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ORIGINAL ARTICLE

The Hidden Faces of Paleontology: Some Case Studies in Central Mexico

Katia Adriana González-Rodríguez[1] · Víctor Manuel Bravo-Cuevas[1] · Consuelo Cuevas-Cardona[1] · Miguel Ángel Cabral-Perdomo[1] · Elizabeth Ortiz-Caballero[1]

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Abstract

Mexico has a diverse fossil record which ranges from the Paleozoic to the Pleistocene, depicting both marine and continental environments. Some of these paleontological sites are exploited by ordinary people to obtain rocks for the construction industry. These non-professionals whom we refer as "the hidden faces for paleontological studies" have enabled the preservation, conservation, and study of many fossils. The effort and compromise that these people show when collecting fossils is widely unknown; their names and faces are barely exposed in publications or reports. This work pretends to tribute their enormous commitment to conserve the paleontological heritage of Mexico, by showing some examples of their contributions, and the way we partially acknowledge their invaluable help. Likewise, the importance of private fossil collections and the creation of local museums is commented.

Keywords Paleontological heritage · Fossils · Conservation · Paleodiversity · Non-professionals · Mexico

Introduction

Fossils constitute an important part of the natural heritage of countries; therefore, they are usually protected by laws in many nations around the world. In Mexico, the "Instituto Nacional de Antropología e Historia" or INAH (National Institute of Anthropology and History) is designated to protect and preserve the paleontological heritage. Fossils protection is enclosed in the Article 28 Bis of the "Ley Federal de Monumentos y Zonas Arqueológicos, Artísticos e Históricos" (Federal Law of Monuments and Archaeological Zones, Artistic and Historical from INAH). This work is conducted under the observation of the Council of Paleontology, since 2000 (Aguilar-Arellano and Alvarado-Mendoza 2020). However, the development of paleontological collections as reservoirs for the conservation of paleodiversity in several museums of Mexico, as well as the protection of fossil localities in their natural environment, are the clue to preserve the fossils found in the territory, many of which were collected by non-professionals.

The first reports of fossil material in Mexico come from pre-Hispanic times, when they were used as tributes in religious ceremonies, but since the Spanish conquest in the sixteenth century, reports of fossil discoveries were frequently exposed by some conquerors, such as missionaries (Carreño and Montellano-Ballesteros 2005); nevertheless, there is scarce information about the collectors and the final destination of most material during this time. From the seventeenth century forwards, many fortuitous discoveries were made by common people, and paleontological studies started in the country. These formal investigations were conducted primarily by foreign geologists dedicated to the exploration of the territory searching for mineral resources (such as oil), but in their way, they used to find diverse fossil material that was briefly described (Cuevas-Cardona 2009). The exploration for fossil continues until the present day; however, little attention has been paid to the non-professional collectors that have contributed to the study and conservation of this patrimony.

✉ Katia Adriana González-Rodríguez
katiag@uaeh.edu.mx

Víctor Manuel Bravo-Cuevas
vbravo@uaeh.edu.mx

Consuelo Cuevas-Cardona
cuevas@uaeh.edu.mx

Miguel Ángel Cabral-Perdomo
cabralma@uaeh.edu.mx

Elizabeth Ortiz-Caballero
elizabeth_ortiz@uaeh.edu.mx

[1] Instituto de Ciencias Básicas E Ingeniería, Área Académica de Biología, Universidad Autónoma del Estado de Hidalgo, Pachuca, México

In 2015 a group of professors from different universities of Mexico led by researchers of the Universidad Autónoma del Estado de Hidalgo (UAEH), decided to recognize those non-professionals who have contributed in many ways to the development of science. The outcome of these ideas was the book named "Los rostros ocultos de la ciencia" (the hidden faces of science) (Cuevas-Cardona and González-Rodríguez 2015).

At that time, we included ethnobiological and paleontological case studies in Mexico to show the contributions of the working class in scientific studies. Quarry laborers, country people, farmers, among others, have helped to build part of the science in the country. Every time we have published an article, we have intended to acknowledge their invaluable help, either to discover or to preserve the materials; nevertheless, we believe that a wider audience around the world should know their names and supporting aid.

The purposes of the present study are to present some examples of the hidden faces that have helped to increase the knowledge of the Mexican paleodiversity, starting with the review of some fortuitous discoveries of fossils in the Valley of Mexico during the nineteenth century, to continue with case studies of well-documented paleontological localities in the states of Puebla (Tlayúa Quarry and Pie de Vaca) and Hidalgo (Muhi Quarry), and commenting the significance of fossil collections by non-professionals.

Fortuitous Discoveries of Fossils in the Valley of Mexico During the Nineteenth Century

During pre-Hispanic times it is known that the Mexica Empire was able to prevent the flooding of their capital city Tenochtitlán thanks to the construction of a complex drainage system. Its destruction when the Spanish arrived in the sixteenth century led to frequent flooding in Mexico City during colonial times. In subsequent years, the construction of several drainage systems, provided partial solutions; however, they were continually interrupted by the lack of funds and political conflicts (Miranda-Pacheco 2019). One of these projects was the Tajo de Huehuetoca in the State of Mexico, which took 150 years to be completed and that is still part of the drainage system of Mexico City (Ramírez de Alba 1995). Another one is the Tequixquiac Tunnel, which was begun during the time of the emperor Maximilian, later continued under President Benito Juárez, and finally completed during the government of President Porfirio Díaz (Miranda-Pacheco 2019). President Díaz was pressured by various social sectors to hurry the completion of the project. Doctors argued that stagnant waters caused diseases, while landowners and officials wished to take advantage of drained land to expand their holdings and engineers wanted to finally put an end to the countless floods that kept swamping Mexico City (Miranda-Pacheco 2019).

