Geosites, Sites of Special Scientific Interest, and Potential Geoparks in the Anti-Atlas (Morocco)

Géosites, Sites Géologiques d'Intérêt Scientifique Spécial et potentiels géoparcs dans l'Anti-Atlas (Maroc)

الجيومواقع، المواقع الجيولوجية ذات الأهمية العلمية الخاصة والجيومتنزهات ذات المؤهلات بالأطلس الصغير (المغرب)

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Abstract

An inventory of the geoheritage features of the Anti-Atlas region has been performed to promote geoheritage and geoconservation in Morocco. This latter is best achieved after assigning heritage values to these features and identifying geosites, specific areas of special value or interest (Geological Sites of Special Scientific Interest, or SSSI) that usually are of International significance, or by viewing sites as integrated geological ensembles with significant geology that needs to be protected as an ensemble (Geoparks). Sites that could function as geosites, SSSI and/or as geoparks have a special significance for research, education and geotourism. The Anti-Atlas geology reflects its tectono-metamorphic and magmatic evolution from the Proterozoic to Mesozoic with plate collision, subduction and obduction witnesses, Mesozoic stratigraphic sequences, fossil-bearing strata, and arid zone landforms. Sites that could function as SSSI include pre-Pan-African doleritic dykes, the Bou Azzer and Siroua Ophiolites, the Pan-African diamictites, the Major Anti-Atlas Fault, the Late Neoproterozoic stromatolites, the unconformity between the late Neoproterozoic Ouarzazate volcanic Supergroup and Cambrian Tata Group, the contact between Taghdout Group and the Zenaga Eburnian (Palaeoproterozoic) formations, the contacts between three Pan-African Groups, viz., Saghro Group—Mgouna Group—Ouarzazate Group, the Ediacaran Iknioun granodiorite and the Devonian Kess Kess carbonate mounds. Sites that could function as geoparks include: the Zenaga inliers, the Neoproterozoic passive margin (Taghdout Group), and the Jurassic Foum-Zguid dyke traversing various formations. The Anti-Atlas region also hosts numerous internationally important fossil localities that could function as SSSI, e.g., the large Cambrian trilobite (Paradoxides), Ordovician trilobites (Asaphus) as death assemblages, Silurian and lower-most Devonian Orthoceras-rich black limestones, Frasnian plants

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from the Drâa Valley and ammonite-rich limestones. The geological areas that host these SSSI could function as geoparks.

Résumé

Un inventaire des caractéristiques géologiques de la région de l’Anti-Atlas a été entrepris pour promouvoir le géopatrimoine et la géoconservation au Maroc. Cette dernière est mieux assurée après l’attribution des valeurs géopatrimoinales à ces caractéristiques et l’identification des sites de valeurs ou d’intérêts particuliers (Sites géologiques d’Intérêt Scientifique Spécial, ou SISS) ou en considérant les sites comme un ensemble géologique intégré qui a besoin d’être protégé dans le cadre de géoparcs. Les géosites qui peuvent fonctionner comme SISS et/ou géoparcs ont une importance particulière pour la recherche, l’éducation et le géotourisme.La géologie de l’Anti-Atlas reflète son évolution tectono-métamorphique et magmatique durant le Protérozoïque et le Mésozoïque avec différents témoins de subduction, d’obduction, des séquences stratigraphiques, des niveaux fossilifères et des paysages des zones arides. Les sites, qui pourraient fonctionner comme SISS sont les dykes doléritiques pré-panafricains, les complexes ophiolitiques de Bou Azzer et de Siroua, les diamictites panafricaines, l’accident majeur de l’Anti-Atlas, les stromatolites Néoprotérozoïques, la discordance entre les formations volcaniques Néoprotérozoïque et les formations cambriennes, le contact entre le Groupe de Taghdout et les formations Eburnéennes (paléoprotérozoïque) de Zenaga, les contacts entre les trois groupes panafricains (Groupe Saghro—Groupe Mgouna—Groupe Ouarzazate), la granodiorite Ediacarienne d’Iknioun et les monts carbonatés Dévonien du Kess Kess. Les sites qui pourraient servir de géoparcs sont les boutonnières de Zenaga, la série Néoprotérozoïque de marge passive (Groupe de Taghdout), et le dyke Jurassique de Foum Zguid. L’Anti-Atlas contient aussi de nombreux sites fossilifères d’importance internationale qui pourrait fonctionner comme SISS tels que les trilobites géant du Cambrien (Paradoxides); les trilobites de l’Ordovicien (Asaphus) comme assemblages fossilifères, les calcaires noirs à Orthocères du Silurien et du Dévonien inférieur, les plantes frasniennes de la vallée du Drâa et les calcaires riches en ammonites. Les régions géologiques qui abritent ces SISS peuvent fonctionner comme geoparcs.

ملخص

لقد تم القيام بجرد للخصائص الجيولوجية لمنطقة الأطلس الصغير لتعزيز الجيوتراث والجيومحافظة بالمغرب. هذه الأخيرة أضحت مؤكدة بشكل أفضل بعد منح قيم جيوتراثية لهذه الخصائص وتحديد المواقع ذات قيمة أو أهمية خاصة) مواقع جيولوجية ذات أهمية علمية خاصة) أو تقييم المواقع كوحدة جيولوجية مدمجة تحتاج إلى حماية في إطار الجيومنتزهات. الجيومواقع التي يمكن أن تكون بمثابة مواقع جيولوجية ذات أهمية علمية خاصة أو جيومنتزهات هي ذات أهمية خاصة للبحث، التربية والجوسياحة. تعكس جيولوجية الأطلس الصغير تطوره التكتوني التحولي والصهاري خلال الحقبين البروتروزويك و الميزوزويك مع مختلف دلائل الطمر، الطفو، تسلسل الطبقات الرسوبية، ومستويات أحفورية ومناظر مناطق جافة. المواقع التي يمكن أن تصنف بمثابة مواقع جيولوجية ذات أهمية علمية خاصة هي العروق الدوليريتية ما قبل البان إفريقي، و مجمعي أفيوليت بوعزار وسيروا،و الصخورالجليدية البان إفريقية، و الفالق الرئيسي للأطلس الصغير، والستروماتوليت النيوبرتيروزوية، والتماس بين الصخور البركانية النيوبرتيروزوية والصخور الكمبرية، و تنافر بين مجموعة تغدوث وصخور البروتيروزوي القديم لزناكة، و تنافرات بين المجموعات البان إفريقية الثلاثة، وكرانوديوريت إكنيون وقعيرة جبل كيسان الأوردوفيسي، وتلال كس كس الكلسية الديفونية. المواقع التي يمكن استخدامها كجيومنتزهات هي عروة زناكة، وسلسلة الهامش غير النشيط النيوبرتيروزوية (مجموعة تغدوث) ، والعرق الجوراسي لفم زكيد.ويحتوي الأطلس الصغير أيضا على عدد من المواقع الأحفورية ذات الأهمية الدولية علمية خاصة مثل ثلاثية الفصوص الكمبري، والكلس الأسود ذات الارثوسير السيلوري والديفوني الأدنى، والنباتات الفرسنية لوادي درعة والكلس الغني بالآمونيت يمكن للمناطق الجيولوجية التي تؤوي هذه المواقع الجيولوجية أن تعمل كجيومنتزهات.

Keywords

Morocco • Anti-Atlas • Geoheritage • Geosite/SSSI • Geoconservation • Geoparks

Mots-clés
Maroc • Anti-Atlas • Géopatrimoine • Géosite/SISS • Géoconservation • Géoparcs

الكلمات الرئيسية
المغرب • الأطلس الصغير • جيوتراث جيومواقع/مواقع جيولوجية ذات أهمية علمية خاصة • جيومحافظة • جيومنتزه

1 Introduction

The history of planet Earth since its formation ca 4.6 Ga ago is recorded in its rocks, fossils, minerals, landscapes, etc. This story can be read from large scale (e.g., the evolution of the Andes Mountain Chain), to medium scale (such as the historically important site at Siccar Point where Hutton first described and conceptualised the importance of unconformities; Hutton 1788), to fascinating aspects at the micro-scale (e.g., the story inherent in the zoning, corrosion, inclusions, fracturing-and-healing, and overgrowths of the Archaean zircons of Jack Hills, the oldest crystals on Earth; Wilde et al. 2001). The story of the Earth and its products are linked to the ongoing history of human development, providing natural resources, a sense of place, and have scientific, historical, cultural, aesthetic, and religious values. In addition, Earth systems are the foundation of all ecological processes, are part of the heritage of our sciences (Torfason 2001), and have been an inspiration and a framework to other sciences, such as astronomy, chemistry, evolutionary biology, archaeology, arts, etc.

Geology is the library of Earth and life histories. The conservation of representatives of its features across continents and regions ensures that the witnesses to this history are available for present and future generations. Thus geoconservation is an important endeavour to preserve scenically-and/or scientifically-important areas for a number of reasons. From environmental management considerations, it ensures that the Earth functions in an environmentally sustainable way to maintain ecosystems for the well-being of their inhabitants. Geoconservation ensures also that Earth history, as a field textbook, is preserved in critical areas to be examined by scholars, researchers, students, and the interested public. Geoconservation ensures that key areas are available for geotourism considerations. Destruction of in-field information deprives future researchers and students of the opportunity to test, learn on-site, revise, or extend information in the light of new technology or new concepts. However, as a result of the ongoing tension between resource exploitation and resource conservation, geoconservation brings with it the questions—what to preserve, and how much to preserve? To this objective, geoconservation practitioners worldwide have been working towards raising the consciousness of land managers, governments, scientists, and the public to the importance of geoheritage, and geoconservation, and towards developing strong criteria to ensure representative and adequate geoconservation of Earth.

Building on geoheritage from global reviews to local principles for conservation and planning (Brocx 2008), a “tool-kit”, termed here the “Geoheritage Tool-kit” has been developed to address geological and geomorphological features that should be encompassed under the umbrella of geoheritage (Brocx and Semeniuk 2009, 2011). In a given area, geoheritage features of geoconservation significance can range from large- to small-scale, from international to local in significance, can encompass a wide range of geological/geomorphological features, and can occur in isolation, or in inter-related suites that should be viewed and preserved as an ensemble. The Geoheritage Tool-kit has been designed to systematically address and assess this diversity. This paper outlines the concepts underpinning the approach adopted to geoheritage and geoconservation, describes the Geoheritage Tool-kit as developed in Western Australia, and applies it to the Anti-Atlas in Morocco to identify sites and regions that may be targeted either as SSSI or as aspiring geoparks. This work aims also to contribute to enhance geoconservation and promote Moroccan geoheritage.

2 Scope, Scale, and Levels of Significance of Geoheritage Features, and Terms/Definitions

In terms of scope, since geoheritage and geoconservation are concerned with heritage and conservation of geological matters, then all components of geology should be part of geoheritage (Brocx and Semeniuk 2007). This includes the subsidiary disciplines of geology such as igneous, metamorphic and sedimentary geology, igneous, metamorphic and sedimentary petrology, stratigraphy, structural geology, mineralogy, palaeontology, geomorphology, pedology, hydrology, and surface processes such sedimentology. This list covers a large variety of processes and products but, in addition, it also traverses a wide range of scales, from global tectonics, mountain building, and landscape evolution, to local surface processes such as weathering, erosion and sedimentation and, at microscale, diagenesis, crystal defects and deformation, amongst others. This perspective definitively places many aspects of geology, perhaps previously not recognised as part of the spectrum of geoheritage (Brocx and Semeniuk 2007).

