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A survey of the paleontological heritage of Paraná State, Brazil

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Abstract

The state of Paraná has a considerable area with sedimentary outcrop rocks from the Paraná Sedimentary Basins (Paleozoic and Mesozoic) and Bauru (Mesozoic), Curitiba Basin (Cenozoic), and metasedimentary basement rocks (Proterozoic) with fossiliferous content. The state's paleofauna and paleoflora, geologically distributed over more than one billion years, are diversified and acknowledged in several scientific publications. On this regard, a survey of the main collections and paleontological sites in Paraná state was conducted to provide a basis for the conception of a geoscience museum and with the scope of presenting representative fossils of the geological history of this region. The methodological procedures consisted of literature search, consultations with paleontologists, visits to various state institutions and a selection of the samples in different sectors of the State University of Ponta Grossa (UEPG). The surveyed set of paleontological collections and sites indicate the heritage that is known by the state research institutions and museums and allowed to organize and quantify the set of fossils that comprise the collection of the UEPG's Museum of Natural Sciences, which now exhibits to the public the evolutionary history of Paraná's fossils. The survey identified 25 geosites in the state and 10 museological institutions located in 20 municipalities, which represent the most valuable scientific and educational paleontological heritage, as emphasized in this text.

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1. Introduction

In Paraná State (southern Brazil) important fossils are found in its territory, indicating the existence of a significant geological, paleontological and cultural heritage, which is acknowledged in various recent scientific publications (e.g. Bosetti 2007, Liccardo and Weinschütz 2010, Manzig and Weinschütz 2012, Sedor et al. 2017, Kellner et al. 2019, Langer et al. 2019, Fraga and Vega 2020). The paleofauna and paleoflora in Paraná State are diversified, with important discoveries having been recorded in the past years but still unknown to the public in general. Fossil representatives of the different geological periods are found, which together tell the evolution of life on Earth, from the Proterozoic period (about 1.1 billion years ago) to the Cenozoic period (Pleistocene, until 11,700 years ago).

This work aimed to conduct a data survey of the *in situ* paleontological heritage (paleontological sites) and *ex situ* (paleontological collections) in the state of Paraná in order to provide a detailed picture of this heritage and define the representativeness of the fossils on display at the *Museu de Ciências Naturais* (MCN) [Museum of Natural Sciences] of the State University of Ponta Grossa (UEPG).

The records of fossils found in the rocks of the studied region indicate different paleoenvironments, paleoclimates

and distinct stages of life evolution in the past, which characterize an *in situ* geological heritage, that is, the outcrop areas that preserve these records or geosites. Brilha (2005) considers as geosites locations of occurrence of one or more elements of geodiversity (outcrops formed by the action of natural processes or human intervention), geographically well-defined and which have a significant value from the scientific, didactic, historical, touristic, or other, viewpoint. Rocks, minerals or fossils collected and preserved in collections comprise the *ex situ* geological heritage (Ponciano et al. 2011, Viana and Carvalho 2019) and its scientific/cultural contents refer directly to the geological characteristics of the geosites.

In Paraná, the stromatolites in meta limestones and marbles of the Crystallin Basement are the most ancient fossils, roughly 1.1 billion of years ago, and are located in the First Plateau of Paraná, in the rocks of the Capirú Formation (Guimarães et al. 2002, Piekarsz 2011).

In the Paraná Sedimentary Basin, in the region that comprises the Second Plateau of the state, there are numerous fossiliferous records along each lithostratigraphic unit (Furnas, Ponta Grossa, Itararé, Rio Bonito, Palermo, Irati, Serra Alta, Teresina, Rio do Rasto, Botucatu Formations) that date back between 419 and 65 million of years ago. Since the discovery of the first fossils in Paraná State (late



nineteenth century), the Second Plateau has been the focus of numerous paleontological researches that revealed important scientific discoveries throughout the geological units cited (e.g. Mac Gregor 1908, Clarke 1913, Rosler 1974, Matsumura et al. 2013). The most representative fossils of this region are ichnofossils and invertebrates of the Devonian period (Furnas and Ponta Grossa Formations), plant fragments of the Permian Period (Rio Bonito Formation), mesosaurids and crustaceans of the Permian Period (Irati Formation), silicified woods and stromatolites and invertebrates of the Permian period (Teresina Formation) and amphibians, fishes and plant leaves of the Permian (Rio do Rasto Formation), found in the Second Plateau of Paraná.

