

Dynamics of sedimentary basins and underlying lithosphere at plate boundaries: The Eastern Mediterranean
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The Middle Atlas Geological karsts forms: Towards Geosites characterization

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Abstract. Rich limestone Jurassic formations and huge water reservoir are natural characteristics of the Middle Atlas Chain in Morocco, which, therefore, offers geodiversity of karst geosystems. The geological, tectonic and hydro-geo-morphological nature of the history of Atlas orogeny has affected the eastern part of the Middle, ensuring the evolution of karst features on various sites of this zone. This study presents some touristic offers specific to the Middle Atlas, particularly in terms of genesis, structures, and functions that could develop and promote public tourism offers. It argues that this development depends on future geological funds identification and classification as Geosites. On the basis of the patrimonial process characterising the Middle Atlas, this study suggests the creation of a Geopark in the Middle Atlas, within the framework of the evaluation criteria of the UNESCO. The implementation of this suggestion would contribute to the socioeconomic development of this region of Morocco.

1 Introduction

Morocco is located northwest of the mainland of the African plate. This part of the plate is characterized by a long evolution from the Proterozoic to the present time.

The consequences have been: (i) the installation during the Proterozoic of agglomerated Cratonic blocks, (ii) a peneplanation starting at the beginning of the Phanerozoic (De Wit *et al.*, 2001), (iii) the Cenozoic convergence of Africa-Europe, in the context of the evolutions of the Atlantic ridge and the aborted Atlasic rift. During these evolutions, several sequences of carbonate deposits occurred in the Thetys Ocean, in the north-eastern part, and in the Atlantic Ocean in the western part.

All along the intense tectonic and geological evolution, several episodes of orogenesis took place, notably that in the Atlas uplift (Frizon de Lamotte *et al.*, 2008; Gasquet *et al.*, 2005).

In this work, we focus on the identification of specific characters of the karst features and, due to the specificities of the geological context, their characterizations as geo heritage and patrimonial sites that would lead to a Geosite by local, national, and international arenas.

2 The geological context of the Middle Atlas

The geodynamic evolution in the Middle Atlas began at the Triassic by inherited structures of the Variscan orogenesis,

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resulting in an uplifted mountain range oriented from south-west to north-east and extended to the centre of Morocco (Fig. 1). Hence, the Middle Atlas is formed by a juxtaposition of two structural domains that separate the Northern Middle Atlasic Fault (ANMA), stretched over more than 500 km, from Guercif plain up to Azilal in the southwest (Arboleya *et al.*, 2004; Colo, 1961; du Dresnay, 1963; Termier, 1936). The geodynamic processes have led to three major geomorphic entities: The Tabular Middle Atlas (TMA), The High Moulouya/Missour Basin (HMMB) area, and The Folded Middle Atlas (FMA) (Fig. 2).

The TMA is the north-eastern portion of the Moroccan Meseta. This is mainly relatively flat lying Mesozoic strata and an important phase of Quaternary volcanism.

The FMA is separated from TMA by ANMA. This area is more mountainous than the Middle Atlas Causse and is characterized by flexible deformation, forming faulted folds, oriented NE-SW, with a succession of fractured anticlines-synclines (Fig. 2).

The HMMB area (Médard *et al.*, 2014) is located between the tabular plateau in the North and the thrust of the High Atlas to the South. This is a large corridor with different evaporitic series installed during the evolution of the Messinian subsident basin inside the folded upper Jurassic limestone.

2.1 Geology

From a geological viewpoint, the outcropping rocks are of metamorphic, sedimentary and volcanic origin and cover a lapse of time ranging from Silurian to Holocene

