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Geosites of High Atlas of Marrakech (Morocco): Geological Characterization, Accessibility, and Potential Interests for Sustainable Tourism

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Abstract

Geosites constitute a significant natural resource for ecological use and sustainable development in Morocco, and thus, their geological characterization and accessibility are of crucial importance. In this study, we investigated the geological structures, historical status, and accessibility of four potential geosites in the High Atlas of Morocco. Field visits, starting from the city of Marrakech to the top of Toubkal Mountain, were used to determine the nature and date of geological structures, while GIS tools were used to delimit the study geosites and their accessibility. Obtained results showed that studied geosites disposed of a variety of natural landscapes, geological structures, and accessibility. Paleozoic and Triassic geostructures infiltrated by a fault-dominated Tahannaout and crossed by the Ghighaya river. In Moulay Brahim, basalt sections of the finished-Triassic age, surmounted by deposits of the Lias dominated the southeast, while sandstone-silty bars of the Middle Jurassic to Lower Cretaceous age in the northeast. Reverse faults with N90 direction, the Mesozoic series, and the Paleozoic massif of Jbel Khelout added more good looks. Imlil known for its diversity of landscapes counting the national park of Toubkal, RAMSAR Lake of Ifni, and the endangered stands of thuriferous juniper, was dominated by Cretaceous structures in reversed series, overlapped by Precambrian sections thanks to the fault of the Aït Lachen. These geosites are linked by well-developed roads and disposed of hotel infrastructures, which make them very attractive for tourism of the mountains. However, more studies are needed to clarify more features of these geosites, to promote sustainable tourism.

Keywords Accessibility · Geosites · Geotourism · Geological structures · High Atlas · Morocco

Introduction

Tourism is an important source of economic prosperity in Morocco (Bouzahzah and El Menyari 2013; El Menyari 2021). Thanks to its interesting geographical location between Europe and Africa, Morocco has a wide range of natural landscapes, topographical structures, and biological diversity that offer necessary elements for tourism (Salah et al. 2018; Stenner 2019; Deil et al. 2021; Berred and Berred 2021). Morocco's comparatively high volume of tourists has also been aided by its location, specific attractions, and relatively low prices (Suárez-Ortega and García-Cabrera 2022). This North African country hosts a variety of geosites, wetlands, and natural parks that need more attention to enhance other sustainable ecotourism forms (Mohamed and Rachid 2019).

The geological structures are the heritage of the geological past that corresponds to the natural outcrops,

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geological formations, landforms, geomorphological edifices, deposits, fossils, mines, and quarries (Németh et al. 2021; Szakács and Kovacs 2022). Each element witnesses the history of our planet, some are spectacular and others ordinary, making it possible to understand the event which follows one another and retraces the history of the earth (Liotta et al. 2021; Saurabh et al. 2021). Equally, these geological creatures could be used for sustainable tourism such as ecotourism and geotourism (Chicote 2021; Tripathi 2021). In Morocco, the geosites are abundant in the Atlas Mountainous chains counting the High and Middle Atlas (i.e., M'Goun UNESCO Geopark in Central High Atlas) (Oukassou et al. 2019; Baadi et al. 2020; Elkaichi et al. 2021) and Rif (i.e., natural areas around Ghomara coast and Talassemtane National Park) (Aoulad-Sidi-Mhend et al. 2019; Salhi et al. 2020). These geosites are used for geotourism purposes to increase the revenue of rural populations, such as the case of geosites inventoried in the northwestern Tabular of Middle Atlas (El Wartiti et al. 2008) and geosites recorded currently in the Rabat-Tiflet region (Mehdioui et al. 2020).

Despite the diversity and abundance of geological structures (geosites, geoparks, volcanic sites, and geological landscapes) (Wartiti et al. 2009; Salhi et al. 2020), these ecosystems are not well investigated and the degradation impacts the majority of them (Mirari et al. 2020). For example, Khnefiss National Park combines Saharan dunes, a coastal band of cliffs, the lagoon zone, and Atlantic costs, suffers from human impacts (i.e., mass of visitors, fishing, and heavy metals pollution) and natural factors such as desertification and climate changes (Mirari et al. 2020; Tnoumi et al. 2021, 2022). Thus, to ensure the sustainability of this geological history, these ecosystems need more investigations to clarify their importance, ecological services, and economic revenues and to establish suitable conservation measures (Baadi et al. 2020; Mehdioui et al. 2022). Further, the conservation of the entire geological biotopes is suggested to protect surrounding biological entities counting faunae and florae.

