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ORIGINAL ARTICLE

Inventory and Quantitative Assessment of Geosites in Rabat-Tiflet Region (North Western Morocco): Preliminary Study to Evaluate the Potential of the Area to Become a Geopark

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Abstract
The Rabat-Tiflet area (north-western Morocco) has a complex geological setting and a high geodiversity, two reasons that justify the geoheritage inventory done in this work. The inventoried 13 geosites were quantitatively assessed and clearly show that the Tortonian/Messinian Akrech River GSSP Stratotype is the most important geosite in the area due to its high international scientific value. In addition, the majority of the other geosites are characterized by moderate scientific, educational, and touristic values and high degradation risk. Therefore, a geoconservation strategy should be implemented in this area by national and local authorities to protect and conserve this geological heritage. This study may help the development of a new geopark project in Morocco, a country where the geopark concept is still emerging.

Keywords Rabat-Tiflet area · Geosites · Inventory · Quantitative assessment of geosites · Geotourism · Geopark

Introduction

The Moroccan geoscientific community has recently started to work on geoheritage and geoconservation. The first law for the protection of the Moroccan geoheritage has just been published (BO 6807, August 2019), which could cause a very important turnover in the present deficient situation of the national geoheritage. In the last 13 years, several inventories of geosites were carried out in different regions of Morocco and with different aims (Malaki 2006; De Waele et al. 2009; El Wartiti et al. 2009, 2017; Tahiri et al. 2010a; El Hadi et al. 2011, 2012, 2015; Nahraoui et al. 2011; Nahraoui 2016; Enniouar et al. 2013, 2015; Errami et al. 2013, 2015a, 2015b; Druguet et al. 2015; Noubhani 2015; Saddiqi et al. 2015; Bouzekraoui et al. 2017; Arrad et al. 2018; Bouzekraoui et al. 2018; El Hassani et al. 2017; Khoukhouchi et al. 2018; Aoulad-Sidi-Mhend et al. 2019; Beraaouz et al. 2019; Berred et al. 2019; Oukassou et al. 2019). However, many of these works did not follow a systematic inventory method nor a numerical assessment of the geosite value. The systematic inventory and quantitative assessment of geoheritage is very important in any geoconservation strategy and considered as the base for the establishment of geoparks and development of geotourism (Henriques and Brilha 2017). The establishment of a geopark in the study area could be helpful for the improvement of the social level of the local community and a good opportunity to share the cultural traditions of the region with national and international visitors, as well as to raise the economical level through a well-founded geotourism action plan.

The Rabat-Tiflet area in North-western Morocco has a complex geology and a high geodiversity. The age of the rocks range from the Ediacaran (Tahiri et al. 2010b) to the Quaternary (Vidal 1989; Hilgenet al. 2000; Dayja et al. 2005). Due to this long and complete geological record, several geosites with high scientific, educational, and touristic values were previously identified (Tahiri et al. 2010a) but a systematic inventory of geosites in the area

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was never done. This paper intends to fill this gap and presents the results of the inventory and quantitative assessment of geosites in the Rabat-Tiflet area.

Geographical and Geological Setting

The Rabat-Tiflet region in north-western Morocco is located between latitude 35°58′N and 33°53′N and longitude 6°53′ and 6°17′ W (Fig. 1). From the administrative point of view, the studied area is integrated into the Rabat-Salé-Kenitra region and accessible through roads P4027 and N6. The Mediterranean climate (Daget 1977; Emberger 1930; Emberger 1939; Sauvage 1963) is semi-arid with an annual average rainfall of 459 mm and an annual mean temperature of 17.5 °C, with a minimum of 1.5 °C during the winter and a maximum of 40.5 °C in the summer.

The Rabat-Tiflet area is located on the northern border of the North-West Meseta (Figs. 1 and 2) and comprises three main components (Fig. 1b, c): the Caledonian Sehoul block, the BouRegreg anticlinal axis, and the northern border of the Sidi Bettache Basin. These three components are related through a roughly East-West trending thrust (Piqué 1979; Cailleux et al. 1983, 1984; El Hassani 1990-1991). Palaeozoic formations crop out in the bottom of valleys and are covered by Miocene-Plio-Quaternary formations (Piqué 1979; Vidal 1989; El Hassani 1990-1991).

The Sehoul Block is mainly formed by phyllades and quartzo-phyllades. This block is considered “exotic” because it is the only known occurrence related to the Caledonian