In the Bauru Sedimentary Basin, Third Plateau, in the Mesozoic period, sedimentary rocks of the Goio-erê Formation (Caiuá Group) preserved important bone fragments from lizards, pterosaurs and dinosaurs dated 145 to 66 million years ago. Also found in rocks of this formation are ichnofossils of Tetrapoda (Silva 2002, Langer et al. 2019).

Finally, from the Cenozoic times, there are records of fossils of crocodylomorphs, testudines, mammals and gigantic birds of the Curitiba Sedimentary Basin (Guabirota Formation – Paleogene, 66 to 23 million of years). In addition to these, fossils of Pleistocene mammals (2.5 million of years to 11,000 years) were found in alluvial deposits in Chopinzinho and Pinhão (Third Plateau), recorded by Pillati and Bortoli (1978) and Sedor and Born (1999), as well as records of vertebrates and invertebrates in several caves in Paraná (Sedor et al. 2004).

2. Material and methods

Ponciano et al. (2011) identified a possibility of classifying the geological/paleontological heritage as *in situ* in the case of geosites and *ex situ* heritage for the cases where the material was removed from the place of origin and kept in museums and scientific collections. In the case of paleontological heritage, the connection between the samples in museums and their places of origin (geosites) is very close, which requires a constant correlation between the sample contents and their geological context if an exhibition is considered.

Firstly, a survey of the main paleontological sites of the state of Paraná was conducted, based on the database available from the Brazilian Commission of Geological and Paleobiological Sites (SIGEP, terminated in 2013). According to the publications "Sítios geológicos e paleontológicos do Brasil" [Geological and paleontological sites in Brazil] volumes I, II and III, published between 2002 and 2013, three major sites in Paraná have been found to date. In addition to these three sites identified by SIGEP, other important outcrops and collections were acknowledged in several scientific publications, which, after analysis and selection, were incorporated to this study. Field activities for recognition of these locations were performed for data collection, image recording and videos.

After the geosites' identification, a search for the paleontological collections in the state was carried out. We visited the major research institutions on paleontology, among them, the Federal University of Paraná (UFPR), State University of the Midwest (UNICENTRO), State University of Ponta Grossa (UEPG), which have paleontological collections available to public visitors. Regarding other institutions, e.g.,

State University of Londrina (UEL), State University of Paraná (UNESPAR) and the Paleontological Museum of Cruzeiro do Oeste), we contacted the coordinators to obtain information about the collections. The relevant data were then organized to allow an appropriate selection and geologically identified according to the maps available from the Institute of Water Bodies and Lands (IAT).

3. Results and discussion

Fossils, records of any kind of life on Earth as belonging to a geological period before the present one (Holocene), i.e., remains and traces of animals and plants older than 11,000 years (Branco 2014) are considered as Natural and Cultural Heritage, article 216 of Brazil's Constitution (Brasil 2016), included as "Union's Assets" and protected by law 4.146/42 (Brasil 1942). Furthermore, due to their scientific and cultural value, they represent the Planet's Biological Memory, which must be preserved for future generations.

Every fossil is a scientific and cultural heritage by definition, but for the development of this work a broad criterion of representativeness was used in the selection of the main fossils found in Paraná which could concisely present the biogeographic history of this region and the scientific evolution. Museological criteria were considered, such as aesthetics, to exhibit it as a collection piece. Thus, a total of 25 fossiliferous deposits of great importance in the state and ten collections from public institutions that preserve important fossils were identified, comprising 20 municipalities (Table 1).

Table 2 describes the paleontological sites of the greatest scientific and educational importance in the state, the geological unit where the fossils are found, the municipality and the geographic coordinates of each geosite. This survey can be useful in the development of future measures of protection of paleontological sites in Paraná. The collected data were synthesized in a map (Figure 1), which shows the geographic distribution of the paleontological sites and collections in the state. This link between the location and institutional preservation, in universities or public museums, for example, where the fossils can be safeguarded for future generations to appreciate and learn from them is of vital importance (Page 2018). On this regard, the Museum of Natural Sciences of UEPG is near the Campus site of UEPG (100 meters away), having fossils of Devonian invertebrates. Part of the material that has been removed over the years is housed or exposed in this museum.

