PALÆO VERTEBRATA

New datation of the Tafna Basin (Algeria): a combination between biochronological and magnetostratigraphical data

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Abstract: The Tafna Basin corresponds to the lowlands, which are located in front of Tessala and Traras ranges, below the Tlemcen mountains, Algeria. This basin displays a complete sedimentary cycle dominated by lagoonal-fluvial and marine deposits. The continental formations located at the base of these deposits are mainly composed of alternating sandstones and clays. An early late Miocene age has been previously attributed to them, based on direct correlations with marine deposits. Search for micromammal fossils led to the discovery of three different rodent species from a single level of the Djebel Guetaf section, located at the bottom of these deposits. The rodent assemblage indicates a late Miocene age. Combined magnetostratigraphical and biostratigraphical investigations were carried out to provide a more accurate age control of these continental deposits. Sixty-four oriented rock samples were collected for a magnetostratigraphic study along a 92 meters thick section including the fossiliferous layer. Rock magnetic investigations indicate the presence of both high and low coercivity minerals. Specimens subjected to progressive thermal demagnetization procedures show that the samples exhibit a high temperature magnetization component and display a normal polarity. Based on biostratigraphic constraints, the Guetaf section is correlated with Chron C4An, indicating an age ranging from 9.1 to 8.7 Myr.

Keywords: North Africa, Late Miocene, Rodentia, correlations

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INTRODUCTION

The northwest Neogene basins of Algeria extend parallel to the Mediterranean Coast, the genesis of which is related to the Alpine orogeny (Perrodon, 1957). In relation with their intra-mountainous character, the sediments were deposited in various environments: continental, lagoonal, and marine (Thomas, 1985). The Tafna Basin is the most western Algerian nearshore Neogene basin of the southern margin of the Mediterranean Sea (Fig. 1). It is crossed by the Tafna River from which it takes its name. The Traras Range constitutes its northwestern limit.

The Tlemcen and Rhar Roubane mountains separate the Tafna Basin from the high plains and high lands of Oran in the southern part. In the central part, the Sebaa Chioukh constitutes a relatively high relief area that extends over to the East of Tessala Range. The Tafna Basin consists essentially of continental deposits with detrital material accumulated in depressions (Perrodon, 1957; Guardia, 1975). Vertebrate remains were previously recovered from one site, the Feid el Atteuch locality, which is located in the lowermost continental levels of Tafna Basin (Dalloni, 1915; Arambourg, 1959). The fossils included molars of rodents and of the perissodactyl *Cormohipparion africanum* (Jaeger *et al*., 1973; Ameur-Chehbeur 1979; Bessedik *et al*., 1997). Recent field expeditions have led to the discovery of a new micromammal site from the continental beds of this basin, named Tafna TA2 rodent locality, which is located at 20 km of Feid el Atteuch locality in the Djebel Guetaf section (Fig 1). Three additional rodent genera are reported in this work, notably *Myocricetodon ouaichi,* which is represented by a scarce material and reported for the first time in Algeria. In order to provide an accurate chronology, a biostratigraphic study was combined to a magnetostratigraphic study. The purpose of this paper is to refine the dating of these deposits and to establish precise correlations between the continental deposits of this basin and other North African basins. This study is worthwhile, since it is the first to be carried out in the Neogene continental deposits of Tafna Basin. The establishment of a new correlation within the late Miocene will be also used as a reference to assess correlations between fossil faunas of numerous North African Neogene basins.

GEOLOGICAL SETTING

The Tafna Basin belongs to the Tellian Zone, whose structural evolution corresponds to the Alpine phase. This basin acquired its morphogenesis characteristics during the early Miocene (Fenest, 1975). During the late Miocene, the sea receded and a continental sedimentation began with the deposition of an abundant detrital material with heterogeneous series deposited in depressions (Guardia, 1975; Saint Martin, 1990). The continental deposits, which are represented by conglomerates, sandstones, blackish clays and marls (Belkebir *et al*., 1996), expand across throughout the basin with an average thickness of 150 m. The continental episode ended with the Messinian, which is marked by a marine transgressive episode, as a shallow sea covers the entire basin.

Biostratigraphic and magnetostratigraphic studies were carried out on the continental deposits, in a place referred here as Djebel Guetaf (Fig. 2). The studied section is located on the left bank of the Tafna River at 120 km West of Oran and 30 km North of Tlemcen. This section has been chosen because of the large outcrops and the occurrence of micromammal remains in

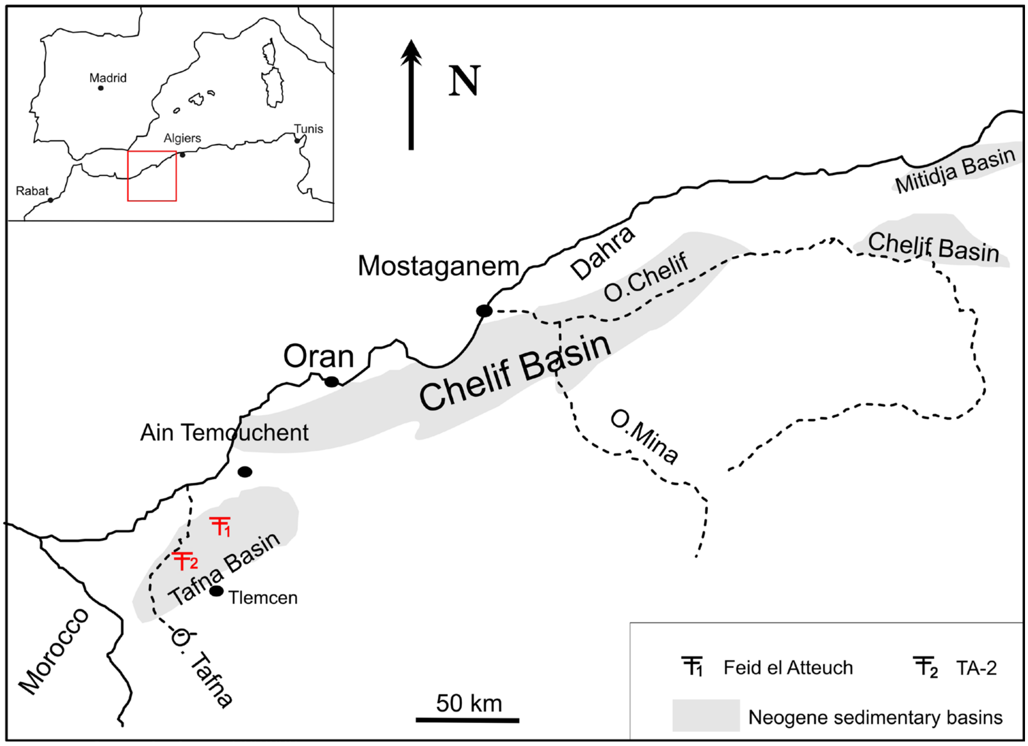

Figure 1. Location map of Neogene basins in northern Algeria, with location of Tafna-2 and Feid el Atteuch localities (after Perrodon, 1957).

the blackish clay level located in its lower part.