Sites of geoheritage significance can be assigned to one of four categories (Brocx 2008; Fig. 1). Scale is important to consider in geoheritage/geoconservation since features of significance can range from crystals, bedding planes and outcrops, to that of landscapes and phenomena at montane-scale. In many locations, sites are important because of crystal-sized features and crystal fabrics, and it is often at this scale that the story of Earth unfolds. At the next scale, features of geoheritage significance are represented by outcrops and bedding scale features. Important geological/geomorphological features continue to occur in increasing scale, up to the scale of mountain ranges, extensive landforms, and major drainage basins. Scales and levels of significance assigned to geoheritage are given in Figs. 2 and 3.

Geoconservation involves preservation of specific sites (special sites), or of geological ensembles. The former is where a significant geological feature occurs in isolation, or may have historical or cultural significance. The term SSSI (Bowen et al. 1996) refers to a small or isolated site that has special significance. The encompassing local geology of these features may not be significant nationally or regionally. In contrast, the term "geosite" is used to refer to a small location that has been identified as having geological attributes but has not been allocated special significance. In this paper, most of the identified geosites are, in fact, SSSI.

Geoconservation of geological ensembles involves preservation of areas that contain a range of significant geological features. Geological ensembles can be viewed as a suite of inter-related SSSI occurring in the same area.

Globally, a geopark is defined as a territory encompassing one or more sites of scientific importance, not only for geological reasons but also by virtue of its archaeological, ecological or cultural value. The European Geoparks Network, established in 2000 (Zouros 2000) defines a geopark as an area to conserve and valorise geological heritage through an integrated and sustainable development of their territories. The Asia Pacific Geoparks Network, founded in 2007, defined a geopark as a nationally-protected area containing a number of geological heritage sites of particular importance, rarity or aesthetic appeal. These Earth heritage sites are part of an integrated concept of protection, education and sustainable development. The African Geoparks Network created by the African Association of Women in Geosciences in 2009 (Errami et al. 2012a, b) defines a geopark as an area where geoheritage could be used as a tool to enhance human sustainable development. All these initiatives aim to protect geodiversity, promote geological heritage, and to support local sustainable economic development, thus involving

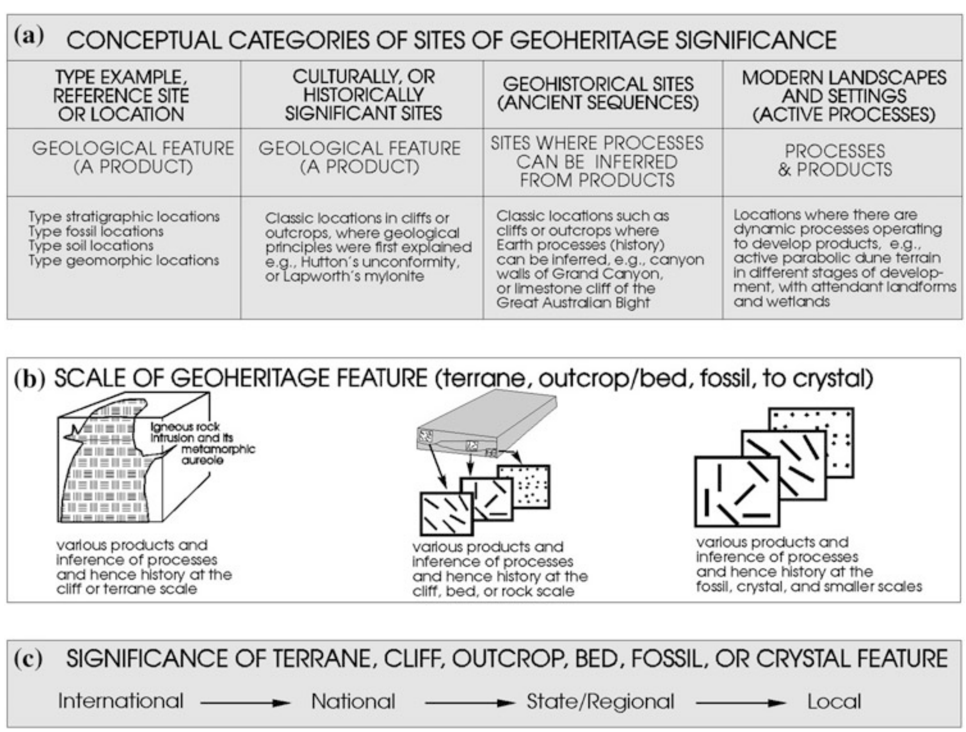

Fig. 1 The essentials of geoheritage (Brocx 2008). **a** The four categories of sites of geoheritage significance. **b** The use of scale. **c** Designating a level of significance

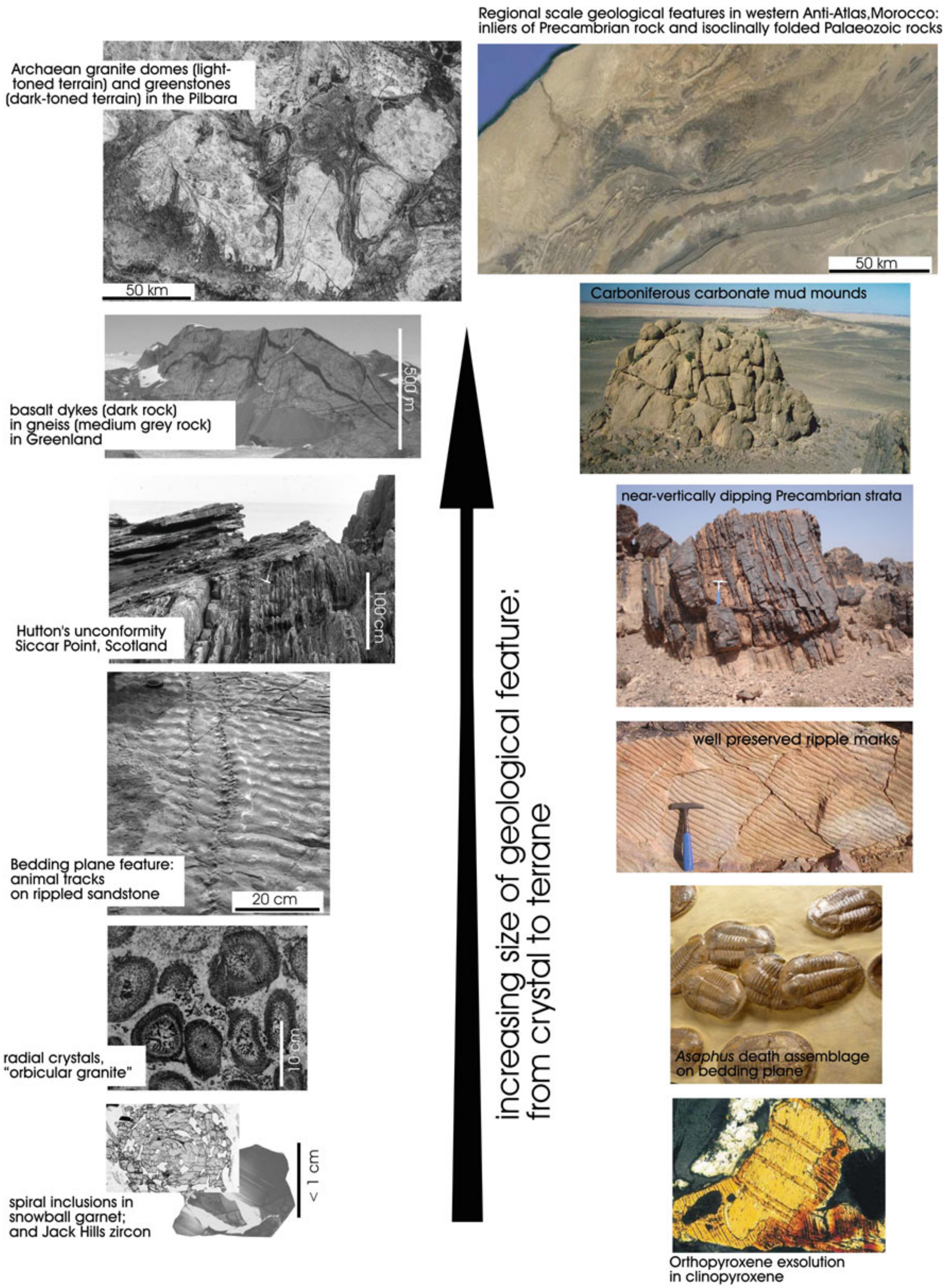

Fig. 2 Scales of geological phenomena from crystal size to montane terrains. The *left* hand side of the diagram shows the original range of features as illustrated by Brocx and Semeniuk (2007) and the *right* hand side shows examples of geological features from Morocco

community and commercial interests. We view geoparks as conservation, promotional valorization entities focused on geological and geomorphological attributes for local sustainable development. That is, to provide a comparative context and example, using a biological analogue, if a region can be conserved for its biological attributes and biodiversity,

