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ORIGINAL PAPER

Dimitris S. Kostopoulos · Sevket Sen · George D. Koufos

Magnetostratigraphy and revised chronology of the late Miocene mammal localities of Samos, Greece

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Abstract The late Miocene mammalian record in Samos Island, Greece, is extremely important for the Eurasian Neogene mammalian history and chronology. However, due to the mixed nature of old fossil collections and controversies on the stratigraphic position of fossil quarries, great confusion has arisen concerning the recognition of distinct faunal assemblages, their age(s) and biostratigraphic significance. This paper presents the magnetostratigraphy of the late Miocene continental deposits of the fossiliferous Mytilinii Basin, Samos Island, Greece. Old and new sites are stratigraphically controlled with accuracy and correlated with each other. The magnetostratigraphy of seven individual sections, covering the entire Mytilinii Formation, provides good correlation with the Geomagnetic Polarity Time Scale (GPTS). These results, as well as the relocation and precise litho- and magnetostratigraphic correlation of the old and new mammal localities, combined with new and reviewed paleontological data and thorough studying of the numerous radiometric dates, allowed us to define five biostratigraphic horizons. Their correlation with, and implications to the European Neogene mammal chronology ages and zones make up the following discussion and provides a modified determination of the middle Turolian (MN 12) boundaries.

Keywords Magnetostratigraphy · Mammal biochronology · Late Miocene · Samos · Greece

Abbreviations *GPTS* Geomagnetic Polarity Time Scale · *IPGP* Institute de Physic du Globe de Paris · *MGL* Musée Cantonal de Géologie, Lausanne · *MNHA* Museum of Natural History of the Aegean, Samos · *BMNH* · Natural History Museum of London · *Q* quarries · *Fm* Formation

D. S. Kostopoulos (✉) · G. D. Koufos
School of Geology, Department of Geology,
Aristotle University of Thessaloniki,
54124 Thessaloniki, Greece
e-mail: dkostop@geo.auth.gr
Tel.: +30-310-998540

S. Sen
Laboratoire de Paléontologie,
Muséum National d' Histoire Naturelle, CNRS-NMR8569,
8 rue Buffon, 75005 Paris, France

Introduction

More than one century after the first reports on the presence of vertebrate fossils in Samos Island, Greece (Forsyth-Major 1888), the discussion about the relocation and stratigraphic position of the old fossiliferous quarries, the homogeneity of the collected material and the age of the recorded fauna(s) is still active.

A great number of old and new studies referred to the mammal taxonomy and chronology of Samos' vertebrate fauna (Forsyth-Major 1891; Brown 1927; Melentis 1969; Van Couvering and Miller 1971; Sondaar 1971; Gentry 1971; Koufos and Melentis 1982, 1984; Bernor et al. 1980, 1996; Solounias 1981 and literature listed). Moreover, the type specimens of more than 20 common late Miocene mammal species are based on the Samos material. Among the most complete works is that of Solounias (1981), who tried to present a synthetic study, reviewing all previous efforts as well as relocating old quarries. Nonetheless, his faunal lists include an extremely high number of large mammals far beyond the usual number of taxa ever recorded in other Eurasian localities of this time interval (late Miocene). The absence of a complete review of the mammal species reported from Samos based on modern knowledge is more than obvious. It is not worthless to note that a great part of the collected specimens from Samos stored today in several Museums across the world, has never been systematically studied.

The Neogene deposits of Samos are situated in two main basins referred to as the Eastern and Western basins. Meissner (1976), Theodoropoulos (1979) and Weidmann et al. (1984) extensively discussed the stratigraphy of the Eastern (fossiliferous) Basin. This basin is also known as the Mytilinii Basin; we prefer the spelling "Mytilinii" instead of "Mytilini" as being closer to the original Greek pronunciation of this local name. The commonly used name Mytilini corresponds to the capital city of another Greek island, Lesvos.

The lack of stratigraphic information concerning the fossil samples collected between 1890–1970 and the mixing of the Samos material from several horizons does not permit us to "distinguish evolutionary stages between the faunas of different localities in order to separate biostratigraphic horizons" (Sen and Valet 1986). Generally, and according to the biochronological scale used in Europe, the Samos fauna is considered to be of Turolian age. Early workers (Gentry 1971, Sondaar 1971, Heissig 1975, Bernor et al. 1980) whose research was based mainly on paleontological data, recognized two distinct faunal assemblages: one of early and another one of middle–late Turolian age. Several later authors (e.g., Steininger et al. 1996) follow this option. However, Solounias (1981) partly changed this point of view having considered that the main fossiliferous layers were deposited in a very short time-interval, and therefore the faunal assemblages could be regarded as more or less homogeneous and therefore isochronous.

On the other hand, old and new radiometric data (Van Couvering and Miller 1971; Weidmann et al. 1984; Swisher 1996) showed that the fossiliferous deposits span a time interval over 2.5 million years. The main chronological problem concerns the absence of the accurate correlation between the fossiliferous horizons and the radiometric sampling, allowing Bernor et al. (1996) to note that "In the absence of accurate locality descriptions, the relocation of old quarries and classic collections is often complicated by the presence of beds of quite different ages in close proximity to one another." Finally, the magnetostratigraphic results of Sen and Valet (1986) showed three possible correlations between the local magnetostratigraphy and GPTS, indicating a relative disagreement with the reported radiometric data.

Trying to eliminate the above-mentioned problems, a team of paleontologists and stratigraphers from the Laboratory of Geology and Paleontology of Thessaloniki University lead by the third author (G.K.), started a new campaign in the island in 1993. Relocation and excavations in old and new quarries, stratigraphic investigations, pollen analysis and magnetostratigraphic studies were undertaken. The present work is a part of the above-mentioned project and deals with the magnetostratigraphy and vertebrate biostratigraphy–biochronology of the fossiliferous Mytilinii Formation. The sections were sampled by D.K. and G.K. during the summer of 1998. The magnetic measurement of the samples were obtained by the first author in collaboration with S.S.

Our effort is focused on the magnetostratigraphy of the entire Mytilinii Formation including the checking and completing of previous works, the relocation and accurate stratigraphic correlation of old and new fossiliferous sites, the correlation of old and new mammal localities with the available radiometric data, and the biochronologic–biostratigraphic review of the fauna of Samos.

Geological setting

Samos Island belongs to the Atticocycladic Zone but it also seems to be related to the western margin of the Menderes Massif (Papanikolaou 1979). The pre-Neogene basement of the island is divided into four tectonic units (Kerketeas, St. Ioannis, Ampelos and the Vourliotes Unit) mainly consisting of marbles, phyllites and mica-schists (Papanikolaou 1979).

The Neogene sediments of the Mytilinii Basin are grouped into five lacustrine-fluviatile formations (Meissner 1976; Weidmann et al. 1984), which from the base to the top are: basal conglomerate, Pythagorion Fm., Hora Fm., Mytilinii (Mytilini)Fm. and Kokkarion Fm. (Figs. 1, 2). Nevertheless, the lithostratigraphic division of the entire section is currently under review. All the known mammalian fossiliferous sites of Samos Island are situated in the Mytilinii Fm., which overlies the limestones of Hora Fm. and underlies the Kokkarion Fm. According to Weidmann et al. (1984), the contact between Mytilinii and Hora Fm. is a discordance or pseudodiscordance. Our field observations along the Kalathi stream, where this contact is well exposed, as well as in the "Theopiito Gefyri" district, did not reveal any discordance between these two formations. In these areas at least, the Mytilinii Fm. conformably overlies the limestones of the Hora Fm., while between the two main lithostratigraphic units, a thin grit-stone sometimes appears.

Solounias (1981) and Weidmann et al. (1984) subdivided the Mytilinii Fm. into five lithostratigraphic members, which are from the base to the top: Old Mill Beds (OMB), Gravel Beds (GB), White Beds (WB), Main Bone Beds (MBB) and Marker Tuffs (MT; Figs. 1, 2). Comprehensive lithologic descriptions are given by the same authors. Nevertheless, the boundaries between these members are not always clear in the field; Gravel Beds and/or White Beds progressively replace Old Mill Beds, while the relative thickness of the Marker Tuffs varies considerably (from about 40 m at Stefana Hill down to 5 m in the Tsarouchis district). The general lithologic character of the Mytilinii Fm. corresponds to volcanoclastic fluvio-lacustrine sediments: tuffs, silts, clays, massive and unconsolidated conglomerates, sands, marly limestones and volcanoclastic marls predominate. The underlying Hora Fm. consists of thin-bedded freshwater limestones while the overlying Kokkarion Fm. consists mainly of fluvio-lacustrine sediments, mainly algal limestones with stromatolites intercalated with clays and marls.