What no one imagined was that over time, thanks to observant construction workers, numerous fossils would be discovered, enriching the paleontological knowledge, mainly of the nineteenth century naturalists. Starting in 1864 and 1865, when studies for the tunnel had begun, engineers and workers who started digging found numerous fossils, some nearly on the surface and others 14 m underground. Among the fossils found were *Elephas*, *Macrauchenia*, and *Equus*. The bones were kept safe by Jesús Manzano, the engineer who started the work. Manzano and others who continued the excavations made the fossils available to the paleontologists of the time, Mariano Bárcena and Antonio Del Castillo. In 1871, during President Benito Juárez government, Del Castillo sent a letter to the Ministry of Development to tell him that on December 5, the acting director of the drainage works had shown him the fossils that had been discovered up to that point. These fossils belonged to a post-Tertiary fauna which included new families and genera previously unknown in the Valley of Mexico. One example was a huge armadillo, a glyptodont like the one found in the pampas of Buenos Aires, Argentina, and which was held by the British Museum "as the only specimen in the world." Del Castillo concluded his letter by acknowledging the work of the director, who had "collected and preserved the aforementioned fossils, which have furnished science with their advances" (Del Castillo 1871).

On February 4, 1870, a bone that attracted much attention was found. It was a sacral bone of a llama (*Palauchenia mexicana*) that had been carved by a human. This led to numerous hypotheses being formulated about the possible coexistence of humans with the post-Tertiary fauna whose fossils had been discovered. Mariano Bárcena wrote that apparently the artist who carved it had tried to represent the face of a pig, although it could also have been a coyote or some other meat-eating mammal. He quoted an engineer named Tito Rosas who stated that he had not extracted the fossil bone himself but had been present when it was removed and attested that it had been found at a depth of 12 m (Bárcena 1882).

Later, an engineer involved with the drainage works during the Porfiriato (dictatorial period of Porfirio Diaz's presidency) was Luis Espinosa, who directed the project for several years. In June 1901, several newspaper editors went to Zumpango to observe the progress of the works, and they were offered a meal in Tequixquiac. There they were invited to Espinosa's house and were able to view the numerous fossils that were stored on the second floor. The author of the article said that the best-preserved specimens had been taken to the National Museum and that a site museum was expected to be opened (Zumpango 1901).

But the drainage works were not the only diggings that led to the discovery of fossils by hidden or little-known figures. An 1872 article stated that a fossilized skeleton of a horse had been discovered in the Olivar del Conde neighborhood and that the person who had found it had informed the Mexican Society of Natural History (Hallazgo 1872), although no information in this regard could be found in the Society's journal. Thereafter, in 1880 a publication claimed that fossil remains which appeared to be mastodons and mammoths had been found at some excavations in Totimehuacán, Puebla state. The article compared these remains with those that had been extracted from the post-Tertiary layers at Tequixquiac. The Senior Official of the Ministry of Development had already asked members of the Geographical–Explorer Commission to go and examine them and to study the nature of the layers in which they were found (Datos paleontológicos 1880). Several years later, during the excavation of the collector drain no. 12, the remains of a proboscidean, possibly of the genus *Elephas*, were unearthed in Santa Anita, an indigenous town to the east of Mexico City. The person who announced the discovery was Enrique Díaz Lozano, a researcher of the Institute of Geology of the Universidad Nacional Autónoma de México (UNAM). However, he clarified that the discovery had been made by workers of the drainage project. He thanked the engineer, Othón Salvador Orozco, head of the Water Bureau, and the personnel who worked under him, for the courtesy they had shown him (Díaz-Lozano 1936).

Contributions of Some "Hidden Faces" to Paleontological Studies in Central Mexico

The Tlayúa Quarry of Tepexi de Rodríguez, Puebla

The Tlayúa Quarry of Tepexi de Rodríguez, state of Puebla in central Mexico is one of the most important Cretaceous localities in the country. The quarry is a Konservat-Lagesttäte because of the high-quality preservation of thousands of fossils found there. The locality has been exploited to obtain limestone for the building and construction industry for more than 50 years by the Aranguthy family, owners of the quarry (Fig. 1). Since 1980, the Universidad Nacional Autónoma de México (UNAM) manages the study and conservation of the fossils donated by the family. The history of the discoveries made by the Aranguthy family has been documented in diverse publications (e.g. Applegate 1996, Espinosa-Arrubarrena and