This section shows two formations, the Guetaf Formation and the overlaying Bled Madroum Formation (Fig. 2) (Ameur-Chehbeur, 1979). The Guetaf Formation is 82 m thick and is composed of alternating marls and sandstones. The sandstone layers are indurated, often showing cross bedding, and their thickness varies between 0.15 m and 0.80 m. The grains are generally fine to coarse with a limestone/sandstone cement. The lagoonal facies are characterized by dark marls containing brackish gastropods (Potamididae and Cerithiidae) and rodent fauna, which are studied in this work, the whole being overlain by conglomerates.

The Bled Madroum Formation is 10 m thick, corresponding to marine deposits, with homogeneous and monotonous sandy marls. This formation has yielded exclusively a marine fauna represented by diversified oysters and foraminifera: *Bolivina, Uvigerina, Cibicides, Florilus, Nodosaria, Orthomorphina, Elphidium, Astigerina, Globigerina bulloïdes, G. apertura, Globigerinoïdes ruber, G. praebulloïdes, G. quadralobatus, Neogloboquadrina acostaensis, N. dutertrei, N. incompta, Orbulina universa, O. situlari*s, and *Globorotalia conomiozea conoidea*. This faunal assemblage belongs to the N17 Blow biozone, which indicates a late Miocene age (Belkebir & Bessedik, 1991).

SYSTEMATIC PALEONTOLOGY

The fossil rodents were collected from a 60 cm thick blackish clay bed, but unfortunately screen washing of 150 kg did not yield many fossils. This fossiliferous layer produced only 24 isolated rodent molars, belonging to three genera: *Myocricetodon ouaichi* Jaeger, 1977, *Progonomys* cf. *cathalai* Schaub, 1938 and *Zramys* sp. The terminology used for the description of teeth is that of Mein & Freudenthal (1971) for the Myocricetodontinae (Fig. 3A) and that of Michaux (1971) for the Muridae (Fig. 3B). All the material is stored in the collections of iPHEP, Université de Poitiers (France).

Class MAMMALIA Linnaeus, 1758
Order RODENTIA Bowdich, 1821
Family GERBILLIDAE Stehlin & Schaub, 1951

Subfamily MYOCRICETODONTINAE Lavocat, 1961
Genus *Myocricetodon* Lavocat, 1952
Myocricetodon ouaichi Jaeger, 1977
(Fig. 4: A-D)

Holotype. Left upper M1 (KO-8) (Pl. VII, fig. 8 *in* Jaeger, 1977a). Collections du Service Géologique du Maroc, Rabat.

Type-locality and age. Khendek el Ouaich, North Eastern Morocco; Late Turolian.

Referred material from Tafna-2 (TA2). 4 right M1 (TA2-01-04, Fig. 4A), 3 left M1 (TA2-05-07), 2 right M2 (TA2-08-09, Fig. 4B), 3 left M2 (TA2-10-12), 1 right m1 (TA2-13, Fig. 4C), 1 left m1 (TA2-14), 5 right m2 (TA2-15-20), 1 left m2 (TA2-21, Fig. 4D).

Measurements. See Table 1.

	Length (mm)		N	Width (mm)	
	range	mean		range	mean
M1	1.64 - 1.81	1.71	7	0.88 - 0.96	0.92
M2	1.02 - 1.14	1.08	5	0.79 - 0.86	0.84
m1	1.49 - 1.59	1.54	2	0.81 - 0.85	0.83
m2	0.99 - 1.14	1.08	6	0.81 - 0.93	0.86

Table 1. Dental measurements of *Myocricetodon ouaichi* from the TA2 locality.

Description

M1s. Seven isolated and moderately well preserved specimens were collected. Their occlusal dental pattern is similar to the M1 referred to *Myocricetodon ouaichi* but are slightly smaller in size. In one specimen (TA2-03, Fig. 4A) the lingual cusp is clearly isolated. A large anterocone is placed labially and bears two asymmetrical cusps that are separated by a narrow and shallow valley. The anterocone has a postero-lingual inclination. An anterolophule connects the anterior arm of the protocone to the labial cusp of the anterocone. The lingual edge is convex with a small inward curve on the outline between the anterocone and protocone. The longitudinal crest is short and connects the posterior part of the protocone to the base of the anterior part of the hypocone. The short anterior arm of the hypocone is directed towards the labial edge. A lingual tubercule is highly developed, and connected to the posterior arm of the protocone on six specimens. The protocone is less developed than the paracone. The mesoloph is present in two specimens (TA2-05, TA2-06). The teeth have three roots.

M2s. On these teeth, the labial branch of the anteroloph is long, but it does not reach the paracone. The lingual branch of the anteroloph is absent. The anterior arm of the protocone is connected to the labial branch of the anteroloph. All the specimens have a well-developed accessory lingual cusp, which is connected to the posterior arm of the protocone, but only one specimen displays an isolated cusp (TA2-12). The paracone is slightly larger than the protocone and situated distally. The hypocone and metacone are twinned. This fusion is visible on highly worn teeth (TA2-11, Fig. 4C). There is no connection between the anterior and posterior part of the tooth, with the exception of one specimen (TA2-09). In this specimen the connection is made by a crest that connects the anterior arm of the hypocone to the posterior arm of the paracone. These teeth are tri-rooted: two anterior roots, the labial root being

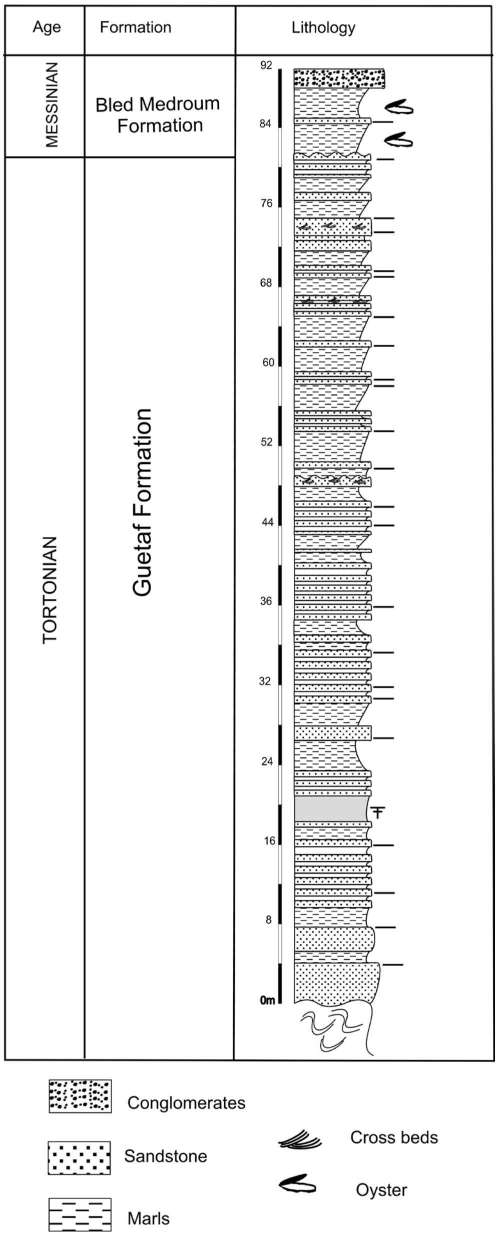

Figure 2. Stratigraphy of the Djebel Guetaf section with position of the TA-2 fossiliferous level and the sampling levels for the magnetostratigraphical study.

