INVENTORY AND ASSESSMENT OF GEOSITES AND GEODIVERSITY SITES OF THE AIT ATTAB SYNCLINE (M'GOUN UNESCO GEOPARK, MOROCCO) TO STIMULATE GEOCONSERVATION, GEOTOURISM AND SUSTAINABLE DEVELOPMENT

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Abstract: The Ait Attab syncline, in the southwestern part of the Moroccan Central High Atlas (CHA), is a vast basin characterised by an exceptional geodiversity illustrating the complete sedimentary series in the CHA. This series offers the opportunity to study regional palaeogeography, transgressive and regressive megasequences, Jurassic-Cretaceous volcanism and Atlas tectonics, and various fossils, including dinosaur footprints. The study area also harbours considerable landscape and cultural wealth that can play a significant role in sustainable geotourism and geoeducation development. To promote and protect this geoheritage wealth, the present work provides the first quantitative and qualitative inventory of geosites of interest by adopting Brilha's (2016) method. Thus, 3 geotrails covering 8 geosites and 11 geodiversity sites have been selected. The evaluation of these sites confirms their scientific and educational importance, which helps understand the geological, tectonic and palaeogeographical evolution of the Ait Attab syncline. The tourist value of these sites is also high, explained by the high interpretative potential of the geosites and their location as a gateway to the M'Goun Unesco geopark. The degradation risk assessment showed that most of these sites have a medium risk, except for palaeontological and magmatic sites, which have a high degradation risk.

Key words: inventory, assessment, geoheritage, geotrail, geoconservation, cultural heritage, Ait Attab

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Introduction

In recent years, the geoheritage concept has started to develop at the national level and has triggered a profound reflection on geoconservation, especially with the emergence of geosite inventory attempts by some Moroccan universities (Piqué, Bouabdelli 2000, Taj-Eddine, Pignone 2005, Pique et al. 2007, De Waele, Melis 2009, El Wartiti et al. 2009, Tahiri et al. 2010, El Hadi et al. 2011, Nahraoui et al. 2011, Zahra et al. 2011, Errami et al. 2012, Saddiqi et al. 2015, Bouzekraoui et al. 2018, Rais et al. 2021, Ait Barka et al. 2022, Louz et al. 2022). These studies

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often apply inventory and evaluation methodologies that aim to promote and enhance geoheritage (Coratza, Giusti 2005, De Wever et al. 2006, Ruban et al. 2010, Brilha 2016, Reynard et al. 2016, Henriques, Brilha 2017, Reynard et al. 2017, Ruban 2017, Bruschi, Coratza 2018, Zwoliński et al. 2018); but most of them focus only on sites of international importance, while other sites are neglected despite their regional and local importance. Concerning this, in 2004, geopark territories, with the assistance of UNESCO, launched the initiative of the geopark network as a method for the sustainable development of territories (Martini 2010, McKeever et al. 2010); they based their strategy on two main axes: geotourism as a means of socio-economic development and geoeducation as a tool for popularising geosciences. Thus, creating a geopark is conditioned by geosites and geodiversity sites with a high scientific tourist and educational value. These values are appreciated based on a precise quantitative evaluation to help the managers propose adequate geoconservation actions that will contribute to the territorial development.

The inventory is the most effective method to highlight the representative sites of the regional geological context; it is a way to diagnose the geodiversity quantitatively and qualitatively to preserve it as a memory of the earth and popularising it through educational and tourist activities. However, the inventory is just a first step that allows obtaining a broad knowledge of the territorial heritage potential and provides managers with a database to implement geoconservation measures. In this perspective, it is important to inventory sites of relevant scientific value (SV) and geosites of educational and touristic interest that constitute a means to disseminate the geoheritage and geoconservation concept to the local population. Therefore, it is necessary to differentiate between a geosite, a site of high SV, and a geodiversity site, which includes all sites of educational, touristic and cultural interest (Brilha 2016).

The Ait Attab syncline hosts a set of sites of sedimentological, palaeontological, karstic, geomorphological and magmatic interest of high heritage value that has been used for a long time as a fertile field for training courses and excursions organised by the Faculty of Science and Technology of Beni Mellal. This geodiversity is mainly due to the diversity of geological formations dating from the Triassic to the recent Quaternary, and to the succession of sedimentological, magmatic and structural phenomena over time. Despite its exceptional richness and the large number of scientific publications that have been made on its formations, this geoheritage has never been inventoried and has not benefitted from any structure of promotion and conservation, or even knowing that two panoramic views of this syncline are included to the M'Goun UNESCO geopark, but the municipalities of syncline are not included in the labelled geopark boundaries. Thus, they are considered satellite geosites (Hobléa et al. 2014). On the other hand, the hierarchical exploitation of geological formations (for road construction) risks, making a large part of the regional geopatrimony disappear. The lack of a legal status that ensures its protection and poor knowledge and management by the community and local authorities aggravate the problem. To fill this gap, this work aims to present the rich heritage of the Ait Attab syncline through an inventory made by a quantitative and qualitative assessment. The results of the evaluation provide a basis for proposing conservation and promotional measures according to the recommendations of UNESCO and Global Geoparks Network.

Study area

Geographical location

The Ait Attab syncline is located in Afourer Atlas near the northern edge between latitudes 32.10′N and 32.04′N. It includes three rural communes, Moulay Aissa Ben Driss, Tisqui and Taounza, which belong to Azilal province and Beni Mellal-Khenifra region (Fig. 1). The climate is Mediterranean, characterised by abundant rainfall during winter and spring, with an average of 494 mm/year (Ouchbani, Romane 1995, Salak et al. 2018). The study area belongs to the Atlantic floristic domain (Emberger 1928, 1939, Sauvage et al. 1952–1954) represented mainly by *Quercus ilex*, *Tetraclinis articulata*, *Juniperus phoenicea* and *Juniperus oxycedrus* in addition to *Euphorbia resinifera* and other secondary plant groups that constitute a favourable habitat for various animal species.

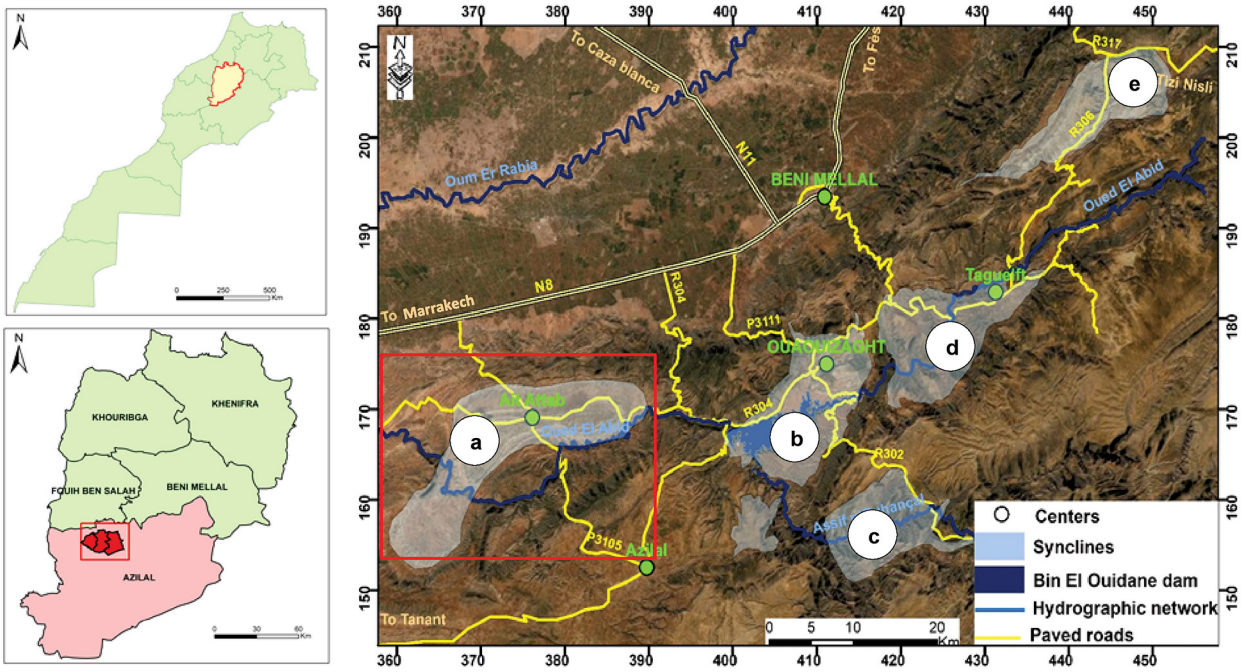

Fig. 1. Geographical location of Ait Attab syncline (study area).

Geological data

The Central High Atlas (CHA) is a large intracontinental chain trending ENE-WSW (Bensalah et al. 2013) derived from the convergence between Africa and Europe during the Cretaceous-Neogene (Ziegler et al. 1995, Moussaid et al. 2015). The rifting of the Triassic and Middle Jurassic gave rise to basins, seat of varied carbonate and detrital sedimentation (Ziegler et al. 1995, Souhel 1996, Laville et al. 2004, Haddoumi et al. 2010, Moussaid et al. 2015). During the Middle and Upper Jurassic, fracturing caused differential subsidence, resulting in flat-bottomed synclines. These received terrigenous sedimentation from the Upper Jurassic to the Cretaceous before the uplift of the Liassic anticlinal wrinkles (Souhel 1996, Löwner 2009). The Ait Attab syncline is one of the largest and most spectacular synclines in the Moroccan Central High Atlas (Couvreur 1988, Moussaid et al. 2015) (Fig. 1); it has a curved geometry formed by a sedimentary series considered the most complete in the CHA (Moussaid et al. 2015). This basin is bounded to the north by the Ait Imelloul syncline, to the south by the Ouzoud syncline and to the west by the Elkaria syncline. It is essentially filled with Jurassic-Cretaceous terrigenous (Fig. 2). The Triassic outcrops at the major accidents of the northern edge of the Beni-Mellal Atlas; it is constituted of a pink continental formation, rich in salt banches (Rolley 1973, Guezal et al. 2011) covered by the Jurassic carbonate sediments that occupy the majority of the syncline. The Lower Lias facies are essentially marly-dolomitic, often karstified and rich in onchoids with occasional gypsum; these formations are surmounted by the calcaro-dolomites of the Jbel Rat Formation of Upper Sinemurian age (Souhel 1996, Ettaki et al. 2007). The Jbel Rat Formations are succeeded by the carbonate deposits of the Aganane formation of the Upper Sinemurian-Middle Domerian age (Septfontaine 1985, Souhel 1996, Ettaki et al. 2007). The transition from carbonate to terrigenous facies is marked by the marl-sandstone sediments of the Azilal Formation of Toarcian-Aalenian (Souhel 1996, Ettaki et al. 2011). The Middle Jurassic facies are represented by Bin El Ouidane Groups I, II and III; it is two limestone bars framing a marly series (Monbaron, Taquet 1981). BI includes limestones lite to bird eyes covered by marls and marly bioclastic limestones BII, and the bar BIII is an alternation of limestone onchoides in the form of slabs rich in rhynchonelles. After the Aalenian-Bajocian transgression, a series of three red continental layers gradually begin to fill the syncline. The Gettioua Formation consists of pelites, silts, clays and conglomerates of the Bathonian