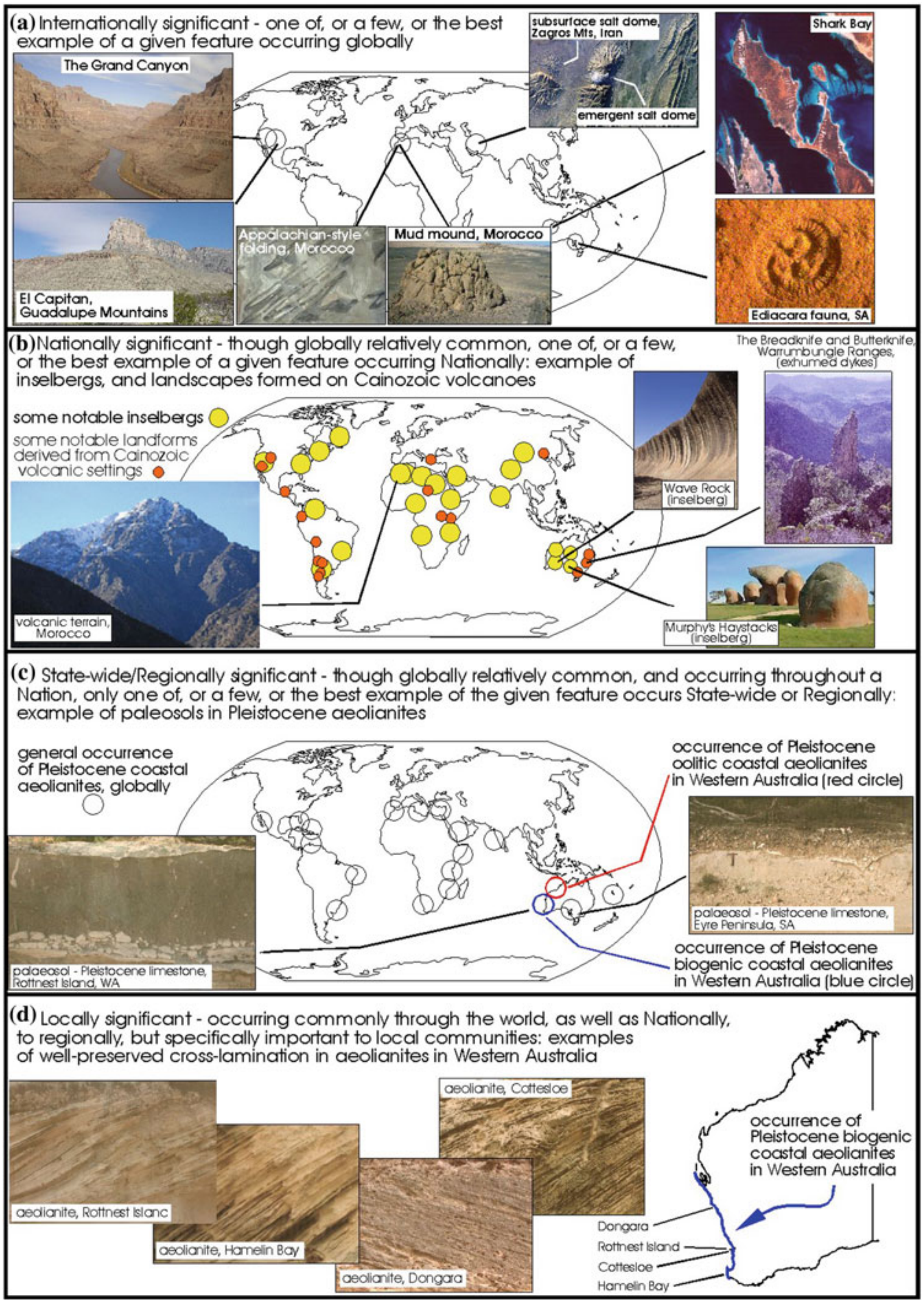

Fig. 3 Summary of criteria for assessment of level of significance, modified after Brocx and Semeniuk (2007), with added examples from Morocco for International and National significance (viz., the Appalachian-type folds, and carbonate mud mounds, and Cainozoic volcanic geology). Examples from Western Australia are used to illustrate State-wide/Regional, and Local significance

the same rationale can and should be applied to areas manifesting ensembles of inter-related significant geological and geomorphological features. The first can be considered to be worthy of conservation as a "biopark" and the second as a "geopark". Once protected in conservation parks, both can be utilised for local socio-economical sustainable development through ecotourism or geotourism (i.e., as "biotours" or as "geotours") and for Science and Education.

3 Identifying Sites of Geoheritage Significance by Defining Geological Regions and Developing an Inventory of Their Geological Essentials

There are a number of ways to identify sites of geoheritage significance. Numerous scientific works provide information as to how this has been achieved in many European countries, with the final outcome being a regional and/or a national inventory-based approach (Doyle et al. 1994; Wimbledon et al. 1995; Wimbledon 1996; De Wever et al. 2006; Brocx 2008; Garcia-Cortès and Carcavilla 2009; Lalanne and Egoroff 2012). In 2001–2002, ProGEO contributed to a number of important geoconservation initiatives that included the incorporation of a policy statement relating to the importance of geology and physical landscapes in the Pan-European Biological and Landscape Diversity Strategy, and an alliance with the International Union of the Geological Sciences (IUGS) and UNESCO for the purpose of compiling a European inventory for the geosites project (ProGEO 2002). Currently, many national and/or regional geosites inventories are in progress (Garcia-Cortès and Carcavilla 2009; Errami 2012c, Lalanne and Egoroff 2012; Errami et al. 2013a, b).

Our inventory-based approach aims to identify geological regions and their geological essentials or their fundamental geological features as a first step. Identifying the geological essentials provides an inventory of geological features characteristic of a given region that can be systematically assessed as to their significance in isolation or within an ensemble. It is important to note that not all aspects of geology of the Earth are necessarily present in any one region and, conversely, many geological regions may have unique or peculiar features. Further, many aspects of the geology of a region may be globally common but not necessarily of geoheritage significance. As such, there is a need to recognise the unique occurrence, rarity, or representativeness of some geological features and to apply some measure of significance. A geological region carries a distinctive Earth history and has a degree of geological consistency in terms of age, structural and tectonic history, and suite(s) of lithology.

The geological essentials of a region can be identified using a three-pronged approach to compile information or a database and to potentially identify sites of geoheritage significance. The first step is based on published literature. The second draws on the experience of geologists still practising in the field, providing information and personal insights about the geoheritage potential of an area. The third, after identifying gaps in information seeks to systematically obtain further information, if necessary, directly from the field. For all three approaches, there will be some degree of overlap in information and outcomes.

Identifying the various geological regions, and their characteristic, representative, unusual, or peculiar geological features, therefore, is the first stage of a systematic inventory-based approach to develop a database for sites of geoheritage significance according to the scope of geoheritage (i.e., all matters geological). This does not necessarily translate to just listing isolated sites of geoheritage significance, but also attempts to identify ensembles of features where they are inter-related. This is followed by identifying, within a given geological region, good examples, regardless of scale, of any special isolated features, or of inter-related ensembles of features. These features are assessed according to the significance criteria outlined above.

4 The Geoheritage Tool-Kit for Use in Identifying SSSI and Geological Ensembles

The Geoheritage Tool-kit provides the procedure to identify geological components across various geological sub-disciplines and at various scales, to assign geological sites to various conceptual categories of geoheritage, and to assess the levels of significance of the various geological features (Fig. 4) (Brocx and Semeniuk 2009, 2011). Once the inventory of components and their level of significance is compiled, and enough geological features have been ranked as being of significance, the last step is used to determine whether the area can be proposed for geoconservation at a regional, state, national/continental or international level for one or a few of its components, or for the integrated ensemble of its components. The area may be designated as a geosite, an SSSI or viewed as a geopark especially if it consists of a range of inter-related geological features that ranked highly in assessment of significance.

The Anti-Atlas provides a good example of the application of the principles of the Geoheritage Tool-kit as it consists of a wide diversity of geological features ranging from large to fine scale, crossing a wide variety of geological phenomena, and ranging in significance from International, National, Regional to Local.

5 The Geology of the Anti-Atlas Region

By its position at the North Western edge of the West African Craton (WAC) and at the junction between the African and European plates, and earlier at the triple-junction of the African, European, and American Plates, and its marginal history interfacing with the Tethys Sea, Morocco presents a varied and globally-important geology reflecting its successive geological settings. This provides a rich geological history largely unique globally, with a wide variety

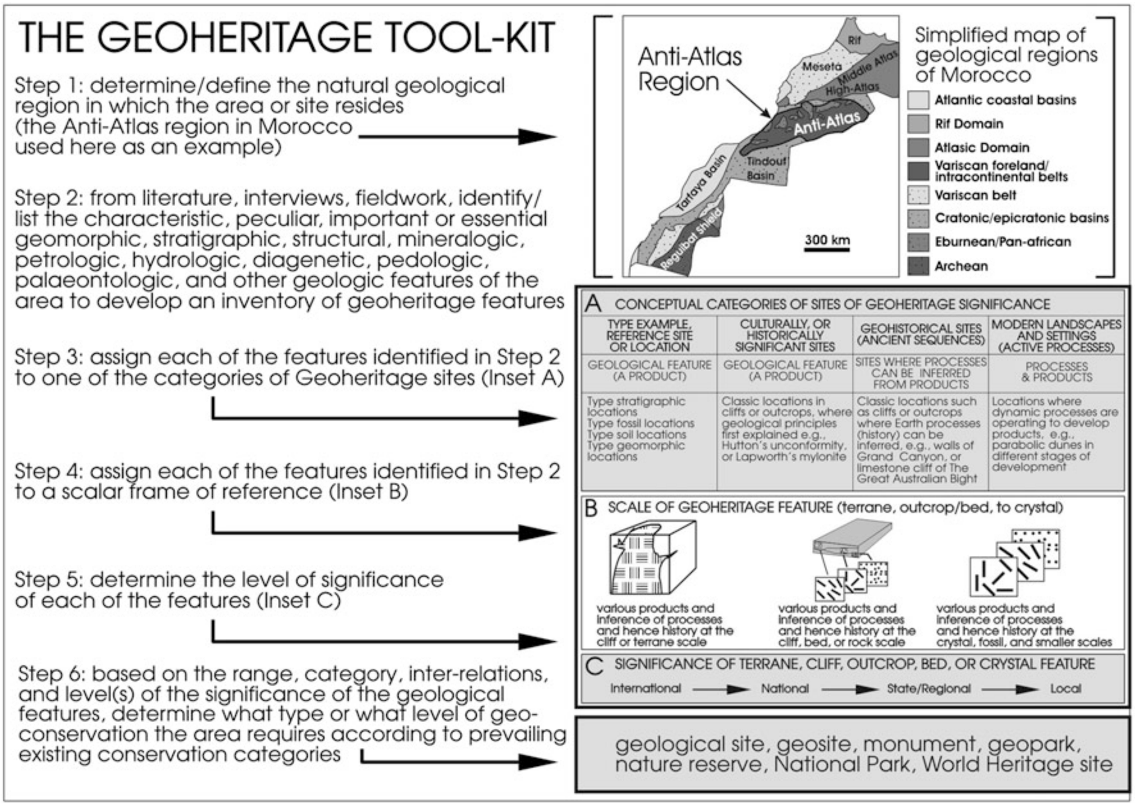

Fig. 4 The elements of the Geoheritage tool-kit showing the six steps in its application leading to assessment of types of geoconservation (modified after Brocx and Semeniuk 2011). The map in Step 1 shows the simplified geological regions of Morocco (after Michard et al. 2010) and the location of the Anti-Atlas

of geological features of various ages from Archaean to Quaternary, from large- to small-scale, and varying in significance from International to Local. The location of Morocco in semiarid to arid environment provides excellent exposures of many of these features.

Geology in the region strongly controls physiography. For example, where the folding is isoclinal, there is development of ridge-and-valley topography and linear ridges, and fold limbs develop linear ranges. Lithology plays a major part in the style of drainage and development of topography. Physiographically, the geological regions, their lithology, and the surrounding climate and earlier Quaternary climates have been and are the influences on developing the landforms. The major geological regions (whether folded and faulted rocks corresponding to tectonic belts, intrusive batholiths, or sedimentary basins) influence the development of the major physiographic regions, each with their own megascale geomorphic expression and relief. Thus the physiographic regions of the Rif, Meseta, High and Middle Atlas, Anti-Atlas, and Saharan Plateau largely correspond to the geological regions (Choubert 1963; Michard 1976; Piqué 1994; Chevalier et al. 2000; Gresse et al. 2000; Michard et al. 2008; Soulaimani and Burkhard 2008; Fig. 5).

