Geoheritage (2022) 14:103
https://doi.org/10.1007/s12371-022-00736-2

ORIGINAL ARTICLE

The Geoheritage of the South-Eastern Frontal Zone of the Middle Atlas (Morocco): First Inventory and Assessment

Kawtar Ech-charay[1] · Khadija Boumir[1] · Driss Ouarhache[1] · Mustapha Ouaskou[1] · Anass Marzouki[1]

Received: 18 January 2022 / Accepted: 19 August 2022
© The Author(s), under exclusive licence to International Association for the Conservation of Geological Heritage 2022

Abstract
The frontal zone of the south-eastern Middle Atlas is a natural barrier dominating the Middle Moulouya plain. It corresponds to the anticlinal ridge, the southernmost and highest of the Middle Atlas, with the famous Jbel Bou Naceur, which reaches 3326 m, and Jbel Tsiouant (2467 m). Jbel Bou Naceur represents a particular ecosystem of the high mountains. Its biodiversity is rich and varied so much that it has been classified as a Site of Biological and Ecological Interest. This area is formed mainly by limestone, dolomite, and marl deposits from the Jurassic period, where tectonic and erosion have shaped remarkable landscapes. Our study consists of a first inventory and assessment of geosites and geomorphosites between the Jbel Tsiouant and the Jbel Bou Naceur. Geosites and geomorphosites are classified and inventoried by adopting a new assessment approach resulting from the merger of two recent methodologies, modified and adapted to our project. Eleven geosites and eleven geomorphosites were selected. For each site, the scientific, educational, geotouristic, ecological, cultural, and aesthetic values, the potential for use, and the risk of degradation are quantified. The aim is to facilitate interpretation for eventual geoconservation. The present work, which contributes to the preservation of this rich geodiversity, could constitute a database for the future Geopark project that the national and regional authorities intend to create in the Middle Atlas.

Keywords Inventory · Geoheritage · Middle Atlas · Morocco

Introduction

Recently, many scientific, legislative, and governmental initiatives have demonstrated a growing interest in geological heritage and the development of sustainable geotourism in Morocco. These efforts were successful and were crowned by creating the 1st Geopark in Africa: the M'goun Geopark, located in the High Atlas, which received the Global Geopark label from UNESCO in 2014 and was renewed in 2018. Some works focusing on the geoheritage of this region were published later (Bouzekraoui et al. 2018a, 2018b; Arrad et al. 2018, 2020; Ait Omar et al. 2019; Rais et al. 2021). Research has multiplied throughout the country to inventory and valorize Morocco's geodiversity in order to create more Geoparks (Sadki et al. 2016; El Wartiti et al. 2017; Berred et al. 2019a, 2019b, 2020, 2022; Aoulad-Sidi-Mhend et al. 2019; Beraaouz et al. 2019; Lahmidi et al. 2020, 2021, 2022; Mehdioui et al. 2020, 2022).

The Middle Atlas is one of the regions that arouse a growing interest in geoheritage. It offers a wide variety of remarkable geological, geomorphological, and landscape sites with interesting scientific, educational, geotourism, ecological, cultural, and aesthetic values. Indeed, the Middle Atlas is a mountain chain consisting mainly of carbonate rocks covered in its western part by Plio-Quaternary basaltic flows. Some works have emphasized the singularity and the great diversity of volcanic sites in this area (Eddif et al. 2018a, 2018b; Abdelmounji et al. 2019; Mountaj et al. 2019; Baadi et al. 2021). Other works have focused on the paleontological, structural, hydrogeological, and karstic heritage (De Waele and Melis 2008; El Wartiti et al 2009; Mounir et al. 2019, 2021; Baadi et al. 2020). To highlight this rich heritage, geotouristic trails and geological tours have been proposed in the region (Charrière et al. 2011; Oukassou et al. 2019).

The main studies on the geological heritage are concentrated in the western and central parts of the Middle

✉ Kawtar Ech-charay
kawtar.echcharay@usmba.ac.ma

1 Faculty of Sciences Dhar El Mahraz, Geosciences, Environment and Associated Resources Laboratory, Sidi Mohamed Ben Abdellah University, BP: 1796 Atlas, 30003 Fez, Morocco

Atlas. However, no geodiversity study has been undertaken previously in the south-eastern area of this mountain. The present study provides a first selection and assessment of the geoheritage of the south-eastern Middle Atlas frontal zone, which corresponds to a natural barrier dominating the Moulouya plain. This area is rich in interesting geological sites and singular geomorphological landscapes shaped by various erosion processes combined with tectonic. The enhancement of this geoheritage is regarded as a contribution to the future Geopark project that national and local Moroccan authorities are considering to create in the Middle Atlas.

The selection and inventory of geosites and geomorphosites are considered a fundamental step in the strategies of evaluation and geoconservation (Santos et al. 2020). The need to select the most important sites has led to the development of many inventories and assessment methodologies, including those of Wimbledon et al. (1995), Wimbledon (1999, 2011), Pralong (2005), Reynard (2005, 2009), Reynard et al. (2007, 2016), Pereira and Pereira (2010), Wimbledon and Smith-Meyer (2012), Pereira et al. (2013), Brilha (2015, 2016, 2018), Sellier (2016), Sanchez and Brilha (2017), Reynard and Brilha (2018), Zwoliński et al. (2018), Mucivuna et al. (2019), and Santos et al. (2020).

For a successful geoheritage study, the inventory should be well structured and based on a reliable methodology. A well-organized inventory allows for a qualitative and quantitative assessment that leads to a comparison of geoheritage sites on a well-defined basis and to keep the most important elements of geodiversity, preserve them, and promote responsible geotourism. Otherwise, relevant sites may be undervalued or not identified (Santos et al. 2020).

Our work's objectives consist of the selection and valorization of the geoheritage of the region located between Jbel Tsiouant and Jbel Bou Naceur, which constitutes the transition zone between the Eastern Middle Atlas and the Missour Basin. For this paper, we propose an assessment methodology that merges two recent methodologies, one from Brilha (2016) and the other from Santos et al. (2020), which we believe is more appropriate to our research area.

The methodology proposed by Brilha (2016) distinguishes geosites with an interesting scientific value from geodiversity sites that have educational and tourist touristic values by making an inventory of the sites and a quantitative evaluation of their values based on four components: (i) scientific value (SV), (ii) potential educational use (PEU), (iii) potential touristic use (PTU), and (iv) degradation risk (DR).

However, the methodology proposed by Santos et al. (2020) aims to inventory and evaluate the geomorphological sites of a given region. The evaluation of the sites includes their scientific, educational, geotouristic value, promotion conditions, and degradation risks. The objective is to develop an environmental management support product focused on geoconservation and sustainable use of geomorphosites.

The combination of the two methodologies mentioned above is justified because Brilha's (2016) methodology develops more the evaluation of scientific, educational, and geotouristic values. However, Santos et al. (2020) methodology emphasizes and describes in detail the additional values, such as aesthetic, ecological, and cultural values.

We added a crucial step named specific evaluation to these two methodologies to distinguish and evaluate geosites and geomorphosites separately. On the other hand, some elements have been modified and adapted to our study area, such as the parameters of degradation risk for more reliability evaluation.

Geographic and Geologic Settings

The Middle Atlas is an intracontinental alpine chain, about 400 km long and 100 km wide in the SW-NE direction. The Rif mountain chain surrounds it to the north and the High Atlas to the south, from which it is separated by the Saïs plain and the Moulouya plain, respectively (Fig. 1). The mountain chain as we know it today was formed in the Tertiary (-35 Ma) during the alpine orogeny resulting from the approach and collision between the lithospheric plates of Africa and Laurasia (Michard et al. 2008). The tectonic style of the Middle Atlas is characterized by flexible and brittle deformation (Jura style tectonic).

The current structure of the Middle Atlas allows us to distinguish two domains:

- The tabular Middle Atlas in the NW is formed by plateaus between 1000 and 2000 m. It is intersected by N40 faults such as the Tizi n'Tretten Fault (TTF) and N120 to N140 transverse faults (Figs. 1 and 2). Its limits to the West and the North are characterized by scarps that can reach 300 to 400 m. It consists mainly of dolomites and limestones of the Lower and Middle Liassic, deposited in a continental platform environment (Charrière 1990; Sabaoui 1998; El Arabi 2001).
- The SE folded Middle Atlas is a mountainous region that peaks at Jbel Bou Naceur at 3326 m. The Meso-Cenozoic series is well developed. It is essentially composed of limestones, marlstones, and marls. Two major faults delimit this area longitudinally: to the NW, the North Middle Atlas Fault (NMAF), which mostly forms the tectonic and morphological limit with the tabular Middle Atlas, and to the SE, the South Middle Atlas (SMAF), which marks the contact with the Moulouya plain (Termier 1936; Colo 1962; Du Dresnay 1963) (Figs. 1 and 2). These accidents, inherited from the Hercynian orogeny, played an important paleogeographic

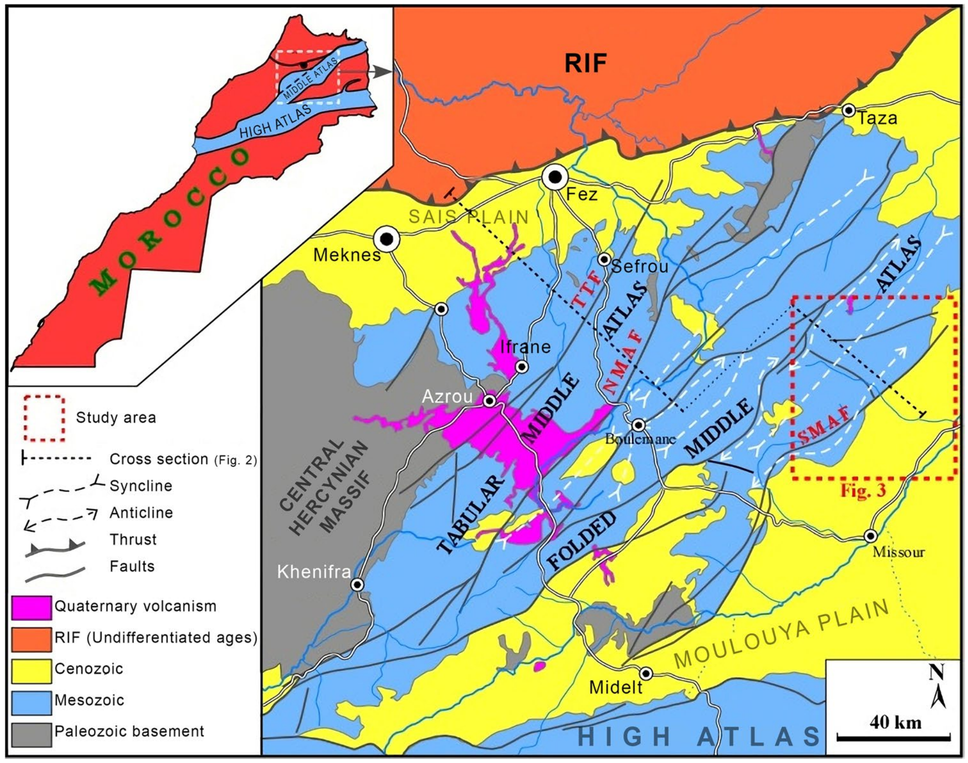


Fig. 1 Simplified geological map of the Middle Atlas and location of the study area. Redrawn from the Moroccan geologic map of 1:1,000,000 (Hollard et al. 1985). TTF, Tizi n'Trhetten Fault; NMAF, North Middle Atlas Fault; SMAF, South Middle Atlas Fault

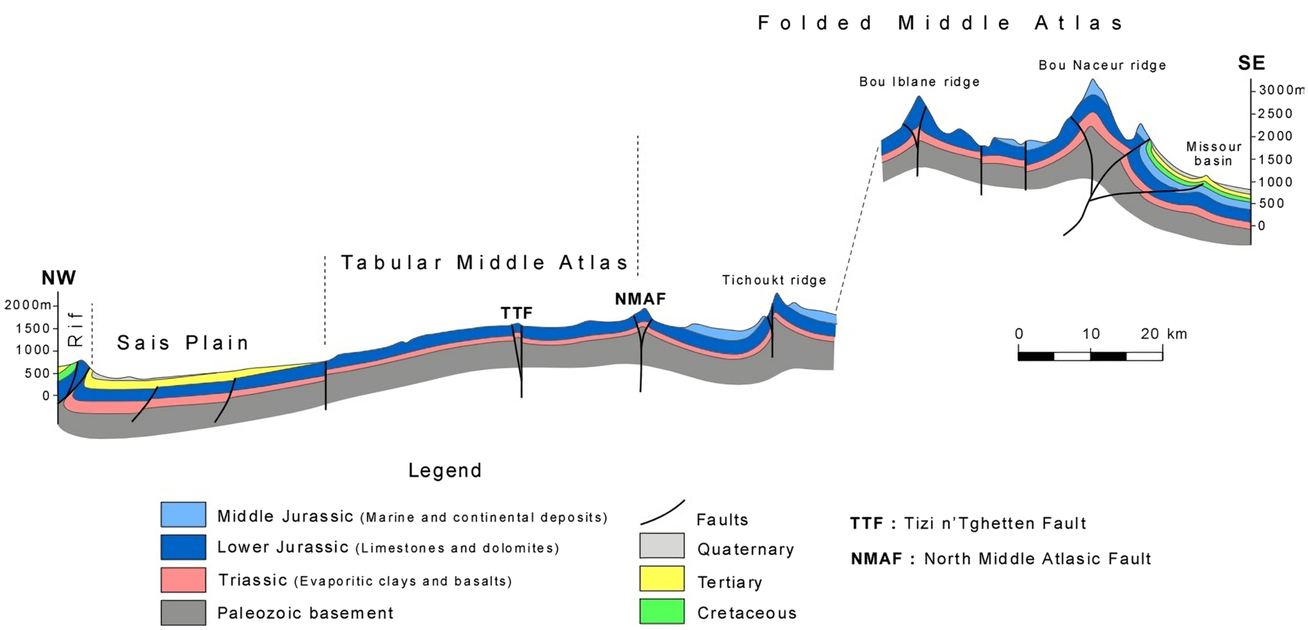


Fig. 2 Schematic cross-sections of the Middle Atlas belt. TTF, Tizi n'Trhetten Fault; NMAF, North Middle Atlas Fault (see Fig. 1 for locations)

role during the Meso-Cenozoic (Fedan 1988; Charrière 1990; Sabaoui 1998; El Arabi 2001).

