6 The Palaeontological Heritage of Vertebrates in the Middle Atlas (Morocco): Initiatives of Inventory and Assessment for a Rare Heritage Threatened with Degradation

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Abstract

Recognized by its paleontological sites of *in-situ* and *ex-situ* vertebrates, the Middle Atlas is the subject of increased attention and offers geoscientists and paleontologists a vast field of predilection for one of the richest fossiliferous deposits in the country and even to the world. The paleontological heritage "paleontoheritage" is considered as an indispensable resource in regional and national socio-economic development. In the region, vertebrate paleontological sites are under strong degradation pressure leading to the deterioration of this heritage despite some promotion and preservation initiatives. An inventory and a quantitative assessment of these sites by determining their degree of deterioration is necessary to preserve this paleontoheritage. The inventory resulted in 35 geosites inventoried *in situ*, of which 34.2% of the geosites held medium to high scores during the quantitative assessment (Ss) and the rest of the geosites presented average scores during the assessment of the degree of deterioration (Sd). Among the sum of the geosites, four (Aït Bazza, Ancherif, Boulahfa and El Mers) were chosen and studied due to their high scoring value of representativeness, rarity and geological diversity criteria.

Keywords

Paleontoheritage · Vertebrate paleontological sites · Inventory · Assessment · Middle Atlas

6.1 Introduction

Paleontology has always fascinated geoscientists and paleontologists who have tried to discover, through fossils and their traces, evidence of the evolutionary history of life on Earth. It is a "time machine" that allows other sciences to discover geological time and allows each of us to embark on imaginary adventures in the Earth's past (Ward 1998). Recently, biodiversity has begun to occupy a primordial place in the research of scientists, public opinion and the political world. Its protection and preservation has become an irreversible whose awareness is relatively recent. The study of current biodiversity is inseparable from the paleontological study. To retrace the history of biodiversity and to analyze it, it is necessary to use fossils, which are thus the keys to understanding the evolution of biodiversity (Neagu 2010).

Great interest has been shown in the paleontology of vertebrates in the Middle Atlas, the first studies of which date back to 1927 (Termier 1927). Since that date, several works have appeared (De Lapparent 1942; Jenny et al. 1981; Monbaron and Taquet 1981; Jenny 1982; Monbaron 1983; Monbaron et al. 1999; Allain et al. 2004; Hadri and Pérez-Lorente 2012; Marinheiro et al. 2014; Marinheiro 2015; Maidment et al. 2020, 2021). The vertebrate paleontology of the Middle Atlas, compared to other Middle Jurassic localities (England, United States and Portugal), presents the greatest paleontological diversity (Hadri and Pérez-Lorente 2012). The Middle Atlas is home to a rich and diversified paleontological heritage by holding the most important fossiliferous deposits of vertebrates in Morocco. The paleontological heritage, including fossils and ichnofossils, represents essential witnesses for deciphering and reconstructing the history of our planet through numerous fossiliferous deposits despite their fragility. Through the diversity of its geological history, the Middle Atlas conceals fossiliferous deposits of global importance which have given rise to numerous works attracting the attention of several international paleontologists. Deposits known and described since the beginning of the twentieth century by many authors and have provided material for several collections, the richest fossil collections in the world, in various national and international museums.

Some sites are unique in Morocco and even in the world. The richest areas of the entire Middle Atlas chain, by their

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wealth in ichnofossils and bones, are those of El Mers, Boulemane, Imouzzer Marmoucha and Oulad Ali. Even today, several discoveries of bones in the region are made. Examples include the recent discovery of dinosaur footsteps in Jbel Oudiksou (Gandini and Ahalfi 2015) and dinosaur bones in Boulahfa (Maidment et al. 2020, 2021).

The paleontological heritage of Morocco and of the Middle Atlas in particular is subject to considerable pressure, without much of an inventory or basis for legal protection. To achieve a truly respectful sustainable development and its regulatory organization, it has become urgent to carry out an inventory of this heritage in the Middle Atlas.

This present chapter focuses on the paleontological heritage "paleontoheritage"and emphasizes the paleontological heritage of vertebrates and their ichnofossils. The latter are of remarkable importance in paleoecology, providing information that allows paleoenvironmental reconstructions. The paleontological sites of the vertebrates of the Middle Atlas which are presented in this chapter reveal a unique character in Morocco and all the data which can be retained from them are confirmed to be essential for deciphering the stratigraphic and sedimentary history from the Jurassic to the Pleistocene. The objective is therefore multiple, scientific, heritage and preservation.

6.2 Paleontological Heritage of Vertebrates

The paleontological heritage of vertebrates from the Middle Atlas has made a substantial and decisive contribution to understanding and clarifying the evolution of vertebrates and their distribution on a national and international scale. The fossiliferous diversity provided crucial information on the evolution and paleobiogeography of the Middle Atlas chain and also provided some of the most remarkable ichnological sites in Morocco.

The Middle Atlas is today world famous for having provided the richest and most diversified fossil bones in Africa and even in the world. As a result, it is considered the crossroads of new discoveries that attract several researchers around the world. The majority of these discoveries are assembled in the Bathonian deposits of the Boulemane and El Mers region.

6.2.1 Inventory and Assessment

The development of an inventory and an assessment will allow the identification of a series of sites of particular scientific interest. Each site inventoried and assessed will subsequently contribute to the protection and preservation of these sites by enabling them to reveal their heritage value. In this present work, the inventory led to an inventory of 35 paleontological sites of vertebrates (Table 6.1). This inventory will serve as a support presenting the most important fossiliferous deposits of the Middle Atlas chain. These sites present fossiliferous sites that cover a time interval from the Jurassic to the Pleistocene. These are geosites of footprints, bones and fossiliferous skeletons.

During the quantitative assessment (Table 6.2), 5 geosites out of 35 inventoried geosites presented an $Ss \geq 2.5$, 8 sites a $1.5 \leq Ss < 2.5$, and the remaining 22 had an $Ss < 1.5$. The latter were withdrawn from the selection given their low scientific value.

