



# The Volcanism of the Plio-Quaternary of Azrou-Timahdite Plateau (Central Middle Atlas, Morocco): Potential for Geotourism Development

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## Abstract

In the Plio-Quaternary, the central Middle Atlas, considered to be “the country of lakes and volcanoes”, was the seat of alkaline volcanism, located on the Azrou-Timahdite Plateau. The latter is the most recent and largest volcanic field in Morocco. It includes countless volcanic devices over a length of 50 km. These volcanic devices constitute by their form, genesis and representativeness an example of an exceptional volcanic heritage through a varied volcanic range and a typicality of sites unique in Morocco. Of these, eight were selected for this study. They include the Cone-Maar (Ouest Hébré), the maars (Lechmine Ait el Haj, Michlifène, Lechmine Bou-Ibalrhatène and Lechmine n’Ikettane) and the cones (Bou-Teguerrouine, El Koudiate and Outgui). The elevations of these geosites range between 1747 and 1905 m with diameters and depths up to 1300 and 110 m respectively. The outcrops of volcanic rocks, in particular pyroclastic products (lapilli, bombs, breccias, etc.), basalts and associated reliefs make them exceptional sites. The different eruptive dynamisms that presided over the construction of these geosites give them an undeniable educational value. These are real natural potentialities whose enhancement through geotourism will contribute to their sustainable management. In this work, valuation strategies for geotourism purposes are proposed for local development.

## Keywords

Volcanic geosite · Promotion · Geotourism Azrou-Timahdite Plateau · Middle Atlas

## 14.1 Introduction

The geological heritage is often dominated by numerous exceptional geosites. A geosite is a delimited space which offers the possibility of observing geological elements and/or phenomena of interest for the understanding of Earth sciences (De Wever et al. 2006). One can distinguish as many types of geosites as there are disciplines and sub-disciplines of Earth Sciences. However, we distinguish the volcanic geosites which result from several processes among which we find explosions (strombolian), effusions (fissures), extrusions (domic and pelean). All these processes give natural forms to diversified reliefs because their formation takes place outside of human intervention (Portal 2010). These forms, like geosites, contribute to the formation of the landscape and include, among others, domes, cones, maars, cone-maar, multiple cones, tuff rings, lava flows, etc.

These volcanic geosites are undeniable assets for the promotion of geotourism. The purpose of geotourism is to promote consciously and voluntarily the objects of study of the Earth sciences (Reynard 2004). It is a type of tourism through which tourists can acquire more information and a full understanding of the geological and geomorphological processes of the area concerned (Komoo and Kadderi 1997). More recently, Newsome and Dowling (2010) define geotourism as a form of tourism in natural areas that focuses specifically on landscape and geology, and their promotion, interpretation and conservation through appreciation and education. Over the last decade, many researchers have taken an interest in the study of volcanic geosites (Erfurt-Cooper 2010a, b; Erfurt-Cooper 2011; Thomas 2012; Moufti and

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Németh 2013; Erfurt-Cooper 2014; Moufti et al. 2015; Rapprich et al. 2017; Gałaś et al. 2018; Różycka and Migon 2018; Pijet-Migon and Migon 2019; Scarlett and Riede 2019; Pérez-Umaña et al. 2020). In Africa, we can cite the works of Andrianaivo and Ramasiarinoro (2011); Asrat et al. (2012); Errami et al. (2015); Henriques and Neto (2015); Zangmo Tefogoum et al. (2014, 2017, 2019), Ziem à Bidias et al. (2020); Baadi et al. (2021). All this work aims to enhance the geological heritage of the volcanic type while seeking the most obvious ways in terms of their management and conservation. In recent years, geotourism has experienced considerable growth worldwide and it is appreciated and accepted as a useful tool to promote natural and cultural heritage and to foster local and regional economic development, especially in rural areas (Kubalíková and Bajer 2018). For Alexandrowicz and Alexandrowicz (2022), the main areas of interest for geotourism are geological features and, in particular, geological and/or geomorphological sites. Its development offers opportunities for the promotion of geological knowledge and supports the conservation of geodiversity (Alexandrowicz and Alexandrowicz 2022; Gordon et al. 2018).

In Morocco, research on geological heritage for geotourism purposes is quite developed for paleontological, archaeological, karstic sites, etc. (Fröhlich et al. 1998; Malaki 2006; Ezaidi 2007; Beraaouz et al. 2010; Lefebvre et al. 2010; Baadi et al. 2020). However, work on the geological heritage in a volcanic environment, with a view to setting up geotourism, remains very limited. However, Malaki (2006) studied some volcanic geosites of the central Middle Atlas, more precisely in the region of Ifrane and Azrou. This study highlights the scientific and cultural interest of these geosites for economic purposes. Later, De Waele and Melis (2009); Eddif et al. (2017, 2018); Abdelmounji et al. (2019) carried out a geomorphological and heritage study of the central Middle Atlas. Subsequently, Baadi et al. (2020) carried out a systematic inventory and quantitative assessment of the volcanic geosites of the Azrou Timahdite Plateau. However, this work has focused on the study of certain geosites.

We propose, within the framework of this work, to study in more detail certain volcanic geosites of the Azrou-Timahdite Plateau. This would make it possible to enhance these exceptional geological and geomorphological entities by their form, their rarity and their geological characteristics in order to establish geotourism in the region. This study is part of the Moroccan geological heritage relating to volcanoes and more particularly to those of this plateau. The interest we have in this concept of geosites of great diversity which constitutes a scientific database, stems from two main reasons: on the one hand, a still incomplete knowledge of the volcanic heritage and on the other hand, the urgency to promote this heritage in order to make it known to the general public.

