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Emergency of Protection and Valorisation of the Fossiliferous Site of Ambatolafia, Middle Cretaceous of the Mahajanga Basin

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ABSTRACT

There is a badly considered heritage in Madagasikara, that of the palaeontological heritage with multiple range of which: scientific, ecological, tourist, cultural, and economic-commercial. The current uncontrolled overexploitation challenges us and foramt our country also possesses a palaeontological endemicity; this wealth there is unfortunately not renewable but must be of a durable valorization The Ambatolafia quarry sites allow us to trace the lithological sequences of the Lower Albian summit, dated by ammonites found at several levels. A layer of greyish-green glauconitic clays in the *Cleoniceras besairiei* zone yields a rich, well-preserved fauna of marine invertebrates such as brachiopods, gasteropods, bivalves lammellibrans and cephalopods. According to this investigation, the exploitation of ammonites in the quarries of Ambatolafia constitutes threats and risks to the degradation of its fossiliferous sites if there are not measures to safeguard them by the installation of protected areas and the patrimonialization of the reserves. The final objective is to be able to develop, manage and protect the geological heritage of Madagasikara.

Keywords: assessement - protection - valorisation - fossil - Madagasikara

I. Introduction

The geological heritage concept has found in the early 90's. Geological diversity potential was recognized as heritage value (Aertgeerts et al, 2011). Thus, its development is remarkable by a family of words revolving round the prefix "geo-" geoheritage (Coratza & De Waele, 2012) (Dumbar, 2007) , geotope (Lugon & Reynard, 2003) (Pagano, 2008), geosites (Wimbledon, 1996) (Wimbledon et al, 2001) (Ilies & Josan, 2009) , geodiversity (Gray, 2004) (Duff, 1994) (Blank, 1988) (Sharples, 1995), geopark.and recently geowatching (Garofano, 2014) for geological resources and "paleo-" (paleosites, paleodivesity, paleopark ...) for paleontological resources (Duval & Ganchon, 2010).

In the Mahajanga basin, the locality of Ambatolafia is currently an area of commercial exploitation of Ammonites by the local population: the sites could disappear completely if measures are not taken to safeguard them (Rakotonimanana, 2006). Ammonites have been most vulnerable to illegal commercial exploitation since 1999. Currently, the sites are in catastrophic degradation due to the absence of control measures and regulations regarding exploitation. As rare, fragile and diverse material goods, created and inherited from nature, fossils must be protected and passed on to future generations (Desvallées, 1995) (Davallon, 2002). New investigations are necessary, with the strategy of safeguarding and sustainable management of palaeontological heritage. The aim of this article is to call for protecting fossil sites in Ambatolafia area. In support of this goal, this paper will show: the richness and beauty of geodiversity, the special features and the great potential in the sedimentary formations of the Ambatolafia area.

II. Materials and methods

II-1-Geographic location and geological survey

The study area Ambatolafia is located 30 km North North Est of the Sitampiky village, 100km south of the Mahajanga city and 60 km South west of Ambato Boeny It belongs in the Commune of Bekipay (Fig1) limited the geographical coocdonates between south latitude and Est longitude as a map is showig as a folow.