According to Page (2018), the five main factors of degradation of fossiliferous deposits are: 1. Natural degradation and vegetation growth – including chemical and physical actions, weathering and erosion; 2. Agricultural, forestry and other land management practices or contamination of sites and hiding by tree cover; 3. Engineering works, including infrastructure, industrial and housing construction works and coastal protection works / flood protection works – which includes physical damages, filling and contamination, removal, hiding and burial; 4. Extraction of mineral aggregates and restoration of work sites (comprising wastes removal) – which includes physical damages, filling, hiding, burial or removal of deposits; 5. Excessive or improper use - including physical damages, exhaustion / removal of deposits and/or loss of important specimens of interest to the global market and private collections.

Table 1: Main paleontological sites in Paraná State

Town/Site	Age	Stratigraphic Unit	Coordinates	Fossil type	References
Almirante Tamandaré Parque Aníbal Curi	Proterozoic	Capirú Formation	25°18,801' S 49°17,930' W	Columnar stromatolites	Guimarães, Neto & Siqueira, 2002; Piekarz, 2011.
Campo Largo/ Rio da Prata	Proterozoic	Camarinha Formation	25° 27' 32" S 49° 31' 55" W	Bodies of <i>Beltanelliformis</i> organisms	Drefahl & Silva, 2007
Balsa Nova/ São Luiz do Purunã	Devonian	Furnas Formation Paraná Group	25° 28' 03" S 49° 39' 28" W	Worm-like <i>Palaeophycus</i> ichnofossils and possibly also <i>Planolites</i> . Ichnogenera (<i>Cruziana</i> and <i>Rusophycus</i>) associated with trilobate arthropods at rest and in locomotion.	Guimarães, Assine; Netto; Melo; Góis, 2013. (SIGEP)
Ponta Grossa/ Estrada do Alagados	Devonian	Furnas Formation Paraná Group	25°04'17.8"S 50°06'23.4"W	Plant imprints assigned to <i>Psilophytales</i>	Rodrigues, Pereira, Bergamaschi, 1989
Ponta Grossa/ UEPG Campus	Devonian	Ponta Grossa Formation araná Group	25°05'33.0"S 50°06'20.3"W	In the outcrop area are found species of bivalve and univalve brachiopods, multi-elements of crinoids and trilobites ichnogenus <i>Zoophycos</i> isp.	Horodyski, Bosetti, Myszynsky, 2006. Bosetti, Horodyski, Matsu- mura & Junior, 2013.
Ponta Grossa/ Caniú River	Devonian	Ponta Grossa Formation Paraná Group	25°18'51"S 50°05'33"W	Detailed classification of asteroid and ophiuroid fossils of the following species: <i>Paranaster crucis</i> ; <i>Magnasterella darwini</i> ; <i>Encrinaster pontis</i> and <i>Marginix notatus</i>	Clarke, 1913 Fraga & Vega, 2020.
Ponta Grossa/ Sant'ana Airport	Devonian	Ponta Grossa Formation Paraná Group	25°10'48"S 50°08'47"W	Detailed classification of asteroid and ophiuroid fossils of the following species: <i>Paranaster crucis</i> ; <i>Magnasterella darwini</i> ; <i>Encrinaster pontis</i> and <i>Marginix notatus</i>	Clarke, 1913 Fraga & Vega, 2020.