The folded Middle Atlas consists of narrow, often asymmetrical anticlines separated by broad, undulating synclines (Figs. 1 and 2). The synclines correspond to basins formed as a result of the uplift of the ridges in the Upper Dogger. The filling of these synclines was controlled by active synsedimentary tectonic which is visible at the contacts of the anticlinal flanks. The synclines of the eastern zone are essentially filled by a regressive sedimentary series of the Bathonian-?

Callovian age which is overlain, in the western synclines, by a transgressive sedimentary series of Cretaceous and Tertiary age.

The anticlinal ridges, whose core consists essentially of Lower and Middle Liassic carbonate formations, with occasional Triassic outcrops in the major faults, are organized along directions inherited from the late-Hercynian system (NE-SW). Four ridges can be distinguished, each consisting of a succession of daisy-chain anticlines (Fig. 1). The first ridge in the NW corresponds to the NMAF passage and marks the transition from the tabular Middle Atlas to the folded Middle Atlas (Fig. 2). The second ridge (Tichoukt ridge, culminating at 2793 m) and the third (Bou Iblane ridge, culminating at 3172 m) are located in the middle of the chain. The fourth (Bou Naceur ridge, culminating at 3326 m) coincides with the passage of the Southern Middle Atlas Fault (SMAF). It ensures the connection of the reliefs to a plain landscape, whose axis is occupied by the Moulouya river. With a level difference exceeding 1000 m in places, the brutal contact is marked by several glacises and tiered alluvial fans.

The fourth ridge is of great geological interest because it constitutes the transition zone between two different types of Jurassic facies (Fig. 3), those of the folded Middle Atlas and those of the High Plateaux, located east of the Moulouya plain. Indeed, the Middle Jurassic (Dogger) series in the Middle Atlas are formed essentially by marlstones and marls, deposited in relatively deep subsiding basins, whereas that of the High Plateaux is a reduced series formed by dolomitic limestones of the platform (Benshili 1989; Beauchamp et al. 1996). The boundary between the two domains is marked by the SMAF, which played an important role in the differentiation of paleogeography during the Jurassic (Fedan 1988, du Dresnay 1988).

This accident, with normal movement during the Jurassic, evolved into a thrust or reversed fault during the tightening of the Alpine orogeny (Beauchamp et al.1996; Gomez et al. 1996; Sani et al. 2000). As a result, the current front of the SMAF is shifted towards the SE compared to its position during the Jurassic (Fig. 3). This front is still active, as shown by the deformations of the Plio-Quaternary deposits, at the NW border of the Missour Basin (Fig. 3), at the foot of the folded Middle Atlas reliefs (Gomez et al. 1996; Delcaillau et al. 2007; Laville et al. 2007).

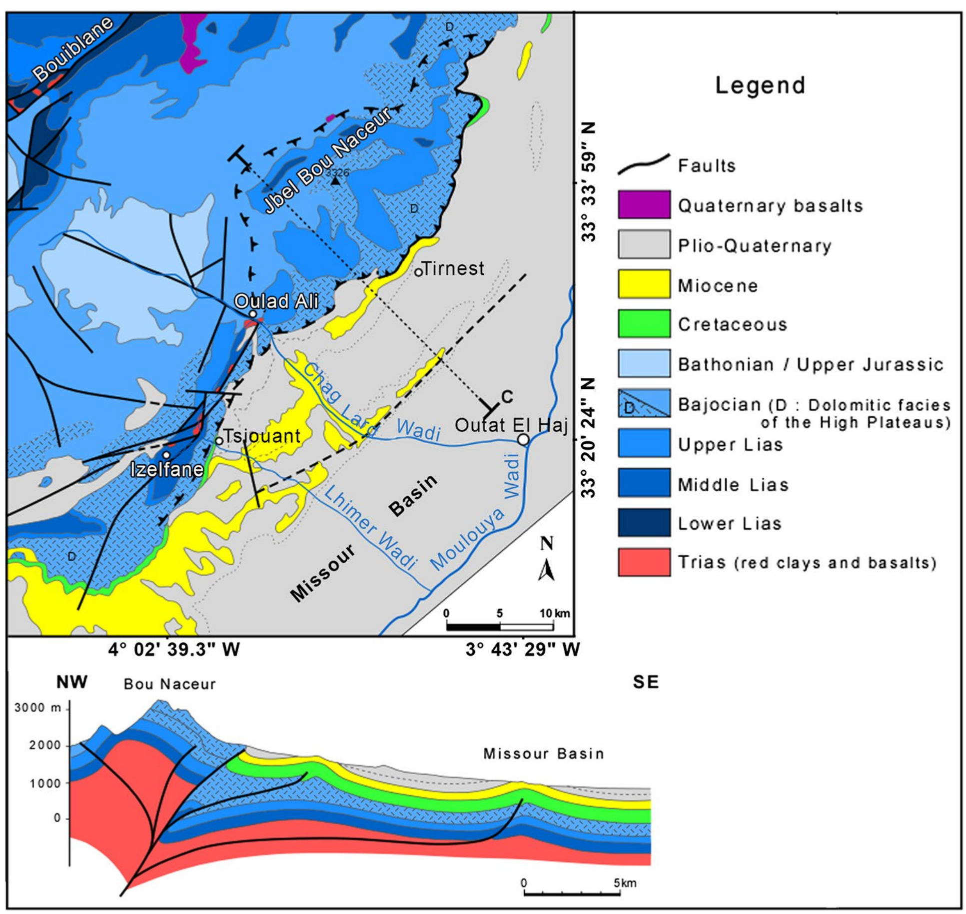


Fig. 3 Simplified map and cross-section through the Middle Atlas front and the Missour Basin. (Map inspired from the geological map of Oujda, 1/500000, the deep structures of the cross-section are inspired from Laville et al. 2007)

Methodology

After consulting several methodological approaches to geosite and geomorphosite assessment, we selected the methodology of Brilha (2016) and Santos et al. (2020), which we merged, modified, and then adapted to our project. Thus, we propose a procedure for the evaluation of geoheritage sites that proceeds in three successive stages: (i) preliminary evaluation, (ii) specific evaluation, and (iii) quantitative evaluation (Fig. 4). The first step aims to define the study area and select the sites. The second step is dedicated to the scoring and classification of the sites. The third step concerns the complete evaluation of the sites.

Preliminary Assessment

We started our project by defining and delimiting the study area following a bibliographic synthesis, the examination of topographic maps, scale 1:50,000 (Almis Marmoucha and Oulad Ali), as well as geological maps (geological map of Morocco, scale 1:1,000,000, and geological map of Oujda, scale 1:500,000).

Subsequently, we have carried out several field missions to select geoheritage sites with scientific relevance and potential for educational and/or tourist use. Finally, we compiled a preliminary list of all selected sites in our study area.

Specific Assessment

After compiling the preliminary list of sites, we prepared an identification sheet for each selected site in which we specify the name of the site, its geographical location, a geological description, and the most outstanding geological features that justify the need to consider the site as a geosite, or the most outstanding geomorphological features that justify the need to consider the site as a geomorphosite (Table 1). We specify that our study area is not subject to legal protection, and all selected sites are located in state territories.

Then, we performed an initial evaluation of the sites based on the parameters and scores displayed in Table 1. The main purpose of this step is to avoid including irrelevant sites in the next procedure (quantitative evaluation), which requires more time to carry out. Only sites with a high score are selected. There is no specific score to achieve. The evaluator can decide on the minimum score taking into account the specific aspects of his work (Santos et al. 2020). We selected sites with: (i) rarity, (ii) an interesting score of the main parameters, regardless of the score of the additional parameters and the use and management parameters, and (iii) a significant geological interest.

This step aims to identify, score, and elaborate two lists of sites to be quantitatively evaluated: one for the geosites and one for geomorphosites.

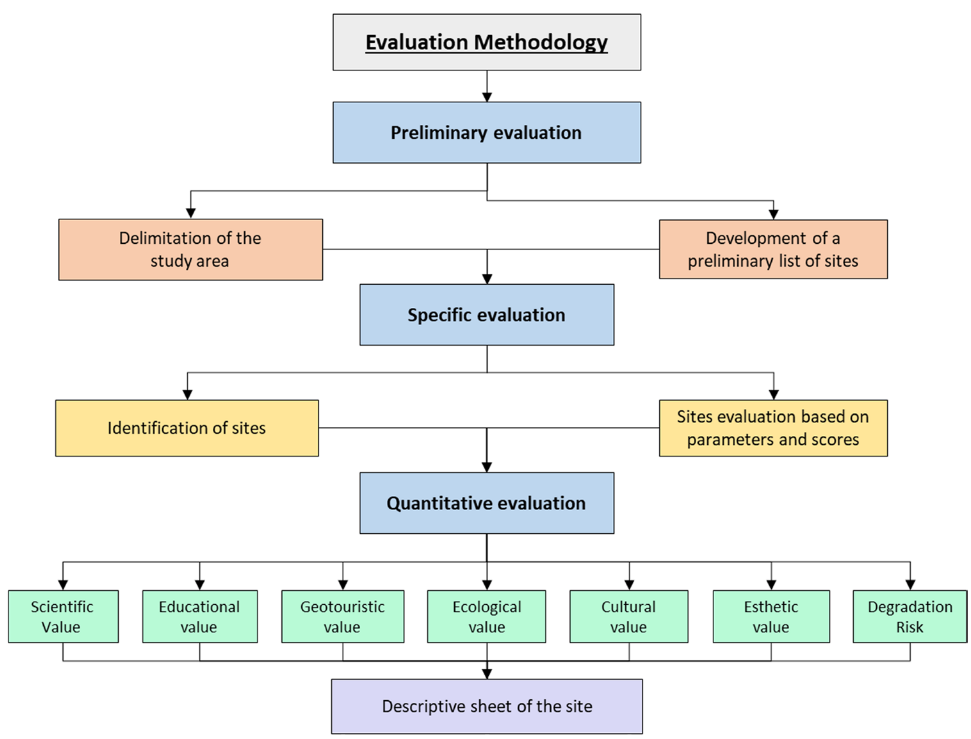


Fig. 4 Flowchart diagram of the used methodology showing its different stages (modified after Brilha 2016 and Santos et al. 2020)

Table 1 Classification and criteria for identification and evaluation of preliminary list sites (adapted after Brilha 2016; Santos et al. 2020)

Type of site	Identification criteria	Evaluation criteria	Scores
Geosites	- Site name - Geographic coordinates - Site classification - The most notable geological features that justify the need to consider the occurrence as a geosite	• *Central parameters* Representativity Integrity (geological interest) Rarity Scientific knowledge	 1 — low 2 — medium 3 — high 4 — very high
		• *Additional parameters*	
Geomorphosites	- Site name - Geographic coordinates - Site classification - The most notable geomorphic features that justify the need to consider the occurrence as a geomorphosite	Geological relevance Ecological relevance Cultural relevance Aesthetic relevance	0 — no 1 — low 2 — medium 3 — high
		• *Use and management parameters* Accessibility Safety Infrastructure Visibility Fragility and vulnerability	 1 — low 2 — medium 3 — high

We note that each site can be used for educational and/or touristic purposes if the conditions are met. For example, a site with a high scientific value can be used for educational and/or geotouristic purposes if it presents a geological phenomenon easily understood by students and pupils or is characterized by interesting views, landscapes, and cultural heritage.

Quantitative Assessment

The objective of quantitative geoheritage assessment is to reduce the subjectivity associated with any assessment procedure and to define management priorities (Brilha 2016). In this sense, Brilha (2016) proposed evaluating the scientific, educational, and geotouristic values of the sites and their risk of degradation. However, the methodology of Santos et al. (2020) focuses on evaluating the potential of use of the site by evaluating three values: scientific, educational, and geotouristic values. That is, the evaluation of the conditions of visit in order to determine if the site is suitable to be promoted for visitors or if it requires prior management actions. Thus, Santos et al. (2020) preferred to also assess ecological, cultural, and aesthetic values, which will be used both as parameters to assess use values, and also displayed as additional values in the final result. In addition, they proposed to assess quantitatively the degradation risks, as this is a fundamental issue in geoconservation.

In the present study, we used the criteria for the quantitative assessment of scientific, educational, and geotouristic values (Brilha 2016) by adding the promotion parameters for the assessment of ecological, cultural, and aesthetic values (Santos et al. 2020) (Table 2).

Degradation Risk

To accomplish the quantitative evaluation of sites, it is necessary to assess the value of their degradation risk. It provides the competent authorities with an idea of which sites are at risk and require special protection. Assessing the degradation risk of a site is of crucial importance for the preparation and implementation of a management plan (Brilha 2016). For degradation risk assessment, Brilha (2016) proposed using the concept of geological features deterioration as a basis: a site that is threatened with losing its geological features automatically loses its scientific value. For this reason, this parameter was considered the most important one as well as the proximity to the sites of areas/activities could affect the site. Accessibility to the site, which we consider to be an important factor in the degradation risk, was considered in our assessment.