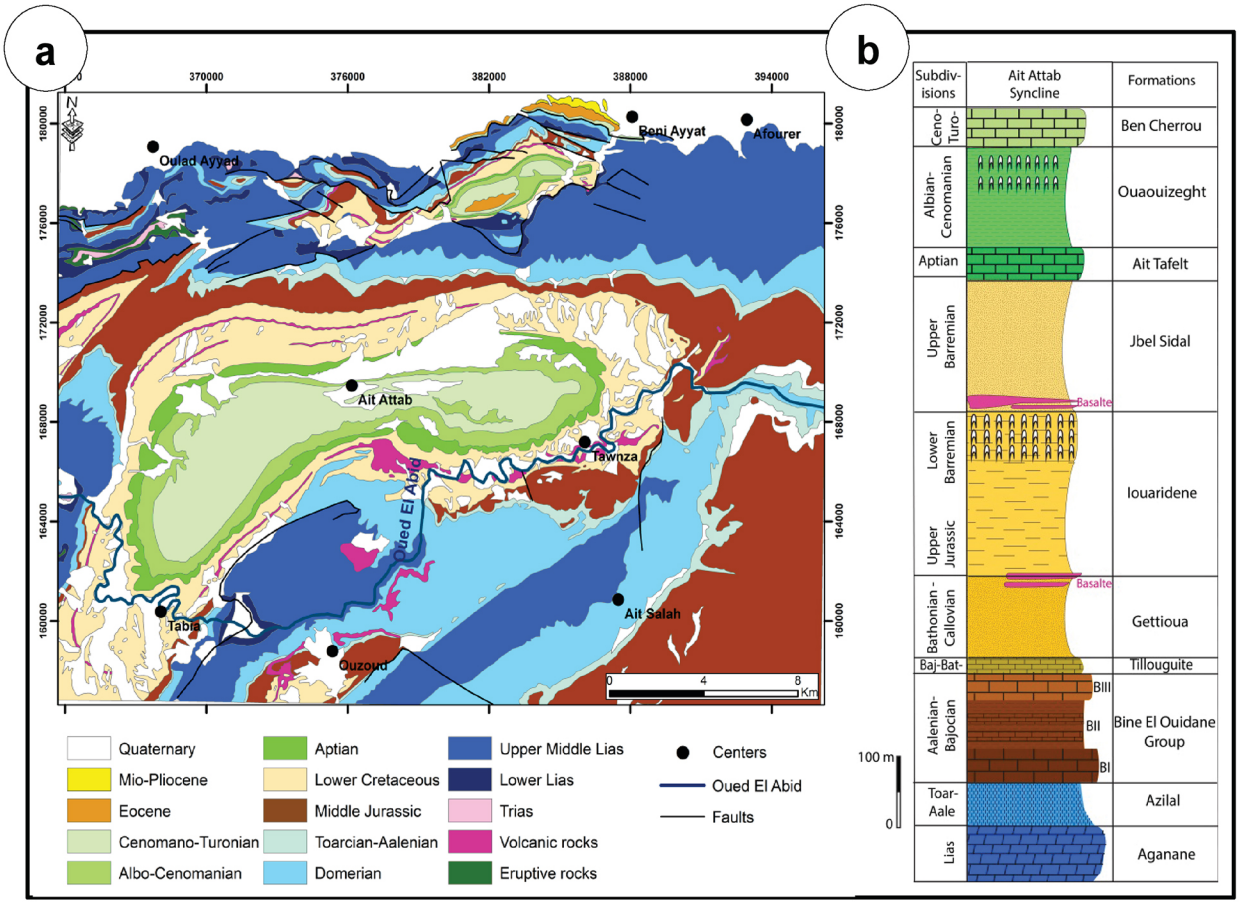

Fig. 2. a) Geological map of Ait Attab syncline (Extract from the geological map of Morocco at 1/100 000, Afourer sheet, modified); b) Simplified lithostratigraphic log of study area (Haddoumi, 2010 modified): Ceno-Tur: Cenomano-Turonian; Baj-Bat : Bajocian-Bathonian; Toar-Aale: Toarcian-Aalenian.

age (Jenny et al. 1981, Monbaron, Taquet 1981, Souhel 1996, Haddoumi et al. 2010). The first basaltic episode B1 of Jurassic and Cretaceous caps its summit. The Iouaridene Formation is formed by pelites and marls of the lower Barremian age (lagoon or sebkha environment) (Haddoumi et al. 2010), and it contains at its base a B1 basaltic flow, while greenish clays and dolomites form its summit with gypsum and a B2 basaltic flow. The Jbel Sidal Formation contains sandstone facies intercalated with red pelites and dolomitic levels, sometimes containing fossils (Haddoumi et al. 2010). These red terrigens are covered by the marly limestones of the laguno-marine formation of Ait Tafelt generally rich in ammonites (Choubert, Faure-Muret 1960–1962, Souhel 1987, Andreu et al. 2003). Over the Aptian bar are deposited gypsum marl and dolomites of the Ouaouizeght Formation of the Albo-Cenomanian age (Rahhali 1979). The Ben Cherrou Formation is composed of fine limestones with foraminifers in the form of a Cenomanian-Turonian marine bar (Rahhali 1979, Souhel 1987, Haddoumi et al. 2010).

Methodology

The geodiversity concept is recently emerging as a tool for implementing any geoconservation and valorisation policy of local geological heritage (Bétard, Peulvast 2019). In Morocco, this concept still remains underdeveloped compared to the biodiversity concept, and it requires the development of new methods that can assess this geodiversity and determine the various threats caused by natural and anthropogenic activities. This essentially means making the geological wealth known for the benefit of the local population while conserving this wealth sustainably. The geoconservation strategy has increasingly preoccupied the geological community. It is a set of actions that aim to conserve the abiotic heritage

(Cendrero 2000, Brilha 2005, Henriques et al. 2011) and promote it as a natural object with an educational, aesthetic and socio-cultural aspect. Indeed, the geoconservation strategy is based on five successive actions that start with 1 – inventory, 2 – assessment, 3 – conservation measures, 4 – interpretation and 5 – follow-up (De Wever et al. 2006, Brilha 2018). However, the most works on geoheritage do not respect all steps of geoconservation, and the actions of conservation and follow-up are often lacking; the main reason for this is the absence of legal protection and the lack of collaboration between researchers and local managers.

Regarding evaluation, different efforts have been made to define criteria for evaluating sites of interest; most of them suggested taking into account the scientific, aesthetic, economic, cultural and educational values of geosites (Panizza 2001, Pereira et al. 2007, Pereira, Pereira 2010, Ruban 2010, Bâca, Schuster 2011, Brilha 2016, Reynard et al. 2016, Reynard, Brilha 2017, Bouzekraoui et al. 2018, Brilha 2018). They also proposed to assess these values using numerical scores, sometimes weighted. These quantitative approaches give a global assessment of sites in terms of scientific representativeness and conservation priority and thus reduce the subjectivity of the evaluator, unlike the qualitative approach that is based on description and morphogenesis without assigning a numerical score (Wimbledon et al. 2000). Table 1 shows the values adopted during the evaluation of geosites in some scientific publications.

During this work, data collection was based on literature reviews and consulting specialists in geosciences to select potential sites. Later, field trips were planned to visit these sites of interest, collect data and finally define sites with remarkable geoscientific relevance. This relevance is often based on scientific publications (books, chapters, articles, theses and dissertations); however, despite their representativeness of the regional geology and palaeoenvironment, some sites have yet to be the subject of any scientific publication, which negatively affects their numerical scores. The fieldwork also includes taking photographs,

Table 1. Some methodologies used to evaluate geoheritage sites.

Publication	Scientific	Additional				Use	Use and management	Use and protection
		Cultural	Economic	Aesthetic	Educational			
Grandgirard (1999)	*							
Bruschi and Cendréro (2005)	*		*				*	
Serrano and González-Trueba (2005)	*	*					*	
Coratza and Giusti (2005)	*					*		
Pralong (2006)	*	*	*	*		*		
Zouros (2005, 2007)	*							*
Reynard et al. (2017)	*	*	*	*	*		*	
Pereira et al. (2007)	*	*		*	*	*		*
Comanescu et al. (2011)	*	*	*	*				
Pereira and Pereira (2010)	*	*		*	*			*
Bosson and Reynard (2012)	*			*		*		
Comanescu et al. (2012)	*	*	*	*			*	
Del Monte et al. (2013)	*	*		*	*	*		*
Grangier (2013)	*	*		*	*			*
Stevanovic (2015)	*	*		*	*			*
Reynard et al. (2016)	*	*		*	*		*	
Kubalíková and Kirchner (2016)	*		*					*
Pica et al. (2017)	*	*		*		*		
Niculiță and Mărgărint (2017)	*	*	*	*	*			

* – values adopted in the publication.

Table 2. Assessment criteria used to evaluate geosites and geodiversity sites (Brilha 2016).

Scientific value (SV)	
Criteria	Weights [%]
Representativeness (Rp)	30
Key locality (Kl)	20
Scientific knowledge (Sn)	5
Integrity (I)	15
Geological diversity (Gd)	5
Rarity (R)	15
Use limit (Ul)	10
Degradation risks (DR)	
Criteria	Weights [%]
Deterioration of geological elements (Dg)	35
Proximity activities cause degradation (Pa)	20
Legal protection (Lp)	20
Accessibility (Ac)	15
Density of populations (Dp)	10

Potential value			
Educational (PEU)		Touristic (PTU)	
Weights [%]	Criteria		Weights [%]
10	Vulnerability (V)		10
10	Accessibility (A)		10
5	Use limit (Ul)		5
10	Security (S)		10
5	Logistics (L)		5
5	Density of populations (Dp)		5
5	Association with other values (Av)		5
5	Scenery (Se)		15
5	Uniqueness (U)		10
10	Observation conditions (Oc)		5
20	Didactic potential (Dp)	Interpretive potential (Ip)	10
10	Geological diversity (Gd)	Economic level (El)	5
		Proximity to recreational areas (Pa)	5

geographical coordinates, and collecting information. The next step requires the quantitative assessment of the selected sites. To do this, we chose the approach proposed by Brilha (2016); it is a quantitative assessment methodology based on four sets of values: SV, potential educational use (PEU), potential tourism use (PTU) and degradation risks (DR) (Table 2). The choice of this method, among others, is explained by its remarkable objectivity and its adaptation to different geological, geomorphological and even legal contexts (Brilha 2016). It also constitutes a synthesis of previous methodologies (Wimbledon et al. 1996, Grandgirard 1999, Gray 2004, Brilha 2005, García, Carcavilla 2009, Tomić 2011, Reynard and Coratza 2013, Tomić and Božić 2014) intending to choose the most relevant criteria for a good selection and assessment of geoheritage.

The scientific value is considered central and exigent when talking about geosites, and it takes into consideration the research previously carried out on the study area to understand the geological landscape. The assessment of this value is based on seven main criteria: representativeness (Re), key locality (Kl), scientific knowledge (Sn), integrity (I), geological diversity (Gd), rarity (Ra) and use limits (Ul), each of which is weighted to reflect its importance. By contrast, potential educational and tourism values play a crucial role in all geotourism and geoeducational development projects and are required for selecting geodiversity sites (Brilha 2016). The assessment of these two values considers several weighted criteria, ten (10) of which are common to both values, with two additional specific criteria for the potential educational value and three for the potential tourism value (Table 2).

The assessment of the degradation risk is the main step that must be adopted before launching any geoconservation and heritage management plan; in other words, it is a diagnosis of the protection status of sites. The appreciation of this value is based on five criteria: accessibility, population density, legal protection, proximity to human settlements and deterioration of geological features.

Each criterion is noted on a scale of 1–4, but a score 3 is eliminated for SV to more clearly distinguish between geosites with four points (Brilha 2016); these criteria are also weighted according to their importance, with a sum of 100 per value. Each value's final score is assigned by adding the weighted scores of all its criteria. In light of these evaluations, sites with a value between 0 and 100, 101 and 200, 201 and 300, and 301 and

400 are called low, moderate, high and very high, respectively. Sites with an SV of more than 300 are considered geosites of high scientific interest. Similarly, if the tourism and/or educational values each exceed 300, the site is classified as a geodiversity site suitable for tourism and/or educational uses.

Results

Presentation of the geological and cultural heritage of the Ait Attab syncline

The inventory of geological heritage in the study area reveals the existence of approximately 30 sites of interest from which we selected 8 geosites and 11 geodiversity sites (Fig. 3), which have unique scientific interests and are representative of the geological and geomorohological context of the region. Thus, each site has more than two different scientific interests, a high scenic value and good accessibility (Table 3); this wealth is explained by the important size of the syncline (the largest syncline of the CHA) and the large number of sedimentological, stratigraphic, structural and palaeontological studies that have been made on its facies (Souhel 1987, Haddoumi 1988, Haddoumi et al. 2002, Andreu et al. 2003, Moussaid et al. 2015, Makrini et al. 2017). The classification of selected sites by geological interest has allowed the inventory of five stratigraphic

Table 3. Brief characterisation of geotours, geosites (GS) and geodiversity (GD) sites of the Ait Attab syncline.