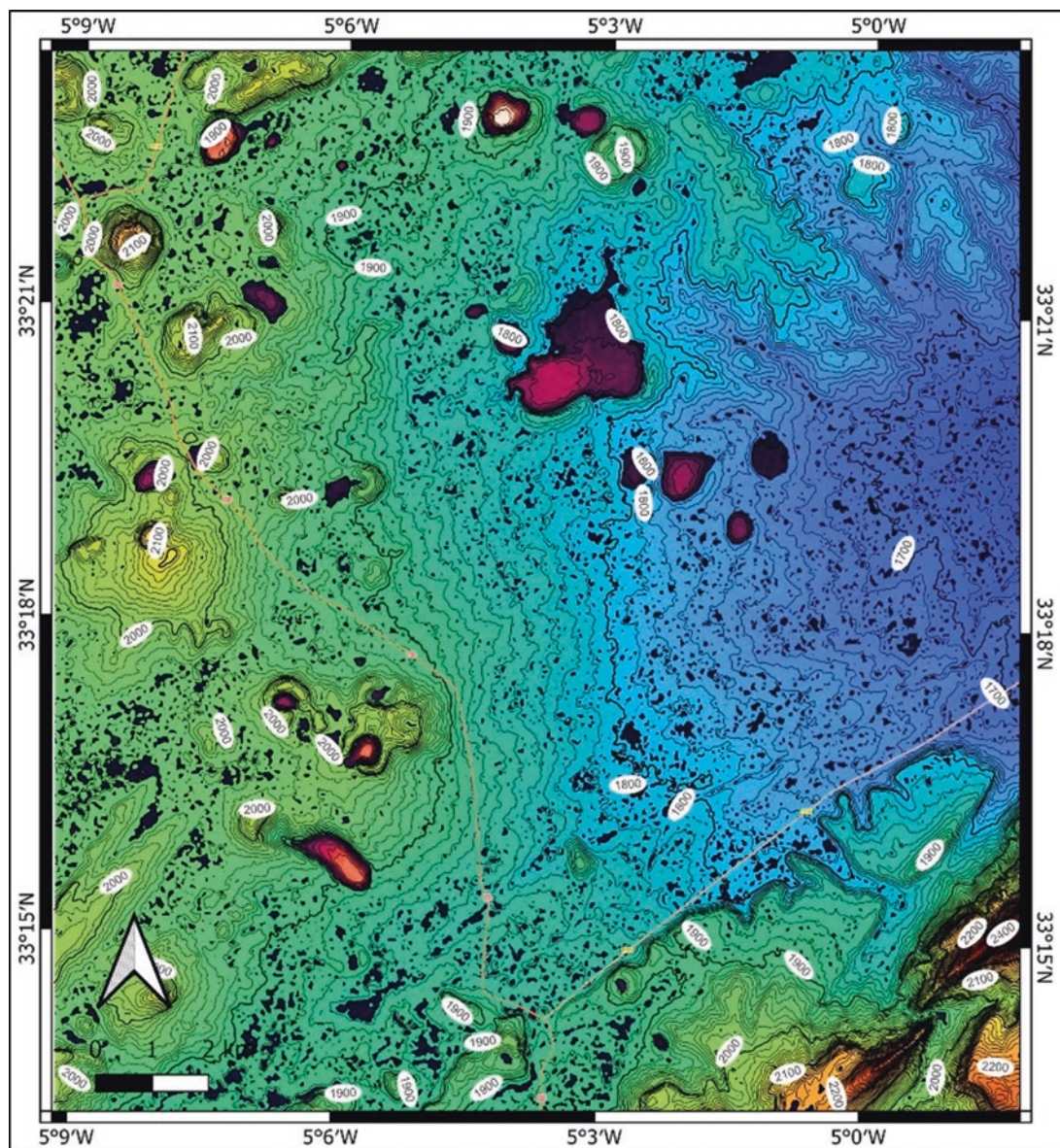
## 14.2 Geological and Geomorphological Context

The Middle Atlas is an alpine intracontinental chain and has undergone a long period of structuring which began in the Upper Cretaceous. It is subdivided longitudinally into two large units separated by the North Middle Atlas Fault (NMAF) which runs NE-SW (Termier 1936; Colo 1961). It is subdivided into the northern Middle Atlas and the central Middle Atlas. The latter, it is subdivided in subtabular Causse, in the NW, and in pleated Middle Atlas, in the SE.

The subtabular Causse, composed mainly of Lower Jurassic carbonates, is structured in tiered plateaus that reflect an organization in tilted blocks where more than 80% of the volcanoes are located, largely covered by Quaternary basalt of the monogenetic volcanoes. The folded Middle Atlas is organized in anticlinal ridges which separate large synclinal depressions whose outcrops are from the Dogger and the Cretaceous and Tertiary formations. Between these synclines, which are sometimes very wide, the anticlines form narrow faulted links which can reach an altitude of 2797 m at Jbel Tichoukt.

The overall geomorphology of the Azrou-Timahdite Plateau is essentially the product of a combination of mainly inherited and active landforms. The current morphodynamics is mainly correlated with the processes of karst denudation, the weathering of alkaline basalts and the dynamics of the slopes, reinforced by strong agricultural activities, with the formation of badlands, ravines, etc. heavy precipitation in the form of rain and snow, make the subtabular Causse the water tower of Morocco and the land of lakes and volcanoes. Most of the volcanic units cover the flat karst surface of the Lower Jurassic dolomitic limestone tabular plateau and appear to be continuous in the central part of the range between Azrou and Timahdite. This karst surface is dominated by innumerable closed depressions (Fig. 14.1).

Quaternary volcanic activity occupies a large part of the Middle Atlas Causse. The karstic phenomena did not only occur on the margins of the flows; they are also responsible for a large number of closed depressions (Fig. 14.1) of varying shapes and sizes. More than 300 cavities have been identified. The most spectacular are the cylindrical or funnel sinkholes, with steep sides towering over the slopes of large blocks of fallen basalt. As explained by Gentil (1916), the genesis of these karstic cavities is due to the collapse of the roof of certain basaltic caves formed by the digging of a fairly thick mass of lava, and therefore to lava tunnels. They are considered as false craters, which would result either from a progressive landslide, or from a sudden collapse of the basaltic cover above the collapses of the underlying karstic galleries (Termier and Dubar 1940).



**Fig. 14.1** Map of closed depressions in the Azrou-Timahdite Plateau

In some areas, the lava has formed underground tunnels. The Ifri-Ouska hole is a 15 m long cave with two close entrances, containing some small lava stalactites. It is in fact the remnant of one of these underground tunnels.

Several volcanic devices dot the landscape, the most important of them are Jbel Habri, Jbel Hébrî, Tit Ouagmar, Lechmine Izgar, Bou-Ibalrhatène, Chedifat-Tit Ouagma, Bou-Teguerrouine, Tahebrite and Sidi Aziz. Lava flows overlying karst topography has led to a convergence of forms with large cryptokarst sinkholes sometimes collapsing due to the presence of underlying lava, but usually related to deep karst tunnel collapse in the Liassic limestone (Martin 1981).

### 14.3 Identification of Volcanic Sites

Our results come from a bibliographic research, a cartographic study and field work which allowed us to select all the volcanic geosites of the Azrou-Timahdite Plateau for their geotourism value. The inventory and selection of the various proposed geosites were carried out based on the work of Baadi et al. (2021). The choice of geosites for the geotourism promotion was based mainly on altitude, surface area and accessibility. These geosites constitute a crossroads of nationally renowned sites that deserve to be recognized by the general public.

