



Research Paper

Inventory and Management of Dinosaurs Traces: A case Study of Azilal Region, Morocco

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Abstract: The preservation of geosites in the heritage framework is necessary at a time when urbanization, the exploitation of fossils and minerals are real threats to this irreversible heritage. This work is a contribution to the preservation and development of dinosaur trace deposits by geological and geomorphological description of the study area, then by mapping using Geographic Information Systems (GIS) and finally by the proposal of the models of development and preservation of these geosites.

Keywords: Azilal region, Morocco, Geoheritage, Geo-Routes, GIS, Geotouristic Interest Local, Dinosaurs.

INTRODUCTION

Located along the northwestern edge of the West African Craton (WAC), Morocco is a tourist destination for 3S (sand, sea and sun) market. Present-day Morocco forms a mosaic of different tectonic plates and structural domains (called “paradise of geologists”; Michard et al., 2008). The area

under considerations has been the scope of numerous geological studies since the 20th Century and particularly in the past 30 years. Recent advances have revealed that geotourism is an emerging and still underdeveloped face of tourism, mainly in Morocco, and mapping the geoheritage of Azilal region remains lacunars. The importance of study of geoheritage of the Azilal Region is related the dinosaurs traces, worked by many paleontologists and geologists (Dresnay, 1971, 1975; Couvreur, 1977; Dutuit & Ouazzou, 1980; Jenny et al., 1981a,b; Laville, 1981; Monbaron, 1978, 1980, 1981, 1982a, b, 1983; Biron, 1982; Jenny & Jossen, 1982; Septfontaine, 1984; Laville, 1985; Monbaron & Dejoux J. Demathieu, 1985; El Youssi, 1986; Fadile, 1987; Souhel, 1987; Jacobshagen, 1988; Ishigaki, 1988, 1989; Souhel, 1996; Nouri et al., 1997; Souhel et al., 1998; Monbaron et al., 1999; Nouri et al., 2001; Haddoumi et al., 2002; Andreu et al., 2003; Charrière et al., 2005; Boutakiout et al., 2006; Belvedere et al., 2007; Belvedere, 2008; Boutakiout et

al., 2008; Nouri, 2008; Mojon et al., 2009; Haddoumi et al., 2009; Boutakiout et al., 2009 a, b; Belvedere & Mietto, 2009, 2010; Boutakiout et al., 2010; Nouri et al., 2011; Guezal et al., 2011; Marty et al., 2012; Boutakiout et al., 2014; Boutakiout et al., 2017; Boudchiche et al., 2017). Recently, more studies have been primarily targeted for the emergence of geotourism and geoeducation activities at Azilal (Central Haut-Atlas, Morocco) [e.g., Monbaron & Monbaron, 2015: The guide booklet contains geotourism circuits largely commented on through the different sectors of the M'Goun Geopark; Bouzekraoui et al., 2018 and Boutakiout, 2018: Geotourism and geoeducation]. In Azilal Region, the bid to improve the economy has necessitated the rapid development and rehabilitation of available tourism potentials.

The M'Goun Geopark is a mountainous region of often high altitude of which Jbel Ighil M'Goun culminates at 4068 m and Jbel Azourki at 3690 m and the age of the geological grounds goes back to the secondary era. This study area is part of the Geopark M'Goun, is the first UNESCO Global Geopark in Africa and the Arab world, that is given the label by Global Network of National Geoparks (GGN) developed under the auspices of UNESCO, during the 6th World Conference on Geoparks at « Stone-hammer Geopark » in Canada in September 22, 2014 (Bouzekraoui et al., 2018; Boutakiout, 2018). Because of the beauty of its landscapes and the diversity of its geological structures, the High Central of Azilal, was chosen by A. Faure-Muret, M. Boutakiout and A. Souhel during the preparation of the exhibition "Morocco: Memory of the Earth" in Paris in 1999-2000, as a territory to evolve towards a park or geological reserve (Boutakiout, 2018). The M'Goun Geopark has a peculiar interest from a paleontological point of view

(discovery of bones and footprints of dinosaurs, Iouaridène, Ait Mimoun, Ait Mimoun Ouffelah, Ait Blal), archeology (presence of engravings rock; Tizi n'Tirghist), geomorphological (geological curiosities such as Tamda Cathedral, Tamda Gorge ...), lakes (Ben Ouidane), mountains (Jiber, Sidal, Tamadout), waterfalls of Ouzoud, Iminifri and Tamda, chasms (Tawaya), natural bridge of Iminifri, and ecological (natural reserve of Tamda). It is in this regards that this study seeks to investigate give more information and management of the dinosaurs traces in this area. However, beside a general appreciation of their richness fossils and dinosaurs traces, a valorization is missing so far. Furthermore, integration and acquisition of additional data from the excellent Azilal Region outcrops has great potential for valorization and management of dinosaur's geosites. The geosite definition by Brilha is "geosites set of a local, geographically delimited, where there are geodiversity elements with unique values from a scientific point of view, educational, cultural or tourist. It consists of all non-renewable natural resources, whether geological or geomorphological formations, landscapes, mineralogical and paleontological outcrops" (Brilha in Pereira et al. 2018). More contributions about the geoheritage, history of geoconservation and geotourism in the worldwide consulted in this papers (i.e., Reynard, 2005; Piacente, 2005; Bureck & Prosser, 2008; Duhem, 2008). The history of this region goes back to millions of years during which was constituted of a privileged geological belt, which is distinguished by the presence of famous and spectacular footsteps of sauropod dinosaurs [see Ibrahim et al. (2017) and references therein; for more historical review and recent work of the dinosaurs of Morocco]. This richness must be preserved; including models of

development must be developed to set up fences, signage, mounting a life-size dinosaur resin, etc. Really, in some of them the dinosaurs traces have started to deteriorate, as well as suffering alteration in their primitive morphology.

1. Geological and Geomorphological Context of the Study Area

The central High Atlas is bounded by the Marrakech-Ouarzazate crossroads to the west and the Oued Ziz valley to the east (Mattauer et al., 1977). Permo-Triassic red terrigenous deposits are surmounted by white carbonates of Lower Jurassic age. In the Middle and Upper Jurassic, there are still red terrigenous deposits, this time strongly thickened. The rare outcrops of the Cretaceous and Tertiary, often eroded, are preserved on the only edge of the chain or in the center of the synclines. In addition, the presence of Triassic and Liassic basalts, as well as alkaline gabbros of Jurassic and Cretaceous age. The uplift of the High Atlas is the result of a structural inversion from

the Cretaceous and Cenozoic, during which the post-Hercynian cover was folded and peeled on the Triassic detrital. Because of these deformations, the High Atlas is furrowed by large flat-bottomed synclines, filled by thick Jurassic and Cretaceous series, which are often strongly eroded. The study area stretching from Demnate through Imi'n'ifri to Souk Sebt in the east to Lhwant is a sedimentary series consisting of two major lithological units. The 1st unit is the lower to middle Lias is formed by carbonate with large lamellibranchs. The 2nd unit is of Lias Superior age consists of detrital rocks alternating with red marl (Mattauer et al., 1977). The region is characterized by the predominance of sedimentary Jurassic series with local Triassic outcrops and quaternary deposits. The Triassic is represented by basalts that are outcropping in several parts: Aroui Valley, Tizi n'Tirghist. These basaltic flows are often accompanied by comings of red clays. In addition, the contact between basalts and surrounding limestones is often emphasized by a level of pink salt clay.

