EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2023, 24(7), 105–128
https://doi.org/10.12912/27197050/168576
ISSN 2719-7050, License CC-BY 4.0

Received: 2023.05.23
Accepted: 2023.07.12
Published: 2023.08.15

Inventory and Quantitative Assessment of Belyounech Commune Geosites (East of the Site of Biological and Ecological Interest of Jbel Moussa, Northern Moroccan Rif)

Soumaya Ben Ali[1*], Ali Aoulad-Sidi-Mhend[2], Zohra Bejjaji[1], Ali Maâté[3], Sakina Mehdioui[1], Marouane Mohammadi[2], Mohammed Tayebi[1] and Said Mirari[4]

[1] Geosciences Laboratory, Faculty of Sciences, Ibn Tofaïl University, B.P. 133, 14000 Kenitra, Morocco

[2] Geo-Biodiversity and Natural Patrimony Laboratory (GeoBio), Geophysics, Natural Patrimony Research Center (GEOPAC), Scientific Institute, Mohammed V University in Rabat, Morocco

[3] Laboratory of Environmental Geology and Natural Resources, Department of Geology, Faculty of Sciences, Abdelmalek Essaâdi University, B.P. 2121, 93002 Tetouan, Morocco

[4] Laboratory of Tourism Engineering, Heritage and Sustainable Development of the Territories, Faculty of Science in Rabat, Mohammed V University, Rabat P.O. BOX 1014, Morocco

* Corresponding author's e-mail:benali.soumaya7@gmail.com

ABSTRACT

In the commune of Bel Younech, which constitutes the eastern part of the Site of Biological and Ecological Interest (SBEI) of Jbel Moussa (Tangier, Tetouan, Al Hoceima, NW Morocco), 13 geosites have been selected along a 14-stop georoad. These sites are characterized by relevant geological diversity representing structural geology, stratigraphy, sedimentology, petrology, geomorphology, hydrogeology and hydrology. Some of these geosites also have a very interesting geoculture. The geodiversity sites have been evaluated using a numerical methodology based on recent literature that aimed to reduce the subjectivity related to any evaluation process. The evaluation concerned the scientific value (SV), the potential for educational use (PEU), the potential for tourist use (PTU) and the risk of degradation (DR), which was quantified using various criteria by assigning scores ranging from 0 to 4. The results of the quantitative assessment show that 8 sites with a scientific value greater than or equal to 3.5; this value allows them to be considered as geosites. The average values of the PUE and PUT were very high (3.7 and 3.5) while the risk of degradation was moderate (2.03). The values obtained justify the need of valorization and conservation of Bel Younech commune geosites by integrating the fundamental concepts of sustainable development. In fact, all the geosites are located on a 14-stop georoad; this could serve the geotourism as well as promote the activity and economic development of this commune. This work could be used for scientific, educational (within the framework of earth sciences) and touristic purposes.

Keywords: geodiversity, geological heritage, inventory, Bel Younech commune, Site of Biological and Ecological Interest, Jbel Moussa, Northern Rif.

INTRODUCTION

The geological heritage is a major asset in the Belyounech commune which characterized by geosites of varying nature and size, ranging from microscopic to outcrop scale. These geosites offer a high potential for scientific, educational uses, but also recreational, scenic, cultural, economic and geotouristic ones in the context of sustainable development. The paroxysm of this exceptional geodiversity is reached due to the famous geological form of a sleeping woman named "la Mujer muerta". This geodiversity is essentially seen in the structural formations that are an integral part of the Rifan chain. This geodiversity needs to be conserved for the future generations and used in order to develop the economical level of the area through the geotourism. However, the inventory of geosites is done only in the National Park of Talassemtane and the Ghomara coast (Northern Rif, northwestern Morocco) by Aoulad Sidi Mhend et al., 2019; Aoulad Sidi Mhend et al., 2022. This work aimed to perform the inventory and quantitative assessment of the commune of Bel Younech geosites.

Making inventory of geosites in the study area aimed to enhance its richness in terms of geodiversity. This begins with the identification of geosites (GS) (Brilha, 2016), followed by the characterization and quantitative assessment of its. In order to achieve this goal, the general public must be aware of the interest of these GSs, in addition to the development of geotourism and geo-education activities accompanied by the proposal of georoads.

The inventory and the quantitative assessment of geosites in the Bel Younech commune was performed using the methodology proposed by Brilha, 2016, since it prioritizes scientific value over other values for selection of geosites. It also gives a major importance to the Potential Educational Use (PEU), Potential Touristic Use (PTU) and Risk of Degradation (DR) of the GSs.

SITUATION AND GENERAL DESCRIPTION OF THE SBEI OF JBEL MOUSSA

The SBEI of Jbel Moussa is located on the Strait of Gibraltar, in the extreme northwest of Morocco in the northern Rif, with Lambert coordinates: 35°54'N – 5° 25' W between the village of Ksar Sghir and the city of Sebta (Fig. 1). SBEI is characterized by a typical Mediterranean climate (SPA/RAC – UN Environment/WFP & HCEFLCD,2019). Rainfall comes from Atlantic perturbations (Azores), which are the main origin of humid air masses in the Rif, and Mediterranean perturbations (related to the arrival of cold air masses from the North). The latter are less frequent but generally humid. The SBEI of Jbel Moussa is among the sites of biological and ecological interest, with a major priority in the Master Plan of Protected Areas of Morocco (PDAPM, 1996). It is located in the area designated as the Mediterranean Intercontinental Biosphere Reserve (MIBR) integrating a marine part of 14.45 km^2 and a terrestrial part covering 35.55 km^2, particularly in the Communes of Belyounech (Mdiq-Fnidaq province), Taghramt and Kasr El Majaz (Fahs-Anjra province) (Fig. 1).

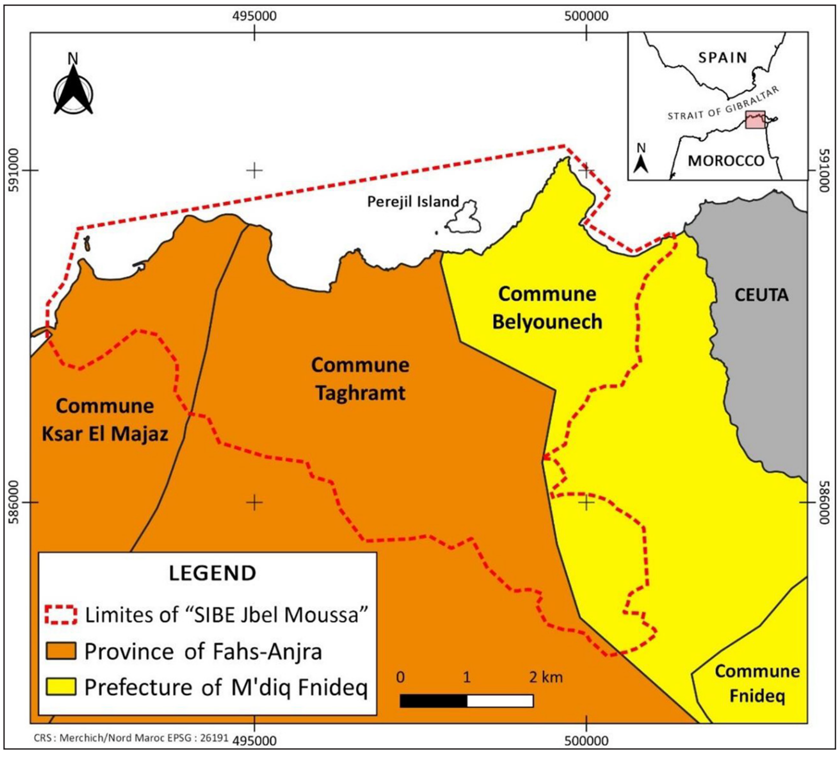

Figure 1. Administrative situation of SBEI of Jbel Moussa

SBEI of Jbel Moussa is also listed as a Ramsar site in 2019 (FDR, 2019). The site is characterized by its exceptional strategic position, where the Atlantic meets the Mediterranean. The type of rock and the type of climate have favored the development of ecosystems rich in fauna (at least 175 taxa) and flora (Fennane and Ibn Tattou, 1988). It is an important corridor for the passage of marine turtles, birds (raptors and passerines) and mammals (HCEFLCD, 2008). There are about 24 species of rare or remarkable fish, and species of *anthozoans*, such as *Corallium-rubrum* or *Ellisellaparaplexauroides*, which are threatened with extinction. Among its remarkable land mammals, the Berber macaque (*Macacasylvanus*) is also endangered. The cliffs have little vegetation but there are endemic plants such as *Stauracanthusboivinii* and *Rupicapnosafricana*.

The (SBEI) of Jbel Moussa located between three economically dynamic areas (Fahs-Anjra provinces (Tangier), Mdiq and Fnidaq). In this area, the management of African human migration to Europe and illegal trafficking is difficult (Al Hachimi et al., 2022).

GEOLOGICAL SETTING

Geologically, Jbel Moussa SBEI is located at the northernmost end of the Rif, which is structurally subdivided into 3 domains (Fig. 2): the Outer Rif, the Flysch domain and the Inner Rif (Durand Delga et al., 1960-62; Michard, 1976; Suter,1980a and b; Feinberg et al., 1990; Maâté et al., 1993; Piqué, 1994; Guerrera and Martín-Martín, 2014). The richness of the SBEI of Jbel Moussa is closely related to its geological diversity that includes all the domains of the Rif in its territory in the form of thrust sheets carried on each other (Nold et al., 1981; EL Kadiri, 1991). From the East to the West: the metamorphic units of the upper Sebtides, especiallythe shale of the Tizgarines, the sandstone shale units of the Ghomarides represented by the Akaili (Chalouan, 1986) (Paleozoic), the calcareous ridge (Griffon, 1966; Raoult, 1966; Kornprobst, 1969; Gutnic, 1969; Leikine, 1969; Mégard, 1969; Wildi et al., 1977; Wildi, 1979; Nold et al., 1981; Ben Yaich et al., 1986; Ben Yaich et al., 1988; El Hatimi et al., 1991; El Kadiri et al., 1992; Maâté et al., 1993, Baudelot et al., 1993 etc.) is materialized by Jbel Fahies (internal ridge) and Jbel Moussa (Tariquid Domain) (Durand-Delga et al., 2005) which are calcaro-dolomite formations of the Mesozoic.The Predorsalian sandstones (El Hatimi et al., 1985), the Beni Ider, the Tisirene and the Numidian representing the Flysch domain (Piquet et al., 2006), and the External Rif is represented by the Internal Tangier unit which can be seen between it (Fig. 2).

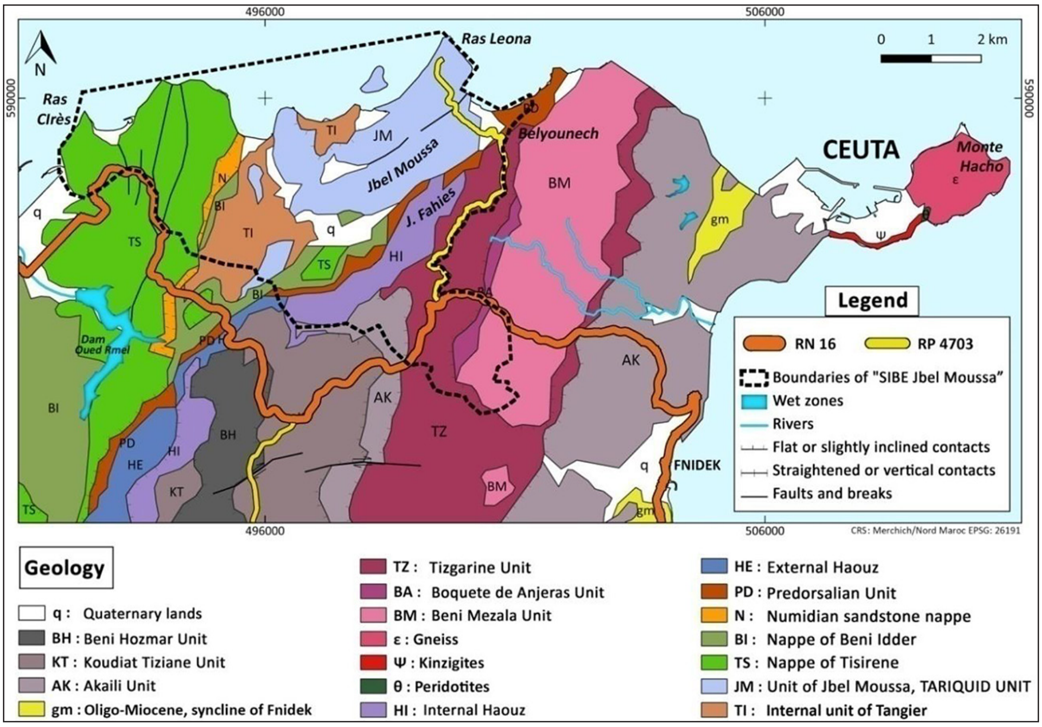

Figure 2. Geological component of the SBEI of Jbel Moussa

The SBEI of Jbel Moussa constitutes by a complex geological structure, cracked and very karstified at the carbonate massifs and also a hydrological network underground and surface (Fig. 3). The richness of this network is reflected by sources, caves, waterfalls, while rivers and waterways are often seasonal and characterized by low flow, due to the relief that is marked by steep slopes accelerating the runoff (Sdaud, 2004).

