A paleoichnological itinerary through the Cenozoic of the Pre-pyrenees and the Ebro Valley (Aragón, Northeast Spain)

R. Rabal-Garcés[1,2], D. Castanera[3], A. Luzón[4], J.L. Barco[1,5], J.I. Canudo[1,6]

[1]Aragosaurus–IUCA, Área de Paleontología, Departamento de Ciencias de la Tierra, Universidad de Zaragoza, Pedro Cerbuna 12, 50009, Zaragoza, Spain

[2]Geopirene S.C., C/Sancho Ramírez 3, 22700, Jaca (Huesca), Spain, raquelrabal@hotmail.com

[3]Bayerische Staatssammlung für Paläontologie und Geologie and GeoBioCenter, Ludwig-Maximilians-Universität, Richard-Wagner-Str. 10, 80333 Munich, Germany

[4]Departamento de Ciencias de la Tierra, Universidad de Zaragoza, Pedro Cerbuna 12, 50009, Zaragoza, Spain

[5] Paleoymás S.L., Retama, 17, nave C-24, 50720, Cartuja Baja (Zaragoza), Spain

[6]Museo de Ciencias Naturales de la Universidad de Zaragoza. Plaza Basilio Paraíso, 50008 Zaragoza, Spain

ABSTRACT

This work aims to display the value of the great wealth of mammal and avian tracksites of the Cenozoic from the Pre-pyrenees and the Ebro Valley of Aragón (Spain), by designing a paleoichnological itinerary, which includes the main tracksites. Currently scientific research in these fields is being carried out, with very interesting preliminary results as a consequence of the poor ichnofossil record in the Paleogene worldwide. But in addition to the scientific importance, we want to emphasize the value of this paleontological heritage as a tourist and didactic resource as well the geoconservation work carried out in the tracksites. In some of these sites (Fondota, Sierra de Luna and La Playa Fósil), conservation and adaptation actions have been implemented over the last decades. These actions have allowed people to access and visit these tracksites, and thus, strengthening them as socio-economic resource of this region.

KEY WORDS

Palaeontological heritage, vertebrate tracksites, Cenozoic, Pyrenees, Ebro Basin.

ACKNOWLEDGMENTS

The scientific study of the tracksites has benefited from two grants from the “Instituto de Estudios Altoaragoneses” and the “Centro de Estudios del Somontano de Barbastro”, (2015 call). This paper forms part of the project CGL2014-53548-P and is partially subsidized by the Spanish Ministry of Economy and Competitiveness, the European Regional Development Fund and the Government of Aragón (‘Grupos Consolidados’). DC is supported by the Alexander von Humboldt Foundation (Humboldt Research Fellowship for Postdoctoral Researchers).The authors also acknowledge the field support of Sergio Rasal, Jesús Revuelto, Roi Silva, and Jorge Esteve.

INTRODUCTION

Paleontological sites, in general, and the tetrapod tracksites, in particular, are included in the Natural and Cultural Heritage in many of the Spanish autonomous communities through different protection regulations (Country level (Spain): "Ley 16/1985, de 25 de junio, del Patrimonio Histórico Español"; Autonomous community level (Aragon): "Ley 3/1999, de 10 de marzo, del Patrimonio Cultural Aragonés"). In Spain there has been an increased interest in the geological heritage in recent years (Carcavilla et al. 2009). Increasingly, Palaeontology, and Paleoichnology by extension are strengthening as an important tourist resource which can lead to certain socioeconomic benefits for some inland areas of Spain, far away from the traditional "sun and beach" tourism. There are many examples of this: Dinópolis and the "Ruta de las huellas de dinosaurios" in Teruel (Alcalá et al. 2006), the dinosaur tracksites from La Rioja (Pérez-Lorente 2015), the "Ruta de las icnitas de las Tierras Altas de Soria" (Barco et al. 2013; Castanera et al. this volumen) or the "Museo Jurásico de Asturias" (MUJA) and their tracksites (García-Ramos et al. 2003). All of these receive thousands of visitors each year, and they have brought about a great economic benefit in these areas of Spain. Paleoichnological sites enclose a significant tourist and didactic value as they are true natural museums, allowing people to contemplate the natural resource, in this case the trace fossils, in their own geographical and geological context. Therefore, some of the more outstanding trascksites of several autonomous communities have been prepared for tourist visits following the criteria of conservation, protection and accessibility to facilitate their visit. These actions include the installation of information panels that aid the interpretation of this paleontological heritage. This has been carried out especially on dinosaur tracksites in the provinces of La Rioja (Pérez-Lorente 2000; Díaz-Martínez et al. 2010; García-Ortíz et al. 2014; Fuertes-Gutierrez et al. 2016), Asturias (García-Ramos et al. 2006; García-Ramos and Piñuela Suárez 2006), Teruel (Cobos 2004; Mampel et al. 2009; Alcalá et al. 2016), Burgos (Torcida Fernández-Baldor et al. 2015) and Barcelona (Bates et al. 2008; Vila et al. 2008;). Some Spanish authors (Mampel et al. 2009; Alcalá et al. 2016) have developed a specific numeric methodology to estimate the heritage value of the tetrapod tracksites based on certain factors: scientific value, socio-cultural value and the risk of deterioration. The socio-cultural value is calculated according to a series of indicators that include, among others, tourist and educational potential, accessibility and available infrastructure. Through this methodology it is possible to assess the possibility of creating measures to further the conservation and awareness of certain sites.

In the rest of Europe there is also an increasing interest in the geoconservation of the dinosaur tracksites of the Jurassic and Cretaceous periods (e.g: Marty et al. 2004; Santos et al. 2008; Díaz-Martínez et al. 2010b; Wings et al. 2012). However, the Cenozoic period lacks the paleoichnological richness of the Mesozoic (Lockley y Meyer 2000). During the Cenozoic the great diversification and expansion of mammals occured worldwide (Novacek 1997), with thousands of fossil localities that yielded body fossils. In contrast, the record of their footprints is scarce (McDonald et al. 2007; Costeaur 2009). But in Spain, there is a significant number of Cenozoic mammal and bird tracksites, mainly in the northeast region of the country (Astibia et al. 2007; Antón et al. 2004; Casanovas-Cladellas and Santafé-Llopis 1982; Prats and López 1995). It is also important remember the site of the Hoya de la Sima in Jumilla, Murcia (in the south east of Spain), because it is prepared for visits (Pérez-Lorente et al. 1999; Vilas et al. 2006).

