THE KARST LANDSCAPES OF BENI MELLAL ATLAS (CENTRAL MOROCCO): IDENTIFICATION FOR PROMOTING GEOCONSERVATION AND TOURISM

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Manuscript received: March 1, 2022
Revised version: June 1, 2022

Ait Barka A., Rais J., Barakat A., Louz E., Nadem S., 2022. The karst landscapes of Beni Mellal Atlas (central Morocco): identification for promoting geoconservation and tourism. *Quaestiones Geographicae* 41(3), Bogucki Wydawnictwo Naukowe, Poznań, pp. 87–109. 13 figs, 2 tables.

Abstract: The Atlas of Beni Mellal is located in the Moroccan central High Atlas, characterized by an important geo-diversity that attracts tourists every year. However, the number of visitors remains limited due to the lack of the promotion means, enhancement and mediation of this heritage. The obtained data indicate that the studied area preserves a great number of karst geosites, such as ruiniform landscapes, caves, poljes, sinkholes, Karren, shaft cave and many remarkable reliefs such as canyons and cliffs. This work concerns the inventory, the quantitative evaluation and the enhancement of the remarkable geomorphosites. The results reveal the presence of 21 sites, including six karst forms; five ruiniform landscapes and one karren form, one enviable panoramic viewpoint and five karst springs, four caves, two travertines, two waterfalls, and one structural relief geosite; canyon, and one tepee structures. However, these sites are not protected against all types of degradation, because the general public does not recognize them. These karst forms are very vulnerable, they cannot reproduce quickly, and their deterioration leads to their permanent disappearance. That is why this heritage must be the object of a particular attention of the whole community. The valorisation of these geomorphologic assets is the proposal of a number of circuits and geo-tourist routes from the perspective of local and integrated development.

Key words: karst landscapes, geo-tourism, Central High Atlas, Atlas of Beni Mellal

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Introduction

During the last three decades, the identification, valorisation and conservation of the natural heritage, particularly geological, is the subject of undercurrent of multidisciplinary research. This considerable attention paid to the study of geoheritage at the international level has resulted in the inscription of several geosites and logical geomorphosites on the World Heritage list, and in the development of the geoparks network. Morocco is not idle either, since several actions to inventory, enhance and safeguard geoheritage have been taken to sustainably develop territories, in particular through the labelling of geoparks as M'Goun Geopark. The labelling of the M'Goun Geopark by UNESCO located at the central of High Atlas chain, has represented

https://doi.org/10.2478/quageo-2022-0027
ISSN 2082-2103, eISSN 2081-6383

a significant advance in tourism attractions such as geotourism. Geologically, the central High Atlas Mountain in Morocco is composed of much folded structural formations forming alternate valleys and ridges. It is particularly remarkable for its geodiversity. Consequently, assuming that karstic landscapes as a component of the heritage of a territory, any initiatives aimed at its valorising may be essential to encourage people to partake in sustainable geotourism. Recently, many studies in Morocco were conducted to inventory, map, and describe geosites based on scientific, cultural and aesthetic considerations (Bourchich et al. 2015, Beraaouz et al. 2017, El Hassani et al. 2017, Arrad et al. 2018, Khoukhouchi et al. 2018, Oukassou et al. 2018, Rais et al. 2021).

These studies conducted in different regions of Morocco, with the aim of enhancing the geological heritage through the proposal of a geotouristic itinerary. Also, in different European countries, several initiatives for the valorisation of the geological heritage were made notably, Panizza (2012) that has enhanced the geomorphosites of the karst area of Supramonte (central-eastern Sardinia) in Italy through the proposal of a geotouristic itinerary linking the natural heritage with its geological and geomorphologic characteristics to the numerous cultural aspects. According to previous studies, the proposal of a number of geotouristic circuits and itineraries demonstrated useful tools for the valorisation of geomorphological assets.

This approach is based on knowledge (Soulier et al.2011, Panizza et al. 2012), it represents the correct way to make local authorities aware of the value of the geological and geomorphologic heritage of their territory. Also, served to give useful information to visitors, allow them to study the different aspects of the visited areas, by giving them information on the various heritage aspects (geology, geomorphology, cultural and architectural). A geotourism circuit is a route that forms a loop with the same point of departure and arrival, it is chosen according to several criteria, namely ease of access, scenic value and potential for education and tourism (Pralong 2005, Martin et al. 2010). Also, some fundamental characteristics of geosites, such as geological relevance, quality of exposure, scientific value, representativeness, aesthetic value and rarity (Panizza et al. 1993, Grandgirard 1999, Reynard 2005, Reynard et al. 2016). This geo-tourism project based on remarkable geosites that enhance its value by constituting a key element of economic profitability.

The Atlas of Beni Mellal endowed with a very diversified karstic heritage and of great scientific interest; it is the subject of several studies in geology (Benzaquen 1963, Rolley 1973, Monbaron 1981, Morel et al. 2000, Charrière et al. 2011, Guezal et al.2013, Barakat et al. 2015, Charrière et al.2016, Bouitrane et al. 2018), hydrogeology (Bouchaou 1997, Taibi et al. 2007, Barakat et al. 2013, Finigue 2017, Barakat et al. 2018, El Ghachi et al. 2020) and geomorphology (Couvreur 1988). The area has a safe road infrastructure for traveling from one location to another and allowing visitors to access to the karst landscapes, overlooking the plain of Tadla, which is become increasingly urbanized. Other tracks that lead to building materials quarries, installed along the foothill zone, near series of faults, exploiting the dolomite and limestone of the Lower Lias**.** Barakat et al. (2015) facilitate access to attractive cultivated landscapes. The representation of this heritage in space and its relationship with time are concepts that are difficult to understand without having expertise in the field. The latter remains an important pedagogical tool in this discipline; teaching and restitution of the history of the Earth. It's like an open-air museum that illustrates the territory's past, its preservation as priority, and it must be subject to clear and efficient regulations and a protection and promotion strategy.

For these reasons, the present study aimed to identify attractive karstic landscapes of the atlas of Beni Mellal for their valorisation and protection, through the proposal of a certain number of geo-hiking trails and circuits in a perspective of local and integrated development.

Study area

The Atlas of Beni Mellal known for its spectacular karst landforms developed mainly in Jurassic formations. The area lies in Beni Mellal- Khenifra region, Morocco (Fig. 1). It is between 5° 55'0"–6°35'0" W and 32° 11'0"–32°35'0" N, which covers a surface of 1009 km^2. Its topography is generally mountainous with an elevation ranging between

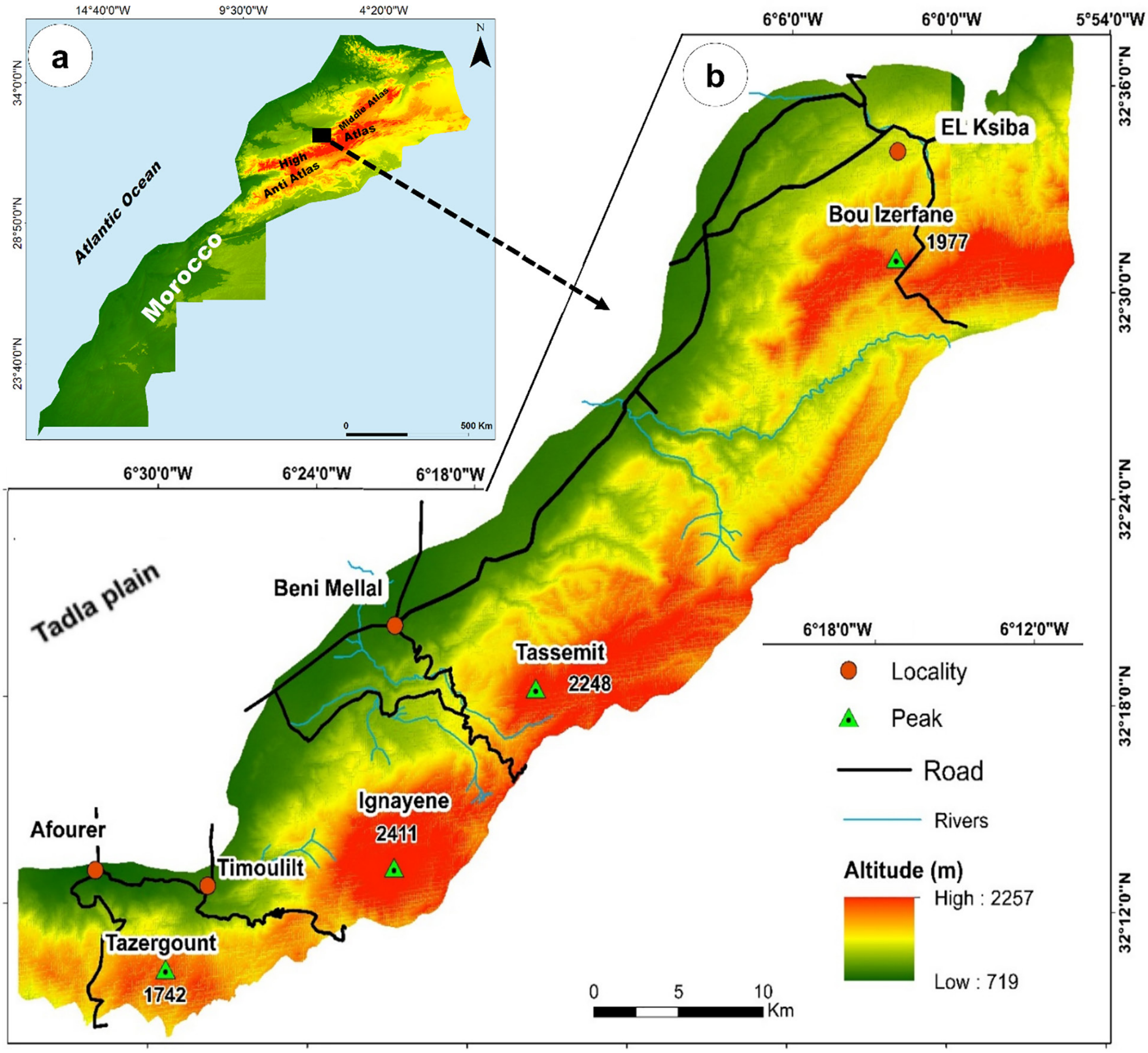

Fig. 1. Location of the study area.
a) Map of Morocco showing the geographical position of the study area, b) map of the study area.

