

Journal of Chemical, Biological and Physical Sciences



An International Peer Review E-3 Journal of Sciences

Available online at www.jcbps.org

Section D: Environmental Sciences

CODEN (USA): JCBPAT

Research Article

From scientific inventory to socio-economic sustainable development: Tidzi Diapir geosite (Essaouira basin, Morocco)

T.Y. Arrad, E. Errami, N. Ennih

Equipe de Géodynamique, Géo-éducation et Patrimoine géologique, Département de Géologie, Faculté des Sciences, Université Chouaib Doukkali, El Jadida 24000, Maroc.

Received: 19 October 2018; **Revised:** 31 October 2018; **Accepted:** 10 November 2018

Abstract: Geology and geomorphology, called commonly geoheritage, play an important role in any sustainable development process. Moreover, a growing interest in the preservation and enhancement of geodiversity is attested by the proliferation of scientific research in this area. The present work concerns the geology of the Tidzi Diapir geosite that is a part of the inventory project of the geological and geomorphological heritage of Essaouira province. The approach used is inspired by the methodology developed by the IUGL, modified according to the need of the study. The results are stored in a database and visualized via interactive digital mapping. The goal is to develop an inventory that preserves geoheritage and promotes it as a lever for local socio-economic development through the creation of new income-generating activities through geotourism. This initiative is important in a region with a high unemployment, harsh natural conditions and impressive geodiversity.

Keywords: Geoheritage, geosite, inventory, promotion, diapir, Tidzi, Essaouira, Morocco.

INTRODUCTION

Geodiversity is defined as the set of geological objects present in a specific territory^{1, 2, 3}. The geological heritage concerns the most representative sites, because of the scientific importance of their geodiversity⁴.

Commonly called geosites, these portions of the geosphere provide information on the history of the Earth evolution.

The interest of the geoheritage lies not only in the fact that it should be protected and transmitted to future generations, but also in the opportunities that it could offer for local socio-economic development of the concerned area. Thus, the definition of geoheritage passes obligatorily by the establishment of a detailed and objective inventory. It is, in this perspective, that different inventory methodologies were performed¹⁻⁶. Several countries undertake their national geological inventory that allow them to protect and to valorize their geoheritage through the creation of geoparks and the development of new forms of tourism, namely geotourism⁷⁻¹⁰ and geoeducation^{11,12}.

Africa and the Middle East consist of a rich geodiversity, which is regrettably not well known by the public. This is due partly to limited research and studies undertaken in geoheritage and geoconservation in these parts of the world, especially those with intent to explore, inventory and valorize such inherent geodiversity¹³. To contribute to improving this situation, the Moroccan geoscientific communities are undertaking numerous studies related to geoheritage and its inventory, its assessment¹⁴, its valorization and its promotion in different regions in Morocco. As a part of the inventory project of the geological and geomorphological heritage of the Essaouira province, this article focuses on the geoheritage inventory and assessment of the Tidzi Diapir.

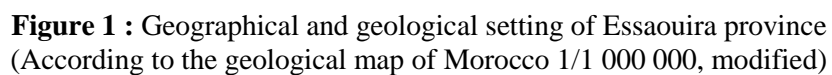
GEOGRAPHIC AND GEOLOGICAL SETTINGS

The Tidzi Diapir geosite is located 5 km north of Smimou village and 30 km south of Essaouira city (**Figure 1**). The climate is generally of temperate arid type and the precipitation is very irregular and does not exceed an average of 300 mm per year^{15, 16}.

This geosite consists of a complex and asymmetrical diapiric structure, formed since the birth of the Atlasic basin since the Triassic era¹⁷ and continues during the generalized Jurassic-Cretaceous subsidence phase that affected the passive Atlantic margin¹⁸⁻²⁰. The northern part of the diapir is oriented NNE-SSW, while its southern part is oriented E-W. Its geological and geomorphological configuration is unique throughout the Essaouira province.

Within the great Moroccan Atlantic Basin (BAM) that is extended from El Jadida city in the North to Dakhla city in the South, the Essaouira sedimentary basin is a key area for the understanding of the major Meso-Cenozoic geological events. The Tidzi Diapir that is situated in the Essaouira sedimentary basin is an essential site for the study of tectonic, halokinetic and sedimentary phenomena related to the opening of the Atlantic Ocean and to the Atlasic orogeny^{19,21}. It also helps to understand the fundamental role of the basement as a motor of the diapirism of the Triassic evaporites during the emplacement of the Atlantic margin during the Jurassic and Lower Cretaceous eras^{15, 22}.