Geotrail	No	Name	Code	Coordinates	GS GD	Scientific interests
Beni Ayyat – Ayt Bouyqben	1	Panoramic view of overturned bar of Iferghas	Stra01	X = 387858 Y = 179058	GS	Stratigraphic, structural
	2	Karst cliff of Ighir-n-Oumejjad	Kar02	X = 384756 Y = 177043	GD	Karstic, geomorphological
	3	Panoramic view of the Ait Attab syncline	Stra03	X = 382007 Y = 174573	GS	Stratigraphic, structural, scenic
	4	The tectonic deformations of Jbel Hassan	Stru04	X = 382025 Y = 173773	GD	Structural
	5	The ruiniform limestones with ammonite of the Ben Cherrou Formation	Pal05	X = 377397 Y = 186281	GS	Palaeontological, karstic
	6	Panoramic view of the Cretaceous cuestas	Geom06	X = 778875 Y = 166099	GS	Geomorphological
	7	The bad land of Ait Ouabit	Flu07	X = 379108 Y = 165506	GD	Fluvial
	8	Gorges of Ait Ouabit	Geom08	X = 379104 Y = 163634	GD	Geomorphological
	9	Conglomerate terraces of Oued El Abid	Stra9	X = 381055 Y = 165129	GD	Stratigraphic, fluvial
	10	The footprints of sauropod dinosaurs of Ayt Bouiqban	Pal10	X = 382226 Y = 164873	GS	Palaeontological, scenic
	11	Lower limit of the basaltic flow B2	Stra11	X = 377188 Y = 166975	GS	Stratigraphic, magmatic
Afourer – Taounza	12	Jurassic-Cretaceous unconformity and volcanic activities	Stra12	X = 391673 Y = 170160	GS	Stratigraphic, magmatic
	13	Bioclastic limestone with ammonite of the Bine El Ouidane BIII Formation	Pal13	X = 391105 Y = 169708	GD	Palaeontological
	14	Panoramic view of Oued El Abid from the old Caida of Taounza	Flu14	X = 387128 Y = 166982	GD	Fluvial, scenic
Tisqi – Ouled Ayyad	15	Caves of cats and the spring of Tisqui	Spel15	X = 371295 Y =168639	GD	Speleological
	16	Bioclastic marly limestone of Ait Tafelt Formation	Pal16	X = 375908 Y = 170508	GD	Palaeontological
	17	Eroded sandstone of Jbel Ilaghmane	Geom17	X = 374969 Y = 171017	GD	Geomorphological, scenic
	18	Panoramic view of the red formations separated by the BI and BII magmatic events	Stra18	X =374470 Y = 371140	GS	Stratigraphic
	19	Ruiniform reliefs of Jbel Al Maqçoura	Kar19	X = 369907 Y = 174781	GD	Karstic

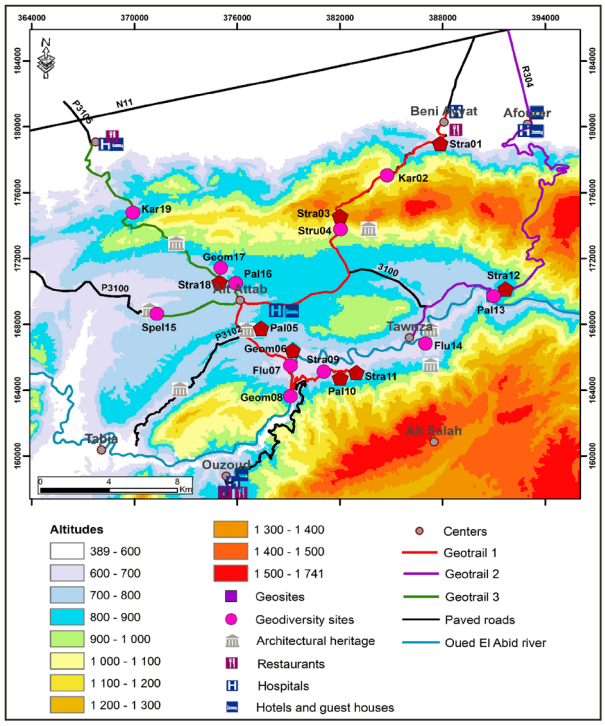

Fig. 3. Mapping of geotrails with inventoried geosites and geodiversity sites as well as the tourist infrastructure of the Ait Attab syncline.

geosites (Stra01, Stra03, Stra11, Stra12 and Stra18), two palaeontological geosites (Pal05 and Pal10) and one geomorphological geosite (Geom06). The remaining 11 sites are geodiversity sites with high tourist and/or educational potential.

The eight geosites and eleven geodiversity sites are located along three main roads corresponding to communication routes allowing accessibility to the Ait Attab syncline. These routes with the geosites and geodiversity sites are considered georoutes (Fig. 3). The first route is named Beni Ayyat-Ait Bouykban Geotrail with six geosites and five sites of geodiversity; it extends over 36 km, thus offering beautiful panoramic views and excellent geological outcrops. The second georoute starts from Afourer and goes towards Taounza on a 28 km distance; it includes one geosite and two geodiversity sites. The last georoute, Tisqi-Ouled Ayyad, includes four sites of geodiversity and one geosite over a 20 km distance. These itineraries can be accessed by car or hiking with several easy hiking trails around Oued El Abid by passing through douars rich in architectural and religious heritage. The tourist infrastructure has started to develop in recent years due to the increase in tourist flow; thus, the number of guest houses and accommodation structures has increased, and catering and sale of local products have also evolved. To give an overview of the wealth of the study area in sites of scientific, touristic and educational interest, we have chosen to describe in detail these sites considered representative of Afourar's High Atlas geology and Ait Attab syncline in particular.

Geosites

Stratigraphic geosites

Overlapping of Jurassic on the Cretaceous (overturned bar of Iferghas)

This geosite is located 4 km south of Beni Ayat. It is a spectacular panoramic view of the Iferghas session that illustrates the North-Atlasic overlap (Fig. 1); it exposes from North to South and from the bottom to the top Mio-Pliocene conglomerates surmounted by phosphate deposits of Upper Cretaceous and Eocene at the top of which are deposited the limestones of the Cenomano-Turonian (Rolley 1973, Charrière et al. 2011). These overturned formations (Couvreur 1988) are covered by an upper set composed of marls intercalated with Turonian-Aalenian limestone surmounted by massive limestones of the Lower Lias intensely deformed in the form of faults and folds, clearly visible (Fig. 4). The contact between the two sets occurs at the level of a large overlapping fault (Fig. 4). The detailed study of this section provides a greater understanding of the atlasic tectogenesis and deduces the succession of tectonic events responsible for the atlasic chain formation.

This site allows visitors the opportunity to discover curiosity hidden behind the ancient granaries built in stones and adobe (Ait Ali and Ait Chabbouri) (Fig. 4) in altitudes that dominate the area. The architecture used to build them reflects their social importance. Their doors are perfectly made with traditional curves and engravings, without forgetting the presence of Matfias, which allow the water management during drought periods. Unfortunately, most of these granaries have been neglected and now fall into ruin.

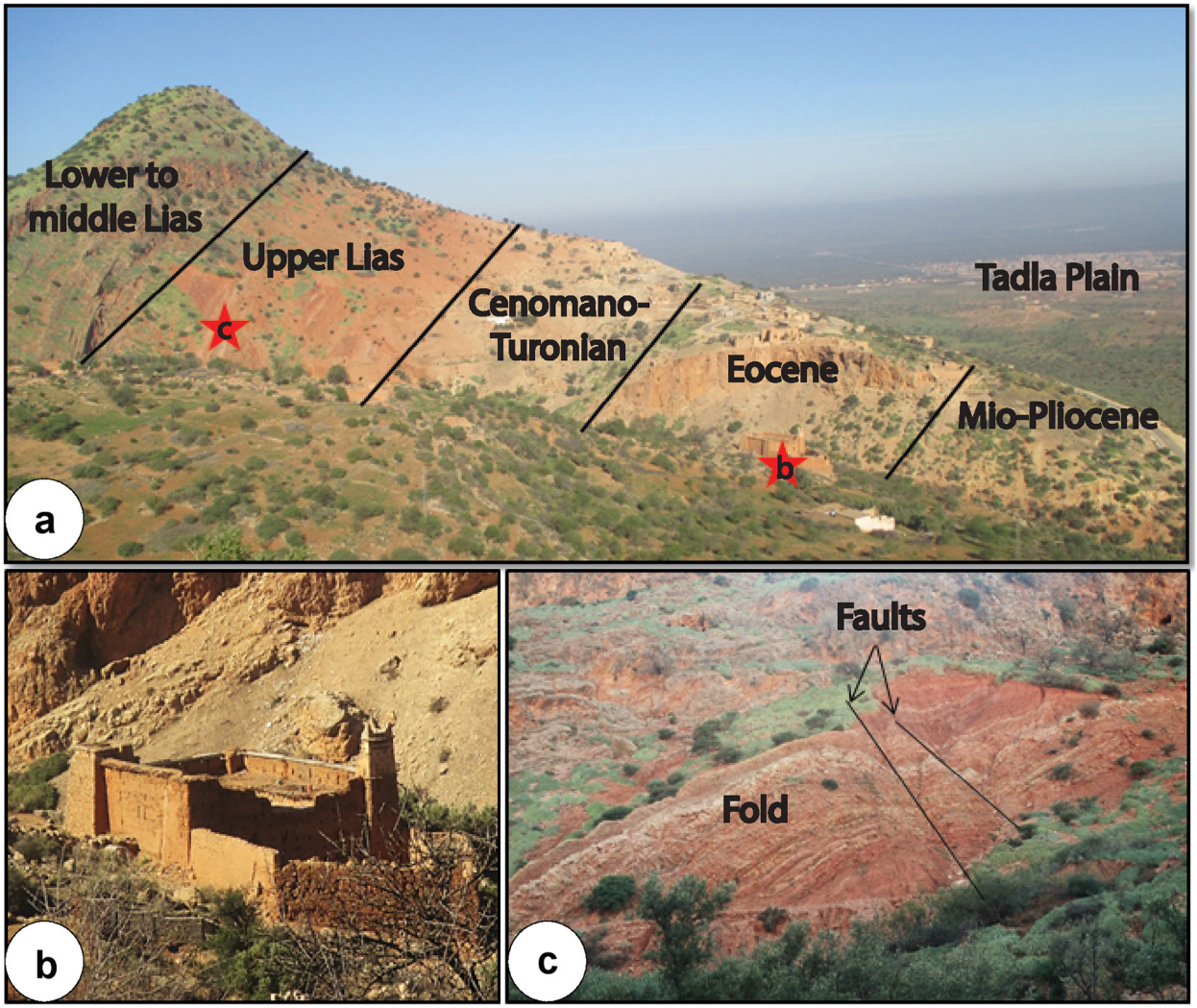

Fig. 4. a) Overlap of the Jurassic on the Cretaceous; b) N'Ait Belhaj Community Granary; c) tectonic deformations (fold and faults) which affected the Lower Lias.

Panoramic view of the Ait Attab syncline (by Beni Ayyat)

This geosite offers a beautiful panoramic view of the Ait Attab syncline, a panorama that illustrates more than 100 million years of earth history from the Lower Jurassic to the Upper Cretaceous (Fig. 5). Indeed, the view shows a succession of transgressive and regressive megasequences formed by alternating continental red formations (Tillouguit, Gettioua, Jbel Sidal, Iouaridene and Ouaouizaght) with marine yellowish formations (Bin El Ouidane Group, Ait Tafelt and Ben Cherrou). This alternation reflects a significant shift in the deposit environment. The syncline's centre is occupied by Cretaceous formations, whose outcrop is linked to the Cretaceous basins' opening cycle (Löwner 2009, Haddoumi et al. 2010). This view also displays two significant effusive tectonic events from the third extensive phase of the CHA (Löwner 2009, Haddoumi et al. 2010). These are two basaltic flow horizons B1 and B2 dated from the Middle Jurassic to the Lower Cretaceous period. The B1 horizon is associated with the upper part of Gettioua Formation, while the B2 horizon marks the base of Jbel Sidal Formation (Haddoumi et al. 2010). This geosite is interesting to understand the Atlas tectonics, the Jurassic-Cretaceous magmatism and the change of deposit environments. Its classification as a geosite in the M'Goun Global geopark has increased its attractiveness; it has become a popular tourist resort for visitors.

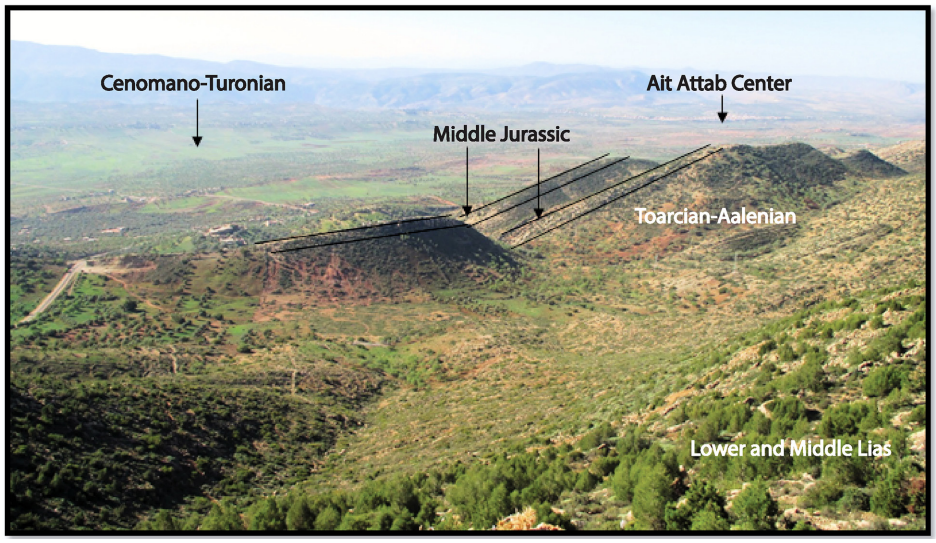

Fig. 5. Northern panoramic view of the Attab syncline.

