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A (Digital) Future for Saharan Rock Art?

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Abstract First visited by westerners in the mid-nineteenth century, Saharan rock art has since received a great deal of attention. The richness and diversity of this region is recognised by the inclusion on the UNESCO World Heritage list of three properties: Tassili-n-Ajjer in Algeria, Tadrart Acacus in Libya, and Ennedi in Chad. The situation in many North African countries now makes this vast region very difficult to access: safety in the field is not guaranteed and few research funds are available. Today, a new generation of African and foreign scientists has no access to rock art sites in the north of the continent and the lack of fieldwork may entail a lack of safeguard and awareness. The growth of digital technologies over the last 15 years has revolutionised methods for recording rock art sites. Digital technologies are also used to mitigate the gap between artworks and accessibility in those countries where turmoil and social instability make fieldwork impossible. However, much of the documentation and most digital recordings of artworks currently available on the Internet lack an archaeological context. Equally, many of these websites barely mention methodological and theoretical aspects. It is also difficult to understand the extent of awareness among local communities in remote areas—sometimes suffering a digital and linguistic divide—and if (and how) they are genuinely able to exploit these digital resources. Here, I collate some examples from different parts of the Sahara illustrating that the recording, management and dissemination of rock art still present highs and lows. I argue that we should share theories and methods within the digital scientific community, with a view to adopting a shared nomenclature and a public thesaurus, making our cataloguing criteria explicit and, finally, developing an ethical code of conduct involving local communities.

Résumé L'art rupestre saharien, visité pour la première fois par les occidentaux au milieu du XIXe siècle, a reçu beaucoup d'attention depuis lors. La richesse et la diversité de cette région sont reconnues par l'inscription sur la Liste du patrimoine mondial de l'UNESCO de trois biens: Tassili-n-Ajjer en Algérie, Tadrart Acacus en Libye et Ennedi au Tchad. La situation dans de nombreux pays d'Afrique du Nord rend cette vaste région très difficile d'accès: la sécurité sur le terrain n'est pas garantie et peu de fonds de recherche sont disponibles. Aujourd'hui, une nouvelle génération de chercheurs africains et étrangers n'a pas accès aux sites d'art rupestre dans le nord du continent et le manque de travail sur le terrain peut entraîner un absence de sauvegarde et de sensibilisation. La croissance des technologies numériques au cours des 15 dernières années a révolutionné les méthodes d'enregistrement des sites d'art rupestre. Les technologies numériques sont également utilisées pour combler le fossé entre les œuvres d'art et l'accessibilité dans les pays où les bouleversements et l'instabilité sociale rendent le

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travail de terrain impossible. Cependant, une grande partie de la documentation et la plupart des enregistrements numériques d'œuvres d'art actuellement disponibles sur Internet ne sont pas liés à un contexte archéologique. De même, beaucoup de ces sites internet ne mentionnent guère les aspects méthodologiques et théoriques. Il est également difficile d'évaluer le niveau de sensibilisation des communautés locales dans les zones reculées - qui souffrent parfois d'une fracture numérique et linguistique - et si (et comment) elles sont réellement capables d'exploiter ces ressources numériques. Ici, je rassemble quelques exemples de différentes parties du Sahara illustrant les inégalités des modalités (ou moyens) d'enregistrement, de gestion et de diffusion de l'art rupestre. Je soutiens que nous devrions partager les théories et les méthodes au sein de la communauté scientifique numérique, en vue d'adopter une nomenclature commune et un thésaurus public, de rendre explicites nos critères de catalogage et, enfin, d'élaborer un code de conduite éthique impliquant les communautés locales.

When practiced as a science, rock art research is a global community endeavour. (Guy Gibbon 2017, p. 18)

Introduction

The Sahara—the largest hot desert in the world—is far from being a unitary context. Though iconically represented in our collective imagination by vast dunes, much of it consists of flat, stony surfaces and large mountain ranges. The former have attracted considerable attention since the pioneering western explorations of the nineteenth century, when the first artworks were "discovered" (Barth 1857-1858). Countless explorations and publications during the twentieth century and up to the present day make the Sahara a privileged location for the study of rock art, certainly one of the world's hotspots (di Lernia 2017a). However, despite a long research tradition complemented by programmes

of archaeological and environmental investigation, the increasing threats to its preservation and exploitation for tourism, Saharan rock art has failed to become truly mainstream (sensu Conkey 2012), making a weaker and less innovative contribution to the broader scientific debate than might be expected (Chippindale, quoted in Keenan 2005).

Furthermore, after the beginning of the "Arab Spring" (2011), the situation in many North African countries has made this vast region difficult to access, with social media often representing the only means of connections with the rest of the world. Given the security constraints and social instability, safety in the field is not guaranteed and few research funds are available (di Lernia 2015). Although this is particularly true of Libya, other countries such as Egypt, Tunisia, Chad, Niger, and Mali suffer from tragically similar problems. Today, a new generation of African and foreign scientists has no access to archaeological and rock art sites in the north of the continent. Unfortunately, this lack of fieldwork may entail an absence of safeguard, and raising awareness among school-age children and young people is becoming progressively more difficult. In this context, digital technologies may play a crucial role in helping to overcome at least some of these obstacles.

This paper draws on our experience in the Tadrart Acacus and Messak mountains in south-western Libya to offer a critical review of some central issues such as site recording, site management, the durability of electronic archives and the digital dissemination of rock art in the Sahara. While the main focus is on the key interface between rock art and its archaeological context, I hope that a critical reassessment of these various topics may represent a useful contribution to the broader debate on digital technologies in cultural heritage studies.

The Tadrart Acacus and Messak as Proxies for the Larger Sahara

Fieldwork Area

The Tadrart Acacus mountains and the Messak plateau are located in south-western Libya, bordering the Tassili-n-Ajjer in Algeria to the west, and the Algerian Tadrart and the Plateau of Djado (Niger) to the south. All together these mountains form the core of the central Saharan massifs. After some occasional visits between the late nineteenth century and World War II (Barth

1857-1858; Durand and Lavauden 1926; Foureau 1894; Frobenius 1925; Graziosi 1942), the Tadrart Acacus and Messak were intensively investigated during the twentieth century and up to the present day. Fabrizio Mori (1956, 1965) wrote the first book dedicated exclusively to this area, focusing mainly on the Tadrart Acacus massif. He and his colleagues later extended their research to the surrounding regions, studied primarily by the Sapienza University of Rome, which is still active in the area (e.g., Barich 1987; Cremaschi and di Lernia 1998; di Lernia 1999b; di Lernia and Manzi 2002; di Lernia and Zampetti 2008; Garcea 2001). The Messak plateaux owe their world-wide reputation in the field of rock art to several scholars (e.g., Jelinek 1984a, c, 1985; Le Quellec 1996, 1998; Muzzolini 1995; Van Albada and Van Albada 2000), whereas environmental and archaeological research has significantly increased in the last two decades (e.g., Biagetti et al. 2013; Cancellieri and di Lernia 2013; Foley et al. 2013; Gallin and Le Quellec 2008; Gallinaro et al. 2012; Garcea 1996; Mattingly et al. 2007). To this information, we should add the numerous publications, mostly focusing on rock art sites, not possible to review here.

Located in the very heart of the Sahara, our licenced study area covers over 60,000 km^2. It comprises a variety of geographical features: the aforementioned Tadrart Acacus and Messak mountain ranges, the vast sand dunes of the Edeyen of Murzuq and Erg Uan Kasa, the river valleys of Wadi Barjuj and Wadi Tanezzuft (Fig. 1). Since 1990, our research in this region has been undertaken on a territorial scale, combining large-scale "fast" surveys and intensive "slow" field checks and excavations (e.g., Cremaschi and di Lernia 1999).

The principal strengths of our research derive precisely from the vast extent of the study area and the diversity of its landforms. These can be classified according to a "macro-physiographic" system (lowlands, highlands, plateaux, fluvial valleys, oases), in turn broadly corresponding to rough environmental categories—not unlike the concept of "mega-patches" (Beaton 1991). In this sense, and with some caveats, our study area can be considered representative of the Sahara as a whole, not just for its variety of geographical, geomorphological and cultural features, but also for the duration and multi-disciplinary nature of our (past and present) research. Indeed, our archive materials range from the handmade copies of rock art paintings executed by Piero Guccione and Lorenzo Tornabuoni who accompanied Mori in the 1950s, to the 3D georeferenced

map of a rockshelter. We have thus experienced many of the problems faced by a scientific team in the field and in all subsequent phases of research (Fig. 2).

