The Geoheritage of Kerdous Inlier (Western Anti-Atlas, Morocco): Pages of Earth History in an Outstanding Landscape

La géologie: de l'Antiquité à nos jours Le géopatrimoine et la géoconservation, cas de la Grande-Bretagne

جيوتراث عروة "كردوس" (غرب الأطلس الصغير- المغرب) : صفحات من تاريخ الأرض في مشهد طبيعي استثنائي

E. Druguet, A. Rahimi, J. Carreras, L.M. Castaño, and I. Sánchez-Sorribes

Abstract

The Kerdous massif (Anti-Atlas of Morocco) consists of outstanding geological features and landscapes, such as many fascinating erosion landforms. Moreover, the outcropping rocks in the area comprise a unique record of multiple processes in the Earth geological evolution. The first list, resulting of the preliminary inventory of the most relevant and representative geosites in the region includes four large zones of exceptional value. These are the granite landforms of Tafraoute (south of Tafraoute village), the Ameln valley (north of Tafraoute), the Aït-Mansour gorges (southeast of Tafraoute) and the Izerbi plain (south of the Kerdous inlier). Their features make the Kerdous area worthy of conservation as a natural-cultural site deserving a Global Geopark status. The protection of these geosites is compatible with their use as a cultural resource. Geoheritage-based tourism activities could be promoted under an appropriate management plan based on geoeducation and geoconservation.

Résumé

Le massif de Kerdous (Anti-Atlas, Maroc) est caractérisé par une importante géodiversité due à sa structure géologique complexe et aux reliefs et paysages exceptionnels qui lui sont associés. Dans cette région, un grand nombre de sites géomorphologiques et géologiques offrent un potentiel, très important et unique dans son genre au Maroc, pour des usages scientifiques, éducatifs et touristiques. La première liste résultant de l'inventaire préliminaire-des géosites les plus pertinents et les plus représentatifs de la région, inclut quatre grandes zones les plus remarquables. Il s'agit de Tafraout connue par ses curieuses et impressionnantes formes modelées dans le granite rose, la vallée d'Ameln et ses paysages pittoresques, les gorges d'Ait Mansour et la plaine d'Ait Ouafka-Izerbi. A ces paysages magnifiques, il faut ajouter d'autres patrimoines d'intérêt particulier du point de vue archéologique (gravures sur

An erratum to this chapter can be found under DOI 10.1007/978-3-319-10708-0_19

E. Druguet (✉) · J. Carreras · L.M. Castaño · I. Sánchez-Sorribes
Departament de Geologia, Universitat Autònoma de Barcelona, 08193 Bellaterra (Barcelona), Spain
e-mail: elena.druguet@uab.cat

A. Rahimi
Faculté des Sciences d'el Jadida, Université Chouaib Doukali, 24000 El Jadida, Morocco

E. Errami et al. (eds.), *From Geoheritage to Geoparks*, Geoheritage, Geoparks and Geotourism, DOI 10.1007/978-3-319-10708-0_5

les rochers), architectural, écologique, historique et culturel. La protection de ces géosites est compatible avec leur utilisation comme une ressource culturelle. Les activités touristiques basées sur le géopatrimoine pourraient être promues dans la cadre d'un plan de gestion approprié basé sur l'éducation et la géoconservation.

ملخص

تتميز عروة " كردوس"، المتواجدة بالأطلس الصغير – المغرب، بجيوتنوع هام وذلك راجع إلى بنيتها الجيولوجية المعقدة والتضاريس والمناظر الطبيعية الخلابة المرتبطة بها.في هذه المنطقة تمنح العديد من المواقع الجيومورفولوجية والجيولوجية مؤهلات هامة وفريدة من نوعها بالمغرب، لأغراض علمية، تربوية وسياحية. القائمة الأولى، الناتجة على الجرد الأوليلأهم الجيومواقع، مَكّنَت من تسليط الضوء على أربعة مناطق الأكثر أهمية.يتعلق الأمر بـ " تافراوت" المعروفة بجرانيتها الوردي المنحوث على أشكال مثيرة للإعجاب، وادي " املن" ومناظره الطبيعية الخلابة، ومضيق " آيت منصور" وسهل " آيت وفقه- ازربيي". لهذه المناظر الطبيعية الخلابة ينبغي إضافة أنواع أخرى من التراث ذات أهمية خاصة من وجهة نظر أثرية (المنحوتات على الصخور)، هندسية، ايكولوجية، تاريخية وثقافية.إن المحافظة على هذه الجيومواقع تتلائم مع استخدامها كمورد ثقافي. ويمكن تعزيز الأنشطة السياحية التي تستند على الجيوتراث في سياق خطةِ تدبيرٍ مناسبةٍ تنبني على التربية والجيومحافظة.

Keywords
Anti-Atlas • Geotourism • Geoconservation • Geopark • Kerdous inlier • Tafraout

Mots-clés
Anti-Atlas • Boutonnière de kerdous • Géotourisme • Géoconservation • Géoparcs • Tafraout

الرئيسية الكلمات
الأطلس الصغير • عروة "كردوس" • جيوتراث • جيومحافظة • جيومنتزه • تافراوت

1 Introduction

Geoheritage is represented by all those geological elements of significant value to humans, including scientific research, education, aesthetics values and cultural developments (Dixon 1996; Sharples 2002). Thus, it can be represented either by minerals and fossils, or by geomorphological, stratigraphic, tectonic, magmatic, metamorphic, old mining sites or by any outstanding geological feature. The Global Geoparks Network supported by UNESCO aims to protect and develop territories which include particular geological heritage of international significance. The geological heritage of these Global Geoparks is being used to promote the sustainable development of the local communities who live there, and they are protected under local, regional or national legislation as appropriate.