Recently, Bernor et al. (1996: p. 142), considering it as a distinct and possibly separate unit, transferred the Marker Tuffs member to the base of the Kokkarion Fm. According to these authors, the contact between the Marker Tuffs and the rest of the Mytilinii Fm. is an erosional surface. Our field investigations at Stefana Hill, Limitzis and Tsarouchis districts do not confirm this conclusion. It is worth noting that the field workers of the Samos stratigraphy (Meissner 1976; Theodoropoulos 1979; Weidmann et al. 1984; Sen and Valet 1986) never mentioned disconformity between the Main Bone Beds and the Marker Tuffs. Moreover, the fresh water limestones of Kokkarion Fm. overlie con-

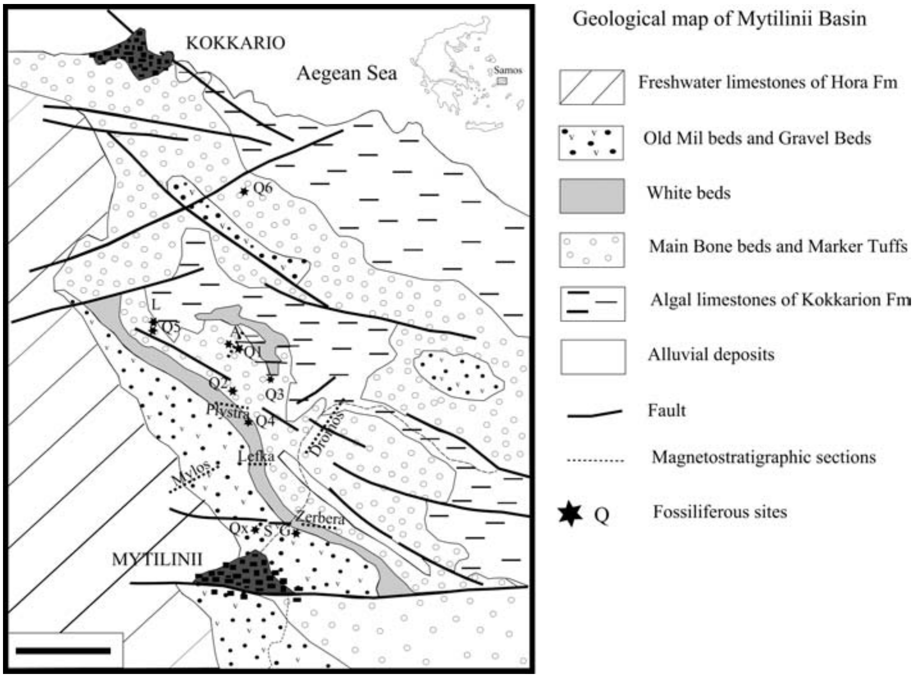


Fig. 1 Geological map of the Mytilinii Basin (after Weidmann et al. 1984, modified with data from Mountrakis et al. 1998 and personal data) with location of old quarries (after Solounias 1981) and sampled sections. *Scale bar* 1 km

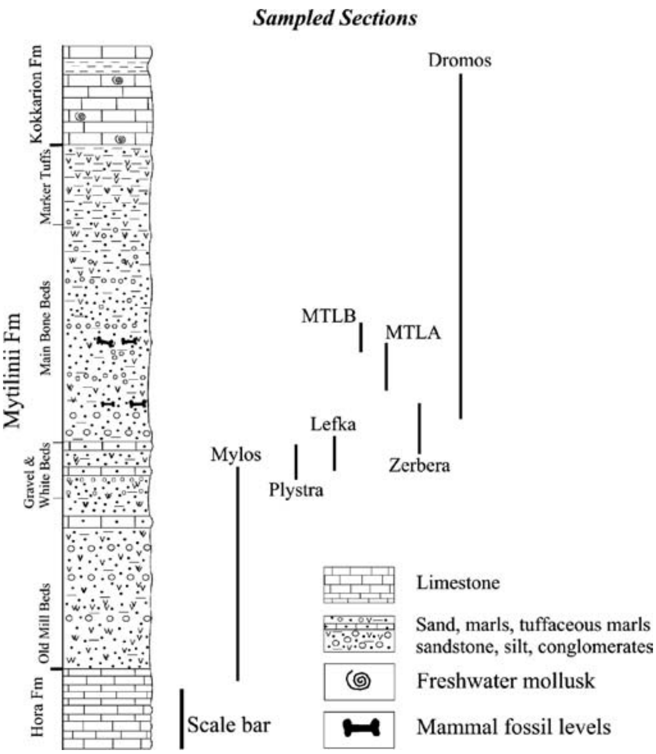


Fig. 2 Synthetic lithostratigraphic column of the Mytilinii Fm. and position of the sampled sections. *Scale* 35 m

formably the Marker Tuffs (Meissner 1976; Weidmann et al. 1984; personal observation), while the presence of intercalated clays and marls in the basal part of the Kokkarion Fm. rather indicates a progressive transition from the one lithological unit to the other.

The Mytilinii Basin presents several ESE–WNW to E–W trending normal faults, as well as some NE–SW faults with a clear strike-slip component (Fig. 1). The restricted area around the Mytilinii village shows two main faults: the first one (E–W) is just situated on the southern edge of Mytilinii village, while the second (WNW–ESE) is located north of Stefana Hill (Fig. 1). Another significant fault of E–W direction occurs along the southern borders of Stefana Hill. According to Weidmann et al. (1984) this fault continues westerly to the road connecting Mytilinii with Vathi village. However, Meissner (1976), Theodoropoulos (1979), Mountrakis et al. (1998) and our own field data show that this fault stops before the road. The fossiliferous area presents several smaller faults of E–W direction; their displacement varies from a few centimeters to about 10 m, but in most cases it is under stratigraphic control.

Magnetostratigraphy

Sections and sampling

Two main and five secondary sections that cover the entire Mytilinii Fm. have been sampled for this study (Figs. 1, 2):

- Mylos section covers the upper 7 m of the Hora Fm. and the lower 100 m of the Mytilinii Fm. (including Old Mill Beds and the Gravel/White Beds members). No physical gaps or faulting have been observed (Figs. 1, 2)
- Dromos section covers the basal part of the Kokkarion Fm. (95 m) and the upper 180 m of the Mytilinii Fm.

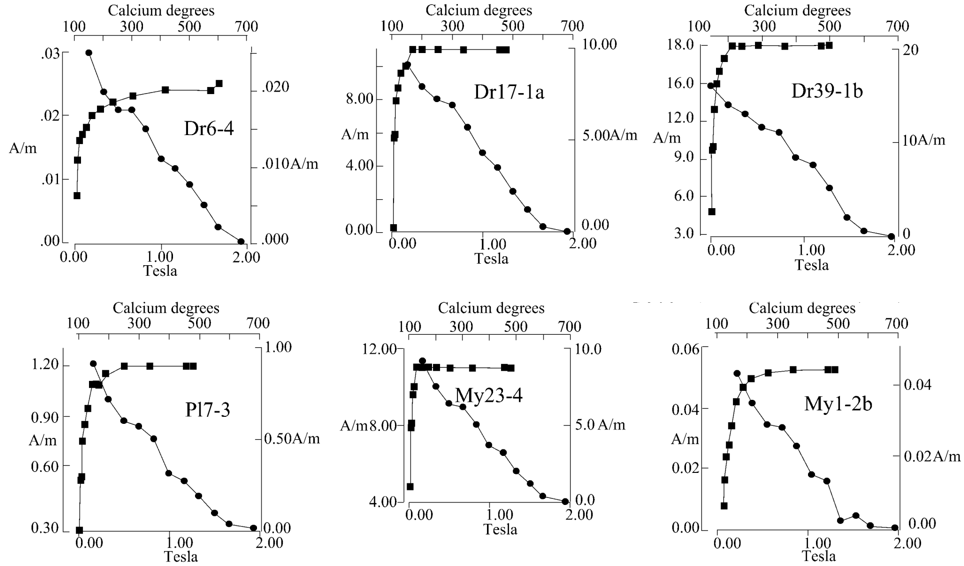


Fig. 3 Examples of IRM acquisition and demagnetization of samples of the studied sections. Abbreviations: *My* Mylos section, *Dr* Dromos section, *Pl* Plystra section. *Sample Dr6–4* Kokkarion limestone; *Dr17–1a* Marker Tuffs; *Dr39–1b* Main Bone Beds; *Pl3–3* White Beds; *My 23–4* Old Mill Beds; *My1–2b* Hora limestone

(Fig. 1, 2). A parallel section has been used by Sen and Valet (1986) for their magnetostratigraphic studies. Nevertheless, the new outcrops on the road offer a clearer and more extensive view of the sedimentary succession. In the basal part of the Kokkarion Fm. and between the sampled horizons Dromos-7 and Dromos-8, there is a natural gap of about 70 m due to faulting. Another smaller gap (15 m) has been recognized between the sampled horizons Dromos-39 and Dromos-40 in the upper part of the Main Bone Beds member (Fig. 2).

- Zerbera section is 22 m thick and is stratigraphically placed between the two previous sections. The sections of Plystra and Lefka are 12 m thick each (Figs. 1, 2) and more or less parallel to each other. They are correlated with the uppermost part of the Mylos section, completing the sampling of the Mytilinii Fm.
- Two additional sections of 17 and 20 m, respectively, have been sampled in the Andrianos ravine (Figs. 1, 2), across the two main mammal localities MTLA (Mytilinii-1A) and MTLB (Mytilinii-1B) of the recent excavations (Koufos et al. 1997). The presence of a fault between them cannot be excluded, but its displacement should be of minor importance. Another small section of 5 m has been sampled across the new mammal locality MYT (Mytilinii-3).

In summary, 178 horizons from the 7 sections were sampled; 133 of them by drilling cores (3–5 cores per sampling level) with a portable standard driller. Compass oriented blocks were taken from 45 horizons when sediments were unsuitable for drilling. Standard paleomagnetic sampling techniques were used. Because of the variable lithologies, the sampled levels were unevenly spaced, ranging from 1 to 3 m in the sections with a mean step of 2 m. Where the stratigraphic sequence was not well exposed, the relative thickness of the gap was calculated from the measurements of the horizontal distances, the azimuth between successive sampling levels and the strike and inclination of the bedding plane.