One of the areas with the greatest wealth of mammal and bird ichnites of the Paleogene and Neogene of Spain is located in Aragón, specifically in the Pre-pyrenees and the North of the Ebro Valley. The most important tracksites are situated in the municipalities of Peralta de Calasanz, Abiego, Bailo, Santa Cruz de la Serós y Loarre, in the province of Huesca, and Sierra de Luna, in the province of Zaragoza (Canudo 2007; Rabal-Garcés and Díaz-Martínez 2010; Castanera et al. 2016a; Castanera et al. 2016b). The region of the Pre-pyrenees - Ebro Valley has the necessary resources to design a paleoicnological itinerary that encompasses the main Cenozoic tracksites, emphasizing its value as a touristic and didactic resource. In recent years, geoconservation work has been done in some of these sites and, as a result, they are conserved for public display. The aim of this work is to make a proposal, for the first time, of an itinerary which allows people to visit the Cenozoic tracksites of Huesca prepared for public visits.

GEOLOGICAL SETTING

The geological framework of the set of sites discussed in this work is the Cenozoic units deposited during the Pyrenean orogeny. The Pyrenean Range presents a WNW-ESE orientation and is divided into several structural units, including two foreland basins, which from north to south are: Aquitaine Basin, North Pyrenean Zone, Axial Zone, South Pyrenean Zone and Ebro Basin. Within the South Pyrenean Zone is located the Jaca Basin, a sinorogenic basin whose sedimentary record has a Paleocene-Early Oligocene age, and consists of marine,

transitional and continental materials (Puigdefábregas 1975; Teixell and García-Sansegundo 1995; Montes Santiago 2009). The site of Bailo is located in the Jaca Basin, in a transitional facies of the Late Eocene. The sites of La Playa Fósil, Fondota and Casa de la Tejera are located on the northern edge of the central area of the Ebro Basin, close to the External Sierras to the west and the Marginal Sierras to the east. The site of Sierra de Luna remains more in the center of the basin (Fig. 1b). The Ebro Basin is the youngest southern foreland basin of the Pyrenees. From the Late Eocene to the Middle–Late Miocene (Salazar 2003) it was isolated from marine influence, and alluvial fan systems developed from the mountainous elevations of the basin's margins, that transformed into well-developed carbonate or saline lacustrine environments in the basin centre (Cuenca et al. 1992; Arenas and Pardo 1999; Muñoz et al. 2002; Pardo et al. 2004; Luzón 2005).

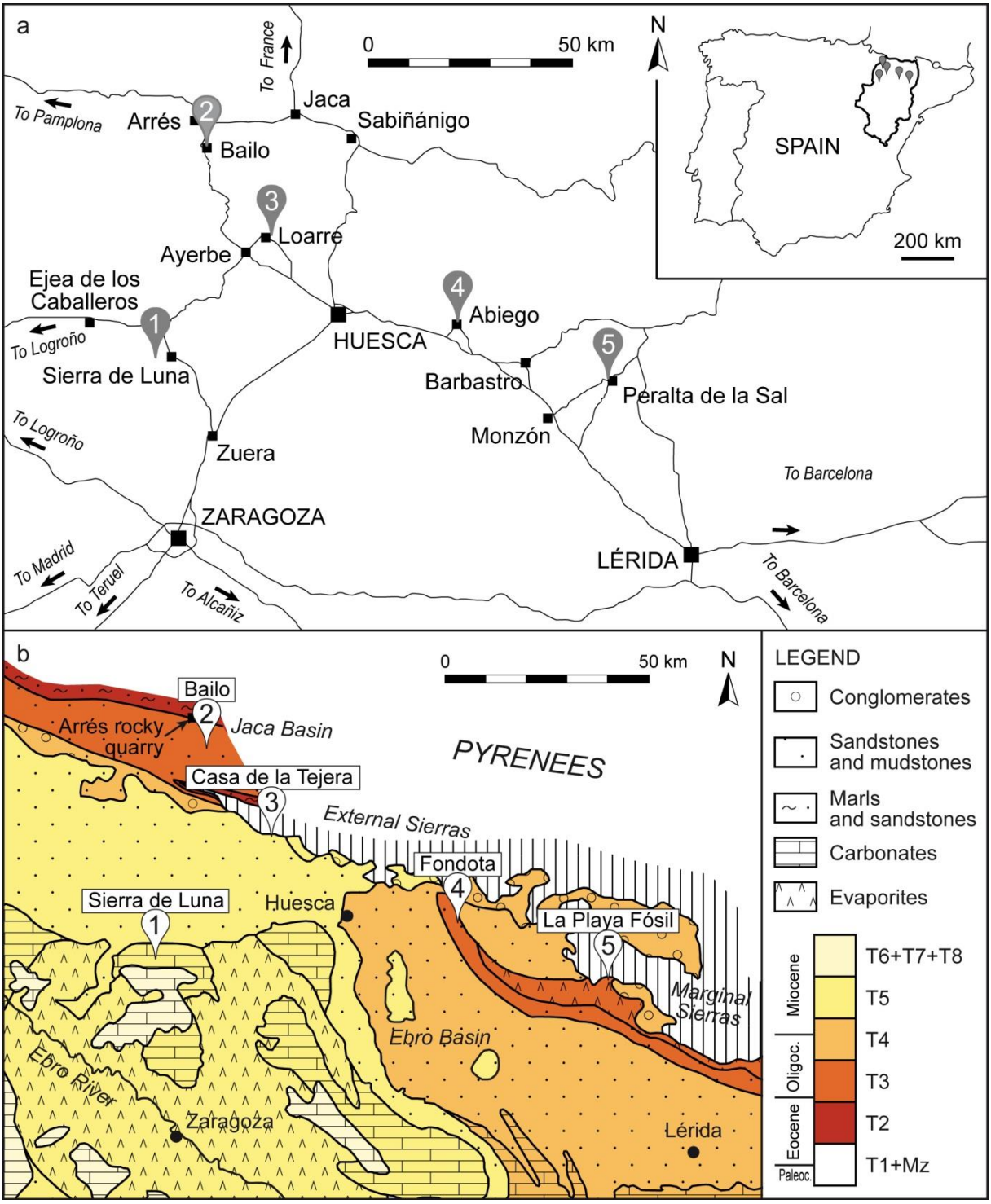

Fig. 1 a Geographic situation of the paleoichnological points (tracksites) that constitute the paleoichnological itinerary of the Pre-Pyrenees-Ebro Valley. 1: Sierra de Luna, 2: Bailo, 3: Casa de la Tejera, 4: Fondota, 5: La Playa Fósil; **b** Geological framework of the paleoichnological itinerary (tracksites), T: Tectosedimentary units of the Cenozoic of the Ebro Basin, Mz: Mesozoic (Modified from Alonso-Zarza et al 2002).