Morocco is unanimously recognised for the richness and the diversity of its landscapes, largely due to its geological history. However, it was not until the last few years that an Association for the Protection of Moroccan Geological Heritage (APPGM) was created and that the outstanding geological heritage of Morocco has started to be promoted internationally. Examples of areas where and inventory and protection plan has been promoted are as the M'Goun Geoparc in the High Atlas mountains (El Khalki et al. 2009), the Ait Hajji geomorphosite in Central Morocco (Nahraoui et al. 2011) and the Bou Azzer area in the Anti-Atlas (El Hadi et al. 2011). Relevant to geoconservation of geoheritage in Morocco is the recent initiative of the African Geoparks Network (AGN) to promote African geoheritage and geoparks. This was stated in El Jadida Declaration (Errami et al. 2012) that come out from the First International Conference on African and Arabian Geopark held on November 2011 in El Jadida (Morocco), where the Moroccan geoheritage was widely promoted (Errami and Al-Aawah 2011). Besides this, the Ministry of Energy and Mines of Morocco has been working on a regulation and legislation project for the national geological heritage, in which different geozones are grouped into three main categories: sites of geological interest, geotopes and geoparks (El Hadi et al. 2011).

Among the zones in Morocco being of a particular interest from a geological and geomorphological point of view is that of the western Anti-Atlas Kerdous inlier. The present work aims to demonstrate the didactic, scientific, cultural and geotouristic values of the area. The valorisation and the promotion of these values will help to improve the leaving standards of local population and promote the Kerdous inlier as a main geotouristic destination. Based on that, an action

plan is proposed which comprises the compilation of an inventory of the geological heritage and the diagnosis of the anthropic negative impacts that may threaten them, as well as identification of local development projects for its restoration, protection and cultural and economic development. Moreover, this contribution aims to persuade not only geologists, but decision makers that are responsible for land policies and management about the importance of this geological heritage, and to consider the potentiality of the Kerdous area to achieve the status of Geopark.

2 Geological Framework of the Kerdous Inlier

The NE-SW oriented Anti-Atlas belt is characterized by the presence of several large Precambrian erosional windows called inliers or "boutonnières" (Choubert 1963). These inliers form a complex assemblage of basement rocks (Paleoproterozoic, Neoproterozoic) rimmed by a cover of Lower Paleozoic rocks (Gasquet et al. 2008). The current configuration where the Precambrian rocks are outcropping within these inliers is due to the Alpine uplift of the Anti-Atlas (Choubert 1963; Cahen et al. 1984).

The Anti-Atlas marks the northern boundary of the Eburnian West African Craton (WAC) (Ennih and Liégeois 2001; Thomas et al. 2004) and is characterized by a local display of the effects of the Neoproterozoic Pan-African orogeny.

The Kerdous inlier, located at about 100 km SSE of Agadir and with Tafraoute as the main town on its eastern flank (Fig. 1a), is one of the largest Precambrian inliers of the Anti-Atlas belt. The area has been a subject of numerous scientific studies devoted specifically to its geology (Choubert and Faure-Muret 1972; Hassenforder 1987; Nachit et al. 1996; Malek et al. 1998; Thomas et al. 2004; Soulaimani and Piqué 2004; Gasquet et al. 2004; Pons et al. 2006; among others).

As most other inliers of the Anti-Atlas, the Kerdous inlier is formed by three main lithological units (Fig. 1b): (1) A Paleoproterozoic basement of crystalline metamorphic and magmatic rocks, traditionally designated in the literature as PI (Choubert 1963; Choubert and Faure-Muret 1983) or as Eburnean. The metamorphic rocks, predominantly of sedimentary origin (slates, phyllites, schists and migmatites) were