Geomorphologically, the SBEI of Jbel Moussa is provided with a remarkable position on a global, continental, regional and national scale. It represents a rocky promontory overhanging the Strait of Gibraltar with a strong land-sea contrast and offering an exceptional landscape forming the arc of Gibraltar. The topography is characterized by steep slopes, white limestone cliffs and narrow flats. The contact with the sea is made by sharp cliffs, steep in places, which prevent the installation of wide beaches. In the center of the SBEI, the islet Leïla is a huge block 200m away from the coast. Only the beach of Bel Younech (300m), to the east, is easily accessible, made up of fine sand (Pdapm, 1996).

The interest of SBEI is very marked by its geological units resulting from several phenomena and processes that followed each other in time and that led to the construction of the Gibraltar arc. It should be noted that SBEI is the only structure offering evidence of all the marine transgressions recorded in the Mediterranean geological history (El Kadiri et al., 2010) and constituting the abrasion platform of Cape Leona and Leila Islet.

METHOD AND MATERIALS

The inventory of geosites is a sensitive issue that requires the implementation of a scientific method in order to surround all the aspects that govern it. This requires a literature review on the subject. The methods and techniques used to select a geological site emphasize the importance of clearly defining the objectives of the inventory, choosing a method that allows the identification, characterization, evaluation and proposals for the development of GSs integrating the fundamental principles of sustainable development. Similarly, the choice of criteria that should be used for site selection must be appropriate. These criteria are mentioned in almost all literature concerning geoheritage, such as JNCC (1977); Lapo et al. (1993); Wimbledon et al. (1995); Grandgirard (1999); Alexandrowicz and Kozlowski (1999); Parkes and Morris (1999); Gray(2013); Brilha (2005); Pralong & Reynard (2005); Malaki, 2006; Reynard et al., 2007; García-Cortés and Carcavilla Urquí (2009); Fuertes Gutiérrez and Fernández-Martínez (2010); Díaz Martínez and Díez-Herrero (2011); Wimbledon (2011); Reynard and Coratza (2013); De Wever et al., 2014; Brilha (2016); Reynardetal., (2016); Bouzekraoui et al., 2017; Aoulad Sidi Mhend et al., 2019; Aoulad Sidi Mhend et al., 2020; Mehdioui et al., 2020; Mehdioui et al., 2022; Mirari et al, 2020;Martin- Martin et al., 2021; Salvador et al., 2022.In this work, the criteria proposed by Brilha 2016 are going to be used which are:

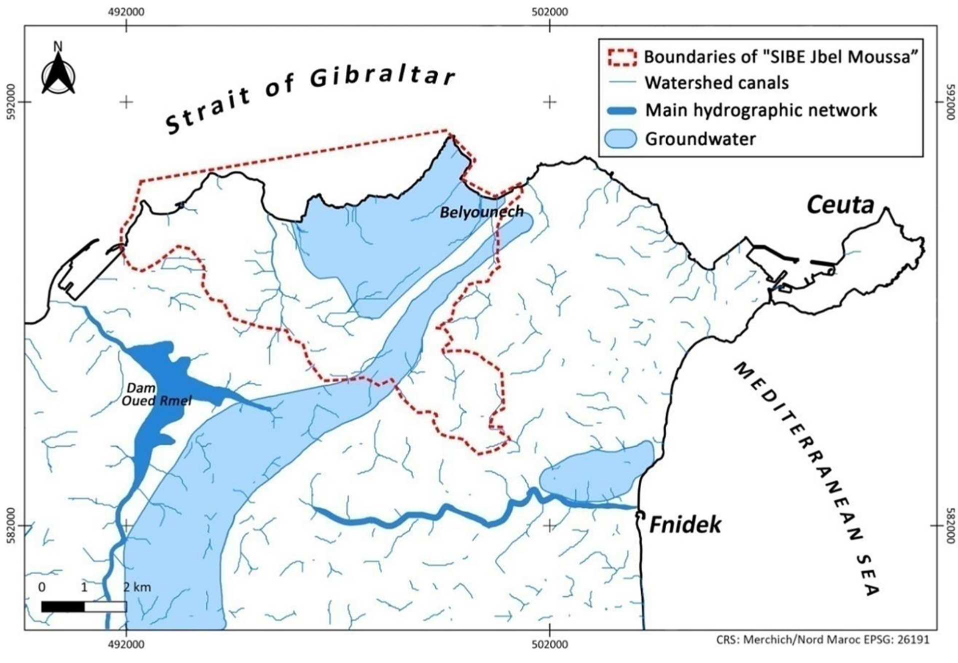

Figure 3. Surface and groundwater resources at the SBEI of Jbel Moussa

Integrity (Int), representativeness (Rpt), rarity (Rar), key locality (KL), scientific knowledge (SK), geological diversity (GD), and Use limitations (UL), to characterize the scientific value (SV).

Vulnerability (Vul), Accessibility (Acc), Use limitations (UL), Safety (Sef), Logistics (Log), Population Density (PD), Association with Other Values (AV), Scenery (Sce), Uniqueness (Uni), Observation conditions (CO), Didactic potential (DP), and Geological Diversity (GD), to characterize the potential for educational use (PEU).

Vulnerability (Vul), Accessibility (Acc), Use limitations (UL), Safety (Sef), Logistics (Log), Population Density (PD), Association with Other Values (AV), Scenery (Sce), Uniqueness (Uni), Observation conditions (CO), Interpretative potential (IP), Economic level (EL), Proximity of recreational areas (PRA) to characterize the potential for touristic use (PTU).

Deterioration of geological elements (Dge), Proximity to areas/activities with potential to cause degradation (PPD), legal protection (LP), accessibility (Acc), and population density

Table 1. The criteria of scientific value, educational use potential, and risk of degradation, their scores and weights

Value	Criteria (scores 0 to 4)	Weights (%)
Scientific value (SV)	Representativeness (Rpt)	30
	Integrity (Int)	20
	Rarity (Rar)	5
	Key locality (KL)	15
	Scientific knowledge (SK)	5
	Geological diversity (GD)	15
	Use limitations (UL)	10
Potential Educational Use (PEU)	Vulnerability (Vul)	10
	Accessibility (Acc)	10
	Use limitations (UL)	5
	Safety (Saf)	10
	Logistics (Log)	5
	Density of population (DP)	5
	Association with other values (Av)	5
	Scenery (Sce)	5
	Uniqueness (Uni)	5
	Observation conditions (OC)	10
	Didactic potential (DP)	20
	Geological diversity (GD)	10
Potential Touristic Use (PTU)	Vulnerability (Vul)	10
	Accessibility (Acc)	10
	Use limitations (UL)	05
	Safety (Saf)	10
	Logistics (Log)	05
	Density of population (DP)	05
	Association with other values (Av)	05
	Scenery (Sce)	15
	Uniqueness (Uni)	10
	Observation conditions (OC)	05
	Interpretative potential (IP)	10
	Economic level (EL)	05
	Proximity of recreational areas (RA)	05
Degradation risk (DR)	Deterioration of geological elements (Dg)	35
	Proximity to areas/activities with potential to cause degradation (PD)	20
	Legal protection (LP)	20
	Accessibility (Acc)	15
	Density of population (DP)	10

(PD), to characterize the risk of degradation (RD).

For the inventory of GSs, the sheets have been used and filled (Aoulad Sidi Mhend et al., 2019, Aoulad Sidi Mhend et al., 2020, Aoulad Sidi Mhend et al., 2022), established for these purposes, during the field trips that were carried out in order to study the sites with geological values and can be used as thematic stops. For the identification of these studied sites, land sections were made, panoramic and close-up views of landscapes and photos with details were taken.

The characterization of their values: scientific, potential of use and risk of degradation, was based on the above-mentioned criteria the scores and weights which are grouped and collated in Table 1.

For the quantification of the GSs, we use the same sheet that was used for their identification and characterization. The sheet includes in addition to identification and description part, other parts that are used for characterization and quantitative evaluation. The method used for the quantification of SGs was mentioned in the works of Brilha (2016); Reynardet al. (2016); Aoulad-Sidi-Mhend et al. (2019), Aoulad-Sidi-Mhend et al. (2020), Aoulad-Sidi-Mhend et al. (2022) and Mirari et al. (2020).

The authors proceed by calculating the values of the GSs by the sum of the estimation of their weighted criteria with the following formulas:

$$SV = (Rpt + Int + Rar + KL + SK + GD + UL) \quad (1)$$

$$PEU = (Vul + Acc + UL + Saf + Log + DP + AV + Sce + Uni + OC + DP + GD) \quad (2)$$

$$PUT = (Vul + Acc + UL + Saf + Log + DP + AV + Sce + Uni + OC + IP + EL + RA) \quad (3)$$

$$RD = (Dg + PD + LP + Acc + DP) \quad (4)$$

This quantification was done by assigning scores 1, 2, 3, and 4 (low, moderate, high, and very high, respectively) for each criterion. The values of the GSs described in this work were calculated by the sum of these weighted criteria (Brilha, 2016; Aoulad Sidi Mhend, 2019).

RESULTS

The first result was obtained after several field trips, literature review and contact with owners (Aoulad Sidi Mhend, 2014) existing within the territory. The identification of the geological sites that constitue the geodiversity of the commune of Bel Younech of the SBEI of Jbel Moussa has allowed to establish a list of 13 GSs due to their representativeness, rarity and integrity, and also because they are located in the most accessible part of the study area.

The Tizgarines of Bel Younech

The Tizgarine unit (Figs. 2, 4a) is part of the Federico (Upper Sebtides) unit (Michard et al., 2008; Chalouan et al., 2011), which are from bottom to top, Beni Mezala (BM), Boquete Anjera (BA) and Tizgarine (TZ) (Fig. 4a). All the formations of the Fedirico unit display the imprint of alpine metamorphism. Recrystallization of iron oxides changes the color of Permian metapelites from one unit to another; they are red in the upper unit (Tizgarine), violet-pink in the middle unit (Boquete Anjera), and smoke-colored in the deep units (Beni Mezala 2 and 1). This evolution of color can be correlated with a change in the grade of metamorphism (Durand-Delga and Kornprobst, 1963).

The presentation of the constituents of the Tizgarine unit is made through two stops, the first is located at (35.875804/-5.402824) at the edge of the N16 road (Fig. 4b) on the western flank of the Beni Mezala nappes anticline (Fig. 2). It is a petrological site that shows the lower constituent of the Tizgarines unit (Permo-Carboniferous shales and grauwackes) (Chalouan et al., 2011) with conglomerate (Fig. 4c). This facies makes visible steeply dipping NE-SW faults (Fig. 4b). They are materialized by mirrors in which streaks are abundant and tectoglyphs indicate a dextral strike-slip. This is probably a replica of the large dextral fault of the J.Facies (Chalouan et al., 2011). The second stop is 2.5 km (35.882494/-5.405385) from the first, after leaving the N16 road by taking the RP 4703 road (Fig. 4d). It offers the possibility to see the shiny shales and sandstones (Fig. 4d), with laminated arrangement and red color (wine-red) that are clearly visible. These rocks have undergone BP-BT metamorphism (3-1 kbar and 300 °C) (e.g., Michard et al., 1997, Bouybaouene, 1993, Bouybaouene et al., 1995). This latter is surmounted by white quartzites, vermiculated limestones and massive dark Dolomites. These rocks took the name of the village of Tizgarine which outcrops 6 km from Oued Laou south of Tetouan (Aoulad Sidi Mhend et al., 2022).