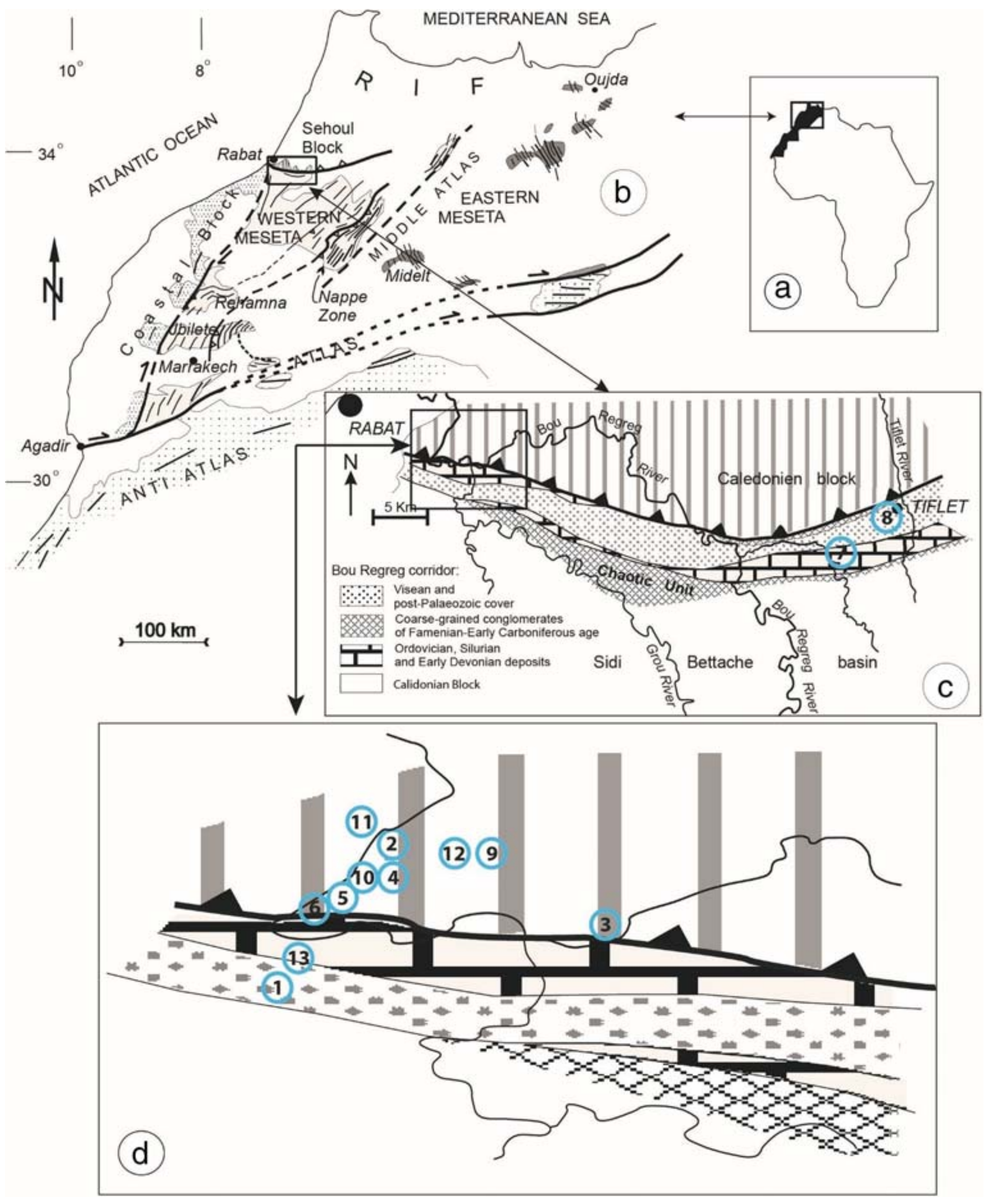

Fig. 1 **a** General location of the study area in NW Morocco. **b** Geological sketch of the north Moroccan Variscides (in Tahiri et al. 2010b, simplified). **c** Geological map of the study area. **d** Enlarged area showing the geosite location (same legend of **c**); 1: Messinian/Tortonian GSSP Stratotype of Oued Akrech, 2: Upper Devonian Granite of Rabat, 3: Lower Ordovician Amphibolite of Rabat, 4: Lower Ordovician Pillow lava, 5: Siluro-Lochkovian Limestones Turbidites, 6: Praguian Nodular limestone, 7: Ediacaran Granite of Tiflet, 8: Strunian Limestone Conglomerate of Tiflet, 9: Lower Visean red conglomerate, 10: Lower Ordovician-Upper Silurian unconformity, 11: Miocene/Lower Devonian unconformity, 12: Miocene/Lower Visean unconformity, 13: Miocène-Quaternary unconformity

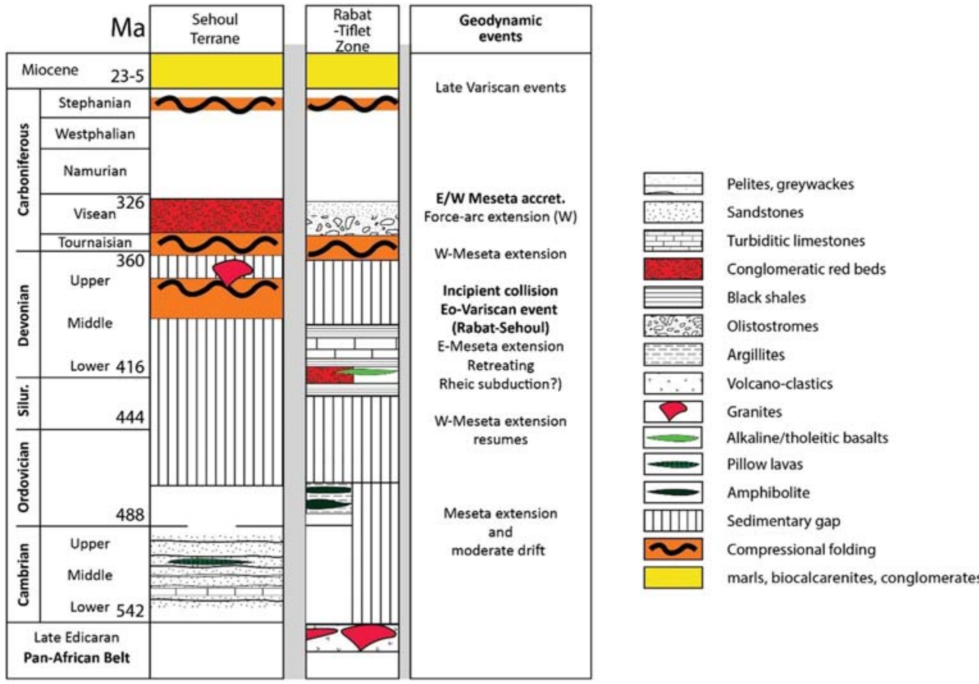

Fig. 2 Stratigraphic log of the Sehoul tarran and the Rabat-Tiflet zone (From Michard et al. 2010, simplified)

orogeny in Morocco (El Hassani 1990-1991; Piqué et al. 1993). This block is being thrusted southward to the Meseta at least since Lower Devonian (Piqué 1979), probably before according to Piqué (1982). The block is characterized by 500-m-thick middle Cambrian to Ordovician detrital (deltaic) series (El Hassani 1990-1991) affected by syn-metamorphic isoclinal Caledonian (?) folds (Piqué 1979; El Hassani et al. 1991) and a penetrative cleavage contemporaneous with a low-grade metamorphism (Piqué 1979; El Hassani 1990-1991; El Hassani et al. 1991; Piqué et al. 1993). The southern boundary of this block is marked by plurimetric tectonic lenses composed of deformed granites dated to 367 Ma (Tahiri et al. 2010b), andalusite-bearing micaschists and amphibolites.

The BouRegreg (or Rabat-Tiflet) anticlinal axis is composed of sedimentary deposits dating from Lower Ordovician (Rahmani 1978) to upper Visean (Vidal 1989; Izart 1990) with a Middle Ordovician to middle Silurian gap (Piqué 1979; El Hassani 1990-1991). The Lower Ordovician siliciclastic platform deposits are overlapped by a thick (200 m) upper Silurian-Lower Devonian series composed by a succession of (marine) microconglomeratic and black shales, turbiditic limestone (Siluro-Lochkovian; Bhija et al. 1999; Bhija 2000), nodular limestones (Praguian), and Eifelian shales. This component is also composed by pillow lavas and dolerites (Piqué 1979; El Hassani 1990-1991; El Hadi et al. 2014) which are interbedded with Lower Ordovician deposits.

Finally, the northern border of the Sidi Bettache Basin is characterized by a Famennian-Tournaisian up to upper Visean chaotic detrital deposits constituted by rock fall deposits coming from the dismantlement of the Sehoul block ridge (Padgett et al. 1977; Piqué 1979; El Hassani 1990-1991; Izart 1990).

Materials and Methods

Geoconservation strategies are based on a sequence of steps (inventory, quantitative assessment, conservation, interpretation, promotion, and monitoring of sites) aiming to achieve an effective management of geoheritage (Brilha 2018).

Different methodologies are proposed regarding the inventory and qualitative assessment of sites. Methodologies of assessment specifically addressed to geomorphosites were suggested by Panizza (2001) and Reynard et al. (2007), as well as procedures for their mapping (Reynard et al. 2016). Ruban (2010) proposes a methodology of assessment of geodiversity and geodiversity loss. A Geosite Assessment Model is proposed by Vujičić et al. (2011) for the planning and management of geosites and their adaptation to become tourism attractions.