Background on Archaeology and Rock Art

The archaeological record forms an indispensable background to the study of rock art and is the only way of contextualising the artworks. Combining the different types of fieldwork outlined above—a coarse-textured fast extensive survey with far more detailed studies based on archaeological excavations, with more than 45 contexts tested—we have built up a series of GIS maps summarising the major trends in human occupation during the Holocene (e.g., Biagetti and di Lernia 2013; Cremaschi and di Lernia 1999, 2001; Cremaschi and Zerboni 2011; di Lernia 2002; di Lernia and Gallinaro 2010; di Lernia and Tafuri 2013; di Lernia et al. 2013). Needless to say, such maps should be approached with caution. The number of "sites" is very large (≈ 8000 contexts), in part because a "site" may be anything from an isolated arrow-head to a large Garamantian fort (Fig. 3). Our archaeological data are supported by a series of radiocarbon dates (≈ 320), allowing for the chronological reconstruction of the Holocene occupation, and also providing interesting clues to explain the exploitation of the landscape and human dynamics for coping with climate change. The combined use of environmental data, settlement organisation and chronological information forms the backbone of any reconstruction of cultural dynamics in the region, including artistic expressions, extensively published elsewhere and therefore not discussed here.

The diverse landscape of our study area is mirrored by the different social and cultural adaptations taking place during the Holocene. Rock art forms part of this complex picture: it is perfectly representative of the art of the central Sahara, presenting recurrent features often used by scholars to define the principal styles. Given the frequently acrimonious tone of the scientific debate (Smith 2013), I will avoid discussing stylistic issues.

Most rock art is concentrated in the outcrops of the Tadrart Acacus and Messak, but there are also several concentrations in the river valleys and around the oases, each with its own specific physiographic and topographical setting (Fig. 4). Without going into excessive detail, Table 1 summarises the main features of each rock art style and its (presumed) archaeological context as reconstructed in recent years for our study area (e.g., di Lernia and Gallinaro 2011; Gallinaro 2013).
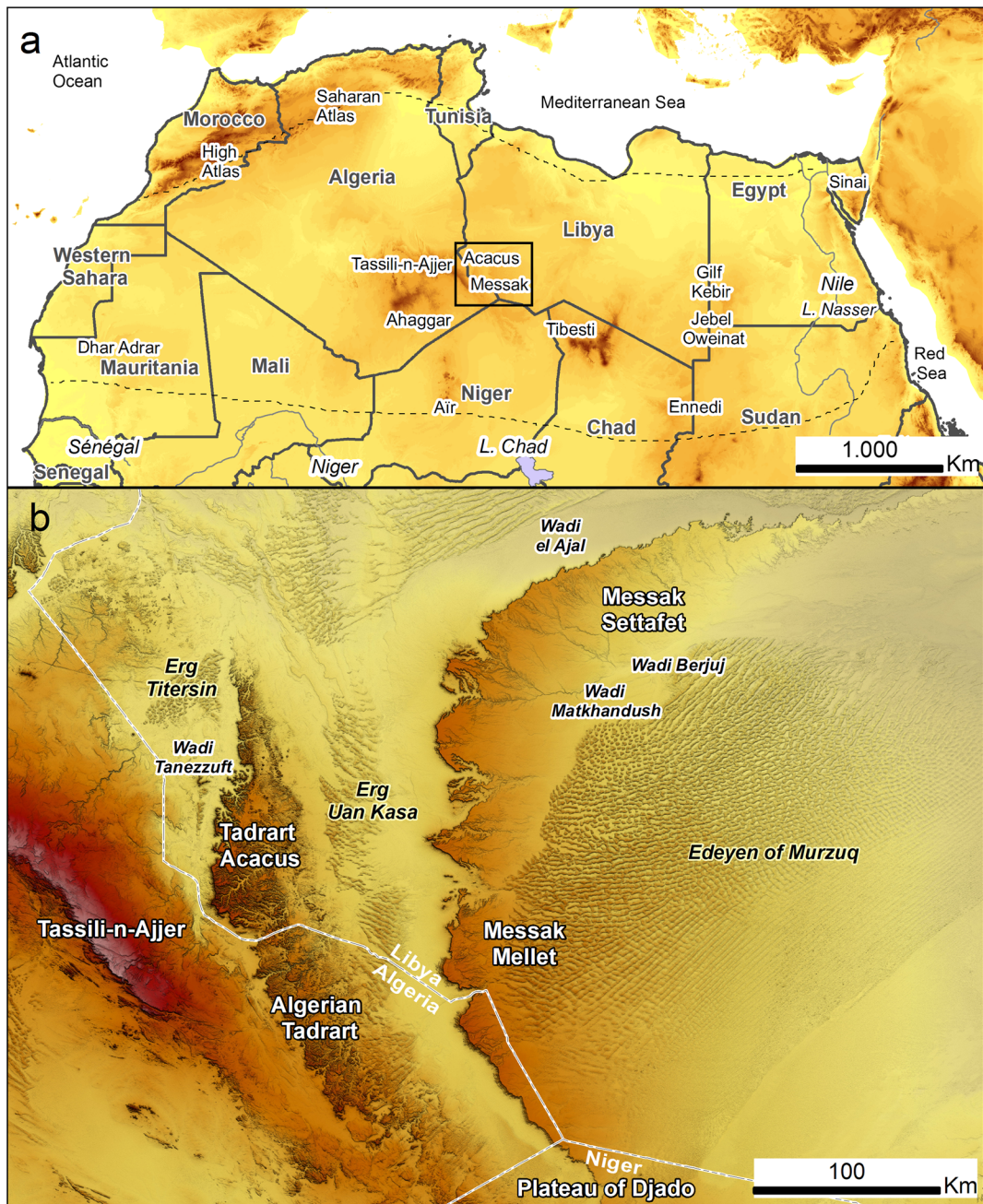
Fig. 1 Map of the main rock art regions in North Africa (**a**): dashed lines indicate the approximate present limits of the Sahara. The study area in south-western Libya (**b**). (Images in full colour online)

Regardless of the accuracy of our reconstruction, rock art is part of the archaeological landscape (e.g., Bradley et al. 1994; Chippindale and Taçon 1998), and the archaeological context must be considered in any form of rock art recording, management and dissemination, as discussed in further detail below.

Go Digital: Some Issues on Site Recording

A Digital Divide?

Our research in south-western Libya is a good model for testing the pitfalls and potential of digital technologies

Fig. 2 History of site recording from manual copy to computer-generated models in the Tadrart Acacus and Messak. Piero Guccione (ca. 1955) executing a contact copy of paintings at Uan Tabu (**a**) and Uan Afuda (**b**), central Tadrart Acacus; scaffolding at Afozzigiar II (**c**), southern Tadrart Acacus (ca. 1970), to prepare the full tracing of the Round Head paintings; (**d**) differential GPS mapping of cattle engravings at Wadi Beddis (ca. 1995), central Messak Settafet; (**e**) high-resolution digital camera recording of the Matkhandush crocodile, central-southern Messak Settafet (ca. 2000); (f) Arcscene© 3D model of Tifinagh writings from Site 09/08, Wadi Tanezzeft, Northern Tadrart Acacus (2009). All illustrations, unless otherwise specified, based on "Archive of the Archaeological Mission in the Sahara, Sapienza University of Rome"
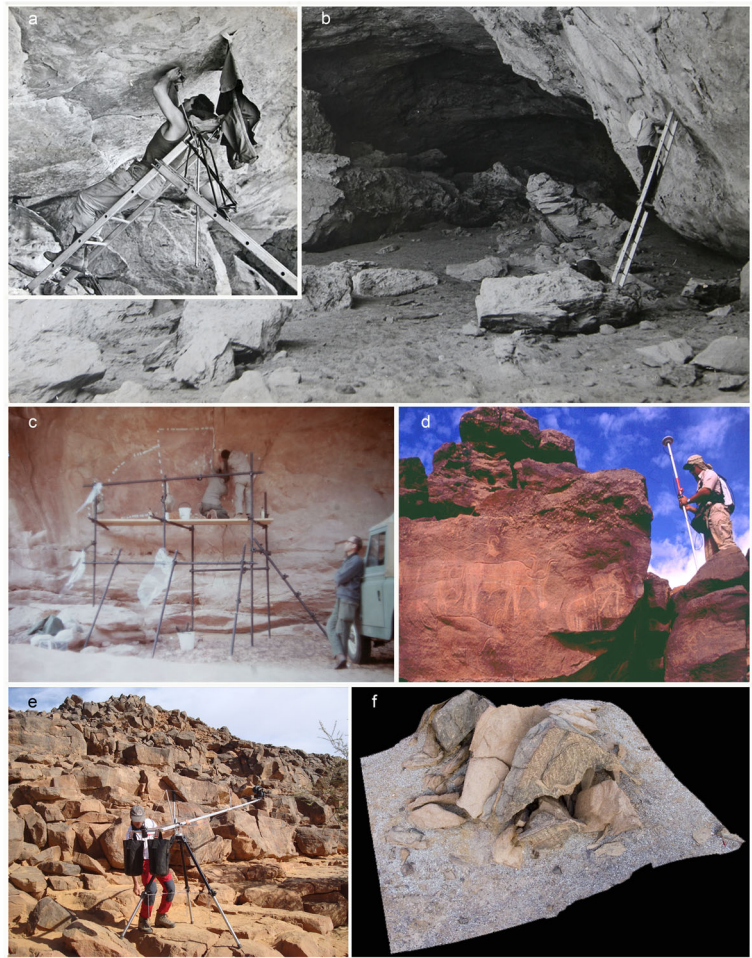
in rock art studies. Indeed, the different aspects outlined above (the vastness of the area, its diverse landscape, the variability of the archaeological record, its differing archaeological visibility, etc.) require a diachronic and multidimensional approach, with a high degree of flexibility in the field and modularity during digital recording.

