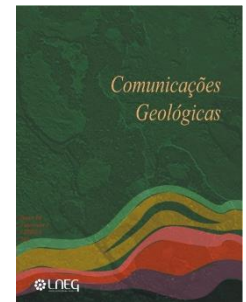


Didactic and outreach possibilities of the Cretaceous palaeontological site of Figueira da Foz (Portugal)

Didáctica e possibilidades de divulgação do sítio paleontológico do Cretácico da Figueira da Foz (Portugal)

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Abstract: The sedimentary exposures and the palaeontological site of Figueira da Foz (Portugal) are located near the coastal town of the same name, in front of the Mondego river estuary, where a set of mid Cenomanian to lower Turonian (Upper Cretaceous) marine beds of the West Portuguese Carbonate Platform are recorded by the Costa d'Arnes Formation. The 65 meters thick of the stratigraphic succession holds several fossiliferous units with diverse ammonite species and other abundant benthic invertebrates with Tethyan affinities, quite accessible for outreach activities. This context allows to combine indoor and out-of-school learning strategies along with diverse didactic methodologies, aiming to reach a meaningful learning by carrying out didactic activities at the site and other contemporary outcrops such as Tamajón (Spain). These initiatives will incentive positive Geoconservation attitudes towards Natural Heritage, by means of outreach and Geotouristic events at the Figueira da Foz site, and related museums and interpretation centres.

Keywords: Earth Science Education, Learning activities, Geoconservation, Geotourism, Out-of-school Education.

Resumo: Os afloramentos e o sítio paleontológico da Figueira da Foz (Portugal) localizam-se junto da cidade com o mesmo nome, em frente ao estuário do rio Mondego. Correspondem a uma sucessão de estratos marinhos do Cenomaniano médio a Turoniano inferior (Cretácico Superior) da Plataforma Carbonatada Ocidental Portuguesa, pertencente à Formação de Costa d'Arnes. Os 65 metros de espessura da sucessão estratigráfica contêm várias unidades fossilíferas com amonites e abundantes invertebrados bentónicos com afinidades tetisianas, bastante acessíveis para actividades de divulgação. Este contexto permite combinar estratégias de aprendizagem dentro e fora da escola, e diversas metodologias didácticas, para se alcançar uma aprendizagem significativa através da realização de actividades didácticas no geossítio e em outros afloramentos contemporâneos, como em Tamajón (Espanha). Estas iniciativas poderão motivar atitudes positivas de Geoconservação do Património Natural, se incluídas em eventos geoturísticos e de divulgação no geossítio da Figueira da Foz, em museus e em centros de interpretação.

Palavras-chave: Educação em Ciências da Terra, Actividades de aprendizagem, Geoconservação, Geoturismo, Educação fora da escola.

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1. Introduction

The Mesozoic basins of Iberia are known to yield a rich stratigraphic and palaeontological record, where outstanding Cretaceous sites illustrate the diversity of life's evolution across this period of Earth History. Through this exceptional operational basis with field-rocks and fossils, and museological and scientific collections, the palaeontological scientific methods can be shown to general public, facilitating to understand the importance and scope of this discipline (e.g. Ozkaya de Juanas *et al.*, 2020). Furthermore, Cretaceous geological formations and lithologies can be easily found and accessed around the World, allowing to replicate scientific outreach and education strategies in other regions. The Cenomanian (Upper Cretaceous, ca. 100.5 to 93.9 Ma) is one of the most interesting intervals of Earth History for educational purposes, illustrating highly diverse palaeoenvironments inhabited by fascinating fauna, such as marine reptiles or dinosaurs, that inspire children's and adult's imagination, together with a worldwide natural garden where flowering plants blossomed. Therefore, visiting sites through out-of-school education for the teaching-learning of Earth Science is ideal for non-formal scientific outreach and educational purposes.