Based on several methods previously published, Brilha (2016) proposes a method that can be applied to all types of geological sites. According to this method, the selection of geosites must prioritize the scientific value, independently of the possibility of educational and touristic values being also relevant. During this work, all sites were assessed for their scientific, educational, and touristic uses, as well as their risk of degradation, following Brilha (2016) method. This method can help decision-makers concerning geoconservation, geotourism, and regional sustainable development strategies.

Among a list of potential geosites collected after a literature review, fieldwork, and information provided by experts, geosites were selected using the following qualitative criteria: representativeness, integrity, rarity, and scientific knowledge.

Table 1 Criteria, indicators, and numeric parameter to quantify the scientific, educational, and touristic values, together with the degradation risk of the Rabat-Tiflet geosites (Brilha 2016)

	Points
Representativeness (SVW = 30; EVW = 0; TVW = 0; DRW = 0)	
The geosite is the best example in the study area.	4
The geosite is a good example in the study area.	2
The geosite is a reasonable example in the study area.	1
Key locality (SVW = 20; EVW = 0; TVW = 0; DRW = 0)	
The geosite is recognized as a GSSP or ASSP by the IUGS or is an IMA reference site.	4
The geosite is used by international science.	2
The geosite is used by national science.	1
Scientific knowledge (SVW = 5; EVW = 0; TVW = 0; DRW = 0)	
There are papers in international scientific journals about this geosite.	4
There are papers in national scientific publications about this geosite.	2
There are abstracts presented in international scientific events about this geosite.	1
Integrity (SVW = 15; EVW = 0; TVW = 0; DRW = 0)	
The main geological elements are very well preserved.	4
Geosite not so well preserved, but the main geological elements are still preserved.	2
Geosite with preservation problems and with the main geological elements quite altered or modified.	1
Geological diversity (SVW = 5; EVW = 0; TVW = 0; DRW = 0)	
Geosite with more than three types of distinct geological features with scientific relevance.	4
Geosite with three types of distinct geological features with scientific relevance.	2
Geosite with two types of distinct geological features with scientific relevance.	1
Rarity (SVW = 15; EVW = 0; TVW = 0; DRW = 0)	
The geosite is the only occurrence of this type in the study area.	4
In the study area, there are two to three examples of similar geosites.	2
In the study area, there are four to five examples of similar geosites.	1
In the study area, there are over than five examples of similar geosites.	0
Use limitations (SVW = 10; EVW = 0; TVW = 0; DRW = 0)	
The geosite has no limitations (legal permissions, physical barriers…) for sampling or fieldwork.	4
It is possible to collect samples and do fieldwork after overcoming the limitations	2
Sampling and fieldwork are very hard to be accomplished due to limitations difficult to overcome (legal permissions, physical barriers…).	1
Vulnerability (SVW = 0; EVW = 10; TVW = 10; DRW = 0)	
The geological elements of the geosite present no possible deterioration by anthropic activity.	4
There is the possibility of deterioration of main geological elements by anthropic activity.	2
There is the possibility of deterioration of main geological elements by anthropic activity.	1
Accessibility (SVW = 0; EVW = 10; TVW = 10; DRW = 0)	
Site located less than 100 m from a paved road.	4
Site located less than 500 m from a paved road.	3
Site accessible by bus but through a gravel road.	2
Site with no direct access by road but located less than 1 km from a road accessible by bus.	1
Use limitations (SVW = 0; EVW = 5; TVW = 5; DRW = 0)	
The site has no limitations to be used by students and tourists.	4
The site can be used by students and tourists but only occasionally.	3
The site can be used by students and tourists but only after overcoming limitations (legal, permissions, physical, tides, floods…).	2
The use by students and tourists is very hard to be accomplished due to limitations difficult to overcome (legal, permissions, physical, tides, floods, …).	1
Safety (SVW = 0; EVW = 10; TVW = 10; DRW = 0)	
Site with safety facilities (fences, stairs, handrails, etc.), mobile phone coverage and located less than 5 km from emergency services.	4
Site with safety facilities (fences, stairs, handrails, etc.), mobile phone coverage and located less than 25 km from emergency services.	3
Site with no safety facilities but with mobile phone coverage and located less than 50 km from emergency services.	2
Site with no safety facilities, no mobile phone coverage and located more than 50 km from emergency services.	1
Logistics (SVW = 0; EVW = 5; TVW = 5; DRW = 0)	
Lodging and restaurants for groups of 50 persons less than 15 km away from the site.	4
Lodging and restaurants for groups of 50 persons less than 50 km away from the site.	3
Lodging and restaurants for groups of 50 persons less than 100 km away from the site.	2
Lodging and restaurants for groups less than 25 persons and less than 50 km away from the site.	1
Density of population (SVW = 0; EVW = 5; TVW = 5; DRW = 0)	
Site located in a region with more than 1000 inhabitants/km^2.	4
Site located in a region with 250–1000 inhabitants/km^2.	3
Site located in a region with 100–250 inhabitants/km^2.	2
Site located in a regionwith less than 100 inhabitants/km^2.	1
Association with other values (SVW = 0; EVW = 5; TVW = 5; DRW = 0)	
Occurrence of several ecological and cultural values less than 5 km away from the site.	4
Occurrence of several ecological and cultural values less than 10 km away from the site.	3
Occurrence of one ecological value and one cultural value less than 10 km away from the site.	2
Occurrence of one ecological or cultural value less than 10 km away from the site.	1
Scenery (SVW = 0; EVW = 5; TVW = 15; DRW = 0)	
Site currently used as a tourism destination in national campaigns	4
Site occasionally used as a tourism destination in national campaigns.	3
Site currently used as a tourism destination in local campaigns.	2
Site occasionally used as a tourism destination in local campaigns.	1

Table 1 (continued)

