The Awareness of Danger. African Rock Art in the Archive of the Italian Institute of Prehistory and Protohistory

SILVIA FLORINDI and ANNA REVEDIN, Istituto Italiano di Preistoria e Protostoria, Italy
LUCA BACHECHI, Università di Firenze, Italy

Paper is fragile, but so is rock. The "Italian Institute of Prehistory and Protohistory" (IIPP) choose to take fragility as the main topic to communicate the heritage of the Institute, more specifically that of the photographic archive which conserves evidence of one of the most ancient human heritage at risk of disappearing forever. The IIPP archive consists predominantly of images and films related to Prehistory, produced by its founder Paolo Graziosi between the 1930s and 1970s, during several missions he carried out to study the rock art of the Horn of Africa and Libya, including in the "Rock-Art sites of Tradart Acacus", which has been inscribed in the UNESCO World Heritage list since 1985 and in the "World Heritage in Danger" list since July 2016. The digitization project has given rise to the exhibition "*The Fragility of the Sign. African Rock Art in the Archives of the Italian Institute of Prehistory and Protohistory*". The exhibition aims at protecting the photographic archive left to the Institute by its founder, and to make it accessible to the greater public. Through an immersive itinerary, it was possible to make known some of the most ancient and extraordinary examples of human artistic expression, situated in places that are currently inaccessible as a result of domestic and international conflicts. The purpose of the present work is to share an experience of public archaeology carried out through the use of visual and immersive technologies.

Key words:
African rock art, UNESCO, Archive, Immersive exhibition, Digitization.

CHNT Reference:
Silvia Florindi et al. 2018. The Awareness of Danger. African Rock Art in the Archives of the Italian Institute of Prehistory and Protohistory.

INTRODUCTION

Prehistoric rock art can be analysed from several different points of view: iconography, various execution techniques, the cultures and the people that made it, the meaning of this art. The "Italian Institute of Prehistory and Protohistory" (IIPP) designed and implemented its own project on prehistoric rock art that starts from the key assumption that it is possible to communicate and to preserve great human heritages (like prehistoric rock art specimens) only through enhancing the awareness of the risk of damaging such heritages. The IIPP was founded in 1954 to coordinate, promote and intensify, on a national and international level, research and studies of prehistory and protohistory by proposing initiatives and projects [Revedin 1996; Tarantini 2004]. Like other international institutions that preserve important archives on prehistoric art, such as the "Trust for African Rock Art" (TARA) [Anderson et al. 2018], the "African Archaeological Archive" (AAArC) [Lenssen-Erz et al. 2018] and the Centro Camuno di Studi Preistorici [Anati 2004], the IIPP is constantly engaged in protecting, managing and enhancing its specialised documentary heritage, unique within the rich Italian archaeological panorama. The IIPP set up, protects and manages a large documentary and photographic archive, highly specialised in prehistoric art and archaeology, together with a highly specialised library [Bachechi 2012]. The IIPP team focused on two key aspects of modern archeological and conservation practices to accomplish the preserving and the valorisation mission of the institute: fragility and technology. Fragility is an urgent theme for those who work in monumental heritage, such as rock art, particularly in war zones, as well as for those who deal with an inner heritage, such as archives. Technology provides new instruments, new possibilities to preserve and show this heritage. The scientific team decided to

Authors addresses: Silvia Florindi and Anna Revedin, Istituto Italiano di Preistoria e Protostoria, Via della Pergola, 65, 50121, Firenze, Italy; email: (silvia.florindi, annarevedin)@iipp.it; Luca Bachechi, Dipartimento di Biologia, Università degli Studi di Firenze, Via del Proconsolo, 12, 50122, Firenze, Italy; email: luca.bachechi@unifi.it

promote and valorise the IIPP archive through the use of new visual technologies, in order to reconstruct and spread the knowledge of the archaeological heritage in danger in Libya and the horn of Africa. The IIPP choose to start from those two conflict zones because it has inherited some of the most important photographic archives regarding the prehistoric rock art of Libya and the Horn of Africa.

AFRICAN ROCK ART: GEOPOLITICAL ANALYSIS OF THE HERITAGE LOCATIONS

Before diving into the valorisation project of the IIPP archive, it is necessary to briefly define and analyse the political situation of Libya, Somalia and Ethiopia, and the consequences towards their archaeological heritage.

Even after gaining its independence from the United Nations Trusteeship Council in 1951, Libya remained a deeply divided country, a classic example of colonial era improper borders drawing, irrespective of the cultural differences existing in the country. In 1969 Colonel al-Qadhafi overthrew the monarchical government and found the Libyan Arab Republic. However, his regime turned with time more and more dictatorial. In 2011, a civil war erupted between al-Qadhafi loyalists and rebels, that quickly transformed into a more complex internal conflict once the former dictator was killed in October 2011.

In 1985 the prehistoric rock art site of Tradart Acacus entered the UNESCO World Heritage List [UNESCO 1985]. The last monitoring mission in the site dates back to the beginning of the latest conflict, in January 2011. After that time, local authorities tried to provide annual reports, where emerged that this region is exposed to unprecedented rates of human presence due to migratory movements and are increasingly exposed to vandalism too (Fig. 1). The consequences of these risks over the site are evident in the subsequent reports: vandalism, deliberate destruction of heritage and illegal activities [UNESCO 2018] have been all reported. In light of this unfortunate situation, the rock-art sites of Tradart Acacus has been inscribed in the UNESCO List of World Heritage in Danger in 2016 [UNESCO 2016].

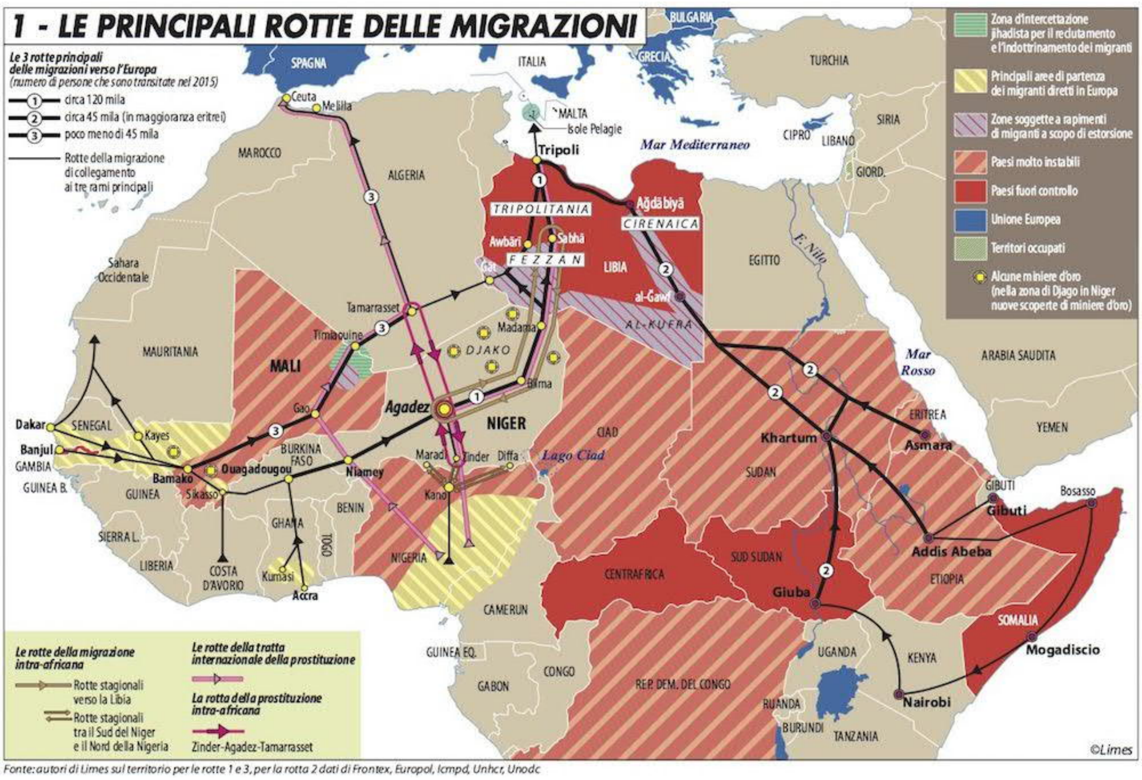

Fig. 1. The African's migration route, according to Frontex, Europol, Icmpd, Unchr, Undoc and Limes data, in Limes 7/2016 (© Limes, map edited by Laura Canali). Note the Fezzan crossroads, linking southern Libya to the Sahel and sub-Saharan migrant routes to northern Libya and onto Europe

Today's Somalia consists of a war-torn country made of three main and often conflicting regions, without a reliable central government: Somaliland, Puntland, and south-central Somalia. Because of this fragmented political environment, very little effort has been made to ensure the preservation of Somali cultural heritage and archaeological remains. In the last 20 years, warlords have commissioned illicit diggings to finance the war, while the poverty also has led to others taking up looting and selling of artefacts. Prior to the conflict and the current geopolitical situation, in colonial times and postcolonial times, Somali cultural heritage and archaeological research have not been preserved sufficiently. The result is one of the worst records of loss of archaeological remains in the Horn of Africa [Mire 2011].

Internal instability has been a chronical feature of, and a great threat to Ethiopia. In the last years there have been numerous anti-government protests, often marked by the loss of civilian lives. These protests were mainly led by the ethnic groups of the Oromo and the Amara, with the participation of other minority groups. Conflicts and instability grew in volume and importance also among the more than 80 ethnic and religious groups dwelling in Ethiopia: this led to an increase in internally displaced people that rose to 1 million in total between April and June 2018, according to UN data. In September fights between groups caused more than 75 casualties in the capital alone. We can also report some positive developments in the Horn of Africa region; the young leader Abiy Ahmed is working for the modernisation of Ethiopia and the peace process with Eritrea has just been concluded with the signature of the peace treaty between the two former Italian colonies. Another positive development is the election of the first female president of the country, the long-term diplomat Sahle-Work Zewde[1]. Unfortunately, Ethiopian rock art is heavily threatened by the natural degradation process and by the human factor: vandalism and pillaging occur regularly in the most remote areas, while conflicts and the increased flow of tourists contribute to the destruction of the rock-art sites [Bachechi 2014].

Given the critical geopolitical situation in the area, the IIPP took it upon itself to showcase the prehistoric rock paintings and engravings produced by man between 10.000 and 2.000 years ago. This is an invaluable heritage for all humanity that cannot be forgotten. This challenge is the core part of the IIPP mission.

THE IIPP ARCHIVE PROJECT

To understand the ambitious mission of the IIPP project in Libya and the Horn of Africa it is fundamental to know the founder of the IIPP, Paolo Graziosi, one of the most important prehistory researchers, active in Italy from 1930 to 1980. His research focused not only on prehistoric art but also on anthropology and ethnography. The largest part of his activity on the field was devoted to research projects in Africa, between 1933 and 1972 [Graziosi 1940; Graziosi 1962]. In this timespan, Graziosi held 20 scientific missions in Libya and East Africa [Vigliardi 1992]. Paolo Graziosi became one of the first Italian archaeologists to document all his missions with graphic procedures, photographs, and footage (Fig.2, a-b).

Fig. 2. Paolo Graziosi, the founder of the IIPP, collecting pictures and data in two different missions in Libya a) 1938, Ghira, Fezzan, AFIIPP 3069; b) 1968, Tilizzaghen, Libya, AFIIPP 5706 (©IIPP)

[1] for the updated geopolitical situation in Ethiopia see https://www.ezega.com/News/

All results of this intense research lead to the creation of an important photographic archive, left to the IIPP. The IIPP photographic archive counts 10460 digitized pictures (colour and b/w slides, colour and b/w pictures, colour and b/w negatives), 69 real scale graphic reliefs of rock-art paintings and engravings (Fig. 4), and dozens of films. A relevant section of the archive concerns Africa: almost 60% of the entire archive is referred to various Graziosi's research missions in Libya and in the Horn of Africa between the thirties and the seventies [Bachechi 2012]. The IIPP wants to increase access to and the visibility of the collection, in parallel with the raising awareness on the importance of preserving historical scientific and artistic heritage. Between 2016 and 2017 the IIPP scientific team designed and implemented the project "Archaeology in the desert. Photographs and documents of Paolo Graziosi in the archive of IIPP", funded by the Italian ministry of education and research, and by Fondazione CR Firenze [Florindi and Lucarelli forthcoming]. The goals of this project were the conservation of documental heritage of IIPP related to African rock-art to one hand, and to another hand to focus on the future of ancient and meaningful evidence of humankind in areas tormented by war and destructive ideologies.

Fig. 3. A young girl in Riccab, Eritrea, 1961, AFIIPP 3491 left: Scan of the original photo; right: After the digital restoration (©IIPP)

The project consists of two different phases. In the first phase, focused on conservation, the whole group of images related to Africa was digitized in high definition. About 3000 images were scanned (2500 dpi) following the standards given by the "Italian Institute of Union Catalogue" (ICCU), using an Epson Perfection V850 Pro scanner and the software Silverlight. After that, a digital restoration of a first group of 250 slides and photographs was carried out. The restoration consisted in reconstructing the original colours of the films and in removing the traces of mould, scratches, and dust, using the image editing software Adobe Photoshop CC (Fig. 3). The first operation consisted in the elimination of the frame, followed by correction of the color balance, to offset the deterioration caused by the chromatic alteration. Lastly, scratches, cuts and traces of dust where removed from the film mainly using the clone tool. The footage of the archive has been digitized and restored thanks to the collaboration with the University of Florence. The real scale graphic reliefs on paper were also inventoried and photographed. The original pieces were in a precarious state of conservation and therefore they were rolled in non-acid paper to ensure their conservation, awaiting proper intervention.

The second phase focused on increasing the visibility to the collection from a scientific and historical perspective, by producing an exhibition called "*The fragility of the sign*", edited by Anna Revedin, Luca Bachechi, Andrea De Pascale and Silvia Florindi [Bachechi and De Pascale 2017]. The exhibition was hosted by the National Archaeological Museum of Florence from September to December 2017. The importance and the urgency of the exhibition were recognised by both the Italian National Commission for UNESCO and the UNESCO. The inauguration event was enriched with a performance designed by the artist Virgilio Sieni, on the theme of fragility. The visitors discovered the rock art of the Horn of Africa and of Libya via the images from the IIPP archives. The immersive exhibition itinerary, realized by Vincenzo Capalbo and Marilena Bertozzi, evolves through three sections: An introductive space on the "heritage in danger" theme, with a video mosaic of the international media coverage of the most brutal scenes of heritage destruction throughout the world. The second section was dedicated to the prehistoric art of the Horn of Africa, recorded by Graziosi and preserved in our archive. The visitors were guided into Eritrean and Somali rock art paintings and engravings thanks to the reproduction of three real scale reliefs of the Horn of Africa. The presentation was enriched with two monitors with sliding images and footages of Paolo Graziosi's missions with an ethnographic and anthropological perspective. In the last space, the visitors were surrounded by evocative sounds and an immersive projection (Fig. 5), showing animations, images and footage of great suggestion about rock art and the ethnographic research in Libya made by Graziosi. The immersive presentation used the pictures of the prehistoric rock art representing engravings and paintings of man and animals as a starting layer over which multiple lines emphasized the contours of the subjects.

Fig. 4. Real scale relief of a rock art painting sited in Carora – Eritrea (312x115 cm) made with pencil and tempera on paper during a mission directed by Paolo Graziosi. IIPP Archive, RG 20 (©IIPP)

These effects were animated to bring life to the prehistoric art depicted on rocks using the software 3DStudio Max and Cinema 4D and the video was projected over multiple panels using three projectors synchronized by the software Watchout and BrightAutor.