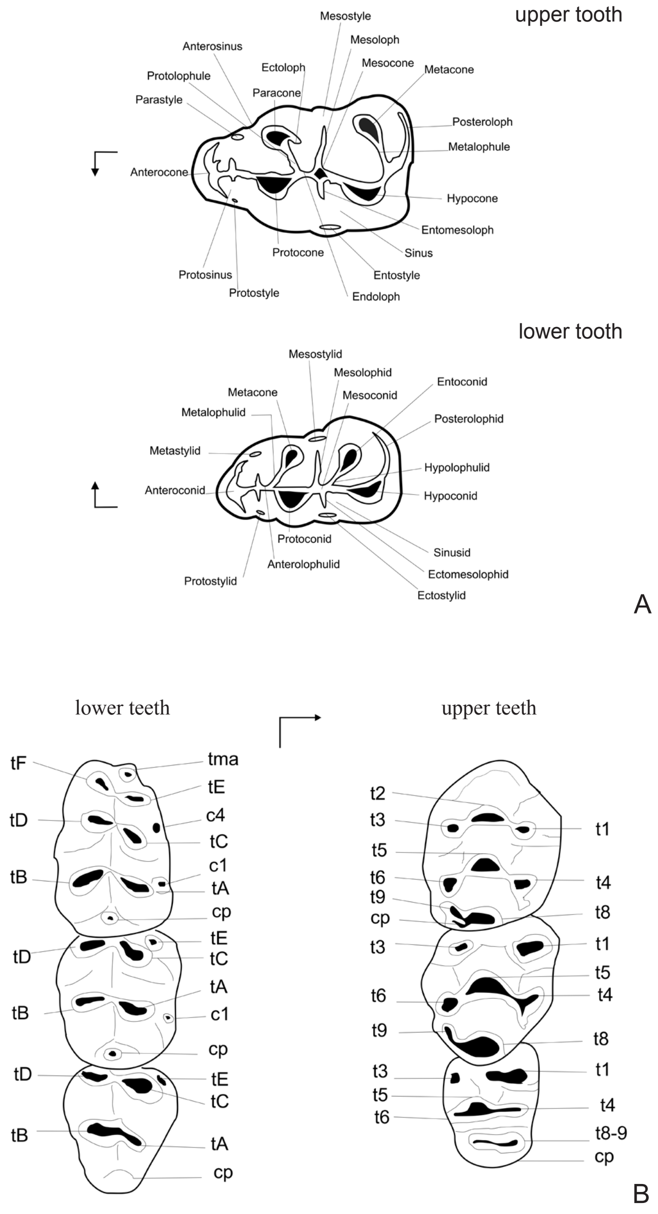

Figure 3. Dental terminology used in the description of Myocricetodontinae (A) and Muridae (B) (modified from Mein & Freudenthal, 1971 and Michaux, 1971, respectively).

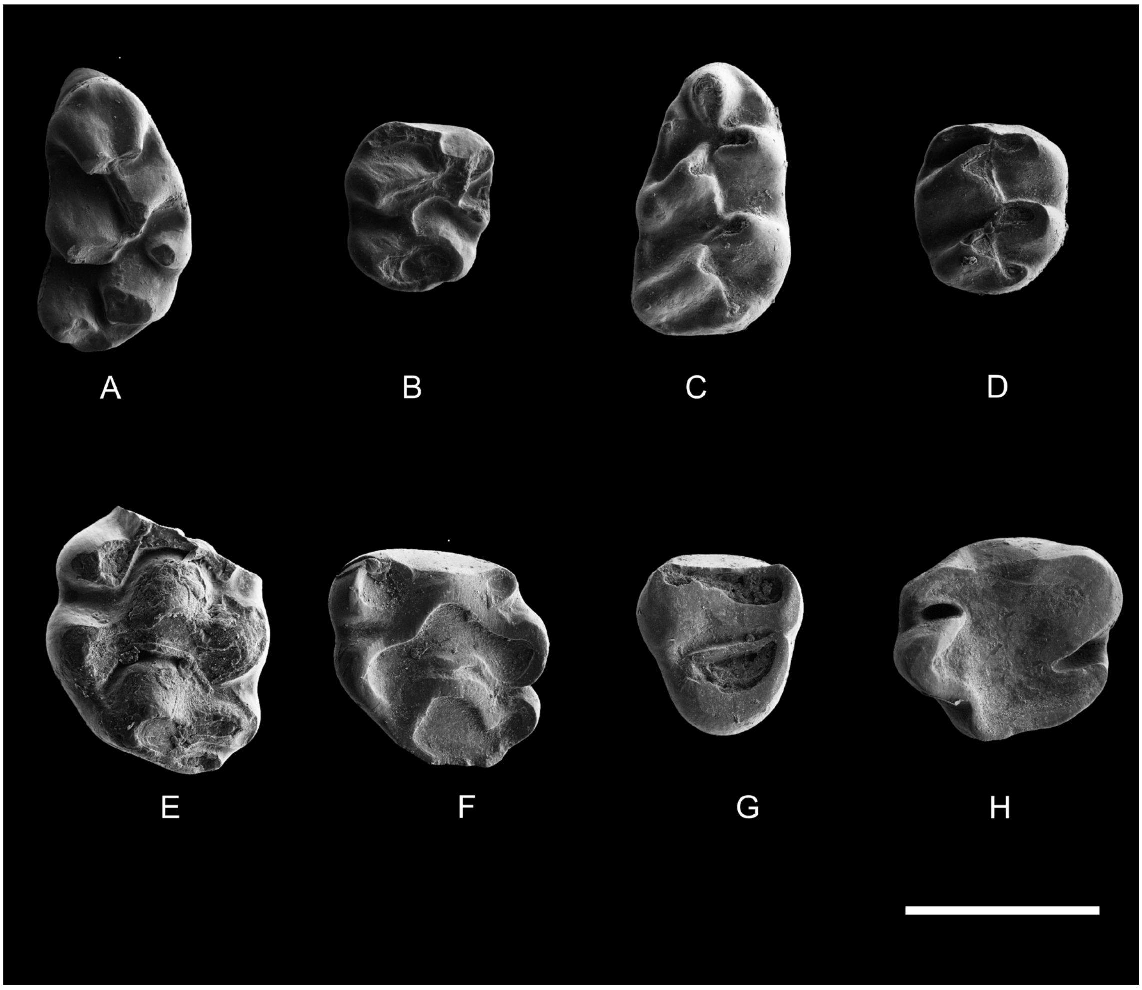

Figure 4. Isolated teeth of rodent taxa from Tafna-2 (TA2). **A-D**, *Myocricetodon ouaichi*, A: right M1 (TA2-03); B: right M2 (TA2-08); C: left m1 (TA2-13); D: left m2 (TA2-15). **E-G**, *Progonomys* cf. *cathalai*, E: left M1 (TA2-22); F: left M2 (TA2-23); G: right m3 (TA2-24); **H**, *Zramys* sp., right M3 (TA2-25). Scale bar = 1 mm.

larger than the lingual one, and a posterior root.

m1s. The prelobe of these teeth (two specimens; TA2-13, Fig. 4C and TA2-14) is short with a simple anteroconid cusp, which is situated near the metaconid and protoconid. The lingual anteroconid is merged with the anterior part of the metaconid and protoconid. The hypoconid is connected to the posterior part of the entoconid. The posteroconid is present on the two specimens, and it is connected to the posterior part of the hypoconid. The longitudinal ridge is present; it connects the four principal cusps with the anteroconid. Two roots are present on one specimen. The anterior root has a rounded section, while the posterior one is larger than the anterior one.

m2s. These teeth (six specimens) are rectangular in occlusal view. The protoconid and hypoconid appear more inclined toward the lingual surface relative to m1s. A long longitudinal crest connects the protoconid with the antero-labial part of the entoconid (Fig. 4D). The posterior cingulid is inflated, forming a small tubercle, which is coalescent with the posterior arm of the hypoconid. A short ridge is present in one molar on the edge of the labial sinusid (TA2-21).