	Points
Site has no use as a tourism destination	0
Uniqueness (SVW = 0; EVW = 5; TVW = 10; DRW = 0)	
The site shows unique and uncommon features considering this and neighbouring countries.	4
The site shows unique and uncommon features in the country.	3
The site shows common features in this region but they are uncommon in other regions of the country.	2
The site shows features rather common in the whole country.	1
Observation conditions (SVW = 0; EVW = 10; TVW = 5; DRW = 0)	
All geological elements are observed in good conditions	4
There are some obstacles that make difficult the observation of some geological elements.	3
There are some obstacles that make difficult the observation of the main geological elements.	2
There are some obstacles that almost obstruct the observation of the main geological elements.	1
Didactic potential (SVW = 0; EVW = 20; TVW = 0; DRW = 0)	
The site presents geological elements that are taught in all teachinglevels	4
The site presents geological elements that are taught in elementaryschools	3
The site presents geological elements that are taught in secondaryschools	2
The site presents geological elements that are taught in theuniversity	1
Geological diversity (SVW = 0; EVW = 10; TVW = 0; DRW = 0)	
More than 3 types of geodiversity elements occur in the site (mineralogical, paleontological, geomorphological, etc.)	4
There are 3 types of geodiversity elements in the site	3
There are 2 types of geodiversity elements in the site	2
There is only 1 type of geodiversity element in the site	1
Interpretative potential (SVW = 0; EVW = 0; TVW = 10; DRW = 0)	
The site presents geological elements in a very clear and expressive way to all types of public	4
The public needs to have some geological background to understand the geological elements of the site	3
The public needs to have solid geological background to understand the geological elements of the site	2
The site presents geological elements only understandable to geological experts	1
Economic level (SVW = 0; EVW = 0; TVW = 5; DRW = 0)	
The site is located in a municipality with a household income at least the double of the national average	4
The site is located in a municipality with a household income higher than the national average	3
The site is located in a municipality with a household income similar to the national average	2
The site is located in a municipality with a household income lower than the national average	1
Proximity of recreational areas (SVW = 0; EVW = 0; TVW = 5; DRW = 0)	
Site located less than 5 km from a recreational area or tourist attraction	4
Site located less than 10 km from a recreational area or tourist attraction	3
Site located less than 15 km from a recreational area or tourist attraction	2
Site located less than 20 km from a recreational area or tourist attraction	1
Deterioration of geological elements (SVW = 0; EVW = 0; TVW = 0; DRW = 35)	
Possibility of deterioration of all geological elements	4
Possibility of deterioration of the main geological elements	3
Possibility of deterioration of secondary geological elements	2
Minor possibility of deterioration of secondary geological elements	1
Proximity to areas/activities with potential to cause degradation (SVW = 0; EVW = 0; TVW = 0; DRW = 20)	
Site located less than 50 m of a potential degrading area/activity	4
Site located less than 200 m of a potential degrading area/activity	3
Site located less than 500 m of a potential degrading area/activity	2
Site located less than 1 km of a potential degrading area/activity	1
Legal protection (SVW = 0; EVW = 0; TVW = 0; DRW = 20)	
Site located in an area with no legal protection and no control of access	4
Site located in an area with no legal protection but with control of access	3
Site located in an area with legal protection but no control of access	2
Site located in an area with legal protection and control of access	1
Accessibility (SVW = 0; EVW = 0; TVW = 0; DRW = 15)	
Site located less than 100 m from a paved road	4
Site located less than 500 m from a paved road	3
Site accessible by bus through a gravel road	2
Site with no direct access by road but located less than 1 km from a road accessible by bus	1
Density of population (SVW = 0; EVW = 0; TVW = 0; DRW = 10)	
Site located in a region with more than 1000 inhabitants/km^2	4
Site located in a region with 250–1000 inhabitants/km^2	3
Site located in a region with 100–250 inhabitants/km^2	2
Site located in a region with less than 100 inhabitants/km^2	1

SVW scientific value weight, *EVW* educational value weight, *TVW* touristic value weight, *DRW* degradation risk weight

Table 2 Brief characterization of 13 geosites of the Rabat-Tiflet.

Geosites	Geographical coordinates	Main features	Relevance	Main threats	Type of geosite[a]	Notes	Sizes
Geosite (1): Messinian/Tortonian GSSP Stratotype of Oued Akrech	33°56′13″ N 6°48′45″ W	Messinian/Tortonian GSSP Stratotype.	International	Road, Mining activities and residential area	Section	Urgent conservation measures are necessary	Hectometric
Geosite (2): Upper Devonian Granite of Rabat	33°56′34,05″ N 6°47′ 18,07″W	The only Devonian magmatic rocks in the region (Tahiri et al. 2010b).	National	River flooding	Point	Legal protection is necessary	Hectometric
Geosite (3): Lower Ordovician Amphibolite of Rabat	33°56′07,92″ N 6°46′ 01,07″W	The only evidence in north Morocco of the Palaeozoic high grade regional metamorphism.	International	Road, river flooding, construction of dams and highway bridge	Point	The outcrop has a high degradation risk due to its small size	Hectometric
Geosite (4): Lower Ordovician Pilow lava	33°56′26,54″ N 6°47′ 22,48″W	Ordovician Pillow lava, the only evidence of the Rheic (?) ocean floor in Morocco.	International	Road, river flooding	Point	Potential educational use due to the rarity of the occurrence, Legal protection is necessary	Hectometric
Geosite (5): Siluro-Lochkovian Limestone Turbidites	33°56′21,53″ N 6°47′ 26,64″W	The only example of the Lochkovian limestone turbidites in Morocco	International	Road, river flooding	Section	Potential educational use due to the rarity of the feature	Hectometric
Geosite (6): Praguian Nodular limestone	33°56′19,05″ N 6°47′ 32,61″ W	The best example of the Pragian nodular limestone in this part of Morocco	National	Road, river flooding	Section	Potential educational use due to the rarity of the feature	decametric
Geosite (7): Ediacaran Granite of Tiflet	33°50′ 07,16 N 6°28′ 26,38″ W	The only Late Proterozoic (605–609 Ma), granite in north western Morocco.	Local	river flooding, Mining activities	Area	Potential educational use due to the rarity of the feature	Hectometric
Geosite (8): Strunian Limestone Conglomerate of Tiflet	33°52′52,50″ N 6°17′ 34,54″W	Best rock fall deposits example	National	Road	Point	Potential educational use due to the rarity of the feature	Hectometric
Geosite (9): Lower Visean red conglomerate	33°56′41,44″ N 6°46′ 18,39″W	Continental undeformed fluviatile red conglomerate with plant remains.	National	Road, river flooding	Point	Potential educational use due to the rarity of the feature	Hectometric
Geosite (10): Lower Ordovician-Upper Silurian unconformity	33°56′22,51″ N 6°47′ 26,09″W	Gap between Lower Ordovician and Upper Silurian (Silurian marine transgression)	National	Road	Viewpoint	Potential educational use due to the rarity of the feature	Decametric
Geosite (11): Miocene/Lower Devonian unconformity	33°56′33,05″ N 6°47′ 19,27″W	Mio-Pliocene (Atlantic and/or Tethys) transgression	National	Road	Viewpoint	Potential educational use due to the rarity of the feature	Hectometric
Geosite (12): Miocene/Lower Visean unconformity	33°56′34,25″ N 6°47′ 18,07″W		National	Road, Mining activities	Viewpoint	Potential educational use due to the rarity of the feature	Hectometric
Geosite (13): Pliocene-Quaternary unconformity	33°56′34,48″ N 6°47′ 19,27″W	Gap between Miocene and Quaternary	National	Road	Viewpoint	Potential educational use due to the rarity of the feature	Hectometric

[a] Fuertes-Gutiérrez and Fernández-Martínez (2010)

Concerning the quantification process, 26 criteria were used, with numerical scores ranging from 1 to 4, according to the above referred method (Brilha 2016, Table 1). Some indicators under certain criteria were adapted taking into account the region's specificities, namely, rarity, accessibility, and scenery.

Results

Geosites Inventory of Rabat-Tiflet Region

Thirteen geosites in the Rabat-Tiflet area were inventoried; 11 in the Akrech region and two in the Tiflet area (Figs. 1 and 2; Table 2). The general description of these geosites is presented below.

