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ORIGINAL ARTICLE

The Araripe Geopark (NE Brazil): Discovering the Earth's Past as a Driver of Economic and Social Transformation

Ismar de Souza Carvalho [1,2] · Ronald Raminelli [3] · Maria Helena Paiva Henriques [2,4] · Rafael Celestino Soares [5] · José Artur Ferreira Gomes de Andrade [6] · Francisco Idalécio de Freitas [5]

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Abstract

The territory of the Araripe Geopark, located in Northeast Brazil, covers a wide range of aspects related to earth and life sciences, as well as other aspects in the socio-cultural sphere that result from a complex interaction linked to the geology of the region. A key element for this diversity is the paleontological heritage that exists in the area and which was one of the bases for the creation of this geopark. The knowledge of the diversity and exquisite preservation of the fossils from the Araripe Geopark results from a long history of prospection of natural resources, starting in the eighteenth century. Since these first discoveries, the records of life in the area of the Araripe sedimentary basin were exceptional. To this day, the first natural resources prospected by João da Sylva Feijó transcend the perception of fossils as mere remains of past life on Earth. The excellent quality of these paleontological records enables new understanding of organic matter preservation processes. This knowledge built over 200 years of research and results in a new perception of the relevance of the Araripe Geopark fossils. Thus, the history of paleontology in this geopark intertwines with the history of scientific knowledge since the eighteenth century. Observation and exploration of natural resources have led to the first discovery of fossils in the region, as well as the scientific understanding of the importance of these records of past life on Earth. Additionally, that increase in scientific knowledge about nature enabled solutions to political and economic problems. Two centuries after their first discovery, the fossils belonging to Araripe Geopark are part of the main paleontological collections of universities and museums around the world. We evaluate how the ex situ paleontological heritage, resulting from the long history of studies in this geopark, may drive the economic development of the region through geotourism activities. The fossil heritage represented by the museum collections in exhibition or those in research collections, whether or not located in the Araripe Geopark region, should be considered as potential paths for disseminating information and encouraging geotourism. The possibility of learning the geological history of the area's landscape, fossils, and human interactions, by means of the various museum collections, represents an enormous potential to stimulate visits to the Araripe Geopark, thereby assisting in the economic development of the region.

Keywords Geoheritage · Paleontological heritage · Araripe Geopark · NE Brazil

✉ Ismar de Souza Carvalho
ismar@geologia.ufrj.br

Ronald Raminelli
rjraminelli@gmail.com

Maria Helena Paiva Henriques
hhenriq@dct.uc.pt

Rafael Celestino Soares
rafaelcsoares@outlook.com

José Artur Ferreira Gomes de Andrade
jartur.andrade@yahoo.com.br

Francisco Idalécio de Freitas
idaleciocrato@gmail.com

[1] Departamento de Geologia, Universidade Federal do Rio de Janeiro, CCMN/IGEO 21.949-900 Cidade Universitária - Ilha do Fundão, Rio de Janeiro, Brazil

[2] Centro de Geociências, Universidade de Coimbra, Rua Sílvio Lima, 3030-790 Coimbra, Portugal

[3] Departamento de História, Universidade Federal Fluminense, Rua Professor Marcos Waldemar de Freitas Reis, s/n, Campus do Gragoatá, Bloco O. São Domingos 24.210- 201 Niterói, Rio de Janeiro, Brazil

[4] Departamento de Ciências da Terra Faculdade de Ciencias e Tecnologia, Universidade de Coimbra, Rua Sílvio Lima, 3030-790 Coimbra, Portugal

[5] Araripe UNESCO Global Geopark, Universidade Regional do Cariri Rua Carolino Sucupira s/n, Pimenta, Crato, Ceará 63.100-490, Brazil

[6] Agência Nacional de Mineração, Praça da Sé, 105 Centro, Crato, Ceará 63.100-440, Brazil

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Introduction

In the eighteenth century, the geological sciences rose to prominence for locating and studying natural resources such as metallic minerals and coal, which drove the economies of Europe at the time. This resulted in increasingly detailed knowledge of events and processes whose understanding would make it easier to find mineral and rock deposits. For example, the publication by Abraham Werner (1749–1817) of procedures for identifying minerals, in 1774, enabled the prospecting of relevant exploration sites.

At the time, specific scientific methods were developed to describe and interpret data. This led to the emergence of a new perspective of the history of Earth, so far understood primarily from a religious point of view. In his book *Histoire Naturelle* (1749), Georges Louis Leclerc (Count of Buffon, 1707–1788) presents through experiments a new date for the origin of Earth. This demonstrated the need for further reflection on the meaning of the planet's lifetime. Another revolutionary publication was Hutton (1788) *Theory of the Earth*, in 1788. Through the detailed observation of contemporary geological processes and their comparison with records in the rocks, Hutton demonstrated that time had a much larger scale than previously imagined. Thus, the history of Earth could be analyzed from the observation of the current environment, establishing a methodological procedure known as the uniformitarian principle.

In paleontology, Georges-Louis and de Buffon (1749) carried out comparative anatomy studies starting in 1778, such as the anatomical description of living elephants and fossil sloths, enabling a first interpretation of the temporal and evolutionary meaning of fossils (Rudwick 2010). From an economic standpoint, William Smith (1769–1839) discovered the most important application for fossils when, in the late eighteenth century, he used them to identify rock strata found in different sites in the UK. His experience as a mining engineer led him to the understanding that successive rock strata could be correlated when associated with specific fossil groups. The application of this knowledge for prospecting mineral resources, such as coal, was evident.

Thus, the early history of paleontology at the Araripe Geopark (Ceará State, Brazil) intertwines with the history of scientific knowledge since the eighteenth century. The observation and prospecting of natural resources within the captaincy of Ceará, especially the search for saltpeter and gold, would lead to the first discovery of fossils in the region, as well as the scientific recognition of the importance of these records of past life on Earth.

Before investigating the peoples and nature of Ceará, the Portuguese crown financed and planned philosophical travels to Brazil (Pará, Rio Negro, and Mato Grosso), Cape Verde, Angola, and Mozambique. These enterprises began in 1783 and planned at the University of Coimbra, intending to map the peoples and the wealth of the Portuguese colonies. In the following years, the explorers roamed vast territories to identify their economic potential, due the close relationship between economy and natural history. Control over nature made it possible to find solutions that would boost the economy in Portugal and in its territories overseas. The use of scientific knowledge applied to nature aimed to relieve trade balance issues and provide solutions to increase the re-exporting of products from the colonies to other European nations. Geographic knowledge, especially the mapping of rivers and borders, made it possible to protect their possessions and locate mineral resources. The territory's inventory also included indigenous peoples, as it sought to create ways to "civilize" and convert them into vassals of the King (Raminelli 2008).