For the degree of deterioration, 13 geosites were therefore selected (Table 6.3). Among these 13 geosites: no site has an $Sd \geq 2.5$, 5 geosites have an $Sd < 1.5$, and 8 geosites have a $1.5 \leq Sd < 2.5$.

As for the results of the calculation of their total value, this was positive for 12 geosites, the only remaining one therefore has an $Sv < 0$.

6.2.2 Paleontological Geosites of Vertebrates

Four vertebrates paleontological geosites are studied. They are chosen among the geosites selected during the quantitative assessment and the degree of deterioration by their high score of criteria of representativeness, rarity and geological diversity as well as their state of preservation.

6.2.2.1 Aït Bazza

Aït Bazza (Pal03) is located 6 km south of Imouzzer Marmoucha. This site (Fig. 6.1a) houses a cemetery which holds the most numerous dinosaur bones in the Middle Atlas. It extends over a length of 3 km and a width of 2 km.

The dinosaur remains of the Aït Bazza geosite are found in the marls of the Lower Bathonian El Mers 1 formation. We find their ribs (Fig. 6.1b) and various bones (Fig. 6.1c).

The geosite of Aït Bazza is an important site and constitutes a reference by its originality, its representativeness and by the extension of the remains of the dinosaurs. Unfortunately, it is seriously degraded and in need of urgent conservation. This geosite has not, until now, known work on the remains of the dinosaurs.

6.2.2.2 Ancherif

Ancherif (Pal04) is located 24 km northwest of Boulemane, at the NW end of the El Mers syncline. This site shows a strong paleontological potential of a relatively little explored area.

The Ancherif geosite (Fig. 6.2a) is located on the edge of Oued Guigou. It is located in Middle Pleistocene deposits.

Table 6.1 Inventory of paleontological geosites of vertebrates

Geosites	Identification code	Type of geosite	Coordinates			Administrative location	Property	Accessibility	Protected area
			X	Y	Z				
Aïn ou N'Jourh	Pal01	*Cetiosaurus* sp.	33°28′30.24″N	4°27′14.37″W	1451	El Mers	Public	Medium	–
Aït Abdellah	Pal02	–	33°25′3.30″N	4°26′35.60″W	1628	El Mers	Public	Medium	–
Aït Bazza	Pal03	*Iguanodon*	33°24′35.75″N	4°18′35.86″W	1463	El Mers	Public	Medium	–
Ancherif	Pal04	*Elephas recki recki*	33°29′1.38″N	4°36′48.31″W	1132	Taghrout	Public	Medium	–
Botane	Pal05	Teleosauridae	33°28′48.62″N	4°27′56.01″W	1597	El Mers	Public	Medium	–
Botane Sud	Pal06	*Steneosaurus* sp.	33°28′27.54″N	4°27′45.55″W	1575	El Mers	Public	Medium	–
Bou Ifraoun	Pal07	*Steneosaurus* sp.	33°24′54.67″N	4°22′34.52″W	1449	El Mers	Public	Medium	–
Bou Ifraoun Ouest	Pal08	*Steneosaurus* sp.	33°24′55.89″N	4°22′51.24″W	1422	El Mers	Public	Medium	–
Boulahfa	Pal09	*Adratiklit boulahfa; Spicomellus*	33°17′48.56″N	4°42′13.76″W	1930	Boulemane	Public	Difficult	–
Darak	Pal10	*Steneosaurus* sp.	33°25′24.34″N	4°27′9.68″W	1709	El Mers	Public	Medium	–
Djmila	Pal11	*Steneosaurus* sp.	33°30′41.97″N	4°26′6.74″W	1359	El Mers	Public	Medium	–
EL Mers	Pal12	*Megalosauripus; Breviparopus*	33°26′49.82″N	4°26′41.61″W	1491	El Mers	Public	Facile	–
Jbel Oudiksou	Pal13	–	33°14′57.86″N	4°49′46.46″W	2110	Boulemane	Public	Medium	–
Ksar Aït Moulay (Tisfoula Tasra)	Pal14	*Steneosaurus* sp.	33°26′37.48″N	4°23′29.45″W	1274	El Mers	Public	Medium	–
Oued Boukamouche	Pal15	–	33°26′48.72″N	4°25′21.25″W	1410	El Mers	Public	Medium	–
Oued Mers	Pal16	*Lepidotes* sp.	33°26′42.10″N	4°18′57.47″W	1410	Imouzzer Marmoucha	Public	Medium	–
Oued Tamemchet	Pal17	*Steneosaurus* sp.	33°25′47.74″N	4°23′50.28″W	1436	El Mers	Public	Medium	–
Oued Tamghilt	Pal18	–	33°26′35.63″N	4°19′2.71″W	1401	El Mers	Public	Medium	–
Oulad Ali	Pal19	Sauropoda; Theropoda	33°27′52.66″N	3°58′17.24″W	1447	Oulad Ali Youssef	Public	Medium	–
Selghert	Pal20	–	33°08.82′N	04°58.82′W	1970	El Mers	Public	Medium	–
Taghit	Pal21	*Cetiosaurus mogrebensis; Megalosaurus mersensis*	33°27′27.07″N	4°27′35.14″W	1536	El Mers	Public	Easy	–
Taghit Aït Youssef	Pal22	–	33°27′22.09″N	4°27′12.51″W	1561	El Mers	Public	Medium	–
Taghit Tissenflet	Pal23	–	33°27′3.18″N	4°25′23.05″W	1540	El Mers	Public	Medium	–
Taghrout	Pal24	*Cetiosaurus* sp.	33°27′0.94″N	4°28′0.06″W	1598	El Mers	Public	Medium	–
Taghzout	Pal25	–	33°27′23.38″N	4°23′24.73″W	1277	El Mers	Public	Medium	–
Tamgert Iktaaïn (Tizi N'Julierh)	Pal26	Teleosauridae; Testudinata	33°28′1.58″N	4°26′58.67″W	1532	El Mers	Public	Medium	–
Tamgert N'Tarit	Pal27	*Cetiosaurus* sp.	–	4°26′3.45″W	1424	El Mers	Public	Medium	–
Tamgert N'Tarit Nord	Pal28	Testudinata; Cetiosaurus; Protocardia; Ostreidae	33°28′1.50″N	4°26′0.40″W	1488	El Mers	Public	Medium	–
Tamguert N'rate	Pal29	–	33°27′14.27″N	4°18′44.32″W	1525	Imouzzer Marmoucha	Public	Medium	–
Tasra	Pal30	Steneosaurus sp.	33°27′35.43″N	4°23′35.06″W	1237	El Mers	Public	Medium	–
Tasra Est	Pal31	Steneosaurus sp.	33°27′34.43″N	4°23′10.71″W	1280	El Mers	Public	Medium	–
Tichniouine	Pal32	*Cetiosaurus* sp.	33°25′36.80″N	4°25′10.59″W	1453	El Mers	Public	Medium	–
Tichou Moulay Said	Pal33	Steneosaurus sp.	33°26′28.11″N	4°23′43.34″W		El Mers	Public	Medium	–
Tirardine	Pal34	*Steneosaurus* sp.	33°26′9.43″N	4°21′32.85″W	1458	Imouzzer Marmoucha	Public	Medium	–
Vértébrés d'El Mers	Pal35	Theropoda	33°27′0.04″N	4°25′59.75″W	1523	El Mers	Public	Medium	–