The assessment of the degradation risk proposed in this work is based on four criteria, namely: (i) natural factors, (ii) anthropogenic factors, (iii) geolocation of the site (positioning), and (iv) infrastructure (Table 3).

The results of the different assessments are then presented in a diagram to facilitate a comparison between the assessments of the different studied sites.

Descriptive Sheet

In this study, we have proposed a descriptive sheet (Table 4). It summarizes the preliminary and quantitative evaluations of the selected sites to be inventoried and readable to the reader and the competent authorities.

Table 2 Quantitative assessment criteria (adopted from Brilha 2016; Santos et al. 2020)

Criteria (scored 0 to 4)	Weighting (%)
Scientific value (SV)	
1. Representativeness: capacity of a geosite to illustrate geological elements or processes (related to the geological framework under consideration when applicable)	30
2. Key locality: the importance of a geosite as a reference or model for stratigraphy, paleontology, mineralogy, etc	20
3. Scientific knowledge: the existence of published scientific studies about the geosite (related to the geological framework under consideration when applicable) reflects the SV given by the geoscientific community	5
4. Integrity: related to the conservation status of the main geological elements (related to the geological framework under consideration when applicable); the better the integrity, the higher the SV	15
5. Geological diversity: a high number of different geological elements with scientific interest (related to the geological framework under consideration when applicable) in a geosite implies a higher SV	5
6. Rarity: a small number of similar geosites in the study area (representing the geological framework under consideration when applicable) increases the SV	15
7. Use limitations: the existence of obstacles that may be problematic for the regular scientific use of the geosite impacts the geosite's SV	10
Educational value (EdV)	
1. Vulnerability: the existence of geological elements that students can destroy decreases the EdV of the site	10
2. Accessibility: the easier and shorter the walk between the means of transportation and the site, is the higher the EdV	10
3. Use limitations: the existence of obstacles that may be problematic for the development of educative activities impacts the site's EdV	5
4. Safety: when the field activity can be carried out under low-risk conditions for students, the EdV of the site increases	10
5. Logistics: the existence of facilities to receive students, such as accommodation, food, and toilets, increases the site's EdV	5
6. Density of population: the existence of a population near the site, potentially providing students who will use the site, increases its EdV	5
7. Association with other values: the existence of other natural or cultural elements associated with the site may justify interdisciplinary field trips and increase the EdV of the site	5
8. Scenery: represents the beauty of the geological elements that could stimulate students' interest in the site and thus increases its EdV	5
9. Uniqueness: concerns the geodiversity element's distinctiveness and rarity that could promote students' interest in the site and raise its EdV	5
10. Observation conditions: the better the conditions for observing all the geodiversity elements on the site, the higher its EdV	10
11. Didactic potential: the use of the site by students of different education levels increases the EdV of the site	20
12. Geological diversity: a high number of different geological elements with didactic potential increases the EdV of the site	10
Geotouristic value (TV)	
1. Vulnerability: the existence of geodiversity elements that visitors can destroy decreases the TV of the site	10
2. Accessibility: the easier and shorter the walk between the visitors' transportation (bus, car, etc.) and the site is, the higher the TV	10
3. Use limitations: the existence of obstacles that may be problematic for the development of touristic activities impacts the site's TV	5
4. Safety: if the visit can be made under low-risk conditions for visitors, the site's TV increases	10
5. Logistics: the inexistence of facilities for receiving tourists, such as information centers, accommodation, food, and toilets, decreases the site's TV	5
6. Density of population: the existence of towns/cities near the geosite as a potential source of visitors to the site increases its TV	5
7. Association with other values: the occurrence of other natural or cultural elements associated with the site may increase the number of potential visitors and, consequently, the site's TV	5
8. Scenery: represents the beauty of the geodiversity element that might attract visitors, increasing the site's TV	15
9. Uniqueness: concerns the distinctiveness and the rarity of the geodiversity elements that could stimulate a sense of satisfaction for the visitors	10
10. Observation conditions: the better the observation of all the geodiversity elements of the geosite, the higher its TV	5
11. Interpretative potential: related to the capacity of a geodiversity feature to be easily understood by people with no geological background, i.e., typical members of the general public	10
12. Economic level: the high income level of people living near the site suggests a higher probability of it being visited	5

Table 2 (continued)

Criteria (scored 0 to 4)	Weighting (%)
13. Proximity of recreational areas: a touristic visit to a site may benefit from the existence of well-known tourist attractions in the surrounding area	5
Ecological value (EcV)	
1: The site has a direct relationship with some biotic aspects. (1) The site has a direct relationship with some special biotic aspects (rare, endemic, threatened, etc.). (2) The site shows clear conditioning of geomorphology over some biotic aspects. (3) The site represents a special case of a relationship between geomorphology and biodiversity. (4)	100
Cultural value (CV)	
1: There are elements with cultural importance but not directly related to the geological or geomorphological setting of the site. (1) There are elements with cultural importance directly related to the site setting, or the site has economic importance. (2) The site is/was occupied or is highly relevant for some traditional community, or the site was used to develop a geological or geomorphological model. (3) The main geomorphological feature is anthropic, or represents an icon of a people/region, or is highly relevant for the history of geology or geomorphology. (4)	100
Aesthetic value (EsV)	
1: There are significant difficulties in visualizing the site. Being impossible to see it in its totality. (1) There are significant difficulties in visualizing the site, but it is possible to see it in its totality. (2) The site can be seen with no difficulties, but only from specific viewpoints. (3) The site can be seen with no difficulties without going to specific viewpoints. (4)	30
2: Site highly altered/degraded. (1) Site partially altered/degraded. (2) Site with alterations but with low influence on its aesthetics. (3) The site is in a very good state of conservation. (4)	30
3: Low (the aesthetic dimension does not contribute to attract visitors). (1) Medium (the aesthetic dimension may be attractive to a specific public). (2) High (the aesthetic dimension may highly contribute to attract visitors). (3) Exceptional (site already widely recognized by its aesthetic dimension). (4)	40

Table 3 Criteria used to assess the degradation risk of the geosites and geomorphosites

Criteria (scored 0 to 4)	Weighting (%)
Degradation risk (DR)	
1: Natural factors: erosions, seisms, storms, floods, climate change, and all types of natural risks that can affect the geological and/or geomorphological elements of the site, etc	30
2: Human factors: all types of human degradation. In the absence of judicial protection, many geoheritage sites are affected by: illicit plundering and traffic (ammonites, dinosaur bones, etc.), illegal exploitation of the natural resources of the basement, demographic expansion, irresponsible tourism, irrational use of fresh and thermal springs, etc	30
3: Site geolocation (positioning): the sites proximity of the entertainment stations, factories, quarries, roadworks, big cities, etc	20
4: Infrastructure (road, hotel, etc.): a good infrastructure means easy access to the sites which leads to many tourists visiting but also affecting and damaging some sites. This diminishes their aesthetic value	20

The Heritage of the Study Area

The fourth ridge of the folded Middle Atlas is a mountainous front overlapping the NW border of the Missour's sedimentary basin. It is formed by the majestic Jbel Bou Naceur (3326 m) and Jbel Tsiouant (2465 m) (Fig. 5). These reliefs are essentially constituted of a Dogger dolomitic limestone, which is the extension towards the W of the High Plateaux facies. This mountainous barrier is incised transversely by two main rivers: Tittaouine wadi and Lemsareh wadi, which become Lhimer wadi and Chag Lard wadi in the plain, respectively (Fig. 5). This region of the Middle Atlas is distinguished by its remarkable biological potential. Indeed, the Jbel Bou Naceur is classified as a Site of Biological and Ecological Interest (SBEI). It harbors a significant diversity of endemic flora and fauna, including *Artemisia flahaultii Emb.* associated with two rare species: *Juniperus communis L.* and *Daphne laureola* (Rhanem 2018), and *Uromenus trochleatus* Chopard (François 2012).

The study area illustrates the geological history of the Middle Atlas from the Triassic to the Quaternary. We

Table 4 Descriptive sheet for each selected site

Evaluation results	
Identification	Site type:
	Name:
	Location:
	Geographic coordinates:
	Altitude:
Geological and/or geomorphological interest	A brief explanation of the site's geological and/or geomorphological interest (structural, paleontologic, stratigraphic, sedimentologic, petrographic, paleoclimatic, karstic, etc.)
Associated interests	A brief explanation of each associated interest (high geodiversity, other geoscience fields, ecological, cultural, etc.)
Use and management	Accessibility (from the nearest town or village): public/private transportation; trails; wheelchair access (consider the possibility of different specific viewpoints)
	Safety
	Basic infrastructure (proximity to tourist facilities)
	Visibility
	Integrity and protection status
	Fragility and vulnerability
	Landscape
	Recommended season for visiting
	Activities that can promote the site attractive
Quantitative evaluation	Graph showing the results of the quantitative evaluation
Photos and references	

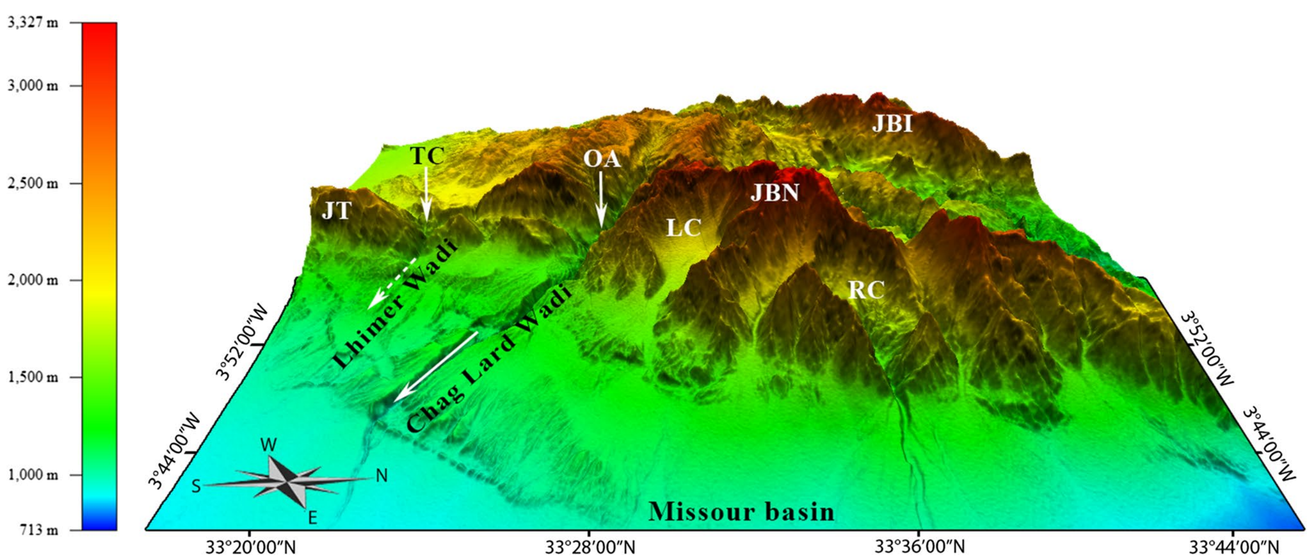


Fig. 5 The study area 3D representation. JT, Jbel Tsiouant (2465 m); TC, Tsiouant Canyons; OA, Oulad Ali; JBN, Jbel Bou Naceur (3326 m); JBI, Jbel Bou Iblane (3172 m); LC, Laatchana Cirque; RC, Rawyana Cirque

observe a succession of diverse geological formations deposited in both marine and continental environments. This succession results in a great diversity of facies, especially carbonates. The limestones contain an important marine fauna, including ammonites, brachiopods, and lamellibranchs. Also, in this area, the tectonics is well highlighted by various folds and faults of different dimensions.