### 14.3.1 Lechmine Ait el Haj

The Lechmine Ait el Haj geosite (Figs. 14.2 and 14.3a) culminates to an altitude of 1747 m. It is located south of Michlifène, it is a maar 900 m in diameter and 110 m deep. It is located east of the main volcanic alignment. It is subcircular in shape surrounded by walls of volcanic breccias (Fig. 14.3b), lapilli and ash rising up to 95 m above the crater floor. In its borders and especially in its northern part, the Liassic limestones are cut by the chimney and covered by a ring of tuff. Towards the top, the phreatomagmatic tuff is covered by a semicircular ring of juvenile scoriacal deposits and in blocks, formed by the phreatomagmatic fragmentation of the incoming lava flow (Mountaj et al. 2014). The basanites of Lechmine Ait el Haj cover the alkaline basalt flows and are dated 0.5 Ma (Harmand and Cantagrel 1984). Part of this flow came from the Tazouta volcano in the north.

Lechmine Ait el Haj holds the largest pozzolan deposit in the region. The existence of significant quantities of pozzolan at the edge of the maar implies progressively drier conditions or alternating with wet phreatomagmatic and dry strombolian eruptions (Houghton et al. 1996; Saucedo et al. 2017; Abdelmounji et al. 2019).

### 14.3.2 Michlifène

The Michlifène geosite (also called Lechmine-Chreb-ou-Horb) (Fig. 14.4a), culminates at an altitude of 1868 m. It is located in the southern part of Ifrane Causse. It corresponds to a maar (Fig. 14.4b) of wet phreatomagmatic activity, accompanied by a settling of the chimney, like a sort of

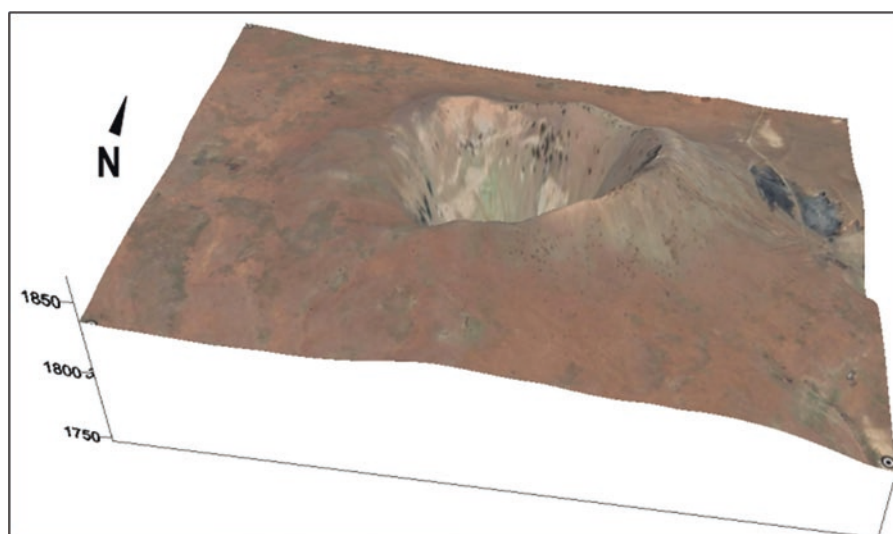
closed funnel, with a depth of more than 100 m and nearly 850 m in diameter. The Michlifène geosite is inscribed in the Lower Lias dolomites, covered by Middle Lias limestones, the sills of which retain volcanic breccias with Liassic fragments.

This volcanic geosite has been very largely covered, at least in its central part, with volcanic products which form enormous spreading spread over almost 300 km<sup>2</sup>. This geosite contains ski facilities and a small lodge-hotel.

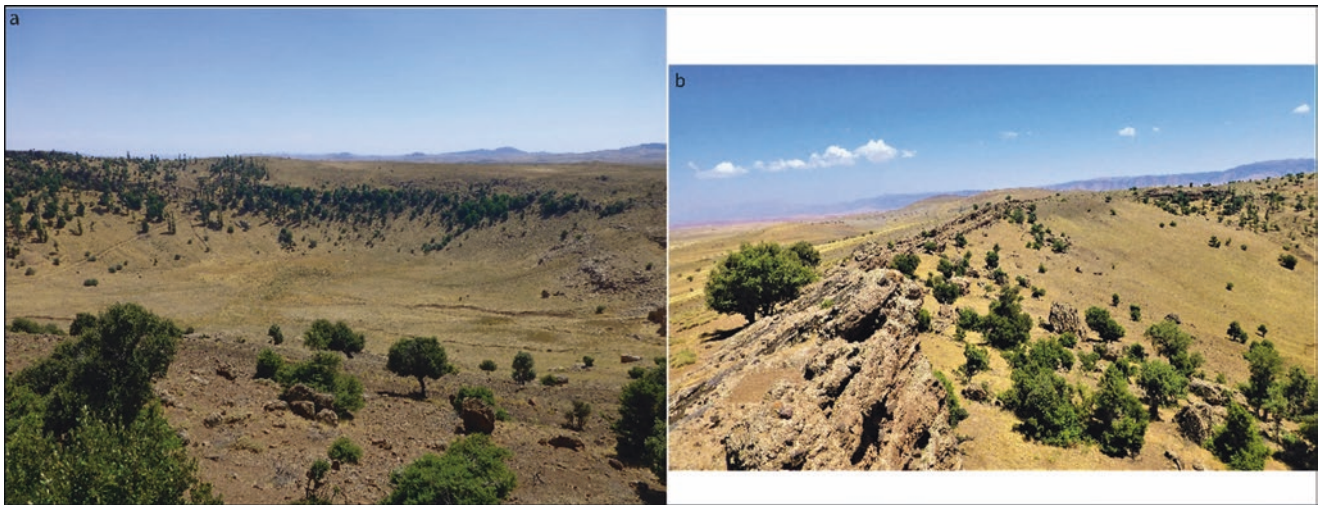
### 14.3.3 Lechmine Bou-Ibalrhatène

The Lechmine Bou-Ibalrhatène geosite (Fig. 14.5) culminates at an altitude of 1806 m. It is a huge complex of five coalescing craters that exhibit Liassic dolomites on their sides. The craters reach 1300 m in diameter and 45 m in depth. The origin of these craters is very similar to that of the Michlifène crater, whose explosion washed away the Liassic substratum which is well preserved on the walls. The volcanic edifice of Lechmine Bou-Ibalrhatène essentially shows a form of stripping and gullying. It is associated with a grouping of phreato-magmatic apparatuses which form a complex of maars. To the south (Fig. 14.6a), an important relief ravined with lapilli and breccias stands out. The northern part of the maar (Fig. 14.6b) collapsed following the passage of the N60 direction fault; giving rise to sinkholes.