Out-of-school education allows the development of important didactic strategies focused on learning Geology at an outdoor context and can be a complement to seminar practical activities about minerals, rocks, fossils, sedimentary and tectonic structures and models. In recent years, these strategies have been popularized among teachers and students from different educational levels, from Primary Education up to University studies. Overall, out-of-school activities can be valuable didactic resources for learning at natural environments (e.g. Audije-Gil *et al.*, 2018; Segura *et al.*, 2019), museums (e.g. Callapez *et al.*, 2015; Rodrigo, 2017) and interpretation centres (e.g. Callapez *et al.*, 2018a). They also allow to develop basic skills and competences in Geosciences, easing to understand concepts which require high abstraction levels (such as Geological Time, Macro and Microevolution, and Fossil Record) and enabling to reach meaningful learning (sensu Ausubel, 1968). In addition, educational approaches at non-formal or informal contexts also help to raise awareness about the importance of protecting Natural Heritage, as well as promoting positive

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Geoconservation actions among society in a spirit of Citizenship Education (*e.g.* Gómez-Heras *et al.*, 2017; Ozkaya de Juanas and Barroso-Barcenilla, 2019; Carvalho *et al.*, 2020).

Focusing on advancing in outdoor Palaeontology teaching, through a context of Iberian cooperation, this work explores the Cenomanian-Turonian stratigraphic section of Figueira da Foz (Portugal) as a multifaceted resource for educational purposes, which yields a remarkable scientific and educational value (Fig. 1).

2. Geological context and palaeontological content

The Portuguese section of Figueira da Foz (Portugal) is located near this coastal town of west central Portugal, in front of the Mondego river estuary and very close to the entrances of the A14 and A17 highways (Fig. 1a). Local accessibility is excellent, including a direct access to Coimbra, Aveiro and the A25 highway to Spain. This site has been early studied since 1849, and repositories of its fossil assemblages are housed at the Geological Museum (Museu Geológico, MG, LNEG, Lisbon) and at the University of Coimbra (Universidade de Coimbra, UC, Coimbra), among other Portuguese institutions, demonstrating its scientific and educational value (Callapez *et al.*, 2013).

The main available exposures are found in two old quarries (Salmanha), where a set of mid Cenomanian to lower Turonian (Upper Cretaceous) marine beds of the West Portuguese Carbonate Platform are recorded by the Costa d'Arnes Formation (Fig. 1a). The 65 meters thick of the stratigraphic succession, holds several fossiliferous units with a diverse ammonite content (*e.g.* Barroso-Barcenilla *et al.*, 2011), such as the remarkable *Vascoceras gamai* and *Neolobites vibrayeanus* assemblages, and abundant benthic invertebrates with Tethyan affinities, including many species of bivalves, gastropods and echinoderms (*e.g.* *Neithea hispanica*, *Tylostoma ovatum*, *Hemister scutigera*) (Fig. 1b), quite accessible for outreach activities.

3. Didactic and outreach possibilities of the Figueira da Foz site

Didactics, understood as the way of teaching meaningfully to others, is an essential tool in educational contexts. Therefore, it is interesting to take this into account when scientists undertake the last step in their works, inreach and outreach, transmitting their research findings to the scientific community and society in general. An appealing way to develop these activities is throughout out-of-school education, which considers the natural environment crucial in the learning-teaching process, especially in the field of Earth Science, as it allows to understand and inquire about geological and natural phenomena which could not be experienced at indoor settings (Orion, 2007).

Figueira da Foz has an exceptional scientific relevance, as described above. However, showing and teaching these palaeontological sites has mainly been restricted to field trips at University levels, and visits to the museums where the fossil samples are housed. Consequently, it is here proposed to design didactic sequences that include indoor and complementary outdoor activities around the Cenomanian-Turonian (Upper Cretaceous) section of Figueira da Foz, visiting the accessible quarries to teach about how the fascinating Cretaceous life evolved in this area, showing likewise the importance of the palaeontological-scientific work, and how researchers make use of different tools and methodologies to infer and demonstrate their findings. In addition to field trips, other scientific content will be included in a transdisciplinary way by means of a variety of didactic methodologies (*e.g.* Multiple Intelligence Theory: Gardner, 1985),

facilitating the development, among participants diversity, of skills related to Systems Thinking Theory.