Discussion

The dental pattern of the specimens described above matches those characterizing the different species of the *Myocricetodon* lineage (*M. parvus, M. seboui* and *M. ouaichi*), which show an increase in size from the Astaracian to the middle Turolian. Jaeger (1977b) used distinct morphotypes that were defined by the combination of some characteristic features of M1s and M2s in the recognition of these species. On the basis of the changes occurring in the frequencies of these features, a higher evolutionary grade is suggested for specimens with a bi-cuspid anterocone (X2), with an interrupted longitudinal ridge (Y2), and with a strong entostyle and protocone connection (Z3). In all specimens, the lingual cusp of both the M1s and M2s is well connected to the protocone, with the exception of one specimen (TA2-03, Fig. 4A) which has an isolated lingual cusp. This represents a useful character, which allows for a clear distinction between the species from TA2 and the other *Myocricetodon* species. In this representation, the teeth of TA2 exhibit the X1 Y2 Z3 or X2 Y2 Z3 morphotypes. These two morphotypes are more abundant in the two species *M. seboui* and *M. ouaichi* than in other species (*Myocricetodon irhoudi*, *M. ouedi, M. ultimus*, *M. asphodelae*, *M. parvus*, and *M. intermedius*). The specimens described here are slightly smaller than the single tooth of *M. ouaichi* described by Jaeger (1977a) from Khendek el Ouaich, Morocco. Another population has been described from the Oued Tabia locality, also in Morocco (Benammi, 1997), although the specimens from TA2 are slightly larger. Regarding the morphological features, the dental material from TA2 cannot be distinguished from the original material referred to *M. ouaichi*. However, although consisting in only a few teeth, the TA2 material falls outside the known size range of this latter species. In the absence of morphological details that could justify the presence of a distinct species of *Myocricetodon* in TA2 (except the larger size of the hypocone *versus* the protocone), we thus refer these teeth from TA2 to *Myocricetodon ouaichi* pending the recovery of additional material.

Subfamily MYOCRICETODONTINAE Lavocat, 1961

Genus *Zramys* Jaeger & Michaux, 1973

Zramys sp.

(Fig. 4: H)

Only one right M3 of *Zramys* sp. (length 1.07 × width 1.26, Fig. 4H) was collected in TA2. It is heavily worn, which limits the scope of description and comparison. In size and outline, this tooth is comparable to the M3s of *Zramys.*

Family MURINAE Gray, 1821

Genus *Progonomys* Schaub, 1938

(Fig. 4: E-G)

Type species. *Progonomys cathalai* Schaub, 1938.

Type-locality and age. Montredon, France, Vallesian.

Progonomys cf. *cathalai* Schaub, 1938

Referred material and measurements (in mm). 1 left M1 (TA2-22: length (broken) × width 1.2, Fig. 4E), 1 left M2 (TA2-23: length 1.48 × width 1.31, Fig. 4F), 1 right m3 (TA2-24: length 1.19 × width 0.95, Fig. 4G).

Locality. Tafna-2 (TA2), Algeria.

Description

Only three isolated teeth have been referred to this species.

M1. The anterior part of TA2-22 is broken. The t1 is placed in backward position, and is not connected to t4-t5. The t4-t5 connection is well developed, but not as wide as the t5-t6 connection. The position of the t6 is slightly posterior to the t5, and the t4 is more backwardly located. The t4 and t8 are connected by a crest. The t9 and t8 are opposed labiolingually. The posterior cingulum is present and connected to t8.

M2. TA2-23 is very worn, and as such it is difficult to provide a precise description of its cusps. The voluminous bases of t1, t3, t4, and t6 create an irregular outline. The t1 is larger than t3. The t4 and t6 are at the same level. The t5 is elevated compared to t4 and t6. The t9 is smaller than t4 or t1. The crest connecting t8-t9 has a slightly forward orientation.

m3. The outline of TA2-24 is triangular, with a longer lingual margin. The tE is absent, the tD and tC are merged. The tB is slighly connected with tD. cP and tA are absent.

Discussion

The type species of *Progonomys* is *P. cathalai* from Montredon, Southern France (Jaeger, 1977a). A comprehensive diagnosis of this species has not been given. *Progonomys cathalai* is the only species of this genus that has been reported in the North African Vallesian deposits (Ameur-Chehbeur, 1988; Coiffait, 1991). The size of the teeth of *Progonomys woelferi* is significantly larger than those of the TA2 locality. *Progonomys hispanicus* has dimensions somewhat comparable, but with the absence of the complete upper molar, we cannot make an exhaustive comparison. *Progonomys* from TA2 locality falls into the range of variation of the *Progonomys cathalai* described from the Oued Zra locality (Morocco) (Benammi, 1997). According to the scarcity of the material, with the absence of lower molars, we tentatively assign these teeth to *Progonomys* cf. *cathalai.*

PALEOMAGNETIC ANALYSES

Sampling and laboratory procedures

The Djebel Guetaf section was sampled for magnetostratigraphy. In this part of the basin, only one section is well exposed along the Tafna River, and yields favorable conditions for sampling. In the field, a total of 64 rock samples were collected using a portable drill from 22 stratigraphical levels along a section of 92 m thick. The sampling was carried out only in the sandstone levels (Fig. 2). Three drilled samples were collected from each horizon (site). The cores were oriented with a magnetic compass. The stratigraphic distance between the sites, depending on the availability of exposures and suitable sediments for sampling varies from 2 to 8 m, with an average of 4.2 m. All samples were subsequently cut into standard cores of 2.5 cm long.

Paleomagnetic analyses were undertaken at the “Institut de Paléoprimatologie, Paléontologie Humaine: Evolution et Paléoenvironnements” (iPHEP) of the “Université de Poitiers”. Paleomagnetic samples were subjected to the progressive thermal demagnetizations from 100 °C to 600 °C at 25–50 °C intervals, until the magnetization intensity fell below noise level or the direction became erratic. Stepwise acquisition of Isothermal Remanent Magnetization (IRM) was used to identify the magnetic carriers in eight samples distributed all over the section. Samples were submitted to an increasing direct field steps up to 2 T. IRM acquisition was performed using a pulse magnetizer. The intensity of the remanent magnetization was measured after each step on a JR6 spinner magnetometer.