The main objective of this study is the geological characterization and accessibility of potential geosites surrounding the Marrakech empirical city. These circuits located in High Atlas of Marrakech (Ghighaya valley) are suggested to attract sustainable forms of tourism counting geotourism and ecotourism due to their vicinity to Marrakech being well equipped with advanced infrastructures counting airports, road traffics, and suitable climate (Ouariti and Jebrane 2020). We aimed to investigate the geological structures and history of geosites located in the High Atlas of Marrakech in order to promote their geotourism potential based on their accessibility, road traffic, and hotel infrastructures.

Material and Method

Study Area

This study was conducted in the Marrakech-Safi region located in central Morocco (Fig. 1). This area corresponds to the western part of the central High Atlas, which is the most elongated mountain in Morocco, with a range over 800-km long from the WSW–ENE direction and 40 to 70-km wide. The High Atlas of Marrakech extends between Toubkal (Jbel Toubkal: 4167 m altitude) and the alignment of Tamellalt. Geographically, the region is limited to the north by the regions of Casablanca-Settat, to the west by the Atlantic Ocean, to the east by the region of Béni Mellal-Khénifra, and to the south by the mountainous chain of the High Atlas (regions Souss-Massa and Drâa-Tafilalet).

Marrakech has a hot Mediterranean climate with dry summers. Over the year, the average temperature in Marrakech is 19.7 °C and rainfall is around 290.6 mm. The geological structures of the area are dissimilar and support an important vegetation cover that varies from the mountains to the lowlands.

In this study, four sites counting Tahannaout, Moulay Brahim, Asni, and Imlil were selected and investigated. These sites were selected based on four characteristics: i) their proximity to Marrakech considered the capital of tourism in Morocco and North Africa (Almeida-García 2020; González et al. 2021), ii) their natural and geological potentials, iii) the abundance of local and international tourists in these areas, and iv) the increasing problems of classic forms of tourism that cause deterioration of natural landscapes (Almeida-García 2020). The study circuit started from Marrakech to Imlil on the High Atlas. We selected these geosites based on their touristic value (they receive a huge amount of local and international visitors every day), panoramic view (from Imlil valley, tourists can observe the entire region of Marrakech), natural resources (rivers, faunae and florae diversity, and lake of Ifni), and non-investigated geological structures (the objective of this study).

Field Materials

We prepared the necessary materials prior to field visits, including topographic map of the area (we used only copies covered by plastic for protection), compass (Topochaix 1015A) (used to find one's bearings and to measure the directions and dip (clinometer) of ground strata), GPS receiver (Garmin GPSMAP 64), hammer (used to extract a fresh sample from a rocky outcrop), binoculars,