PALEOICHNOLGICAL ITINERARY

The proposed paleoichnological itinerary connects the main Cenozoic trascksites of the Pre-Pyrenees-Ebro Valley region (Aragón) along about 250 km (Fig. 1a). The itinerary includes four paleoichnological points. Three of them are prepared for visits, with sign-posted access, implemented conservation and protection measures and information panels: La Playa Fósil (Peralta de Calasanz, Huesca), Fondota (Abiego, Huesca) and Sierra de Luna (Sierra de Luna, Zaragoza). The fourth paleoichnological point, Bailo (Bailo, Huesca), has none of them yet, but has a significant importance and should be included in the itinerary. Furthermore, we want to include an additional site, Casa de la Tejera (Loarre, Huesca), that has not been designated as a paleoichnological point due to its minor importance from both scientific and didactic point of views but it is very close to the itinerary route and it is located close to the romanic castle of Loarre which is one of most visited monuments of Huesca. The tracksites are complementary in their fossil content and geology, so that visitors to all the sites can purchase and enjoy a wide knowledge of the paleogeography and sedimentology of this part of the Iberian Peninsula during a part of the Cenozoic time and to know part of the interesting continental vertebrate fossil history.

Paleoichnological point: La Playa Fósil

Location and measures adapted for visiting

The tracksite of La Playa Fósil (UTM coordinates 31T X283023 Y4652716) is located in the municipality of Peralta de Calasanz (Huesca), very close to the village of Peralta de la Sal. To access the site we need to go 400 m NW of the village across the road A-2215 and then take a path to the right for 200 m until reaching the rocky outcrop (Fig. 2a).

The site is completely surrounded by a protection fence to prevent spoilage and has an information panel about the footprints and the geology of the outcrop (Fig. 2). This work was carried out in the late 90s thanks to an

initiative of the socio-cultural association of the village, called Castell de la Mora, and the municipal council of Peralta de Calasanz and funded by the Comarca de la Litera.

Fig. 2 a General view of La Playa Fósil tracksite; **b** the tracksite completely surrounded by a protection fence, and it is equipped with an information panel.

Description and highlights

It is an exceptional tracksite because it has preserved many bird footprints with excellent preservation, some of them forming long trackways (Fig. 3d, e). This tracksite has been known since 1929 and constitutes the first citation of Cenozoic vertebrate footprints of Spain (Hernández-Pacheco 1929). The author identified two different types of bird footprints (Fig. 3b, c). The tracksite is located at the top of a level of sandstone with a vertical arrangement that presents various sedimentary structures like ripples or crescents (Fig 3a). Geologically these layers are part of the south flank of the Peralta anticline and they belong to the Peralta Formation (Early Oligocene) (Fig. 1b), which has been interpreted as deposited in a short alluvial fan with high gradient passing laterally to the marginal part of a dominantly saline lake where there were precipitations of evaporites and carbonates in lesser amounts (Senz and Zamorano 1992). The tracksite is located in levels that represent distal areas of the alluvial fan. Currently studies point to a similar trackmaker of the two types of footprints (Castanera et al. 2016b). The differences between the two types of traces would be due to the distinct consistency of the sediment on which birds walked, and the different degree of water saturation of the sediment. All the footprints are tridactyl, characterized by a foot with three digits pointing forward. For the depositional environment and the type of traces, the bird that produced them would be closely linked to watery environments, like rivers and lakes,

as today are the groups of shorebirds. In addition, the tracksite shows an interesting sample of traces of invertebrates (Fig. 3f), which together with the bird footprints and the sedimentary structures makes it an exceptional site to explain the connection to geology today. A visitor can easily interpret that present sedimentary structures (ripples) are similar to those formed in current beaches, where sometimes different shorebirds peck the sand searching for invertebrates to feed on. Nevertheless, in La Playa Fósil tracksite the rock material was deposited in a completely continental environment, like the shore of a lake with detrital inputs or a lateral backwater area of the mainstream.

Fig. 3 a La Playa Fósil tracksite in a stratum of sandstone with a vertical arrangement, with various sedimentary structures (ripples, crescents); **b**, **c** the two different types of bird footprints; **d** birdfootprints forming a long trackway; **e** bird footprints in a lot of orientations; **f** invertebrate trace

Paleoichnological point: Fondota

Location and measures adapted for visiting

Fondota tracksite (UTM coordinates 30T X742534 Y4667764) is located close o the village of Abiego. To access it, you should take the road A-1227, starting from Abiego in north direction. Almost without leaving the village you should take a turn to the right (east) marked by a sign of "Fossil footprints" and go over 400 m to the outcrop. The tracksite has very recognizable footprints, so traditionally it was known as the place where "the goats climbed".

Due to the spectacular nature of the outcrop, in 2004 the Comarca del Somontano de Barbastro financed a conservation project and prepared for visits to the Fondota tracksite. The works allowed installing a protective wall in the upper part of the tracksite to avoid both falling debris from higher areas as water runoff, one of the most important deterioration agents of the ichnites (Fig. 4a). Moreover, the Government of Aragón funded the mapping of all the fossil traces and a preliminary scientific study of them. This allowed for gathering information to make various information panels about the tracksite, the footprints and the trackmakers (Fig. 4e). In order to enable visitors to identify the footprints, some of them were marked with natural paints (Fig. 4c). The scientific study was done by the University of Zaragoza and the preparation for visits by the Paleoymás company. After the initial preparation of the tracksite, it was included in a program of maintenance, cleaning and conservation of outdoor paleontological sites, developed until 2012 and funded by the Government of Aragon. The work carried out under this program included cleaning and repainting the footprints, removing vegetation and consolidating the ichnological surface, which minimizes the deterioration of the tracksite and keeps it in good condition for visits. Thanks to all this effort for preparing and preserving the tracksite, recently Fondota has been included in the catalog of Geosites (Lugares de Interés Geológico-LIG) through the "Decreto 274/2015, de 29 de septiembre, del Gobierno de Aragón", this tracksite being the only one considered LIG of all those mentioned in the present article.