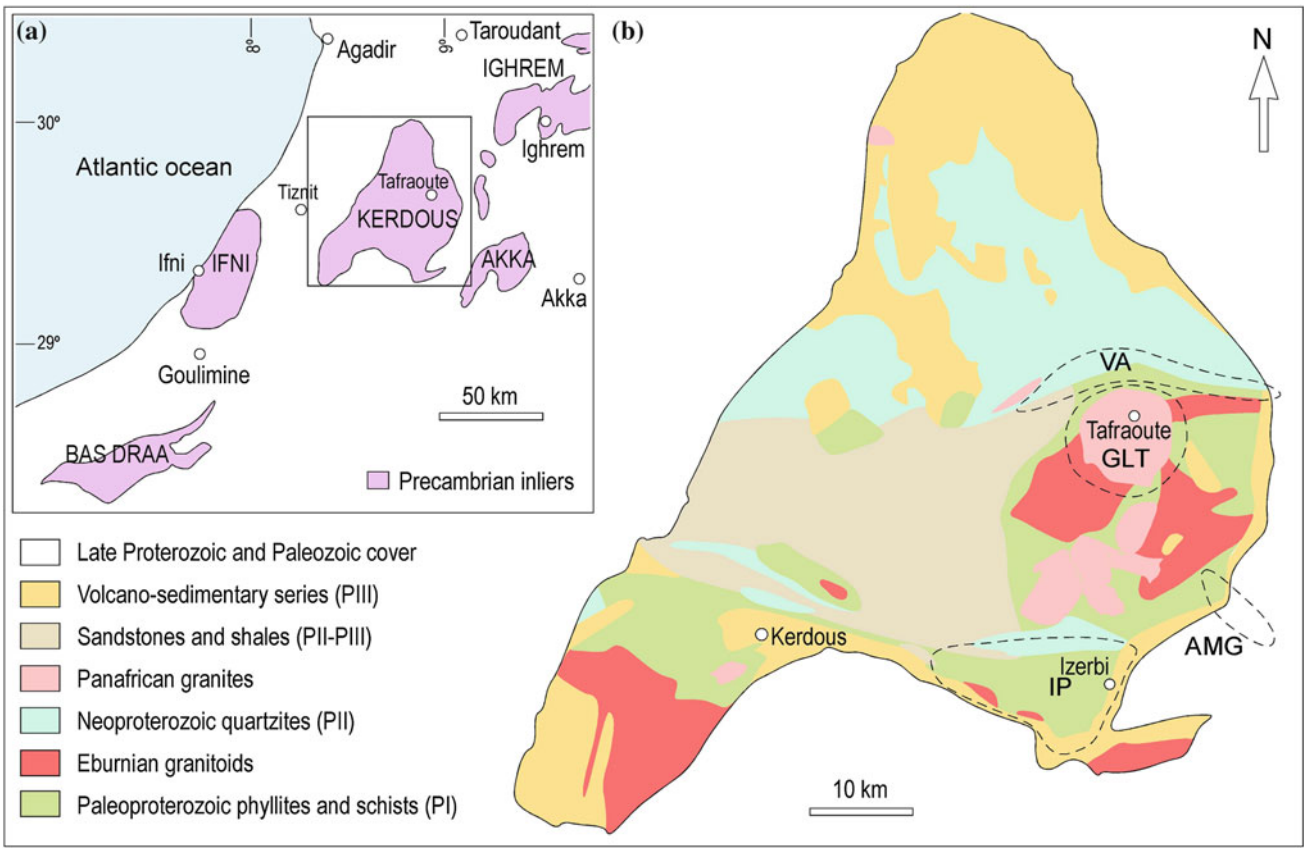

Fig. 1 Location (**a**) and schematic geological map (**b**) of the Kerdous inlier in the southern Anti-Atlas of Morocco, after Choubert (1963) and Hassenforder (1987). *VA* Valley of the Ameln; *GLT* granitic landforms of Tafraoute; *AMG* Aït-Mansour gorges; *IP* Izerbi plain

deformed and metamorphosed during the Eburnian Orogeny (~2.000 Ma) and the Eburnean magmatic rocks, mostly granitoids, are considered to be emplaced synchronically with this tectonometamorphic event (Charlot 1978).

(2) Several sedimentary (mainly quartzites) and volcanic sequences of lower to mid-Neoproterozoic age, which are locally affected by the Pan-African orogeny and intruded by Pan-African granitoids (known as PII, of ages ranging between 630 and 550 Ma, Gasquet et al. 2008). The Paleoproterozoic basement rocks were also heterogeneously affected by the Panafrican deformations (folds and shear zones) and metamorphism.

(3) An upper Neoproterozoic (known as PIII) to Paleozoic cover which unconformably overlies the earlier units (PI and PII). These cover rocks are disposed sub-horizontally, although they are locally affected by Variscan folds.

3 Sites of Significant Geoheritage Value in the Kerdous Region

The Kerdous massif includes outstanding landscapes which largely reflect a variety of geological components. Besides the contribution of the geology to the design of magnificent landscapes, the outcropping rocks in the area and their intrinsic characteristics comprise a unique record of multiple processes in the Earth geological evolution. Obviously because of the prevalence of basement rocks, most (if not all) existing peer-review international publications devoted to the Kerdous inlier are dealing with structural, igneous and metamorphic features and with their geodynamic aspects (see references in the previous section). These studies evidence that the area is of great local, national and international scientific interest.

As a precursory step in the compilation of a more complete and systematic inventory of the study area, we present here a first list of sites of geological and geomorphological interest. Four large zones (geozones) of exceptional value have been selected on the basis of their representativeness and the diversity of their geological configurations. Their locations and approximate boundaries are outlined in Fig. 1b. Each geozone may include several smaller spots or geotopes. These four geozones are described below.

3.1 Granite Landforms of Tafraoute, South of Tafraoute Village (GLT)

The arid and semi-arid landscapes, surrounding Tafraoute village (Fig. 1b), are characterized by magnificent landforms which are being developed on the Neoproterozoic granitic pluton of Tafraoute. Also known as the Tafraoute granites, these intrusive rocks represent the youngest rocks of the Pan-African episode (549 ± 6 Ma according to Pons et al. 2006). While the Tafraoute granites are relatively homogeneous from the petrologic point of view, their geomorphologic scope makes them more interesting and famous. Particularly remarkable are the forms that result from weathering along joints (Figs. 2a and 3c, d), dome-shaped inselbergs (Fig. 3a, b) and tafoni. These features resulted from wind and water weathering. Some of these natural sculptures have become part of the popular heritage, such as the "Chapeau de Napóleon" (Napoleon's Hat, Fig. 2b) or the Elephant. A proof of the relevance of this geozone is the science promotional video by Lüning and Geiger (2005) on the geology and geological history of Morocco, in which a section is dedicated to the Tafraoute granites. A photograph of "Napoleon's Hat" appears in the video front cover.

Also famous but controversial are the "Roches Peintes" (Painted Rocks or Blue Rocks), a group of granitic small hills and boulders located at 4 km south of Tafraoute village (Fig. 3). In 1984, the Belgian artist Jean Verame lead a project to spray these landforms with several tonnes of blue, red, violet and white paint (Fig. 3b). With time passing, the