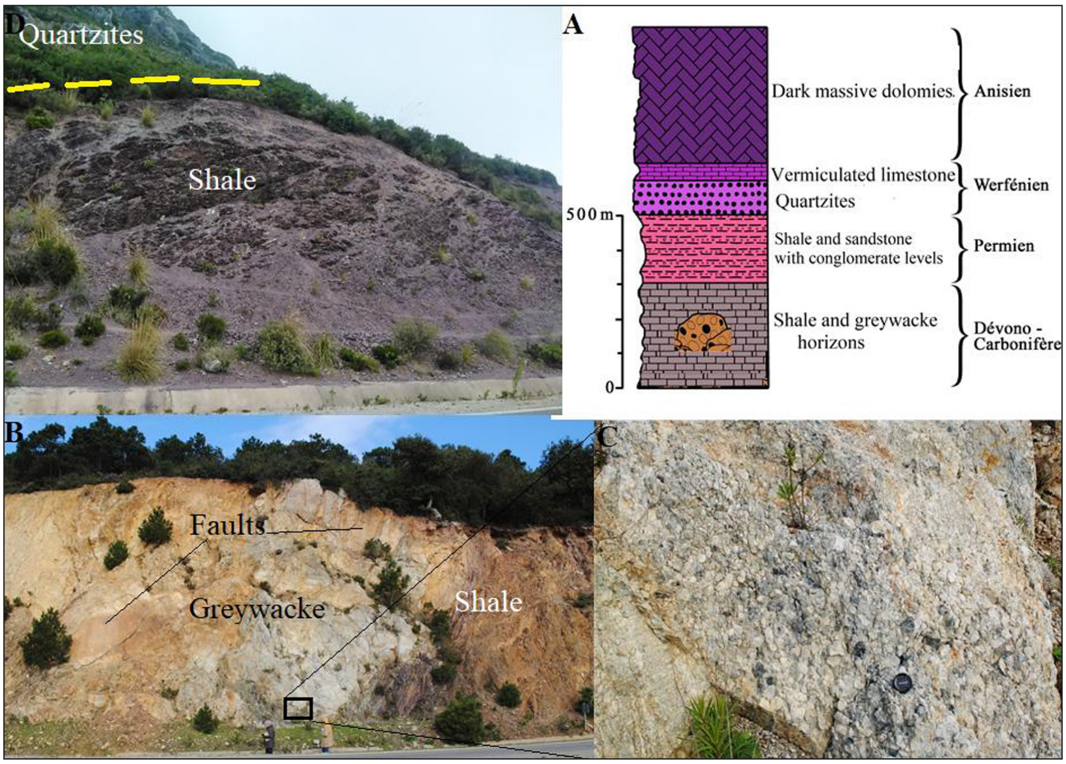

Figure 4. (a) The Tizgarine unit (Septa map 1/50000, Kornprobst and Durant Delga,1985); (b) lower constituent of the Tizgarine unit with fault mirrors; (c) appearance of conglomerates of the lower constituent of the Tizgarine unit; (d) The Tizgarine shales surmounted by the white quartzites

The ruiniform aspects of Bel Younech

Stop 3 allowsthe observation of the ruiniform and kart aspects of Bel Younech at the dolomitic formations of the terminal constituent of the Tizgarine unit. These are Triassic terrains which constitute a real thick grey rocky frame which domain the eastern part of the SBEI of Jbel Moussa. The observation point is at (35.896051/-5.390169) descending through the RP4703 and at an altitude of (400 m). The ruiniform and karst landscape is the result of dissolution processes of carbonate rocks (Dolomite [(Ca, Mg)$(CO_3)_2$] is much less soluble than limestone ($CaCO_3$) in CO_2-charged waters). This phenomenon depends on several factors:

- the rock mineralogical composition and purity (presence of non-soluble elements);
- the degree of compaction and diagenetic cementation of a rock which will determine the intergranular porosity;
- the fracturing of the rocks which can be acquired early by simple deconfinement, (Goldscheider and Drew, 2007).

This process is often irregular, and will create very irregular landforms. This tendency to produce ruiniform reliefs is also reinforced in the case of a limestone crossed by a group of diaclases. There is dissolution along the diaclases, which makes it in the form of "walls" or "pinnacles". Other forms of karstic manifestations are formed there like caves, abris, and Lapiez (Fig. 5).

Figure 5. Ruiniform appearance and karst manifestations

The Abdessamad cave

Stop 4 corresponds to the Abdessamad cave discovered by chance by an inhabitant of Bel Younech named Abdessamad, hence the name of the cave. It is one of the natural cavities located in the massive dolomites constituting the terminal formations of the Tizgarine unit (upper Sebtide) (Figs. 4a, 6a). The opening of the cave is quite large (Fig. 6b) allowing easy access for lovers of underground landscapes. The visit can take a whole day.This type of cave is a witness to the power of water to carve extraordinary shapes (Fig. 6c) with spectacular rock formations appearing at every turn and waterfalls falling over cliffs. This process of formation is called karstification which takes place, over thousands of years, by dissolution of carbonate rocks in contact with water charged with carbonic acid (CO_2 increases with pressure, low water temperature and abundance of living beings that release CO_2).

Thus, the development of the Abdessamad cave is favored by the kind of rock and its tectonic history, the abundance of water and its CO_2 content and of course, the water-rock contact time.

During its infiltration underground, the water continues to gnaw at the rock, forming galleries and caves, and the water gradually becomes charged with gas and dissolved limestone. When it arrives in a larger cavity, the water degasses due to the change in physico-chemical conditions (pressure drop, temperature change...): it is therefore less acidic. The dissolved limestone can therefore recrystallize in the form of stalactite concretions (on the roof) or stalagmite (on the floor) as well as other forms of draperies, and stalagmitic floors. These strange underground landscapes have a striking beauty.

The site allows the observation of corrosion (chemical action of water on limestone) and erosion (mechanical action of water on limestone) figures and recent sedimentary deposits. The expedition is stopped at the 1st level, it still a lot to do for the caving specialists to discover the galleries, the lakes and the underground rivers.

Jbel Chendir and the socio-cultural complex

Stop 5 is represented by a carbonate facies of the western side of Jbel Chendir (450 m), located further north on RP.4703, to the right towards Ras Liona (35.906329/-5.38799). Its structural originality resides in the fact that it represents the normal secondary cover of the non-metamorphic Paleozoic zone, i.e. it has no direct structural link with the limestone ridge (Gharbaoui, 1986). It belongs to the Beni Mzala BM formation (Fig. 2) which is formed by quartzites from the Lower Triassic and dolomitic limestones locally dated to the Middle Triassic by the presence of Dasycladaceae of the genus Gyroporella (Chalouan et al., 2011). The carbonate formations of the BM are weakly metamorphosed and are thrust onthe BA and TZ units.

The tectonic geological history of the study area, the types of rocks and the abundance of the underground water network led to the emergence of several sources at the contact zones between the different formations (the thrusting of the carbonate formations of BM on those of BA and TZ). Likewise, the surface waters have allowed the creation of several karst forests such as caves.

The socio-cultural complex of Dr. Mohamed Masmudise is located downstream from Jbel

Figure 6. (a) Situation of the cave at the massive dolomites of the Tizgarine unit, (b) opening of the Abdessamad cave and mode of penetration, (c) concretions of the wall of the Abdessamad cave

Figure 7. (a) Socio-cultural complex of Dr. Masmudi at the bottom of Jbel Chendir with a view of the village of Bel Younech, (b) the source and catchment basin of the water that supplies the city of Sebta; (c) The Calipso cave

Chendir (35°54'22",45N/5°23'17",11W) (Fig. 7a). The site has assets that allow it to be considered as an initiative for the enhancement of the natural and cultural heritage of the village of Bel Younech. In fact, this complex contains an important source equipped with a water catchment basin (Fig. 7b) that supplies the city of Sebta. Similarly, the abundance of surface water has facilitated the creation of several karst resources, including the Calipso cave, famous and particularly visited by students (Fig. 7c). The name of this cave is derived from the myth that Calipso inhabited it for several years. The Masmudi complex has, therefore, an importance in terms of heritage due to the equipment of the center, to its strategic position that allows the observation of all the assets of the commune and especially to its geological and cultural diversity.

The "Mujer Muerta" or the sleeping beauty

For a panoramic view of "la mujer muerta", stop 6 is located at (35.908787/-5.389026), and forms a unique attractive landscape (Fig. 8a). This exceptional geomorphological site with all the characters of a beautiful sleeping woman, results from the superposition of three geological structures (Fig. 8b): (i) Jbel Fahies, forms the head, consisting of gray dolomites, massive dolomites (Triassic sup, Hettangian) and massive white limestones (Sinemurian) belonging to the internal limestone ridge; (ii) Jbel Moussa, forms the thorax, belongs to the Tariquid domain with clays with dolomite beds, cargneules and massive dolomites of the Upper Triassic and slab limestones of the Lower Lias; (iii) Jbel Moussa block (Ras Leona), forms the feet (Tariquid domain).

The site is famous for its geomorphological interest that masks its structural, sedimentological, stratigraphic, paleontological and geocultural interests. Near the site are built the houses of the commune Bel Younech on the travertine terraces raised during the middle Pleistocene.

At the structural scale (Fig. 8b), the site enables to see the accident of Jbel Fahies (among the major accidents of the Rif that separates Jbel Fahies (The Limestone Dorsal) from Jbel Moussa (Tariquid Domain) The dexter fault (ramp) of J. Fahies.

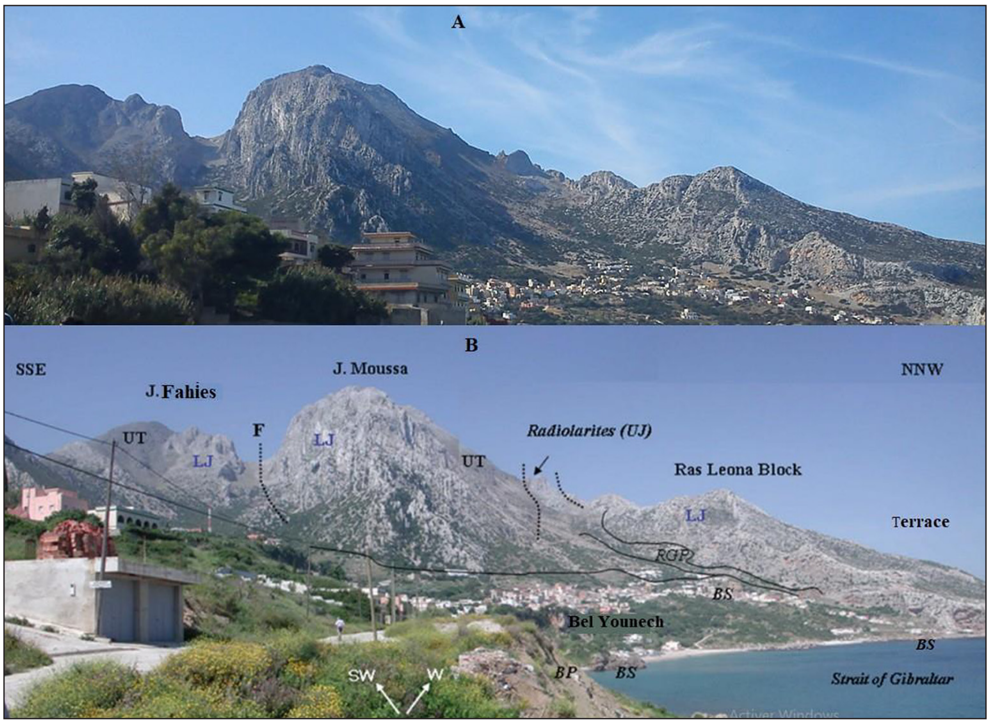

Figure 8. (a) The "sleeping beauty" landscape; (b) structural constituents of the "sleeping beauty" landscape; BP – brown tobacco pelites (Burdigalian); BS – Beliounis sandstone (Aquitanian-Lower Burdigalian); F – fault; LJ – Lower Lias limestone; RGP – Maastrichtian-Paleocene red and gray pelites; UJ – Upper Jurassic radiolarites; UT – Upper Triassic dolomite

At the sedimentological scale, the Jbel Moussa blocks are mainly constituted of dolomites of the Upper Triassic and massive white limestones of the Lower Lias (Carixian included). These shallow platform terms (analogous to the Internal Dorsal) are followed, after emersion and karstification of the massive limestones, by pelagic terms of Middle Lias to Upper Cretaceous age (analogous to those of the External Dorsal but they are very thin and contain many gaps underlined by hard-grounds (El Kadiri et al., 1990; Chalouan et al., 2008, Chalouan et al., 2011).