The oldest rocks in the study area, exhumed by a network of deep faults bordering the diapir structure, are the Triassic syn-rift formations composed of doleritic basalt and red clays (-215 to -204 Ma)¹⁸ (**Figure 2**). The basic magmatic rocks, whose thickness sometimes reaches a hundred of meters, are deposited in superimposed flows and are much altered. They are tholeiitic basalts of grey-green color resulting from a fissural volcanism, linked to the beginning of the opening of the Atlantic Ocean in a distension setting. In some areas, the Triassic formations are uncomfortably covered by Late Jurassic formations, while in other areas they are covered uncomfortably by the Cretaceous series²⁴.



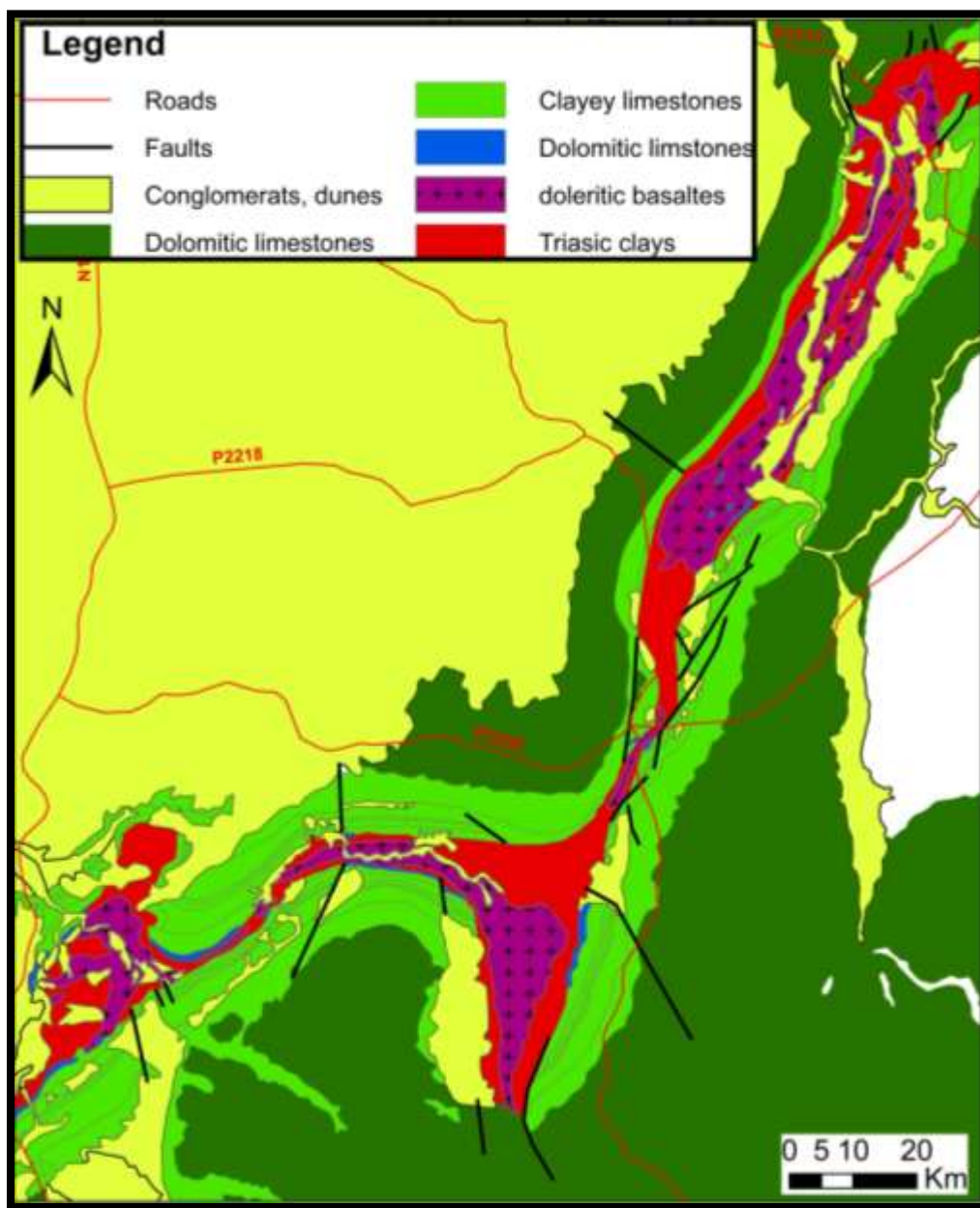


Figure 2 : Geological map of Tidzi diapir
(According to the geological map of Morocco 1/50 000, Tamanar sheet, modified)

The Upper Jurassic is represented by an alternation of dolomites, limestones and marls. The Cretaceous is mainly composed of limestones (clay, dolomitic), marl and red clayey sandstone²⁴. The quaternary is represented by consolidated colluviums and dunes (**figure 3**).

The cover, all around, shows a paleontological (Jurassic and especially lower Cretaceous formations) content quite rich and diversified composed of ammonites, brachiopods, Belemnites rostrums, echinoids, lamellibranchs, and a microfauna of foraminifers and ostracodes^{21,23-25}.