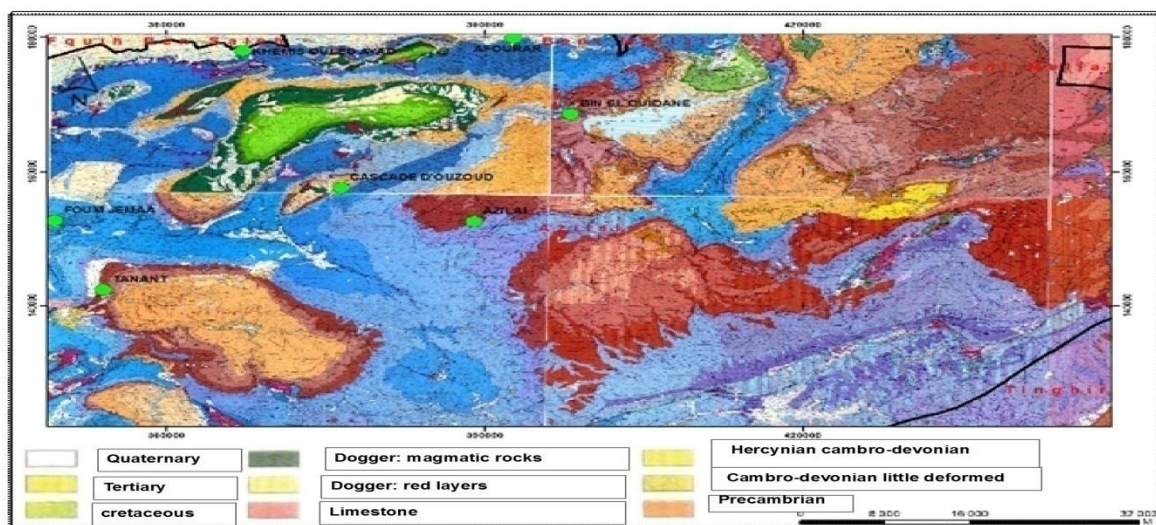


Figure 1. Geological map of the Azilal Region including sections location (1/100 000 scale map), with ArcGis software (Geological map of Morocco, Department of Energy and Mines, Morocco, 1985).

The study area has been subdivided into the following three Formations:

1. "Grès de Guettioa" Formation

This Formation is characterized by its reddish tinge and especially by its accentuated granulometry dominating the milder slopes established at the right of the underlying formation of Tilougguit. Towards the south-east of the High Atlas, it rests unconformably either on the "Cornian limestones" of the Bathonian or on the Formation of Tilougguit. This fact has been observed in the synclines of Ouaouizarth (Souhel, 1997), Iouaridène (Choubert, 1956), Igoudlane (Roch, 1939) and Aglalag (Moret, 1931).

2. "Iouaridène" Formation

This Formation occupies the axes of the High Atlas synclines. Like the other red layers, it is characterized by a series of red pelitic clays. It is also known for its strong erosion and poor preservation. The basis of this Formation is marked by a clear change of facies between the massive sandstones of the "Guettioa" Formation. Directly below this base are often the basalts crowning the

last foundations of the Formation of the "Grès de Guettioa", notably in the synclines of Ait Attab, Ouaouizarth and Aghbala (Monbaron, 1982 & 1985).

The summit of this series is marked by a regional angular discordance, which manifests itself everywhere in the Central High Atlas. The "Iouaridène" Formation is overcome either by the sandstones of the "Jbel Sidal" Formation (Souhel, 1987), notably in the synclines of Ait Attab, Ouaouizarth and Aghbala, or by the limestones of the Formation of Ait Tafelt (synclinal of Aghzif-Naour) (Souhel, 1987).

3. "Jbel Sidal" Formation

It is represented by an alternation of red-orange sandstone benches and red clays. The base of the "Jbel Sidal" Formation is based on the red pelitic clays and the gypsums of the "Iouaridène" Formation. The greenstone silts and greenish clays of the overlying formation show a sudden facies change. The base of the "Jbel Sidal" Formation locally contains a stratiform basaltic flow. Most often it is a single gabbroic casting, which is preserved only on the edges of the buttonholes (Souhel, 1987).

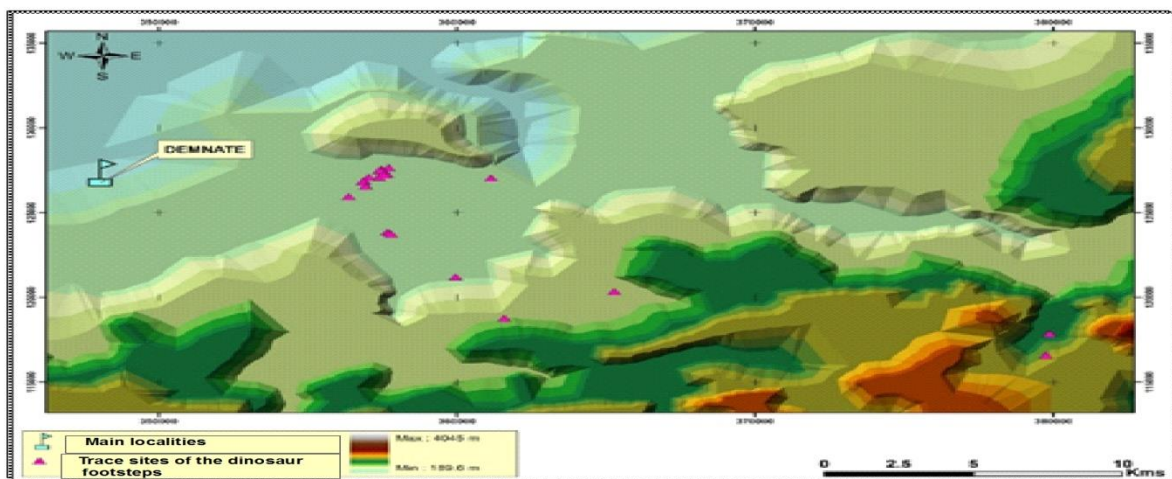


Figure 2. Location map of the footprints of dinosaur footprints in the study area.