At the paleontological scale (Fig. 8b), there are (i) ammonitic-rose facies, radiolarites and filamentary limestones of the Middle-Upper Lias and Lower Dogger; (ii) radiolarites of the Dogger-Malm; (iii) Aptychus limestones of the Upper Tithonic-Berriasian, and (iv) red marls of the Upper Cretaceous-Eocene (Chalouan et al., 2008, Chalouan et al., 2011).

At the stratigraphic scale (Fig. 8b), Jbel Moussa is in a sub-vertical position, like Jbel Fahies that of Ras Leona-Jumia is overturned to the SE (effect of back spill visible on J. Fahies) (Durant Delga et al., 2005; Chalouan et al., 2008, 2011).

These blocks are separated from each other and from the Dorsal by Lower Aquitanian-Burdigalian yellow sandstone and tobacco-brown pelites. These Oligo-Miocene terms attached to the unconformable cover of the Mesozoic blocks are similar to those known in the Dorsal, but here they are designated as Predorsal. The Dorsal, Tariquid, and Predorsal assemblage are thrust NW on Upper Cretaceous argillites attributed either to the Internal Tangier Unit or to the Massylian flysch of Mellousa type (Durand-Delga et al., 2005). The contact with the sea is made through high cliffs or through beautiful marine abrasion platforms and terraces.

On the geo-cultural scale, Masjid Sidi Moussa can befound, a cultural curiosity located at the highest point of Jbel Moussa; the name of the Masjid is attributed to the leader Moussa Ibn Nossair, the leader of the campaign of the crossing of the Mediterranean to Europe led by Tariq Ibn Ziad (711).

Laila Island or Perejil Island/ Isla de Perejil

The observation point of stop 7 was set up to be an observation point of the Laila Islet (Tura Islet) (35.916551/-5.406037). The Laila Islet is located in the Strait of Gibraltar, 8 km west of Sebta and at the bottom of Jbel Moussa, between the points of Marsa to the west and Leona to the east. The site, with an area of 0.15 km, is arid and uninhabited. Geologically, this island is detached

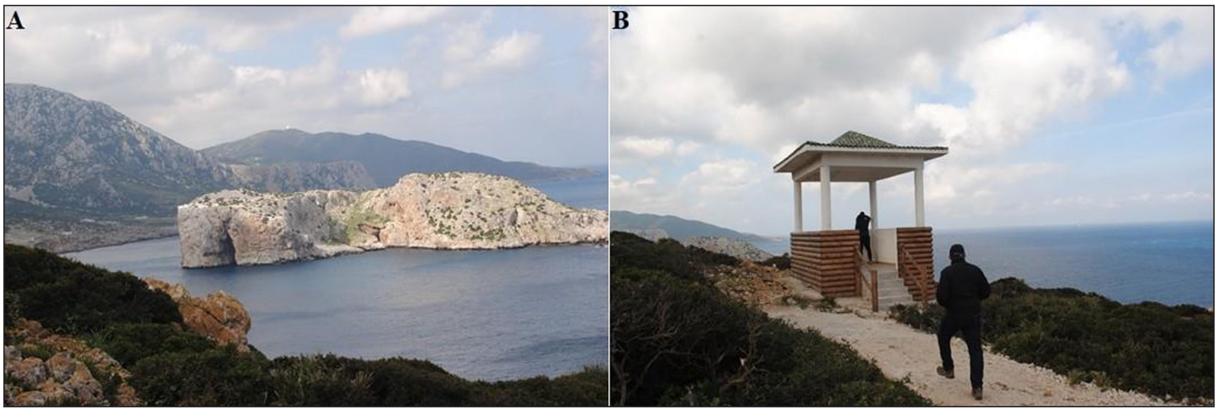

Figure 9. (a) Leila Island, (b) Leila Island observation point

from the African continent by a channel of approximately 200 meters. It is the continuity of the blocks of Jbel Moussa belonging to the Tariquid domain. It is a carbonated and fractured rock which contains a cave resulting from the action of the sea water on the carbonated grounds.

Near the observation point of the island, the structures that take the name of bunkers are found. These are the places used as defensive sites against air and sea strikes during the Second World War. They are scattered over a vast area of the Ras Leona platform and constitute a multitude of mazes embedded in the limestone slabs of the Tariquide domain.

The Terraces of Ras Leona

Stop 8 presents terraces located in the north, at the bottom of Ras Leona (35.920680/-5.401799).

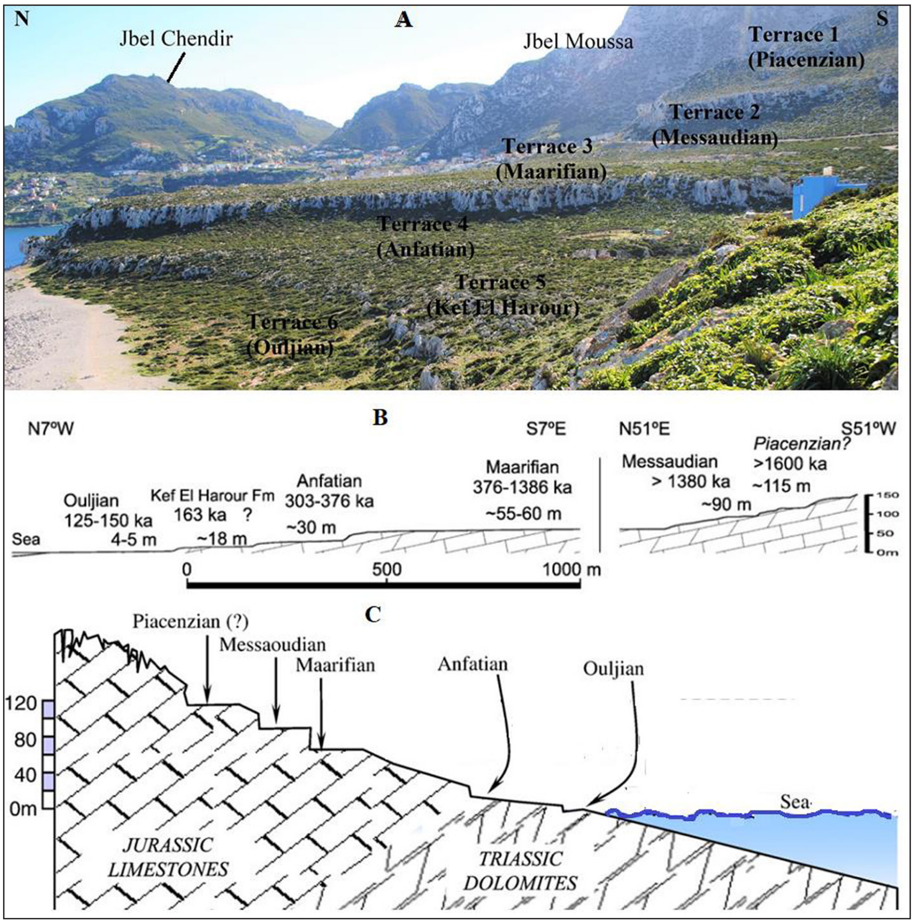

Figure 10. (a) Ras Leona terraces, (b) schematic representation of the terraces and digital numerical characteristics; (c) Proposed scenario for the tectono-eustatic formation of the Ras Leona terraces according to El Kadiri et al., 2010

At this stop, succession of well-preserved Quaternary marine terraces is observed (Fig. 10b). These terraces are of great geological and structural interest because they present the areas that have undergone the highest rates of surrection by local vertical movements that are mainly the result of the African-Iberian convergence with little or no effects related to subduction processes. Indeed, the study of the Quaternary marine terraces (El Kadiri et al., 2010; Zazo et al., 2003; Meghraoui et al., 1996; Gigout et al., 1977; Gibraltar Arc Neotectonics Research Group, 1977) showed that the compartment north of the Jebha Fault is in relative surrection during the Quaternary.

According to Aboumaria et al. (2009), the origin of this uplift shows that these Quaternary marine terraces were uplifted through normal faults oriented ~E/W activated recently. On the other hand, El Kadiri et al. (2010) highlighted the fact that the middle surrection that affected the coasts of the Gibraltar arc and the Atlantic was controlled more by eustatic variations than by tectonic processes.

The correlation of the Ras Leona terraces (in terms of age and altitude) with equivalent, lateral, travertine-covered terraces formed in the SBEI of Jbel Moussa (commune of Bel Younech) and with the terraces located along the Moroccan Atlantic coasts, would suggest that the Ras Leona terraces were mainly formed by eustatic factors.

The staircase terraces of Ras Leona are shown in Figure 10a and b in a southeast view and NE - SW cross section, respectively. These terraces have been correlated according to their altitudes with those along the Moroccan Atlantic coast (El Fahssi, 1999; El Kadiri et al., 2010). Consequently, the classic Moroccan Atlantic chronostratigraphy was assigned to the Ras Leona terraces (Fig. 10b and c), determining from youngest to oldest: (a) the Ouljian terrace, divided into two terraces located at 6 m and 8 m, (b) the Anfatian terrace at 30 m, (c) the Maarifian terrace at 55 m, and (d) the Mesaudian terrace at 90 m.

Ras Leona rocky coast and Karst (Lapiés, doline and cave)

At stop 9, descending towards the coast of the strait and crossing the terraces towards the younger one, the primary rocky coast of Bel Younech can be observed (SBEI Jbel Moussa) from (35.921184/-5.401134) to (35.916944/-5.397057) and the action of the water on the carbonate rocks of Ras Leona can be admired.

Figure 11. (a) Sinkhole in the carbonate platform, (b) rocky coast of Ras Leona, (c) Lapies, (d) Fishermen's cave and erosive action of sea water on the coast

The Lias-Dogger succession of the Ras Leona Tariquids differs from the series of the same age in the tectonically neighboring units of the Limestone Dorsal (Rifan domain).

The Lower Lias platform limestones are ravined in the Domerian, by a continuous open sea series until the Bajocian at Jbel Moussa and its blocks. Elsewhere (Los Pastores type), it is a much thinner series with marls sometimes manganese (Ras Leona), deposited in three independent episodes and dated by calcareous nannofossils, from the Domerian-Toarcian to the upper Bajocian-Bathonian (Durand-Delga et al., 2005).

Being very sensitive to water, this carbonate platform favors the formation of karsts. The first form that appears is that of a bucket sinkhole (Fig.11a). The origin of this sinkhole seems to be due to the existence of an absorption point since the water in the closed depression can only flow, after rain, towards the depth (Derruau, 1974). It is the result of a slumping of fractured carbonate rocks which break up to form an underground cave. The 2nd karstic form appears by following the coastline of the rocky coast of Bel Younech (SBEI of Jbel Moussa), (Fig. 11b). These are well-developed lapiezs with gullies that reach a depth of more than 3 m (El Gharbaoui, 1986) (Fig. 11c). This phenomenon is accentuated by sea spray. The third karst form is a mushroom cliff testifying to the action of sea water on the carbonate rock. At the closest point to Europe to the south, the fishermen's cave can be seen (Fig. 11d).

The travertine terraces of Bel Younech

Once the visit to the rocky coast of Ras Leona and the Karst is over, the return is made by the public transport to continue the itinerary on foot through the three travertine terraces (upper, middle and lower) (Figs. 12a and b) of Bel Younech.The beginning of the crossing begins at (35.907023/-5.393334) by a site that allows the observation of the travertineous accumulations resulting from the precipitation of carbonates (CaCO3) downstream of ancient or current waterways or at the emergences of sources (Fig. 12c). The beginning of the crossing begins at (35.907023/-5.393334) by a site that allows the observation of the travertineous accumulations resulting from the precipitation of carbonates (CaCO3) downstream of ancient or current waterways or at the emergences of sources (Fig. 12c). It is the 10th stop. The travertine is easy to identify, it is a light non stratified rock with many cavities (Fig. 12d). The site allows observing a type of fossilization of short time scale (Fig. 12d).

In fact, during the formation of travertine, the plants growing near the source/stream are petrified and transformed into stone (Fig. 12c) under the action of physicochemical or biological processes.These travertine formations also constitute Quaternary marine terraces after tectono-eustatic actions (El Kadiri et al., 2010). During the medieval period, these terraces (Fig. 12a) are considered appropriate for the construction of cities, as in the case of Tetouan and Chefchaouen. If the path down to the beach is taken, a medieval historical site "the Al Mounyas" built on the middle terrace can be found; it is located in the west and 7 km from Sebta, in front of the strait and at the bottom of Jbel Moussa. It is a medieval city with an Islamic architecture (Fig. 12e) from the Merinid dynasty to the Middle Ages. It is a medieval city with an Islamic architecture (Fig. 12e) from the Merinid dynasty to the Middle Ages. This city was known as a place of rest before the crossing to Andalusia, and then, it became the seat of secondary residences for the wealthy inhabitants of Sebta. Today, this site includes remains of houses, mosques and hammams (Fig. 12e), and even remains of defensive buildings such as bastions.