Measurements

The preparation of the samples and the paleomagnetic analyses was performed in the Laboratory of Paleomagnetism and Geodynamics of the University of Paris VII and IPGP. A Digico susceptibility bridge was used to measure the low field susceptibilities at room temperature and after each demagnetization step. Ninety samples of the entire collected sections were measured.

Isothermal Remanent Magnetization (IRM) analyses on 12 samples from representative lithologies were also performed to identify the magnetic carriers. The method followed involved stepwise magnetization in a DRUSH electromagnetometer up to 1.3T and the consequent stepwise thermal demagnetization of the same samples. The remnant magnetization was measured on a CTF 2-axes cryogenic magnetometer in an antimagnetic room. Only stepwise thermal demagnetization was performed on the samples to identify their magnetic components.

Mineralogical properties

The main sedimentary and mineralogical properties of the Mytilinii Fm. sediments have already been mentioned by Sen and Valet (1986). Low-field magnetic susceptibility did not show important variations except for a large increase in the tuffaceous levels, without however affecting the direction of primary remnant magnetization (see also Sen and Valet 1986).

The upper limestone of the Hora Fm. showed a very low magnetization (Fig. 3). The IRM acquisition indicated that magnetite is the main magnetic carrier, while small percentages of secondary (?) hematite and titano-

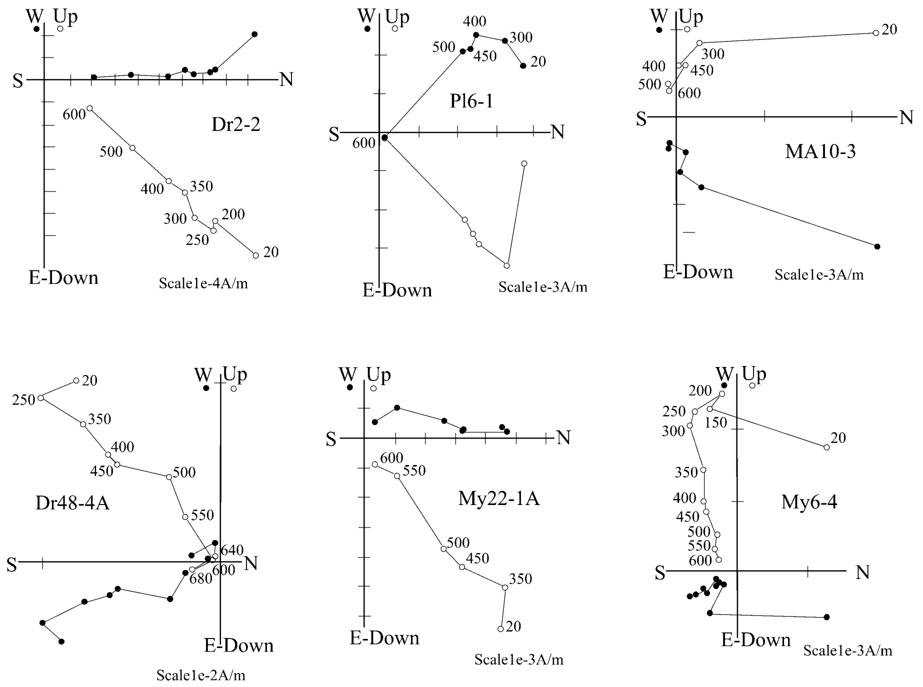


Fig. 4 Thermal demagnetization diagrams for samples from studied sections. *Closed circle/open circle* Projection on the horizontal/vertical plane; values and temperature steps in °C. Abbreviations as in Fig. 3 and *MA* MTLA section

magnetite (x=0,6) also occurred (Lowrie 1990; Fig. 3). The main ferromagnetic mineral of the Kokkarion limestone seems to be hematite (Fig. 3); the magnetization curve did not reach saturation at 1.3T. Low percentages of pyrrhotite and/or titanomagnetite also occurred (Lowrie 1990). Magnetite is the main magnetic carrier of the Mytilinii Fm. (Fig. 3); the magnetization curve reached saturation at 0.3T. Pyrrhotite and/or titanomagnetite also participated in low percentages (Sen and Valet 1986; Lowrie 1990). In a few samples, hematite (probably of secondary origin) is also present in very low percentages. In most cases the demagnetization curve reached zero after the 575 °C demagnetization step.

Paleomagnetic results

Stepwise thermal demagnetization (from room temperature up to 680 °C in steps of 50 °C) was applied to 90 pilot samples (one sample per two magnetostratigraphic levels). Due to their different thermal behavior, 16 calcitic samples from Hora and Kokkarion limestones were demagnetized stepwise from room temperature up to 500 °C (in steps of 50 °C). Another group of 291 samples was rapidly demagnetized from room temperature up to 300 °C and then to 600 °C using steps of 100 °C. A total of 397 samples from 178 levels were thermally demagnetized.

Calcitic samples from Hora and Kokkarion limestones show low intensities and initial susceptibilities (samples My6-4 and Dr2-2 respectively; Fig. 4). Reliable directions were generally obtained between 200 to 350 °C. In a few cases, mainly of Kokkarion samples, the analysis did not allow for the recognition of reliable directions.

Marly sands and clays from the middle stratigraphic levels of the Mytilinii Fm. (White and Gravel Beds), showed relatively high intensities (1–10 °mA/m) and stable components of magnetization, allowing for the identification of easily reliable directions (sample Pl6-1; Fig. 4).

Tuffaceous silty sand and clay (lower and upper levels of the Mytilinii Fm.—Old Mill Beds, Main Bone Beds, Marker Tuffs) show high Natural Remnant Magnetization (NRM) intensities (10 mA/m or over) and initial susceptibilities (50–100 SI). Demagnetization diagrams were generally good and revealed coherent Characteristic Remnant Magnetization (ChRM) components (samples MA10-3, DR48-4A, My22-IA; Fig. 4). A linear decay towards the origin was obtained in most of the cases. A secondary component probably of viscous origin was removed after 200–300 °C. Some samples from the lower part of the Mylos section (especially between the levels My 24–45) show a more complex thermal behavior between 200–600 °C with both normal and reverse components. This is probably due to paleomagnetic disturbances caused by tectonic events which took place in the basin margins during the deposition of the lower part of the Mytilinii Fm. Moreover, the assumed frequent alternations of the magnetic field allow for a relatively high percentage of intermediate samples in the Mylos section, which makes interpretation more delicate. Stereographic projection of the assumed ChRM, shows a very good grouping of both normal and reverse polarities in antipodal displacement (Fig. 5).

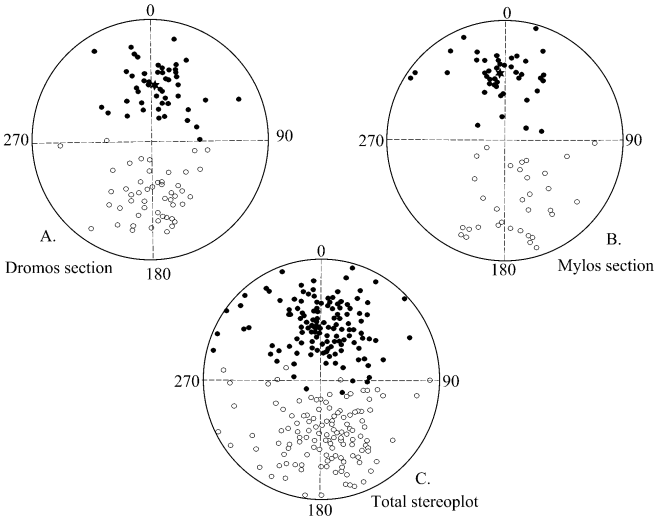


Fig. 5 Stereographic plots of the NRM directions of studied samples. *A* Dromos section, *B* Mylos section, *C* all sections

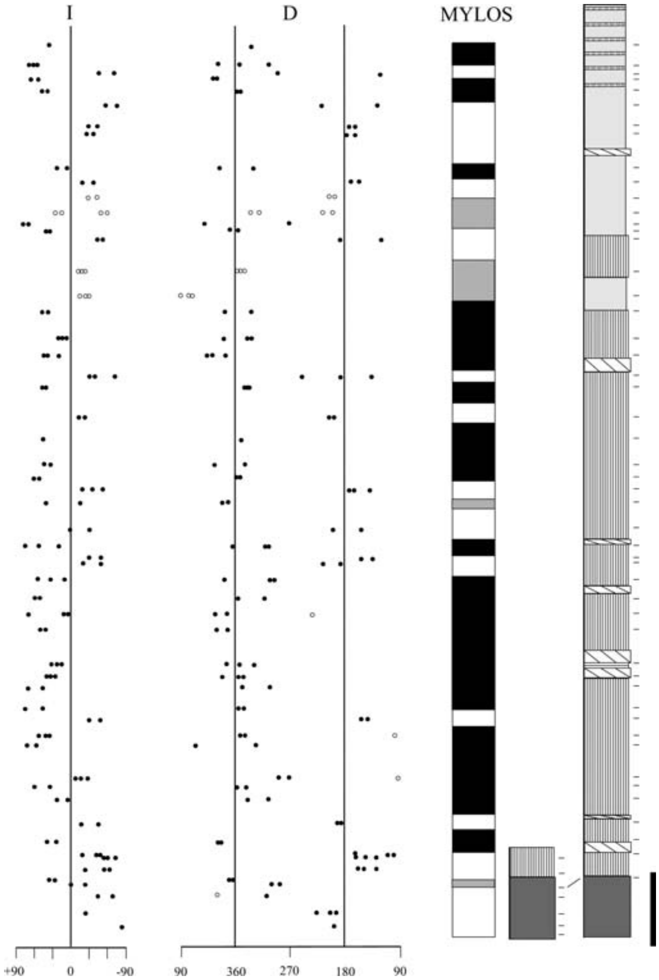


Fig. 6 Lithostratigraphy and magnetostratigraphy of the Mylos section. Lithological symbols: *dark gray* limestone; *vertical lines* tuffaceous marls and silts; *horizontal lines* alternations of sand, silt, clay, pebbles and tuffaceous levels; *oblique lines* conglomerates; *light gray* alternations of white thin marly limestone, silt and sandstones; *open circles horizons* gravels; magnetostratigraphic symbols: *closed (open) circles* reliable (less reliable) characteristic components. *Scale bar* 10 m

