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# The Geoheritage of the Doukkala-Abda Region (Morocco): An Opportunity for Local Socio-Economic Sustainable Development

## Le géopatrimoine de la région Doukkala-Abda (Maroc): une opportunité pour un développement socio-économique local durable

جيوتراث منطقة دكالة-عبدة (المغرب)  
فرصة لتنمية اجتماعية واقتصادية محلية مستدامة

A. Enniouar, E. Errami, A. Lagnaoui, and O. Bouaala

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### Abstract

The Doukkala-Abda region has a rich natural heritage, making it an important attraction for national and international tourists. However, its geoheritage remains little known to the general public, despite the numerous multidisciplinary scientific studies that have been carried out. A preliminary inventory has identified 36 geosites, reflecting the geomorphological, geological and environmental history of the region. The scientific, technical and ecological aspects of 14 of these geosites are described in this paper. They are: the Precambrian rhyolites, the Sidi Saïd Mâachou basin with its numerous geosites, consolidated and unconsolidated dunes, Jbel Irhoud, the escarpments of Jorf Lasfar, Sidi Bouzid and Lalla Fatna, Sidi Moussa-Oualidia lagoon complexes, Zima Lake and El Goraan, El Khenzira and the Oualidia caves. The rich bio- and geodiversity of these sites has an important geotouristic potential. An objective evaluation of these sites is needed. This will allow the development of geotourism and ecotourism as new component of cultural tourism. A network of geotrails linking coastal geosites to sites in the hinterland would help promote socio-economic activities and create jobs which will increase the income of the local population whose economy is mainly based on agriculture and cattle breeding.

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### Résumé

La région des Doukkala-Abda possède un patrimoine naturel riche, qui en fait une attraction importante des touristes nationaux et internationaux, bien que son géopatrimoine reste inconnu pour le grand public. Cela malgré les nombreux travaux scientifiques pluridisciplinaires menés sur le territoire. Un inventaire préliminaire a permis d'identifier trente-six géosites reflétant l'histoire géomorphologique, géologique et environnementale de la région. Dans le présent article, nous avons décrit les aspects scientifiques, techniques et écologiques de quatorze géosites seulement. Ces sites sont: les rhyolites du Précambrien, le bassin de Sidi Saïd Maachou avec ses nombreux géosites, les dunes consolidées et non consolidées, Jbel Irhoud, les falaises de Jorf Lasfar, de Sidi Bouzid et de Lalla Fatna, le complexe lagunaire de Sidi

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Moussa-Oualidia, le Lac Zima, les grottes d'El Goraan, d'El khenzira et de Oualidia. La grande bio-géodiversité de ces géosites leur confère un important potentiel géotouristique. Pour promouvoir ce géopatrimoine et en faire un pilier pour un développement socio-économique local durable, une valorisation rationnelle s'avère nécessaire. Celle-ci pourrait se faire par l'intermédiaire du développement de l'écotourisme et du géotourisme comme nouvelle composante du tourisme culturel dans la région. Ainsi, la création et le développement de géocircuits reliant la zone côtière à l'arrière-pays pourrait promouvoir les activités socio-économiques et la création de l'emploi qui participeront à augmenter les revenus des populations locales dont l'économie est basée principalement sur l'agriculture et l'élevage.

#### ملخص

توفر منطقة دكالة-عبدة على تراث طبيعي غني، يجعل منها عامل جذب مهم للسياح المحليين والدوليين، على الرغم من أن جيوتراثها مازال مجهولاً عند عامة الناس. وهذا برغم الأبحاث العلمية المتنوعة والمتعددة التخصصات التي أجريت على المنطقة. الجرد الأولي مكن من تحديد ستا وثلاثين جيوموقعا يعكس التاريخ الجيومورفولوجي والبيئي للمنطقة. في هذا المقال قمنا بوصف الجوانب العلمية والتقنية والبيئية لأربعة عشر جيوموقعا فقط. وهذه المواقع هي الحمم البركانية للزمن ما قبل الكامبري، حوض سيدي سعيد معاشو بمواقعه العديدة، الكتبان المتماسكة وغير المتماسكة، جبل إيغود، الجرف الأصفر، جرف سيدي بوزيد و جرف لالة فاطنة، مجمع بحيرة سيدي موسى-الوليدية، بحيرة زيمما، كهوف الكوران والخنزيرة والوليدية. إن التنوع البيولوجي والجيومورفولوجي والبيئي الكبير لهذه المواقع يعطيها إمكانات جيوسياحية هامة. لتطوير تراثها الجيومورفولوجي وجعله ركيزة للتنمية الاجتماعية والاقتصادية المحلية المستدامة، فإن التقييم الموضوعي بعد أمرا ضروريا. هذا الأخير يمكن القيام به عبر تنمية السياحة البيئية والجيوسياحية كمنهج جديد من السياحة الثقافية بالمنطقة. إن خلق وتطوير شبكة طرق جيوسياحية تربط المناطق الساحلية بالمناطق النائية، من شأنها تعزيز الأنشطة السوسيو-اقتصادية وخلق فرص شغل بالمنطقة. مما سوف يزيد من دخل الساكنة المحلية التي يعتمد اقتصادها أساسا على الزراعة وتربية المواشي.

#### Keywords

Doukkala-Abda region • Morocco • Geoheritage • Inventory • Geotourism • Local socio-economic sustainable development

#### Mots-clés

Région de Doukkala-Abda • Maroc • Géopatrimoine • Inventaire • Géotourisme • Développement socio-économique durable

#### الكلمات الرئيسية

منطقة دكالة-عبدة • المغرب • الجيوتراث • الجرد • الجيوسياحية • التنمية الاجتماعية والاقتصادية المحلية المستدامة