Low coast of the SBEI of Jbel Moussa and islands

The coastline of Jbel Younech (SBEI Jbel Moussa) is mainly constituted by rocky coasts or cliffs, but descending from Almuniyas, a low coast with fine sand as well as (Fig. 13a), the beach of Bullones can be found at (35.909169/-5.393398). This beach is 300 m long, limited between 2 rocky coasts. Towards the west (Fig. 13b), rocky promontories forming small islands in the form of mushrooms resulting from the erosion by sea water can be observed. Between these rocks, the diving school associations practice their exercises. Further, in the upstream from this small rocky coastline are the remains of a medieval construction (Fig. 13). Within the framework of the development projects of the commune of Bel Younech, the coast has benefited from the development of its hinterland which is the lower terrace, by the construction of a coastline, a port for the boarding of small artisanal fishing boats and the necessary infrastructure to encourage seaside tourism. Within the framework of

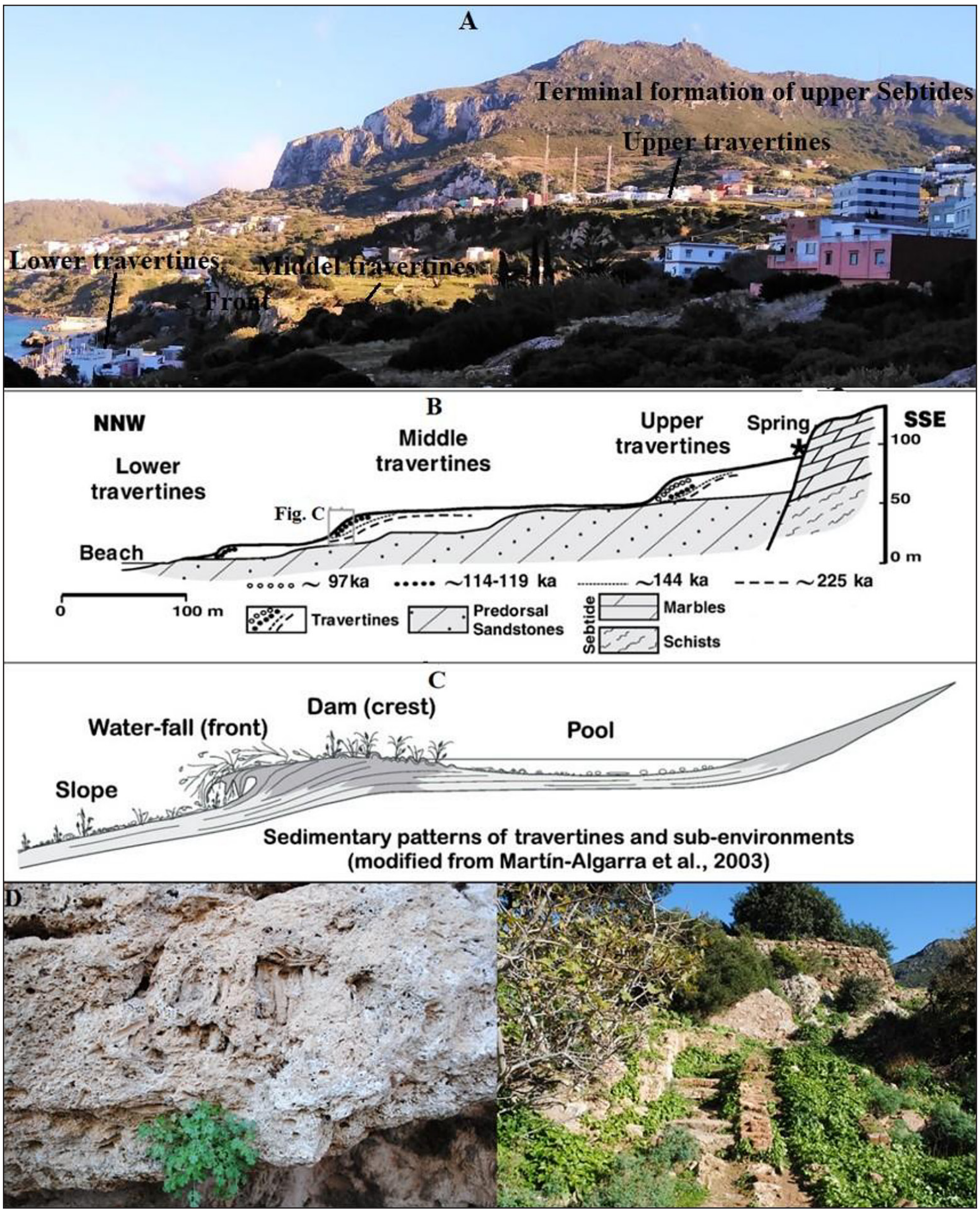

Figure 12. (a) Travertine terraces of Bel Younech, (b) schematic cross-section of the three travertine levels of Ben Younech (El Kadiri et al., 2010), (c) sedimentation model of the travertines (Martin-algarra, 2003), (d) concretions of the travertine, (e) remains of the constructions of Al Mounyas

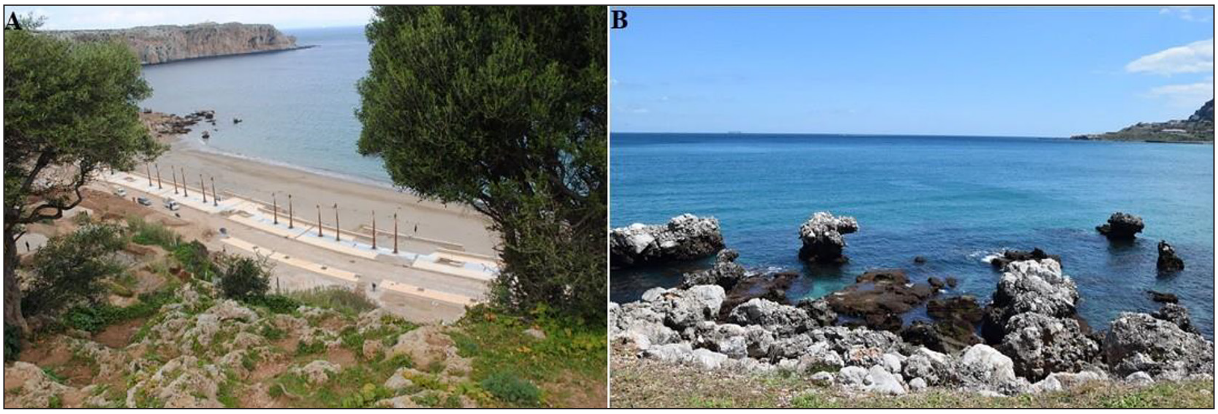

Figure 13. (a) The low coast of Belyounech, (b) The rocky headlands in mushroom

the development projects of the commune of Bel Younech, the coast has benefited from the development of its hinterland which is the lower terrace, by the construction of a coastline, a port for the boarding of small artisanal fishing boats and the necessary infrastructure to encourage seaside tourism.

Predorsal sandstone of Bel Younech (Arrêt12)

The rocky coast of the commune of Bel Younech is also formed by predorsal sandstones (Fig. 2 and Fig. 14a). According to El Hatimi et al. 1985, these are sedimentary klippes that come from the external units of the calcareous Dorsal (Fig. 2), it is an entirely allochthonous domain.

It is debited in layers constituted by clay-sandstone material of Cretaceous and Cenozoic age. At Bel Younech, the predorsalian nappes separate the internal domain from the Tariquid Domain. Towards the southwest, these nappes occupy the structural position between the internal and external domains (Suter, 1965). The matrix is formed of mottled marl, sometimes clay marls; it often has a greenish yellow color, changing upward to clays. The sandstone levels are coarse and sometimes granoclastic containing micas, glauconia and calcite (El Hatimi et al., 1985).

Figure 14. a) Predorsal sandstones of the Bel Younech; b) karstification of the predorsal sandstone due to marine erosion

Figure 15. (a) Ras Leona cliff, (b) Baleinera and reconstruction, (c) habitat construction in a shelter at the Ras Leona cliff

The existence of the site in contact with the sea allows the observation of the selective action/erosion of water on the soft constituents (marls and clays) of the predorsalians (Fig. 14b).

The cliff of Ras Leona

On the way to the cliff of Ras Leona terrace (Fig. 15a), there is an old whale oil crushing factory (Fig. 15b). It was first built by the Norwegians and later handed over to the Spanish. Its functioning was stopped as a result of the treaty protecting whales from fishing. At present, it is restored as a fish processing alimentary and artisanal exhibition complex. Crossing the plant under restoration, there is the Ras Leona cliff (Stop 13) (Fig. 15a and c), belonging to the Jbel Moussa group and the Tariquide domain. The cliff enables to observe the oblique stratification of the carbonate formation. It is vertical and orthogonal to the sea level exposing a set of fault mirrors. The water has carved out a series of caves and shelters (Fig. 15c), some of them are converted into accommodation for the inhabitants. The space between the factory and the cliff is characterized by a considerable depth. It was used in the past as a passageway for hunted whales. Currently, it is a real school of diving known nationally.

The breaches of Bel Younech (stop 14)

The Bel Younech breaches outcrop on the mole of the sea and the RP4703 road (Fig. 16a) leading from the village of Bel Younech to the cornice near the commune's residence. These are recent slope deposits. They have an exceptional quality because of their size and their outcrop on both sides of the road.

The site is in the form of consolidated, heterometric slope breccias with limestone and dolomite materials (Fig. 16b) from the massive Triassic-Liasic formations of Jbel Fahies belonging to the Internal Limestone Dorsal. These slope breccias are post nappe formations of the quaternary consolidated by calcite cement. The emplacement of such sedimentary formations implies steep slopes (fault scarp). These breccias are stratigraphically located on the Tertiary formations of the Pre-Dorsal along the Bel Younech coast. They were formed under certain conditions, probably by a combination of tectonic instability and hydrogeological (chemical) meteorization by streams of calcite-rich water during the Quaternary.

QUANTITATIVE STUDY OF GEOSITES

After a qualitative description of the 13 GSs identified within the most accessible part of the SBEI Jbel Moussa and the commune of Bel Younech, a quantitative evaluation of these geosites was carried out. This step is very important in order to identify the GSs that have a very high scientific value, those that have a very important potential of use and those that are exposed to the risks of degradation. These quantitative values are assessed through the calculation of the scientific value (SV), the potential educational use (PEU), the potential touristic use (PTU) and the risk of degradation (RD).

The scientific value

The results of the scientific value and the averages of these criteria are presented in Table 2. The diversity is represented by 7 types of GSs (petrological, structural, hydrogeological,

Figure 16. (a) Block of the Bel Younech breccia (SBEI Jbel Moussa), (b) materials constituting the breccia

Table 2. Typology and assessment of scientific value criteria of the studied GSs and their weighted average

N°	Name of GSs	Typology	Int	Rpt	Rar	KL	SK	DG	UL	SV
1	The Tizgarines of Bel Younech	Petrology	0.6	1.2	0.3	0.4	0.2	0.05	0.4	3.15
2	The ruiniform aspects of Bel Younech	Geomorphological	0.6	1.2	0.6	0.4	0.2	0.2	0.4	3.60
3	The Abdessamad cave	Hydrogeology	0.6	1.2	0.6	0.2	0.1	0.2	0.4	3.30
4	Jbel Chendir and the complex	Geocultural	0.6	1.2	0.6	0.4	0.2	0.2	0.2	3.40
5	„MujerMuerta" Panorama	Structural	0.6	1.2	0.6	0.8	0.2	0.2	0.4	4.00
6	Laila Island or Perejil Island	Geomorphological	0.6	1.2	0.6	0.8	0.2	0.2	0.1	3.70
7	The terraces of Ras Leona	Geomorphological	0.6	1.2	0.6	0.8	0.2	0.2	0.4	4.00
8	The coast of Ras Leona and Karst	Hydrology	0.6	1.2	0.6	0.4	0.2	0.2	0.4	3.60
9	The travertine terraces of Bel Younech	Geocultural	0.6	1.2	0.6	0.4	0.2	0.2	0.4	3.60
10	The low coast of Bel Younech	Hydrology	0.6	1.2	0.6	0.2	0.1	0.1	0.4	3.20
11	The sandstones of predorsalian of Bel Younech	Sedimentology	0.6	1.2	0.3	0.2	0.2	0.2	0.4	3.10
12	The cliff of Ras Leona	Structural	0.6	1.2	0.6	0.4	0.2	0.2	0.4	3.60
13	The breaches of Bel Younech	Sedimentology	0.6	1.2	0.6	0.4	0.2	0.1	0.4	3.50
Weighted average			0.6	1.2	0.6	0.4	0.2	0.2	0.4	3.5
Weighting			15%	30%	15%	20%	5%	5%	10%	100%

geomorphological, hydrological, sedimentological and geocultural), with their characteristics reflecting the internal geodynamic processes leading to the evolution of the Rifan (Alpine) chain, in its relation with plate tectonics, and in relation with the action of water as well as with the action of Man. Due to their important geodiversity, the Bel Younech GSs present several scientific interests that enhancetheir SV. They have a SV of about 3.5. This value is due to the following facts:

1) The good conservation status of the geosites that is clearly visible with a very high score.
2) The ability of the GSs to illustrate the processes and structures in the study area.
3) The importance of these GSs as references or explaining models of the facts related to the process.
4) The existence of published scientific studies on metamorphism in the Federico Unit areas that host the geosites and their results reflect their SV.