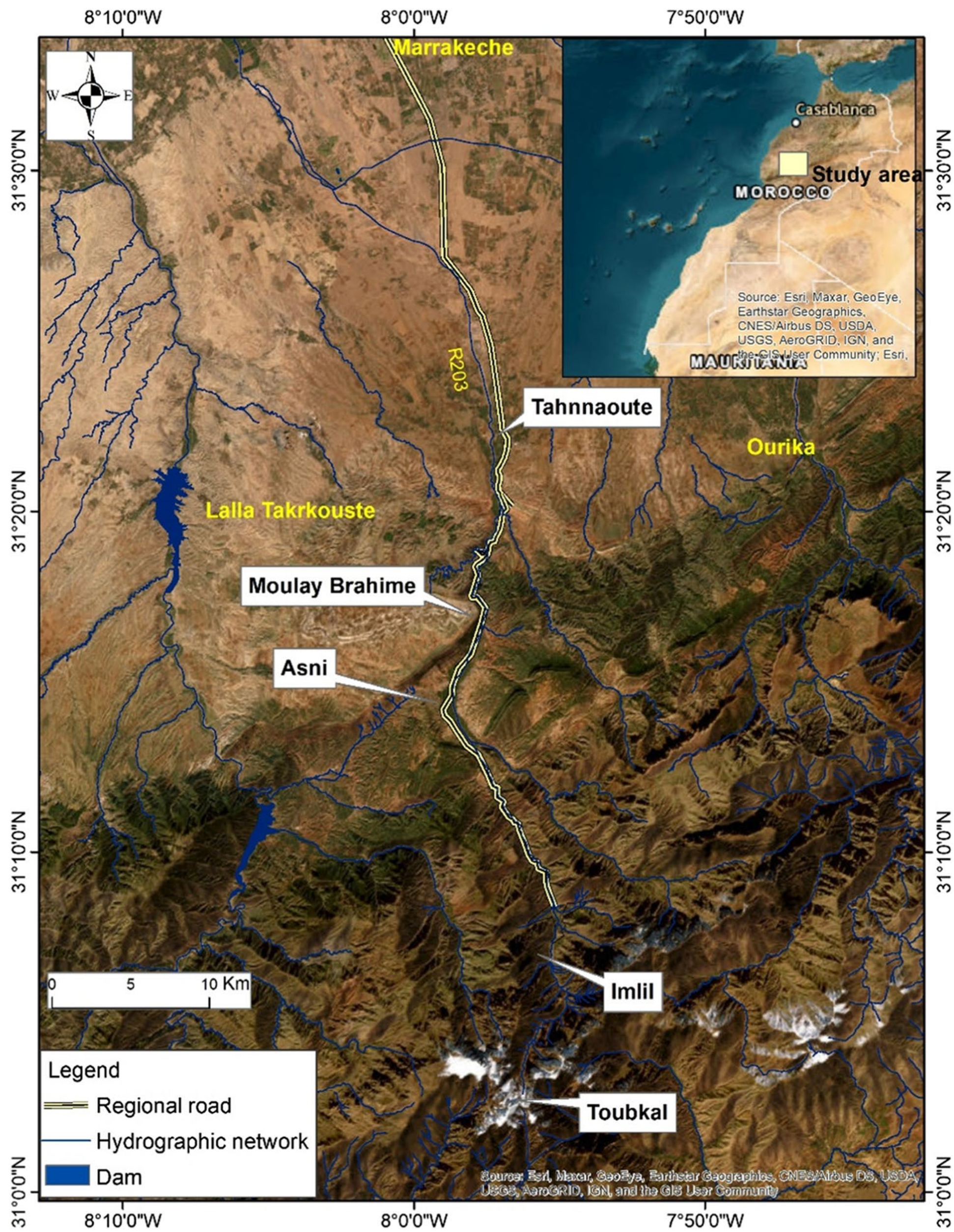

Fig. 1 Location of Marrakech and study sites in central Morocco

magnifying glass (to identify the main components of a rock (minerals, fossils, etc.)), camera (Canon EOS 80d) (to take pictures of landscapes, outcrops, samples, etc.), diluted hydrochloric acid (10%) (produces an effervescent reaction in the presence of calcium carbonate (limestone)), and field notebook. In addition, we verified for all visits date and weather, targeted locations, the description of the area (architecture, lithology, and structure), the orientation and dip measurements of the planes/fractures, and the numbers of the samples to take in the field.

Data Collection

On the field, the circuit started from Marrakech during the morning (06 h) in the direction of the High Atlas of Marrakech. We sampled all the landscapes we encountered along the way (rivers, mountains, geological structures, forests, etc.). In each site (primarily our geosites), we put the map on the ground, placed the compass on it, and rotated the map to coincide its North direction with the indicated North of the compass. Further, we proceeded in the observation of the landscapes and noted the shape of the horizon line, the location, orientation, and shape of the valleys, the presence of sinkholes, etc. We also observed the rocks with our eyes and a magnifying glass (loupe) (description, identification, resistance to erosion, permeability, etc.), and we took the samples to the laboratory for deep identification of minerals and geological dating (based on geological structures and fossils). Before taking samples to the laboratory, we added hydrochloric acid to search for limestone.

Mapping of Geosites and Accessibility

We noted the geolocation of each visited site, then, the mapping method was based on the geographical delimitation of visited habitats. Recorded geographical coordinates (GPS) were imported to Google Earth Pro, and we delimited each geosite on the map of satellite imagery from Maxar (open sources). We created polygons with a WGS coordinate system and we digitized them from imported coordinates. Further, we used QGIS software (version 3.20) to create maps and on the newly prepared maps we pointed out the roads, hotels, and other potential infrastructures that could be useful for sustainable tourism.

Fig. 2 Ghighaya river

Results

Tahannaout

The Tahannaout is located on the right side of Ghighaya river (Fig. 2), located 38 km away from "Douar Sour, opposite Douar Azrou." This area belongs to the northern flank of the central high atlas, oriented North E-SW, about 70-km wide and extends from the Atlantic Ocean to the Algerian Atlas.

On the field, we observed different substrates from the left to the right (Fig. 3A1). The geological formations dominated by grayish color, correspond to the Paleozoic and overlap the whitish part of the Lias with a thickness between 0 and 4 m. Among these formations, we recorded a sub-vertical unit of the Cretaceous, including the red detrital at the base, and the yellowish stain corresponds to the Albian, which was very rich in phosphate. Towards the top, we observed limestone slabs rich in Lamellibranchs and the Cenomano-Tunorian surmounted by a limestone slab dating from the Eocene towards the north of Douar Azrou, a set of conglomeratic sandstones of continental origin which corresponds to the Mio-Paleocene. The