Figure 3: Cretaceous synthetic stratigraphic log of Tidzi diapir²⁶ (modified)

Ages	Formations	Lithologie
Pliocene	Akermoud dune sandstones	
Oligocene	Agadir conglomeratic sandstones	
Eocene	Sand and marl of Imi n'Tanout	
Maastrichian	Phosphated sands of Chichaoua Dolomitic limestones of Tagragra	
Senonian	Oued Lahouar marls	
	Limestone and marl from Ait Abbas	
	Limestones and dolomitic marls of Anou Nfeg	
Turonian	Casbah d'Agadir limestones	
Cenomanian	Ait Lamine marls	
Vraconian	Kechoula dolomitic limestones	
Albian	Oued Tidzi marls	
Barremian	Sandstones and limestone marls of Tamzergout	
Hauterivian	Talmest Marls and sandstones	
	Tamanar reef limestones	
	Sidi Lhoussine marls	
Valanginian	Agroud Ouader marly limestones	

ECOLOGY

Ecologically, the Argan tree (*Argania spinosa*), which is an endemic and emblematic tree of the region, plays a leading local role in the process of sustainable socio-economic development. Thus, it is protected within the framework of the Arganeraie Biosphere Reserve, as a part of Man and Biosphere Programme (MAB) which is an intergovernmental scientific programme that aims to establish a scientific basis for the improvement of relationships between people and their environments. It represents a source of income for the local communities who have structured themselves into women's associations and cooperatives for the extraction and transformation of the fruit into Argan oil and other cosmetic products, with the aim of

encouraging the empowerment of the Amazigh woman, considered the guardian of the ancestral know-how of the Argan tree.

METHODOLOGY

Before the geodiversity inventory, the objectives of the methodology should be defined in any geoheritage-making process⁴. This will allow an assessment that makes it possible to compare the geosites between them on a well-defined basis, depending on the main objective. If this latter is to preserve the most important elements of the geodiversity, then only the geosites with high scientific value should be selected. On the other hand, if the goal is to protect or promote the geodiversity, then all geosites should be taken into account. The close relationship between geodiversity and the immediate environment (culture, aesthetics, ecology ...) should be included in the evaluation and selection process of the geosites.

To inventory and evaluate the geoheritage importance of the Tidzi diapir geosite, we adopt the Reynard *et al.*^{5,6} methodology, developed at the Institute of Geography of Lausanne University (IUGL). This methodology considers the scientific value as a central value, defined by four criteria: integrity, representativeness, rarity and palaeogeographic value. While the additional values (ecological, aesthetic and cultural) are essential supplements of the global value. A set of criteria makes it possible to evaluate quantitatively and qualitatively each of the values considered^{27,28}.

However, this relevant, reproducible and objective methodology is particularly relevant to geomorphological phenomena. It was designed to inventory and assess landforms according to their setting context and the available landscape data, while retaining the possibility of adapting it to the assessment of other types of geosites⁶. Thus, we will use in this work the term geosite for the geomorphosites and the geosites.

The overall procedure follows the same plan as the IUGL methodology, which focuses on two phases: inventory and management (**Figure 4**).

- The inventory data are included in the standard inventory forms that include the presentation, description and assessment of each site of interest. Composed of 6 central sections (General data, description and morphogenesis, scientific value, additional values, synthesis, bibliographic references), each sheet highlights the major assets of the site.
- The evaluation of intrinsic values (scientific and additional) is performed qualitatively and quantitatively. The assignment of scores, in increments of 0.25, ranging from 0 to 1 to the different parameters allows having a global value relative to each geosite (**table 1**).
- The evaluation of usage and management characteristics is done qualitatively.
- The elaboration of a descriptive summary (global value, current use, and preservation and promotion measures) makes it possible to have a global idea on the site.

In this paper, we consider the Tidzi Diapir as a primary geosite that has been declined to 14 secondary geosites. The primary and the secondary geosites are evaluated separately and the mean values of all secondary geosites will be compared to the value obtained directly from the primary geosite.

The management of the geosites will be done based on the proposed strategy of protection and promotion taken in consideration the results of the evaluation. This management will determine the proposed use for each geosite.