The exhibition itinerary was designed as an emotional path, starting with the destruction of the heritage, and ending with the idyllic representation of animal/human relationship as depicted in the prehistoric African rock art. The exhibition has been accompanied by a catalogue, edited by Andrea De Pascale and Luca Bachechi [Bachechi and De Pascale 2017], containing a rich selection of pictures from Graziosi's archive and some brief framework essays written by rock-art specialists and other researchers, realized for a large public.

CONCLUSIONS

The final evaluation of the effectiveness of the project was positive. On the scientific level, an important intervention of conservation and restoration of the documental and photographic archive has been performed, which will help us to protect and spread a so fragile heritage. Regarding communication and awareness-raising, the exposition was visited by around 11.000 people. Furthermore, a brief film has been created based on the exposition material. This video was awarded with the Golden Prize in the category "Creative exhibition installations" at the Festival of Audiovisual International Multimedia Patrimony, organized by AVICOM and with the "Archeo" special mention at the International Festival of Archaeological Cinema of Rovereto. The video is available on YouTube[2] and has allowed a large public to approach the IIPP archive, together with the important documentation and fascinating tales that those archives can tell.

[2] https://www.youtube.com/watch?v=KCDeYE3d5DU&feature=youtu.be

Fig. 5. The immersive section of the exhibition "The fragility of the sign" (©IIPP)

REFERENCES

Emmanuel Anati. 2004. Introducing the world archives of rock art (WARA): 50.000 years of visual arts. New discoveries, new interpretations, new research methods. In XXI Valcamonica Symposium. Capo di Ponte: Edizioni del Centro, 51–69.

Helen Anderson, Elizabeth Galvin, and Jorge de Torres Rodriguez. 2018. Museological Approaches to the Management of Digital Research and Engagement: The African Rock Art Image Project. African Archaeological Review, 35 (2018), 321-337.

Luca Bachechi. 2012. L'archivio fotografico di Paolo Graziosi presso l'Istituto Italiano di Preistoria e Protostoria. Preistoria Alpina, 46, I (2012), 324-325.

Luca Bachechi. 2014. L'arte rupestre dei popoli allevatori del Corno d'Africa: censimento completo e catalogo digitale. Unpublished Ph.D. thesis, Univeristà degli Studi di Siena.

Luca Bachechi and Andrea De Pascale eds. 2017. La fragilità del segno. Arte rupestre dell'Africa nell'archivio dell'Istituto Italiano di Preistoria e Protostoria, Firenze: Istituto Italiano di Preistoria e Protostoria.

Silvia Florindi and Elisa Lucarelli. Forthcoming. L'archivio storico e fotografico dell'Istituto Italiano di Preistoria e Protostoria: il progetto di valorizzazione. In M. Tarantini, A. Pessina eds. Archivi dell'archeologia italiana. Saggi, Pubblicazioni degli Archivi di Stato. Roma: Direzione Generale per gli Archivi.

Paolo Graziosi. 1940. L'età della pietra in Somalia. Firenze: Sansoni

Paolo Graziosi. 1962. Arte rupestre del Sahara libico. Firenze: Vallecchi.

Tilman Lenssen-Erz, Eymard Fäder, Friederike Jesse, and Joana Wilmeroth. 2018. Managing digital rock art: The African Archaeology Archive Cologne (AAArC). African Archaeological Review, 35 (2018), 285-298.

Sada Mire. 2011. The knowledge-centered approach to the Somali cultural emergency and heritage development assistance in Somaliland. African Archaeological Review, 28 (2011), 71-91.

Anna Revedin ed. 1996. Istituto Italiano di Preistoria e Protostoria, Firenze: Istituto Italiano di Preistoria e Protostoria.

Massimo Tarantini. 2004. Dal Fascismo alla Repubblica. La fondazione dell'Istituto Italiano di Preistoria e Protostoria nel quadro delle vicende istituzionali della ricerca (1927-1960). Rivista di Scienze Preistoriche, LIV (2004), 5-82.

Alda Vigliardi. 1992. Ricordo di Paolo Graziosi. In Atti della XXVIII Riunione Scientifica. L'arte in Italia dal Paleolitico all'età del Bronzo, Firenze 20-22 novembre 1989. In memoria di Paolo Graziosi. Firenze: Istituto Italiano di Preistoria e Protostoria, 13–25.

UNESCO. 1985. Convention concerning the protection of the world cultural and natural heritage. World heritage committee. Ninth ordinary session. Paris 2-6 December 1985. Report of the rapporteur. SC-85/CONF.008/9.

UNESCO. 2016. Convention concerning the protection of the world cultural and natural heritage. World heritage committee. Fortieth session. Istanbul 10 -17 July 2016. Report of the decisions adopted during the 40th session of the WHC. WHC/16/40.COM/19.

UNESCO. 2018. Convention concerning the protection of the world cultural and natural heritage. World heritage committee. Forty-second session. Manama 24 June – 4 July 2018. Item 7A of the Provisional Agenda: State of conservation of the properties inscribed on the List of World Heritage in Danger. WHC/18/42.COM/7A.Add.

Imprint:
Proceedings of the 23rd International Conference on Cultural Heritage and New Technologies 2018. CHNT 23, 2018 (Vienna 2019). http://www.chnt.at/proceedings-chnt-23/
ISBN 978-3-200-06576-5

Editor/Publisher: Museen der Stadt Wien – Stadtarchäologie
Editorial Team: Wolfgang Börner, Susanne Uhlirz
The editor's office is not responsible for the linguistic correctness of the manuscripts.
Authors are responsible for the contents and copyrights of the illustrations/photographs.

3D Survey in Extreme Environment: The Case Study of Laetoli Hominin Footprints in Tanzania

SOFIA MENCONERO, DAWID A. IURINO, and GIORGIO MANZI, Sapienza University of Rome, Italy
ANGELO BARILI and MARCO CHERIN, University of Perugia, Italy
GIOVANNI BOSCHIAN, University of Pisa, Italy
ELGIDIUS B. ICHUMBAKI and FIDELIS T. MASAO, University of Dar es Salaam, Tanzania
JACOPO MOGGI CECCHI, University of Florence, Italy

Many cultural assets are in risky situations and they are destined to disappear. Sometimes problems are caused by the anthropic component (e.g. wars) or by natural disasters (e.g. earthquakes and landslides). At other times the cause of deterioration is due to the slow and inexorable action of atmospheric agents and other natural factors present in extreme areas, where preservation of Cultural Heritage is more complex.

This contribution deals with 3D documentation of paleontological excavations in extreme contexts that are characterized by unfavorable climatic conditions, limited instrumentation and little time available. In particular, the contribution is focused on the search for a good working procedure which, despite the problems mentioned above, can lead to valid results in terms of accuracy and precision, so that subsequent scientific studies are not compromised. The proposed case study concerns the recent discovery of fossil footprints at the Site S in Laetoli, within the Ngorongoro Conservation Area (Tanzania), which is a UNESCO World Heritage Site. With the new discovery of Site S it was necessary to implement a 3D survey operative protocol with limited equipment and in a very short time. The 3D models, obtained through the "Structure from Motion" (SfM) technique and topographic support, were used to perform morphological and morphometric investigations on the new footprints. Through the analysis it was possible to estimate height and weight of the footprint makers (hominins of the species Australopithecus afarensis). The collected evidence supports marked intraspecific variation in this species, pointing out the occurrence of a considerable difference in size between sexes and suggesting inferences on reproductive behavior and social structure of these ancient bipedal hominins.

The contribution shows how important is to obtain good 3D documentation, even in extreme environment, in order to reach reliable results for scientific analysis.

Key words:
SfM, 3D documentation, palaeoanthropology, Laetoli, footprints.

CHNT Reference:
Sofia Menconero et al. 2018. 3D Survey in Extreme Environment: The Case Study of Laetoli Hominin Footprints in Tanzania.

INTRODUCTION

This contribution deals with 3D documentation of paleontological excavations in extreme environmental context, characterized by unfavorable climatic conditions, light equipment and little time available. In particular, the contribution is focused on the search for a good working procedure which despite the problems mentioned above,

Authors addresses: Sofia Menconero, Dipartimento di Storia, Disegno e Restauro dell'Architettura, Sapienza Università di Roma, Via del Castro Laurenziano 7/A, 00161 Roma, Italy; email: sofia.menconero@uniroma1.it; Angelo Barili, Galleria di Storia Naturale, Centro d'Ateneo per i Musei Scientifici, Università di Perugia, Via del Risorgimento, 06051 Deruta, Italy; email: angelo.barili@unipg.it; Giovanni Boschian, Dipartimento di Biologia, Università di Pisa, Via Derna, 56126 Pisa, Italy; email: giovanni.boschian@unipi.it; Marco Cherin, Dipartimento di Fisica e Geologia, Università di Perugia, Via Alessandro Pascoli, 06123 Perugia, Italy; email: marco.cherin@unipg.it; Elgidius B. Ichumbaki, Department of Archaeology & Heritage, College of Humanities, University of Dar es Salaam, P.O. Box 35050, Dar es Salaam, Tanzania; email: ichumbaki@udsm.ac.tz; Dawid A. Iurino, Dipartimento di Scienze della Terra, Sapienza Università di Roma, Piazzale Aldo Moro 5, 00185 Roma, Italy; email: dawid.iurino@uniroma1.it; Giorgio Manzi, Dipartimento di Biologia Ambientale, Sapienza Università di Roma, Piazzale Aldo Moro 5, 00185 Roma, Italy; email: giorgio.manzi@uniroma1.it; Fidelis T. Masao, Department of Archaeology & Heritage, College of Humanities, University of Dar es Salaam, P.O. Box 35050, Dar es Salaam, Tanzania; email: fitman@udsm.ac.tz; Jacopo Moggi Cecchi, Dipartimento di Biologia, Università di Firenze, Via del Proconsolo 12, 50122 Firenze, Italy; email: iacopo.moggicecchi@unifi.it

can lead to valid results in terms of accuracy and precision, and can result as reference for further scientific activities in similar contexts.

The workflow is here presented through the description of the multidisciplinary field work carried out on fossil footprints at Laetoli (Tanzania) in September 2015.

In the chapter "Laetoli: old footprints and new discoveries", a brief history of this renowned paleontological site is traced, emphasizing its importance for the knowledge of early human evolution. Particularly, old and new paleontological discoveries, made at the site since the 1970s, are briefly discussed, as is their outstanding contribution to increase our knowledge on the morphology and behavior of the species *Australopithecus afarensis*. In the chapter "The extreme environment of the African Savannah", the geographic, geomorphological, climatic, floristic and faunistic, anthropic and hygienic-sanitary characteristics of the study area are described. The contents of this section highlight how Laetoli is an extreme context subjected to many factors that endanger the conservation of its unique Cultural Heritage. The chapter "Workflow: 3D survey for documentation and analysis" presents the procedure adopted in 2015 from survey planning to fieldwork acquisition, from data processing to morphological and morphometric analysis of hominin footprints. In the last paragraph the conclusions of the work are drawn with hints on future developments related to the conservation of the Laetoli site.

LAETOLI: OLD FOOTPRINTS AND NEW DISCOVERIES

Laetoli is one of the most important paleoanthropological sites in the world. Although known for its scientific relevance since the mid-1930s [Reck and Kohl-Larsen 1936; Kohl-Larsen 1943], the sites reaches planetary knowledge in the 1970s thanks to the discovery of the holotype and other findings of *Australopithecus afarensis* [Leakey et al. 1976; Johanson et al. 1978], as well as of fossil bipedal footprints [Leakey and Hay 1979; Leakey and Harris 1987] on a cemented ash layer produced by a volcanic eruption and dated at 3.66 million years ago [Deino 2011]. The hominin trackways were found by Mary Leakey and collaborators in 1978 at Laetoli Site G and were referred to three individuals (G1, G2, G3) of different boy size: the smallest individual (G1) walked side by side on the left of the largest individual (G2), while the intermediate-sized individual (G3) superimposed its feet over those of G2 [Leakey 1981]. The trackways are usually ascribed, not without controversy [Tuttle et al. 1991; Harcourt-Smith 2005], to *Au. afarensis* [White and Suwa 1987], which is the only hominin species found to date in the Upper Laetoli Beds (i.e. the geological unit that hosts the printed ash layers, which form the so-called Footprint Tuff) [Harrison 2011].

Hominin footprints are very rare and most of them are ascribed to the genus *Homo*. For this reason, the Laetoli footprints, made by members of the hominin species *Au. afarensis* – the same species as the famous "Lucy" from Ethiopia – are extremely important and unique.

Almost forty years after the important discovery of the first footprints, other bipedal tracks were found in Laetoli (Fig. 1). The new trackways reopened old debates and helped to clarify some aspects of the body size of *Au. afarensis* and to suggest inferences on the reproductive behavior and social structure of these ancient hominins.

The new Site S, located about 150 m to the south of Site G, was discovered in September/October 2014 during systematic survey and excavation activities (Cultural Heritage Impact Assessment) aimed at evaluating the impact of a proposed new field museum at Laetoli. A year later, fourteen hominin tracks, associated with tracks of other vertebrates, were unearthed in three test-pits, respectively labelled L8, M9 and TP2 from north to south [Masao et al. 2016] (Fig. 2). A multidisciplinary Italian-Tanzanian research team was involved in studying the findings. Seven bipedal tracks in different preservation state were exposed in L8, four in M9 and two additional tracks of the same individual were found in the eastern part of TP2 [Masao et al. 2016]. Following the code used for the Site G prints [Leakey 1981], the new individual was referred to as S1. One more track referable to a second individual (S2), smaller than S1, was found in the SW corner of TP2 [Masao et al. 2016]. Another test-pit, labelled M10, yielded very abundant non-hominin footprints.

Detailed analysis of the excavation profiles and extended geological observation in the whole Laetoli area indicate with reasonable confidence that the footprints of S1 and S2 lie on the same stratigraphic horizon as those at Site G. It can be consequently inferred that the tracks of the two sites were likely left by a single group of hominins walking on the same palaeosurface, in the same direction and with similar moderate speed [Masao et al. 2016].