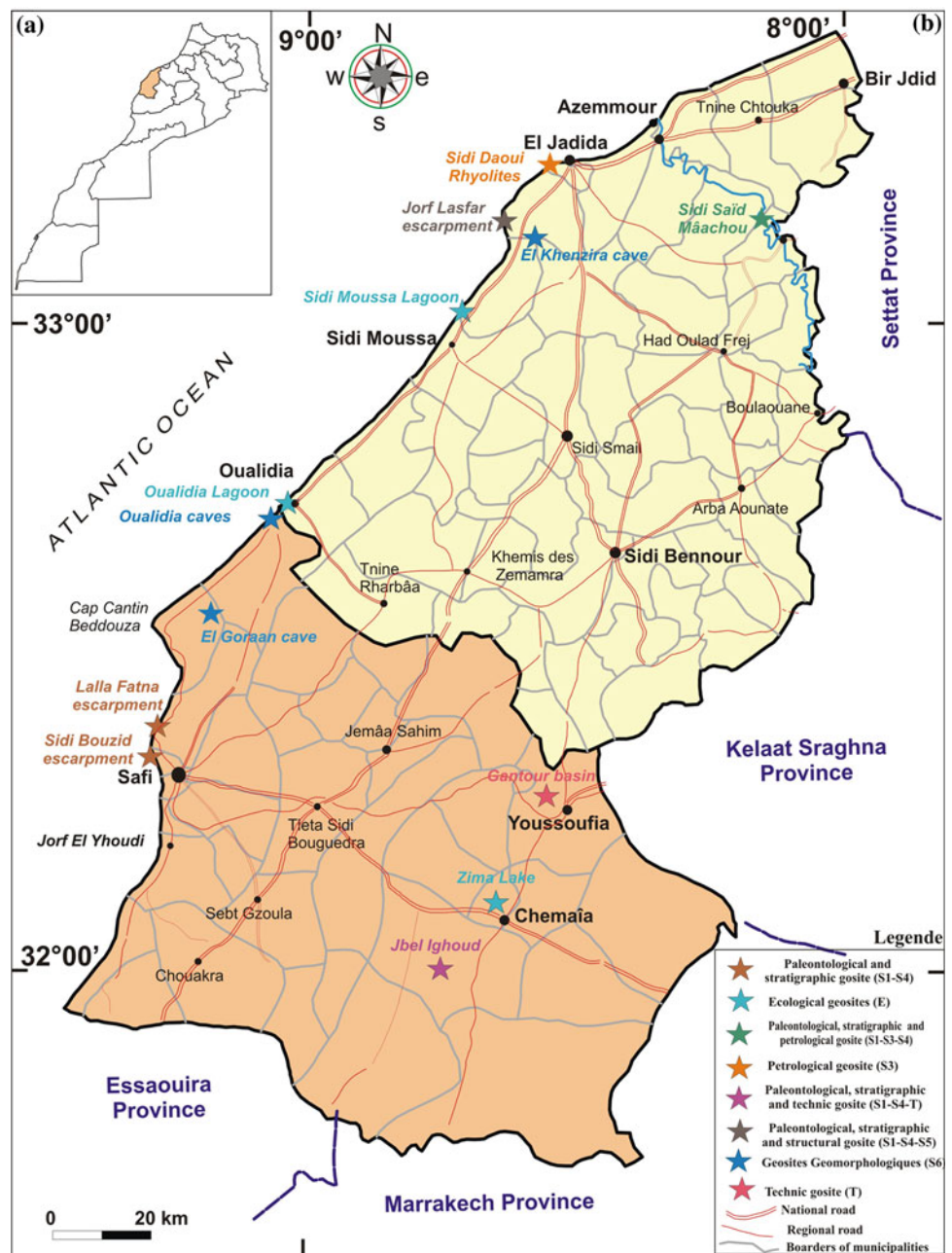
## 1 Introduction

Doukkala-Abda region, study area, is located in the north-western part of central Morocco, bordering the Atlantic coast at the crossroads between three of Morocco's main tourist destinations—Casablanca, Marrakech, and Agadir. It covers an area of approximately 14,285 km<sup>2</sup> and incorporates four provinces, El Jadida, Sidi Bennour, Safi and Youssoufia (Fig. 1). The population of the region is 4,284,039 inhabitants. Geographically, the region consists of two main zones: the coastal zone and the hinterland. The latter, which corresponds to the Doukkala-Abda plain, is characterized by three geomorphological features: (1) base of slope colluvial deposits, described by Gigout (1951) as loose and

unconsolidated sediments deposited at the base of hill-slopes by either rainwash, sheetwash, slow continuous downslope creep, or a combination of these processes; (2) present day and fossil valleys, principally two main river systems, Oued Oum Er-Rbia and Oued Tensift, and several smaller and secondary rivers; and (3) the Plio-Quaternary dunes complex, with regular dune morphology separated by inter-dune depressions, the dune ridges extending over large distances with a SSW trend (Aboumaria 1993).

The coastal area consists of four geomorphological elements: (1) the beaches, which are quite commonly rocky, especially in the south-western part of the region, and sandy in the north-eastern part; (2) the Plio-Quaternary consolidated dunes complex, which is aligned sub-parallel to the present

**Fig. 1** Administrative subdivision of Doukkala-Abda region showing the locations of the geosites described in the paper

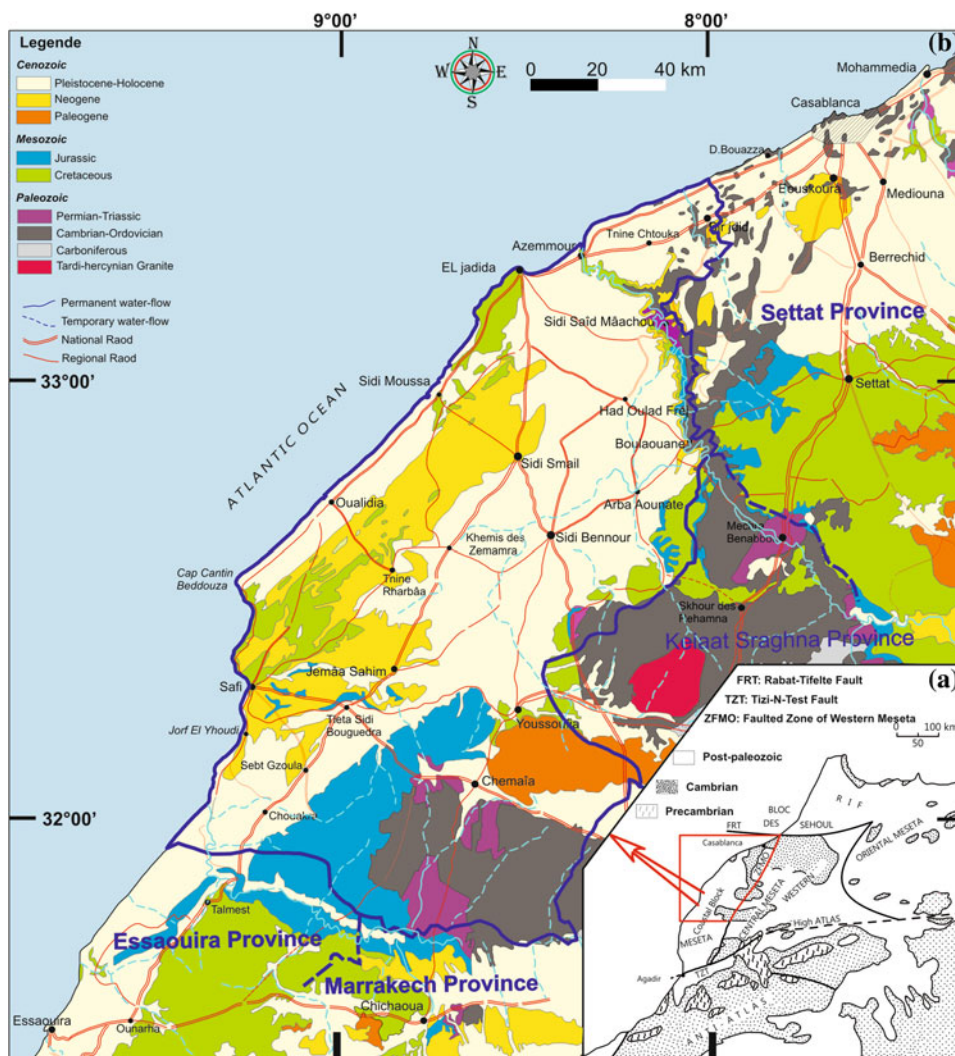


coastline; but is absent in the southern part of the area near Abda; (3) A belt of unconsolidated coastal dunes along the coastal strip; and (4) the fossil escarpments, especially dominating in the south-west part, that were formed during numerous hydrodynamic cycles (Ouada 1998).

The region also displays a wealth of karst landforms, the products of its geology, geography and climate and the prevailing, hydrological conditions. Karst topography, limestone pavements, caves, sinkholes, and uvalas (a collection of multiple smaller individual sinkholes that coalesce into a compound sinkhole) are all represented. From the geological point of view, the Doukkala-Abda region belongs

to the Coastal Block, defined by Michard et al. (1989) as a stable Variscan zone in the coastal part of the western Moroccan Meseta. The Coastal Block comprises subtabular Mesozoic and Cenozoic formations overlying folded Palaeozoic rocks, the Mesozoic succession representing the northern part of the El Jadida-Agadir basin (Bouaouda 2004). The region as a whole, however, is characterized by a wide variety of volcanic, sedimentary and metamorphic rocks that range in age from Precambrian to Miocene, and the older formations are covered by Plio-Quaternary transgressive deposits (Fig. 2) (Ferré and Ruhard 1975; Gigout 1965; Khatmi 1999).

**Fig. 2** Simplified geological map of Doukkala-Abda (adapted from Michard et al. 2008)



This paper aims to present results of the preliminary detailed inventory of the geoh heritage of Doukkala-Abda region. Thirty-six geosites have been classified, taking into consideration their scientific importance and value, their degree of vulnerability and the nature of conservation required, through to proposals for various geotourist trails, in order to offer visitors other activities in addition to enjoying the natural and cultural heritage that exists in the vicinity of the sites.

## 2 Materials and Methods

The Doukkala-Abda region preserves a rich geoh heritage. This paper outlines the results of efforts to prepare an inventory of the main geosites, based on their scientific and/or educational and/or socio-economic attributes and values. The study, undertaken in 2010, is based on literatures and field surveys. The inventory adopts a simplified classification commonly used for the regional geoh heritage (Viette 2007; Table 1). The final aim of that work is to develop

strategies for the protection, the sustainable management of the inventoried geosites and the development of proposals for geotourist trails in the region.