The various geomorphological landscapes in this territory are shaped by tectonic structures, lithology, and erosion processes of glacial, periglacial, fluvial, karstic, and gravity types. Thus, the slopes are strongly dissected and inclined, and the valleys are profound. The originality of this region lies in the presence of the best glacial witnesses of the Quaternary periods, including glacial

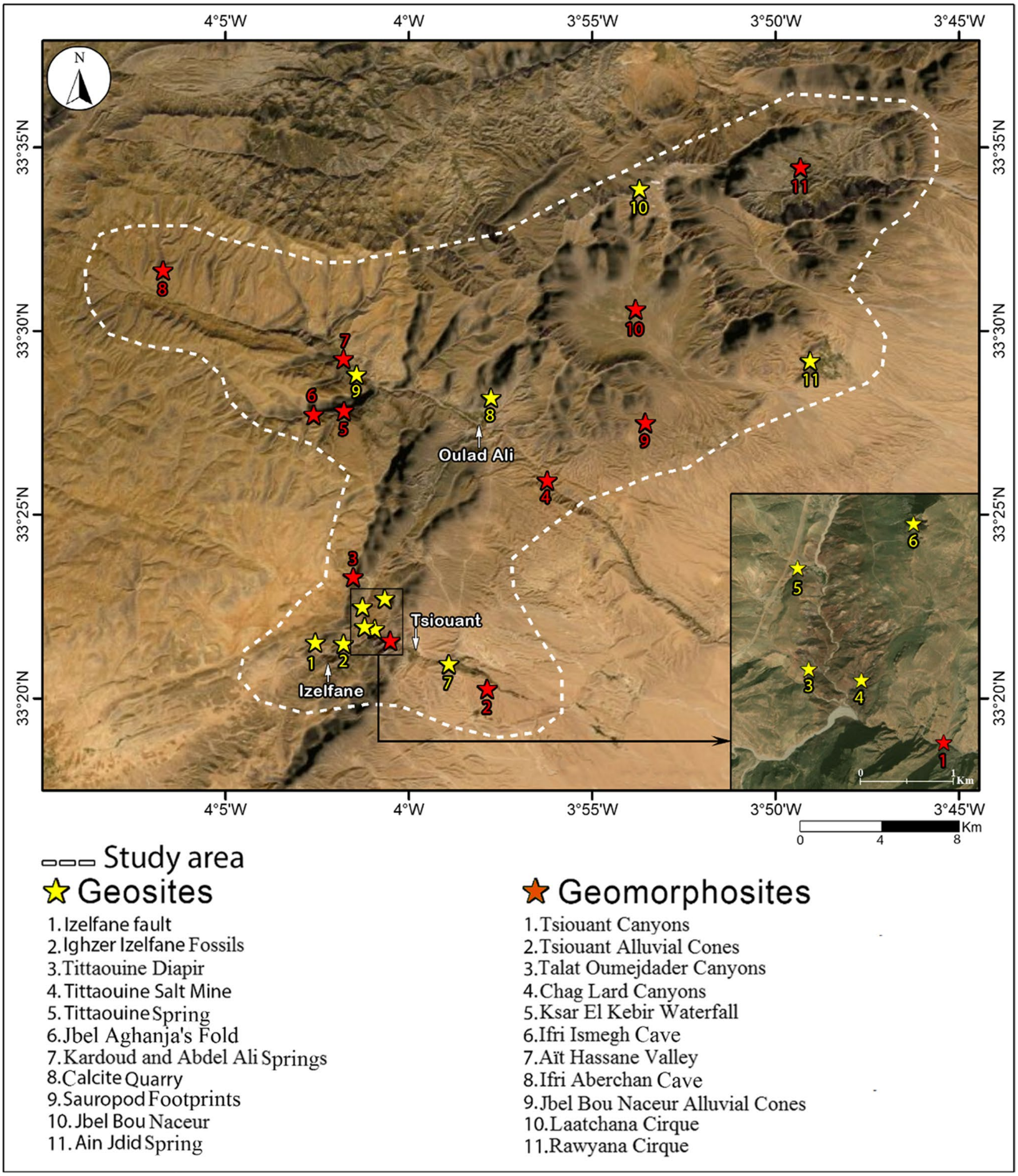


Fig. 6 Limit of the study area (white line) and the preliminary selection of sites

cirques, cryonival niches, knickpoints, and periglacial accumulations (Raynal 1952, 1961; Dresch and Raynal 1953; Raynal et al. 1953; Hughes et al. 2004). Currently, the Jbel Bou Naceur is an important snow-covered area inducing a particularly vigorous gelifraction action during winter. The fracturing of rocks by gelifraction associated with steep slopes caused the accumulation of numerous glacis and alluvial fans of various dimensions,

Table 5 Preliminary list of studied geosites

Site no	Identification criteria	Evaluation of the criteria		
		Central parameters Maximum value 16	*Additional parameters* Maximum value 12	*Use and management parameters* Maximum value 15
1	- Site name: accident of Izelfane - Geographic coordinates: 33°21′25.4 ″N 4°02′39.3 ″W - Site classification: structural - Site description: Izelfane's accident (Fig. 7A) extends from the Izelfane village to the Oulad Ali village over about 29 km and has a width of nearly 2 km. This accident favors the outcrop of saliferous clays and Triassic basalts	13	11	12
2	- Site name: fossils of Ighzer Izelfane - Geographic coordinates: 33°21′28.4 ″N 4°01′46.7 ″W - Site classification: paleontological - Site description: the steep valley of Ighzer Izelfane allows the outcrop of a succession of Jurassic limestone layers rich in fossils, especially ammonites (Fig. 7B,C)	11	5	8
3	- Site name: Diapir of Tittaouine - Geographic coordinates: 33°22′04.3 ″N 4°01′00.1 ″W - Site classification: structural - Site description: in the Tittaouine combe, the Jurassic strata have been pushed back by the rise of the Triassic evaporates (Fig. 7D). It illustrates the tectonics responsible for the uplift of ridges in the Middle Atlas	12	5	9
4	- Site name: salt mine of Tittaouine - Geographic coordinates: 33°22′22.8 ″N 4°01′04.6 ″W - Site classification: geomaterial - Site description: a rock salt mining gallery currently abandoned was dug in the Triassic clays (Fig. 7E). It is a unique site in the region and was the main source of salt for the entire region	12	7	9
5	- Site name: Tittaouine Spring - Geographic coordinates: 33°22′28.6 ″N 4°01′16.4 ″W - Site classification: hydrological - Site description: one of the most important springs in the region (Fig. 7F). It gushes out at the bottom of a combe-shaped in the Triassic saliferous clays and bordered by the Jurassic limestone and dolomitic ridges of the Jurassic. The water of this spring is soft, but it becomes salt after its flow into the Triassic saliferous formations. Then, it forms the Tittaouine wadi which feeds the Tsiouant village	11	7	13
6	- Site name: Jbel Aghanja's fold - Geographic coordinates: 33°22′43.9 ″N 4°00′37.9 ″W* - Site classification: structural - Site description: it is a double fold formed in the Jurassic limestones and dolomites and perched at the top of the mountain (Fig. 7G) (Aghanja means ladle in Amazigh)	11	7	8
7	- Site name: Kardoud and Abdel Ali springs - Geographic coordinates: 33°19′12.6 ″N 3°55′00.6 ″W - Site classification: hydrological - Site description: the two springs are close to each other. The Abdel Ali spring (fresh) gushes out at the foot of the Pliocene–Quaternary conglomerate cliff. In contrast, the Kardoud spring (salty) is located below in the recent alluvium where the salty water of the Tittaouine wadi infiltrates	7	8	11
8	- Site name: calcite quarry - Geographic coordinates: 33°28′15.0 ″N 3°57′49.1 ″W - Site classification: geomaterial Site description: it is located near the Oulad Ali village. It is an open-cast quarry of pure calcite in the faults intersecting the Jurassic carbonates, whose exploitation is stopped recently	9	5	10
9	- Site name: sauropod footprints - Geographic coordinates: 33°28′48.8 ″N 4°01′25.5 ″W - Site classification: paleontological - Site description: the only sauropod footprints known so far in the region of Ait Hessane. We discovered those footprints at the bottom of the Lemsareh wadi's valley, where the runoff water degrading them	11	4	9
10	- Site name: Jbel Bou Naceur - Geographic coordinates: 33°34′14.7 ″N 3°53′16.8 ″W - Site classification: structural - Site description: Jbel Bou Naceur occupies the south-eastern frontal zone of the Middle Atlas. It is a natural barrier that dominates the plain of the Middle Moulouya with steep slopes (Fig. 8A). Jbel Bou Naceur corresponds to the highest summit of the Middle Atlas chain, which culminates at 3326 m. It is an anticline formed by the Jurassic calcareous dolomites	12	12	10
11	- Site name: Ain Jdid - Geographic coordinates: 33°29′10.7 ″N 3°49′01.7 ″W - Site classification: hydrological - Site description: it is a vaucluse spring that gushes out in the Tertiary sandstone-conglomerate formations. A very high flow rate characterizes it. Ain Jdid spring supplies the Tirnest village with drinking and orchards irrigation water	9	9	9

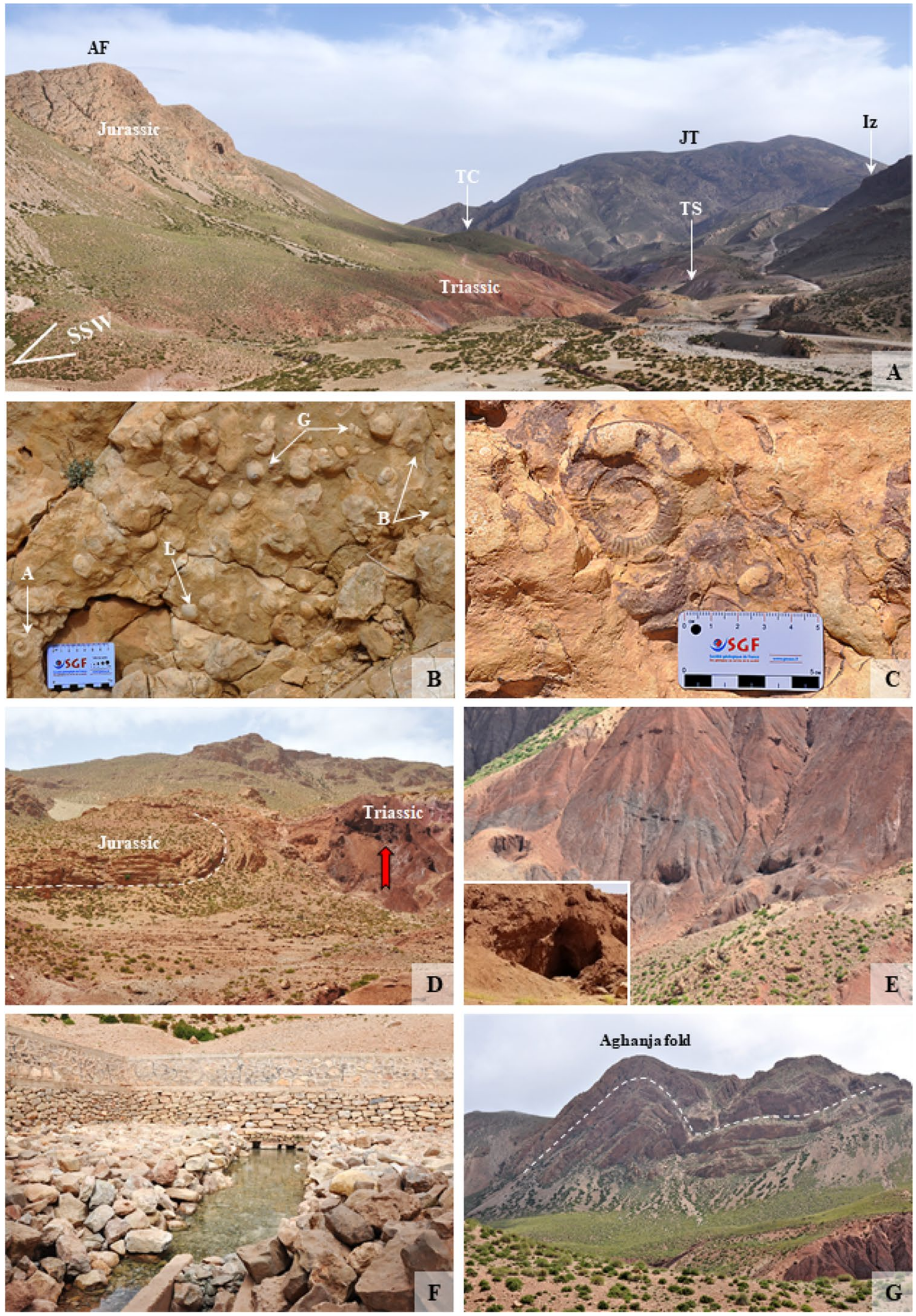


Fig. 7 View of some geosites. **A** Depression corresponding to the passage of the Izelfane fault where the Triassic clay outcrops (AF, J. Aghanja Fold; TC, Tsiouant Canyons; TS, Tittaouine Spring; JT, Jbel Tsiouant; Iz, Izelfane village); **B** the surface of a bank showing basal Dogger fossils in Ighzer Izelfane (A, ammonite; L, lamellibranch; B, brachiopod; G, gastropod); **C** ammonites of Ighzer Izelfane; **D** Tittaouine diapiric structure (red arrow indicates the Triassic diapiric rise); **E** Tittaouine salt mines in the Triassic clay; **F** Titaouine spring; **G** Jbel Aghanja fold in Jurassic limestones and dolomites (Triassic clays correspond to the passage of the Izelfane fault). (The scale cards in images **B** and **C** are respectively 7 cm and 5 cm)

particularly on the Bou Naceur massif's south-eastern slope. In addition, the landscape of this region is characterized by intense karstification, favored by the carbonated nature of the outcrops. Thus, the Jurassic limestones and dolomites of Jbel Tsiouant express one of the most beautiful morphologies of the canyon in the region surrounding the Tittaouine Wadi.

The studied area has a rich geodiversity, biodiversity, and an interesting prehistoric heritage that testifies to this territory's ancient human occupation. Indeed, we discovered many funerary monuments in the form of tumuli identical to those reported by Benlamine (2017) in the central Middle Atlas and which belong to the Protohistoric period. Excavations of some of these monuments

Fig. 8 Panoramic view of the Bou Naceur ridge from the Moulouya plain (**A**); **B** Laatchana Cirque showing U-shaped valley, flat bottom, and steep walls; **C** south-eastern slope of Jbel Bou Naceur plunging towards the Moulouya plain; **D** the esparto and rosemary steppes covering Laatchana Cirque plain; **E** secondary cirques from the last glaciation perched in the wall of Laatchana Cirque; **F** marl and limestone covered by alluvial fans in the lower part of the wall

in the central Middle Atlas have yielded human remains and jewelry (Benlamine et al. 2015).

This high mountain region is also characterized by a rich and diverse vernacular architecture heritage that offers a landscape in perfect symbiosis with its environment. The construction by local materials (stone, mud, and wood) and typical Amazigh style reflect the ingenuity of the indigenous inhabitants, their incredible capacity to adapt to often-austere conditions, and their fascinating maturity in terms of eco-responsibility. This architecture's protection, restoration, and enhancement constitute a vector in its own right to develop responsible tourism (Kharmich et al. 2019).