Geosite 1: Messinian/Tortonian GSSP Stratotype of Oued Akrech (Fig. 3)

This geosite is well-known as an international reference for the Messinian/Tortonian boundary (Benson and Rakic-El Bied 1996; Hilgen et al. 2000). Several sections were under discussion for the selection of the Messinian/Tortonian boundary GSSP (Monte del Casino in northern Italy, Faneromeni, Potamidha, and Kastelli in Grece; Metochia on Grece and Oued Akrech in Morocco) (Hilgen et al. 2000; Krijgsman et al. 1995, 1997; Remane et al. 1996), but in the end, the Oued Akrech section was considered to be the most representative one (Hilgen et al. 1998, 2000). The representativeness, rarity, uniqueness, and high scientific value (370) (see Fig. 15) of this geosite make it very important at the global scale.

Geosite 2: Upper Devonian Granite of Rabat (Fig. 4)

The Devonian in Morocco is usually known by its sedimentary deposits (Cogney 1967; Hollard 1967; Becker 1994; Bhija et al. 1999; Lazreq 1999; Walliser et al. 1995). However, the Rabat granitoids are the only magmatic rocks in the whole western meseta of Morocco with Devonian age (La-ICPMS 367 ± 8 Ma; Tahiri et al. 2010b). Petrographic and geochemical characteristics are evidences of magma emplacement in a subduction context (Tahiri et al. 2010b). This rock is extremely rare in the studied area and should be preserved because it gives an opportunity for scientists to study it deeply to better understand its geodynamic significance. Uniqueness and rarity constitute the main reasons for its selection as a geosite.

Geosite 3: Lower Ordovician Amphibolite of Rabat (Fig. 5)

These amphibolites ($SiO_2 = 47.29\%$) were affected by high regional metamorphism. The only geochemical analysis we have was performed at the University of Granada. Their outcrops are very scarce and present tectonic contacts with the Upper Devonian granites in the south fault zone of Sehoul block. This rock has the same geochemical features of MORB tholeiitic magmas: flat REE patterns and La/Yb ratio close to 1. The similarity of these rocks with the lower Palaeozoic amphibolite of Ossa-Morena (Central Iberian Variscan suture; Gomez-Pugnaire et al. 2003) has led some authors to consider it as a remain of the Rheic ocean in north Africa (Gomez-Pugnaire et al. 2003). The scientific value of this amphibolite comes from its rarity and possibility to support important scientific knowledge.

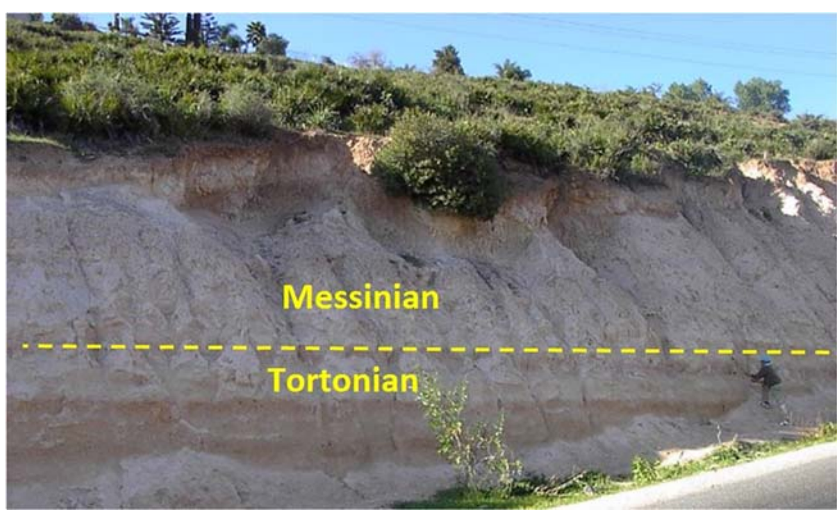

Fig. 3 Messinian/Tortonian GSSP Stratotype of Oued Akrech (geosite 1)

Fig. 4 Upper Devonian Granite of Rabat (geosite 2)

Geosite 4: Lower Ordovician Pillow Lava (Fig. 6)

In the Rabat-Tiflet area, especially near Rabat at the BouRegreg river east bank, there are several outcrops of Ordovician pillow lavas (Lecointre 1931; Termier 1936; Cogney 1957; Piqué 1979; El Hassani and Zahraoui 1984; El Hassani et al. 1988; Vidal 1989; El Hassani 1990-1991). They are intercalated with Lower Ordovician (Rahmani 1978) sandstone, shales, and quartzite sediments and some other basic volcanic rocks (Piqué 1979; El Hassani et al. 1991; El Hadi et al. 2014). These pillow lavas crop out just in this region of Morocco and are a witness of the Rheic Ocean (Gomez-Pugnaire et al. 2003; Simancas et al. 2005; Pérez-Cáceres et al. 2017). This geosite was selected due to its rarity and utility for international scientific correlations.

Geosite 5: Siluro-Lochkovian Limestones Turbidites (Fig. 7)

This geosite represents the only known occurrence in Morocco of the Siluro-Lochkovian turbiditic carbonate sedimentation (Michard 1976; El Hassani et al. 1991) that is still under sedimentological studies (Bhija et al. 1999). The relevance of this geosite comes from its uniqueness and possibility for international correlations. A similar outcrop was reported by Walliser et al. (1995) on Devonian series in the Prague area (Czech Republic).

Geosite 6: Praguian Nodular Limestone (Fig. 8)

The Praguian deposits are marked by gray-blue nodular limestones (griottes) and clay joints with Tentaculites, Brachiopods, and Echinoderms (El Hassani 1990-1991). Structures related to syn-sedimentary slumping and faults are also observed. The nature of the nodular facies suggests slope deposits controlled by (tectonic) instability of the sea bed (Piqué 1979; El Hassani 1990-1991; Zahraoui 1994). This geosite was selected due to its rarity in the Rabat-Tiflet area and its unique sedimentation structures.

Geosite 7: Ediacarian Granite of Tiflet (Fig. 9)

This set of rocks is known as Rabat-Tiflet granitoids (Charlot et al. 1973; Piqué 1979; El Hassani 1990-1991). Based on new geochronological ages determined by Tahiri et al. (2010b), it

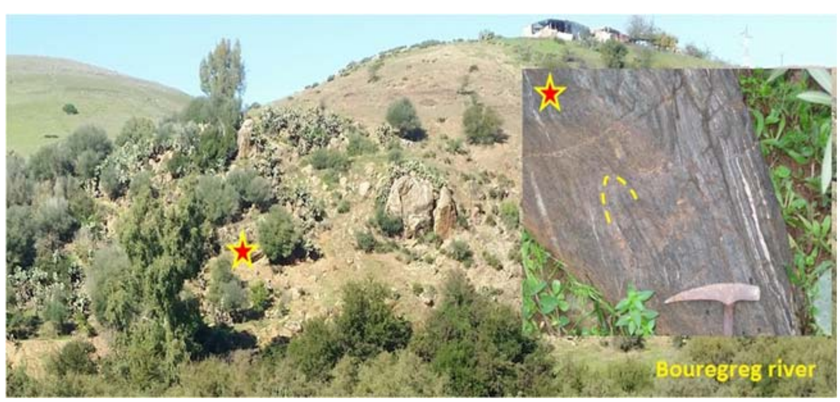

Fig. 5 Lower Ordovician(folded) amphibolite of Rabat (geosite 3)