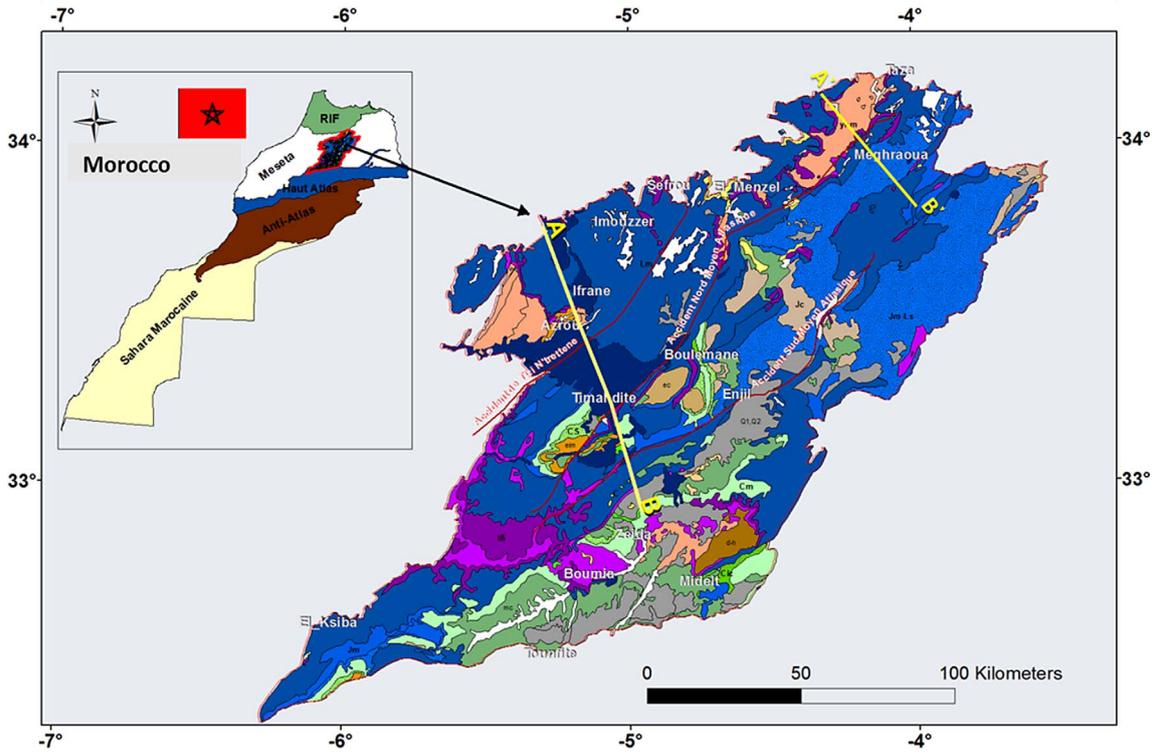


Fig. 1. Geological map of the Middle Atlas (after geological map of Morocco 1/1000 000, 1985).

(Arboleya *et al.*, 2004; Martin, 1981; Missenard *et al.*, 2006).

The uplifted range consists mainly of limestone from Mesozoic with a tabular Northwest (Middle Atlas “Causse”) and wavy southeast structure (FMA). The altitude is between 800 and 1200 m on the Causse and exceeds 3000 m on the eastern links of the folded domain (Charrière, 1990; Charroud, 1990; Frizon de Lamotte *et al.*, 2004, 2008; Sabaoui, 1998).

The “Causse Unit” is constituted by carbonated material presented as stories plateau structured and sown by volcanism. The volcano activity has mainly set in during the Quaternary with specific morphologies of the Alpine orogenic volcanism (Cones, Maar, Lava flows).

In the eastern Middle Atlas, the domed Tazekka massif 1986 m (Tazekka National Park) separates the Causses border from a fold chain of NE-SW orientation (Fig. 3). The latter is formed by paleozoic metamorphic rocks such as schists, pelites and quartzitic sandstones. The South of this massif consists of limestone formation with many karstic features and various landforms (Chaaara, Ain Aouda and Chiker cave; Kaff Sao, Kaff Izoura, Friouato sinkhole, Chaaa underground rive, etc.) in Taza region (Martin, 1977; Tennevin, 1978).

2.2 Climate

Generally, the Middle Atlasic climate is defined as Mediterranean. The region of study is characterized by a spatial contrast of rains, which are guided by the factors as height and exhibition.

The annual average of pluviometry is 563.3 mm in the lowest area (Taza = 500 m), while the reliefs of Bab Boudir and Tazekka (>1300 m of height) get more than 1000 mm (more rain is expected in winter). This difference is due to the exhibition of these reliefs in front of winds encumbered with western humidity (Tab. 1).

Temperature degree is proportional with height, the average temperature is 9.5 °C in January and 28 °C in July and August; it can decrease until 3.9 and 22 °C (Fig. 4). The temperature may drop below 0 °C during the period between October and April (Taous *et al.*, 2009). The inner temperature of caves and abyss of the region varies between 10 and 13 °C, where humidity exceeds 90%.

3 Karstification features

Hydrographic network is almost absent, except for some oueds; as for Oued Lakhal on the custard tart of Tazekka, and Oued Lhaddar that arises from Ras El Maa spring. The waters infiltration in the powerful calcaro-dolomitic fragmented reservoir has led to subterranean flows, flowing from the south to the north.