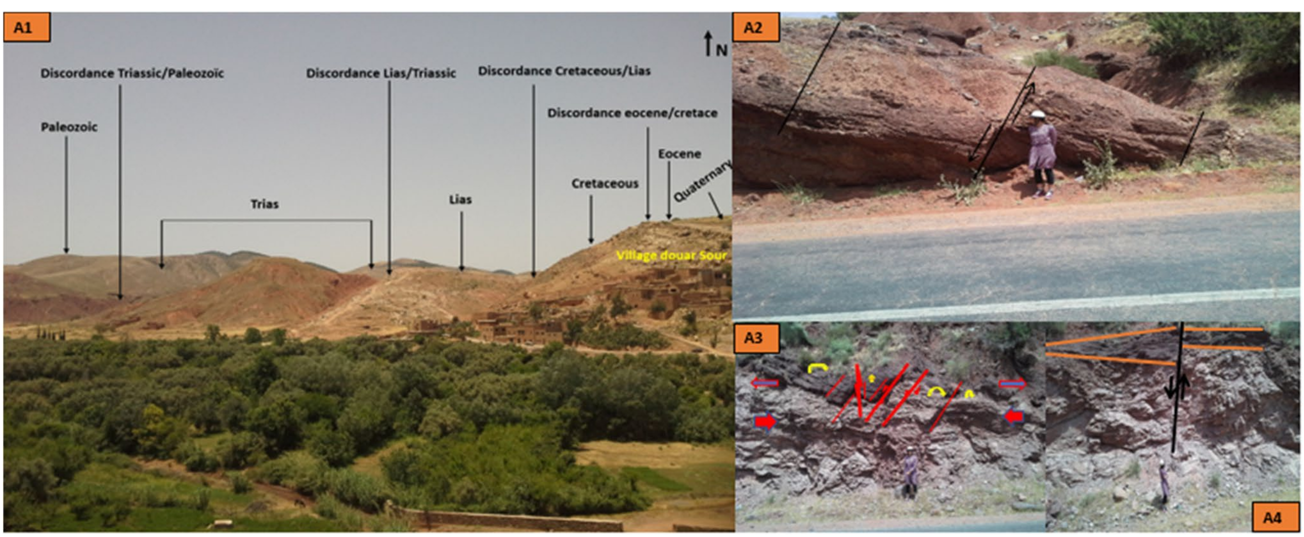

Fig. 3 **A1** Panorama of a geological succession with several unconformities (Tahannaout; Douar Sour). **A2** Normal faults with tilted blocks (Zawyat bou houta). **A3** Syn-sedimentary tectonic geosite: Hemigraben perched on visean basement, graben, tilted block and normal faults (Tibizzit). **A4** Syn-sedimentary tectonic geosite of a normal fault (Aghzane)

contact between the Paleozoic and Triassic marked a fault trending. The predominance of syn-sedimentary normal faults characterized the Triassic with a direction of N 70°, 65° to 70° Nw and numerous graben and horst structures (Fig. 3A2–A4). Equally, the contact Triassic-Paleozoic was a fault, the Lias-Trias was a discrepancy nail, while the Cretaceous-Lias was a progressive discrepancy nail, which becomes more and more damped. The Miopleocene was discordant with the Eocene, which corresponded to the trash or rather the sedimentary deposit environment of the Atlas chain.

The dominated yellowish limestone (rich in phosphate) in the part of the village located on the left bank demonstrated its Eocene age. The Cretaceous "gap" was attributed to the compressive phases of the Atlas orogeny. The Eocene limestones were surmounted by a cartographic unconformity, gullying, and a group of pink conglomeratic sandstones corresponding to the Miocene-Pliocene, which is truncated by Quaternary conglomerates forming a low dipping glacis towards the North.

Moulay Brahim

The southern landscape shows, from right to left of Sidi Bouethmane (Fig. 4), a greenish-gray complex, dominated by the basalts of the Triassic age and surmounted by the whitish bar of the Lias. The overlying formations, oriented to the northeast, represented sandstone-silty bars of the Middle Jurassic to Lower Cretaceous age. A significant reverse fault in the N90 direction dominated gray-colored schist-sandstone set dated from the Visen overlapped the Mesozoic series and the Paleozoic massif of Jbel Khelout. Towards the North–West, the massif of the Kik plateau was a syncline perched, and its northern edge is turned back by a fault of N 110° degree of inclination.

Asni

The Berber village of ASNI is located 50 km south of Marrakech. This area has an altitude between 1.500 and 2.000 m. the valley is predominated by traditional Berber villages, the mule tracks, and small Douars on the hillside which make it a magnificent place for nature lovers and the practice of several tourist activities.

Geologically, two large groups outcrop in the Asni basin, an ancient basement of Precambrian to Infracambrian age located to the south of the basin, and a sedimentary cover of Meso-Cenozoic to Quaternary age. The relationship between the two sets is sometimes stratigraphic or abnormal fault contact.

