Geoheritage
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ORIGINAL ARTICLE

Geoheritage and Education: a Practical Example from the Rhinoceros of Toril 3 (Calatayud-Daroca Basin, Spain)

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Abstract The middle Miocene (Aragonian) sites of Toril 3 (Daroca, Aragón, Spain) have provided one of the most important collections of vertebrates from the Calatayud-Daroca basin. The extremely high fossiliferous sites of Toril 3 have geoheritage values, not only for the diversity, importance, and excellent state of preservation of the ancient life recovered but also for taphonomic, biochronological, and museological interest. Rhinoceroses are mainly represented at the sites of Toril 3A and 3B and form one of the best preserved collection of *Alicornops simorrense* (Lartet) in Europe. *Alicornops* is a hornless rhinoceros with short limbs and a bulky body, which is believed to be one of the few gregarious rhinos that have existed. Some specimens of *A. simorrense*, specifically a skull and a jaw, form part of the permanent exhibition of paleontology in the Museum of Natural Sciences of the University of Zaragoza. We believe that these pieces have great potential as an educational tool to disseminate concepts about bio- and geoconservation to society. Detailed research has been carried out on the paleobiological information that can be obtained by observing the specimens, which can later be adapted for an educational application. The intention is to facilitate for public understanding the results of research based on the material of the museum, as well as providing visitors with an understanding of the depth of history of millions of years for extant organisms, while developing an ethic that includes at its core a long-term custody of both fossil and present day species for future generations to enjoy. In order to achieve this objective, a number of questions about the specimens of *Alicornops simorrense* have been answered with a verbal presentation that can be adapted to different kinds of public in order to facilitate teaching in the museum. This paper also provides different types of resources that can be used to attract people's attention and stimulate visitors during the presentation.

Keywords Geoconservation · Bioconservation · Fossil collections · Teaching resources

Introduction

The importance of Natural History Museums in the field of environmental education seems to be both essential and undeniable, as this education can reach a wide range of visitors (children, adults, and elderly people) combined with the voluntary intention of the person who visits, as the museum is not a part of an institutionalized, formal educational system. For this educational ambit, the exhibition acts as a mediator between the visitors and the meaning of the exhibits, thus allowing a possibility to acquire knowledge, skills, and attitudes through daily experiences. Such informal or voluntary learning is recognized as an important method for the teaching of scientific concepts (Clary and Wandersee 2014).

Conservation is without any doubt one of the most important issues that a Natural Science Museum should convey to the visitor. A paleontological exhibition can be an excellent tool for this purpose, as fossils can be considered to be one of the best tools to introduce concepts regarding bio- and geoconservation, through the attraction created in the public by organisms that once inhabited their country. As shown by surveys carried out in many countries of the European Union, from the full range of geological sciences, issues that deal with

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paleontology or catastrophic events such as mass extinctions are those that most interest a public under 17 years old (Fermeli et al., 2015). This attraction can be easily exploited through the specific specimens shown in a museum exhibition, allowing the public to learn about past biodiversity and the history of life on Earth. It should also be possible to develop principles of ecology and evolution during any presentation, and to introduce concepts of how life has been impacted by both natural and anthropogenic changes, leading to a concept about how to preserve and manage the world today.

Through this paper, these concepts are applied from two selected specimens that form part of the permanent paleontological exhibition of the Natural Science Museum of the University of Zaragoza. The analysis focuses on the study of a skull and a jaw that belonged to two individuals of the hornless rhinoceros *Alicornops simorrense* (Lartet), from the middle Miocene (Aragonian) sites of Toril 3, with an age estimated at 12.67 Ma (Van Dam et al., 2014). These extremely high fossiliferous sites have provided one of the most important collections of vertebrates from the Calatayud-Daroca basin (Aragón, Spain), not only for the diversity, importance, and good state of preservation but also for their taphonomic, biochronological, and museological interest.

However, unlike art museums, where the esthetic values of the pieces may be enough for the enjoyment and motivation, in a Natural Science Museum, it is essential to acquire previous information and knowledge of what is exhibited. For this reason, a greater effort must be employed in explaining the specimens, so that the verbal presentation can be adapted to a greater or lesser degree of complexity depending on the particular visitors. The objective is to set a research process of the paleobiological information that can be obtained by observing the specimens, later adapted in search of its educational application. This action is intended to make the public aware of the results of research based on the material of the museum, as well as providing visitors with an understanding of the depth of history for millions of years of extant organisms, and an ethic that includes at its core a long-term custody of both fossil and present-day species for future generations to enjoy.

Mammals like the rhinoceroses selected for this work are able to attract greater attention from the general public, since the more attractive and spectacular animals often obtain more popular empathy, and also allows a comparison with the status of present day species. This does not mean that a certain species is more important than another, but it makes it easier to introduce numerous concepts that once assumed, can be extended to the whole biodiversity. These concepts may include climatic changes throughout the history of the Earth affecting different species, and comparing them with current climatic change, which can be faster due to anthropogenic activities, hence not allowing the regeneration of species. Thus, a presentation can relate the disappearance of rhinoceros and many other large mammals in Europe with a megafauna extinction event. Subsequently, it can mention the status of decline of the current species of rhinoceros, due to the massive and uncontrolled hunting caused by the elevated value of the horns in illegal markets, surpassing all precious metals.

It should be noted that the evaluation and information provided by the study of the exhibits acquires greater force when the specimens originate, as in this case, from the same region where the museum is located. This helps visitors to value the heritage of the area in which they live, greatly easing the task of conservation and protection, by generating a feeling in the public, who identify the heritage of their own as something unique and characteristic of their land.

Background Information

Rhinoceros: Threatened with Extinction

All five actual rhinoceros species are threatened with extinction:

- *Diceros bicornis* (Linnaeus, 1758): The black rhino, critically endangered. There are four subspecies, all of them from Africa: *Diceros bicornis minor* (Drummond, 1876), the Southern Central black rhino, *Diceros bicornis michaeli* Zukowsky, 1965 *(*Eastern black rhino), *Diceros bicornis bicornis* (Linnaeus, 1758), the South Western black rhino, and *Diceros bicornis longipes* Zukowsky, 1949 (Western black rhino, declared extinct in 2011). The black rhinoceros of Africa used to be the most numerous, numbered around 65,000 in 1973, but this number was reduced to only a few thousand animals by the 1990s due to illegal hunting. However, strategic interventions have helped to slowly recover its population, which has doubled since then.
- *Ceratotherium simum* (Burchel, 1817): The largest rhino, the White rhino, near threatened, with two subspecies in Africa: *Ceratotherium simum simum* (Burchell, 1817) in the south, and *Ceratotherium simum cottoni* Lydekker, 1908 in the north. Although the southern subspecies is one of the most prevalent rhinos nowadays, the northern one was declared extinct in the wild in 2008, with only three remaining individuals in a conservancy park in Kenya (Ol Pejeta) which, unfortunately, are not able to reproduce.
- *Rhinoceros unicornis* (Linnaeus, 1758): Known as the Greater one-horned or Indian rhino, second in size after the White rhino is considered to be a vulnerable species. It can be found in India and Nepal, especially in the foothills of Himalaya. In the past, it roamed all along the valleys of the Brahmaputra, Ganges, and Indus rivers. In the early

nineteenth century, hunting decreased its number to less than 100 individuals, and the last being confined to protected reserves. Today, with great effort from numerous organizations, its population is recovering from the edge of extinction.