Several lithological, structural, and geochemical factors fall within the mode of the karstic structures formation and the contact period of water/rock. Indeed, the genesis of these karst features is marked by an intense hydrothermal activity along fractures surfaces that inhibits carbonate fraction dated Jurassic (Dolomite, flint or fossiliferous limestone). The result of these geochemical processes consists of

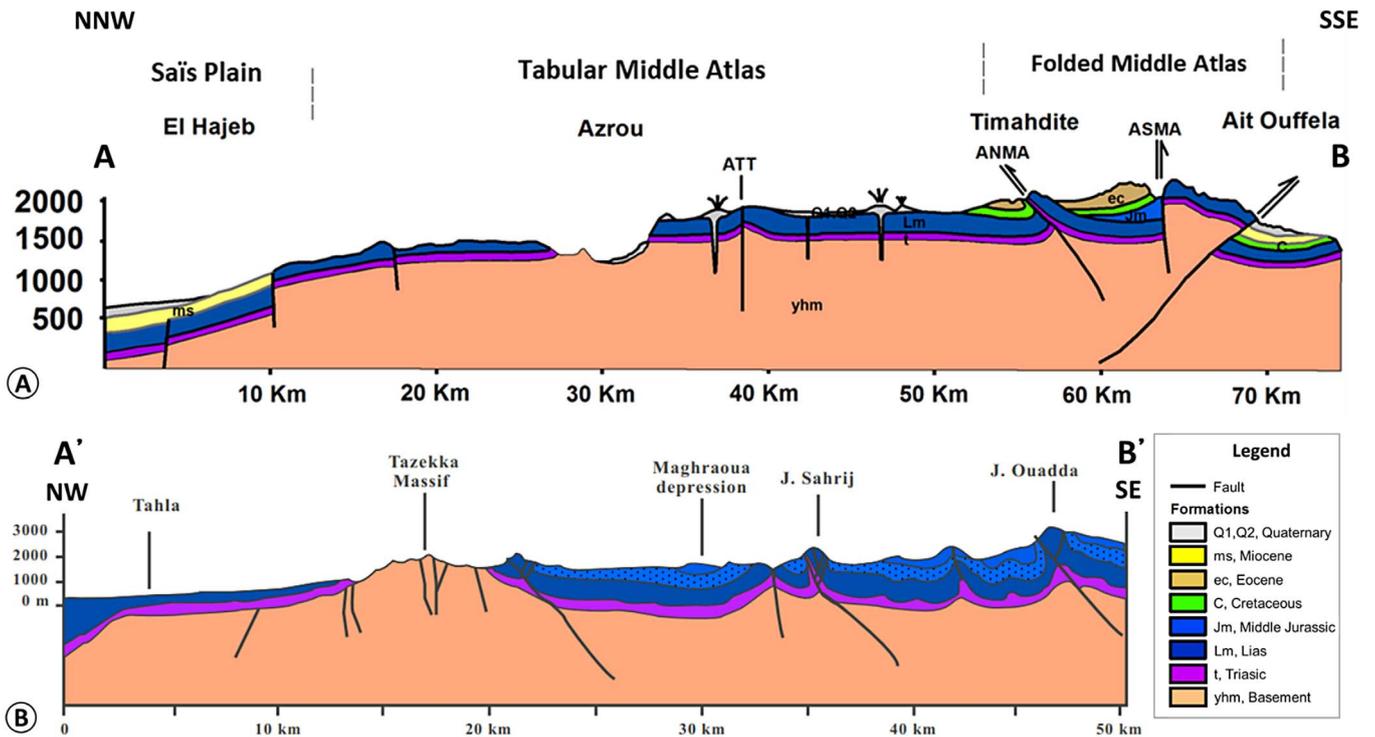


Fig. 2. A) Cross section from the Middle Atlas geological units (after: (AB) Charroud and Mounir, 2016); B) Geological cross section from the Oriental Middle Atlas (after Sabaoui, 1998, modified) (for the localization see Fig. 1).

the development of underground form (cave) of large dimension such as those located in Chiker, Chaara and Ademame region.

Silification and weathering processes (ghost-rock) in the Miocene lacustrine limestone of the Moulouya – Missouri Basin (Medard *et al.*, 2014).

3.1 Karstification

The Middle Atlas comprises wide range of karstic landforms and processes driven by the evolution of the environmental conditions and the geology.

Lithology, morphostructure, Mediterranean bioclimatic, and the floors condition the karstogenesis in Eastern Middle Atlas. These conditions favour the dissolution development of the powerful carbonated Jurassic series that lays on impermeable Triassic formations (Martin, 1981; Taous *et al.*, 2009). Therefore, this explains the geomorphologic evolution of the mountain range since the Miocene in our days (Fig. 3).

Superficial and subterranean waters circulation on fracturing plans allowed the moulding of a diversified karstic system: Superficial karstic forms have developed not only at limestones and dolomites Liasic level, but also in the core of marno-calcareous series of Dogger and sometimes in the clays of Trias (Tennevin, 1978).