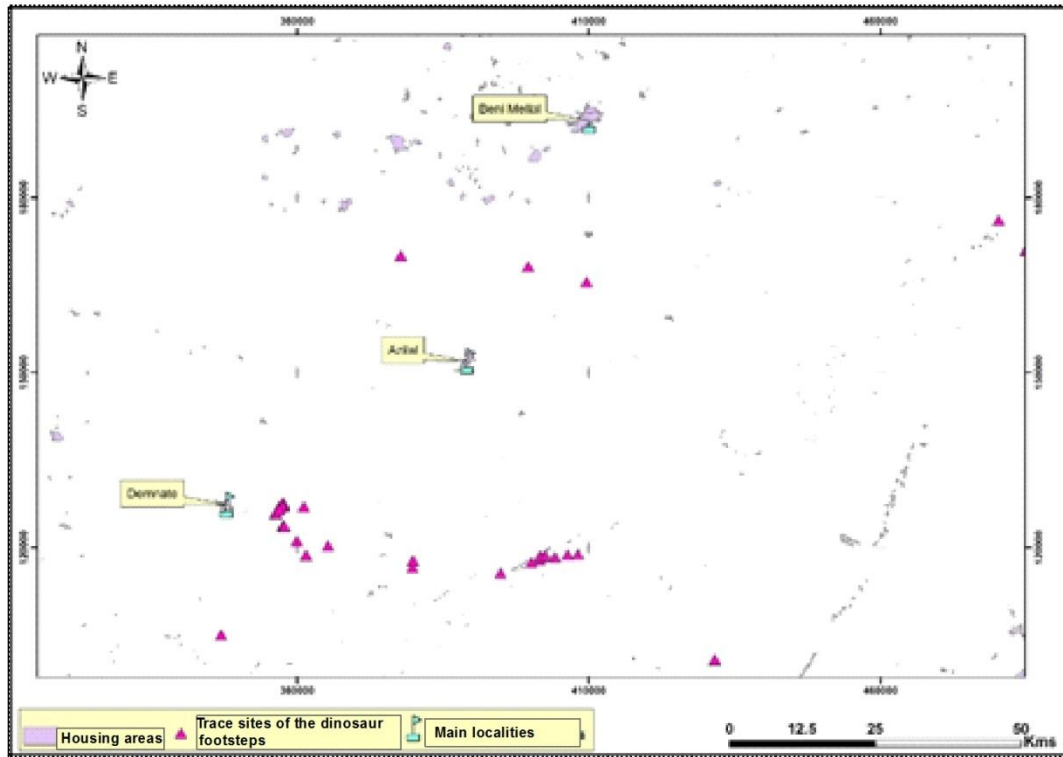


Figure 3. Map of the buffer zones of the footprints of dinosaurs, with ArcGIS software.

2. Data and methods

The database used in this study was by constructed by compilation from many data available in the literature. However, despite extensive research (paleontology, sedimentology, and tectonic) in this area, it is certainly possible that some data have not been considered. Good exposure conditions of the beds from Azilal have enabled us to distinguish the traces dinosaurs. The proposed work involves three sequential phases, currently in development. They are:

- a. Conducting an objective and as complete as possible census of dinosaur footprint sites using Geographic Information Systems (GIS) in the study area using geological maps (Jenny , J., 1985 & 1988) and topographic maps are from the National Agency for Land

Tenure); by collecting data (field surveys and bibliographical references), then developing the databases under GIS, then the spatial analysis and finally the realization of the thematic maps,

- b. On the other hand to contribute to a policy of preservation and enhancement of geological sites with all the partners concerned and to inform the various actors in charge (state services, communities, associations), as well as the general public by proposing models for the development of a few sites that require urgent intervention given the various threats that surround it and,
- c. High-resolution outcrop photographs were taken to aid in the description of the dinosaurs traces.

RESULTS

The M'Goun Geopark covers an area of 5730 km², of which 15 are part of it (Azilal, Demnate, Tilouguite, Zaouit Ahensal, Tabant, Ait M'Hamed, Ait Taguella, Agoudi N'Lkheir, Ait Abbas, Ait Boulli, Ait Blal, Sidi Boukhelf, Tifni, Anergui and Boutferda). It is limited to the North-West by the Provincial Road N° 24 linking Béni Mellal and El Kelâa des Sraghna, to the west by the road Bzou-Demnate and Tessaout, and to the South, by the reliefs of Ighil M'Goun. It is characterized by peaks that vary between 500 m and 4068 m, with major mountains that are Ighil M'Goun (4.068 m) and Azourki (3.690 m).

The Geopark is an operational platform for the flourishing of scientific and environmental research. He came to preserve this rich heritage and contribute to the protection of the geological, natural and cultural specificities of the region and the development of sustainable tourism and the economic fabric.

a. Climate

The study area in general is characterized by a strong spatial variability of precipitations and temperatures with a climatic staging from the plain to the mountain. The rains of the northern slopes of the Middle and High Atlas are of the Mediterranean type with oceanic influences. The mountain is sub-humid to wet (between 550 mm and 700 mm in Azilal and up to 1000 mm in the High Atlas) and cold, and the semi-arid plain (326 mm average rainfall in Fkih Ben Salah) and warm. The climatic seasonality is very marked with a rainy period from October to May, with intense autumn showers, and a dry period from June to September. The thermal seasonality opposes a cold winter, particularly harsh in the mountains, and a hot summer to very hot plain (up to 49° in Kasbah Tadla and average maxima of July higher than 30°) which accentuates the aridity at this period. Snow is a significant part of mountain precipitation in winter.

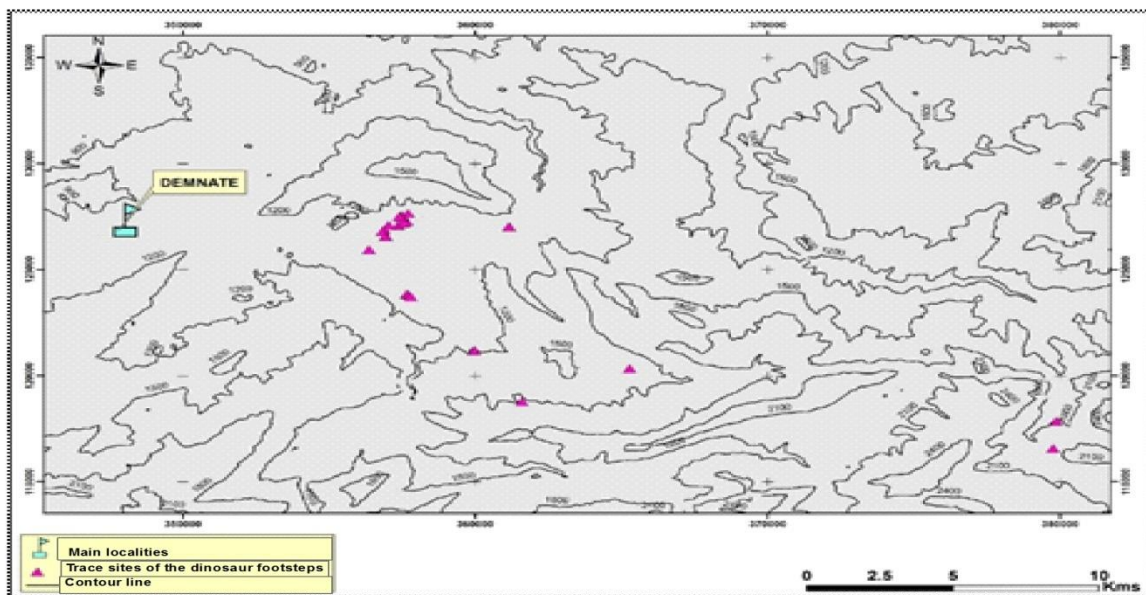


Figure 4. Map of the altitudes of the study area (scale 1/50 000 map), with ArcGis software, Source: National Agency for Land Conservation, Morocco.

b. Agricultural and Forestry Domain

The forest potential of the region contributes to the socio-economic development of the populations by assuring them: the raw material which is the wood, days of employment, routes for breeding, etc. The flora of the Central High Atlas is composed by typical Moroccan plant associations. The forest floor, located between altitudes 1500 m to 2200 m, is the domain of the Green Oak, developed particularly in pure stands (HCWCD, 2010).