Digital technologies have greatly expanded over the years (e.g., Brady and Gunn 2012; Brady et al. 2017; Ch'ng et al. 2013). Given the numerous—principally economic—limitations suffered by the social sciences, it has been difficult to keep pace with these rapid changes. It is hard to raise funds for new technological devices and to train people to implement all the necessary steps in their use. This is particularly true in countries such as Libya—but many other places encounter similar problems. To give just one example, over the last decade or so digital devices have changed (Electronic Total Station, Differential GPS, Laser Scanner, etc.), as has the way we store information, using different types of physical memory and support that also have strong implications for durability. Of course, digital preservation should be considered as a continual process as opposed to an end goal. But, assuming for the sake of argument that this continuous process of digital updating is "easily" affordable in western countries, the same is not true elsewhere. In a word, the rapid technological innovations expected in coming years may further expand the digital divide already suffered by many African countries.

Defining a Site

Landscape, archaeology, rock art and site are all concepts that deserve specific theoretical treatment. Usually, the narrative for recording and classifying artworks
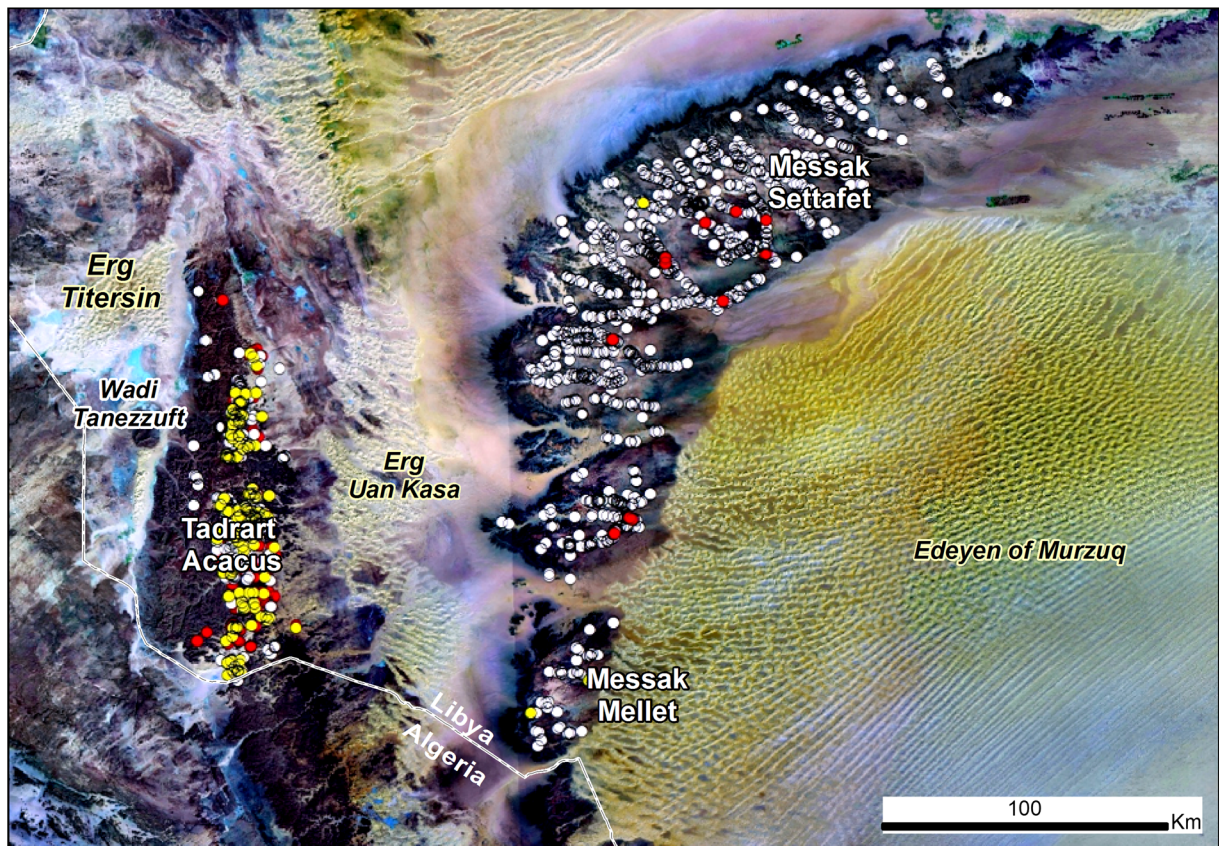
Fig. 3 Simplified map of rock art "sites" in the Tadrart Acacus and Messak (Archive of Sapienza University, The Archaeological Mission in the Sahara). Key: red dots: paintings (≈ 160 Tadrart Acacus; ≈ 15 Messak); white dots: engravings (≈ 390 Tadrart Acacus; ≈ 1300 Messak); yellow dots: paintings + engravings (≈ 150 Tadrart Acacus; ≈ 4 Messak)

in these regions—and likely elsewhere—has followed what we might call a "top-down" approach. By this I mean: physical approach to the "site," site classification and recording, mostly using digital cameras and some DStretch® image processing. Most researchers (sometimes implicitly) apply a structuralist scheme, starting from the analysis of the area surrounding the site, the site itself, usually followed by the wall, the panel, the scene and finally the subject, as a kind of "minimal unit."

Among the different approaches, we may recall the compositional analysis of rock art paintings developed by Augustin Holl, such as the deconstructing studies of the sites of Tikadiouine (1994), Iheren (1999), or Uan Derbuaen (2016) in Algeria. Another interesting perspective is given by Carole Fritz et al. (2013); focussing on the importance of the narrative, these researchers identify an important, theoretical division between synchronic and diachronic (or accumulative) scenes.

Concepts and definitions change from one scholar to another. I anticipate here that one of the limitations of

the digital databases currently accessible is the almost total lack of information on the specific archaeological context of the artworks and on the concepts underlying

Fig. 4 Different locations of rock art contexts. (**a**) Exposed ▶ vertical wall with a series of small superimposed rockshelters at Wadi Inazawan, central Tadrart Acacus, with engravings possibly in the "Wild Fauna" style located (white insert) about 2 m above the artworks in the pastoral styles; (**b**) close-up of the elephant covered in concretions and (**c**) digital tracing after DStretch© rgb0 processing and B&W conversion to enhance readability; (**d**) paintings in the Pastoral style at Uan Amil cave, wadi Teshuinat, central Tadrart Acacus; (**e**) vertical cliff with engraved giraffes in the pastoral style at Wadi Rahrmellen, central Tadrart Acacus; the rockshelter on the upper terrace of Wadi Imha, southern Tadrart Acacus (**f**): the paintings present a diversified distribution, with cattle in the Pastoral style (**g**), hand prints (**h**) and human figures (**i**) in the Round Head style (the location of the inserts approximately indicates the position in the shelter); (**j**) boulder with a series of engravings of Camel style, wadi Ti-n-Lalan, central Tadrart Acacus; (**k**) an isolated boulder with Tifinagh inscription along one of the passageways connecting Wadi Tanezzuft to the upper range of the Tadrart Acacus

Table 1 Main features of rock art styles of the Tadrart Acacus and Messak (modified, after di Lernia 2017b)