Fig. 4 Landscape offering a beautiful geological section of Moulay Brahim

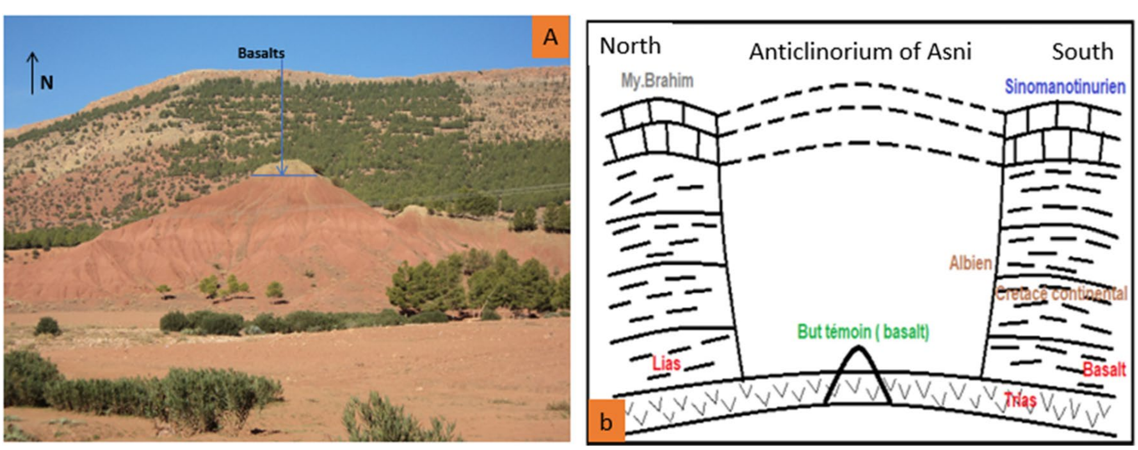

Fig. 5 **A** Asni basin, located at the level of an anticline. **B** Representative diagram of the Asni anticlinorium

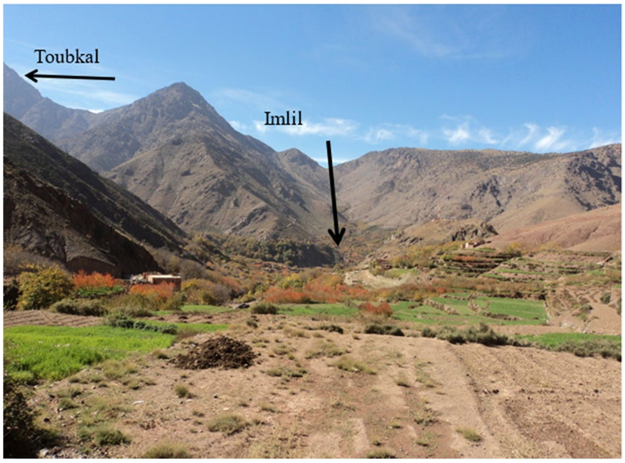

Fig. 6 View of the Imlil village in the Atlas fault at the foot of Toubkal

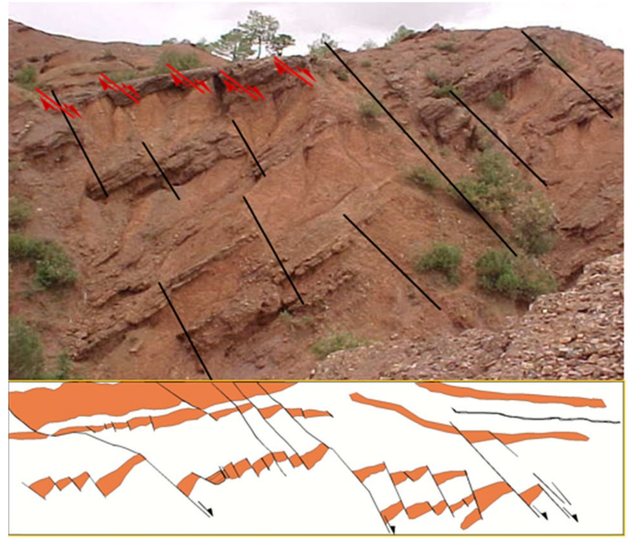

Fig. 7 Syn-sedimentary tectonic geosite and normal faults of Tinitine

In terms of geomorphosite, in the anticlinorium of Asni, we observed dominance of basalt structures at the top which is also found in the Northern and Southern flank (Fig. 5). Further, the Asni basin, located at the anticline, was made up of upper silts of Triassic and basalts.