On these expeditions, naturalists and colonial administrators would collect and prepare specimens from the three natural kingdoms to form or expand the collections of the museums and botanical gardens in Lisbon and Coimbra. Minerals and live or preserved plants and animals traveled a long journey to the deposits of the Museum of Natural History, the archives of the University of Coimbra, and the collections of the Real Quinta de Queluz (Brigola 2003; Felismino 2014). Not only did these collections enable research, classifying species and expanding the production of knowledge, but it also reinforced the connection between Lisbon and its overseas colonies, discovered new natural products, and increased trade. The collections delighted the nobility and quenched its curiosity. In the museums, nobles and scholars could contemplate Natural History and have visual evidence of the vastness of the empire ruled by their sovereign. Museums and botanical gardens collected a testimony of the expanse of the territory, the peoples, and nature under the power of the king.

João da Sylva Feijó: The Past of the Araripe Geopark

In October 1799, the sergeant major of the militias of the captaincy of Ceará, João da Sylva Feijó (1760-1824), arrived in Fortaleza with the task of enabling the economic exploitation of local nature, seeking saltpeter deposits in particular (Pereira and Santos 2012). Born in Guaratiba, state of Rio de Janeiro, Brazil, Feijó trained as an engineer officer at the Military Academy and/or the Royal Navy Academy. He would then become a disciple of Italian professor Domenico Vandelli at the University of Coimbra; there, he earned a bachelor's degree from the Faculty of Philosophy, whose syllabus included Natural History as a basic subject on nature (Amorim da Costa 1988; Ferreira 1990; Paiva 2002).

In 1778, João da Sylva Feijó served as a field assistant under naturalist Alexandre Rodrigues Ferreira at the Buarcos coal mine, in Portugal. Before moving to Ceará, Feijó had been assigned to investigate the islands of Cape Verde, on the west coast of Africa, where he conducted mineralogy and volcanology studies for more than 10 years (Paiva 2002; Oliveira 2014). After this expedition, he returned to Lisbon and was deployed to the newly created captaincy of Ceará as sergeant major. In addition to his military duties, Feijó traveled the captaincy as a naturalist (scientist) in charge of finding saltpeter and assessing its natural resources. Used in the manufacture of gunpowder, saltpeter had strategic importance in a military context. Finding this mineral in the captaincy of Ceará Grande was an advantage, due to its greater proximity to port boarding to Lisbon (Nobre 1997).

Starting on November 24th, 1799, Feijó made successive incursions into the hinterlands of current-day Ceará (Fig. 1). In August 1800, after inspecting the old gold mines of Mangabeira, he visited the locality of the Gameleira mill (Fig. 2), between Missão Velha and Milagres counties. There, he found many fossils, which he described in his reports on December 11th, 1800, possibly addressed to Dom Rodrigo de Sousa Coutinho:

... In addition to those, I am sending a collection of Petrified Fish and Amphibious, which is, in my opinion, the most curious and rare ever found, and which will therefore deserve the attention of the Enthusiasts of Natural History, and perhaps of those who endeavor to deepen the general System of the nature of this Globe; whose contemplation I may eventually discuss in a private Memoir, if my limited knowledge allows, since, despite it being common knowledge among Naturalists that the soft, muscular parts of the Animals can never become petrified, the opposite is noted here, with immense Fish being seen entirely converted into a spar crystal, and wrapped in limestone masses. I have found this Petrification spread all over the land on the Serra, between Missão Velha and the place called Os Milagres, at the Gamelleira Mill: I have also found them beyond the Serra dos Carириz Novos, where the garden is located, whose samples, if they are not submitted with the others, I expect to have the satisfaction of sending them to your Honor soon... Siara, December 11th, 1800, João da Sylva Feijó. (Nobre 1978)

Feijó's description reveals an unusual aspect in fossilization, that is, the preservation of soft and muscular parts, a fact unknown by science until then. This material was initially sent to Portugal, possibly to the Royal Museum of Ajuda, and later stored at the Lisbon Academy of Sciences. During the first Napoleonic invasion of Portugal (1807–1808), this museum was looted, and its collections were sent to the Musée National d'Histoire Naturelle in Paris. Nowadays, five carbonate nodules with the fossil fishes collected by João da Sylva Feijó are housed in the Lisbon Academy of Sciences. They belong to the species *Vinctifer comptoni* and represent the oldest record of Araripe fossils in a scientific collection Telles Antunes et al. (2005).

The Pioneering Studies of the Nineteenth Century

A constant reference in studies on the Araripe Geopark fossils is the work carried out by botanist Carl Friedrich Philipp von Martius (1794–1868) and zoologist Johann Baptist von Spix (1831), who traveled across Brazil for 3 years, starting in 1817. They acted as members of the Austrian Mission, part of the entourage of archduchess Maria Leopoldina Josefa

Fig. 1 João da Sylva Feijó carried out several scientific expeditions throughout the state of Ceará (Brazil), producing, in addition reports on geology and flora and cartographic sketches related to the occurrence of mineral resources. "Topographic chart from Seara [Ceará] to the Salpetra Mine discovered at the Tabajuba site: at a distance of 55 leagues from Villa da Fortalleza. 1800". One hand-drawn map in iron gall ink, 25.5 × 19.5 cm. Available at: <http://objdigital.bn.br/acervo_digital/div_cartografia/cart525963/cart525963.jpg>. Access on: May 2nd, 2018)

Fig. 2 Ruins of the Gameleira mill, where the history of knowledge about the diversity of fossils of the Araripe Geopark begins. In 1800, João da Sylva Feijó wrote the first report on the presence of fossils in this locality in the municipality of Missão Velha, district of Jamacaru (State of Ceará, Brazil)

Carolina, who would become consort of Prince D. Pedro I. In northeastern Brazil, the expedition traveled across the captaincies of Bahia, Pernambuco, Piauí, and Maranhão (Fig. 3).

The result of this expedition was the publication of two important works Spix (1831), *Reise in Brasilien* and *Flora Brasiliensis* (Trip to Brazil and Brazilian Flora), in which they report and describe aspects of Brazilian nature because of their expedition to the Brazilian hinterland (Fig. 4). Although they did not travel across Ceará, they had access to several fossils presented by Major General Manoel Ignacio de Sampaio. They may have met João da Sylva Feijó, who was then professor of mineralogy at the Royal Military Academy of Engineering in Rio de Janeiro and who is mentioned by Spix 1831: 599. In the second volume (1828) of the work *Reise in Brasilien* (Trip to Brazil), they mention the existence of fossil fishes in Araripe, and in its last volume (1831: pl. XXII, Fig. 5), they illustrate a carbonate nodule (Fig. 5), certainly coming from the deposits of the Santana Formation (Fig. 6), which can be attributed to the genus *Rhacolepis* (Telles Antunes et al. 2005) and probably to the species *Rhacolepis buccalis* (Maisey 1991).