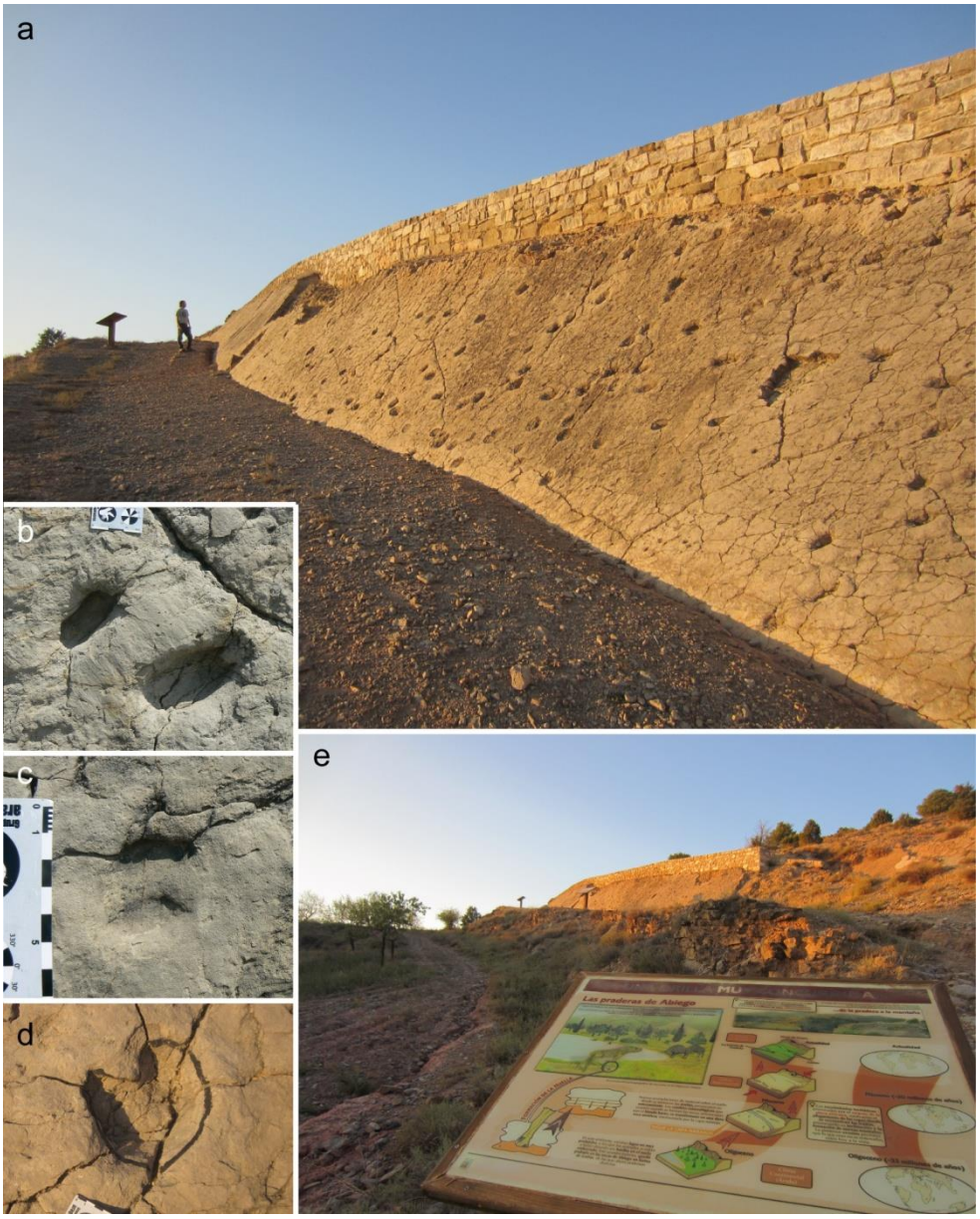

Fig. 4 a Fondota tracksite, equipped with a protective wall in the upper part of the outcrop to avoid both falling debris from higher areas as water runoff; **b, c, d** three types of artiodactyls footprints; **e** general view of the tracksite with the information panels

Description and highlights

The tracksite is located in an inclined stratum of limestones dipping southwest that outcrops along more than 100 m and contains lots of footprints of quadrupedal animals forming multiple trackways (Fig. 4a). Currently studies (Castanera et al. 2016b) have confirmed the existence of three types of ichnites (Canudo et al. 2007),

characterized by didactyl tracks and produced by artiodactyl mammals (a group that includes animals such as camels, pigs, hippos, cows, deer, giraffes, goats, etc.) of different sizes (Fig 4b, c, d). The outcrop is included in the south flank of the Barbastro anticline, situated stratigraphically in the lower part of the Peraltilla Formation (Crusafont et al. 1966), specifically in a carbonated unit called Calizas de Peraltilla. The age of this carbonated unit is traditionally considered as Late Eocene-Early Oligocene, based on the charophytes content (Reille 1967, 1971), although more recent studies suggest an Early Oligocene age based on the micromammals content (Álvarez Sierra et al. 1990) (Fig. 1b). The rock materials of the tracksite were deposited in a shallow carbonate lacustrine system located in the distal parts of alluvial fans coming from the north (Pyrenees), (Luzón 2005) and the layer of the tracksite correspond with the marginal area of this lake (Fig. 5).

Fig. 5 Paleogeographical reconstruction of Fondota tracksite during the Early Oligocene; this illustration can be see in one of the information panels (illustration of Paleoymás)

Paleoichnological point: Sierra de Luna

Location and measures adapted for visiting

Sierra de Luna tracksite (coordinates UTM 30T X669718 Y4656354) is located in the municipality of Sierra de Luna (Huesca). To access it, you should take a path starting from the village with the same name to the east and go over 3.5 km following the indications of the signs for the tracksite. There are two outcrops (strata) with ichnites separated by a few meters (Fig. 6a). Despite having no scientific studies, the Directorate General of Cultural Heritage of the Government of Aragón appreciated the need for preservation of the tracksite and its preparation for visits. Thus, in 2004 the Government of Aragon funded the cleaning and mapping of the tracksite

that provided a basis for the following conservation and dissemination work (Fig. 6, 7a). In 2007, the Comarca de las Cinco Villas and the municipal council of Sierra de Luna funded the installation of a perimeter fencing which surrounds and protects the tracksite and the placing of two information panels (Fig. 7c). In 2010-2011 the ichnological surface was consolidated and the restoration of the tracksite was done, with resin and mortar to seal small and medium cracks (Fig 6b, c). Moreover, following previous geotechnical study, a wall and canals to drain runoff, a retaining wall of the tracksite were built, and accesing to the tracksite was improved (Fig. 6e, f, g, h, i), all financed by the Government Aragon and through SODEMASA (Sociedad para el Desarrollo Medioambiental de Aragón S.A.U.). All these works were carried out by the Paleoymás company. Just like Fondota tracksite, after initial preparation, Sierra de Luna tracksite was also included in a program of maintenance, cleaning and conservation of outdoor paleontological sites, developed until 2012 and funded by the Government of Aragon; including: cleaning and repainting the footprints, removing vegetation and consolidating the ichnological surface, with the objective of minimizing the deterioration of the tracksite.