On the Southern border of the Tazekka range, there is a big poljé of a surface of 20 km² is fed by runoff water. The losses from depression feed the subterranean rivers

and the Liasic karstic network, therefore, giving birth to the big spring of Ras El Ma. The solvent and mechanical actions of subterranean waters favoured the installation of several subterranean karstic forms that are often of an endo-karstic type, represented by abysses, caves, and exceptional gallery networks. In the study area, the karst systems and the major landform are driven by the tectonic, guiding hydrological and hydrogeological systems which are divided into three basins:

- (i) the basin of the Upper Moulouya;
- (ii) the basin of Oum Er Rbia;
- (iii) the Sebou basin.

The resurgence of surface water in the Middle Atlas is closely linked to networks fractures with a dissolution process starting on the bedding planes (S0) (Fig. 3), where chemical exchanges seem important. The first signs of this process can be observed at wide fractured areas and/or at the rock itself (Grillot and Almeida, 1982; Shanov and Kostov, 2015).

3.2 Dissolution-transport-precipitation

In the Middle Atlas, chemical processes act mainly on the features and faults within the carbonate faults. The junction between the antithetic and synthetic faults in the Taza region generates increased groundwater flow (Fig. 3).

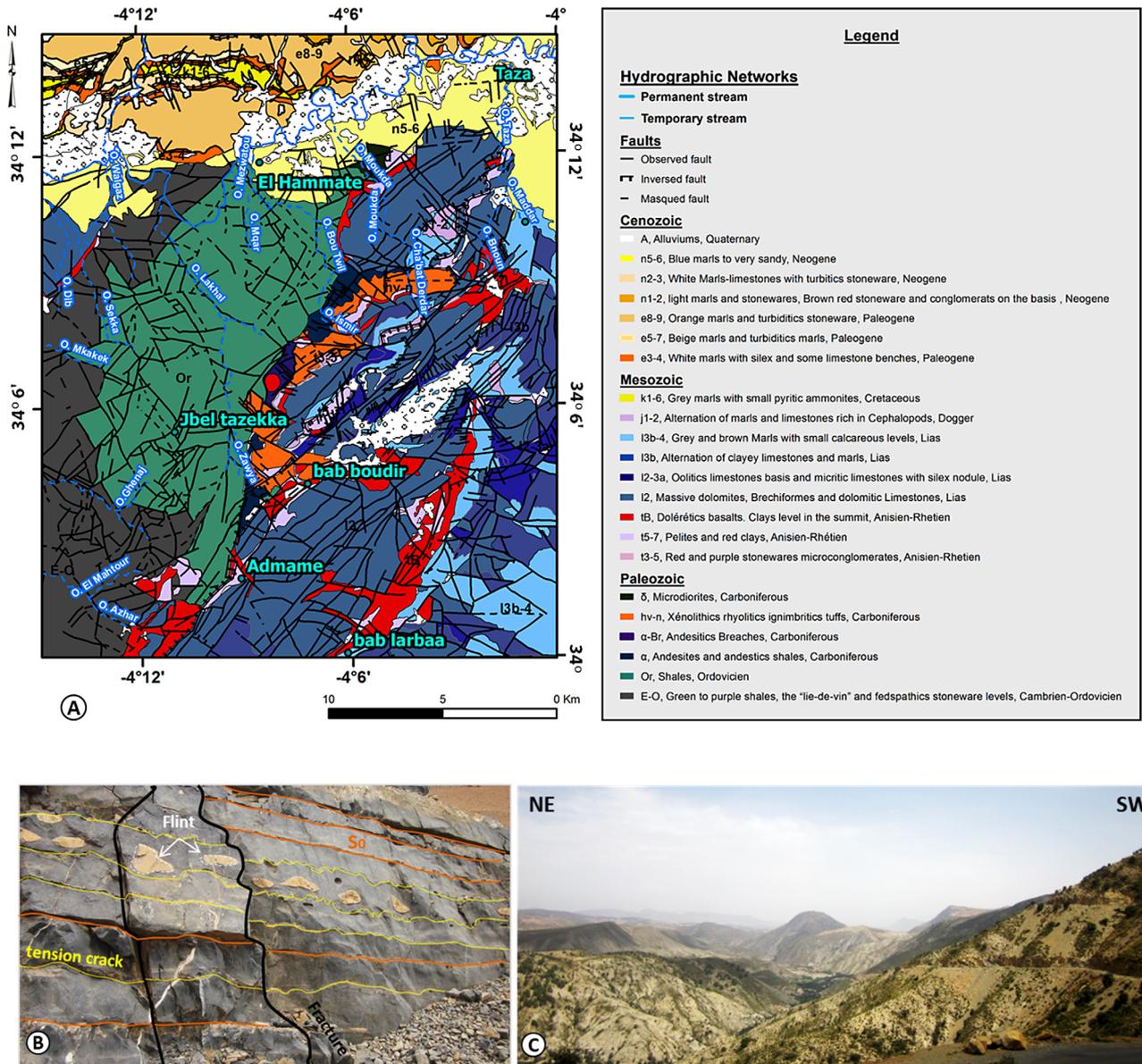


Fig. 3. A) Geological map of Taza (after geological map of Taza 1/50 000, 2005); B) The Bouiblanc limestone with flint Middle Lias; C) Geomorphology accentuated in relief of NW-SE direction (from Tazekka National Park).