1000 and 2411 m a.s.l. The higher elevation points are at the summits of Tassemit and Rhnim. The climate of the study area is continental. The average temperature in Beni Mellal is 18.3°C. The average annual rainfall is 493 mm. With 1 mm, July is the driest month. With an average of 79 mm, March is the rainiest month (Regional council Beni Mellal Khénifra).

The study area is characterized by a dense forest cover represented at the El Ksiba meridian by holm oak (*Quercus ilex*), Zeen oak (*Quercus canariensis*), juniper (*Juniperus*), and the dominating dwarf palm (*Chamaerops humilis*). At the level of the meridian of Afourer, this plant cover is represented by the holm oak, dwarf palm, euphorbia (*Euphorbia*). The anticline centre is an arid area, where karst forms are well exposed, dominated by crops, carob trees (*Ceratonia siliqua*), eucalyptus (*Eucalyptus globulus*) and euphorbias.

Over the last decade, the region has experienced urban renewal, the launch of numerous socio-economic projects, and the rapid population growth. This leads to an aggressive occupation of new land and a high demand for building materials. In exploiting new land, attention should be paid to the geological/geomorphological impact of urbanization and land use.

Geological setting

The High Atlas central corresponds to the Intra-continental mountain range (Choubert et

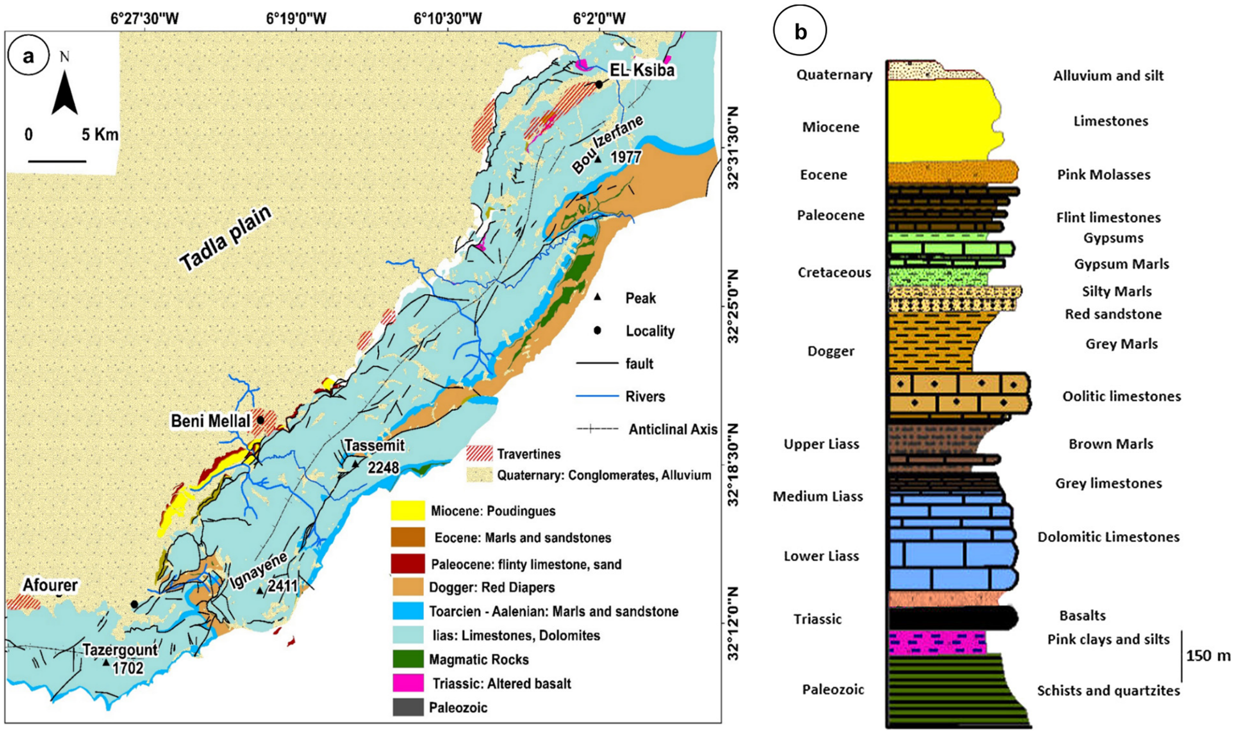

Fig. 2. a) The geological map of the study area. Extracted by the geological map of Morocco 1:100,000. Sheet of Béni Mellal, Afourer and Kasba Tadla. b) Litho-stratigraphic log of Beni Mellal Atlas.

al. 1960–1962, Michard 1976, Mattauer et al. 1977) resulting from the structural inversion of the essentially Jurassic basin (Souhel 1996). The study area corresponding to the Atlas of Beni Mellal is located in the north-western part of the High Atlas central, on the meridian between Afourer and El Ksiba towns. It is bordered to the north by a major fault (Rolley 1973, Souhel 1996, Benammi 2001) separating it from the plain, and to the south by the synclines of Agzif-Naour, Tagleft, Ouaouizaght and Ait Attab (Rolley 1973). The most important high points are at the summits of Tassemit massif (2248 m a.s.l.) and the Rhnim massif (2411 m a.s.l.) on the Beni Mellal meridian, the Tazerkount massif (1702 m a.s.l.) on the Afourer meridian, and the Bou Izerfane massif (1977 m a.s.l.) on the El Ksiba meridian. The Mesozoic series of the Atlas of Beni Mellal show notable variations of facies and environment (Fig. 2), resting on a Palaeozoic basement deformed during the Hercynian orogeny (Hoepffner et al. 2006). It starts with Triassic red clay formations with basaltic intercalations. The first carbonate phase above Triassic detrital and evaporitic sedimentation, of Hettangian – Lower Sinumerian age (Souhel 1996), outcrops sporadically in many areas. It corresponds to the formation of versicoloured marls and platelet dolomites (Monbaron 1985) at the level of the meridian of Beni Mellal, and to the formation of limestones and marls in plates (Verset 1988) on the meridian of El Ksiba, and to the gypsiferous marl-dolomitic (Rolley1973) on the Atlas of Afourer. These formations capped by the massive carbonate of lower Liass. They correspond to the jbel Rat and the Ait Bou Oulli formation, forming the Atlas reliefs dominating the Tadla plain. Generally, they present a massive aspect; dolomite and limestone massive banks of 1 to 3 m, thick rich in brachiopods, lamellibranches and benthic foraminifera of the biozone A (Septfontaine 1984). The Jbel Rat formation differentiated by bird's-eye structures and vadose pisolites, as well as the presence of teepee structures. These structures materialized by calcite levels of centimetric thickness developed over heights of 0.5 to 2 m, observed around jbel Tazerkount and at the level of Timoulilt. The formation of Ait Bou Oulli presents a massive aspect of dolomites and limestones with oncoïdes and ooliths. The massive calcaro-dolomitic formation of the lower Liass followed by carbonate-lit formations of the middle Liass, presented by limestones and oncolite dolomites. The passage from the middle to the upper Liass is marked by the change in sedimentation conditions (Chaubert et al. 1960–1962, Du Dresnay 1979), this change is marked by the passage from carbonate sedimentation to terrigenous sedimentation. The latter corresponds to the terrigenous Toarcien – Aalenien, materialized in our study area by chocolate marls (Rolley 1978, Monbaron 1985, Souhel 1996). In the thalwegs and closed basins, recent formations materialized by medium to coarse alluvium at the level of the thalwegs and decalcification clays, silts and fine eluvium in closed basins. The Beni Mellal Atlas is a flattened anticline fractured by a system of faults (Benammi et al. 2001), the most important of which is the North Atlasic fault (North Atlasic thrust), straddling the Dir composed of Liassic or tertiary scales and travertines of undetermined age plated on the relief. These faults provide conduits for the transport of fluids and the development of a very vulnerable karst that plays an important role in the recharge of the Atlas and Dir Liassic aquifers (Bouchaou et al. 1997).