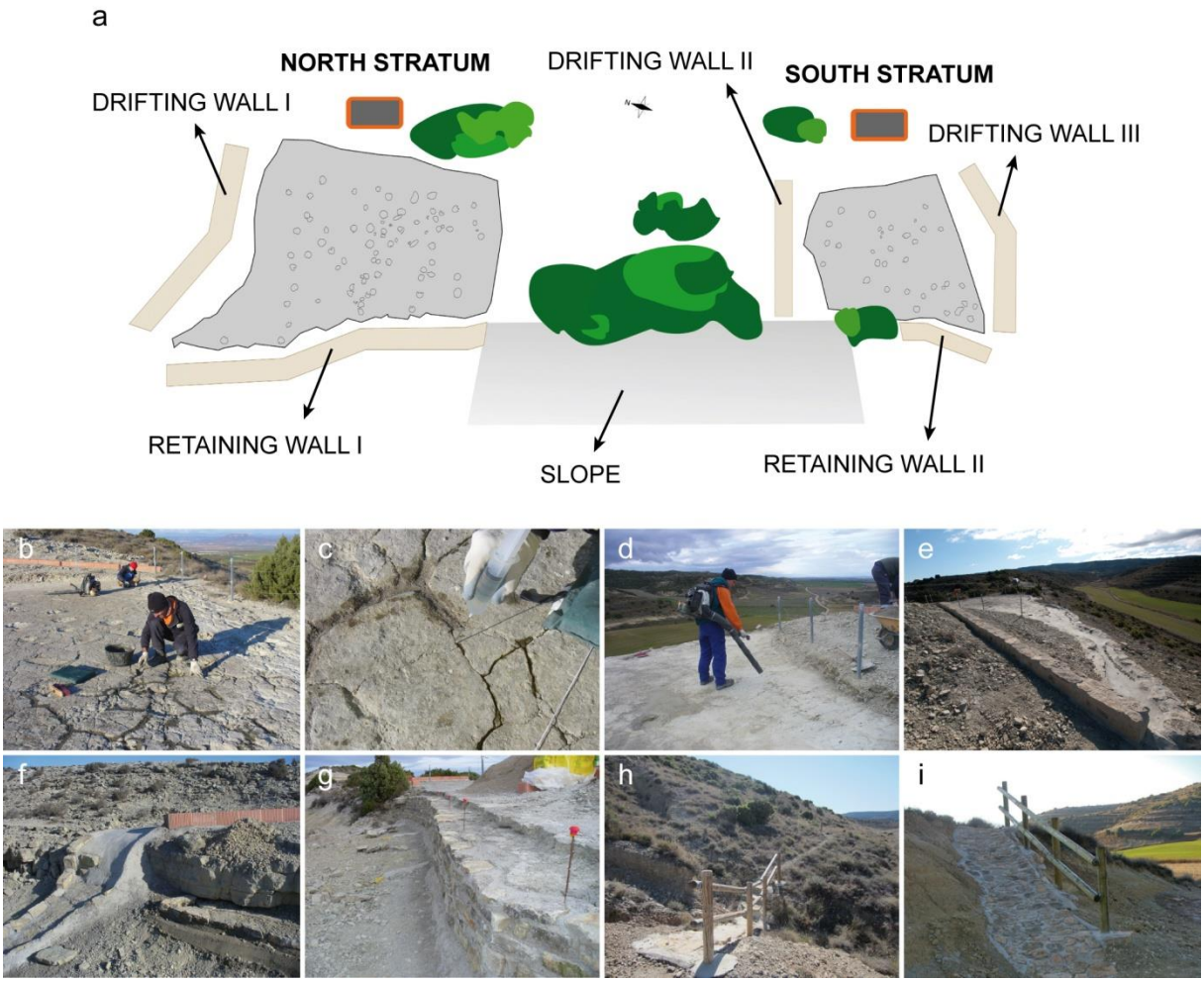

Fig. 6 a Works scheme carried out in Sierra de Luna tracksite funded by the Government of Aragón and executed by Paleoymás; **b, c** consolidation of the tracksite, using resin and mortar to seal small and medium cracks; **d** blowing debris after cleaning; **e, f** wall and canals to drain runoff; **g** retaining wall of the tracksite; **h, i** improving access to the tracksite (all pictures belong to Paleoymás)

Description and highlights

The tracksite is located in a horizontal limestone layer of Early Miocene age (Fig. 1b), belonging to the Alcubierre Formation (Quirantes 1978), and deposited in the marginal parts of a lacustrine system laterally situated to the great river system of Luna, coming from the north (Arenas y Pardo, 1999). In the surface of the stratum remains a great amount of ichnites arranged in various trackways (Fig. 7d), that have been differentiated in two morphotypes. The trackmakers can be large quadrupedal mammals, possibly of the group of perissodactyls although other groups, such as artiodactyls or proboscideans, cannot be ruled out. Sierra de Luna is the tracksite where visitors can see the largest footprints (Fig. 7b) of the whole itinerary with long trackways. Also, it is located in a horizontal level it helps understand the movement of producers along the edge of a lake so close to the shore line (Fig. 8).

Fig. 7 a General view of Sierra de Luna tracksite; **b** a single large footprint; **c** the tracksite with one of the information panels; **d** one of the longest trackways of the tracksite

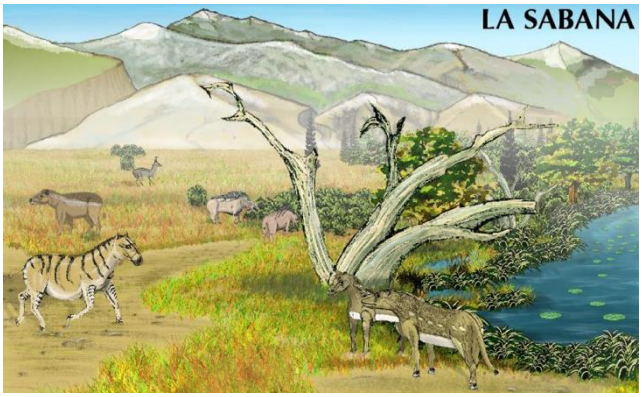

Fig. 8 Paleogeographical reconstruction of Sierra de Luna tracksite during the Early Miocene; this illustration can be see in one of the information panels (illustration of Paleoymás)

Paleoichnological point: Bailo

Location and measures adapted for visiting

In the town of Bailo (Huesca) (coordinates UTM 30T X679863 Y4708689) there are a high number of well-preserved footprints in the slabs of the stone pavement in the streets and especially in the main square of the village (Fig. 9a). Despite being known for years by many villagers, it was not until 2012 when a forester, a Bailo resident, made the General Directorate of Cultural Heritage of the Government of Aragon aware of this finding. This locality has an easy access (footprints are in the middle of the town) and a great fossil wealth. For this reason, although it does not have any signposting to facilitate the visit of the footprints yet, it is probable that in future years, several actions can be carried out to promote the conservation and the awareness of this important paleontological discovery.