Interpretation and correlation

Mylos section. This section spans from the topmost part of the Hora Fm. to the upper part of the White and Gravel Bed members and is 110 m thick (Figs. 2, 6). Lithologically, the upper part of this section is correlated to the sections of Lefka and Plystra. Paleomagnetic results from some horizons of the Mylos section are difficult to accurately interpret. The section includes several short intervals of polarities (one or two sampled horizons), while in other levels, some samples yielded intermediate directions.

Nevertheless, the lowermost 7 m corresponding to the Hora limestones as well as a few sites from the base of the Mytilinii Fm. (Mylos-6, 7), are reversely magnetized (except one site with intermediate directions). The part between sites Mylos-8 to Mylos-23 is dominated by normal polarities with, however, a few samples of intermediate or reverse directions. Carefully examining their paleomagnetic data, we concluded that sites Mylos-9 and Mylos-15 are clearly reverse, and from Mylos-16 to Mylos-23 there is a thick normal interval. Upward, we obtained an alternation of short reverse and normal zones with, however, some uncertainties about the polarity of a few sites (Mylos-27, 37–38, 40–43). From Mylos-30 to Mylos-36, a large normal zone occurs interrupted by two short reverse intervals (Mylos-31, Mylos-33). From Mylos-39 to Mylos-48, a relatively large reverse zone exists interrupted by at least one short normal interval (Mylos-45). The analyses of additional samples from the problematic horizons did not improve the obtained results. In summary, this sections has three relatively thick normal polarity zones interrupted by an alternation of short normal and reverse episodes (Fig. 6).

Plystra–Lefka sections. Both sections correspond mainly to the White Beds and the lower levels of the Gravel Beds member (Fig. 7). Lithologically, the Lefka-1 sampling horizon is correlative to Plystra-3. In both sections, their lower part represents a reverse polarity zone and their upper part represents a normal zone more than 5 m thick. The normal polarity zone for both sections is correlative to the lower normal polarity zone of the Zerbera section, while their lower reverse polarity zone is correlated to the upper large reverse zone of the Mylos section.

Zerbera section. This section represents the lowermost part of the Main Bone Beds and the upper most levels of the White Beds (Fig. 8). Both members are normally magnetized except for a very short reverse interval (~2 m) which interrupts them. The upper normal polarity zone (13 m) of this section is correlative with the lower 14-m-normal interval of the Dromos section.

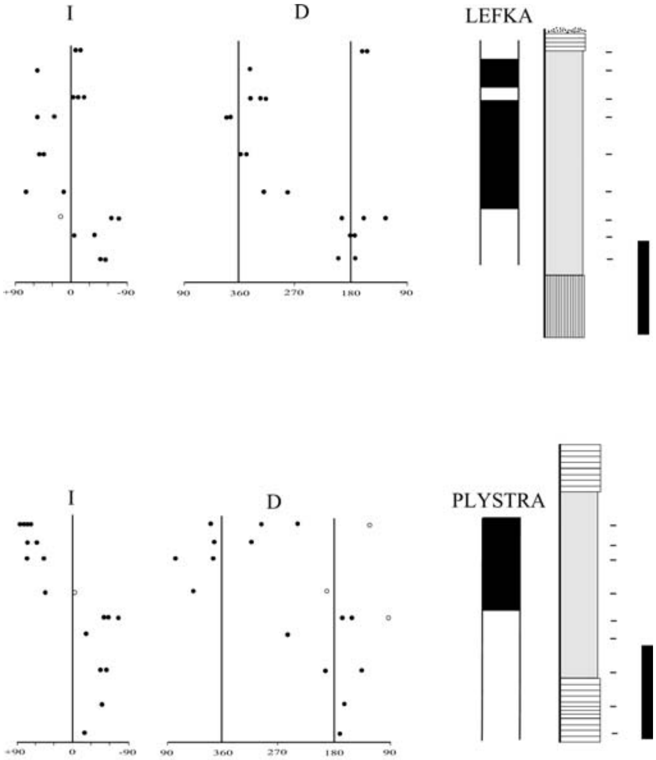


Fig. 7 Lithostratigraphy and magnetostratigraphy of the Plystra–Lefka sections. Symbols as in Fig. 6. *Scale bar* 5 m

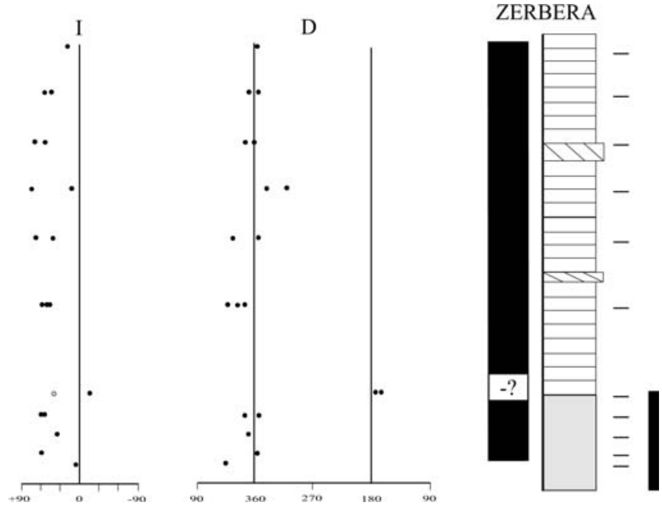
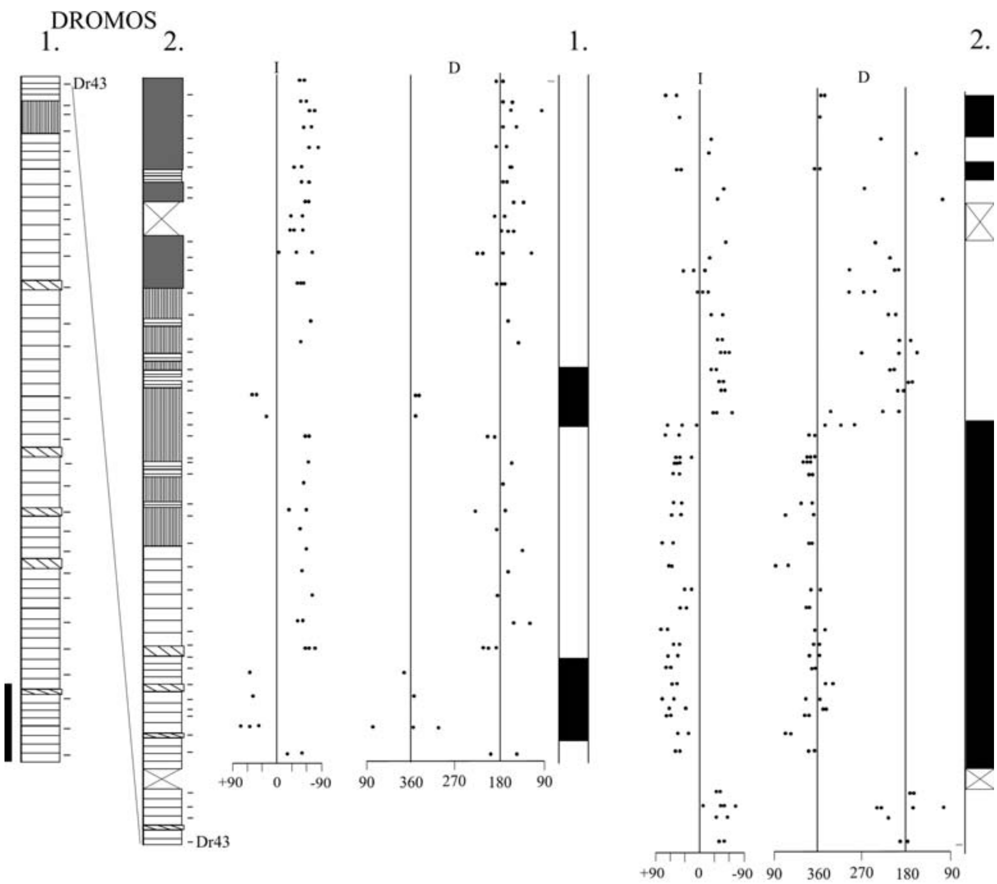


Fig. 8 Lithostratigraphy and magnetostratigraphy of the Zerbera section. Symbols as in Fig. 6. *Scale bar* 5 m