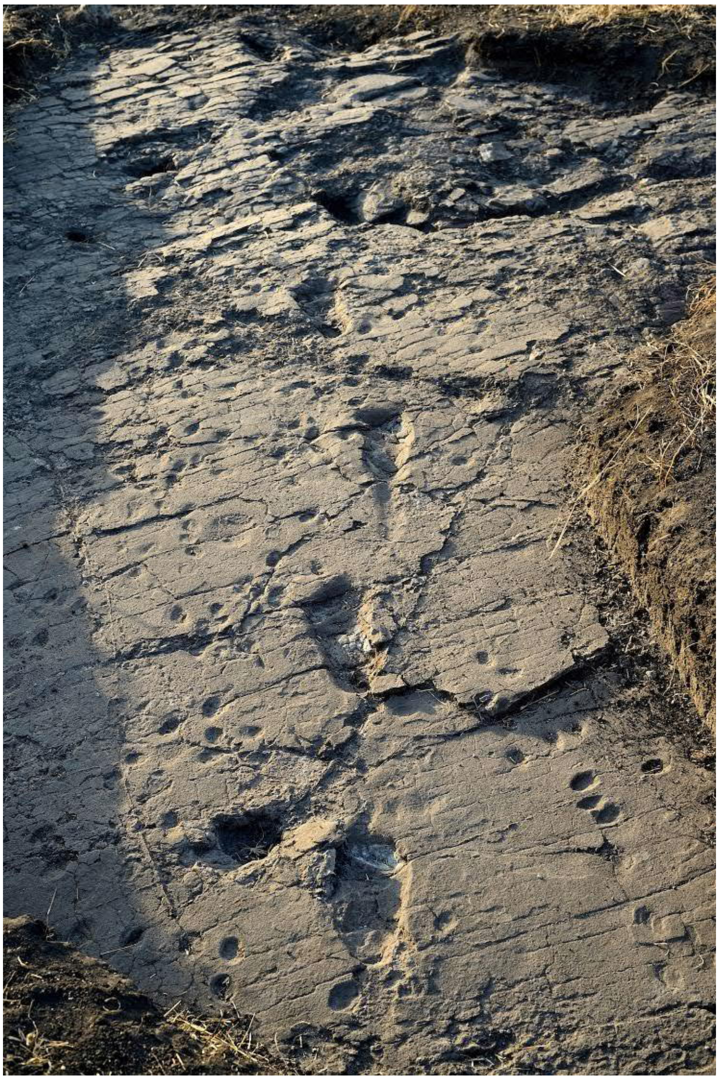

Fig. 1. Test-pit L8 at Laetoli Site S. In the northern part of the test-pit (at the top), the Footprint Tuff is particularly altered, damaged by plant roots and dislodged along natural fractures

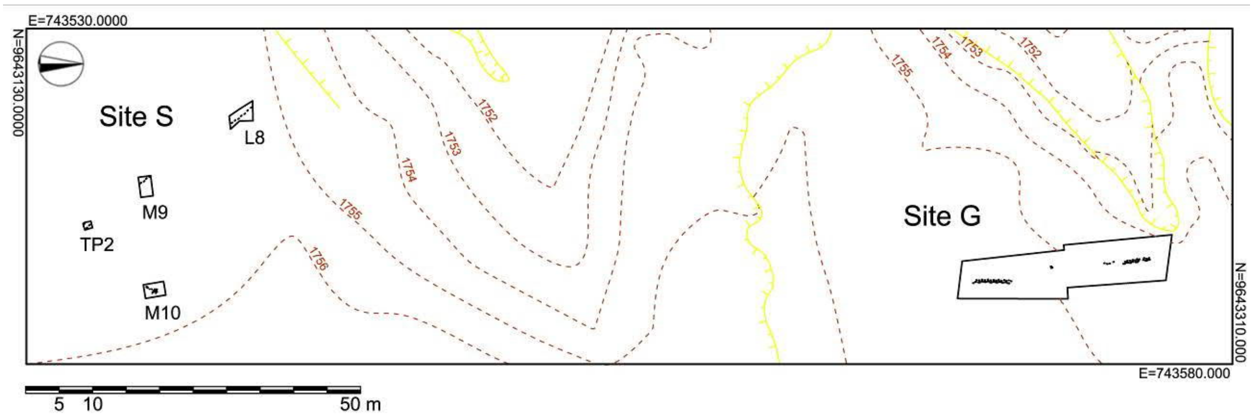

Fig. 2. Location map of the old Site G and the new Site S

The topographic and photogrammetric surveys carried out during the 2015 fieldwork, and explained in the next paragraphs, served to obtain morphological and morphometric data for subsequent analysis. Footprints dimension and distance (e.g. step and stride) were used to estimate walking speed, stature and body mass of the Laetoli track-makers. All the above data were also measured for G1-G2-G3 through a 3D model of a first-generation cast of the southern portion of the Site G trackways [Masao et al. 2016].

The analysis of the new data showed that the two individuals S1 and S2 were taller and had a larger body mass than the G individuals. These results extended the dimensional range of the Laetoli track-makers and identified S1 as a large-sized individual, probably a male. The estimate stature of about 165 cm for S1 is remarkable, exceeds any australopithecine, and falls within the range of modern *Homo sapiens* maximum values [Masao et al. 2016]. These results also supported a nonlinear evolutionary trend in hominin body size [Jungers et al. 2016], contrasting with the idea that the emergence of the genus *Homo* and/or the first dispersal out of Africa was related to an abrupt increase in body size. Moreover, ascribing the S1 tracks to an adult male allowed reconsidering the sex and age of the other Laetoli individuals, which have been the subject of several interpretations since Mary Leakey's work. According to the body-mass estimates from the recent surveys, G1 and G3 fall within the range of putative *Au. afarensis* females, whereas G2 and S2 span across the upper female and the lower male ranges. A possible tentative conclusion is that the Laetoli individuals are: S1, a male; G2 and S2, females; G1 and G3, smaller females or juvenile individuals [Masao et al. 2016]. Both the new composition of the group and the impressive body size difference suggest a considerable sexual dimorphism in *Au. afarensis*, as hypothesized by many scholars on the basis of skeletal remains [Johanson and White 1979; Kimbel and White 1988; McHenry 1991; Richmond and Jungers 1995; Lockwood et al. 1996; Plavcan et al. 2005; Harmon 2006; Gordon et al. 2008]. In turn, this view supports social organization and reproductive strategies closer to those of the polygynous gorillas than to other moderately dimorphic species, like chimpanzees, bonobos or most of the extant and, possibly, extinct humans [Masao et al. 2016] (Fig. 3).

Fig. 3. Reconstruction of the paleoenvironment of Laetoli 3.6 million years ago with the five hominins leaving their footprints

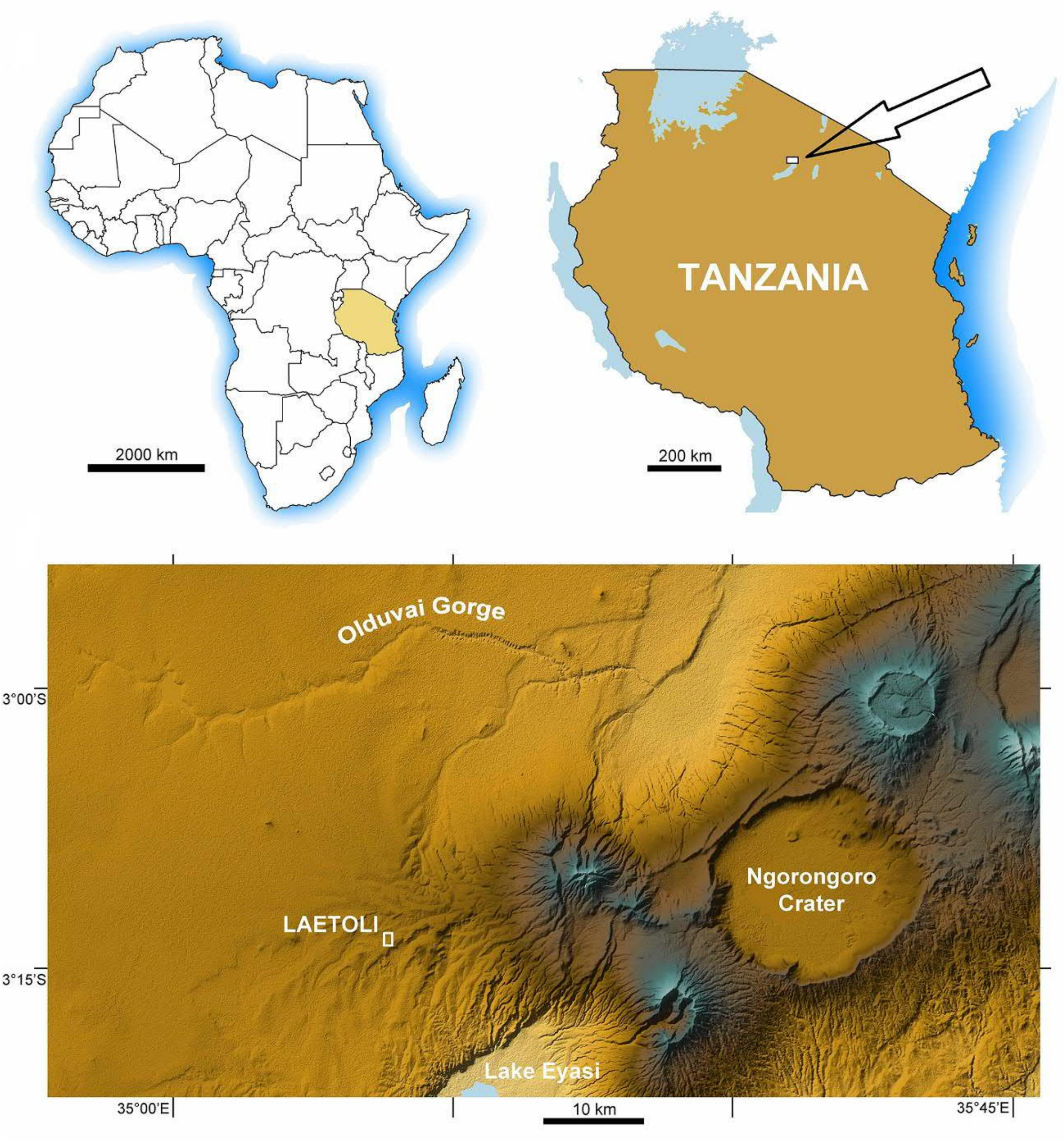

Fig. 4. Geographical location of the Laetoli site

THE EXTREME ENVIRONMENT OF THE AFRICAN SAVANNAH

The geo-paleontological site of Laetoli is located in northern Tanzania (Latitude: 2°59'46.39" S, Longitude: 35°21'8.64" E) and extends over a vast plateau at about 1,700 m above sea level, to the west of the volcanic complex of Sadiman (2,870 m), Lemagrut (3,135 m) and Oldeani (3,200 m), between the south-eastern limits of the Serengeti plains and the Lake Eyasi basin (Fig. 4). Because of its proximity to the Equator, the daily distribution of day and night hours is regular: 12 hours of light and 12 of dark. This means that the working day is quite short because the sunset is at 6:00 pm. The location of the study area is about 16 km west of the small village of Endulen (the nearest village to the site) and about 45 km SW of the famous Olduvai Gorge. The entire territory of Laetoli falls administratively in the Region of Arusha and in the District of Ngorongoro, and within the "Ngorongoro Conservation Area" (NCA), a large protected area of 8,292 km^2. The NCA was established by the Tanzanian government in 1959 with the primary purpose of protecting landscapes, environments, flora and fauna, and of combining the conservation of local natural resources with the traditional pastoral practices of the Maasai people, which represents the largest ethnic group in the region (Fig. 5).

Fig. 5. Current environment of Laetoli area: maasai and giraffe in the Savannah

The plateau is characterized by a mostly tabular or slightly corrugated general morphology. In some areas, the gentle lines of the landscape become more complex and articulated, as the territory is strongly influenced by narrow and variably deep valleys/gorges/gullies originated by small streams with seasonal trends, with springs located on the nearby mountains. Where the consolidated Footprint Tuff is not exposed, the soil is mostly formed by greyish fine sands, deriving from the erosion of the volcanoclastic bedrock. It is worth noting that under equatorial climatic conditions (see below) this process can be extremely hard both in the “dry season” and in the “rainy season”, due to the intense erosional energy of wind and water, respectively.

The Laetoli area has a tropical sub-montane semi-arid climate and is characterized by an average annual temperature of 17.6 °C and an average annual rainfall of 886 mm. The seasonality is considerable, mainly due to the high variability of rainfall and monthly atmospheric humidity gradient, which is not very relevant for temperatures. Rainfall is mostly concentrated in the “rainy season”, which corresponds to the Southern Hemisphere summer (from November to May). On the contrary, months corresponding to the Southern Hemisphere winter (from the end of May to October) are characterized by a long “dry season” with periods of almost complete absence of rains and with atmospheric humidity levels lower than 50 %. Strong dryness causes the pulverization of soil that, combined with the notable windiness of the area, can give rise to frequent “dust storms” which cause difficulties for researchers on fieldwork activities. Seasonal differences in temperature, as already reported above, remain on modest levels for the whole year: averages of 27-36 °C in daytime and 17-19 °C in night-time during the “southern summer”; diurnal averages of 26-30 °C and nocturnal of 13-15 °C during the mild “southern winter”.

The current vegetation cover of this area is primarily determined by topographical and climatic conditions and soil composition [Anderson 2008] (Fig. 6). It has also been influenced by fires of both natural and anthropic origin, as well as by the grazing activity of the huge amount of wild herbivore mammals (especially in the rainy season) and of domestic livestock (cattle, sheep and goats) bred by local tribes with nomadic and semi-nomadic pastoral economy [Holdo et al. 2009]. The vegetation of this territory, widely studied and mapped in detail [Herlocker and Dirschl 1972; Andrews and Bamford 2008], mainly includes various types of thorny thickets and dry bushland, consisting of shrubby and/or arboreal deciduous species of the genus *Vachellia* and *Senegalia* (*V. tortilis*, *V. kirkii*, *V. seval*, *V. drepanolobium*, *S. mellifera*) and *Commiphora* (*C. trothae*, *C. africana*). Specifically for the site of Laetoli, the local plant cover is mainly characterized by a low bushland, dominated by the Whistiling thorn acacia (*V. drepanolobium*), by a scattered woodland, with the Umbrella thorn acacia (*V. tortilis*) and the Honey thorn acacia (*S. mellifera*), which develop along small seasonal streams and near slight humid depressions, and by grassy expanses consisting of various species of Graminaceae (genus *Sporoboro*, *Digitaria*, *Themeda*, *Aristida*, *Brachiaria*, *Cenchrus*, *Chloris*, *Killinga*, etc.) with scattered specimens of shrubs and small trees as the Wild date tree (*Balanites aegyptiaca*). Along small perennial watercourses, that cross the plateau, are sparse riparian woods dominated by the Yellow fever tree (*V. xanthophloea*), scattered specimens of the Apple-ring acacia (*Faidherbia albida*) and different species of wild figs of genus *Ficus*, in particular the Sycamore fig (*F. sycomorus*). Regarding the aforementioned vegetation, the component that causes the greatest disturbance to researchers is certainly the presence of numerous thorny species, which sometimes hinder survey activities.

The Laetoli site, as a large part of the plateau that extends west of Endulen, still has a rich and very interesting fauna, thanks to the low human demographic density of the area, to the persistence of thorny xerophilous scrublands with difficult penetrability and economic use by local pastoral communities, and to the high level of protection guaranteed by the NCA. In addition to numerous species of invertebrates (e.g. insects and arachnids), to few species of fishes and amphibians limited to rare perennial watercourses and ephemeral seasonal wetland, there are many species of reptiles, birds and mammals that characterize the fauna of this territory. Among reptiles, there are many species of the order Squamata (lizards and snakes), including some species of snakes potentially very dangerous to humans, such as the Egyptian cobra (*Naja haje*), the Spitting cobra (*N. nigricollis*), the Black mamba (*Dendroaspis polylepis*), the Green mamba (*D. angusticeps*) and the Puff adder (*Bitis arietans*). Among birds, numerous sedentary and nesting species typical of sub-arid environments, as well as migratory regular or wintering step species are present. Among mammals, there are numerous species of rodents and their predators: small or medium-sized carnivores, in particular mongooses, the Wild African cat (*Felis lybica*) and the Caracal (*Caracal caracal*). There are also many large-sized species, such as various antelopes, from the Grant's gazelle (*Nanger grantii*) to the massive Eland (*Taurotragus oryx*), in addition to the Grant's zebra (*Equus quagga boehmi*), the Maasai giraffe (*Giraffa camelopardalis tippelskirchii)* and the African bush elephant (*Loxodonta africana)*. Many of these large mammals, in particular zebras and elephants, tend to frequent the Laetoli area seasonally, especially during the most humid and vegetation-rich periods. Even the large carnivores, such as the Spotted hyena (*Crocuta Crocuta*), the Cheetah (*Acinonyx jubatus*), the Leopard (*Panthera pardus*) and the African lion (*Panthera leo*) occasionally frequent the most remote areas that surround the site, mainly during periods with great seasonal presence of herds of ungulates. Primates include the small Senegal bushbaby (*Galago senegalensis*), the Brown greater galago (*Otolemur crassicaudatus*) and the Vervet monkey (*Chlorocebus aethiops*) in the riverine forests; the Olive baboon (*Papio aubis*) in scrubland and deciduous xerophilous forests but also in open steppe areas, as well as near the most populated territories including the surroundings of Endulen.