Isothermal Remanent Magnetization (IRM)

The magnetic mineralogy of the Tafna deposits was studied using IRM acquisition curves and subsequent thermal demagnetization of orthogonal component (Lowrie, 1990). IRM curves show two different behaviors (Fig. 5). The first behavior (Fig. 5A) shows that 80 % of magnetization is acquired in a low field (samples 2, 11, 23, 41, 64), but does not saturate above 200 mT. The magnetization increases in high field, indicating that magnetization is carried by both low and high coercivity minerals. In the second behavior (Fig. 5B), the initial increase of magnetization up to 100-150 mT indicates the presence of low coercivity minerals. A saturation was not achieved at 2 T (samples 32, 46). The magnetic properties of the second group samples indicate the presence of low coercivity minerals, but with low concentration, and high coercivity minerals, like goethite or hematite, which are in contrast abundant. However, the sample 54 shows that saturation was not achieved at high field, thereby indicating a dominance of high coercivity minerals.

The determination of the ferromagnetic mineralogy according to their coercivity was improved by stepwise thermal demagnetization from 100 °C up to 620 °C of three axis following Lowrie's method (1990). Differential IRM have been applied along the three orthogonal axes of the samples (0.1 T along the X-axis, 0.5 T along the Y-axis and 3 T along the Z-axis). After their magnetization, the samples were exposed to thermal demagnetization. The demagnetization curves, corresponding to the three axes of the samples, are plotted in Fig. 5 C, D and E. Thermal demagnetization of the sample 2B (Fig. 5C) shows that the soft component displays the prominent inflexion around 450 °C, suggesting the presence of Ti-poor titanomagnetite. Moreover, the three components (X, Y and Z) lost their magnetization above 620 °C, suggesting the contribution of hematite. The thermal demagnetization curves of the hard fraction (0.5-3 T) of the sample 54B (Fig. 5E) shows an unblocking temperature of 100 °C, which suggests the presence of goethite. The soft and medium components of this sample lost their magnetization at 580 °C, which could indicate that the magnetization is borne by magnetite. For sample 32B, the intermediate and high coercivity fraction of the IRM are not completely demagnetized at temperature > 600 °C, indicating the presence of a high-unblocking temperature mineral such as hematite.

The combined results from the IRM acquisition and thermal demagnetization suggest that the main carriers of magnetization in sediments are both low and high coercivity minerals (titanomagnetite, magnetite, goethite and hematite).

Natural Remanent Magnetization (NRM) analysis

The NRM of all samples analyzed was measured using a JR6 magnetometer. Their intensities range between 10.6×10^{-1} A/m and 3.08×10^{-4} A/m. In order to separate the NRM component, progressive thermal demagnetization appeared to be more satisfactory than alternative field demagnetization. Thermal demagnetization treatments of all samples were plotted on orthogonal projection diagrams (Zijderveld, 1967). Demag-

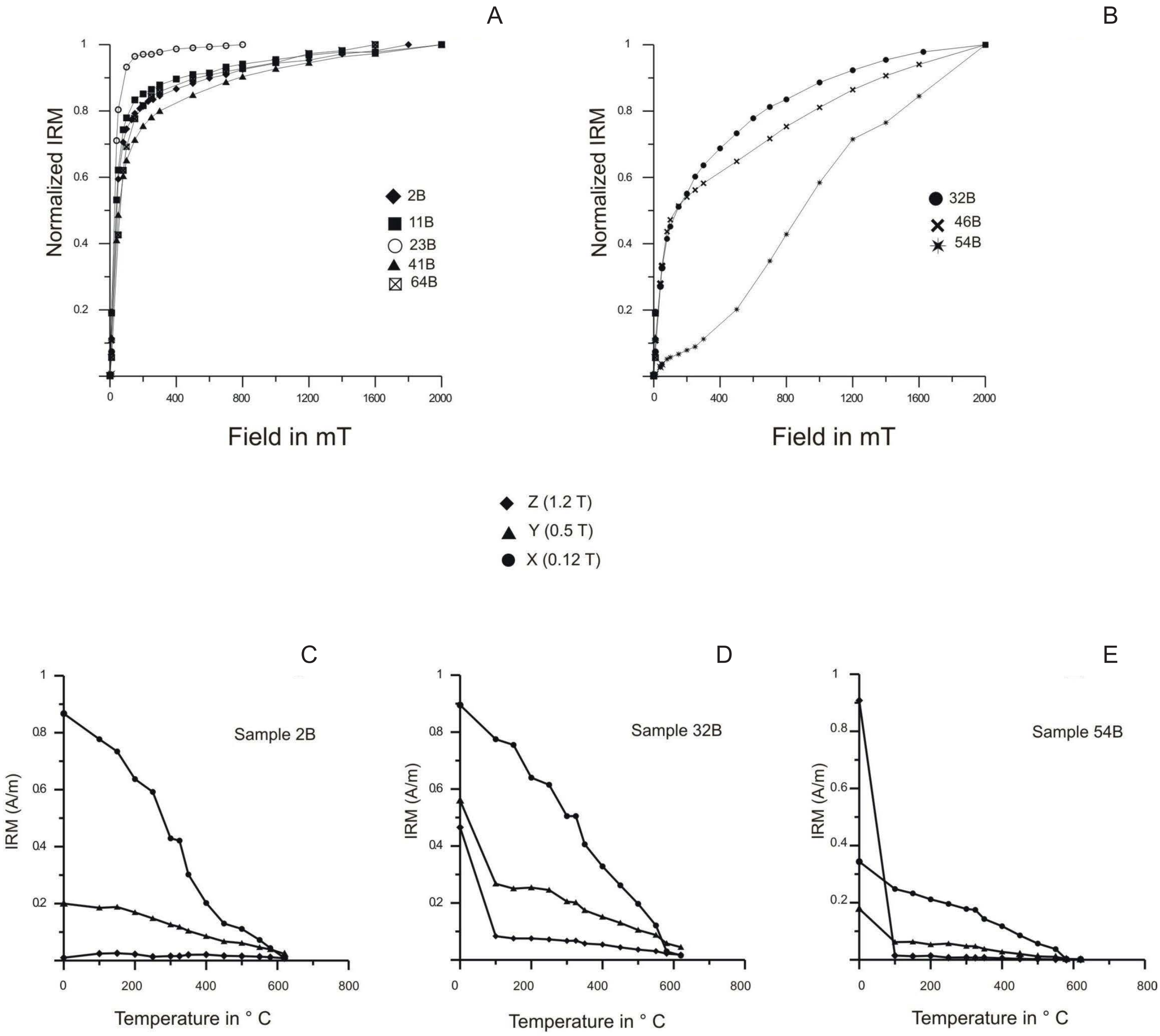

Figure 5. A-B, Isothermal Remanent Magnetization (IRM) acquisition (normalized values) curves of selected samples of the Tafna section. **C-E,** Normalized magnetization intensity curves showing stepwise thermal demagnetization of IRM components for representative specimens of the Tafna section.

netization revealed that most samples were characterized by one or two components, the representative examples are given in Figure 6. A small viscous component with low unblocking temperature was rapidly eliminated after 100 °C; this component is interpreted as a secondary component. In most cases, the higher temperature demagnetization yielded a stable component that decayed toward the origin. This component is considered as a primary component. Thermal demagnetization shows that the characteristic remanent magnetization resides mainly in (titano-) magnetite since most of the total NRM was removed at temperature comprised between 200 °C and 500 °C (Fig. 6). However, in a few samples, some magnetic component remained up to temperature of 580 °C, denoting the presence of magnetite or hematite, a composition which is consistent with IRM studies.