The Anti-Atlas (AA) consists of a NE-SW-trending belt of discontinuous Palaeoproterozoic to Neoproterozoic inliers surrounded by Palaeozoic formations ranging in age from Cambrian to Carboniferous and are well exposed in large folded structures. These inliers from the SW to NE are Bas Drâa, Ifni, Kerdous, Tagragra d'Akka, Igherm, Sirwa, Iguerda, Zenaga, Bou Azzer, Saghro and Ougnat (see Fig. 5, and Thomas et al. 2004)

The AA is separated from the northern regions (Meseta and High Atlas) by a major north-east trending fault, the South Atlasic Fault which extends from the Atlantic Ocean to Gabès in Tunisia. It is classically subdivided into two main domains by the Anti-Atlas Major Fault (AAMF) (Leblanc and Lancelot 1980) and consists of variable stratigraphy, expressed in lithologically diverse formations (Leblanc and Lancelot 1980; Saquaque et al. 1989; De Kock et al. 2000; Thomas et al. 2002; Walsh et al. 2002; Inglis et al. 2004; Gasquet et al. 2005; Burkhard et al. 2006; D'Lemos et al. 2006; Raddi et al. 2007; Soulaimani and Burkhard 2008; El Hadi et al. 2011a). The Palaeoproterozoic and Neoproterozoic formations are affected by Eburnean and/or Pan-African orogenies, dated at circa 2 Ga and 700–600 Ma, respectively (Leblanc and Lancelot 1980;

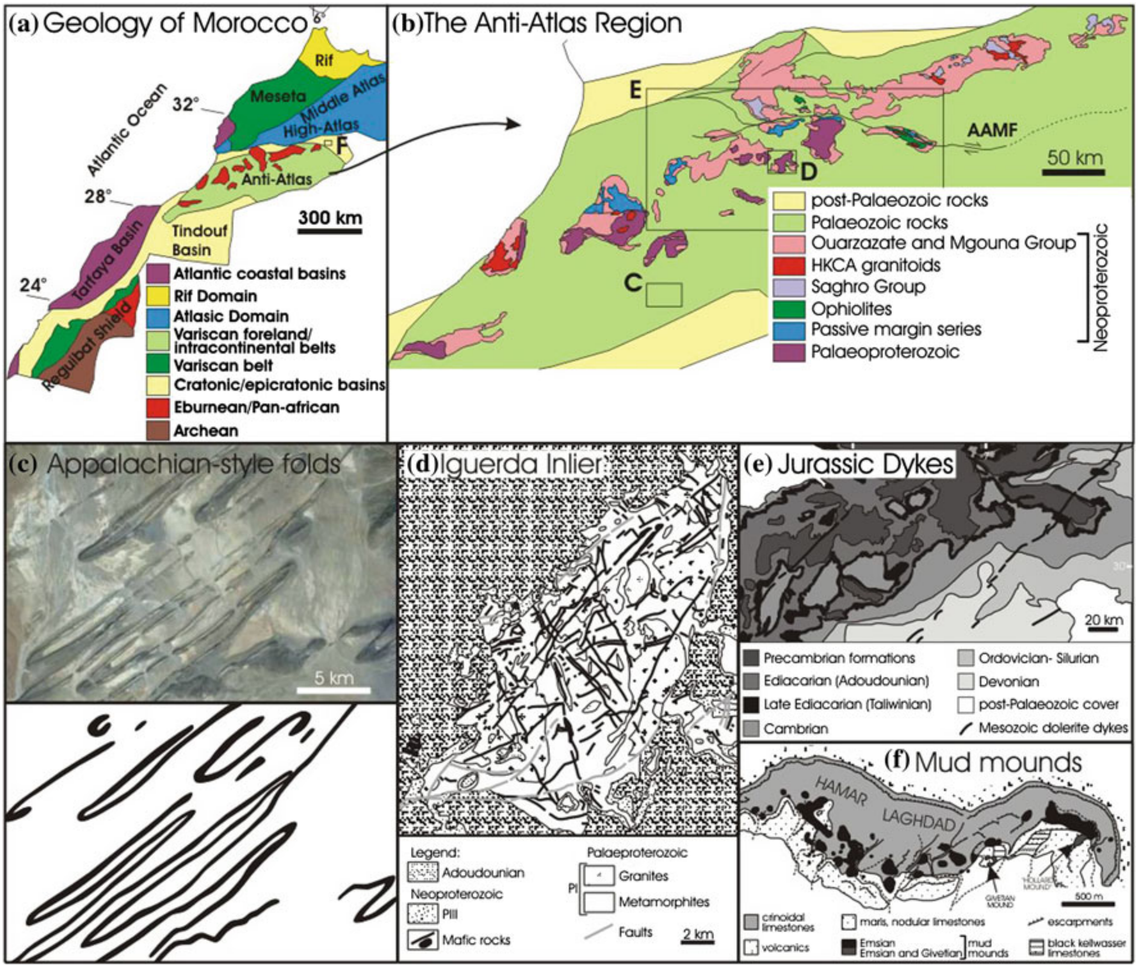

Fig. 5 **a** and **b** Simplified geological map of Morocco showing the location of the Anti-Atlas region. *Insets c–f* show some of the key features of geology of the Anti-Atlas region. **c** Map of the southern Anti-Atlas region showing Appalachian-style folds in Palaeozoic strata. **d** Detailed map of the Iguerda Inlier showing the Palaeoproterozoic inlier surrounded by Neoproterozoic and Adoudounian rocks (El Aouli and Amaouain 2010). **e** Central part of the Anti-Atlas region and the distribution of Jurassic dolerite dykes (after Touil et al. 2008). **f** Eastern Anti-Atlas region (see *Inset a* for location) showing distribution of mud mounds amid crinoidal limestone (Belka 1998)

Saquaque et al. 1989; Aït Malek et al. 1998; De Kock et al. 2000; Ennih et al. 2001b, Thomas et al. 2002, 2004; Walsh et al. 2002; Gasquet et al. 2005, 2008; D'Lemos et al. 2006). Structurally, the AA also exhibits spectacular Appalachian-style folds, ranging from open to isoclinal styles, and locally with dome-and-basin structures, varying in scale from 100 to 10 km (Helg et al. 2004; Burkhard et al. 2006). The Palaeozoic rocks commonly form dome structures around and over the Precambrian inliers.

The AA region is an important metallogenic province. Mineral occurrences are associated with faults, fractures, and igneous intrusions, ophiolites, and some with volcanic-hosted mineralisation. Several mining sites, exploited for a long time, are currently inactive while others are still active, with new mining areas being discovered. The Western Anti-Atlas hosts several gold occurrences such as Iwriren in Tagragra d'Akka inlier. In the Central Anti-Atlas, the Co–Ni–Ag–Au Bou Azzer mine, a most famous mine, has been exploited for over a century, and is still active; mineralization is hosted in serpentinites and podiform chromites (Gasquet et al. 2005). The Bleida mine, exploited for copper during the 1980s and 1990s, is currently inactive but an interesting gold concentration was discovered in fluvial sediments. The Eastern Anti-Atlas is well known for its Imiter Silver mine (Cheilletz et al. 2002). Many mining sites are internationally known for their splendid and diverse mineral deposits, with numerous specimens now in museum collections worldwide.

5.1 The Geoheritage Tool-Kit Applied to the AA to Identify Its Geological/Geoheritage Essentials and to Assess Their Significance

Morocco consists of a rich and diverse geology and geoheritage, however, an inventory in this regard is still in its early stages, despite few localized attempts by research groups from universities (El Hadi et al. 2011b; Errami 2012; Errami et al. 2013a). Numerous sites of outstanding geoheritage value are in need of preservation, e.g. specific palaeontological sites, notably those of the Palaeozoic of southeast Morocco, such as in the Erfoud and Tazarine areas, which are being over exploited either as ornamental rocks or as rare specimens sold for private collections (Errami et al. 2008; El Hadi et al. 2011b). These sites are at risk of serious deterioration.

The key geological features of the Anti-Atlas are listed in Table 1 and are important and distinctive to the region. We have not included in this list geological features such as Tertiary stratigraphy, Quaternary stratigraphy, arid-zone landforms and other geomorphology, and active, modern geological processes in the region, nor the wetlands. The focus has been on Precambrian and Palaeozoic geology involving their stratigraphy, stratigraphic relationships, tectonism, magmatism, metamorphism, structural geology, and the fossil and mineral content of the strata. Describing and assessing the geoheritage of the younger strata and landforms are beyond the scope of this work. Morocco has several type locations for lithostratigraphic sequences that areof National and or international importance.

Due to its tectonic setting, Morocco has a globally distinct and unique geology. Consequently, many of the mega-scale features of geology of the AA stand in contrast to other geological and tectonic settings. These include the extensive and well-preserved examples of plate-edge Precambrian rock sequences (e.g., ophiolites), thick and well-preserved sequences of Palaeozoic sedimentary sequences, and the tectonic relationships between Precambrian rocks and younger strata. This means that many of the mega-scale geological features of the Anti-Atlas are globally unique and significant.

At the medium and smaller scales, because of the well-preserved nature of the Palaeozoic strata in their tectonic setting and in their expression in the present arid climate setting, there is a plethora of biogenic and sedimentary features, such as Palaeozoic carbonate mounds (weathered out in relief) and biostromes, sedimentary (formational) contacts such as unconformities, sedimentary structures, and well-preserved fossils.

A description of the key aspects of these geoheritage features, in terms of their geology, their significance and their scale, whether they are a geological ensemble or an isolated feature, where the features is best developed for geoconservation as a geopark, geosite, or SSSI, and recommended area for geoconservation and what type of activity (strict geoconservation or geopark) is recommended is presented in Table 1. The key features of the geology of the AA listed in Table 1 are ordered with respect to their age. The grading of these essential geoheritage features with respect to International, National and Regional significance, and the rationale for that assessment of these geological features are also outlined in Table 1. Because of their variable size, the geological features, for purposes of geoheritage and geoconservation, will be assigned either to geosites, SSSI and/or to geoparks. Selected photos of geological features are shown in Figs. 5, 6, 7, 8, 9, 10 and 11. Some selected key features of the geology of the AA are described in text form below.

5.1.1 Corridor of Precambrian Inliers

The Anti-Atlas contains a N–E trending corridor of Precambrian inliers (Fig. 5b) surrounded by weakly-folded Palaeozoic strata. It is an unusual structural array, and the significance of this corridor is that it preserves a style of tectonics and folding existent in Palaeozoic times (and probably founded on ancestral Precambrian structures), and the contacts between Precambrian and Palaeozoic rocks, as well as their contrasting tectonic, metamorphic, and structural history.

5.1.2 The Zenaga and Iguerda Inliers

The Zenaga Inlier and Iguerda Inlier occur within the corridor of Precambrian inliers mentioned above and is a well-exposed part of the corridor (Figs. 5d and 6). They provide examples of the internal structure and lithology of Precambrian inliers and their relationship to surrounding Palaeozoic rocks. The Zenaga Inlier consists of granodiorites, syenogranites, and metamorphic rocks, with conjugate fractures and faults and mafic dykes oriented north-east, north-west, and east-west transecting the inlier (Ennih et al. 2001b). Zenaga is an example of a Palaeoproterozoic inlier that has been subjected to Eburnean and Pan-African orogenies and preserved didactic structural witnesses of both orogenies. The main part of the Iguerda Inlier is comprised of quartz diorites, granites, and metamorphic rocks, with conjugate fractures and faults and mafic dykes, oriented north-east, north-west, and east-west transecting the inlier (Fig. 5d; El Aouli and Amaouain 2010). There is a strong structural control of the mafic dykes by the fractures and faults. The margins of the inlier are sharply and discordantly truncated by the surrounding Palaeozoic rocks.