- *Dicerorhinus sumatrensis* (G.Fischer [von Waldheim], 1814): The Sumatran rhino, the smallest one of all species, is critically endangered. It can be found in numerous locations of Southeast Asia, including Sumatra, Indonesia, Buthan, India, southern China, Cambodia, and Borneo. As its numbers are very disperse and live in deep tropical forests, it is difficult to estimate its population, but is now believed to be about 100 individuals or less and decreasing. Because of illegal hunting and destruction of their habitat for agricultural development, this species has been declared extinct in the wild in Malaysia and Vietnam.
- *Rhinoceros sondaicus* Desmarest, 1822: The Javan rhino, also critically endangered, is probably the most problematic rhino. This species only survives in the National Park of Ujung Kulon in Indonesia, where its population has to be estimated by camera trap data. Despite the fact that the number of individuals has recovered from less than 30 in 1967 to approximately 60, the biggest threat of the Javan rhino is that this remaining habitat is not large enough to allow a significant growth in the population, besides of inbreeding problems in such a small population, with loss of genetic variability. This makes establishing a second population the highest conservation priority for saving the Javan rhino.

The number of rhinoceroses has decreased from around 500,000 at the beginning of the twentieth century to approximately 29,000 wild individuals today (Fig. 1). Despite the incessant illegal hunting because of the high value of their horns, the global population is now being increased, but not without great effort. However, the situation is very different for each species. As the most successful case of conservation is that of the southern White rhino, Sumatran and Javan rhinos are both critically endangered, with populations of less than 100 individuals in the wild. Conservationists are working hard, investing efforts in captive breeding, while there are initiatives to monitor and protect the wild ones.

***Alicornops simorrense*: an Extincted Rhinoceros**

The species *Alicornops simorrense* was defined at the Aragonian site of Simorre (France) by Lartet in 1851. However, the fossil record, specifically postcranial, it is now known to be much more abundant and detailed in Spain. Until relatively recently, its systematic position was not well defined, appearing in several studies as *Aceratherium simorrense*, *Alicornops simorrense*, and even *Aceratherium* (*Alicornops*) *simorrense*. Though, recent phylogenetic studies (Antoine et al. 2003, 2010; Becker et al. 2013), on which this work is based, establish the validity of the nomenclature *Alicornops* for this species, differentiating both genres (*Aceratherium* and *Alicornops*).

Alicornops is a hornless rhinoceros with short limbs and a bulky body, which is believed to have been the only known gregarious rhinoceros. *Alicornops* belong to a clade of

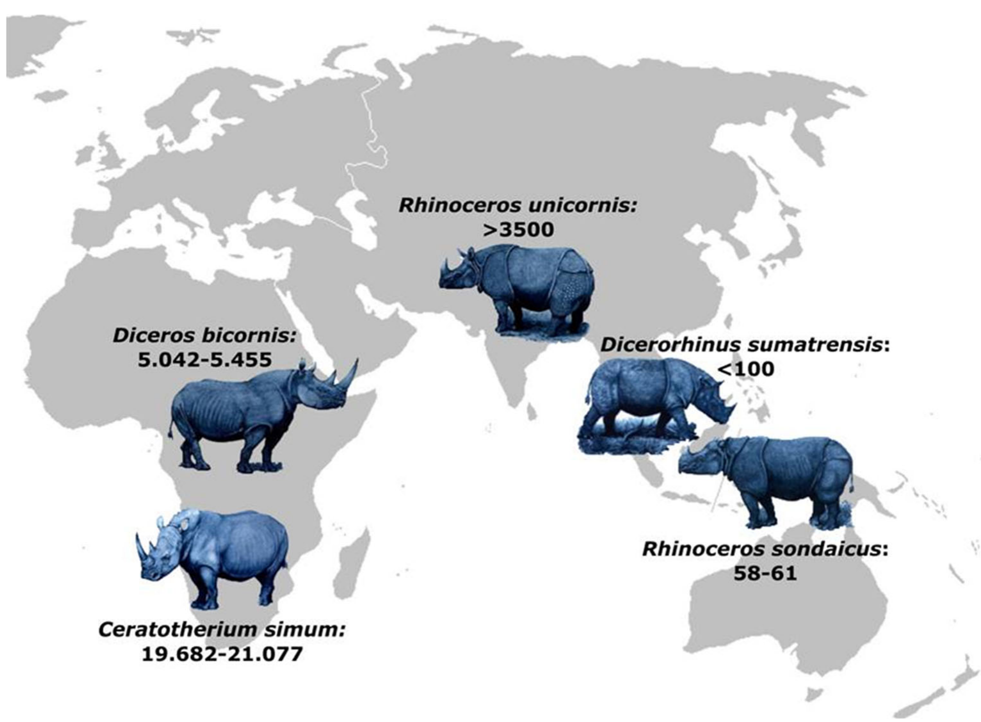

Fig. 1 Current location of the five living species of rhinoceroses, and the estimated number of individuals of each species (data obtained from International Rhino Foundation)

Aceratheriini, along with other genres such as *Acerorhinus*, *Chilotherium*, and *Sinorhinus*, that rise during the late Miocene radiation. However, *Alicornops* represents one of the first members of this clade, as it can be found in Europe since the early Miocene.

Brief Concepts About Rhinoceros Evolution

Among all known mammals, the closed relative to rhinos are tapirs. They probably shared a common ancestor with a "tapiroid" form during the early Eocene (Prothero and Schoch 1989). Then, about 50 million years ago, this group suffered a great diversification, which led to the origin of new groups of perissodactyls that included chalicotheres, lophiodonts, tapirs, and rhinocerotoids in North America (Radinsky 1963, 1965). At this time, North America was still connected to Asia, so the group could spread all over these continents.

The rhinocerotoids diverged on three different main families: Amynodontidae, Hyracodontidae, and, finally, Rhinocerotidae. The Amynodontidae became aquatic grazers, with a hippo-like or tapir-like morphology, while the Hyracodontidae were mostly small running animals with long legs (Prothero 1993). The five living species belong to the family Rhinocerotidae, as well as the majority of the extinct forms, including many hornless rhinoceros like *Alicornops simorrense*. The Rhinocerotidae first appeared in Asia during the Late Eocene. At this point, Asia became a departure point for their big dispersal. Rhinocerotidae spread back to North America, to Africa, and to Europe, where they can be found from the Oligocene. Later, the connection with America severed, and each continent developed endemic species.

With the arrival of the "Ice Ages" about 2.6 million years ago, rhinoceroses disappeared from America, while a great variety of forms remained in Europe, Asia and Africa, including new lineages like the woolly rhinos, whose last living member is the Sumatran rhino (*Dicerorhinus*).

Finally, the climatic change that marked the end of the last glaciation about 10,000 years ago and the human overkill caused the disappearance of rhinoceros in Europe, and they have been in decline since all over the world.

Geoheritage Values of the Vertebrate Sites of Toril 3

The sites of Toril 3 are located in the area between the villages of Daroca, Nombrevilla, and Retascón, in the Comarca of Daroca, at the southwest of the province of Zaragoza (Fig. 2). The area has been extensively studied since the first publication about fossil remains of mammals in the vicinity of Nombrevilla (Ferrando 1925).