Table 6.2 Quantitative assessment (Ss) of paleontological geosites of vertebrates

Geosites	Criteria of quantitative assessment (Ss)					Total pointing	Final scoring matrix (Ss)					Total quantitative assessment	Result (Ss)
	Representativeness	Rarity	Geological diversity	State of preservation	Documentation		Representativeness *24%	Rarity *18%	Geological diversity *20%	State of preservation *24%	Documentation *14%		
Aïn ou N'Jourh	2	1	1	1	2	7	0.48	0.18	0.2	0.24	0.28	1.38	Low
Aït Abdellah	2	1	1	1	2	7	0.48	0.18	0.2	0.24	0.28	1.38	Low
Aït Bazza	3	3	3	1	3	13	0.72	0.54	0.6	0.24	0.42	2.52	High
Ancherif	3	3	3	1	3	13	0.72	0.54	0.6	0.24	0.42	2.52	High
Botane	2	2	1	1	2	8	0.48	0.36	0.2	0.24	0.28	1.56	Medium
Botane Sud	2	2	1	1	2	8	0.48	0.36	0.2	0.24	0.28	1.56	Medium
Bou Ifraoun	2	2	1	1	2	8	0.48	0.36	0.2	0.24	0.28	1.56	Medium
Bou Ifraoun Ouest	2	2	1	1	2	8	0.48	0.36	0.2	0.24	0.28	1.56	Medium
Boulahfa	3	3	3	1	3	13	0.72	0.54	0.6	0.24	0.42	2.52	High
Darak	2	1	1	1	2	7	0.48	0.18	0.2	0.24	0.28	1.38	Low
Djmila	2	1	1	1	2	7	0.48	0.18	0.2	0.24	0.28	1.38	Low
El Mers	3	3	3	1	3	13	0.72	0.54	0.6	0.24	0.42	2.52	High
Jbel Oudiksou	2	2	1	1	2	8	0.48	0.36	0.2	0.24	0.28	1.56	Medium
Ksar Aït Moulay (Tisfoula Tasra)	2	1	1	1	2	7	0.48	0.18	0.2	0.24	0.28	1.38	Low
Oued Boukamouche	2	1	1	1	2	7	0.48	0.18	0.2	0.24	0.28	1.38	Low
Oued Mers	2	1	1	1	2	7	0.48	0.18	0.2	0.24	0.28	1.38	Low
Oued Tamemchet	2	1	1	1	2	7	0.48	0.18	0.2	0.24	0.28	1.38	Low
Oued Tamghilt	2	1	1	1	2	7	0.48	0.18	0.2	0.24	0.28	1.38	Low
Oulad Ali	2	2	1	1	2	8	0.48	0.36	0.2	0.24	0.28	1.56	Medium
Pas d'EL Mers	3	3	3	1	3	13	0.72	0.54	0.6	0.24	0.42	2.52	High
Taghit	2	2	2	1	3	10	0.48	0.36	0.4	0.24	0.42	1.9	Medium
Taghit Aït Youssef	2	1	1	1	2	7	0.48	0.18	0.2	0.24	0.28	1.38	Low
Taghit Tissenflet	2	1	1	1	2	7	0.48	0.18	0.2	0.24	0.28	1.38	Low
Taghrout	3	2	1	1	2	9	0.72	0.36	0.2	0.24	0.28	1.8	Medium

Taghzout	2	1	1	1	2	7	0.48	0.18	0.2	0.24	0.28	1.38	Low
Tamgert Iktaaïn (Tizi N'Julierh)	2	1	1	1	2	7	0.48	0.18	0.2	0.24	0.28	1.38	Low
Tamgert N'Tarit	2	1	1	1	2	7	0.48	0.18	0.2	0.24	0.28	1.38	Low
Tamgert N'Tarit Nord	2	1	1	1	2	7	0.48	0.18	0.2	0.24	0.28	1.38	Low
Tamguert N'rate	2	1	1	1	2	7	0.48	0.18	0.2	0.24	0.28	1.38	Low
Tasra	2	1	1	1	2	7	0.48	0.18	0.2	0.24	0.28	1.38	Low
Tasra Est	2	1	1	1	2	7	0.48	0.18	0.2	0.24	0.28	1.38	Low
Tichniouine	2	1	1	1	2	7	0.48	0.18	0.2	0.24	0.28	1.38	Low
Tichou Moulay Said	2	1	1	1	2	7	0.48	0.18	0.2	0.24	0.28	1.38	Low
Tirardine	2	1	1	1	2	7	0.48	0.18	0.2	0.24	0.28	1.38	Low
Vertébrés d'El Mers	3	3	3	1	3	13	0.72	0.54	0.6	0.24	0.42	2.52	High