Geomorphological setting

The karst landscapes cover a considerable area of the Beni Mellal Atlas (Fig. 3). With the expansion of population and the demand for land use in our study area, the possibility of being affected by karsts has increased considerably. When occupying new land, it must pay attention to the impact of urbanization and land use on karst forms. Karst are more vulnerable; it is a sensitive and a particular environment that imposes constraints on conservation, pollution and their heritage value (Jaillet et al. 2000, Hobléa 2009). In addition, this environment undergoes the ignorance of the majority of citizens, including land managers. Karst landscapes develop in rocks of greater solubility such as limestone, marble and gypsum/anhydrite (Warren 2006) followed by several natural factors (Jeannin 2006, Hili 2016). Due to their immense solubility, Jurassic carbonate (Lias limestones and dolomites) are considering as a regional reference for karst landscapes and underground circulation in

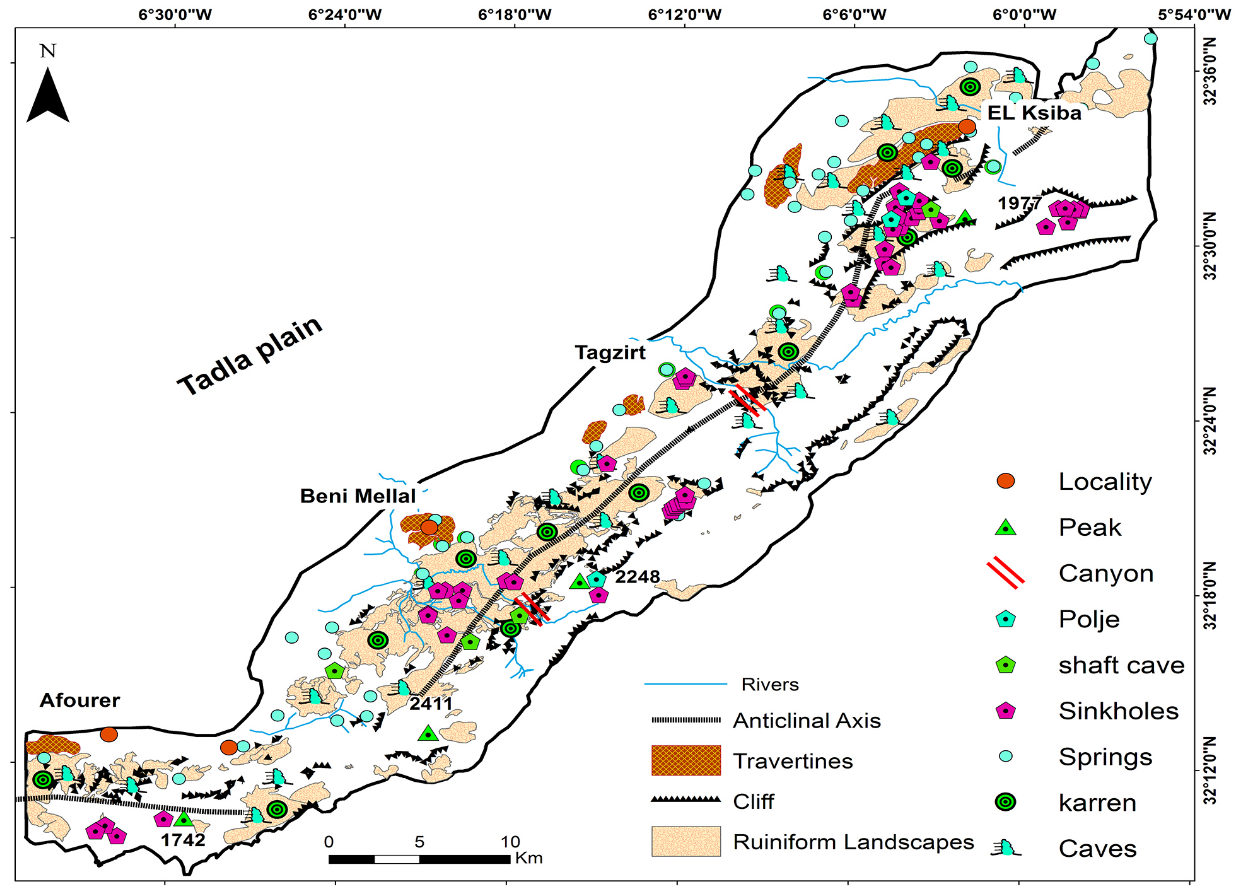

Fig. 3. Geomorphological synthesis map.

carbonate, limestone and dolomitic rocks. They shelter a mature karstic system, including dolomites, caves, poljes, valleys, ruiniform landscapes, chasms and springs of the resurgence type related to fault overflow at high flow rates used from the earliest antiquity for drinking and agricultural water supply (Bouchaou 1988, Couvreur 1988).

The study area meets the necessary conditions for the formation of a karst. It corresponding to flattened and fractured anticline (Monbaron 1981, Monbaron 1985, Bouchaou et al. 1997, Benammi et al. 2001) by extensional faults and open fractures that influence the development of karst. These fractures facilitate the flow of water and accelerate the karst hydrological system (Gustavson et al. 1982, Bosak et al. 1998, Ford et al. 2007, Bruthans et al. 2009, Closson et al. 2009, Zarei et al. 2010, Bruthans et al. 2017).

These faults provide conduits for the transport of fluids and the development of a highly developed exo- and endokarst (underground karsts), to have cavities with concretions, stalactites and stalagmites, and underground streams. The underground karstic network of the Atlas of Beni Mellal developed on Triassic formations, forming the impermeable bedrock at the base of the karstic formations, it flows at the outlet and turbid water during floods, indicating the functioning of a karstic network characterized by a rapid response to rainy events (Bouchaou et al. 1997). The vegetation cover responded; holm oak, red and mastic juniper, carob, eucalyptus, euphorbia, and lithology have participated in the evolution of this karstic system via the production of CO_2 along the different geological periods. Climatic conditions also govern the development of this karst by controlling the hydrological system and the flow of fluids (Bruthans et al. 2017). Most often, the development of carbonate karst occurs mainly in the most humid climates.

Materials and methods

The aim of this study is the inventory and evaluation of the geomorphosites of the Beni Mellal Atlas. This study based on the knowledge and criteria developed in previous studies (e.g. Grandgirard 1999, Reynard et al. 2007, Reynard et al. 2016). These criteria combined in order to use them to evaluate all the values of the geomorphosites. This work performed in three steps, represented in the Table 1.

Geomorphosites inventory

The inventoried objects are distinguished according to their type in isolated reliefs or in small groups of reliefs. After that, we determined the characteristics and values of the geomorphosites (scientific, educational, aesthetic, cultural, historical, religious, tourist). We then selected the geomorphological and geological objects that could be defined as potential geomorphosites according to Grandgirard (1997). The selection was based on the high scientific value of the geomorphosites and that these geomorphosites are representative of the geomorphological diversity of the Central High Atlas.

Documentation of sites

The site documentation consisted of two components: general data and descriptive data (Reynard et al. 2007). The general data included coordinates, elevations, size, and an identification code for the geomorphosite. The identification code was used to locate the geomorphosite

Table 1. Methodology used (based on Reynard et al. 2016).

Geomorhosites inventory	Assessment of intrinsic value	Characteristics of use and management
Identification of potential sites – Field work – Existing bibliography – Geological and geomorphological map	Scientific values – Integrity – Representativeness – Rarity – Paleogeographic	Protection – Protection status – Attacks and threats
Selection geomorphosites – High scientific value – Representativeness of local geomorphology – Aesthetic	Additional values – Cultural value – Ecological value – Aesthetic value – Economic value	Promotion – Accessibility – Environment – Security – Tourisme infrastructure – Educational interest

on the map. This identification code consists of three parts Grandgirard (1997):

1. the abbreviation of the region in capital letters,
2. the processes responsible for the genesis of the geomorphic form in lower case letters,
3. a numerical identifier for the site.

The dominant processes in our study that are used in the identification codes are: STR = structural, FLU = fluvial, KAR = karstic, PAL= palaeontology, SED = sedimentology, HYD = hydrological, ANT = anthropogenic (Reynard 2005). The second step was to include descriptive data. First, a detailed description was included to provide an overview of the site qualities. Then, the determination of the processes responsible for the genesis of the landform or geomorphic object.

Assessment of the intrinsic value

The evaluation of the intrinsic value of the geomorphosites was done according to criteria proposed by Grandgirard (1999). These criteria are divided into two groups: the central value and additional values. Grandgirard (1997) had first proposed to consider four criteria in the analysis of the scientific value of geomorphosites: integrity, representativeness, rarity and paleogeographic value. Each of these criteria is evaluated independently by a numerical score ranging from 0 (null), 0.25 (low), 0.5 (medium), 0.75 (high) to 1 (very high). The final scientific value of the object is obtained by the average of the four criteria that compose it. The additional values were grouped into ecological, aesthetic, cultural, and economic criteria. Each of these criteria is independently evaluated by a numerical score ranging from 0 (none), 0.25 (low), 0.5 (medium), 0.75 (high) to 1 (very high). The final additional value of the object is obtained by the average of the four criteria that compose it (Table 2).

Use and management characteristics

To determine use and management characteristics, the current state of protection of the sites in relation to various human or natural threats, constraints, and preservation issues was described. The characteristics described are related to the conditions experienced at the site at the time of the visit: i.e., safety, environment and presence of tourism infrastructure, educational value, legibility of geomorphological form and processes, and presence of interpretive and promotional facilities such as educational panels and brochures. We found that site conditions were best described qualitatively using the methodology proposed by Reynard et al. 2016. Consequently, we adopted

Table 2. List of selected and evaluated geosites.

No	Name	Commune	Code	Scientific value	Additional value
1	Spring of Ain Asserdoune	Beni Mellal	BEMhyd001	0.95	0.59
2	Spring of Ain El Ghazi	Foum El Ancer	FOMhyd002	0.80	0.12
3	Karren Moudj	Foum El Ancer	FOMkar003	0.90	0.34
4	Ruiniform landscapes of Moudj	Foum El Ancer	FOMkar004	0.90	0.21
5	Canyon of Hansala	Tagzirt	TAGkar005	0.90	0.28
6	Canyon of Moudj	Foum El Ancer	FOMkar006	0.90	0.25
7	Timskar Waterfalls	Foum El Ancer	FOMkar007	0.90	0.25
8	Tazerkount Ruiniformes Landscapes	Afourer	AFOkar008	0.65	0.25
9	Ruiniformes Landscapes of Oribaa	Beni Mellal	BEMkar009	0.95	0.40
10	Caves of Orbiaa	Beni Mellal	BEMkar010	0.80	0.21
11	Caves of Ain El ghazi	Foum El Ancer	FOAkar011	0.60	0.21
12	Ain Orbiaa	Beni Mellal	BEMkar012	0.95	0.28
13	Ruiniformes Landscapes of Tassemit	Beni Mellal	BEMkar012	0.55	0.21
14	travertines of Timskar	Foum El Ancer	FOAhyd013	0.80	0.25
15	Tazzerkount Tepee Structures	Afourer	AFOsed013	0.80	0.25
16	travertines of El Ksiba	EL Ksiba	ELKhyd014	0,80	0.18
17	Ruiniformes Landscapes of EL Ksiba	EL Ksiba	ELKkar014	0.85	0.18
18	Fossils of Moudj	Foum El Ancer	FOApal014	0.95	0.21
19	Panoramic view of Rurate	Afourer	AFOant015	0.95	0.18
20	Spring of Lala Kamria	Foum El Ancer	FOAhyd016	0.65	0.28
21	Spring of Ouchrah	Tagzirt	TAGhyd017	0.95	0.59