Table 1 Essential features of geoheritage that characterise the Anti-Atlas region; Categorising and grading of essential features of geoheritage significance in the AA; the rationale for the assessment and suggested allocation of the sites of geoheritage significance to geosites and SSSI, or geopark

Geological feature	Category of site (from Fig. 1)	Significance	Rationale	Geosite/SSSI, geopark
Corridor of Precambrian inliers	Geohistorical	International	The area hosting the corridor of Precambrian inliers is globally significant	As it involves an area of megascale size it would function as a mega-geopark or as numerous complementary geoparks (e.g., the Zenaga Inlier as a geopark)
Zenaga Inlier Iguerda Inlier	Geohistorical	International	Zenega Inlier and the Iguerda Inlier are of global significance. The Zenega Inlier is unique in the Anti-Atlas as it shows evidence of two orogenies (Eburnean and Pan-African). The main part of the Iguerda Inlier is comprised of quartz diorites, granites, and metamorphic rocks, with conjugate fractures and faults and mafic dykes (Fig. 5d)	The areas hosting Zenaga Inlier and the Iguerda Inlier and their immediately surrounding formations would function as geoparks
Neoproterozoic doleritic dykes (Zenaga, Central AA)	Geohistorical	International	The Palaeoproterozoic basement of Zenaga inlier is cross-cut by tholeiitic dykes that witness to the break-up of the WAC during the Pre Pan-African orogeny around 1,000–800 Ma, and are of International significance	The dyke swarms could also function as a SSSI. The inliers hosting these dyke swarms associated with the other geoheritage components could function as a mega-geopark or a series of complementary geoparks
Neoproterozoic Passive margin with its spectacular sedimentary features	Geohistorical	International	Well preserved Pre-Pan-African sedimentary features are not common globally and the hosting formations can play an important role in regional geological correlation. The whole sequence is internationally significant	The site could function as a SSSI or as could be integrated into a geopark that include the Zenaga inlier
Pan-African ophiolites of Bou Azzer and Siroua inliers, central AA)	Geohistorical	International	Viewed worldwide, Proterozoic ophiolites are globally relatively uncommon. Their occurrence and implications for Proterozoic plate-margin history also renders them globally significant	The Precambrian ophiolites are limited in size, and would function as separate SSSI. They could be also included in a thematic geopark that groups all the ophiolites of the central AA and associated phenomena
Major Anti-Atlas Fault (central AA)	Geohistorical	International	This major fault provides information on crustal tectonics that has a global significance	SSSI
Pan-African Diamictites (Bou-Azzer and Siroua inliers, central AA)	Geohistorical	International	The two Pan-African diamictites consist of mudstone with matrix-supported polymictic boulders and pebbles (Fig. 9a and b). They represent a Precambrian record of glacial conditions (Abati et al. 2010). Proterozoic glaciogene deposits are globally uncommon and of limited occurrence worldwide; as such, this deposit is globally significant	The areas hosting the Precambrian diamictites is limited in size and would function as a SSSI

(continued)

Table 1 (continued)

Geological feature	Category of site (from Fig. 1)	Significance	Rationale	Geosite/SSSI, geopark
Ediacarian Iknioun granodiorites	Geohistorical	National	The granodiorite is a particularly useful tectonic marker for the Ediacaran evolution of this part of the Anti-Atlas along the northern border of the WAC; thus the area is Nationally significant	The area hosting the contacts is limited in size and would function as a SSSI or could be included in a thematic magmatic geopark covering the eastern Saghro Inlier with its rich and varied magmatic rocks
Late Neoproterozoic stromatolites	Geohistorical	National	The late Neoproterozoic stromatolites (Fig. 8i), witness of the oldest life in Morocco (Lottaroli et al. 2009), crop out 25 km south of Ouarzazate on the road to Agdz. Proterozoic stromatolites are relatively common globally; as such, this deposit is Nationally significant	The area hosting the Precambrian stromatolites is limited in size and would function as a SSSI.
Contacts between three Pan-African Groups: Saghro, Mgouna and Ouarzazate Groups	Geohistorical	International	The contacts record the Pan-African geological history of the African crust superposition and orogenies with a variety of lithologies; this sequence is globally important	The area hosting these didactic contacts is limited in size and would function as a SSSI
Contacts between Palaeoproterozoic Zenaga complex, late Neoproterozoic Ouarzazate Supergroup and the Cambrian Tata Group	Geohistorical	National	The contact between the Palaeoproterozoic (Eburnean) Zenaga complex (ca 2 Ga), the Late Neoproterozoic Ouarzazate group volcano-clastic series (580-560 Ma) and the contact between the Ouarzazate Group and the Cambrian Tata Group are well exposed along the road to Bou-Azzer 5 km from Tazenakht village (Fig. 10). These contacts are lithologically distinct and is an interface of National significance	The area hosting the contacts would function as a SSSI
Appalachian type folding in western AA	Geohistorical	International	Appalachian-type folding is not common globally and, in a context of arid-zone weathering/erosion, the Appalachian-type folding in the Anti-Atlas is globally well-preserved; it is also distinct in folding style; as such, it is globally significant	Global Geopark
Large Cambrian trilobite *Paradoxides*	Geohistorical Cultural	International	The occurrence of this large trilobite in abundance is rare, and so this deposit assumes global significance	The area hosting the *Paradoxides* is limited in size and would function as a SSSI or could be included in the Alnif-Erfoud area to form a thematic geopark based on Palaeozoic fossils
Ordovician outcrop of Jbel Kissane	Geohistorical	National	Jbel Kissane is famous as it shows an impressive cliff of Ordovician sedimentary rock of sandstone, shale, and siltstone; it is nationally significant	Geosite
Large Ordovician trilobites (*Asaphus*) death assemblages	Geohistorical Cultural	International	The death assemblages of the large trilobite *Asaphus* occur in Ordovician shales (Fig. 2) in the eastern AA. The trilobite occurs in rippled sandstone in what appears to be a tidal sand deposit. Death assemblages of large trilobites are rare, and so this deposit assumes global significance	The area hosting the *Asaphus* is limited in size and would function as a geosite of SSSI included in the Alnif-Erfoud area in order to form a thematic geopark based on Palaeozoic fossils

(continued)

Table 1 (continued)

Geological feature	Category of site (from Fig. 1)	Significance	Rationale	Geosite/SSSI, geopark
Silurian and lowermost Devonian *Orthoceras*-rich limestones and ammonite-rich limestones	Geohistorical Cultural	International	These deposits are globally distinct and well known and of limited occurrence worldwide; as such, it is globally significant	Both areas hosting *Orthoceras* and goniatites are limited in size and would function as SSSI or could be included in the Alnif-Erfoud area to form a thematic geopark based on the varied Palaeozoic fossils
Early Devonian Kess Kess carbonate mounds	Geohistorical	International	The geology and setting of these unique carbonate mounds provide insight into Devonian ecology and submarine conditions render it a feature of global significance	The site could be considered as SSSI
Middle Devonian coral-stromatoporoid biostrome	Geohistorical	International	This site is one of a limited number of such biostromes and in this context it is globally important	The site and its surrounding stratigraphy would function as SSSI
Green eyes and red Devonian phacopid trilobite	Geohistorical	International	Colour preserved in fossils is rare, and so the occurrence of Devonian phacopid trilobite with green eyes and red colouration from the Hmar Lakhdad (Tafilalt) area, as described by Klug et al. (2009), is significant. Additionally, the eyes of the trilobite still show faceting. The occurrence of these fossils is of International significance	The area hosting the phacopid trilobite is limited in size and would function as a SSSI or could be included in the Alnif-Erfoud area in order to form a thematic geopark based on the varied Palaeozoic fossils
Frasnian plants from the Drâa Valley	Geohistorical	International	Devonian plants are rare globally and point to the early history of plant life on the planet. Thus, the Frasnian plants from the Drâa Valley occurring in marine shales are of global significance	The area hosting the Devonian plants is limited in size and would function as a SSSI
Well preserved shallow-water sedimentary features in Cambrian rocks	Geohistorical	National	Cambrian sedimentary structures are not common globally, and so these geological features, though limited in size and outcrop, and are localised, assume National significance	Geosite
Foum-Zguid Jurassic dyke	Geohistorical	International	Its geological setting renders the Foum-Zguid Jurassic dyke a feature of global significance	The area hosting Foum-Zguid dyke is megascale in size and would function as a geopark.

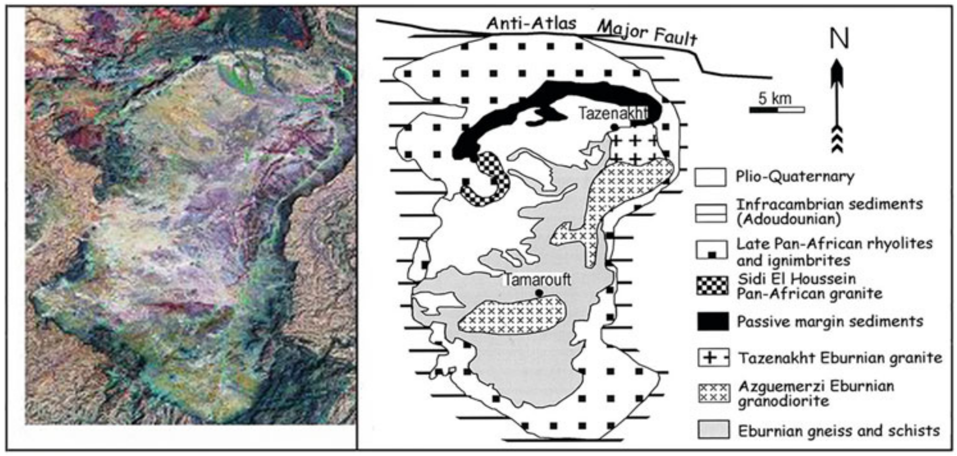

Fig. 6 Landsat TM image of the Zenaga Inlier showing the Palaeoproterozoic surrounded by the Neoproterozoic volcano-sedimentary rocks and Palaeozoic sediment cover (Ennih et al. 2001b)