Fig. 9 a Aerial photo of the locality of Bailo, pointing the location of the footprints in the slabs of the stone pavement of the village; **b** carnivore (felid-like) type track; **c** big artiodactyl type track and perissodactyl type track; **d** perissodactyl type track; **e** small artiodactyl type

Description and highlights

The stones of the pavement where footprints are found are taken out of geological context. In spite of this, thanks to a precise geological study and the information given by ancient stonemasons it has been possible to locate the

location of the slabs. The footprints of Bailo come from a rock quarry located in Arrés (a village close to Bailo), where several similar footprints have been found *in situ* in one of the layers (Fig. 10). These levels are part of a broad syncline fold with E-W direction and belong to a siliciclastic unit known as Arenisca de Yeste-Arrés of Late Eocene age (Fig. 1b). This unit is interpreted as a transitional marine unit, whose facies can be attributed to a shallow environment of a lagoon or a bay (Montes Santiago 2009). One of the most highlighted features of this tracksite is that is one of the oldest set of footprints of the Cenozoic of Spain. Four different types of tracks have been identified, corresponding to four types of mammals: two artiodactyls (Fig. 9c, e), a perissodactyl (Fig. 9c, d) and a carnivore (felid-like) (Fig. 9b). With this association of footprints, the tracksite of Bailo is a place with one of the highest diversity of Eocene footprints worldwide (Castanera et al. 2016b). In particular, one of the strengths of this tracksite is to be able to recognize carnivore footprints, being one of the few examples of carnivore footprints of the Cenozoic of Spain. This type of footprints from Bailo are easily identifiable because they are very similar to the current felids, which makes them attractive to people. Definitely, it is advisable that, in the short run, these footprints on the streets of Bailo should be signposted for the enjoyment of visitors.

Fig. 10 a Rock quarry located in Arrés (a village close to Bailo), belonging to the unit Arenisca de Yeste-Arrés of Late Eocene age; **b** similar footprints as Bailo pavement ones in one of the layers of the quarry (big artiodactyl type and perissodactyl type)

Casa de la Tejera tracksite

Despite this tracksite lacks the great importance of the rest of the itinerary, both from a scientific and didactic point of views, it may be interesting to make a stop in the paleoichnological route to visit it. It is located in the municipality of Loarre (Huesca) (coordinates UTM X30T X696701 Y4687061). The footprints are in the top of a sandstone slab (Fig. 11) (taken out of geological context), which form part of the Uncastillo Formation, Late Oligocene-Early Miocene age (Fig. 1b). This formation is interpreted as a large fluvial system, known as Luna fluvial system (Arenas y Pardo 1996; Arenas et al. 2001). The morphology and size of all footprints are similar, so may be done by the same trackmaker. Although no digit impressions can be discerned, the rounded morphology and the relatively large sized of the footprints suggest that the trackmaker was a mammal. A peculiarity is the mud border around each track, produced by the animal when tread on the substrate.

Fig. 11 Casa de la Tejera tracksite; the footprints are in the top of a sandstone slab.

TOURIST AND DIDACTIC ATTRACTION OF THE ITINERARY

This paleoichnological itinerary has been designed to spread a vision of the paleodiversity of vertebrates that occupied the Pre-Pyrenees and the Ebro Valley before the existence of human beings. This paleontological heritage is a source of knowledge about the natural environment and its history. It has the capacity to transport those who approach it to a different time and place, offering visitors a wider view of the natural world. The strength of the tracksites is the ability to evoke the image of some extinct animals walking in the same place where the visitor is at this moment. By seeing the footprints in the rock visitors can easily imagine the animals

alive, walking towards the shore lake or close to the shore line to drink water or search for food in the mud; as if the fossils come alive. In this sense, the itinerary carries visitors on a trip about 20 ma since Late Eocene to Early Miocene. This period reflects a change both in fauna and depositional environments (from coastal to fluviolacustrine).

The characteristics of this paleoichnological heritage are vital for teaching purposes, as they offer a firsthand way for students to approach the world of Paleontology and Geology. However, it is essential to keep in mind that to obtain a connection between the visitor and the visited object it is indispensable to relate what is shown with something in the personality or experience of the visitor (Tilden 2015). An appropriate tool is using examples of everyday life: this makes possible not only to increase the comprehension of the scientific value of the object, but to raise people's awareness about the importance of its protection and conservation (Magagna et al. 2013).

The Pre-pyrenees, as southern boundary of the Pyrenees Range, has a great appeal in rural and mountain tourism. Nevertheless, this tourism tends to be concentrated in specific locations that are more attractive to tourists because of its beautiful landscape or its rich heritage. The creation of the paleoichnological itinerary presented here could mean a new tourist attraction for different municipalities that are not within the classic tourist destinations. Thus, the tourist offer would be extended in the region.

CONCLUSIONS

The Pre-pyrenees-Ebro Valley region in Aragon (NW Spain) accumulates a high richness of Cenozoic tracksites of mammals and birds, which are relatively scarce worldwide. Some of these tracksites have been conserved for public display, which have allowed people to visit it. In this paper we propose an itinerary that includes the most important tracksites and offers a general and diverse vision of the paleoichnological record: La Playa Fósil, Fondota, Sierra de Luna and Bailo. These tracksites have a good location that makes them easily accessible. All together, they encompass a wide variety of fossil tracks and different sedimentological and lithological features that comprises a time range of about 20 m.a. The promotion of this paleoichnological itinerary as a tourist and

didactic resource can be especially important for the territories where the tracksites are located, making this paleontological heritage into a valuable socioeconomic resource.

REFERENCES

Alcalá L, González A, Aberasturi A. (2006) Teruel, un laboratorio paleontológico. Enseñanza de las Ciencias de la Tierra 14(3):213-221.

Alcalá L, Lockley MG, Cobos A, Mampel L, Royo-Torres R (2016) Evaluating the Dinosaur Track Record: an integrative approach to understanding the regional and global distribution, scientific importance, preservation, and management of tracksites. In: Falkhingham PL, Marty D, Richter A (eds). Dinosaur tracks. The next steps. Indiana University Press, Indiana, pp 100-116.

Alonso-Zarza AM, Armenteros I, Braga JC, Muñoz A, Pujalte V,Ramos E (coords), Aguirre J, Alonso-Gavilán G, Arenas C, Baceta JI, Carballeira J, Calvo JP, Corrochano A, Fornós, JJ, González A, Luzón A, Martín JM, Pardo G, Payros A, Pérez A, Pomar L, Rodríguez JM, Villena J (2002) Tertiary. In: The Geology of Spain, Gibbons W, Moreno T (eds), Geol Soc, London, pp 293-334.