Imlil

The Imlil is located after the Asni basin and is made up of the upper silts (Fig. 6). The Imlil road runs along the course of the Ghighaya and crosses a part of the upper Triassic silts, the basalts, and the Cretaceous series; the Apto-Albian is represented by nearly 70 m of sandstone, limestone, and conglomerate, while at Tagadirt n'Aït Ali, the Cenomano-Turonian is represented by a limestone bar of nearly 55 m of width.

At the Tagadirt, the overall structure of the Cretaceous corresponded to an asymmetrical syncline whose southern flank, in an inverted series, is overlapped by the Precambrian sections thanks to the Aït Lachen fault. From the Tagadirt to the Tinitine-Ouaoussafte (Fig. 7), the landscape was dominated by the Permo-Triassic series. This area is a hemigraben basin with an opening towards the south and folded into a synclinal structure by two inversed faults of the Aït Lahcen to the north and Tinitine to the south.

Accessibility and Other Infrastructures

A total of 4 geosites, Ghighaya rivers, forests, and RAMSAR sites were established in a studied area. The study sites differ by the unique features they represent, their geological status, and their heritage value. These tend to concentrate in Tahannaout (geosites of Douar sour, Zawyat bou houta, tibizzit, and Aghzane and rivers of Ghighaya), Moulay Brahim (geosite of Sidi Bouethmane, river of Ghighaya, and olive agroecosystems), Asni (geosite of Asni, river of Ghighaya, and forest of Asni valley), and Imlil (geosite of tinitine, river of Ghighaya, forest of high mountain of Toubkal, and Ramsar wetland of Ifni) (Fig. 8). The most relevant site is Imlil, because of its location under Tobkal National Park (Fig. 9) near Ifni Lake known for its international and national status. The Zaouïa of Moulay Brahim has one of the most important festival in the High Atlas during the Mouloud period. Saint Moulay Brahim is venerated by women who suffer from sterility. It is a tourist village that welcomes many visitors each year. The Terre d'Amanar tourist site offers several activities such as aerial courses, tree climbing, archery, hiking, horseback riding, mechanical, or electric Mountain biking in addition to other activities (Fig. 8A and B).

All studied sites are located in high altitudes and are linked with sophisticated traffic infrastructures (Fig. 10). The regional road R203 link between Marrakech urban zone and the Asni geosite and crossing by Tahannaout and Moulay Brahim. Further, the Asni is related to Imlil by Provincial road P2005. In Moulay Brahim, the provincial road P2024 links between small villages on both banks of the rivers. Similarly, the P2010 links the villages of Tahannaout. On the contrary, Imlil marked the end of traffic infrastructures and the start of both off-road and mountainous small access, principally in the direction of Toubkal National Park and Ifni Lake located above 2500 m of altitude.

In terms of hotels and restaurants, we recorded nearly 80 places along the circuits from Marrakech to Imlil. These hotels and restaurants present local, national, and international dishes for all kinds of visitors. Equally, we recorded touristic guides and sites for snow sports on High Atlas.

Fig. 8 **A** Aerial courses and **B** tree climbing in Terre d'Amanar tourist site (Tahannaout), and **C** restaurants and **D** coffees in Moulay Brahim Village

Fig. 9 View of the Imlil landscape **A** at the foot of Toubkal (4165 m) and **B**, **C** National Park

Discussion

Marrakech is the most recommended city for tourism in Morocco and North Africa (Safaaa et al. 2017). However, mass tourism causes the degradation of landscapes and neglects natural resources. In this study, we characterized the geomorphological structures, natural landscapes, and infrastructures that can be evaluated for geo and eco-tourism