Almost on the southeastern border of the province, in the small village of Bom Jardim, in the district of Cayriris Novos, there is a very extensive formation of marls containing numerous petrified fossils. They are the same skeletons in tabular, altered, and laminated layers. They belong to many species of fish, such as Loricaria, Cichla, Mugil, etc., perhaps also snakes. (Spix 1831: 599)

However, only after the collections made by Scottish botanist George Gardner, between 1838 and 1839, was it possible to make the scientific description and identification of the new species. In the Ceará hinterland, Gardner found rounded

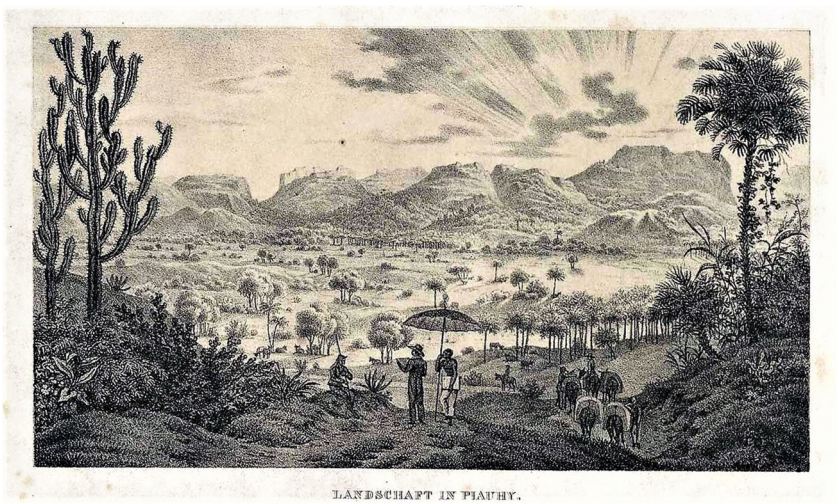
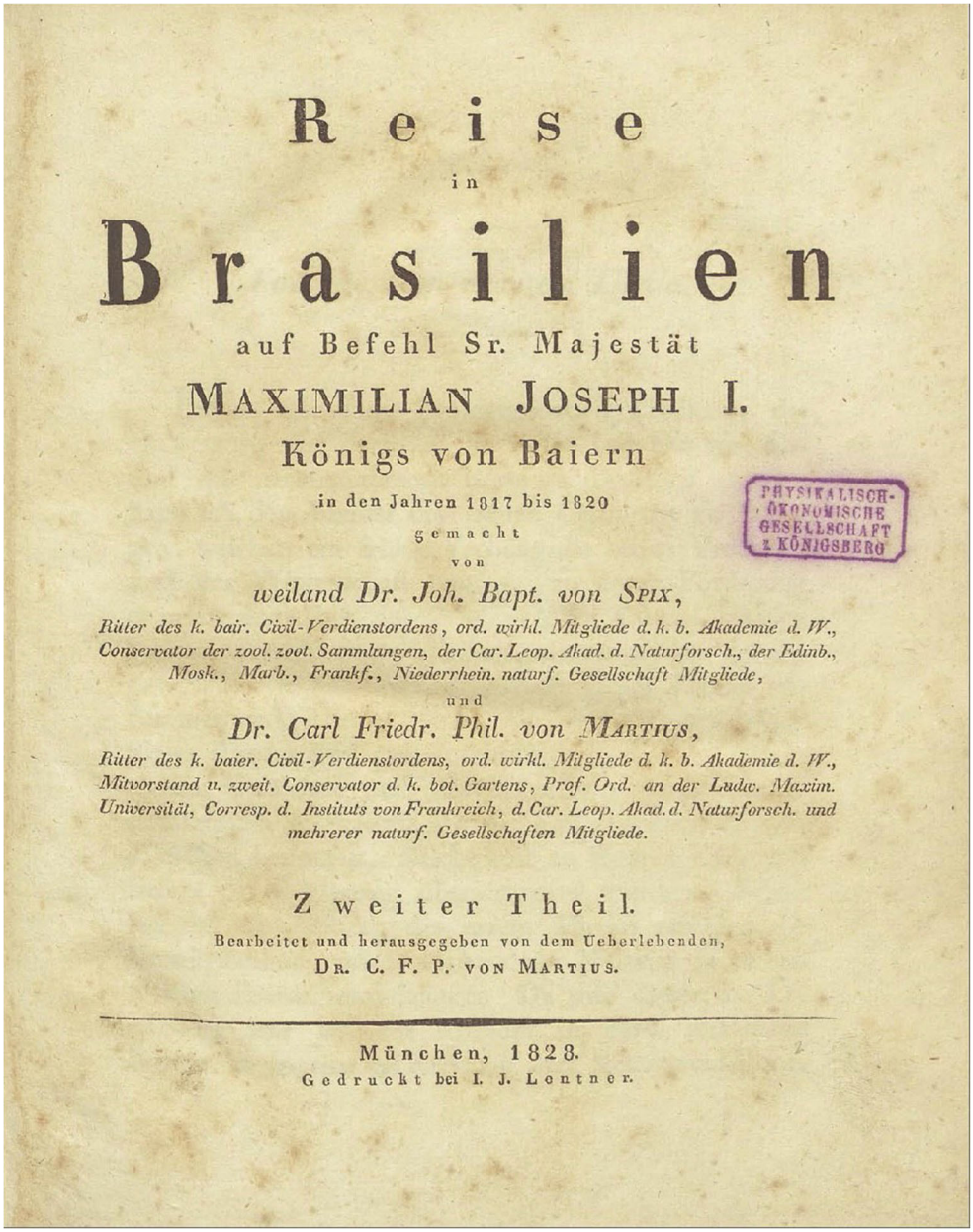


Fig. 3 Illustration made during the expedition of botanist Carl Friedrich Phillip von Martius and zoologist Johann Baptiste von Spix, who traveled across Brazil for 3 years, starting in 1817. Engraving, *Landschaft in Piauhy* by Carl Friedrich Philipp von Martius (1794–1868)