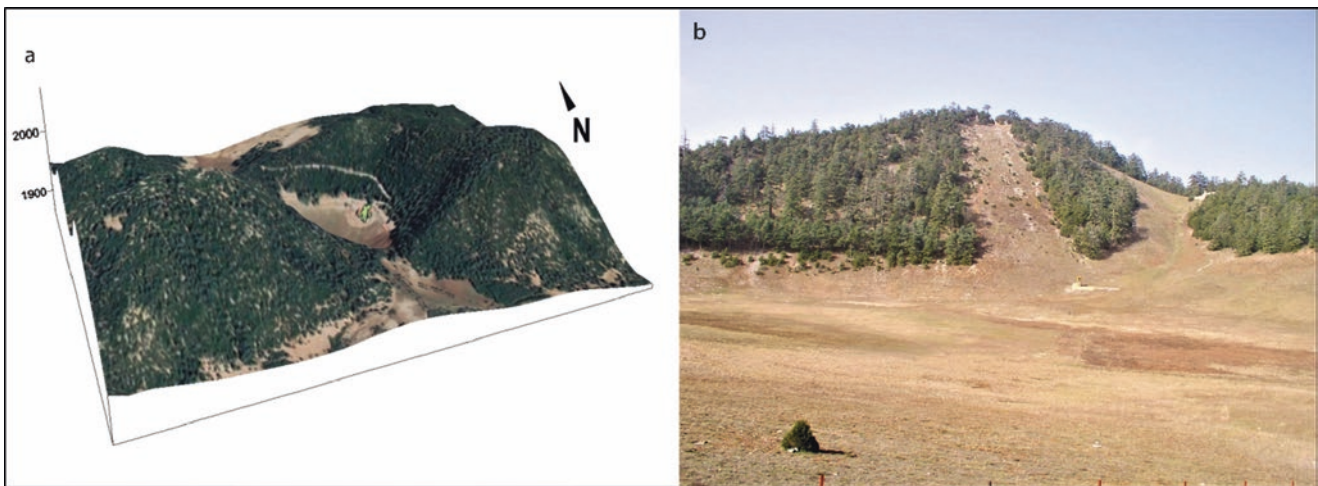
The deep Bou-Ibalrhatène maar contains abundant xenoliths as well as granulites. The Bou-Ibalrhatène xenolith suite includes metasomatic lherzolites and harzburgites bearing amphiboles, wehrlites, websterites, clinopyroxenites and hornblende (Raffone et al. 2009).



**Fig. 14.2** 3D profile of Lechmine Ait el Haj Volcano



**Fig. 14.3** (a) Volcanic site of Lechmine Ait el Haj, (b) Volcano-sedimentary deposits of the eastern slope of the volcano



**Fig. 14.4** (a) 3D profile of the Michlifène volcano, (b) North slope of the Michlifène maar

#### 14.3.4 Ouest Hébrî

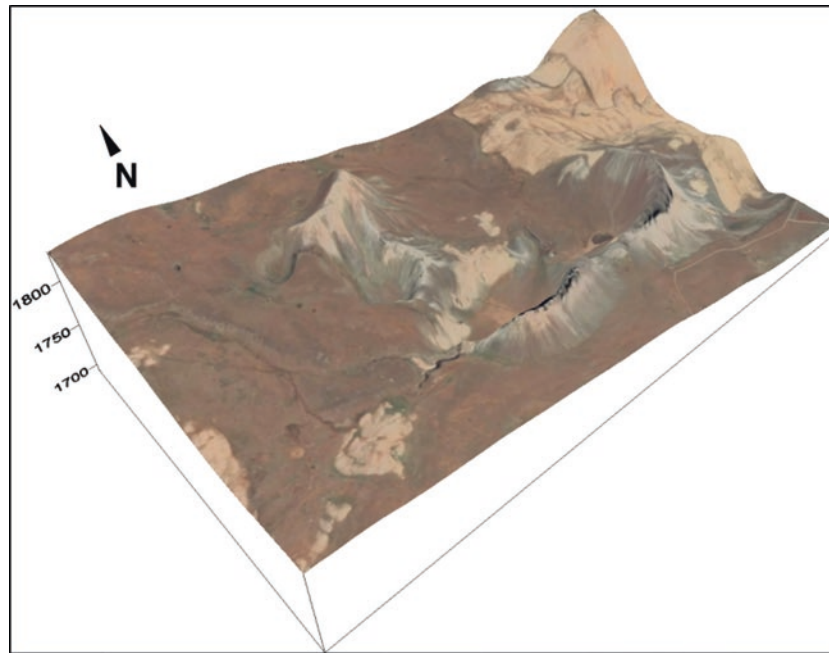
A few meters west of the open summit cone of Jbel Hébrî is the geosite of the Ouest Hébrî (Fig. 14.7). This one, 70 m high and 850 m wide, culminates at an altitude of 1863 m. It is a cone-maar couple which illustrates the transition from strombolian activity followed by phreatomagmatic activity towards the end of the eruption. The cone in the NE part of the volcano (Fig. 14.8a) is eaten away by the work of extracting pozzolan from the strombolian deposits. The face that cut the cone into two parts rise up to 20 m, showing a decimetric alternation of levels rich in slag and levels rich in bombs and ragged lava. These reddish deposits are typical of Strombolian dynamism in the open air. The SW part is rather occupied by a regular maar (Fig. 14.8b) 400–500 m in diameter and 40–50 m deep, surrounded by massive levels of volcanic breccias with basement elements. The mixture of cone and

maar is linked to the appearance of a mass of water during the eruption.

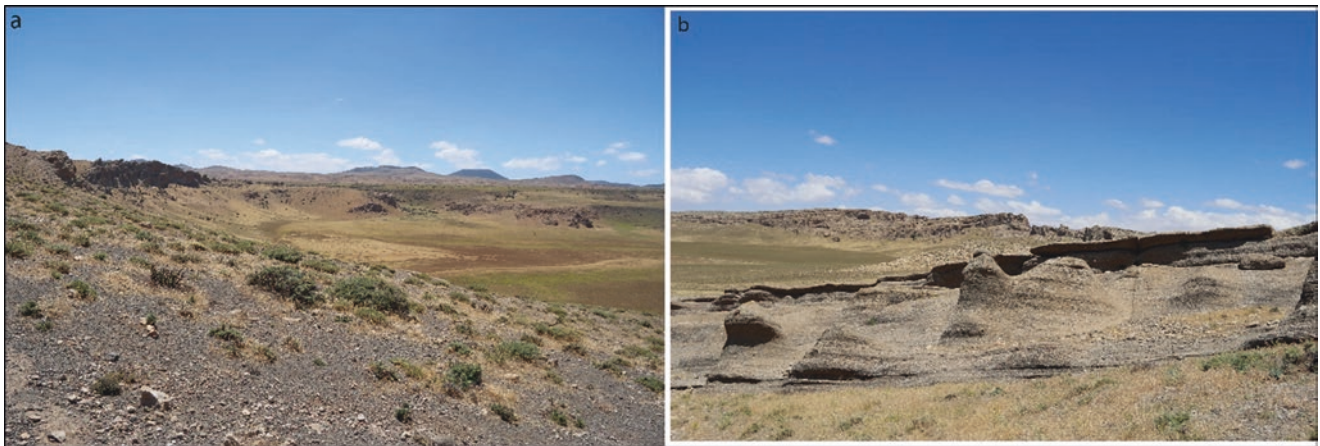
This geosite is unique throughout the Middle Atlas region and exhibits a typical and rare process of a Cone-Maar pair. A few hundred meters away there is a ski area obtained at the expense of the famous cedar groves of Ifrane National Park (*Cedrus atlantica*).