In the northern Atlas region more than 300 groundwater or surface cavities have been discovered until today.

Due to the specificities of the climate (arid and semi-arid), the karst geosystems are trained in environments affected by a very short period of strong hydrodynamic activity and a long dry period with the seepage of the aquifer that is accelerated by degassing the oversaturation responsible solutions to the precipitation buildings formation and travertine crusts the groundwater and Liassic dolomitic aquifers (Aley et al., 1993; Ford and Williams, 1989; Kirkland, 2014, White, 1988).

Karst is a very good indicator of climate change; we are currently working on the dissolution factors and method of this concretion in order to reconstruct paleoclimates that have succeeded in the genesis of court and the spreading

Table 1. Average annual rainfall between 1980 and 2000. Source: National Forestry Research Centre (CNRF).

Station	Latitude (N)	Longitude (W)	Altitude (m)	Rain (mm/an)
Bab	34°04'	4°07'	1570	1191.5
Boudir				
Tazekka	34°11'	4°12'	1380	861.3
Taza	34°13'	4°01'	500	563.3

of the karst (Day, 1983; Smart, 1988; Smart and Worthington, 2003). For these reasons, we are in the petrographic study phase and radio-chronological dating.

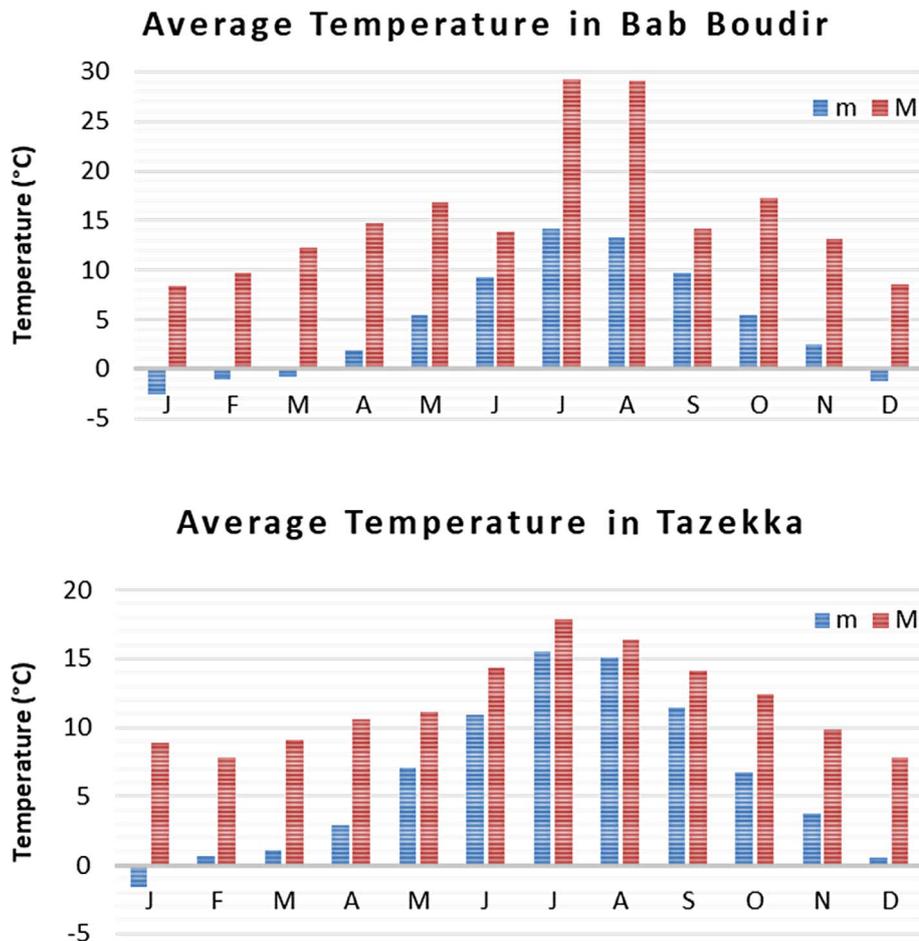


Fig. 4. Monthly average minimum and maximum temperatures at Bab Boudir and Tazekka between 1980 and 2000 (source: CNRF Rabat).