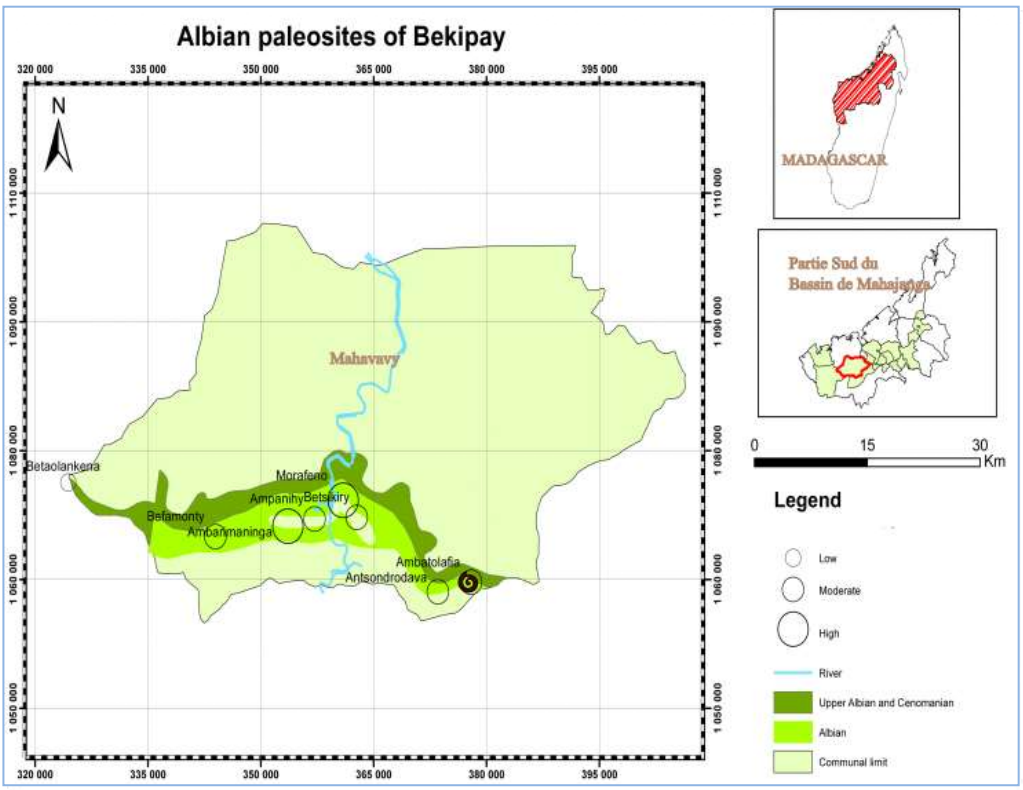

Figure.1: Location of the study site (source: BD 500 Foibentaontsarin'i Madagasikara)

II-2-Methods

Documentary consultation is an essential step in the development of scientific work. The knowledge of the elements useful in the elaboration of the field research has been previously researched bibliographically in the literature of the field of geo-heritage and geo-conservation. In addition, fieldwork is mandatory for all geological research. Three scientific expeditions were made in 2006, 2014 and 2021..

The investigation carried out is part of the characterisation system of the fossiliferous sites exploited in Ambatolafia. The objective was to identify heritage assessments and their degradation on the selected sites. In a practical and technical manner, the field visit was carried out through systematic site surveys and selective investigations. Customary authorities, administrative authorities, miners, fossil collectors and local transporters were the sources for the collection of information through direct interviews using logbooks. Documentary data was used to compare the elements collected in the field with visual support from digital cameras. The logic adopted is a systematic analysis of the complex interactions between the degradation of palaeontological sites and anthropic factors in order to establish a correlation between the characterisation indicators of the sites and their exploitation process.

III-Results

III-1-Toponymy of the site

The fossil sites of Ambatolafia are formed by the whole of the four hills: the first located at the extreme East carries the name Ambohinando then Mandanivatsy; the third is the hill of Andolombazaha; and the last is that of Ambindakely (Fig.2) at the extreme West. This deposit is located on the north and east sides of the villages of Ambatolafia I and Ambatolafia II. The distance between its two East-West extremities is estimated at 5km, and 500m between the base and the top of the hillside. The surface outcrops are difficult to distinguish from each other due to mining operations. The typology of these sites (Tab.1) shows all included objects of scientific interest