Geologically, Toril 3 is located at the central sector of the Cenozoic basin of Calatayud-Daroca, which in turn constitutes the northern part of the Calatayud-Montalbán graben that is extended in a NW-SE direction between these cities. The basin shows an elongated morphology in the general direction of the Iberian Range (NW-SE). It is limited by the mountains ranges of Santa Cruz and Peco, composed mainly of Paleozoic materials which serve as source area of the sediments that fill the basin. In the surroundings of Daroca, the fossiliferous levels appear at three different points (A, B, and C) along the base of a small hill, with an approximate distance of 80 m between each. Only the A and B sites have been excavated, providing abundant remains of vertebrates. Recently, the interest of the sites in relation to the middle-upper Miocene transition has promoted several detailed studies that included the profile of Toril-Nombrevilla (Alcalá et al. 2000; Álvarez-Sierra et al. 2003; Garcés et al. 2003; Van Dam et al. 2014).

The palaeontological sites of Toril 3 have provided fossil evidence of both macro- (Azanza et al. 2004) and microvertebrates (Van der Meulen et al. 2012), and are among the few Spanish sites that have provided complete skulls, plus bones and jaws of mammals (Azanza et al. 2004) and birds (Sánchez-Marco 1996, 2001, 2006), complete turtle shells, or remains of bird eggs (Amo et al. 1999). Thus, the museological interest of many of these fossils is great, and some of the most relevant ones are now on display at the Museum of Natural Sciences of the University of Zaragoza.

Toril 3 represents the type of locality of several species of artiodactyl ruminants such as *Samotragus pilgrimi* (Azanza et al. 1998), *Hispanomeryx daamsi* (Sánchez et al. 2010), *Micromeryx azanzae* (Sánchez and Morales 2008), and also some micromammals.

The sites of Toril 3 belong to the upper Aragonian (local zone G3, MN7/8) and are the oldest of the Toril-Nombrevilla profile, which has allowed to characterize the transition between the Aragonian and the Vallesian both bioestratigraphic and magnetoestratigraphically.

The Aragonian

The "Aragonian" is a regional "continental stage" of the geological time scale which is used to correlate rocks formed in the Neogene continental basins of Europe between 17.2 and 11.2 million years ago (Fig. 3)—therefore covering a time span of nearly 6 million years. The Aragonian is not a standard global stage/age for the Miocene as the stages/ages of the International Chronostratigraphic Chart are defined in marine sediments, in stratigraphic sequences of essentially continuous deposition, chosen for their global correlation potential. However, they are very difficult to apply to deposits of continental basins without a direct correlation with marine sediments. Hence, in the Miocene, regional "continental

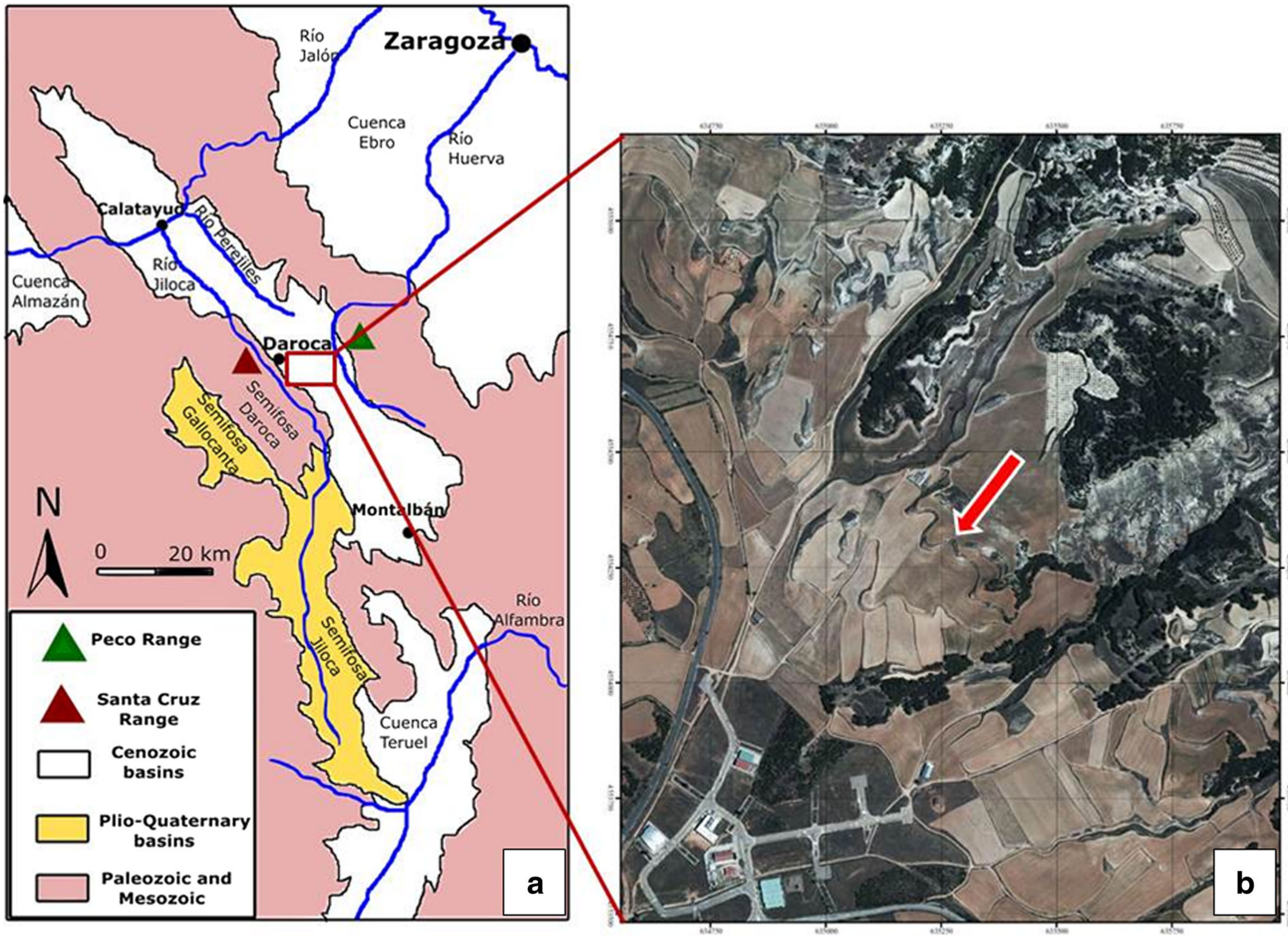

Fig. 2 **a** Geological and geographical location of the study area. Modified from Álvarez-Sierra et al., (2003). **b** Location of the sites of Toril 3. The arrow indicates a foothill in which the sites are located

stages" and "land mammal ages" are the typically used because of their higher accuracy and precision for correlating non-marine sequences.

The name Aragonian, dedicated to Aragón (Spain), was agreed at a scientific congress in Munich (Germany) in 1975 (Daams and Freudenthal 1988), based on the excellent value of mammal fossils from Neogene rocks in the southern Zaragoza Province. Following an intensive systematic search of micromammal sites by a team of Dutch researchers for 2 years, the regional stage was defined in the surroundings of Villafeliche (Daams et al. 1977).

These sites near the city of Daroca are stratigraphically well ordered, meaning that subdivisions of the Aragonian could be established that show a higher correlative resolution that few other Neogene continental basins can provide (Van der Meulen et al. 2012). Also, some of the sites are extraordinarily fossiliferous and have preserved complete skulls, jaws, and bones of macromammals. As well as rhinoceroses being abundant, tridactyl horses, mastodons, pigs, and various groups of ruminants, some with horns, and some without are also common. It is also not uncommon to find carnivores, such as felines, hyaenids, and bears among the largest, and mustelids among the smallest.