Table 6.3 Degree of deterioration (Sd) of paleontological geosites of vertebrates

Geosites	Critera of degree of deterioration (Sd)					Total of pointing	Final scoring matrix (Sd)					Total of Sd	Result (Sd)
	Vulnerability	Fragility	Accessibility	Demography	Number of visitors		Vulnerability *19%	Fragility*19%	Accessibility*25%	Demography*20%	Number of visitors*17%		
Aït Bazza	3	3	3	1	1	11	0.57	0.57	0.75	0.2	0.17	2.26	Medium
Ancherif	3	3	1	1	1	9	0.57	0.57	0.25	0.2	0.17	1.76	Medium
Botane	1	1	2	1	1	6	0.19	0.19	0.5	0.2	0.17	1.25	Low
Botane Sud	1	1	1	1	1	5	0.19	0.19	0.25	0.2	0.17	1	Low
Bou Ifraoun	1	1	1	1	1	5	0.19	0.19	0.25	0.2	0.17	1	Low
Bou Ifraoun Ouest	1	1	1	1	1	5	0.19	0.19	0.25	0.2	0.17	1	Low
Boulahfa	3	3	1	1	1	9	0.57	0.57	0.25	0.2	0.17	1.76	Medium
EL Mers	3	3	3	1	1	11	0.57	0.57	0.75	0.2	0.17	2.26	Medium
Jbel Oudiksou	1	2	2	1	1	7	0.19	0.38	0.5	0.2	0.17	1.44	Low
Oulad Ali	2	2	2	1	1	8	0.38	0.38	0.5	0.2	0.17	1.63	Medium
Taghit	2	2	3	1	1	9	0.38	0.38	0.75	0.2	0.17	1.88	Medium
Taghrout	2	2	2	1	1	8	0.38	0.38	0.5	0.2	0.17	1.63	Medium
Vertébrés d'El Mers	3	3	3	1	1	11	0.57	0.57	0.75	0.2	0.17	2.26	Medium

The deposits of the Ancherif geosite are lacustrine in nature. These deposits contain the remains of fish, continental reptiles, artiodactyls, bones of large mammals, bones of elephants (Fig. 6.2b).

The Ancherif geosite yielded the remains of four elephants and a young adult. This is the species *Elephas recki recki* (Marinheiro et al. 2014). These remains, still well preserved, show shoulder blades (Fig. 6.2c, d), which can reach 1.5 m wide, several bones of the limbs and a pectoral belt (Fig. 6.2e). The presence of these species in colonies is explained by the topographic conditions of the locality. Indeed, it is a mountain lake with steep and slippery edges that could have served as a natural trap (Marinheiro 2015).

The geosite of Ancherif presents a rarity from the paleontological point of view by showing the presence of the first bones of *Elephas* reported in the Middle Atlas and the most recent in Morocco. This geosite testifies to the environment of the region during the Middle Pleistocene.

6.2.2.3 Boulahfa

Boulahfa (Pal09) is located 13 km south of Boulemane. This site presents a singularity in Morocco and even in the world.

The dinosaur bones of the Boulahfa geosite are found at the top of the formation of the versicolored marls of El Mers 2 of Bathonian age (Fig. 6.3a). They correspond to many stegosaur bones (Charroud and Fedan 1992).

Most of the stegosaurs discovered so far have shown that the species lived throughout the Late Jurassic and Cretaceous. The Boulahfa Stegosaurus indicates an age of 168 million years (Bajocian), according to the team of the Museum of Natural History in London. This new specimen (Fig. 6.3b) is named *Adratiklit boulahfa* (Maidment et al. 2020). *Adratiklit boulahfa* is a new species and the oldest of all stegosaurs.

Very recently, in September 2021, a new species was discovered at the site. It is a *Spicomellus afer gen. and sp. Nov.* of Bathonian-Callovian age. This species is the oldest of all ankylosaurs (Maidment et al. 2021). This discovery filled an important gap in the evolution of dinosaurs. The morphology of this *Spicomellus* (Fig. 6.3c) is unprecedented among extinct and extant vertebrates (Maidment et al. 2021) in particular by the discovery of spines attached directly to bones.

Boulahfa holds the oldest stegosaurus discovered so far in the world. The geosite, through its bones, makes it possible to understand the diversity and paleobiogeography of the stegosaurus and ankylosaur dinosaurs.

6.2.2.4 El Mers

El Mers (Pal12) is located in the center of the village of El Mers. It presents the only deposit in the Middle Atlas that shows the footprints of dinosaurs.

Dinosaur ichnites (Fig. 6.4a) are found in deposits of the Bou Akrabène-Ich Timellaline formation (Fig. 6.4b). These are marl-limestone deposits corresponding to alternations of coastal and supratidal marine environments.

In this geosite, there are 101 recorded dinosaur ichnites (Hadri and Pérez-Lorente 2012). They form intersecting tracks or isolated indentations (Fig. 6.4a). They appear on both sides of the Oued Mers (Fig. 6.4a) of which we notice an intense erosion which risks making these imprints disappear. Hadri and Pérez-Lorente (2012) showed the existence of three types of footprints: Those of small theropod dinosaurs with small, narrow and long steps (Fig. 6.4c, d); those of broad-footed theropods with long, broad toes that some authors have associated with the genus *Megalosauripus*. Finally, a third type of footprint attributed to sauropod dinosaurs of the genus *Breviparopus*.