The inventoried sites are classified principally as either type S or T, respectively sites of scientific interest or technical interest, such as mines, quarries, brick-making, etc. However, we have added a third type, E, for the scientific sites which include all biological and ecological features. The 14 geosites described in the paper are listed in Table 2.

## 3 Description of the Doukkala-Abda Geosites

### 3.1 Geosites of Scientific Interest

#### 3.1.1 Late Neoproterozoic Rhyolites

The Precambrian rocks are less well exposed in the Moroccan Meseta than in southern Morocco, in the Anti-Atlas. Their only outcrop in the Doukkala-Abda region is situated on the

**Table 1** Geosites typology (modified after Viette (2007))

Geosites		Including
S1	Palaeontological	All fossil objects of palaeontological and/or palaeoecological interest
S2	Mineralogical	All minerals and mineralization forms
S3	Petrological	All rock types
S4	Stratigraphical	All types of strata, sections and series
S5	Structural	All types of structures
S6	Geomorphological	All models, reliefs and their modes of alteration (including pedological)
E	Ecological	All biological and ecological geosites (lagoons, lakes, etc.)
T	Technical	All technical sites (history of the exploitation of geological resources)

**Table 2** Described geosites of Doukkala-Abda region

Geosites	Geographic coordinates	Typology
Late Precambrian rhyolites of Sidi Daoui	33°14'00"N–8°30'00"W	Petrological geosite (S3)
Sidi Saïd Mâachou Basin	33°00'–33°15'N, 8°00'–8°15'W	Palaeontological, stratigraphical and petrological geosites (S1-S3-S4)
Jbel Irhoud	Not provided, vulnerable geosites	Palaeontological, stratigraphical and technical geosites (S1-S4-T)
Lalla Fatna escarpment	32°23'54, 15"N, 9°15'44, 54"W	Palaeontological and stratigraphical geosites (S1-S4)
Sidi Bouzid escarpment	32°18'01"N–9°15'04"W	
Jorf Lasfar escarpment	33°09'24, 66"N–08°37'24, 74"W	Palaeontological, stratigraphical and structural geosites (S1-S4-S5)
Consolidated and unconsolidated dunes	Sahel of Doukkala region	Geomorphological geosites (S6)
El Goraan cave	32°33'27"N, 9°15'15"W	
El Khénzira cave	33°09'24,64"N–08°37'23"W	
Oualidia caves	32°40'42"–32°47'07", 8°52'30"–9°02'50"	
Oualidia Lagoon	32°40'42"–32°47'07", 8°52'30"–9°02'50"	Ecological geosites (E)
Sidi Moussa Lagoon	32°52'0", 8°51'05"	
Zima Lake	32°04'48"N–08°39'36"W	
Phosphate deposit of Ganntour	32°7'48"N–8°30'0"E Elevation 534 m	Technical geosite (T)

headland at Sidi Daoui, on the Atlantic coast of El Jadida. At this locality, Neoproterozoic rhyolites are exposed in the core of an anticline where they are overlain unconformably by Early Cambrian dolomites (Fig. 3). The correlation of these volcanic outcrops with the late Neoproterozoic formations of the Anti-Atlas (e.g. Ouarzazate Group, Thomas et al. 2002), dated at 543 Ma, is generally accepted (Choubert 1963; Ez-zouhairi et al. 2007).

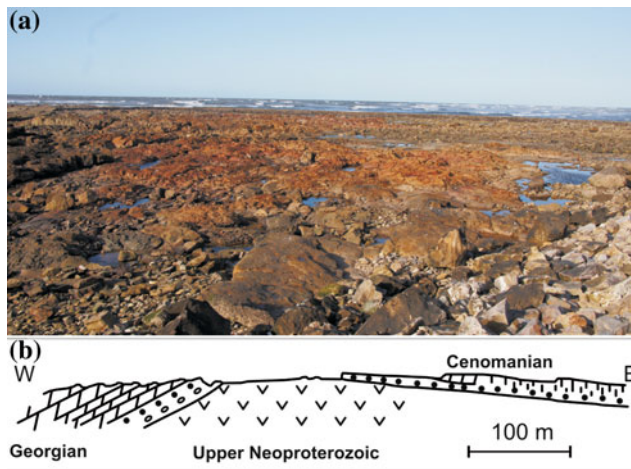
This outcrop provides a fascinating insight into the geological history of the region during the late Neoproterozoic and merits protection. However, the geosite is vulnerable to coastal erosion and weathering. Recently, a large part of the outcrop was covered during the construction of the coastal road between El Jadida town and Sidi Bouzid village.

Nevertheless, despite its vulnerability, the remarkable position of this site enhances its tourist potential.

### 3.1.2 Sidi Saïd Mâachou Basin

The Sidi Saïd Mâachou (SSM) basin is oriented NNW-SSE, covering an area approximately 6 km in length and 4 km in width. Located between two administrative regions, the Doukkala-Abda and Chaouia-Ourdigha (Fig. 1), it consists of numerous stratigraphic, petrological and palaeontological geosites rich in minerals and fossils. The basin is cut by the Oum Er-Rbia River, which presents several geomorphological outcrops of educational value.

Geologically, the basin is comprised of sedimentary, igneous and metamorphic rocks, reflecting continental and



**Fig. 3** **a** The oldest volcanic rocks in Doukkala-Abda (Late Neoproterozoic rhyolites). **b** Simplified lithostratigraphic section of El Jadida headland with late Precambrian rhyolites in the core of the anticline

marine environments. The rocks have been tectonically deformed and show structural features (various foliations, folds, and faults), which are useful both for educational and tourist purposes. The succession is made up of three main formations: middle Cambrian rocks, predominantly shales (Fig. 4a), unconformably overlain by continental Triassic rocks (Fig. 4b) and marine Plio-Quaternary sedimentary units (see Fig. 4c, d, e and Gigout 1956; El Attari 2001; Hminna 2005, Hminna et al. 2013). The volcanic complex of the SSM consists of dolerite dykes and sills feeding basaltic flows on the surface (Fig. 5a, b). The emplacement of the dolerites was synchronous with the sedimentation of the Acadian (Middle Cambrian) Paradoxides shales. It represents a period of extensional intraplate alkaline magmatism within Gondwana during the Cambrian (Ezzouhairi et al. 2004). The Triassic formations correspond to a deposit within a playa-like, fluvio-lacustrine system under semi-arid conditions (Hminna et al. 2013). The Triassic red-beds have yielded the most interesting fossils, which include plant prints, rhizoliths, fish scales, and invertebrate and vertebrate traces (Hminna et al. 2013). Tetrapod footprints recorded in this area are assigned to *Brachychirotherium parvum*, and are considered the first record of Triassic tetrapod footprints in Morocco outside of the High Atlas, and, indeed, the first record of the species in Africa (Hminna et al. 2013). The Late Triassic is marked by several intercalated tholeiitic basalt flows (Fig. 5c), linked to central Atlantic rifting. These flows crop out generally along the Oued Oum Er-Rbia. They vary in thickness and color, the latter ranging from grey to greenish, and they show varying stages of alteration (Hminna 2005).

With its scenic value, the SSM basin is a geosite of high heritage interest that needs to be evaluated with the goal of increasing the income of the local communities (Enniouar

et al. 2011, 2013). It is important to note that almost no socio-economic activities generating revenues for local populations exists in the SSM village, whose name was given to the first dam to be built in Moroccan territory in 1929 (in the official website of Ministry of Energy, Mines, Water and Environment, Department of Water, <http://www.water.gov.ma/index.cfm>) (Fig. 4c). Several 1-day georoutes could be developed within the basin.

### 3.1.3 Jbel Irhoud

Jbel Irhoud (Jbel means mountain in Arabic) represents a faulted anticline of Early Cambrian karstic limestones and shales. The succession in the general vicinity is 400–500 m thick and, in addition to the deformed Palaeozoic rocks, also preserves Triassic red beds and Quaternary calcareous sandstones, in unconformable relationships to the older units. This geosite is one of the most important fossil localities in the Doukkala-Abda region (Fig. 6). It is known for its numerous hominid remains (see below), and also for its barite mines. The Early Cambrian shales preserve *Archeocyathus*, reef-building marine organisms of early Cambrian age that lived in warm tropical and subtropical waters (Huvelin 1977).