#### 14.3.5 Lechmine n'lkettane

The Lechmine n'lkettane geosite (Fig. 14.9) culminate to an altitude of 1905 m and is located at the southwest end of the Bou-Teriouine monoclinial. It is a large closed cavity, perfectly circular, 95 m deep and 1200 m in diameter. It is a maar with a conical structure without root, characterized by a flat bottom which is located at an altitude of 1801 m, or



**Fig. 14.5** 3D profile of the Bou-Ibalrhatène volcanic complex



**Fig. 14.6** (a) View of the southern part of the maar complex of Bou-Ibalrhatène; (b) Northern part of the complex on the flank appears volcano-sedimentary deposits

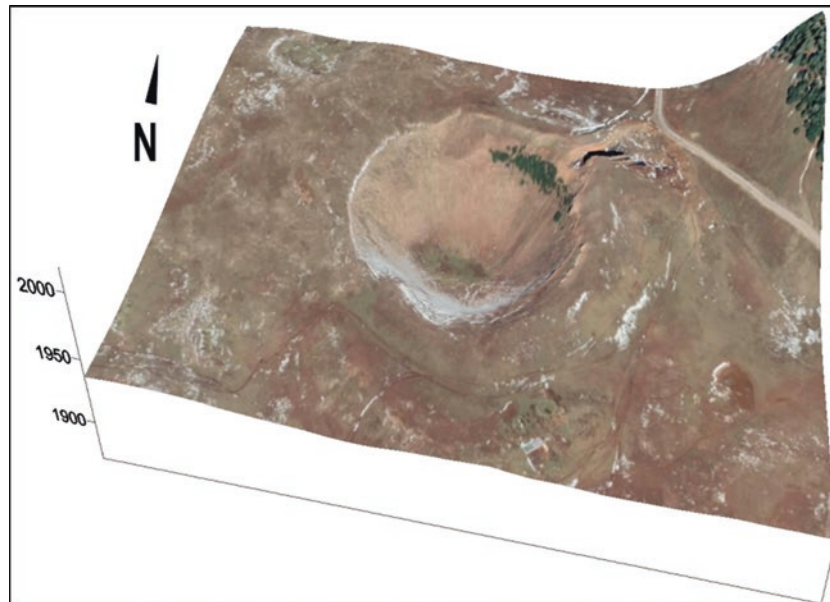
90 m below the basalt plateau. On its south side, there are several hornitos.

The originality of the Lechmine n'Ikettane geosite consists precisely in the total absence of external slopes. Its northern slope corresponds to the faulted fallout of Bou-Teriouine whose limestone banks plunge towards the SE. The lapilli slope exposed to the SE is crowned by a bank of pyroclastic breccias. To the east and west, the beds of these pyroclastic breaches clearly show an external dip. At the foot of the geosite and its slopes, the volcanic ash, a gentle slope, is masked by an irregularity of the underlying lava. From the base to the top, we find pahoe-

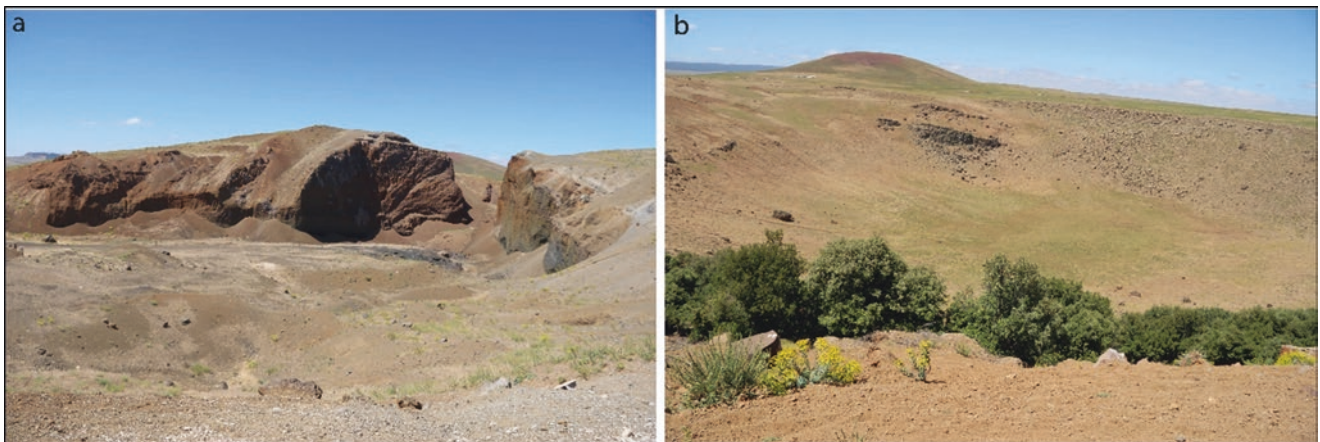
hoe lavas, coarse slag, a large layer of lapilli and finally well-read breccias.

### 14.3.6 Bou-Teguerrouine

The Bou-Teguerrouine geosite (Fig. 14.10a) culminates at an altitude of 1871 m, it is 560 m high and 4500 m wide and is located 10 km north of Timahdite. It is a complex geomorphological (Fig. 14.10b) entity composed of eight nested conical volcanoes, of different sizes, resulting from simultaneous and juxtaposed eruptions, arranged along two faults of