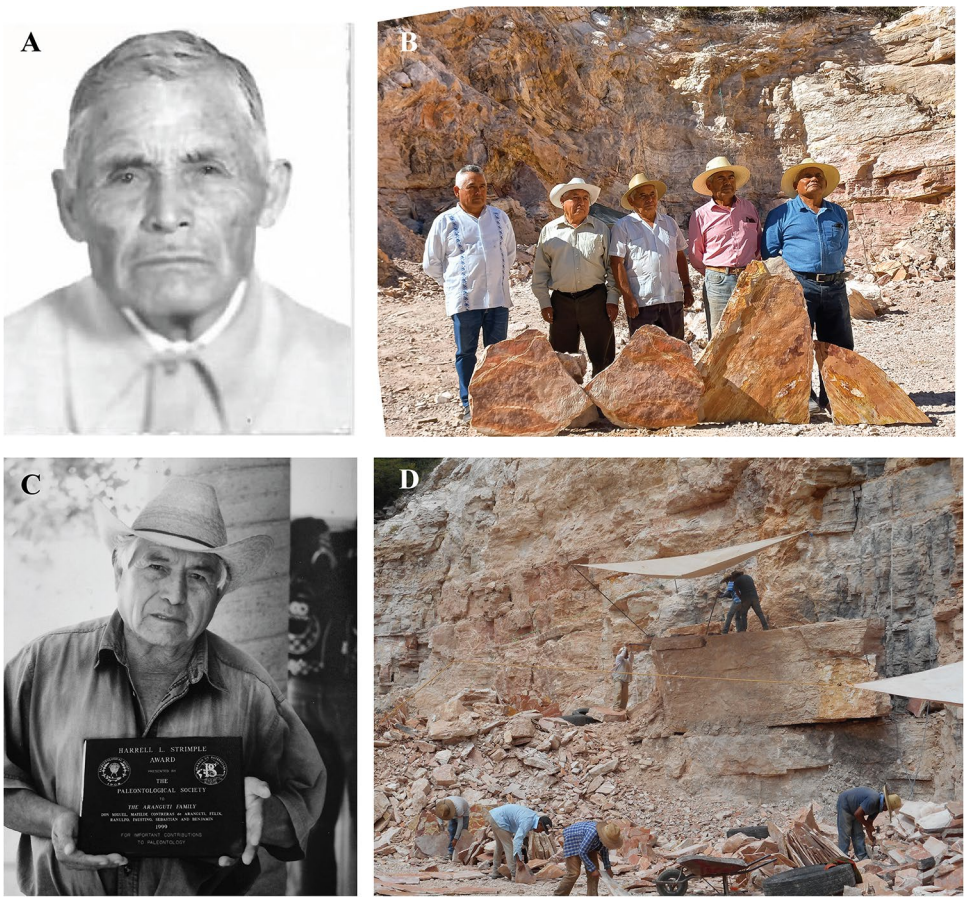

Fig. 1 **A** The patriarch Don Miguel Aranguthy who instilled his family the love for fossils and their conservation; **B** from left to right Don Miguel' sons: Benjamín, Félix, Faustino, Sebastián, and Ranulfo Aranguthy Contreras; **C** Félix Aranguthy holding the Harrell L. Strimple award, granted by the Paleontological Society in 1999 to the Aranguthy family for their dedication and commitment to preserve the Mexican paleontological heritage; **D** workers of the Tlayúa Quarry searching for fossils. Photographs **A**–**C** courtesy of Karmina Aranguthy

Applegate 1996, Alvarado-Ortega 2012, Espinosa-Arrubarrena and Alvarado-Ortega 2010, González-Rodríguez et al. 2015, 2016, Herrera-Flores 2017), but we want to outstand the enthusiasm of Don Miguel (Fig. 1A) and his sons Benjamín, Félix, Faustino, Sebastián, and Ranulfo (Fig. 1B–C) to preserve the paleontological diversity they have discovered during the exploitation of the rocks in the quarry (Fig. 1D).

Little has been told about the first encounters of Don Miguel Aranguthy with fossils, but Félix Aranguthy (personal communication, September 2023) told us part of the story. To support his family, Don Miguel used to work for several years as a miner, extracting lime and white rocks of a nearby quarry. In 1959, he started working on his own land exploiting the rocks of the Tlayúa Quarry where he found the first fishes that he called as the "mojarras petrificadas" (petrified crappies). At the beginning, he did not understand why the petrified crappies were hidden among the slabs, but he thought that it was an important discovery. The need to feed his family drove him to sell the slabs carrying them by donkey to the highway, but at the same time, the family mainly his son Félix, sought for educated people to show them the fossils. Nevertheless, they failed to attract their attention, so they decided to safeguard the fossils in their own house for about 20 years.

It was until 1980, when a reporter from the magazine "Mexico desconocido" (Mexico unknown) visited the site (Molrui 1980) that the Aranguthy family could show their extraordinary findings to the Mexican community. From this moment on, the UNAM knew about these discoveries and visited the locality establishing a collaboration agreement with Don Miguel and his family to preserve and study the Tlayúa Quarry fossils. This first approach was led by Shelton P. Applegate and Luis Espinosa Arrubarrena. The more than two thousand fossils housed at Don Miguel's home were donated to the UNAM and became part of the Paleontological Collection (Felix Aranguthy, personal communication, September 2023). To donate the fossils, Don Miguel Aranguthy made the condition that the fossils should not appear in the chimneys of the millionaires (González-Rodríguez et al. 2015). From that moment the Tlayúa Quarry attracted the attention of national and foreign researchers and today is considered one of the most important Cretaceous localities in Mexico.

The constant effort of the Aranguthy family to preserve this Mexican heritage and their contributions to the progress of paleontological studies in México made them worthy of the prize Harrell L. Strimple in 1999, granted by the Paleontological Society (Fig. 1C).

Most fossils of the Tlayúa Quarry constitute new species, but they also signify the extension of the geologic range or distribution of the taxa. At the same time, many species have contributed to the understanding of the paleoenvironmental conditions that occurred in the site of deposit. Some examples of this significance are shown below.

