



General Palaeontology, Systematics and Evolution (Vertebrate Palaeontology)

The Miocene mammal record of the Vallès-Penedès Basin (Catalonia)



Le registre Miocène des mammifères du Bassin de Vallès-Penedès (Catalogne)

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ABSTRACT

The land mammal record of the Vallès-Penedès Basin (Catalonia, NE Spain) ranges from the early Miocene (Ramblian) to the late Miocene (Turolian), that is from about 20 to 7 Ma. Here we present an updated review of the mammal succession focusing on biochronology as well as on environmental and faunal changes. Based on faunal similarities with central Europe, we interpret this basin as a transitional zone between the forested environments of northern regions and the more arid landscapes of the inner Iberian Peninsula. The quality of the Vallès-Penedès record and its chronostratigraphic control is clearly better for the late Aragonian and the Vallesian (between 12.6–9.0 Ma), especially for small mammals. Therefore, we analyze small mammal diversity dynamics during this interval. Contrary to previous analyses, which found an abrupt extinction event coinciding with the early/late Vallesian boundary (the Vallesian Crisis), our results show that this pattern is due to uneven sampling. Instead, taxonomic richness slowly decreased since the late Vallesian as a result of a series of extinctions that mostly affected forest-dwelling taxa.

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R É S U M É

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Le registre fossile des mammifères du bassin de Vallès-Penedès (Catalogne, Nord-Est de l'Espagne) s'étend du Miocène inférieur (Ramblien) jusqu'au Miocène supérieur (Turolien), soit environ de 20 à 7 Ma. Nous présentons ici une révision actualisée des successions de mammifères, en prêtant attention aux aspects biochronologiques, environnementaux et faunistiques. Sur la base des similarités observées avec les faunes d'Europe centrale, nous interprétons ce bassin, d'une part, comme une zone transitionnelle entre les environnements boisés des régions nordiques et, d'autre part, comme le paysage le plus aride de la partie intérieure de la péninsule Ibérique. La qualité du registre fossile du Vallès-Penedès, ainsi que son contrôle chronostratigraphique, sont nettement supérieurs pour la partie Aragonien supérieur et Vallésien (entre 12,6 et 9,0 Ma), particulièrement pour les petits mammifères. Pour cette raison, nous analysons ici la dynamique de la diversité des petits mammifères pour cette période. À l'inverse des analyses précédentes, qui observaient une extinction brutale à la limite Vallésien inférieur/supérieur, nos résultats montrent que ce modèle résulte en fait d'un échantillonnage inégal. Nous proposons plutôt une diminution lente de la richesse taxonomique à partir du Vallésien supérieur, conséquence d'une série d'extinctions touchant, en priorité, les espèces forestières.

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1. Introduction

The study of the mammal faunas of the Vallès-Penedès Basin (Barcelona, Catalonia) dates back to the late 19th century, when a few mammal remains were found in the short-lasting lignite mine of la Font Santa (next to els Casots site, CS in Fig. 1) and the Molí Calopa brickyard in Rubí (MC, Figs. 1 and 2). These were reported by the priest and geologist Jaume Almera, from the Museum of Geology of Barcelona Seminary, who left the description of these remains (most of them currently lost) in the hands of renowned mammal paleontologists of his time, including M. Boule, C. Depéret and A. Gaudry (Almera, 1898). In the following decades the outcrops of the Vallès-Penedès were surveyed by paleontologists from the Barcelona Seminary resulting in the discovery of new sites, including the ones at els Hostalets de Pierola (Bataller, 1938). However, the systematic sampling of the Miocene outcrops did not start until the 1940s being led by Miquel Crusafont, Josep F. de Villalta and Jaume Truyols. This resulted in the discovery of tens of new sites and the collection of thousands of specimens, most of which are currently housed at the Institut de Paleontologia Miquel Crusafont (ICP) in Sabadell. Crusafont and Villalta focused on the study of mammals and occasionally other vertebrates (Crusafont et al., 1955; Crusafont Pairó, 1950; Crusafont Pairó and de Villalta, 1951; de Villalta Comella and Crusafont Pairó, 1941a, 1941b), whereas Truyols mostly devoted his studies to the stratigraphical context and regional geology of the area (Crusafont Pairó and Truyols Santonja, 1954, 1960; Crusafont et al., 1955). Thanks to their work, the Vallès-Penedès soon became a reference area for the study of European Miocene faunas, and eventually the Vallesian land mammal age was defined based on its record (Crusafont Pairó, 1950). The Vallesian age was quickly accepted and used in other regions of the Old World for the Late Miocene fossil faunas that are characterized by the entry of the first hipparionin horses.

During the 1970s and the 1980s the knowledge of the Vallès-Penedès mammal record improved with the addition of new sites and reviews of important mammal groups such as the rodents, insectivores and artiodactyls (for synthetic reviews, see Agustí et al., 1985 or Golpe-Posse, 1974). The publication of the first comprehensive paleoecological and diversity analyses followed soon after (Agustí and Moyà-Solà, 1990; Agustí et al., 1984), resulting in the definition of a remarkable extinction event during the early late Miocene. The Vallesian Crisis, as it was called, was also recognized in other European regions (Agustí and Moyà-Solà, 1990; Agustí et al., 1997, 1999; Fortelius and Hokkanen, 2001; Fortelius et al., 1996). Finally, during the last two decades, the construction of major works such as highways and landfills has allowed the discovery of hundreds of new sites, mostly of latest Aragonian and Vallesian age. These new sites are placed in long and continuous series that have also been sampled for magnetostratigraphy (Alba et al., 2012a; Garcés et al., 1996; Moyà-Solà et al., 2009). The resulting correlations to the Geomagnetic Polarity Time Scale (GPTS) have allowed a high precision in the age estimation of many sites, which, coupled with the intensive sampling and study of the mammal faunas, open the way for more refined paleoecological and diversity analyses. Here we provide an updated review of the Miocene mammal record of the Vallès-Penedès and its geological context, together with an analysis of the mammal diversity dynamics during the late Aragonian and the Vallesian, which is the best-sampled part of our record.

2. Geological setting

The northwestern Mediterranean was formed during the Latest Oligocene and the Miocene as a result of the subduction of the old oceanic crust of the Tethys Ocean under the Eurasian plate as the African plate progressively converged with it (Roca and Guimerà, 1992; Roca et al., 1999). At the Catalan Continental Margin, a widespread system of NE-SW and NNE-SSW oriented horsts and half-grabens

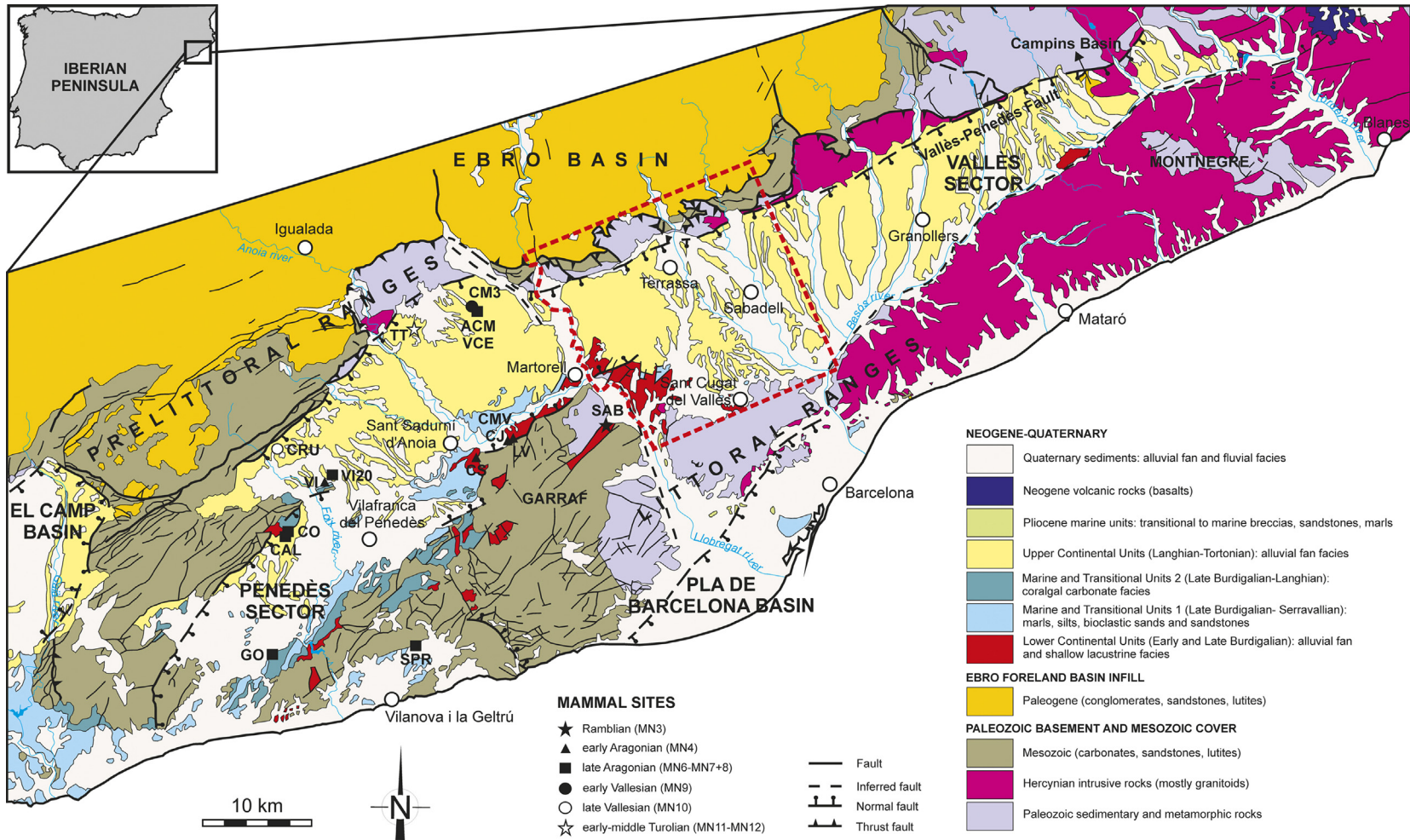


Fig. 1. (Color online.) Simplified geological map of the Vallès-Penedès Basin and major Miocene mammal sites (modified from Institut Cartogràfic i Geològic de Catalunya, 2015). The area enclosed by the dashed perimeter is shown in detail in Fig. 2. For locality acronyms, see Table 1.

Fig. 1. (Couleur en ligne.) Carte géologique simplifiée du bassin de Vallès-Penedès et principaux sites miocènes à mammifères (modifié d'après l'Institut Cartogràfic i Geològic de Catalunya, 2015). La zone délimitée par la ligne en pointillés est montrée en détail sur la Fig. 2. Pour l'acronyme des localités, se référer au Tableau 1.

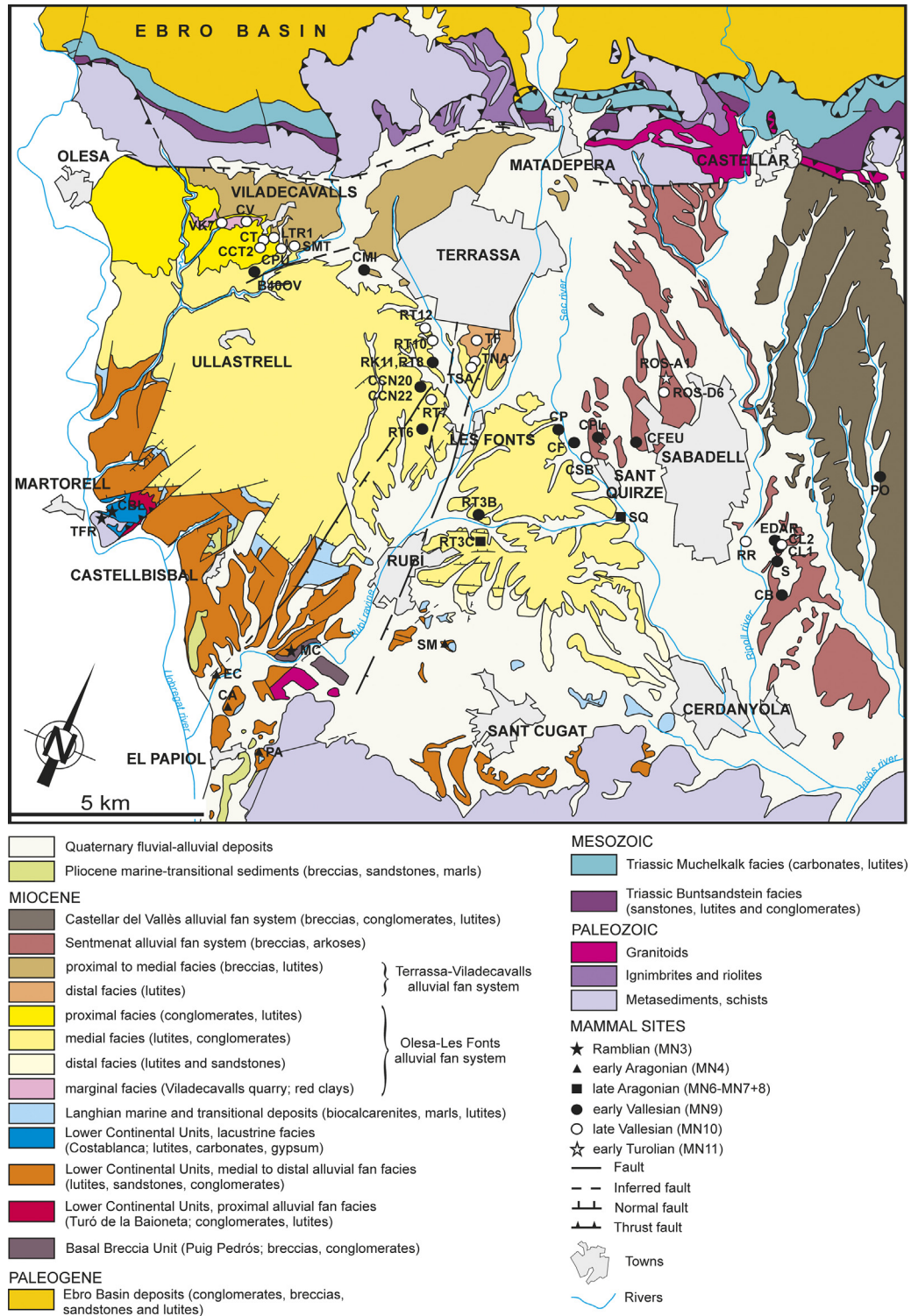


Fig. 2. (Color online.) Detailed geological map of the western Vallès sector (see Fig. 1) showing the position of the main mammal sites (modified after Garcés et al., 1996). For locality acronyms see Table 1.