Paleomagnetic directions were obtained from Characteristic Remanent Magnetization (ChRM), calculated with the principal component analysis (Kirschvink, 1980). All ChRM directions oriented North down were interpreted as the normal polarity. ChRM directions were combined using Fisher statistics (Fisher, 1953) to calculate mean direction and plotted on stereographic diagrams (Fig. 7). The mean directions of site after bedding correction are: declination = 4.02°, inclination = 52.7°, (α_{95} =7, k =10, n = 48) corresponding to a paleomagnetic pole at 86.3°N and 113.4° E (dp = 9.7°, dm = 6.7°). Although the rock magnetic properties suggest that the NRM may be of primary origin, we evaluated other criteria to infer the origin of the observed characteristic remanence. Because of the rather invariant bedding attitude over the sampling sites, we were not able to perform affirmative fold tests. There is no significant difference in the angular dispersion, as the precision parameter *k* remains almost unchanged after tilt correction. *In situ* site mean directions differ strongly from the direction of the axial geocentric dipole and, therefore, exclude a recent magnetic overprint. Aiming to evaluate our results, we compared the mean directions observed from the site with the expected derived from the Apparent Polar Wander (APW) path of Africa for the Miocene (declination = 0.8, inclination = 49.3, α_{95} = 2.9) at 11.9 Myr (Besse & Courtillot, 2002). The observed inclination is slightly higher (2.3± 1.7°) than the expected inclination of the paleomagnetic field at this latitude, although inclination of depositional remanent magnetism is usually shallower than the expected geomagnetic field direction (Krijgsman & Tauxe, 2004). This can be interpreted by the substantial transport of these deposits by the thrust sheets. Hence, the observed differential rotations of the declination may be interpreted here as a response to local tectonic effects rather than a response to regional tectonics. The Virtual Geomagnetic Pole (VGP) latitudes were calculated from the ChRM declination and inclination of each sample. The individual VGP latitudes were plotted according to their stratigraphic levels along the section (Fig. 8), which is characterized by one single long normal polarity event.

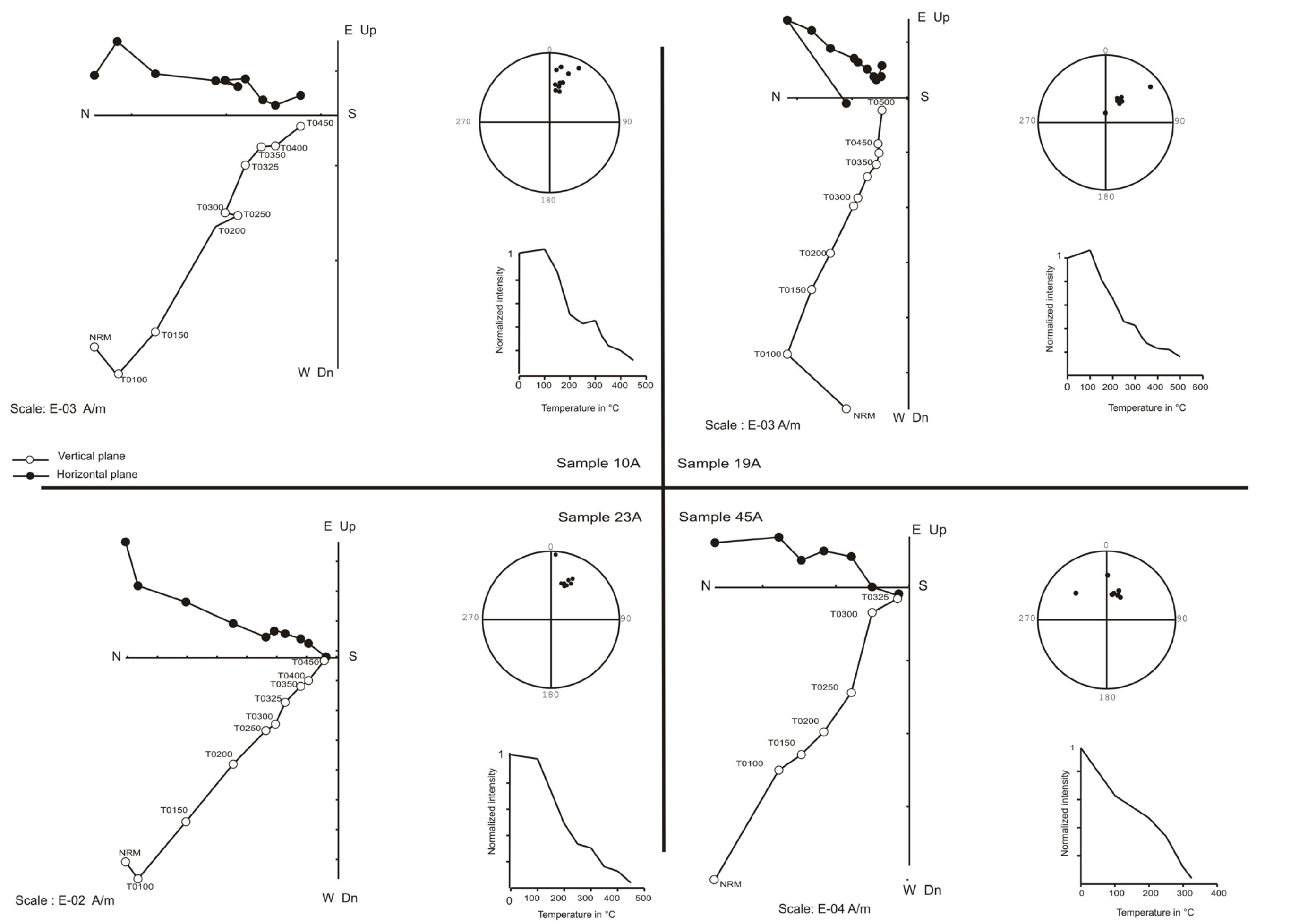

Figure 6. Examples of orthogonal vector diagrams of progressive thermal demagnetization (closed/open symbols correspond to the horizontal/vertical components).

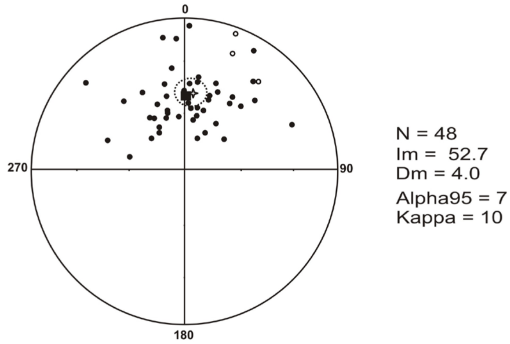

Figure 7. Equal-area stereographic projection of site-mean characteristic directions. Mean direction calculated by Fisher statistics is represented by a star and the ellipse indicates the 95 % confidence. Square shows the direction derived from the 11.9 Ma Apparent Polar Wander Path of Besse & Courtillot (2002).

CORRELATIONS AND DISCUSSION

The Miocene part of the Tafna basin is filled with mixed marine and continental deposits, identified as continental and transitional marine deposits, which correspond to cross-bedded channelized sandstones, coarse conglomerates and claystones. In the eastern part of the studied area, the continental deposits unconformably overlay marine deposits dating from the Serravalian according to their planctonic foraminifera: *Globorotalia mayeri* and *Globorotalia menardii*, which belong to the N14/N15 Blow biozone (Guardia, 1975). In the Hammam Boughrara locality, these marine deposits include rhyolitic dykes, whose radiometric dating gave an age of 13.25 Myr (Megarsti, 1985).