The didactic sequence, based on Orion (2007), starts with previous indoor sessions (Fig. 1c), followed by a field trip that can be complemented with visits to museums and interpretation centres along with the corresponding hands-on activities (Fig. 1d). Ending with post-indoor evaluation activities to settle what has been previously learnt, complementary feedback will be recollected for the improvement of the sequence (*e.g.* Hattie, 2012) (Fig. 1e). Moreover, this program is flexible, allowing teachers and scientists to adapt the stages and activities of each session to the available resources and timing (*e.g.* Ozkaya de Juanas and Barroso-Barcenilla, 2019). These teaching agents (teachers, professors, scientists, museum and geopark guides...) must be aware they are the nexus between participants and the scientific knowledge, and therefore should provide the sufficient tools for them to autonomously reach and use the scientific methods to engage with research concerning Earth Science and natural process (Kali *et al.*, 2003).

The main objective of the previous indoor sessions is to evaluate participants prior knowledge as well as to reduce novelty space (*sensu* Orion and Hofstein, 1994), allowing them to become familiar with the natural environment that will be visited. Concerning the outdoor activities, these are a bridge between concrete concepts, explained in previous sessions, and the abstract, such as those geological processes and phenomena that can only be observed and experienced out of the traditional academic installations, among nature. These activities involve both autonomous and cooperative work, learning to apply the scientific method for problem solving (*e.g.* What can we know from this area by observing the minerals and rocks?; How can we infer the morphology of extinct animals with only partial parts of their fossil body or even single moulds?; What information can we acquire from microfossils, and how?). Finally, the focal objective of the posterior activities, which can be carried out indoors and complemented with visits to museums and interpretation centres, is to support and strengthen previous content, performing as evaluation and feedback recollection. This can be pursued in many ways, such as adapted scientific meetings where each participant (or small group) can choose a topic and create their own poster or oral presentation. In this way, participants apply what has been previously learnt and can use tools for searching and selecting information in documents, books, scientific articles or outreach journals, among other sources, putting into practice critical thinking and other skills related to ICT (Information and Communication Technologies).

Moreover, focalizing in strengthen Iberian cooperation in both scientific and educational areas, visiting contemporary palaeontological sites should also be considered. An illustrative example are the Cenomanian-Turonian sections of Figueira da Foz and of the Spanish outcrop of Tamajón (Fig. 2). The latter is located in the province of Guadalajara, approximately 1 hour away from the northeast of Madrid, and combines high scientific, educational and outreach values (Segura *et al.*, 2016; Barroso-Barcenilla *et al.*, 2017). Its local Cenomanian-Turonian stratigraphic succession reaches around 65 meters thick, being included into the Utrillas, Villa de Vés, and Picofrentes formations (Fig. 2a). The Upper Cretaceous of Tamajón started to be utilized with educational purposes since the first third of the 20th Century (Audije-Gil *et al.*, 2018; Segura *et al.*, 2019), still continuing nowadays with palaeontological field trips carried out by professors and students of the Complutense University of Madrid and the University of Alcalá.