Fig. 2. (Couleur en ligne.) Carte géologique détaillée du secteur ouest de Vallès (voir Fig. 1) montrant la position des principaux sites à mammifères (modifié d'après Garcés et al., 1996). Pour l'acronyme des localités, se référer au Tableau 1.

was created, making up the northwestern margin of the Mediterranean (Bartrina et al., 1992; Cabrera and Calvet, 1996; Cabrera et al., 2004; Roca and Guimerà, 1992; Roca et al., 1999). The onshore zone of this continental margin includes the Vallès-Penedès and el Camp de Tarragona half-grabens that are bounded by the horsts defined by the Pre-littoral range to the northwest and the Littoral range to the southeast (Garraf-Montnegre horst).

The Vallès-Penedès Basin (Fig. 1) is an elongated half-graben of about 100 km long by 12–14 km wide. Its northwestern margin is bounded by the Vallès-Penedès master fault and its basement dips gently towards this margin where it attains up to 4000 m in depth (Bartrina et al., 1992; Roca et al., 1999). Some major faults with a vertical slip larger than 1000 m, associated with minor faults with up to a few hundred meters of slip, occur at this margin. All these southeastern margin faults were overlapped by early to middle Miocene sedimentary sequences, which were affected by later minor fault reactivations (Cabrera, 1981a, 1981b; Cabrera and Calvet, 1996). The sedimentary infill of the Vallès-Penedès Basin started in the early Miocene (Ramblian–early Burdigalian; Cabrera, 1981a; Cabrera et al., 1991, 2004; de Gibert and Casanovas-Vilar, 2011) and ended in the late Miocene (Turolian–Tortonian). Major features of the stratigraphic record in the Vallès-Penedès half-graben were closely controlled by the tectonic activity of its main bounding faults and the sea level changes in the western Mediterranean (Bartrina et al., 1992; Cabrera, 1981b; Cabrera and Calvet, 1996; Cabrera et al., 2004; Roca et al., 1999).

The Miocene record of the Vallès-Penedès Basin has been split into four main lithostratigraphical units dated by means of biostratigraphy and magnetostratigraphy (Agustí et al., 1985, 1990, 1997; Cabrera, 1981a, 1981b; Cabrera et al., 1991; Cabrera and Calvet, 1996; de Gibert and Casanovas-Vilar, 2011; Garcés et al., 1996). The oldest of these units is the Basal Breccia Unit, which crops out at a few points in the Littoral Range. It consists of time transgressive monogenic conglomerates and breccias. In the Vallès sector this unit dates back to the Ramblian (MN3), whereas in the Penedès sector its oldest record is early Aragonian (MN4) in age (de Gibert and Casanovas-Vilar, 2011).

The overlying Lower Continental Units (Figs. 1 and 3) crop out mainly near the southeastern basin margin and consist of intensely red alluvial fan and alluvial-lacustrine deposits corresponding to the Early Miocene (Ramblian–early Aragonian, MN3–MN4). Their oldest reported sedimentary record corresponds to small alluvial-fan facies sourced by local catchments from the southeastern basin margins. The overlying alluvial fan deposits covered wider areas and were also sourced from the northwestern reliefs. Shallow carbonate and evaporitic lacustrine systems developed in zones in the southeastern part of the basin, such as the La Costablanca, Molí de Can Calopa and Sant Andreu de la Barca areas (Cabrera, 1981a, 1981b; Cabrera et al., 1991). These lacustrine deposits are cyclically alternating with distal facies of alluvial fan systems, the latter bearing most of the mammal and plant sites of this age (Agustí et al., 1985; Casanovas-Vilar et al., 2011a).

During the latest early Miocene and the middle Miocene (17–15 Ma) several sea level changes took place in the context of the Mid-Miocene Climatic Optimum (Zachos et al., 2001). The faults that bounded the southeastern basin margin became inactive and the southern structural culminations were extensively overlapped and overlapped by the sedimentary infill (Cabrera and Calvet, 1996; Cabrera et al., 1991; Roca et al., 1999). At least three episodes of marine transgression and regression affected the Vallès-Penedès late Burdigalian, Langhian and early Serravalian (Cabrera and Calvet, 1996; Cabrera et al., 1991; de Gibert and Casanovas-Vilar, 2011; Roca et al., 1999). The sequences deposited at that time make up the Marine and Transitional Units (Figs. 1 and 3). Since the southwestern basin end and its southern margin in the Penedès were more directly connected and open to the sea, carbonate coralgal platform deposits, marine bay and transitional fan-delta siliciclastic systems occupied persistently that area. During Langhian times, the sea level was high enough and marine environments extended up to the Vallès sector with development of shallow marine and transitional deposits. The early Serravalian marine transgression only affected the southwestern basin sectors.

From Serravalian time onwards, sedimentation was again dominated by alluvial fan sediments, which constitute the Upper Continental Units (Figs. 1 and 2). The Vallès-Penedès main fault remained active until the Tortonian, thus controlling the evolution of middle Aragonian to Middle Turolian alluvial fan systems sourced from the northwest reliefs (Fig. 3; Agustí et al., 1985, 1997; Cabrera and Calvet, 1996; Casanovas-Vilar et al., 2008; de Gibert and Casanovas-Vilar, 2011; Garcés et al., 1996; Roca et al., 1999). Thick, coarse-grained sequences were deposited near the northwestern margin of the basin, whereas finer-grained, medial to distal-terminal sequences developed to the south and southeast. Large alluvial fan systems (e.g., Olesa-les Fonts fan) attained a radius of 10–15 km, while others were restricted to a few km of radial spread. The middle and distal areas of these fan systems interferred and coalesced with each other during their evolution. Most of the mammal sites of the Vallès-Penedès Basin are located in the distal to terminal, mudstone-dominated facies (Fig. 2).

The Messinian event resulted in a major interruption of the sedimentation as the Mediterranean sea level experienced a major lowering (Cabrera and Calvet, 1996). Later on, during the Early Pliocene, alluvial-fluvial (Gallart, 1981) and shallow marine deposits (Martinell, 1988) were deposited over deeply entrenched erosive surfaces affecting both the basement and earlier Miocene sequences. Finally, Pleistocene–Holocene terraced alluvial and colluvial sediments were deposited unconformably overlying Neogene series.

3. Materials and methods

3.1. Collecting techniques

The Vallès-Penedès Miocene mammal record comprises more than 300 sites ranging from the Late Ramblian to the Middle Turolian, that is from about 19.6 Ma (Larrasoaña et al., 2006) to 7.4/6.8 Ma (Agustí et al., 2001; Hilgen

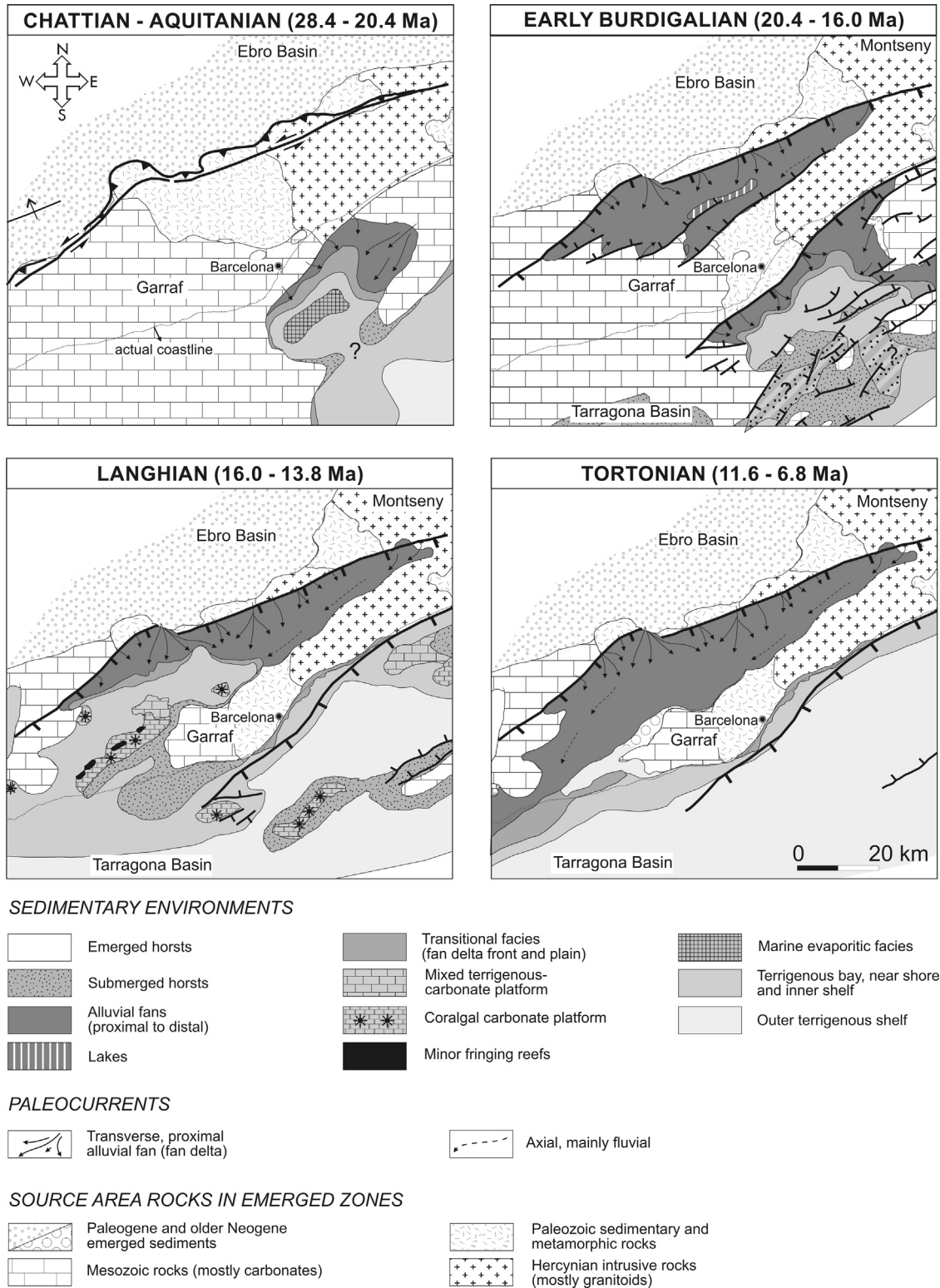


Fig. 3. Paleogeographic schemes showing the evolution of the Vallès-Penedès Basin during the Late Oligocene and the Miocene: a: Chattian–Aquitainian (late Oligocene–earliest Miocene); b: early Burdigalian; c: Langhian; d: Tortonian. Note the extension of shallow marine environments and reef systems during the Langhian (see also Fig. 1). Modified after Cabrera et al. (2004).

Fig. 3. Présentation de l'évolution du bassin de Vallès-Penedès au cours de l'Oligocène supérieur et du Miocène: a: Chatten-Aquitainien (Oligocène supérieur-Miocène basal); b: Burdigalien basal; c: Langhien; d: Tortonien. Noter l'extension des environnements marins peu profonds et des récifs coralliens au cours du Langhien (voir aussi Fig. 1). Modifié d'après Cabrera et al. (2004).