The prints are digitigrade tridactyl or semiplantigrade tetradactyl. The length of the footprints, tridactyle or tetradactyle, varies between 18 and 30 cm, with a depth reaching 10 cm. The most apparent tracks are those of large quadrupeds. The shape and size of these ichnites show that the dinosaurs moved at an average speed of 5 km/h (Hadri and Pérez-Lorente 2012). Further south in the same formation are other dinosaur footsteps, 40 cm wide, with blunt toes.

El Mers is unique in its many dinosaur footsteps from different genera of theropods and sauropods. These ichnites show a variety of morphotypes and structures that help to understand the size, shape and behavior of these dinosaurs.

6.2.3 Paleontoheritage: Between Degradation and Preservation Initiatives

Morocco has for years carried laws protecting the environment, soil and subsoil with more attention to the protection and preservation of water resources due to its importance on all scales: scientific and economic, with less important or even incomplete for the preservation of the paleontological heritage. Like Law 33-13 relating to mines, which regulates all exploitation of Moroccan mineral resources, no law regulates the overexploitation of fossiliferous resources. The lack of a legal framework that adopts protective laws and limits the collection of fossils means that the country and especially the Middle Atlas is subject to uncontrolled exploitation by national and international researchers but also by fossil looters with their action on certain fossils. Have found their way into museums abroad.

Recently, several initiatives have emerged in Morocco to preserve and protect the country's paleontological heritage, considered unique, rare and irreversible. Among these initia-

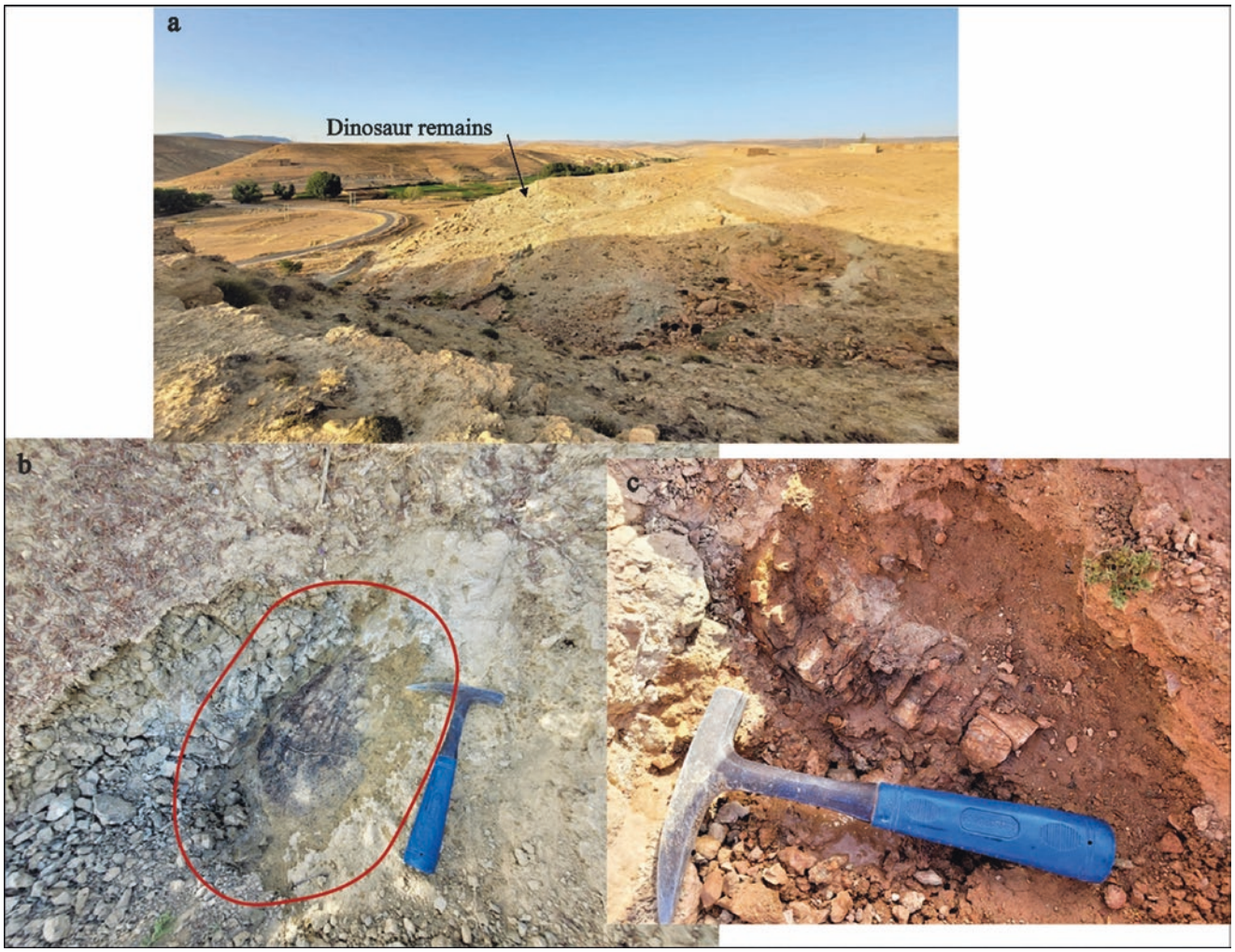

Fig. 6.1 (**a**) View of the location of one of the bones of the Aïn Bazza geosite; (**b**) Dinosaur rib; (**c**) Well-degraded dinosaur bone

tives, in 2014, the Scientific Institute of Rabat "Israbat" carried out an inventory of a collection of national fossils which presents a century of research in Morocco of more than 12,000 samples. It is an inventory of certain groups of fossils, animals and plants, of the country as well as of the prehistoric industry and ichnofossils (Fedan 2014). The samples presented during this inventory were deprived of certain details of their location, their state of preservation and their current state in the field. The vertebrate samples are not marked with the name of the species found but only with bones. These samples are exhibited in the institute's museum.