Protaegla miniscula is a crab belonging to the Aeglidae family which record in the Tlayúa Quarry extends the geologic range from Maastrichtian to Albian and supports the hypothesis that the family arose in a marine environment and subsequently adapted to freshwater habitats (Feldmann et al. 1998).

The holothurians described by Applegate and collaborators (2009) constitute the second record of complete holothurians in the New World and the first record of complete Mesozoic holothurians from Mexico. The authors described two new genera and species, one of them is *Parapsolus tlayuensis* which tributes the Tlayúa Quarry. Buitrón-Sánchez et al. (2015), described four genera of Asteroidea (*Astropecten*, *Plutonaster*, *Tamaria*, and *Echinaster*) that correspond to the first report of Cretaceous asteroids in Mexico.

Other specimens collected by the Aranguthy family constitute records of new fish taxa. That is the case of the extinct Macrosemiidae family which presence in the Tlayúa Quarry signifies the first report of the taxon in the Americas, extending its distribution from Eastern to Western Tethys Sea before its extinction. González-Rodríguez et al. (2004) described the new genus and species *Macrosemiocotzus americanus* which received the nickname of "bird fish" by Felix Aranguthy because of its long dorsal fin. The same year González-Rodríguez and Reynoso (2004) described the new species of macrosemiid *Notagogus novomundi* which depicts the first *Notagogus* species in the New World.

Likewise, Alvarado-Ortega and collaborators (2020) in 2020 described *Armigatus carrenoae* n. sp., and later Than-Marches and Alvarado-Ortega (2022) described *Armigatus felixii*, which correspond to the first records of the genus in the Americas and the oldest members of *Armigatus*, expanding the geographical and temporal ranges of the genus up to America and the middle-late Albian. Alves et al. (2020) described the new genus and species *Epaelops martinezi*, which corresponds to a new Mesozoic record of Elopiformes of the Western Tethys.

One way to recognize the effort of the Aranguthy family in the collection and preservation of fossil material recovered in the Tlayúa Quarry has been to designate some fossils either with their given names or with the name of their locality or municipality. Some of them have already been mentioned, nonetheless, a summary of these designations can be observed in Table 1. There is a feeling of pride when they know that a collected fossil will be named after them or after the locality or region they belong to; it provides motivation to continue searching and preserving the fossil material they found.

Table 1 Summary of the species names of the Albian Tlayúa Quarry fossils, honoring the Aranguthy family, the municipality, or the Mixteca Poblana region of central Mexico

Taxonomic categories	Scientific name	In honor to
Holoturoidea/ Psolidae	*Parapsolus tlayuensis* Applegate, Buitrón-Sánchez, Solís-Marín, Laguarda-Figueras 2009	Tlayúa Quarry
Malacostraca/Isopoda	*Archaeoniscus aranguthyorum* Feldmann, Vega, Applegate, Bishop 1998	Aranguthy familiy
Insecta/Odonata	*Ixtahua benjamini* Feldmann, Vega, Applegate, Bishop 1998	Benjamín Aranguthy
Arachnida/Aranea	*Atocatle ranulfoi* Feldmann, Vega, Applegate, Bishop 1998	Ranulfo Aranguthy
Decapoda/Brachiura	*Tepexicarcinus tlayuaensis* Feldmann, Vega, Applegate, Bishop 1998	Tepexi municipality and Tlayúa Quarry
Neopterygii/†Pycnodontidae	*Tepexichthys aranguthyorum* Applegate 1992	Tepexi municipality and Aranguthy family
Neopterygii/†Semionotidae	*Tlayuamichin itztli* López-Arbarello and Alvarado-Ortega 2011	Tlayúa Quarry
Clupeocephala/Clupeomorpha	*Ranulfoichthys dorsonudum* Alvarado-Ortega 2014	Ranulfo Aranguthy
Clupeomorpha/†Ellimmichthyiformes	*Armigatus felixi* Than-Marchese and Alvarado-Ortega 2022	*Felix Aranguthy*
Lepidosauria/Sphenodontia	*Pamizinsaurus tlayuaensis* Reynoso 1997	*Tlayúa Quarry*
Lepidosauria/Squamata	*Huehuecuetzpalli mixtecus* Reynoso 1998	*Mixteca Poblana*
Lepidosauria/Scincomorpha	*Tepexisaurus tepexii* Reynoso and Callison 2000	Tepexi municipality

The Pie de Vaca Track Site in Tepexi de Rodríguez, Puebla

This is another important fossil locality in Tepexi de Rodríguez. Around 200 years ago, Don Anselmo Aranguthy and his wife Doña Ángela Mota settled in what is today known as the Colonia Morelos outside Tepexi de Rodríguez. Don Anselmo Aranguthy was the landlord of several pieces of land at the Tepexi area, including a zone where camelids, felids, peccary, and flamingo tracks and traces can be seen. He named the place "Pie de Vaca" (Cow's foot) since he thought that the footprints were made by bovine; nevertheless, most of the fossil footprints preserved in the area belong to camelids.

Since 1980, this locality has been known for science, when the Instituto de Geología (Institute of Geology) of the UNAM (IGLUNAM) started the Tlayúa Quarry investigations. At the beginning, it was thought that the footprints were made by dinosaurs, because of its closeness to the Cretaceous Tlayúa Quarry (just 1 km away), but this assumption was revised by Cabral-Perdomo (1995, 2013), who assigned the footprints to mammals and birds. This interpretation was corroborated later by Cabral-Perdomo et al. (2018) and Bravo-Cuevas et al. (2019).