Table 1

Localities mentioned in the text and figures arranged alphabetically following the acronyms used in Figs. 1, 2 and 4. For each site we indicate its correlation to the local zones as well as to the MN units. In the case of long local sections that comprise several sites (ACM, ECM, EDAR) we give the acronym for the series but not individual acronyms for each site. In the case of the ACM series the whole biostratigraphic range covered by the series is given.

Tableau 1

Localités mentionnées dans le texte, ainsi que les figures classées dans l'ordre alphabétique, en référence aux acronymes utilisés pour les Fig. 1, 2 et 4. Pour chaque site, nous avons indiqué sa corrélation à la zone locale ainsi qu'à l'unité MN. Dans le cas de coupes longues, incluant plusieurs sites (ACM, ECM, EDAR), nous donnons l'acronyme de la coupe, mais pas celui de chaque localité. Dans le cas de la coupe ACM, toute la gamme biostratigraphique couverte par la série est donnée.

Acronym	Site/Series	Local zone	Local subzone	MN unit
ACM	Abocador de Can Mata series (includes more than 250 sites)	<i>Hispanomys</i> assemblage	<i>M. crusafonti</i> + <i>D. larteti</i> – <i>D. crusafonti</i> – <i>Hippotherium</i> interval	MN6□MN7 + 8
B400V	Autovia Orbital de Barcelona B40 Tram Olesa de Montserrat-Viladecavalls (includes 6 sites)	<i>Cricetulodon</i> range	<i>C. hartenbergeri</i>	MN9
CA	Can Canals	–	–	MN4
CAL	Ca n'Almirall	<i>Hispanomys</i> assemblage	<i>M. crusafonti</i> + <i>D. larteti</i>	MN6
CB	Castell de Barberà	<i>Hispanomys</i> assemblage	<i>Hippotherium</i> – <i>C. hartenbergeri</i> interval	MN9
CBL	la Costablanca	–	–	MN3
CCN20	Creu Conill 20	<i>Hispanomys</i> assemblage	<i>Hippotherium</i> – <i>C. hartenbergeri</i> interval	MN9
CCN22	Creu Conill 22	<i>Hispanomys</i> assemblage	<i>Hippotherium</i> – <i>C. hartenbergeri</i> interval	MN9
CCT2	Camí de Can Tarumbot 2	<i>Rotundomys</i> abundance	<i>R. montisrotundi</i>	MN10
CF	Can Sant Feliu (also known as Can Feliu)	<i>Hispanomys</i> assemblage	<i>Hippotherium</i> – <i>C. hartenbergeri</i> interval	MN9
CFEU	Can Feu (includes 2 sites)	<i>Cricetulodon</i> range	<i>C. hartenbergeri</i> – <i>P. hispanicus</i> interval	MN9
CJ	Can Julià	–	–	MN4
CL1	Can Llobateres 1	<i>Cricetulodon</i> range	<i>C. hartenbergeri</i> – <i>P. hispanicus</i> interval	MN9
CL2	Can Llobateres 2	<i>Cricetulodon</i> range	<i>C. sabadellensis</i> + <i>P. hispanicus</i>	MN10
CM1	Can Mata 1	<i>Hispanomys</i> assemblage	<i>D. crusafonti</i> – <i>Hippotherium</i> interval	MN9
CM3	Can Mata 3	<i>Hispanomys</i> assemblage	<i>Hippotherium</i> – <i>C. hartenbergeri</i> interval	MN7 + 8
CMI	Can Missert	<i>Hispanomys</i> assemblage	<i>Hippotherium</i> – <i>C. hartenbergeri</i> interval	MN9
CMV	Can Martí Vell (includes 2 sites)	–	–	MN4
CO	les Conilleres	<i>Hispanomys</i> assemblage	<i>M. crusafonti</i> + <i>D. larteti</i>	MN6
CP	Can Poncic 1	<i>Cricetulodon</i> range	<i>C. hartenbergeri</i>	MN9
CPL	Can Pallars de Llobateres (includes 2 sites)	<i>Cricetulodon</i> range	<i>C. hartenbergeri</i> – <i>P. hispanicus</i> interval	MN9
CPU	Can Purull	–	–	MN10
CRU	Can Cruset (includes 2 sites)	<i>Rotundomys</i> abundance	<i>R. bressanus</i>	MN10
CS	els Casots	–	–	MN4
CSB	Can Casablanca	<i>Rotundomys</i> abundance	<i>R. montisrotundi</i>	MN10
CT	Can Turu	<i>Rotundomys</i> abundance	<i>R. bressanus</i>	MN10
CV	Ceràmiques Viladecavalls	<i>Rotundomys</i> abundance	<i>R. montisrotundi</i>	MN10
EC	el Canyet	–	–	MN4
ECM	Ecoparc de Can Mata series (includes 12 sites)	<i>Hispanomys</i> assemblage	<i>Hippotherium</i> – <i>C. hartenbergeri</i> interval	MN9
EDAR	Estació Depuradora d'Aiguës Residuals del Riu Ripoll (includes 15 sites)	<i>Cricetulodon</i> range	<i>C. hartenbergeri</i>	MN9
GO	La Gornal	–	–	MN6?
LTR1	La Tarumba 1	<i>Rotundomys</i> abundance	<i>R. montisrotundi</i>	MN10
LV	Les Cases de la Valenciana	–	–	MN4
PA	Les Escltxes del Papiol	–	–	MN4
PO	Polinyà (includes 4 sites)	–	–	MN9

Table 1 (Continued)

Acronym	Site/Series	Local zone	Local subzone	MN unit
RK11	Autopista de Rubí-Terrassa K11	<i>Hispanomys</i> assemblage	<i>D. crusafonti</i> – <i>Hippotherium</i> interval	MN7 + 8
ROS-A1	Ronda Oest de Sabadell A1	Zone K (Teruel Basin)	–	MN11
ROS-D6	Ronda Oest de Sabadell D6	<i>Rotundomys</i> abundance	<i>R. bressanus</i>	MN10
RR	Riu Ripoll	<i>Rotundomys</i> abundance	<i>R. montisrotundi</i>	MN10
RT10	Autopista de Rubí-Terrassa 10	<i>Rotundomys</i> abundance	<i>R. montisrotundi</i>	MN10
RT12	Autopista de Rubí-Terrassa 12	<i>Cricetulodon</i> range	<i>C. sabadellensis</i> + <i>P. hispanicus</i>	MN10
RT3B	Autopista de Rubí-Terrassa 3B	<i>Cricetulodon</i> range	<i>C. hartenbergeri</i>	MN10
RT3 C	Autopista de Rubí-Terrassa 3 C	<i>Hispanomys</i> assemblage	<i>M. crusafonti</i> + <i>D. larteti</i>	MN6
RT6	Autopista de Rubí-Terrassa 6 (includes 4 sites)	<i>Cricetulodon</i> range	<i>C. hartenbergeri</i>	MN9
RT7	Autopista de Rubí-Terrassa 7 (includes 2 sites)	<i>Cricetulodon</i> range	<i>C. sabadellensis</i> + <i>P. hispanicus</i>	MN10
RT8	Autopista de Rubí-Terrassa 8	<i>Cricetulodon</i> range	<i>C. sabadellensis</i> + <i>P. hispanicus</i>	MN10
SAB	Sant Andreu de la Barca	–	–	MN4
SM	Sant Mamet	–	–	MN4
SMT	Sant Miquel de Toudell	–	–	MN10
SPR	Sant Pere de Ribes (includes the sites: Viñedos and Pedrera C1)	–	–	MN6? MN7 + 8?
SQ	Sant Quirze (includes several classical sites plus 3 microvertebrate sites)	<i>Hispanomys</i> assemblage	<i>D. crusafonti</i> – <i>Hippotherium</i> interval	MN7 + 8
TF	Torrent de Febulines (includes 6 sites)	<i>Rotundomys</i> abundance	<i>R. bressanus</i>	MN10
TFR	Turó de les Forques (also known as Costablanca II)	–	–	MN3
TNA	Trinxera Nord Autopista (includes 2 sites)	<i>Rotundomys</i> abundance	<i>R. bressanus</i>	MN10
TSA	Trinxera Sud Autopista (includes 4 sites)	<i>Rotundomys</i> abundance	<i>R. bressanus</i>	MN10
TT	Torrentet de Traginers (also known as Piera)	Zone L (Teruel Basin)	–	MN12
VI	Vilobí	–	–	MN4
VI20	Vilobí 20	–	–	MN5? MN6?

et al., 2012). However, sampling is uneven and most of the sites correspond to the late Aragonian and early Vallesian. Regarding the localities, approximately two thirds of them have only small mammal remains, but a remarkable number has provided both small and large mammals. A list of the main sites and fossiliferous sections is given in Table 1. Finally, there are a few localities from which mostly large mammal remains have been recovered. Most of the old collections were assembled by the means of surface collecting as a result of quarrying activity at brickyards, where the workers often found mammal fossils during manual digging. The use of systematic collecting techniques increased since the late 1950s and early 1960s. These include planned excavations as well as systematic screen-washing of sediment samples of the major sites. During the early 1980s screen-washing techniques were improved, with the introduction of sieving equipment capable of processing huge sediment samples (Daams and Freudenthal, 1988). Therefore, larger micromammal samples, comprising between fifty to a few hundreds of individuals, could be gathered for many known sites. During the 1990s and the 2000s, most of the mammal sites known to date were discovered as a result of emergency campaigns

coinciding with major construction projects. Macromammal remains were mostly collected after systematic excavation, whereas screen-washing was used for the micromammals. Thus, most of the material has been obtained using standardized collecting methods. The material is kept in the collections of the Institut Català de Paleontologia Miquel Crusafont (ICP) at Sabadell, except for part of the old collections, which are curated in the Geology Museum of the Barcelona Seminary and in the Museum of Natural Sciences of Barcelona.

3.2. Magnetostratigraphy

Magnetostratigraphic sampling in the Vallès-Penedès Basin started during the mid 1990s (Garcés et al., 1996) and focused on the Vallesian successions. More recent studies have complemented these data with those from long sections covering the Late Aragonian and its transition to the Vallesian (Alba et al., 2012a; Moyà-Solà et al., 2009). The sequences studied for magnetostratigraphy include four main sections: Abocador de Can Mata, Les Fonts, Montagut and Viladecavalls, plus a few shorter ones (Fig. 4). These sequences contain abundant mudstone beds, which