Regarding the anthropic aspects, the demographic density of the entire area is quite low and there are few permanent settlements with a population of more than a thousand inhabitants. With regards to scientific field activities, this means that it is not easy to get consumer goods *in situ*, but it is necessary to get food, water and materials from larger villages, such as Karatu, which is a 4-hour drive from Laetoli.

For what concerns hygienic-sanitary aspects, the whole area normally does not present serious problems related to tropical pathologies that are widespread in the nearby low-altitude regions, thanks to the considerable altitude of the plateau between Endulen and Laetoli (about 1,400-2,000 m above sea level) and very dry climate for most of the year. Despite this, in the wettest areas and especially along the few perennial watercourses, there are small stable population of hematophagous dipterans of the genera *Anophele* (potential vectors of protozoa of the genus *Plasmodium*, responsible for malaria) and *Aedes* (carrier of various viruses responsible for serious diseases). Therefore, the risk of malaria, as well as that of yellow fever, is still present, although contained and mainly diffuse during the wettest periods of the year. Other species of hematophagous dipterans belonging to the families Tabanidae (Horse-flies) and Simuliidae (Black-flies) can inflict painful bites and cause serious skin irritations.

Fig. 6. Current vegetation cover of Laetoli area

WORKFLOW: 3D SURVEY FOR DOCUMENTATION AND ANALYSIS

The problems related to the extreme Laetoli environment, which can be found in other similar environments in Africa and other areas, are two types: those that hinder the survey and study of Cultural Heritage, and those that endanger its preservation. The first include short time available, adverse weather conditions, lack of electricity, problems related to natural lighting, etc., and can be minimized with a good survey planning. The second, due to multiple environmental factors (climate, vegetation, animal behaviors, etc.), can be addressed through a comprehensive conservation plan.

In this paragraph we discuss the difficulties concerning fieldwork activities and present the workflow that we implemented, analyzing the problems and proposing the solutions adopted during the research in September 2015.

To structure a good survey plan, clear goals are necessary. In our case, the survey of the new tracks at Site S was focused on obtaining 3D models for documentation and morphometric analysis. The survey method is the “Structure from Motion” (SfM) technique, an image-based process supported by *in situ* topographic measurements [Remondino et al. 2006]. This technique was chosen because of its technical advantages (relatively short time of data acquisition and processing, light and handy equipment, reduced costs) and excellent results in terms of resolution [Cefalu et al. 2013]. The photogrammetric technique was also chosen to survey the Site G during a study campaign on footprints conservation in the 1990s by the team of the Getty Conservation Institute [Getty Conservation Institute 1996].

As mentioned above, hominin and non-hominin tracks were recognized in four test-pits at Site S, namely L8 (about 2 x 4 m), M9 (2 x 2 m), TP2 (1 x 1.3 m), and M10 (2 x 3 m) (Fig. 7).

To optimize the work, each test-pit was entirely surveyed at lower resolution and then detailed 3D models of some inner portions (single prints or groups of close prints) were acquired. After the excavation, targets of the control point system were immediately positioned. We placed four perimeter targets on the ground at the corner of each test-pit, and four inner targets around each sub-area surveyed in detail (14 targets in L8, 10 in M9, 14 in TP2, and 14 in M10) (Fig. 8).

The equipment used in the fieldwork was a DSLR camera with 15 megapixels resolution (4,752 x 3,168 pixel) and two different lenses: 24 mm f/2.8 for general shots of the excavation areas and 50 mm f/1.4 for details of the tracks.

When necessary, the camera was mounted on a 3 m-long telescopic rod. A measuring tape and a water level were used for the measurement of the control points (i.e. circular targets with 35 mm diameter). Topographic measurements are usually recorded by a total station theodolite. We opted for the aforementioned tools, certainly lighter and easier to handle, after considering measuring only 4 points for each test-pit to scale the general 3D models. The detailed 3D models of the single footprints were aligned to the general models with the coordinates of the inner targets. We also ascertained that this measuring technique can provide high precision results because of the small size of the surfaces to be detected.

For the perimeter targets measurement, we placed two rods equipped with a spherical level on successive pairs of targets and we marked points at the same height on the rods for each pair by using the water level device. The vertical distance between these points and the targets, as well as their mutual distance, were recorded. Repeating this process for all pairs of targets, the relative plan position and the height of the control points were determined respectively by trilateration and levelling.

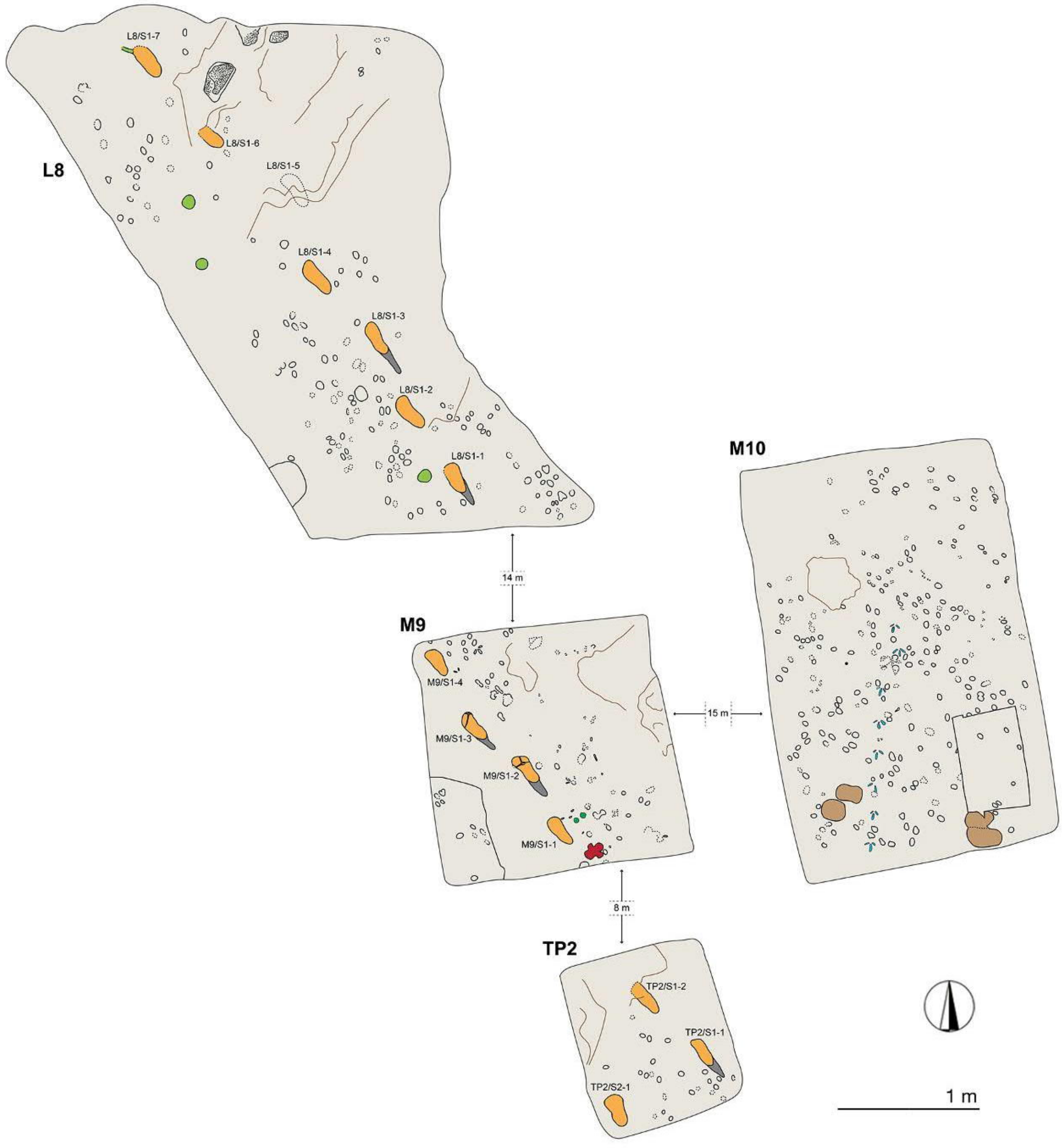

Fig. 7. Plan view of the four test-pits excavated at Laetoli Site S. Dashed lines indicate uncertain contours. Some of the most interesting tracks are colored: hominins in orange (heel drags in dark grey), equid in dark green (M9), rhinoceros in red (M9), giraffe in light brown (M10), guinea fowl in blue (M10). Large roots and bases of trees are

in light green (L8). The main faults/fractures are indicated by brown lines. Raindrop impressions occur in the northern part of L8 (dotted areas)

A preliminary accuracy check was carried out during fieldwork, by using trilateration graphic rules in plan and by the method of successive levelling for heights. By assigning a z-coordinate to the first control point, all subsequent coordinates were derived from addition and subtraction of heights between two successive points. The check was performed by computing the algebraic sum of all height differences, and by verifying that the obtained value was close to zero. Finally, the error obtained in each test-pit was distributed to every z-coordinate of the points, in order to minimize it (Tab. 1).

There were mainly two issues to consider during the photographic acquisition: scene lighting and texture resolution of 3D models. As for the former, since the excavation areas were outdoor, we did not have the possibility to control light intensity and direction. We tried to shoot especially during the central hours of the day (i.e. with sub-vertical sun rays) in order to reduce shadows, but it was not always possible due to the excavation schedule and little time available. A diffuse lighting would be perfect, but it is not always possible to obtain without the aid of artificial lights. The problem of high-contrast shadows was reduced in post-processing, as described below.

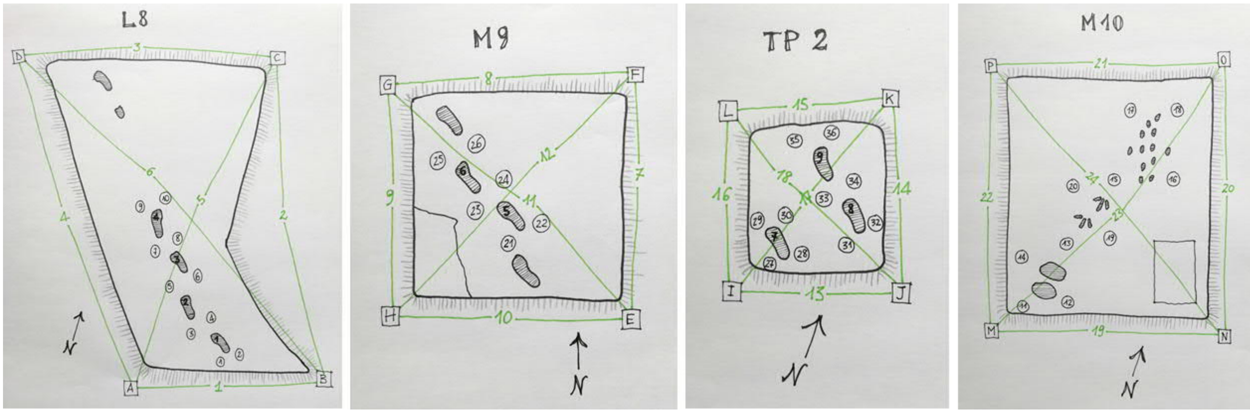

Fig. 8. Eidotypes of the four test-pits

Table 1. Fieldwork measurement acquisition and error calculation

TEST-PIT ID	MEASURE ID	1ST TARGET ID	1ST TARGET ALTITUDE (m)	2ND TARGET ID	2ND TARGET ALTITUDE (m)	DISTANCE (m)	Δ MEASURED (m)	Δ CORRECTED (m)	
L8	1	A	0,775	B	0,725	2,561	0,050	0,051	
L8	2	B	0,774	C	0,921	3,271	-0,147	-0,146	
L8	3	C	0,486	D	0,613	3,441	-0,127	-0,126	
L8	4	D	0,702	A	0,482	3,591	0,220	0,221	
L8	5	A	0,523	C	0,620	4,176	ERROR (m)	ERROR DIVIDING (m)	FINAL ERROR (m)
L8	6	B	0,453	D	0,724	4,894	-0,004	-0,001	0,000

I TRIANGLE CHECK

1ST TARGET ID	1ST TARGET ALTITUDE (m)	2ND TARGET ID	2ND TARGET ALTITUDE (m)	Δ MEASURED (m)
A	0,775	B	0,725	0,050
B	0,774	C	0,921	-0,147
C	0,620	A	0,523	0,097
				ERROR (m)
				0,000

II TRIANGLE CHECK

1ST TARGET ID	1ST TARGET ALTITUDE (m)	2ND TARGET ID	2ND TARGET ALTITUDE (m)	Δ MEASURED (m)
A	0,775	B	0,725	0,050
B	0,453	D	0,724	-0,271
D	0,702	A	0,482	0,220
				ERROR (m)
				-0,001

III TRIANGLE CHECK

1ST TARGET ID	1ST TARGET ALTITUDE (m)	2ND TARGET ID	2ND TARGET ALTITUDE (m)	Δ MEASURED (m)
C	0,486	D	0,613	-0,127
D	0,702	A	0,482	0,220
A	0,523	C	0,620	-0,097
				ERROR (m)
				-0,004

IV TRIANGLE CHECK

1ST TARGET ID	1ST TARGET ALTITUDE (m)	2ND TARGET ID	2ND TARGET ALTITUDE (m)	Δ MEASURED (m)
C	0,486	D	0,613	-0,127
D	0,724	B	0,453	0,271
B	0,774	C	0,921	-0,147
				ERROR (m)
				-0,003

The texture resolution control of 3D models, i.e. the "Ground Sampling Distance" (GSD), can be performed *a priori* using geometric formulas. The calculation is based on the principle of similar triangles, which are found in the geometry of the shooting (Fig. 9). The variables are the "size of the sensor" (Sw) and the "focal length" (Fl) of the camera, the "size in pixel of the images" (Iw) (which depends on the sensor resolution), and the "distance" (H). The triangle with the base Sw and height Fl is similar to the triangle which has the base Gw (width of the image on the ground) and height H, consequently the two triangles have proportional respective sides (Sw : Gw = Fl : H). The GSD is the ratio between the Gw and the Iw multiplied by 100 (GSD = Gw /Iw x 100). Connecting the proportion with the formula of GSD, the final formula GSD = (Sw x H x 100) : (Fl x Iw) is obtained. Among the variables, the one that can be easily managed is the distance H, since all the others depend on the photographic equipment available.

It is not possible to determine a priori the density of the point cloud coming from a photogrammetric process.