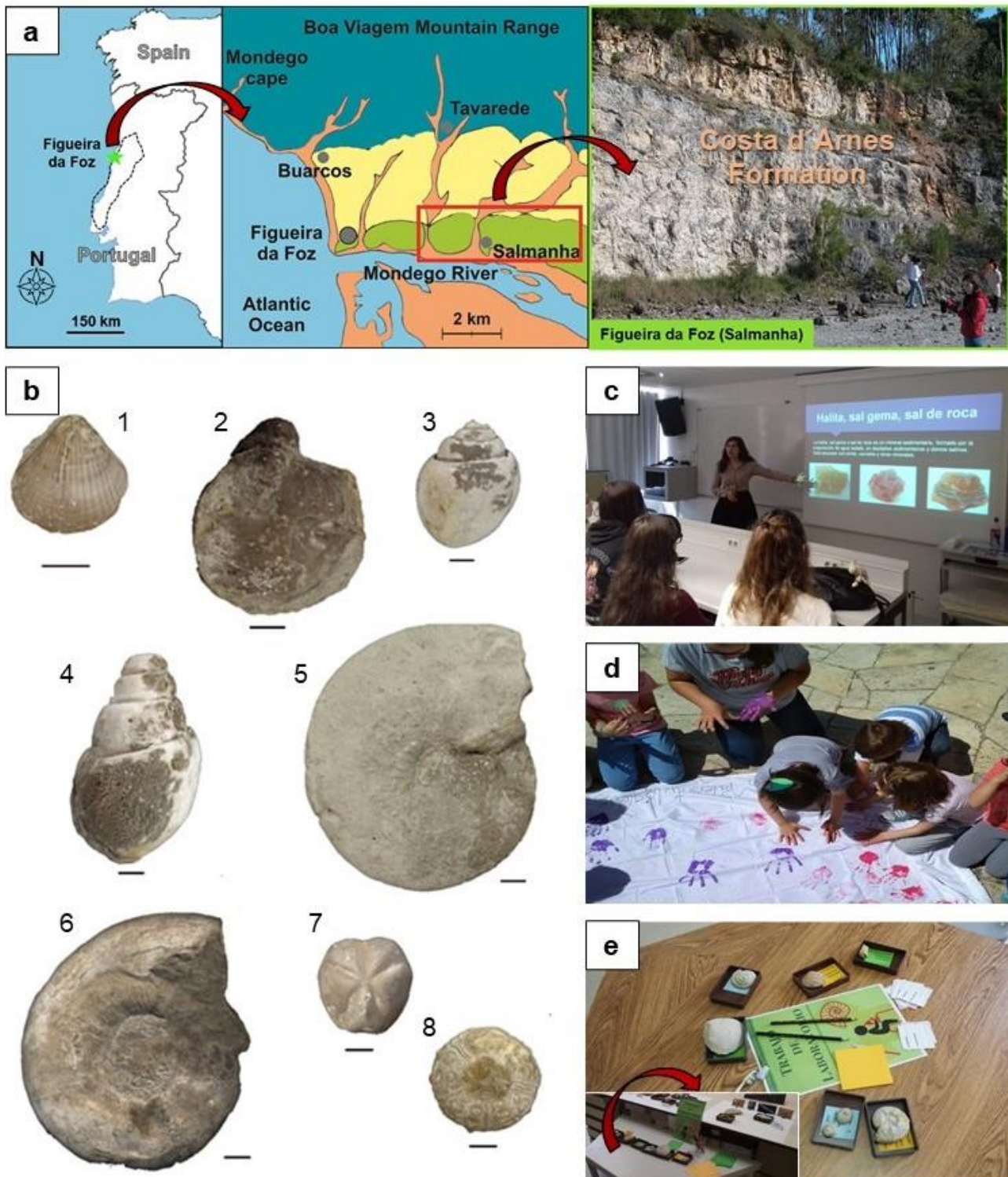


Figure 1. The Cretaceous palaeontological site of Figueira da Foz (Portugal), fossil samples and didactic activities. (a) Geographical and geological context of Figueira da Foz (green star): showing the approximate outline of the West Portuguese Carbonate Platform (dashed line) and the Middle and Upper Jurassic (dark blue), Lower Cretaceous (yellow), Upper Cretaceous (green) and Cenozoic (orange) outcrops, followed by a photograph of a Cenomanian-Turonian outcrop of the Costa d'Arnes Formation. (b) Fossil invertebrates from the palaeontological site: 1: Bivalve *Neithea* (*Neithea*) *hispanica*, 2: Bivalve *Rhynchostreon suborbiculatum*, 3: Gastropod *Tylostoma ovatum*, 4: Gastropod *Tylostoma torrubiae*, 5: Ammonite *Neolobites vibrayeanus*, 6: Ammonite *Vascoceras gamai*, 7: Echinoderm *Stereocidaris figueirensis*, 8: Echinoderm *Mecaster scutiger*. (c) Example of a previous indoors learning activity. (d) Development of an out-of-school didactic activity at natural environments with Primary Education pupils. (e) Sample of an immersive hands-on activity utilizing real fossils for classification of marine invertebrates.

Figura 1. O sítio paleontológico do Cretácico da Figueira da Foz (Portugal), fósseis e atividades didáticas. (a) Contexto geográfico e geológico da Figueira da Foz (estrela verde), mostrando o contorno aproximado da Plataforma Carbonatada Ocidental Portuguesa (linha tracejada) e os afloramentos do Jurássico Médio e Superior (azul-escuro), Cretácico Inferior (amarelo), Cretácico Superior (verde) e Cenozoico (laranja), seguido por uma fotografia do afloramento do Cenomaniano-Turoniano da Formação de Costa d'Arnes. (b) Invertebrados fósseis da Figueira da Foz: 1: Bivalve *Neithea* (*Neithea*) *hispanica*, 2: Bivalve *Rhynchostreon suborbiculatum*, 3: Gastrópode *Tylostoma ovatum*, 4: Gastrópode *Tylostoma torrubiae*, 5: Amonite *Neolobites