Some of these mammals, like mastodons, are of African origin, and are recorded for the first time in Spain at the beginning of the Aragonian age, marking an event of great importance: the "Proboscidean Datum." The dispersal of the Proboscideans, the groups of the elephants from Africa, took place when Africa temporarily connected with Eurasia during the early Miocene before the final closure of the Tethys Seaway due to continued northward continental drift.

Environmental Changes Detected in the Basin in Relation to Climatic Changes During the Middle Miocene

During the Aragonian, the basin landscape changed radically. At the beginning of the Aragonian, the climate was warm, much more than at present, and forest vegetation dominated the landscape. Later, aridity increased, temperatures dropped, and large open spaces were developed, dominated by herbaceous plants. By the end of the

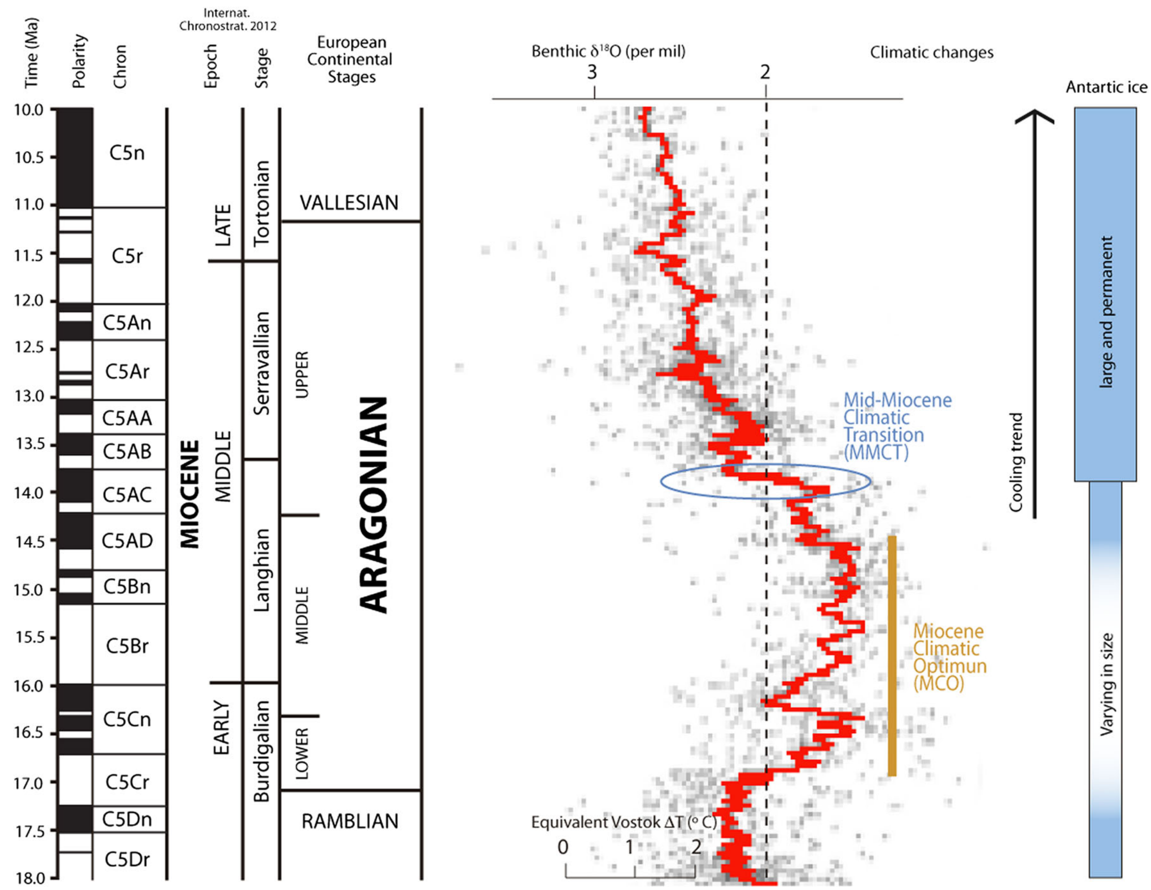

Fig. 3 Equivalence between the standard stages of the International Chronostratigraphic Chart and the European "continental stages" for the middle Miocene (extracted from Hilgen et al. 2012), together with isotopic curve and climatic and Antarctic ice changes during this interval (from Zachos et al. 2001)

Aragonian, humidity was significantly increased, and once more, wooded areas began to develop, although global temperatures did not recover (Fig. 3). There was a short process of global warming, known as the Miocene Climatic Optimum (17–15 Ma, Zachos et al. 2001), followed by a drastic cooling trend, known as the Middle Miocene Climatic Transition (14.2–13.8 Ma [Shevenell et al. 2004]). These changes were due to ice accumulation in Antarctica and a transition to a colder planet as the climate became more seasonal.

Animals adapted to these changes. Some herbivores began to feed on grass and their teeth were modified. Others adjusted their life cycle to the increased seasonality, and some developed cranial appendages. Those that could not adapt, emigrated or, simply, became extinct. *Alicornops* is among the survivors that managed to adapt to these changes.

The Aragonian age represents further evidence of how the climate has changed during the past million years and how living things become involved in these changes. The lower-middle Aragonian evidenced a much warmer period than that of today, which can serve as a model to where we are going if the current trend of global warming continues.

The Rhinoceroses from Toril

In the collection provided by the site, the remains of rhinos are relatively abundant, making up a total of 7.38% of the remains recovered (percentage estimated without discounting unidentifiable pieces and excluding non-mammals such as turtles).

The material previously deposited in the National Museum of Natural Sciences (CSIC, Madrid) has already been the subject of several studies (Cerdeño and Sanchez 2000), which attribute the complete specimens of rhinoceros to the species *Alicornops simorrense*.

The material used for this study was obtained in the methodical excavations that begun in 1989, and which have been deposited in the Museum of Natural Sciences of the University of Zaragoza. The fossils of *Alicornops simorrense* that belong to the area of Daroca have a great scientific relevance, as they are the best known representation for this species in Western Europe. Two of the most emblematic pieces, a skull of a calf and a jaw of a subadult female (Fig. 4), now form part of the permanent exhibition of paleontology in the Museum, which can be seen by the public.

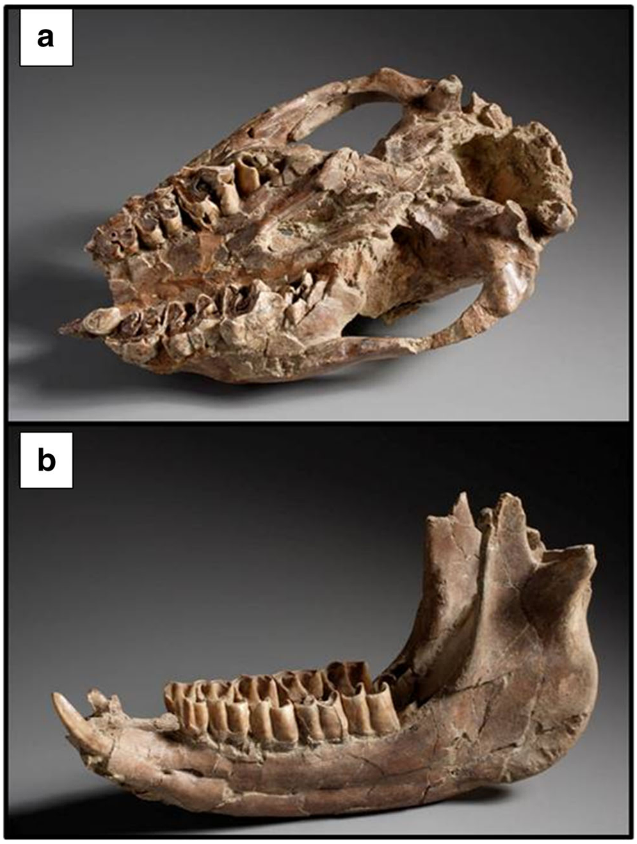

Fig. 4 **a** Skull (MPZ-2006/285) inn ventral view. **b** Complete jaw (MPZ-2006/6) of *Alicornops simorrense.* Both images provided by The Museum of Natural Sciences of Zaragoza.