Lower limit of the basaltic flow B2

The basaltic flow B2 corresponds to the second episode of Jurassic-Cretaceous magmatic events, and it marks the limit between the fluvio-deltaic deposits of Jbel Sidal and the lagoon sediments of the F. Iouaridene of Lower Hauterivian-Barremian age (Mojon et al. 2009, Haddoumi et al. 2010) (Fig. 6). Its emplacement is associated with the third extensive tectonic phase at the Lower Barremian-Upper Barremian transition (Löwner 2009, Haddoumi et al. 2010). These flows of Barremian age (Charrière et al. 2011) and greyish-black colour are highly eroded with a massive and vacuolar aspect at the top, generally rich in olivine and plagioclase phenocrysts (Fig. 6), and their thickness reaches its maximum near the village Taounza. The choice of this geosite is based on its representativeness, beauty and importance for the palaeogeographic reconstruction. It is the only place where we can see the contact surface between the Iouaridene Formation and the B2 basaltic flow; the well-contrasted colours of these deposits increase the representativeness of this site.

Jurassic-Cretaceous unconformity and B2 volcanic activities

This geosite is located in the southeast of the Ait Attab basin. It can be observed from the road P3100, and the lagoon deposits of the Iouaridene Formation rest in unconformity on the Aaleno-Bajocian limestones of Jbel Tagoudit, while the Gettioua Formation is entirely absent (Fig. 7). This testifies to a post-rift movement of the syncline during the Bathonian age, forming a half-graben associated with the play of synsedimentary normal faults (Haddoumi 1988) and/or differentiation of the high Atlas basins in the Lower Cretaceous (Hardenbol et al. 1998). The top of the Iouaridene Formation is indicated by a B2 basaltic flow of the Barremian age (Charrière et al. 2011). These greyish-coloured flows are locally eroded and have a vacuolated appearance at the top, where they are generally filled with erosion products. The absence of contact metamorphism in the surrounding formations attests to a basaltic effusion rapidly cooled at the surface (Guezal et al. 2013). This geosite clearly shows the role of tectonics during the Middle Jurassic in the uplift of the syncline edges following the reactivation of synsedimentary fault.

Panoramic view of red formations separated by magmatic events

This stratigraphic geosite belongs to the Jurassic-Cretaceous red layers, which correspond to a continental sedimentation essentially detritic deposited on the Tillouguite Formation after the closure of the Atlassic-Thysian marine trench in the Middle Jurassic (Löwner 2009). These layers are divided into three distinct units, well developed to the north of the Ait Attab syncline (Fig. 8); thus, we find at the lower end the fluvial deposits of the Gettioua Formation of the Bathonian-Callovian age surmounted by the evaporitic playa deposits of the Iouaridene Formation of

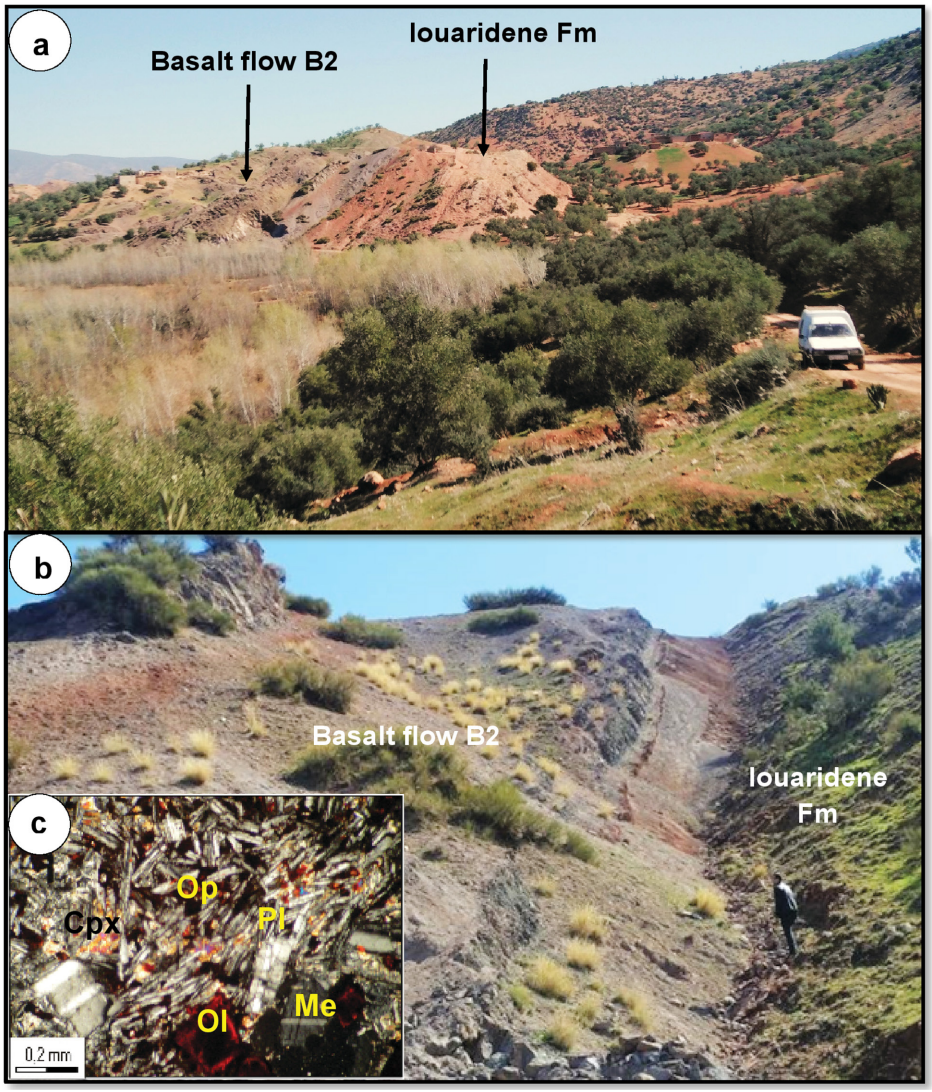

Fig. 6. a–b) Lower limit of the basalt flow B2. Fm: formation; c) Basalt B2 with porphyry texture. Ol: olivine; Pl: plagioclase ; Op: ferrotinasated oxide (Guezzal 2017).

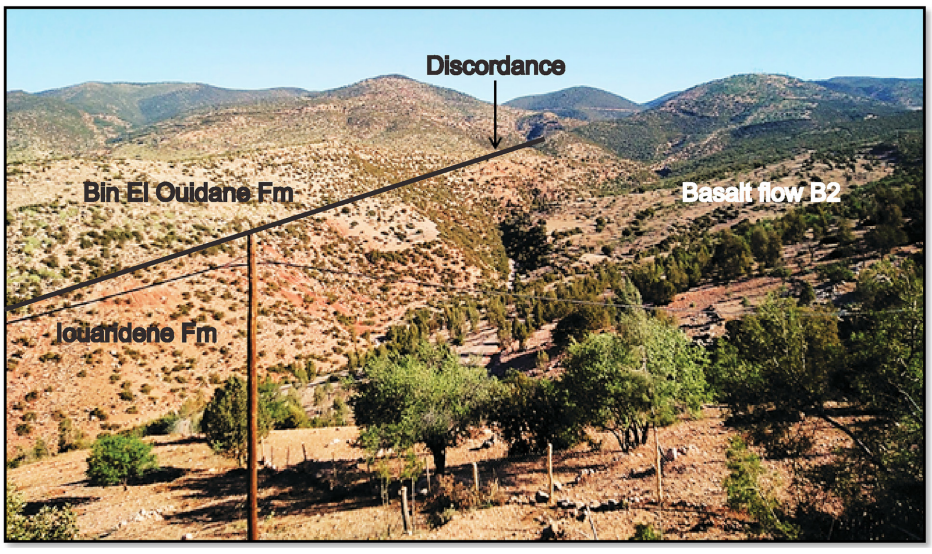

Fig. 7. Jurassic-Cretaceous discordance.

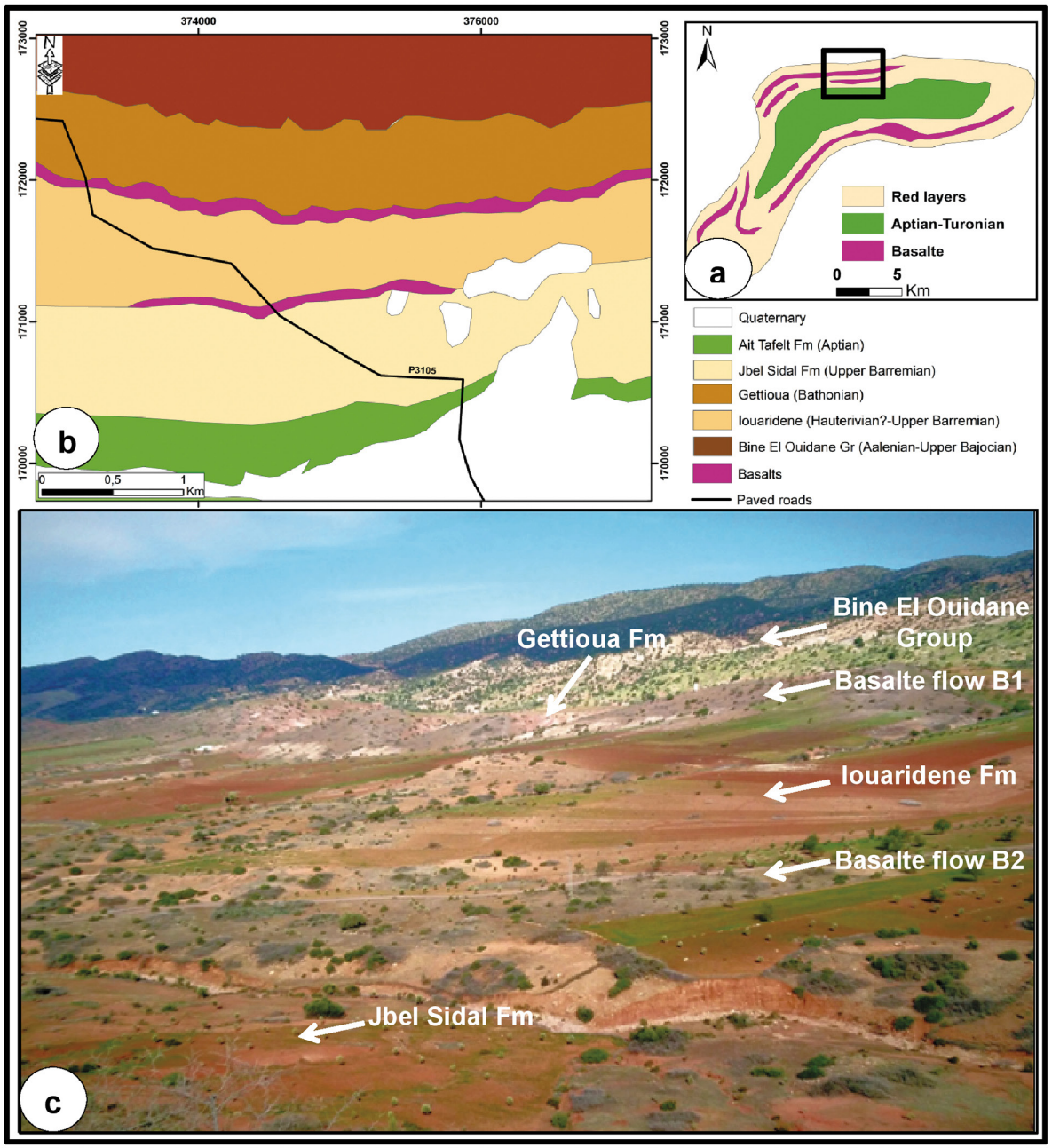

Fig. 8. Simplified geological map of the Ait Attab syncline (Rolley, 1978); b) red layers in the northern flank of the syncline; c) panoramic view of the red layers separated by the B1 and B2 magmatic events.

the Hauterivian-Lower Barremian age, and then at the upper end the Jbel Sidal Formation of the Upper Barremian age (Haddoumi et al. 2010). These red formations are separated by two volcanic events that facilitate the distinction between them; the first event occurred during the Middle Jurassic on top of the Gettioua Formation, while the second event marks end of the Iouaridene Formation deposition, which dates back to the Barremian age (Haddoumi et al. 2010). The micropalaeontological data of these formations have allowed researchers to frame, for the first time, the Jurassic-Cretaceous boundary (Haddoumi et al. 2010) and also testify to a regressive evolution, giving rise to basin filling in Afourer atlas (Löwner 2009). This trilogy has delivered various fossiliferous deposits of great SV including bones and footprints of dinosaurs (Haddoumi et al. 2002, 2010, 2016), which testify to a marshy environment. The Kimmeridgian microfauna provide information about a lacustrine domain, while the ostracods and lituolidates discovered in the

Lower Barremian layers indicate the existence of the first marine ingression. Such discoveries confer to these layers a major importance of the restitution of the atlas' Mesozoic history (Löwner 2009, Haddoumi et al. 2010) and any biostratigraphic correlation and palaeoenvironmental interpretation.