vibrayeanus*, 6: Amonite *Vascoceras gamai*, 7: Equinoderme *Stereocidaris figueirensis*, 8: Equinoderme *Mecaster scutiger*. (c) Exemplo de uma atividade de aprendizagem de interior prévia. (d) Desenvolvimento de uma atividade didáctica extra-escolar em ambientes naturais com alunos do Ensino Primário. (e) Amostra de uma atividade envolvente de *hands-on*, utilizando fósseis reais para a classificação de invertebrados marinhos.

Both Figueira da Foz and Tamajón Cretaceous sections present analogous stratigraphic contexts concerning their age, lithofacies, fossil content and inferred palaeoenvironments, showing that despite their distance, contemporary palaeontological sites are easily comparable, facilitating learning experiences for pupils from different educational levels, from Primary Education up to University (*e.g.* Barroso-Barcenilla *et al.*, 2011; Callapez *et al.*, 2019). Likewise, a high diversity and abundance of fossil remains also stand out, including microfossils, plant remains, invertebrates, vertebrate parts, and ichnites (mainly produced by invertebrates, fishes, crocodylomorphs and theropod dinosaurs). This fossil content records the biota which dwelled the Iberian Peninsula

during this long period of Earth History (Callapez *et al.*, 2018b), when sea-level and global average temperature were much higher than nowadays.

Therefore, complementing visits to the Figueira da Foz and Tamajón sites, would be highly recommended for outreach and teaching purposes, as both outcrops are easily accessible for the diversity of the public following García-Frank *et al.* (2018). Furthermore, the new Palaeontological and Archaeological Interpretation Centre of Tamajón (CIPAT for its acronym in Spanish: Centro de Interpretación Paleontológica y Arqueológica de Tamajón, Barroso-Barcenilla *et al.*, 2019) has opened this 2021 (Figs. 2b-e). Its Palaeontological and Didactic Areas house real