Álvarez Sierra M, Daams R, Lacomba JI, López Martínez N, Van der Meulen AJ, Sesé C, Visser JD (1990) Palaeontology and biostratigraphy (micromammals) of the continental Oligocene-Miocene deposits of the North-Central Ebro Basin (Huesca, Spain). Scripta Geologica 94:1-75.

Antón M, López G, Santamaría R (2004) Carnivore trackways from the Miocene site of Salinas de Añana (Álava, Spain). Ichnos 11(3-4):371-384.

Arenas C, Millán H, Pardo G, Pocoví A (2001) Ebro Basin continental sedimentation associated with late compressional Pyrenean tectonics (north-eastern Iberia): controls on basin margin fans and fluvial systems. Basin Res 13:65–89.

Arenas C, Pardo G (1999) Latest Oligocene–Late Miocene lacustrine systems of the north-central part of the Ebro Basin (Spain): sedimentary facies model and palaeogeographic synthesis. Palaeogeogr Palaeocl 151:127-148.

Astibia H, Pereda Suberbiola XP, Payros A, Murelaga X, Berreteaga A, Baceta JI, Badiola A (2007) Bird and mammal footprints from the Tertiary of Navarre (Western Pyrenees). Ichnos 14(3-4):175-184.

Barco JL, Castanera D, Canudo JI, Pascual C, Rubio CJ, Rubio C (2013) Aula Paleontológica y Ruta de las Icnitas de Soria: un espacio paleontológico musealizado con fines didácticos y turísticos. HER&MUS 12:132-138.

Bates KT, Rarity F, Manning PL, Hodgetts D, Vila B, Oms O, Galobart A, Gawthorpe RL (2008) High-resolution LiDAR and photogrammetric survey of the Fumanya dinosaur tracksites (Catalonia): implications for the conservation and interpretation of geological heritage sites. J Geol Soc 165(1):115–127. doi:10.1144/0016-76492007-033

Canudo JI, Barco JL, Cuenca-Bescós G, Rubio J (2007) Icnitas de Abiego. Prames, Zaragoza.

Carcavilla L, Durán JJ, García-Cortés Á, López-Martínez J (2009) Geological heritage and geoconservation in Spain: past, present, and future. Geoheritage 1(2-4):75-91.

Casanovas-Cladellas ML, Santafé-Llopis JV (1982) Icnofauna oligocena de Agramunt (Lérida, España). Acta Geológica Hispánica 17(1-2):113-119.

Castanera D, Barco JL, Díaz-Martínez I, Pérez-Lorente F, Canudo JI (2011). New evidence of a herd of titanosauriform sauropods from the Lower Berriasian of the Iberian Range (Spain). Palaeogeogr Palaeocl 310:227-237.

Castanera D, Luzón A, Rabal-Garccés R, Revuelto J, Díaz-Martínez I, Canudo JI (2016) Mammal and avian tracksites from the lower Oligocene in the North of Ebro Basin (Aragón, Spain). Ichnia 2016: abstract book. UNESCO Geopark Naturtejo/International Ichnological Association, Castelo Branco, pp 164-165.

Castanera D, Pascual C, Canudo JI, Barco JL (this volumen) Bringing together research, geoconservation and reaching a broad public in the form of a geotourism project: the Ichnite Route of Soria (Spain). Geoheritage.

Castanera D, Rabal-Garccés R, Silva R, Canudo JI, Díaz-Martínez I (2016b) Mammal tracks from the Eocene of the Jaca Basin (Spain). 1st International Meeting of Early-stage Researchers in Palaeontology XIV EJIP, Alpuente, 90.

Cobos A (2004) Valoración patrimonial de las icnitas de dinosaurio de la provincia de Teruel. Geogaceta 36:191–194

Costeur L, Blame C, Legal F (2009) Early Oligocene Mammal Tracks from Southeastern France. Ichnos 16:257-267.

Crusafont M, Riba O, Villena J (1966) Nota preliminar sobre un nuevo yacimiento de vertebrados Aquitanienses en Sta. Ciclia (Río Formiga, prov. Huesca) y sus consecuencias geológicas. Notas y comunicaciones del IGME 83:7-14.

Cuenca G, Canudo JI, Andrés JA, Laplana C (1992) Bio y Cronoestratigrafía con mamíferos en la Cuenca terciaria del Ebro. Ensayo de síntesis. Acta Geológica Hispánica 27(1-2):127-143.

Díaz-Martínez I, García-Ortiz E, Ortega Girela JM, Hurtado Reyes A, Aldaiturriaga L, Benito J, Colina A, Fernández A, Martínez J, Ortega A, Pereda JC, Requeta LE, Sainz JL Pérez-Lorente F (2010a) Treinta años de trabajo de campo en los yacimientos icnológicos de La Rioja (1980-2010). Zubía 28:167-178.

Díaz-Martínez I, Ladel L, Zurita-Calvo C, Haddad S, Durán I, Trachi M, Porres L, Boukil B, Sigrid Beníted S, Masrour M, Pérez-Lorente F, Boutakiout M (2010b) Importancia y vulnerabilidad del Patrimonio Paleoicnólogico del Alto Atlas marroquí. Cidaris 30:107-112.

Fuertes-Gutiérrez I, García-Ortiz E, Fernández-Martínez E (2016) Anthropic Threats to Geological Heritage: Characterization and Management: A Case Study in the Dinosaur Tracksites of La Rioja (Spain). Geoheritage 8(2):135-153.

García-Ortiz E, Fuertes-Gutiérrez I, Fernández-Martínez E (2014) Concepts and terminology for the risk of degradation of geological heritage sites: fragility and natural vulnerability, a case study. Proc Geol Assoc 125:463–479. doi:10.1016/j.pgeola.2014.06.003

García-Ramos JC, Lires J, Piñuela L (2003) Dinosaurios: rutas por el Jurásico de Asturias. La voz de Asturias, Lugones.

García-Ramos JC, Piñuela Suárez L (2006) El Muja: Un Museo en torno a las icnitas asturianas de dinosaurios. In: Fundación del Patrimonio Histórico de Castilla y León (ed) Actas Simposio Internacional Huellas que perduran. Icnitas de Dinosaurios: patrimonio y recurso. pp 245-264.

García-Ramos JC, Piñuela L, Lires J (2006) Atlas del Jurásico de Asturias. Ediciones Nobel, Oviedo.

Hernández-Pacheco F (1929) Pistas de aves fósiles en el Oligoceno de Peralta de la Sal (Lérida). Memorias de la Real Sociedad Española de Historia Natural, XV:379-382.