Reise
in
Brasilien
auf Befehl Sr. Majestät
MAXIMILIAN JOSEPH I.
Königs von Baiern
in den Jahren 1817 bis 1820
gemacht
von
weiland Dr. Joh. Bapt. von SPIX,
Ritter des k. bair. Civil-Verdienstordens, ord. wirkl. Mitgliede d. k. b. Akademie d. W., Conservator der zool. zoot. Sammlungen, der Car. Leop. Akad. d. Naturforsch., der Edinb., Mosk., Marb., Frankf., Niederrhein. naturf. Gesellschaft Mitgliede,
und
Dr. Carl Friedr. Phil. von MARTIUS,
Ritter des k. baier. Civil-Verdienstordens, ord. wirkl. Mitgliede d. k. b. Akademie d. W., Mitvorstand u. zweit. Conservator d. k. bot. Gartens, Prof. Ord. an der Ludw. Maxim. Universität, Corresp. d. Instituts von Frankreich, d. Car. Leop. Akad. d. Naturforsch. und mehrerer naturf. Gesellschaften Mitgliede.
Zweiter Theil.
Bearbeitet und herausgegeben von dem Ueberlebenden,
DR. C. F. P. VON MARTIUS.
München, 1828.
Gedruckt bei I. J. Lentner.
PHYSIKALISCH-ÖKONOMISCHE GESELLSCHAFT z. KÖNIGSBERG

Fig. 4 *Reise in Brasilien* (Trip to Brazil), a book published in three volumes between 1823 and 1831 by zoologist Johann Baptiste von Spix and botanist Carl Friedrich Phillip von Martius, which contains the first printed and widely disseminated mention of the Araripe fossil fishes

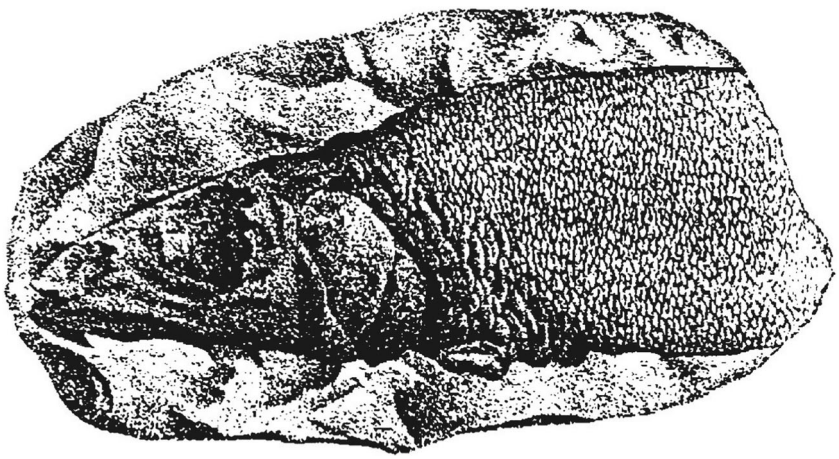


Fig. 5 In the second volume (1828: 599) of the work *Reise in Brasilien* (Trip to Brazil), Spix and Martius mention the existence of fossil fish in the Araripe; in the last volume of the work (1831: pl. XXII, Fig. 5), they illustrate a carbonate nodule with a specimen of fossil fish

Fig. 6 Carbonate concretions of the Araripe Basin (Santana Formation), in the municipality of Jardim (State of Ceará, Brazil), where the occurrence of fossils from the Cretaceous period is common. Concretions usually contain a fossil fish and are therefore referred to as ichthyoliths. The exceptional quality of preservation of organic remains includes the presence of tissues such as the intestines, ovaries, and heart

limestones that revealed fossil fishes inside them when broken. He located large deposits of fossil fishes in a locality called Mundo Novo, three leagues west of Barra do Jardim (Gardner 1846: 203–216), currently the municipality of Jardim in the state of Ceará.

The Diversity of Paleoichthyofauna and Dating the Araripe Geopark Rocks

Louis Agassiz, a Swiss native and scholar of zoology, paleontology, and geology, studied the Araripe fossils. As a professor at Harvard University, he sought to prove creationism and fiercely opposed Darwin's evolutionism.

Based on the fossils given by George Gardner, Agassiz published in 1841 the following species, *Calamopleurus cylindricus*, *Cladocyclus gardneri*, *Lepidotes temnurus*, *Notelops brama*, *Rhacolepis buccalis*, *Rhacolepis latus*, and *Vinctifer comptoni* (Agassiz 1841), thus began the growing interest in Araripe fossils, which would reveal many new species.

Based on paleoichthyofauna, Agassiz (1844) performed the first dating of sedimentary strata of the Araripe Basin, defining it as Cretaceous. In addition to the relevance of determining the age of the rocks in this sedimentary area, such dating represents a historical milestone for Brazilian geology. This was the first time that a Brazilian geological formation was dated on a paleontological basis (Carvalho and Santos 2005). Later, Agassiz visited Brazil in 1865, in charge of the *Thayer Expedition*, financed by an American industrialist and aimed at studying the ichthyological fauna of the Amazon basin. In fact, Agassiz intended to take advantage of the expedition to prove the fallacy of Darwinist theses and to prove the lack of variability of the species (Kury 2001).

Still in the nineteenth and early twentieth centuries, Araripe fossil fishes were also analyzed by researchers such as Edward D. Cope, Arthur S. Woodward, David S. Jordan, and John C. Branner, who published important paleontological literature in the *American Philosophical Society*, *Proceeding of Zoological Society*, and the *Smithsonian Miscellaneous Collection* (Cope 1871; Woodward 1887, 1890; Jordan and Branner 1908).

The Improvement of Knowledge: Rebuilding the Earth's Past

After Agassiz (1841, 1844), several studies revealed a huge number of new animals and fossil plants, enabling the reconstruction of an important period in Earth's history — the Cretaceous. In 1907, through the creation of the Geological and Mineralogical Service of Brazil, a new phase of paleontological material collection began. R. Crandall (1910) and Horace L. Small (1913), in expeditions for hydrogeological studies coordinated by the "Inspectorate of Works against the Droughts," enabled a better understanding of the stratigraphic aspects of the region. D.S. Jordan (1923) published a monographic study on fossil fishes, followed by the works of G. D'Erasmo (1938) and D. H. Dunkle (1940).

In a context hitherto taken over by foreign researchers, it is from the 1940s that studies conducted by Brazilians began: Rubens da Silva Santos, who described several new species of fish (Santos 1945, 1947, 1958, 1960, 1968), and Llewellyn Ivor Price, who named the first crocodyliforms of the Araripe Basin, *Araripesuchus gomesii* (Price 1959). Other fossil groups were also found, such as invertebrates, identified by Karl Beurlen (Beurlen 1963, 1964, 1966).