Results

Preliminary Assessment

After several field visits, during which we delineated the study area and defined the main geological features of our region, 22 sites were selected and are included in

Table 6 Preliminary list of studied geomorphosites

Site no	Identification criteria	Evaluation of the criteria		
		Central parameters Maximum value: 16	*Additional parameters* Maximum value: 12	*Use and management parameters* Maximum value: 15
1	- Site name: Tsiouant Canyons - Geographic coordinates: 33°21′38.3 ″N 4°00′48.9 ″W - Site classification: fluvial - Site description: Tittaouine wadi, a tributary of Moulouya river, crosses the Triassic formations, followed by the Jurassic limestones and dolomites, creating a deep notch. This notch can reach 100 m of depth in the redressed layers by forming a real canyon of approximately 2 km in length. The succession of layers that characterizes these canyons offers an exceptional geological section, exposing different carbonate facies and tectonic structures (Fig. 9A,B,C,D,E)	13	11	12
2	- Site name: Tsiouant Alluvial Cones - Geographic coordinates: 33°20′17.8 ″N 3°57′31.9 ″W - Site classification: gravity - Site description: these cones, accumulated at the bottom of the reliefs around the Tsiouant Village, are a Quaternary conglomeratic formation, showing a clear discordance on the Cretaceous deposits (Fig. 9F). Its elements are essentially carbonates. The size of these elements goes from centimeters to meters. The thickness of these cones exceeds 30 m	9	7	10
3	- Site name: Talat Oumejdader Canyons - Geographic coordinates: 33°23′17.9 ″N 4°01′34.5 ″W - Site classification: fluvial - Site description: these are dry gorges carved in the straightened and faulted carbonates of the Dogger. The access to these gorges is difficult because of the path's abandonment and the accumulation of nearby boulders placed by the intense floods	8	10	10
4	- Site name: Chag Lard Canyons - Geographic coordinates: 33°25′55.2″N 3°56′13.0 ″W - Site classification: fluvial - Site description: downstream of the Oulad Ali village and up to Beni Hayoune village, the Chag Lard wadi has carved profound canyons (Fig. 10D) in the Cretaceous and Tertiary sandstones and pelites where the differential erosion leaves a magnificent landscape. These canyons show a section illustrating the tectonic evolution of this Middle Atlas border	8	10	9
5	- Site name: Ksar El Kebir Waterfalls - Geographic coordinates: 33°29′46.8 ″N 4°02′08.5 ″W - Site classification: fluvial - Site description: Lamsareh wadi presents several small waterfalls at the bottom of the very steep valley near the Ksar El Kebir village. They are generated by a stepped topography of Jurassic marlstone (Fig. 10B)	10	9	10
6	- Site name: Ifri Ismegh Cave - Geographic coordinates: 33°27′43.0 ″N 4°02′36.0 ″W - Site classification: karstic - Site description: Ifri Ismeg (Ifri means cave in Amazigh) is one of the most impressive caves in the region, inside which flows an underground river. The explored part exceeds 3 km. It requires development so that it is accessible to the public	11	8	9
7	- Site name: Aït Hassane Valley - Geographic coordinates: 33°29′11.8 ″N 4°01′45.4 ″W - Site classification: fluvial - Site description: a wonderful steep valley located upstream of the Oulad Ali village (Fig. 10A). It follows the path of a dextral strike-slip fault and has very steep slopes. It is distinguished by its agricultural terraces (Fig. 10C) carved on the steep slopes. The villages clinging to the slopes of this valley are built with local materials. They appear in harmony with their environment and show a distinguished cultural identity	11	11	11
8	- Site name: Ifri Aberchan Cave - Geographic coordinates: 33°31′39.0″N 4°06′42.0 ″W - Site classification: karstic - Site description: Ifri Aberchan (means in Amazigh, black cave) is located at 800 m to the NW of the Lemsareh village at an altitude of 2192 m, more precisely on the left bank of a small dry valley in the Jurassic carbonates. It presents a small entrance, and inside, the two explored kilometers show two siphons and a small waterfall	10	8	9
9	- Site name: Jbel Bou Naceur Alluvial Cones - Geographic coordinates: 33°28′16.1 ″N 3°49′56.5 ″W - Site classification: gravity - Site description: the southern slope of Jbel Bou Naceur has a very large elevation change of more than 1000 m. The disintegration of large limestone and dolomite cliffs feeds large alluvial cones during Pliocene and Quaternary	10	7	9

Table 6 (continued)

Site no	Identification criteria	Evaluation of the criteria		
		Central parameters Maximum value: 16	*Additional parameters* Maximum value: 12	*Use and management parameters* Maximum value: 15
10	- Site name: Laatchana Cirque - Geographic coordinates: 33°29′58.6 ″N 3°53′30.0 ″W - Site classification: glacial - Site description: Laatchana Cirque is a majestic glacier cirque characterized by its horseshoe shape (Fig. 8B,C,D), its kilometric dimensions (about 7 km in diameter), and its valley with a flat bottom. It is the most imposing of all the Middle Atlas glacial cirques, whose very steep cavity presents slopes topped by dolomite and limestone cliffs. Laatchana Cirque is an arid area with no crops due to the water lack (Laatchana means the dry area in Arabic)	12	11	11
11	- Site name: Rawyana Cirque - Geographic coordinates: 33°34′15.5″N 3°48′49.8″W - Site classification: glacial - Site description: a glacier cirque oriented E-W, located to the East of Jbel Bou Naceur, presents the same morphological forms as the Laatchana Cirque but with smaller dimensions. It is characterized by a watercourse (Assif Beni Ouriach) where water flows during a large part of the year (Rawyana means wet in Arabic). The bottom marly of this cirque is very dissected by erosion	9	10	7

the preliminary list (Fig. 6). These sites were selected for their scientific, educational, and geotouristic importance.

Specific Evaluation

The 22 selected sites were divided into geosites (Table 5) and geomorphosites (Table 6). We prepared an identification sheet and a complete evaluation for each site using the parameters and scores listed in Table 1. The maximum value of the basic parameters is 16. We chose a threshold of 11; an arbitrary value chosen by considering the overall scores of the different sites studied. This value allowed us to select those characterized by interesting integrity and attractive representativeness among the many sites inventoried. After evaluation, eight geosites and four geomorphosites had a core parameter score greater than 11. They were selected for inclusion in the inventory and quantitative evaluation based on their rarity, scientific, educational, and geotouristic relevance, and their high core parameter score that indicates their relevance. The two geosites eliminated are the salt mine (geosite 4) and the sauropod footprints (geosite 9). The salt mine has a score of 12 (Table 5), but had to be eliminated due to lack of safety. It needs to be developed to make it accessible. With a score of 11 (Table 5), the site of the sauropod footprints was removed because of its fragility due to its location in the Aït Hassane valley, where water erosion is very severe.

Quantitative Evaluation

The ten selected sites were evaluated quantitatively (Table 7 and Fig. 11). We note that the different sites often have a very high scientific value ranging from 72.5 to 97.5%. On the other hand, their educational, geotouristic, ecological, aesthetic, and cultural values are low to high. In addition, the risk of degradation is low for most sites. This risk is mainly related to natural phenomena, while the human risk is almost negligible since the sites are located in sparsely populated and rarely visited regions. The main anthropic degradation factors of sites could be: (i) illegal exploitation of natural resources, (ii) irrational use of fresh and thermal water sources, (iii) plundering and illicit traffic of fossils (ammonites, dinosaur bones, etc.), (iv) irresponsible tourism, etc. Those factors affecting and damaging sites. To preserve the integrity of this geoheritage, some measures are necessary such as: (i) the sensitization of the residents about the importance of their geoheritage, (ii) the impact study before any development project, and (iii) the mobilization of scientists, NGOs, and public authorities to create modes of conservation (natural reserves, museum, etc.).

The results obtained allow rapid identification of the values of each geoheritage site, their suitability to promote their exploitation, and the prediction of their degradation risks. In addition, these results also facilitate the selection of areas that require improvement in exploitation potential, geoconservation, and basic infrastructure development.

We have chosen to present two sites, one geosite and one geomorphosite, which have received the best ratings, namely Jbel Bou Naceur and Tsiouant Canyons. The Jbel Bou Naceur geosite has very interesting scores for most of the values, except for the moderate geotouristic value, although the site has a very high aesthetic value

Fig. 9 Some of geomorphosites: **A** panoramic view of Jbel Tsiouant anticline; **B** Tsiounat village near the canyons entry; **C** south-eastern bank of Jbel Tsiouant anticline showing the variation of the layer dip towards the plain; **D** waterfall in Tsiouant canyons; **E** Tsiouant Canyons through the Dogger limestones and dolomites verticalized and folded; **F** Tsiwouant Alluvial fan above the sub-verticals Tertiary layers (So: sedimentary stratification, D: erosional unconformity)

(Table 8). This is due to the lack of basic infrastructure such as roads, reception structures, trail development, marking, and security. However, the risk of degradation is very low. Thus, existing trails in the region could integrate this site considering prior development as it is not vulnerable to this activity.

The second example is Tsiouant Canyons (Table 9). It has high to medium scores for most values, except for the ecological value which is low. Despite the lack of infrastructure, the site can be considered usable due to its proximity to the Tsiouant village, where the local population has made some arrangements to make the gorges accessible and safer. The Amazigh population of this region offers accommodation in host families, so that one can get to know the traditions and local gastronomy.

Discussion

The Bou Naceur ridge constitutes a very rich heritage region where various and remarkable natural monuments are mixed. It is observed both in geological and geomorphological sites which have required the development of an inventory and a comprehensive assessment of the various values. This approach aims to provide a tool for environmental management and use in a geoconservation context.

Several research works have highlighted the importance of geoheritage site inventories as a tool for environmental management (Santos-González and Marco-Reguero 2019; Santos et al 2020). This requires the development of reliable methodology that can be applied to all types of geoheritage

Fig. 10 Geomorphological units of Aït Hassane Valley. **A** Oulad Ali Village on the two banks of Chag Lard Wadi; **B** one of Ksar El Kbir Waterfalls; **C** panoramic view of the Aït Hassane village hanging on the slope within agricultural terrasses; **D** Chag Lard Canyons through Tertiary continental siltstones

sites and easily interpreted. In this sense, we have developed a new assessment method resulting from merging two methodologies, those of Brilha (2016) and Santos et al. (2020) which we have modified and adapted to our approach. The modifications made concern the addition and deletion of some evaluation criteria, the classification and weighting,

Table 7 Quantitative evaluation results of the scientific, educational, touristic, ecological, cultural, and aesthetic values and the degradation risk of the selected sites

Type of sites	Name of sites	Scientific value	Educational value	Geotouristic value	Ecological value	Cultural value	Aesthetic value	Degradation risk
Geosite	Tittaouine Spring	72.5%	75%	60.25%	25%	75%	72.5%	47.5%
Geosite	Tittaouine Diapir	86.25%	70%	48.75%	25%	0%	57.5%	20%
Geosite	Ighzer Izelfane Fossils	78.75%	57.5%	36.25%	25%	0%	50%	27.5%
Geosite	Izelfane Fault	80%	67.5%	43.75%	50%	50%	80%	17.5%
Geosite	Jbel Bou Naceur	97.5%	72.5%	56.25%	75%	75%	92.5%	17.5%
Geosite	Jbel Aghanja's Fold	80%	61.25%	41.25%	25%	50%	90%	17.5%
Geomorphosite	Tsiouant Canyons	86.25%	75.25%	66.25%	25%	75%	60%	35%
Geomorphosite	Aït Hassane Valley	76.25%	75%	70%	50%	75%	90%	27.5%
Geomorphosite	Laatchana Cirque	86.25%	71.25%	56.25%	75%	75%	90%	27.5%
Geomorphosite	Ifri Ismegh Cave	76.25%	52.5%	45%	25%	50%	57.5%	20%

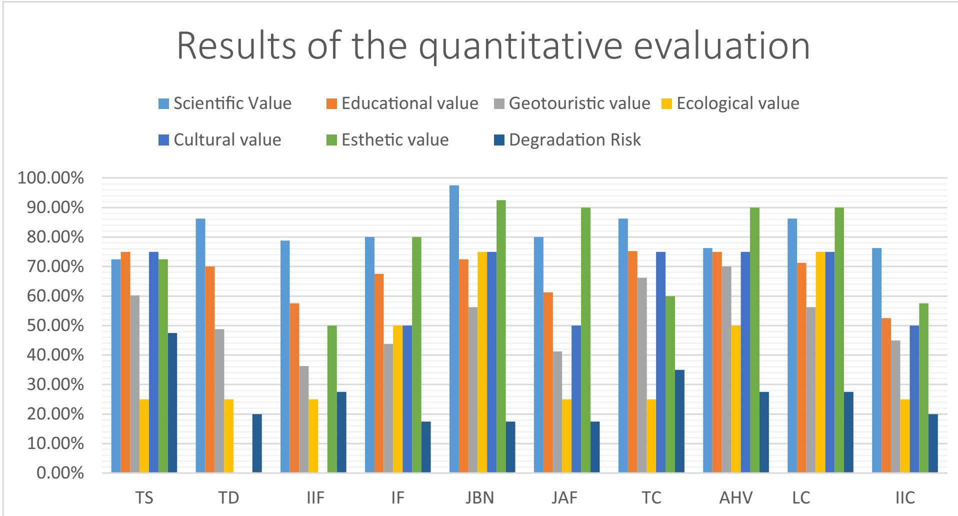


Fig. 11 Graphical representation of the results of the scientific, educational, geotouristic, ecological, cultural, and aesthetic values and the degradation risk of the sites. TS, Tittaouine Spring; TD, Tittaouine Diapir; IIF, Ighzer Izelfane Fossils; IF, Izelfane Fault; JBN, Jbel Bou Naceur; JAF, Jbel Aghanja's Fold; TC, Tsiouant Canyons; AHV, Aït Hassane Valley; LC, Laatchana Cirque; IIC, Ifri Ismegh Cave

and the integration of the specific evaluation step in the evaluation process.