Dromos section. This section is 270 m thick and includes four normal and four reverse polarity zones (Fig. 9). From the top to the bottom, most of the basal sediments of Kokkarion Fm. have been deposited during a reverse magnetic field (4R). The upper part of the Marker Tuffs member (17 m) was deposited during the same reverse

Fig 9 Lithostratigraphy and magnetostratigraphy of the Dromos section. Symbols as in Fig. 6. *Scale bar* 10 m



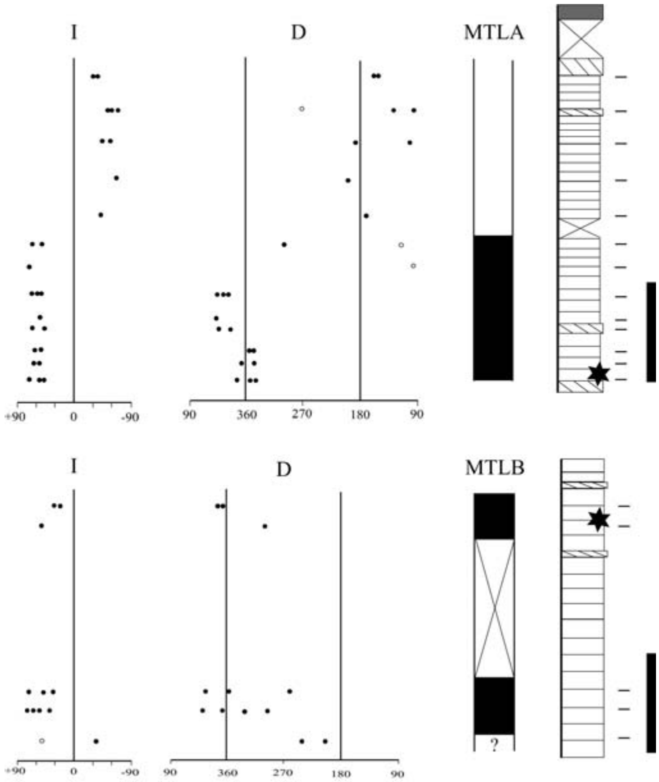


Fig. 10 Lithostratigraphy and magnetostratigraphy of the Andrianos MTLA and MTLB sections. Symbols as in Fig. 6. *Asterisks* indicate fossil sites. Scale bar: 5 m

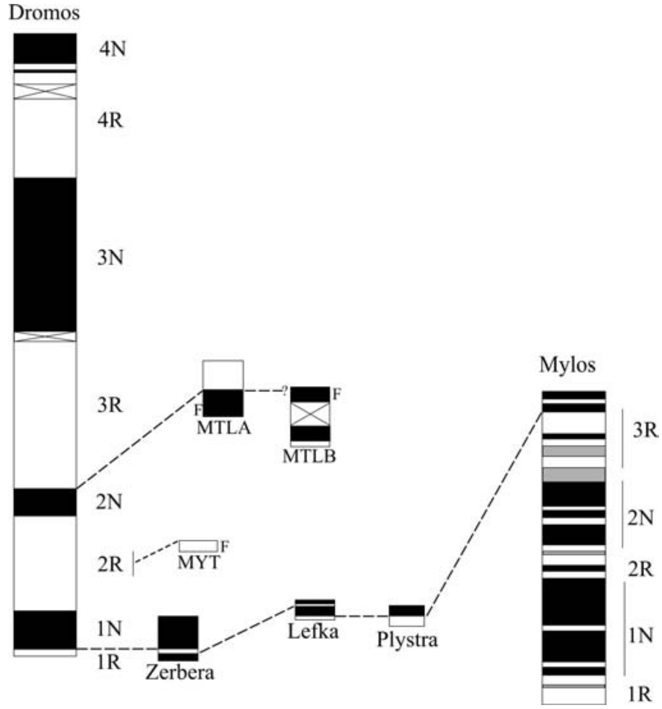


Fig 11 Magnetostratigraphic correlation between the sampled sections of Mytilinii Basin. *F* Fossil levels

magnetic field (4R), while the lower 29 m was deposited in a normal zone (3N).

The rest of the section (about 130 m) corresponds to the Main Bone Beds member. During its deposition two important reverse episodes (2R, 3R) occurred. Between them a short normal magnetic field (2N) of 7.5 m was recorded. The lowermost part of the section corresponds to a 14 m normal zone (1N). There is very good agreement between these results and those of Sen and Valet (1986); the upper large normal zone of these authors is correlative to the zone 3N of the Dromos section.

MTLA–MTLB–MYT sections. The sections MTLA and MTLB are located on both banks of the Andrianos ravine, and represent the lithological succession of the homonymous fossiliferous sites (Koufos et al. 1997). Both are placed into the Main Bone Beds member (Fig. 10). The MTLA section presents two polarity zones: a normal one at the base, followed by a reverse one at the top. The locality MTLA is located at the base of the normal zone. The MTLB section is more difficult to be interpreted because of the presence of an important gap (10 m). Nevertheless, all the sampled horizons yielded normal polarities, which might correlate to the normal zone of the MTLA section (Figs. 10, 11). The mammal locality MTLB is placed at the top of this normal interval zone, while the locality MTLC is just a little below the base of the section. According to the available information, we believe that this normal episode should correspond to the normal zone 2N of the Dromos section (Fig. 11). The short MYT section (~5 m) was sampled along the homonymous fossiliferous site in the Potamies ravine (Koufos et al. 1997). All samples yielded reverse polarities. Figure 11 summarizes all the possible correlations between local magnetostratigraphic columns. Lithostratigraphic information has also been used in order to control and link horizons.

Correlation to the GPTS

The combination of the available magnetostratigraphic data from isolated sections (Fig. 11) allows the reconstruction of the composite magnetostratigraphic column of the Mytilini Basin (Fig. 12). Correlation of the composite Mytilinii section to the GPTS (Fig. 12) was realized by reference to the versions of Bergreen et al. (1995) and Cande and Kent (1995). Taking into account that most radiometric and paleontological data (discussed below in detail) indicate a late Miocene age (mainly Turolian) for the main part of the section, one reliable correlation can be made. Changes in the sedimentation rates between the Mylos section (low rates according to lithologies) and the Dromos section (higher rates; Sen 1988) provide some incongruities with the GPTS. As a whole, the Mytilinii composite section covers a time interval over more than 2.0 Ma; the base of the section

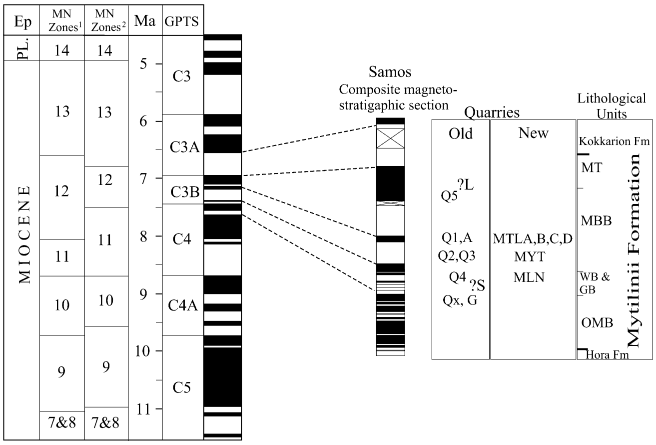


Fig. 12 Correlation of the composite magnetostratigraphic section of Mytilinii with GPTS and MN-Zones, in connection with lithological subdivisions and fossiliferous sites. *1* MN zone boundaries according to Steininger et al. 1999; *2* MN zone boundaries according to Krijgsman et al. (1996), Sen (1997), and Agusti et al. (2001)

corresponds to chron C4r (8.7–8.1 Ma) and the top corresponds to chron C3An.2n (6.3–6.5 Ma; Fig. 12). The Mytilinii Fm., being part of this section, covers a time span of about 1.4 Ma; its top corresponds to chron C3Ar (~6.7 Ma) and its base corresponds to the boundary C4n/C4r (~8.1 Ma) (Fig. 12). The Old Mill Beds member is correlated to C4n.2n–C4r.1n (7.6–8.3 Ma) while the Main Bone Beds member corresponds to C3Bn–C3Br.3r (6.9–7.4 Ma; Fig. 12). The White Beds and Gravel Beds members correlate to C3Br.2n–C4n.1n (7.3–7.6 Ma), while the Marker Tuffs member correlates to C3Ar–C3Bn (6.5–7.1 Ma). The main fossiliferous level of the Andrianos ravine—Andriano of Forsyth-Major (1891, 1894) and Melentis (1969), Q1 of Brown (1927), MTLA, MTLB, MTLC of Koufos et al. (1997)—most probably correlates to chron C3Br.1n with an estimated age range of approximately 7.13–7.17 Ma (Berggren et al. 1995). The short section of the locality MYT, indicating reverse polarity, most probably correlates to chron C3Br.2r (7.17–7.35 Ma; Berggren et al. 1995).