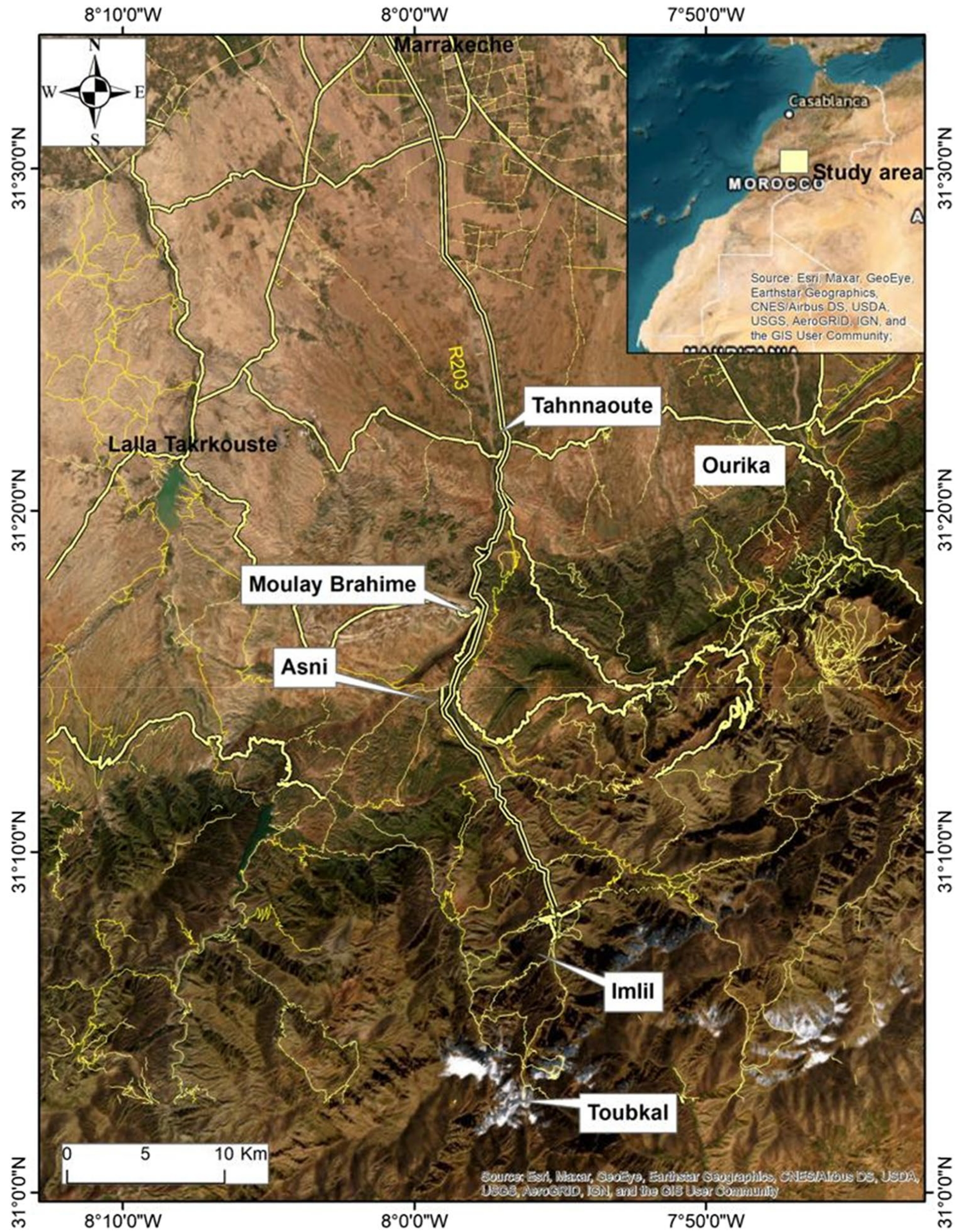

Fig. 10 Traffic roads in the study area

in the vicinity of Marrakech, which is suggested to integrate natural landscapes in the middle of touristic activities. Obtained results described the geological, landscape, and infrastructure potentials in the study sites around Marrakech city for the first time. Equally, our data is suggested to promote sustainable tourism in the study sites, which is suggested to maintain the natural landscapes, while mass tourism necessitates massive mobilization of natural resources, infrastructures, etc. (Chong 2020).

In this study, we defined the geological characteristics and landscape features in four geosites counting Tahannaout, Moulay Brahim, Asni, and Imlil located in the vicinity of Marrakech. These sites are the most visited by ecotourists in this region (Konopíková and Soukup 2014). In Tahannaout, located on the right bank of the Ghighaya river, we recorded geostructures dominated by the Paleozoic and Triassic formations infiltrated by faults, which is in agreement with results cited by El Youssi (1986) and Ben Mlih et al. (2004). These authors have confirmed the dominance of Triassic, Lias, and Paleozoic sections infiltrated by limestone and faults. This geotope, composed of several geosites, corresponds to a panorama of a geological succession that can attract sustainable tourism or for educational purposes (El Wartiti et al. 2008; Mehdioui et al. 2020). In Moulay Brahim, the landscape offers a beautiful section composed of basalts of the finished-Triassic age, surmounted by deposits of the Lias. In the northeast, sandstone-silty bars of the Middle Jurassic to Lower Cretaceous age dominate the area.