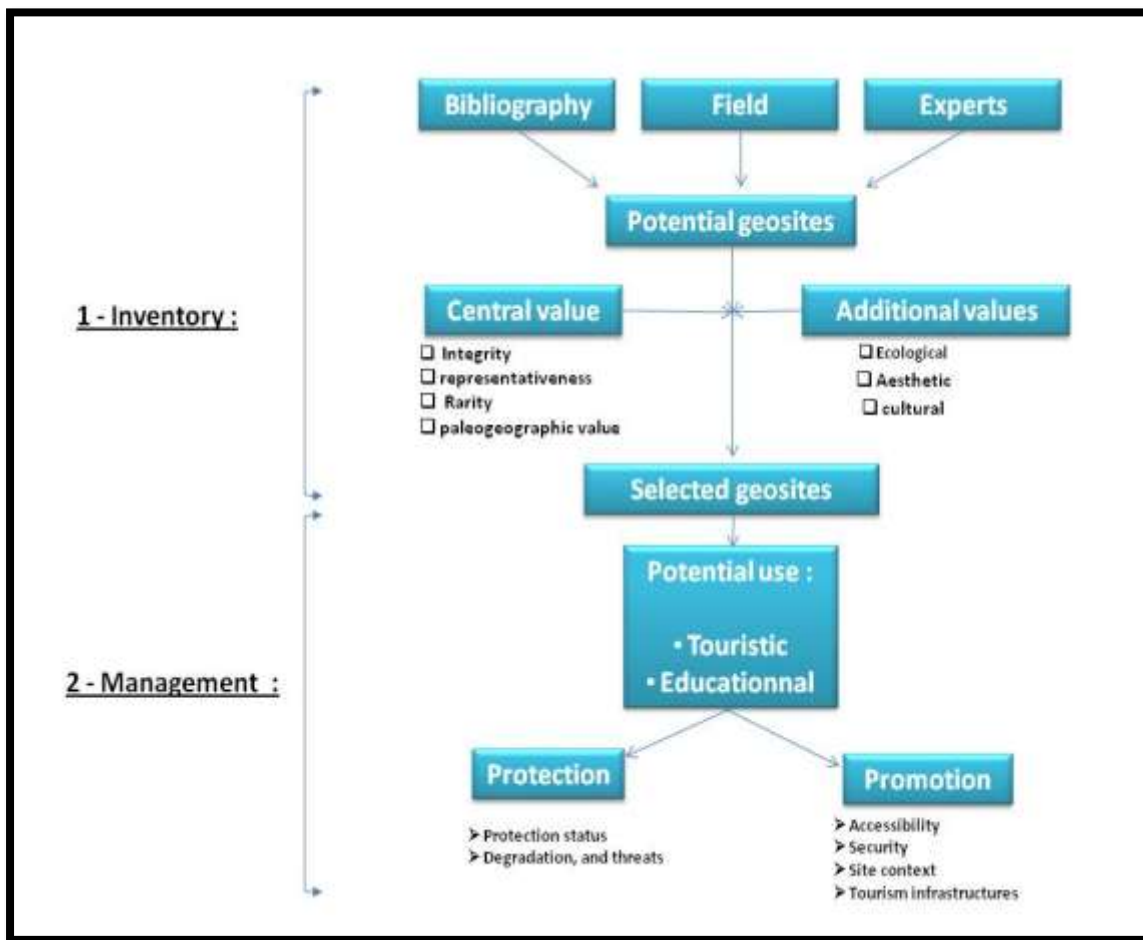


Figure 4: Inventory methodology proposed by Reynard^{5,6} (modified)

Table 1: Parameters for quantitative evaluation of the geosites values ⁶

Scientific value	$(\text{Integrity} + \text{Representativeness} + \text{Rarity} + \text{Paleogeographic Value}) / 4$
Ecological value	$(\text{Ecological Influence} + \text{Protected Site}) / 2$
Aesthetic value	$(\text{Point of view} + \text{Landscape effect}) / 2$
Cultural value	The highest score of the 5 criteria is retained (historical, artistic, economic, religious, geohistorical)

RESULTS

The inventory leads to the identification of 14 secondary geosites within the Tidzi Diapir primary geosite (**Figure 5**). The results of the quantitative assessment of their scientific values are presented in **table 2**. The mean scientific value of the secondary geosites has been assigned to the Tidzi Diapir primary geosite. We conclude that the Tidzi Diapir primary geosite have a high scientific value (0,75).

The results of the assessment of the additional values of the primary and secondary geosites are given in **table 3**. Their mean values are assigned to the Tidzi Diapir primary geosite, that are 0.45 for the aesthetic value, 0.13 for the ecological value and 0.14 for the cultural value.

In a global approach of assessment, Tidzi Diapir geosite scientific value scored 1 and its additional values scored 1. Those values are higher, when compared with the values given to Tidzi Diapir primary geosite.