The age of the continental deposits was based on biostratigraphical data and direct marine-continental correlations (Bessedik *et al*., 1997). The micromammal fauna occurrences

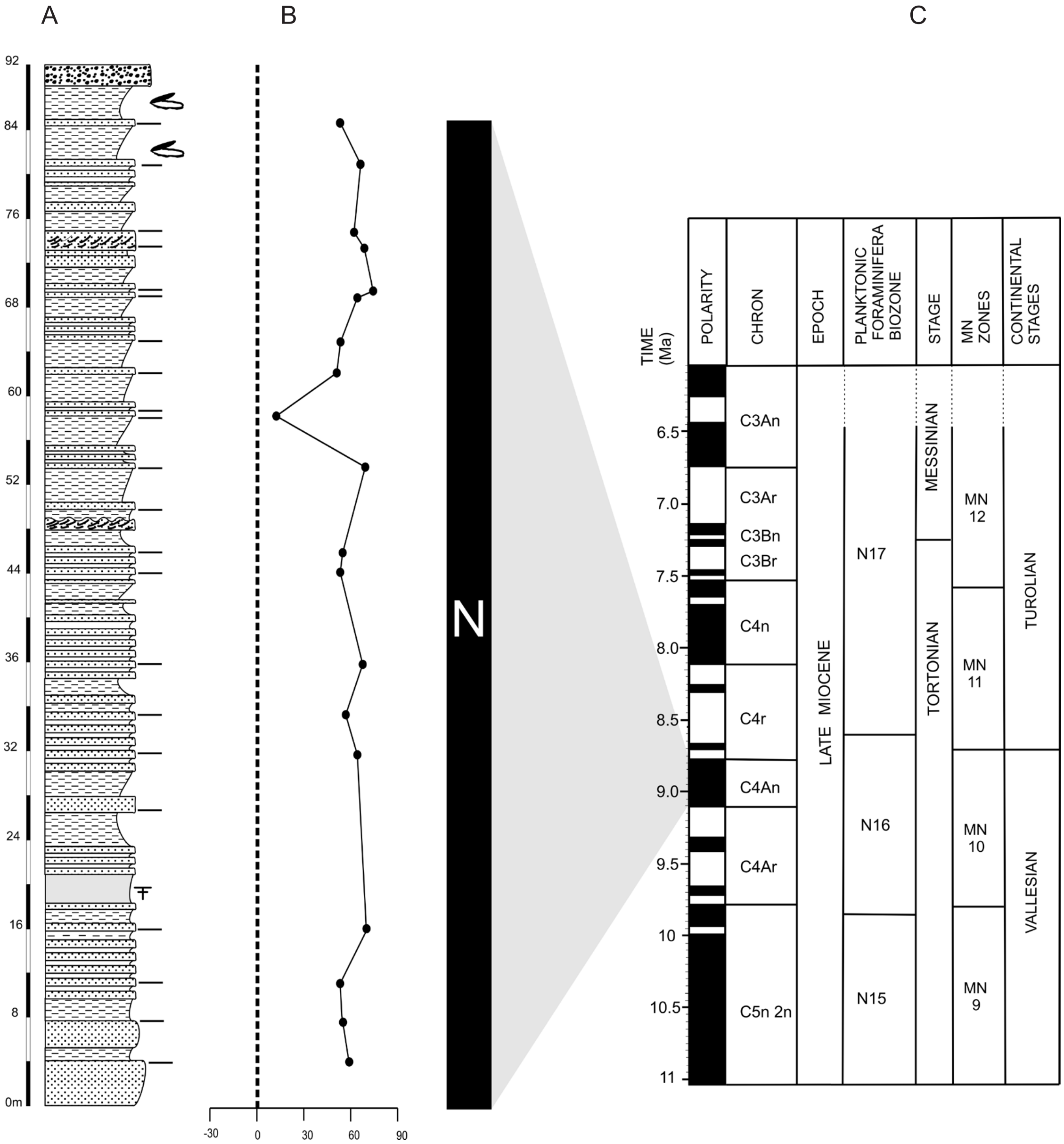

Figure 8. Lithology, magnetostratigraphy, and stratigraphic position of sampling sites of the Tafna section. **A,** Lithological section, lines at the right of the column indicate the position of the paleomagnetic sites. **B,** Latitude of virtual geomagnetic pole (VGP) of characteristic remanent magnetization (ChRM). **C,** Polarity column (black bar: normal polarity zone), MN zones of Agustì *et al*. (2001) and potential correlations with the GPTS of Gradstein *et al*. (2004).

are rare in this area, and they are restricted to a few localities. The age of the continental deposits were only known from their vertebrate fauna collected in Feid El Atteuch, a locality located at about 20 km North-East of the Tafna section. This locality yielded remains of the perissodactyl *Cormohipparion africanum* (Dalloni 1915; Arambourg, 1959). According to these fossils, these formations were considered as late Miocene in age. The first appearance datum (FAD) of the genus *Cormohipparion* was used for defining the lower limit of the Vallesian stage (11.1 Myr); and the upper limit was set at 8.7±0.1 Myr based on magnetostratigraphical study (Gracès *et al*., 1996). *Cormohipparion* is also known in the Bou Hanifia locality (Chelif Basin, Northwest of Algeria). A magnetostratigraphic study indicated an age of 10.3 Myr for Bou Hanifia 5 (Sen, 1986) based on correlation with the polarity time scale of Harland *et al*. (1982). A revision of this result in the light of the GPTS of Gradstein *et al*. (2004) indicates an age of 10.9 Myr.

The population of *Myocricetodon ouedi* of the Feid el Atteuch locality is more derived than that of Bou Hanifia 5. The *Myocricetodon* teeth of the Feid el Atteuch locality show the same dental pattern, size, and evolutionary stage, as those described from Oued Zra (Morocco) (Ameur-Chehbeur, 1979). This supports the hypothesis of contemporaneity between both localities. Nevertheless, the Oued Zra mammal locality was dated at 9.7 Myr to 10.0 ± 0.5 Myr, according to radiometric dating of a volcanic material (Jaeger *et al*., 1973). Another radiometric dating correction was carried out by Harland *et al*., (1982), giving a slightly older age of 10.10 ± 0.7 Myr. The faunal assemblage of Feid el Atteuch indicates a middle Vallesian age (Ameur-Chehbeur, 1979; Coiffait, 1991).

