaris *et al.*, 2014). The Vathylakkos Fm, includes several localities but the most important with a relatively rich fauna are five (Ravin des Zouaves 5, Vathylakkos 1, 2, 3 and Prochoma) dated the first one to the early Turolian, MN 11 and the others to the middle Turolian, MN 12 (Figure 3a). The Dytiko Fm includes three fossiliferous sites (Dytiko 1, 2, 3) which provided one of the best known late Turolian, MN 13 faunas of the Eastern Mediterranean region; recent correlations suggested a pre-Messinian age for these localities, more precisely between 7.0-6.0 Ma (Koufos and Vasileiadou, 2015 and ref. therein).

The Mytilinii Basin, Samos Island, Greece (Figure 1) is well-known since the middle of the 19$^{th}$ Century for its Late Miocene mammal sites; numerous fossils have been collected from them which dispersed in various European and American museums and institutes. Although the rich collections the absence or limited stratigraphic information make impossible a clear age determination. An extensive field work in Samos during 1993-2007 including stratigraphy, excavations and fossil collection, as well as magnetostratigraphic study of the sections allows the precise dating of the localities. The Samos Late Miocene localities are dated from the upper part of early Turolian, MN 11 to the beginning of late Turolian, MN 13 and more precisely from 8.0-7.8 Ma to 6.9-6.7 Ma, while four different faunal assemblages have been recognized (details in Koufos and Nagel *eds.*, 2009).

The Nikiti fossiliferous sites are known since 1990 when the first fossils were discovered in the area (Figure 1); two main localities Nikiti 1 and Nikiti 2 provided a rich mammal fauna. The biochronological data provided from the study of this fauna suggest a correlation of Nikiti 1 to the terminal Vallesian (end of MN 10) and Nikiti 2 to the early Turolian (lowermost MN 11), (Figure 3); more details for the stratigraphy, fauna and age of the Nikiti localities are given in Koufos and Kostopoulos, *eds*, (2016). The fossiliferous site Perivolaki, Volos, Thessaly (Figure 1) is a new fossiliferous site with a rich and well-studied mammal fauna. The biochronological and magnetostrati-graphic data suggested a correlation with the middle Turolian, MN 12 (Figure 3a) and provided an estimated age between 7.3-7.1 Ma (Koufos, *ed*., 2006).

The Kerassia locality in Evia Island (Figure 1) was known since the beginning of the 1980's and a new series of excavations started in 1992 provided a rich fauna, part of which has been studied. Theodorou *et al*. (2003), correlated Kerassia fauna to the middle Turolian, MN 12; based on the available data a similar age is proposed by Koufos (2013), by pointing out that the results of the bovid's study can change it. Except these well-known, several other late Miocene localities are given in the biostratigraphic table of Figure 3; more details about their fauna and age are given in Koufos (2006, 2013 and ref. therein).