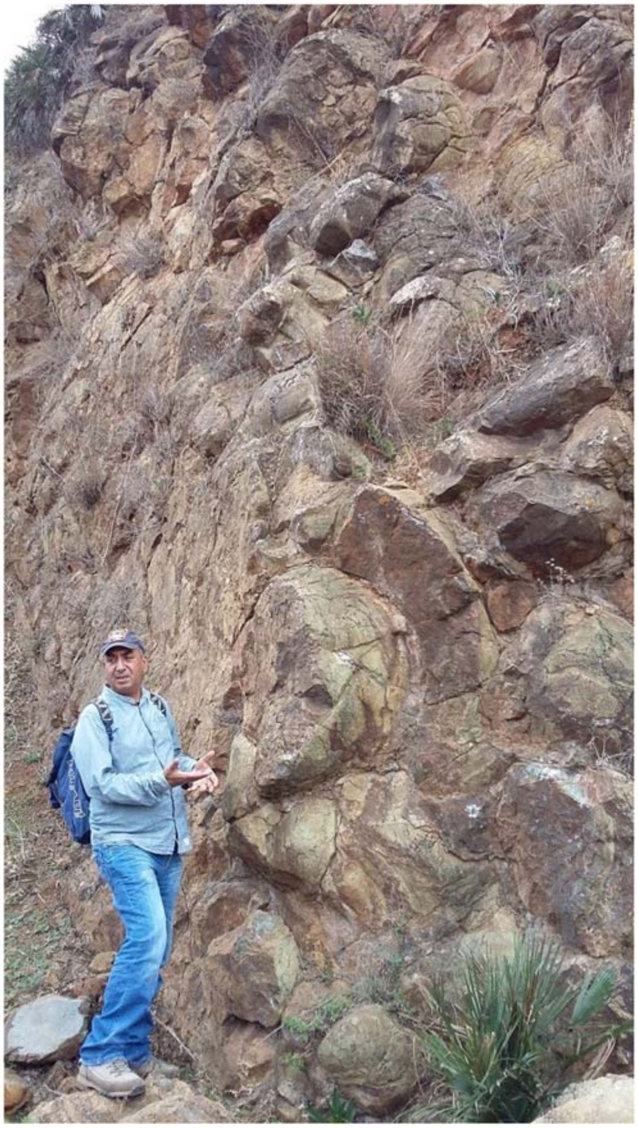

Fig. 6 Lower Ordovician Pilow lavas (geosite 4)

was possible to distinguish two granites. The granite of Rabat of upper Devonian age (367 Ma, U–Pb La-ICPMS) and the granite of Tiflet of Ediacarian age (609 Ma, U–Pb La-ICPMS) (Fig. 2). The Tiflet granite, like other outcrops in El Jadida (El Houicha et al. 2018; El Haibi et al. 2019) or in north eastern Central Morocco (Ouabid et al. 2017), is considered as the ancient Precambrian basement in north western Morocco. This geosite is the only occurrence of the Ediacarian granite in the study area.

Geosite 8: Strunian Limestone Pebble Conglomerate of Tiflet (Fig. 10)

In the north boundary of the Sidi Bettache basin (Fig. 1), coarse detrital rocks, namely the limestone pebble conglomerate of Tiflet river (Piqué 1979; El Hassani 1990-1991; El Haibi et al. 2015), overlapped by quartz-pebble conglomerate, shales, and *Spiriferverneuilli* lumachelic sandstones, suggest a Strunian age (Lecointre and Delepine 1933). These conglomerates are considered the best example for the mixed chaotic Famenno-Tournaisian sedimentation in north western Morocco (Izart 1990).

Geosite 9: Lower Visean Red Conglomerate (Fig. 11)

The outcrops of this conglomerate in the Rabat area, mainly in Jebel Bakkach and Bouregreg river border, are the only known occurrences in Morocco. These conglomerates are interpreted as fluvial cone deposits (Izart and Vieslet 1988) and are transgressive over the Sehoul block terranes (Piqué 1979; El Hassani 1990-1991; Fadli 1994). The occurrence of flora, such as *Sphenopteridiumdissectum*, *Rhacopteris*, and *Astercalamitesscrobiculatus*, indicates a Lower Visean age (Danze-corsin 1960). This is a very important outcrop at national scale due to its rarity.

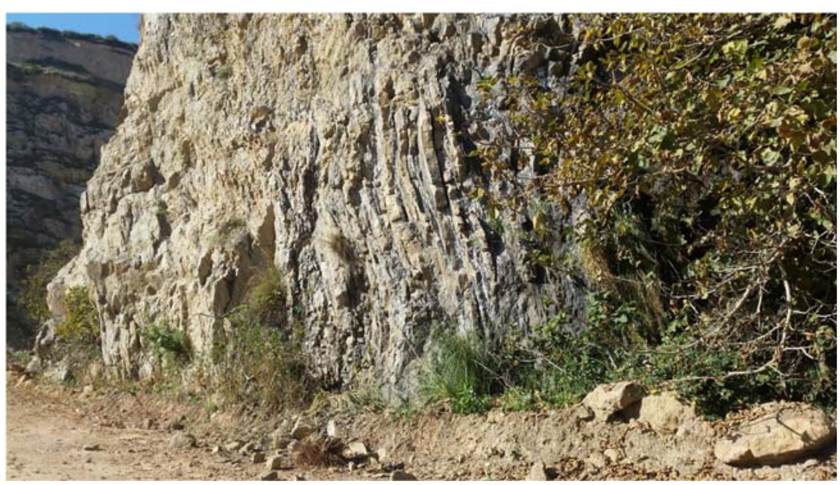

Fig. 7 Siluro-Lochkovian limestone turbidites (geosite 5)

Fig. 8 Praguian nodular limestone (geosite 6)

Geosite 10: Lower Ordovician-Upper Silurian Unconformity

The Middle and Upper Ordovician and the Lower and Middle Silurian are absent from the geological record in this region. Therefore, the Upper Silurian (Pridoli) is directly transgressive over Lower Ordovician deposits (Rahmani 1978; El Hassani et al. 1988; Zahraoui 1994). This unconformity is often related to Caledonian tectonics (Piqué 1979; El Hassani 1990-1991; Simancas et al. 2005, 2009; Michard et al. 2008).