Ponta Grossa/ Curve 2 Section Cescage Section	Devonian	Ponta Grossa Formation Paraná Group	25°03'50.0"S 50°07'58.2"W 25°05'86" S, 50°07'95" W	Examples of fossils found in the outcrop sections: Bivalve Brachiopods, <i>Australospirifer iheringi</i> ; <i>Australocoelia palmata</i> ; <i>Australospirifer iheringi</i> ; <i>Orbiculoidea</i> spp; <i>Gigadiscina collis</i> ; <i>Derbyina</i> sp; <i>Derbyina whitiorum</i> ; Univalve <i>Schuchertella</i> sp. such as <i>Tentaculites</i> sp., in addition to Crinoid pluricolumnal, Pygidium of trilobite Calmonyd, Ichnogenus <i>Zoophycos</i> isp.	Bosetti, Horodyski, Matsu- mura & Junior, 2013.
Jaguariaíva-Arapoti railway extension	Devonian	Ponta Grossa Formation Paraná Group	24°14'50.5"S 49°43'18" W	Diverse invertebrate fossils (Conulariida, Brachiopoda Articulata and Inarticulata, Mollusca Bivalvia and Gastropoda, Tentaculitoidea, Trilobita and Crinoidea). Asteroids and Ophiuroids are also found. Microfossils: plant cuticles, sporomorphs, Chitinozoa, Acritarch, Tasmanaceae and scolecodonts. Among ichnofossils are the ichnogenera <i>Planolites</i> sp., <i>Paleophycus</i> sp., <i>Bergaueria</i> sp. and <i>Zoophycus</i> sp.	Clarke, 1913 Bolzon, Azevedo, Assine, 2013 (SIGEP). Fernandes (1996) Fraga & Vega, 2020.
Tibagi/Itáytyba Transbrasiliana highway	Devonian	Ponta Grossa Formation araná Group	24° 23 '55 "S 50° 20 ' 16 "W	Vascular plants: <i>Spongiophyton lenticulare</i> ; <i>Palaeostigma seawardii</i> Irregular <i>Haplostigma</i>	Matsumura, Iannuzzi, Bosetti, 2013.
Tibagi/ Wolff Site	Devonian	Ponta Grossa Formation araná Group	24°33'42" S 50°31'00" W	Vascular plants: <i>Spongiophyton lenticulare</i> ; <i>Palaeostigma seawardii</i> Irregular <i>Haplostigma</i>	Matsumura, Iannuzzi, Bosetti, 2013.
São João do Triunfo/ Permian Flora	Permian	Rio Bonito Formation Guatá Group	25° 40' 58"S 0° 17' 49"W	Plants assigned to the following species: <i>Sphenophyllum brasiliensis</i> ; <i>Annularia occidentalis</i> and <i>Annularia readi</i> .	Rosler, 1974
Figueira/Coal Mine	Permian	Rio Bonito Formation Guatá Group	23°49'17.4"S 50°24'59.4"W	Paleoflora examples: Lycophytes of the genus <i>Brasilodendron</i> , <i>Sublagenicula</i> and <i>Lagenosporites</i> . Sphenophytes: <i>Paracalamites australis</i> ; <i>Sphenophyllum brasiliensis</i> , <i>Annularia occidentalis</i> . Phyllocladaceae: <i>Arterotheca derbyi</i> . Pteridosperms: <i>Pecopteris cambuyensis</i> , <i>Sphenopteris lobifolia</i> . and <i>Glossopteris communis</i> . Coniferous genera such as <i>Paranocladus</i> , <i>Buriadia</i> <i>Paranospermum</i>	Branco & Rösler (2004)
Irati / Gutierrez Station	Permian	Irati Formation Passa Dois Group	25°31'4.45"S 50°39'28.33"W	<i>Mesosaurus tenuidens</i> ; <i>Stereosternum tumidum</i> and Crustaceous	Mc Gregor, 1908 Gervais, 1864.,
São Mateus do Sul / Petrosix	Permian	Irati Formation Passa Dois Group	25°51'39"S 50°23'50"W,	<i>Mesosaurus tenuidens</i> ; <i>Stereosternum tumidum</i> and Crustaceous	Mendes, 1954

Table 1: Main paleontological sites in Paraná State (continued)