4 Specificities and patrimonial interest

4.1 Geological interest

Geosites (geotopes), geomorphosites, and geopark are strategies aiming at the preservation, education and areas' sustainable development. In addition, they have geologic and geomorphologic meanings, which is a special key to understand the earth history (Reynard, 2004; Ruban, 2010). The geological heritage and values are bound in the "Patrimonialisation process and territories construction" (Debevec et al., 2018; Di Méo, 2007). Society, and particularly, geoscientists, agencies' administrators of management resources and political owners tend to rate the site value (Reynard and Giusti, 2018).

Scientists consider karst as a great wealth of natural and cultural resources which, once scientifically deciphered, can be valued as a natural heritage product (Williams, 2008; Mounir et al., 2015a; UNESCO, 2012, 2015). Knowing that a geopark is a set of territories possessing a remarkable geological heritage, and this is the case of the karst landscapes of the Middle Atlas (Fig. 6). The scientific study, in a patrimonial aspect (identification, characterization

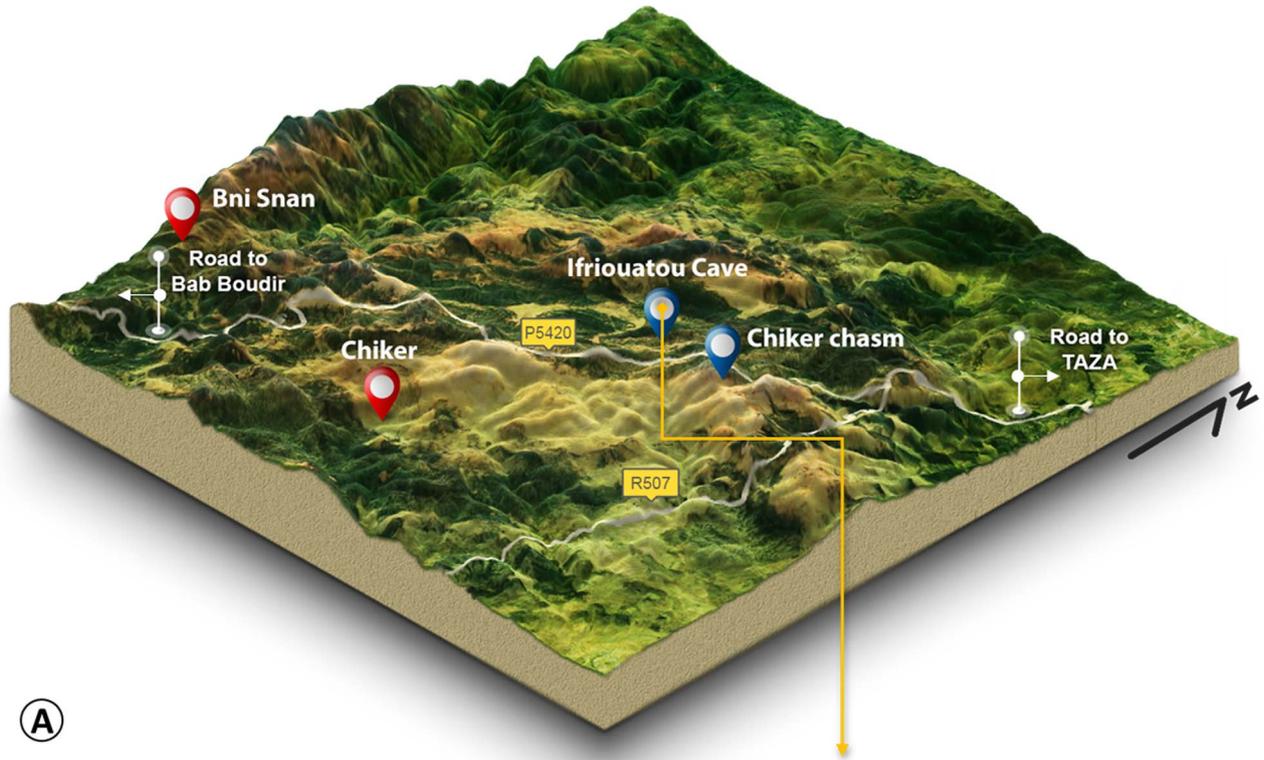
and enhancement) can be beneficial to describe a Geopark in Middle Atlas.