**Fig. 14.7** 3D profile of the cone-maar Ouest Hébrî



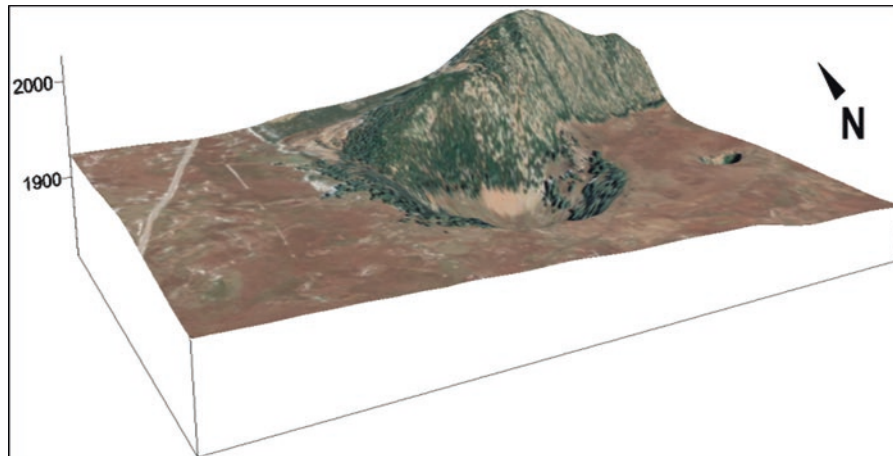
**Fig. 14.8** (a) View of the NE part of the Cone of Ouest Hébrî; (b) View of the SW part of the Maar of Ouest Hébrî

direction N60° and N140°. Three of them reach an altitude of 2006 m, or a drop of around 200 m, and are taller than the others. Bou-Teguerrouine was formed by the accumulation of slag, bombs, scraps of lava and large lava flows towards the end of its activity. This volcano gave birth to the great basaltic layer of Adaou.

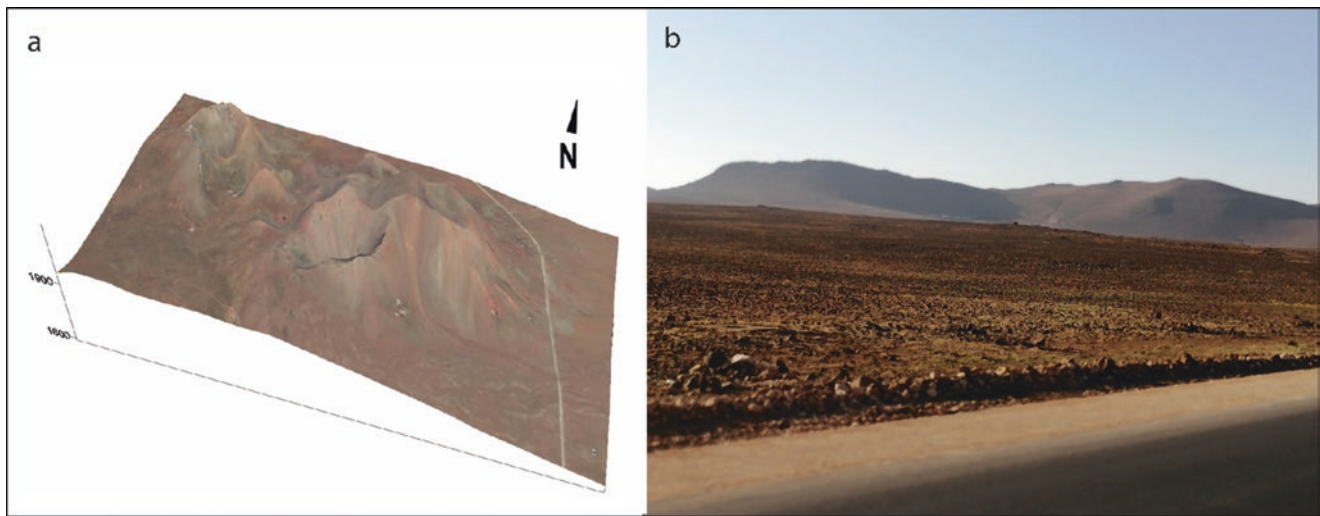
The very steeply sloping Bou-Teguerrouine composite volcano has a crater at the top and features a cluster of air vents. Highly explosive eruptions produced a larger volume of pyroclastic material than lava flows. These lavas are scoriaceous and bulleous and have a rough topography. The Bou-Teguerrouine geosite is the only volcanic device made up of eight craters in the Middle Atlas.

### 14.3.7 El Koudiate

The El Koudiate geosite (Fig. 14.11a) culminates to an altitude of 1785 m, it is 95 m high and 1200 m wide, it is widely spread out and is located 5 km west of Ifrane. It is a volcanic complex made up of three volcanoes called El Koudiate, Ariana and Tamahrart. These last are twin volcanoes and are found to the west. The sub-alkaline basalt flows of this set are very fluid and cover, in chaotic layers, the inequalities of the Ifrane Causse, creeping into the various valleys such as that of Oued Tizguite and heading north. The strombolian cone of El Koudiate (Fig. 14.11b),



**Fig. 14.9** 3D profile of the maar Lechmine n'Ikettane



**Fig. 14.10** (a) 3D profile of the geomorphological complex of Bou-Teguerrouine; (b) View of the northern part of the complex of Bou-Teguerrouine

the very rough top part of which is nested in the center of the dismantled crater. This geosite presents one of the most important volcanic structures in the Plateau.

### 14.3.8 Outgui

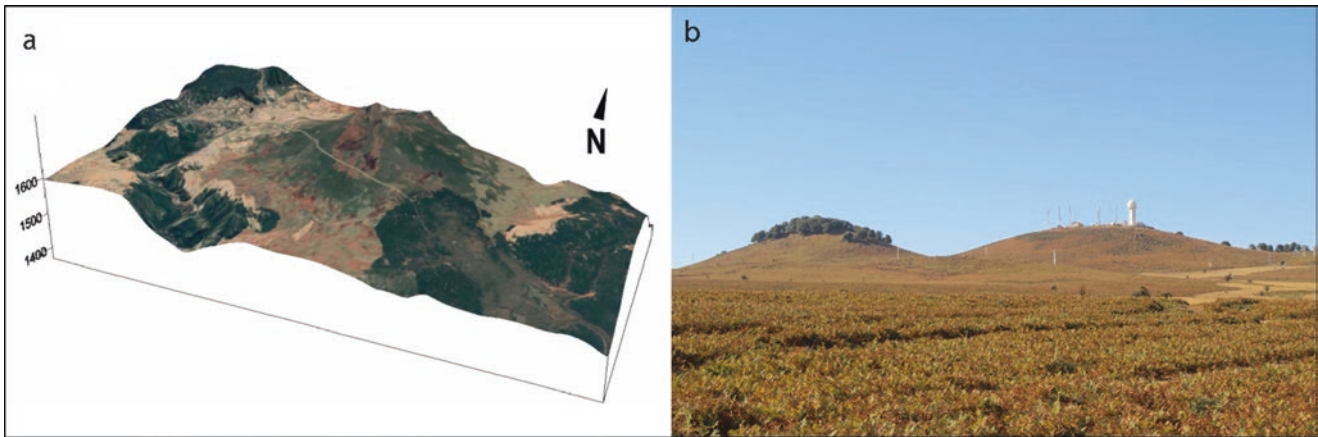
The Outgui geosite culminates to an altitude of 1411 m and is located 15 km southeast of the city of El Hajeb. It is a shield volcano, 100 m high and 500 m wide (Fig. 14.12), clearly visible in the landscape of the El Hajeb and Ifrane Causses. Along with El Koudiate, it presents one of the most important volcanic structures in the Ifrane and El Hajeb region. Its pahoehoe lava flows, of alkaline type, spread over more than 30 km and fill different valleys by changing the beds of rivers.