In 2016, another initiative was launched in the Middle Atlas with the inauguration of the Middle Atlas Heritage Interpretation Center (CIPMA). It has various facilities with a cultural, scientific and educational vocation. The latter exhibits a set of objects that trace the history of the region from the Lower Palaeolithic to the present day and which cover both the natural, archaeological and ethnographic side. Among the objects exhibited in this center are certain bones of *Elephas* from the geosite of Ancherif (Fig. 6.5a, b).

The paleontological resources of the Middle Atlas are rapidly disappearing as development, construction, industrialization, vandalism and the harvesting of fossils by professionals, amateurs and commercial collectors continues. The majority of the sites visited during the inventory carried out in this work are extremely degraded and even in some sites we find only traces of the fossils collected.

The implementation of a site preservation and protection strategy is essential to guarantee the preservation of this national paleontological treasure. Understanding the history of life on Earth is done through this preservation which provides a framework of understanding of materials for scientific research of the past, today and tomorrow.

Although a serious and reasonable work must be done for a good preservation of the sites on the ground and even in museums. *In-situ* geosites provide other data that cannot or

Fig. 6.2 (**a**) General view of the location of the Ancherif geosite; (**b**) Shoulder blade of Ancherif *Elephas* with part of the rib on top; (**c**) Shoulder blade of *Elephas recki recki*; (**d**) Scapula of a juvenile *Elepha*; (**e**) rib of Ancherif *Elephas*

are not commonly preserved in museums, such as features and structures of sedimentary rocks, associated trace fossils, data from contiguous layers, etc. Therefore, urgent conservation of *in-situ* geosites is a priority.

Authorities need to consider that people are interested in these types of sites and are willing to support them at the local level because of the income, attention and educational opportunities they generate. As a result, they present an economic opportunity that serves to generate considerable income for the local population if this initiative will be accompanied by professionals hired to manage the site.

6.3 Discussion

During the inventory, 35 vertebrate paleontological geosites were inventoried. For the total value of the geosites, only 1 geosite had a total value less than 0 ($Sv < 0$) and 12 geosites had a positive total value ($Sv > 0$) which represents 34.2% of all geosites inventoried.

The selection of the four geosites studied in this work is based on the scoring of the criteria of representativeness, rarity and geological diversity (a score of 3). Indeed, the uniqueness of vertebrate paleontological geosites reflects the geographical position of the Middle Atlas chain during the

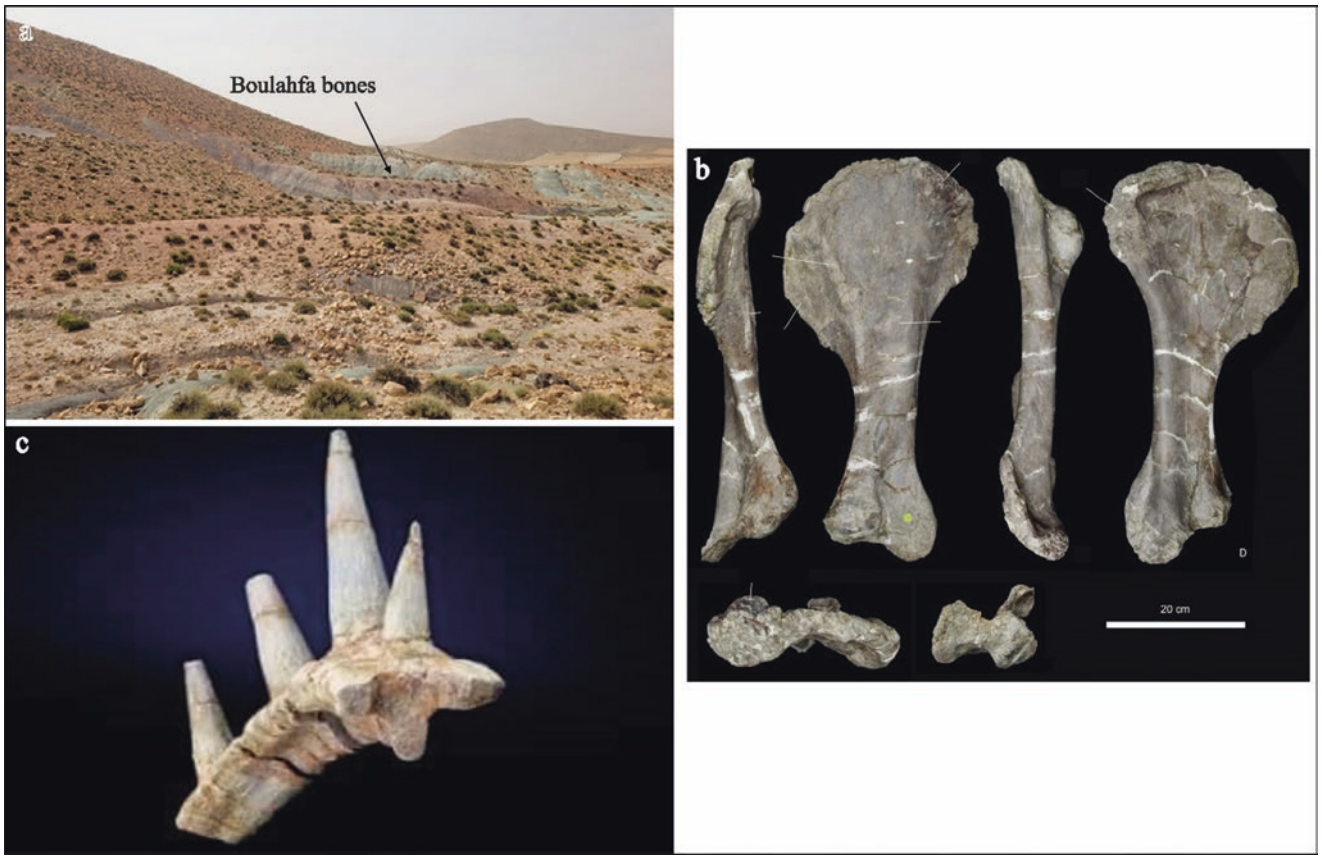

Fig. 6.3 (**a**) General view of the location of the bones of the Boulahfa geosite; (**b**) Left humerus of Boulahfa's stegosaurus. (Maidment et al. 2020); (**c**) *Spicomellus* rib. (Maidment et al. 2021)

Jurassic and Pleistocene. These 4 geosites all had an Ss ≥ 2.5 (Aït Bazza (Ss = 2.52), Ancherif (Ss = 2.52), Boulahfa (Ss = 2.52) and El Mers (Ss = 2.52)).