From the late 1960s to the early 1970s, studies that address the geological contextualization of fossils began. They enabled the use of fossils for paleoecological, paleoenvironmental, and paleoclimatological interpretation (Santos and Valença 1968; Mabesoone and Tinoco 1973). A new milestone for regional studies is due to Oscar Braun (1966), who correlated the Araripe Basin and other hinterland basins of northeastern Brazil based on their ostracods. In the 1970s, studies on Araripe began to reflect the great biological diversity among the fossils described (Carvalho and Santos 2005), namely, plants (Duarte and Japiassu, 1971), copepods (Cressey and Patterson 1973), ostracods (Bate 1972), insects (Silva and Arruda 1976), chelonians (Price 1973), pterosaurs (Price 1971; Wellnhofer 1977), and also new species of fish (Santos 1970, 1971; Taverne 1974, 1976; Wenz 1977).

Since then, a number of new publications have enabled the expansion of perspectives on the diversity of Araripe's fossil biota (Maisey 1991; Martill et al. 2007) and its evolutionary implications for the history of life on Earth.

Araripe Lagerstätten: A New Perception of the Relevance of the Geopark

The Araripe Geopark is located in the hinterland in northeast Brazil, where there is a geological and paleontological record of the Gondwana Lower Cretaceous, in a geodiversity hotspot context (Bétard et al. 2018). In particular, the exceptional state of preservation of its fossils enabled its endorsement by UNESCO in 2015 UNESCO (2017a, b, c) as a geopark. Despite the fact that the Global Geoparks Network (GGN) was officially at UNESCO only in 2015, the Araripe Geopark has been recognized as a geopark since 2006. Despite the importance of its geological heritage, the main regional economic activity is the extraction of rocks for cement production and construction, which leads to a process of progressive degradation of the landscape and its natural heritage. However, such a vast territory as the Araripe Geopark enables the use of its geodiversity beyond mineral exploration, namely, in the design and implementation of resources for scientific, educational, and tourism purposes (Henriques et al. 2020). Geoparks are known around the world as ideal training scenarios for excursions, as well as powerful resources to promote significant and relevant learning in geology and geoconservation (Ruban and Yashalova 2018; Henriques et al. 2011; Gabriel et al. 2018; Soares et al. 2018; Nascimento et al. 2020; Ruban and Ermolaev 2020). Then, there is an integration of academies' social responsibility engaging science and local communities in a mutually beneficial way (UNESCO, 2015; Henriques et al. 2020). The implementation of targeted local projects with global impact, rooted in culturally specific values, demands appropriate strategies to result in economic benefits to the population of the small communities in the geopark area (Henriques and Brilha 2017).

The area of the Araripe Geopark covers the Araripe Basin, where one can find two fossil conservation and concentration Lagerstätten (Martill 1997) of great importance in Lower Cretaceous rocks (Santana Formation, Crato, and Romualdo members). These are the Crato and Romualdo Lagerstätten, which can be considered as the best-known Mesozoic Lagerstätten of Gondwana.

The Crato Lagerstätten contains an abundance and excellent preservation of a diverse biota, preserved in laminated limestones. It is a fossil assemblage comprising fungi, animals, and plants from terrestrial and freshwater environments. Arthropods are the most represented invertebrates (Fig. 7), such as arachnids, crustaceans, insects, and millipedes. Among vertebrates, there are numerous endemic species of fish, anurans, squamates, testudines, crocodiles, pterosaurs, and birds. Among the plants, the oldest known angiosperms stand out (Grimaldi 1990; Menon and Martill 2007; Martill et al. 2007; Carvalho et al. 2015, 2019).

Meanwhile, in addition to containing abundant fossils of exceptional quality and high diversity of biota (Bate 1971; Cressey and Patterson 1973; Maisey 1991; Martill and Brito 2007; Brito and Yabumoto 2011), the Romualdo Lagerstätten is characterized by the three-dimensional preservation of specimens, without compression of organic remains, enabling both a perception of the volumetry of fossils in carbonate concretions and the identification of anatomical structures with exceptional preservation (Fig. 8). They include ostracods, copepods, echinoids, mollusks, decapods, fishes, chelonians, crocodyliforms, dinosaurs, and pterosaurs, in a biota that enables the understanding of the Early Cretaceous ecosystem, at a time of deep environmental changes in the Gondwana supercontinent. The fossils have easily recognizable anatomical characteristics, often preserving tissues and muscles of delicate structures, such as gonads, spermatozoans, gills, stomach contents, and even hearts (Maldanis et al. 2016).

The first collection of fossils carried out in Brazil with the recognition of their scientific importance occurred in outcrops of the area we now call Romualdo Lagerstätten. Fossil fishes discovered in the late eighteenth century by João da Sylva Feijó came from the carbonate concretions of the Santana Formation (Romualdo Member), so the special character of preservation of these fossils was already well-known (Feijó 1800). The exceptional nature of this conservation is reflected in the preservation of both original biominerals

Fig. 7 An insect preserved in the laminated carbonate of Crato Lagerstätte, in which the morphological details and color patterns are preserved. Federal University of Rio de Janeiro Collection, Geology Department (Brazil)

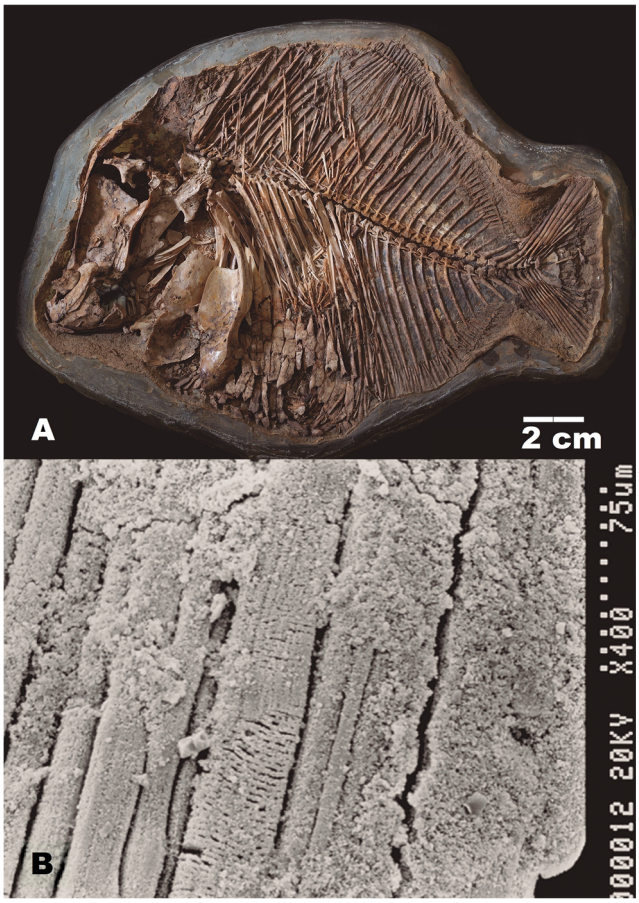


Fig. 8 **A** *Neoproscinetes penalvai* a ray-finned fish in a carbonate nodule from Santana Formation (Romualdo Member) with an exquisite preservation. **B** Muscular fibers preserved as francolite in a fossil fish from the Romualdo Lagerstätte. Rio de Janeiro State University Collection, Rio de Janeiro (Brazil). Photo courtesy of Paulo M. Brito

(bone and teeth) and fossilized soft tissues composed of the calcium phosphate mineral francolite. In some tissues, the preservation reaches the organelle level where cells are preserved (Martill and Brito 2007).