Its basaltic flows seem fresh and relatively intact. They covered a vast area of karst. Its volcanic activity has been characterized by both effusive and explosive eruptions. This volcanic cone probably started its eruptions at the end of the Pliocene although the K/Ar dates gave ages between 0.6 and 1.8 Ma (El Azzab and El Wartiti 1998).

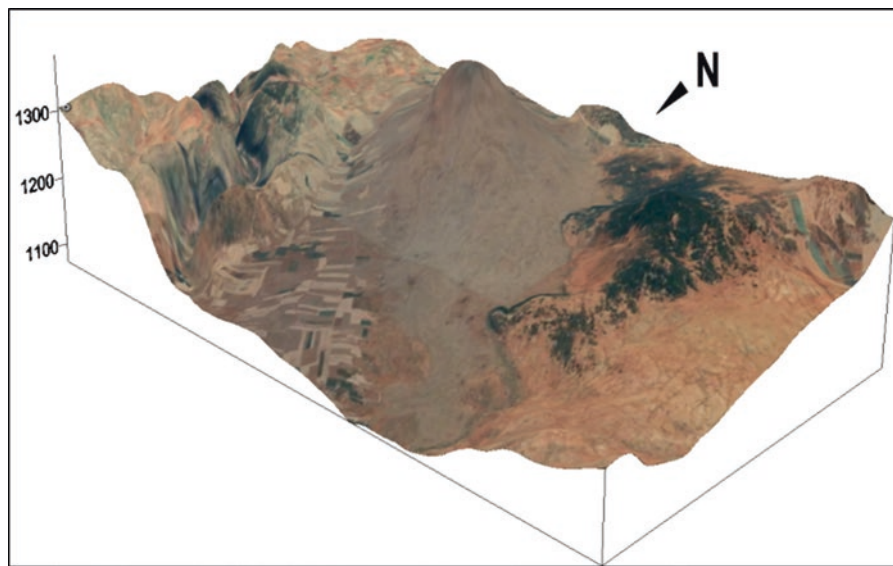
## 14.4 Promotion of Azrou-Timahdite Plateau Sites

Thus, the implementation of strategies for the promotion of Azrou-Timahdite geosites will be an important way to developed geotourism activities in the area. Some strategies have been developed and proposed by several authors in many countries across the world to solve that issue (Edgell 2006;





**Fig. 14.11** (a) 3D profile of the volcanic complex of El Koudiate; (b) Overview of the southern part of the El Koudiate cone



**Fig. 14.12** 3D profile of the cone of Outgui

Reynard 2008; Han et al. 2018; Abdou et al. 2019; Frey 2021; Alexandrowicz and Alexandrowicz 2022). Among those strategies the following suit very well with the context of Azrou-Timahdite:

Develop and establish geo-interpretative panels near selected geosites by using the data provided in this work. Interpretation is a very important component of geotourism, that is, to explain, perhaps visually, how the rocks were formed; how if crops out, how it changes with time, etc.;

Raising the awareness of the local and international community about the importance of geosites for the economic development of the region;

Involving the local community in the sustainable management plans of geosites for geotouristic purposes. This will

be accompanied by the training of guides about the main geotouristic attractions of the region;

Networking (cooperation between scientists, tourist offices, municipality and other stakeholders) and influencing regional planning, policy development and practice;

Establishing regular guided tours for students from universities and secondary schools and, the civil society actors during the main season;

Developing a communication network with a functioning distribution and marketing structure with existing tourism organizations present in the region, and, the local competent authorities;

The marketing of geotourism should begin with an awareness campaign that will target the local, national and international community developing, creating, and utiliz-

ing media and communication forms; e.g., flyers and leaflets to websites, newspapers, magazines, television, radio, Facebook, and Instagram. For local people, the marketing must be done using sometime the local languages;

Another interesting way for the promotion of geological issues can be the development of special applications that can be downloaded to mobile phones for free. It is also important to ensure that these attractions are well-marked, and potentially dangerous places are secured.

## 14.5 Discussion

For nearly a decade, scientific research has accelerated in the field of geoheritage in general, and in that of volcanic heritage in particular. Thus, we can note the book by (Erfurt-Cooper and Cooper 2010) *Volcano and Geothermal Tourism, sustainable geo-resources for leisure and recreation*, entirely devoted to this subject. In addition, there is an issue of “special issue”, entirely devoted to volcanic heritage, entitled “Volcanic Geoheritage” in the journal *Geoheritage*, Volume 9, Issue 3, of September 2017, and a special issue, in progress, and titled “Geomorphology, Geoheritage, Geoparks and Geotourism in Volcanic Areas” in the *Geosciences journal of 2020*. In addition, in recent years, several articles dedicated to volcanic heritage have been published in specialist journals. It is therefore clear that the interest of researchers in geo-heritage in the volcanic environment is growing today.

In Morocco, as in several African countries, the geological heritage remains, in the majority of cases, unknown to the competent authorities and the general public (Asrat et al. 2012; Bakka Male 2011; Henriques and Neto 2015; Errami et al. 2015; Zangmo Tefogoum et al. 2017; Williams 2020; Baadi et al. 2020; Baadi et al. 2021). Volcanic buildings, as geosites, ultimately offer very diverse landscapes rich in impressive geological “monuments” and therefore constitute a real heritage. According to Schmincke (2004), volcanic activity is generally covered by the media when the lives of surrounding populations are in danger or infrastructure is damaged. Moreover, although tourism to volcanoes is increasingly popular in many countries around the world (Hansell and Oppenheimer 2004), academic and general literature on volcanic environments rarely mentions established tourism in these areas.

The geoheritage study on the Azrou-Timahdite Plateau (Central Middle Atlas) is part of this perspective. This study area experienced very diverse volcanic events between the Pliocene and the Quaternary. These events were at the origin of several geosites, 8 of which were selected in this work. The geosite of El Koudiate and Bou-Teguerrouine are composed of several explosion products including volcanic breccias, lapilli and ashes. These solid products are arranged in layers, reflecting the rhythm of the explosions that animated

the history of these volcanoes. Similar structures are observed on several cones on the slopes of Mount Manengouba (Cameroon), in particular on Njombé, Njom, Ndom and Ekoh (Zangmo Tefogoum et al. 2014), in Mt Scoria, Australia; Wizard Island, Crater Lake/Oregon, USA; Cerro Negro, Nicaragua; Pu’u O’o, Hawaii (Erfurt-Cooper 2010a, b) and the cones of Harrat Khaybar, Saudi Arabia (Németh and Moufti 2017). The peculiarity of the Bou-Teguerrouine geosite, with its eight volcanoes, is that it is disgusted. Its breaking is due to the bottom cones flows which occur at the terminal phase of the volcanic manifestations and which carry with them a side of the cone mainly composed of loose pyroclastic rocks. The same phenomenon was at the origin of several cones as in the Valley of the Volcanoes in Andagua, in Peru (Gałaś et al. 2018) and in Gabal Mayesra in Egypt (Khalaf et al. 2019).