Gallery Information

The Museum of Natural Sciences of the University of Zaragoza (Fig. 5a) stores two major collections:

The first is the collection of Longinos Navas, which was collected and classified by that naturalist, and deposited on the University of Zaragoza in 1988. This collection is mainly composed of over 400 naturalized animals from Africa, South America, and the Philippines, plus mollusk shells, a great number of plants and around 7300 insects.

The second is the paleontological collection which mainly comes from diverse researches carried out in Aragón. This collection currently includes about 100,000 fossil pieces, with an archive of more than 30,000 records. In the permanent exhibition of the museum, a room is dedicated entirely to the Cenozoic Era, with a special section dedicated to the Aragonian. Furthermore, there is also an audiovisual about the Aragonian that also gives information about the environmental and climatic changes during this stage, and how mammals managed to adapt to these changes (Fig. 5b).

In this area, several specimens of vertebrates are available, including proboscideans, suids, and the rhinoceros *Alicornops simorrense*, among others (Fig. 5c).

Gallery Activities

The following questions and answers have been proposed as a possible framework for the teachers or guides that will need to present the exhibition to the visitors. The information here provided includes some divulgative concepts as well as others with a little bit more of complexity, so the idea is that it can be easily adapted to different kinds of public. Some of the questions can be answered with a simple visual analysis of the specimens, so that visitors can consider the results themselves and discuss them.

Fig. 5 **a** Museum entrance. **b** An audiovisual about Aragonian Stage. **c** Numerous pieces of large mammals from this stage, including *Alicornops simorrense*

How Do We Know That the Pieces Belong to a Rhinoceros, and Specifically to *Alicornops simorrense*?

There are some morphological criteria that allow to identify a rhinoceros cranial specimen. Rhinos show an elongated skull, which is elevated on the posterior part, and the braincase tends to be small. Nasal bones are greatly projected forward and can extend above and beyond the premaxillae in some cases. In the case of horned rhinos, the nasal bones show a though convex insertion surface, on which the horn is placed. As *Alicornops* being a hornless rhino, this surface is flattened. The incisors have a great root and have been developed as tusks. The main characteristic to identify this species is the marked leg shortening, especially in metapodial bones, which became short and with broad epiphyses, while long bones are not so obviously shortened (Cerdeño and Sanchez 2000). *Alicornops simorrense* is also a small rhino.

How Do We Know That the Two Pieces Do Not Belong to the Same Individual?

To distinguish whether the two specimens belong to different individuals or not can be done through a simple visual analysis. The used criteria is the number of teeth present in each of the pieces and, secondly, their size and morphology.

Thus, it can be observed in the case of the skull that the set of deciduous teeth is present, as well as the first one of the molars, which is still in the process of eruption, so that its morphology is not worn, while the second and third molars are absent. However, in the jawbone, the whole premolar series are present, as well as the first and second molars, being the third molar in an eruption process in this case (Fig. 6).

At this point of the analysis, there are enough criteria to say that both pieces do not belong to the same individual, so the sex and ontogenetic stage has to be determined independently for each one.

How Do We Know Their Biological Age?

Rhinoceroses, like other mammals, have a first deciduous dentition in their youth, which is later replaced in different stages by a permanent dentition, the molar pieces being the last to appear, as part of the final series. Therefore, the first part of the analysis is based on a correct identification of the pieces of the dental series presented in both the skull and jaw in order to be able to apply any age criteria.

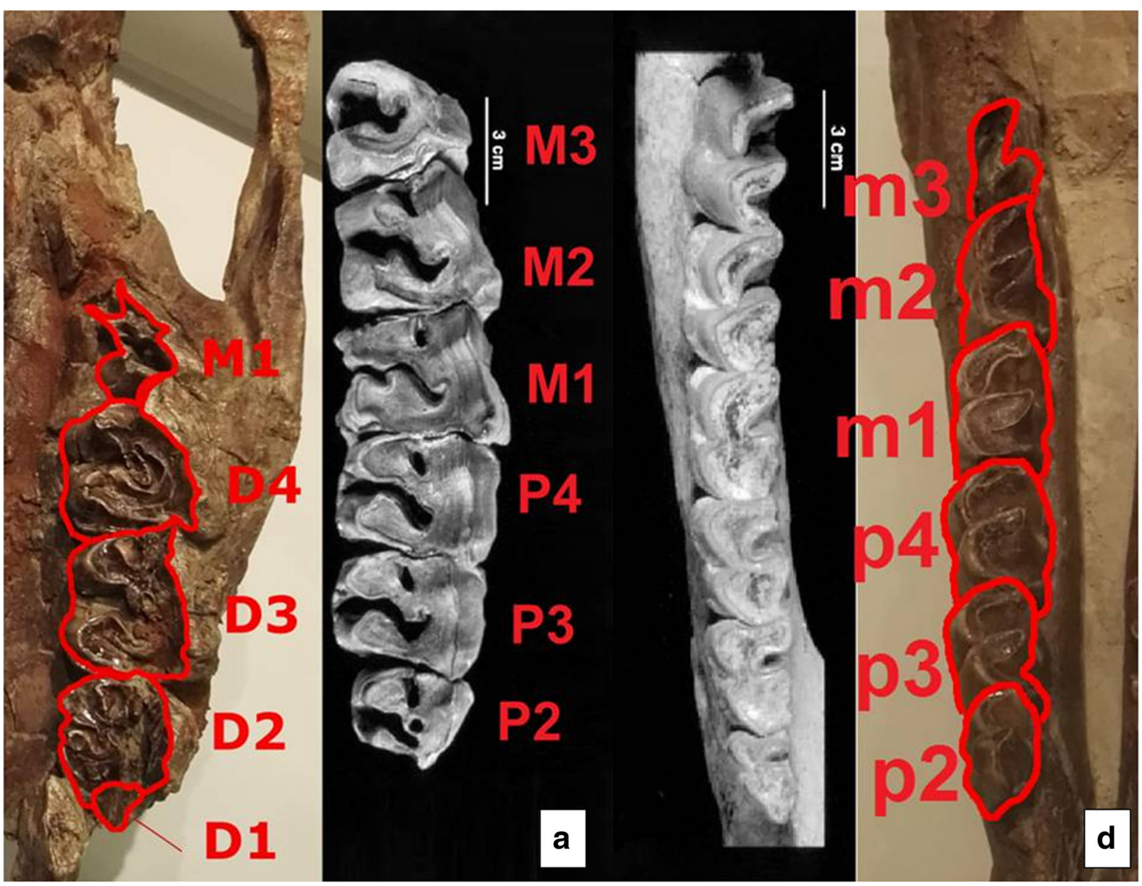

Fig. 6 A comparison between the dental series shown by the studied specimens and the definitive permanent dentition of *Alicornops simorrense* (modified from Cerdeño and Sanchez 2000). **a** Upper series (skull). **b** Lower series (jaw)

For its nomenclature, teeth belonging to the upper series (skull) are represented by upper case letters, and teeth belonging to the lower series (jaw) are represented by lower case letters: D/d: deciduous teeth (non-permanent), I/i: incisors, PM/pm: Premolar (permanent), and M/m: Molar (permanent). The incisors are not taken into account for the determination of age in this case.