The value of potential educational use

The PEU value reflects the relationships and effects of the external environment, i.e., natural and/or cultural aspects on the GSs. It assesses the conditions of observation by students, and the resistance of SGs to possible destruction by visitors (vulnerability). It also highlights the state of the infrastructure (accessibility, accommodation, restoration, communication network and security).

All the values of these criteria are presented in the PEU evaluation table, together with their weighted average (Table 3).

From the discussion of the criteria for the value of the potential educational use mentioned above, and the calculation of the average PEU of the GSs in Bel Younech, which is about 3.7, it is concluded that the PEU value is very high. This value is explained by the proximity of most of the GSs to paved roads and accessibility by all types of transport, without any restrictions. The association of all these sites with sites of ecological and/or cultural interest gives them an additional value to the GSs as well as enhances their resistance to destruction by visitors (low vulnerability). The value of the PEU is kept very high due to the good observation condition and the good state of conservation of the sites.

The value of the potential touristic use

The PTU value shows the relationships and influence of the external environment, i.e. natural and/or cultural appearances on the geosites. It evaluates the conditions of observation by the general public, and the resistance of the sites to possible destruction caused by visitors (vulnerability). It also highlights the state of the infrastructure (accessibility, accommodation, restoration, communication network and security). All the values of these criteria are presented in the (Table 4).

From the discussion of the criteria for PTU value above, and the calculation of the average of

Table 3. Appreciation of educational value criteria and their weighted average for every GS

N°	Name of GSs	Vul	Acc	UL	Saf	Log	DP	AV	Sce	Uni	OC	DP	GD	PEU
1	The Tizgarines of Bel Younech	0.4	0.4	0.2	0.3	0.2	0.1	0.2	0.1	0.1	0.4	0.4	0.2	3.0
2	The ruiniform aspects of Bel Younech	0.4	0.4	0.2	0.3	0.2	0.1	0.2	0.2	0.15	0.4	0.8	0.4	3.8
3	The Abdessamad cave	0.4	0.3	0.2	0.3	0.2	0.1	0.2	0.2	0.15	0.4	0.8	0.4	3.7
4	Jbel Chendir and the complex	0.4	0.4	0.15	0.4	0.2	0.1	0.2	0.2	0.20	0.4	0.8	0.4	3.9
5	„Mujer Muerta" Panorama	0.4	0.4	0.20	0.3	0.2	0.1	0.2	0.2	0.20	0.4	0.8	0.4	3.8
6	Laila Island or Perejil Island	0.4	0.4	0.20	0.4	0.2	0.1	0.2	0.2	0.20	0.4	0.8	0.4	3.9
7	The terraces of Ras Leona	0.3	0.4	0.20	0.3	0.2	0.1	0.2	0.2	0.20	0.4	0.8	0.4	3.7
8	The coast of Ras Leona and Karst	0.4	0.1	0.20	0.3	0.2	0.1	0.2	0.2	0.20	0.4	0.8	0.4	3.5
9	The travertine terraces of Bel Younech	0.4	0.4	0.20	0.3	0.2	0.1	0.2	0.2	0.20	0.4	0.8	0.4	3.8
10	The low coast of Bel Younech	0.4	0.4	0.20	0.3	0.2	0.1	0.2	0.2	0.15	0.4	0.8	0.4	3.7
11	The sandstones of predorsalian of Bel Younech	0.4	0.4	0.20	0.3	0.2	0.1	0.2	0.15	0.15	0.4	0.8	0.4	3.7
12	The cliff of Ras Leona	0.4	0.4	0.20	0.3	0.2	0.1	0.2	0.2	0.2	0.4	0.8	0.4	3.8
13	The breaches of Bel Younech	0.3	0.4	0.20	0.3	0.2	0.1	0.2	0.05	0.10	0.4	0.8	0.4	3.5
Weighted average		0.40	0.4	0.2	0.3	0.2	0.1	0.2	0.2	0.2	0.4	0.8	0.4	3.7
Weighting		10%	10%	5%	10%	5%	5%	5%	5%	5%	10%	20%	10%	100%

Table 4. Appreciation of touristic value criteria and their weighted average for every GS

N°	Name of GSs	Vul	Acc	UL	Saf	Log	DP	AV	Sce	Uni	OC	IP	EL	RA	PTU
1	The Tizgarines of Bel Younech	0.4	0.4	0.2	0.3	0.2	0.1	0.2	0.3	0.2	0.2	0.4	0.1	0.2	3,2
2	The ruiniform aspects of Bel Younech	0.4	0.4	0.2	0.3	0.2	0.1	0.2	0.6	0.3	0.2	0.4	0.1	0.2	3,6
3	The Abdessamad cave	0.4	0.3	0.2	0.3	0.2	0.1	0.2	0.6	0.3	0.2	0.4	0.1	0.2	3,5
4	Jbel Chendir and the complex	0.4	0.4	0.2	0.4	0.2	0.1	0.2	0.6	0.4	0.2	0.4	0.1	0.2	3,8
5	„Mujer Muerta" Panorama	0.4	0.4	0.2	0.3	0.2	0.1	0.2	0.6	0.4	0.2	0.4	0.1	0.2	3,7
6	Laila Island or Perejil Island	0.4	0.4	0.2	0.4	0.2	0.1	0.2	0.6	0.4	0.2	0.4	0.1	0.2	3,8
7	The terraces of Ras Leona	0.3	0.4	0.2	0.3	0.2	0.1	0.2	0.6	0.4	0.2	0.4	0.1	0.2	3,6
8	The coast of Ras leona and Karst	0.4	0.1	0.2	0.3	0.2	0.1	0.2	0.6	0.4	0.2	0.4	0.1	0.2	3,4
9	The travertine terraces of Bel Younech	0.4	0.4	0.2	0.3	0.2	0.1	0.2	0.6	0.4	0.2	0.4	0.1	0.2	3,7
10	The low coast of Bel Younech	0.4	0.4	0.2	0.3	0.2	0.1	0.2	0.45	0.3	0.2	0.4	0.1	0.2	3,5
11	The sandstones of predorsalian of Bel Younech	0.4	0.4	0.2	0.3	0.2	0.1	0.2	0.45	0.3	0.2	0.4	0.1	0.2	3,5
12	The cliff of Ras Leona	0.4	0.4	0.2	0.3	0.2	0.1	0.2	0.60	0.4	0.2	0.3	0.1	0.2	3,6
13	The breaches of Bel Younech	0.3	0.4	0.2	0.3	0.2	0.1	0.2	0.15	0.2	0.2	0.4	0.1	0.2	3,0
Weighted average		0,4	0.4	0.2	0.3	0.2	0.1	0.2	0.5	0.3	0.2	0.4	0.1	0.2	3.5
Weighting		10%	10%	5%	10%	5%	5%	5%	15%	10%	05%	10%	05%	05%	100%

the GSs is about 3.5, it can be inferred that the PTU value is high. This value is explained by the proximity of most of the sites to paved roads, the existence of an important tourist infrastructure, and the association of the GSs with an exceptional richness of biological and/or cultural diversity. The opening of the new TGV and other ways of transport has favored the accessibility to the commune of Bel Younech, as well as the inexistence of restrictions of use in almost all the GSs of the territory.

The value of the risk of degradation

The risk of degradation assessment is based on five criteria. Its importance is linked with the fact that the features of the geological elements

Table 5. Assessment of degradation risk value criteria of the studied GSs and their weighted average

N°	Name of GSs	DG	PD	LP	Acc	DP	RD
1	The Tizgarines of Bel Younech	0.35	0.20	0.80	0.60	0.10	2.05
2	The ruiniform aspects of BelYounech	0.70	0.20	0.40	0.15	0.10	1.55
3	The Abdessamad cave	0.70	0.20	0.40	0.45	0.10	1.85
4	Jbel Chendir and the complex	0.70	0.20	0.20	0.15	0.10	1.35
5	„Mujer Muerta” Panorama	0.70	0.20	0.40	0.15	0.10	1.55
6	Laila Island or Perejil Island	0.70	0.20	0.20	0.15	0.10	1.35
7	The terraces of Ras Leona	0.70	0.60	0.40	0.60	0.10	2.40
8	The coast of Ras leona and Karst	0.70	0.80	0.40	0.15	0.10	2.15
9	The travertine terraces of Bel Younech	0.70	0.60	0.40	0.60	0.10	2.40
10	The low coast of Bel Younech	0.70	0.20	0.40	0.60	0.10	2.00
11	The sandstones of predorsalian of Bel Younech	0.70	0.80	0.40	0.60	0.10	2.60
12	The cliff of Ras Leona	0.70	0.80	0.40	0.60	0.10	2.60
13	The breaches of Bel Younech	0.70	0.80	0.40	0.60	0.10	2.60
Weighted average		0.67	0.45	0.40	0.42	0.10	2.03
Weighting		35%	20%	20%	15%	10%	100%

have a high probability of being damaged by anthropogenic or natural factors:

- When the site is not protected by legal laws;
- When it is close to natural hazard areas and potentially degrading activities.

Table 5 presents the values of the risk of degradation, the 5 criteria and the weighted averages of each of the GSs of the commune of Bel Younech.

The average degradation risk of the studied GSs is moderate, in the order of 2.03.It wasnoted that 62% of these GSs have a moderate risk of degradation (Table 5) because the main features of the geological elements have probability degradation by anthropogenic or natural factors. This is due to the lack of access control even though GSs that have legal protection. This factor is combined with the proximity of the majority of sites in the study area to roads and unplanned land developments. In contrast, 38% of the sites in the study area have a low DR (Table 5).

GEOROAD

At the end of this work, a georoad have been proposed (Fig. 17) which is accessible and has infrastructures suitable for use as an educational

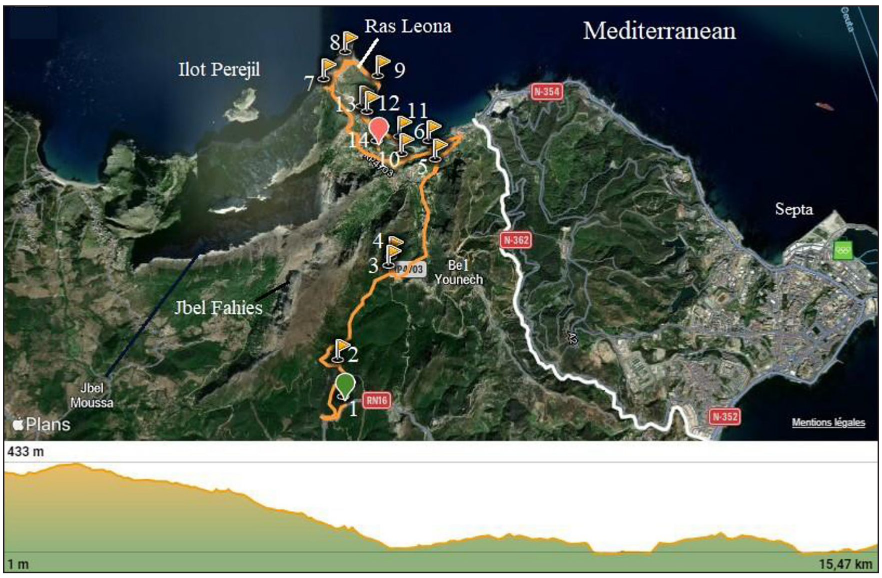

Figure 17. The stations of the Bel Younech itinerary on the Google satellite image (https://www.wikiloc.com/hiking-trails/georoute-de-bel-younech-124855395)

Table 6. Technical Characteristics of the Bel Younech georoad

Length	15,47 km
Difficulty	Low
Altitude min	1 m
Altitude max	433 m
Start	Before
End	Residence of the commune of Bel Younech
Total time	5h 30mn
Durée de déplacement	1h 04mn

and tourist road. The characteristics of this georoad, as it has been traced, are presented in the following table (Table 6).