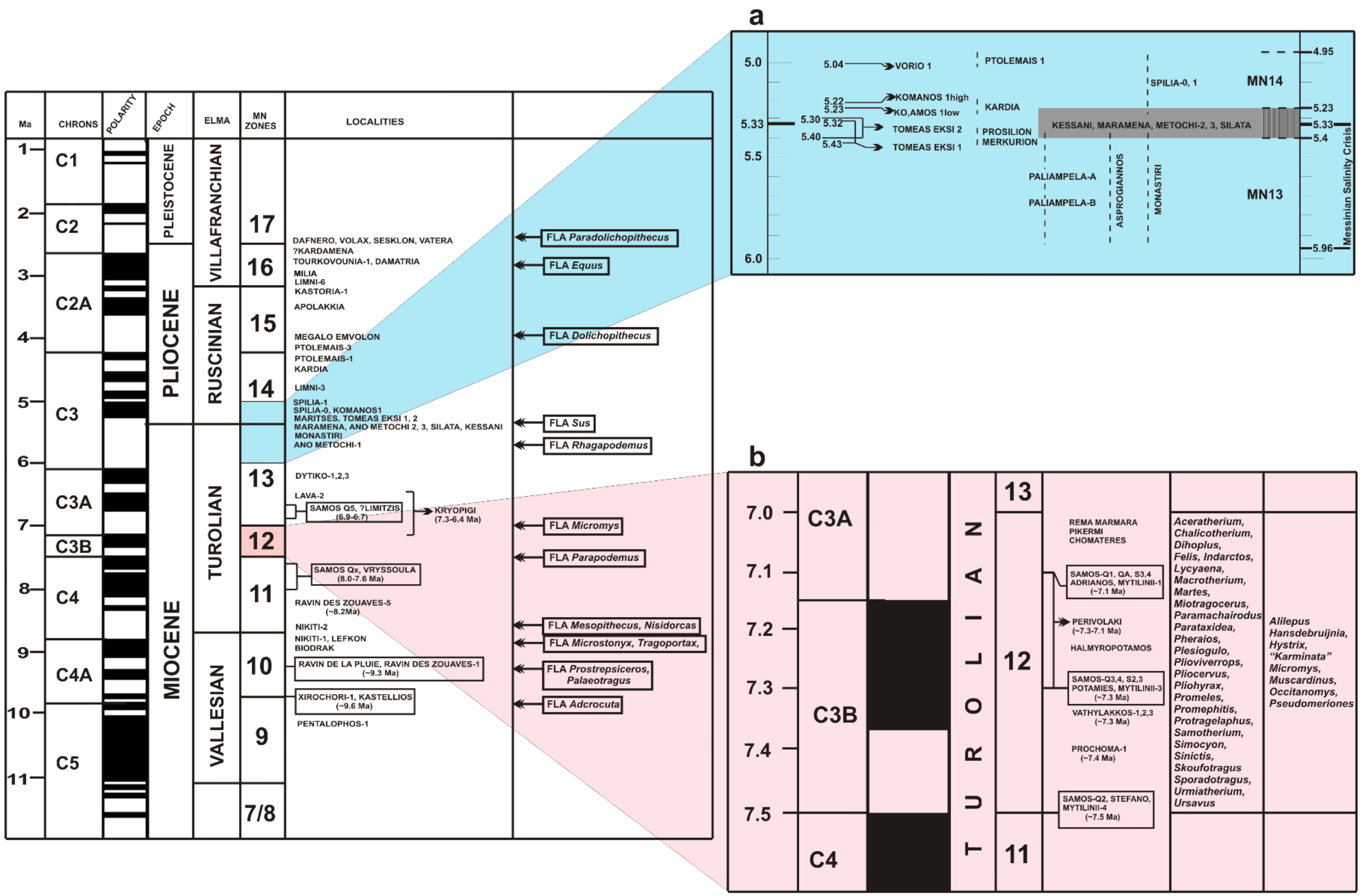

**Figure 3 - Biostratigraphy of the Late Miocene mammal localities of Greece with the first local appearance (FLA) of some important taxa; a. Biostratigraphy of the middle Turolian mammal localities, b. Details about the age of the Miocene/Pliocene transitional mammal faunas. Data source: Koufos (2006, 2013) and Koufos and Vasileiadou (2015); GPTS from Cande and Kent (1995) and MN zone boundaries from Steininger (1999).**

The end of the Miocene and the beginning of the Pliocene is marked well by a number of localities found mainly in Northern Greece. The most important are Maramena and Ano Metochi 1, 2 (Serres Basin), a number of sites in Ptolemais Basin (Tomeas Eksi 1, 2 and Komanos1, 2), Silata (Chalkidiki Peninsula) and Kessani (Thrace). All these localities provided a transitional mammal fauna from Miocene to Pliocene and they are correlated to the Turolian/Ruscinian (MN 13/14) boundary, more precisely between 5.40-5.23 Ma (Figure 3b), (Schmidt-Kittler, ed., 1995; Hordijk and de Bruijn, 2009; Koufos and Vasileiadou, 2015 and ref. therein).

## 4. Pliocene-Pleistocene

The Pliocene mammal fossiliferous sites of Greece are scarce with poor faunas providing limited biochronological data. The majority of the known localities include mainly micromammals. One of the oldest known large mammal locality is Megalon Emvolon, Macedonia (Figure 1) which provided a macro- and micro-mammal fauna correlated to the late Ruscinian, MN 15 (Figure 4), (Koufos, 2006, 2013 and ref. therein).

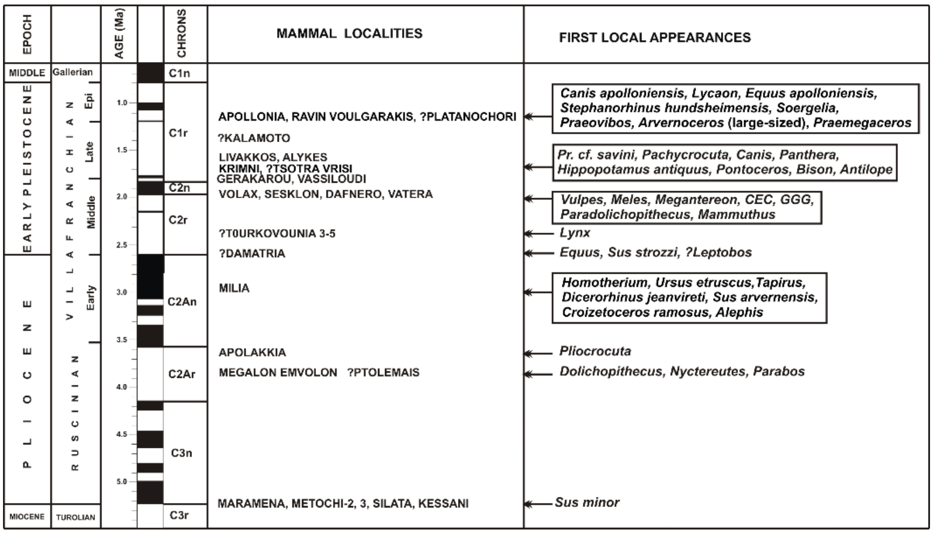


**Figure 4 - Biostratigraphy of the Pliocene and Pleistocene mammal localities of Greece with the first local appearance (FLA) of some important taxa. Data source: Koufos (2006, 2013) and Koufos and Kostopoulos (in press); GPTS from Cande and Kent (1995) and MN zone boundaries from Steininger (1999).**