The forest floor from 2200 m to 2500 m altitude is that of the juniper thuriferous,

noble tree and majestic foothills of the Atlas, it is the value tree victim of degradation. The forest floor of 2500 m at 3600 m altitude is home to an endemic flora, typically Moroccan. Characteristic associations are found, growing in cliffs, tabular peaks, and humid depressions, giving rich pastures. Beyond that, most of the plant landscape consists of very typical spiny cushions. Above 3600 m, the pads gradually disappear, vegetation becomes lean and often absent.

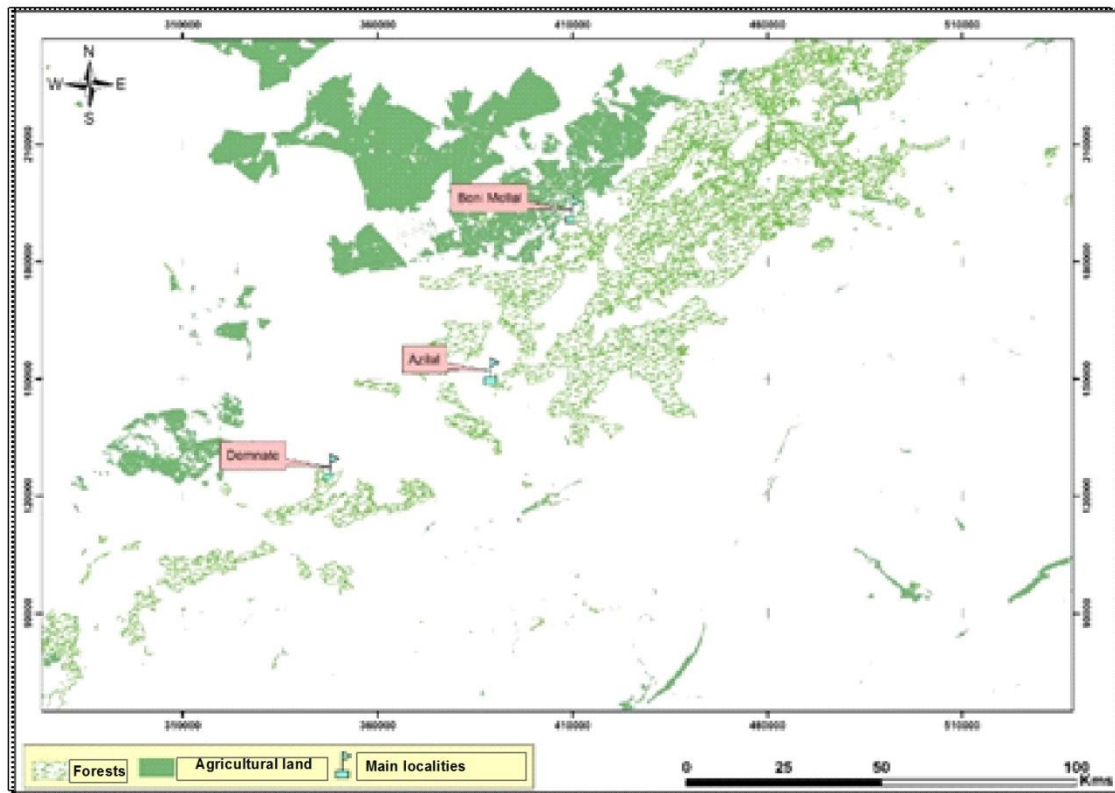


Figure 5. Map of the agricultural and forestry domain, with ArcGis software, Source: High Commission for Water and Forests, Morocco.

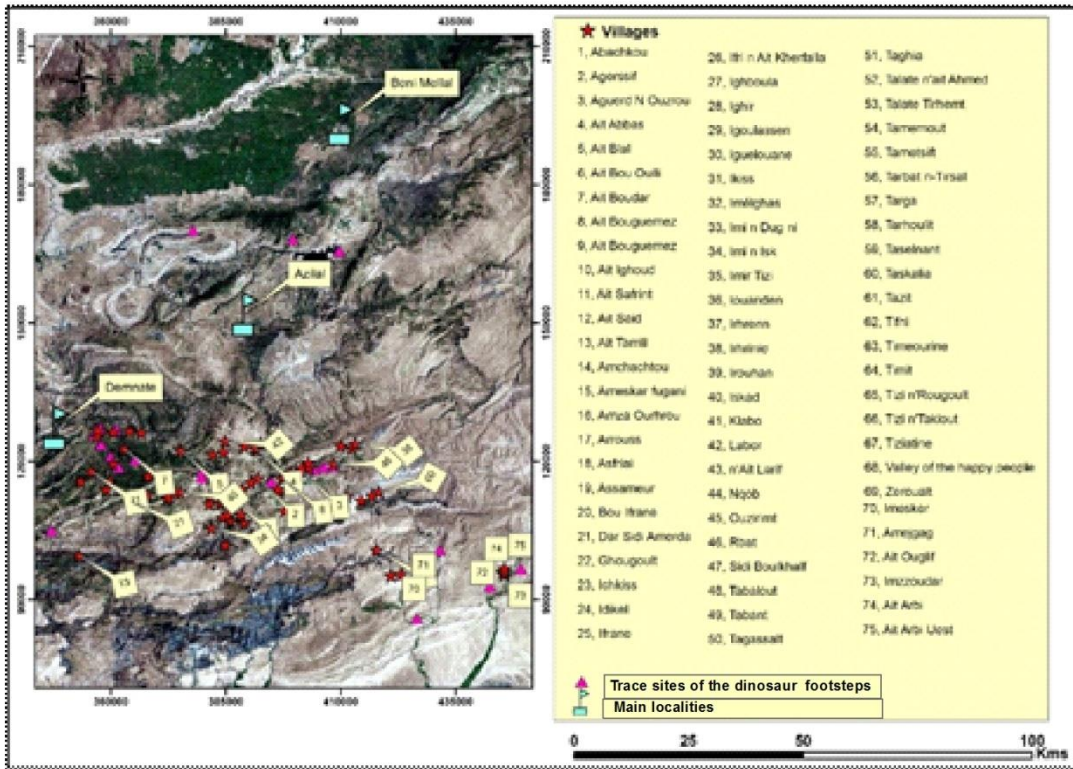


Figure 6. Map of small localities, with ArcGis software, Source: Ministry of Urban Planning, Morocco.

c. Roads

The total length of the network in the region is about 2432 km, of which 87% is paved. It is divided into National Roads (212.71 km), Regional Roads (903.57 km) and Provincial Roads (1315.43 km). For our study area, the distributions are as follows: National roads: 26.983km, Regional roads: 608,557 km and Provincial roads: 425,832 km. Paved roads leading to the center of the studied sites have deteriorated, having a negative influence on the preservation of the geological heritage, because it crosses the slabs of the dinosaur steps on the sites of Youridène and Ait Mimoun.

Using ArcGis spatial analysis extensions, we made buffers around dinosaur footprint sites. Indeed, these sites are invaded by the hydraulic degradation, as long as it is located in the low level of altitude of the syncline, by favoring the accumulation of the waters which increase in volume at the summer period, causing the deterioration slabs that conceal this heritage. In addition, the collapse of the ground remains among the constraints that negatively influence on the reservation of the footprints of the dinosaurs.