Over the two centuries after the first discovery, the fossils from Romualdo Lagerstätten were included in the main paleontology collections of international universities and museums, such as the Lisbon Academy of Sciences (Portugal), American Museum of Natural History (USA), Field Museum of Natural History (USA), British Museum of Natural History (England), Musée National d'Histoire Naturelle (France), Staatliches Museum für Naturkunde Karlsruhe (Germany), Museum für Naturkunde der Humboldt-Universität zu Berlin (Germany), and Kitakyushu Museum of Natural History and Human History (Japan). They were also included in some of the main collections of Brazilian museums and universities, such as the Plácido Cidade Nuvens Museum of Paleontology (Santana do Cariri, State of Ceará), the Federal University of Pernambuco (state of Pernambuco), the Federal University of Rio de Janeiro the State University of Rio de Janeiro (State of Rio de Janeiro) and São Paulo University (USP, São Paulo State). This is a result of their abundance, their importance to scientific research activities, and the possibility of dissemination and popularization of paleontology. As they are examples of easy recognition and of high scenic content, the fossils of the Santana Formation have enormous potential for use in exhibition collections in museum spaces (Henriques et al. 2020).

Preserved Heritage: Father Neri Feitosa and Early Institutional Collections at the Araripe Geopark

The task of preserving the ex situ heritage at the Araripe Geopark began with Neri Feitosa, born April 4th, 1926, in Inhamuns, state of Ceará. Feitosa was an important educator in religious schools, due to his ordination as a priest in 1950. He served in the Crato Seminar and created the school Educandário Padre Amorim, located in Jamacaru, state of Ceará (Brazil).

The activities developed by Father Neri Feitosa have always focused on education and social actions, leading him to create the Museum of Palaeontology of Jamacaru (Fig. 9), the first institution in the state of Ceará dedicated to the preservation of paleontological materials from the Araripe Basin. This museum was established on May 18th, 1967, in association with Educandário Padre Amorim, and hosted a unique collection of fossils found in Jamacaru, district of Missão Velha, and nearby locations such as Porteiras and the São Felipe mountain range. The performance of the students from the Educandário was relevant to the management of the museum, which organized lectures on various topics of interest to the local community. Initially containing 500 specimens, the collection had the collaboration of scientists such as Geraldo da Costa Muniz, Antonio Campos e Silva, Luiz Eurico Moreira, Mario de Biase, Enio Soliani Junior, and Frederic Nagy for the taxonomic classification of its material. In 1970, the fossil collection of the Brazilian Cretaceous housed in this museum was the largest in the country, with six thousand specimens including fishes, pterosaurs, mollusks, ostracods, and silicified woods. In 1971, it was deemed a public utility by the municipality of Missão Velha, state of Ceará. Father Neri Feitosa also demanded from federal institutions, such as the National Scientific and Technological Development Council (CNPq), Institute of National Historical and Artistic Heritage (IPHAN), and the National Department of Mineral Production (DNPM), the creation of an open park in the municipality, where people could observe the abundant fossils in nature; this was an impressive forecast of the creation of a geopark in Araripe to preserve and promote its precious fossils (Monteiro et al. 2009).

It is important to note the context in which this museum appears. The locality of Jamacaru is a rural region, whose main economic activity relates to the planting of sugar cane.

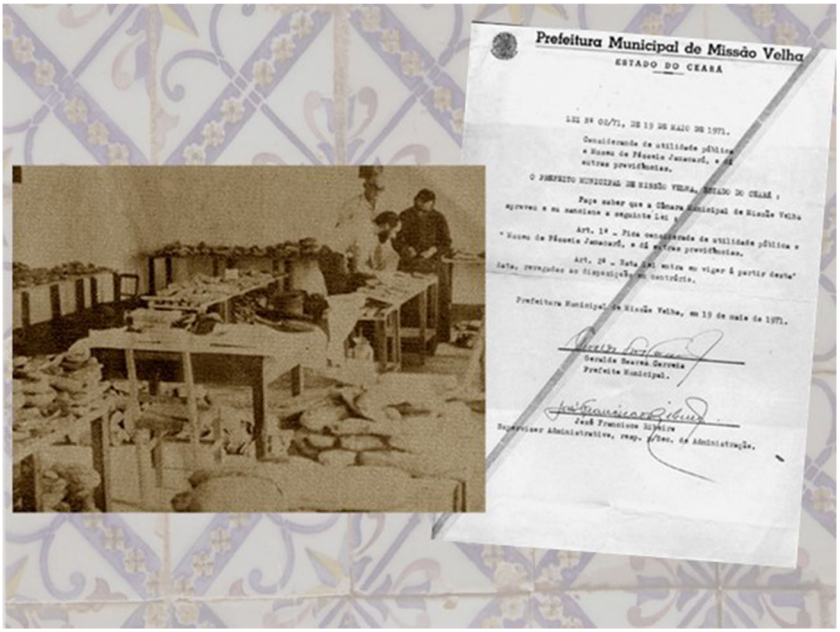


Fig. 9 Museum of Paleontology of Jamacaru, the first institution in the State of Ceará with a collection dedicated exclusively to the fossil record of Araripe Basin. It was founded by Father Neri Feitosa on May 18th, 1967, and deemed a public utility institution by the municipality of Missão Velha in 1971

This is the location of Gameleira mill, which was visited in 1800 by João da Sylva Feijó and the source of the first fossils identified for the Araripe Basin. Thus, the initiative of Father Neri Feitosa in creating the Museum of Paleontology of Jamacaru proved to be an important milestone for further actions to preserve the paleontological heritage in the region.

The museum was deactivated in the late 1970s; however, its existence had important developments. In 1988, with the purpose of preserving the fossil specimens in the municipalities of origin, two institutions were created: the Chapada do Araripe Paleontological Research Center, in the city of Crato, belonging to DNPM (current National Mining Agency), and the Santana do Cariri Paleontological Museum, created by Plácido Cidade Nuvens — a former student of Greek and Latin under Father Neri Feitosa.