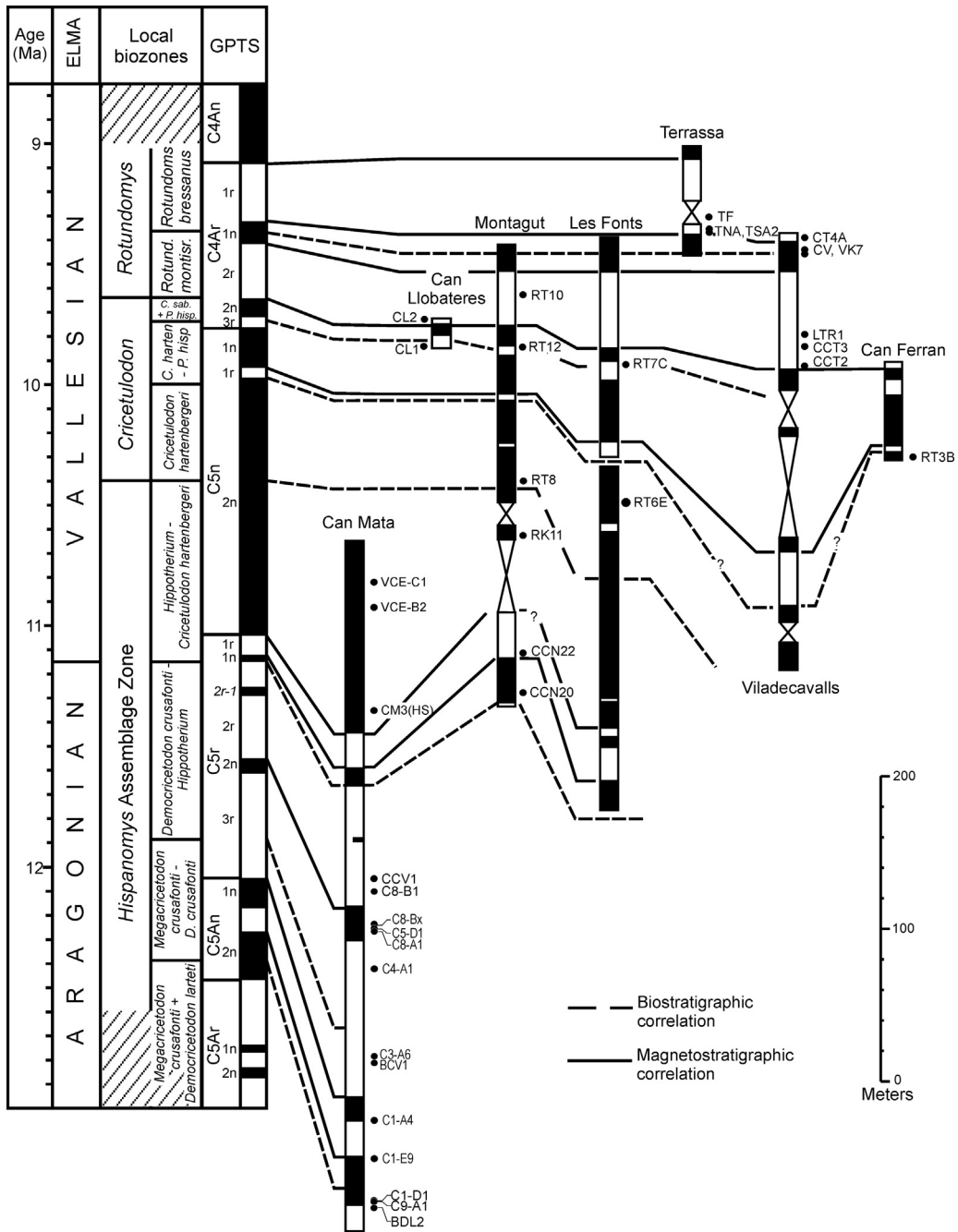


Fig. 4. Correlation of the key local magnetostratigraphical sections of the Vallès-Penedès Basin to the Geomagnetic Polarity Time Scale (GPTS). The European Land Mammal Ages (ELMA) and local biozones of the Vallès-Penedès are also indicated. We have indicated some of the major sites in the Can Mata composite series. Abbreviations in the Can Mata composite series refer to different sectors of the landfill and nearby farm houses as follows: ACM: Abocador de Can Mata [Can Mata landfill]; BCV: Barranc de Can Vila [Can Vila ravine]; BDL: Bassa de Decantació de Lixiviats [setting pond of leachates]; C1–C9: ACM cells 1 to 9; CCV: Camí de Can Vila [Can Vila road]; CM: Can Mata. For other locality acronyms, see Table 1. Neogene time scale and boundaries after Hilgen et al. (2012). GPTS after Ogg (2012).

Fig. 4. Corrélation des coupes clés magnétostratigraphiques locales du bassin de Vallès-Penedès à la Geomagnetic Polarity Time Scale (GPTS). Les European Land Mammal Ages (ELMA), ainsi que les biozones locales de Vallès-Penedès, sont aussi indiqués. Nous avons indiqué quelques-uns des sites majeurs de la série composite de Can Mata. Les abréviations de la série composite de Can Mata font référence aux différents secteurs de la décharge et des fermes environnantes, comme suit : ACM : Abocador de Can Mata [décharge de Can Mata] ; BCV : Barranc de Can Vila [ravine de Can Vila] ; BDL : Bassa de Decantació de Lixiviats [bassin de décantation de lixiviate] ; C1–C9 : ACM cellules 1 à 9 ; CCV : Camí de Can Vila [route de Can Vila] ; CM : Can Mata. Pour les autres acronymes des localités, voir Tableau 1. Échelle temporelle néogène et limites d'après Hilgen et al. (2012). GPTS d'après Ogg (2012).

allowed a tight sampling resolution of 1–2 m/site. Routine stepwise demagnetization of the natural remanence magnetization revealed the presence of a stable magnetization carried by iron oxides such as magnetite and hematite. Since magnetostratigraphy relies on the demonstrably primary character of the rock magnetization, a number of stability tests (Opdyke and Channel, 1996) were performed. In the Vallès-Penedès sequences, the relative uniformity of bedding dip attitudes made the fold test insignificant, but a northerly directed mean direction after tilt correction suggests a pre-folding magnetization. A positive conglomerate test further supported a primary, synsedimentary origin. More significantly, magnetostratigraphic results could be cross-checked with biostratigraphy along multiple composite sections of Montagut, Les Fonts, Terrassa and Viladecavalls (Fig. 4), thus indicating that the retrieved magnetic zonation bears chronostratigraphic significance.

3.3. Calculation of sampling probability and taxonomic richness

Time series diversity analyses require a great accuracy in the dating of individual sites as well as a well-resolved taxonomy (see Badgley et al., *this issue*). Considering the quality of our data, diversity analyses can only be performed for the late Aragonian and early Vallesian, for which most of the sites have associated bio- and magnetostratigraphical data of high quality. Regarding the taxonomic data, the quality of the record is not the same for all mammal groups. Small mammals, and in particular the orders Rodentia and Eulipotyphla, are more abundant and have a more continuous record than large mammals. Furthermore, they have been thoroughly reviewed and genus-level identifications are available (Casanovas-Vilar et al., research in progress). Between the late Aragonian (12.6 Ma) and the end of the Vallesian (9.0 Ma) these orders are represented by more than 20,000 specimens from nearly 200 different sites. Our calculations are carried out at the genus level, excluding all the material that could not be identified to this taxonomic rank.

The calculation of sampling probability and generic richness requires the use of quantitative data. In this regard, we used the maximum number of individuals of each taxon, since this information is routinely written down in our collection inventories. Sampling probability was calculated using the method devised by Barry et al. (2002) (see also Badgley et al. and Flynn et al., *this issue*) as modified by Van der Meulen et al. (2005) and Van Dam et al. (2006). This method considers the probability of finding a given taxon based on its abundance and sample size:

$$p = 1 - (1 - q)^r$$

where q is the relative abundance of the taxon in the interval where it was first (or last) recorded and r is the additional number of specimens sampled. A genus is considered to be absent when the cumulative probability of finding it over preceding or succeeding time intervals is greater than 0.9. Not surprisingly, the inferred range for a given taxon may extend beyond its last observed record

and earlier than its first observed record. This is ultimately related to its abundance, so that rare taxa tend to have long inferred ranges unless sample size is large enough to reject that they were present. We used a range-through assumption, so we consider a genus to be continuously present between its first and last appearances. This assumption is in contrast with Van der Meulen et al. (2005) who interpreted discontinuous ranges as local extinctions followed by subsequent migrations. In our case only a few very rare taxa show discontinuous ranges, so we rather attribute their absence to sampling biases. The studied time span (12.6–9.0 Ma) was divided into 0.1 Myr bins, and observed and inferred genera ranges were used to calculate generic richness for each bin (Fig. 7). Considering that the typical extent of time-averaging for terrestrial vertebrate assemblages in fluvial systems and surface accumulations oscillates between 100 and 100,000 years (Behrensmeyer, 1982; Behrensmeyer et al., 2000), shorter time bins are not recommended. Finally, we have evaluated the effects of sample size in the calculation of these richness measures using the Spearman's rank order correlation test.

4. Chronological framework and locality age estimation

The chronostratigraphic framework of the Vallès-Penedès Basin is based on a combination of magneto- and biostratigraphic data. Unfortunately, magnetostratigraphic studies are still in progress for the older part of the record (Ramblian–middle Aragonian), so for this interval the age of the sites and main bioevents can only be constrained on the basis of biostratigraphy. The same applies to the Turolian sites. In contrast, most of the Late Aragonian and Vallesian sites are placed in the composite magnetostratigraphic framework, which have a total thickness of approximately 700 m (Fig. 4). The overall record results in a long pattern of polarity reversals, which allows a correlation with the GPTS (Ogg, 2012) using the unambiguous identification of chron C5n, a distinctly long normal chron that characterizes the Early Tortonian as a reference point. This chron is recognized both in the Vallès sector (Garcés et al., 1996) and in the Can Mata composite series of els Hostalets de Pierola (Moyà-Solà et al., 2009), in the Penedès sector. The overall magnetostratigraphic sequence represents a time span of approximately 3.6 Myr, from 12.6 to 9.0 Ma (Fig. 4). Shorter sections, such as Terrassa or Can Llobateres, cannot be directly matched to the GPTS, but can be reliably correlated to longer sections on the basis of biostratigraphical and magnetostratigraphical data. An absolute age up to the 0.1 Myr bin could be assigned to most of these sites. Finally, approximately 35% of the sites (mostly older collections) of this period lack associated magnetostratigraphical data. Therefore, their correlation relies entirely on local biostratigraphy, which usually implies an age uncertainty not higher than 0.3 Ma (see below and Fig. 5). However, our analyses require that each site is assigned an absolute age, so a random age between its maximum and minimum possible ages is given to the sites with only biostratigraphical data.

Concerning the sites with associated magnetostratigraphical information, an absolute age can be estimated

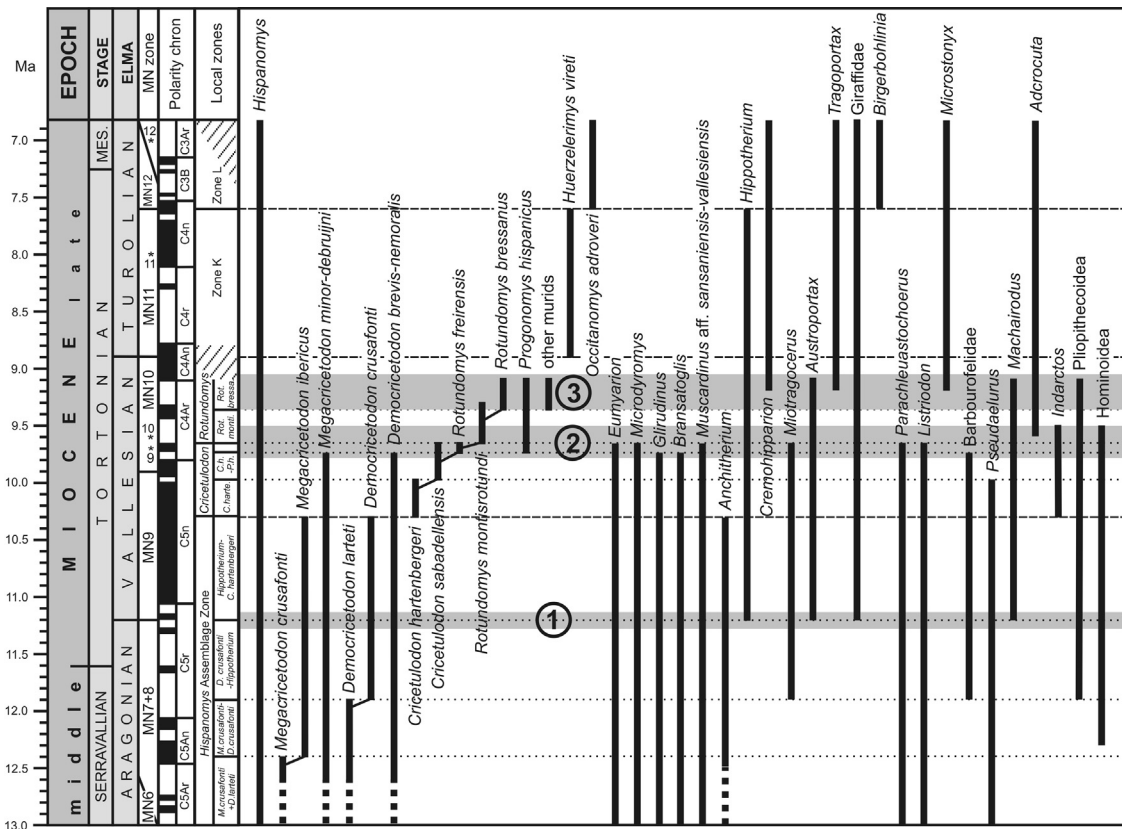


Fig. 5. Local biozonation of the Vallès-Penedès Basin for the late Aragonian to the middle Turolian. The observed ranges of the biostratigraphically important taxa are indicated. The shadowed time intervals highlight the times of major faunal turnover: 1) dispersal of hipparionin horses and some eastern faunal elements (*Machairodus*, Giraffidae) at the Aragonian/Vallesian boundary; 2) Vallesian Crisis, implying the disappearance of many forest elements of middle Miocene origin and coinciding with the first record of murids (*Progonomys hispanicus*) and the cricetines of the genus *Rotundomys*; 3) diversification of the murids and dispersal of the first 'Pikermian' elements such as the bovid *Tragoportax* and the hyaenid *Adcrocuta*. See main text for details. In the case of the MN zones, asterisks indicate the chronological position of their reference sites, whereas their boundaries are defined on the basis of selected appearance events (see Hilgen et al., 2012). Neogene time scale and boundaries after Hilgen et al. (2012). GPTS after Ogg (2012).