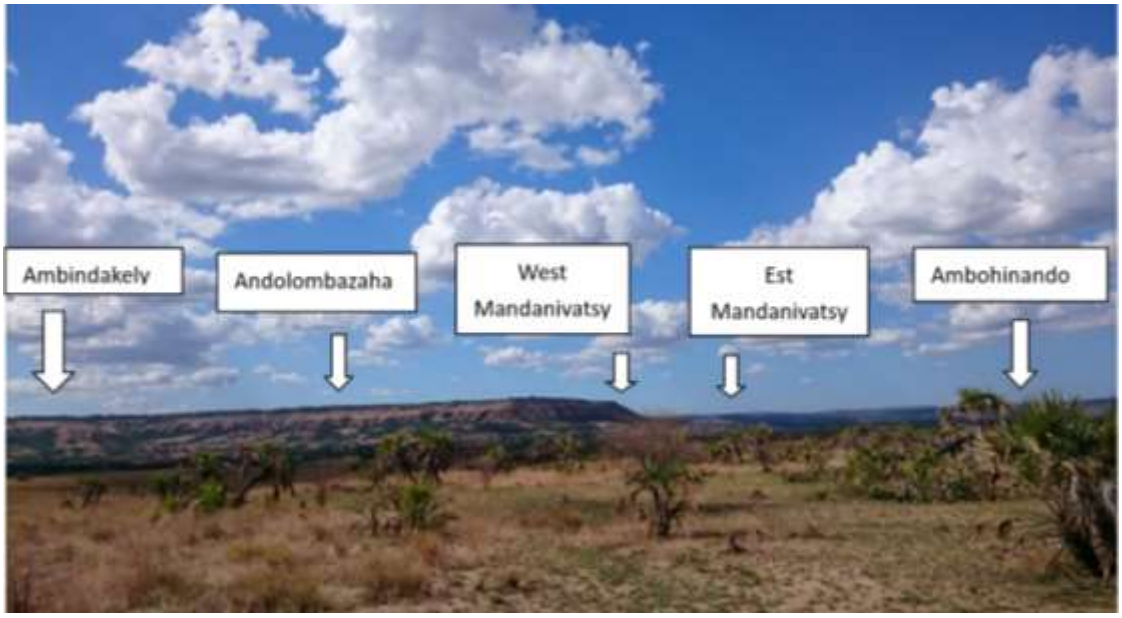

Figure.2: Fossiliferous sites in the Ambatolafia locality

All of those sites contain a remarquable geological object :

- S1: Palaeontological geosite (fossil site) Site containing a fossil formation remarkable for its abundance, quality of preservation or palaeobiodiversity. Presence of fossil fauna enabling the evolution of species to be understood and reconstructed and/or presence of fossil communities and paleoenvironments enabling the evolution of environments to be understood and reconstructed;
- S2: Mineralogical geosite: Site containing one or more remarkable mineral formations;
- S3: Petrological-sedimentological geosite: Site showing one or more remarkable rock formations Site showing remarkable sedimentary formations or figures;
- S4: Stratigraphic Geosite: Site showing a remarkable sedimentary sequence or series;
- S6: Geomorphosite (geomorphotope): A site with a remarkable shape for the understanding of the phenomena that led to the formation of the relief;
- T: Site of technical interest: Presence of remarkable remains or maintenance of traditional activity (mines, underground quarries, wells, boreholes).

Table.1: typology of geological sites in Ambatolafia locality

typology	Ambindakely	Andolombazaha	West Mandanivatsy	Est Mandanivatsy	Ambohinando
S1	+	+	+	+	+
S2	+	+	+	+	+
S3	+	+	+	+	+
S4	+	+	+	+	+
S5	-	-	-	-	-
S6	+	+	+	+	+
T	+	+	+	+	+

+: remarquable, -: not remarquable, S5: site of structural intesest

III-2-Geological diversity

Paleobiodiversity: The sites contain numerous interesting fossils , particularly the macrofossils of invertebrates. They contain a fossiliferous formation that is remarkable for its abundance of cephalopods, quality of preservation and paleontological diversity distributed in very unequal proportions(Fig.3).

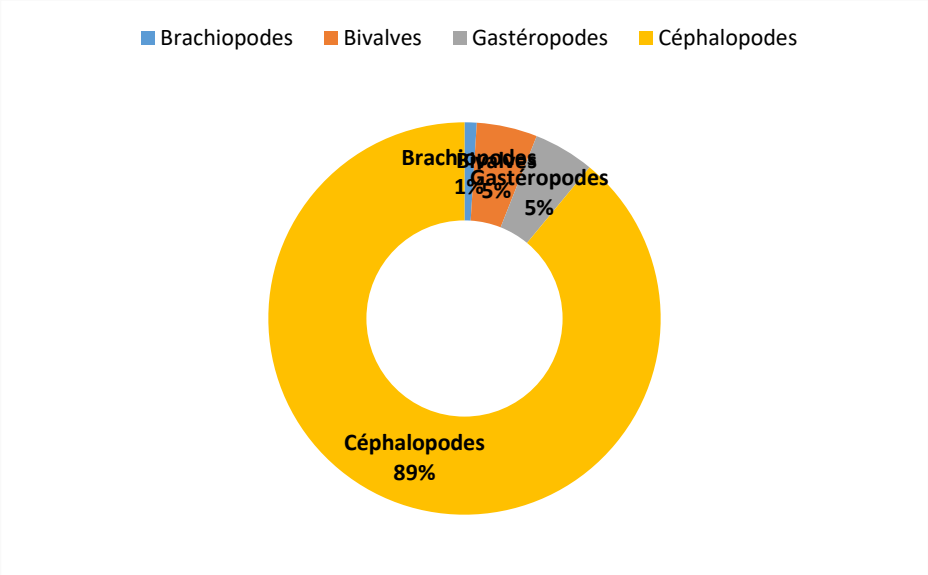

Figure.3: abondance of fossile in the Ambatolafia locality

The Albian fauna species at Ambatolafia is represented by four classes: Brachiopods, Bivalves, Gqsteropods and Cephalopods (Tab.2).