Paleontological Heritage: The Foundations of the Araripe Geopark Economy

The understanding of the preservation mechanisms of the Crato and Romualdo Lagerstätten fossils in the Araripe Geopark and their relevance for paleoenvironmental interpretation enable the valuation of other heritage contents, namely, indicial and documental, which results into a significant increase in their heritage value (Henriques et al. 2020; Carvalho-Neta et al. 2019). The exceptionality of its organic matter conservation processes (Catto et al. 2016; Osés et al. 2016, 2017; Selden and Nudds 2012; Dias 2020; Barling et al. 2020) demonstrates the influence of geochemical events and interrelations with the bacterial microbiota. Moreover, the geographical and geological position of the Araripe Geopark means its fossils are key elements for the paleoenvironmental interpretation of rocks related to the marine ingression and formation of the South Atlantic Ocean. In the frame of basin analysis procedures, they display an enormous economic importance, associated with the Brazilian oil and gas deposits, namely, through the development of advanced training activities in the context of the hydrocarbon exploration models (Fig. 10, Henriques et al. 2020; Pena dos Reis and Henriques 2018).

Specimens displaying indicial content are often selected to illustrate concepts and ideas in textbooks, encyclopedias, and scientific journals; when they also display scenic content, they can be particularly useful for educational purposes (Henriques et al. 2020). This is the case of the fossil record from the Crato and Romualdo Lagerstätten, which represent important educational resources and/or attractive geotourism products.

One of the main issues related to the increase of geotourism in the Araripe Geopark region regards to its ex situ heritage, represented by thousands of fossil specimens distributed in several museum or research collections. It is widely known that geological collections, like any other scientific heritage, are important resources for education. However, they also have enormous economic importance, since they can be references for the prospecting of mineral resources, stimulating elements of the cultural industry or valuable trade objects due to their rarity.

Collections generally comprise a set of cultural assets, grouped according to a specific logic, by selecting components by processes of attribution of meaning, linked to the valuation of their items. They are subject to special protection and may or may not be exposed to the public (Lima and Carvalho 2020a, b). Every collection has thus a sacred

Fig. 10 Santana Formation outcrop at the Araripe Geopark, in which the lower section composed of gypsite represents the first marine ingression during the breakup of Gondwana and the opening of South Atlantic

character, related to the special protection to which it is subject and which gives it a special value directly associated to knowledge.

Regarding the in situ paleontological heritage, Brazil has a set of specific laws, decrees, and ordinances regulating fossil conventions and mining practices (Brasil 1942, 1967, 1990a, b, 1991; Carvalho 1993). Based on the legislations, minerals and fossil deposits constitute a state monopoly, which is an important legal basis for the preservation of relevant deposits for geological heritage. However, it is undeniable that a huge number of specimens, in collections established before the current legal system or obtained by inter-institutional agreements, make up a large ex situ heritage of fossils collected from the Araripe Geopark.

The fossil record represented by the museum collections, in exhibition or housed in research collections, whether or not located at the Araripe Geopark region, is part of the geological heritage of the Earth. As such, the inventory and evaluation procedures currently used in geoconservation, which focus mainly on geosites, need to be considered from a broader perspective to ensure that they include the entire fossil record and should be understood as potential ways of promoting earth science literacy and stimulating the development of geotourism (Henriques et al. 2020; Fig. 11).

Geoconservation in areas such as the Araripe Geopark has been mostly focused on aspects of protection and the scientific and educational use of geosites (Brito and Perinotto 2012; Wimbledon and Smith-Meyer 2012; Brilha 2018; Fornaro and Fernandes 2018; Bétard and Peulvast 2019). However, as stated in the UNESCO Global Geoparks guidelines, in addition to aspects of geoconservation and educational actions, geoparks should provide economic and social benefits for the communities involved (UNESCO 2016, 2017c; Brilha 2018). The question that arises is how fossils can improve the economic benefits to this geopark

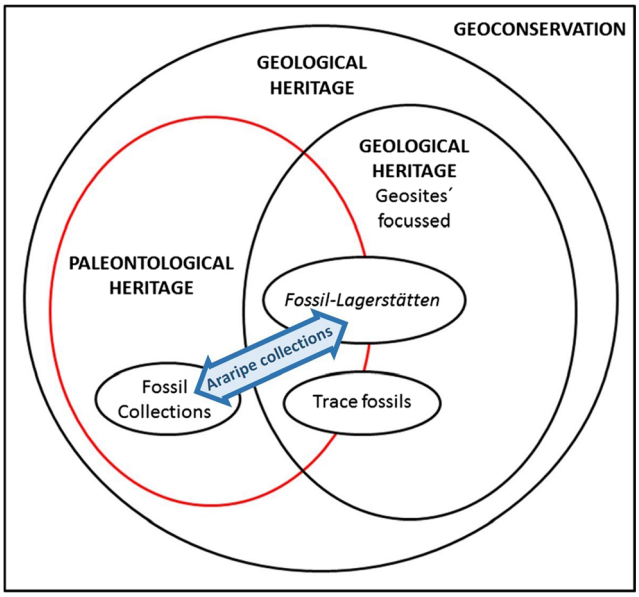


Fig. 11 The geoconservation of the paleontological heritage of the Earth requires the extension of the concept of geological heritage to ex situ geological objects (e.g., fossil collections) as aim of concern and action, namely, in the frame of geoeducation and geotourism (modified after Henriques et al. 2020)

Ex Situ Paleontological Heritage and Economic Benefits

Currently, the preservation of the paleontological heritage of the Araripe Geopark (and other regions of Brazil) has quite complex aspects. Despite the social recognition of the importance of fossil sites, destruction and illegal excavations continue to occur. In addition, mining activities carried out on sedimentary rocks have an important economic impact on local communities (Bétard et al. 2017), where fossiliferous outcrops have been used as a means of economic transformation, through strategies such as paleontological tourism and preservation of fossiliferous sites.

In the case of ex situ heritage, since the eighteenth century, the fossils of the Konservat-Lagerstätten of the Araripe Geopark are housed over many museum collections or national and international research centers, which primarily could represent a conflict for geoconservation in the region. However, such specimens can also be perceived as a geological object with heritage value, capable of driving curiosity and interest in knowing their provenance areas. In this perspective, they reveal enormous potential for an economic return through geotourism, as well as through research and training activities on geosciences (Carvalho et al. 2020; Henriques et al. 2020; Ruban 2015). The results of a research focused on the role of the Arouca Geopark (Portugal) as a tool to provide educational opportunities have shown that educational interventions using geoparks can contribute to promote significant and relevant learning on geology and on geoconservation, as well as to stimulate curiosity and interest for visiting other geoparks (Henriques et al. 2012).