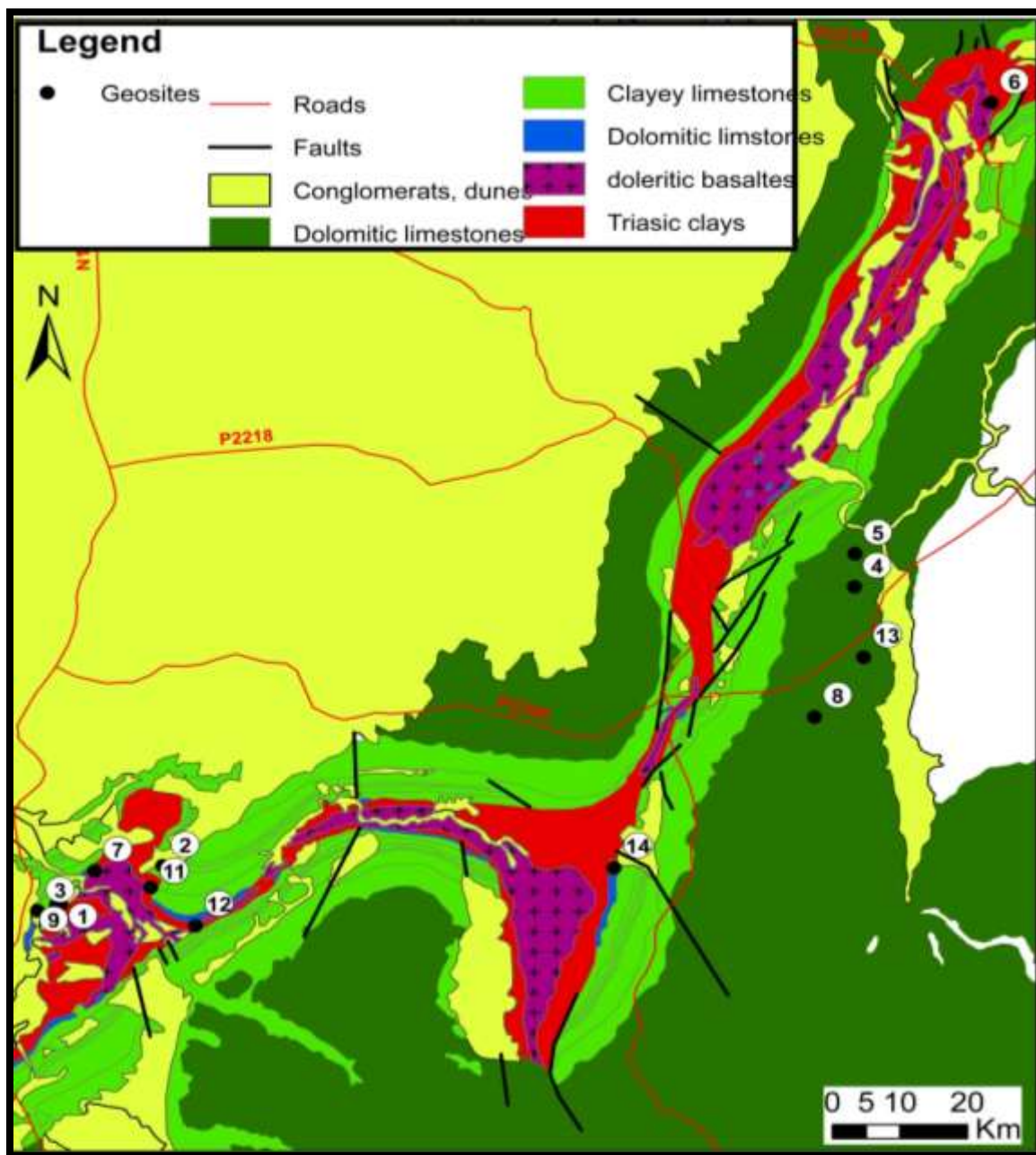


Figure 5: Tidzi diapir primary and secondary geosites

Table 2 : The quantitative assessment of the secondary geosites scientific value

Code	Description	Type	Scientific value				
			Integ.	Repre.	Rari.	Pal.V	Total
TID-sed-1	Cretaceous lumachellous limestone	Sedimentological & Paleontological	0,75	1	0,25	1	0,75
TID-sed-2	Cretaceous marly limestone with thalassinoids	Sedimentological & Paleontological	1	1	0,75	1	0,9375
TID-pal-3	Terrier in cretaceous limestones	Paleontological	0,75	1	0,25	1	0,75
TID-strat-4	Turonian escarpment	Stratigraphic	1	1	1	1	1
TID-sed-5	Alternation of marl and chalky limestone with spectacular flint nodules	Sedimentological	1	1	0,75	1	0,9375
TID- str-6	Subverticalized Triassic doleritic basalts in contact with red clays	Structural	1	1	0,75	1	0,9375
TID-str-7	Tectonic contact between the Triassic and cretaceous formations	Structural	1	0,75	0,5	1	0,8125
TID- str-8	Verticalized Triassic and Jurassic formations unconformably covered by Quaternary deposits	Structural	1	1	0,75	1	0,9375
TID-str-9	Verticalized Cretaceous formations covered unformably by the Quaternary formation	Structural	0,75	1	0,5	1	0,8125
TID- sed-10	Quaternary fluvial conglomerate	Sedimentological	0,5	1	0,25	1	0,687
TID-gmr-11	Effects of fluvial erosion on Triassic red clays	Geomorphological	0,75	0,75	0,25	1	0,687