Style	Chronology (calBP)	Cultural phase	Main characteristics			Main subjects/themes
			Technique	Varnish	Colour	
Wild Fauna/ Bubaline	c. 11,200–9900	Early Acacus (?)	Engravings (deep groove)	Dark; eroded	nd	Big animals of wet environments
Round Heads	c. 10,200–7200 (?)	Late Acacus / Early Pastoral (?)	Mainly paintings; engravings not frequent	Dark	Single colour and polychromies; paint of good quality	Anthropomorphic subjects, without expressed physiognomy; Animals represented: principally wild (mostly antelope and Barbary sheep); domestic very rare (cattle?) Apparently "ritual" scenes, dances, masks, etc.
Pastoral/Bovidian	c. 8300–3400	Pastoral (Early, Middle, Late)	High variability: graffiti, engravings, paintings	Medium dark	Paint of good quality; higher prevalence of red tones	Anthropomorphic subjects: many details and great variability of "physical types" Animals represented: emphasis on domestic cattle (bulls, cows, calves), rarer but present ovicaprines; wild animals also frequent (elephants, rhinos, hippos, etc.); Daily scenes: camps, milking, huts, etc. Scenes of hunting are frequent
Horse/Bitriangular	c. 3700–2300	Final Pastoral / Early Garamantian	Graffiti, engravings, paintings	Light	More diluted colour; prevalence of red tones	Anthropomorphic subjects: geometric bitriangular representation; Animals represented: cattle, sheep and goats, but above all domestic horse (also with chariots); Pastoral, domestic, oasis scenes, but also conflicts with armed subjects; Many objects, musical instruments, etc.
Camel	?IV BCE – VI/XI? CE	Garamantian (Mature, Classic, Late)	Graffiti, engravings, paintings	Light-absent	The colour is more diluted; Mostly red, with various tones; Black and white are rarer	Anthropomorphic subjects: bitriangular representations are increasingly stylized; Animals represented: ovicaprines, horses. Introduction of the dromedary; Caravan scenes, conflict scenes, etc.
Libyco-Berber Tifinagh	VII/VIII CE – today	Post-Garamantian	Graffiti, engravings, paintings	Absent	Red, very diluted, prevails; black frequent	Tifinagh writings often associated with camels
Arabic writings	c. XI - today		Graffiti, engravings, paintings	Absent	Red, white, black	Arabic writings

the recording and classification of the subjects. The definition of "site" itself is also problematic (e.g., Bahn 2010; Brady et al. 2017; Sundstrom 2012; Whitley 2011; Wienhold and Robinson 2017) and has been hotly disputed over the years; again, our Saharan evidence may provide additional food for thought.

The Uan Afuda cave in the central Tadrart Acacus is a "perfect" case study (Fig. 5): a physically delimited landscape (a cave), a single wall, paintings of limited size—all in the "Round Heads" style—and an exclusively pre-pastoral occupation in the excavation and surface record (di Lernia 1999a). In this case, our definition of "site" (including its digital recording and, more importantly, its dissemination) will approximate reality, but this is a quite infrequent situation. A very different instance is the rockshelter in the middle course of Wadi Teshuinat. Here we are dealing with over 120 m of nearly continuous artworks (paintings and engravings) that Mori (1965) classified as two "sites" (Teshuinat IV-

V) based on the (hypothetical and largely subjective) physical discontinuities of the shelter's walls. Yet the physical boundaries are unclear and the artworks present a complex series of superimpositions forming a true palimpsest. Using the technological devices available until just a few years ago (early 2000s) but now completely obsolete, the digital images were processed in the laboratory and digitally traced to create a map of the shelter, and a more accurate reconstruction of the spatial organisation of the artworks. The digital tracing process was time-consuming and costly. Today this approach—in any case still much used—has been superseded by low-cost digital photogrammetry, but the problem of site definition remains. Significantly, the copies executed by Piero Guccione in 1958 under Mori's direction present similar problems and the results are inaccurate in terms of site definition, the representation of the paintings and their internal relationships (Fig. 6).
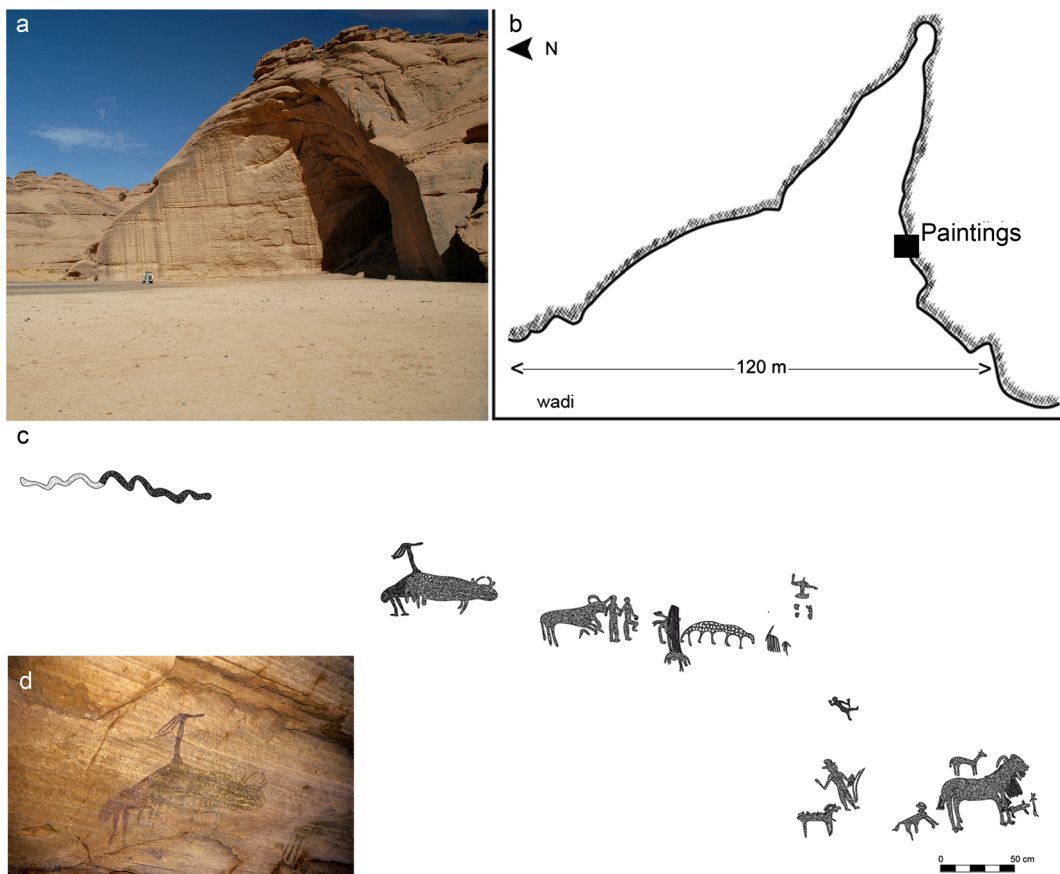

Fig. 5 The Uan Afuda cave, wadi Kessan, central Tadrart Acacus. (a) The cave seen from the south-west; (b) plan of the cave with location of the painted wall (black square); (c) digital tracing of Round Head artworks and (d) close-up of two superimposed painted animals (modified, after di Lernia 1999b)
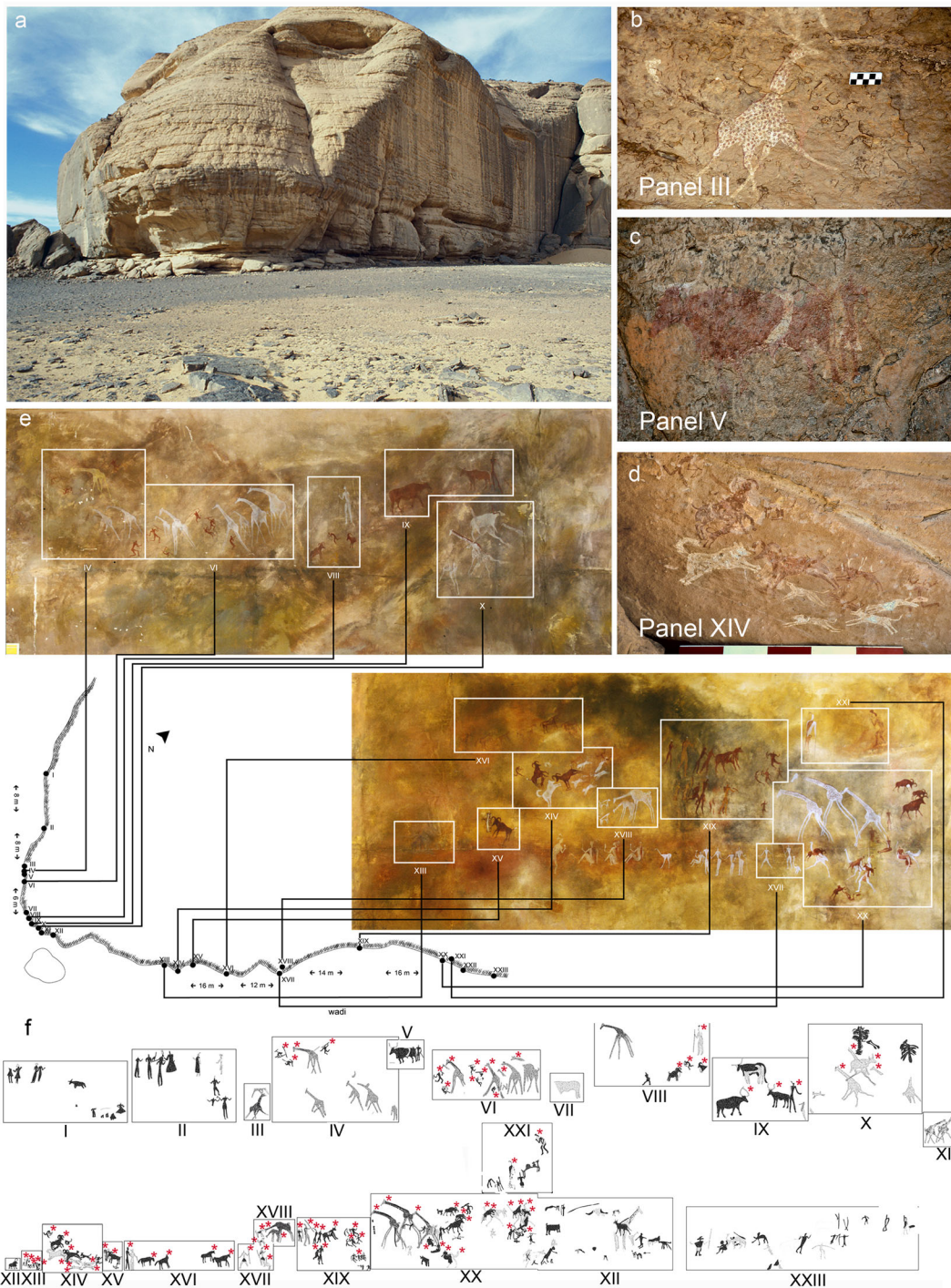
Fig. 6 Teshuinat rockshelter IV-V, central Tadrart Acacus. (**a**) The shelter seen from south; a giraffe (**b**), a cow (**c**) and an archer hunting Barbary sheep using dogs (**d**) are examples of pastoral paintings whose copies, executed in the 1950s by P. Guccione and F. Mori on two canvasses measuring ca. 5 × 2 m (**e**), were wrongly located in the space, as indicated by the mapping of all the panels (see the position of panels III, V and XIV on the canvas and on the map); (**f**) digital tracing of the artworks grouped by panels, undertaken in the early 2000s (modified, after di Lernia and Zampetti 2008)