Fig. 5. Biozonation locale du bassin de Vallès-Penedès de l'Aragonien supérieur au Turolien moyen. Les domaines stratigraphiques des taxons importants du point de vue biostratigraphique sont indiqués. Les intervalles de temps ombrés soulignent les changements fauniques majeurs: 1) dispersion des chevaux hipparionins et des éléments fauniques orientaux (*Machairodus*, Giraffidae) à la transition Aragonien/Vallesien; 2) crise vallesienne, impliquant la disparition de nombreuses formes forestières trouvant leur origine au Miocène moyen, et synchroniquement, l'apparition des muridés (*Progonomys hispanicus*) et des cricétinés du genre *Rotundomys*; 3) diversification des muridés et dispersion des premiers éléments « pikermiens », comme par exemple le bovidé *Tragoportax* et le hyaenidé *Adcrocuta*. Se reporter au texte pour les détails. Pour ce qui concerne les zones MN, les astérisques indiquent la position chronologique des localités références, tandis que leurs limites sont définies sur la base de la sélection de premières apparitions de taxa sélectionnés. Échelle temporelle néogène et limites d'après Hilgen et al. (2012). GPTS d'après Ogg (2012).

using the methods of Barry et al. (2002). The calculations are based on the stratigraphic position of a given site in the local magnetostratigraphic series. The interpolation must be done between two points of known ages, namely polarity changes in the section that correspond to chron boundaries. Then age is calculated as follows:

$$Age = UAge + \left(\frac{LAge - UAge}{T} \cdot SD \right)$$

where *Age* is the estimated absolute age of the locality; *UAge* and *LAge* are the ages of the upper and lower boundaries of the geomagnetic chron, respectively; *T* is the stratigraphic thickness of that magnetozone in the local section; and *SD* is the stratigraphic distance between the locality and the top of the magnetozone in the same section. When one of the chron boundaries is not recorded

in the section, *Age* is calculated using the composite sections that do record the chron boundaries. This method assumes constant sedimentation rates within each magnetozone, a condition which strictly speaking will not be fulfilled because the sedimentation in alluvial fan systems is episodic and there are short periods of erosion, leading to the existence of many short hiatuses (Sadler, 1981). However, if these hiatuses are randomly distributed within the sections and their duration is not large compared to the duration of an interval, this approach will give reliable results (Badgley et al., 1986; Barry et al., 2002; Johnson et al., 1988). In our study case, the relative stratigraphic thickness of the corresponding geomagnetic intervals is comparable between sections, implying similar sedimentation rates. Furthermore, no major hiatuses are known during the late Aragonian and the Vallesian.

5. The Miocene mammal succession: biostratigraphy, main bioevents and paleoenvironmental reconstruction

Throughout the text, the Vallès-Penedès record is correlated to the European Land Mammal Ages as well as to the MN zonation. We have used the mammal ages that are customarily used for the Iberian record. This implies some differences for the Early and Middle Miocene, since the Aegelian, Orleanian and Astaracian ages are replaced by the Ramblian and the Aragonian ages (see [Steininger, 1999](#)). For the internal subdivision and boundaries of these ages, the reader is referred to [Daams and Freudenthal \(1989\)](#), [Agustí et al. \(2011\)](#) and [Larrasoña et al. \(2006\)](#) for the Ramblian, and to [Daams et al. \(1999\)](#), [Agustí et al. \(2011\)](#), [Van der Meulen et al. \(2011, 2012\)](#) and [García-Paredes et al. \(this issue\)](#) for the Aragonian. As far as MN zones are concerned, we follow the more 'biostratigraphical' concept of the MN zones (see [Hilgen et al., 2012](#); [Van Dam, 2003](#)) and use the boundaries for western Europe. The MN boundaries for central Europe are significantly older, particularly for the early Miocene; the reader is referred to [Van der Meulen et al. \(2011, 2012\)](#) for a comparison. MN zone boundaries are based on different sources: for the Ramblian, zone boundaries follow [Larrasoña et al. \(2006\)](#), [Agustí et al. \(2011\)](#) and [Hilgen et al. \(2012\)](#); for the Aragonian, they are mostly based in [Daams et al. \(1999\)](#), [Agustí et al. \(2011\)](#) and [Van der Meulen et al. \(2011, 2012\)](#); those of the Vallesian follow [Agustí et al. \(2001\)](#) and [Hilgen et al. \(2012\)](#); and finally, for the Turolian we follow [Van Dam et al. \(2001, 2006\)](#) and [Hilgen et al. \(2012\)](#).

5.1. The Ramblian (ca. 20.4–16.8/17 Ma)

The early Miocene successions of the Vallès-Penedès Basin have produced relatively few sites, and many of them, particularly the older ones, are very poor. [Crusafont et al. \(1955\)](#) systematically surveyed this part of the record and found about fifteen mammal-bearing sites, although many of them have since been destroyed ([Casanovas-Vilar et al., 2011b](#)). In recent years, some classical sites (such as Costablanca or Molí Calopa) have been surveyed again in order sample microvertebrates, which had been overlooked by earlier researchers. The correlation of these localities is entirely based on biostratigraphy. Magnetostratigraphical studies are now in progress.

The oldest site in the Vallès-Penedès Basin is Turó de les Forques (TFR, [Figs. 1 and 2](#)), which is located in a small outcrop of the Basal Breccia Unit. This site contains scarce macromammal remains and a richer rodent assemblage that includes the cricetid *Melissiodon*, the eomyid *Ligerimys* cf. *fahlbuschi*, the glirid *Pseudodryomys ibericus*, and scarce remains of the cricetodontine *Democricetodon*. The first common occurrence of *Democricetodon* marks the beginning of the Aragonian, but this genus is already recorded in the latest Ramblian, though it is very rare ([Van der Meulen et al., 2012](#); [García-Paredes et al., this issue](#)). Therefore, this site is correlated with the late Ramblian zone A, which according to the latest data from the Ebro Basin would range between 19.6 and 16.8–17 Ma ([Larrasoña et al., 2006](#)). The Ramblian is chronologically equivalent

to zone MN3 and its upper part corresponds to the so-called "cricetid vacuum" ([Daams and Freudenthal, 1989](#)), that is, the time interval between the last occurrence of the old Oligocene cricetids of the genus *Eucricetodon* and the earliest cricetodontines of the genus *Democricetodon*. During this time *Melissiodon*, a peculiar genus showing a unique "honeycomb" molar morphology, is the only cricetid present in western Europe.

The remaining Ramblian sites of the Vallès-Penedès show a similar rodent fauna dominated by the glirid genera *Pseudodryomys* and *Simplomys*, as well as eomyids of the genus *Ligerimys*. Relatively rich Ramblian macromammal faunas are known from Molí Calopa, Costablanca and Sant Andreu de la Barca (MC, CBL and SAB in [Figs. 1 and 2](#)). These include abundant remains of the minute artiodactyl *Cainotherium miocaenicum*, although the cervid *Procerulus dichotomus* is also common ([Casanovas-Vilar et al., 2011a, 2011b](#)). The equid *Anchitherium* and the felid *Styriofelis* are present at various sites, whereas the first gomphotheres (*Gomphotherium*) are recorded at Sant Andreu de la Barca ([Agustí and Galobart, 1997](#)). [Mein \(1975a\)](#) used the earliest record of proboscideans in Europe to characterize the MN4 zone (16.8/17–16/16.4 Ma), but for Western Europe the first common occurrence of *Democricetodon* is now used as diagnostic criterium for the base of this zone and the beginning of the Aragonian ([Hilgen et al., 2012](#); [Van der Meulen et al., 2011, 2012](#)). In the Vallès-Penedès (Sant Andreu de la Barca) and France (Navère; [Bulot and Ginsburg, 1993](#)) the record of proboscideans precedes that of *Democricetodon*, and is therefore placed in the late MN3, with an age ranging from 19.6 to 16.8/17 Ma. This age is congruent with recent dating of the proboscidean dispersal event in Central Europe at ca. 17.5 Ma ([Pálffy et al., 2007](#)). However, the appearance of this order in other areas of Eurasia is substantially older, with deinotheres present at the Pakistan Siwaliks at around 23 Ma ([Flynn et al., 2013](#)) and an unidentified elephantoid having been reported from the Latest Oligocene of the Bugti Hills ([Antoine et al., 2003, 2013](#)).

Macroplant remains are abundantly reported from the shallow lacustrine levels of the Costablanca series and offer a detailed picture of the local paleoenvironment surrounding the humid areas ([Sanz de Siria Catalán, 1993, 2001](#)). The recovered flora points to a tropical to subtropical climate with rainfall seasonality ([Sanz de Siria Catalán, 1993, 2001](#)). This reconstruction is congruent with the small mammal fauna, which is dominated by glirids with a simple dental pattern that purportedly preferred more arid environments than most of their relatives ([Van der Meulen and De Bruijn, 1982](#)). However, the large mammal fauna, which includes basal pecorans (*Amphitragulus*), cervids (*Procervulus*) and small browsing equids (*Anchitherium*), is more consistent with forested environments ([Casanovas-Vilar et al., 2011a](#)).

5.2. The early Aragonian (16.8/17–16/16.4 Ma)

The early Aragonian is chronologically equivalent to the MN4. The sites are located in facies of small lacustrine systems or in distal facies of alluvial fans ([Figs. 1 and 2](#)). Most of the known localities were first reported by [Crusafont et al. \(1955\)](#). The richest sites belong to the Subirats unit,

in the Penedès sector, which is defined by an alternation of lutites and carbonates that correspond to shallow lakes and the distal facies of alluvial fans (Agustí and Cabrera, 1980; Cabrera, 1981a, 1981b). These include les Cases de la Valenciana, Can Martí Vell, and more importantly els Casots (LV, CMV and CS, Fig. 1). Els Casots was excavated during the 1990s and has produced a rich collection of micro- and macromammals in a remarkable state of preservation (Casanovas-Vilar et al., 2011c). In the Vallès sector, the early Aragonian sites are located in red lutites corresponding to the distal facies of major fan systems. Some sites, such as les Escletxes del Papiol or Sant Mamet (PA and SM, Fig. 2) are just a few meters below the Langhian marine units. The Vallès sites have mostly micromammals.

The beginning of the Aragonian is marked by the first abundant occurrence of the cricetidontines *Democricetodon* and, slightly later, *Megacricetodon* (Daams and Freudenthal, 1988, 1989; Daams et al., 1999; Van der Meulen et al., 2012; García-Paredes et al., this issue). These cricetids originated in Asia (Flynn and Wessels, 2013; Maridet et al., 2011) and soon after their earliest record in Western Europe they became major components of the Aragonian and earliest Vallesian faunas (e.g., Daams et al., 1988). In the Aragonian type area, the Calatayud-Montalbán Basin, the presence of *Megacricetodon* distinguishes local zones B and C, both covering the early Aragonian (Daams and Freudenthal, 1988; Daams et al., 1999; Van der Meulen et al., 2012; García-Paredes et al., this issue). In the Vallès-Penedès, *Democricetodon* (*D. hispanicus*) and *Megacricetodon* (*M. primitivus*) coexist in all the studied localities but in Sant Mamet. However, the absence of *Megacricetodon* may be due to insufficient sampling. Furthermore, the paracricetidontine *Eumyarion* (*E. weinfurteri*) is also present in this site (Agustí, 1981), and its first appearance in other Spanish basins is in zone C (Daams and Freudenthal, 1974; Ruiz-Sánchez et al., 2003; Van der Meulen et al., 2012; García-Paredes et al., this issue). Even though *D. hispanicus* and *M. primitivus* dominate the rodent assemblages in most sites, the eomyid *Ligerimys ellipticus* and the gliroids *Pseudodryomys ibericus* and *Simplomys simplicidens* are common components as well (Agustí, 1981, 1983; Agustí and Llenas, 1993; Casanovas-Vilar et al., 2011c). None of the known sites in the Vallès-Penedès could be correlated to the lowermost Aragonian (zone B), where characteristically *Democricetodon* is the only cricetid genus present. Interestingly, the Calatayud-Montalbán local zones could be extended to the Ramblian and Early Aragonian record of the Vallès-Penedès (Casanovas-Vilar et al., 2011a, 2011b), a situation contrasting with that of the late Aragonian and especially the Vallesian, when the rodent succession shows marked differences between these areas.

Most of our data on the Early Aragonian large mammal faunas of the Vallès-Penedès come from the site of els Casots (Casanovas-Vilar et al., 2011c and references therein). The suid *Eurolestriodon*, the early bovid *Eotragus* and the tragulid *Dorcatherium* appear for the first time (Agustí et al., 1985; Casanovas-Vilar et al., 2011a, 2011c). At this time, deinotheres are first recorded, being scarcely represented at els Casots and les Escletxes del Papiol.

Cainotherium persists, but is rarer than in earlier sites. The suoids (*Eurolestriodon*, *Taucanamo*), paleomerycids (*Ampelomeryx*) and some rhinoceroses (*Plesiaceratherium*) are common among the large mammal faunas. The most abundant carnivores are the amphicyonids (*Amphicyon*) and ursids (*Hemicyon*, *Plithocyon*).