Palaeontological geosites

The ruiniform limestones with ammonite of the Ben Cherrou Formation

The Ben Cherrou Formation, which was formerly called Formation Ait Attab (Souhel 1987), is one of the most relevant formations from a stratigraphic and a palaeontological point of view. It was the site of several discoveries of typical fauna essential for the biostratigraphic correlation and palaeoecological and palaeoenvironmental interpretations (Ettachfini et al. 2005, Moussaid et al. 2015). It is an alternation of nodular limestone, marl and beige chalky limestone, forming a corniche that can be observed along the road P3105 (Fig. 9). The ruiniform aspect of these carbonates gives them a high aesthetic value. These marl limestones outcrop on 10–85 m thickness, forming cliffs, which dominate the syncline. In the stratigraphic context, the formation comprises five lithostratigraphic units limited by sedimentary discontinuities of regional order (Ettachfini et al. 2005), each of which is marked by the succession of chalky

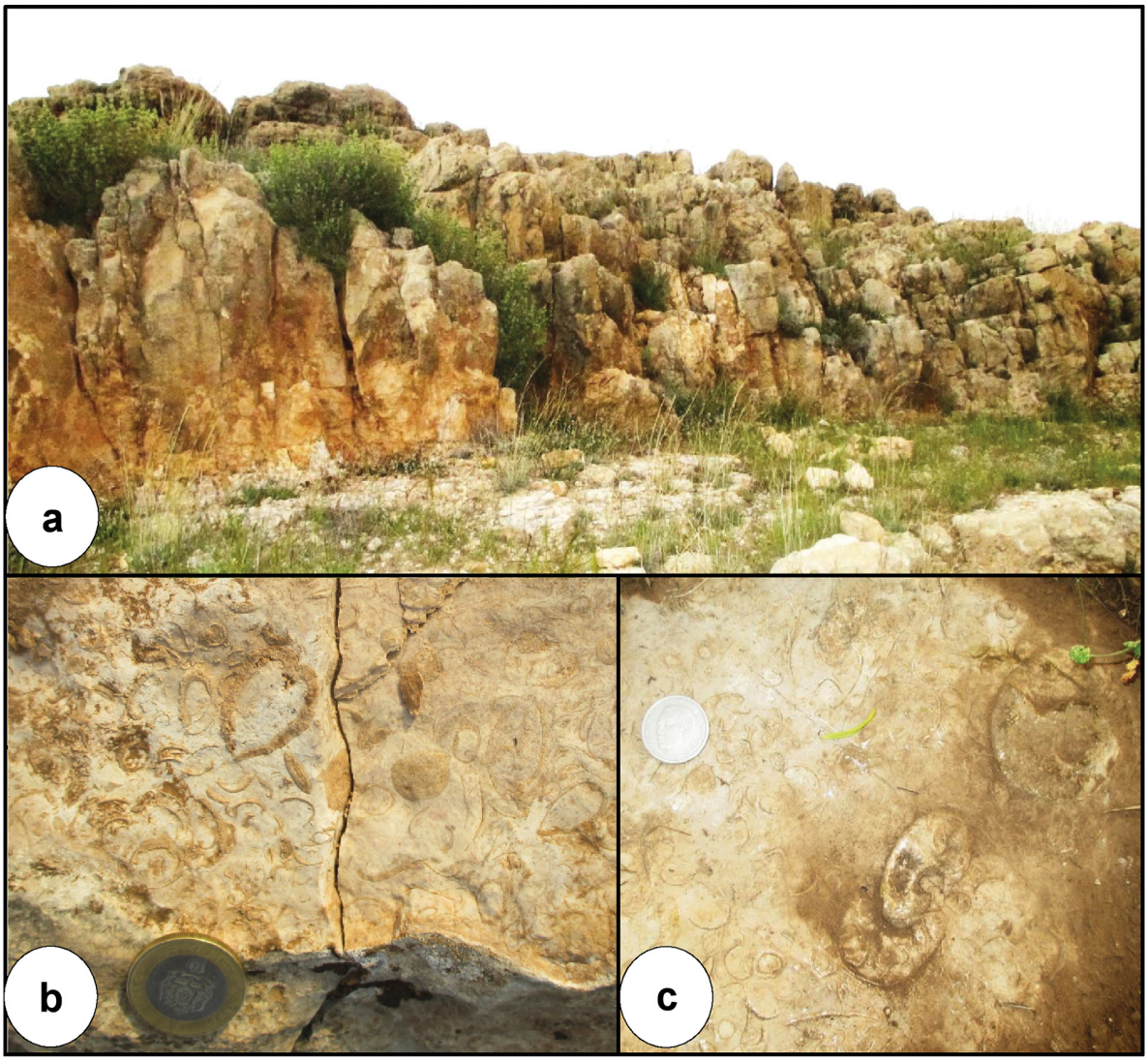

Fig. 9. a) Ruiniform reliefs of Ben Cherrou formation; b) Bioclastic limestone with gastropods and lamellibranchs; c) Bioclastic limestone with ammonite fossils.

limestone beds rich in foraminifera and ammonites (Fig. 9) and bioclastic beige limestones. This abundant and diversified fauna gives a global view of the palaeoecosystem that reigned during the Cenomano-Turonian interval. The arrangement of strata and the presence of sedimentary discontinuities give this site an important stratigraphic value that attests to the Tethysian origin of the major Cenomano-Turonian transgression (Moussaid et al. 2015).

Sauropod dinosaur footprints in Ait Boyekbane

The CHA harbours a set of spectacular deposits of sauropod and theropod dinosaur footprints and bones discovered generally in the Lower and Middle Jurassic and Lower Cretaceous deposits (Monbaron 1978, Jenny et al. 1981, Souhel 1987, Haddoumi 1988, Taquet 1999, Nouri et al. 2011, Amine et al. 2018, Boutakiout et al. 2019). The sedimentological studies that have been made on the Ait Attab basin have revealed the existence of three deposits of dinosaur bones and footprints, one of which is located SW of the syncline within the Gettioua Formation (Jenny et al. 1981). Another deposit of tridactyl footprints was discovered by Haddoumi (1988) in the sandstones of the Jbel Sidal Formation north of the basin; however, these footprints are in a bad condition. In our study, we found, for the first time, three

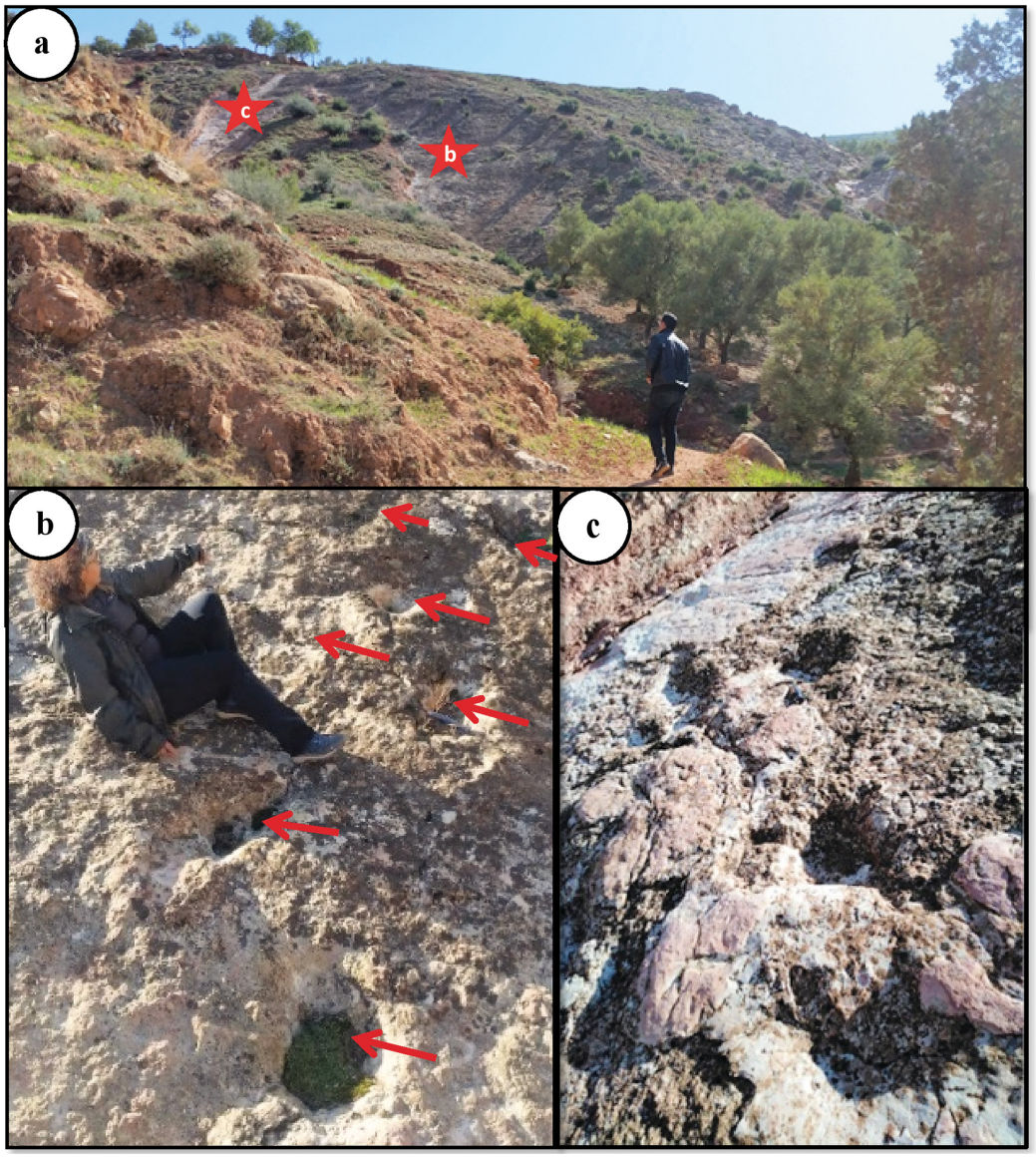

Fig. 10. a) Panoramic view of the dolomitic limestone of Iouaridene formation containing sauropod dinosaur footprints; b–c) Sauropod dinosaur footprints.

cross tracks of oval and more or less hollow dinosaur footprints (5–10 cm) that show a crown or half-crown bead (Fig. 10). These characteristics allow deducing that they are footprints of sauropod dinosaurs printed on a dolomitic level at the top of the Iouaridene Formation. These footprints are probably formed on a shallow emerged floodplain. Such a discovery will increase the scientific, educational and touristic interest of the syncline, especially with the facility of its access, its proximity to the big urban centres (Beni Mellal, Marrakech) and its educational importance, which can be used as didactic support for university courses and field visits.