In the preliminary assessment, we added the delineation of the study area as a criterion that allowed us to work in a well-delineated area to conduct a better field study. This study allowed us to identify sites of geological and geomorphological interests since geosites and geomorphosites do not have the same geological value. Geosites illustrate the region's geological history such as paleontology, stratigraphy, and tectonics, while geomorphosites illustrate landforms and the role of erosion in shaping the landscape. For this reason, it was necessary to add another step to the evaluation process. It is the specific assessment whose main objective is to distinguish the geosites from the geomorphosites since they do not have the same geological values.

For the quantitative evaluation, we merged the methods of Brilha (2016) and Santos et al. (2020) and used the same weights for all criteria. Furthermore, we decided to independently evaluate the additional values, namely ecological, cultural, and aesthetic values, and reporting them in the final results. Many geoheritage sites have very high ecological value. Linking geodiversity to biodiversity is therefore crucial to improve conservation efforts (Matthews 2014; Santos et al. 2020). Similarly, most sites have interesting cultural values that can be essential for enhancing geotourism (Pralong 2005; Coratza et al. 2016; Santos et al. 2020). Also, aesthetic value has an important role in promoting geotourism. It is the most important factor in attracting visitors (Santos et al. 2020). Finally, the degradation risk assessment parameters are developed according to the risks in our study area. Therefore, to promote geoconservation and responsible geotourism in a region, it is necessary to conduct a comprehensive site assessment to obtain more reliability and a better result.

The specific evaluation was applied to the 22 selected sites. This allowed us to create two tables (Tables 5 and 6), one for the geosites and the other for the geomorphosites. Thus, ten sites were selected for quantitative evaluation (Table 7) after we selected a threshold of 11 out of 16 to evaluate the central parameters. The elimination of the other sites from the quantitative assessment does not mean that they have no scientific, educational, geotouristic, ecological, aesthetic, and/or cultural values. However, it does mean that they are less representative, have average geological or geomorphological interest, or are simply not rare in the region.

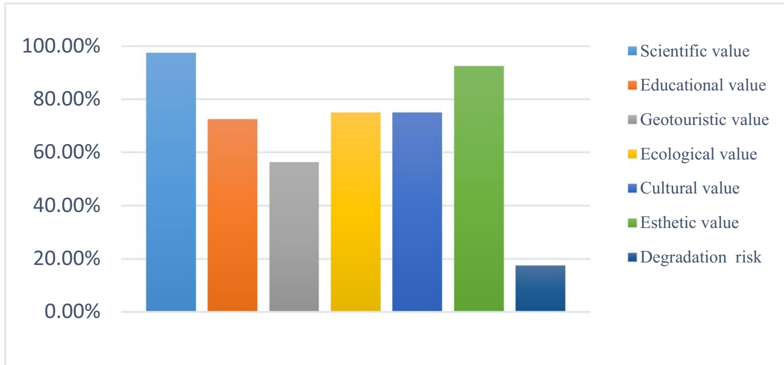
The value of the use parameters is higher than 11 for most of the selected sites (Tables 5 and 6), which now guarantees their use, except four sites. These are one geomorphosite and three geosites. The geomorphosite Ifri Ismegh needs to be developed to make it accessible to the public. The three geosites are the Diapir of Tsiouant, which is fragile and low visibility, Jbel Aghanja, and Jbel Bou Naceur's folds whose access is difficult and less secure.

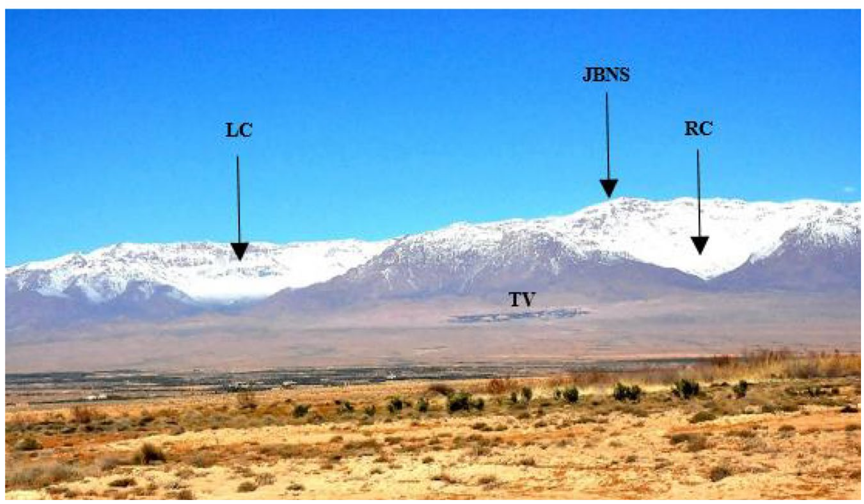
The ten sites assessed quantitatively have a scientific value more than 70%, reflecting the geological and geomorphological interests of the study area (Fig. 12). These sites have a relatively high educational value, except for two sites that are difficult to access. The lack of basic infrastructure and remoteness from major cities affect the geotouristic value, which remains low for most studied sites. The same is true for ecological value, which is severely compromised by the region's semi-arid climate and the irrational use of natural resources. The important values that attract a large public, namely the cultural and aesthetic values, are good. The risk factors for degradation of most of the sites are low as there are no significant

Table 8 Full description of the Bou Naceur geosite

Evaluation results	
identification	Site type: geosite Name: Jbel Bou Naceur Locality: Southern Middle Atlas Geographical coordinates : 33°34'14.7 "N 3°53'16.8 "W Altitude: 3326 m.
Classification	Structural.
Geological and/or geomorphological interest	The majestic Jbel Bou Naceur is located in the south-eastern frontal zone of the Middle Atlas, coinciding with the transit zone of the South Middle Atlas Fault (SMAF. It is the highest peak of the Middle Atlas and forms a natural barrier dominating the Middle Moulouya plain. It is characterized by the presence of the most beautiful glacial cirques whose heart is occupied by the marls of the Upper Liassic, while the limestones and dolomites of the Dogger form the walls. The Dogger occurs in this region under two facies: the dolomitic facies of the High Plateaus and the marl-limestone facies of the Folded Middle Atlas.
Associated interests	**Ecological and biological interest:** Jbel Bou Naceur is considered as Site of Biological and Ecological Interest. (*SIBE*). It is characterized by a remarkable endemic floristic diversity, including *Artemisia flahaultii Emb*. (Rhanem 2018). The main vegetation units characterizing the Jbel Bou Naceur according to the bioclimatic stage include the Esparto Steppes covering the foothills of the massif, the matorrals, the Tetraclinaie, the Red Juniper, the Rahallaisse, the Aleppo Pine Forest, the Maritime Pine Forest, the Buxaie, the Green Oak Forest, the Cedar Forest and the Thuriferous Xerophytes that cover the summits of the massif (Rahou 1996). There is also a characteristic residual fauna and several species of birds. **Cultural interest:** despite the physical factors, such as the high summit, the steep slope, and the cold, which limit the human presence, the site represents a landscape unit of the typical Middle Atlas rural habitat. The building architecture, the local products, and the ancestral construction technique increase the site's cultural value (Obda et al. 2009).
Use and management	**Accessibility:** the site can be reached from several villages, such as the Oulad Ali village and the Tirnest village, etc. There is no bus or taxi station. It can only be reached by organized trips from the larger towns or on your own. **Safety:** Due to snow storms, access to the site is difficult, especially in the fall and winter months. **Basic infrastructure:** the site is accessible from the Oulad Ali village, where is two average quality hotels. The nearest town with accommodation and transport facilities is Missour, the distance between the site and this town is approximately 80 km. **Visibility:** the site has excellent visibility given its high altitude. **Integrity and protection status:** the site is marked by a protected area: Site of Biological and Ecological Interest (*SIBE*). **Fragility and vulnerability**: there are no significant factors that could increase the fragility and natural vulnerability of the site. However, the unreasonable use of the site's biological resources (collection of medicinal and aromatic plants) may reduce its ecological value. Thus, climate change may disrupt the bioclimatic stage of vegetation that characterizes the site. **Landscape:** the site offers the opportunity to enjoy various landscapes. **Recommended season to visit:** the site can be visited at any season of the year, but in winter, be careful not to get trapped by the snow storms. **Activities that can promote the site**: mountaineering, skating, parachuting, paraglider, hang-gliding and hiking.

Table 8 (continued)

<table>
<tr>
<td>Quantitative evaluation</td>
<td>


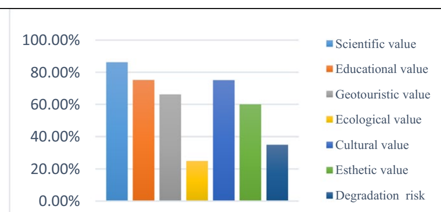
</td>
</tr>
<tr>
<td>Photos
References</td>
<td>
Delcaillau B, Laville E, Carozza J-M, Dugué O, Charroud M, Amrhar M (2007) Morphotectonic evolution of the Jebel Bou Naceur in the South Middle Atlas Fault Zone (Morocco). Comptes Rendus Geoscience 339, 553-561.
Obda K, Akdim B, Tribak A, Lopez Lara E, Miranda Bonilla J (2009) Les unités écopaysagères de l'habitat rural du Moyen Atlas septentrional : un patrimoine à valoriser. Geomaghreb 5, 113–122.
Rahou A (1996) Aperçu sur le climat et la végétation de Bou Naceur (Moyen-Atlas oriental, Maroc). Bull. Inst. Sci., Rabat, 20, 113-122.
Rhanem M (2018) Le versant sud du Jbel Bou-Naceur, un refuge insolite réunissant Juniperus communis L. et Artemisia flahaultii Emb. & Maire d'une haute signification biogéographique et écologique au Maroc – Evaxiana 4, 5-18.


Jbel Bou Naceur covered with snow in Winter in contrast with the aridity of the Middle Moulouya plain. JBNS : Jbel Bou Naceur Sommit, LC : Laatchana Cirque ; RC : Rawyana Cirque, TV : Tirnest village.
</td>
</tr>
</table>

factors that could increase the fragility and vulnerability of the sites. The site of the Tittaouine spring, the only water source supplying the two villages of Tsiouant downstream, has a moderate degradation risk due to its easy accessibility.

Based on the results obtained, we believe that the methodology used is perfectly applicable to geosites and geomorphosites, regardless of their characterization. Moreover, the geodiversity of the region can now be used for scientific, educational, and geotouristic purposes.

Table 9 Full description of Tsiouant Canyons geomorphosite

Evaluation results	
identification	Site type: geomorphosite Name : Tsiouant Canyons Locality: Southeastern Middle Atlas Geographical coordinates : 33°21'38.3"N 4°00'48.9"W Altitude: 1850 m
Classification	fluvial.
Geological and/or geomorphological interest	The Tsiouant canyons extend for about 2 km between the Tsiouant village and the salt mine. The gorge is about 140 m deep and only 1.5 m wide in some sections. Large boulders brought by floods and stuck in the narrow parts of the canyon create small waterfalls. You can follow a natural geological "section" in the limestones and dolomites of the Liassic and Dogger along the canyon. The facies are very diversified and include varied marine fauna (brachiopods, lamellibranchs, ammonites, etc.).
Associated interests	**Cultural interest:** The canyons represented the main passage connecting the Tsiouant village to Tittaouine spring, Izelfane village, and Jbel Tmatert, before the construction of the present road linking these places.
Use and management	**Accessibility:** the site is accessible from the Tsiouant village which you can reach by taxi from Outat El Haj, Imouzzer Marmoucha, or Missour. **Safety:** no major risks. **Basic infrastructure:** Missour is the closest city where hotels are available. There is no accommodation in Tsiouant. The nearest is about 25 km away in the Oulad Ali village (two average quality hostels) and in Missour (a few hotels) about 62 km away. **Visibility:** the existing landforms in the area affect the site's visibility. **Integrity and protection status:** the site is well preserved. There is no legal protection (parks, laws, etc.), but the local population contributes to its protection. **Fragility and vulnerability:** the process of fluvial erosion and the slippage of massive scree slopes may affect the aesthetic value of the site, but they cannot be considered as major factors that may increase its degradation. **Landscape:** the site offers the opportunity to enjoy unique and authentic landscapes. **Recommended season to visit:** summer and spring seasons. It is not recommended to visit the site during the winter and autumn seasons and afternoons to avoid possible flooding due to storms. **Activities that can promote the site:** hiking and mountaineering.
Quantitative evaluation	
Photos **References**	Laville E, Delcaillau B, Charroud M, Dugué O, Ait Brahim L, Cattaneo G, Deluca P, Bouazza A (2007) The Plio-Pleistocene evolution of the Southern Middle Atlas Fault Zone (SMAFZ) front of Morocco, Int. J. Earth Sci. 96 (3), 497–515. Termier H (1936) Recherches Géologiques sur le Maroc septentrional et le Moyen Atlas occidental. Notes et Mémoires du Service des Mines et de la Carte Géologique du Maroc, N° 33, 2 tomes. 