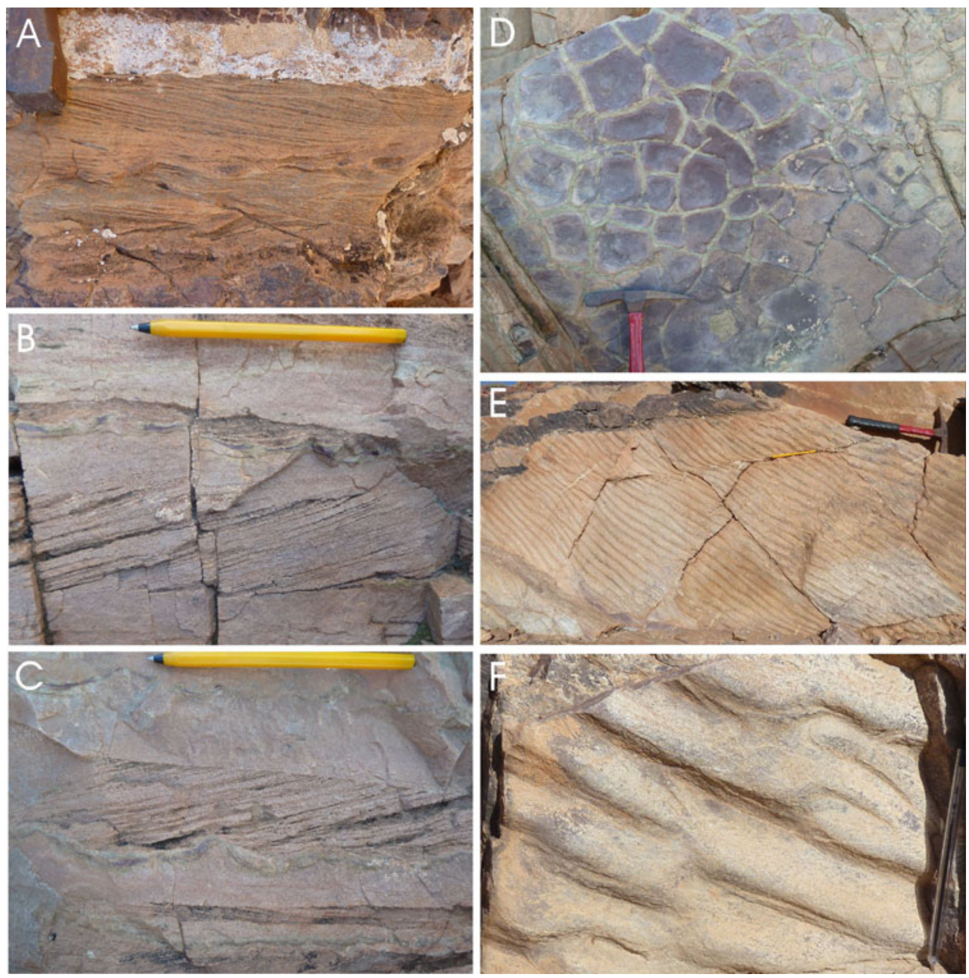

Fig. 7 Sedimentary structures of the Precambrian rocks of the Taghdout Group in the Anti-Atlas. **a** Complex of ripple-drift lamination, and ripple lamination in sandstone (**b**) and (**c**). Small scale ripple lamination, horizontal lamination, mud drapes, buried ripple bedforms, and larger-scale cross lamination. **d** Mud cracks exposed on a bedding surface—the cracks are filled with syndepositional sand. **e** Rippled sandstone. **f** Close-up of rippled sand showing asymmetric ripples

5.1.3 Neoproterozoic Doleritic Dykes (ca 1,000–800 Ma)—Witness of the Break-Up of the WAC During the Pre-pan African Orogeny

The Palaeoproterozoic basement of the Zenaga inlier is cross-cut by tholeiitic dyke swarms in N–S, NW-SE and NE-SW directions (Ennih et al. 2001a; Hafid et al. 2001). These dykes consist mainly of gabbro, dolerite and trachy-andesites. They often preserve their original texture and their primary mineralogy, in spite of a secondary hydrothermal alteration under greenschist facies (epidotization, hematitization) probably related to the Pan-African orogeny. The primary mineral assemblage consists of plagioclase, clinopyroxene (augite), very rare orthopyroxene, ilmenite, apatite,

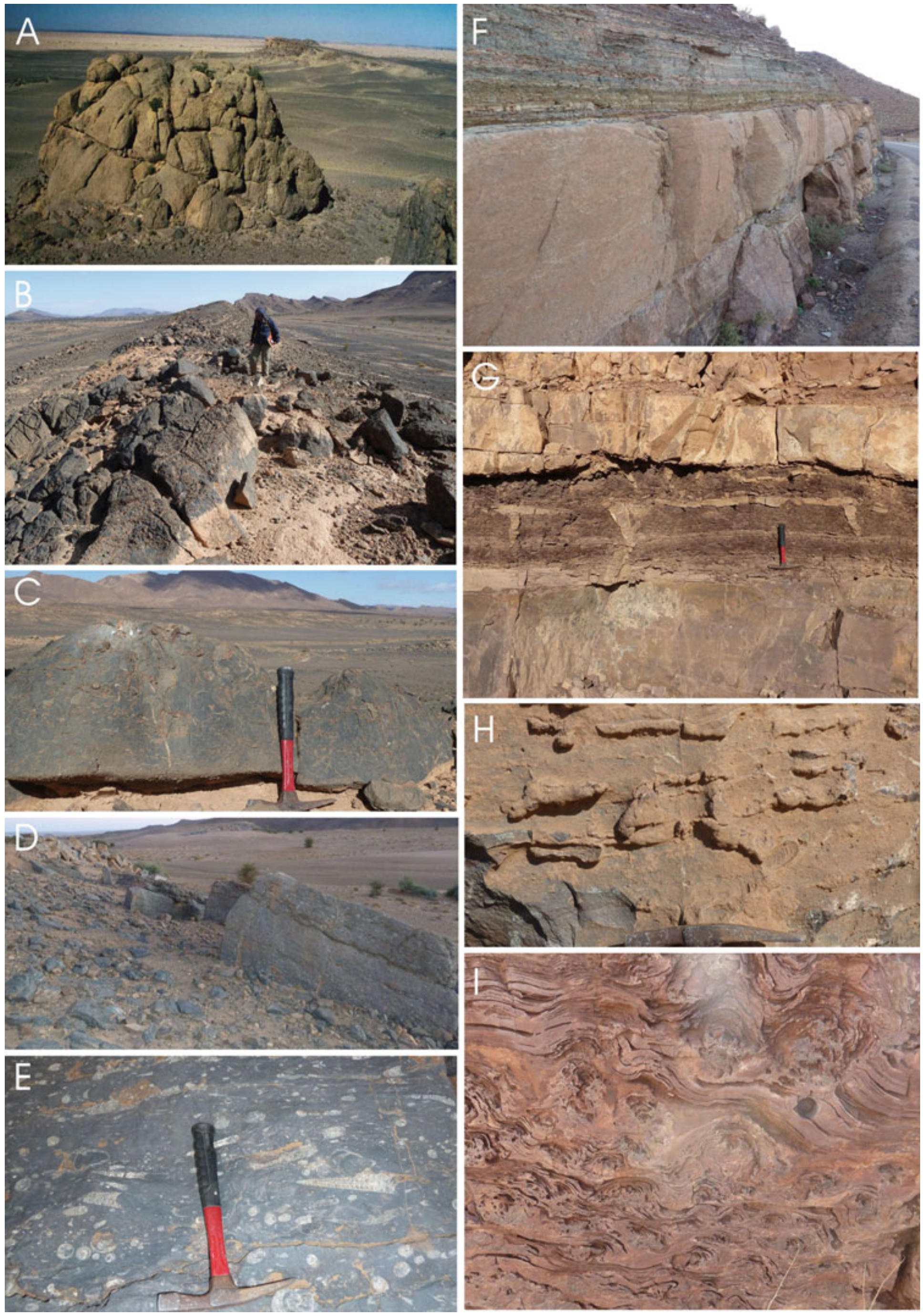

Fig. 8 Examples of stratigraphy and sedimentary features in strata of Proterozoic to Devonian age in the Anti-Atlas. **a** Kess Kess mud mound. **b** Hill-capping Devonian coral-stromatoporoid biostrome limestone. **c** Close-up of coral-stromatoporoid biostrome limestone. **d** Outcrop of Orthoceras-bearing limestone. **e** Close-up of *Orthoceras*-bearing limestone showing current-oriented *Orthoceras*. **f** Stratiform sheets of Cambrian sandstone and shale. **g** Sand dykes in Cambrian sandstone and shale sequence. **h** *Horizontal* and *vertical* burrows in Devonian Goniatite-bearing limestone. **i** Lamination in Proterozoic stromatolites (vertical section)

micropegmatite, hornblende and biotite. The secondary mineralogy includes albite, chlorite, actinolite, epidote, sphene, calcite and quartz. These doleritic dykes are occasionally deformed where they are intersected by mylonite. These basic rocks are also interbedded in the sedimentary passive margin series. Similar basic rocks were defined in the western Anti-Atlas inliers (Iguerda, Tagragra d'Akka, Bas Dràa, Ighrem and Kerdous) and are described as witness of the break-up of the WAC during the Pre-Pan-African orogeny around 1,000–800 Ma.

5.1.4 Neoproterozoic Passive Margin Series (Taghdout Group) with Its Well-Preserved Sedimentary Features (ca 800 Ma) and Its Pre-Pan-African Doleritic Sills

Neoproterozoic (ca 800 Ma) volcano-sedimentary sequences of the northern rifted margin of the WAC are exposed in the central and western Anti-Atlas inliers. The Zenaga Eburnian gneisses are overlain in their northern edge by Neoproterozoic quartzite and carbonate rocks with interbedded continental tholeiitic basaltic lavas. These sedimentary rocks are

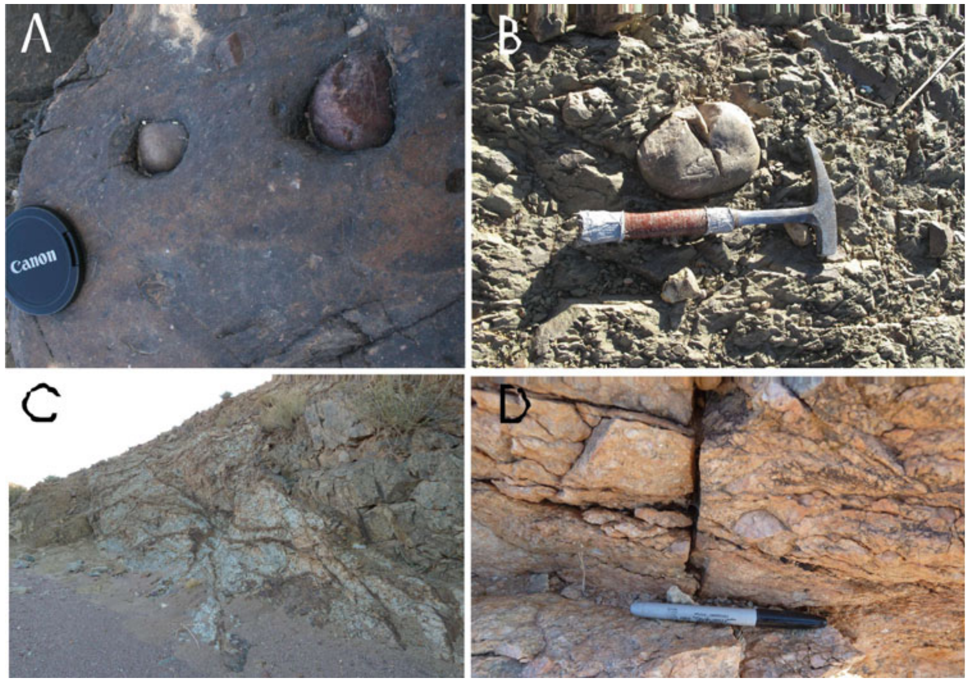

Fig. 9 **a** and **b** The diamictite from the Bou-Azzer inlier (**a**) and from the Siroua inlier (**b**). **c** and **d** Features of the Anti-Atlas major fault. **c** Shear zone with network of sigmoidal slip surfaces; the shear zone transects shales (which are splintered) and diamicitite. **d** Closeup of conglomerate within the shear zone with fracture surfaces and fragmented pebbles