The Jebel Irhoud limestones contain many caves and other examples of karst landforms. One of the caves, which might have been used by Neanderthals, has yielded several discoveries, the most important being that of the juvenile *Homo sapiens*, dated at 160,000 years. It is the oldest member of modern *Homo* known with developed features in Morocco (Hublin et al. 1987; Hublin and Tillier 1988; Amani and Geraads 1993, 1998; Smith et al. 2007). The cave has also provided more than 425 pieces of worked stone and tools of a Levallois-Mousterian technique. The smoothness of some tool-tips suggests the high level of intelligence of the Neanderthals (Hublin and Tillier 1988).

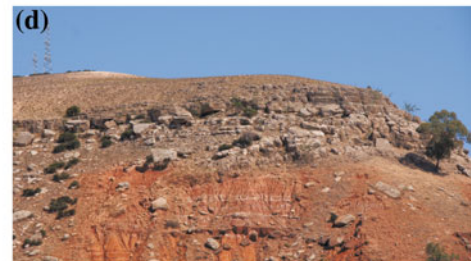
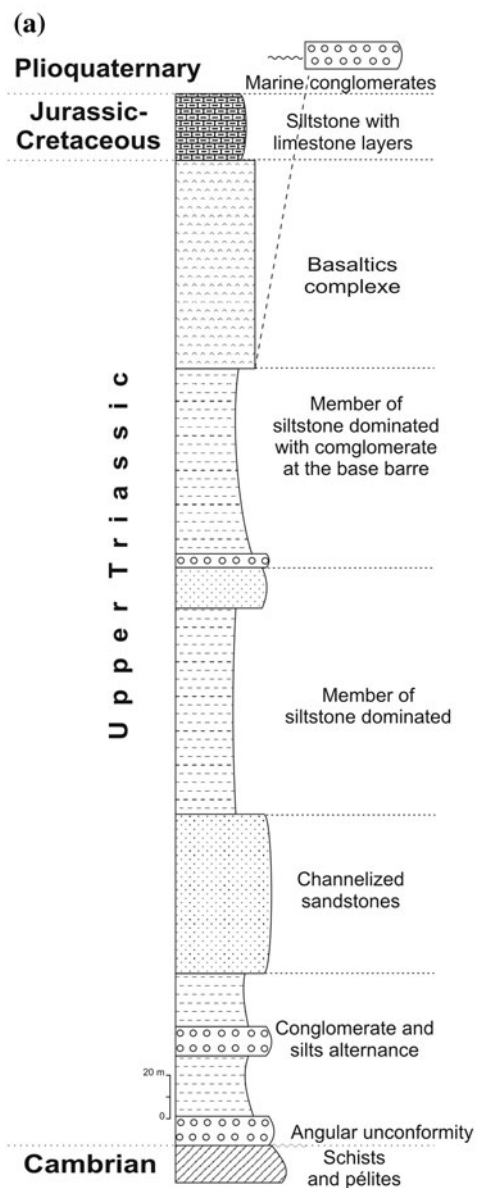
In summary, the stratigraphical, palaeontological and archaeological richness of Jbel Irhoud makes it one of the most important geosites in the region. Its scientific, historical and cultural values make it a site of heritage importance; however, its location in a remote mining area increases its vulnerability. Its preservation should be a matter of priority for the local authorities.

### 3.1.4 Lalla Fatna Escarpment

The Lalla Fatna geosite offers two contrasting coastal attractions: one scientific, the other touristic. The escarpment, comprising a rock sequence of Mesozoic age, is situated at the top of a sandy beach, and is a rich source of fossils (ammonites, brachiopods, bryozoa, cnidaria, echinoids). The beach itself offers considerable tourist potential.

The escarpment ranges between 115 and 150 m in height. It consists mainly of three geological units forming part of an anticlinal structure. (Fig. 7a, b, Ettachfini et al. 1998). The units mark a transition from the Jurassic to the Cretaceous

**Fig. 4** **a** Lithostratigraphic subdivision of the Palaeozoic and Mesozoic formations in the Sidi said Mâachou basin. **b** Middle Cambrian shales and sandstones. **c** Triassic sandstone-dominated *red-beds*. **d** Plio-Quaternary conglomerates rich in marine fossils (*Photo e*)



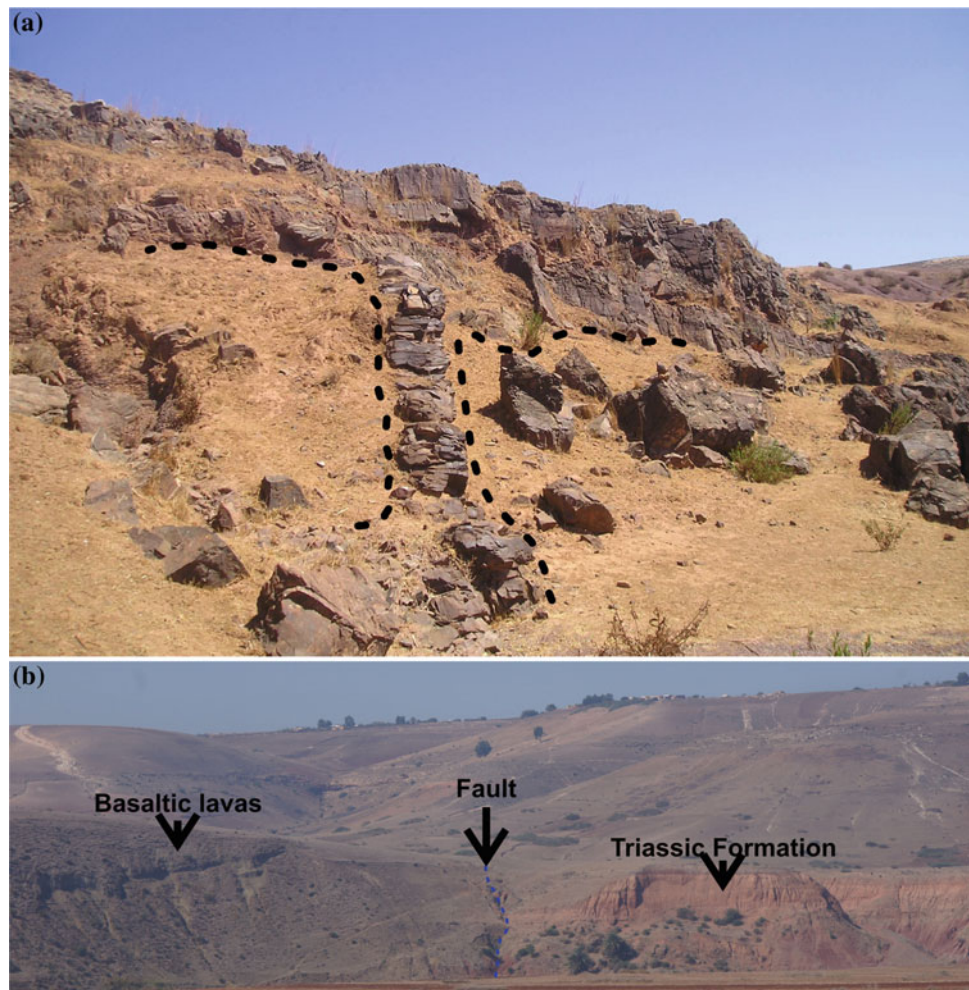
(Fig. 7a); from the base of the escarpment to the top these are:

- (1) A basal unit of white-coloured gypsiferous evaporites displaying salt tectonic structures, overlain by alternating dolomite, marl and gypsum layers showing a variety of sedimentary features (laminations, tepee structure, breccia and bioturbation). These rocks are overlain by massive and azoic yellowish dolomites. The basal unit was deposited during the Late Jurassic in a confined hot, arid environment.
- (2) The Lower Limestones is a unit formed principally of limestones preserving a rich marine fauna (ammonites, brachiopods, gastropods and echinoids). They are capped by a red oxidized ferruginous surface ('hard

- ground'), which is also rich in marine fossils (brachiopods, bryozoa, cnidaria, and echinoids). An extensive marine depositional environment, possibly associated with rapid sea-level rise, and accompanying low sedimentation rates, is invoked (Fig. 7a, b, Ettachfni et al. 1998), however the hard ground could be an indicative of oxidation in a subaerial tropical environment.
- (3) The uppermost rocks exposed in the escarpment are mainly brown clay stones with a few intercalated limestone layers deposited in an open marine environment such as platform type (Ettachfni et al. 1998).