Based on correlations made in the field, following a marker horizon (Bessedik *et al*., 1997), the new Tafna TA2 locality is stratigraphically located above the Feid el Atteuch locality. Accordingly, from a biochronological point of view, this new fossiliferous level (TA2) indicates a younger age with a different rodent assemblage: *Myocricetodon ouaichi, Zramys* sp., and *Progonomys* cf. *cathalai*. The upper molars (M1) of *M. ouaichi* display a split anterocone and an oblique longitudinal ridge that connects the paracone with the hypocone. These teeth are characterized by a strong lingual cusp, which

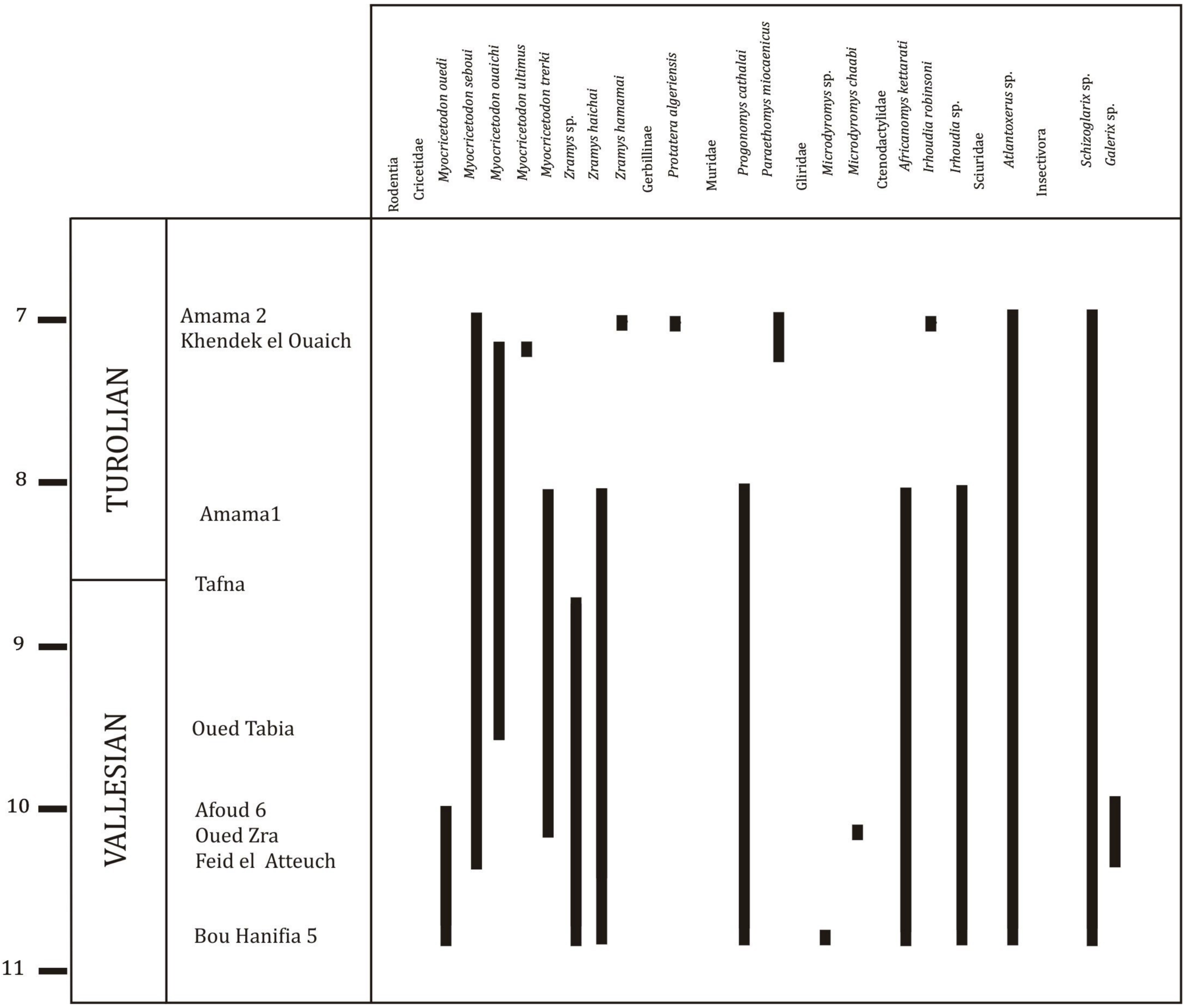

Figure 9. Stratigraphic range of rodent fauna chart in some northwest African localities.

is connected to the protocone in most of the specimens, and shows strong morphological similarities with the *M. ouaichi* described from Khendek el Ouaich (Jaeger, 1977a). The first appearance of this species out of the type locality is reported from the Oued Tabia locality in Southern Morocco, dated at 9.6 Myr, according to magnetostratigraphy (Benammi, 1997; Benammi, 2001). Despite being remarkably larger, the teeth described in this work show the same morphological characteristics as those observed in the Oued Tabia population. As it was previously shown by Jaeger (1977a), the genus *Myocricetodon* displays an increase in size through time. According to the known stratigraphic range of this species and the evolutionary degree, the stage of evolution of the rodent specimens collected in TA2 locality suggest an age ranging from the late Vallesian to the early Turolian. At the top of the continental deposits, conglomerates, sandstones, blue marls, diatomite, limestone and gypsum indicate the return of the sea. Aside benthic foraminifera assemblages, *Neogloboquadrina humerosa/N. dutertrei*, which belongs to the N17 Blow biozone, indicate a Messinian age (Belkebir *et al*., 1996). As mentioned above, in view of the biochronological constraints, an optimized bracket of 9.5-8.2 Myr is assigned to the Tafna section.

The polarity zone can be used to estimate the temporal duration represented in the Guetaf section. In order to correlate our polarity with the GPTS of Gradstein *et al*. (2004), we calculated the sedimentation rate of the studied section using the statistical method of Johnson & McGee (1983). According to this method, we can therefore exclude the chrons that are inconsistent with the sedimentation rate. Among the four normal polarity chrons (C4Ar.1n-C4r.1n) included in the late Vallesian-early Turolian part of the GPTS, the correlation of the 92 m thick section with short duration chrons (>100 kyr) are excluded because they imply a huge net minimum sedimentation rate (>100 cm/kyr), which is unlikely for a fluvial sedimentation regime (Sen, 1988) (Fig. 9). Nevertheless, the correlation of the normal polarity event with the Chron C4An, is the most consistent with the sedimentary regime. This correlation suggests a numerical age for the fossiliferous layers of the Tafna Basin between 9.1 and 8.7 Myr. This sedimentary interval, which lasted 0.6 Myr, indicates that the rate of sedimentation would have been of 19 cm/Kyr (Sen *et al*., 1986; De Leeuw *et al*., 2011; Coster *et al*., 2012).

CONCLUSIONS

The new TA2 rodent locality, situated in the western part of the Tafna Basin in Algeria, has yielded three rodent taxa, including *Myocricetodon ouaichi*, which is reported here for the first time in Algeria. Biostratigraphic data restrict the age of the Tafna rodent-bearing layers to the late Vallesian–early Turolian interval. The magnetostratigraphic study of the 92 m thick Guetaf section has provided for the first time a direct magnetostratigraphic framework for the Tafna Basin. Using rodent assemblages and benthic foraminifera as a rough age indicator, correlations with the only normal polarity magnetozone recorded along the studied section can be established with the GPTS (Gradstein *et al*., 2004). It corresponds to Chron C4An (9.1 to 8.7 Myr). The allocation of the Tafna rodent locality TA2 to a precise chronological framework represents a major advancement to achieve biostratigraphic correlations and provides the first numerical age for these rodent remains. The established chronology allows a direct comparison between the fossiliferous level of that new locality and other North African fossil rodent sites, such as Oued Zra, Oued Tabia, and Khendek el Ouaich localities in Morocco (Jaeger, 1977a; Benammi 1997, 2001), and Amama 1, Amama 2, and Feid el Atteuch in Algeria (Jaeger, 1977a; Ameur-Chehbeur 1979) (Fig. 9).

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