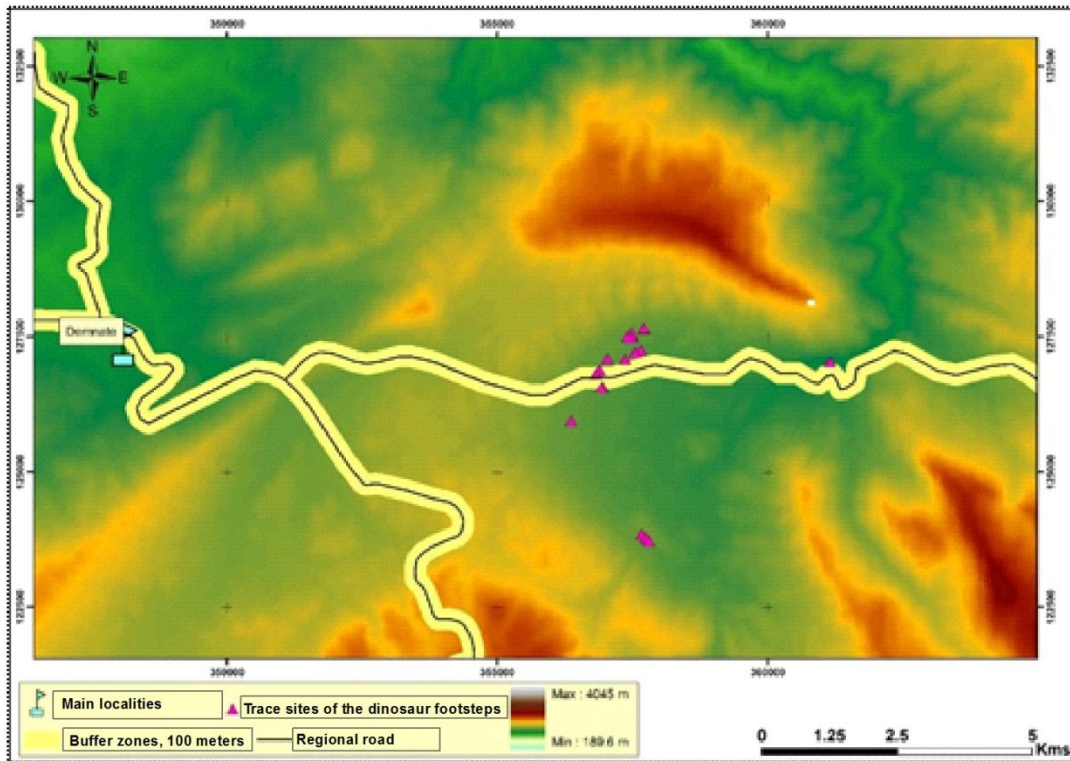


Figure 7. Map of the road network of the study area, with ArcGIS software, Source: Ministry of Transport and Logistics, Morocco.

d. Urban Agglomerations

According to the General Population and Housing Census of Morocco in 2014, the Béni Mellal-Khénifra region has 2,520,776 inhabitants, compared to 3,873,207 in 2004, of which 49.14% are urban, lower than the national rate (60 , 36%).

Also the region known a density of 88.8 inhabitants per km², very high compared to the national average (47.6 hab/ km²), thus occupying the 6th position in terms of density at the national scale.

The study area is characterized by the presence of a very large amount of small

localities exactly "douars" (Lecestre-Rollier, 1992). They are almost dispersed over the whole of the study area, with a rather remarkable filling in four points of the zone (Tirika, Taghbalout, Aït Mimoun, and Bou Ifrane). Most of the buildings in the region have an ancestral architecture. Indeed, newly built buildings are found in the center of the douars. The direct implantation of the electric poles on the footprints and the passage of the cattle on the deposits of the imprints cause a rather considerable deterioration.

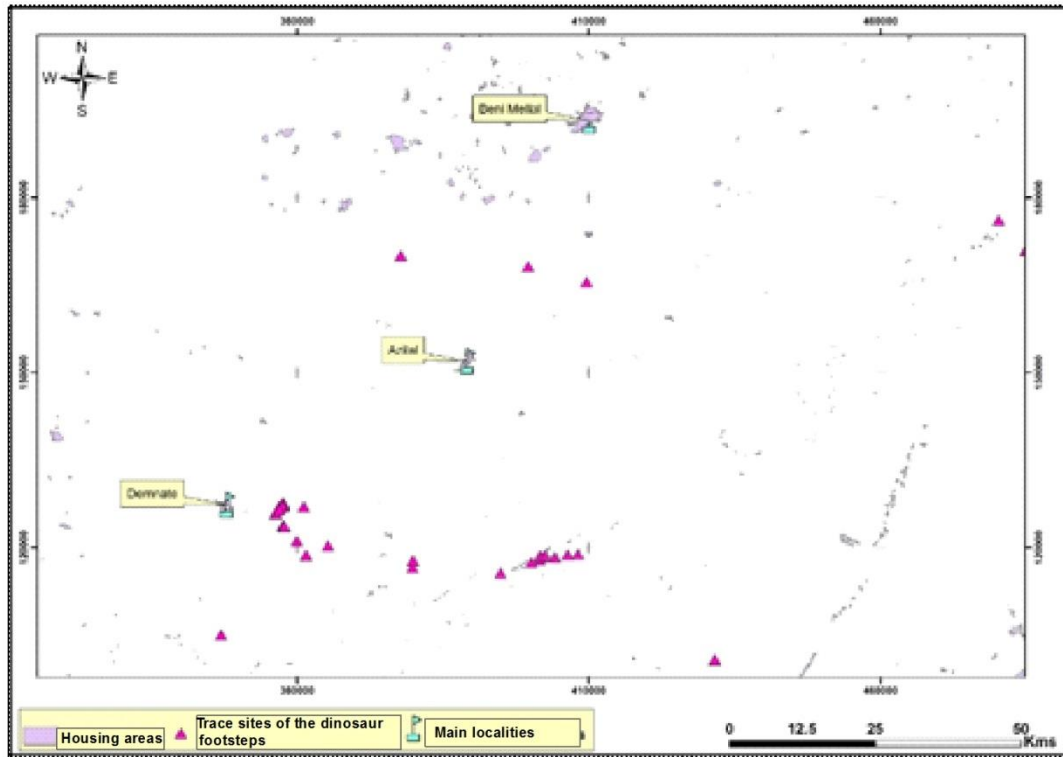


Figure 8. Agglomerations map, with ArcGis software, Source: Ministry of Urban Planning, Morocco.

e. Hydrography

The karst of the region is well developed in the limestones and dolomites of the lower and middle Lias as well as the limestones of Middle Jurassic and Turonian (Bouchaou, 1988). These karst complexes, from a few km² to about 365 km² for the most important, are related to the geological conditions (low extension of the carbonate complex, high intensity of the tectonics), but also the variations of base level, responsible for the creation of numerous karst duct

networks more or less superimposed (case of high mountain karst systems). These karstic systems and the associated aquifers contribute in a remarkable way to the durability and the support of the low water levels of the Atlas Rivers subjected to the Mediterranean climatic constraints. The presence of a remarkable mass of footprints near the water networks gives hypotheses on the places of concentration and passage of the dinosaurs at the time.