The ex situ geoheritage, like paleontological collections, are remnants of nature, usually linked to ideas and concepts of nature. They are a powerful resource for education, promoting creativity and social coherence. Different values can be attributed to this heritage such as economic, political, cultural, scientific, spiritual, and aesthetic; however, the in situ and ex situ items can be integrated as a unique paleontological heritage, especially concerning the specimens of ex situ geological collections (Lima and Carvalho 2020a, b). As they are also cultural heritage collections of science and technology, they are related to the scientific and technological knowledge produced by humanity and testimonies of the scientific process (Araújo and Granato 2017; Araújo et al. 2017; Lima and Carvalho 2020a, b).

The valuing of geological heritage is a crucial task in geoconservation, but generally, it only considers aspects of the in situ heritage. However, the fossil record of the Earth is not limited to the specific places where fossils remain in situ (Henriques et al. 2020). In geoparks, there is a permanent tension between geological resource exploration and geoconservation. New projects concerning the promotion of links between geological heritage and all other aspects of Araripe's natural and cultural heritage are important to the social improvement in the geopark area (Mochiutti et al. 2012; Moura-Fé 2016; Brasil et al. 2019; Carvalho et al. 2020; Freitas et al., 2018).

In this context, the effective protection of geological heritage transcends the involvement of communities in geoconservation actions (Tavares et al. 2015; López-Otálvaro 2019). The ex situ heritage dispersed in several museum collections outside the Araripe Geopark (Nunes and Pioker-Hara 2019) area plays a decisive role in a holistic view of preservation at an international level, connecting the concepts of protection, education, research, and sustainable development as proposed by UNESCO Global Geoparks (UNESCO 2017c). Thus, it should also take into account the educational power of paleontological ex situ collections spread in global institutions, which enable the construction of a bridge awareness between the local actions and global effects, promoting a culturally differentiated way to achieve global sustainability and awareness (Werlen et al. 2016).

Rocks, minerals, and fossils in ex situ collections can be valued as cultural and geological heritage at the same time (Lima and Carvalho 2020a, b). These objects are usually linked to ideas and concepts of nature, allowing them to reinforce the desire of field interpretation in the areas where the fossils were found, through geotourism.

Geotourism implies activities that involve aesthetic and emotional experiences and interpretation through cultural filters. These aspects stimulate the rediscovery of the sense of wonder at the geological history of landscape and human

interactions. The presence of these elements in different museum collections gains enormous potential for stimulating visits to the Araripe Geopark, thus representing an important resource for geotourism activities in Brazil (Haag and Henriques 2016). Recent research on the activities developed at Casa da Pedra Reference Center located at Inhumas, Santana do Cariri, shows the attractiveness of the Araripe Geopark to universities and people from different countries that carry out teaching and research projects and/or geotourism activities in the area (Carvalho et al. 2020).

The interpretative possibility of ancient ecosystems and some elements of its complexity, from predation to parasitism, enable an "affective" immersion in the geological heritage and geodiversity of the Araripe Geopark through insights into the nature and evolution of the Gondwana terrestrial faunas. Besides, the quality of preservation of the biota provides opportunities to paleobiology and paleoecology and the complexity of a changing ecosystem related to the opening of South Atlantic. The impact caused by the Romualdo Lagerstätten biota becomes very evident since its first reporting by João da Sylva Feijó, in 1800.

According to Gordon (2018), geotourism is essentially a cultural response to the landscape, a combination of tourism based on geological elements of appropriate sites for interpretation, education, and leading to the awareness of the need for geoconservation and sustainable economic benefits for the communities in which the geoheritage lies (Farsani et al. 2011; Gordon et al. 2012; Cordeiro et al. 2015; Gordon 2016). Thus, the ex situ paleontological heritage makes it possible to complement the interpretive possibilities of the landscape. It represents a stimulus for the visitation of the sites where the fossils occur and fulfills one of the objectives of geoconservation, which is to stimulate economic actions that enable the improvement of social conditions of the region where the geological heritage is located. It should also be emphasized that, based on this understanding, the recognition and valuation of this ex situ heritage means the alignment with the provisions of the objectives of the Geopark Araripe (Ceará 2012 item 1): "Protect and conserve the sites of greatest cultural scientific relevance, called geosites." After all, it is a heritage that already exists outside the territory and that may have the function of stimulating interest for visitation in situ, also corroborating with the objectives of Araripe Geopark that is to "encourage quality tourism, based on in the multiple valences of the territory, through an international promotion and dissemination strategy" (Ceará 2012 item 6).

Importantly, the protection of the fossil heritage is not just a legal issue, but also an educational and economic need, since the protection system of this type of heritage demands actions of heritage education Schwanke and Silva (2004). As pointed by Wild (1988), fossiliferous sites should be considered as "natural cultural monuments" because of their scientific importance and public interest. For proper and lasting use of paleontological heritage, it is important to establish monitoring and conservation protocols, which, integrated with education and diffusion, will enable science and are effective job creators, thus improving income and life conditions of the population engaged in geotourism (Carvalho 2018; Carvalho and Stock Da-Rosa 2008).

Conclusion

The preservation and monitoring of fossiliferous sites as cultural elements are vital for the development of economic activities and, through scientific tourism, provide new ways to promote the improvement of social conditions where the fossils are found.

Fossiliferous sites represent a unique moment of the geological history of our planet, helping us to understand the past and the ecological and environmental changes of the present time or even the evolution of life and the meaning of living beings on our planet. This is the main attraction produced by paleontology. The growing interest in this science comes from this perception of life and how can be extemporaneous our existence.

In the two centuries resulting from the first discovery, the fossils of Romualdo Lagerstätten were included in the main paleontological collections of international museums and universities. It is a long history, started more than 200 years ago, with the discovery by João da Sylva Feijó, and that today it is consolidated through the management of the territory within the Araripe Geopark. Nevertheless, contrary to what usually is postulated, this paper argues that these ex situ collections, housed in different museum collections around the world, should not be seen only as a result of heritage theft. In fact, and largely due to the various heritage contents they hold (indicial, documental, and scenic), they are tools to promote curiosity and interest for visiting the Araripe Geopark. The ability to stimulate the discovery of the geological history of landscape, fossils, and human interactions, through activities involving aesthetic and emotional experiences, has a huge potential to stimulate visits to the Araripe Geopark and therefore a huge potential for an economic return to the territory through geotourism.

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