During the Neogene, the sedimentation in the South Rifain Corridor was marly, marine, and relatively deep (Dayja 2002; Dayja et al. 2005). The Rabat area corresponds to the SW corner of the South Rifain Corridor and shows evidence of the Neogene marine transgression over a peneplain surface constituted by Palaeozoic deformed terranes (of both Sehoul Block and Bouregreg Axis). The occurrence of horizontal Miocene unconformity notably on Lower Devonian (Lochkovian and/or Praguian) limestones (Geosite 11: Miocene/Lower Devonian unconformity, Fig. 12) and on lower Visean red conglomerate (Geosite 12: Miocene/Lower Visean unconformity, Fig. 13) is common. The selection of these three geosites (10, 11, 12) is based on the scientific value (180, 230, and 230, respectively; see Fig. 15) and on their importance for paleoenvironmental reconstitution.

Geosite13: Pliocene-Quaternary Unconformity (Fig. 14)

At this site, the unconformity shows the gap between the last horizontal Pliocene marly horizons and the conglomerate and lumachellic levels (as well as dune sandstones) of the upper Pliocene/lower Quaternary ("Moghrebian" or "Villafranchian") (Vidal 1989). These "Moghrebian" deposits are considered as

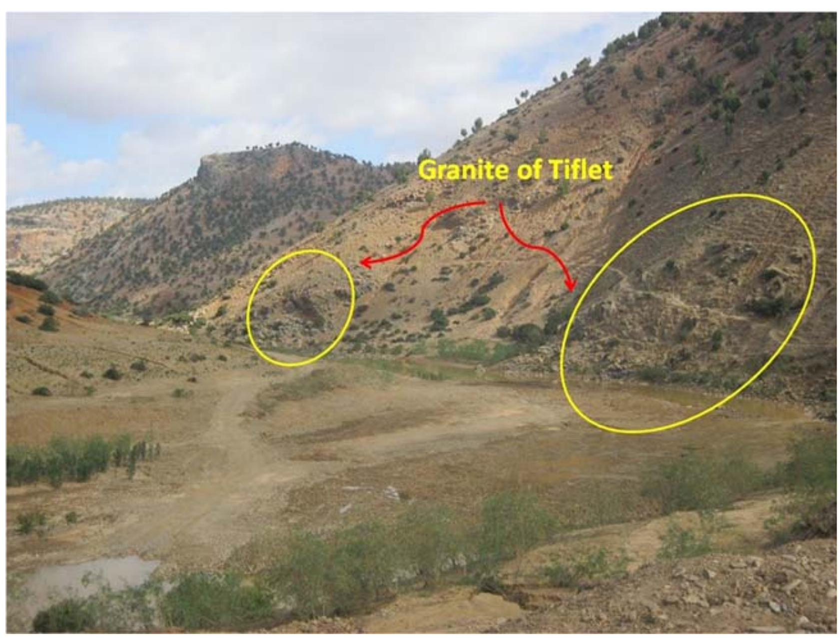

Fig. 9 Two lenses of Ediacaran Granite of Tiflet (geosite 7)

witnesses of the first quaternary marine incursion (Choubert and Ambroggi 1953) or represent the deposit of the Pliocene regression (Gigout 1960; Biberson 1961). Other authors describe them as plio-quaternary deposits representing a regressive marine series (Cirac 1987; Flinch 1993).

Quantitative Assessment of Geosites

The quantitative assessment of the scientific value and degradation risk of geosites is an important tool for the development of geoconservation strategies. In addition to this assessment, it was also done the quantification of the potential educational and touristic uses for the 13 geosites (Fig. 15).

In general, Rabat-Tiflet geosites are characterized by a moderate-high scientific value. Ten geosites have a moderate scientific value and two geosites have a high scientific value (Messinian/Tortonian GSSP Stratotype and Conglomerates of Tiflet). Only one geosite has low scientific value (Ordovician-Silurian unconformity). These results are justified by the high geodiversity and uncommon geological features outcropping in the area, some of them unique in the whole Morocco.

The results of the assessment also show that Rabat-Tiflet geosites have potential educational and tourism uses. Four geosites have a high educational value (the Conglomerates of Tiflet has the highest score), and nine geosites have a moderate educational value, while all geosites have a moderate touristic value. It is interesting to note that in spite the Messinian/Tortonian GSSP Stratotype, geosite has the highest scientific value, it does not have a high potential for educational and touristic uses.

Regarding the degradation risk assessment (Fig. 15), ten geosites have high risk. Among these ten geosites, there are three in the top 10 for the scientific value: Messinian/Tortonian Stratotype, Conglomerates of Tiflet, and granite of Rabat. The conjugation of a high scientific value with a high degradation risk justifies a top priority in the implementation of management strategies for those geosites.

The degradation risk comes from the possible threat caused by the river flooding (BouRegreg Akrech Rivers), roads, and quarrying activities. The outcrops in some geosites have a small area of exposure which is also a justification for a high degradation risk.

Discussion

The inventory of geological heritage can optimize the management of geological resources, environment, and nature landscapes. In addition, it can contribute to the preservation of relevant geosites, especially those considered fragile and vulnerable to natural and anthropogenic threats, such as those inventoried in this work (Fig. 15 and Table 2).

The selection of geosites using qualitative criteria (Brilha 2016)—representativeness, integrity, rarity, and scientific knowledge—constitutes a good procedure to guarantee a systematic inventory of geosites based on their scientific significance. However, this type of selection requires the existence of a solid scientific knowledge about the geological evolution of the area. Field work and cooperation with experts are also essential requirements.

Fig. 10 Strunian Limestone Conglomerate of Tiflet (geosite 8)

Fig. 11 Lower Visean red conglomerate (geosite 9)

The quantitative assessment of geosites is an important tool to support decision-making concerning which geoconservation strategies should be implemented. This tool helps to know the strengths and weaknesses of each geosite and also to establish priorities for the implementation of management actions.

The quantitative assessment allows us to sort a list of geosites. The "rarity" and the "key locality" criteria are responsible for the final low score (< 200) of geosite 10: Lower Ordovician-Upper Silurian unconformity. Two geosites have obtained final scores higher than 300, geosite 1: Messinian/Tortonian GSSP Stratotype of Oued Akrech clearly denoting its international relevance (Table 2) and geosite 8: Strunian Limestone Conglomerate of Tiflet mainly due to the "rarity" criterion.

Concerning the educational value, geosites with a score lower than 300 indicate poor conditions related with "vulnerability", "safety", "logistics", and "scenery" criteria. Four geosites have score of 300 or higher due to "logistics" and "didactic potential" criteria.

All geosites have a score higher than 200 in the touristic potential assessment. This result is mainly justified by the reasonable conditions regarding "safety", "logistics", and "scenery" criteria in all geosites.