Lockley MG, Meyer C (2000) Dinosaur tracks and other fossil footprints of Europe. Columbia University Press, New York.

Luzón A (2005) Oligocene–Miocene alluvial sedimentation in the northern Ebro Basin, NE Spain: Tectonic control and palaeogeographical evolution. Sediment Geol 177:19-39.

Magagna A, Ferrero E, Giardino M, Lozar F, Perotti L (2013) A Selection of Geological Tours for Promoting the Italian Geological Heritage in the Secondary Schools. Geoheritage 5:265-273.

Mampel L, Cobos A, Alcalá L, Luque L, Royo-Torres R (2009) An Integrated System of Heritage Management Applied to Dinosaur Sites in Teruel (Aragón, Spain). Geoheritage 1:53-73.

Marty D, Cavin L, Hug WA, Jordan P, Lockley MG, Meyer CA (2004) The protection, conservation and sustainable use of the Courtedoux dinosaur tracksite, Canton Jura, Switzerland. Revue de Paléobiologie 9:39-49.

McDonald, H.G., White, R.S., Lockley, M.G. y Mustoe, G.E. 2007. An indexed bibliography of Cenozoic vertebrate tracks. Cenozoic vertebrate tracks and traces 42:275-302.

Montes Santiago MJ (2009) Estratigrafía del Eoceno-Oligoceno de la Cuenca de Jaca. Sinclinorio del Guarga. Instituto de Estudios Altoaragoneses (Diputación de Huesca), Huesca.

Muñoz A, Arenas C, González A, Luzón A, Pérez A, Villena J, Pardo G (2002) Ebro Basin (Northeastern Spain). In Moreno, T. y Gibbons, W. (eds) Geology of Spain, Geological Society of London, London, pp 301-309.

Murelaga X, Baceta JI, Astibia H, Badiola A, Pereda Suberbiola X (2000) Icnitas de perisodáctilos en el Oligoceno de Navarra: posición estratigráfica y sistemática. Geogaceta 27:15-17.

Novacek MJ (1997) Mammalian evolution: An early record bristling with evidence. Curr Biol 7(8):R489-R491.

Pardo, G. Arenas, C. González, A. Luzón, A. Muñoz, A. Pérez, A. Pérez-Rivarés, J. Vázquez, M. y Villena, J. 2004. Cuencas Cenozoicas: La Cuenca del Ebro. In: Vera JA (ed) Geología de España, SGE-IGME, Madrid, pp 533-543.

Pérez-Lorente F (2000) Experiencias de Geoconservación en La Rioja. In: Barettino D, Wimbledon WAP, Gallego E (eds) Patrimonio Geológico y Gestión. Instituto Tecnológico y Geominero de España: 179–196.

Pérez-Lorente F (2015) Dinosaur Footprints and Trackways of La Rioja. Indiana University Press.

Pérez-Lorente F, Rodríguez T, Mancheño MA, Aerrano F, Romero M (1997) Pisadas fósiles de mamíferos en el Mioceno superior de la Hoya de la Sima (Jumilla, Murcia, España). Revista Española de Paleontología 14:257-267.

Prats M, López E (1995) Síntesi de la icnofauna del sinclinal d'Àgramunt entre el Meridià d'Agramunt i el riu Segre (Prov. de Lleida). Paleontologia i Evolució 28-29:247-267.

Puigdefábregas C (1975) La sedimentación molásica en la Cuenca de Jaca. Pirineos 104:1-188.

Quirantes J (1978) Estudio sedimentológico y estratigráfico del Terciario continental de Los Monegros. Institución Fernando el Católico (CSIC), Zaragoza.

Rabal-Garcés R, Díaz-Martínez I (2010) Primeras icnitas de mamífero carnívoro en el Paleógeno de Aragón (España). In: Moreno-Azanza M, Díaz-Martínez I, Gasca JM, Melero-Rubio M, Rabal-Garcés R, Sauqué V (coords) VIII Encuentro de Jóvenes Investigadores en Paleontología, volumen de actas, Cidaris 30:259-264.

Reille JL (1967) Subdivisions stratigraphiques et phases de plissement dans le Paléogène continental sudpyrénéen (Région de Barbastro, prov. de Huesca). Comptes Rendus de l'Académie de Sciences (París) 265:852854.

Reille JL (1971) Les relations entre tectogénese et sédimentation sur le versant Sud des Pyrénées centrales, d'après l'étude des formations tertiaires essentiellement continentales. Dissertation, Université de Montpellier, Montpellier.

Salazar A (2003) El final del endorreismo terciario en la Cuenca del Ebro. Geotemas 5:205-8.

Santos VF, da Silva CM, Rodrigues LA (2008) Dinosaur track sites from Portugal: Scientific and cultural significance. Oryctos 8:77-88.

Senz JG, Zamorano M (1992) Evolución tectónica y sedimentaria durante el Priaboniense superior-Mioceno inferior, en el frente de cabalgamiento de las Sierras Marginales occidentales. Acta geológica hispánica 27(1-2):195-209.

Teixell A, García-Sansegundo J (1995) Estructura del sector central de la Cuenca de Jaca (Pirineos meridionales). Revista de la Sociedad Geológica de España 8(3):215-228.

Tilden F (2015) La interpretación de nuestro patrimonio (Pablo Salas Rojas, trad.). Asociación para la Interpretación del Patrimonio (Original work published in 1957).

Torcida Fernández-Baldor F, Díaz-Martínez I, Contreras R, Huerta P, Montero D, Urién V (2015) Unusual sauropod tracks in the Jurassic-Cretaceous interval of the Cameros Basin (Burgos, Spain). Journal of Iberian Geology,41(1):141-154.

Vila B, Oms O, Marmi J, Galobart A (2008) Tracking Fumanya footprints (Maastrichtian, Pyrenees): historical and ichnological overview. Oryctos 8:115-130.

Vilas L, Arias C, Rozicky A, Herrero C, Martínez-Abellán R (2006) El yacimiento de icnitas de vertebrados de la Hoya de la Sima (Mioceno terminal). Jumilla, Murcia, España. De Re Metallica 6-7:1-6.

Wings O, Falk D, Knötschke N, Richter A. 2012. Excursion guide B1: the Early Cretaceous dinosaur trackways in Münchehagen (Lower Saxony, Germany)—the natural monument ‘Saurierfährten Münchehagen’ and the adjacent Wesling Quarry. In: Dinosaur tracks 2011. An international symposium, Obernkirchen, April 14–17, 2011. Abstract volume and field guide to excursions. Göttingen: Universitätsdrucke Göttingen. 113-142