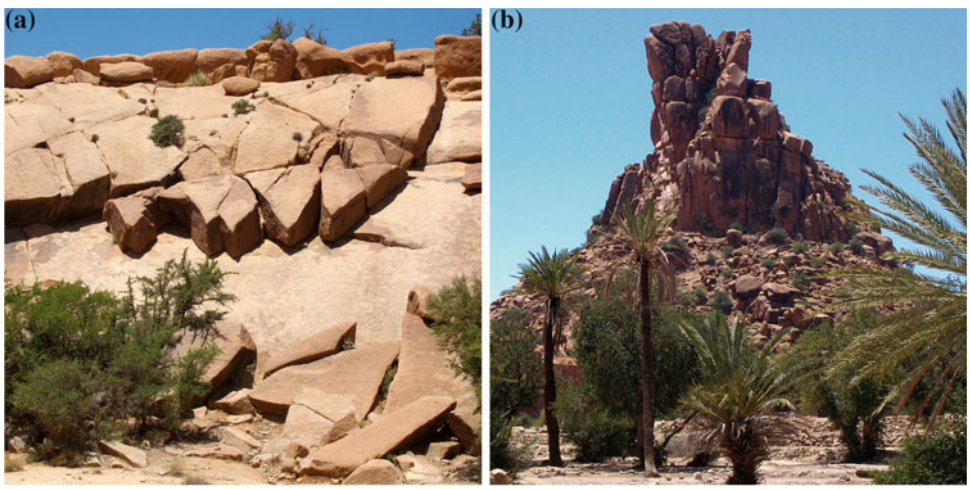

Fig. 2 Granite landforms. **a** Prismatic shapes resulting from erosion along the jointed Tafraoute granite. **b** The emblematic granitic figure "Chapeau de Napóleon" (Napoleon's hat) in the village of Aguerd Oudad, 2 km south of Tafraoute

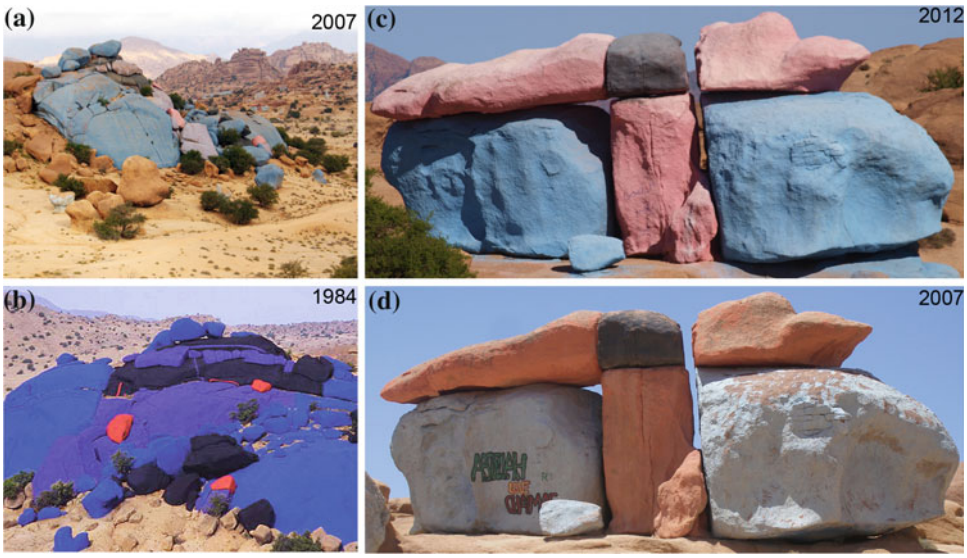

Fig. 3 Examples of one of the landscape paintings performed by the Belgian artist Jean Verame in granitic landforms near Tafraoute, known as the "Roches Peintes". Since created in 1984, the colours become increasingly loose and faded due to weathering by the wind and the strong solar radiation. In 2010, the enterprise "Peintures Atlas" has re-painted some of the site to its former Verame's colours. **a** Some of the painted forms photographed in 2007. **b** The same forms as in (**a**) photographed in 1984 (Verame 1984, reproduced with author's permission, http://www.jeanverame.com/anglais/maroc.php). **c** Another popular form photographed in 2012, 2 years after being re-painted. **d** The same form as in (**c**) photographed in 2007. Notice the presence of superposed graffiti

colours become increasingly loose and faded due to weathering by the wind and the strong solar radiation (Fig. 3a, d). In 2010, the enterprise "Peintures Atlas" went through a renovation project that restored part of the site to the former Verame's colours (Fig. 3c). Divergent opinions exist between those who consider this type of human modification of natural formations as an artwork that improves the landscape and those who object and refute these kind of practices that are damaging the landscape.

The cultural and archaeological heritage of the small villages in the area aesthetically harmonizes with this geological landscape heritage. This is the case of the ancient villages such as Adai, Imyane and Tazekka (Fig. 4a). Many traditional Berber houses were built on the slopes of the granitic promontories and, in this cases, the materials and shapes used in these buildings perfectly match with the natural pinkish-orangish smooth boulders of granite. Finally, it is important to mention here that prehistoric art is also locally represented in this area in the form of rock engravings or petroglyphs. Among them, one of the most visited and appraised carving is the Gazelle near Tazekka (Fig. 4b).

3.2 Valley of the Ameln, North of Tafraoute (VA)

This is a scenic valley bounded to the north by an impressive mountain cliff made of sub-vertical beds of Neoproterozoic (PII) quartzitic rocks (Fig. 5). A sharp contact separates the PII quartzites from the Paleoproterozoic metasedimentary rocks (PI) at the bottom of the valley, a contact which corresponds to a Pan-African shear zone (the Ameln Valley shear zone; Hassenforder 1987; Soulaimani and Piqué 2004).

Several small villages of great beauty and historical-cultural value are harmonically aligned along the base of the cliff such as Tighzt, Tandite and Oumesnate (Fig. 5b). Unfortunately, most of the ancient buildings in the valley are partly or totally abandoned and threatened by ruin.