TID-sed-12	Salt deposit	Sedimentological	0,5	0,75	0,25	0,5	0,5
TID- gmr-13	Cave of Imi N'Taquendout, place of worship for the Haha tribes. It hosts a sacred water source used for their therapeutic virtues.	Geomorphological, Hydrogeological & Cultural.	0,25	1	1	1	0,8125
TID-cult-14	Caid Neknafi Kasbah, an architectural beauty in ruins. It occupies a high position that dominates the area	Cultural	0	0	0	0	0
Values based on the mean values of the secondary geosites							
TID-gmr-0	Tidzi Diapir primary geosites	Geomorphological	0.73	0.88	0.46	0.89	0,75
Values based on a holistic assessment of the Tidzi diapir primary geosite							
Tidzi geosite	Tidzi Diapir geosite	Geomorphological	1	1	1	1	1

Table 3: The quantitative assessment of the additional values

<u>Code</u>	<u>Types</u>		Additional values		
			Aesthetic value	Ecological value	Cultural value
Secondary geosites					
TID-pal-1	Sedimentological & Paleontological		0,25	0	0
TID-sed-2	Sedimentological & Paleontological		0,25	0	0
TID-pal-3	Paleontological		0,25	0	0
TID-strat-4	Stratigraphic		0,25	0	0
TID-strat-5	Stratigraphic, Sedimentological		0,25	0	0
TID-str-6	Structural		0,5	0,75	0
TID-str-7	Structural.		0,5	0,25	0
TID-str-8	Structural		1	0,75	0
TID-str-9	Structural		0,5	0	0
TID-sed-10	Sedimentological		0,25	0	0
TID-gmr-11	Geomorphological		0,25	0	0
TID-sed-12	Sedimentological		0,25	0	0
TID-gmr-13	Geomorphological, Cultural	Hydrogeological,	0,75	0	1
TID-cult-14	Cultural		1	0	1
Mean values of the secondary geosites			0,45	0,13	0,14
Values based on a the mean values of the secondary geosites					
TID-gmr-0	Geomorphological		0,45	0,13	0,14
Values based on a holistic assessment of the Tidzi diapir primary geosite					
Tidzi geosite	Geomorphological		1	1	1

The graphical analysis of the scientific and the additional values of Tidzi Diapir primary and secondary geosites are given in **Figure 6**. The first statement is that the scientific values of the assessed secondary geosites are in general much more important than their additional values. However, an exception has been noted for the cultural geosites that show higher cultural and aesthetic values. The second observation is that almost all the secondary geosites have a higher scientific value than the average, which is of 0.5. In opposition, the additional values of the majority of the secondary geosites are lower than the average, which is of 0.5.

Yet, when the Tidzi Diapir primary geosite is assessed independently, its scientific and additional values scored 1. When its values are deduced from the mean values of the secondary geosites, they scored respectively 0,75 for the scientific values and 0.45 for the aesthetic value, 0.13 for the ecological value and 0.14 for the cultural value. This allows us to conclude that the holistic and hierarchical assessments give different results. Accordingly, taking into consideration that a geosite can host one or more secondary geosites, the scientific and additional values of the primary geosite are more accurate when assessed hierarchically. This hierarchy based assessment seems to be an objective way to evaluate such geosites.