The outcrop represents a small segment of the Pie de Vaca Formation described by Pantoja-Alor et al. (1989), composed of a sequence of lacustrine limestone from the Late Paleogene-Early Neogene. This formation has also been identified in several localities around the Tepexi de Rodríguez municipality, most of them bearing tracks and traces of birds and mammals (Cabral-Perdomo 1995).

Nowadays, the Pie de Vaca outcrop belongs to Félix Aranguthy, Don Anselmo's great-grandson, who has protected it for more than 50 years. Félix is an exceptional enthusiast concerning the preservation of the cultural heritage of the Mixteca Alta Poblana region. He has always made sure that the people and politicians who have come to know the area, appreciate, and understand the importance of fossils. Pie de Vaca is one of the mandatory visits for groups of students from many universities in Mexico that come to explore the Mixteca Poblana region, especially those who study subjects related to Paleontology and Geology.

An example of the above was on March 19, 1985, when the former President of Mexico Miguel de la Madrid Hurtado accompanied the governor of the state of Puebla on a working tour around the Mixteca Poblana. On that occasion, a ceremony to honor the paleontological heritage of the area was held in Pie de Vaca. The authorities were informed about the importance of the fossils, as well as of the scientific and cultural projects that were carried out between the community and the IGLUNAM. On September 30, 1989, the Pie de Vaca Paleontological Museum was created. Today, the museum is named Museo Regional Mixteco Tlayúa (Fig. 2A–B) and it exhibits an important sample of the paleodiversity that has been recovered in the region.

The work of Félix in the conservation of the Pie de Vaca locality has been decisive to prevent the loss of this heritage. For example, the taphoglyph (impression of an animal carcass, sensu Sarjeant 1975) of a flamingo, considered a paleontological rarity (Lockley 1991), was also found here. In May of 1994, this fossil suffered an act of vandalism, consequently, Félix allowed the specimen to be removed from the site (Fig. 3) placing a bronze replica in its place. The original slab is housed in the Colección Nacional de Paleontología of IGLUNAM.

Fig. 2 **A** Front of the Museo Regional Mixteco Tlayúa in Tepexi de Rodríguez, Puebla; **B** exhibition vitrines showing examples of the marine diversity of the Albian Tlayúa Quarry

Another example of the work in support of the conservation of the Pie de Vaca locality carried out by Félix was during the first decade of this century. In that occasion, the government of Tepexi de Rodríguez planned to build a highway that would surround the city to avoid the traffic of heavy transport through downtown. The original project contemplated that the new road would pass over the ichnofossiliferous locality, to which Félix was opposed. At the end, the new road was built at one side of the locality, avoiding the destruction of the fossils.

The enthusiasm of Félix has allowed to continue appreciating the Pie de Vaca ichnofossils, unlike some other nearby sites where footprints and traces of birds and mammals were also found. These other fossiliferous sites were not protected or supervised by the community, so the action of weathering and human activities caused their disappearing. Such is the case of a site that was located just 300 m from the Pie de Vaca locality known as "Pochote-Elefante" where there was a single trace of proboscidean (Cabral-Perdomo 1995, 2013) that is currently completely covered with soil.

The Pie de Vaca footprints include nine camelid trackways, assigned to the ichnospecies *Lamaichnum guanicoe*, three felid trackways assigned to the morphofamily Felipedidae (Cabral-Perdomo et al. 2018), and one peccary trackway referable to a new ichnospecies *Tayassuichnum felixarangutii* (Fig. 4). This fossil is the first of its kind to be described from Mexico and the second report of peccary trackways for the North American subcontinent (Bravo-Cuevas et al. 2019). The new species is dedicated to Félix Aranguthy as a recognition of his willingness and dedication to the conservation of the paleontological heritage of Tepexi de Rodríguez.

In 1998, the former governor of Puebla Manuel Bartlett Diaz declared the locality Pie de Vaca, the Tlayúa Quarry, and the museum Pie de Vaca (today Museo Regional Mixteco Tlayúa) "Patrimonio Cultural del Estado de Puebla" (Cultural Heritage of the State of Puebla) (Espinosa-Arrubarrena and Alvarado-Ortega 2010).

The Muhi Quarry of Zimapán, Hidalgo

The Muhi Quarry is a Fossil Lagerstätte of the state of Hidalgo, central Mexico, which has been exploited for flagstones for more than 30 years. The quarry consists of a sequence of laminated micritic limestone with bedded/nodular chert and intercalated layers of a mixture of siliciclastic clay and calcium carbonate that indicates a marine neritic platform environment (Bravo-Cuevas et al. 2012). The locality belongs to the La Negra Facies of the El Doctor Formation of Albian-Cenomanian age; nevertheless, a recent study on the ammonites of the site indicates that the outcrop is of late Albian age (López-Palomino et al. 2021).

Sergio and Ignacio Yáñez, together with María Victoria Labra (Fig. 5A), have been working in the quarry for more than 20 years extracting the laminated rocks to sell. During the exploitation they have found about 2000 marine fossils of invertebrates and vertebrates that suggest an endemic fauna to Mexico (González-Rodríguez et al. 2013a, 2023). When we first visited the site, there was an atmosphere of mistrust and suspicion because they did not understand why we were so interested in the rocks that contained what seemed like marine fauna. Of course, they were unaware of the importance on their findings, so after we explained the significance of the fossils, they started saving the material for us instead of selling it together with the rocks they obtained.