Table.2: Inventory of species fossils from the Ambatolafia site

Brachiopods.	Bivalves	Gasteropods.	Cephalopods.
Rhynchonella cf. sulcata Davns.	*Ostrea canaliculata* Sow.	*Scala (confusiscala) franciscae* nov. sp.	*Nautilus (Cymatoceras) sakalavus* nov. sp.
Terebratula subrotunda Sow.	*Ostrea besairiei* nov. sp.	*Scala (confusiscala) odilae* nov. sp.	*Phylloceras velledae* Mich.
Terebratula subrotunda Sow. var *subundata* SroL.	*Neithea quinquecostata* Sow.	*Cyrodes aff. tenellus* Stol	*Ammonoceratites cf. mahadeva* Stol
Terebratula obesa Sow.	*Neithea cf. aeguicostata* D'Orb	*Fossarus besairiei* Delpey.	*Argonauticeras besairiei* nov. sp.
Terebratula diphimorpha Stol	*Prohinnites fawrei* Pict	*Delpeya cottreaui* nov.gen. nov. sp.	*Pictetia Astieri* D'Orb.
Terebratula dutemplei D'Orb.	*Gervilleia sp* 2	*Leptomaria magneti* nov. sp.	*Eotetragonites umbilicostriatus* nov. sp.
	Isognomon chavan nov	*Euchelus lenoblet* nov. sp.	*Jauberticeras besairiei* nov. sp.
	Modiola recta nov	*Solarium bassae* nov. sp.	*Paragaudryceras sakalavum* nov. sp.
	Modiola rotundata nov	*Cerithium coxI*, nov.sp.	*Anisoceras trituberculatum* nov. sp.
	Modiola subcapitata nov	*Cerithium delpeyae* nov. sp.	*Protanisoceras breistroiferi* nov. sp.
	Modiola roedereri nov	*Cerithium subspinosum* sp.	*Protanisocerass hourcqi* nov. sp..
	Pinna dechazeauxae nov	*Metacerethium sp*. Mich	*Beudanticeras hourcqi* nov. sp.
	Arca chavani nov. sp.	*Perissoptera besairiei* nov. sp.	*Latidorsella latidorsata* Mich
	Trigonoarca sp. indet. alf. elongata Rennie	*Pterodonta besairiet* nov. sp.	*Uhligella dubia nov*. sp.
	Trigonia sp ?	*Ringinella hourcqi* nov sp.	*Puzosia quenstedti* Breistr
	Sphaera besairiei nov. sp.	*Cocculina rathbuni* Dall	*Douvilleiceras mamillatum* Schlot
	Protocardia sphaeroidea Forbs	*Solarium bassae* Coll	*Douvilleiceras nnonile* Sow.
	Yeniella etheridgei nov	*Natica gaultina* D'orb	*Duvilleiceras inaequinodum* nov.
	Veniella lineolata Sow.	*Solarium moniliferum* Mich	*Douvilleiceras benonae* Besr.
	Opis hugardi D'Orb.	*Semisolarium bassae nov sp*	*Archoplites sp. aff. achromensis* Nik.
	Panopaea gurgitis Brongt.	*Ampullina gaultina nov sp*	*Cleoniceras besairiei Coll*
	Panopea carteroni d'Orb.	*Metacerithium aff. trimoline*	*Cleoniceras Madagasikaraense Coll*
	Panopaea inaequivalvis D'Oku.	*Cirsocerithium collignoni nov sp*	*Cleoniceras ptychitiforme Coll*
	Panopaea triangula nov. sp.	*Zardinistylus cretaceus nov sp*	*Cleoniceras cleoniformes Coll*
	Panopaea submandibula nov. sp.	*Pommerozygia aff. albensis nov sp*	*Cleoniceras crassefalcatum Coll*
	Panopaea intermedia nov. sp.	*Pommerozygia mahajangensis*	*Cleoniceras ambiguum Coll*
	Anatina agassizi DORB.	*Opaliopsis franciscae nov sp*	*Cleoniceras quercifolium Coll*
	Corbula hourcqi nov. sp.	*Opaliopsis aff. dupinianum*	
		Conjectura minuta nov sp	
		Buvignieria berwaldi nov sp	
		Latiala besairiei nov sp	
		Tessarolax retusa nov sp	