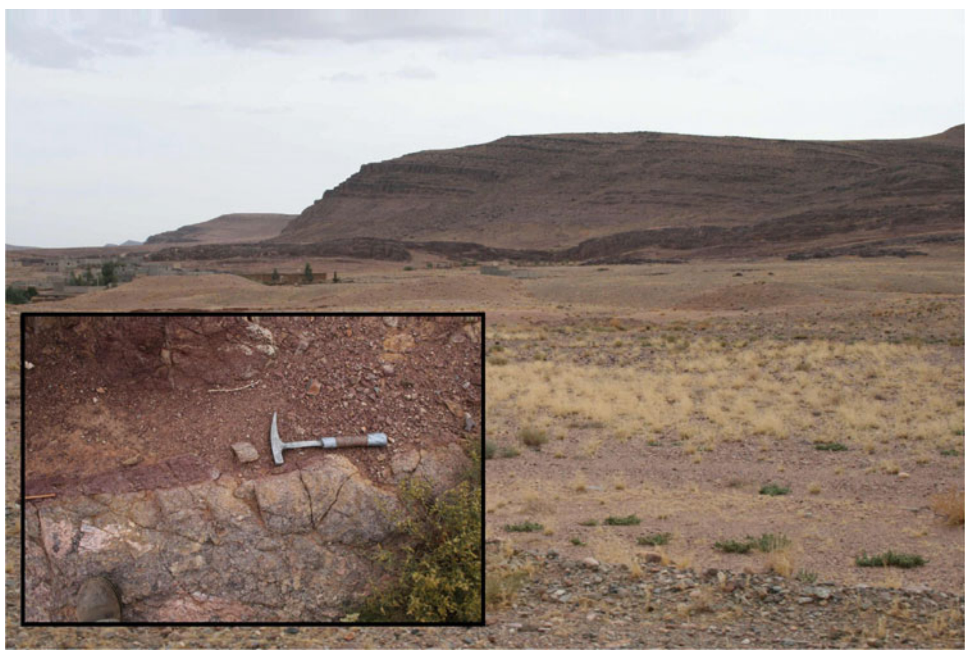

Fig. 10 Overview of contact between Palaeoproterozoic basement and Ouarzazate Group and the Tata Group. *Inset* shows contact marked by micro-conglomerates and thin layers of rhyolitic tuff

Fig. 11 Jbel Kissane showing well layered sequence of sedimentary rocks of Ordovician age

composed of limestones, jaspilites and quartzites where spectacular shallow-water sedimentary features (ripple marks, mud cracks, cross-bedding) are well preserved (e.g., at Jbel Mimount) (Fig. 7). The stromatolitic strata and cross beds, and occasional herring-bone cross-stratification indicate that this series was deposited in a shallow marine-tide and wave-agitated environment.

5.1.5 Bou Azzer Pan-African Ophiolite (Bou Azzer Inlier, Central AA)

The Bou-Azzer ophiolite, an old fragment of oceanic crust (697 ± 8 Ma; El Hadi et al. 2011a), is a witness of the Pan-African suture marking the boundary between the Palaeoproterozoic Eburnean basement forming the WAC in the south and the Neoproterozoic accreted arcs to the north. This ophiolite plays an important role in the geodynamic interpretations of the AA during the Pan-African orogeny that occurred between 650 and 580 Ma (Leblanc 1976, 1981; Bodinier et al. 1984; Saquaque et al. 1989; Hefferan et al. 2000; Admou et al. 2002; Gasquet et al. 2005; D'Lemos et al. 2006; El Hadi et al. 2011a; Ouanaimi and Soulaimani 2011). The ophiolite consists of serpentines (mainly harzburgites with chromite pods), gabbroic cumulates and gabbros, and limited sheeted dyke complexes. Only rare metasediments associated with volcanic layers are found on top of the oceanic complex (e.g., Ambed Co-bearing calcareous jaspers). The ophiolite sequence was obducted onto the WAC during a southward-dipping subduction (Leblanc and Lancelot 1980) or northward-dipping subduction (Saquaque et al. 1989). It hosts the famous Co–Ni–Ag–Au Bou Azzer mine.

The unusual character of this Neoproterozoic magmatic and tectonic geoheritage site, together with the excellent quality of the outcrops in a desertic landscape of ca 15 km length and 4 km width and the relatively easy access to the area, make this complex attractive from both a scientific, an educative and a geotouristic perspective (El Hadi et al. 2011b).

5.1.6 The Khzama Pan-African Ophiolite (Siroua Inlier, Central Anti-Atlas)

The well-preserved Pan-African dismembered Khzama ophiolitic complex, an old oceanic crust, forms a 4 km wide E-W-striking outcrop. Geochronological data give an age of 760 ± 1 Ma for Khzama plagiogranite that cross-cuts the ophiolite (Admou et al. 2002; Samson et al. 2004). The ophiolitic complex is partly bound by normal faults and is covered either by the Ouarzazate Group or by the Neogene Siroua volcanic rocks. The complex comprises mantle harzburgites, and a crustal sequence typical for oceanic ridges, including layered gabbros and sheeted dykes beneath the pillow basalts section. Only rare metasediments associated with volcanic layers are found on top of the oceanic complex (e.g., keratophyric tuffites and flows). It is composed of a succession of metamorphosed ultramafic rocks and minor acid volcanic and plutonic rocks (Schermerhorn et al. 1986; Wallbrecher 1988; El Boukhari et al. 1991, 1992; Admou and Soulaimani 2011). It consists of serpentine and talc schist, hornblendite and tremolite schist, amphibolites as well metamorphosed quartz keratophyre and plagiogranite. Khzama ophiolite is of tholeiitic affinities (El Boukhari et al. 1991, 1992). Schermerhorn et al. (1986) concluded that the ophiolite sea-floor spreading was in a fore-arc environment, also borne out by the high-Mg low-Ti boninitic nature of the ophiolite.

5.1.7 The Major Anti-Atlas Fault (Central Anti-Atlas)

The Anti-Atlas Major Fault, located south of the South Atlas Fault, is an important fault in Morocco (Fig. 9c, d), which provides information on crustal tectonics that has global significance. The fault is underlain by Bou-Azzer and Siroua ophiolitic complexes and has been viewed formerly as separating two geological domains in the Anti-Atlas, namely, the Pan-African domain 600–700 Ma in the North-East and the ∼2 Ga Eburnian domain in the South-West (Leblanc and Lancelot 1980; Saquaque et al. 1989). Recent studies by Ennih and Liégeois (2001), Gasquet et al. (2008), Errami et al. (2009) on the Zenaga and Saghro inliers suggest that the Eburnian and Pan-African materials occur throughout the Anti-Atlas region and that the entire Anti-Atlas is underlain by Eburnian crust, unconformably overlain by a lower Neoproterozoic passive margin. Allochthonous Pan-African ocean crustal slices were thrust onto the WAC passive margin sequence ∼685 Ma ago as a result of Pan-African accretionary tectonics.

5.1.8 Ediacaran Iknioun Granodiorite (Eastern Anti-Atlas)

The Ediacaran Iknioun amphibole-bearing granodiorites are intruded into the Saghro Group volcano-sedimentary formations and are intruded by the Iskn'Allah pink granite and covered by ignimbrite/rhyolite flows of Jbel Amalou'n Mansour. The area is providing didactic contacts between the main Ediacaran formations of Eastern Saghro, Saghro and Ouarzazate Groups (Errami et al. 2011) It hosts basic rock enclaves that point to a mixed origin for these granitoids (Errami et al. 2009). Iknioun granodiorite displays a regular pattern of magmatic lineations and foliations determined through the anisotropy of magnetic susceptibility (AMS) study. S-sigmoid features outlined by these lineations and top-to-the-SE movements in the adjacent country rocks show that the emplacement of this pluton was related to the E-W-trending dextral transpressive movements previously described in the Saghro inlier. Consequently, this pluton appears as a particularly useful tectonic marker for the Ediacaran evolution of this part of the Anti-Atlas which constituted the northern border of the WAC (Errami and Olivier 2012).

5.1.9 Imider Geosite: Contacts Between Three Pan-African Groups: The Saghro Group, Mgouna Group and Ouarzazate Group

This site, occurring in the eastern Saghro inlier, shows spectacular contacts between the three main Pan-African formations (Saghro Group, Mgouna Group and Ouarzazate Group). The Mgouna Group, which discordantly covers the volcano-sedimentary Saghro Group and the associated HKCA granodiorite, consists of a volcano-sedimentary sequence formed mainly by arkose, micro-conglomerates, sandstones, tuffs and pyroclastites (Chakir et al. 2007; Otmane et al. 2007). The conglomerates occupying the summit of hills in the area of outcrop marks the limit between Mgouna and Ouarzazate Groups. The Mgouna Group is covered discordantly by the Ouarzazate Group which consists mainly, in this part of the Anti-Atlas, of ignimbrite and rhyolite. The emplacement of these volcanic rocks and the basic dykes, which cross-cut all the Neoproterozoic formations, has occurred along sinistral faults during the late Pan-African Orogeny (Azizi et al. 1990; Otmane et al. 2007). This site gives an overview about the geological evolution of this part of the AA during the Neoproterozoic time (Errami et al. 2011).

5.1.10 Appalachian-Type Folding in the Western Anti-Atlas

The south-west of the AA manifests large-scale folding of the Appalachian style, best exposed in the southwest region in the vicinity of Guelmim-Es Smara (Fig. 5c). The Appalachian-type folding in this region extends over an area of 500 km long by 50 km wide. The rocks involved in the folding are Palaeozoic sequences, with the limbs of the folds moderately inclined, and fold axes generally oriented NE-SW. In the arid, vegetation-sparse setting of Morocco, the folds are well exposed. Helg et al. (2004) consider that this folding represents a special type of foreland fold belt with a striking absence of observable thrusts. In terms of folding and deformation style, they recognize four structural units with different wave lengths and amplitudes, corresponding to four distinct stratigraphic levels, separated by the thick incompetent units of the Middle Cambrian, Silurian, and Upper Devonian respectively. Helg et al. (2004) consider that the Anti-Atlas folded Palaeozoic rocks are similar in tectonic style to the Appalachian Valley and Ridge province.

Appalachian-type folding is not common globally. There are a limited number of locations where it is best developed, for instance, in the Appalachian Mountains of the USA, comprising Palaeozoic rocks such as clastic sedimentary rocks, dolomite and limestone, in the MacDonnell Ranges in central Australia, comprising Proterozoic rocks such as shale, dolomite and chert, in the Capricorn Ranges in the southern Pilbara region of Western Australia, comprising Proterozoic rocks such as shale, dolomite and chert, in the King Leopold Ranges in the south-western Kimberley of Western Australia, comprising Proterozoic rocks such as quartzite, other metasediment, shale, and ironstone, along the eastern margin of the Andes Mountains, and in the northern Sahara to southern Algeria region, comprising Proterozoic rocks. Not all Appalachian-type folding is comparable because, in the different regions, there are differences in rock types, ages, and styles of metamorphism. The limited range of Appalachian-type folding worldwide means that those of the Anti-Atlas are globally significant. Additionally, each region of Appalachian-type folding worldwide, though broadly similar, have details of smaller scale effects and lithological response that renders each region globally distinct and, as such, in this context, the Appalachian-type folding of the Anti-Atlas become further globally significant.

5.1.11 Large Cambrian Trilobite *Paradoxides*

Large *Paradoxides* occur in the middle Cambrian rippled sandstone such as in the Bardou Mountain area (Eastern AA). The trilobites are in various degrees of taphonomic preservation (from complete to disarticulated fossils). The local population considered, until the beginning of the 1970s, that collecting trilobites brought bad luck which actually resulted in their preservation and protection, until foreign tourists collecting these fossils changed this tradition.