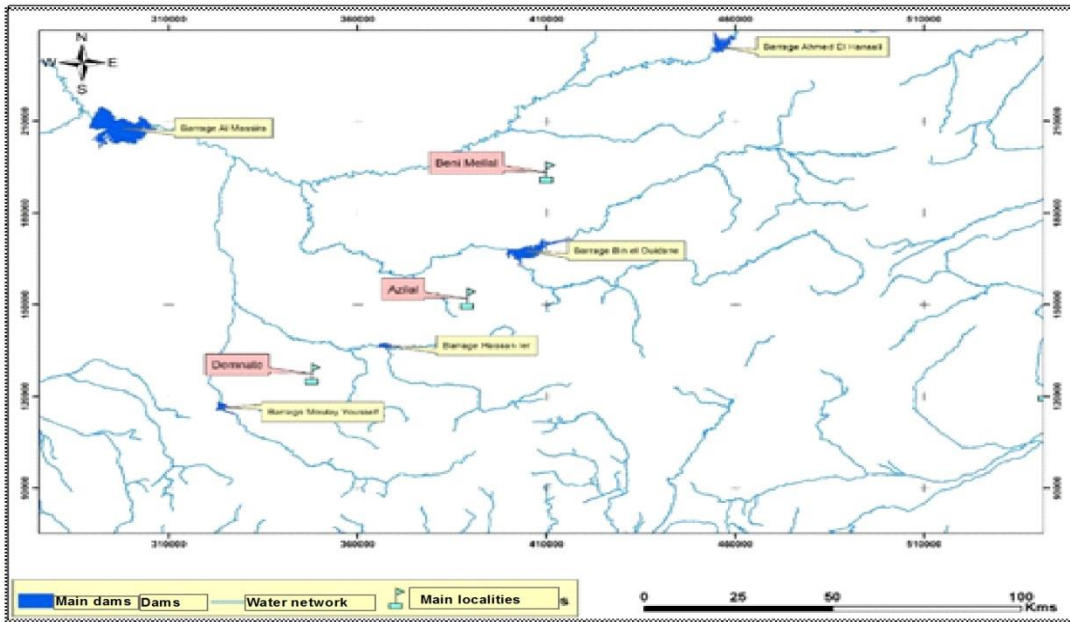


Figure 9. Hydrology map of the study area, with ArcGis software, Source: Oum Er Rbia Hydraulic Basin Agency, Morocco.

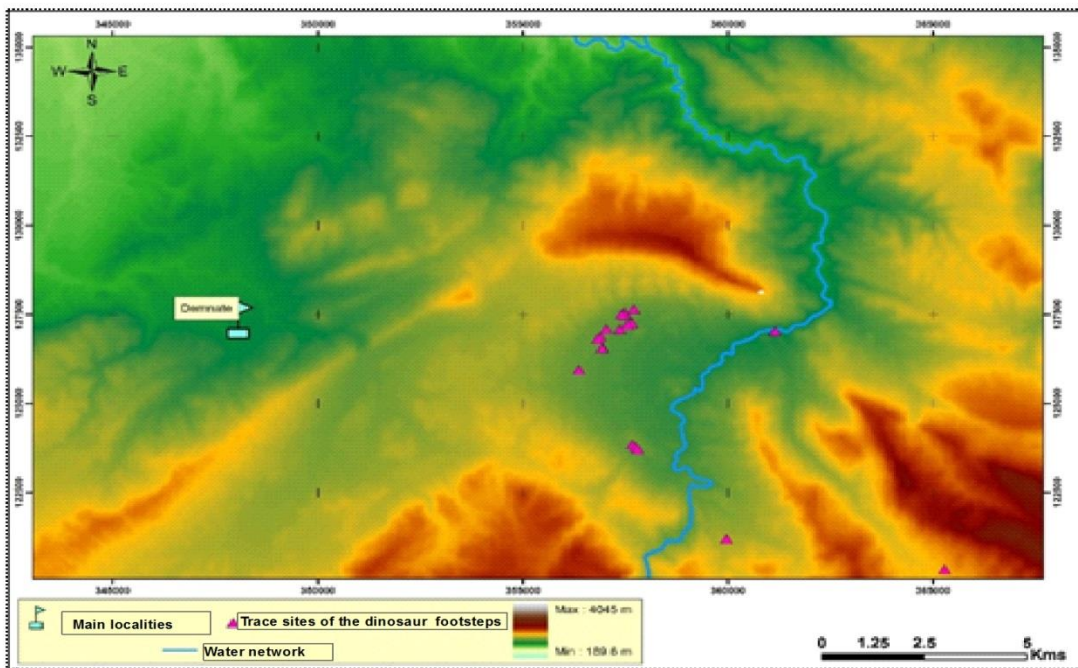


Figure 10. Map of the Digital Terrain Model and Hydric network, with ArcGis software.

f. Geoheritage and Geoconservation

The study area offers various forms of tourism: green tourism, hiking tourism, tourism related to hunting and fishing, ecotourism and geotourism. It is full of natural sites worthy of a guided tour, given the importance of the tourist industry's spillover effects on the economy of the region, in terms of jobs and the financial revenues generated, this activity requires, in return, the availability of adequate and quality tourist structures. The Iouaridène and Ait Mimoun deposits are rich for the dactyl traces of Upper Jurassic dinosaurs; it is located 10 km from Demnate.

The footprints of dinosaurs are abundant, they come from herbivorous theropod carnivorous individuals, sauropods, they appear either scattered, or in solitary tracks or herds.

The Iouaridène basin corresponds to a synclinal depression framed by Liassic wrinkles and filled with red detrital sediments called the "Guettioua Sandstone"

or the red layers of the Dogger. The dinosaur fingerprints are printed on the succession of four clay assemblages each ending in clay-hardened surfaces indicating a temporary lagoon-type continental environment. Indeed, the central High Atlas of Azilal is during this time a marine golf course open to the NE on the Tethyan domain and bordered SE by vast coastal plains momentarily flooded by the sea and traversed by channeled rivers, which generates red detritic deposits of the synclinal cuvettes, among others that of "Iouaridène".

The Ait Mimoun deposit is located near the first "Iouaridène" deposit, except that this site is characterized by the presence of two major species (theropods and sauropods), which makes it unique on the scale of the various other deposits. The traces of sauropods belong to the species "*Breviparopus tagnbaloutensis*" and "*Boutakioutichnium atlasicus*" for those of the theropods".