Town/Site	Age	Stratigraphic Unit	Coordinates	Fossil type	References
Prudentópolis / Prud 1 Quarry	Permian	Teresina Passa Dois Group	25°12'30.8"S 50°57'12.4"W	Bivalves in limestones, coquinas	Neves, Rohn & Simões, 2010
Prudentópolis / Prud 2 Quarry	Permian	Teresina Formation Passa Dois Group	25°12'25.1"S 50°56'56.4"W	Bivalves in limestones, coquinas	Neves, Rohn & Simões, 2010
Prudentópolis / "Pinheiro de Pedra" [Stone Pine Tree]	Permian	Teresina Formation Passa Dois Group	25°22'12"S 51°00'58"W	Fossil trunks of conifers	Pontes-Filho et al. 2019
Jacarezinho/ Bony Fish	Permian	Rio do Rasto Formation Passa Dois Group	23°10'08.40"S 49°57'49.48"W	Shark fin spines of the following species: <i>Sphenacanthus riorastoensis</i> and <i>Sphenacanthus riorastoensis</i>	Pauliv et al, 2012
Mauá da Serra – Ortigueira (Serra do Cadeado)	Permian	Rio do Rasto Formation Passa Dois Group	23°58'30"S 51°05'30"W; 23°58'30"S 51°09'00"W; 24°00'15"S 51°05'30"W 24°00'15"S 51°09'00"W	Paleontological record of plants (<i>Schizoneura</i> , <i>Glossopteris</i> , <i>Paracalamites</i> , <i>Pecopteris</i>), bivalves (<i>Leinzia</i> , <i>Palaeomutela</i> , <i>Terraia</i>), gastropods, conchostraceans (<i>Pseudestheria</i> , <i>Monoleiophus</i> , <i>Euestheria</i> , <i>Asmussia</i> , <i>Liograptus</i>), oysters and some insects, and an especially significant fauna of tetrapods. This includes the dicynodont <i>Endothiodon</i> , a small-to-medium size terrestrial herbivore, and two forms of temnospondyl "amphibians", one with long rostrum, <i>Australerpeton cosgriffi</i> , and another with short rostrum.	Langer et al, 2009 (SIGEP)
Cianorte/ Indianópolis	Cretaceous	Rio Paraná Formation Caiuá Group	23°40'26.9"S 52°37'02.9"W 23°25'39.23"S 52°38'0.41"W	Ichnofossils assigned to small theropods, and primitive mammals.	Leonardi, 1977
Cruzeiro do Oeste	Cretaceous	Goio-Erê Formation Caiuá Group	23°45'35"S 53°03'53"W	Pterosaur: <i>Caiujara dobruskii</i> Iguanid lizard: <i>Gueragama sulamericana</i> Dinosaur (theropod): <i>Vespersaurus paranaenses</i> Pterosaur: <i>Keresdrakon vilsoni</i>	Manzig et al, 2014 Simões et al, 2015 Langer et al, 2019 Kellner et al, 2019
Curitiba	Paleogene	Guabirota Formation	25°30'30"S 49°20'30"W	First discovery: Ziphodont type tooth assigned to Crocodylomorph. Guabirota Fauna: Mammals (Cingulata, Notoungulata, Astrapotheria and Metatheria). Fossil remains of seven armored xenarthra are identified, including a description of a new species and genus named <i>Proeocoleophorus carlinii</i> . The Guabirota ungulates are assigned to Interatheriidae, Oldfieldthomasiidae and Astrapotheria. The metatherian mammals are represented by one sparrow-dont, one paleotentoid and one argyrolagoid.	Liccardo & Weinschütz, 2010 Sedor et al, 2017
Chopininho	Pleistocene	Recent sediments	25°51'24"S 52°32'11"W	Mastodont: <i>Stegomastodon waringi</i>	Pillati & Bortoli. 1978.
Cerro Azul/ "Caverna Toco-que-não-cai" (Cave)	Pleistocene	Recent sediments in caves of the Votuverava Formation of the Açungui Group.	24°46'31.0"S 49°06'45.0"W	Tooth fragment, Pleistocene mastofauna of the genus <i>Tapirus</i>	Sedor, Born & Santos, 2004.

Table 2: Main paleontological collections in Paraná State.