5.3. The middle Aragonian (16/16.4–13.8 Ma)

During the Langhian (15.97–13.65 Ma), great parts of the basin were covered by a shallow sea embayment, so it is not surprising that no mammal sites are correlated to the approximately time-equivalent middle Aragonian, which equals to MN5. However, some portions of the Vallès sector were exposed at that time, so they might potentially yield sites of this age. On the other hand, there are numerous paleobotanical sites around the towns of Martorell and Sant Sadurní d'Anoia. These have produced a rich collection of macroflora, indicating that the environment was slightly more arid than during the Ramblian (Sanz de Siria Catalán, 1993, 2001). In addition, palynological samples have been collected from marine sediments close to the small reef systems of Sant Pau d'Ordal, located just a few kilometers to the south of Sant Sadurní d'Anoia (Bessedik and Cabrera, 1985). The pollen assemblage indicates the presence of *Avicennia* mangroves in the coastline.

5.4. The late Aragonian (13.8–11.2 Ma)

The late Aragonian is one of the best represented time intervals in the Vallès-Penedès Basin. Most of our knowledge of this period derives from the study of the intensively-sampled Can Mata composite series at els Hostalets de Pierola (Penedès sector; Fig. 1). This series (Fig. 4) comprises the sections of the Abocador de Can Mata landfill (ACM), the Ecoparc de Can Mata (ECM), and a few nearby classical sites (Can Mata 1 and 3), which together include more than 200 mammal sites that have produced tens of thousands of specimens (Alba et al., 2011). The Can Mata composite series ranges from about 12.5 Ma to 10.6 Ma, the age of the sites being well constrained thanks to a combination of detailed litho-, bio- and magnetostratigraphical data (Fig. 4; Alba et al., 2011; Casanovas-Vilar et al., 2011d; Moyà-Solà et al., 2009). In addition to the Can Mata series, there are a number of other sites that have been correlated to the Late Aragonian. These include the classical Sant Quirze sites (SQ, Fig. 2), Ca n'Almirall and les Canilleres (CAL and CO, Fig. 1; Agustí et al., 1985). The latter two are placed in the upper transitional facies of the Marine and Transitional Unit and in palustrine facies related to fluvial sequences in the Penedès sector. Agustí et al. (1985) reported the presence of the cricetids *Cricetodon* aff. *jotae*, *Eumyarion medium* and *Megacricetodon crusafonti*, which would indicate a correlation to MN6. However, the fauna has not been studied in detail, so other correlations cannot be ruled out. On the other hand, certain sites that had been traditionally placed in the Late Aragonian, namely Can Missert and Castell de Barberà (CM and CB, Fig. 2), are here correlated to the Early Vallesian because scarce hippariionin remains were identified during a recent review of the collections (Robles et al., 2011; Rotgers and Alba, 2011).

A high-resolution biozonation for the late Aragonian and Vallesian has been devised on the basis of the rodent fauna (Casanovas-Vilar et al., 2011d and research in progress). The late Aragonian rodent assemblages are characterized by the dominance of the cricetids *Hispanomys*, *Democricetodon* and *Megacricetodon*. Usually, *Hispanomys* is the most abundant taxon, being represented by several different species during this time interval. This allows defining a long *Hispanomys* Assemblage Zone that covers the late Aragonian and earliest Vallesian (c. 12.5–10.3 Ma, Fig. 5). The coexistence of different species of *Megacricetodon* and *Democricetodon*, as well as the first record of the equid *Hippotherium*, allow the subdivision of the *Hispanomys* zone into four subzones (Fig. 5): *M. crusafonti*+*D. larteti* Concurrent Range Subzone (?–12.4 Ma); *M. crusafonti*–*D. crusafonti* Interval Subzone (12.4–11.9 Ma); *D. crusafonti*–*Hippotherium* Interval Subzone (11.9–11.2 Ma); *Hippotherium*–*Cricetulodon hartenbergeri* Interval Subzone (11.2–10.3 Ma). The last corresponds to the earliest Vallesian, whereas the previous three correlate to the late Aragonian. Even though the faunal succession is not the same, these subzones can be correlated with the local zones of the Calatayud-Montalbán Basin (Daams et al., 1999). Subzone G2 from Calatayud-Montalbán would be approximately equivalent to the *M. crusafonti*+*D. larteti* subzone, whereas the subzone G3 would be equivalent to the *M. crusafonti*–*D. crusafonti* and the *D. crusafonti*–*Hippotherium* interval subzones in the Vallès-Penedès. Similarly, our zones can be correlated to the MN units, with the three Late Aragonian subzones being equivalent to the MN 7+8 (Hilgen et al., 2012). Nevertheless, if one follows the definition of the MN zones of Agustí et al. (2001) or Mein (1999), the older subzone (*M. crusafonti*+*D. larteti*) would be equivalent to uppermost part of the MN6.

As explained above, the late Aragonian small mammal faunas are dominated by *Hispanomys*, *Democricetodon* and *Megacricetodon*. The paracricetodontine *Eumyarion* may be very common at certain sites, such as ACM/BCV1 (see Fig. 4). The glirids are diverse though not abundant and include mostly purported forest-dwelling genera (*Bransatoglis*, *Muscardinus*, *Glirudinus*, *Myoglis*). The small eomyids *Keramidomys* and *Eomyops* as well as the flying squirrels (*Albanensia*, *Miopetaurista*) are first recorded in the *M. crusafonti*+*D. larteti* subzone, ca. 12.5 Ma. Castorids (*Chalicomys*) are first recorded ca. 11.9 Ma, but are very rare. The hypsodont cricetid *Anomalomys*, appears for the first time at ca. 11.8 Ma. The eulipotyphlan faunas are diverse (e.g., Furió et al., 2011, 2015) and include talpids (*Desmanella*, *Talpa*), dimylids (*Plesiodymylus*), heterosoricids (*Dinosorex*), abundant erinaceids (*Galerix*, *Parasorex*) and crocidossoricine soricids.

The large mammal faunas are also diverse (Alba et al., 2011). The megaherbivores include two different genera of proboscideans (*Gomphotherium*, *Deinotherium*), rare chalicotheres (*Anisodon*) and diverse rhinos (*Alicornops*, *Hoploacatherium*, *Lartetotherium*). The suoids (*Albanohyus*, *Conohyus*, *Listriodon*, *Propotamochoerus*) are also diverse and common, whereas the cervid *Euprox* may be common at some sites. There is a remarkable diversity of carnivorans, including mustelids, hyaenids,

felids (*Pseudaelurus*, *Styriofelis*) and false sabertooths (the barbourfelid *Albanosmilus*). The suid *Listriodon splendens*, the small and short-legged rhino *Alicornops* and specially the moschid *Micromeryx* are the most abundant large mammals in the Can Mata composite series. Hominoids (*Anoiapithecus brevirostris*) are first recorded at around 12.3–12.4 Ma (Alba et al., 2013). This group shows a remarkable diversity around 11.9–12 Ma (*M. crusafonti*–*D. crusafonti* Interval Subzone), being represented by the genera *Dryopithecus*, *Anoiapithecus* and *Pierolapithecus* (Casanovas-Vilar et al., 2011d). Pliopithecoids first occur slightly later, at around 12 Ma (Alba et al., 2012b), but are mostly recorded between 11.8–11.7 Ma (*D. crusafonti*–*Hippotherium* Interval Subzone), being represented by the genus *Pliopithecus*. The cervid *Euprox furcatus*, a common component of the fauna, is first recorded during the *M. crusafonti*+*D. larteti* subzone. Other ruminant groups, such as the bovids and the tragulids, are generally rare. Amongst the bovids, *Miotragocerus* and *Tethytragus* first occur during the *D. crusafonti*–*Hippotherium* Interval Subzone. *Tethytragus*, an abundant genus in the inner Iberian basins, is restricted to this zone, being represented by scarce remains only.

Overall, the late Aragonian faunas of the Vallès-Penedès Basin stand out by their high diversity due to the presence of a number of taxa that are extremely rare or not recorded at all in other Iberian Basins (Agustí, 1989; Casanovas-Vilar and Agustí, 2007; Casanovas-Vilar et al., 2008; DeMiguel et al., 2011). These taxa are traditionally recognized as forest dwellers, shared by the Vallès-Penedès and other European regions such as France and Germany, but absent from inner Spain. Amongst the small mammals these include certain eulipotyphlans (dimylids, talpids), arboreal glirids, pteromyinins, eomyids, and certain cricetids such as *Eumyarion* and *Anomalomys*. The large mammal faunas are congruent with the occurrence of more forested environments, since certain taxa such as hominoids, pliopithecoids or chalicotheres are not recorded from elsewhere in the Iberian Peninsula. Others, such as suoids and rhinocerotids, are more abundant and usually more diverse in the Catalan basins. Unfortunately, there are no time-equivalent paleobotanical data that could provide a more complete picture of the Late Aragonian paleoenvironments in the basin.

5.5. The early Vallesian (11.2–9.73 Ma)

The Vallesian mammal successions have been the subject of multiple reviews, given that the Vallès-Penedès is the type area for this mammal age (Agustí and Moyà-Solà, 1990; Agustí et al., 1985, 1997; Casanovas-Vilar et al., 2011a, 2011d; Moyà-Solà and Agustí, 1987, 1989). Most of the Vallesian sites are placed near the towns of Sabadell and Terrassa, in the Vallès sector of the basin (Fig. 2), and have associated magnetostratigraphical data (Fig. 4; Agustí et al., 1997; Garcés et al., 1996).

Crusafont Pairó (1950) defined the Vallesian on the basis of the coexistence of the first hipparionin horses with faunal elements that were characteristic of the forest faunas of the Middle Miocene, such as certain rhinos, cervids, suoids and chalicotheres. Previously, hipparionins were thought to be characteristic of the so-called Pikermian faunas, after

the Turolian site of Pikermi, near Athens (Greece). The Pikermian faunas are dominated by open country herbivores, such as antelopes, giraffes and horses, whereas forest elements, such as deer, are rare (Bernor et al., 1996; Eronen et al., 2009; Solounias et al., 1999). Such faunas represent a rather uniform mammal community from the standpoint of their ecological characteristics, not necessarily at the taxonomic level of genera and species. The Pikermian fauna expanded its range into Western Europe during the Turolian (Bernor, 1983, 1984; Eronen et al., 2009). However, Crusafont Pairó (1950) showed that some 'Pikermian' taxa such as the earliest hipparionins dispersed earlier. Currently this dispersal is placed within chron C5r.1n in the Vallès-Penedès Basin, with an estimated age of 11.2 Ma (Garcés et al., 1996, 1997; dates recalculated taking into account the latest version of the GPTS after Ogg, 2012). This age is not inconsistent with the record of the Calatayud-Montalbán Basin, where the entry could be placed between 11.2 and 10.8 Ma (Garcés et al., 2003; Van Dam et al., 2014; García-Paredes et al., this issue). It is also congruent with the data from Central Europe (Bernor et al., 1988; Woodburne, 2009; Daxner-Höck et al., this issue), but it is somewhat older than age estimates for this event in other areas (Sinap Formation, Siwaliks), which range from 10.8 to 10.3 Ma (Barry and Flynn, 1989; Barry et al., 1982, 1985, 2002; Flynn et al., 2013; Kappelman et al., 2003). The oldest occurrence of hipparionins (*Hippotherium*) is recorded at the lowermost part of the Montagut composite section (Fig. 4). However, the Aragonian/Vallesian transition is documented in the Can Mata composite series, the sites belonging to the ECM section and the classical locality of Can Mata 3 (CM3) being correlated to the Vallesian (Fig. 4). CM3 has numerous hipparionin remains, which would be slightly younger than the ones of the Montagut section. On the other hand, these equids are not recorded in any of the ECM sites. The earliest Vallesian rodent faunas cannot be distinguished from those of the Latest Aragonian and are placed within the *Hispanomys* Assemblage Zone (Fig. 5). Only the presence of the equid *Hippotherium* confirms their Vallesian age. The *Hippotherium*-*Cricetulodon hartenbergeri* Interval Subzone defines the Earliest Vallesian. In some rodent faunas, the cricetodontine *Megacricetodon ibericus* may be extremely abundant, such as Creu Conill 22 or Can Feliu (CCN22, CF, Fig. 2).