In summary, the sedimentary and palaeontological information preserved in the rocks, that form the escarpment,

**Fig. 5** **a** Middle Cambrian dolerite dykes and sills associated to Paradoxides schists. **b** Triassic basaltic lava flows; linked to the rifting of the central Atlantic, in faulted contact with the Triassic siltstones



make a valuable contribution to palaeo-biogeographical and palaeoclimatic interpretations as well as to stratigraphical correlations both regionally and globally. In addition, the Lalla Fatna beach is a popular tourist destination. Recently, the road to the beach was paved and the stairs upgraded.

### 3.1.5 Sidi Bouzid Escarpment

The Sidi Bouzid escarpment extends for several kilometres along the coast South-West from Safi town. It offers a panoramic view over the town and provides a beautiful beach frequently visited by vacationers. The 160–200 m thick succession of Early Cretaceous sedimentary rocks making up the escarpment is subdivided into three formations which are, from the base to the top:

- (1) The Late Berriasian—Early Valanginian Lower Limestone Formation, contains a concentrated marine fauna (Rey et al. 1989; Ettachfni et al. 1998).
- (2) The early Late Valanginian Brown Claystone Formation which overlies both the previous formations, and is rich in ammonites (Rey et al. 1989; Ettachfni et al. 1998).

- (3) The Late Hauterivian Dridrat Limestone Formation is rich in marine fossils, including cup corals, brachiopods, bryozoa, echnoids, serpulids, spatangoids, ammonites and calpionellids (Gigout 1951).

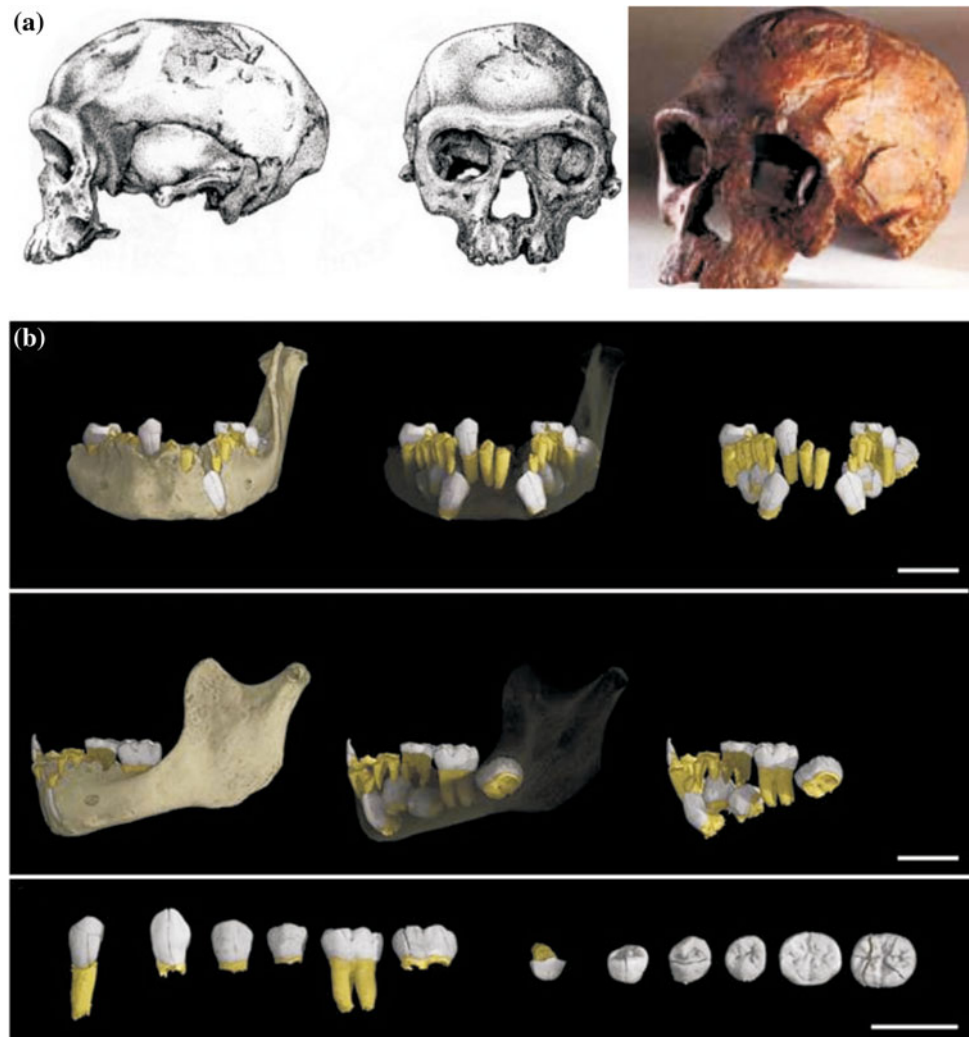
The various palaeontological assemblages found at this site are of great scientific interest in terms of their palaeo-ecological and palaeo-bio-geographical significance. In addition, the site has proven tourist value. According to the magazine “Surf”, Safi has one of the ten best surfing waves in the world, related to large depressions in the seabed, especially in autumn, and due to the physical presence of Sidi Bouzid escarpment. Prominent among the artistic and cultural activities organized each year in Safi town is the “Amwaj Assafi” festival (“Amwage” meaning ‘waves’ in Arabic). The festival aims to promote Safi as a town of art and culture, and as a tourist destination.

### 3.1.6 Jorf Lasfar Escarpment

The Jorf Lasfar escarpment gives rise to beautiful landscape along the coastal road and provides a good view of Jorf Lasfar harbour. The escarpment has a markedly yellow



**Fig. 6** Human remains excavated from Jbel Irhoud, Western Jbilet. **a** Skull of the Juvenile *Homo sapiens* of Jbel Irhoud. **b** Remains of jaws and teeth of *Homo Sapiens* of Jbel Irhoud. Bar scales 2 cm. Photos taken from Smith et al. (2007)



colour as indicated by the name of the site, “Jorf Lasfar” meaning “yellow cliff” in Arabic. The geology consists of Cretaceous formations with neotectonic activity (Ouadaia 1998). Furthermore, the morphological changes of the shoreline inform the teaching of modern concepts of vertical weathering changes in cliffs and the lateral changes of the present shoreline (Duane 2013).

### 3.1.7 Consolidated and Unconsolidated Dunes

The coastal area of Doukkala-Abda region consists of varied landscapes comprising mainly consolidated and unconsolidated dunes (Aboumaria 1993; Ouadia 1998). The decrease in sea level and the action of trade winds are responsible for the development of the old dune cordons of late Pleistocene (Soltanian) age (Weisrock 1982; Ouadia et al. 1993). These dunes trend Northeast-Southwest and the slope is steeper on the inland, Oulja (Coastal wetland influenced by swamp) side, than on the Ocean side (Ouadia 1998), reflecting a wind direction from West to East (Gigout 1951). Both the consolidated and unconsolidated dunes are very important for