	Collections	Institution	Location	Coordinates
1	Museum of Natural Sciences	UEPG	Ponta Grossa	25°05'29.1"S 50°06'13.3"W
2	Laboratory of Paleontology and Stratigraphy	UEPG	Ponta Grossa	25°05'22.6"S 50°05'38.1"W
3	Campos Gerais Museum	UEPG	Ponta Grossa	25°05'47.4"S 50°09'31.2"W
4	Museum of Natural Sciences	UFPR	Curitiba	25°26'51.3"S 49°13'58.3"W
5	Laboratory of Paleontology	UFPR	Curitiba	25°27'04.5"S 49°13'53.9"W
6	Museum of Natural Sciences	UNICENTRO	Guarapuava	25°21'07.0"S 51°28'14.5"W
7	Museum of Geosciences	UNICENTRO	Irati	25°32'00.5"S 50°39'24.7"W
8	Museum of Geology	UEL	Londrina	23°19'35.9"S 51°12'05.1"W
9	Cruzeiro do Oeste Museum	City Museum	Cruzeiro do Oeste	23°46'37.0"S 53°03'57.2"W
10	Museum and Laboratory of Geology	UNESPAR	Campo Mourão	24°02'36.5"S 52°23'12.7"W

Table 2 describes the location of the collections found with samples of high scientific and educational value not only in the state of Paraná but from other Brazilian and world regions. The collections are visited by students from primary and secondary schools, high school, and universities, and the community in general.

According to Mansur et al. (2013), the environment of a collection represents a safety area because the collection can be easily recorded, documented and undergo interventions to maintain its integrity and appropriate housing. In the most institutions, *ex situ* paleontological heritage is protected by the trustee systems in force and by the codes of conduct and guidelines set out by the Brazilian Museum Institute, Law 11.904 of January 14, 2009 (Brasil 2013). These management, preservation, documentation, disclosure and protection procedures must ensure perfect preservation, representation and communication of existing materials (Viana and Carvalho 2019). According to these authors, musealization must therefore potentialize the educational content of the fossil and strengthen the actions of preservation of the cultural heritage.

Carvalho (2016) emphasizes that fossils represent two important elements for the management of a territory and are inseparable from the paleontological heritage. The first one is *social identity*, in which the record of life in a scale of time much larger than the historical time, allows a valorization of the geographic space and the communities that exist there,

enhancing the feeling of belonging. The second element is *economic relevance*, because people's interest in paleontology allows the development of job-generating activities in the cultural industry and geotourism.

The first definition of geotourism appeared in England (Hose 1995) proposing to "facilitate understanding and provide service facilities for tourists to acquire knowledge of the geology and geomorphology of the site, going beyond mere spectators of an aesthetic beauty". Thus, the essential idea of geotourism is to aggregate the scientific knowledge to the natural and cultural heritage in a pleasant and understandable manner, valuing it and allowing touristic visitation to occur in a sustainable way (Jorge and Guerra 2016). This tourism segment has used the interpretation of the cultural/scientific content offered by fossils in collections or in geosites as a strategy for valuing the heritage and contributing for its popularization and preservation. Geotourism is closely linked to the strategies of preservation of the geological and paleontological heritage.

4. Conclusion

The survey of the main paleontological collections and sites in Paraná identified 25 geosites and 10 museological institutions located in 20 municipalities, which represent the most valuable scientific and educational paleontological