The nature of Saharan artworks, where palimpsests consisting of hundreds of images are common, and their physical distribution in the landscape may create serious problems for the definition of the site. In this context, new digital technologies greatly increase our ability to overcome these obstacles by adopting a "bottom-up" approach. Wadi Matkhandush is a good example: this place, also known as In Habeter, is part of the Wadi Barjuj system in the southern Messak Settafet. Here, engravings, graffiti, high reliefs, bas-reliefs and other rock markings are scattered in no apparent order along a ca. 1.5 km long cliff (Fig. 7). The area has been intensively studied by various scholars over time (e.g., Frobenius 1925; Graziosi 2005; Jelinek 2004, 1984b, c; Le Quellec 1998; Van Albada and Van Albada 2000). This has resulted in schematic maps of the cliff, dots locating "panels" or "friezes," the subjective selection of some artworks, all without a comprehensive map and complete catalogue of the rock art. This is principally due to technical limitations and difficulty of coherently publishing this astonishing number of artworks. The cultural context has also been insufficiently recorded: for example, the only archaeological data provided by Sbodova are 54 stone tools (in Jelinek 1984c). My intention here is not to criticise anyone, but to underline some of the attitudes underlying rock art research in the Sahara, resulting mainly from technical limitations, but also due to the historical and cultural milieu of these studies. Today, high-resolution digital photography of each engraved/pecked subject combined with rapid geo-localization and low-cost 3D photogrammetric rendering, saved on the cloud, would be a cost-effective way of creating a complete and detailed map of the artworks. Spatial analysis, already in the field, can be used to group subjects and help to identify "sites" or "aggregations" and assist in their digital classification for future dissemination. This was the approach attempted in the framework of the "Messak Project," unfortunately halted by the civil war in Libya (Gallinaro et al. 2012). Campaigns of laser scanner mapping of various artworks at Wadi Matkhandush were carried out by the Trust of African Rock Art (TARA), with the support of the National Geographic Society in 2008. Although not yet fully published (David Coulson, pers. comm.), these are also a good way of encouraging the digital preservation of these monuments, seriously endangered by oil infrastructure and the current political situation. An extraordinary example of a "bottom-up" approach in the Sahara made possible by new technologies (although the economic investments were particularly significant and unaffordable to many research teams) is the study of the "Cave of the Beasts" at Wadi Sura in Egypt (Kuper 2013). In the Sahara as a whole, however, these are still rare if not unique examples.

Preserving and Managing Rock Art Sites in the Sahara

Tassili-n-Ajjer and Tadrart Acacus, Two Different Fates

The specific nature of Saharan archaeology and rock art also has significant implications for the ways in which we preserve and manage this record, but a shared approach and database are still lacking. In the past, many researchers have tried to overcome these limitations, but in our area, these were mostly individual initiatives and/or the result of specific project needs (e.g., Le Quellec et al. 2003; Liverani et al. 2000). UNESCO thus remains the main organisation encouraging and supporting preservation and management plans. Although the inclusion of a site in the UNESCO list now mandatorily requires a conservation strategy, management plan, full operational capability and economic self-sufficiency, these criteria are (and were) hardly ever met. Significant variations occur from country to country. For example, there is a considerable difference between access to and management of the Tassili-n-Ajjer National Park in Algeria, whose rock paintings were added to the World Heritage List in 1982, and the situation in the adjacent Tadrart Acacus massif in Libya, enrolled in 1985 (Fig. 8). Now separated by a political border, but belonging to the same cultural landscape, these properties have had very different fates. The Algerian state has actively protected the extraordinary environment of the Tassili-n-Ajjer, creating a national park in 1972, supporting its inclusion on the UNESCO WH list in 1982 (criteria I, III, VII, VIII), then protecting its environmental features by making it a "UNESCO biosphere reserve" in 1986 and listing the Iherir valley as a RAMSAR site in 2001 (Convention on Wetlands). Since its creation, the park has fulfilled its purpose in an exemplary fashion, favouring a careful and sustainable use of environmental and cultural features by tourists, and undertaking important conservation work (e.g., Karzabi et al. 1982). The Tadrart Acacus, by contrast, has never changed status after its inclusion on the list (1985, criterion III) and the Libyan state has never

Karte 3
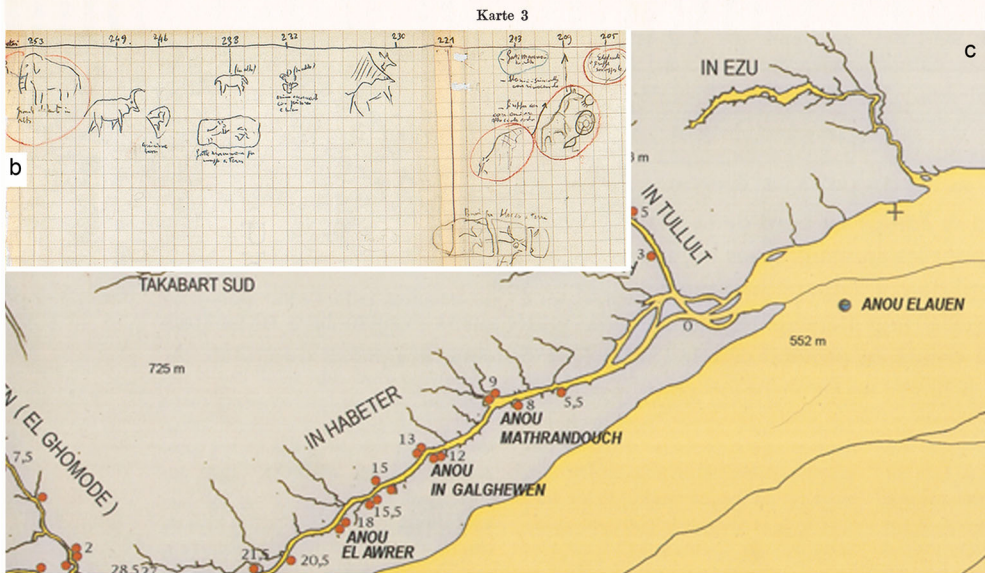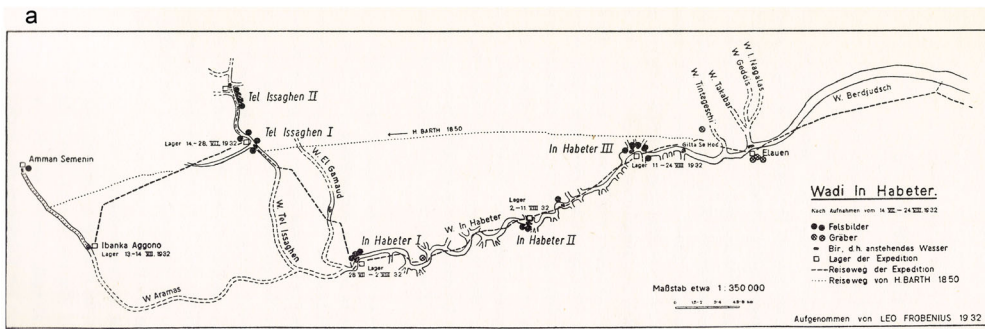
◄ **Fig. 7** Wadi Matkhandush, southern Messak Settafet. (**a**) Original map (1932) by L. Frobenius (later republished with modifications by I. Jelinek 1984b; 2004); (**b**) field notes by P. Graziosi of the early 1960s (2004); (**c**) map of the area by A. and A.-M. Van Albada (2000); (**d**) view of the cliff in 2011, with engraved crocodile in the foreground