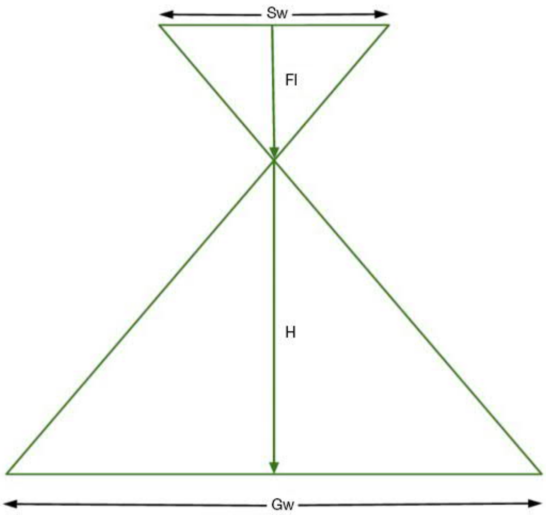

Fig. 9. Similar triangles and nomenclature

In the case of the Laetoli footprints, the goal was to obtain a texture resolution less than 0.1 cm/px. This was achieved by choosing suitable shooting distance both for the acquisition of the whole test-pits and for that of individual footprints (Tab. 2). The photographic survey was carried out by three shooting modes: (1) using the camera with the 24 mm lens, mounted on a telescopic rod at 3 m above the test-pit ground; (2) using the camera freehand with the 24 mm lens, in order to acquire additional shots of each test-pits; and (3) using the camera close to the ground with the 50 mm lens, in order to acquire detailed sub-areas. More than 2,000 photos were taken, for a total of about 50 GB. Especially when working in remote areas, where it is difficult to come back in case of lack of data, it is important not to economize on shots and possibly make a selection *a posteriori*.

Table 2. Ground Sampling Distance calculation

Ground Sampling Distance for the entire test-pit

Sw	22,3	= the sensor width of the camera (millimeters)
Fl	24	= the focal length of the camera (millimeters)
H	3	= height or distance (meters)
Iw	4752	= the image width (pixels)
Ih	3168	= the image height (pixels)
GSD	**0,06**	**= Ground Sampling Distance (centimeters/pixel)**
Gw	2,79	= width of single image footprint on the ground (meters)
GH	1,86	= height of single image footprint on the ground (meters)

Ground Sampling Distance for single footprint

Sw	22,3	= the sensor width of the camera (millimeters)
Fl	50	= the focal length of the camera (millimeters)
H	1	= height or distance (meters)
Iw	4752	= the image width (pixels)
Ih	3168	= the image height (pixels)
GSD	**0,01**	**= Ground Sampling Distance (centimeters/pixel)**
Gw	0,45	= width of single image footprint on the ground (meters)
GH	0,30	= height of single image footprint on the ground (meters)

The whole fieldwork lasted three days, from the 5th to the 8th of September 2015.

Data processing was carried out once we came back to Italy and started with checking measurements in plan and height. This step is preliminary to the definition of the control point coordinates. The trilateration method was used to obtain x,y coordinates of the control points in plan. For each test-pit, six measurements were taken at the same height: the length of the four sides of the perimeter and the length of the two diagonals. Redundant measurements were used to compute the errors. In addition to a preliminary graphical control by CAD software (*Autodesk Autocad*[1]), we used an automatic calculation software (*MicroSurvey STAR*NET*[2]) to adjust, by least squares technique, a new set of x,y coordinates and heights of the control points. The report provided by the software shows that the residues of adjustments never exceeded 10 mm, which is fully acceptable figure considering the size of test-pits. We used the adjusted x,y,z coordinates of the control points to scale and locate, in the 3D space, the 3D models built by the SfM technique.
The pictures were catalogued and post-processed in *Adobe Lightroom*[3] to amend the effects of different lighting conditions and homogenize them. The tone adjustment consisted in lighten the shadows and darken the highlights. These settings work best if the shots are recorded in *raw* format.

Subsequently, a photogrammetric software (*Agisoft Photoscan Pro*[4]) was used to generate 3D spatial data starting from the pictures, through the following phases: alignment of the images; creation of the dense point cloud; transformation of the dense point cloud into a surface (mesh); application of the texture to the mesh (Tab. 3). A series of orthophotos (with and without textures) were extracted from the 3D models (Figs. 10, 11) [Chiabrando et al. 2015]. A check on point cloud density was also carried out by a software for 3D point cloud and mesh processing and analysis (*CloudCompare*[5]). The average density found in the Laetoli point clouds is around 20 points/cm^3 for the test-pits and 1,500 points/cm^3 for the detailed footprints (Fig. 12).

Table 3. Report of the photogrammetric processing.

ID DATA	PICTURES (n°)	TIE POINTS (n° points)	DENSE CLOUD (n° points)	MESH (n° faces)	TEXTURE (pixel)
L8	171	15.755	6.523.219	6.000.000	6.000 x 6.000
L8/S1-1	31	4.885	12.788.392	1.000.000	4.096 x 4.096
L8/S1-2	31	5.105	11.956.726	1.000.000	4.096 x 4.096
L8/S1-3	34	6.721	14.577.445	1.000.000	4.096 x 4.096
L8/S1-4	38	5.754	13.849.615	1.000.000	4.096 x 4.096
M9	277	16.752	5.520.206	5.000.000	6.000 x 6.000
M9/S1-2	97	7.095	3.044.911	1.000.000	4.096 x 4.096
M9/S1-3	90	6.695	3.024.744	1.000.000	4.096 x 4.096
TP2	180	14.476	4.803.978	4.000.000	6.000 x 6.000
TP2/S2-1	89	6.326	9.388.424	1.000.000	4.096 x 4.096
TP2/S1-1	55	4.434	3.624.823	1.000.000	4.096 x 4.096
TP2/S1-2	56	3.991	4.127.016	1.000.000	4.096 x 4.096
M10	127	11.254	4.969.463	5.000.000	6.000 x 6.000
M10/AF1	33	3.704	1.879.530	1.000.000	4.096 x 4.096
M10/AF2	34	3.512	2.204.826	1.000.000	4.096 x 4.096
M10/AF3	42	4.322	3.306.688	1.000.000	4.096 x 4.096

At the end of field season, we also surveyed a first-generation fiberglass cast of the southern portion of the Site G trackway (about 4,7 m in length) kept in the Leakey Camp at Olduvai Gorge (Fig. 13). Data acquisition and processing were performed following the same workflow described above for Site S. We positioned four perimeter control points and 11 inner targets. The latter were used to model in detail six selected tracks. The 3D data were used to compare the old trackways discovered by Mary Leakey and the new ones unearthed in 2015.
The 3D data obtained by the above procedures were also used in the morphometric analysis of the hominin tracks through a contouring and modelling software (*Golden Software Surfer*[6]) that transforms x,y,z data into maps (Fig. 14). The x,y,z-format files were imported into the software and transformed into grid files. The software uses randomly spaced x,y,z data to create regularly spaced grids composed of nodes with x,y,z coordinates. The

[1] https://www.autodesk.com/products/autocad/overview
[2] https://www.microsurvey.com/products/starnet/
[3] https://www.adobe.com/it/products/photoshop-lightroom.html
[4] https://www.agisoft.com/
[5] https://www.danielgm.net/cc/
[6] https://www.goldensoftware.com/products/surfer

triangulation with linear interpolation gridding method was applied, because it works better with data that are evenly distributed over the grid area. This method uses data points to create network of triangles without edge intersection and computes new values along the edges. It is fast and does not extrapolate beyond the z-value of the data range. The grid spacing was set at 1 mm.

On the contour maps we took morphometric measurements: footprint length (maximum distance between the anterior tip of the hallux and the posterior tip of the heel); footprint max width (width across the distal metatarsal region), footprint heel width; angle of gait (angle between the midline of the trackway and the longitudinal axis of the foot); step length (distance between the posterior tip of the heel in two successive tracks); stride length (distance between the posterior tip of the heel in two successive track on the same side) (Fig. 15). All the above measurements were also taken manually both on the original tracks during the September 2015 field season, and on 1:1 scale sketches of the test-pits, hand-drawn on transparent plastic sheets [Masao et al. 2016].

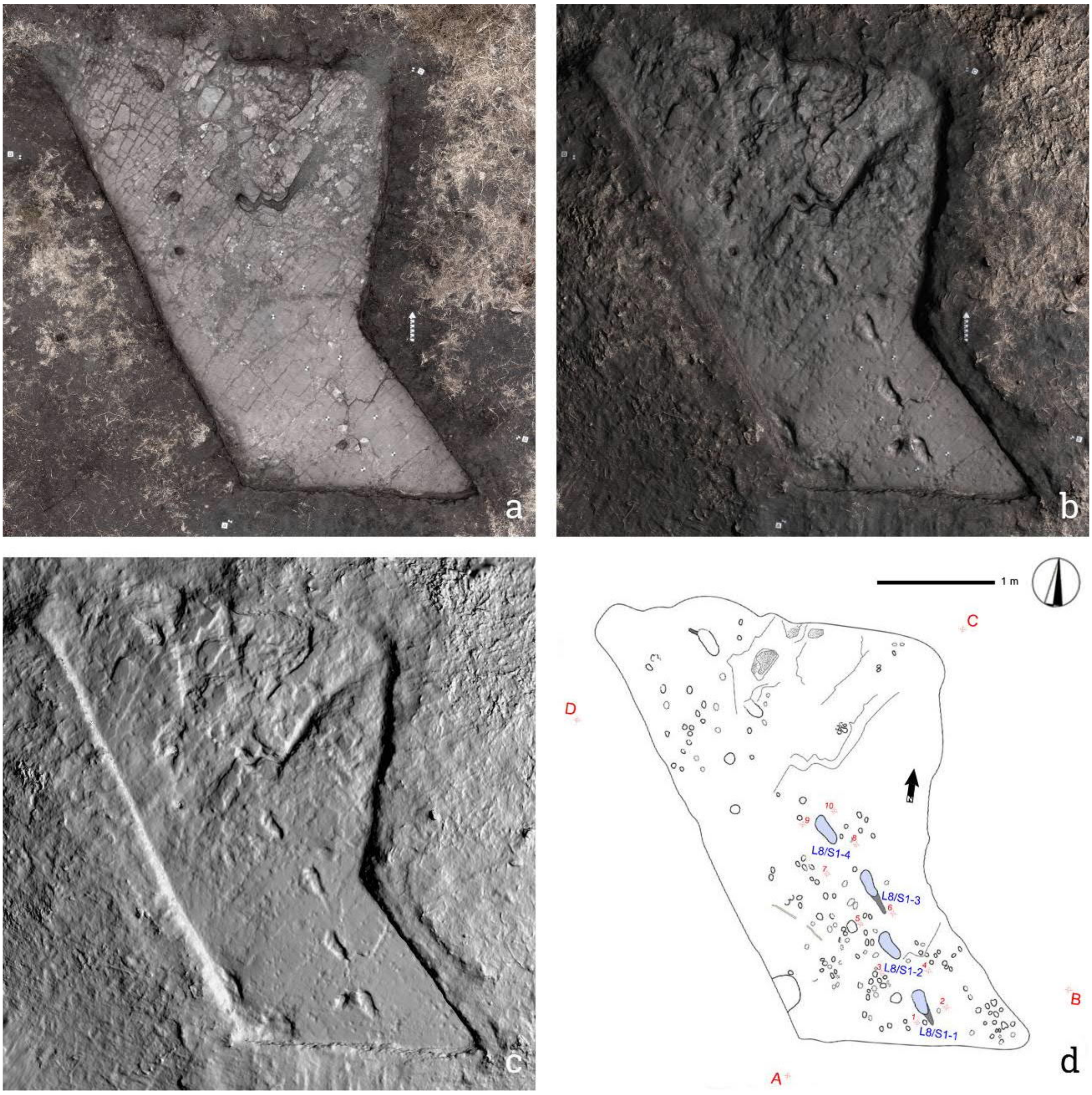

Fig. 10. Orthophotos and drawing of L8 test-pit: (a) textured model, (b) textured and shaded model, (c) shaded model, (d) drawing

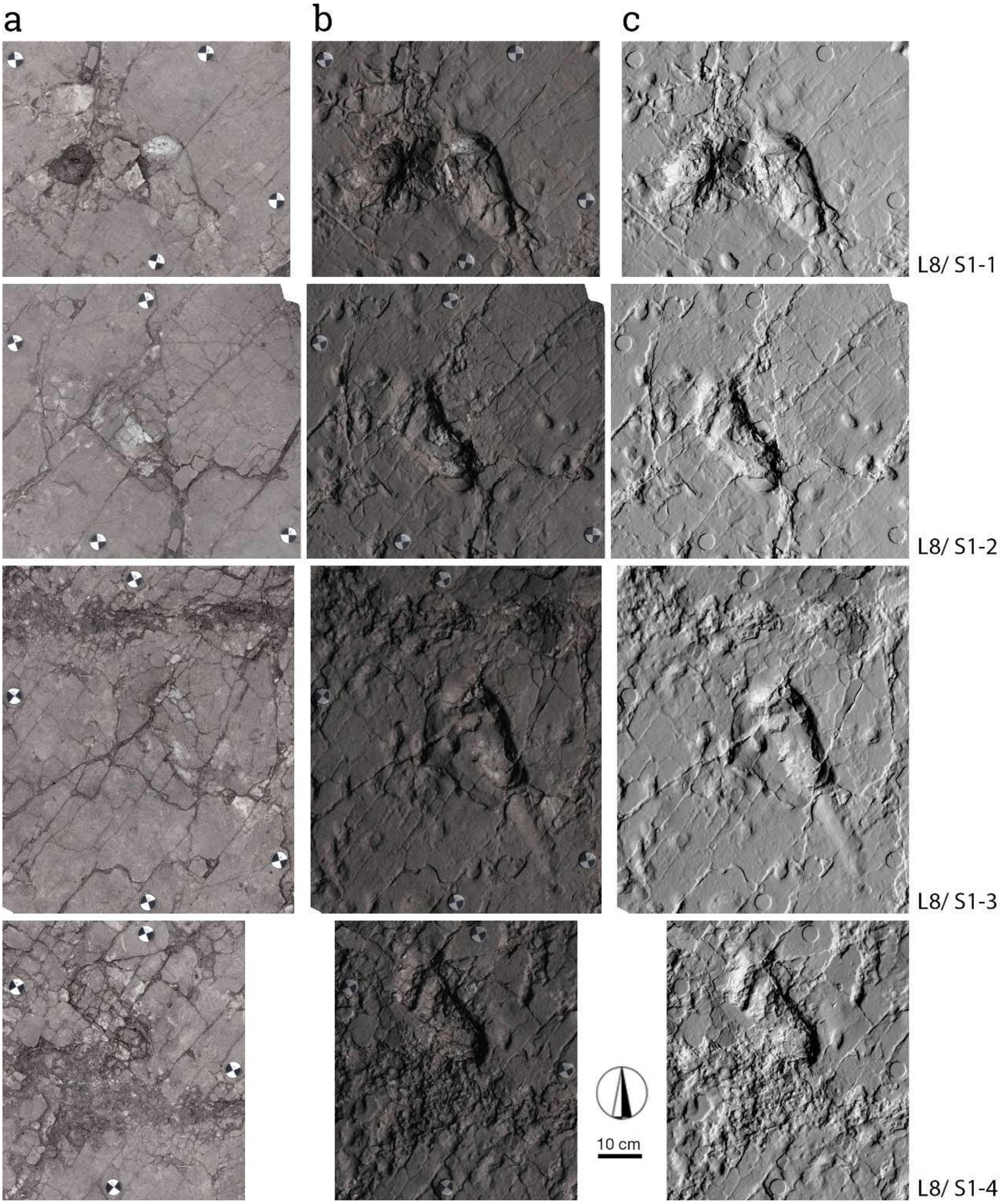

Fig. 11. Orthophoto of the best-preserved footprints in L8: (a) textured model, (b) textured and shaded model, (c) shaded model