Thus, in a perspective of preservation by enhancement of these 13 GSs, divided into 14 stops (Fig. 17) according to an itinerary with different themes: i) the regional geology in its relationship with the internal geodynamics responsible for the structural evolution of the peri-plate chain of the Rif, ii) the external geodynamics that illustrates the action of water on carbonate rocks, terraces and Karst formations, iii) the structuring of the landscape in the commune of Bel Younech where the Man has well enhanced its natural surroundings.

Other actions can be undertaken to establish the basis for sustainable development:

a) publication of a geological guide with the inventory of the 13 geosites with emphasis on the geological diversity of the SBEI.
b) taking the actions to ensure sustainable development of the area, including geotourism projects, where the above-mentioned sites and possible future sites can be integrated as natural heritage, thus offering local and foreign visitors the opportunity to discover this exceptional geological heritage.
c) Signage systems should be introduced along the access roads to the commune and at the observation point of the site of geological interest.
d) establishment of a possible natural history museum of the SBEI of Jbel Moussa in the old whale house to illustrate the richness of the marine and terrestrial area by producing guides and leaflets containing information on the sites of geological interest, and with interpretive panels regarding the geology and the sites of the SBEI.
e) Set up awareness campaigns for the different actors concerning the conservation of the geological heritage, accompanied by strategies for the sustainable development of the SBEI.
f) Promote the SBEI of Jbel Moussa from the point of view of sustainable geotourism by exploiting all the tools and methods, such as information and communication technologies, to illustrate the best sites of geological interest of the commune of Bel Younech.

CONCLUSION

The study of geodiversity along the commune of Bel Younech (SBEI Jbel Moussa) has identified thirteen (13) geosites across 14 stops. The results revealed that the SVs of geosites have a high average estimated at 3.50. 8 sites achieved a very high value that exceeds or equals 3.5, which allows them to be considered as geosites. The average values of PEU and PTU are very high (3.7 and 3.5) and the risk of degradation is moderate, around 2.03. The obtained values for DR of GSs indicate that some measures should be taken to protect them. For all these reasons, it is imperative that all the actors involved (local-regional authorities, local population, universities and scientific institutes, NGOs, etc.) face up to their responsibilities in order to make efforts to implement the protection of the geological heritage of the commune of Bel Younech included in the territory of the SBEI of Jbel Moussa.

REFERENCES

1. Aboumaria K., Zaghloul M.-N., Battaglia M., Loiacono F., Puglisi D., Aberkan M. 2009. Sedimentary processes and provenance of Quaternary marine formations from the Tangier Peninsula (Northern Rif, Morocco). Journal of African Earth Sciences, 55, 10–35. https://doi.org/10.1016/j.jafrearsci.2008.12.004
2. Alexandrowicz Z., Kozlowski S. 1999. From selected géosites stooge diversity conservation- Polish example of modern framework. In: Barettino D, Vallejo M, Gallego E (eds) Towards the balanced management and conservation of the geological heritage in the new millenium. Sociedad Geológica de España, Madrid, Spain, 40–44.
3. Al Hachimi S., Omar Belkheiri O., Benarrosh Y. 2022. Distorsions économiques et spatiales dans le Nord du Maroc. Quels mondes en présence et quelle intégration possible ? Le cas de Fahs Anjra », Les Cahiers d'EMAM [En ligne], 34, mis en ligne le 22 décembre 2022, consulté le 01 février 2023. URL : http://journals.openedition.org/emam/4788. https://doi.org/10.4000/emam.4788

4. Aoulad-Sidi-Mhend A. 2019. Caractérisation et valorisation du patrimoine géologique du Parc National de Talassemtane et de la côte des Ghomara (Rif septentrional, nord-ouest du Maroc). Doctorat National Université Ibn Tofail Faculté des Sciences de Kénitra, 306.
5. Aoulad-Sidi-Mhend A., Maaté A., Amri I., Hlila R., Chakiri S., Maaté S., Martín-Martín M. 2019. The geological heritage of the Talassemtane National Park and the Ghomara coast Natural Area (NW of Morocco). Geoheritage, 2019(11), 1005–1025.
6. Aoulad-Sidi-Mhend A., Maaté A., Hlila R., Martín-Martín M., Chakiri S., Maaté S. 2020. A quantitative approach to geosites assessment of the Talassemtane National Park (NW of Morocco). Estudios Geológicos enero-junio, 76(1).
7. Aoulad Sidi Mhend A., Cherai B., Maaté A., Hlila R., Amri I., Chakiri S., Maaté S. 2022. Contribution à l'inventaire du patrimoine géologique du Maroc: Les géosites du métamorphisme des Sebtides le long de la côte des Ghomara (Rif interne, NW Maroc). Bulletin de l'Institut Scientifique, Rabat, Section Sciences de la Terre, 2022, 44, 71–91, 2458–7184.
8. Baudelot S., Durand-Delga M., Esteras M., Freneix S. 1993. Le Trias des « Tariquides » (arc de Gibraltar), indice d'une zone paléogéographique originale à l'ouest de la Méditerranée, C. R. Acad. Sci. Paris, Ser., II 317, 1649–1658.
9. BenYaïch A., Durand-Delga M., Feinberg H., Maaté A., Magné J. 1986. Implications de niveaux du Miocène inférieur dans les rétrocharriages de la Dorsale rifaine (Maroc): signification `a l'´echelle de l'arc de Gibraltar, C. R. Acad. Sci., 302. 587–592.
10. Ben Yaïch A., Duée G., El Hatimi N., El Kadiri K. 1988. La formation a klippes sédimentaires d'âge oligo-burdigalien du Rif septentrional (Maroc): signification géodynamique, Notes Serv. Géol. Maroc, 334, 99–126.
11. Bollati I., Smiraglia C., Pelfini M. 2013. Assessment and Selection of Geomorphosites and Trails in the Miage Glacier Area (Western Italian Alps). Environmental Management, 51, 951–967.
12. Bollati I., Leonelli G., Vezzola L., Pelfini M. 2015. The role of ecological value in geomorphosite assessment for the debris-covered Miage Glacier (Western Italian Alps) based on a review of 2.5 centuries of scientific study. Geoherigate, 7, 119–135.
13. Bollati I., Crosa Lenz B., Golzio A., Masseroli A. 2018. Tree rings as ecological indicator of geomorphic activity in geoheritage studies. Ecol Indic, 93, 899–916.
14. Bouybaouene M.L. 1993. Etude pétrologique des métapelites des Sebtides supérieures. Rif interne. Maroc. Thèse Doct. Etat. Univ. Mohamed V. Rabat, 160.
15. Bouybaouene M.L., Goffé B., Michard A. 1995. High pressure, low temperature metamorphism in the Sebtides nappes. Northern Rif. Morocco. Geogaceta, 17, 117–119.
16. Brilha J. 2005. Património Geológicoe Geoconservação: a Conservaçãoda Nature zanasua Vertente Geológica. Palimage Editores, 183.
17. Brilha J. 2016. Inventory and Quantitative Assessment of Geositesand Geodiversity Sites: Geoheritage, 8, 119–134.
18. Bruschi V.M., Cendrero A. 2009. Direct and parametric methods for the assessment of geosites and geomorphosites. In: Reynard, E., Coratza, P., Regolini-Bissig G (eds) Geomorphosites. Verlag Dr. Friedrich Pfeil, München. Section, 2, 73–88.
19. Bruschi V.M., Cendrero A., Albertos J.-A.-C. 2011. A statistical approach to the validation and optimisation of geoheritage assessment procedures. Geoheritage, 3(3), 131–149.
20. Chalouan A. 1986. Les nappes Ghomarides (Rif septentrional, Maroc). Un terrain varisque dans la chaîne alpine. PhD. Thesis, University Louis Pasteur, Strasbourg, 371.
21. Chalouan A., Sanz de Galdeano C., Galindo-Zaldívar J., Julià R., El Kadiri K., Pedrera A., Hlila R., Akil M., Ahmamou M. 2008. Los travertinos de Beni Younech (SE de lEstrechode Gibraltar, Marruecos). Geogaceta. Comparacióncon las terrazas marinas de Ras Leona, 45, 35–38.
22. Chalouan A., Michard A., El Kadiri K., Saddiqi O. 2011. Rif Central et Nord-Occidental central Rif oriental. Volume 5. Notes et mémoires du service géologique du Maroc., 560, 121.
23. Coratza P., Giusti C. 2005. Methodological proposal for the assessment of scientific quality of geomorphosites. II Quaternario, Italien. Journal of Quaternary Science, 18(1), 307–313.
24. De Lima F.F., Brilha J.B., Salamuni E. 2010. Inventorying geological heritage in large territories: a methodological proposal applied to Brazil. Geoheritage, 2(3–4), 91–99.
25. Derruau M. 1974. Précis de géomorphologie, Paris, Masson, 261.
26. De Wever P., Le Nechet Y., Cornée A. 2006. Vade-mecum pour l'inventaire du patrimoine géologique national. Mémoire hors service Société géologique de France, 12, 162.
27. De Wever P., Egoroff G., Cornée A., et al. 2014. Géopatrimoine en France. Mémoire Hors-Séries de la Société géologique de France, 14, 180.
28. Díaz-Martínez E., Díez-Herrero A. 2011. Los elementos biológicos y culturales de interés geológico: un patrimonio aconservar. In Fernández Martínez E, Castaño de Luis R (eds) Avances y retosenla conservación del Patrimonio Geológico en España. Actas de la IX Reunión Nacional de la Comisión de Patrimonio Geológico (Sociedad Geológica de España), Universidad de León, 85–90.