supported the creation of a park; in this regard, the many petitions by different scholars and institutions have been unsuccessful (di Lernia 2008 for a review). The result was—at least until the beginning of the civil war in 2011—an indiscriminate and often unchecked exploitation of its exceptional environmental and cultural features, causing severe and often irreparable damage.

The different status of these two properties has created a strong cultural divide in management plans. In the Tassili-n-Ajjer, both natural and cultural criteria were emphasised from the outset, whereas in the Tadrart Acacus "only" one cultural aspect was included. To this, we should add the dramatic situation after the beginning of the war: since 2016, the rock art sites of the Tadrart Acacus have been declared endangered (whc.unesco.org/en/danger).

Awareness and Politics

Past "mistakes" have had a serious impact on the neighbouring region of the Messak Plateau, completely lacking the protective measures implemented in the Tassili-n-Ajjer and, to a lesser extent, the Tadrart Acacus. The oil companies that had significantly damaged the landscape and endangered the rock art only later started promoting compensation projects (e.g., Anag et al. 2002; Kröpelin 2002; Le Quellec et al. 1999). Among these, the Messak Project was launched in 2010 with the aim of combining the databases compiled by different researchers and undertaking new fieldwork. The outcomes were used to create a GIS platform, recording over 9000 heritage contexts, for use by local stakeholders and international institutions for future management plans (Biagetti et al. 2013). If we consider that most of the research and documentation undertaken in the Sahara have been done by foreign missions and individual researchers, an extraordinary effort must be undertaken to recover the scattered documentation, and build an open access, web-based, database: the example of the Messak Project is enlightening in this respect. I believe that UNESCO, as well as other *super partes* bodies, should take the initiative and persuade the researchers to share their databases and increase relationships with local institutions.

In the Sahara, the difficulties of reconciling the exploitation of underground resources, the need for infrastructure development and the management and safeguard of cultural heritage are clearly apparent in the recent case of the Ennedi Mountains (Chad). On
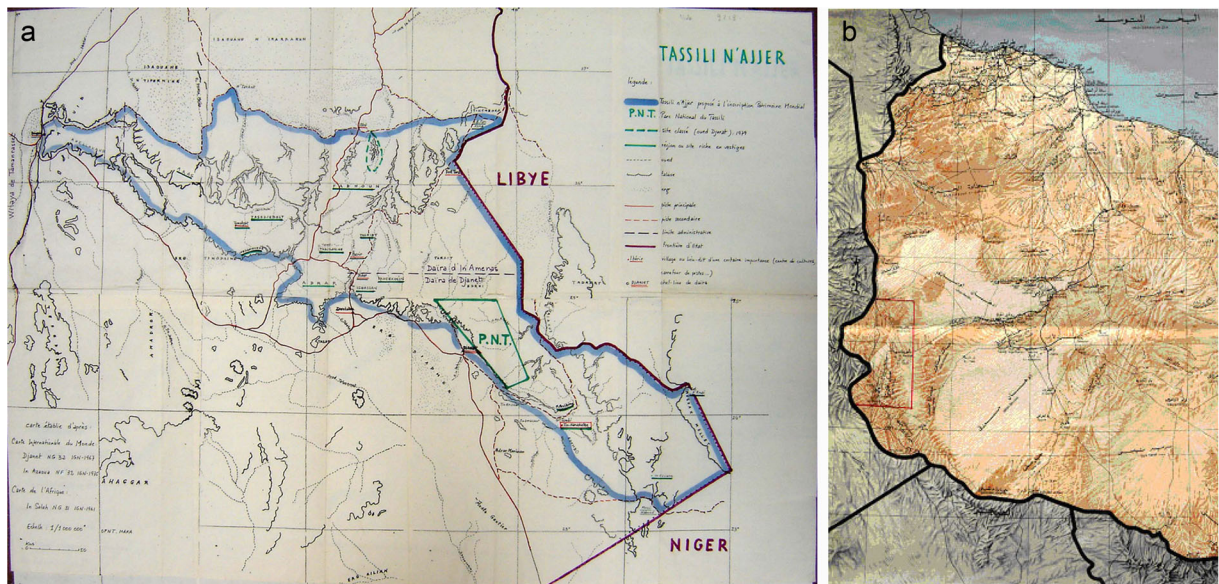

Fig. 8 Maps of the regions to be inscribed in the UNESCO World Heritage list of the Tassili-n-Ajjer (**a**) and Tadrart Acacus (**b**), as submitted by the State parties in 1981 and 1983 respectively

(source: whc.unesco.org). Note the incorrect limits of the Tadrart Acacus, with its southern Libyan edges not included

February 2016, this magnificent region was included on the UNESCO list as a mixed—natural and cultural—property (criteria III, VII, IX). However, only a few weeks before the final decision (25/2/2016), the State Party submitted a new map (Fig. 9) deviating from the original proposal sent to the various bodies for the nomination process. The nominated area was cut in the north to follow the 17th parallel, reducing the total area by about 20%; the buffer zone to the north was completely removed, and it was limited to only a 1 km corridor to the east and south. As a result, one of the most important Ennedi rock art sites, Niola Doa, falls outside the property (http://whc.unesco.org/en/decisions/6793). This occurred because, between the original submission and the final step, the

Chadian government awarded a concession for oil exploration in the region north of the Ennedi massif, thereby reducing the size of the property, limiting its integrity and excluding Niola Doa. As stated by ICOMOS (2016, p. 25), "*following the present major boundary reduction of the nominated property, ICOMOS does not consider that integrity and authenticity are any longer met.*" This is a serious matter that will hopefully not compromise one of the masterpieces of African rock art and the surrounding archaeological contexts. As we have seen, the failure to include the Messak in the UNESCO WH list in the 1980s dramatically affected the region for three decades, with effects still visible in the natural and cultural landscape.
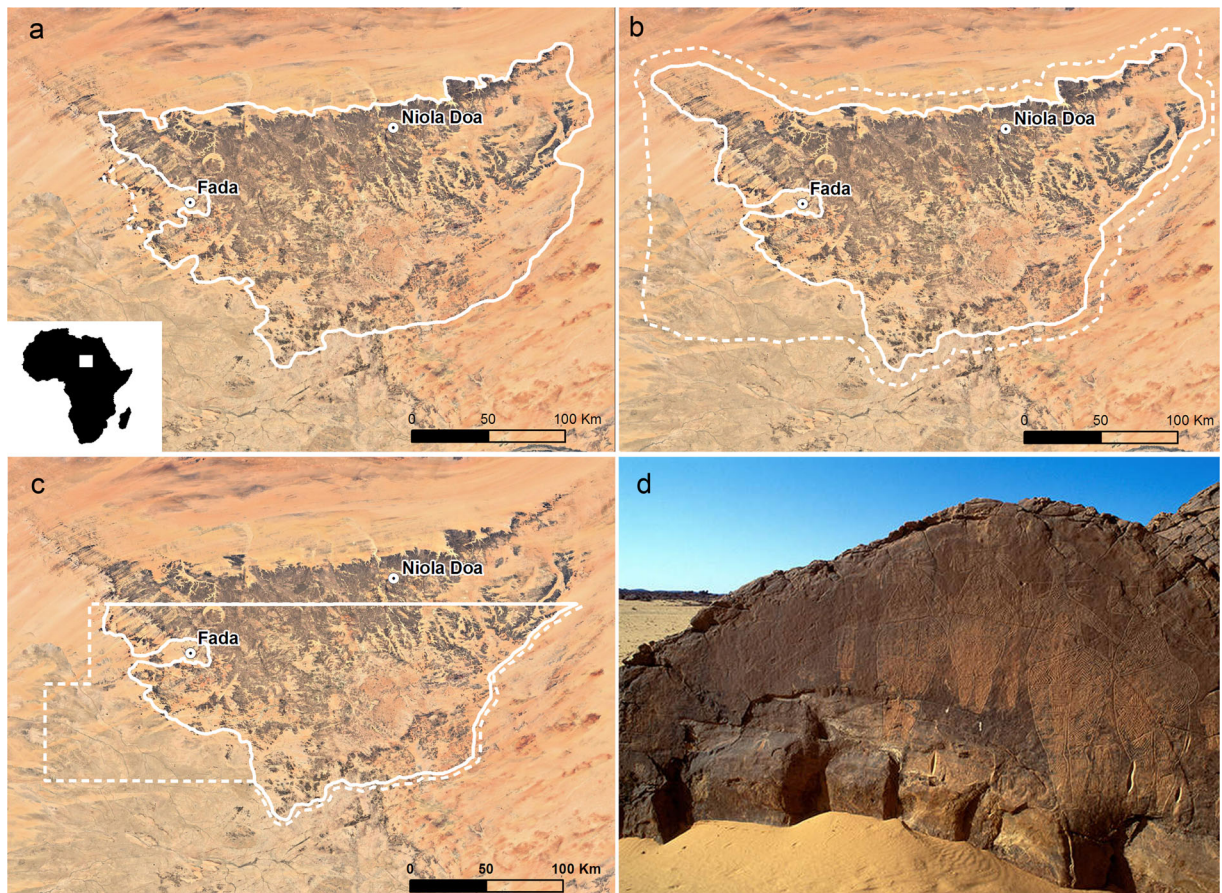