Fig. 12 Miocene/Lower Devonian unconformity (geosite11)

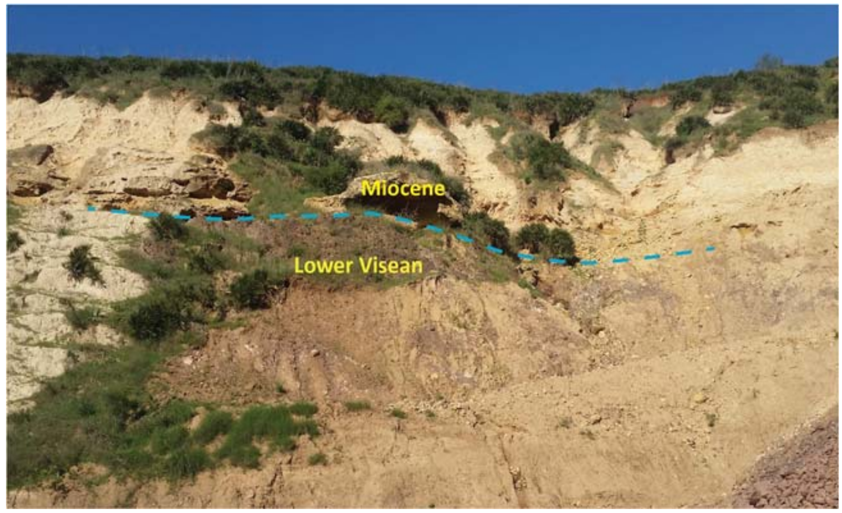

Fig. 13 Miocene/Lower Visean unconformity (geosite 12)

Finally, it is worthwhile to underline that the majority of geosites have a degradation risk higher than 300. This fact is justified by the poor conditions related with "Deterioration of geological elements", "Proximity to areas/activities with potential to cause degradation", "Legal protection" criteria.

Conclusion

The majority of the geosites inventoried in the Rabat-Tiflet area have a moderate scientific, educational, and touristic values and a high degradation risk. One of the geosites has as high scientific value, already certified by the international scientific community. According to these results, the geoheritage of this area has a high potential to support a future geopark project. In fact, one of the most important requisites to become a UNESCO Global Geopark is the existence of geological heritage of international significance (Henriques and Brilha 2017). However, this is not enough. The decision to develop a geopark project in the region should be taken by the local communities and competent authorities. This decision could not only contribute significantly to conserve these relevant geosites with the involvement of local communities, but also to raise their awareness about this heritage, its meaning, and relevance. In addition, the development of geotourism in the area as a consequence of the geopark creation could bring alternatives to these communities, namely creating jobs for young people, which could constitute a good example for other regions in Morocco and even for other countries in Northern Africa.

Through this potential geopak, a geotourism action plan could be created in order to promote the sustainable development in the region. It would be an opportunity to introduce the ethnic character, local culture, and history to

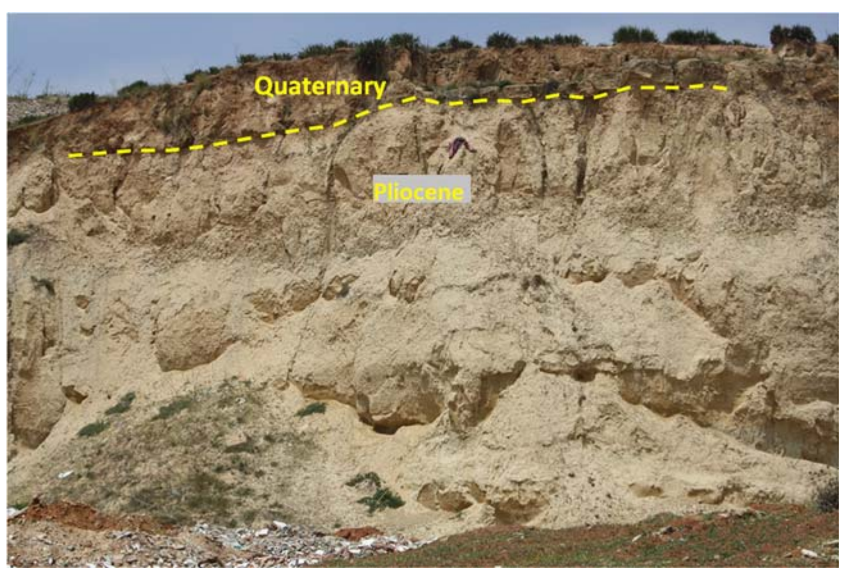

Fig. 14 Pliocene-quaternary unconformity (geosite 13)

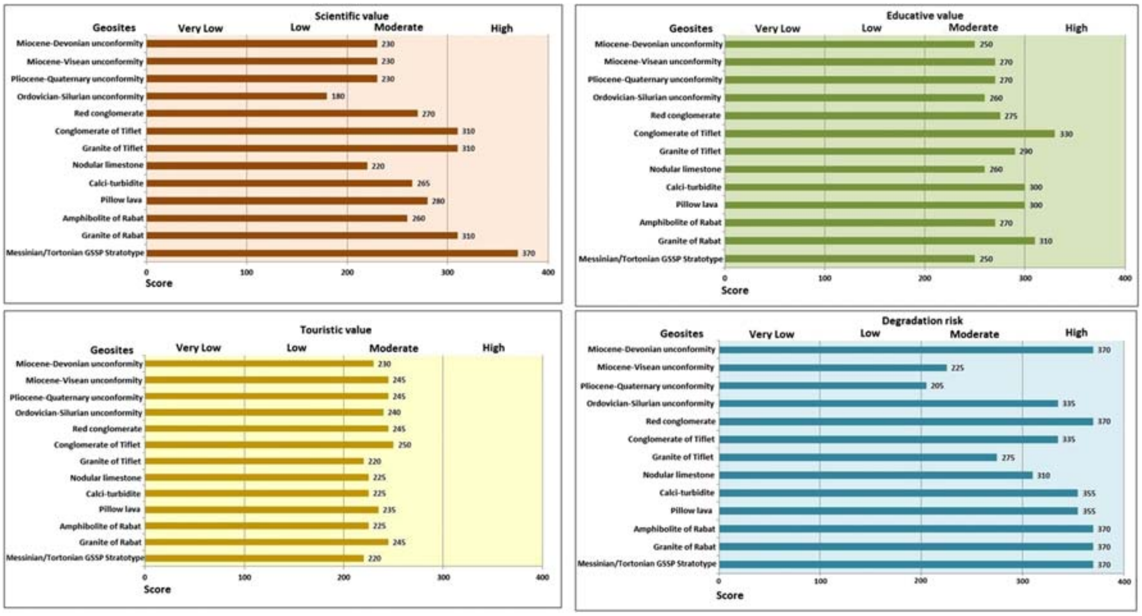

Fig. 15 Final score of geosites

tourists. Rural areas as the one studied in this work can obtain different benefits from the creation of a geopark. For instance, the establishment of small businesses related with accommodation, food, and handcraft, and improvements of the infrastructure like roads and communication. The education of local communities and visitors about the importance of natural and cultural heritage of the area is also vital. The creation of a visitor center with a solid interpretation program would also contribute for the engagement of local population in the geopark strategy.

The results expected from the creation of a geopark are not easy or fast to achieve. They depend on a series of requisites, such as the involvement of local communities, support of authorities, funding to support a dedicated working team and action plan, protection of the most relevant and threatened geosites, and existence of educational and geotourism activities. However, this study has demonstrated that at least one of these conditions is already fulfilled: the Rabat-Tiflet area has geoheritage of international significance that can support a future geopark project.

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