3.3 Aït-Mansour Gorges, Southeast of Tafraoute (AMG)

This is another site of prime geological and geomorphological heritage. Here, narrow gorges were carved by the river through the PIII Cambrian limestones at the bottom of which there is a magnificent palm forest (Fig. 6). Also prominent from the geoscientific point of view is the unconformity between the folded metamorphic rocks and migmatites of the Eburnian basement and the horizontal Cambrian limestones (Fig. 6a) that can be observed along the zig-zagging road that drives down to the oasis. The most striking scene of this geozone is given by the strong contrast between the brownish rocky cliffs and the green landscape of dense palm trees that dominate the bottom of the valley (Fig. 6b).

Fig. 4 **a** The ancient Berber houses in the village of Tazekka represents a superb example of integrating traditional building with the rocky (here the Tafraoute granite) landscape. On the contrary, mismatching elements are rather frequent in the contemporary architecture (note the white frame on the *lower-right* side of the photograph). **b** Prehistoric rock carving of a gazelle near Tazekka

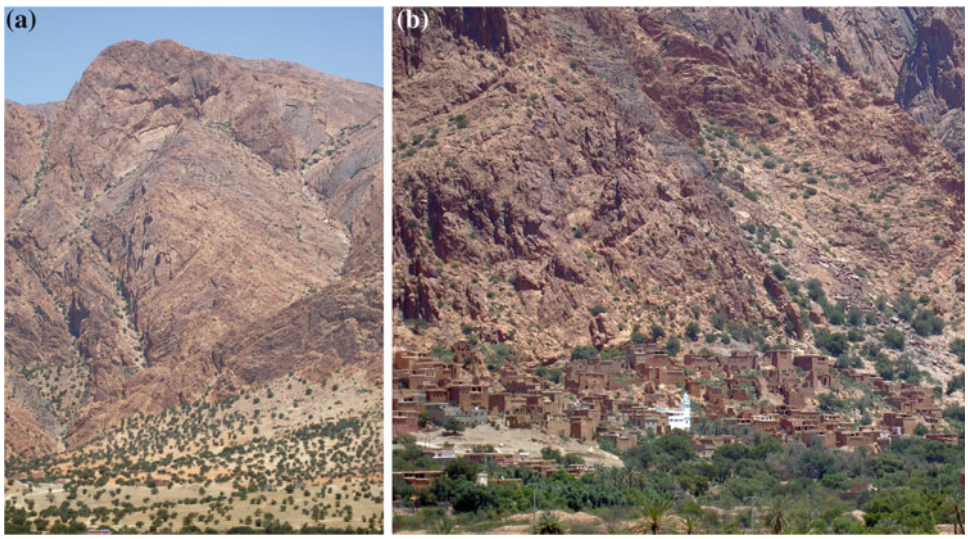

Fig. 5 The PII quartzites conform the impressive cliffs that flanks the Ameln valley to the north (north of Tafraoute). **a** The famous Lion's head, another natural sculpture on top of the quartzite cliffs. **b** View of Oumesnate, one of the many small picturesque towns in the Ameln valley, with the typical adobe constructions only disturbed by a few modern concrete houses and parabolic antennas

3.4 Izerbi Plain (IP)

A singular characteristic of this geozone concerns the contrasting landforms of geological predominance. The Izerbi plain, an extensive semi-desertic flatland conformed by extremely eroded rocks of the Eburnian basement, is bordered to the north by the irregularly shaped mountain cliffs that consist of steeply dipping Neoproterozoic PII quartzites (Fig. 7a). However, the most remarkable aspects of this geozone concerns Earth processes heritage. The contact between both Eburnean and PII units is represented by an east-west trending Pan-African shear zone (the Tasrirt-Tahala shear zone). Together with the previously mentioned Ameln Valley shear zone, northwards in the Kerdous massif, both shear zones represent the major structural features in the Kerdous inlier (Hassenforder 1987; Soulaimani and Piqué 2004). The tectonic structures outcropping in the metamorphic Eburnean basement rocks (folds, crenulations and kink-bands, e.g. Fig. 7b) are of special interest and relevant for the understanding of the Pan-African orogeny. Another remarkable feature in these basement rocks is the widespread presence of swarms of mafic (mainly doleritic) dykes (Fig. 7a; Carreras et al. 2006; Castaño 2010). These mafic dyke swarms are also common in other adjacent inliers (e.g. Ikenne 1997; Hafid 1999), but are especially well exposed in Kerdous inlier, where many intriguing internal and marginal deformation structures in contact with the hosting metamorphic rocks are displayed. These dykes are almost exclusively intruded into the Eburnean metamorphic and granitic rocks, although geochemically affine sills were found in the PII materials (Hassenforder 1987). A debate still remains regarding whether there is one or more magmatic

Fig. 6 The Aït-Mansour Gorges, on the southeast border of the Kerdous inlier. **a** Unconformity between the deformed metamorphic rocks and migmatites of the Eburnian basement (PI) and the horizontal cambrian limestones (PIII). **b** Panoramic view of the Aït-Mansour gorges carved by the sidi mansour river (view is down valley, towards the east). Note the contrasting landscape between the rock walls made of PIII limestones and the palm oasis at the bottom of the valley