An important Pliocene locality is Apolakkia, Rhodes Island (Figure 1) dated to late Ruscinian and including the last occurrence of *Hipparion* as the overlied Damatria locality includes the FLA of *Equus* (Van der Meulen and van Kolfschoten, 1988). A number of Ruscinian mammal localities with micromammals are known from Ptolemais Basin, Western Macedonia (Figures 1, 3b), (Hordijk and de Bruijn, 2009). The locality Milia, Grevena Basin provided a rich large mammal fauna, including several taxa dated to the early Villafranchian, more precisely to 3.0-2.5 Ma (Logchem *et al.*, 2010; Guerin and Tsoukala, 2013).

Recent decision of the International Commission on Stratigraphy defined the Pliocene/Pleistocene boundary at 2.58 Ma; hence a number of localities dated to Pliocene (Koufos, 2006, 2013) now must be referred to Pleistocene. The oldest Pleistocene locality is Damatria, Rhodes Island (Figure 1) with *Equus*. A number of localities (Dafnero, Volax, Sesklon, Vatera) with rich and well-known fauna have been dated to the Early Pleistocene or Middle Villafranchian (Figure 4), (Koufos and Kostopoulos, in press and ref. therein). The localities Gerakarou and Vassiloudi, Mygdonia Basin, (Figure 1) marks the beginning of Late Villafranchian as indicated by their faunal elements, especially the coexistence of *Pliocrocuta perrieri* and *Pachycrocuta brevirostris* and the presence of *Canis* (Koufos, 2013 and ref. therein; Koufos and Kostopoulos, in press and ref. therein). Several mammal localities as Krimni and Kalamoto of Mygdonia Basin, Livakkos in Western Macedonia, and Alykes in Thessaly are dated to the Late Villafranchian (Figures 1, 4). The preliminary study of the collected material from the newly discovered large mammal locality Tsotra Vrissi, Mygdonia Basin (Figure 1) suggests a correlation with late Villafranchian (Konidaris *et al*., 2015). The localities of Apollonia and Ravin of Voulgarakis in Mygdonia Basin (Figure 1) include a macro- and micro-mammal fauna respectively and they are correlated to epi-Villafranchian (Figure 4), (Koufos and Kostopoulos, in press and ref. therein). The newly discovered locality Platanochori (Figure 1) provided a poor fauna suggesting similarities to that of Apollonia and can be probably correlated to epi-Villafranchian (Figure 4), (Konidaris *et al.*, 2015). The Early Pleistocene faunas of Greece are the best studied and dated in Eastern Mediterranean region and they are used as reference for comparisons and age reference.

Although listed many Middle-Late Pleistocene fossiliferous sites, the known collections are fragmented with few or individual findings. Also a large number of these sites originated either from caves or fissure fillings, which makes difficult the correlation with those from open areas. One of the best known area with Middle-Late Pleistocene fossils is Megalopolis Basin in Peloponnesus (Figure 1) with a rich mammal fauna including also *Homo* remains and artifacts (Panagopoulou *et al*., 2015 and ref. therein). In the Late Pleistocene mammal localities belong also the "dwarf" faunas found in the islands of Crete, Rhodes, Naxos, Tilos, etc. (Theodorou, 1983 and ref. therein). Several Pleistocene mammal remains are also known from the caves of Greece but a small number of them are well-studied; the better known are those from Petralona Cave (Chalkidiki Peninsula), Apidima (Southern Peloponnesus) - the genus *Homo* is present in these two caves- Loutraki Cave (Western Macedonia) and Vraona Cave (Attica, near Athens), (Tsoukala, 1989 and ref. therein; Symeonidis and Rabeder *eds*., 1995; Chatzopoulou, 2014 and ref. therein).

## 5. Conclusions

Numerous palaeontological researches carried out on the Neogene-Quaternary continental deposits of Greece have been provided a lot of data, allowing their biostratigraphic classification. The available data allowed a quite detailed biostratigraphy for the Late Miocene and the Middle-Latest Villafranchian, as there are several known mammal localities and well-studied and dated faunas. The biostratigraphic classification of the Early-Middle Miocene is limited with several gaps because of the entirely absence of corresponding mammal localities. But, if someone compares what we know about this time-span before two decades, he will ascertain that the investigations provided several new evidences during the last years. The localities of Gavathas, Lapsarna, Antonios, Karydia I+II, the presence of the small mammals and the numeric age of the Thymiana localities were unknown. Despite the remarkable increase of the new fossiliferous sites in the Pliocene and Middle-Late Pleistocene, the absence or the chronologically sporadic data cannot provide a complete and precise biostratigraphy for the continental deposits. In conclusion there is a lot of work for the palaeontologists to complete the continental biostratigraphy of Greece. The efforts must be focused, not only to the discovery of new fossiliferous sites and the study of their fauna, but also to the more precise dating of them, using different chronometric methods.

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