Reynard et al. (2016) method because we considered that the use and management characteristics were not part of the quality of the geomorphosite. Therefore, they were not considered as a site's value, but qualitatively described, which we found more useful than the numerical scores, particularly for tourists and sites managers

Results and Discussion

Most remarkable geosites

Several natural factors make the Atlas of Beni Mellal a karstic area of excellence: lithology, structure, hydrogeology and bioclimatic conditions. The lithology manifests itself by the karstified liassic limestones and dolomites, which are quite massive, forming an anticline whose axis plunges northwest. The ruiniform landscapes distributed throughout the studied sector are mostly lapidated on the surface. The northern part of the study area (Bou Izerfane massif, 1977 m a.s.l.) constitutes one of the great karstic expanses of the Atlas, where ruiniform landscapes, poljes, avens, and elongated or circular dolines with flat bottoms are concentrated. These expanses decrease as one moves south-westward through the Study Area. In the central part, around Beni Mellal (Oued Kikou and Massif of Tassemit, 2248 m a.s.l.), a typically karstic morphology is manifested, with an interesting manifestation of exokarst described by (Couvreur 1988), which is increasingly rich in ruiniform landscapes and an important number of dolines. Furthermore, Endokarst materialized by elongated and circular caves of important depth and height, arranged in the majority of cases by inhabitants like parks of their herds, or for their own dwelling. This also characterizes the southwestern part of the study site and the area of Tagzirt and Rhorm Alem. The variety of well-developed karst forms (karren, sinkholes, uvalas, poljes) influences the development of endokarst, manifested by underground streams and caves concreted with stalactites and stalagmites, this underground karst network provides a medium for the water flow and accelerating the karst hydrological system (Bouchaou et al. 1997). Moreover, numerous karst sources can be observed over the entire study area (Finigue 2017). These sites are less known, especially by visitors, but with great scientific and aesthetic value (Table 2) such as the resurgences of Ain Asserdoune, Foum El Ancer and Taghbalout Ouhlima, as well as the ruiniform landscapes of Oued Kikou and Moudj, where the fields of the lapiaz are rich in Cephalopods, gastropods. These karst sites inventoried and evaluated according to the method by Reynard et al. (2016). Over the entire area studied, 30 geosites were analysed, 21 of which were selected considering certain fundamental characteristics such as the quality of the exhibition, ease of access, educational statue, and visitors safety, as well as their scientific values based on four criteria, namely integrity, representativeness, rarity and paleogeographic interest (Table 2). Each criterion was evaluated and scored from 0 to 1, with additional values (Grandgirard 1997, Reynard et al. 2007, Reynard et al. 2015, Reynard et al. 2016). According to these values, all the selected geosites may constitute potential geotourism destinations, considered as tools for local development of the region.

The springs

The Atlas of Beni Mellal has a significant number of springs, about 42 springs, considered as discharge points of the karstic system returning water to the surface (Bouchaou et al. 1997, Finigue 2017), which are well presented throughout the entire anticline (Fig. 3). These include the overflow springs by faults located along the northern border of the study area, such as the resurgences of Ain Orbiaa, Ain El Ghazi, Ain Asserdoune (Figs 4a, b), Foum El Ancer, Taghbalout Ouhlima (Figs 4c, d), Tamoudjout (Fig. 4e), Tagzirt, and Ochrah (Fig. 4f). These springs have a great tourist, scientific and religious importance (Table 2). Ain Asserdoune resurgence (Figs 4a, b) which is located in the city of Beni Mellal, and has a significant scientific value (Table 2), because it is the subject of several scientific research (Bouchaou et al.1988, Finigue 2017, El Ghachi et al. 2020). It is the most important source with significant water flow of about 200 $dm^3 s^{-1}$ on the average, coming essentially from the Liassic aquifer of the atlas fed by a superficial karst functioning in high water periods (Fig. 5). This water used for various uses or activities; for the production of drinking water for the town of Beni Mellal and its region, and for agricultural activity. Ain Asserdoune's spring water is also relevant for the tourist development of the city. It is a touristic site, which in

Fig. 4. The most springs visited by tourists and hikers.
(a, b) Spring of Ain Asserdoune. (c), (d) Spring of Taghbalout Ouhlima. (e) Spring of Tamoudjout. (f) Springs of Ochrah.

the water and its fascinating nature attract many visitors every year.

The Foum Al Ancer spring is a karstic spring located at 14 km northeast of Beni Mellal. At an altitude of 684 m a.s.l. with a flow of 128 $dm^3 s^{-1}$ on average, it is a touristic site by excellence with a beautiful nature of Eucalyptus (*Eucalyptus globulus*) that dominates near the springs, and Euphorbia (*Euphorbia*) on the peaks carved by caves of different size and form, most of which are developed by the residents. The Taghbalout Ouhlima site (Figs 4c, d) is located at 2 km north-east of El Ksiba city at an altitude of 1140 m, with an area of 7 hectares. This place includes a several springs and streams converge, a pleasant place characterized by a sub-humid climate, and a very diverse fauna and flora.

These are the springs of overflow by faults, gushing at the foot of the dolomitic limestone massif of the lower Lias. They are directly fed by rapid infiltration points (shaft cave, poljes, sink-holes, and karren) of Beni Mellal Atlas (Fig. 6).

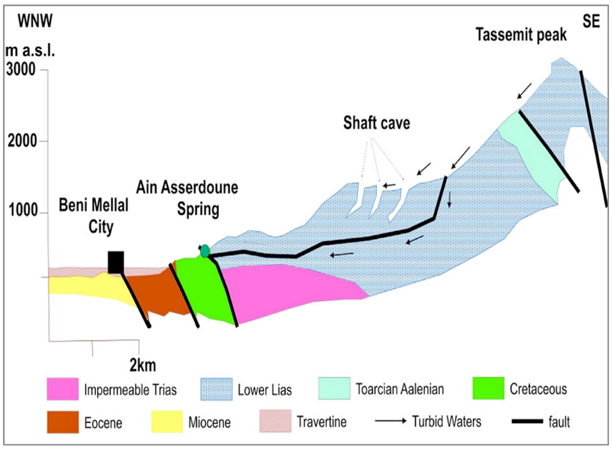

Fig. 5. Hydrogeological section showing the emergence conditions of Ain Asserdoune, Beni Mellal.

These sites constitute a perfect pedagogical example of hydrogeological functioning (Table 2), which need to be protected against all types of degradation and used to enhance public awareness of the geomorphological value. These sites present anthropogenic change for tourism and environmental reasons. The main causes of environmental degradation of these springs are different types of pollution, for example in Ain Asserdoune spring, where there is waste left by street vendors and visitors.

Sinkholes

The sinkholes correspond to circular karstic forms, of size of several tens to thousands of square meters. The residual deposits of clay that accumulate at the bottom of these dolines, giving it a relative impermeability, which makes it favourable for water retention, fertile and cultivable. These forms are the most abundant in the study area (Figs 6a, b, c). The north part of study area, with an important vegetation cover, a large number of elongated flat-bottomed cultivated sinkholes. The temporary flow traces in case of flooding seem to be more important and more active in their erosion process. The flow traces are cutting by a shaft cave at the small cliff. Also, in the centre of the anticline, where the vegetation cover is less, represented by carob trees and small shrubs of Holm oak (*Quercus ilex*), the sinkholes are very abundant (Oued KiKou, Tassemit massif), partially arranged by the residents to retain water, used in agricultural activities and breeding. On the meridian of Afourer, with a dense vegetation cover, the sinkholes are abundant and natural without any anthropogenic modification. The natural or anthropogenic attacks, which can deteriorate these karstic assets, are the complete vegetation of the sinkhole, example of a sinkhole of Oued Kikou that would not be visible anymore, the pollution and the development of territory. These threats must be considered because the tourist attractiveness of a place is linked to the beauty and the state of its landscapes (remain natural).

Shaft cave and polje

The shaft cave is a hole formed in a soluble rock by the action of water, used to conduct surface water to an underground passage. Blind valleys and streams are abundant in the northern part of the study area associated with shaft cave and poljes. Throughout the study area, shaft cave are observed as vertical dissolution shafts on the northern and central parts of the anticline (Fig. 10 E). They correspond to narrow holes of size from one decimetre to one meter, which leads in most cases to very deep caves. They represent in some cases semi-vertical entrance shafts with open to filled bottoms or with openings wide enough for the passage of a man. They play an important role in the conveyance of water to the subsoil. These forms observed in poljes, or carved in the massive rocks of the lower Lias. They are located at the level of the Bou Izerfane area of Orbiaa, Moudj and Foum El Ancer. The poljes (Figs 6d, e, f) are produced mainly by the same karstic processes of the sinkholes (Fig. 6a), and correspond to the big temporary lakes at the snow melt or at the rainy period. Considering the sinkholes and the surrounding valleys, it corresponds to the big elongated lakes with flat bottom, not cultivated in the north part of study area. In the other parts of the study area, they corresponding to the fertile areas, and cultivated.