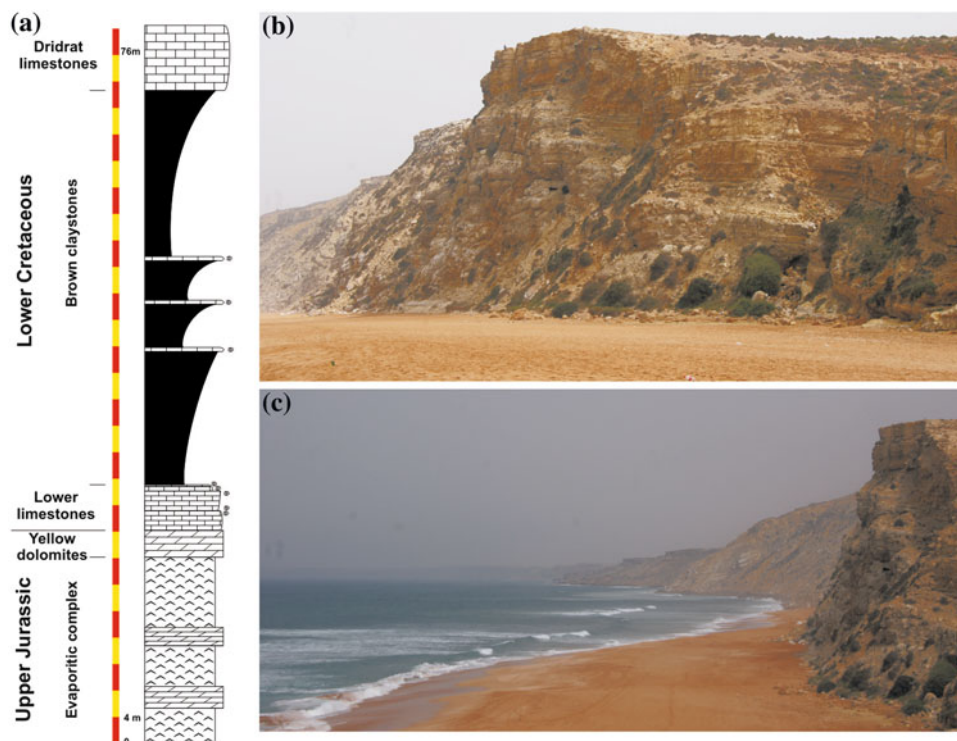
the stability of the inland and coastal ecosystems, protecting coastal areas from erosion and the hinterland from winds and desertification. The intensive quarrying of sand from these dunes (at 147 quarries sites, according to the Ministry of Equipment and Transport 2013) is causing serious damage to the environment. The recognition of just one of the extraction sites as a designated geosite would help to demonstrate the value of the dune fields as a whole, and the importance of preserving them, and it would play an important role in alerting the local population and the decision-makers.

### 3.1.8 Karst Landscapes

The Doukkala-Abda region is characterized by its karstic features and landscapes, especially in the coastal zone where caves, which were used and adapted by prehistoric man during the Quaternary, are one of the most important geomorphological features. Two types of cave are distinguished: dissolution caves and man-made caves. Climatic parameters (wet), the geological and the structural characteristics

**Fig. 7 a** Lithostratigraphic subdivision of Mesozoic deposits of Lalla Fatna escarpment (After Ettachfni et al. 1998).

**b** Panoramic view of Lalla Fatna escarpment. **c** Lalla Fatna beach



(fractured limestones), hydrogeological and geographical barriers to the flow of surface water into the ocean all contribute to the karstification of the substrate.

Several caves have been described in the region (Ouada et al. 2008). The best known are El Goraan and El Khenzira caves, which are judged to be significant archaeological sites in need of special investigation by archaeologists and palaeoanthropologists. The variation in the functional role of caves in this area in the past provides a good example of the interrelationship between man and his environment. Caves at three sites are described below:

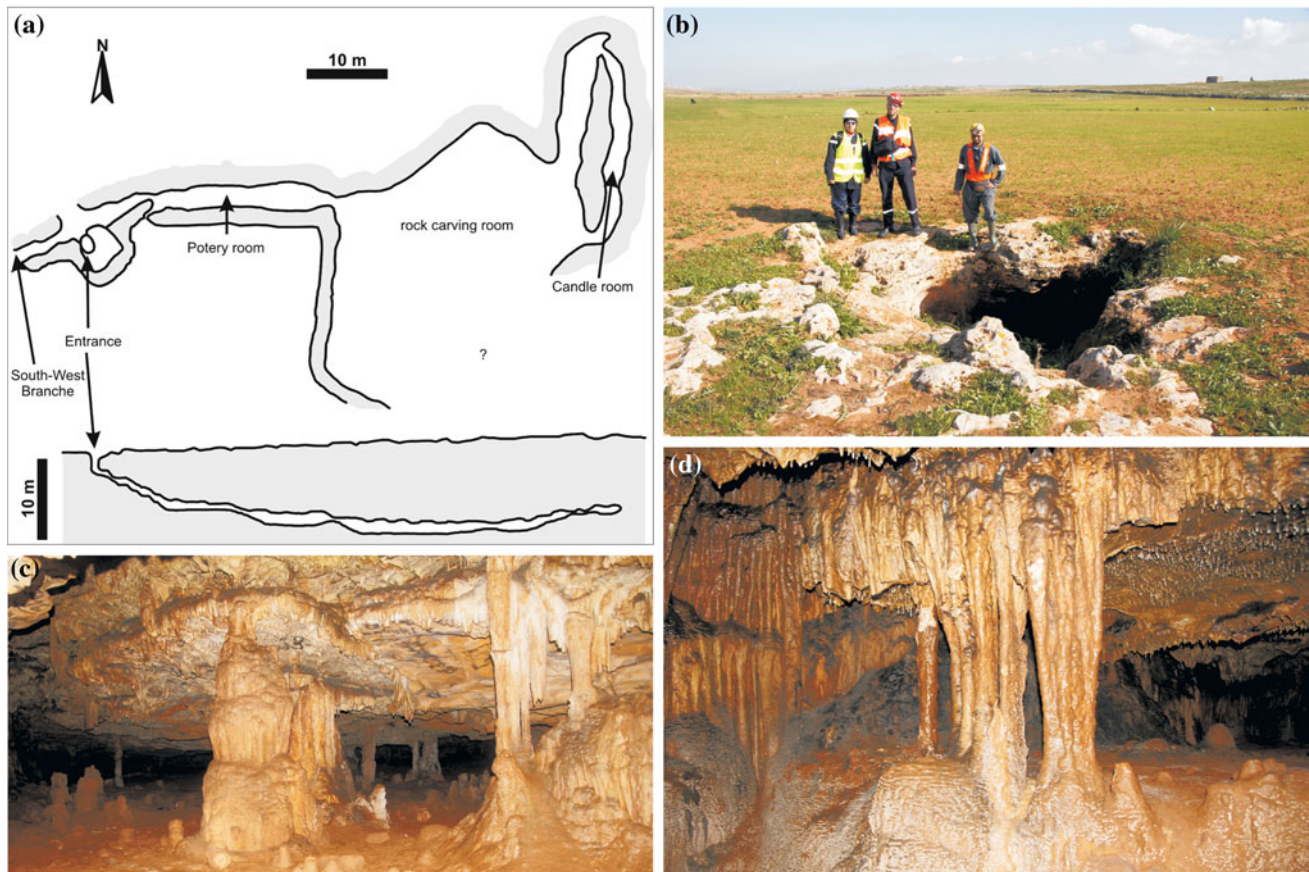
*El Goraan*: El Goraan is a deep cave with an entrance about 2 m in diameter (Fig. 8a, b). It consists of several chambers and branching tunnels, some of which have been investigated, while others are still unexplored (Boualla and Mehdi 2011). The cave's interior reveals splendid stalactites, stalagmites, draperies, eccentrics and pillars, all of which reflect long-term dissolution of the limestones (Fig. 8c, d). Some rock carvings featuring boomerangs and arrowheads have been discovered, as well diverse pottery fragments, as yet unstudied, indicating that the cave was used as a human refuge.

*El Khenzira*: It is one of the most studied deep and natural caves (Ouada and Aberkan 1992; Ouadia et al. 1993). It has yielded man-made tools attributed to the Aterian, again witnessing the use of the cave as shelter for prehistoric humans (Ruhlmann 1936).

*Oualidia*: At least three caves are natural and result from marine erosion. They are only accessible at low tide (Fig. 9). Recently, they have been subject to many changes made by visitors, such as the construction of additional window-like openings to the sea. In addition to the sea caves, several shelters under overhanging rocks are visible along the escarpments around Oualidia village. These have been used, as shelters and watchtowers, by sailors and soldiers who have haunted the coast, certainly since the Phoenician period (Ouada et al. 2008).