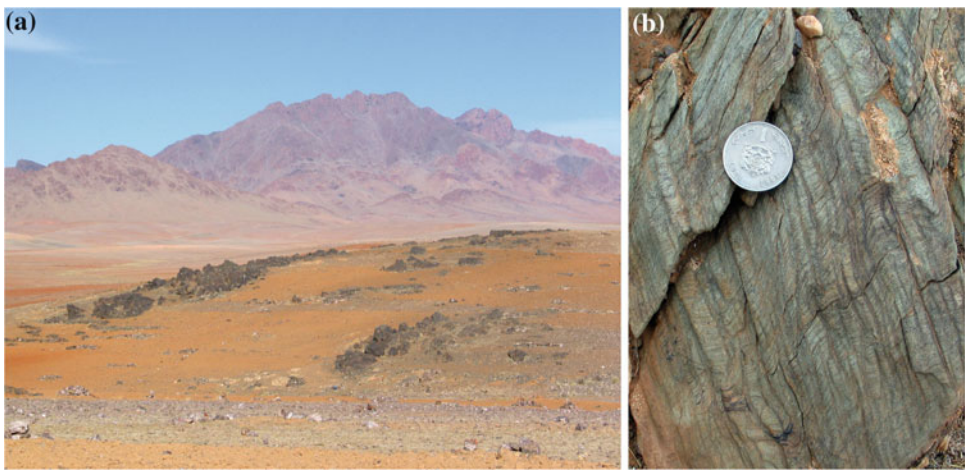

Fig. 7 **a** View to the north of the Izerbi plain. The *dark* rocks that stand out in the landscape are dolerite dykes (likely Panafrican in age) intruded into the brownish Eburnian phyllites that dominate the plain. The cliffs are made of PII quartzites. **b** Fine crenulation cleavage developed in phyllites from the Izerbi plain

events responsible of these mafic dykes, and about their ages and geotectonic significance (Carreras et al. 2006), evidencing that further investigation is required on this subject.

In the four geozones described above, geoheritage is associated to archaeological and architectural heritages, particularly in the Tafraoute granite landforms and Ameln Valley zones. Moreover, geological heritage also coexists with biodiversity in the Kerdous inlier, where several unique animal and vegetal species and ecosystems are present, some of which are under threat. This is the case of the endemic argan tree, the wild boar and the gazelle and other ungulates. Thus, the Kerdous inlier consists of a typical example of convergence of the three main groups of heritage values: geological, historical/archeological, and ecological/biotic.

4 Current State of the Kerdous Geoheritage: Positive Developments Versus Negative Impacts and Threats

A complete assessment of natural and/or cultural heritages requires an evaluation of the nature and quality of the sites (i.e. throughout inventories) but also an estimation of their conservation and vulnerability. This is therefore something to be performed for the case of the Kerdous geoheritage. In what follows we present an outline of the main aspects behind these issues. The present condition of the Kerdous geoheritage is an outcome of the confluence of several socio-economic and cultural circumstances, some of which are

generally shared by other Moroccan and North-African countries; others are more specific of this region.

The mainly rural character of the zone and the up-to-date low degree of urban and industrial development allow vast areas of this massif keeping relatively pristine compared to other sites where geological heritage is located in highly urbanized areas. Thus, a large proportion of surface area of the sites of geological interest described in the previous section is in a good state of conservation. Agricultural development is rather restricted to fertile valleys or plains and to cultivations in semi-arid and arid forests such in the case of the Argan, Olive and Almond trees, and they do not imply any significant perturbation or negative impact on the landscapes and/or on the geological formations. Livestock activities (mostly sheep and goats) extend further across the mountains, also being usually well integrated into the landscape.

Negative impacts related to urban development are rather restricted to villages that are growing without environmental-friendly urbanization plans. This is mostly happening around the ancient Berber houses in the villages along the Ameln valley, where modern, but mismatching concrete constructions are proliferating.

As regards to mineral resources, the mining industry is currently increasing in this region, with several gold-bearing (and other metals) deposits being object of exploration in the Kerdous and adjacent inliers, as reported by the Moroccan National Office of Hydrocarbons and Mining (ONHYM) on its web page (http://www.onhym.com/Mining/). Most occurrences are located in the Eburnian basement around the Izerbi plain, the scenic landscapes there being potentially threatened. However, the implementation by ONHYM of an environmental strategy for these mining activities offers certain warranty for geoconservation.

The recent increase of touristic development in this region has also proved to be crucial and particularly challenging in terms of landscape and geological heritage conservation. Tafraoute has become one of the most famous and well reputed touristic destination of the Anti-Atlas region, not only because it is a charming village with a variety of cultural values, but also because it is strategically located in the middle of the picturesque lands whose natural heritage attracts many visitors every year from all around the world. The type of tourism developed on this region plays in favour of geoconservation, because cultural, sportive (hiking, cycling, rock climbing) and general nature leisure activities predominate. The touristic actions that are being developed around Tafraoute can be broadly regarded as positive, because they are mostly based on a sustainable grow and promote a respectful use of landscapes and cultural values. Especially defendable are those actions which are aimed to restore ancient buildings to be used as touristic infrastructures (e.g. rural hotels), and the local and private activities promoting the cultural and natural values (including geological heritage) of the region (e.g. touristic pamphlets provided by some hotels).

On the other hand, the lack of effective geoconservation plans under specific protection policies and regulations make this geological heritage extremely vulnerable to bad use and degradation. The granite landforms, surrounding Tafraoute village, are particularly vulnerable as they are most accessed, being exposed to various threats which are likely to involve their degradation or even their total destruction. These threats come from some bad practices by local populations or by visitors unaware about the geological values and the landscape itself. In this way, certain landforms are masked by mismatching installations (e.g. Fig. 4a) and others are sometimes used for placing advertising panels or making graffiti (e.g. Fig. 3d).

A particular situation is that of the Painted Rocks in the geozone referred here as Granite landforms of Tafraoute, where natural landscape has been artificially modified to some extend through rock painting activities. As stated before, whether this action represents a positive or negative impact to geoheritage is presently a matter of discussion. As recommended by Carreras et al. (2012), in those situations where the effects of human action amplify the interests and enhance access to geological values, the resulting balance should be considered positive and compatible with geoconservation. In the Painted Rocks case, access to and curiosity for geoheritage are clearly amplified, since visitors are attracted by the site, but the enhancement or decrease of the intrinsic geological values is a debatable issue. We consider that the paintings can be maintained as far as the affected area is not further expanded, that is, that the "painted domain" remains restricted to its present location, and if appropriate measures are taken to ensure compatibility between landscape safeguarding and geotourism.