Fig. 9 The different boundaries of the area of the Ennedi Massif (Chad) included on the UNESCO World Heritage list in 2016 (modified, after ICOMOS 2016). During the nomination process, the area was dramatically reduced (≈20%) from the initial submission. Key: (**a**) original map showing the boundaries of the nominated property (included in the nomination dossier), with a buffer zone (dashed line) including Fada; (**b**) revised map (30/11/2015) with a much larger buffer zone (dashed line); (**c**) final map (25/02/2016), with Niola Doa (**d**), a major Saharan rock art site, falling outside the new nominated area (photo courtesy David Coulson/Trust for African Rock Art). The buffer zone (dashed line) was eliminated to the north, reduced to the west and virtually cancelled to the south-east, where it was limited to 1 km only (not to scale on the map for reasons of legibility)

Another example of the difficulties involved in safeguarding major rock art regions is the proposed trans-boundary heritage site including the Sudanese, Egyptian, and Libyan parts of Jebel Oweinat and surrounding areas. In 2004, UNESCO invited the Heinrich Barth Institute in Cologne to evaluate the principal natural and cultural features of this property, strongly recommending the creation of the trans-boundary World Heritage site (UNESCO 2004). Unfortunately, the project was never implemented, mostly due to the political weakness of the State parties and probably to geopolitical problems as well, because the area lay along a crucial route for numerous illicit forms of trafficking (including human trafficking) in that part of North Africa, a phenomenon that has dramatically increased since the Arab Spring (e.g., Micallef 2017; UNSMIL 2016).

Although not uniquely directed towards rock art, a positive example is the White Desert National Park project, an area north of Farafra oasis in Egypt. Here, cooperation between Egypt and Italy allowed for the implementation of conservation plans supported by the United Nations Development Programme (www. egyptheritage.com/eco_rayan.html). Similarly, the recent creation (2007) of the national park of Gilf Kebir should favour its preservation and sustainable tourist use, including the rock art evidence (Kuper 2007).

In any case, too many extraordinary regions of the Sahara still completely lack even basic protection, and effective management plans remain very rare. It is important to note that virtually no rock art site is present today in the updated UNESCO Tentative list, despite the richness of Saharan and North African rock art (Table 2). The only site clearly focused on rock art is the "Gravures et peintures rupestres de l'Ennedi et du Tibesti" (presented as a cultural property in 2005 and partially successful: only the Ennedi was inserted as mixed property in the WH list in 2016). Though it is not clearly stated, the "Réserve Naturelle Nationale de l'Aïr et du Ténéré" in Niger includes the rock art of these mountains among the main aspects of outstanding value, together with other cultural features. Much further south, but geographically in the Sahelian belt of Burkina Faso, we have "Les gravures rupestres du Sahel burkinabè: Pobé-Mengao, Arbinda et Markoye," still to be inscribed.

Many archaeological and rock art contexts are still inhabited by nomads, whose role in actively protecting heritage and increasing awareness should be seriously

Table 2 Numbers of sites from North African/Saharan countries in the UNESCO Tentative list, sorted by country and type of property (http://whc.unesco.org/en/tentativelists, accessed June 2017)

	Natural	Cultural	Mixed	Total
Algeria	0	5	1	6
Chad	3	4	0	7
Egypt	7	23	3	33
Libya	0	0	0	0
Mali	2	9	0	11
Mauritania	0	3	0	3
Morocco	4	9	1	14
Niger	6	8	4	18
Sudan	2	3	0	5
Tunisia	5	6	1	12
total	29	70	10	109

considered (e.g., Bennett and Barker 2011). Across the Sahara, the exploration and exploitation of underground resources is a major threat as is evident from the recent UNESCO nomination of the Ennedi mountains. After several decades, rock art contexts such as those in the disputed area of Western Sahara still suffer dramatic problems, including the vandalism perpetrated by UN officers (Brooks 2005). Today, we must add the instability and turmoil affecting the northern countries of Africa. This brings us back to the need to increase significantly the digitization of rock art archives, most of which are scattered among different universities, individual researchers and travellers. Most of them (or rather us) are non-African, and based outside the Sahara.

Presenting and Disseminating Rock Art: a Remote Perspective

Digital Repositories

Until the beginning of the Arab Spring, rock art and desert archaeology were important tourism assets and a strategic source of revenue for several North African countries. The war in Libya and socio-political instability elsewhere completely changed this. Site monitoring by local institutions and scientific research undertaken by foreign missions decreased. In a sense, we can now view rock art only virtually on computer screens, and this increases our digital involvement. Examining the

major databases, such as the African Rock Art Digital Archive of the Rock Art Research Institute (www.sarada.co.za), a world-renowned institution based at the University of Witwatersrand in Johannesburg, it is clear that these are designed mostly for researchers. In a sense, the same is true of many other digital repositories. It might be helpful to consider the experience of an "average user" when accessing any of these databases, viewing these digital archives from a different perspective and not just from a professional/scientific one. Most webpages are in English, which is not the most widely spoken language in North Africa (or of many other countries across Africa). The images are generally given code names, as geographical references are not always available. Overall, these databases mostly seem designed for passive use. It is difficult for a nonspecialist in rock art to navigate these sites and the experience can be a frustrating one; meanwhile, the specialist might be frustrated by the lack of contextual information described before.

These limitations could be overcome, given also that most databases were born at the dawn of the digital era. However, most of the possible solutions can actually be cost prohibitive, requiring investments in IT support and development of the personnel that would require extra effort in fund-raising by research institutions.

We all owe a great deal to these pioneering experiences, intended to create a digital record of artworks that might otherwise be in danger of vanishing. But in a sense, the digital recording and dissemination of artworks today are theoretically not so distant from the handmade copies of the last century. The danger we should avoid is saving terabytes of beautiful rock art images in the cloud, but without any context or archaeological background. The digital scientific community must share theories and methods with a view to adopting a shared nomenclature, creating a public thesaurus, making our classification criteria explicit and adopting an ethical code of conduct. This may require a two-pronged strategy: on the one hand increasing the quality and scientific utility of our digital archives (implementing scientific metadata and increasing information on the archaeological/cultural background), and on the other, aiming for a more immersive and virtual experience, expanding multimedia and multi-language resources, as for example proposed by the British Museum, with the VR experience of Game Pass shelter in South Africa (http://vr.africanrockart.britishmuseum.org). This may help to raise awareness among different audiences and encourage the involvement of nonprofessionals.

Accessing and Connecting to the Internet in Africa

Since databases are digital repositories technically accessible from the internet, we must also consider the penetration of the web among local populations and internet connection speeds.