The great diversity of the karstic features in this area is of high scientific value. The study of their forms and the nature of the caves and, importantly, their contents helps to reconstruct the palaeoclimatic, palaeoenvironmental and geomorphological evolution of the region during the Quaternary (Ouada et al. 2008). Furthermore, the discoveries of rock carvings and man-made tools reveal that the caves have been used by human beings since prehistoric times, demonstrating their archeological importance (Ruhlmann 1936; Ouadia et al. 2008).

A multidisciplinary study of the caves would provide yet more information about their mode of formation and their use, and, again, would help to raise awareness of their value and the need for their protection. In addition, such studies would assist in the development of their tourist potential and thereby contribute to local development and the local economy. For many years the Doukkala-Abda region has



**Fig. 8** a Simplified sketch and longitudinal section of the eastern branch of the El Goraan cave in Beddouza headland. b The entrance to

the cave. c, d Diverse stalactitic and stalagmite structures, resulting from ground-water flow



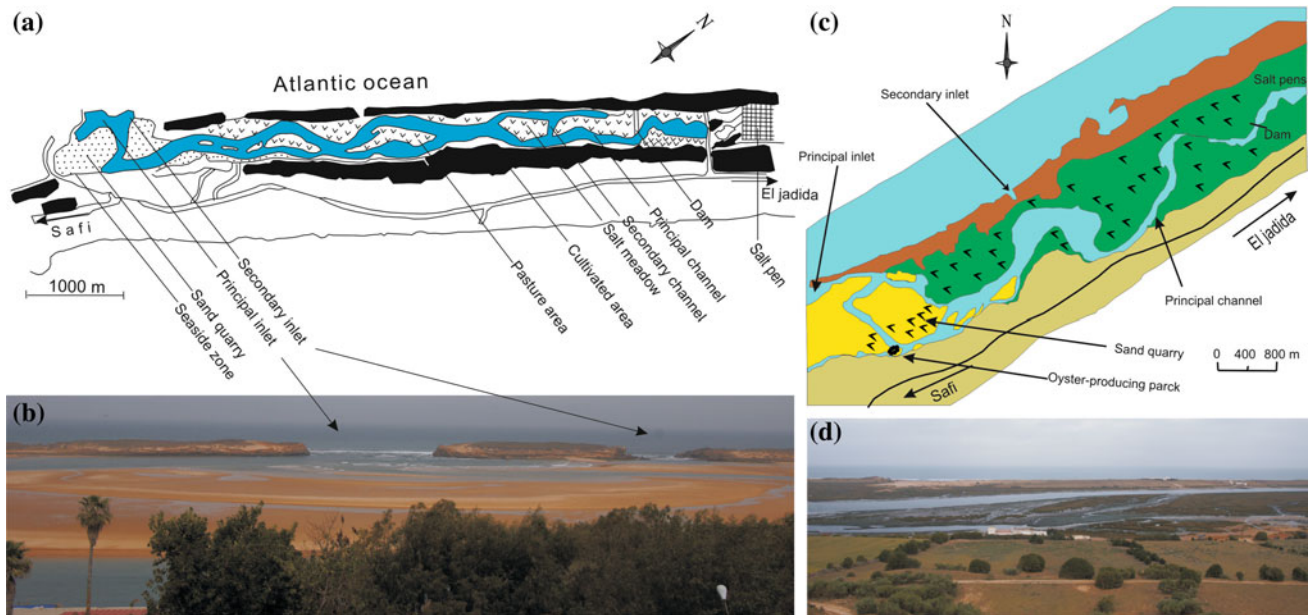
**Fig. 9** Oualidia cave of marine origin, modified by human activities

also been well known for the instability and subsidence of its substrate, leaving the coastal escarpments vulnerable to collapse. A detailed study of the area is considered necessary, in order to minimize the consequences of any such collapse which would impact on the local inhabitants and infrastructure.

## 3.2 Ecological Geosites

### 3.2.1 Wetlands: Sidi Moussa—Oualidia Lagoon Complex

The region, situated along the Atlantic coast, is well known for its wetlands, which are resources with a rich biodiversity. Covering an area of approximately 10,000 ha, the Oualidia and Sidi Moussa lagoons were classified as a *Ramsar* site in 2005, and as a Site of Biological and Ecological Interest (SIBE) (Fig. 10). These ecosystems are relatively rich in endemic species and represent important breeding and wintering sites as well as a stopover area for hundreds of thousands of migratory birds. Several rare or endangered species at risk of extinction, such as the *Black-winged Stilt*, are resident here: The lagoons are the only site of international importance for the *Black-winged Stilt* in Morocco (El Hamoumi et al. 2000; El Hamoumi and Dakki 2010; Benajah et al. 2010), and the wetlands play a key role in maintaining the ecological balance of most ecosystems, in addition to the important socio-economic benefits they bring to the surrounding areas, especially through tourism.



**Fig. 10** a Morphological map of Oualidia lagoon; b Oualidia lagoon's principal channel, with primary and secondary tidal inlet. c Morphological map of Sidi Moussa lagoon. d Sidi Moussa lagoon's principal and secondary channels

The geology of the Oualidia lagoon (Fig. 10a, b) consists of clayey sands, sandstones and calcareous and marl formations of Late Jurassic age, overlain by Plio-Quaternary consolidated dunes (Canérot et al. 1982; Taj-Eddine et al. 1985; Witam 1988; Ouadia 1998; Fakir 2001). The numerous geological, ecological and biological investigations made of this lagoon reflect its regional and global importance. Furthermore, it is one of the few sites in Morocco where traditional oyster cultivation has been developed since the 1950s. The lagoon is characterized by special species such as *Chondrus crispus*, *Palmaria palmata*, *Sacchoriza polyschides*, *Enteromorpha crista* and *Ulva linza* (Farid et al. 2009). The variety of species is influenced by environmental factors, such as substratum, water temperature, light, wave action, salinity and pH (Fang et al. 1996).

The Sidi Moussa lagoon (Fig. 10c, d) is a marginal system with a significant marine influence. It is classified in the semi-arid range (Atillah 1994), and is characterized by warm temperate climate (Maanan 2003). Geomorphologically, it consists of a depression resulting from the post-Ouljian regression (Quaternary) (Bidet and Carruesco 1982; Carruesco 1989). It is biologically rich, comprising a variety of fish exhibiting seasonal variability (sole, bar, etc.) and several invertebrates such as decapods, isopods, cnidarians, gastropods and bivalves (Bennouna 1999). Fishing is one of the important activities in this area, but it is still traditional and seasonal.

The Sidi Moussa-Oualidia lagoon complex has an exceptionally rich and diverse heritage as it performs several ecological functions such as: control and self-purification of

water, protection against floods, organic production, special biotope of bird species for nesting and breeding with high heritage value (migratory birds), and growth of a remarkable flora (Hammada 2007). Moreover, it is a field-area for palaeoclimatic and climatic studies, drawing upon evidence of historical weather events preserved in the fine-grained sediments.

These wetlands are, however, subject to conflicts of interest between the economy and ecology (Guo and Ma 2008). The protection of bird species is dependent on the protection of their wetland habitats. Without adequate conservation measures, these stopover sites may become the weak link in the chain of migration, which, if broken, will probably result in the extinction of the wild bird populations that depend on them (Higuchi 1991). Consequently, the preservation of this heritage will contribute to improvements in the quality of life of the local population. Due to anthropogenic pressures, the wetland areas are at risk (drying, salt-water intrusion in the coastal border, over-exploitation of marine organisms, and destruction of natural barriers (sand dunes etc.). Accordingly, a better understanding of these ecosystems is necessary to improve and rationalize their management in order to preserve them against environmental threats. In fact, conflicts of interests between the use of the wetlands and ecosystem protection need careful evaluation to contribute in the local development.

### 3.2.2 Zima Lake

The Zima Lake is a salt wetland of 600 ha (Fig. 11). It has a high ecological potential and is classified as a *Ramsar* site,

**Fig. 11** Panoramic view of Zima lake with drain water channel, vegetation and salt deposit



as a site of biological and ecological interest (SIBE), and as a reserve where hunting is strictly forbidden.