Figure 2. From Figueira da Foz (Portugal) to Tamajón (Spain), localization of the corresponding Upper Cretaceous section, and didactic and outreach activities at the Palaeontological and Archaeological Interpretation Centre of Tamajón (Centro de Interpretación Paleontológica y Arqueológica de Tamajón: CIPAT). (a) Localization of Figueira da Foz and Tamajón sites (green stars) in the Iberian Peninsula, followed by a photograph of the Cenomanian-Turonian section of Tamajón recorded by the Utrillas, Villa de Vés and Picofrentes formations. (b) Reconstruction of the Cretaceous crocodylomorph “Tami”, the probable main trackmaker at the cenomanian tracksite of Tamajón. (c) Reconstruction model (diorama) of the palaeoenvironment of Tamajón during the Upper Cretaceous, land (bottom left) and marine life (bottom right). (d) Activity “Palaeontology vs. Archaeology” at the Didactic Area of Tamajón. (e) Group of scholars and teachers learning about contemporary palaeontological sites of the Upper Cretaceous of Portugal and Spain.

Figura 2. Da Figueira da Foz (Portugal) a Tamajón (Espanha), localização da secção do Cretácico Superior correspondente e atividades didáticas e de divulgação no Centro de Interpretação Paleontológica e Arqueológica de Tamajón (Centro de Interpretación Paleontológica y Arqueológica de Tamajón: CIPAT). (a) Localização dos sítios da Figueira da Foz e de Tamajón (estrelas verdes) na Península Ibérica, seguida de uma fotografia da secção do Cenomaniano-Turoniano de Tamajón representando as formações de Utrillas, Villa de Vés e Picofrentes. (b) Reconstrução do crocodylomorfo cretácico “Tami”, o provável principal produtor das impressões visíveis na jazida cenomaniana de Tamajón. (c) Modelo de reconstrução (diorama) do palaeoambiente de Tamajón durante o Cretácico Superior, terra (inferior esquerdo) e vida marinha (inferior direito). (d) Actividade “Paleontologia vs. Arqueologia” na Área Didáctica de Tamajón. (e) Grupo de alunos e professores a aprender sobre sítios paleontológicos contemporâneos do Cretácico Superior de Portugal e Espanha.

fossils from the region, models and dioramas (Fig. 2b-c), along with a wide range of didactic activities for the better understanding of the extraordinary life during the Cretaceous Period in Tamajón and Figueira da Foz (e.g. Ozkaya de Juanas *et al.*, 2018, 2019) (Fig. 2d-e).

This scientific outreach initiative in the localities of Figueira da Foz and Tamajón, together with the researchers involved with these palaeontological records, is fundamental, not only to preserve its scientific value, but also for the socioeconomic development of the rural area through Geotourism, promoting the local Geoheritage and motivating positive Geoconservation actions towards Natural Heritage in general (Berrocal-Casero *et al.*, 2018; Newsome and Dowling, 2018). It also provides an opportunity to enjoy, learn and understand the importance of Palaeontology in particular.

4. Conclusions

Towards an effective learning of Earth Science, for both formal and non-formal educational contexts, fieldwork activities have always played an important role in schools, universities, as well as for scientific outreach. A wide-range of possibilities are available for the implementation of out-of-school learning strategies, developing didactic sequences fully complemented with indoor and outdoor activities in academic installations, museums, interpretation centres and natural environments such as palaeontological sites.

The Cenomanian-Turonian section and fossil site of Figueira da Foz, is an ideal environment to undertake these didactic sequences, allowing to base activities upon a variety of pedagogic methodologies and educational strategies to reach meaningful learning among students and the general public involved in them. These didactic sequences are organized following a series of indoor and outdoor sessions for an effective educational experience, allowing science to be understandable, perusable, and achievable for everyone.

Furthermore, teaching Earth Science through Iberian cooperation allows to understand that despite distance, two contemporary palaeontological sites are easily comparable. Specially, with the Cenomanian-Turonian sections of Figueira da Foz (Portugal) and Tamajón (Spain), where field trips can be complemented with the visit to the Palaeontological and Archaeological Interpretation Centre of Tamajón (CIPAT). Furthermore, these initiatives promote the socioeconomic development of rural areas through Geotourism, enhancing the importance of preserving Geoheritage and of practicing positive Geoconservation actions towards Natural Heritage in general.

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