Method 1: Bohmer

In order to determine the age of the individuals from the analysis of the dentition, it has been using in first place the method used by Böhmer et al. (2016).

This method is based on the morphological stages that take place during the development of dental ontogeny in present-day species of rhinoceros, trying to differentiate these same steps in a Miocene rhinoceros (*Prosantorhinus germanicus*), thus allowing to assign an approximate age by comparison. To realize this comparison with actual species, the author used the studies of Hitchins (1978) and Goddard (1970) about black rhinoceros (*Diceros bicornis*) and of Hillman-Smith et al. (1986) about white rhinoceros (*Ceratotherium simum*).

- Skull: It should be noted in this piece that the permanent premolar series has not appeared yet, the deciduous teeth being present, and that the individual still has a residual D1, a dental piece that is commonly lost during the juvenile stage, and is not subsequently replaced in the final permanent series. For this dental configuration, according to the method used for the comparison, the skull would correspond with a stage 3 (Fig. 7), which belongs to a juvenile of *Alicornops,* which is still accompanied by his mother, but is close to an independent stage of his life.
- Jaw: It can be observed in this case an almost complete definitive dental series with the exception of the third molar, partly developed but not yet fully formed. In any case, it is clear that this is a more developed individual than the previous one. According to the comparative method, it belongs to a stage 9 (Fig. 7), which is attributed to a subadult specimen, which has already reached sexual maturity, but not yet full weight.

Method 2: Individual Dental Age Stages

While the age criteria used before (Böhmer et al. 2016) is complex and detailed, it is based in a comparison with actual species whose kinship with *Alicornops simorrense* is distant, so a second general method has been applied in order to contrast the reliability of the obtained results.

The IDAS, or "individual dental age stages" (Anders et al. 2011) is a system that is also based on the eruption and wear of the dentition that is applicable to virtually all mammals with the exception of marsupials, proposing six stages: (0: prenatal, 1: infant, 2: juvenile, 3: adult, 4: late adult, and 5: senile). This is possible due to having estimated the duration of each stage for each group of mammals and correlated with maximum life expectancy for each case.

- Skull: The appearance of the first molar represents the passage of the individual from the stage 1 or infant to the stage 2 or juvenile, in which the final dental series will be almost fully developed, causing a change in behavior so that the animal is able to feed on its own. Although reaching this stage takes no more than 1 year for most mammals, large and long-lived species such as rhinoceroses are an exception, allowing to infer that the individual exceeds at least 1 year of age.
- Jaw: In this case, the stage of development of the third molar establishes the progress of the individual from stage 2 or juvenile to stage 3 or adult, a stage characterized for

Fig. 7 Chart established from the method used by Böhmer et al. (2016), which relates dental stages with life stages of rhinoceroses. These criteria are valid for both upper and lower teeth

Dental eruption stages		Condition of visible teeth	Life stage
0	d2 d3	d2 and d3 erupting	Newborn infant
1	d1 d2 d3 d4	d1 and d4 erupting; d2 and d3 in wear	Unweaned infant
2	d1 d2 d3 d4	Full deciduous complement in wear	Calve still nursing
3	d1 d2 d3 d4 m1	Full deciduous complement; d2–d4 in wear; m1 erupting	Calve still accompanying mother
4	d1 d2 d3 d4 m1	Full deciduous complement; d2–d4 in wear; m1 not in wear	Adolescent independent of mother, not yet reproductive mature
5	d2 d3 d4 m1	d1shed;d2–m1 in wear	Adolescent independent of mother, not yet reproductive mature
6	d2 d3 d4 m1 m2	d2–m1 in wear; m2 erupting	Adolescent independent of mother, not yet reproductive mature
7	p2 d3 d4 m1 m2	p2 erupting (replacing d2); d3–m1 in wear; m2 erupting	Subadult (reproductive mature but not yet full weight)
8	p2 p3 d4 m1 m2	p2;d4–m2 in wear; p3 erupting (replacing d3)	Subadult (reproductive mature but not yet full weight)
9	p2 p3 p4 m1 m2 m3	p2–p3; m1–m2 in wear; p4 erupting (replacing d4); m3 erupting	Subadult (reproductive mature but not yet full weight)
10	p2 p3 p4 m1 m2 m3	p2–m3 in wear	Adult

the use of the fully permanent dental series. According to the IDAS (individual dental age stages) method, this is the stage when the majority of female mammals reproduce.

Both methods employed separately agree in general terms on the ontogenetic analysis of the studied individuals, setting the first one in a juvenile stage, close to independent living, and the second one in a subadult stage, close to adulthood and being reproductively mature.

How Do We Know the Sex of the Individuals?

When trying to determinate the sex of an individual, there are several features of sexual dimorphism in *Alicornops simorrense*. Among the most notorious, adult males can be differentiated as they tend to be significantly larger than females and also show a greater incisive (i2) in the jaw, both in length and width of the incisor (Fig. 8).

The analysis is complex in the case of the skull of the juvenile. Having not completed its growth does not allow to perform comparisons based on size.

Jaw As the individual is interpreted as a subadult, so it has not reached its maximum size, the distinction of sex can be made analyzing the length of the incisives. The measurement of the incisive of the jaw has been estimated in 20.15 cm. The individual studied can be interpreted as a female, as the dimensions of the incisor fall within the range given for females (19.5 to 23.3 cm). This measure is far from the minimum measures given to males (29.4 cm) that are about 50.15% larger (Fig. 9).

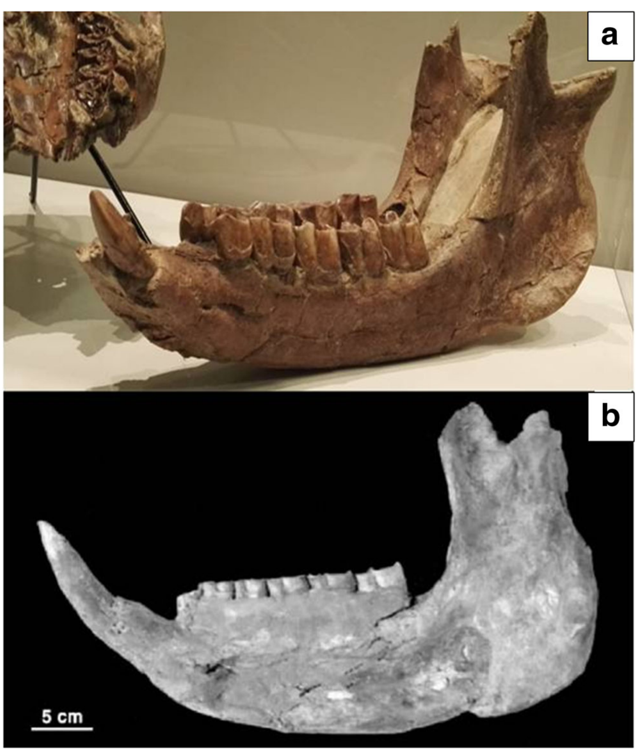

Fig. 8 **a** Jaw of the museum specimen in comparison with the left hemimandible of a male from Toril 3, MNCN 31856 (**b**). The difference in size between both incisors can be observed (modified from Cerdeño and Sanchez 2000).