5 Integrating Geoeduction, Geoconservation and Geotourism: A "3Geos" Development Plan for the Kerdous Area

As described in the previous section, geoheritage of the Kerdous inlier is vulnerable to certain negative human impact. The development of merely protectionist policies and regulations can help to prevent the hazards and threats to geological heritage. However, truly effective geoconservation includes the need for educational outreach programs on the significance and need for conservation of the geological heritage. Furthermore, touristic activities and infrastructures, if properly managed, can be not only compatible but also mutually complementary with geoconservation. These are the main principles of geotourism, either if regarded as the

tourism that enhances the qualities of a place, including its environment, culture, aesthetics, heritage, and the well-being of its residents (Boley et al. 2011), or more strictly concerning to tourism that is based on sites of geological interest (Hose 2000; Dowling and Newsome 2006; Newsome et al. 2012). It seems then obvious that different public or private organizations or institutions and individuals that are in charge of management of the geotouristic activities in this region are aware of its geological heritage and of geoconservation strategies. Geotourism and geo-education are therefore also directly linked, and together with geoconservation they form a "triangle" of interlinked and interdependent strategies. In the case of the Kerdous inlier, we believe that geoeduction, geoconservation and geotourism should be integrated and mutually considered in any development plan.

In light of these principles and of the specificities of the Kerdous inlier, we consider that this area meets the conditions suitable for being a Global Geopark, as this initiative is specifically targeted to stimulate sustainable economic and cultural development of a region based on the presence of significant geological sites.

A series of stepped actions have to be carried out in order to reach the Geopark tag or any other status that can be satisfactory for the social and cultural development of the Kerdous area and compatible with conservation of its geological heritage. Such actions require intercommunication and coordination between individual geoscientist, scientific or academic institutions (i.e. universities and research centres), industrial developers and local, regional and national authorities and institutions responsible for land management.

The scientific community may take part in these activities through:

- the development of inventories and creation of databases of sites of geological and geomorphological interest;
- evaluating the state of the conservation of the different geosites, the present and potential threats, and suggesting possible solutions to mitigate negative impacts;
- the promotion of geoconservationist and geo-educational values.

Within the framework of these action plans, the regional and local authorities (e.g. municipalities) should consider:

- the geoheritage of this region when implementing rural and urban development plans;
- contributing to geo-education through giving support to information and educational programs (e.g. at the schools) in the field of geoconservation, to increase citizens sensibility towards the geological values;
- setting up measures specific to encourage local and regional, private and public industries (e.g. mines) which deal with land management to implement geoconservation strategies;

The governmental organizations should be able to contribute through, for instance:

- strengthening the co-operation with scientific international organizations and institutions working on the field of the geoheritage conservation.
- ensitizing and educating people and organizations on the geoheritage values and their capabilities for social, cultural and touristic development of the country;

6 Conclusions

Through this work, we have tried to demonstrate the outstanding geological values of the Kerdous inlier in the Western Anti-Atlas of Morocco. The region contains at least four large geozones of international scientific interest which, in addition, include many unique geomorphological features and a variety of scenic geological landscapes. These principal geozones are the granite landforms of Tafraoute (south of Tafraoute village), the Ameln valley (north of Tafraoute), the Aït-Mansour gorges (southeast of Tafraoute) and the Izerbi plain (south of the Kerdous inlier).

This geological heritage of the Kerdous inlier is vulnerable to certain types of human activities. Consequently, it is recommended that regional and local strategies should reconcile the need for economic development and the geoconservational duties. Moreover, it is crucial that any land management activities considers the interdependency between geotourism, geo-education and geoconservation, and the need for coordinating actions among individuals, local associations and regional or national initiatives.

Because of its extraordinary geological heritage, the Kerdous area deserves protection as a natural-cultural site, and it is worthy of acquiring a 'Global Geopark' status. A Geopark in this area will enhance its social, cultural and economic development.

Tafraoute is strategically located and has the potentials to become the "capital" of the aspiring Kerdous Geopark. The Painted Rocks site near Tafraoute, if regulated and managed under geoconservation criteria, could even become a paradigm for geocultural tourism.

Acknowledgments This work was funded by the 'Agencia Española de Cooperación Internacional'—AECI (project A/6943/06).

References

Boley BB, Nickerson NP, Bosak K (2011) Measuring geotourism: developing and testing the geotraveler tendency scale (GTS). J Travel Res 50:567

Cahen L, Snelling NJ, Delhal J, Vail JR (1984) The geochronology and evolution of Africa. Clarendon Press, Oxford

Carreras J, Druguet E, Rahimi A, Castaño LM, Griera A, Gómez-Rivas E (2006) Contribución del estudio estructural del enjambre de diques básicos del Precámbrico del Anti-Atlas al conocimiento de su significación geotectónica en la orogenia panafricana. Geogaceta 40:139–142

Carreras J, Druguet E, Siddoway CS (2012) Geological heritage beyond natural spaces: the red rocks amphitheatre (Morrison, CO, USA), an example of syncretism between urban development and geoconservation. Geoheritage 4:205–212

Castaño LM (2010) Emplazamiento y deformación de venas y diques magmáticos en cinturones tectonometamórficos: Análisis a partir de estudios de campo y modelización analógica. Dissertation, Universitat Autònoma de Barcelona

Charlot R (1978) Caractérisation des événements éburnéens de l'AntiAtlas marocain. Dissertation, Université Rennes

Choubert G (1963) Histoire géologique du Précambrien de l'Anti-Atlas. Notes et Mémoires Service Géologique Maroc 162:352

Choubert G, Faure-Muret A (1972) Carte géologique du massif de Kerdous (Aït Baha-Tanalt-Anzi-Tafraout) au 1/200000e