Geomorphological geosite

The Cretaceous cuestas

Around 5 km south of the centre of Ait Attab, on the P3105 road, we observe well-cleared cuestas of the Upper Cretaceous that extend eastwards towards Tawnza (Fig. 11). The origin of the cuestas is generally related to the combined action of stratigraphy, tectonics and climatic factors (Grujenschi et al. 1977). Indeed, the cuestas represent one of the main features of the geomorphology in the study area, and they highlight the difference in mechanical strength between the sedimentary formations. The resistant layers

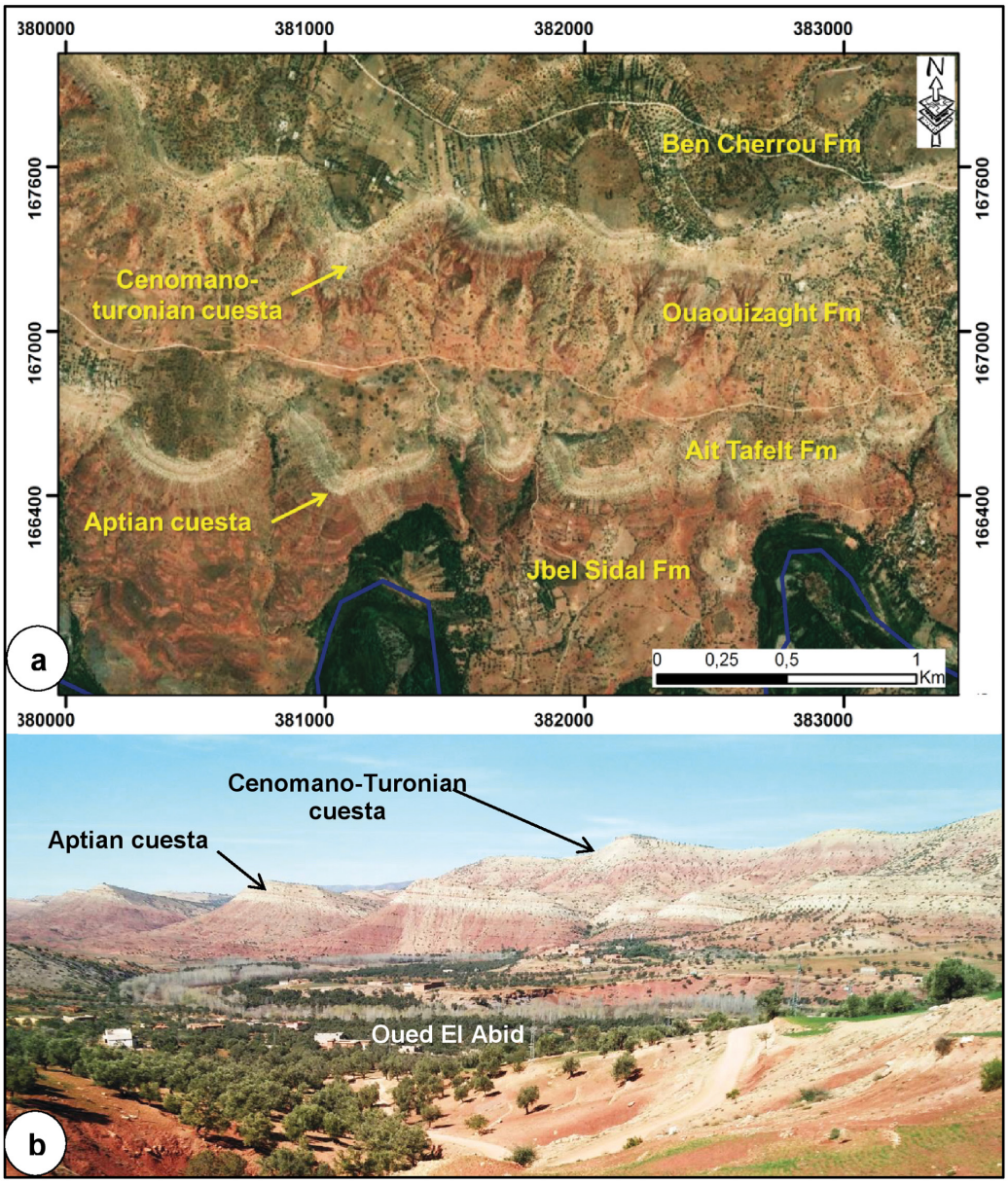

Fig. 11. Google earth image (a) and photo (b) showing the Cretaceous cuestas of Ait Attab syncline.

(limestone and sandstone) are in relief, forming the front of the cuesta, while the soft layers (clay and marl) form the reverse of the cuesta.

The particularity of the Ait Attab syncline resides in the fact that it regroups two Cretaceous cuestas, an upper Cenomano-Turonian and a lower Aptian (Fig. 11). The cuestas layers are slightly inclined with a steep front whose foot is cut by a depression dug within the soft layers under the action of the regressive erosion of slope. This erosion gives rise to badlands, which affect the clays of the Jbel Sidal Formation. The contrast between the red ochre and beige sedimentary layers and the green vegetation cover creates a picturesque landscape that fascinates visitors.

Geodiversity sites

Geodiversity sites means sites with low to medium SV, but which contain high tourism and/or educational potential (Brilha 2016). Contrary to geosites with a scientific interest, geodiversity sites have a great interest in popularising science through fieldwork and other informal educational activities. Their role is also crucial in any tourism development projects that can generate social and economic benefits for the local population (Brilha 2016).

The Ait Attab syncline is the most extensive syncline of the CHA; it contains an exceptional diversity with the most dominant and spectacular features of the area, which helps in palaeogeographic reconstruction and understanding of the Cenozoic setting of the study area. In this study, we selected 11 geodiversity sites based on Brilha's (2016) method, and these sites are located on seven geological units and cover several interests: stratigraphic, structural, palaeontological, geomorphological, karst and speleological. The karst phenomena mainly affect the limestones and dolomites of the Lias, forming karst cliffs of high aesthetic value as in the geodiversity site Kar02 (Fig. 12) or ruiniform reliefs as in the site Kar19. These karst forms constitute currently the most popular tourist destination, and this is explained by its high aesthetic value in addition to the diversity of activities related to these geological forms (trip, climbing, hiking, etc.). The limestones and dolomites of the Lias are also affected by a succession of major tectonic events. Indeed, on the road linking Beni Ayyat to Ait Attab about 13 km from Elgarage, we find the Stru05 site, which represents a good example of atlasic neotectonics associated with thrust operation (Moussaid et al. 2015). These are two isopaque folds, one straight and the other recumbent, separated by a normal fault (Fig. 12) affecting the limestones, marls and dolomites of the Domerian. This type of tectonic deformation has a great pedagogical interest illustrating the tectonic movements relative to the Atlantic opening. On the other side of the syncline, Oued El Abid, main affluent of Oum Er Rabia river, crosses geological formations of different ages giving several exceptional panoramic views as in the site Flu15 (Fig. 12) near the ancient Kaida of Taounza. This Oued also gives rise to large fluvial terraces, the most representative of which are located to the north-east of Ait Attab syncline (Stra10). They appear in the form of extensive plateau of Plio-quaternary conglomerates (Couvreur 1988) with often rounded pebbles of centimetric size consolidated by limestone cement. These conglomerates are deposited in angular unconformity on the sandstones and clays of Jbel Sidal Formation and on the basaltic flow B2 (Fig. 12). The pedagogical interest of these terraces helps to teach principles of relative datation. The Oued El Abid continues its course towards the south-east and sculpts, over centuries, a stratigraphic column from the Domerian to the Middle Jurassic forming a narrow gorge: this is the Geom08 site located about 8 km from Elgarage, near the old bridge of Ait Ouabit (Fig. 12). The typical morphology of this gorge offers an important aesthetic value thus increases the number of tourists. Not far from these gorges, the clays of the red formations present specific geomorphological structures linked to erosion called the badlands of Flu07. The same erosive phenomena have given, on the other side of the syncline, a specific geomorphological structure well observed from the road P3105 about 10 km from Elgarrage. These are silty banks or finely sandstone (Rolley 1973, Haddoumi et al. 2010) that have been affected by erosion, giving blocks of decametric order with micro-reliefs at the base in the form of alveoli. The fragility of these sandstones is explained by the low strength of the generally siliceous cement (Ostanin et al 2017). These banks also contain oblique stratifications, slightly discordant at the base and bevelled at the

Fig. 12. a) Karstic cliff of Ighir-n-Oumejjad; b) Tectonic deformations of Jbel Hassan mountain; c) Panoramic view of Oued El Abid from the ancient Caida of Taounza; d) Conglomerate terraces of Oued El Abid ; e) The gorges of Ait Ouabit ; f) Panoramic view of the eroded sandstones of Jbel Iloghman with oblique stratifications; g) Bioclastic marl of the Ait Tafelt formation; h) Bioclastic ammonite limestone of the Bine El Ouidane formation BIII; i) Cave of cats (Ghiran Lemchach).

end (Fig. 12). The choice of this site is based on its restricted value in the detailed study of palaeocurrents and surface erosion.

The study area also harbours a palaeontological interest that attracts both fossil-collecting tourists and earth science teachers who exploit it as a teaching station during field studies. The first site Pal16 is located 5 km north of Ait Attab, in the Aptian bar of the Ait Tafelt Formation, which constitutes the first marine pulse of the Cretaceous after marine transgression of the Dogger. It is constituted of marly limestone and whitish to yellowish marls that are highly fossiliferous containing oysters, lamellibranchs, gastropods, brachiopods and small regular sea urchins (Rolley 1973, Haddoumi et al. 2002) with some levels of lumachelic banks formed most often by shells of oysters (Fig. 12). The second Pal13 site was discovered in the Bin El Ouidane III Formation of the Upper Bajocian age (Ettaki 2003). It is a succession of slabbed oncoid limestone, lined with ammonites, traces of bioturbation and sedimentary breccias (Fig. 12) alternating with sandstone marls with coral reefs. This fossiliferous formation is also characterised by a benthic microfauna represented by bivalves, echinoderms, brachiopods and corals testifying to a peri-reef environment (Ettaki 2003, Ettaki et al. 2007). This site may constitute a preferable educational station for understanding fossilisation phenomena.

The study area also hosts a speleological site Spel14, located in Tisqui village, about 6 km from Elgarrage. It is a deep cave (Fig. 12) having various branches inside. According to the inhabitants, this cave contains several water springs with a large chamber used by women to perform some rituals to expel misfortunes and have children. During these rituals, women leave some clothes and brushes in place, which results in the accumulation of waste inside the cave. This site is highly regarded and visited by tourists because of its cultural importance and the beauty of its landscapes, which are favourable for camping.

Cultural diversity

In addition to the geological heritage, Ait Attab is also a territory quite unique in terms of cultural heritage; it is a Berber tribe of the Sanhaja branch having a considerable historical and cultural dimension. It is home to a valuable tangible and intangible cultural heritage that communicates social, architectural and economic messages to present and future generations. The main elements of this heritage are architecture, the Mellah and the Jewish cemetery, shrines, Moussems and traditional crafts.

The Berber architecture is manifested in Ait Attab by dozens of lineage granaries (Ighrem) (Fig. 13) of ancient buildings whose diversity of style and construction materials helps to follow evolution of their architecture over time. Indeed, each Douar contains at least one perched, fortified and imposing granary, and the most interesting buildings are located in the Douars Ait Iazem, Ait Ighir, Ait Issa, Ait Jabri and Ait larbi. This richness constitutes a curiosity for the tourists, especially foreigners because it reflects the community aspect of the Berber villages belonging to the Senhaja tribe. Unfortunately, most of these buildings are abandoned and sometimes substituted by concrete constructions, which risks the disappearance of a great part of cultural and historical heritage of the region. The Ismaili Kasbah (Fig. 13) constitutes a heritage of high value, and it is a fortified building of military, judicial and administrative roles built during the reign of Sultan Moulay Ismail at the Siba period (period of insecurity) to limit the battles between the neighbouring tribes. In the religious and social context, Ait Attab was, for a long time, a territory of religious freedom, where Muslims and Jews lived together in harmony, and the latter accounted for 10% of Ait Attab's population in the 1880s (De Foucauld 1880), leaving as evidence of this coexistence a Mellah (Fig. 13) and a Jewish cemetery. The religious heritage is also represented by dozens of mausoleums: ancient Sufi shrines containing the body of the deceased of a holy man (Azilal Handicraft Delegation 2007) scattered throughout the territory of the tribe, and the most important mausoleum is the mausoleum Moulay Aissa Ben Driss (Fig. 13) located in Douar Seddat. This mausoleum is considered one of the most important and oldest Sufi monuments, whose history is still relevant, especially through the annual organisation of regular visits to its shrine classified by the Ministry of Culture. This mausoleum was built by Sultan Abo Lhassan El-Marini as part of the care attributed to the Idrissid nobles. Every year, in April, a Moussem (festival) is organised in the

name of Moulay Aissa Ben Driss, which is a day of celebration where the inhabitants of the syncline meet and exchange their local products (olive oil, almond trees, carpets and honey). They enjoy the presence of singing groups named Abidat Rma (Fig. 13) and folk dance called Ahouach as well as fantasia competitions: Tbourida (Fig. 13) between the different tribes. From an economic point of view, agriculture and animal husbandry are the main activities of the local population. The commerce exercised by the inhabitants is associated with the sale of food products and the