The above-mentioned correlation with GPTS is quite different than that given by Sen and Valet (1986). According to these authors, the statistical comparison of their polarity sequence with three magnetic polarity scales gives three possible solutions. Excluding the proposed time interval 11.6–12.5 Ma, which is incompatible with the biostratigraphic and radiometric data, the two other possibilities concern the time intervals 8.7–7.4 and 6.8–5.7 Ma (Sen and Valet 1986: Fig. 8, p. 173). Although the first one seems most probable, following the statistical data, the authors choose the last one because of its good agreement with the available radiometric information. It must be noted, however, that between the Harland et al. (1982) polarity time scale used by Sen and Valet (1986) and the recent ones used in our study, there is a time difference of about 0.5 Ma. This means that the intended correlation of Sen and Valet (1986) is in fact a half million years older than it was primarily suggested, and therefore some of the radiometric data used as a standard for their correlation (e.g., 5.4-Ma-sample SK19 from Marker Tuffs; Weidmann et al. 1984) are still outside of the time interval covered by the section. Moreover, Sen and Valet (1986) note that the radiometric results associated with the upper levels of the Main Bone Beds do not overlap the time interval deduced from their study.

Radiometric data given by Weidmann et al. (1984) and Swisher (1996) are in good accordance with the magnetostratigraphic results presented, which estimate an age of about 7.5 Ma for the base of the Main Bone Beds and about 7.0 Ma for its top. Swisher (1996) suggests a relatively younger age for the Marker Tuffs member (C3An.2n) and correlates the fossiliferous part of the Main Bone Beds to C3Br.2r. Obviously, the main differences between magnetostratigraphic and radiometric data concern the Marker Tuffs. However, as it is already mentioned, this member presents a high variation in development, probably affecting the results. It seems that the deposition of the Marker Tuffs is not isochronous within the whole basin, showing a delay in the western part, where most of the radiometric samples come from. Nevertheless, a detailed discussion on the available radiometric ages is given in the next section.

Discussion

Biostratigraphical–biochronological problems

Solounias (1981) made an extensive relocation of the old quarries (especially those of B. Brown's excavations between 1921 and 1924) and their respective position in the stratigraphy of the Mytilinii Fm. The relative disposition of B. Brown's quarries by Solounias (1981) was totally revised by Weidmann et al. (1984; Table 1). The difference in their interpretations is mainly due to the source of radiometric data used by these authors. Solounias (1981) used the K/Ar dating of Van Couvering and Miller (1971), while Weidmann et al. (1984) processed new K/Ar dating. Koufos et al. (1997), after an extensive survey in the Mytilinii area, located several fossiliferous sites and tried to correlate them with the old quarries. At the same time, Swisher (1996) reprocessed samples previously dated by Van Couvering and Miller (1971) and Weidmann et al. (1984), using the single crystal A^{39}/Ar^{40} method for the sanidine. Bernor et al. (1996) propose a new stratigraphic ordering of the old quarries, taking into account the new radiometric data provided by Swisher (1996; Table 1).

Our stratigraphical observations during 1996–1998, led to some interesting remarks concerning the location of old quarries and their correlation to the new ones, as preliminarily reposted by Koufos et al. (1997).

Table 1 Stratigraphic position of Samos fossiliferous sites associated by radiometric dating according to several authors. Lines indicate suggested correlation between quarries and radiometric samples (see text). Samples in italics (right column) represent best indication of radiometric samples/ages per fossil level

	Solounias 1981	Van Couvering and Miller 1971	Weidman et al. 1984 (using relocation of Solounias 1981)		Bernor et al. 1996	Swisher 1996	Present work
	Localities	Ages (Ma)	Localities	Ages (Ma) (samples)	Localities	Ages (Ma) (samples)	Old & New Localities
Marker Tuffs	Q5	9.0-9.6		6.14-6.74 (SK1, SK2, R105)			?L
				5.41 (SK19)			Q5 *(R105)*
Main	Q6	8.0-8.6	Q1	6.89-7.75 (SK17, SK5 R106)			Q1-MTLD, MTLB,
Bone			Q5, L, A			?8.58 (SK5)	MTLA, MTLC, A
Beds	Q2	9.2			Q1,2,3,5	7.09 (SK17)	
			Q2,3	7.4-7.55 (R102)	S3,4		Q2, S2, S3
			S2,3,4	7.52 (SK18A)		7.28 (SK18A)	MYT- Q3, S4
White beds			Q4		Q4	7.66 (R102)	MLN-Q4
Gravel beds							
			G	8.38-8.57 (SK16)	G		S, Q6
Old			?Q6	7.8-8.26 (SK3, SK6)			G, QX *(SK3)*
Mill							
Beds	Q4	9.0		8.0-8.57 (R104)			
	Q3	7.4-8.4	Qx		Qx		

Old Mill Beds fossil sites

Three fossiliferous sites refer to the lower part of the Mytilinii Fm. (Old Mill Beds member): Q6, Qx and locality G. The first two are B. Brown's quarries, while the third one was found and excavated by German collectors (see also Solounias 1981). Q6 is located in Tholorema stream and according to Solounias (1981) is placed stratigraphically in the upper levels of the Old Mill Beds. The site was relocated during the 2002 expedition on the island but the few collected fossils don't give additional information at the moment. Stratigraphically, Q6 is placed just above a white tuffaceous level of a 0.5–2 m thickness. The local litho-stratigraphic column indicates strong similarities with the upper part of Old Mill Beds, confirming previous correlations and radiometric dating. Weidmann et al. (1984) reported radiometric samples SK3 and SK6 from this area, with an age of 7.8–8.2 Ma, which is compatible with the new magnetostratigraphic data.

Solounias (1981) and Weidmann et al. (1984) placed Qx at the base of the Old Mill Beds and locality G at the top. Qx is geographically located at the NE end of Mytilinii village (Solounias 1981). At present, this area is inside an army base. During the summer of 1998, some fragmentary fossil material was unearthed from the volcanoclastic beds cropping out in this military area. We correlate this site to Qx with certainty. Solounias (1981) and Bernor et al. (1996) placed this locality 10 m above the base of the formation. Our field observations, as well as the control of the geological parameters (azimuth, dipping, etc.) showed however that Qx and locality G are close together stratigraphically, and are placed at the middle–upper horizons of the Old Mill Beds member, in contrast to previous suggestions. In our magnetostratigraphic study, this part of the Old Mill Beds correlates with Chron C4n.2n: 7.6–8.0 Ma (Berggren et al. 1995; Cande and Kent 1995; Fig. 12).

Weidmann et al. (1984) correlated Qx to the radiometric sample R104 of Van Couvering and Miller (1971), and locality G to the sample SK16. Both samples gave an age between 8.0 and 8.6 Ma, which appears slightly older than the magnetostratigraphic one provided in this study. However, according to the location of R104 (Van Couvering and Miller 1971: Fig. 1), the sample must correspond to the basal part of the Old Mill Beds. Moreover, both SK16 and R104 come from the area NW of Mytilinii village (Weidmann et al. 1984) and they are in no way correlative to the geographic locations of Qx and G. We consider both samples as being more representative of the basal part of the Old Mill Beds member.

According to Forsyth-Major (1894) the Stefano site (also referred to as locality S) is located at the base of Stefana Hill (NE of Mytilinii village), without however, more precise information. Solounias (1981: Fig. 11) placed stratigraphically this locality in the Main Bone Beds. Both field observations and literature sources come to the conclusion that localities G and Stefano are located south of Potamies stream and east of the main road connecting the Mytilinii and Vathy villages, in an area occupied by the upper levels of Old Mill Beds. The MGL Barbey-Forsyth-Major collection of Samos, contains fossils from the three fossil sites Andriano, Potamies and Stefano. Between the Andriano and Stefano collections of MGL there are clear faunal differences: *Samotherium* from Stefano is smaller and more primitive than that from Andriano (Geraads 1994, personal data). The *Gazella* (specimen S950) from Stefano is very small, similar to that from Kemiklitepe D (MN 11, Turkey; Bouvrain 1994) and completely different from that of Andriano. *Palaeoreas* from Stefano (S23, 24, 25) corresponds to a new bovid genus (Kostopoulos 2003) which is also present in Kemiklitepe D but is missing from Andriano. A skull specimen of *Microstonyx* from Stefano (S197) is clearly more primitive than that from the new site MTLA from the Andrianos ravine: smaller size, persistence of P1 in contact with P2, less developed alveolar crests, more complicated teeth morphology. This skull appears more similar to the latest Vallesian–earliest Turolian *Microstonyx* from Nikiti-1, Greece (Kostopoulos 1994). A great part of the Forsyth-Major collection in the

Natural History Museum of London comes most probably from the same or a correlative fossiliferous horizon; we find again here the small samothere and gazelle and the new counterclockwise spiral-horned antelope of Stefano (specimen BMNH M4192 previously ascribed to *Prostrepsiceros zitteli*; Kostopoulos 2003). Solounias (1981: p.33) also mentioned that Forsyth-Major's collection of 1889 (the greatest part of which is stored in BMNH) most probably comes from the area of the so-called Vryssoula district, which is identical to the wider Qx area. The faunal similarities between Stefano and Kemiklitepe D, rather indicate an early Turolian age for the first locality. Since a comparison between the faunal assemblages from Stefano, Qx, and G is not feasible, we cannot come to a conclusion about their chronological relationships. However, it seems more reliable that the Stefano locality is better correlated, from both a stratigraphic and paleontological point of view, either to Qx and G or to the slightly younger Q4 than to the other fossiliferous sites of the area.

White Beds fossil sites

Between the fossiliferous levels of Old Mill Beds and Main Bone Beds, another mammal locality exists: B. Brown's Q4, which, according to Solounias (1981) is placed at the top of the White Beds member (Solounias 1981). Koufos et al. (1997) discovered, in the southern outcrops of Potamies stream, the locality MLN, which is stratigraphically placed at the very top of the White Beds inside the thin calcitic-marly layers of this unit. The geographic and stratigraphic position of MLN fits pretty well to that of B. Brown's Q4 given by Solounias (1981). Consequently, we consider these two sites as identical.