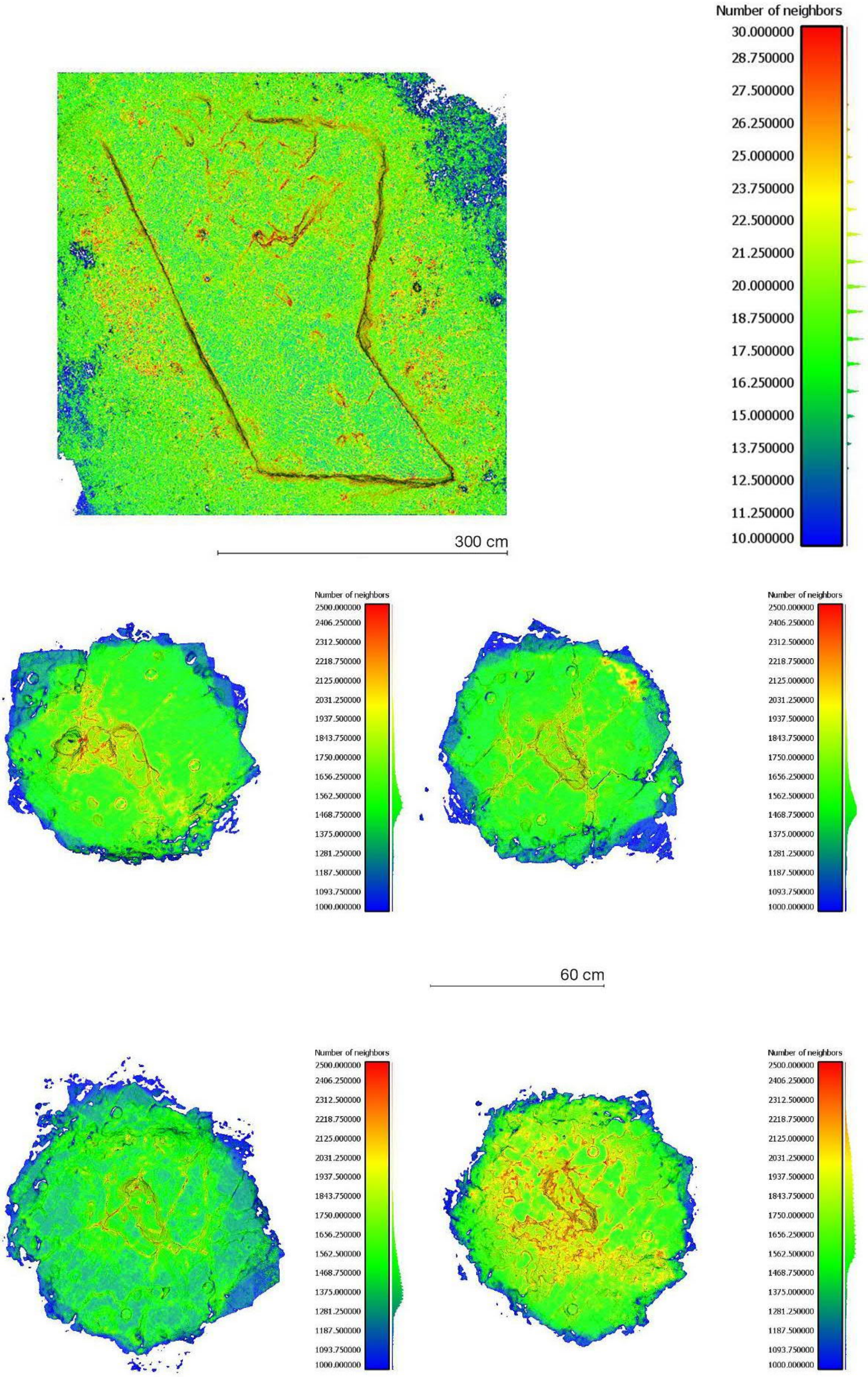

Fig. 12. Density of the point cloud by determining the number of nearest neighbors in a sphere with 0.5 cm radius

Fig. 13. Orthophoto of a cast of the southern portion of the Site G trackway: (a) textured model, (b) textured and shaded model, (c) shaded model

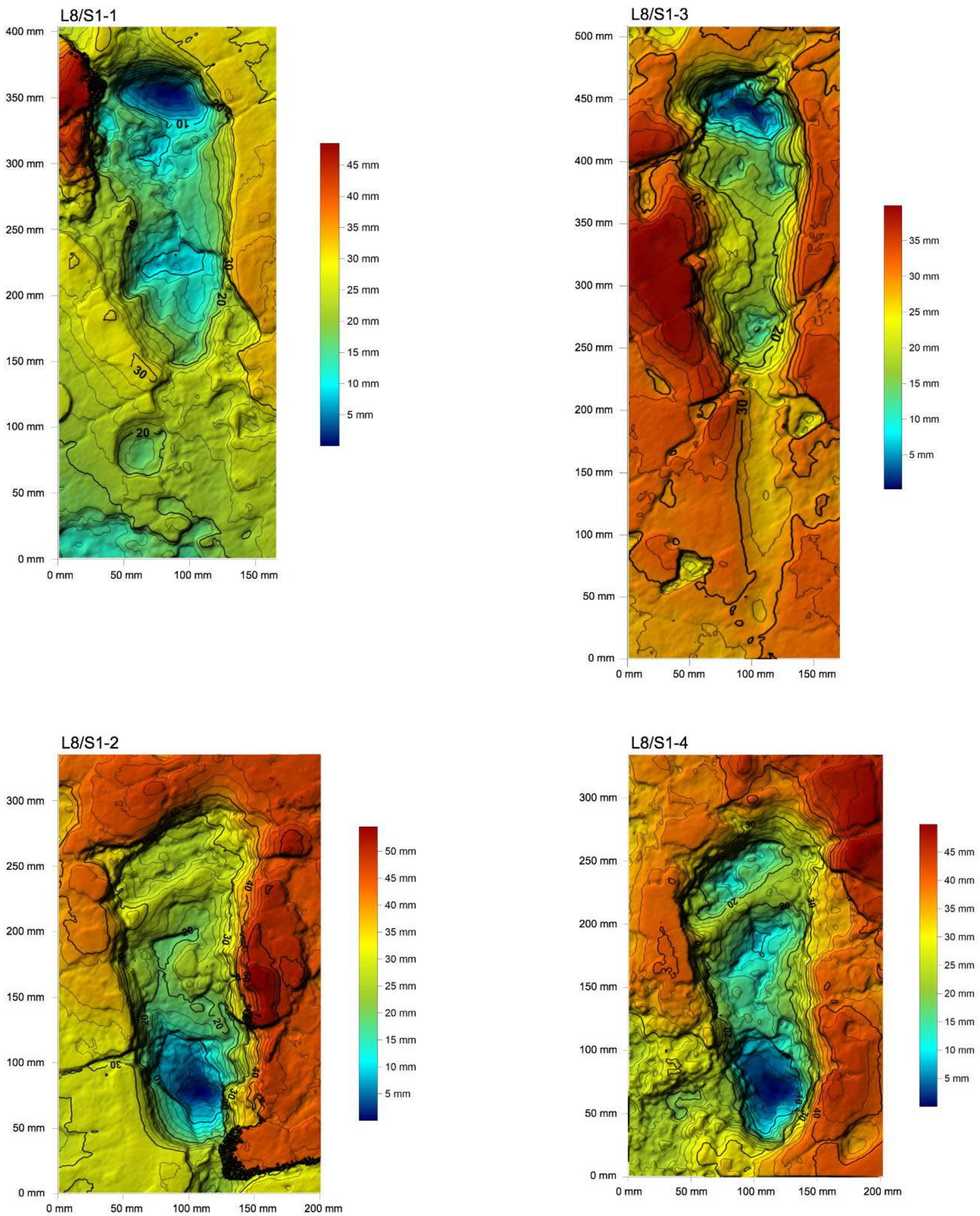

Fig. 14. Shaded 3D photogrammetric model of close-up of the best-preserved tracks with contour lines. Color is rendered with 10-mm isopleths for the trackway and 2-mm isopleths for the single tracks

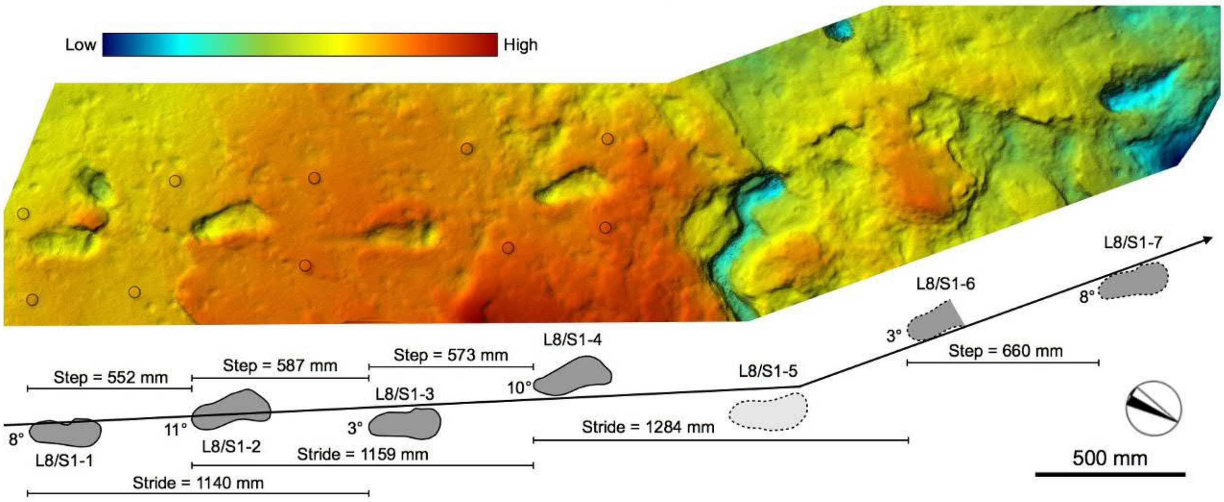

Fig. 15. Shaded 3D photogrammetric model of the L8 trackway. Color is rendered with 10-mm isopleths. The empty circles indicate the position of the targets of the 3D imaging control point system

CONCLUSIONS

Many cultural assets are in risky situation and they are destined to disappear. Sometimes problems arise from human presence/behavior (e.g. wars) or from natural disasters (e.g. earthquakes or landslides). At other times the cause of deterioration is due to the slow and inexorable action of atmospheric agents and other natural factors acting in extreme areas, where the preservation of Cultural Heritage is much more complex.

The proposed workflow and its results are an ideal starting point for further conservation actions, because they allowed obtaining a 3D state-of-art documentation of Cultural Heritage that could disappear in a relatively short time due to environmental factors. Moreover, the obtained data were (and will be) a valuable support for the study of paleontological findings. The procedure described above make the getting of 3D documentation relatively easy and fast, minimizing most of the severe issues that researchers can face in extreme geographical contexts.

In the case of the Laetoli footprints, conservation is particularly difficult because most of the footprints exposed in the test-pits are already severely threatened by natural agents and are at risk of disappearing even if unexcavated. Apart from the unearthed tracks, many other unknown footprints could still be underground, in danger. Numerous perpendicular fractures lead to the disintegration of part of the tuff layer, and plant roots are dislodging the sequence of strata.

In the 1990s, the Site G footprints were subjected to a complex project of consolidation, re-burial, and protection [Musiba et al. 2012]. On that occasion various scholars expressed their concerns about the conservation status of the site [Feibel et al. 1996; Getty Conservation Institute 1996; Agnew and Demas 1998]. To block or reduce this relatively fast deterioration, we need an effective and rapid strategy supported by further analysis. The loss of the Laetoli tracks would be a huge loss for humanity. These footprints, like a spotlight on a prehistoric scene, come from a series of fortuitous and rare events: the volcanic eruption, the rain that made the ash wet, the hominins that walked on it, another eruption and other ash that covered and preserved the printed surface until its discovery 3.66 million years later. The Laetoli footprints are a unique source of information on the morphology and biology of early bipedal hominins and represent, to date, the earliest direct evidence for such a locomotion pattern among our ancestors. Laetoli is also the only site in the world providing data about body size variation within a single population of australopithecines. Therefore, Laetoli is among the most significant and iconic sites for the study of human origins. For this reason, the whole scientific community is called upon to collaborate in the development of a long-term conservation project of this heritage [Cherin et al. under review].

ACKNOWLEDGEMENTS

This research is supported by the Italian School of Paleoanthropology (University of Perugia[7]), under the auspices of the Italian Ministry of Foreign Affairs and International Cooperation (Italian Archaeological, Anthropological and Ethnological Missions Abroad) and the Italian Embassy in Dar es Salaam, Tanzania. The authors are grateful to the

[7] www.paleoantropologia.it/en

University of Dar es Salaam; the Ngorongoro Conservation Area Authority; the Antiquities Division, Ministry of Natural Resources and Tourism, Tanzania; R. Rettori for the organization of the field season; S. Grassi and A. Grassi for 3D data processing and logistical support; R. Pellizzon for photographs; N. Santopuoli and S. Sarmati for the preliminary conservation plan; all the Italian and Tanzanian students and the Maasai Community, assistants and workers for the field work.

AUTHOR'S CONTRIBUTIONS

The work presented here was carried out in collaboration between all authors. E.B.I. and F.T.M. discovered the new footprints and co-directed field work. M.C. and G.M. co-directed field work. M.C., A.B., G.B., D.A.I. F.T.M., S.M. and G.M. carried out field work and analyzed the data. S.M. wrote the chapters "Introduction", "Laetoli: old footprints and new discoveries", "Workflow: 3D survey for documentation and analysis" and "Conclusions"; A.B. wrote the chapter "The extreme environment of the African Savannah". M.C. supervised the final version of the article. All authors defined the research theme, discussed analyses, interpretation and presentation, and have contributed to, seen and approved the manuscript.

REFERENCES

Neville Agnew and Martha Demas. 1998. Preserving the Laetoli footprints. In *Scientific American*, 262, 44-55.

T. Michael Anderson. 2008. Plant compositional change over time increase with rainfall in Serengeti grasslands. In *Oikos*, 117: 675-682. DOI: 10.1111/j.2008.0030-1299.16516.x.

Peter Andrews and Marion Bamford. 2008. Past and present vegetation ecology of Laetoli, Tanzania. In *Journal of Human Evolution*, 54, 78-98. DOI: 10.1016/j.jhevol.2007.05.012.

Alessandro Cefalu et al. 2013. Image based 3D Reconstruction in Cultural Heritage Preservation. In *Proceedings of the 10th International Conference on Informatics in Control, Automation and Robotics* - Volume 1: ICINCO, ISBN 978-989-8565-70-9, 201-205. DOI: 10.5220/0004475302010205.

Marco Cherin et al. (under review). New footprints from Laetoli (Tanzania, 3.66 Ma): discovery, analysis, inferences, research project and conservation plans. In *Arid Zone Archaeology*, Monographs.

Alan L. Deino. 2011. ^{40}Ar/^{39}Ar dating of Laetoli, Tanzania. In Terry Harrison (eds) *Paleontology and Geology of Laetoli: Human Evolution in Context*, Vol. 1. New York: Springer, 77-97. DOI: 10.1007/978-90-481-9956-3_4.