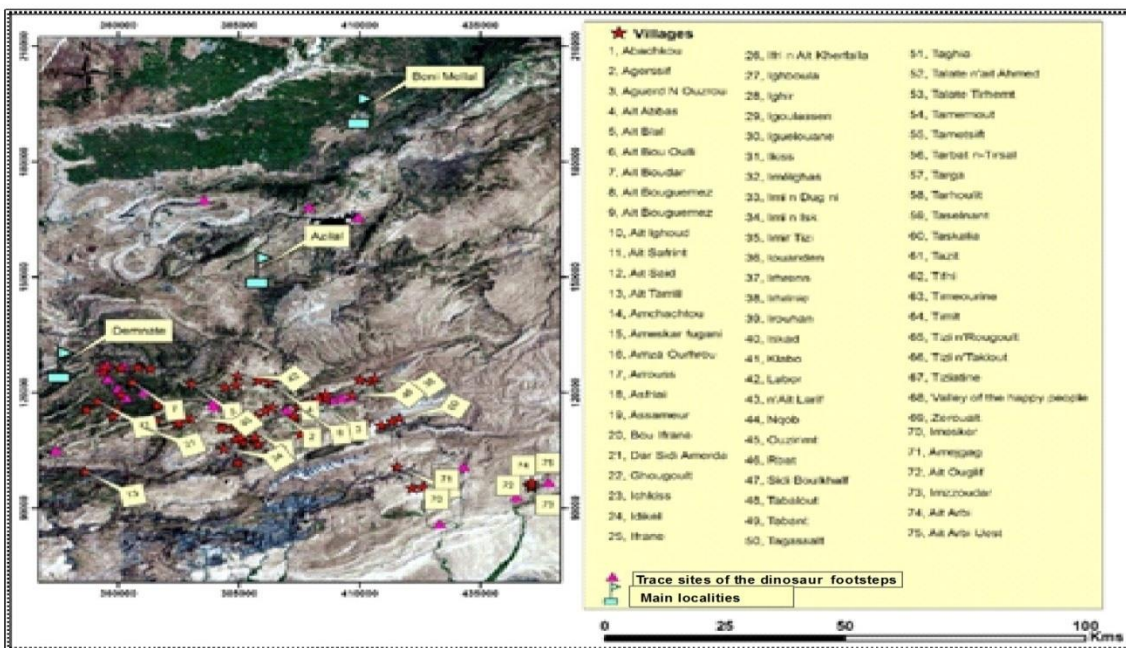


Figure 11. Location map of hotels and inns in the study area with ArcGis software, Source: Ministry of Tourism, Morocco.

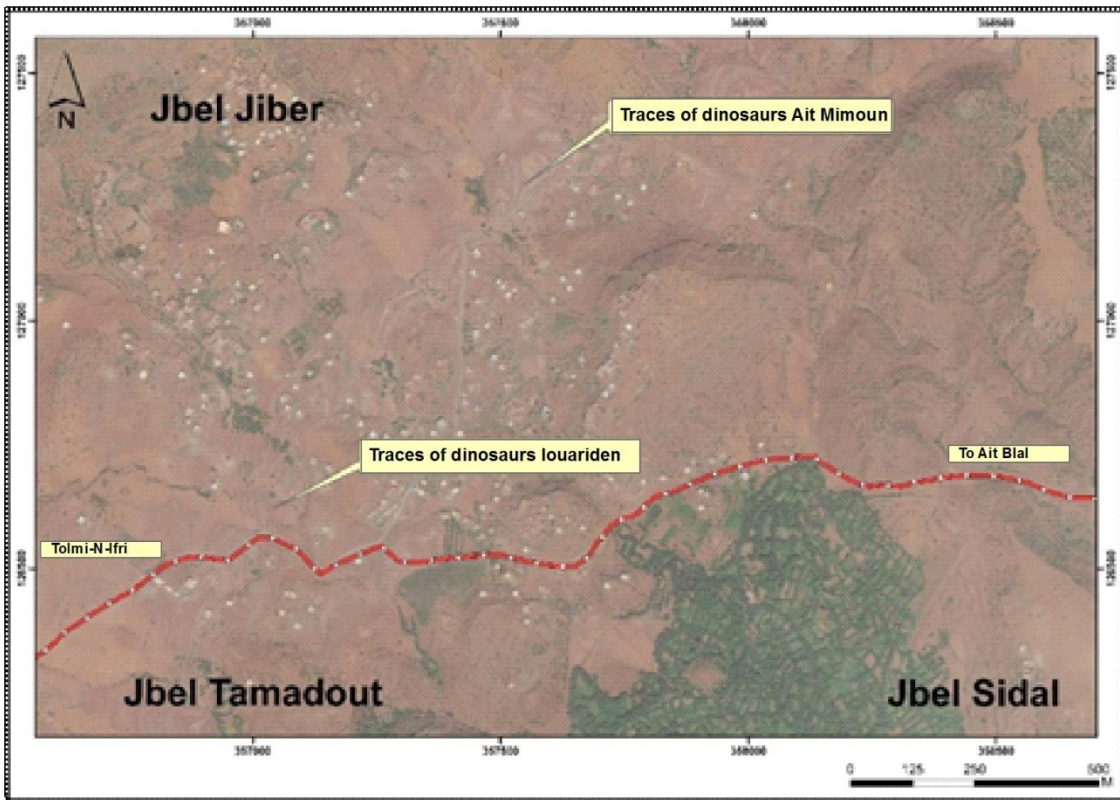


Figure 12. Map of the dinosaur footprints deposits of Iouaridène and Ait Mimoun Ouffelah, with ArcGis software, Source: Google Earth satellite image, Morocco.

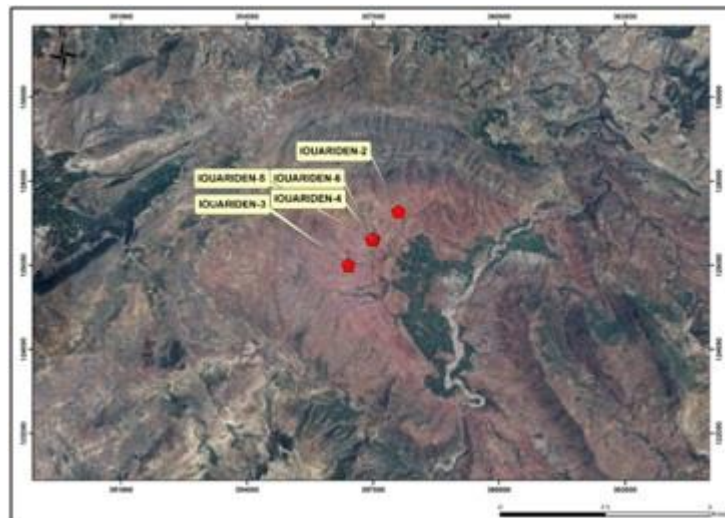


Figure 13. Map of the dinosaur footprints deposits of Iouaridène, with ArcGis software, Source: Google Earth satellite image, Morocco.

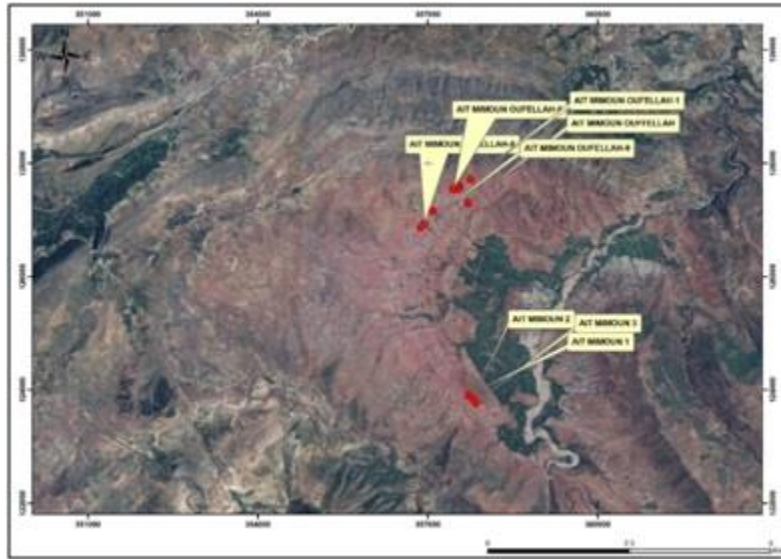


Figure 14. Map of the dinosaur footprints deposits of Ait Mimoun and Ait Mimoun Ouffelah, with ArcGis software, Source: Google Earth satellite image, Morocco.