The sites selected, *in situ*, present footprints, bones of dinosaurs or mammals, from the Jurassic and the Pleistocene. The remaining geosites have been excluded from this description due to their similar intrinsic characteristics, which is why we have not duplicated their description multiple times. On the other hand, *ex-situ* sites have not been included in the inventory of these geosites such as museum collections and reconstitution exhibitions.

Despite the fact that no geosite had a high deterioration score, all the geosites are relatively degraded by human activity, due to the proximity of villages and infrastructures, and inducing the harvesting of the majority of bones (at except for the dinosaur footsteps) currently *ex situ*. These sites are endangered by economic development, construction, extraction and vandalism. Wild harvests unfortunately end up in museums abroad, like the remains of fossils from the Boulahfa geosite, exhibited at the Natural History Museum in London. On the other hand, the natural action has also altered their condition. This is the case of dinosaur footsteps found in the beds of Oueds which are permanently exposed to water erosion.

The results highlight these geosites with top priority for management due to their high scientific value and degree of deterioration. Although the geosites selected during the assessment of the degree of deterioration obtained a positive (Sv), we do not recommend these geosites for tourist uses because of their fragility and the difficulty of their preservation with respect to the action of looters and tourists.

6.4 Conclusion and Perspectives

Recognized for a century, the Middle Atlas is the subject of increased attention and offers geoscientists and paleontologists a vast field of predilection for one of the richest fossiliferous deposits in the country and even in the world. Vertebrate palaeontology in the region has thus made a consistent and decisive contribution to understanding and documenting the origin and evolution of numerous groups of vertebrates from the Jurassic to the Pleistocene.

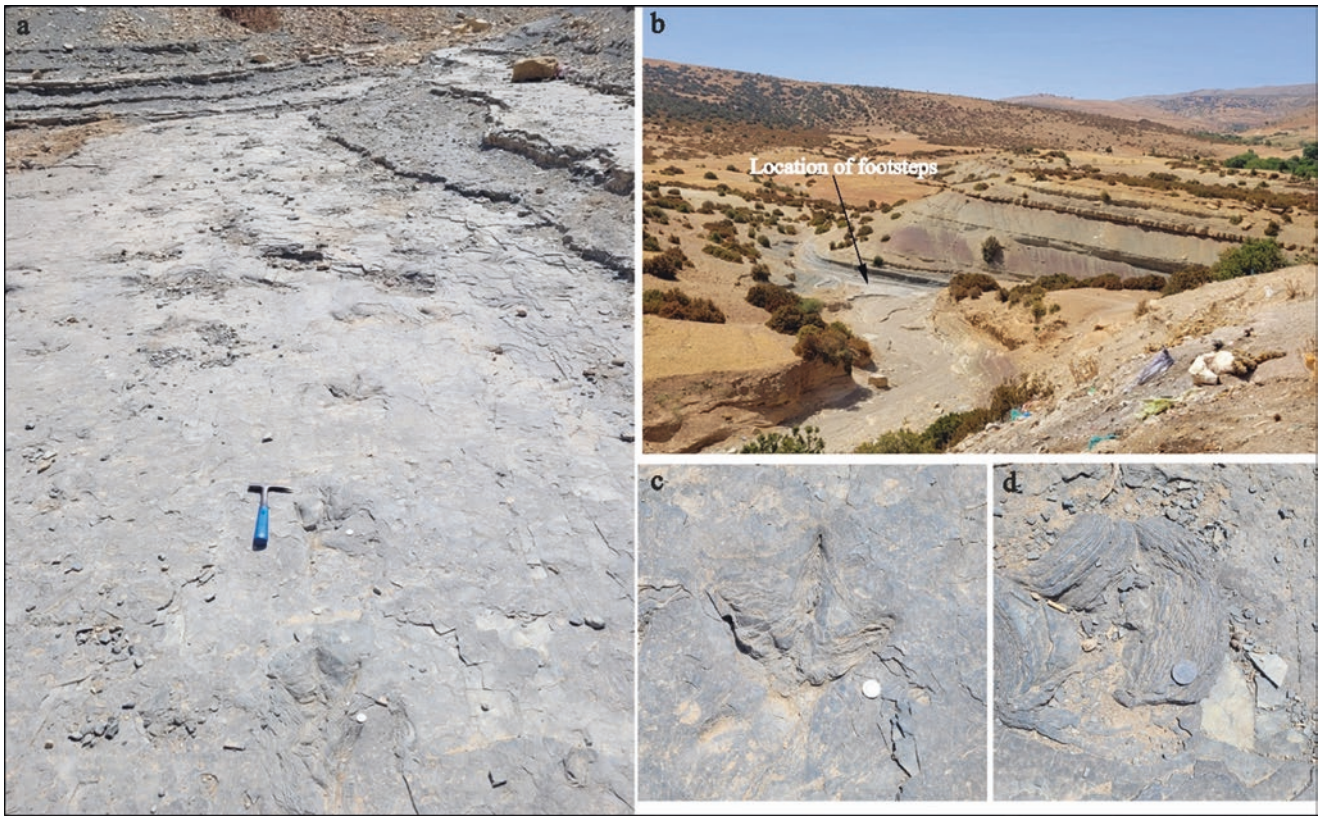

Fig. 6.4 (**a**) Dinosaur footsteps crossing each other on the limestone slab of the Bou Akrabène-Ich Timellaline formation; (**b**) Location of El Mers dinosaur footsteps; (**c**) and (**d**) Footprints of theropod dinosaurs