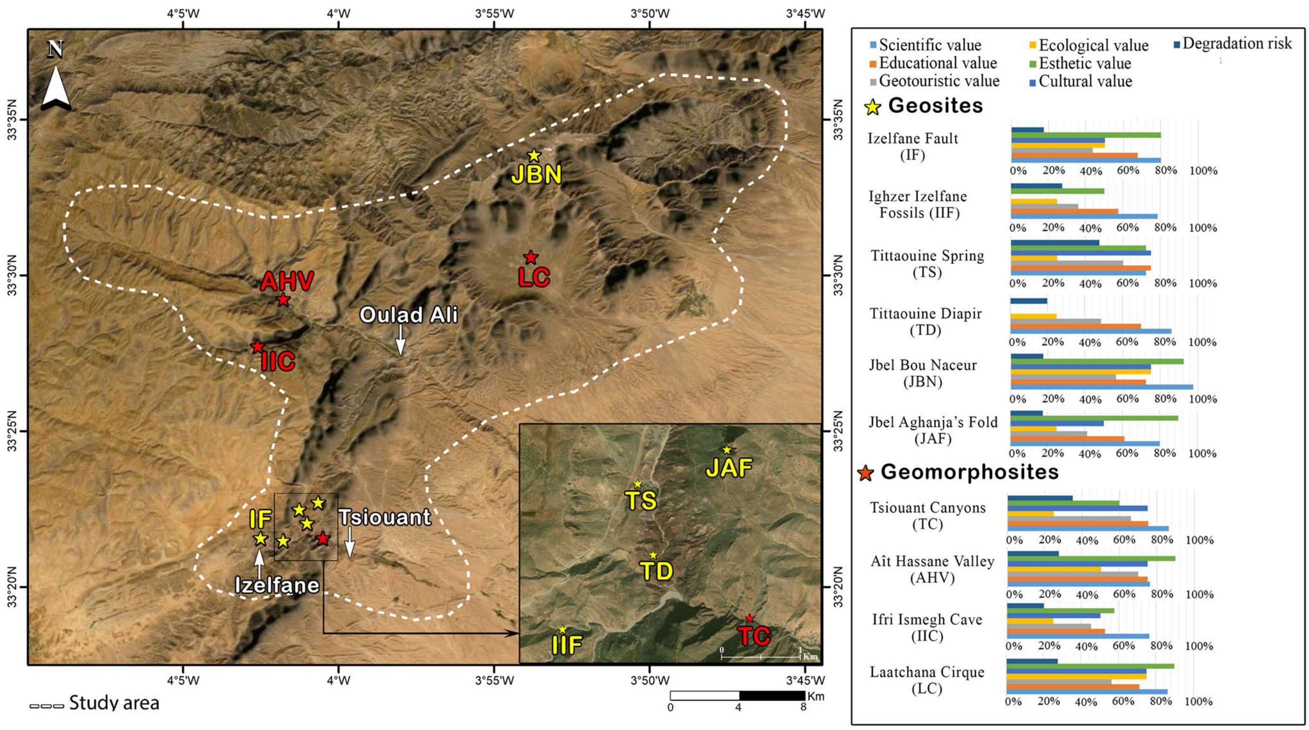


Fig. 12 Representation of the study area, the location of the selected sites, the results of the scientific, educational, geotouristic, ecological, cultural, aesthetic values, and the degradation risk of the sites

Conclusion

The frontal zone of the south-eastern Middle Atlas is a natural barrier dominating the Middle Moulouya plain. It corresponds to the southernmost and highest anticlinal ridge of the Middle Atlas, with the famous Jbel Bou Naceur, the highest peak of the chain, that culminating at 3326 m. This territory is characterized by an important number of geosites and geomorphosites in a good state of conservation, which can be used as valuable resources for local economic development.

This study is the first inventory of geological and geomorphological sites in the surroundings of Jbel Bou Naceur that are of scientific, educational, and/or geotouristic interests. The aim is to provide managers and decision-makers with a tool to support the geoconservation and protection of the geoheritage and its use for sustainable socio-economic development. This equation can be achieved by promoting responsible geotourism and proposing geo-educational and geotourism tours.

The various geosites and geomorphosites identified are classified and evaluated using two recent evaluation procedures modified and adapted to our approach. Most sites have an important scientific value and several additional values: (i) an educational value; (ii) a geotouristic value; (iii) an ecological, aesthetic, and/or cultural value.

This evaluation procedure was conducted in three phases: preliminary, specific, and quantitative. The first phase involved the collection of bibliographic data and a field study. In this way, we identified 22 sites of geological and geomorphological interests. The second step is dedicated to the specific evaluation. Following this step, we elaborated two lists, one for geosites and one for geomorphosites. The different sites were identified and evaluated according to parameters and scores that determine the relevance of each site. Only sites with high scores were selected. The third and final step involves the quantitative evaluation of the selected geosites and geomorphosites. This leads to an assessment of their scientific, educational, geotouristic, ecological, cultural, and aesthetic value, as well as their degree of degradation.

This study reveals that the Bou Naceur region has a very rich geological and geomorphological heritage. Most of the sites studied have significant scientific value and additional multiple educational, geotouristic, ecological, aesthetic, and/or cultural values. However, due to the isolation of this area and its distance from urban centers, this natural and cultural heritage remains unknown to the general public. Great efforts are needed to develop and promote all these values. The rehabilitation of basic infrastructure, the signposting of roads, and the marking of trails are important measures to ensure the welcome and safety of visitors. The conservation of this heritage requires a multidisciplinary study to identify its assets and vulnerability. The use of this heritage in the development of responsible geotourism can only benefit the whole region in terms of job creation and income diversification. To meet this challenge, efforts must be made in infrastructure, particularly roads and accommodation.

In this context, the present work contributes to the conservation of this rich geodiversity, which could be useful for the future project of a Geopark that the national and regional authorities consider establishing in the Middle Atlas.

Acknowledgements We gratefully acknowledge Professor Moha Ikenne from the Ibnou Zohr University and the Reviewer 2 for reviewing our work and we greatly appreciate their constructive and helpful comments that allowed us to improve our manuscript. We would like sincerely to express our thanks to Professor André Charrière from the Toulouse University for his attentive proofreading of our manuscript and his precious advices.

Declarations

Competing Interests The authors declare no competing interests.

References

Abdelmounji A, El Hassani El Amrani I, Remmal T, El Kamel F, Van Wyk de Vries B, Boivin P (2019) Geomorphological classification and landforms inventory of the Middle-Atlas volcanic province (Morocco): scientific value and educational potential. Quaest Geogr 38:107–129. https://doi.org/10.2478/quageo-2019-0010

Ait Omar T, Taïbi A N, Hannani M, Khalki Y (2019) Géomorphosite karstique d'Ain Asserdoune, Atlas de Béni Mellal (Maroc) : inventaire, évaluation et mesures de durabilité. Journal International des Géosciences et de l'Environnement, dynamique environnementale, p 249–255. https://doi.org/10.4000/dynenviron.4604

Aoulad-Sidi-Mhend A, Maaté A, Amri I, Hlila R, Chakiri S, Maaté S, Martín-Martín M (2019) The geological heritage of the Talassemtane National Park and the Ghomara coast natural area (NW of Morocco). Geoheritage 11(3):1005–1025. https://doi.org/10.1007/s12371-019-00347-4

Arrad TY, Errami E, Ennih N (2018) From scientific inventory to socio-economic sustainable development: Tidzi Diapir geosite (Essaouira basin, Morocco). J Chem Biol Phys Sci 9(1):1–17

Arrad TY, Errami E, Ennih N, Ouajhain B, Bouaouda MS (2020) From geoheritage inventory to geoeducation and geotourism implications: insight from Jbel Amsittene (Essaouira province, Morocco). J A Earth Sci 161:103656. https://doi.org/10.1016/j.jafrearsci.2019.103656

Baadi K, Sabaoui A, Tekiout B (2020) Methodological proposal for assessment geosites: its application in Bou-Iblane region (Middle Atlas, Morocco). Geoheritage 12:55. https://doi.org/10.1007/s12371-020-00476-1

Baadi K, Amine A, Tefogoum GZ, Sabaoui A, Tekiout B (2021) Volcanic geosites assessment in the Plio-Quaternary Azrou-Timahdite Plateau (Middle Atlas, Morocco). J A Earth Sci 184:104352. https://doi.org/10.1016/j.jafrearsci.2021.104352

Beauchamp W, Barazangi M, Demnati A, El Alji M (1996) Intracontinental rifting and inversion: Missour Basin and Atlas Mountains, Morocco. AAPG Bull 80:1459–1482

Benlamine LK (2017) Les monuments funéraires de la région de Boulemane: situation géographique, architecture et rites funéraires. Thèse de doctorat, Univ. Sidi Mohamed Ben Abdallah, Fès, 183 p., inédite.

Benlamine L, Benabdelhadi M, Oujaa A, Gourari L, Fontugne M (2015) Etude anthropologique et comparative des mandibules humaines de la Cité des Pierres (Moyen Atlas) à celles de Taforalt. Eur Sci J Eur Sci Inst 11(17):369–388. ⟨hal-02504857⟩

Benshili K, (1989) Lias- dogger du Moyen Atlas plissé (Maroc). Sédimentologie, biostratigraphi et évolution paléogéographique. Thèse Doctorat Etat, Univ Claude-Bernard, Lyon 1:285 p.

Beraaouz M, Macadam J, Bouchaou L, Ikenne M, Ernst R, Tagma T, Masrour M (2019) An inventory of geoheritage sites in the Draa Valley (Morocco): a contribution to promotion of Geotourism and sustainable development. Geoheritage 11(2):241–255. https://doi.org/10.1007/s12371-017-0256-x

Berred S, Fadli D, Berred K (2019) Aerial interference of Hercynian folds and their morphological peculiarities in the Bani Geopark of southern Morocco. Arab J Geosci 12:351. https://doi.org/10.1007/s12517-019-4537-3

Berred S, Fadli D, El Wartiti M et al (2019) Geomorphosites of the semiarid Tata region: valorisation of an unknown geoheritage for geotourism sustainable development (Anti-Atlas, South Morocco). Geoheritage 11:1989–2004. https://doi.org/10.1007/s12371-019-00414-w

Berred S, Fadli D, Gregorio FD, Berred K (2020) Geological and landscape particularities of Issafen-style chevron pattern in Tata region (anti-Atlas, South Morocco). Arab J Geosci 13:689. https://doi.org/10.1007/s12517-020-05713-z

Berred S, Berred K, Fadli D (2022) Geodiversity of Morocco kingdom: Tata province geomorphosites inventory for creating a geopark project (anti-Atlas). Int J Geoheritage Parks 10(3):367–382. https://doi.org/10.1016/j.ijgeop.2022.07.001

Bouzekraoui H, Barakat A, Touhami F, Mouaddine A, El Youssi M (2018) Inventory and assessment of geomorphosites for geotourism development: a case study of Aït Bou Oulli Valley (central highatlas, Morocco). Area 50(3):331–343. https://doi.org/10.1111/area.12380

Bouzekraoui H, Barakat A, Elyoussi M, Touhami F, Mouaddine A, Hafid A, Zwoliński ZB (2018a) Mapping geosites as gateways to the geotourism management in Central High-Atlas (Morocco). Quaestiones Geographicae 37(1), Bogucki Wydawnictwo Naukowe, Poznań, 87–102. https://doi.org/10.2478/quageo-2018-0007

Brilha J (2015) Concept of geoconservation. In: Tiess G, Majumder T, Cameron P (Eds.), Encyclopedia of Mineral and Energy Policy. Springer-Verlag, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-40871-7_2-1.2p

Brilha J (2016) Inventory and quantitative assessment of geosites and geodiversity sites: a review. Geoheritage 8:119–134. https://doi.org/10.1007/s12371-014-0139-3

Brilha J (2018) Geoheritage: inventories and evaluation. In: Geoheritage. Assessment, protection and management, E. REYNARD et J. BRILHA édit., Édit. Elsevier, Amsterdam, 67–86. https://doi.org/10.1016/B978-0-12-809531-7.00004-6

Charrière A (1990) Héritage hercynien et évolution géodynamique alpine d'une chaîne intracontinentale : le Moyen Atlas au SE de Fès (Maroc), Unpubl Doct Etat thesis, Univ Paul-Sabatier Toulouse, p 589

Charrière A, Ouarhache D, El-Arabi H (2011) Le Moyen Atlas. Notes et Mém. Serv. Géol. Maroc 559, 11–108. In Nouveaux Guides géologiques et miniers du Maroc / New Geological and Mining Guide books of Morocco, Michard A, Saddiqi O, Chalouan A, Rjimati E, Mouttaqi A (Eds), Notes et Mémoires du Service géologique du Maroc, 2011, n^{os} 556–564.

Colo G (1962) Contribution à l'étude du Moyen-Atlas septentrional. Notes. Mém. Serv. Géol. Maroc, Rabat, n°139:226.