4.2 The specificities of the karst in the Eastern Middle Atlas

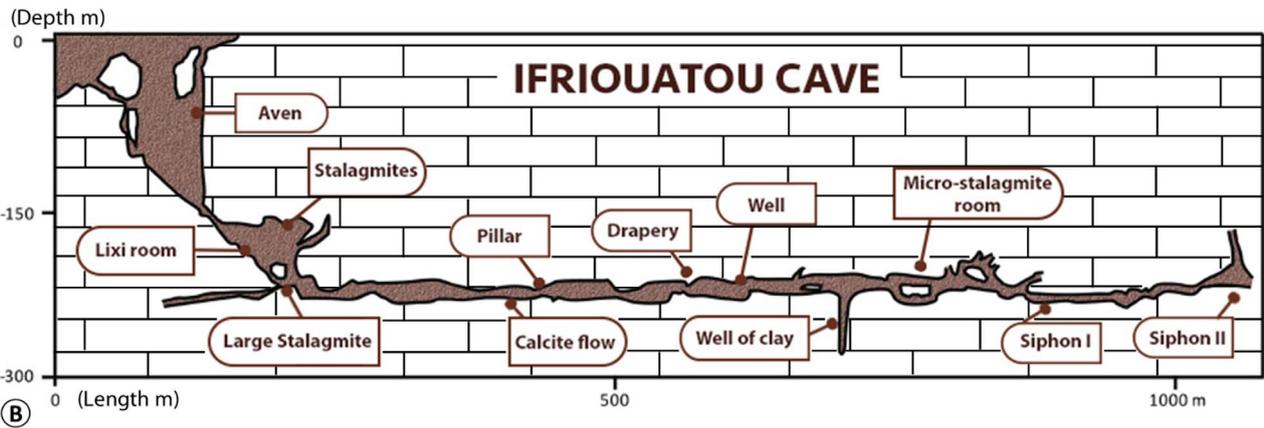
The Middle Atlas karsts are known in Morocco as a good example that could be karstic geoheritage with several stages of reef and karst evolution in the region, and exceptional tectonic, geochemical, and geomorphological features and their important scientific and educational value (Mounir et al., 2015b).

For instance, some areas in the Eastern Middle Atlas are characterized by high karst density (Ifriouatou- Chiker-Chaara- Kaf Sao-Kaf Ain Aouda...) (Tazekka National Park, 2017; Tribak et al., 2006).

In these conditions, we can find remarkable mineralization called concretions. These formations are displayed with different tints and different formation type (calcite and/or aragonite), where their characteristics offer a typical example of the karstic environments and establish a beautiful demonstration of this natural phenomenon (Fig. 6).



(A)



(B)

Fig. 5. A) Raised-relief map showing the locations of Ifriouatou and Chiker geosites and the east portion of the Tazekka National Park; B) Vertical cross-section of the Ifriouatou Cave and gallery.

The exceptional characteristics of Dolomitic and limestones geological formations, tectonic specificities, geomorphological and hydrological guided the development of several underground and superficial cavities networks (avens, caves, abysses, sinkholes, poljés, and subterranean rivers) in the Eastern Middle Atlas as for:

(a) Ifriouatou Chasm (271 m) is considered as the only Karst that fit out for the tourists. It is also classified as the third deep abyss of Morocco, with a length of 3500 m, the abundance, the diversity and the

spectacular landscape with attractive calcite formation and gypsum accumulations that exceed 8 m in elevation (Fig. 5).

- (b) The Chiker Cave (146 m of deepness) with a 3856 m of length, gathers the Daya Chiker water (Fig. 5), where they continue to shape underground networks of different forms (Ek and Mathieu, 1964).
- (c) The underground river and cave of Chaara (the second lengthiest cave in Morocco and the fourth in Africa), is a very developed network with 7500 m of karstic emergence.