The rest of the Vallesian subzones are defined on the basis of the evolution of the cricetine genera *Cricetulodon* and *Rotundomys*. The species present are members of a well-known anagenetic lineage (*C. hartenbergeri*-*C. sabadellensis*-*R. montisrotundi*-*R. bresanus*), characterized by its increasing hypsodonty coupled with a simplification of the molar pattern into a continuous sigmoidal crest (Freudenthal, 1967; Freudenthal et al., 1998; Mein, 1975b). The *Cricetulodon* Range Zone (Fig. 5) covers most of the early Vallesian (MN9) and the beginning of the late Vallesian (MN10). This zone is divided into three subzones depending on the *Cricetulodon* species present: *C. hartenbergeri* Range Subzone (10.3–10 Ma); *C. hartenbergeri*-*Progonomys hispanicus* Interval Subzone (10–9.7 Ma); and the short-lasting *C. sabadellensis*+*P. hispanicus* Concurrent Range Subzone (9.7–9.6 Ma). *Cricetulodon* is the most common element in these subzones

and it may define up to 70% of the recovered remains. The genera *Democricetodon* and *Megacricetodon* are rare and only represented by the small-sized species. The castorids (*Chalicomys*, *Euroxenomys*) and the paracricetodontine *Eumyarion* are common at certain sites such as Can Llobateres 1 (CL1, Fig. 2). The micromammal faunas of this subzone are diverse in forest elements, particularly glirids. Eulipotyphlans reach their highest diversity, with at least three genera of erinaceids, two genera of dimylids and talpids, and four of soricids (Van den Hoek Ostende and Furió, 2005). The hitherto persisting heterosoricid *Dinosorex* is still a common element, but suddenly disappears from the micromammal assemblage at the very beginning of the Vallesian (Furió et al., 2015). The first occurrence of murids in Western Europe defines the boundary between Early and Late Vallesian, or between MN9 and MN10 (Agustí et al., 1997, 2001; Hilgen et al., 2012). *Progonomys hispanicus* is the earliest murid in the Vallès-Penedès, being recorded at several sites in the uppermost part of chron C4Ar.3r (Figs. 4 and 5), with an estimated age of 9.7 Ma. This rodent family evolved in the Middle Miocene in Pakistan (Jacobs, 1977), while the genus *Progonomys* first appeared in that area around 12 Ma (Barry and Flynn, 1989; Barry et al., 1982, 2002; Flynn et al., 1995, 2013; Wessels, 2009). Updated stratigraphic correlations attained in the Calatayud-Montalbán Basin (Van Dam et al., 2014; García-Paredes et al., this issue) show a very rare presence of *Progonomys* during the Early Vallesian, at 10.4 Ma, and a common occurrence of this form after 10.0–9.9 Ma. In Turkey, its first record is slightly older, at 10.1 Ma (Kappelman et al., 2003). In our study area, the dispersal of *Progonomys* coincides with the first appearance of *Rotundomys* (*R. freirensis*), although *C. sabadellensis* is still the dominant rodent in most assemblages. At the same time, a number of taxa are no longer recorded, including the cricetids *Democricetodon*, *Megacricetodon*, *Eumyarion* and the glirids *Microdyromys*, *Glirudinus*, *Bransatoglis* and *Muscardinus vallesiensis*. Castorids and pteromyines become rarer. This set of local extinctions is part of the Vallesian Crisis (see below).

Regarding the large mammals, the early Vallesian faunas retain large numbers of Late Aragonian components, so that the immigration of *Hippotherium* did not coincide with any noticeable extinction event (Agustí et al., 1997). Giraffids, the felid *Machairodus* and the bovid *Austroportax* immigrated at the same time (Casanovas-Vilar et al., 2011a; Fig. 5). The long-ranging felid *Pseudaelurus* is last recorded within the *C. hartenbergeri* subzone. The hominoid *Hispanopithecus* is recorded at several sites from the *Cricetulodon* zone (Casanovas-Vilar et al., 2011d). Overall, the Early Vallesian faunas are extremely diverse, including a high diversity of medium to large-sized herbivores and carnivorous species (Agustí et al., 1997, 2001; Casanovas-Vilar et al., 2011a). Bovids became more diverse and abundant. This assemblage is very similar to that of contemporaneous sites from Central Europe (Casanovas-Vilar et al., 2008, 2010), such as Rudabánya in Hungary (Bernor et al., 2005), which on the other hand has also produced great ape remains. Finally, the Early/Late Vallesian transition witnessed the extinction of several large mammal taxa of Middle Miocene origin in the context of the

Vallesian Crisis (see below). These include the barbourofelid and amphycionid carnivorans, the suids *Listriodon* and *Parachleuastochoerus*, and the bovid *Miotragocerus*.

5.6. The Late Vallesian (9.7–8.9 Ma)

Even though the murids are continuously present in the Vallès-Penedès Basin, they remain usually rare components of the mammal faunas. This contrasts with the late Vallesian assemblages of other Iberian basins, such as the Teruel Basin, where murids are dominant and define the basis for local biostratigraphy (Van Dam, 1997; Van Dam et al., 2001). By contrast, the genus *Rotundomys* is the most abundant component of the faunas in the Vallès-Penedès, defining the *Rotundomys* Abundance Zone that covers most of the late Vallesian (Fig. 5). This is divided into two subzones according to the member of the anagenetic lineage present: *R. montisrotundi* Lineage Subzone (9.6–9.4 Ma) and the *R. bressanus* Lineage Subzone (9.4–8.9 Ma). As the upper boundary for this zone we take the Vallesian/Turolian age boundary in the Teruel Basin (Krijgsman et al., 1996; Van Dam et al., 2001), since it is not recorded in any of the magnetostratigraphical sections of the Vallès-Penedès. The rodent faunas are less diverse than during the early Vallesian, although a number of forest elements are present in low numbers (Agustí et al., 1997, 1999; Casanovas-Vilar et al., 2011a, 2014). In the *R. montisrotundi* subzone, *Progonomys hispanicus* is the only murid species present, whereas in the *R. bressanus* subzone the murid assemblage is enriched with the appearance of *P. cathalai* and *P. woelferi* as well as the genera *Parapodemus* and *Huerzelerimys*. *Rotundomys montisrotundi* coexists for some time with its putative descendant, *R. bressanus*. The large mammal faunas record a number of new eastern immigrants, particularly during the *R. bressanus* subzone (Agustí et al., 1997; Casanovas-Vilar et al., 2011a, 2011d). These include the suids *Schizoporcus* and *Microstonyx*, the equid *Cremohipparion* and the bovid *Tragoportax*, which will later become major components of the Turolian faunas. Amongst the carnivorans, the hyaenid *Adcrocuta* is first recorded within the *R. montisrotundi* subzone, whereas the ursid *Indarctos* is last recorded at the same time. Finally, hominoid primates (*Hispanopithecus*) are last recorded within this subzone, at the site of La Tarumba 1 (LTR1, Fig. 2), which has an estimated age of about 9.6 Ma (Casanovas-Vilar et al., 2011d). Pliopithecoids survived into the *R. bressanus* subzone, being last recorded at 9.1 Ma at Torrent de Febulines (TF, Fig. 2; Moyà-Solà et al., 2001).

The Vallesian biozonation of the Vallès-Penedès can be recognized in other Catalan basins, such as La Seu d'Urgell or the Empordà basins (Casanovas-Vilar et al., 2011b). However, it is different from that in other areas of Spain, such as the Calatayud-Montalbán Basin (Daams and Freudenthal, 1988; Daams et al., 1999) or the Teruel basins (Van Dam et al., 2001; Van de Weerd, 1976). While the order and timing of the main bioevents, such as the first record of *Cricetulodon* and *Progonomys*, are roughly the same, the major components of the faunas that are the basis for the local biozonations differ. For example, *Rotundomys* is not recorded in Teruel, and in the Vallès-Penedès the murids are too rare to be considered for the definition of

local biozones. Casanovas-Vilar and Agustí (2007) emphasized these differences and related them to the occurrence of more humid and forested environments in the Vallès-Penedès, particularly during the Late Vallesian. Such an interpretation is supported by the distribution of other mammal taxa such as certain glirids, the flying squirrels, chalicotheres and hominoid primates, to name just a few examples.

Regarding the Vallesian paleoenvironment, the diverse mammal fauna, rich in forest elements, has been interpreted as indicative of subtropical to warm-temperate humid forest environments (Agustí and Moyà-Solà, 1990; Agustí et al., 1984, 1999; Casanovas-Vilar and Agustí, 2007; Morales et al., 1999). Unfortunately, the paleobotanical information of this period is very scarce, and has to be complemented with data from other Catalan basins (Empordà, Cerdanya). These show that the zonal vegetation consisted of a warm-temperate mixed forest defined by evergreen laurels, together with leguminous trees and shrubs as well as a significant proportion of deciduous elements (Sanz de Siria Catalán, 1993, 1994). The subtropical taxa would have been mostly restricted to the humid areas in the lowlands (Marmi et al., 2012). The rich Late Vallesian macroflora from Trinxera Sud Autopista 2 near Terrassa (TSA2, Fig. 2) indicates the presence of a warm-temperate mixed forest with up to 40% of deciduous taxa (Agustí et al., 2003).

5.7. The Turolian (8.9–5.3 Ma)

Only two Turolian sites are well known from the Vallès-Penedès: Ronda Oest de Sabadell A1 in Sabadell and Torrentet de Traginers in Piera (ROS-A1 and TT, Figs. 1 and 2). However, some fossiliferous areas, particularly around Viladecavalls and Piera, might potentially yield new Turolian sites. Furthermore, the Vallesian/Turolian transition could be recorded at the Ronda Oest de Sabadell succession (Fig. 2), although these faunas and their stratigraphical context have not been studied in detail yet. ROS-A1 has a relatively rich small mammal sample dominated by the murid *Huerzelerimys vireti*, which would indicate an early Turolian (MN11 or zone K) age (Agustí et al., 2001; Van Dam et al., 2001, 2006). The large mammals are insufficiently known, but the faunas are significantly impoverished with bovids and *Hippotherium* dominating the assemblage. In contrast, Torrentet de Traginers (also known in the literature as Piera) has produced a rich large mammal fauna that includes more than 2700 specimens. Its diversity is remarkably low, far below that of the Vallesian assemblages. The fauna is overwhelmingly dominated by the bovid *Tragoportax gaudryi*, with the equid *Cremohipparion mediterraneum* and the giraffid *Birgerbohlinia schaubi* as major components (Fig. 6). The remaining taxa include the suid *Microstonyx* and the hyaenid *Adcrocuta*, amongst others. Forest elements are extremely rare, but chalicotheres (*Anisodon*) and rhinoceroses (*Aceratherium*, *Dihoplus*) are still present. Intensive screen-washing has not been carried out at this site, so the small mammal sample size is very limited, consisting of just twenty molars belonging to the murid *Occitanomys adroveri*, which indicates a Middle Turolian (MN12 or zone L) age (Agustí et al., 2001; Van Dam et al., 2001, 2006). This contrasts

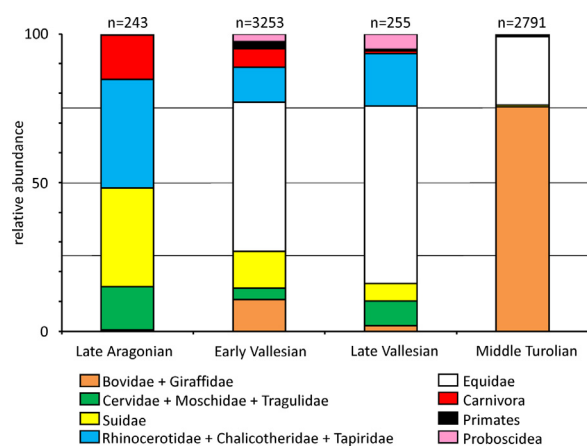


Fig. 6. (Color online.) Composition of the large mammal faunas from the Late Aragonian to the middle Turolian. *n* stands for the maximum number of individuals identified to the genus level. The late Aragonian faunas are represented by the Sant Quirze sites; the early Vallesian includes Creu Conill 20, Can Missert, Castell de Barberà, Can Poncic, Santiga and Can Llobateres 1; the late Vallesian includes Trinxera Sud Autopista, Trinxera Nord Autopista and Torrent de Febulines; finally, the Middle Turolian is solely represented by Torrentet de Trageners. Note the evenness of the late Aragonian faunas, the abundance of equids during the Vallesian, and the dominance of bovids during the middle Turolian. See text for further details.

Fig. 6. (Couleur en ligne.) Composition des faunes de grands mammifères de l'Aragonien tardif au Turolien moyen. *n* correspond au nombre maximum d'individus identifiés au niveau générique. Les faunes aragoniennes tardives sont documentées par les sites de Sant Quirze; le Vallésien précoce comprend Creu Conill 20, Can Missert, Castell de Barberà, Can Poncic, Santiga et Can Llobateres 1; le Vallésien tardif comprend Trinxera Sud Autopista, Trinxera Nord Autopista et Torrent de Febulines; enfin, le Turolien moyen est seulement représenté par Torrentet de Trageners. À noter l'égalité des faunes de l'Aragonien tardif, l'abondance des équidés durant le Vallésien, et la dominance des bovidés durant le Turolien moyen. Se reporter au texte pour un complément d'information.

with previous correlations, which mostly on the basis of the large mammal fauna had correlated this site to MN11 (Agustí et al., 1985, 1997; Casanovas-Vilar et al., 2011a). The composition and structure of the mammal fauna are very similar to those of contemporaneous sites of the Teruel Basin (Alcalá, 1994; Alcalá et al., 2000), pointing to a similar arid and warm environment in both regions. This is in sharp contrast with the situation seen during the Vallesian, when the environment was clearly more humid and forested in the Vallès-Penedès Basin. Furthermore, although biostratigraphical data are preliminary, the Teruel rodent-based local zonation can apparently be extended to the Vallès-Penedès Basin.