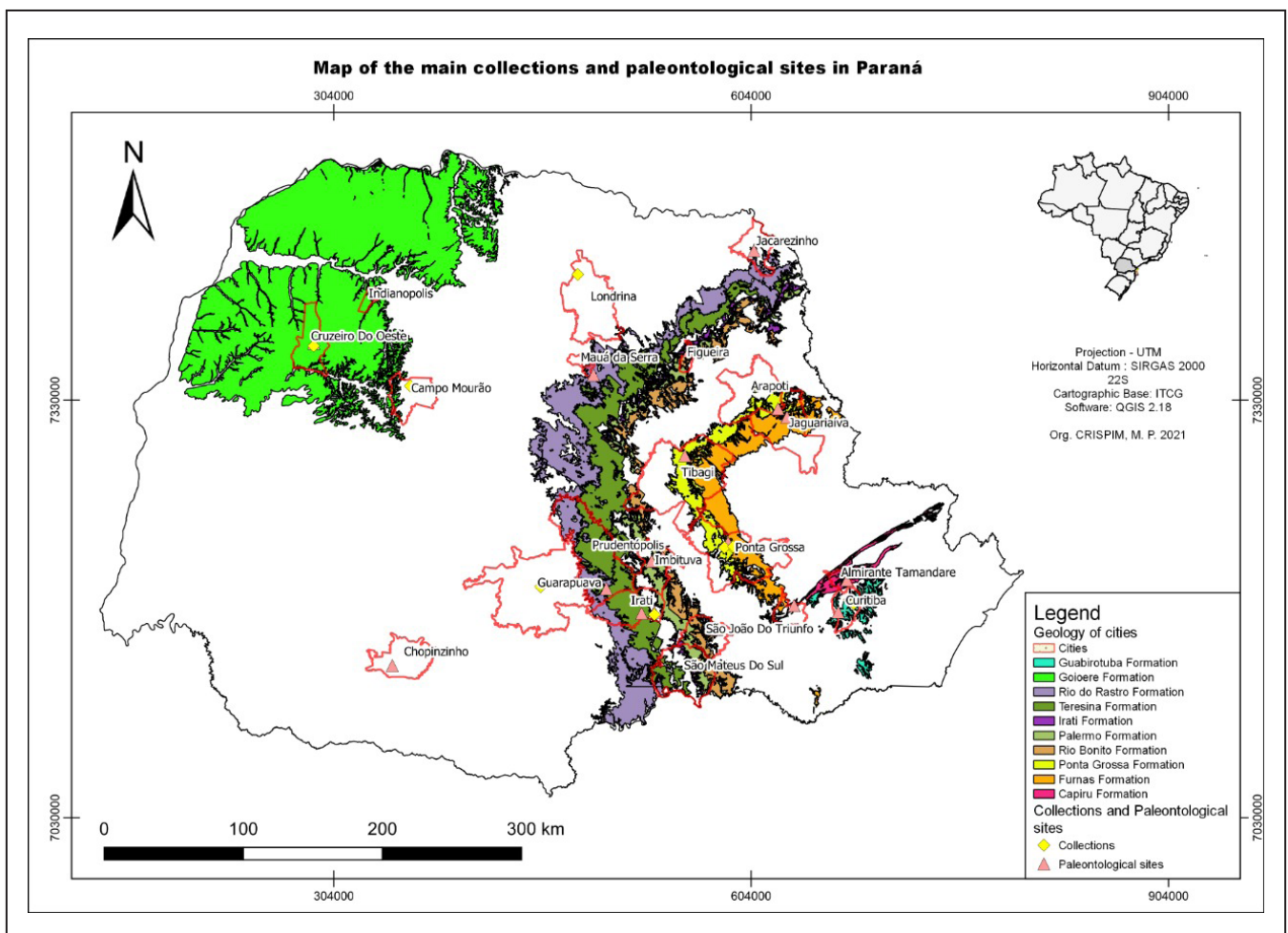


FIGURE 1. Map of Paraná State with location of the cities that house in their territories collections and/or paleontological sites of great scientific and educational importance.

heritage, comprising the main fossils that cover the geological timeline known in the state, from Proterozoic to Cenozoic. This selection illustrates the conception of the paleontological exhibition of the UEPG's Museum of Natural Sciences, which seeks to show the biological memory of Paraná.

The paleontological heritage of the state is diversified, and the institutions that preserve it not always exhibit it according to the evolution timeline over the geological timeline, but fulfill a major role in the preservation of *ex situ* heritage. The surveyed data set indicated the potential educational value of the collections, and the correlation between the fossil and the geosites is shown to be essential to understanding the territory.

Public communication of geoscientific information in museums requires synthesis surveys like the present one for the development of an effective planning and directed to different target audiences among visitors. This set of information can also provide different usages such as the production of catalogues, communication and educational materials based on the data presented here, which also serves as support to appropriate touristic releases.

There is a strong potential for inclusion of this heritage in the development of geotourism in Paraná, and this survey may provide the basis for future actions of protection and preservation of the sites of great paleontological importance and offer access to geoscientific knowledge to the population in general.

The paleontological exhibitions of various institutions in Paraná ensure preservation of the heritage and its scientific-educational communication but tend to underestimate the geotouristic potential of the collections and the geosites as well. A refinement of this analysis may contribute to strategies developed to reframe the paleontological heritage considering the relationship between geotourism and paleontology.

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