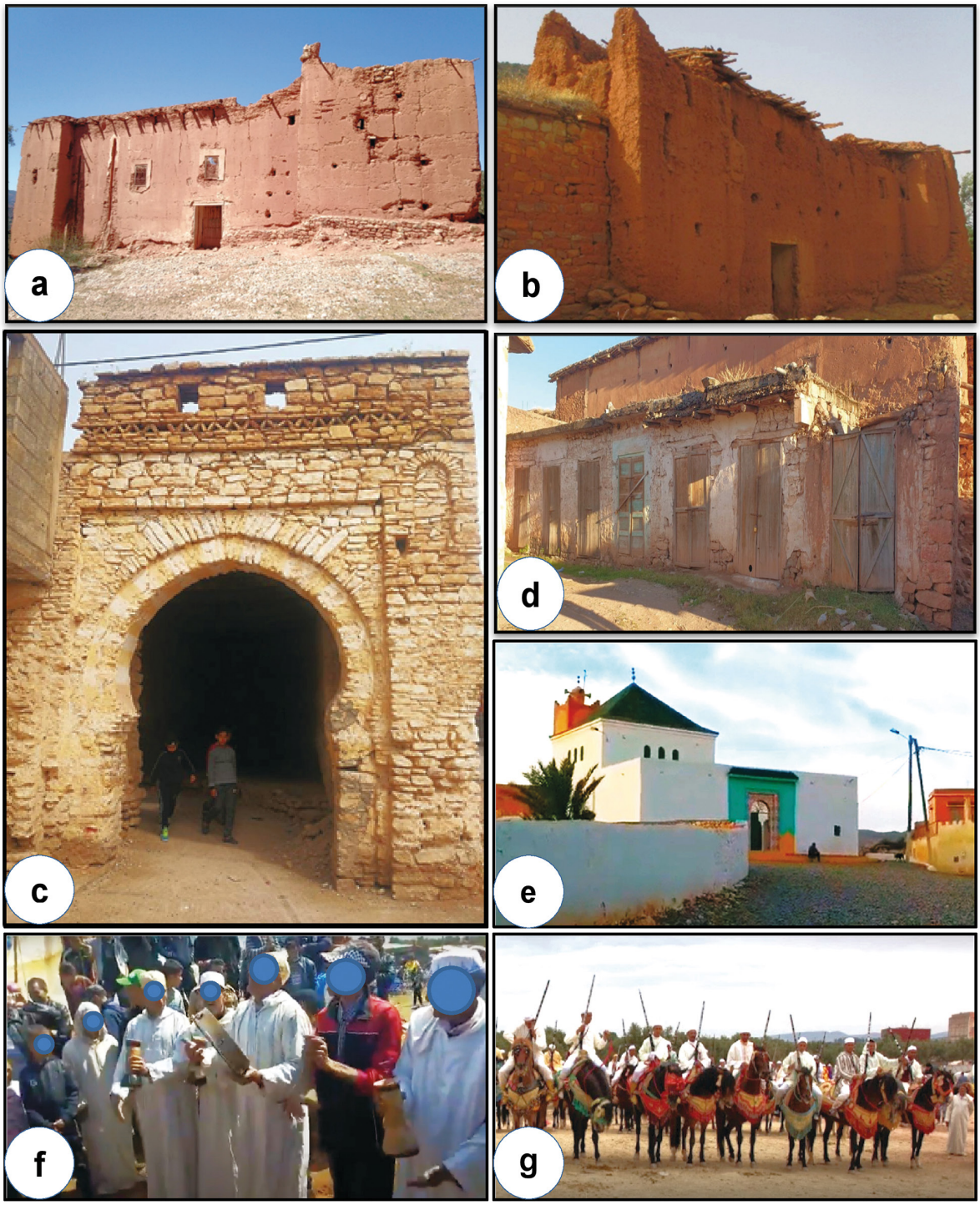

Fig. 13. a) The adobe granary of El Had douar; b) The fortified granary of Ait Sri; c) The gate of the Ismaili kasbah of Seddat douar; d) Moulay Aissa Ben Driss's Mosaule; e) The old Jewish quarter (Mellah); f) The folkloric singing group (Abidat Rma); g) The Tborida (Fantasia) team participating in a compitition.

marketing of olive oil, honey and almond fruit. Regarding craft activities, the traditional tannery (Azilal Handicraft Delegation 2007) has been the most popular activity in Ait Attab due to the abundance of raw material, especially goat skin (Landel 2007). Unfortunately, there are few artisans who practice this activity famous for the use of a minimal quantity of chemical products (Azilal Handicraft Delegation 2007).

Evaluation of geosites and geodiversity sites

Assessment of scientific values

The SV assessment (Table 4) shows that the selected geosites have a high SV, while the geodiversity sites have a moderate SV. The stratigraphic geosites present a national relevance that illustrates the most complete geological formations of the CHA, with a lateral variation of facies. They also show several tectonic events, volcanic eruptions and marine fluctuations. The study of these formations allows scientists to reconstruct the Mesozoic history of the region, interpret the palaeoenvironment and establish biostratigraphic correlations. The most important geosite is the panoramic view of the Ait Attab syncline (350) inscribed in the UNESCO M'Goun World geopark; it presents a high representativeness and integrity in addition to a high degree of scientific knowledge. It is also a key locality for following the change over time of depositional environments in relation to major transgressions and regressions. The palaeontological sites present a rich and diversified fauna essential for establishing biostratigraphic correlations and important for palaeoecological and palaeoenvironmental interpretation (Ettachfini et al. 2005). The recently

Table 4. Quantitative assessment of the scientific value (SV) of the selected geosites and geodiversity sites in the Ait Attab syncline.

Code	Name	Criteria of scientific value							Total
		Representa-tiveness	Key locality	Scientific knowledge	Integrity	Geological diversity	Rarity	Use limit	
Stra01	Panoramic view of overturned bar of Iferghas	4	2	4	2	2	4	4	320
Kar02	Karst cliff of Ighir-n-Oumejjad	2	1	1	4	1	2	4	220
Stra03	Panoramic view of the Ait Attab syncline	4	2	4	4	2	4	4	350
Stru04	The tectonic deformations of Jbel Hassan	4	1	1	4	4	2	4	295
Pal05	The ruiniform limestones with ammonite of the Ben Cherrou Formation	4	2	2	4	4	2	4	320
Geom06	Panoramic view of the Cretaceous cuestas	4	1	2	4	4	2	4	300
Flu07	The bad land of Ait Ouabit	2	1	2	2	1	2	4	195
Geom08	Gorges of Ait Ouabit	4	1	2	4	1	2	4	285
Stra9	Conglomerate terraces of Oued El Abid	4	1	2	4	2	2	4	290
Pal10	The footprints of sauropod dinosaurs of Ayt Bouiqban	4	1	1	4	4	4	4	325
Stra11	Lower limit of the basaltic flow B2	4	2	4	4	2	2	4	320
Stra12	Jurassic-Cretaceous unconformity and volcanic activities	4	1	1	4	4	4	4	325
Pal13	Bioclastic limestone with ammonite of the Bine El Ouidane BIII Formation	4	1	1	4	1	2	4	280
Flu14	Panoramic view of Oued El Abid from the old Caida of Taounza	2	1	1	2	2	2	4	195
Spel15	Caves of cats and the spring of Tisqui	4	2	1	2	2	2	4	275
Pal16	Bioclastic marly limestone of Ait Tafelt Formation	2	2	4	4	4	2	4	270
Geom17	Eroded sandstone of Jbel Ilaghmane	2	1	1	4	4	4	4	265
Stra18	Panoramic view of the red formations separated by the BI and BII magmatic events	4	2	4	2	4	3	4	315
Kar19	Ruiniform reliefs of Jbel Al Maqçoura	2	0	0	4	2	2	4	200

discovered site of sauropod dinosaur footprints (325) testifies that the syncline was also populated by these giant animals. The geomorphological site of the Cretaceous cuestas (300) gives a global vision on the result of the combined action of stratigraphy, tectonics and erosive phenomena in landform development.

Assessment of educational value (potential educational use)

The results of the potential educational use assessment (Table 5) revealed a high value in geosites Stra01, Stra03, Pal 05, Geom06, Pal10, Stra11, Stra12 and Stra18 and geodiversity sites Kar02, Stra04, Flu07, Geom08, Stra09, Pal 13, Flu14, Pal16 and Geom17. These values are explained by the high degree of uniqueness of these sites, which artistically and clearly represent rare and uncommon geological components at the regional and national levels. Additionally, their ease of access, geology diversity and great didactic potential increase their values. These sites can be educational stations to teach different sections of the earth sciences, such as stratigraphy, palaeontology, tectonics, karstology and the restitution of the geographical and palaeoecological history of the study area. This is the reason why the syncline is used as a fertile field for geological field trips organised by the Department of Geology of the University of Sultan Moulay Slimane. Fossil sites can be used as educational stations to

Table 5. Quantitative assessment of potential educational uses of selected geosites and geodiversity sites in the Ait Attab syncline.

Code	Name	Criteria for potential educational use												Total
		Vulnerability	Accessibility	Use limit	Security	Logistics	Density of populations	Association with other values	Scenery	Uniqueness	Observation conditions	Didactic potential	Geological diversity	
Stra01	Panoramic view of overturned bar of Iferghas	2	4	4	4	3	1	2	4	2	4	4	3	330
Kar02	Karst cliff of Ighir-n-Oumejjad	4	4	4	3	3	1	2	3	3	4	4	2	330
Stra03	Panoramic view of the Ait Attab syncline	4	4	4	2	3	1	2	4	3	4	4	4	345
Stru04	The tectonic deformations of Jbel Hassan	2	4	4	4	3	1	2	1	2	4	4	2	305
Pal05	The ruiniform limestones with ammonite of the Ben Cherrou Formation	3	3	4	2	3	1	3	4	3	4	4	2	310
Geom06	Panoramic view of the Cretaceous cuestas	4	3	4	2	4	1	4	2	3	4	4	2	320
Flu07	The bad land of Ait Ouabit	3	4	4	3	3	1	4	1	2	4	3	3	305
Geom08	Gorges of Ait Ouabit	4	4	4	3	3	1	2	3	2	4	4	2	325
Stra9	Conglomerate terraces of Oued El Abid	4	2	4	2	3	1	4	2	2	4	4	3	310
Pal10	The footprints of sauropod dinosaurs of Ayt Bouiqban	4	2	4	2	3	1	3	0	4	4	4	3	305
Stra11	Lower limit of the basaltic flow B2	4	3	4	3	3	1	3	3	3	4	4	3	335
Stra12	Jurassic-Cretaceous unconformity and volcanic activities	4	4	4	2	3	1	3	3	2	4	4	3	330
Pal13	Bioclastic limestone with ammonite of the Bine El Ouidane BIII Formation	4	4	4	3	3	1	3	3	2	3	3	2	300
Flu14	Panoramic view of Oued El Abid from the old Caida of Taounza	4	3	3	4	3	1	3	4	2	4	2	2	290
Spel15	Caves of cats and the spring of Tisqui	3	4	4	3	3	1	3	3	3	4	2	2	285
Pal16	Bioclastic marly limestone of Ait Tafelt Formation	2	4	4	4	3	1	3	1	2	4	4	2	310
Geom17	Eroded sandstone of Jbel Ilaghmane	4	3	4	2	3	1	2	2	2	4	4	4	320
Stra18	Panoramic view of the red formations separated by the BI and BII magmatic events	4	4	4	3	3	1	3	3	3	4	4	3	345
Kar19	Ruiniform reliefs of Jbel Al Maqçoura	4	4	4	3	3	1	3	4	1	4	2	2	290

understand the different modes of fossilisation, to view well-preserved dinosaur footprints and to collect fossils for use in ex situ courses.