Coratza P, Gauci R, Schembri J, Soldati M, Tonelli D (2016) Bridging natural and cultural values of sites with outstanding scenery: evidence from Gozo Maltese Islands. Geoheritage 8(1):91–103. https://doi.org/10.1007/s12371-015-0167-7

De Waele J, Melis MT (2008) Geomorphology and geomorphological heritage of the Ifrane-Azrou region (Middle Atlas, Morocco). Environ Geol 55:587–599. https://doi.org/10.1007/s00254-008-1533-4

Delcaillau B, Laville E, Carozza J-M, Dugué O (2007) Charroud M (2007) Morphotectonic evolution of the Jebel Bou Naceur in the South Middle Atlas Fault Zone (Morocco). Comptes Rendus Géoscience, Elsevier Masson 339(8):553–561. https://doi.org/10.1016/j.crte.2007.06.005

Dresch J, Raynal R (1953) Les formes glaciaires et periglaciaires dans le Moyen Atlas. Compte Rendu Sommaire des Séances de la Société Géologique de France 11–12:195–197

Du Dresnay R (1963) - Données stratigraphiques complémentaires sur le Jurassique moyen des synclinaux d'El Mers et de Skoura (Moyen-Atlas, Maroc). Bull Soc Geol de France, Paris,5(7):883–900. https://doi.org/10.2113/gssgfbull.S7-V.6.883

Du Dresnay R (1988) Recent data on geology of the Middle Atlas (Morocco). In: Jacobshagen V (ed) The Atlas system of Morocco. Springer, Berlin Heidelberg New York, pp 293–320

Eddif A, Ouazzani H, Sadkaoui I, Tajdi A, Aghbal A, Hamid A (2018) La chaîne volcanique du Moyen Atlas au Maroc: patrimoine géologique encore peu connu. Int J Innov Appl Stud 24(1):117–129

Eddif E, Selmaoui S, Chakour R (2018) Images of Moroccan geological heritage in life and earth sciences textbooks of second year college from 2004 to 2017: case of the volcanic chain of the Middle Atlas. J Educ Soc Behav Sci 28(2):1–11. https://doi.org/10.9734/jesbs/2018/45256

El Arabi H (2001) La plateforme carbonatée jurassique (Héttangien ? - Aalénien) du Moyen Atlas occidental (Maroc), zone de transition entre le sillon moyen atlasique et le bassin occidental du Selloum. Unpublished Thesis (Thèse Doctorat d'Etat). Sidi Mohamed Ben Abdellah University, Fès, Morocco, p 294

El Wartiti M, Zahraoui M, El Hassani A (2017) Les marqueurs permiens comme patrimoine géologique à promouvoir et à protéger dans le massif hercynien du Maroc central. Société Géologique De France 194:118–126

El Wartiti M, Malaki A, Zahraoui M, Di Gregorio F, De Waele J (2009) Geosites and touristic development of the north-western Tabular Middle Atlas of Morocco. In: Marini A (ed) Proceedings of desertification and risk analysis using high and medium resolution satellite data. Springer Netherlands:Toze ur Tunesia pp 143–159

Fedan B (1988) Evolution géodynamique d'un bassin intraplaque sur décrochement. Thèse de Doctorat Es-Sciences, Université Bordeaux I, Le Moyen Atlas durant le Méso-Cénozoïque, p 480

François A (2012) Redécouverte d'*Uromenus trochleatus* Chopard, 1937 dans le Moyen Atlas marocain (Orthoptera : Tettigoniidae). Bulletin De L'institut Scientifique, Rabat, Section Sciences De La Vie, No 34(1):19–22

Gomez F, Barazangi M, Bensaïd M (1996) Active tectonism in the intracontinental Middle Atlas Mountains of Morocco: synchronous crustal shortening and extension. J Geol Soc London 153:389–402. https://doi.org/10.1144/gsjgs.153.3.0389

Hollard H, Choubert G, Bronner G, Marchand J, Sougy J (1985) Carte géologique du Maroc, scale 1: 1,000,000. Serv. Carte géol. Maroc, 260(2).

Hughes P D, Gibbard P L, Woodward J C (2004) Quaternary glaciation in the Atlas Mountains of North Africa. Quatemary glaciations — extent and chronology, part III, Editors J. Ehlers and P.L. Gibbard, 2004 Elsevier, 225–260. https://doi.org/10.1144/gsjgs.153.3.0389

Kharmich H, Sedreddine M, El Rharbi S (2019) Les matériaux de construction locaux, un appui pour une architecture contextuelle autosuffisante en énergie. Afr Mediterr J Archit Urban. https://doi.org/10.48399/IMIST.PRSM/amjau-v1i2.18794

Lahmidi S, Lagnaoui A, Berrada I, El Adnani A, Saadi M, Bahaj T (2021) The Ordovician Foum Larjamme Tunnel Paleo-valleys from Bani Geopark Project—assessment of geological heritage for geo-education and geotourism purposes. Geoheritage 13(4):1–22. https://doi.org/10.1007/s12371-021-00630-3

Lahmidi S, Lagnaoui A, El Adnani A, Berrada I, Saadi M, Bahaj T (2022) Integrating geological and archaeological heritage for conservation and promotion of Foum Larjamme Geosite from Bani Geopark Project South-Eastern Morocco. Geoheritage 14(3):1–20. https://doi.org/10.1007/s12371-022-00718-4

Lahmidi S, Lagnaoui A , Bahaja T, El Adnani A, Fadli D (2020) First inventory and assessment of the geoheritage of Zagora province from the project Bani Geopark (South-Eastern Morocco). Elsevier 511–527. https://doi.org/10.1016/j.pgeola.2020.05.002

Laville E, Delcaillau B, Charroud M, Dugué O, Ait Brahim L, Cattaneo G, Deluca P, Bouazza A (2007) The Plio-Pleistocene evolution of the Southern Middle Atlas Fault Zone (SMAFZ) front of Morocco. Int J Earth Sci 96(3):497–515. https://doi.org/10.1007/s00531-006-0113-7

Matthews TJ (2014) Integrating geoconservation and biodiversity conservation: theoretical foundations and conservation recommendations in a European Union context. Geoheritage 6(1):57–70. https://doi.org/10.1007/s12371-013-0092-6

Mehdioui S, El Hadi H, Tahiri A, Brilha J, El Haibi H, Tahiri M (2020) Inventory and quantitative assessment of geosites in Rabat-Tiflet region (North Western Morocco): preliminary study to evaluate the potential of the area to become a geopark. Geoheritage 12:1–17. https://doi.org/10.1007/s12371-020-00456-5

Mehdioui S, El Hadi H, Tahiri A, El Haibi H, Tahiri M, Zoraa N, Hamoud A (2022) The geoheritage of Northwestern Central Morocco Area: inventory and quantitative assessment of geosites for geoconservation, geotourism, geopark purpose and the support of sustainable development. Geoheritage 14(3):1–26. https://doi.org/10.1007/s12371-022-00712-w

Michard A, Saddiqi O, Chalouan A, de Lamotte D F (2008) Continental evolution: the geology of Morocco. Structure, stratigraphy, and tectonics of the Africa-Atlantic-Mediterranean triple junction. Springer-Verlag, Berlin Heidelberg 116, p 404. https://doi.org/10.1007/978-3-540-77076-3

Mounir S, Saoud N, Charroud M, Mounir K, Choukrad J (2019) The Middle Atlas geological karsts forms: towards geosites characterisation. IFP Energies Nouvelles 74:17. https://doi.org/10.2516/ogst/2018089

Mounir S, Saoud, N, Mounir K, Choukrad J, Berbeche A, Charroud, M (2021) The middle Atlas domain of Morocco: Geoheritage conservation allowing development in a sustainable manner. Proceedings of the 5th International Young Earth Scientists (YES) Congress "Rocking Earth's Future", 5th International Young Earth Scientists (YES) Congress "Rocking Earth's Future" (Berlin, Germany 2019), 24.https://doi.org/10.2312/yes19.24

Mountaj S, Remmal T, Lakroud K, Boivin P, El Amrani IEEH, El Kamel F, Jounaid MS, Amraoui F, Soufi M (2019) The volcanic field of the Middle Atlas Causse: highlights and heritage appropriation. Geogr Bull 60(2):127–147

Mucivuna V, Reynard E, Garcia M (2019) Geomorphosites assessment methods: comparative analysis and typology. Geoheritage 11:1–17. https://doi.org/10.1007/s12371-019-00394-x

Obda K, Akdim B, Tribak A, Lopez Lara E, Miranda Bonilla J (2009) Les unités écopaysagères de l'habitat rural du moyen Atlas Septentrional : un patrimoine à valoriser. Geomaghreb 5:113–122

Oukassou M, Boumir Kh, Benshili Kh, Ouarhache D, Lagnaoui A, Charrière A (2019) The Tichoukt massif: a Geotouristic Play in

the Folded Middle Atlas (Morocco). Geoheritage 11:371–379. https://doi.org/10.1007/s12371-018-0287-y
Pereira P, Pereira DI (2010) Methodological guidelines for geomorphosite assessment. Géom Relief Proc Environ 2:215–222. https://doi.org/10.4000/geomorphologie.7942
Pereira DI, Pereira P, Brilha J, Santos L (2013) Geodiversity assessment of Parana State (Brazil): an innovative approach. Environ Manag 52:541–552. https://doi.org/10.1007/s00267-013-0100-2
Pralong JP (2005) A method for assessing tourist potential and use of geomorphological sites. Geomorphol Relief Process Environ 3:189–195. https://doi.org/10.4000/geomorphologie.350
Rahou A (1996) Aperçu sur le climat et la végétation de Bou Naceur (Moyen-Atlas oriental, Maroc). Bull Inst Sci Rabat 20:113–122
Rais J, Barakat A, Louz E, Barka AA (2021) Geological heritage in the M'Goun geopark: a proposal of geo-itineraries around the Bine El Ouidane dam (Central High Atlas, Morocco). Int J Geoheritage Parks 9:242–263. https://doi.org/10.1016/j.ijgeop.2021.02.006
Raynal R (1952) Quelques exemples de l'action du froid et la neige sur les formes du relief au Maroc. Notes Marocaines 2:14–18
Raynal R (1961) Plaines et piémonts du bassin de la Moulouya (Maroc oriental): étude géomorphologique. Rabat, Imframar, Thèse doctorat, p 617
Raynal R, Dresch J, Joly F (1953) Deux exemples régionaux de glaciation quaternaire au Maroc: Haut Atlas Oriental, Moyen Atlas Septentrional. IV Congrès INQUA, Rome-Pisa, 65.
Reynard E (2005) Geomorphosites et paysages. Geomorphologie 3:181–188. https://doi.org/10.4000/geomorphologie.338
Reynard E, Fontana G, Kozlik L, Scapozza C (2007) A method for assessing "scientific" and "additional values" of geomorphosites. Geogr Helv 62:148–158. https://doi.org/10.5194/gh-62-148-2007
Reynard E (2009) Geomorphosites: definition and characteristics. In: Reynard E et al (eds) Geomorphosites. Verlag Pfeil, Munich, pp 51–63
Reynard E, Perret A, Bussard J, Grangier L, Martin S (2016) Integrated approach for the inventory and management of geomorphological heritage at the regional scale. Geoheritage 8:43–60. https://doi.org/10.1007/s12371-015-0153-0
Reynard E, Brilha J (2018) Geoheritage: a multidisciplinary and applied research topic. In: Reynard E, Brilha J (eds) Geoheritage: assessment, protection and management. Elsevier, Netherlands, pp 3–9. https://doi.org/10.1016/B978-0-12-809531-7.00030-7
Rhanem M (2018) Le versant sud du jbel Bou-Naceur, une refuge insolite réunissant *Juniperus communis* L. et *Artemisia flahaultii* Emb. & Maire d'une haute signification biogéographique et écologique au Maroc – *Evaxiana* 4:5–18.
Sabaoui A (1998) Rôle des inversions dans l'évolution Méso–Cénozoïques du Moyen Atlas septentrional (Maroc). L'exemple de la transversale El Menzel–Ribat El Khayr–Bou Iblane. PhD Thesis, Université Mohammed V Rabat, p 1–432
Sadki R, El Wartiti M, Azelmad R, Berred S (2016) Identification, Valorisation Et Protection Des Géomorphosites Pour Le Développement Du Géotourisme Intégré Dans La Région D'errachidia (Maroc). Int J Innov Appl Stud 19 N° 3, 784–793.
Sanchez JP, Brilha J (2017) Terrestrial impact structures as geoheritage: an assessment method of their scientific value and its application to Brazil. Ann Acad Bras Ciênc 89:825–834. https://doi.org/10.1590/0001-3765201720160081
Sani F, Zizi M, Bally A (2000) The Neogene-Quaternary evolution of the Guercif Basin (Morocco) reconstructed from seismic line interpretation. Mar Petroleum Geol 17(3):343–357. https://doi.org/10.1016/S0264-8172(99)00058-6
Santos DS, Mansur KL, Seoane JCS, Mucivuna VC, Reynard E (2020) Methodological proposal for the inventory and assessment of geomorphosites: an integrated approach focused on territorial management and geoconservation. Environ Manage 66(3):476–497. https://doi.org/10.1007/s00267-020-01324-2
Santos-González J, Marcos-Reguero A (2019) Applying the geological heritage in land management: cartography and management proposals of geosites in Burgos Province (Spain). Geoheritage 11(2):485–500. https://doi.org/10.1007/s12371-018-0301-4
Sellier D (2016) A deductive method for the selection of geomorphosites: application to Mont Ventoux (Provence, France). Geoheritage 8(1):15–29. https://doi.org/10.1007/s12371-015-0144-1
Termier H (1936) Recherches Géologiques sur le Maroc septentrional et le Moyen Atlas occidental. Notes et Mémoires du Service des mines et de la carte géologique du Maroc, N° 33:2 tomes.
Wimbledon WA (1999) Geosites: an International Union of Geological Sciences initiative to conserve our geological heritage. Polish Geol Inst Spec Papers 2:5–8
Wimbledon WA (2011) Geosites: a mechanism for protection, integrating national and international valuation of heritage sites. Geologia Dell'ambiente Supplemento N 2(2011):13–25
Wimbledon WAP, Smith-Meyer S (2012) Geoheritage in Europe and its conservation. ProGEO, Oslo
Wimbledon WA, Benton MJ, Bevins RE, Black GP, Bridgland DR, Cleal CJ, Cooper RG, May VJ (1995) The development of a methodology for the selection of British geological sites for geoconservation: part 1. Mod Geol 20:159–202
Zwoliński Z, Najwer A, Giradino M (2018) Methods for assessing geodiversity. In: Reynard, E., Brilha, J. (Eds.), Geoheritage: assessment, protection, and management. Elsevier, 27–52. https://doi.org/10.1016/B978-0-12-809531-7.00002-2

Springer Nature or its licensor holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.