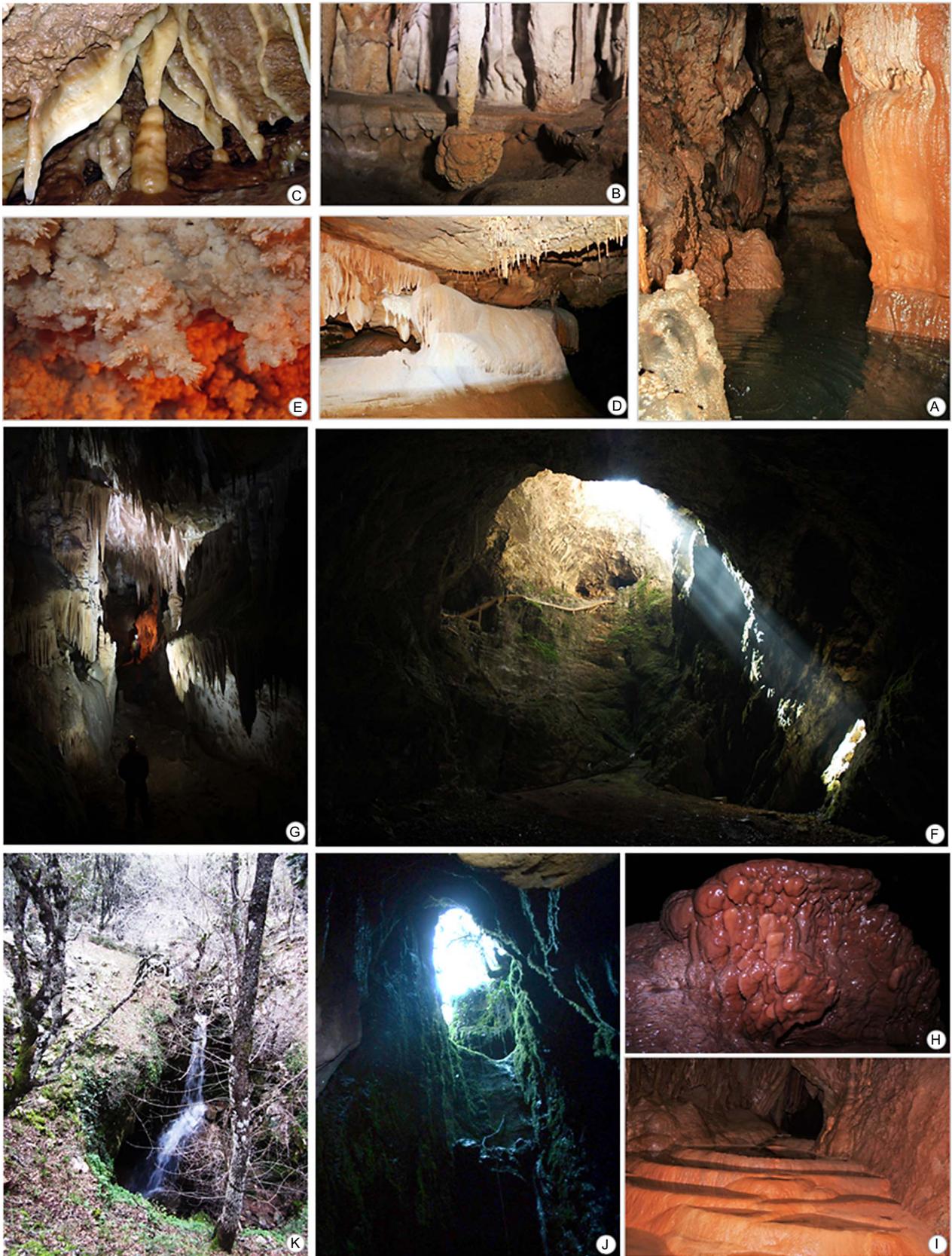


Fig. 6. Landscape character Geosites (karst Modelling and forms): A) Kaf El Ma; B) Chaara Chasm; C) Lazrek Cave; D) Chiker Cave; E) Ain Aouda Cave; F–I) Ifriouatou Chasm; J) Kaf El Ma; K) Izoura Chasm.

- (d) At the central part of the Middle Atlas, there are some karstic systems with edifices forms, travertine crusting and waterfalls at the hydrothermal source of Imouzzer Marmoucha and the Skoura waterfalls.

5 Conclusion

At the Moroccan scale, the Middle Atlas was highly rated for its karstic and natural heritage importance. It offers an ample karstic geodiversity in a very limited space that contributes to strengthening the sustainable development strategies, based on sites of karstic preservation and environmental state, which includes ecological, geologic, mineralogical, paleontological and prehistoric wealth.

The Mesozoic indicates a fracturing state that guided hydrological and hydrogeological canal system shelters essential karstification of the Middle Atlas and grabs international attention.

Referred to as the Castle of water, the Middle Atlas and especially its eastern part is known with a strong concentration of caves, where the precipitation abundance favoured the solvent and the mechanical actions of underground waters. These actions had helped to form various architectural structures and offered a touristic aspect to the region. Unfortunately, the Middle Atlas deserves to have more than “The Friouato Abyss” as the only karst site that fitted out the touristic scale.

The karsts of the Chiker, Chaara, and Ademame regions are exceptional for their volume and by their natural attractiveness. This allows thinking to qualify them as “Geosites”. Within local heritage staging, more efforts are necessary to smooth the running of preservation system, to offer executive territorial ideas, and to guarantee the transmission of these geological paths.

During the last decades, mountainous regions of the Middle Atlas contributed to the advancement of the karst sciences whether it is in karstic hydrogeology, in karstic geomorphology, or in paleoclimatology field and paleoenvironments. These structures have the aptitude and the opportunity to be integrated in effective sustainable development strategies based on the positive functioning, the effective World Network of Geoparks and UNESCO support.

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