In addition to significant reverse faults in the N90 direction, the Mesozoic series and the Paleozoic massif of Jbel Khelout form a great geosite that could attract goetourists. Currently, El Bamiki et al. (2023) investigated the geochemical in the High Atlas of Morocco, including the zone of Moulay Brahim and Toubkal Mountains, using scanning electron and optical microscopies (SEM and OM), X-ray diffraction (XRD), inductively coupled plasma mass spectrometry (ICP-MS), and inductively coupled plasma optical emission spectroscopy (ICP-OES) techniques. Geochemical results revealed variations in the geological composition of the different structures. Cretaceous-Paleogene phosphate deposits, Precambrian-Paleozoic basement, and Mesozoic-Cenozoic sedimentary sequences were the most dominant geological structures. Similar results were mentioned currently in Aït Bou Oulli Valley located also in Central High-Atlas by Bouzekraoui et al. (2018), who also announced that the geotourism map and geological characterization of such sites is suggested to promote sustainable tourism interested in geological structures, which is suggested to protect this geoheritage. In our case, the area is well equipped with restaurants such as that of R'ha de My Brahim located only 47 km away, small hostels, and road traffic which are necessary to support ecotourism in mountainous areas (Singh and Mishra 2004; Badar and Bahadure 2020). Equally, Berred et al. (2022) inventoried geosites in Rabat, Salé, and Kénitra region located in Northwest of Morocco to promote Regional Geotourism activities close to these cities will equipped with sophisticated infrastructures. Similar results were also reported in Rabat-Tiflet Region (North Western Morocco) and Central Moroccan massif, where Mehdioui et al. (2020, 2022) inventoried geosites to evaluate the potential of the area to Become a Geopark.

The most relevant result of this study is the geological characterization of the Imlil area. Because Imlil is known for its diversity of landscapes counting the national park of Toubkal, Lake of Ifni was considered a RAMSAR site with an altitude of 2295 m (Kacem et al. 2016), and the forest cover is dominated by endangered stands of thuriferous juniper, carob, wild olives, and lentisk pistachio (Gauquelin et al. 1999; Powell et al. 2014). Currently, Elkaichi et al. (2021) revealed similar results concerning the diversity of geological elements (i.e., minerals, rocks, and fossils), geomorphology, and hydrology in M'Goun UNESCO Geopark located in Central High Atlas. In our case, we recorded the dominance of *Cretaceous* structures in reversed series in Tagadirt, overlapped by Precambrian sections thanks to the fault of the Aït Lahcen which is similar to the results recorded by Proust (1973) and Bellaoui (2005) in the same area. In Tinitine-Ouaoussafte, we observed the series of Permo-Triassic inversed by two faults of the Aït Lahcen to the north and Tininite to the South, which confirms the results mentioned by El Youssi (1986).

The most important elements to support the ecotouristic roles of the geosites recorded in the areas are the accessibility (Rais et al. 2021; Mikhailenko et al. 2021) and the high-quality infrastructures counting roads, hostels, and well-trained personnel (Forje et al. 2021). These elements are necessary for these mountainous areas to facilitate the circuits for visitors and to discover the richness of landscapes. In a current study, Kaefer (2022) revealed that Mike McHugo founded Discover in the High Atlas Mountain, village of Imlil, opening as Kasbah du Toubkal and in 5 years later, becoming one of the most award-winning hotels in the country. In the same way, Rais et al. (2021) proposed two new geosites in the M'Goun geopark and characterized their accessibility and geoitineraries near the El Ouidane dam. Generally, accessibility and itineraries are the most important elements to promote geotourism in mountainous areas and to promote the creation of income for rural populations (Rais et al. 2021). On the other hand, the study area is rich in animal species counting iconic birds: the globally threatened European Turtle doves (*Streptopelia turtur*) (Hanane 2016) and the bearded vulture (*Gypaetus barbatus*) (Cuzin 2010) that can be used for ecotourism activities such as birding or sustainable hunting for the dove (Mansouri et al. 2019). These activities are suggested to create new income for local residents (Rais et al. 2021). Similar results were published currently in central and eastern High Atlas, where Wakass et al. (2023) recorded 20 avian species characterized by ecotouristic interests counting birdwatching and sport hunting. In fact, many tourists of local and international nationalities were encountered during our field visits, while no educational activities were observed. These tourists visit mostly the Imlil and Toubkal sites. Despite the ectoutistic features of the study sites, decision-makers should pay more attention to natural disasters such as the extreme flows mentioned currently in Tahanaout station (El Alaoui El Fels et al. 2022) and Asni (Hajhouji et al. 2022).

Conclusion

In summary, this study investigated for the first time the geological structures and potential ecotouristic features of High Atlas in the vicinity of Marrakech. We characterized the richness of geomorphological structures of four areas in the circuit of Tahannaout-Imlil. Obtained results support the importance of the area to host the ecotourism interested in geological and natural landscapes, which is suggested to evaluate the area and reduce the negative impact of mass tourism that characterizes the Marrakech region. However, more ecological and social studies are needed to define the levels of diversity in geosites, natural landscapes, faunae and florae, cultural heritage, and how the local population can benefit from them in a sustainable way.

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Data Availability The datasets used and/or analysed during the current study are within the manuscript.

Declarations

Conflict of Interests The authors declare no competing interests.

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