Valleys and canyons

The Atlas of Beni Mellal is a very hilly area with steeply sloping valleys, most of which are V-shaped, narrow and winding, with little or no water, seasonal and variable in quantity. These valleys are abundant in the study area to such an extent that they have given rise to several canyons, an example of a Moudj canyon (Figs 7a, b, c) with an important scientific and Aesthetic value (Table 2). These forms carved in the limestone

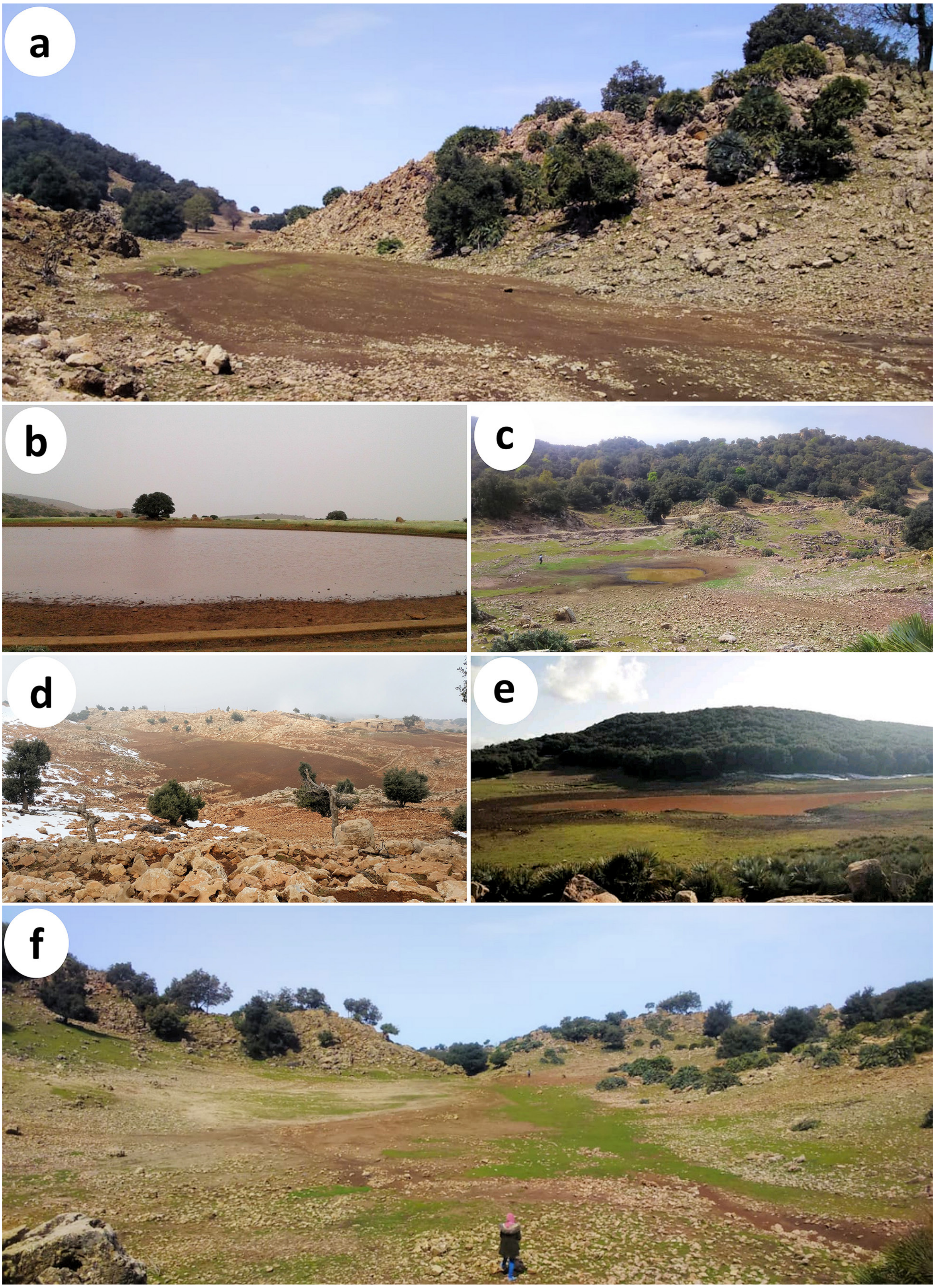

Fig. 6. The important sinkholes in the Study Area.
(a) Sinkholes River at the level of El Ksiba. (b) Sinkhole at the Orbia developed to retain water. (c) Sinkhole at the level of El Ksiba. (d) Polje at the level of Tassemit. (e) Polje at the site of Tazerkount. (f) Giant Polje at El Ksiba filled with alteration products of clays and limestones.

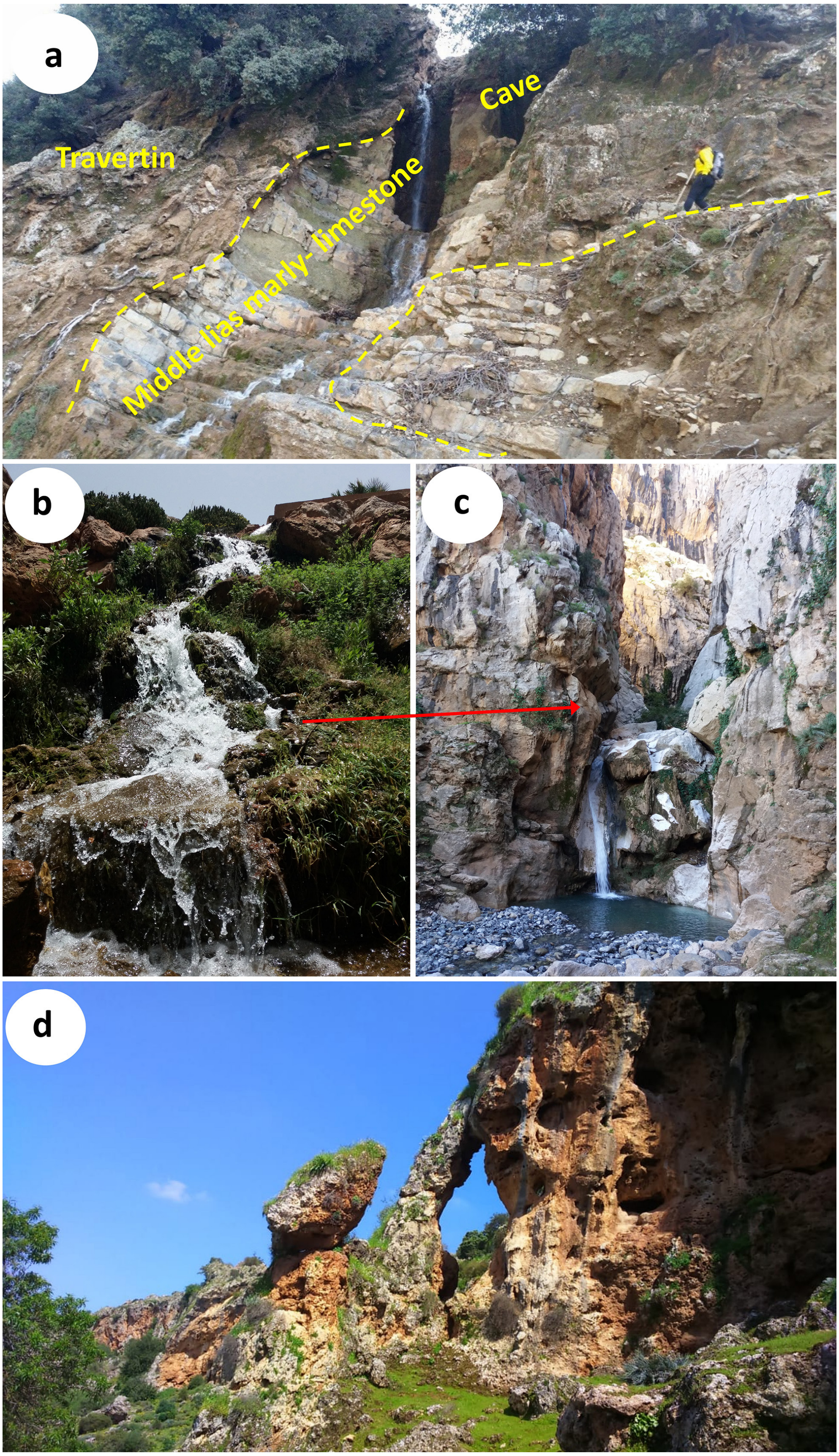

Fig. 7. The travertine, canyon and waterfalls of Moudj.
(a) waterfall of Timskar. (b) Moudj waterfall. (c) Canyon of Moudj, (d) El Ksiba travertine.

and dolomite rocks of the Lias below the level of Bou Tout River, a tributary of El Handak River. Like morphology, valleys are the most visible relief forms that distinguish the study area from neighbouring lands. In the northern part of the anticline, blind valleys and streams are abundant, associated with shaft caves, poljes and sinkholes. The development of these karsts forms leads to dry valleys with dolines. In the centre of the anticline, with the increase in altitude (Tassemit and Ghnim massifs), the valleys are deeper and more incised.

The travertines and waterfalls

The travertines are non-marine carbonate accumulations, formed at waterfalls, rivers, streams and caves. These are biochemical limestone with approximately grey to yellowish vacuolar concretion appearance, and quaternary age. These biochemical limestones are highly responsive around the mountain waterfalls and in the Foum El Ancer region (Oued Bou Tout waterfalls) (Figs 7a, b, c) and the north of the study area (Fig. 7d). In addition, there are both active and dried-up waterfalls where the travertines are still witnessing karst activity. These formations related to the rapid precipitation of carbonates are caused by the release of CO2 from karstic water. They contain plant and animal remnants (leaves, trunks, molluscs…), which make it possible to reconstruct the bioclimatic conditions of their establishment. The study of these travertine formations has several interests, including information on the past functioning of karst and its palaeotopography (surfaces, valleys, terraces…).