Teaching Resources From the scientific study, experiences, comparisons, and anecdotes should be communicated in order to generate in the visitor a positive attitude toward the learning process. The same presentation can be adapted with different degrees of complexity, depending on the kind of audience of each case.

In this way, the idea is to find connecting links that allow visitors to empathize with the exhibited specimens, to generate a positive feeling toward the specimen, or to allow comparisons with elements or situations that they can easily identify. Paleontology conforms to a particular branch of science that facilitates this task, as it deals with the study of ancient living things, so that the following actions can be proposed:

- The paleobiological analysis of the selected specimens has allowed the identification of a juvenile individual in the case of the skull, and a subadult reproductively mature female in the case of the jaw, both of them belonging to the species *Alicornops simorrense*. Although no data is available to establish a possible family relationship between the two individuals, it could be proposed in the presentation a hypothetical mother and son association. The objective of this proposal is to generate a bit more of depth in the contextual framework, and a sense of empathy in the visitor, especially in the case of families.
- This comparison leads to an activity in which the visitors themselves are able to distinguish which one of the specimens belong to each individual (the juvenile and the subadult female) through a simple visual analysis. The female possesses a higher number of teeth due to the fact that its

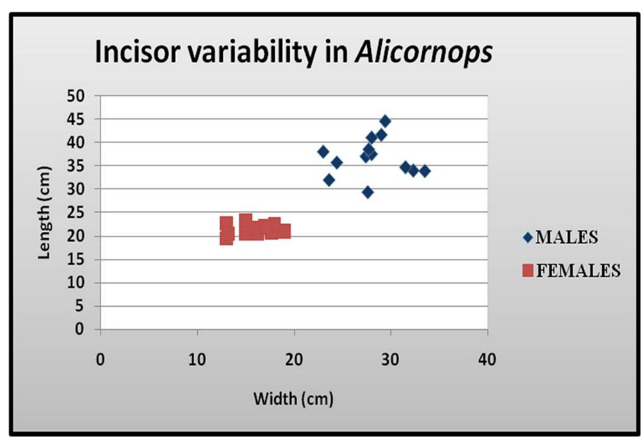

Fig. 9 Scatter chart showing the relationship between two different measures of both male and female incisors of *Alicornops simorrense* (data from Cerdeño and Sanchez 2000)

dental series is complete, and younger individual still has "milk teeth," or deciduous teeth present. This kind of resources brings about a more easy way of participation of the public, as all visitors can meditate and reach the results on their own, instead of being simple listeners.

- These individuals, if considered to be mother and son, can be treated as main characters of a presentation in which issues of great geological and biological relevance can be introduced. This includes climatic changes as that which occurred during the Aragonian, when a relatively colder period comes over a warm period, as well as biological concepts about the species *Alicornops simorrense*. It should be noted that facts and ideas such as rhinoceroses living in Europe, and the existence of some hornless species with short limbs and a gregarious behavior, can draw a special draw public attention, being contrary to the current generalized concept of rhinoceros as powerful animals with a lonely way of life, as today in the African savannah. At this point in the presentation, the extinction of the megafauna (rhinoceros included) in Europe can be introduced and related with the end of the last ice age, as well as the expansion of the modern humans across the continent. Finally, this allows the establishment of a comparison between the critical status of the five living species of rhinoceroses due to human actions.
- In the case of a school visit, it is recommended that activities are developed that promote imagination and creativity. One of the best examples can be that each child makes a drawing of the animal according to the description given by the guide/teacher. This process allows a greater internalization of the information about the pieces exhibited in the museum. This type of activity can also be adapted to different age ranges, from child drawings to anatomical schemes in high school students, and even to a university level, such as a resource to support a lesson about vertebrate anatomy. Later, it is possible to allude to the importance that this kind of drawing in the development of the natural sciences, such as those that can be observed in the museum by the naturalist Longinos Navas.

Some Interesting Facts about Rhinoceros

Next, there are expose 12 curious facts about rhinoceroses that can be used to attract attention and stimulate the visit. This can be employed during the verbal presentation as a didactic tool for teaching biological concepts about these mammals while maintaining attention levels.

1. **Rhinoceros is a word that combines two Greek words: rhino, meaning "nose" and "ceros," meaning horn:** In addition, a great number of animals that show horn-like appendages are named after the rhinoceros, including the rhinoceros auklet, rhinoceros beetle, rhinoceros chameleon, rhinoceros cockroach, rhinoceros fish, rhinoceros hornbill, rhinoceros iguana, rhinoceros rat snake, rhino shrimp, and rhinoceros viper.
2. **Rhinoceros were once considered to be pachyderms:** Many years ago, zoologists called pachyderms a diverse group of animals with thick skin, such as rhino, elephants, hippos, tapirs, horses. The group Pachyderms is not currently in use.
3. **Rhino horns are made of keratin, the same material that hair or fingernails, not of bone.** Rhinos horns are made of a compacted mass of hair that never stop growing during the animal life. This is why we do not find rhino horns in the fossil record.
4. **Rhinos skulls were once interpreted as dragon skulls:** In the city of Klagenfurt, Austria, a woolly rhino skull from the "Ice Ages" served as a model for an ancient dragon sculpture around the year 1500.
5. **A big group of rhinos is called "a crash"**: This is the same as when we call a group of bats a colony, a group of bees a swarm, or a group of wolves a pack.
6. **Black rhinos are not black in color and white rhinos are not white**: Both species are gray.
7. **Rhinos defend by using their teeth, not horns:** Horns are mainly reproductive structures. When male rhinos fight, they bite each other using incisors or molars.
8. **The largest land mammal that ever lived was a rhino:** The species *Paraceratherium*, also known as giraffe-rhinoceros was a gigantic hornless rhino with an enormous neck.
9. **In rhinos, pregnancy can last over 16 months:** This is the longest known pregnancy period after elephants, which lasts over 2 years.
10. **Rhinoceros calves never meet their fathers:** Living rhinos have a solitary life, and males leave when females are pregnant.
11. **Rhino horns have been traditionally used in Asia as a medicine, but there is no proof that they can cure anything:** This is one of the main reasons for the high price that horns reach in illegal markets.
12. **Each year, on September 22, World Rhino Day is celebrated**—as part of the campaigns to save rhinos from extinction.

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References

Alcalá L, Alonso-Zarza AM, Álvarez-Sierra MA, Azanza B, Calvo Sorando JP, Cañaveras JC, Dam JA, Garcés M, Krijgsman W, Van der Meulen AJ, Morales J, Peláez-Campomanes P, Pérez-González A, Sánchez Moral S, Sancho R, Sanz Rubio E (2000) El registro sedimentario y faunístico de las cuencas de Calatayud-Daroca y Teruel. Evolución paleoambiental y paleoclimática durante el Neógeno. *Revista de la Sociedad Geológica de España* 13:323–343

Álvarez-Sierra MA, Calvo JP, Morales J, Alonso-Zarza AM, Azanza B, García-Paredes I, Hernández Fernández M, van der Meulen AJ, Peláez-Campomanes P, Quiralte V, Salesa MJ, Sánchez IM, Soria D (2003) El tránsito Aragoniense-Vallesiense en el área de Daroca-Nombrevilla (Zaragoza, España). Coloquios de Paleontología 1:25–33

Amo O, Azanza B, Sánchez A, Sánchez IM, Morales J (1999) First record of ornitoid prismatic eggshells from the Miocene of Spain. IV European workshop on vertebrate palaeontology:16–17