No radiometric data from the vicinity of Q4 are known. Solounias (in Bernor et al. 1996) noted that the maximum age for Q4 is best estimated by the sample R102, derived from the area east of Mytilinii village. This sample gave an age of 7.55 (K/Ar) or 7.66 Ma (Ar^{39}/Ar^{40}; Weidmann et al. 1984, Bernor et al. 1996; Swisher 1996). Although the geographic location of R102 (far east of Mytilinii village; Van Couvering and Miller 1971: Fig. 1) is in no way correlative to that of Q4 (NW of Mytilinii) and is most probably related to the upper parts of the Old Mill Beds, we agree with Solounias' opinion regarding an age of about 7.5 Ma. According to magnetostratigraphic correlation, the transition between the White Beds and the Main Bone Beds where MLN and Q4 are located, should be placed in chron C4n.1n/1r, indicating an age of 7.45–7.65 Ma (Berggren et al. 1995; Cande and Kent 1995). Fossil material from MLN (NHMA) confirms the presence of a faunal assemblage in Samos older than that of the Main Bone Beds fossiliferous levels (see below). *Samotherium* from MLN shows strong similarities with that from Forsyth-Major's Stefano, while the hipparion assemblage from this site is quite different than that from the Main Bone Beds fossiliferous levels. Nonetheless, the relationships between the faunas from MLN/Q4 and Qx, G are unclear, since the known fossil material is poor, and therefore we must wait for a more detailed study. However, it is quite possible that the fossil mammals from the upper levels of Old Mill Beds (Qx, G, Stefano) and White Beds (Q4, MLN) belong to the same mammalian evolutionary stage.

Main Bone Beds fossil sites

The greatest part of the Samos mammalian fossils was undoubtedly unearthed from the Main Bone Beds member. Fifteen fossiliferous lenses are known: Q1, Q2, Q3, Q5 of B. Brown; Andriano and Potamies of Forsyth-Major; S2, 3, 4 of Solounias; locality L of Acker (data from Solounias 1981); and MYT, MTLA, MTLB, MTLC, MTLD of Koufos et al. (1997).

Our field data allow us to recognize three fossiliferous horizons in the Main Bone Beds. The first and older one is located in the Potamies ravine (northern outcrops), while the second one is located in the Andrianos ravine. Another couple of mammal localities, referred probably to a younger faunal association, is known from the Limitzis district.

Potamies ravine

"Potamies" of Forsyth-Major (1894), and Q2 and Q3 of B. Brown (Solounias 1981) are located in the northern outcrops of Potamies ravine. Solounias (1981) also mentions the localities S2, 3, 4 from the Potamies ravine yielded mainly micromammals. Koufos et al. (1997) recognized another locality in the northern outcrops of the Potamies ravine, named Mytilinii-3, MYT. The latter one is located at the junction of a small stream with the Potamies ravine just below Megalos Vrachos Hill and in front of MLN. Between them and along the Potamies stream an E–W trending fault can be recognized. This location matches that of B. Brown's Q3 (Solounias 1981) and therefore the two fossiliferous localities are considered to be identical (see also Koufos et al. 1997). S4 of Solounias (1981) is probably situated at the same level. Stratigraphically, the locality MYT (=Q3) is situated 80–100 m below the base of the Kokkarion Fm. and 20–30 m above MLN.

The remains of another old excavation corresponding to Q2 have been relocated in the northern outcrops of the Potamies ravine, more or less at the same stratigraphic level with MYT (=Q3). The micromammalian localities S2 and S3 (Solounias 1981) are located a few meters above it. Unfortunately, no new material has been unearthed to date from these localities.

The small magnetostratigraphic section (5 m), sampled across the fossiliferous layers of MYT clearly shows a reversed polarity, which probably correlates to C3Br.2r, indicating an age of about 7.3 Ma. These data suggest the presence of an intermediate fossil horizon between MLN (~7.5) and MTLA-B (Andrianos ravine; at about

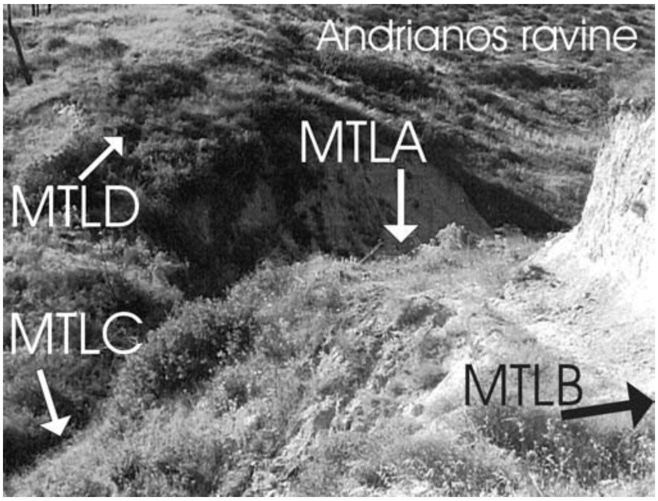


Fig. 13 View of the Andrianos ravine with the new fossil localities MTLA, MTLB, MTLC and MTLD=Q1 indicated

~7.15 Ma). Although age differences between these three fossil levels are not very strong, the faunal assemblage collected from MYT clearly distinguishes it from both MTLA-B and MLN. *Samotherium* from MYT is dimensionally placed between those from the other two sites. *Protoryx* from MYT is smaller and clearly different to that from MTLA-B, while the hipparion association shows differences from that of both MTLA-B and MLN.

The radiometric sample SK18A, taken from the vicinity of S3 and placed some meters above B. Brown's Q2 (Solounias 1981), is considered to be characteristic of this fossil level. The sample provided an age of 7.52 (K/Ar) or 7.27 Ma (Ar^{39}/Ar^{40}; Weidmann et al. 1984; Swisher 1996), which is in good agreement with the magnetostratigraphic data.

Andrianos ravine

Andrianos ravine is the main fossiliferous area of the Mytilinii Basin. The sites Andriano (or locality A) of Forsyth-Major (1891, 1894), Andrianos of Melentis (1969) and Q1 of B. Brown (Solounias 1981) are located there. Koufos et al. (1997) retrieved four fossiliferous sites, named MTLA, MTLB, MTLC and MTLD. MTLA is identical to the excavation site of Melentis (1969), while MTLC is, with certainty, situated at the same horizon (Fig. 13). MTLB is situated 50–60 m away from MTLA and almost 15 m above it and MTLC. Koufos et al. (1997) already mentioned that at least two different fossiliferous levels can be recognized in the Andrianos ravine: MTLA/C and MTLB. The locality MTLD, is located some meters (~8 m) above MTLA and in close topographic proximity. In fact MTLD is the leftovers of an old excavation from which several bones have been collected. Looking at the old photographs from the area (Brown 1927), we are convinced that MTLD is directly correlated to Q1 of B. Brown (Fig. 13). Stratigraphically, MTLD is correlative with MTLB. Bernor et al. (1996) report a thick resistant limestone conglomerate below Q1, Q2 and Q5 as a stratigraphic marker but their suggestion seems quite optimistic: three successive conglomerates were observed in the fossiliferous ravine of Andrianos; and one of them is situated just below the fossiliferous level of MTLA.

Radiometric data (samples SK17 and R106) provided an age about 7 Ma for Q1 (Weidmann et al. 1984; Swisher 1996). Swisher (1996) suggested a reversed polarity for the fossil localities and correlated them to C3Br.2r (7.17–7.34 Ma). Nevertheless, the new magnetostratigraphic data show that both MTLA and MTLB are placed in a normal polarity chron, which should be correlated to C3Br.1n, with an age of 7.13–7.17 Ma (Bergreen et al. 1995), strengthening the radiometric data. Although MTLA/C is somewhat older than MTLB/D (=Q1), there are not faunal differences between them.

Limitzis district

Q5 of B. Brown and locality L of Acker are known as being from Limitzis district (Solounias 1981). A great confusion in the literature concerns the position and the age of Q5. Weidmann et al. (1984) put Q1 and Q5 (as well as the localities L and A) at the top of the Main Bone Beds member, while Q2 and Q3 (as well as S2, 3, 4) at its base (Table 1). Solounias (1981) suggested that the locality Q5 is placed at the base of the Marker Tuffs member. Nevertheless, in their recent work Bernor et al. (1996) placed all these localities (Q1, 2, 3, 5, A and S3, 4) in the lower part of the Main Bone Beds.

In 1994, locality Q5 was rediscovered and very few fossil fragments were collected, without however any important contribution to the problem, except perhaps of the first occurrence of a large *Pliocervus,* which could indicate a younger age. According to the paleontological data given by Solounias (1981) and Bernor et al. (1996), the Q5 faunal assemblage does not reveal any differences to those of the rest of the localities of the Main Bone Beds. However, Sondaar (1971), Gentry (1971) and Heissig (1975) indicate more advanced mammalian forms from this horizon.