Ruiniform landscapes

Ruiniform landscapes are among the most fascinating surface karst forms in the study area. They present an aspect of ruins, typical of karstic regions spread over the entire study area. They are forms due to the chemical erosion of water loaded with CO_2. Their development linked to the unequal action of erosion on the subsoil, which is heterogeneous (limestone and dolomite). Consequently, the most resistant rocks form reliefs while the less resistant rocks disappear and form voids. They are forms of relief very widespread throughout the area studied. The ruiniform landscapes characterized by large giant reliefs of different size and shape that can fascinate the visitor's imagination; some are in the form of an elephant, and others in the form of a mouse or squirrel, the face of a man and a lion. Most of these landscapes are observed in the less vegetative areas at Oued Kikou and around Tassemit (Figs 8 and 9), where these forms are well exposed and more visited, despite their important scientific and pedagogical values (Table 2), and which requires special attention. Whereas in the north of the anticline, these karsts properties are less visible and less visited, because of the dense vegetation cover in this environment. These forms are endangered by many effects; the installation of quarries of building materials in the middle of the fields of these forms, waste dumped by visitors, and removal of these reliefs by owners of land for agricultural purposes or the construction of houses.

Travertines and waterfalls

The travertines are non-marine carbonate accumulations, formed at waterfalls, rivers, streams and caves. These are biochemical limestone with approximately gray to yellowish vacuolar concretion appearance, and with a quaternary age. These biochemical limestone are highly responsive in the north of the study area (Fig. 7b), and around the mountain waterfalls and those in the Foum El Ancer region (the Oued Bou Tout waterfalls (Fig. 7a, c). In addition, there are active waterfalls and dried-up waterfalls where the travertines are still witnessing karst activity. These formations related to the rapid precipitation of carbonates are caused by the release of CO_2 from karstic water They contain plant and animal remnants (leaves, trunks, molluscs...), which make it possible to reconstruct the bioclimatic conditions of their establishment. The study of these travertine formations has several interests, including information on the past functioning of karst and its paleo topography (surfaces, valleys, terraces...)

Caves and underground streams

The Caves are large sub-surface voids, formed by the dissolution of carbonates (limestone and dolomite) by rainwater loaded with carbon dioxide. This slowly dissolves the limestone along the joints, bedding planes and fractures, some of which become large enough to form caves. These caves present inside a variety of speleothems formed by the precipitation of minerals. The

Caves are the most abundant forms in our study area with different size and depth. The caves of Foum El ancer and El ksiba area are the deepest with a height of about five meters. These forms leading sometimes to underground karst paths concreted with stalactites and stalagmites, these underground karst paths function during floods; high flow at the outlet and turbid water at the springs linked to this system (Bouchaou et al. 1997). Two types of caves observed in the study

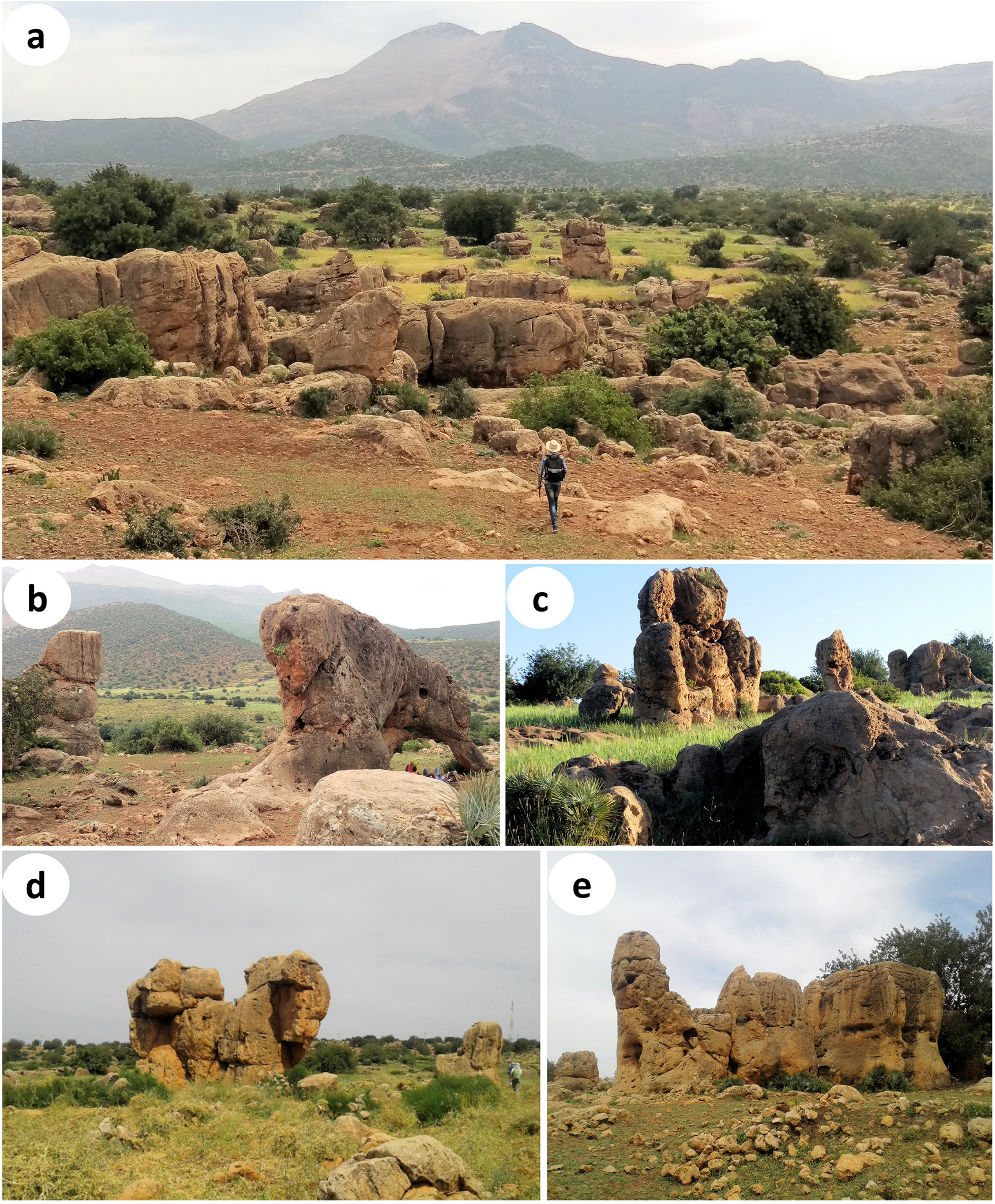

Fig. 8. The ruiniform landscapes of the Orbia site of varying shapes and sizes.
(a) Panoramic view of the Orbia site. (b), (c), (d), (e) The different shapes of the ruiniform landscapes of the Orbia site.

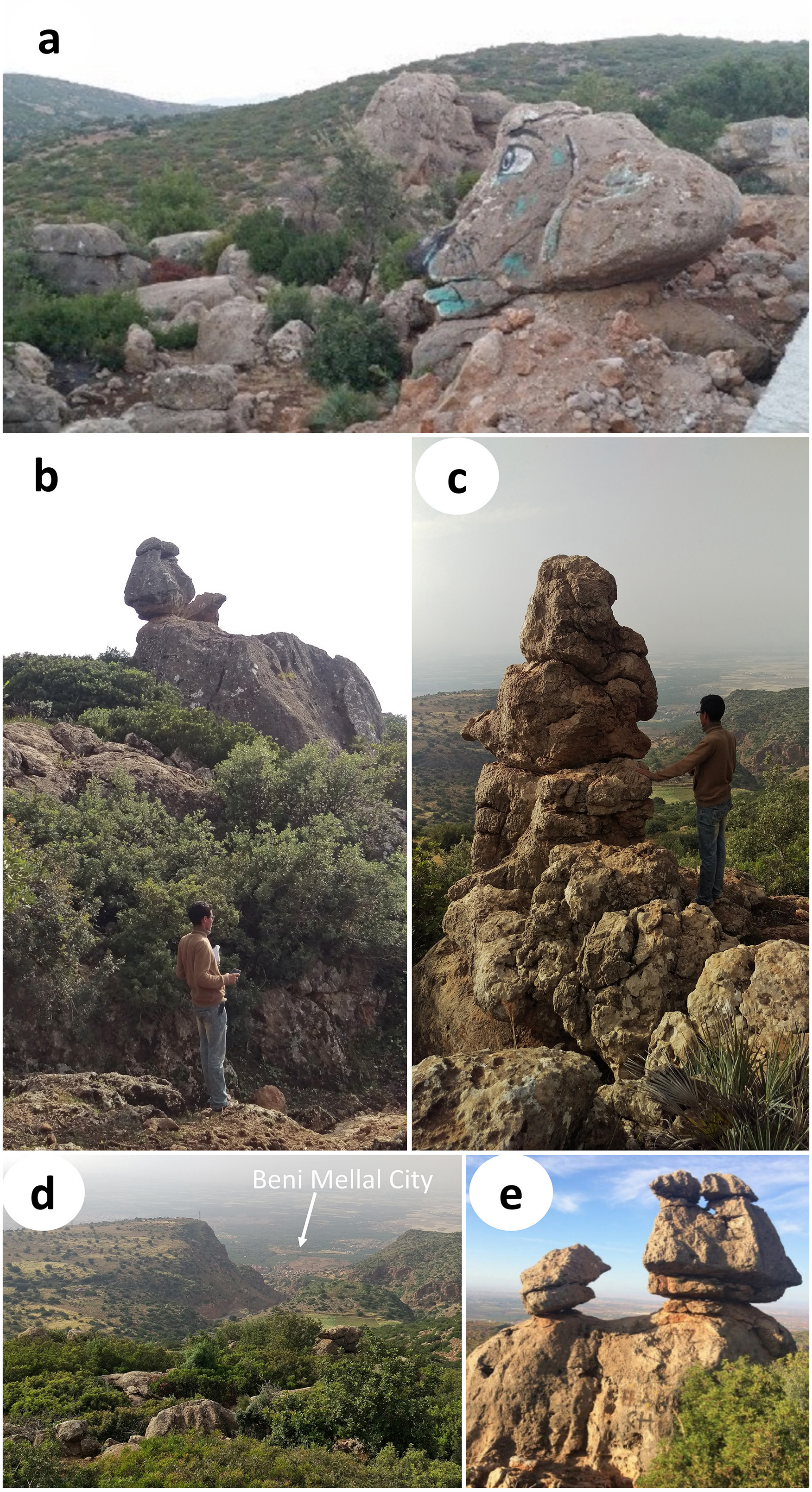

Fig. 9. The ruiniform landscapes of Ain el Ghazi site of varying shapes and sizes.
(a), (b), (d), (e) The different shapes of the ruiniform landscapes of the Ain el Ghazi site. (c) Panoramic view of the Ain el Ghazi site and city of Beni Mellal.