Anders U, von Koenigswald W, Ruf I, Holly Smith B (2011) Generalized individual dental age stages for fossil and extant placental mammals. Paläontol Z 85:321–339

Antoine PO, Duranthon F, Welcomme JL (2003) Alicornops (Mammalia, Rhinocerotidae) dans le Miocène supérieur des collines Bugti (Balouchistan, Pakistan): implications phylogénétiques. Geodiversitas 25(3):575–603

Antoine PO, Downing KF, Crochet JY, Duranthon F, Flynn LJ, Marivaux L, Métais G, Rajpar AR, Roohi G (2010) A revision of Aceratherium blanfordi Lydekker, 1884 (Mammalia: Rhinocerotidae) from the early Miocene of Pakistan: postcranials as a key. Zool J Linnean Soc 160(1):139–194

Azanza B, Nieto M, Morales J (1998) Samotragus pilgrimi n. sp., a new species of Oiocerini (Bovidae, Mammalia) from the Middle Miocene of Spain. *Comptes rendus de l'Académie des sciences. Série 2*. Sciences de la terre et des planètes 326(5):377–382

Azanza B, Alonso-Zarza AM, Álvarez-Sierra MA, Calvo JP, Fraile S, García-Paredes I, Gómez E, Hernández M, van der Meulen A, DeMiguel D, Montoya P, Morales J, Murelaga X, Peláez-Campomanes P, Pérez B, Quiralte V, Salesa M, Sánchez I, Sánchez A, Soria D (2004) Los yacimientos de vertebrados continentales del Aragoniense superior (Mioceno medio) de Toril, Cuenca de Calatayud-Daroca. Geo-Temas 6(2):271–274

Becker D, Antoine PO, Maridet O (2013) A new genus of Rhinocerotidae (Mammalia, Perissodactyla) from the Oligocene of Europe. J Syst Palaeontol 11(8):947–972

Böhmer C, Heissig K, Rössner GE (2016) Dental eruption series and replacement pattern in Miocene *Prosantorhinus* (Rhinocerotidae) as revealed by macroscopy and X-ray: implications for ontogeny and mortality profile. J Mamm Evol 23:265–279

Cerdeño E, Sánchez B (2000) Intraespecific variation and evolutionary trends of *Alicornops simorrense* (Rhinocerotidae) in Spain. Zool Scr 29:275–305

Clary RM, Wandersee JH (2014) Lessons from US Fossil Parks for Effective Informal Science Education. *Geoheritage* 6:241–256

Daams R, Freudenthal M (1988) Synopsis of the Dutch-Spanish collaboration program in the Aragonian type area, 1975–1986. In: Freudenthal M (ed) Biostratigraphy and paleoecology of the Neogene micromammalian faunas from the Calatayud-Teruel Basin (Spain), *Scripta Geologica*, special issue 1. Rijksmuseum van Geologie en Mineralogie, Leiden, pp 3–18

Daams R, Freudenthal M, van de Weerd A (1977) Aragonian, a new stage for continental deposits of Miocene age. Newsl Stratigr 6(1):42–55

Fermeli G, Hevia GM, Koutsouveli A, Dermitzakis M, Calonge A, Steininger F, D'Arpa C, Di Patti C (2015) Geoscience teaching and student interest in secondary schools-preliminary results from an interest research in Greece, Spain and Italy. Geoheritage 7(1):13–24

Ferrando P (1925) Nota preliminar sobre el yacimiento fosilífero de Nombrevilla. Revista de la Academia de Ciencias Exactas Físico-Químicas y Naturales 9(1924):10–13

Garcés M, Krijgsman W, Peláez-Campomanes P, Álvarez-Sierra MA, Daams R (2003) Hipparion dispersal in Europe: magnetostratigraphic constraints from the Daroca area (Spain). *Coloquios de paleontología, vol. extr.* 1: 171–178

Goddard J (1970) Age criteria and vital statistics of a black rhinoceros population. East Afr Wildl J 8:105–121

Hilgen FJ, Lourens LJ, Van Dam JA with contributions by Beu AG, Boyes AF, Cooper RA, Krijgsman W, Piller WE, Wilson DS (2012) The Neogene Period. In: Gradstein FM, Ogg JG, Schmitz M, Ogg G (Eds.) *The Geologic Time Scale 2012.* Elsevier B.V., pp. 923–978

Hillman-Smith K, Owen-Smith RN, Anderson JL, Hall Martin AJ, Selaladi JP (1986) Age estimation of the white rhinoceros (Ceratotherium simum). J Zool 210:355–379

Hitchins PM (1978) Age determination of the black rhinoceros (Diceros bicornis Linn.) in Zululand. S Afr J Wildl Res 8:71–80

Lartet E (1851) Notice sur la coline de Sansan, suivie d'une récapitulation des diverses espèces d'animaux vertébrés fossiles trouvés soit à Sansan, soit dans d'autres gisements du terrain Miocène dans le bassin sous-pyrénéen. J.A. Portes, Auch, pp 1–45

Prothero DR, Schoch RM (1989) The evolution of perissodactyls Oxford University Press pp 1–573

Prothero DR (1993) Ungulate phylogeny: molecular vs. morphological evidence. In: Szalay FS, Novacek MJ, McKenna MA (eds) Mammal phylogeny: placentals. Springer, New York, pp 173–181

Radinsky L (1963) Origin and early evolution of North American Tapiroidea. Peabody Museum of Natural History Bulletin 17:1–103

Radinsky LB (1965) Early tertiary Tapiroidea of Asia. Bulletin of the AMNH 129:181–264

Sánchez IM, Morales J (2008) Micromeryx azanzae sp. nov.(Ruminantia: Moschidae) from the middle-upper Miocene of Spain, and the first description of the cranium of Micromeryx. J Vertebr Paleontol 28(3):873–885

Sánchez IM, Domingo MS, Morales J (2010) The genus *Hispanomeryx* (Mammalia, Ruminantia, Moschidae) and its bearing on musk deer phylogeny and systematics. Palaeontology 53(5):1023–1047

Sánchez-Marco A (1996) Tertiary avian localities of Spain. Acta Universitalis Carolinae Geologica 39:719–732

Sánchez-Marco A (2001) Strigiformes from the Neogene of Spain. Ibis 143(2):313–316

Sánchez-Marco A (2006) Miophasianus and Palaeoperdix (Galliformes, Aves) from three Miocene localities of Spain. Estud Geol 62(1): 249–256

Shevenell AE, Kennett JP, Lea DW (2004) Middle Miocene Southern Ocean cooling and Antarctic cryosphere expansion. Science 305: 1766–1770

Van Dam JA, Krijgsman W, Abels HA, Álvarez-Sierra MA, García-Paredes I, López-Guerrero P, Peláez-Campomanes P, Ventra D (2014) Updated chronology for middle to late Miocene mammal sites of the Daroca area (Calatayud-Montalbán Basin, Spain). Geobios 47:325–334

Van der Meulen AJ, García-Paredes I, Álvarez-Sierra MA, Hoek-Ostende L, Hordijk K, Oliver Pérez A, Peláez-Campomanes P (2012) Updated Aragonian biostratigraphy: small mammal distribution and its implications for the Miocene European Chronology. Geol Acta 10(2):159–179

Zachos J, Pagani M, Sloan L, Thomas E, Billups K (2001) Trends, rhythms, and aberrations in global climate 65 Ma to present. Science 292:686–693