Assessment of tourism value (potential tourism use)

The results of the quantitative assessment of tourism value (Table 6) show that the geosites Stra01, Stra03 and Stra18 and the geodiversity sites Kar02, Geom08, Flu14, Spel15 and Kar19 have a high potential tourism use due to their unique scenic beauty, their proximity to leisure areas and the ease of access that guarantees safety for visitors. These characteristics give these sites the possibility of hosting various tourist activities, such as hiking, climbing, camping and guided tours during, which tourists can enjoy a set of panoramic views, visit cultural and religious sites and carry out cultural exchange with the local population. The remaining 11 sites have a moderate potential for tourist use related to the criteria of accessibility, safety and uniqueness. It is important to note that the situation of study area as a transit zone for tourists who are heading to the Ouzoud Waterfalls and Bin El Ouidane Dam ensures a considerable tourist flow capable of improving the socio-economic situation of the inhabitants and will further develop a sustainable geotourism. It is sufficient to highlight the

Table 6. Quantitative assessment of potential tourist use of selected geosites and geodiversity sites in the Ait Attab syncline.

Code	Name	Criteria for tourism potential use													Total
		Vulnerability	Accessibility	Use limit	Security	Logistics	Density of populations	Association with other values	Scenery	Uniqueness	Observation conditions	Interpretive potential	Economic level	Proximity to recreational areas	
Stra01	Panoramic view of overturned bar of Iferghas	2	4	4	4	3	1	2	4	2	4	3	1	4	305
Kar02	Karst cliff of Ighir-n-Oumejjad	4	4	4	3	3	1	2	3	3	4	3	1	3	305
Stra03	Panoramic view of the Ait Attab syncline	4	4	4	2	3	1	2	4	3	4	3	1	2	305
Stru04	The tectonic deformations of Jbel Hassan	2	4	4	4	3	1	2	1	2	4	3	1	2	250
Pal05	The ruiniform limestones with ammonite of the Ben Cherrou Formation	3	3	4	2	3	1	3	4	3	4	3	1	2	290
Geom06	Panoramic view of the Cretaceous cuestas	4	3	4	2	4	1	4	2	3	4	3	1	2	280
Flu07	The bad land of Ait Ouabit	3	4	4	3	3	1	4	1	2	4	2	1	2	250
Geom08	Gorges of Ait Ouabit	4	4	4	3	3	1	2	3	2	4	4	1	3	305
Stra9	Conglomerate terraces of Oued El Abid	4	2	4	2	3	1	4	2	2	4	3	1	2	255
Pal10	The footprints of sauropod dinosaurs of Ayt Bouiqban	4	2	4	2	3	1	3	0	4	4	4	1	2	250
Stra11	Lower limit of the basaltic flow B2	4	3	4	3	3	1	3	3	3	4	2	1	2	285
Stra12	Jurassic-Cretaceous unconformity and volcanic activities	4	3	4	3	3	1	3	3	3	4	2	1	2	285
Pal13	Bioclastic limestone with ammonite of the Bine El Ouidane BIII Formation	4	4	4	3	3	1	3	3	2	3	2	1	1	275
Flu14	Panoramic view of Oued El Abid from the old Caida of Taounza	4	3	3	4	3	1	3	4	2	4	4	1	2	315
Spel15	Caves of cats and the spring of Tisqui	3	4	4	3	3	1	3	3	3	4	4	1	2	305
Pal16	Bioclastic marly limestone of Ait Tafelt Formation	2	4	4	4	3	1	3	1	2	4	3	1	1	250
Geom17	Eroded sandstone of Jbel Ilaghmane	4	3	4	2	3	1	2	2	2	4	2	1	1	240
Stra18	Panoramic view of the red formations separated by the BI and BII magmatic events	4	4	4	3	3	1	3	3	3	4	3	1	2	305
Kar19	Ruiniform reliefs of Jbel Al Maqçoura	4	4	4	3	3	1	3	4	1	4	3	1	3	305

heritage wealth that the syncline harbours to exploit them in any tourism development project. The objective is to make the territory not only a transit area but a tourist attraction.

Degradation risk assessment

The degradation risk assessment (Table 7) revealed a medium to high value at all selected geosites and geodiversity sites. Palaeontological sites Pal05, Pal10, Pal13 and Pal 16 are the most vulnerable areas and have a high degradation risk (≥300). These values are related to the lithological nature of geological formations, which are highly prone to natural erosion factors, and the proximity of these sites from areas of anthropic activity also increases the risks of degradation. The geosite of Ait Bouikbane dinosaur footprints is one of the sites that require special consideration. Its location near a busy trail and its proximity to the Ait Bouikbane douar increase its risk of degradation. The Pal05 and Pal16 sites are threatened by fossil collectors who tear off hundreds of fossil samples, destroying a large part of the palaeontological diversity. The Stra12 site is threatened by the extraction of magmatic rocks for road construction. The caves of cat is a special case; this

Table 7. Quantitative assessment of degradation risks (DR) of selected geosites and geodiversity sites in the Ait Attab syncline and required protections.

Code	Name	Degradation risks					Total	Required protection
		Deterioration of geological elements	Proximity activities cause degradation	Legal protection	Accessibility	Density of populations		
Stra01	Panoramic view of overturned bar of Iferghas	2	1	4	3	2	235	Medium
Kar02	Karst cliff of Ighir-n-Oumejjad	2	1	4	3	1	225	Medium
Stra03	Panoramic view of the Ait Attab syncline	2	3	3	4	1	260	Medium
Stru04	The tectonic deformations of Jbel Hassan	2	3	4	4	1	280	Medium
Pal05	The ruiniform limestones with ammonite of the Ben Cherrou Formation	3	3	4	3	1	300	High
Geom06	Panoramic view of the Cretaceous cuestas	2	3	4	3	1	265	Medium
Flu07	The bad land of Ait Ouabit	3	3	4	4	1	315	High
Geom08	Gorges of Ait Ouabit	2	2	4	4	1	260	Medium
Stra9	Conglomerate terraces of Oued El Abid	2	3	4	3	1	265	Medium
Pal10	The footprints of sauropod dinosaurs of Ayt Bouiqban	3	3	4	3	1	300	High
Stra11	Lower limit of the basaltic flow B2	3	3	4	4	1	315	High
Stra12	Jurassic-Cretaceous unconformity and volcanic activities	4	2	4	4	1	330	High
Pal13	Bioclastic limestone with ammonite of the Bine El Ouidane BIII Formation	3	3	4	4	1	315	High
Flu14	Panoramic view of Oued El Abid from the old Caida of Taounza	3	3	4	2	1	285	Medium
Spel15	Caves of cats and the spring of Tisqui	4	3	4	3	1	335	High
Pal16	Bioclastic marly limestone of Ait Tafelt Formation	3	4	4	4	1	335	High
Geom17	Eroded sandstone of Jbel Ilaghmane	3	3	4	3	1	300	High
Stra18	Panoramic view of the red formations separated by the BI and BII magmatic events	3	2	4	4	1	295	Medium
Kar19	Ruiniform reliefs of Jbel Al Maqçoura	2	2	4	4	1	260	Medium

site is threatened mainly by the rituals that are exercised inside the cave by women and belongings that are left behind by them, which disrupt the beauty of the landscape.

Discussion

Many researchers emphasise the importance of geoconservation (Gray 2004, Giurginca et al. 2010, Dowling 2011, Prosser et al. 2013, Ruban 2015, Brilha 2016, Khalaf 2022) as a means to enhance and promote areas of exceptional geodiversity. Geoconservation measures also aim to increase awareness of geoheritage to make it suitable for sustainable use (Kubalíková, Kirchner 2016) in geoeducation and geotourism. Given that the level of geoconservation differs from site to site and from country to country depending on the conservation needs and financial sources mobilised for each region. It can also vary according to priorities and territorial circumstances.

In Morocco, the interest in geoconservation continues to increase in recent years, with the aim of ensuring sustainability of geoheritage within the national territory. It is a rational management based on the evaluation of threats and sensitivities of geosites to natural and anthropic factors. The climate, which is generally arid with alternating wet and dry periods, progressively destroys the history engraved on the geological formations, causing the loss of exposure and the irreversible elimination of various wealths (fossils, minerals, caves, etc.); thus, preservation and enhancement of these geosites is a priority. Conservation work must be preceded by an inventory and assessment to define the vulnerability of the geosites to different threats.

In this work, the inventory of the geological heritage in the Ait Attab syncline has given rise to 8 geosites and 11 sites of geodiversity divided into 7 geological interests. These sites reflect a geodiversity that tells the geological history of more than 200 MA from the Triassic to the Quaternary, including the various tectonic movements, marine fluctuations and magmatic events. Of these 19 sites, only one geosite is included in the territory of the M'Goun UNESCO Global geopark; others have not benefitted from any inventory or protection despite their strong scientific, tourist and educational potential. The analysis of the selected sites revealed important strengths that may explain the choice of the study area:

- the great geological and geomorphological diversity;
- the high degree of representativeness and the good contrast of the formations intervene to facilitate the pedagogical and educational interpretation of the landscape;
- the diversity of cultural heritage offers a range of opportunities to enhance the geotourism experience;
- the ease of access associated with the progressive development of the road infrastructure;
- the beauty of the natural sites that offer excellent panoramic views;
- proximity to the M'Goun UNESCO Global geopark and major urban centres.

These strengths are hindered by some behaviours on the part of decision-makers and the local population, who are often unaware of the geoconservation concept, causing its exclusion from the management and development of the territory. To fill this gap, this work highlights the heritage potential of the syncline and quantitatively evaluates its sites to promote and enhance them for geotourism and geoeducation activities. Geotourism development could be the best solution to address various socio-economic problems (poverty, migration, etc.) in rural areas (Errami et al. 2015, Ngwira 2015, Zagmo 2016). Thus, geotourism activities are likely to create jobs and encourage investments, which will improve the socio-economic situation of the rural population. These activities, if carried out in a conscious manner that respects the environment, can contribute to sustainable development within the region. The interconnection between geoheritage and cultural heritage (more specifically architectural heritage) is a basis for diversifying the tourism offer. Indeed, the closer the links between geology and culture, the more the visitors will be interested in geoheritage and its preservation (Corbí et al. 2019).

Inventory is only a first step to disseminate knowledge of geoheritage and introduce regional geodiversity, while evaluation serves as a guide to decision-makers to formulate suitable approaches for sustainable management and conservation of this heritage, a conservation that requires the installation of covers for small sites, and fences for large sites to both enjoy the

aesthetic and scientific interest of sites without altering and threatening these properties. Such an initiative can certainly reinforce equipment and income-generating tourist activities and encourage associations and local communities to disseminate the notion of geoconservation among public. The application of these guidelines presents gaps related mainly to the absence of a legal status charged to geoconservation, and the lack of a real administrative will of regional development. In this sense, the Ministry of Energy and Mines launched in 2017, a draft decree on the implementation of Article 116 of Law No. 33-13, aims to regulate the exploitation of the Moroccan geological heritage, which is to be implemented. In 2019 and during the second National Day of Geological Heritage of Morocco, the Association for the Protection of Moroccan Geological Heritage (APPGM) in partnership with the Ministry of Energy and Mines proposed a project of framework law that will allow the protection of the Moroccan geological heritage, which needs sincere will of regional and local authorities.

Conclusion

Based on the fieldwork and the results of the assessment of scientific, touristic and educational interest as well as the risks of degradation, three georoutes linking 19 geosites and geodiversity sites were selected and described in this work. The choice of these georoutes takes into account the accessibility and tourist potential of the sites, which must be very interesting and representative in terms of natural geological and cultural diversity. Thus, each site has two or three distinct interests that have geological characteristics of regional to national relevance. The chosen sites generally have scientific and/or educational significance and cover various disciplines of earth science, including stratigraphy, sedimentology, tectonics, palaeontology, geomorphology, magmatism and karstology. This makes the proposed georoutes like field classrooms that further enhance the understanding of geosciences among both students and the general public. On the other hand, these geotours offer tourists the opportunity to experience an emotional and aesthetic experience with attractive geological and geomorphological landscapes and exceptional panoramic views that merge with an important cultural wealth. So tourists can visit lineage granaries of various architectures, the Ismaili Kasbah, Jewish Mellahs and sanctuaries; these buildings are generally made from local materials, which reflects the traditional lifestyle of the Atlas Berber population. However, there is still a need to improve the infrastructure by creating hiking trails equipped with interpretation panels and training centres, and it is also important to take advantage of the potential offered by new digital technologies (websites, mobile applications, digital advertising sheets, etc.) to ensure that the geosites, trails and georoutes are widely known.

The enhancement and promotion of geoheritage through georoutes allow the development of recreational tourism, which supports the economy of the rural population and, at the same time, permits the dissemination of scientific information to the general public. On the other hand, the results of the numeric assessment provide a database that can help decision-makers to propose appropriate geoconservation and management measures for each site.

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Authors' contribution

EL and JR: geologic field investigation, inventory, characterisation, classification and discussion, manuscript preparation. AB: data analysis, manuscript preparation, proofreading. AAB and SN: geologic field investigation and data analysis.

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