Although reliable data are difficult to find, we can propose a rough estimate (Table 3). The figures for Saharan and more broadly for North African countries are apparently good compared to other parts of Africa; currently, roughly a third of the population of these countries has access to the internet, compared to the African average of 28%. However, there are significant differences between countries such as Algeria and Libya, with almost 50%, and Niger or Chad where less than 3% of the population has access. These figures indicate the need for a targeted approach (Table 4). Although Africa is home to roughly 16.5% of the world's population (and these numbers will dramatically increase in future decades to reach approximately 2.4 billion by 2050), under 10% are internet users. This digital divide will probably narrow in the near future, but these numbers are a starting point for deciding how to use our digital information. A related issue is the connection speed; as already mentioned, this may significantly compromise the internet experience of nonprofessional users accessing a rock art database from a shared internet point/device. Again, reliable sources are hard to find, but it is generally accepted (by, among others, Speedtest.net metrics), that the African country with the fastest internet connection is Ghana, which ranks only 77th in the world list (Smith 2017). Compared to the rest of the world, broadband speeds in Africa are almost without exception extremely low (Fig. 10). Developing the necessary broadband and optical fibre infrastructure will take time, and the political situation may affect the speed of implementation in the near future. In this context, Long Term Evolution (LTE), 4G and other mobile systems are probably the best way of improving connection speeds, a key factor in telecommunications, data sharing and internet use, interfaced with dedicated smartphone applications. Africa, and particularly the Sahara, have an uneven distribution of this type of connectivity; some countries still have GSM connections, while a few towns have LTE/4G/3G. No 5G tests are currently in progress, and this will widen the future digital divide (http://www.worldtimezone.com/5g.html).

In any case, based on this very preliminary analysis, our digital repository of rock art contexts should be

Table 3 Frequency data on internet usage in North Africa/Saharan countries (modified, after http://www.internetworldstats.com/stats1.htm#africa accessed June 2017)

	Population* (est. 2017)	Internet users (31/12/2000)	Internet users (31/03/2017)	Penetration (% population)	Internet growth (2000–2017)
Algeria	41,063,753	50,000	18,580,000	45.2%	37,060.0%
Chad	14,965,482	1000	387,063	2.6%	38,606.3%
Egypt	95,215,102	450,000	34,800,000	36.5%	7633.3%
Libya	6,408,742	10,000	2,800,000	43.7%	27,900.0%
Mali	18,689,966	18,800	2,212,450	11.8%	11,668.4%
Mauritania	4,266,448	5000	714,132	16.7%	14,182.6%
Morocco	35,241,418	100,000	20,207,154	57.3%	20,107.2%
Niger	21,563,607	5000	439,164	2.0%	8683.3%
Sudan	42,166,323	30,000	10,886,813	25.8%	36,189.4%
Tunisia	11,494,760	100,000	5,800,000	50.5%	5700.0%
Total North Africa/Sahara	291,075,601	769,800	96,826,776	33.3%	12,578.2%
Total Africa	1,246,504,865	4,514,400	353,121,578	28.3%	7722.1%

*Estimates on population numbers are provided by UN (http://www.un.org/en/development/desa/population/)

aimed more at smartphone/tablet devices than at laptop/desktop facilities.

Final Remarks

Saharan rock art is a crucial aspect of Africa's cultural heritage, and its analysis, understanding, conservation, management and dissemination should be a priority not only for scientists, but also for local and international institutions, NGOs and stakeholders. As noted by Gibbons (2017, p. 18). "When practiced as a science, rock art research is a global community endeavour. In fact, the progress of rock art science relies on interaction within that global community." The aftermath of the "Arab Spring" has created a highly critical situation in the Sahara and in North Africa more generally. Conflict

and turmoil have almost destroyed the global community, making digital resources essential for achieving the priorities outlined above. It is clear that the—already deep—digital divide in North Africa may widen further in the very near future. This necessarily requires a diversified strategy. Existing institutional digital repositories should provide more information on the archaeological and environmental contexts of artworks, at present virtually absent. However, since access to the area is now almost impossible, this will entail retrieving the contextual information scattered around the archives of foreign missions. UNESCO, ICOMOS and other UN-based institutions should be involved to facilitate this process. The mission of such digital databases should be mainly directed at institutions, stakeholders and scientists. Theoretical aspects should be discussed and agreed upon, to create a shared protocol for recording and

Table 4 Internet usage in Africa and the rest of the world (modified, source http://www.internetworldstats.com/stats1.htm#africa, accessed June 2017)

	Population* (2017 Est.)	Population % (2017 Est.)	Internet users (31/03/2017)	Penetration (% population)	Internet (% users)
Total for North Africa/Sahara	291,075,601	3.8%	96,826,776	33.2%	2.6%
Total for Africa	1,246,504,865	16.6%	353,121,578	28.3%	9.4%
Rest of World	6,272,524,105	83.4%	3,386,576,922	54.0%	90.6%
World	7,519,028,970	100%	3,739,698,500	49.7%	100.0%

*Estimates on population numbers are provided by UN (http://www.un.org/en/development/desa/population/)
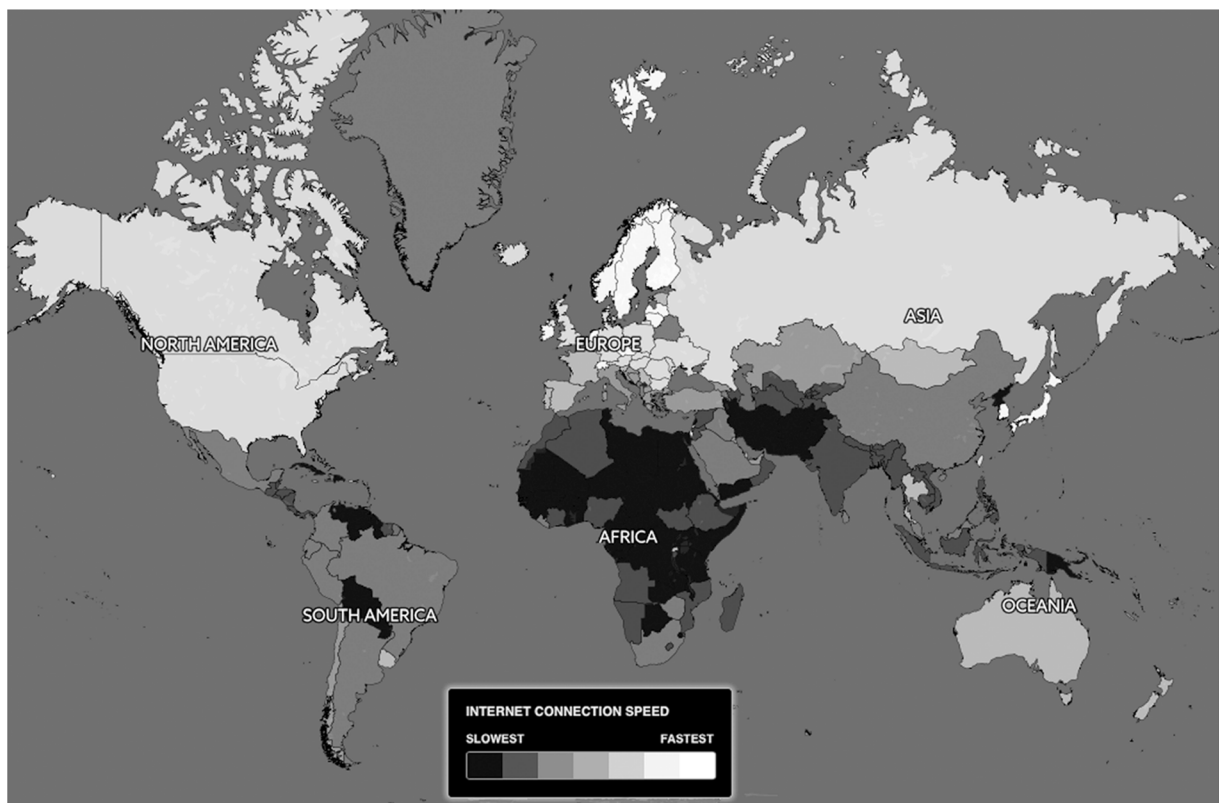
Fig. 10 Map of the world average speed of broadband Internet connection, as of June 2017 (modified, after Smith 2017)

storing information, and to allow open access to this information that in turn may be used by different subjects. Given the current situation, digital information is our only means of keeping interest in these countries alive. When and if fieldwork will resume, we should bear in mind the existing digital divide and choose low-cost technologies, given that many institutions in North Africa cannot afford either the technological devices or the professional software needed to process digital recordings. Implementing such digital repositories with contextual information on rock art sites—i.e., not limited to close-up photographs of the painted or engraved panel—may also be of great help in revitalising local UNESCO representatives, in order to at least try to resume the preparation of nomination files, today virtually nonexistent.

A second digital strategy should focus on creating mobile, user-friendly, multi-language immersive experiences using smartphones/tablet devices. It is likely that broadband connections will slowly become more widely available in North Africa, whereas LTE/4G/3G will become common. The virtual experience and fruition of digital information on rock art contexts will become easier, ultimately favouring its knowledge and dissemination in places that currently have little access to even basic necessities.

It might seem *bizarre* to insist on such aspects, but culture and knowledge represent the foundation for any enduring reconciliation and peace-keeping process.

Compliance with Ethical Standards

Conflict of Interest   The author declares that he has no conflict of interest.

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