Fig. 10. The different caves encountered in the study area.
(a) Caves of the cliffs of Timoulilte. (b) Caves of the cliffs of Tit n'ziza at dir d'El Ksiba. (c) Cave of the cliffs of Tanougha. (c) Cave of Tazart n'amar at Tanougha. (e) Cave of Foum El Ancer. (f) View from inside Foum El Ancer cave. (g) Cave of Orbiaa site. (h) Stalactites inside Orbiaa cave.

area (Fig. 10); elongated caves and circular caves up to five meters high. Some caves developed by many families at the Dir level, which used as a park for their herds, as well as hay and grain stores. According to the historian Gautier (1925), these called Tighramt (a castle), formed naturally in very rugged relief, invisible to their enemies. Moreover, his noted that *these caves are collective granaries intended for the protection of all that is precious during war; herds, cereals, children and women*. These caves present an invaluable treasure of the study area and among the most important tourist assets, which require a reform related to visitor safety and legal status. They play a major role in

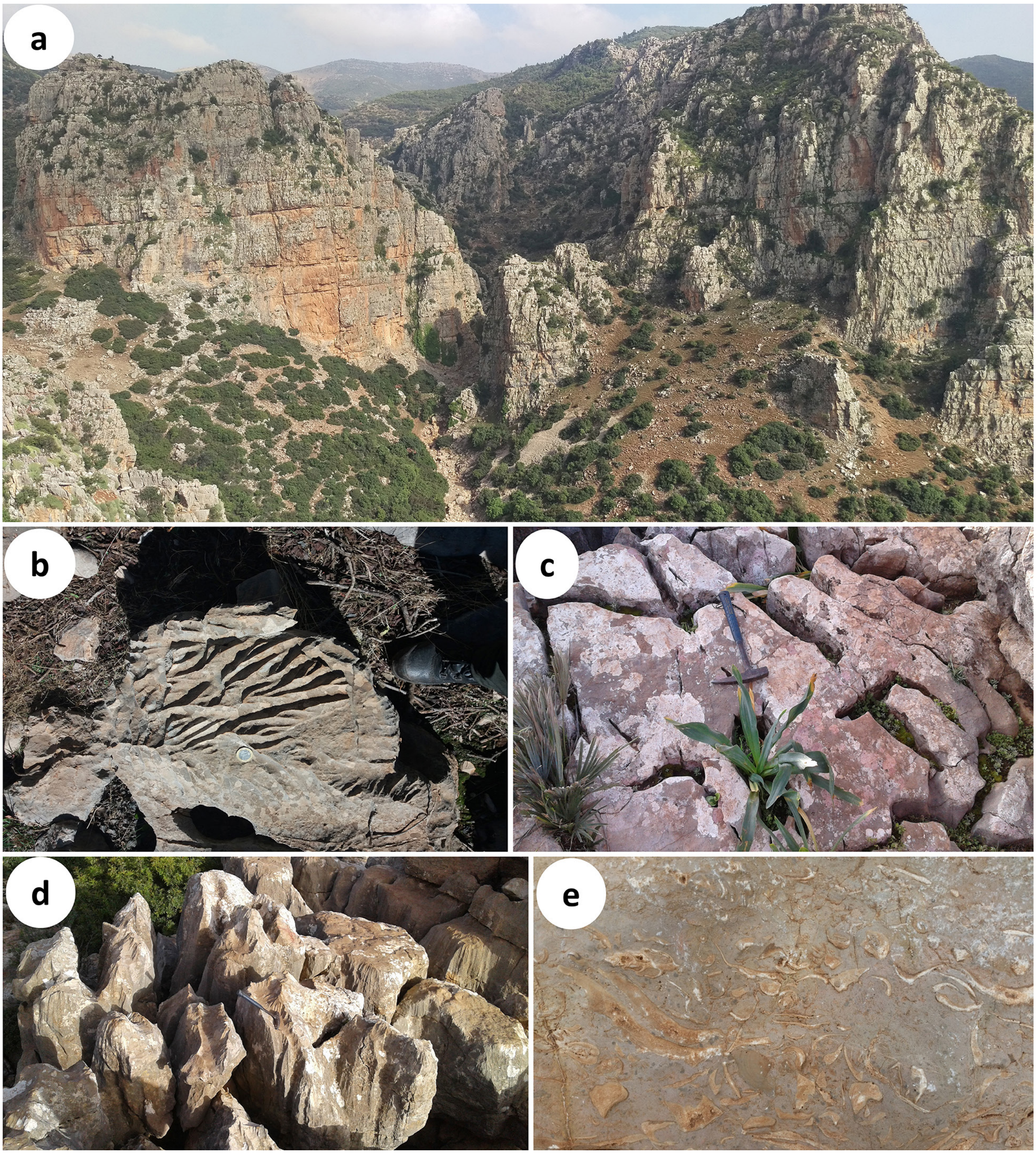

Fig. 11. Cliffs and karren of Moudj.
(a) Giant grikes. (b) Incipient karren. (c) Freeze and thaw karren. (d) Grikes. (e) Limestone of the massive carbonates of Liass lower Sineurian age fossilized from the Gastropods and Lamellibranchs.

tourism development and participate in the local development of rural areas such as the case of the regions of Ifrane, Timahidet, Azrou, and Tazza.

Karren

Karren are formed when water flows over a sloping soluble rock surface example of limestone, dolomite and gypsum. Water dissolving the rock as it flows. When the surface solution forms a shallow groove in the direction of flow, the water flows into the groove and through it, digging deeper and deeper. Eventually, the entire rock surface is drained by the karren. Rinnenkarren are the most abundant forms of karren in the study area. They correspond to channels or runnels with a direction of dip, their width and depth can extend from a few centimetres to 20 cm. While their length can reach a few meters. Occupy the entire study area (Fig. 3). Especially at high altitudes, near Tassemit Mountain, where they are highly developed (Fig. 11). they appear as grooves ranging from micro-fissures to macro-fissures oriented ENE–WSW, and grouped on limestone slabs of Jbel Rat formation of Upper Sinemurian age. Because of its natural assets, the area of Moudj has recently become a tourist site by excellence, the anthropogenic attacks, and tourist activities, are the main possible factors to affect these karstic forms.

Valuation

The studied area are defined as an area marked by particular karstic heritage, requiring a strategy of protection and enhancement based on sustainable economic development of this area (Rais et al. 2021). The economic development of a territory is achieved by strengthening the scientific mediation of geomorphosites and the development of tourist infrastructure. In this sense, a process of valorisation of the karstic heritage (itineraries and geotouristic circuits) can generate a valorisation of exotic and endo-karstic landscapes as well as other landscape elements (Hobléa 2004). The process goal is the recognition, firstly, by the local population, and secondly, by the tourists. Enhancing the value of these sites, helps raise awareness in all areas of the environment, and thus promote self-protection of these sites (Panizza et al. 2013). The sustainable development of territories has recently become a challenge that has mobilized scientific communities (EL Hassani 2015, Bouzekraoui et al. 2018, Rais et al. 2021). Within this framework, the geomorphological heritage and landscapes of the Atlas of Beni Mellal present a great potential for the socio-economic development of the region through the proposal of some itineraries and a geo-touristic circuit that seeks to enhance the geo-heritage of this area. Figure 12 presents the proposed geotourism itineraries and circuit according to the following criteria of easy access, scenic value and potential for education and tourism. They are about 122 km long and can be completed in four days depending on the tool used, it takes one day for the circuit and three days for the itineraries; one day for each one. The car, the bike, mules or geo-hiking, can reach out these geo-touristic routes. The circuit starts from the Beni Mellal town to El Ksiba, by the provincial road P3208, passing through the villages of Tagzirt and Tanougha. It is a circuit of 89 km, it has several access points (Fig. 12); from the national road RN8 in the direction of Marrakech or Kasba Tadla, which gives access to several roads mentioned in the Geotouristic map (P3206, P3227, P3204, P3229, R317) that facilitate access to the study area.

The first itinerary: Orbiaa's karstic landscapes itinerary

The first proposed itinerary is 7 km, a walking route that starts from the town of Beni Mellal to the karstic landscapes of Orbiaa (Fig. 8). It can be done by car, bicycle, and geo-hiking in half a day. It is a site rich in karst landscapes of scientific interest, with sinkholes, ruiniform landscapes, and resurgences.