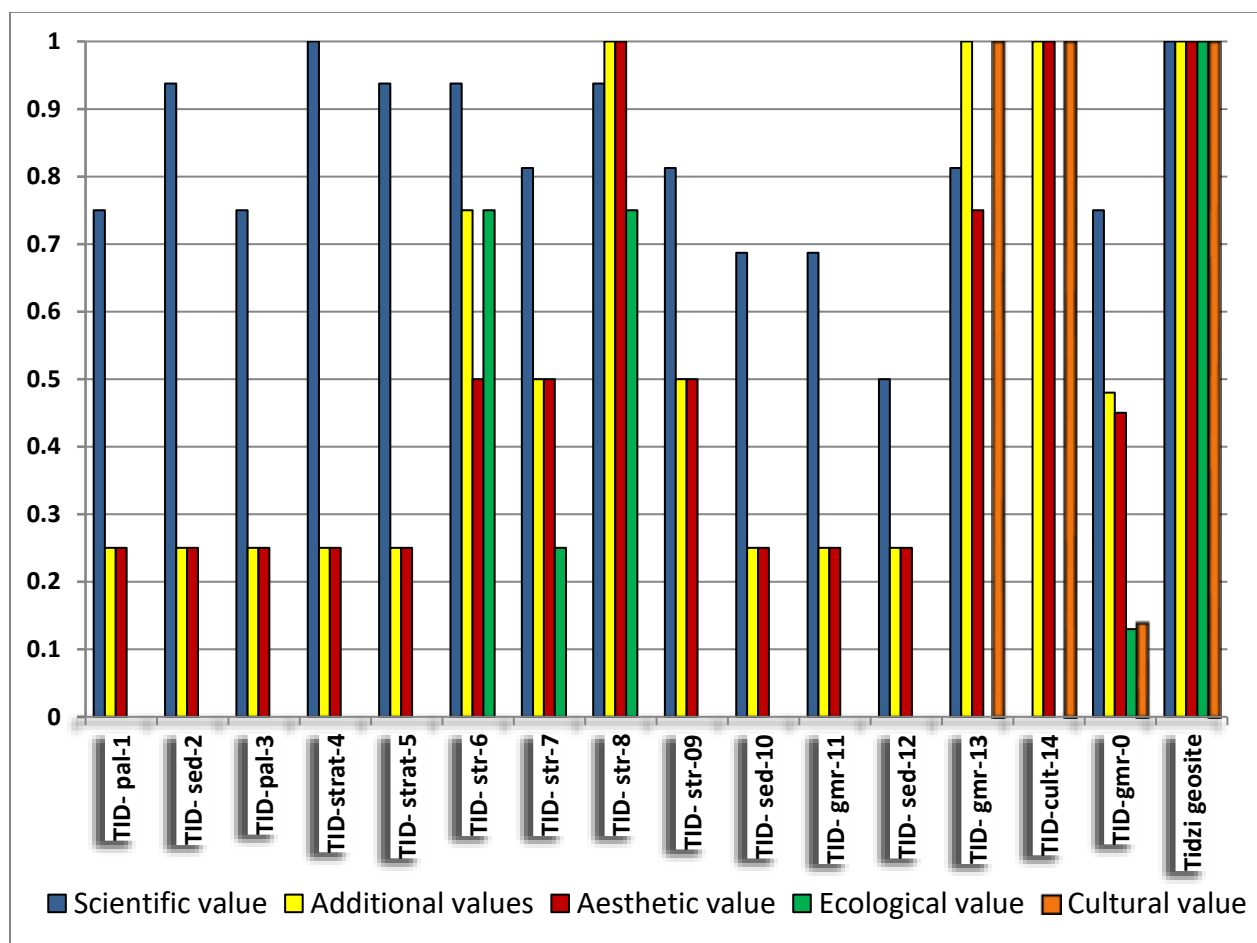


Figure 6: Comparison of the scientific and the additional values of primary and secondary geosites

The qualitative assessment, of the potential uses of the primary and secondary geosites, is given in **table 4**. Because of their important scientific value they are more suitable for a geopromotion based on research and geoeeducational activities.

After identifying all points of interest of Tidzi diapir primary geosite (**figure 7**), the protection needs of each geosite were defined according to the conservation status parameters and the current degradation anthropogenic and natural threats. Proposals for promotion are advanced according to the main assets of each geosite. The assessment of their need of protection shows how geoconservation actions should be taken urgently to protect this geoheritage before using it in geotourism development.

Table 4 : Qualitative assessment of potential use of all geosites

Code	Primary value	Need of protection	Promotion
TID-pal-1	Scientific	High	Research & Earth Science education
TID-sed-2	Scientific	High	Research & Earth Science education
TID-pal-3	Scientific	Middle	Research & Earth Science education
TID-strat-4	Scientific	High	Research & Earth Science education
TID-strat-5	Scientist	Middle	Research & Earth Science education
TID-str-6	Scientist	Low	Research & Earth Science education
TID-str-7	Scientific	High	Research & Earth Science education
TID-str-8	Scientist	High	Research & Earth Science education
TID-str-9	Scientific	Middle	Research & Earth Science education
TID-sed-10	Scientific	Middle	Research & Earth Science education
TID-gmr-11	Scientific	Middle	Earth Science education
TID-sed-12	Scientific & economic	Middle	Earth Science education & Geotourism
TID-gmr-13	Scientific & cultural	Urgent	Geotourism
TID-cult-14	Cultural & aesthetic	Urgent	Geotourism
Statements based on a holistic assessment of the Tidzi diapir primary geosite			
TID-gmr-0	Scientific & economic	Middle	Geotourism, Earth Science education & Research