Filiberto Chiabrando, Elisabeta Donadio and Fulvio Rinaudio. 2015. SfM for orthophoto generation: a winning approach for cultural heritage knowledge. In *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, XL-5/W7 (5).

Craig S. Feibel et al. 1996. The Laetoli hominid footprints – A preliminary report on the conservation and scientific restudy. In *Evolutionary Anthropology*, 5, 149-154.

Getty Conservation Institute. 1996. *Laetoli Project: Conservation of the Hominid Trackway Site at Laetoli, Tanzania: Report on the 1995 Field Season (July 3 – September 2, 1995).* Los Angeles, Getty Conservation Institute.

Adam D. Gordon, David J. Green, and Brian G. Richmond. 2008. Strong postcranial size dimorphism in *Australopithecus afarensis*: results from two new resampling methods for multivariate data sets with missing data. In *American Journal of Physical Anthropology*, 135, 311-328.

William E.H. Harcourt-Smith. 2005. Did *Australopithecus afarensis* make the Laetoli footprint trail? New insight into an old problem. In *American Journal of Physical Anthropology*, S40, 116. DOI: 10.1002/ajpa.20217.

Elisabeth H. Harmon.2006. Size and shape variation in *Australopithecus afarensis* proximal femora. In *Journal of Human Evolution*, 51, 217-227.

Terry Harrison. 2011. Hominins from the Upper Laetolil and Upper Ndolanya Beds, Laetoli. In Terry Harrison (eds) *Paleontology and Geology of Laetoli: Human Evolution in Context*, Vol. 2. New York: Springer, 141-188.

Dennis J. Herlocker and H.J. Dirschl. 1972. *Vegetation of Ngorongoro Conservation area, Tanzania*. Ottawa: Canadian Wildlife Service. Illustration, maps Geog 5.

Ricardo M. Holdo et al. 2009. A Disease-Mediated Trophic Cascade in the Serengeti and its Implications for Ecosystem C. In *PLoS Biol*, 7(9): e1000210. DOI: 10.1371/journal.pbio.1000210.

Donald C. Johanson and Tim D. White. 1979. A systematic assessment of early African hominids. In *Science*, 202: 312-330.

Donald C. Johanson, Tim D. White and Yves Coppens. 1978. A new species of the genus *Australopithecus* (Primates: Hominidae) from the Pliocene of eastern Africa. In *Kirtlandia*, 28, 1-14.

William L. Jungers et al. 2016. The evolution of body size and shape in the human career. In *Philosophical Transactions of the Royal Society*, B 371: 20150247.

William H. Kimbel and Tim D. White. 1988. Variation, sexual dimorphism and the taxonomy of *Australopithecus*. In Frederick E. Grine (eds) *Evolutionary history of the "robust" australopithecines*. New York, Aldine de

Gruyter, 175-192.
Ludwig Kohl-Larsen. 1943. *Auf den Spuren des Vormenschen*, Vols. 1 and 2, Strecker und Schröder, Stuttgart.
Mary D. Leakey. 1981. Tracks and tool. In *Philosophical Transactions of the Royal Society*, B 292, 95-102.
Mary D. Leakey et al. 1976. Fossil hominids from the Laetoli Beds. In *Nature*, 262, 460-466. DOI: 10.1038/262460a0.
Mary D. Leakey and John M. Harris. 1987. *Laetoli: A Pliocene site in northern Tanzania*. Oxford: Claredon.
Mary D. Leakey and Richard L. Hay. 1979. Pliocene footprints in the Laetoli Beds at Laetoli, northern Tanzania. In *Nature*, 278, 317-323. DOI: 10.1033/278317a0.
Charles A. Lockwood et al. 1996. Randomization procedures and sexual dimorphism in *Australopithecus afarensis*. In *Journal of Human Evolution*, 31, 537-548.
Thomas Luhmann et al. 2014. *Close-range photogrammetry and 3D imaging*, 2nd ed. Berlin: Germany: De Gruyter.
Fidel T. Masao et al. 2016. New footprints from Laetoli (Tanzania) provide evidence for marked body size variation in early hominins. In *eLife*. DOI: 10.7554/eLife.19568.
Henry M. McHenry. 1991. Femoral length and stature in Plio-Pleistocene hominids. In *American Journal of Physical Anthropology*, 85, 149-158.
Charles Musiba et al. 2012. Tanzania and the outstanding universal value of its paleoanthropology: approaches at Laetoli and lessons learned. In *UNESCO World Heritage Series*, 33, 115-125.
Michael J. Plavcan et al. 2005. Sexual dimorphism in *Australopithecus afarensis* revisited: How strong is the case for a human-like pattern of dimorphism?. In *Journal of Human Evolution*, 48, 313-320.
Fabio Remondino and Sabry El-Hakim. 2006. Image-based 3D modelling: a review. In *The Photogrammetric Record*, 21 (115).
Brian G. Richmond and William L. Jungers. 1995. Size variation and sexual dimorphism in *Australopithecus afarensis* and living hominoids. In *Journal of Human Evolution*, 29, 229-245.
Hans Reck and Ludwig Kohl-Larsen. 1936. *Geol Rundsch*, 27, 401-441. DOI: 10.1007/BF01765919.
Russel H. Tuttle, David Webb & Michael Baksh. 1991. Laetoli toes and *Australopithecus afarensis*. In *Human Evolution*, 6, 193-200.
Efstratios Stylianidis and Fabio Remondino. 2016. *3D recording, documentation and management of cultural heritage*. Dunbeath, Caithness: Whittles Publishing.
Tim D. White and Gen Suwa. 1987. Hominid footprints at Laetoli: facts and interpretations. In *American Journal of Physical Anthropology*, 72, 485-514. DOI: 10.1002/ajpa.1330720409.

Imprint:
Proceedings of the 23rd International Conference on Cultural Heritage and New Technologies 2018.
CHNT 23, 2018 (Vienna 2019). http://www.chnt.at/proceedings-chnt-23/
ISBN 978-3-200-06576-5

Editor/Publisher: Museen der Stadt Wien – Stadtarchäologie
Editorial Team: Wolfgang Börner, Susanne Uhlirz

Documentation – Observation – Evaluation. Ancient Yemen Digital Atlas (AYDA). A WebGIS Based Monument Information System

JOSEPHINE SCHOENEBERG, German Archaeological Institut, Germany

Almost unnoticed by the world public, the war in Yemen is destroying a unique cultural heritage. Due to a lack of accessibility and information, it is difficult for the Yemeni "General Organization of Antiquities and Museums" (GOAM) to document these damages on site, so that hardly any countermeasures can be taken to protect the cultural heritage. Since 2017 the Sanaa Branch and the IT Department of the "German Archaeological Institute" (DAI) developed a WebGIS-based monument information system of Yemeni sites. Financed by cultural conservation funds from the Federal Foreign Office, the system is to be linked with various databases that contents historically, archaeologically and for conversion measures relevant data. System tasks will be research, monitoring and management of Yemeni sites, not only operated by the DAI, but in particular by the Yemeni Antiquity Authority GOAM, which can enter its own data into the system. Up to now, about 4200 archaeological sites have been mapped and important site plans digitized. Besides the digitalization of published sites and storage of factual data, site management is an important aspect in the creation of the digital atlas. By monitoring satellite images, changes in the state of conservation of archaeological sites and their surroundings can be quickly and clearly detected and structural changes caused by destruction or looting can be documented. A WebGIS developed especially for the "Ancient Yemen Digital Atlas" (AYDA), whose user interface will be available in English and Arabic enables GOAM to enter new information about sites or even new sites, to use the data scientifically and to plan measures for the preservation of their own cultural heritage.

Key words:
Yemen, German Archaeological Institut, Cultural Heritage, GIS, Digital Atlas, Remote Sensing, Google Earth, Monitoring and Site Management, Archaeological Risk Assessment

CHNT Reference:
Josephine Schoeneberg. 2018. Documentation – Observation – Evaluation. Ancient Yemen Digital Atlas (AYDA). A WebGIS Based Monument Information System

INTRODUCTION

The country historically known as "Arabia Felix", meaning "Happy Arabia", is facing now the threat of destruction of its history and heritage. Since 2015 Yemen has been caught up in a complex civil war, mainly between the internationally recognized Yemeni government, led by Abdrabbuh Mansur Hadi, and the Houthi armed movement (Ansar Allah), along with their supporters and allies [e. g. Khalidi 2017]. Besides the humanitarian catastrophe, the war threatens the unique cultural heritage of Yemen: mosques, Islamic shrines, medieval villages, and also UNESCO world cultural heritage sites such as Shibam[1], Zabid[2] and the old town of Sanaa[3] with its traditional clay and stone

Author's address: Josephine Schoeneberg, DAI Orient Department, Sanaa Branch, Podbielskiallee 69-71, 14195 Berlin, Germany. mailto: josephine.schoeneberg@gmail.com

[1] The old town of Shibam in Hadramawt, with its five to eleven story mud brick skyscrapers known as the "Manhattan of the Desert", was damaged in November 2016 as collateral damage by IS. The main target was a military checkpoint of Yemeni troops. https://www.globalresearch.ca/yemen-one-of-the-oldest-civilizations-crimes-against-humanity-saudi-bombings-of-yemens-heritage-sites/5512617 Accessed 25.01.2019.

[2] During an attack on the historical city Zabid, former capital of Yemen between the 13th and 15th century, some historical houses were destroyed by coalition bombs [e.g. Khalidi 2017].

[3] Coalition bombs hit Sanaa's old city in 2015, targeting two neighborhoods. Beside houses and mosques, numerous antique alabaster windows of the old buildings were destroyed as collateral damage [e.g. Khalidi 2017].

architecture as well as 3000 year old temples, palaces, settlements, dams and cemeteries, right up to entire museum buildings[4] with thousands of objects that altogether fall victim to the conflict (Fig. 1). A total of about 80 partially damaged or completely destroyed sites have been listed by the Yemeni “General Organization of Antiquities and Museums” (GOAM)[5] so far. The number of unreported cases is significantly higher. The full range of the plundering and destruction of archaeological sites and cultural treasures can only be estimated to a certain extent due to the limited accessibility of the various regions of the country affected by the armed conflict. The documentation of these damages is therefore only possible to a small degree, so that countermeasures to protect the cultural heritage can only be taken in rare cases.

Fig. 1. Examples of destruction of Yemeni cultural heritage. a) Museum of Dhamar before[6] and b) Museum of Dhamar after[7]. c) Nakrah Temple of the ancient city of Baraqish before (© Alessandro de Maigret) and d) Nakrah Temple completely destroyed (© GOAM Mohanad al-Sayani)

Since the late 1960s the “German Archaeological Institute’s” (DAI) research field has expanded to the southwest Arab region and is continuously and systematically dedicated to the study of South Arabian cultures, culminating in the founding of a branch in Sanaa in 1978, which was assigned to the Orient Department in 1996. The success of this research activity is based on the close cooperation with various cooperation partners and local institutions, in

[4] In May 2015 the Dhamar Archaeological Museum, which housed more than 12500 objects and numerous unregistered archaeological remains, was completly destroyed by Saudi Arabian coalition bombs. http://aiys.org/blog/?p=1884 Accessed 28.01.2019. In February 2016, the National Museum in Ta’izz came under artillery fire. The museum, which includes rare manuscripts and pre-Islamic and traditional artifacts, was almost completely burned. https://www.globalresearch.ca/yemen-one-of-the-oldest-civilizations-crimes-against-humanity-saudi-bombings-of-yemens-heritage-sites/5512617 Accessed 28.01.2019.

[5] The list is provided by Mohanad al-Sayani, president of the Yemeni General Organization of Antiquities and Museums (GOAM), and being updated continuously.

[6] Licenced by https://creativecommons.org/licenses/by-nc-nd/4.0/

[7] Photo Link: https://americaforyemen.wordpress.com/2017/03/01/dhamar-regional-museum-yemen-before-after/ Accessed 10.02.2019. Licenced by: https://creativecommons.org/licenses/by-nc-nd/4.0/

particular the GOAM. Since 2013 it has not been possible for foreign missions to travel into Yemen. Also staff of the local Antiquities Authority has not been able to visit all cultural heritage sites safely. It is therefore not possible to monitor and observe the condition of the sites on ground. For this reason, possibilities were considered to carry out these tasks off-site.

ANCIENT YEMEN DIGITAL ATLAS

AYDA, the Ancient Yemen Digital Atlas is a system planned to work spatially in the sense of a "Geographical Information System" (GIS) and enables the mapping as well as the collection and retrieval of geographical data. When creating the system under the direction of Iris Gerlach, particular importance is attached to the use of existing open source solutions. In addition, the software must be completely installable and operable in Yemen. This also includes a user and rights management system that can be used independently by the Yemeni side. Since the end of 2017, a WebGIS-based monument information system for Yemeni sites has been set up with funding from the Cultural Preservation Programme of the Federal Foreign Office of the Federal Republic of Germany. The system is to be created and maintained together with our Yemeni colleagues from GOAM and at the end will link each site with as much historical, archaeological and conservation data as possible. This includes the interconnection to various research projects, image and object databases. The software programming has not yet been completed. In this respect, the entire system is not available with all its application features now.

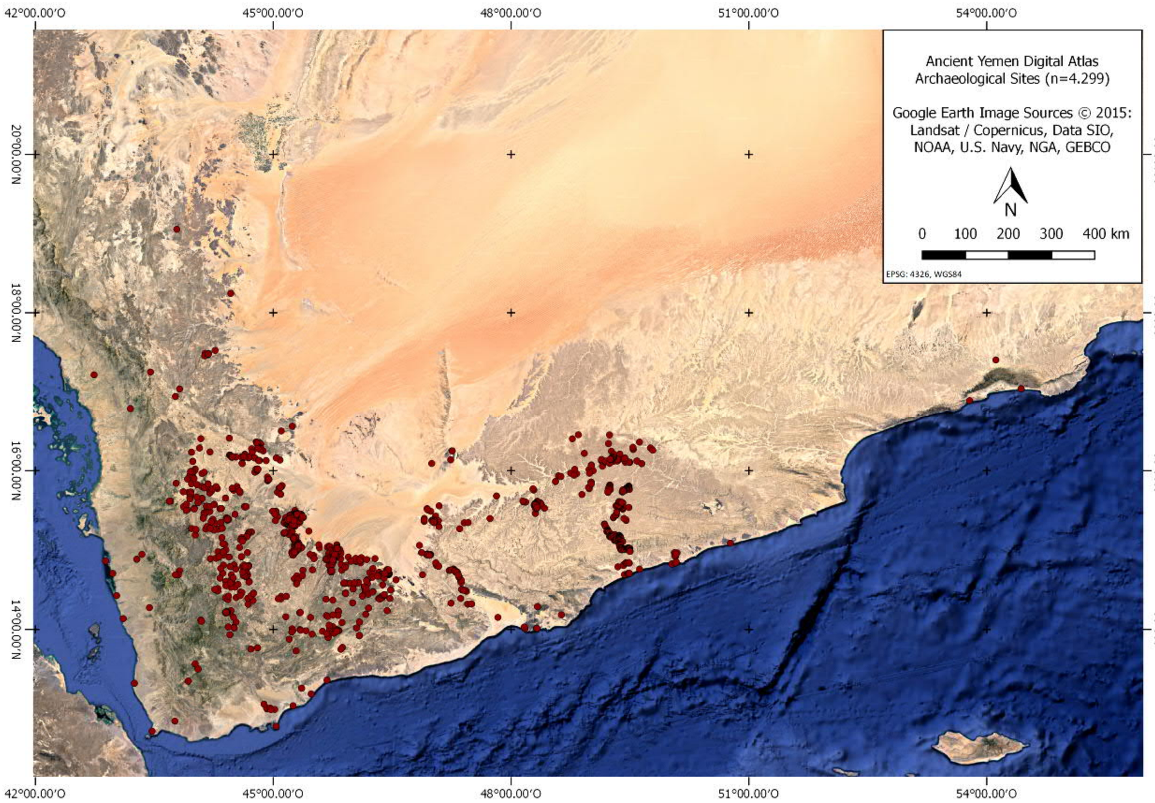

Fig. 2. South Arabian Archaeological Sites mapped in QGIS as ground database for AYDA (© Josephine Schoeneberg / DAI)

- GIS System[8]: The geodatabase serves as primary storage for the AYDA basic data. The Digital Atlas is mainly based on the extensive archaeological data collected by the Sanaa branch of the DAI during more than 40 years of research. To date, a large part of this data is only available in analogue form, which is why, in addition to programming the entire system, the digitalization of research data was implemented in a first step. Old data on already published sites, such as maps, siteplans and aerial photos, play an important role in the compilation of the state monument register: These are systematically digitized, georeferenced, checked on current satellite images and entered into the digital atlas with relevant factual data such as ancient and/or modern name, type, dating, short description, source, threat or condition. In this way, about 4200 archaeological sites have been mapped and up to 40 important site plans have been digitized (Fig. 2).