The second itinerary: Moudj Gorges itinerary

At 18 km south of Beni Mellal village, at an altitude of about 1170 m a.s.l., there is one of the most spectacular canyons of Morocco, the Moudj canyons (Figs 7a, b, c). These spectacular canyons formed by seven waterfalls (Fig. 7b) with the highest is 25 meters in the middle of limestone and dolomite rocks of the lower Lias (Jbel Rat Formation), near the Moudj douar at the level of Bou Tout River, a tributary of the El handak river. It is a small narrow and deep (110 m) valley suitable for the growth and development of floristic species such as mastic grass, carob, juniper,

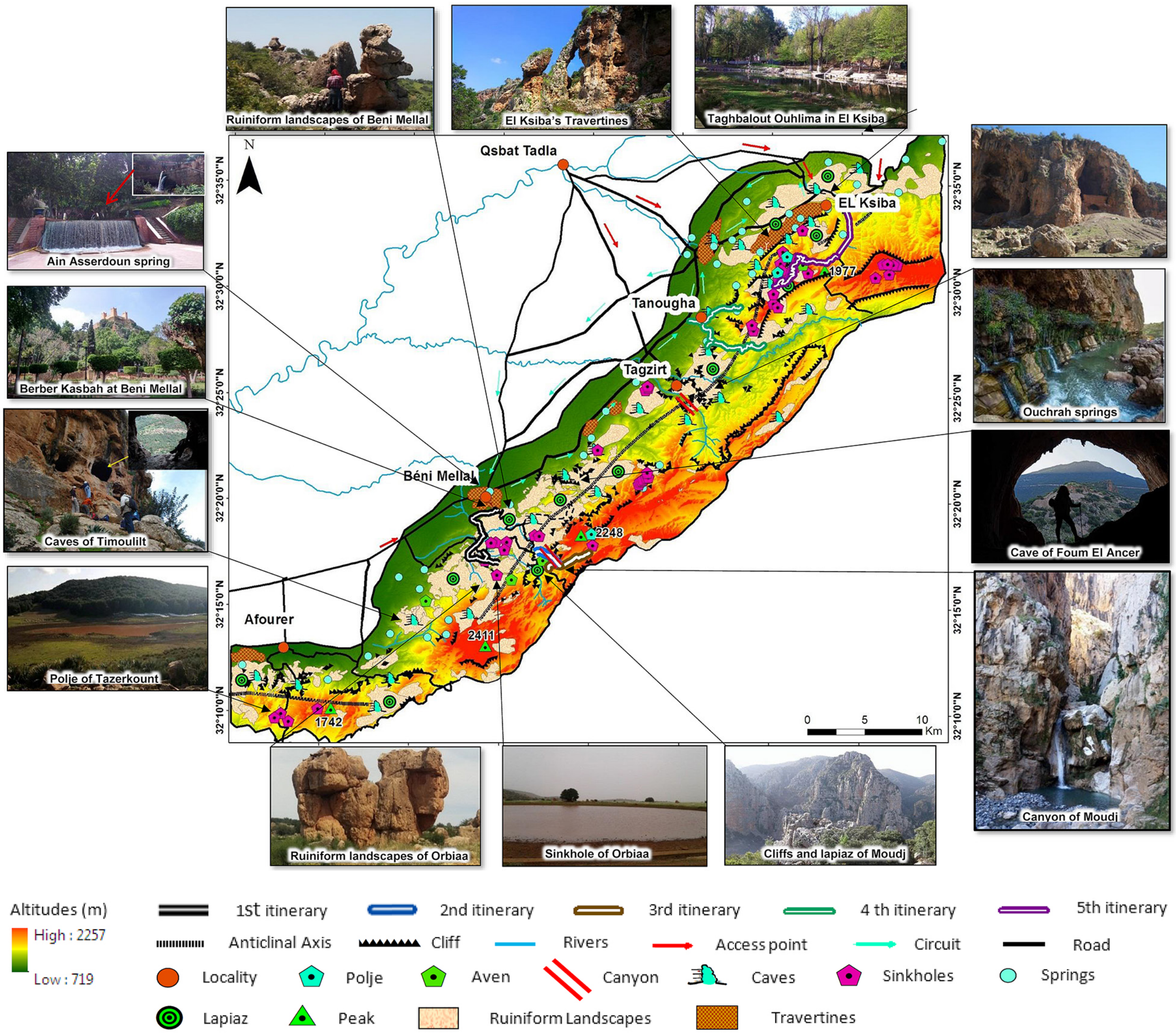

Fig. 12. Geotouristic map of the study area.

holm oak, euphorbia and oleaster (EL Khalki et al. 2005). This site is characterized by a relevant attempt of development that is the proposal of a trail of two kilometres, which can be covered in half a day of activity (Fig. 13). The starting point is located at the Moudj village being at an altitude of 1124 m a.s.l, along the valley of Bou Tout with its natural landscapes. The Gorges waterfall is accessible to all types of people with only one option of travel, geo-hiking. The climbing to reach other waterfalls starts just after arriving at the gorge.

The third itinerary: waterfall itinerary

The trail begins at the Gite (N 32°16'51.1", W °17'19.39") and goes through lower carbonate and middle terrigenous dolomites and sandstones to the Moudj waterfalls (Figs 7a, c) and Timesker landscape. This trail presents panoramic views of the Moudj canyon, formed by fossilized lamellibranch limestone and ruiniform landscapes. For the waterfalls, two of which are seasonal and three permanents, with travertine formations often white, beige, gray, brown, yellowish or reddish, with impurities and roots of vegetation. The trail also provides a very important palaeontology of great scientific value (Table 2), presented by ammonites and flattened nodules. This site can be used for the search of fossils along with observing an alternation of greenish marl and limestone, as well as extraordinary landscapes.

The fourth itinerary: Tanougha itinerary

The fourth itinerary is 11 km, which can be done by car, bicycle and on geo-hiking. which is from Tanougha to Tazart n'Amar, where ruiniform

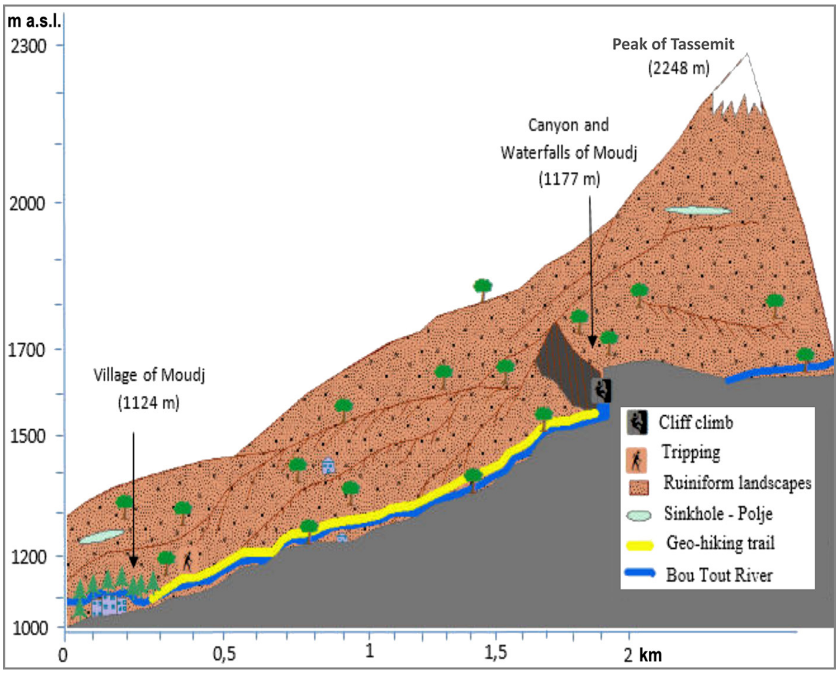

Fig. 13. Moudj canon geo-hiking trail.

landscapes and caves are widespread. The itinerary proposed also the area of Tamoudjout where the visitor can express himself through beautiful mountain views and resurgence.

The fifth itinerary: itinerary of Jbel Bou Izerfane.

The fifth route started from the city of El Ksiba to the natural landscapes of Jbel Bou Izerfane. At the beginning of this itinerary, is located on the site of Taghbalout Ouhlima (Figs 4c, d), with an area of 7 ha, located 2 km northeast of the town on the road (R317) leading to Aghbala. This site is a place of convergence of several resurgences, it is a pleasant place characterized by a sub-humid climate and very diversified vegetation (pine, acacias, poplars, ashes, etc.). At 5 km from this site, there is a forest track of 12 km, which crosses a natural area densely wooded and suitable for geo-hiking. Where a diverse range of plants such as dwarf palm, holm oak (*Quercus ilex*), juniper (*Juniperus*) and Zeen oak (*Quercus canariensis*) exist. Within which, we observe various forms of karstification: teepee structures, ruiniform landscapes, and dolines with a width of about 15 m of rounded shape. additionally, it is filled with rainwater that circulates towards an avenue, flat-bottomed poljes, entirely closed with a dimension of a few hundred meters, formed of Liassic limestone in oncolite belonging to the Jbel Rat formation and others in bird's-eye structures belonging to the Ait Bou Oulli formation.

Conclusion

The geomorphological properties in the study area represent exceptional wealth related to karstic phenomena. Proposing the geo-touristic circuits is a real initiative for the valorisation of these karstic assets. It combines the sensitization of local communities to the value of the geological and geomorphological heritage of their territory and serves to give useful information to visitors on the geological, cultural (tangible and intangible) and architectural heritage, as well as information on the history and biodiversity of the study area. Furthermore, it represents a useful way to awaken public opinion to the environment. Consequently, it helps to encourage visitors to understand the landscape as a whole, in all its dynamic aspects, starting from the formation of the landscape to its modification by the recent occupation of local communities. The study area by its richness of various karstic forms and processes (caves, sinkholes, underground streams, karren...) constitutes a great geological and geomorphological diversity along with the biological and cultural diversity of the study area, which can become an attractive territory and an important economic resource for the local population in terms of sustainable development. The proposed circuit and geotourism trails were designed to better enhance this karstic heritage by reinforcing the attractiveness of the study area.

Acknowledgements

The authors wish to express their great gratitude to all those who participated in the realization of this work, also to the anonymous reviewers for their valuable and constructive suggestions during the development of this article.

Authors' contribution

AAB and JR made 60% of contributions to the paper about geologic field investigation, inventory, characterization, classification, and discussion about heritage sites, as well as manuscript preparation. AB made 30% of contributions to the paper regarding data analysis, manuscript preparation, and proofreading of the final version. HL and SN-10%- contributed to geologic field investigation and data analysis.

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