Since then, many species have been described corresponding to new genera and species, for instance, the acanthomorph fish *Muhichthys cordobai* (González-Rodríguez and Fielitz 2008), named to honor the locality; the new species of fish *Heckelichthys preopercularis* (Baños-Rodríguez et al. 2020), aside from the oldest record of taxa, as the extinct aulopiform fish *Enchodus zimapanensis* (Fielitz and González-Rodríguez 2010); moreover, some

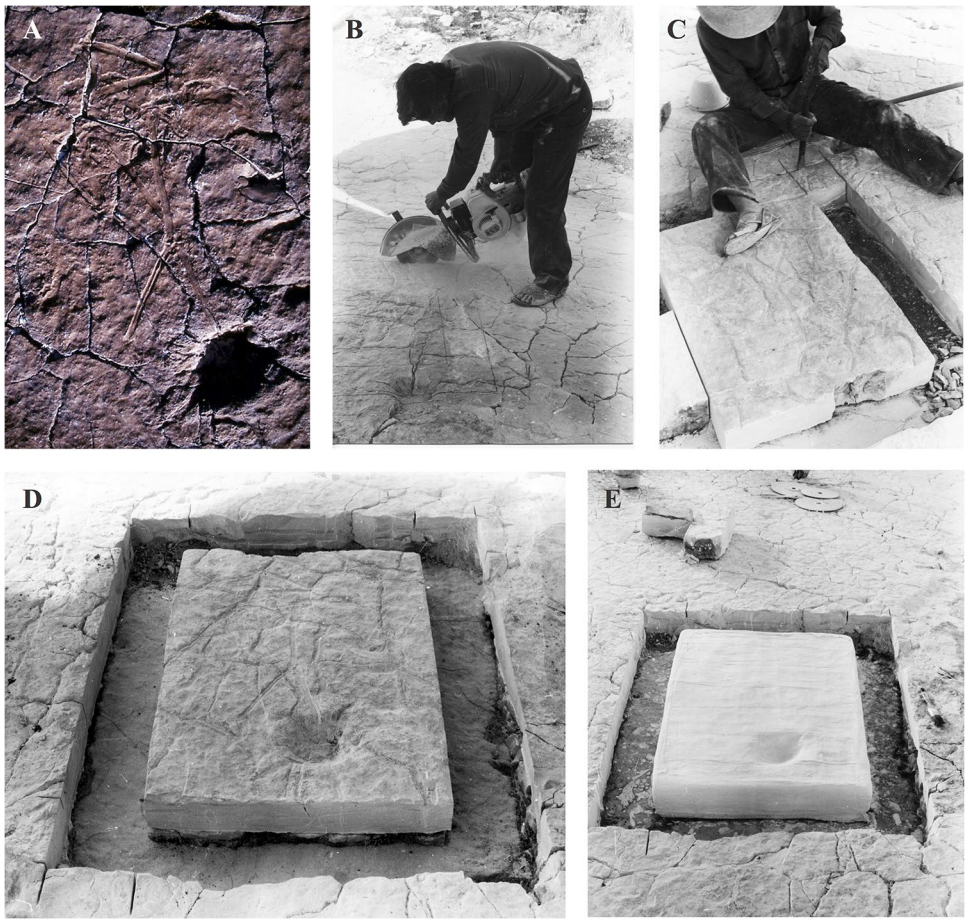

Fig. 3 The flamingo taphoglyph from the Pie de Vaca locality; **A** the specimen and a camelid footprint; **B–E** collecting process of the specimen from sawing (**B**) and removing the rock (**C**) around the specimen, to **E** the fossil packed in plaster

corresponding to the first records in the Americas, such as the shrimp *Aeger hidalguensis* (Feldmann et al. 2007), and the aulopiform fish *Ichthyotringa mexicana* (Fielitz and González-Rodríguez 2008).

During a field trip in 2012, we arrived at the quarry and María Victoria Labra received us with several slabs containing small fossils of fishes and something else unknown for us at that moment. All fossils were in the same layer suggesting they died at the same time. Fishes of no more than 5 cm of total length, had strong ornamented plates covering the complete body, and the small unknown specimens with trapezoidal shapes were about 1 cm in length. It could not be possible to find the specimens without paying strong attention during the exploitation of the rocks. The delicate and careful work made by María Victoria allowed us to describe the new family of fishes Pseudomocentrididae that represents an early record of advanced acanthomorphs and the only miniature armored acanthomorphs in the Cretaceous (González-Rodríguez et al. 2013b) and to exhibit the first known occurrence of Mesozoic thylacocephalans (Crustacea) in the Western Hemisphere (Hegna et al. 2014). To acknowledge the lady of the quarry her effort in collecting the specimens, we decided to name one of the Thylacocephala new species as *Victoriacaris muhiensis*.

Another highlight within the hidden faces of paleontological studies are the children living around the Muhi Quarry, some of which are related to the Yañez brothers. Since our first approach to the quarry in 1998, we met several kids (Fig. 5B–D) whose natural curiosity motivated them to look for fossils in the quarry rubbles. They found over 200 specimens of the smallest fish in the outcrop, before they became teenagers and lost interest in hunting fossils. Nowadays, they are adults, some of them have their own children, but they remember the days they spent in the quarry helping us to find fishes.