Our data locate Q5 in the upper parts of the Main Bone Beds, covered by a thick calcitic conglomerate and followed by the Marker Tuffs, which, however, are less developed in the Limitzis area than in Stefana Hill. The radiometric sample SK5, which was previously correlated to Q1 (Weidmann et al. 1984), was recently considered as coming from the vicinity of Q5 (Swisher 1996). Ar^{39}/Ar^{40} analysis on SK5 sanidine crystals provided a problematic age of about 8.3–8.7 Ma (Swisher 1996). These contradictions make questionable the correlation between Q5 and the rest of the fossiliferous levels. Radiometric data from the Marker Tuffs could indicate a minimum age for the Q5 fossil horizon. The samples SK19 and SK2 gave ages between 5.41 (SK19) and 6.14 Ma (SK2) (Weidmann et al. 1984), which are quite younger than those estimated from the magnetostratigraphic study for the Marker Tuffs (C3Ar–C3Bn; ~6.5–7.1 Ma). However, R105 sampled from the Marker Tuffs of Stefana Hill provided a quite compatible age of 6.5–6.7 Ma (Van Couvering and Miller 1971, Weidmann et al. 1984). Since Q5 is placed just below the Marker Tuffs, an estimated age between 7.0–6.7 Ma seems quite reliable.

Local biochronology

As it has already been mentioned, several authors tried to correlate the Samos fauna to the European Neogene continental "stages" (Fahlbush 1976) and the Mammal Neogene zones (Mein 1975, 1990; Steininger et al. 1996; Steininger 1999). It is generally accepted that the entire Samos fauna is of Turolian age, a statement confirmed by the present magnetostratigraphic study. However, opinions about the dating of specific localities and faunal assemblages diverge significantly, since everyone uses different or modified stratigraphical, chronological and paleontological data sources. According to the most recent and widely accepted view presented by Swisher (1996) and Bernor et al. (1996) and adopted by Steininger et al. (1996), the Samos fauna contains three faunal assemblages: a late early Turolian (MN 11) one including the localities Qx, Q6 and G; a late middle Turolian one (MN 12) including Q1, Q2, Q3, A, S3, S4, Q5; and an earliest late Turolian one (base of MN 13) including locality L. Q4 is missing from this consideration but an age earlier than Q1 is generally accepted (Swisher 1996).

The combination of all the available paleontological, biochronological, radiometric and magnetostratigraphic data allows us, in ordering and improving this scheme, to recognize four to five successive mammalian assemblages in Samos.

The fossil assemblages from Qx, G, and most probably Q6 constitute the oldest known mammal record on the island, and correspond to an age between 7.8–8.0 Ma, which has been estimated both magnetostratigraphically and radiometrically. On a local scale, this faunal stage underlies that of the mammal assemblage from MLN/Q4 with a late early Turolian (MN 11) aspect. A magnetostratigraphic age of 7.45–7.65 Ma is provided for the MLN/Q4 biostratigraphic horizon. Since the collection labeled Stefano (MGL) shares great faunal similarities with early Turolian assemblages from the eastern Mediterranean region, as well as with MLN/Q4, it should be placed in the present or in the previous faunal stage. Even if a direct faunal comparison with Qx is not feasible at the moment, it is quite possible that these first two levels could belong to the same biostratigraphic horizon. The overlaying faunal stage corresponds to the localities MYT/Q3 and probably Q2 with an age at about 7.3 Ma estimated both magnetostratigraphically and radiometrically. The faunal character of MYT/Q3 appears different from that of MLN/Q4, having an intermediate aspect towards and rather closer to that of the next stage, represented by the faunal assemblage of Andriano(s)/MTLA, B, C and Q1/MTLD. The fossil mammal collection from the latter sites shows a great resemblance to those of late middle Turolian (MN 12) age of the eastern Mediterranean. A magnetostratigraphic age of 7.1–7.2 Ma is estimated for this biostratigraphic horizon. The local succession ends with Q5 and locality L with a predicted magnetostratigraphic age of about 6.7–7.0 Ma for the first. Although faunal data from this biostratigraphic horizon are insufficient for certain conclusions, the mammal assemblage of this stage looks more advanced than that of the previous one. Figure 12 and Table 1 summarize the results of this analysis.

Implications of late Miocene chronology

In the present study, we tried to combine all available paleontological, biochronological, radiometric and magnetostratigraphic data with the aim to correlate the mammal localities of Samos with the MN zones. Taking into account the great interest concerning the MN boundaries and their correlation to the GPTS, we shall also try to improve the current knowledge, based on the revised magnetostratigraphy and biochronology of the Samos fauna, focusing on the Turolian MN zones. There is a general agreement within the correlation of all these records, except these concerning the MN 11–MN 12 boundary. Steininger et al. (1996), Steininger (1999) and Opdyke et al. (1997) put the base of MN 12 in the lower part of the upper chron C4n.2n, i.e. at 8.1 Ma (Fig. 12), while Agusti et al. (1997) placed it in the middle of chron C4r (8.4 Ma). Following this point of view, and according to magnetostratigraphy, all the known faunal assemblages from Samos must belong to MN 12 or younger (Fig. 12), which is in disagreement with the available paleontological and biostratigraphical data exposed previously.

Krijgsman et al. (1996) and Sen (1997: p. 194) argued for a younger age of the MN 11/12 boundary at the base of C4n.1n, or 7.5 Ma (Fig. 12), a suggestion adopted by Daams et al. (1998) and also by Agusti et al. (2001). Sen's objections are mainly based on data from the Turkish sections, especially Kemiklitepe in western Turkey (Sen et al. 1994). Both Kemiklitepe and Samos belong to the eastern Aegean Sea region and show similar depositional phases during the late Miocene. Two fossiliferous levels have been recognized at Kemiklitepe: KTD and KTA-B. An early Turolian age (MN 11) has been suggested for the first one and a middle Turolian (MN 12) for the other (de Bonis et al. 1994). Sen et al. (1994) and Sen (1997) correlated the lower fossil horizon (KTD) with C4n.2n and the upper one (KTA-B) with C3Bn/C3Br.1r. This correlation seems identical to that of Samos, where Qx and G are correlated with C4n.2n and Andriano, Q1 and MTLA-B-C with C3Br.1n (Fig. 12).

According to the paleontological data from Stefano the faunal character of this level obviously corresponds to MN 11. Moreover, the faunal similarities between Stefano, MLN/Q4 and KTD are obvious. On the other hand the faunas from KTA-B and Q1/MTLA-D strongly justify a late MN 12 age. Thus the MN 11/12 boundary should correspond to somewhere between these two biostratigraphic levels within the time interval C4n.1n/1r–C3Br.1r (or 7.56–7.13 Ma; Berggren et al. 1995). Additionally, the faunal character of the locality MYT/Q3 appears to be closer to the middle Turolian one, restricting the previous suggested range to between C4n.1n/1r–C3Br.2r (or 7.56–7.34 Ma; Berggren et al. 1995). Taking into account that the faunas from Vathylakkos and Prochoma (northern Greece) still have an intense early Turolian aspect and are placed in C4n.1n (Sen et al. 2000, de Bonis and Koufos 1999), we suggest that the MN 11/12 boundary would be better placed in the C3B/C4n limit, at about 7.43 Ma (Berggren et al. 1S995). This age is slightly younger than previously suggested but satisfies the majority of the biostratigraphic observation in both western and eastern Europe. The biostratigraphic/biochronologic distribution of the localities L34 (dated magnetostratigraphically at 7.6 Ma) and L26 (~7.3 Ma) of the middle Sinap Kavak Dere section (Kappelman et al. 1996; Lunkka et al. 1999) might also support the age estimation provided here, but additional information on the faunas is necessary for the conclusion to be certain.

At the upper part of the Samos faunistic succession, the available data are less enlightening regarding the late Miocene chronology. Judging by recent studies on the MN 12–MN 13 transition, an age between 6.6–7.1 Ma is suggested for this boundary (Van Dam 1997, Opdyke et al. 1997, Sen 1997, Garcés et al. 1998, Agusti et al. 2001, Steininger 1999). This age estimation appears very close to the recommended magnetostratigraphic age of Q5 (6.7–7.0 Ma). Since the available paleontological data from this site do not show any significant differences from Q1/MTLA-D, we should accept that Q5 is still placed into MN 12. This suggestion lets us propose an age of about 6.9 Ma (base of chron C3Ar) for the MN 12/13 boundary. The advanced character reported for the Q5 faunal assemblage is consequently fully supported by the transitional position of the locality.

Conclusion

The detailed magnetostratigraphic study of seven late Miocene continental sections covering the entire mammal-bearing Mytilinii Fm. of Samos island, provides a reliable correlation with the GPTS. The base of the sequence is correlated to the upper part of C4r and its top to C3Ar, covering a time span of about 2 Ma. Moreover, new investigations in the island provide comprehensive data on the stratigraphic position of old quarries and their correlation to the new ones as well as to existing radiometric dating. Combining all the available information, two successive mammal zones (MN) can be recognized: MN 11 (Qx, G, S, Q6, MLN) and MN 12 (MYT, Q1–3, A, MTLA-D,). During MN 12, two faunal assemblages can be distinguished in Samos: an early MN 12, corresponding to the sites Q2, Q3=MYT and S2, 3, 4; and a late middle MN 12, corresponding to Q1, A, MTLA-D sites. Another relatively younger fossiliferous horizon (Q5) should be correlated to C3Bn, indicating a latest middle Turolian age.

The obtained magnetostratigraphic results and their combination with paleontological data and literature sources allowed us to further determine the Turolian MN zone boundaries, suggesting a 7.43 Ma age for the base of MN 12 (top of chron C4n) and a 6.9 Ma age (base of chron C3Ar) for the base of MN 13.

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