		Mahajangina weitschati nov sp *Paladmete? Rasoarinoroa nov sp* *Tomura ambatolafiensis nov sp* *Carinathilda parvuruga nov sp* *Carinathilda bandeli nov sp* *Ampezzanildid larval nov sp*	*Cleoniceras inaequale Coll* *Clmeoniceratidae Coll* *Cleoniceras tenuicostulatum Coll*

Lithofacies: In addition to fossils, the ambatolafia locality contains remarkable gypsum mineral deposits. It also shows Albian (marine deposit) and Cenomanian (continental deposit) sedimentary formations (Fig.4) which present sedimentary sequences constituted by deposits of clay, marl, sandstone and limestone showing extraordinary strata inluenced by some seismic structures.

Figure.4: Sedimentary formation in the Ambatolafia site

III-3-Heritage assessment

The inventory established during the field investigation (Tab.3) shows the diagnostic result which applies to the objective evaluation of the paleontological sites of Ammbatolafia based on its scientific characteristics

Table 3: Heritage assessment of the locality of Ambatolafia

Criterion	level	Point assigned
rarity	Fairly rare : 4 sites: Mandanivatsy, Ambindakely, Andolombazaha, Ambohinando	8
examplarity	More representative reference layer: *Cleoniceras besairiei* zone	12
quality	Fossil in good state of preservation: pearly fossil	8 (*****)
palaeontological diversity	Exceptional: palaeontological and stratigraphical interest	8 (*****)
Pedagogical	Major pedagogical interest for the teaching of historical geology: biostratigraphy and paleoenvironment	16 (*****)
Scientific	Major scientific interest, of reference involving research of international impact	16 (*****)
vulnerability	More vulnerable, important factor and threat: risk of disappearance in the short term	16 VVV

context	Favourable: suitable for protection and enhancement	8 FF

III-4-Land degradation, paleodiversity loss

This heritage is damaged due to the backfilling quarries and the pillage of the fossil sites (Fig4). For these same reasons, the majority of paleosites still accessible today will more or less disappear shortly.The conservation of these witnesses as natural wealth but also as high educational and scientific places is seriously threatened.

The areas of fossil sites that have fallen victim to uncontrolled mining in Ambatolafia (open pit, stripping, drilling and wells) are expanding eastwards. The miners make another new quarry after having abandoned a finished quarry and so on: the mining of ammonites had started in the sites of Ambindakely, in the sites of Andolombazaha, then in Mandanivatsy West and East, expanded currently in the sites of Ambohinando. For 24 years, from 1999 to 2021, the surface area degraded by mining operations is estimated at 250 hectares.

Figure.5: Surface appearance after ammonite mining in Ambatolafia in November 2022

IV-Discussions

IV-1-Why and what to do to preserve the paleosites

Some paleosites may contain priceless heritage treasures allowing us to better understand the history of life and the Earth. Being awareof the fact that a site cannot be moved (except special cases) or a destroyed site can never be restored, we have to know as well that it is our duty to make an inventory of these sites and protect them according to their heritage value. These sites should be preserved for several reasons:

- as part of the natural heritage: the link between ecosystems and geosystems is obvious, geology allowing to understand the evolution of life and the current biodiversity;
- for their appearance: tourist-oriented sites have an economic value; it is essential to ensure their preservation in good state and the respect of their environmental value;
- for their educational value: the practical field study is mandatory for the teaching of the Earth Sciences. Preserving sites having educational value is essential for education and requires the public consciousness-raising;
- for their contribution to Sciences: knowledge enrichment about the origin, operation and evolution of Earth and life, are based on field studies as well. Also, sites can be international references likethe stratotypes;
- for socio-cultural purposes: some sites are evidence of the past; it is important to understand the historical background of a region, inform the public at large and to restore historical monuments.
- to try to stop this threat, some public actors will undertake site protection and restoration by starting to consider the paleontological heritage while implementing actions towards natural heritage

IV-2-Conservation perspectives

Many important fossil deposits provide essential data for understanding past biodiversity and the evolution of life through time (Hayward, 2009).