The El Koudiate and Bou-Teguerrouine geosites are examples which perfectly illustrate the strombolian dynamism in the region. They give an overall illustration of the activity of the majority of the volcanoes of the Azrou-Timahdite Plateau which have experienced this type of dynamism. In addition, the drained cones can be used as drainage basins for teaching hydrology.

On the other hand, the geosites of Lechmine Ait el Haj, Lechmine Bou-Ibalrhatène and Bou-Teguerrouine consist of an alternation of flows and pyroclastic products thus defining stratovolcanoes which dominate in several volcanic environments in the world, notably the Snaefellsjökull from Iceland; St Helens, Washington; Mt. Fuji, Japan; Cotopaxi, Ecuador; Mayon, Philippines; Vesuvius and Stromboli, Italy; Nevado del Ruiz, Colombia; Merapi, Indonesia; Nyiragongo, in the Democratic Republic of Congo, and Mount Manengouba and Mount Bambouto in Cameroon (Kagou Dongmo et al. 2005; Wood 2009; Erfurt-Cooper 2010a, b; Wantim et al. 2013; Zangmo Tefogoum 2016). Stratovolcanoes have a strong educational value because they allow us to understand the transitions between the effusive and explosive phases (Németh and Moufti 2017) of the history of a volcano. Thus, stratovolcanoes are sufficiently represented in the World Heritage list (Wood 2009). The Lechmine Bou-Ibalrhatène geosite and the Lechmine Ait el Haj geosite are made up of different coalescing structures. In addition, coalescing volcanoes are also observed on Nyiragongo (Kazadi Sanga-Ngoie 2010) and on the Erazu volcano in Costa Rica (Pérez-Umaña et al., 2020). This testifies the degree of fracturing of the basement and the internal geodynamic processes which took place on the Azrou-Timahdite Plateau in particular and in the central Middle Atlas and Morocco in general. The presence of maars as in the environment of the geosites of Lechmine Bou-Ibalrhatène, Lechmine Ait el Haj, Michlifène and Lechmine n’Ikettane, improve the educational value of the study area because it tells us about the phreatomagmatic dynamism which sums up the meeting of an ascending

magma and an underground or subsurface water table leading to significant explosions. Maars according to Joyce (2010), are destructive volcanic forms because they cause the pre-existing reliefs to collapse.

The presence of xenoliths in the rock formations of the Lechmine Bou-Ibalrhatène geosite tells us about the magmatic source of the different rocks of this geosite. The composition of these xenoliths, namely spinel lherzolites, harzburgites and pyroxenites, allows us to conclude that these rock formations are of mantle origin. The outcrop of volcanic products in strata and the presence of xenoliths in certain rocks make it possible to make a relative chronology of the geological events that have occurred in certain sites of the study area, thus giving them significant educational value.

Beyond the possibilities offered by the Michlifène geosite for recreational activities, it has a ski facility, promoting the practice of this sport as on the Hokkaido volcano in Japan. This is what Erfurt-Cooper (2010a, b) calls volcanic sports like surfing.

The Outgui geosite is a shield volcano which is materialized by very fluid lava flows in several directions. We can cite the case of the Piton de la Fournaise (Gaudru 2010); the Hallasan shield volcano in South Korea (Woo et al. 2010); the Bambouto Mountains, in Cameroon (Tchoua 1972; Youmen 1994).

It clearly appears that the geosites of the Azrou-Timahdite Plateau, although little known, are of very high scientific and educational value. They constitute a geological heritage which deserves to be valued. Since the main objective of geotourism is education in Earth Sciences, this enhancement would be more effective through the implementation of geotourism in the study area. Geotourism in volcanic environments is attracting increasing numbers of visitors (Erfurt-Cooper 2010a, b). These include countries that are sufficiently advanced in this area such as Japan, New Zealand, Greece and Italy. Certain active volcanoes which offer observable eruptive phases attract more geotourists than dormant or extinct volcanoes. The latter category nevertheless offers unique landscapes for the development of geotourism and recreational activities. Geosites of the Azrou-Timahdite Plateau which, despite the absence of volcanic activity nowadays, present several assets that can help attract a large number of visitors through geotourism. This geological heritage remains very even unknown and little protected. According to Zafeiropoulos et al. (2021), the importance of establishing a legal framework for the protection of geosites is underlined by the fact that their promotion and rational management create opportunities for sustainable development, as well as to become quality tourist destinations (geotourism) through nature protection and education. It would be important for the competent Moroccan authorities to promote the Azrou-Timahdite Plateau geosites through education

through geotourism, which would indirectly secure their protection and conservation for future generations. In addition, educational values of the sites presented above will contribute to the promotion of the knowledge of Earth science and, eventually, to the intensification of activities aiming at conservation of the geological heritage (Alexandrowicz and Alexandrowicz 2022).

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## 14.6 Conclusion

Morocco, called the “Paradise of geologists”, has aroused growing interest in recent years for the scientific study of its geoheritage. Geosites are an integral part of geoheritage. The Azrou-Timahdite Plateau has 81 geosites of variable volcanic and morphological structures representing 70% of the geosites in the region (Baadi et al. 2021). Their good state of conservation is due to their location in the Ifrane National Park (INP). This work proposed the study of 8 volcanic geosites of high scientific, educational and geotouristic value. They display spectacular volcano-morphological characteristics, emphasizing the style of eruptive dynamism, shapes, position, crater size, and pyroclastic products. Information on geology, geomorphology and geodiversity is also given.

On the Azrou-Timahdite plateau, there are volcanoes of both Strombolian and phreatomagmatic origin or of both origins (strombolian and phreatomagmatic). This is the case of the Ouest Hébré geosite. It is the originality of the volcanic geosites of the Plateau compared to the other volcanic geosites of Morocco. The diversity of geosites in the region is linked to the karstic and hydrogeological setting due to the carbonated aquifer of the underlying Lias revealing superb hydro-volcanic reliefs.

The Azrou-Timahdite Plateau is known for the quality and state of preservation of its outcrops. It has the full range of existing volcanological phenomena and therefore constitutes an excellent educational region to attract the attention of researchers, students, pupils as well as the general public. These geosites therefore constitute a veritable open-air “museum” by providing a large database usable for geotourism purposes and for promoting the socio-economic development of the region.

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