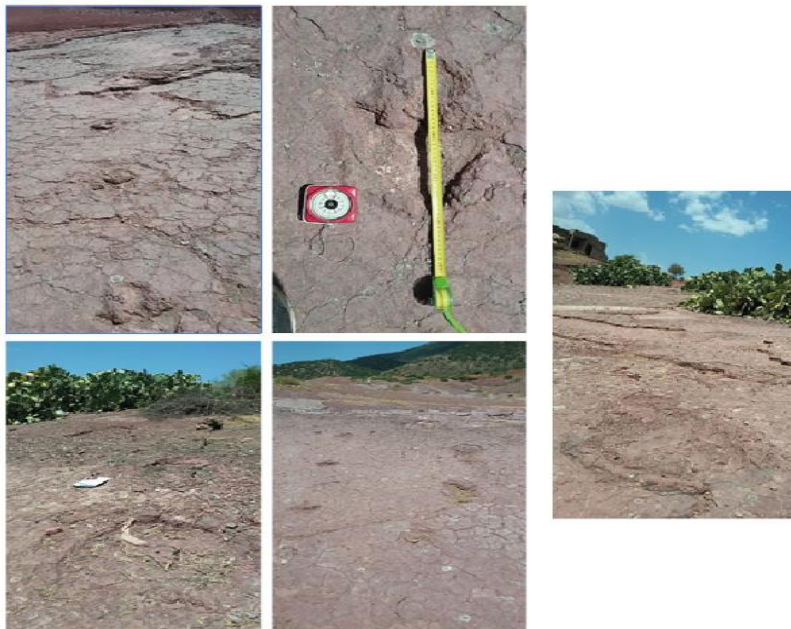


Figure 15. Examples of images showing deposits of dinosaur tracks (theropods and sauropods). Photograph provided by F. Amine.

From this, we have made management proposals for both deposits, and these

models are just an initiative in the sense of contributing to protection and valorization.

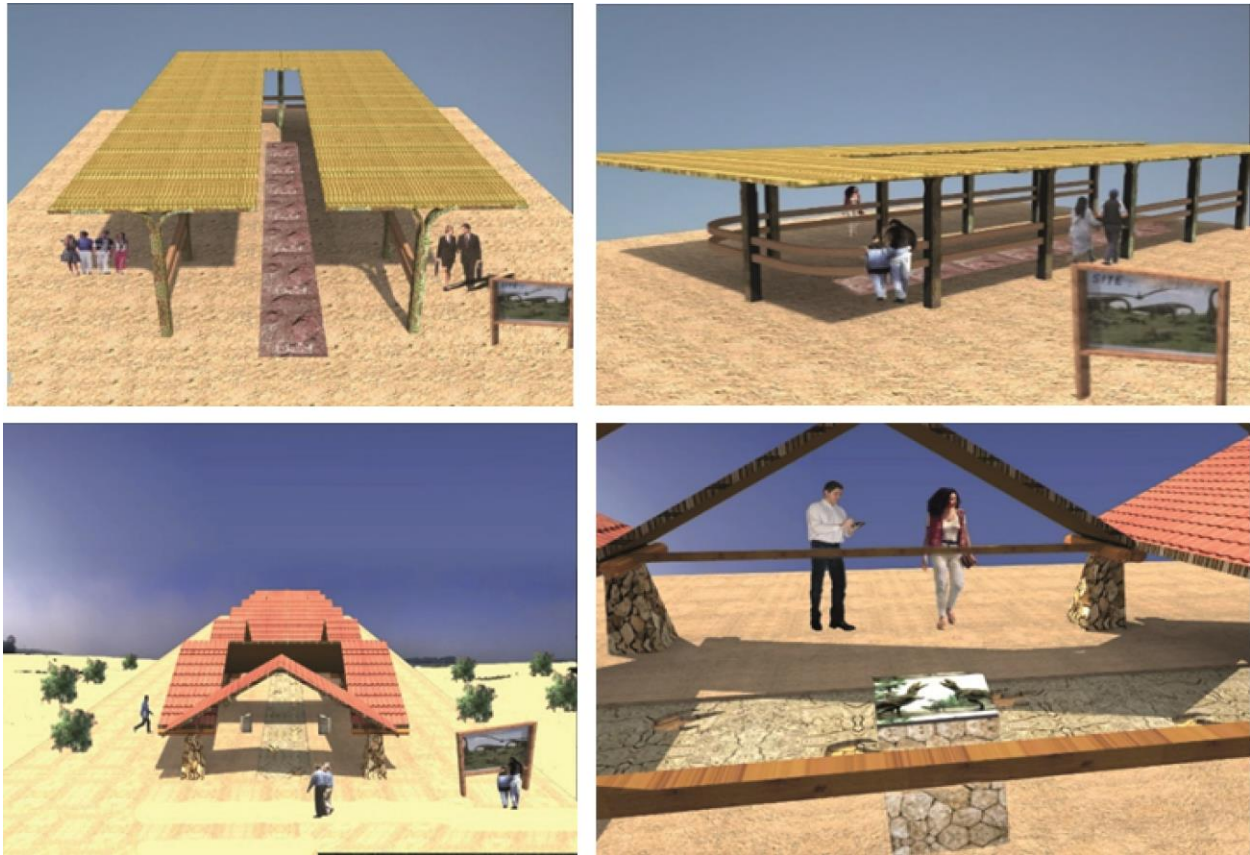


Figure 16. Architectural models of a dinosaur site.

Conclusion and Recommendation

The geological heritage is considered as heritage of humanity, which requires the realization of a complete inventory of large scale dinosaur footprints sites for protection and valorization. The two deposits of traces are in a bad state (sites without shelter, surrounded by buildings, absence of development, track close to the site and they are threatened with deterioration following the man and the degradation of the landscape quality. these sites and to this day do not have a law in view of protection and valorization of this geological heritage, more of the diversity of the actors and the absence of a strategic vision with the decision-makers to guarantee the durability of these deposits, it is necessary to set the framework conditions favorable to economic development, to favor the development of

each territory by valuing its specific assets, to promote slow journeys (on foot, by bike, etc.) for the daily and leisure activities, to implant the equipments and services to the population and to promote the whole territory re, a soft tourism and leisure activities, in connection with nature, culture and health, by the installation of equipment and infrastructures, provide a parking space for possible shuttle buses without necessarily waterproofing the ground with certain types of coverings, propose constructions (useful for the site or others) or developments compatible with the architecture (use of local materials) and the local landscape and well integrated in the natural environment.

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