However, it should be regretted that some fossils are lost or held by private collectors (Billet, 2002) . In order to protect this natural heritage, the creation of regional palaeontological museums and parks is recommended (De Wever et al, 2004) through the efforts of several organisations: the Department of Mineral Resources, Universities, local government administrations, public enterprises and several private companies (Gaitán & Álvarez, 2009).

Giving more value to remarkable geological sites means:

- protecting them from all actions leading to their destruction, to the loss of their remarkable features;
- enhancing their value so that they can be of benefit both to the surrounding localities and to the country as a whole;
- ensure better management of these sites with a view to their "sustainability" and profitability in relation to the objective(s) set beforehand (preservation of the environment, field of experimentation for scientists, etc.).

There are different ways to protect remarkable geological sites, namely:

- raising awareness among local residents about the existence of the site and its importance and interest;
- physical protection of the site, e.g. delimiting the perimeter with coloured and very remarkable wires.

In the case of an important collection of fossils or minerals or rocks, the construction of a museum is most advisable because, as mentioned above, everything changes over time, the fossils may disappear, so exploitation is favoured; on the other hand, in the case of a vulnerable site, exploitation should be avoided even if it contains very important elements (Derieux, 1998).

For fauna and flora, the statutes and structures of integral reserves (followed by Madagasikara national parks) have already been established in the form of Decrees since December 1927 in Lamberton's time until the current protected areas (Ramakavelo et al, 2003) but there is no parallel or analogous for fossils. It is high time to stop the in situ vandalism, the export haemorrhage limit.

To do this, four fundamental points should be considered:

- fill in the gaps in the mining code, in particular the consideration of research institutions that act upstream (academic research) and downstream (applied research) of the knowledge and preservation of this national heritage (scientific, economic, socio-cultural);
- institutionalising (e.g. Ministry of Culture, Ministry of Information, Ministry of Research, Ministry of Education, etc.) a public education programme (training, information) concerning this non-renewable but potentially sustainable source of wealth;
- formalise an official management status for the preservation and/or protection of fossils and fossiliferous sites in the same way as the integral reserves and their flora-fauna components;
- develop partner protocols with foreign organisations with a view to restoring expatriated forms.

Finally, it should be remembered that Palaeontology is a discipline that is scientifically unavoidable and economically indispensable in rich countries (Pagès, 2009), whereas it remains neglected or unknown elsewhere (Lipps, 2009).

IV-3-Passing illegal to legal work

Malagasy laws protect Madagasikara'scultural heritage from any kind of commercialization. These laws consider our paleontological heritage on the same level of archeological and cultural heritage, as it occurs in other several countries from Italy to Luxembourg, from France to Iceland. According to the regulations, no private searchers, collectors or sellers of fossils are out of laws and they would be subjected to legal action and to possible penalty. Besides, other possible troubles await those who destroy some important outcrops, as it is the case in this work.

On the other hand, it is unbelievable to put someone to jail or to make him pay very expensive economic penalties for having collected stones. In a near future, fossil collection and selling may become the only job opportunity for the whole community in an emerging country.

Starting from that position developing a geosite or paleosite into a geopark the outcrop study may be considered as an opportunity, which allows the transformation of an illegal routine into a new and lawful true job position. Both Old Searcher and Expert Geologists may become guides, or may work together to create and manage a local museum of paleontology and geology. Geologist and local ex-searcher and ex-collectors may cooperate to promote to touristic sites and outcrops without breaking the law.

V-Conclusion

In conclusion, the Project that establishes protected areas in fossil sites is urgent in the conservation of the Albian fossil deposits in Ambatolafia, the southern part of Mahajanga Basin. The reasons are as a follow:

- the Albian of Ambatolafia (Mahajanga Basin) has a unique set of fossil deposits - the scientific, historical and educational interest of which justifies the implementation of geosites protection means in Madagasikara.
- the project of regulation about the fossil exploitation requires prior knowledge of the sites. Thus, return to work is essential. Major issues concerning

the taphonomy of the deposits, the chronology of the Albian and paleogeographic evolution of Mahajanga Basin require new fieldwork demonstrating that Geological outcrops heritage has to be preserved.

- the fossil sites in the Albian of Mahajanga Basin (like Ambatolafia locality and other) bring a vital contributionto the paleontological knowledge.
- the site conservation showing the nature and organization of the land is necessary in scientific study and in geodiversity teaching.

The ultimate goal is to develop, manage and protect the fossil sites. The information from this paper will be made available for managers and decision-makers of the territory as an information tool and decision support.

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