29. Durand-Delga M., Kornprobst J. 1963. Esquisse géologique de la région de Ceuta (Maroc). Compte Rendu Sommaire des Séances de la Société Géologique de France. https://doi.org/10.2113/gssgfbull.S7-V.7.1049.
30. Durand-Delga M., Gardin S., Esteras M., Paquet H. 2005. Le domaine Tariquide (arc de Gibraltar, Espagne et Maroc) : succession sédimentaire et événements structuraux au Lias et au Dogger. C. R. Geoscience, 337, 787–798. https://doi.org/10.1016/j.crte.2005.03.009
31. El Fahssi A. 1999. Tectonique alpine néotectonique et étude des formations marines quaternaires de la rive sud du Détroit de Gibraltar entre Tanger et Sebta (Rif, Maroc). Thèse, Univ, Mohammed V. Rabat, 253.
32. El Hatimi N., Duée G. 1989. Les séries jurassiques et éocrétacées du Groupe du Moussa (Rif septentrional, Maroc), témoins d'une tectonique distensive en blocs basculés, C. R. Acad. Sci. Paris, Ser., 2(308), 1789–1796.
33. El Hatimi N., Duée G., Hervouet Y. 1991. La Dorsale calcaire du Haouz: ancienne marge continentale passive téthysienne (Rif, Maroc), Bull. Soc. Géol. Fr., 79–90, 162.
34. El Gharbaoui A. 1986. L'homme et la montagne dans la dorsale calcaire du Rif (Maroc septentrional). In: Revue de l'Occident musulman et de la Méditerranée, 41–42, 197–208.
35. El Kadiri K., Linares A., Olóriz F. 1990. Les éléments du groupe du J.Moussa (chaîne du Rif, Maroc). Évolution stratigraphique et géodynamique au cours du Jurassique Crétacé, Comm. Serv. geol. Port., 76 141–161.
36. El Kadiri K. 1991. La Dorsale calcaire (Rif interne, Maroc). Stratigraphie, sédimentologie et évolution géodynamique d'une marge alpine durant le mésozoïque. PhD. Thesis, Abdelmalek Essâdi University of Tetouan, 400.
37. El Kadiri K. 1992. Description de nouvelles espèces de radiolaires jurassiques de la Dorsale calcaire externe (Rif, Maroc), Rev. Esp. Paleont., num. extra., 37–48.
38. El Kadiri K., Faouzi M. 1996. Les formations carbonatées massives de la Dorsale calcaire externe (Rif interne, Maroc), un exemple de plate-forme tidale sous contrôle géodynamique durant le Trias moyen-Lias inférieur. Mines Géol., Rabat, 55, 79–92.
39. El Kadiri K., Sanz de Galdeano C., Pedrera A., Chalouan A., Galindo-Zaldívar J., Julià R., Akil M., Hlila R., Ahmamou M. 2010. Eustatic and tectonic controls on Quaternary Ras Leona marine terraces (Strait of Gibraltar, northern Morocco). Quaternary Research, 74(2), 277–288. https://doi.org/10.1016/j.yqres.2010.06.008
40. FDR. 2019. Site n° 2381, Littoral de Jbel Moussa, Maroc. 17p. https://rsis.ramsar.org/ris/2381.
41. Fennane M, Ibn Tattou M. 1988. Catalogue des plantes vasculaires rares, menacées ou endémiques du Maroc. Bocconea 8, 252., H.M.P., Palermo.
42. Feinberg H., Maaté A., Bouhdadi S., Durand-Delga M., Maate M., Magné J., Olivier P. 1990. Signification des dépôts de l'Oligocène supérieur-Miocène inférieur du Rif interne (Maroc), dans l'évolution géodynamique de l'Arc de Gibraltar. C.R.Acad.Sc. Paris, 310(2), 1487–1495.
43. Fuertes-Gutiérrez I., Fernández-Martínez E. 2010. Geosites inventory in the Leon Province (Northwestern Spain): a tool to introduce geoheritage into regional environmental management. Geoheritage, 2(1–2), 57–75.
44. Fuertes-Gutiérrez I., Fernández-Martínez E. 2012. Mapping Geosites for Geoheritage Management: A Methodological Proposal for the Regional Park of Picos de Europa (León, Spain). Environmental Management, 50, 789–806. http://dx.doi.org/10.1007/s00267-012-9915
45. García-Cortés A., Carcavilla Urquí L. 2009. Documento metodológico para la elaboración de linventario español de lugares de interés geológico (IELIG), version 12. Instituto Geológico y Minero de España, Madrid, 64.
46. Goldscheider N., Drew D. 2007. Methods in Karst Hydrogeology. International Contributions to Hydrogeology 26, International Association of Hydrogeologists, Taylor & Francis, London, 264.
47. Grandgirard V. 1999. Inventaire des géotopes d'importance nationale. GeologiaInsubrica, 4(1), 25–53.
48. Gray J.M. 2013. Geodiversity: valuing and conserving abiotic nature, 2nd édition. John Wiley& Sons, Chichester.
49. Griffon J-C.L. 1966. Etudes géologiques sur la chaine du Rif. Notes et mémoires du service géologique. Maroc, 184.
50. Guerrera F., Martin-Algarra A., Perrone V. 1993. Late Oligocene-Miocene syn- /-late- orogenic successions in Western and Central Mediterranean Chains from the Betic Cordillera to the Southern Apennines. Terra nova., 5, 525–544.
51. Gutnic M. 1969. La dorsale rifaine dans la région d'Asifane. Notes et Mémoires du Service Géologique du Maroc, 194, 51–122.
52. Gigout M., Cadet J.-P., Fourniguet J., Guillemin M., Pierre G. 1977. La chronologie du Quaternaire. Bulletin de la Société Geologique de France, 584–590.
53. Groupe de recherche néotectonique de l'arc de Gibraltar. 1977. L'histoire tectonique récente (Tortonien à Quaternaire) de l'arc de Gibraltar et des bordures de la mer d'Alboran, Bull. Soc. geol. France, 7(19) 575–614.
54. HCLCD. 2008.Aire protégée de Jbel Moussa Plan d'aménagement et de gestion, 2008–2013, 155.

55. Henriques M.H., Pena dos Reis R., Brilha J., Mota T. 2011. Geoconservation as an emerging geoscience. Geoheritage, 3(2), 117–128.
56. Hlila R. 2005. Evolution tectono-sédimentaire tertiaire au front oust du domaine d'Alboran (Ghomarides et Dorsale calcaire).PhD. Thesis, Abdelmalek Essâdi University of Tetouan, 351.
57. JNCC. 1977. Guidelines for selection of Earth Science SSSIs.
58. Kornprobst J., Durand-Delga M. 1985. Carte géologique du Rif à1:50000, feuille «Sebta», Notes Mém. Serv. géol. Maroc, 2.
59. Lapo A.V., Davydov V.I., Pashkevich N.G. et al. 1993. Methodic principles of study of geological monuments of nature in Russia. Stratigraphy and GeologicalCorrelations, I(6), 636–644.
60. Leikine M. 1969. La chaîne de Haouz au nord de Tétouan (Jbel Dersa). Notes et Mémoires du Service Géologique du Maroc., 194, 7–43.
61. Maaté A., Martín-Algarra A., O'Dogherty L., Sandoval J., Baumgartner P.O. 1993. Découverte du Dogger dans la Dorsale calcaire interne au S de Tétouan (Rif septentrional, Maroc). Conséquences paléogéographiques. C.R. Acad. Sc. Paris, 317(2), 227–233.
62. Maaté A. 1996. Estratigrafíay evolución paleogeográfica alpine del dominio Gomáride (Rif interno, Marruecos). PhD. Thesis, University of Granada, 317.
63. Martín–Algarra A., Martín–Martín M., Andreo B., Julià R., González–Gómez C. 2003. Sedimentary pattern in perched spring travertines near Granada (Spain) as indicators of the paleohydrological and paleoclimatological evolution of a karst massif. Sedimentary Geology, 161, 217–228.
64. Martín-Martín M., Sanz de Galdeano C., Moliner-Aznar S. 2021. The Geological Heritage of Salobreña (South Spain): example of a touristic area". American Research Journal of Humanities and Social sciences, 2(1), 1–17.
65. Meghraoui M., Morel J.L., Andrieux J., Dahmani M. 1996. Tectoniqueplio-quaternaire de la chaîne tello-rifaine et de la mer d'Alboran. Une zone complexe de convergence continent–continent. Bulletin de la Société Géologique de France, 167(1), 141–157.
66. Mehdioui S., Hadi H.E., Tahiri A., El Haibi H., Tahiri M., Zoraa N., Hamoud A. 2022. The Geoheritage of Northwestern Central Morocco Area: Inventory and Quantitative Assessment of Geosites for Geoconservation, Geotourism, Geopark Purpose and the Support of Sustainable Development. Geoheritage, 14, 86. https://doi.org/10.1007/s12371-022-00712-w
67. Mehdioui S, El Hadi H., Tahiri A., Brilha J., El Haibi H., Tahiri M. 2020. 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. Geoheritage, 12, 1–17.
68. Mégard F.R. 1969. La partie orientale du massif des Bokkoya. Notes et Mémoires du Service Géologique du Maroc, 194, 123–181.
69. Michard, A. 1976. Eléments de géologie marocaine. Notes et Mém. Serv. géol. Maroc, 252, 420.
70. Michard A., Goffé B., Bouybaouene L. et al. 1997. Hercynian Mesozoic thinningin the Alboran Domain. Metamorphic data from the northern Rif, Morocco. Terrra Nova, 9, 171–174.
71. Mirari S., Aoulad-Sidi-Mhend A., Benmlih A. 2020. Geosites for Geotourism, Geoheritage, and Geoconservation of the Khnefiss National Park, Southern Morocco. https://doi.org/10.3390/su12177109
72. Moliner-Aznar S., Martín-Martín M., Rodríguez-Estrella T., Romero-Sánchez G., García-Lara A. 2021. Geogical Sites in Sierra Espuna-Mula depression area (Murcia province, SE Spain). Revista de la Sociedad Geológica de España, 34(1), 43–56.
73. Nold M., Uttinger J., Wildi W. 1981. Géologie de la Dorsale calcaire entre Tétouan et Assifane (Rif interne, Maroc). Notes et Mémoires du Service Géologique du Maroc, 300, 233.
74. Olivier, P. 1984. Évolution de la limite entre zones internes et zones externes dans l'arc de Gibraltar (Maroc, Espagne), thèse, université Toulouse-3, 229.
75. Parkes M.A., Morris J.H. 1999. The Irish Geological Heritage Programme. In: Barettino D, Vallejo M Gallego E (eds) Towards the balanced management and conservation of the geological heritage in the new millenium. Spain, Sociedad Geológica de España, Madrid, 60–64.
76. PDAPM. 1996. Plan Directeur des Aires Protégées, 3. Les sites d'intérêt biologique et écologique du domaine littoral. BCEOM/SECA, BAD, EPHE, ISR, IB, 166.
77. Pralong J.P., Reynard E. 2005. Aproposalfortheclassificationofgeomorphologicalsites depending on their tourist value. Quaternario, 18(1), 315–321.
78. Pereira P., Pereira D.I. 2010. Methodological guide lines for geomorphosite assessment. Géomorphol Relief, Processus, Environ, 2, 215–222.
79. Pereira P., Pereira D.I. 2012. Assessment of géosites tourism value in geoparks: the example of Arouca Geopark (Portugal). Proceedings of the 11th European Geoparks Conference, Arouca, 231–232.
80. Piqué A. 1994. Géologie du Maroc. Les domaines régionaux et leur évolution structurale. Ed. Pumag, Rabat, 284.
81. Raoult J.F. 1966. La chaîne du Haouz,du col d'Azlu d'Arabia au Bab Aonzar. Notes et Mém. Serv. géol. Maroc, 184, 61–131.
82. Reynard E., Fontana G., Kozlik, L., Scapozza C. 2007. A method for assessing scientific and

additional values of geomorphosites. Geographica Helvetica. GeogrHelv, 62(3), 148–158.

83. Reynard E., Fontana G., Kozlik L. et al. 2007. A method for assessing scientific and additional values of geomorphosites. Geographica Helvetica. Geographica Helvetica, 62(3), 148–158.
84. Reynard E. 2009. The assessment of geomorphosites. In:Reynard E,CoratzaP, Regolini- Bissig G (eds) Geomorphosites. Pfeil, Munchen, 63–71.
85. Reynard E., Coratza P. 2013. Scientific research on geomorphosites. A review of the activities of the IAG working group on geomorphosites over the last twelve years. Geografia Fisica e Dinamica Quaternaria, 36, 159–168.
86. Reynard E., Perret A., Bussard J. et al. 2016. Integrated Approachfor the Inventory and Management of Geomorphological Heritage at the Regional Scale. Geoheritage, 8, 43–60.
87. Romagny A. 2014. Evolution des mouvements verticaux néogènes de la chaîne du Rif (Nord-Maroc) :apports d'une analyse structurale et thermo-chronologique. Sciences de la Terre. Université Nice Sophia Antipolis. Français, 272.
88. SPA/RAC - ONU Environnement/PAM & HCE-FLCD. (2019). L'aire protégée de Jbel Moussa: une perle dans le Détroit de Gibraltar. Par : Ali Aghnaj, Hocein Bazairi et Atef Limam. Ed. SPA/RAC. Projet MedMPA Network, Tunis, 38.
89. Suter G. 1965. La région du moyen Ouerrha (Rif, Maroc) : étude préliminaire sur la stratigraphie et la tectonique. Maroc, Notes Mémoires Services géologiques, 183, 7–17.
90. Suter G. 1980. Carte géologique du Rif, 1/500.000. Notes et Mémoires du service géologique du Maroc, 245.
91. Wildi W., Nold M., Uttinger J. 1977. La Dorsale Calcaire entre Tétouan et Assifane (Rif interne, Maroc), Eclogae Geol. Helv., 70, 371–415.
92. Wildi W. 1979. Evolution de la plat-forme carbonatée detypeaustro-alpin de la Dorsale calcaire (Rif interne, Maroc septentrional) au Mésozoique, Bull. Soc. Géol. Fr., (7)21, 49–56.
93. Wimbledon W.A., Benton M.J., Bevins R.E. et al. 1995. The development of a methodology for the selection of British Geological sites for geoconservation: part 1. Modern Geology, 20, 159–202.
94. Wimbledon W.A. 2011. Geosites: A mechanism for protection, integrating national and international valuation of heritage sites. Geologia del l'Ambiente, supplement, 2/2011, 13–25.
95. Zazo C., Goy J.L., Dabrio C.J., Bardají T., Hillaire-Marcel C., Ghaleb B., González Delgado J.A., Soler V. 2003. Pleistocene raised marine terraces of the Spanish Mediterranean and Atlantic coasts: records of coastal uplift, sea-level highstands and climate changes. Marine Geology, 194(1–2), 103–133.