Geologically, the Zima Lake is located in sandstones in the core of a Palaeozoic syncline. These sandstone beds are overlain by Permo-Triassic deposits which consist of red sandstone and marl with salt intercalations, succeeded by Late Jurassic and Cretaceous sedimentary rocks, predominantly marls and marly-limestones with gypsum intrusions. The sequence is completed by various Quaternary deposits, saline silts, sands, conglomerates, gravels and calcretes. The surrounding soils are carbonated humus, very dark, sometimes red (El Mokhtar et al. 2012).

The area is characterized by low rainfalls (150–200 mm), a very high evaporation (876 mm in 1993–1994) and a Mediterranean arid to temperate winter climate.

The entire wetland is surrounded by a belt of halophytic vegetation covered by a thick layer of filamentous algae and angiosperms *Potamogeton pectinatus* providing great floristic richness (Negre 1960; Abbad 1993). More than thirty species of plants have been documented at this locality including *Aeluropus littoralis*, *Agrostis stolonifera*, *Arthrocnemum indicum*, and *A. halimus*, among others. Moreover, the Lake supports many species adapted to hypersaline seasonal wetlands, including two rare endemic plants, species of Caryophyllales (Angiosperms): *Halopelis amplicauli* and *Spergularia tenuifolia*.

This site also has great ornithological value, for both wintering and breeding. It hosts abundant aquatic birds: 99,000 during wet years and an average of 3,860 birds during the period from 1996 to 2000 (Radi et al. 2004; Thévenot et al. 2003). Furthermore, this vast wetland could

become one of the most important areas in Morocco for avifauna which includes *Gull-billed Tern*, *Kentish Plover*, *Black-winged Stilt* and *White Stork*, if it were to benefit from even a minimum of protection. More than forty species of birds have been recorded in the salt sabkha, with a maximum number of 3000 birds recorded during the last 12 years, including approximately 1,000 *Pink Flamingo* and 2,000 *Anseriform* birds with at least two interesting species, *Shelduck* and *Marbled Teal*, as well as *Shoveller*, *Northern Pintail* and *Ruddy Shelduck*. The lake is home to several threatened and vulnerable bird species listed on the Red List of the International Union for Conservation of Nature, such as: *Marbled teal Marmaronetta angustirostris* and *Ruddy Shelduck Tadorna ferruginea*, *Greater Flamingo Phoenicopterus ruber*, *Shelduck* and *Tadorna tadorna*; and some protected species in France that are listed in category A2 of the Agreement on migratory birds of African-Eurasian Migratory Water-birds (AEWA), such as *Sterne Hansel*, *Sterna nilotica* (Radi et al. 2004; Thévenot et al. 2003).

The Zima Lake is known for its salt deposits, and is considered one of the most important continental salt sources in Doukkala-Abda region, with an annual production of 30,000 tons. The salt derives from sub-surface saline flows at shallow depth, migrating from the ground-water of the Chemaia plain (El Mokhtar et al. 2012). Extraction of the salt, for use by the food-industries, is undertaken by the Cherifian Society of Salt (SCS) that provides jobs for fifty workers from the surrounding villages.

The lake area supports, particularly, pastoral agriculture, and possesses high aesthetic and recreational value, which could be better promoted to encourage recreational activities.

However, the preservation of this rich biodiversity and enhancing recognition of its value is an indispensable preliminary step towards the sustainable development of geotourism, especially ecotourism.

#### 4 Technical Geosites: The Mining Heritage of Doukkala-Abda

The mineral potential of the Doukkala-Abda region is significant and well known. The main deposits are the phosphates of the Ganntour basin, which represent 37 % of the national reserves (Annual Report of the Chérifian Office of Phosphates 2011), the barite deposits worked at Jbel Irhoud, the gypsum vein deposits of the Chemmaia basin, and the Zima Lake salt deposits.

We focus here only on the Ganntour sedimentary phosphate deposit, because it is Morocco's most important mineral resource. The Ganntour basin deposit underlies an area of approximately 125 km in length, 15 km in width and oriented E-W. The reserves are estimated to be 2 billion m<sup>3</sup> (*Official website of the Cherifian Office of Phosphate (OCP)*).

The phosphates were deposited during the Late Cretaceous (Maastrichtian) to Early Eocene (Early Lutetian) interval (Noubhani 1993). The sedimentary rocks that host the deposits are also some of the country's richest in fossils, yielding many marine varieties and, occasionally, as in the Ouled Abdoun basin, well-preserved continental vertebrate remains. Apart from Selachian (sharks, rays) teeth, which are the most abundant and diversified fauna (see below), they contain bony fishes, marine reptiles including plesiosaurs, mosasaurs, crocodiles, as well as terrestrial sauropods and mammals (the oldest proboscideans) (Bardet et al. in press). The Ganntour basin has provided 138 species of Selachians, including species identified here for the first time and which are exclusive to this basin. They include *Ginglymostoma erramii*, *Ginglymostoma botmaense*, *Plicatoscyllium gharbii*, and *Fountizia gadaensis* (Noubhani 1993; Noubhani and Cappetta 1997).

In the framework of the OCP Group's recent ecological and sustainable development strategy, some of the phosphate deposits merit formal declaration as geoparks (Noubhani 2011). The palaeontological wealth of the phosphate formations has, however, led the OCP Group to plan the establishment of a museum of palaeontology in the mining town of Khouribga, to display the fossils collected from the phosphate basins.

In this context the Gantour basin could also form part of the proposed thematic geotrail, linking key phosphate outcrops and industrial areas (extraction sites and treatment). A combined interpretative center and museum would assist to promote sustainable socio-economic activities in the region, cf. the museum planned for the Ouled Abdoun basin (Noubhani 2011).

#### 5 Discussion and Conclusions

An aspiring geopark region, the Doukkala-Abda is characterized by a varied and rich natural heritage, which includes geomorphological, geological and cultural features. Its biodiversity and geodiversity and significant geotourist potential offer the prospect of sustainable development cultural geotrails for both education and tourism. This will require full evaluation and, at present, the geoheritage component in particular is currently under-valued and poorly known by the local communities, visitors and policy makers. Indeed, visitors come, for the most part, during the summer holidays to enjoy the region's numerous and beautiful beaches. In order to stimulate their interest towards other kinds of activities, and to encourage them to learn more about the region they are visiting, appropriate methods need to be promoted, such as the creation of interpretative centers and information panels, and museums. Moreover, the development of instructional geotrails linking geosites in the coastal zone to those in hinterland will help to develop the region in a sustainable and holistic way, and will offer a new year round tourist product (Errami et al. 2013). This strategy will promote and benefit rural destinations situated in the hinterland of the region.

However, this process of evaluation and strategy development should include all the components of the region's heritage, not only the many sites and features of geological interest and value. For this reason, several mechanisms and measures are highly recommended:

- (1) The continued preparation and completion of detailed inventories of sites of high patrimonial significance through the creation of a GIS databases (Geographic/Geologic Information System database);
- (2) The promotion of geoheritage and its importance to society by offering organized field trips for not only scientists, but students, scholars, associations, the local people and the wider public, including tourists. Such activities could provide a source of entertainment and intellectual enrichment;
- (3) To increase awareness of the importance of natural, geographical, geological, and cultural heritages through the organization of cultural activities such as conferences, workshops, exhibitions, and use of 'the media' via local and national TV, publications radio and Internet based systems;
- (4) The creation of indicative and interpretative panels, interpretative centers, museums, and geotrails will help to emphasise the importance of valuing and conserving our regional heritage, and provide the opportunity to promote and develop our local products.
- (5) A closer link between the geosites outlined in this paper and the historical and cultural monuments of the

Doukkala-Abda region (e.g., the Portuguese city of Mazagan, a World Heritage Site), and also a link to the region's intangible heritage (e.g., falconry at Lakouassem, registered as an Oral and Intangible Heritage of Humanity), all three forming part of the process of promoting local sustainable tourism (e.g. Errami et al. 2013), would give strong support to the realisation of other geotourism projects.

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