Significance of Fossil Collections Assembled by Non-professionals

The participation of non-professionals in discovering and collecting fossils has contributed significantly to the advances of paleontology as mentioned before. The materials integrate fossil collections of scientific, educational, social, and cultural value (Allmon 2005). There are different repositories of fossil collections, including museums,

Fig. 4 **A** Panoramic view of the Pie de Vaca outcrop, where camelid tracks are clearly visible; **B** the peccary trackway *Tayassuichnum felixarangutii*. Photographs by Miguel Angel Cabral and Victor Bravo-Cuevas

universities, public and private associations, government agencies, and individuals (NRC 2002).

In many cases, fossil collections assembled by non-professionals are unknown or kept private by their owners. Therefore, a loss of paleontological information would occur, such as the knowledge of unreported fossil localities and undescribed specimens that could represent new taxa. This situation gets worse when ethical transgressions happen, such as illegal trade of fossils (Watson 2022). Unfortunately, activities like this have conducted colonialism paleontological work which should be a major concern in Mexico (Cisneros et al. 2022). Nevertheless, paleontologists appreciate the enthusiasm and effort of those non-professional collectors that have assembled fossil collections accessible to scholars and ordinary people, promoting the protection of the fossil record. In the following paragraphs, we describe how the fossil collection of the native of the Hidalgo State, Felipe Peña-Martinez was assembled.

Sedimentary sequences of heterogeneous clastic and volcanic material related to fluviolacustrine environments are widespread throughout the state of Hidalgo (López-Ramos 1972, Córdoba et al. 1992), and geomorphologically expressed in floodplains drained by rivers and low hills forming terraces (Bravo-Cuevas 2002). Paleontological work carried out since the late nineteenth century has revealed the fossiliferous potential of these sedimentary sequences. It is noted that fossil mammalian remains such as teeth and bones, are the most common and diverse elements found (Cope 1886; Villarelo and Bosë 1902; Freudenberg 1910, 1922; Castillo-Cerón et al. 1996). The known record testifies part of the geobiological history of central Mexico during

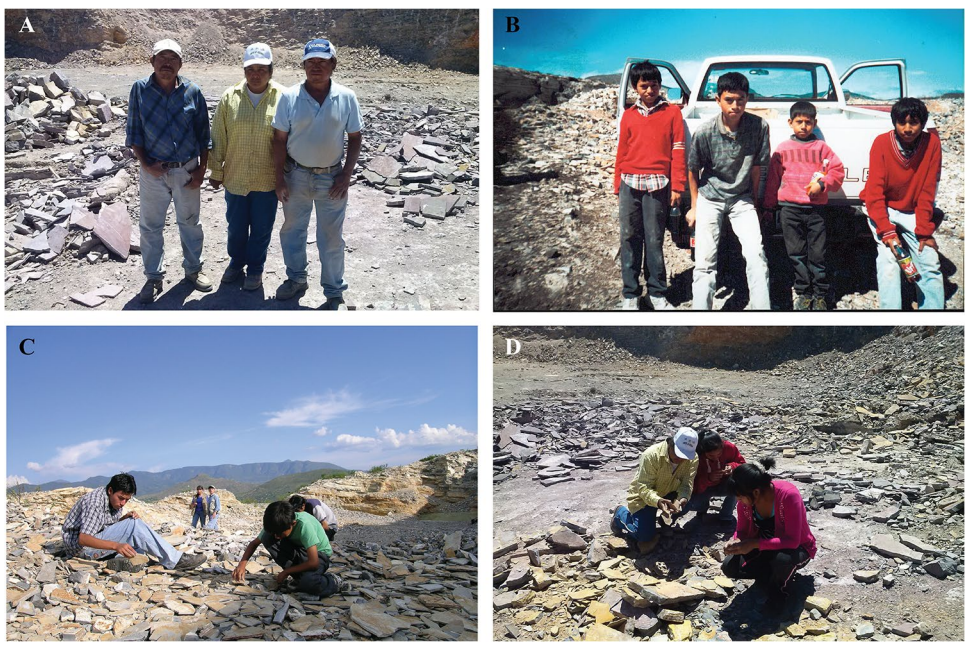

Fig. 5 **A** From left to right: Sergio Yáñez, María Victoria Labra, and Ignacio Yáñez, workers of the Muhi Quarry; **B** from left to right: Rigoberto, Pedro, Antonio, and José Luis Tovar-Yáñez; **C** kids searching for small fishes in the Muhi Quarry; **D** María Victoria Labra and her daughters Valeria and Vanesa Yáñez Labra also searching for small fossils in the rubble of the quarry

the last five million years, from the Pliocene to the Pleistocene geological epochs.

The Pliocene sedimentary units include the Tarango and the Atotonilco El Grande formations, whereas those of the Pleistocene are known as Quaternary alluvial deposits (Córdoba et al. 1992). In 2012, some of the authors (Victor Bravo and Miguel Cabral) prospected potential fossiliferous deposits referable to the Tarango Formation, located near the town Cerritos in the central-western region of the state of Hidalgo. The sedimentary sequences in this area consist of sand and volcanic ash that reach about 2 m thickness, named by the locals as sand mines (Fig. 6A–B).