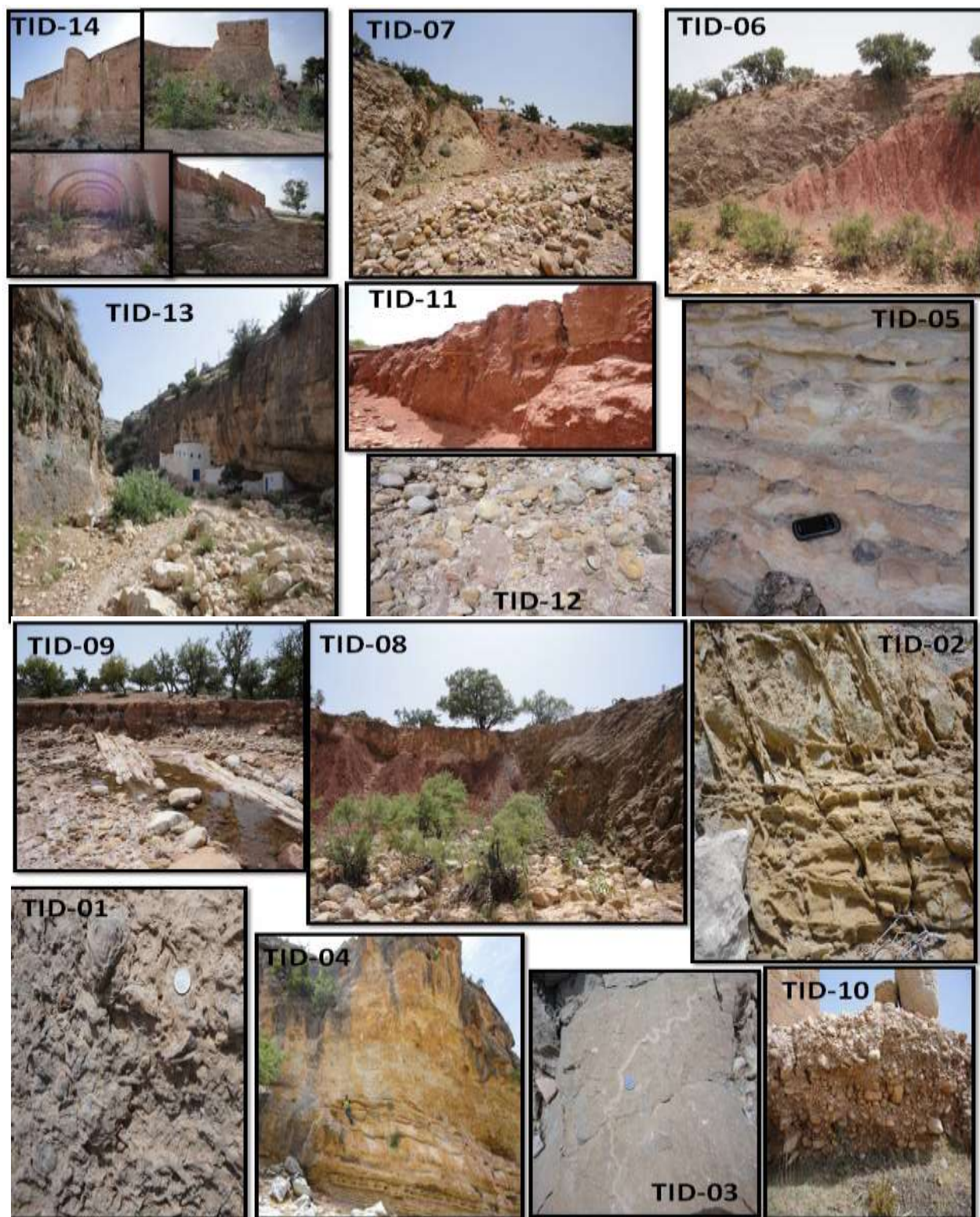


Figure 7: Some pictures of the secondary geosites

CONCLUSION

The inventory and assessment of the geoh heritage components of Tidzi Diapir primary geosite show its scientific, ecologic, aesthetic or cultural importance. It represents an important site for the study and the understanding of the geological and geomorphological evolution of Essaouira basin. The additional values of this geosite make it possible to highlight the relationship between the geology and the natural and human environment. The latter deserves to be valued in the context of the promotion of a sustainable tourism namely ecotourism using already established action plans within Arganeraie Biosphere Reserve and geotourism by developing new attractive products (museums, thematic collections geotours, geosports, geofood...etc). These will create new job opportunities for local population.

The different stakeholders of the region (associations, administrations, cooperatives, local communities, tourism stakeholders, academics ...) are all concerned by the establishment of a legal framework to protect and promote the geoh heritage of the studied area that constitutes the support of the biodiversity that is making the attractiveness of the area. As a first step, it is important to introduce the geoh heritage in the educational curricula of schools based in the area.

It should be noted, however, that this inventory is not exhaustive. Indeed, it remains open to include all geological or geomorphological features of importance to Earth sciences.

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Corresponding author: T.Y. Arrad,

Equipe de Géodynamique, Géo-éducation et Patrimoine géologique,
Département de Géologie, Faculté des Sciences, Université Chouaib Doukkali, El Jadida, Maroc.

Online publication Date: 10.11.2018