Paleontological heritage or "paleontoheritage"is considered an indispensable resource in regional and national socio-economic development. Most paleontological work on vertebrates in the Middle Atlas is insufficiently researched. Faced with the degradation of several fossiliferous sites, it appeared necessary to carry out an inventory, as exhaustive as possible, and to make available as many of these sites as possible. The inventory of vertebrate paleontological geosites led to the inventory of 35 localized sites, almost all of them, in the folded Middle Atlas, 4 of which are described in this work. This inventory revealed a variety and diversity of specimens, bones and ichnites. These are specimens of *Cetiosaurus* sp., *Iguanodon* sp., Teleosauridae (*Steneosaurus* sp.), *Megalosauripus* sp., *Breviparopus* sp., *Lepidotes* sp., *Megalosaurus* sp., Testudinata, *Protocardia* sp., Ostreidae, *Elephas recki* (*recki*), *Adratiklit boulahfa* and *Spicomellus afer*.

Great progress has been made on the study of vertebrate paleontology in the Middle Atlas. Unfortunately, scientific research on these archives of life is often confused by the abusive exploitation that ends up some sites toward destruction. Therefore, it is necessary to restore a protection and conservation status to protect this *in-situ* heritage and limit any action to export *ex-situ* bones.

It is only with full knowledge of the facts that we can take the necessary measures concerning their safeguarding and their enhancement in a dual perspective of scientific and economic development. People must also be made aware of the richness of their heritage and the potential it offers for their development. Professionals, scientists and/or merchants, who know the value of this heritage must be held accountable, particularly in terms of sharing knowledge and specimens: collaborations must be encouraged, and areas of research multiplied.

The best strategy for safeguarding the paleontological heritage of the Middle Atlas is to integrate the local population in the management of paleontological sites through several awareness-raising accompaniments allowing a better knowledge of the scientific, cultural and territorial interest of the region. They are considered with the authorities as the first conservation partners. Their presence in the field is useful for information gathering, but controlling the mobility of heritage objects is a concern. They have a direct link to the conservation and protection of paleontological sites in the region, which requires a vast campaign to raise their awareness of these sites and ignore their interest for the community.

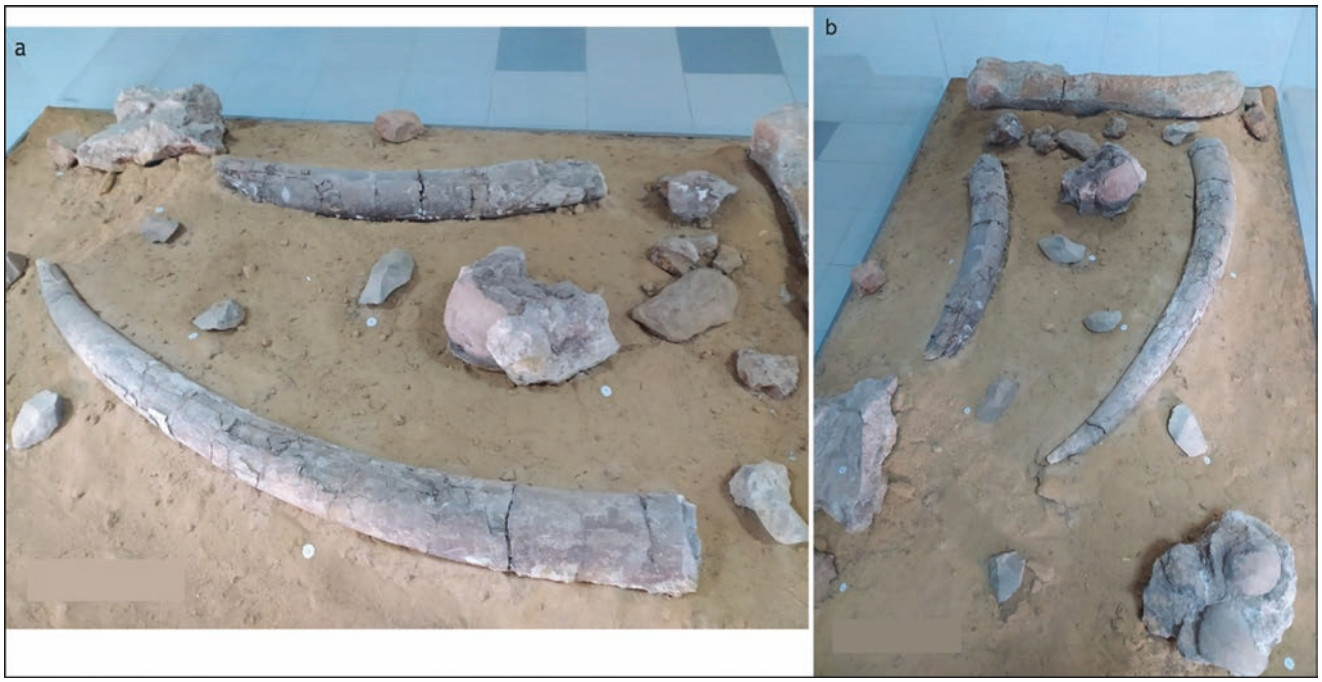

Fig. 6.5 (**a**) and (**b**) Elephas bones preserved in the Middle Atlas Heritage Interpretation Center (CIPMA)

The lack of local or regional museums dedicated to the preservation of paleontological heritage is a cause of anarchy, irregularities and destruction. Thus, the absence of a competent administrative structure, which can make legislative proposals, means that this type of heritage is marginalized and in degradation. However, the authorities must on their part take initiatives to set up a local or regional museum to represent the importance and rarity of this irreversible heritage.

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