5.1.12 Ordovician Outcrop at Jbel Kissane

The eastward view from Agdz on the Jbel Kissane is famous as it shows an impressive Ordovician sedimentary rock pile which consists of shale and sandstone of Arenig and Lianvirn age, sandstones of the 1st Bani (Llandeilian age) followed by the mudstone, shale and siltstone of the Ktaoua Formation (Caradocian age), and the sandstone of the 2nd Bani (Ashgillian age) in the summit (Fig. 11). Jbel Kissane forms the perched syncline core of the east-trending synclinorium which extends between Bou-Azzer and Saghro Precambrian antiforms.

5.1.13 Silurian and Lowermost Devonian Orthoceras-Rich and Ammonite-Rich Limestones

Upper Silurian black limestones containing current-oriented *Orthoceras* occur in the Eastern AA in the Serdrar Mountain locality (Fig. 8d, e). Locally, the limestones are linked to

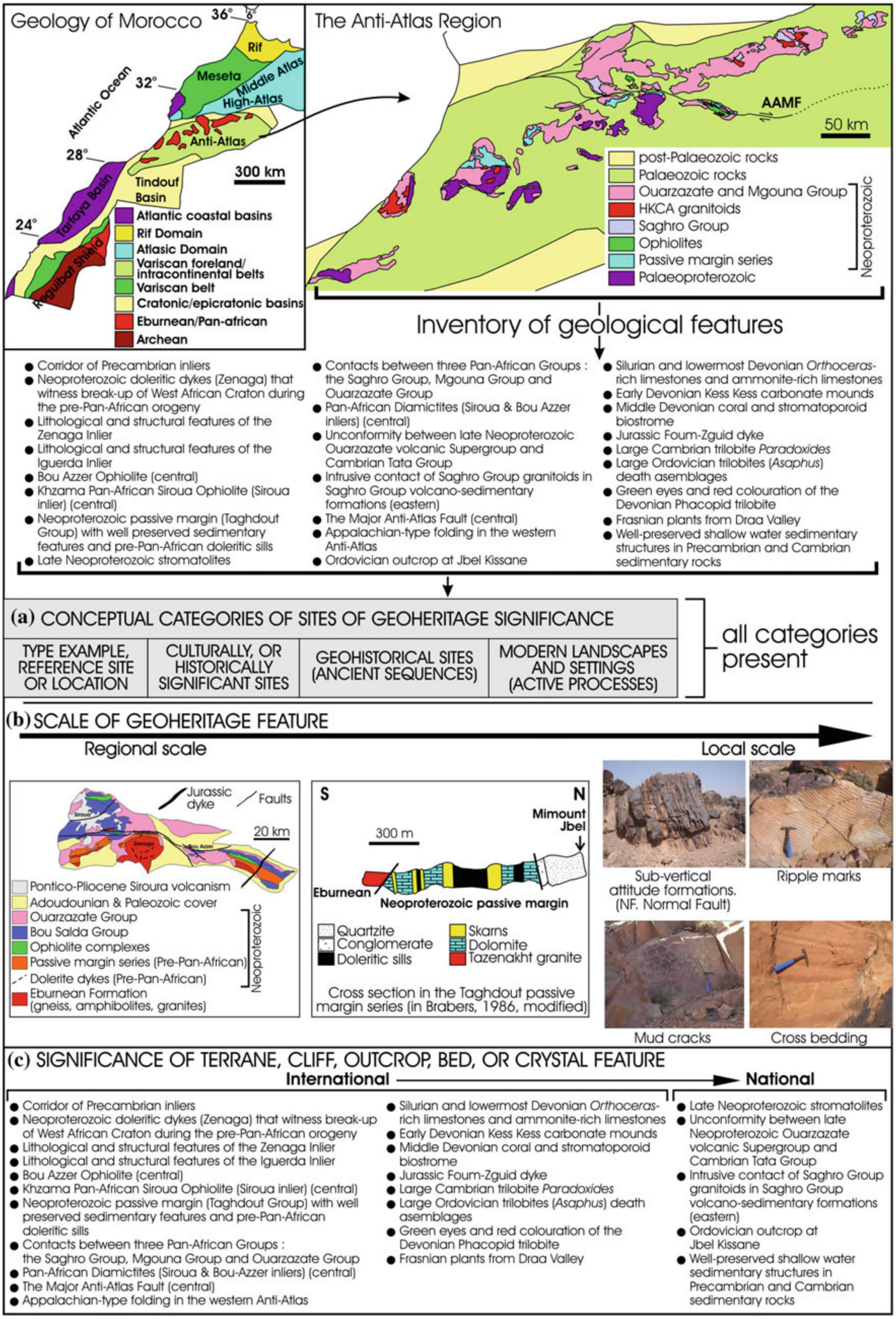

Fig. 12 The Geoheritage tool-kit of Fig. 4 applied to the Anti-Atlas. In *inset a*, categories of geoheritage applicable to this area are highlighted in grey (four categories of sites are present in various localities in the Anti-Atlas). In *inset b*, selected geological features that have geoheritage significance from the Anti-Atlas are illustrated, graded in decreasing scale from *left* to *right*. In *inset c*. all features listed in Table 1 are allocated to a level of significance

cultural legends, where the fossils are seen as "demon plates". The fossil-bearing limestones are internationally well-known as ornamental rock, and fossil-collecting localities. Nearby in the Ighes locality, there are Devonian goniatitic limestones that also contain current-oriented *Orthoceras* and lesser numbers of several species of goniatites. The limestones are skeletal lime wackestone, and some calcarenite, and are burrowed with horizontal and fine vertical burrows, some of which disrupt the current-oriented *Orthoceras*.

5.1.14 Early Devonian Kess Kess Carbonate Mounds

Early Devonian Kess Kess carbonate mounds have been described in the eastern Anti-Atlas by Wendt et al. (2001) and Steven et al. (2002) (Figs. 5f and 8a). They are submarine mounds comprised of skeletal wackestone and lime mudstone, with crinoids, sponges, and bryozoans. From their lithology and facies relationships, four types of mounds are recognised (Wendt et al. 2001): 1. Massive crinoidal wackestone or packstones without stromatactis; 2. Massive crinoidal wackestone or packstones with rare stromatactis; 3. Similar to (2), but allochthonous; and 4. biodetrital (skeletal) grainstone mounds. The mounds stand a few metres to some 30 m emergent above the sea floor, and appear to have been initiated above submarine hot water vents (Cavalazzi 2006).

5.1.15 Middle Devonian Coral and Stromatoporoid Biostrome

A well-preserved and extensive Middle Devonian coral-stromatoporoid biostrome, some 0.5 m thick, outcrops in the Eastern Anti-Atlas (Tamjout n'Ouihlane area) (Fig. 8b, c). The limestone is black lime mudstone with a coral-stromatoporoid skeletal frame, with hemispherical to platy *Favosites* and platy stromatoporoids. The outcrop in the Tamjout n'Ouihlane area shows a vertical and lateral variation in biofacies and lithofacies. Devonian coral and/or stromatoporoid biostromes occur throughout the globe, but are not common.

5.1.16 Well-Preserved Sedimentary Structures in Cambrian Sedimentary Rocks

In various locations throughout the Palaeozoic sequences in the AA, there are occurrences of well-preserved shallow water sedimentary structures. These include mud cracks, rippled sandstone, flaser bedding, wavey lamination, ripple-drift lamination, cross-bedded sandstone, and herringbone structures, and sandstone dykes cutting into a shale sequence, and tidal flat sediments with their array of tidal flat sedimentary structures in Cambrian Tata Group. A selection of these sedimentary features is illustrated in Figs. 7, 8f, g. Cambrian sedimentary structures are common globally, and assume National significance.

5.1.17 Foum-Zguid Jurassic Dyke

The Jurassic Foum-Zguid doleritic dyke, some 120 m wide and over 150 km long, occurs in the central part of the AA (Fig. 5e), and traverses a variety of Precambrian and Palaeozoic sequences (Ouanaimi and Soulaimani 2011). The dyke has been studied from the perspective of its lithology, its internal flow structures, structural relation to enclosing rocks, and metamorphism of the host rocks (Rahimi 1988, Silva et al. 2004, 2010).

5.2 Sites of Geoheritage Significance Allocated to Geosites, to SSSI or to a Geopark

As outlined above, the Geoheritage Tool-kit is used to determine whether an area can be proposed for geoconservation at a Regional, National or International level either as a geosite, a SSSI, or as a geopark. If a geological site is relatively small, and consists of geological features that are not extensive (e.g. a fossil site, sedimentary structures, etc.), depending on their significance, the area may be designated as a geosite (e.g., sedimentary features in Cambrian rocks), or a SSSI (e.g., the coloured phacopid trilobite). These would be small, isolated occurrences of a given important geological feature. In the Anti-Atlas, there are numerous sites that can be designated as geosites or SSSI (Table 1). The results of applying the Geoheritage Tool-kit to the Anti-Atlas are summarised in Fig. 12.

If there are a number of geological features in an area (e.g., the corridor of Precambrian inliers), or if an area manifests an integrated ensemble of geological features (e.g., Zenaga Inlier, Errami et al. 2013a), or if the geological feature is expressed over a large area (e.g., the Appalachian-style of folding), the geological feature(s) or the ensemble may qualify to be viewed as a geopark. The area may be proposed for geoconservation as a geopark especially if there is a range of inter-related geological features that all ranked highly in assessment of significance.

Given the range of inter-related geological features in the AA region, there is a need for geoconservation of individual features and for an integrated geoconservation system of these inter-related ensembles. Thus, in terms of geoconservation, addressing the various features of geoheritage value in different areas of the AA that individually rank from Regional, National to International significance, can be best achieved in many locations by viewing systems as geoparks. In this context, many areas should be viewed as Global geoparks, or African geoparks, or National and/or Regional geoparks. Table 1 lists areas and geological features that are fulfilling criteria for geoparks.

6 Conclusion

The preliminary inventory of sites of geoheritage significance of the AA geological region, using the Geoheritage Tool-kit approach, assigns a level of significance to geological features and, from there, they can be allocated to geosites, to Sites of Special Scientific Interest (SSSI) and/or to geoparks. The geology of the Anti-Atlas was used as a case study because it contains a wide variety of geological features ranging in size from regional scale to fine scale, and varying in significance from International to Regional. Thereafter, in the geoconservation of the identified geosites, SSSI, and potential geoparks, the next step is to inscribe these sites as formal geoconservation sites, and to integrate some of them into the cultural context of the region. For instance, the first interpretative panel of the Bou-Azzer inlier is in progress in collaboration with a local association. The next stage for geoconservation and geoheritage in the Anti-Atlas is to focus on each inlier to identify further sites of geoheritage significance (Errami et al. 2013a).

This paper has emphasised the unique geological setting of Morocco, and the global importance of many sites within the Anti-Atlas. In this context, given their importance, and the current commercial and tourist exploitation of numerous sites, it is clear that many geologically-important areas are in urgent need of protection. All fossiliferous sites are in this category. Adequate capacity building of the local communities and stakeholders will help to increase the awareness about the necessity for the protection and valorisation of their geoheritage.

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