6. Late Miocene diversity dynamics and a re-evaluation of the Vallesian Crisis

Agustí and Moyà-Solà (1990) were the first to recognize the Vallesian Crisis, an important turnover coinciding with the Early/Late Vallesian boundary (around 9.7 Ma), which implied the abrupt extinction of most of the forest-adapted elements that had characterized the middle Miocene. These authors had previously recognized that some rodent and artiodactyl taxa seemed to be missing during the Late Vallesian (Agustí, 1981; Agustí et al., 1984, 1985; Moyà-Solà and

Agustí, 1987, 1989), but later found that other mammals, including certain carnivorans and the primates had disappeared at the same time. The event was initially recognized in the Vallès-Penedès Basin, although they suggested that it had also occurred in other European regions (Agustí and Moyà-Solà, 1990). Later studies supported this conclusion, leading many authors to consider the Vallesian Crisis as a European or even Eurasian event (Agustí et al., 1997, 1999; Fortelius and Hokkanen, 2001; Fortelius et al., 1996). However, the potential causes of the Vallesian Crisis are elusive, since the main climatic (Zachos et al., 2001) and vegetational changes (Mossbrugger et al., 2005) had already started during the middle Miocene, almost six million years earlier. Therefore, the crisis has been related to a complex interplay of climatic factors which would have increased the temperature latitudinal gradient along Europe and, in particular, rainfall seasonality in the peri-Mediterranean area (Agustí et al., 1997, 1999, 2003). In the Vallès-Penedès, the crisis would have been triggered by an increase in temperature seasonality that implied a significant increase of deciduous trees in the zonal vegetation (Agustí et al., 2003). However, deciduous elements were already major components of the floral assemblages in Central Europe (Mossbrugger et al., 2005) and other areas of Catalonia and the Iberian Peninsula (Barrón et al., 2010). More recently, Agustí et al. (2013) admitted the lack of correlation of the Vallesian Crisis with any major climatic perturbations and proposed a rather *ad hoc* new model calling for internal causes. The Vallesian faunas were highly diverse because of the entry of new immigrants and the persistence of most middle Miocene taxa. According to these authors, this resulted in a sort of self-organized climax assemblage that was highly sensitive to environmental changes, so that just small perturbations could make the whole system collapse like a 'House of Cards'.

However, it has been recently shown that previous evaluations of the Vallesian Crisis in the Vallès-Penedès had not taken into account the effects of uneven sampling on diversity estimates (Casanovas-Vilar et al., 2014). Here we present an updated summary of those analyses that incorporates the latest data from the late Aragonian sites of the Can Mata composite series as well as some Vallesian sites that had not been included in previous work (Fig. 7). Only rodents and eulipotyphlans are taken into account. However, rodents in particular are considered to be highly affected by the Vallesian Crisis (Agustí and Moyà-Solà, 1990; Agustí et al., 1997, 1999). For the sake of comparison, we have included sample size in Fig. 7. The quality of the record is clearly better during the late Aragonian and the early Vallesian, with sample size decreasing markedly during the late Vallesian. It is important to note that there is a sampling peak just before the early/late Vallesian boundary, thus immediately preceding the crisis. Genus richness tracks sample size and both variables are significantly correlated, even if a range-through approach is used as in Agustí et al. (2013) ($r_s = 0.418$; P [no correlation] = 0.012). Therefore, the decrease in richness during the Late Vallesian is explained by the poorer quality of the record. Furthermore, the sampling peak in the time interval before the Early/Late Vallesian boundary also helps to distort the pattern. As data simulations have shown

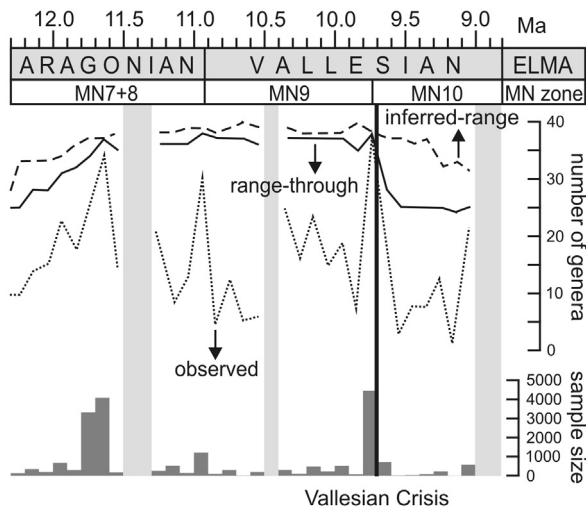


Fig. 7. Small mammal (Rodentia and Eulipotyphla) observed generic richness, sample size (maximum number of individuals) and richness measures for the Late Aragonian and the Vallesian. All the parameters are calculated for 0.1 Myr bins and a range-through approach is used for all richness measures. The light gray areas indicate gaps in the record. Note that 'observed richness' fluctuates importantly with sample size and is strongly correlated with it ($r_s = 0.864$; P [no correlation] = 2.21×10^{-11}). 'Range-through richness' is based on raw specimen counts but uses a range-through approach. Nevertheless, it is also highly correlated with sample size ($r_s = 0.418$; P [no correlation] = 0.012). Therefore, note that the decrease in richness after the Vallesian Crisis is explained by the smaller sample size as compared to the early Vallesian. 'Inferred-range richness' estimates consider the probability of recording a given taxon given sampling effort and are uncorrelated with sample size ($r_s = 0.191$; P [no correlation] = 0.270). Inferred richness shows a gradual decrease during the Late Vallesian instead of an abrupt crisis. See text for further details.

Fig. 7. Richezse g n rique observ e, ainsi que la taille des  chantillons (nombre maximum d'individus) et les mesures d'abondance des petits mammif res Aragonien sup rieur et Vall sien. Tous les param tres sont calcul s pour des intervalles de 0,1 Ma et une approche *range-through* est utilis e pour toutes les mesures d'abondance. Les zones gris clair indiquent des manques dans l'enregistrement.   noter que l'« abondance observ e » fluctue fortement en fonction de la taille de l' chantillon et est aussi fortement corr l e avec elle ($r_s = 0,864$; p [no correlation] = $2,21 \times 10^{-11}$). L'« abondance *range-through* » est bas e sur un comptage des sp cimens, mais utilise une approche *range-through*. Cependant, elle est aussi hautement corr l e   la taille de l' chantillon ($r_s = 0,418$; p [pas de corr lation] = $0,012$). Par cons quent, il est   noter que la baisse de la r chezse g n rique observ e apr s la crise vall sienne est expliqu e par la taille plus r duite des  chantillons, compar e aux donn es fournies pour le Vall sien inf rieur. Les adeptes de l'« Abondance inf r e au domaine stratigraphique » consid rent la probabilit  de r pertorier un taxon donn  selon un effort d' chantillonnage donn  et supposent qu'il n'y a pas corr lation avec la taille de l' chantillon ($r_s = 0,191$; p [pas de corr lation] = $0,270$). L'abondance inf r e montre une baisse graduelle au cours du Vall sien terminal plut t qu'une crise abrupte. Voir le texte pour plus de d tails.

(Foote, 2000), quality peaks will artificially inflate diversity and overestimate extinction rates because many taxa that would have last occurred in a preceding time interval are then last recorded in the interval with the better record. When we use inferred-range diversity estimates, which are uncorrelated with sample size ($r_s = 0.191$; P [no correlation] = 0.270), the Vallesian Crisis changes from an abrupt extinction event to a gradual decrease in genus richness during the late Vallesian (Fig. 7).

The 'victims' of the 'Vallesian Crisis' have two things in common: they are mostly purported forest-dwellers of middle Miocene origin; and, perhaps more importantly, they are generally rare. Amongst the rodents, they mostly include the glirids, which, although diverse in many sites, rarely account for more than 10% of the recovered specimens. The same can be said of certain sciurids, such as the pteromyines, beavers, and the paracricetodontine *Eumyarion*, which are only common at certain sites. Therefore, sample size during the Late Vallesian would not be sufficient to record these rare taxa. This is further supported by our data from a few richer late Vallesian sites, such as Torrent de Febulines. Some of the 'Vallesian Crisis' 'victims' still have been recovered at this site, including a diverse dormice fauna (*Bransatoglis*, *Myoglis*, *Glirudinus*, *Paraglrirulus*), flying squirrels (*Miopetaurista*), beavers (*Chalicomys*) and the eomyid *Eomyops*. Not surprisingly, pliopithecoids, represented by the endemic genus *Egarapithecus*, are also present at Torrent de Febulines (Moy -Sol  et al., 2001). However, some local disappearances seem to have occurred during the Early/Late Vallesian transition, including those of the cricetids *Eumyarion*, *Democricetodon* and *Megacricetodon*, the small castorid *Euroxenomys* and the heterosoricid *Dinosorex*.

The large mammal record of the Vall s-Pened s is not as continuous as that of small mammals and, furthermore, a taxonomic review of certain groups should be carried out before a similar diversity analysis is attempted. However, we can already see that the faunal composition of the Vallesian and, especially, the Turolian large mammal assemblages differs markedly from that of the late Aragonian (Fig. 6). In general, the late Aragonian assemblages consist of an even mixture of rhinocerotids, suoids, cervids and moschids. During the Vallesian, the bovids increase their abundance and hipparionin horses become dominant components of the faunas. Finally, the Turolian assemblages (solely represented by Torrent de Traginers) are the least diverse and are overwhelmingly dominated by the bovid *Tragoportax*, followed by the equid *Cremohipparion* and the giraffid *Birgerbohlinia* as major components. The remaining taxa, which include some forest elements, are very rare. The dominance of savanna-like herbivores is characteristic of the Turolian faunas, but the earlier change in evenness seen in the Vallesian assemblages may indicate that some of the changes that would later shape the Turolian had already started in the Vallesian.

As we have seen, the uneven quality of the record overemphasizes the severity and abruptness of the 'Vallesian Crisis' in the Vall s-Pened s Basin. Some extinctions did occur, but apparently they were merely part of a more protracted turnover event extending into the Turolian. Therefore, it is not surprising that the crisis did not coincide with any remarkable climatic event at 9.7 Ma. The analysis of the geographical range of the 'Vallesian Crisis' is beyond the scope of this paper. However, we must note that, although some disappearances occur, one discrete event is not recognized in other Iberian basins, such as the Teruel Basin, although rodent extinction rates are higher between 10–9.5 Ma in this area (Van Dam et al., 2006). In Central Europe, some forest-adapted taxa (such as chalicotheres, moschids and certain rodents) survived

well into the Early Turolian, being recorded in some Austrian (Kohfidisch, Eichkogel; see [Daxner-Höck et al., this issue](#)) and German sites (Dorn-Dürkheim 1; [Franzen et al., 2013](#)). Finally, the small mammal record of the eastern Mediterranean (Greece, Turkey) does not record significant extinctions ([De Bruijn et al., 1996](#)) and indeed large mammal diversity increased continuously during the Vallesian, peaking at the Early Turolian ([Fortelius et al., 1996](#)).

7. Summary and conclusions

After more than seventy years of systematic survey, the mammal record of the Vallès-Penedès Basin stands out as one of the best Miocene records in Europe, comprising hundreds of sites and tens of thousands of specimens. It includes both large and small mammals and ranges from the early Miocene (Ramblian) to the late Miocene (middle Turolian). However, the quality of the record is uneven and the Late Aragonian and Vallesian successions have been more intensely sampled during the last years. Moreover, a magnetostratigraphical study of the major mammal-bearing successions has been carried out and hence accurate age estimates are available for many of these sites. During most of the Miocene, the Vallès-Penedès represented a transitional area between the Iberian and Central European mammal faunas, so that many of the forest-adapted taxa present in the latter also occur in this basin. By contrast, the faunas of other Spanish basins are indicative of more arid environments that apparently prevented the dispersal of some taxa, such as hominoids, chalicotheres or certain rodents and insectivores, into inner Spain.

As a case study, we have analyzed small mammal diversity dynamics during the late Aragonian and the Vallesian (from 12.6 to 9.0 Ma), which represents our best-sampled interval. Previous studies had recognized a major extinction event, the Vallesian Crisis, characterized by the abrupt disappearance of most forest-adapted taxa at the early/late Vallesian boundary (9.7 Ma). We show that previous diversity analyses were greatly influenced by sampling, so that the decrease in diversity during the late Vallesian is correlated with a decrease in the quality of the record. Clearly, sample size is too poor to record the rare taxa, which mostly turn out to be purported forest dwellers. Nevertheless, diversity slowly decreased during the Late Vallesian as a part of a more gradual extinction event, likely extending into the Turolian. Such analyses cannot be applied to the large mammal faunas yet, although the known Turolian assemblages show a lower diversity than the Vallesian ones, being clearly dominated by a few taxa. Our future goal consists of expanding the temporal and taxonomic range of these analyses, in order to better understand faunal dynamics in this region.

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