Choubert G, Faure-Muret A (1983) Anti-Atlas (Maroc). Lexique stratigraphique international, nouvelle série No. 1. International Union of Geological Sciences, stratigraphic commission

Dixon G (1996) Geoconservation: an international review and strategy for Tasmania. Miscellaneous Report, Hobart, Tas. Parks and Wildlife Service, Tasmania

Dowling RK, Newsome D (eds) (2006) Geotourism: sustainability, impacts and management. Elsevier/Heineman Publishers, Oxford

El Hadi H, Tahiri A, Simancas JF, González-Lodeiro F, Azor A, Martínez-Poyatos D (2011) Geoheritage in Morocco: the Neoproterozoic Ophiolite of Bou Azzer (Central Anti-Atlas). Geoheritage 3:89–96

El Khalki Y, Taïbi AN, El Hannani M, Benyoucef A (2009) Le patrimoine géomorphologique du géoparc M'Goun (région de Tadla-Azilal, Maroc): évaluation et inventaire. In: Géomorphosites 2009: imagerie, inventaire, mise en valeur et vulgarisation du patrimoine géomorphologique. Colloque international de Géomorphologie, Université Paris-Sorbonne (France). Résumés vol. 1:71

Ennih N, Liégeois JP (2001) The Moroccan Anti-Atlas: the West African craton passive margin with limited Pan-African activity. Implications for the northern limit of the craton. Precambr Res 112:289–302

Errami E, Al-Aawah M (2011) Proceedings of the first international conference on African and Arabian Geoparks, Aspiring geoparks in Africa and Arab World, El Jadida (Morocco)

Errami E, Andrianaivo L, Ennih N, Gauly M (2012) The first international conference on African and Arabian geoparks—aspiring geoparks in Africa and Arab world. Episodes 35:349–351

Gasquet D, Chevremont P, Baudin T, Chalot-Prat F, Guerrot C, Cocherie A, Roger J, Hassenforder B, Cheilletz A (2004) Polycyclic magmatism in the Tagragra d'Akka and Kerdous-Tafeltast inliers (Western Anti-Atlas, Morocco). J Afr Earth Sci 39:267–275

Gasquet D, Ennih N, Liégeois J-P, Soulaimani A, Michard A (2008) The Pan-African belt. In: Michard A, Saddiqi O, Chalouan A, Frizon de Lamotte D. (eds) Continental evolution: the geology of Morocco. Structure, stratigraphy and tectonics of the Africa-Atlantic-Mediterranean triple junction. Series: lecture notes in Earth sciences, vol 116, pp 33–64

Hafid A (1999) Magmatisme basique filonien neoproterozoique (Precambrien II Inferieur) dans l'Anti-Atlas central et occidental. Mineralogie, geochimie, petrogenese et implication geodynamique. Dissertation, Université Cadi Ayyad, Marrakech, p 222

Hassenforder B (1987) La tectonique panafricaine et varisque de l'Anti-Atlas dans le massif du Kerdous (Maroc). Dissertation, Université Strasbourg, p 249

Hose TA (2000) European geotourism—geological interpretation and geoconservation promotion for tourists. In: Wimbledon WAP, Gallego E, Barettino D (eds) Geological heritage: conservation and management. IGME, Madrid, pp 127–146

Ikenne M (1997) Les filons basiques des boutonnières du Bas Drâa et de la Tagragra d'Akka: Témoins des distensions néoprotérozoïques de l'Anti-Atlas occidental (Maroc). J Afr Earth Sci 25:209–223

Lüning S, Geiger M (2005) Natural wonders of the Maghreb: expedition through Morocco's earth history. DVD video, Seven Continents Science Productions, Bremen

Malek HA, Gasquet D, Bertrand JM, Leterrier J (1998) Géochronologie U/Pb sur zircon de granitoïdes éburnéens et panafricains dans les boutonniéres protérozoïques d'Igherm, du Kerdous et du Bas Draa (Anti-Atlas occidental, Maroc). C R Acad Sci Paris 327:819–826

Nachit H, Barbey P, Pons J, Burg JP (1996) L'Eburneén existe-t-il dans l'Anti-Atlas occidental marocain? L'exemple du massif du Kerdous. C R Acad Sci Paris 322:677–683

Nahraoui FZ, El Wartiti M, Zahraoui M, Dabi S (2011) Geomorphosite valorization a view to sustainable development: case of Ait Hajji, Oued Boulahmayel Valley, Central Morocco. J Geogr Inf Syst 3:12–17

Newsome D, Dowling R, Leung Y-F (2012) The nature and management of geotourism: a case study of two established iconic geotourism destinations. Tourism Manage Perspect 2(3):19–27

Pons J, Barbey P, Nachit H, Burg J-P (2006) Development of igneous layering during growth of pluton: the Tarçouate laccolith (Morocco). Tectonophysics 413:271–286

Sharples C (2002) Concepts and principles of geoconservation. Tasmanian Online. Department of primary industries, parks, water and environment. http://www.dpiw.tas.gov.au/inter,nsf/WebPages/SJON-57W4FD?open. Accessed 19 Oct 2012

Soulaimani A, Piqué A (2004) The Tasrirt structure (Kerdous inlier, Western Anti-Atlas, Morocco): a late Pan-african transtensive dome. J Afr Earth Sci 39:247–255

Thomas RJ, Fekkak A, Ennih N, Errami E, Loughlin ES, Gresse PG, Chevallier LP, Liégeois JP (2004) A new lithostratigraphic framework for the Anti-Atlas orogen Morocco. J Afr Earth Sci 39:217–226

Verame J (1984) Marocco: Tafraout (Anti-atlas). http://www.jeanverame.com/anglais/maroc.php. Accessed 19 Oct 2012