Felipe Peña Martínez is a local of Cerritos town, who has worked in the extraction of building materials from the sand mines. At present, few deposits continue to be exploited for this purpose. The first paleontological discovery of Felipe occurred in the afternoon of September 8, 1995, while he was working in one of the mines near Cerritos. That day he found a mandible of the gomphothere *Cuvieronius hyodon*. One week later, he conducted a prospection at the same sedimentary sequence, recovering a tusk fragment of the American mastodon *Mammut americanum* and several postcranial remains of horses.

The interest and excitement of Felipe in searching fossil remains have grown, and currently, his whole family participates in this activity, assembling an important fossil collection. He wants a place to exhibit his fossil collection, where the locals and public in general can know the mammalian fauna that inhabited the area of Cerritos during the Cenozoic, as well as to promote curiosity in the children for fossils and their importance, and that eventually, they may become paleontologists.

The fossil collection of Felipe consists of some mandibles, numerous isolated teeth, and several postcranial remains of mammalian herbivores (Fig. 6C). The record includes tayassuids, camels, deer, antilocaprids, horses, gomphotheres, and mastodons (Table 2), supplementing the evidence of late Cenozoic mammals known from central Mexico (Montellano-Ballesteros and Jiménez-Hidalgo 2006; Bravo-Cuevas and Jiménez-Hidalgo 2018). Particularly, some specimens of the collection merit attention, including a metapodial of the three-toed horse *Nannipus* and a

Fig. 6 **A** Sedimentary sequence referable to the Tarango Formation, Hidalgo; **B** close view of a sand mine near Cerritos town, Hidalgo; **C** Felipe Peña-Martínez and his fossil collection; **D** specimens of the fossil collection of Felipe, including a metatarsal of *Nannippus* (left) and antler fragment of *Odocoileus lucasi* (right). Scale bar equals 2 cm

Table 2 The fossil collection of Felipe Peña-Martínez

	Fossil material	Common name
Order Artiodactyla Tayassuidae *Platygonus* sp.	Isolated teeth	Peccary
Camelidae	Postcranial fragment	Camel
Cervidae *Odocoileus lucasi*	Antler fragment	American mountain deer
Antilocapridae	Isolated teeth	American antelope
Order Perissodactyla Equidae *Nannippus* sp.	Metatarsal	Three-toed horse
Equus cf. *conversidens*	Mandible, isolated teeth, and several postcranial remains	Mexican horse
Order Proboscidea Gomphotheriidae *Cuvieronius hyodon*	Mandible and isolated teeth	Gomphothere
Mammutidae *Mammut americanum*	Tusk fragment	Mastodon

fragment antler of the American mountain deer *Odocoileus lucasi* (=*Navahoceros fricki*) (Fig. 6D).

Nannippus was a primitive three-toed horse of the middle Miocene to early Pliocene mammalian faunas from North America (Hulbert 1993). In Mexico, this small-sized hipparionine of gracile extremities is known from Hemphillian and Blancan localities in northern (Chihuahua and Sonora states) and central (Jalisco, Michoacán, Guanajuato, Querétaro, and Hidalgo states) Mexico (Carranza-Castañeda 2006; Palma-Ramírez et al. 2023). There are mentions of *Nannippus peninsulatus* from localities in Hidalgo, although it is one of the lesser-known fossil horse species recorded in this territory (Priego-Vargas and Bravo-Cuevas 2016). The metatarsal of *Nannipus* that is part of the Felipe fossil collection adds to the evidence of this hipparionine and indicates that it was a common inhabitant of areas that currently are part of central Mexico.

Odocoileus lucasi is an extinct large-sized deer well-documented from several Blancan and Irvingtonian localities in the southwestern United States (Kurtén and Anderson 1980). In Mexico, this species is known from early Pleistocene localities in Sonora and Aguascalientes (Mooser and Dalquest 1975; Croxen et al. 2007). Therefore, the antler fragment referable to this species, which is part of the fossil collection of Felipe, is (so far) the unique evidence of this cervid from the state of Hidalgo and widespread its distribution as the southernmost occurrence in Mexico during the late Cenozoic.

In some instances, collections assembled by non-professionals have promoted the creation of local museums, which house the paleontological evidence of a particular region. For example, the Museo Comunitario de Zacuala (local Museum of Zacuala) exhibits fossils that are part of the Pleistocene diversity of southeastern Hidalgo, including bones of horses (*Equus conversidens*), mammoths (*Mammuthus columbi*), and mastodons (*Mammut americanum*).

Conclusions

The Mexican fossil record is extensive. There are many fossiliferous sites that have been discovered accidentally by workers of drainage and other public projects or by local people who were interested in preserving these materials. Without these hidden faces, it would not have been possible to have a partial picture of the diversity in the past, or to discover some key taxa that have contributed to understand pieces of the evolutionary history of certain groups, such as numerous Cretaceous invertebrates and fish recently described in Mexico. Some of them even signify the oldest records of supraspecific taxa in the world, or the first reports in the Americas, representing the raise of new families (González-Rodríguez et al. 2013a, b, 2016; Vega et al. 2022), or the Squamata discoveries in the Tlayúa Quarry, which indicate the presence of relictual forms in the Albian of Mexico (Reynoso 1997, 1998, 2000; Reynoso and Callison 2000).

Non-professionals who have collected fossils with different targets are also important if they have the idea to preserve the fossil material over the creation of personal collections, or by building community museums in their properties. Nevertheless, many others act with the sole aim of trading, destroying the opportunity to preserve the paleontological heritage of Mexico.

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Declarations

Conflict of Interest The authors declare no competing interests.

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