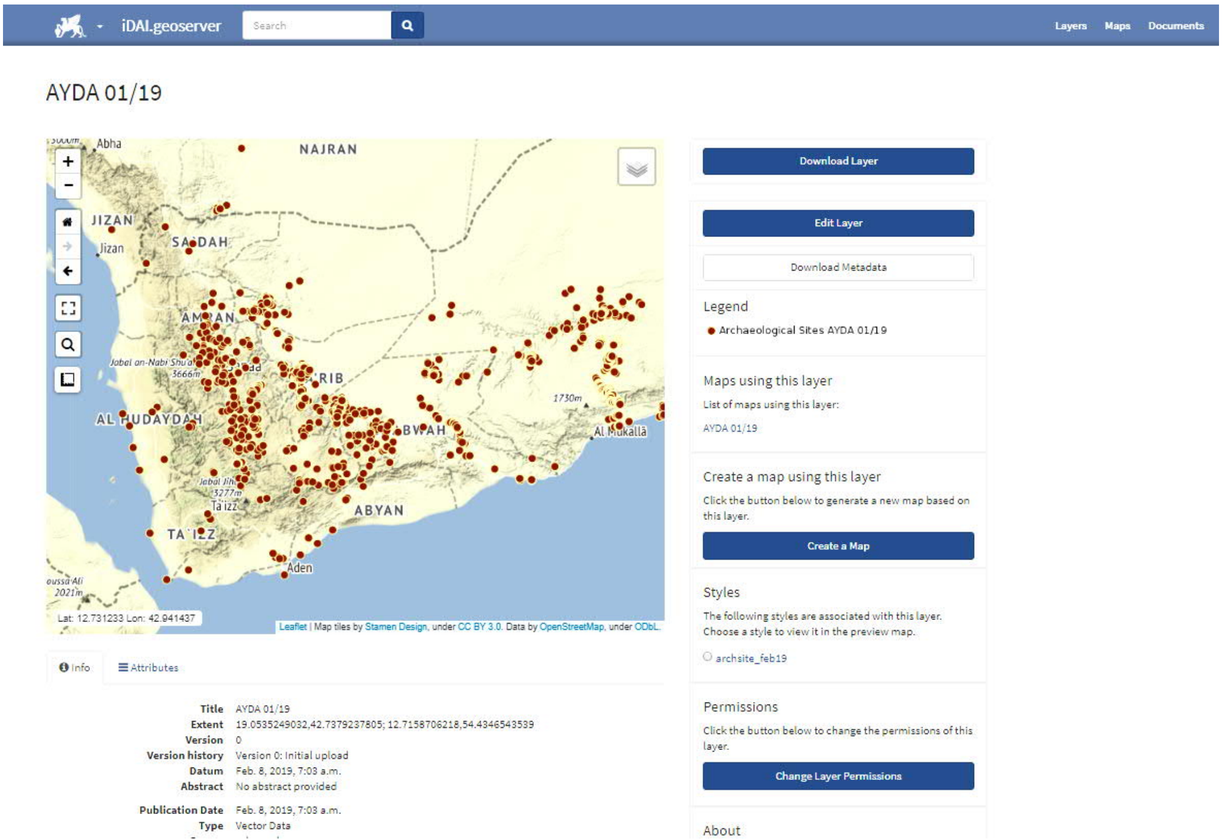

Fig. 3. Yemen Geoserver as tool for sharing geospatial data and maps. The layout is based on the geoserver of the DAI, but has been specially adapted for the Arabian region (© Josephine Schoeneberg / DAI)

- WebGIS[9]: The processing of geodata plays an increasingly important role in archaeological research. Since research projects usually consist of several, sometimes distributed employees, the infrastructure is designed as an online resource. This enables employees to access the common geodata at the same time, which solves the problem of different versions by reason of several editors. For this project, a central geoserver was designed and implemented, which enables the collection, analysis, visualization and archiving of geodata (Fig. 3). In general, the infrastructure consists of open source components in order to be independent of commercial solutions. This online component enables the mapping and retrieval of geodata. At the same time, it represents an easy-to-

[8] QGIS is a free and open-source desktop geographic information system application that supports viewing, editing, and analysis of geospatial data. https://qgis.org/de/site/.

[9] Geoserver serves as an open platform for sharing geospatial data and maps. It hosts GIS datasets, complete maps and various documents related to archaeology and cultural heritage. Registered users can upload and share data and maps with others. http://geoserver.org/.

manage repository in which geodata can be stored, searched and provided with metadata in a structured manner. By granting access rights, sensitive data will only be available to certain user groups. Thematic mapping with layers selected by the user can be directly created and used scientifically. Depending on requirements, the data can be downloaded in various data formats. In addition, the DAI guarantees long-term data storage. This WebGIS, whose user interface is available in English and Arabic, will allow GOAM not only to use archaeological data scientifically, but also to plan measures for the preservation of its own cultural heritage. – *Work in Progress*

- Excavation Database iDAI.field[10]: This component is an easy-to-use application for the management of digital excavation documentation. Part of this module is the migration of the previously used FileMaker databases of the DAI into the new excavation database. This enables users to enter, view and search excavation data online and offline and synchronize it using an own server component. – *Work in Progress*
- Photo Database: This additional online feature is intended to provide photos with a uniform metadata scheme, archive image collections and serve as an image browser. – *Work in Progress*
- Object Database: – The object database of the Sanaa branch office is a pure finds database in filemaker format, which is to be linked to the project. Museum and collection objects are also systematically included and their placement in their spatial find context is possible. – *Work in Progress*

In contrast to other systems [Bewley et al. 2015], which have already been able to map much more ancient sites for Yemen[11], the relatively few sites of the AYDA system have always a name, have been checked and verified for their positional accuracy using satellite images, aerieal photography and well-documented sources. AYDA deliberately uses several sources for the identification of individual sites. The data obtained from remote surveys using free available satellite imagery are only used and integrated into the system if they have been confirmed by other sources (e.g. fieldwork, publications or personal observation). Only a few types of sites such as settlements and the characteristic turret tombs are taken directly from the satellite image analysis. This is specifically noted in the system's factual data. As the EAMENA team could prove in a comparative study of remote survey results and field survey results [Banks et al. 2017], both methods have to be combined in order to arrive at reliable conclusions. In addition, a spot check of sites identified only by satellite image evaluation can already show that many of these points are merely geological or similar formations. In order to exclude misinterpretations, only sites identified by several methods are included in AYDA, which explains their relatively low number.

MONITORING AND SITE MANAGEMENT

In addition to the scientific processing possibilities, like spatial analysis (e. g. viewshed, watershed or least-cost-path-analysis), the Digital Atlas is primarily responsible for monitoring and managing of Yemeni sites in order to protect the national cultural heritage. Aerial photography and satellite imagery have been used for years to explore and monitor archaeological sites around the world [Wilkinson et al. 2006, Parceck 2009, Fowler 2010, Lasaponara and Masini 2011]. By monitoring satellite images, changes in the conservation status of archaeological sites affected by conflicts or natural disasters or looting can be detected quickly and documented remotely. The sites mapped in AYDA are checked for structural changes on old and current satellite images that are mainly available on Google Earth. Google Earth is an easy-to-use tool for identifying archaeological sites [Beck 2006, Ur 2006, Thomas et al. 2008, Kennedy and Bishop 2011, Thakuria et al. 2013] and quantifying looting areas [Contreras and Brodie 2010, Parcak et al. 2016] in arid regions. It is an inexpensive solution to get a first impression of the sites. Imagery resolution ranges from 15 meters to 15 centimeters. Since 2015, the Pro-Version has been available free of charge and enables the storage and print of high-resolution images. Additions to the Google Earth repertoire, such as the "history" feature, allows users to view a decade of images from a single location, provides data that can be used to understand ongoing site-formation processes. In addition to remote monitoring, the constant contact with Yemeni colleagues and their observations on location offers an initial overview of changes and potential dangers at the ancient sites. This is an important step in the initial damage assessment and enables the planning of countermeasures. Unfortunately, the satellite images are exposed to different update intervalls und qualitative

[10] https://www.dainst.org/ergebnis/-/asset_publisher/NZrOgZ37QcYu/content/idai-field Accessed: 14.02.2019.

[11] EAMENA - The Endangered Archaeology in the Middle East and North Africa: The approach for the project is the rapid examination of satellite imagery, historical aerial photographs, and other sources to provide the location and brief description of each site and an assessment of threat. http://eamena.arch.ox.ac.uk/.

differences in the image resolution, so that the same detailed prospection and monitoring cannot take place everywhere by using free sources. For example, images from economically interesting regions such as Marib are updated regularly. In contrast, the latest satellite image from the isolated region around the ancient settlement of Shabwa (Upper Hadramawt) dates to 2010.

Most of the sites mapped in AYDA seem to be in good condition under the given circumstances, but also a variety of destruction caused by human activities through the Yemeni civil war, mainly caused by airstrikes of the Saudi Arabian coalition, looting, urban and agricultural development, could be observed:

- Destruction caused by war: Among the most prominent examples of destruction in the course of the ongoing conflict are the Northern Outlet of the Great Dam of Marib[12], parts of the city wall and the Nakrah Temple of Baraqish[13] or the al-Qahira fortress in Ta'izz[14], which have already been reported on several occasions [Bewley et al. 2015; UNESCO 2016; Khalidi 2017]. Sites still not recognized by UNESCO include the archaeological site of Sirwah, also bombarded by the coalition in April and May 2015. Due to its proximity to local administrative facilities, Sirwah [Gerlach 2003/2004; Gerlach et al. 2011], one of the most important religious and political centres of the Sabaean polity at the beginning of the 1st millennium BCE, suffered severe damage[15]. To avoid further destruction, the DAI in cooperation with other international institutions have provided UNESCO with a "no strike" list of important archaeological sites and museums in Yemen, which has been forwarded to the Saudi government. But, it seems that the Arabian coalition is only partially adhering to this protective list. Information collected from local sources and newspaper articles about these damages as well as significant changes in the satellite image are noted in AYDA.
- Destruction through modern settlement activity: A recent example comes from the Sabaean capital Marib [Eichmann and Hitgen 2003]. New satellite revealed structural changes in the ancient settlement area images in December 2017. Within a month, development areas were marked, old houses were demolished and a modern road system was laid out (Fig. 5). The visible patterns of construction were digitized in GIS and immediately passed on to UNESCO and GOAM by the DAI hoping to prevent the imminent destruction of this most important site of ancient South Arabia (Fig. 4). In other cases, the destruction of previously recorded sites by modern settlement expansion could be documented. This concerns especially ancient animal traps (kites) which were found in dozens in the region around Marib. These kites were digitized in GIS for AYDA. Kite No. 146, for example [Brunner et al. unpublished] was completely destroyed in the course of a new landfill, others were levelled or damaged during road construction (Fig. 6). The extent of destruction, as far as can be seen, was documented for each kite. Later, these informations can be verified on site and if necessary extended with further details.

---

[12] The Great Dam of Marib [Vogt 2007], mentioned in the Qur'an, was built in the middle of the 1st millennium BCE and is considered the largest irrigation system of antiquity. During air raids in 2015, the recently restored [Vogt 2005] northern irrigation outlet was severely damaged.

[13] The Nakrah temple of Baraqish was excavated by an Italian team in the 1980s and 1990s and then extensively restored over several years [de Maigret and Robin 1993]. In 2015 a single air raid strike destroyed the temple and parts of the city wall as well as excavation shelters and depots completely.

[14] The al-Qahira fortress of Ta'izz, a site settled since pre-Islamic times was taken over by Houthi rebels in March 2015 and its fortress subsequently bombed by the Arabian coalition in May 2015.

[15] Yemeni sources reported the DAI several damages at the monumental buildings of the Sabaean city of Sirwah, located about 30 kilometers west of Marib. The ancient site was not the direct target of the attacks, but it was severely damaged in ground battles for nearby administrative structures of the Marib Governement.

Fig. 4. Various layers from AYDA document the construction measures in the ancient settlement area of Marib in December 2017 (© Josephine Schoeneberg / DAI)

Fig. 5. Detailed view north of the settlement. The rectangular construction patterns are clearly visible (Google Earth Image © 2019 Digital Globe)

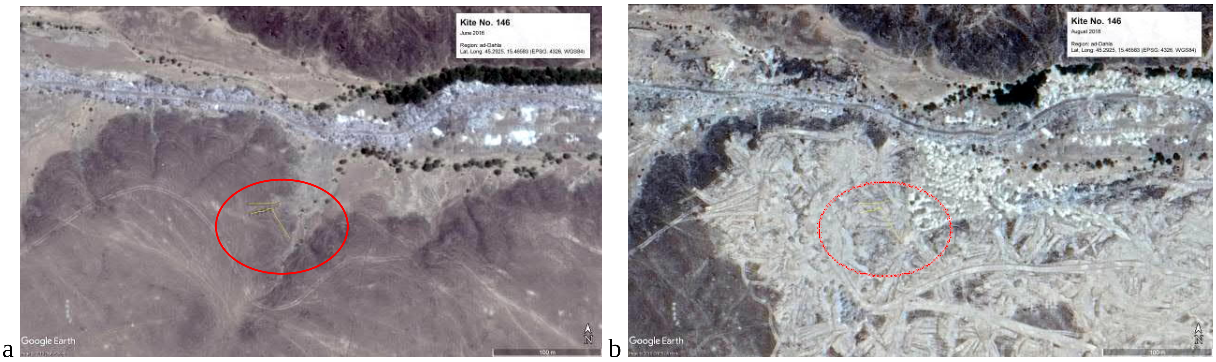

Fig. 6. Complete destruction of Kite No. 146 (about 7 km NW of ancient Marib) by a landfill between a) 2016 and b) 2018 (Google Earth Images © 2019 Digital Globe / CNES / Airbus)

- Illegal Excavations and Looting: Extensive looting and illegal excavations were to be recognized repeatedly during the work on AYDA. This has been a major problem even before the war, especially in the north of the country and on the desert outskirts, where the old South Arabian polities had their centres. Inside and outside the fortified settlement of al-Bayda (ancient Nashq), one of the largest archaeological sites in southern Arabia, illegal excavation holes can be seen side by side (Fig. 7).

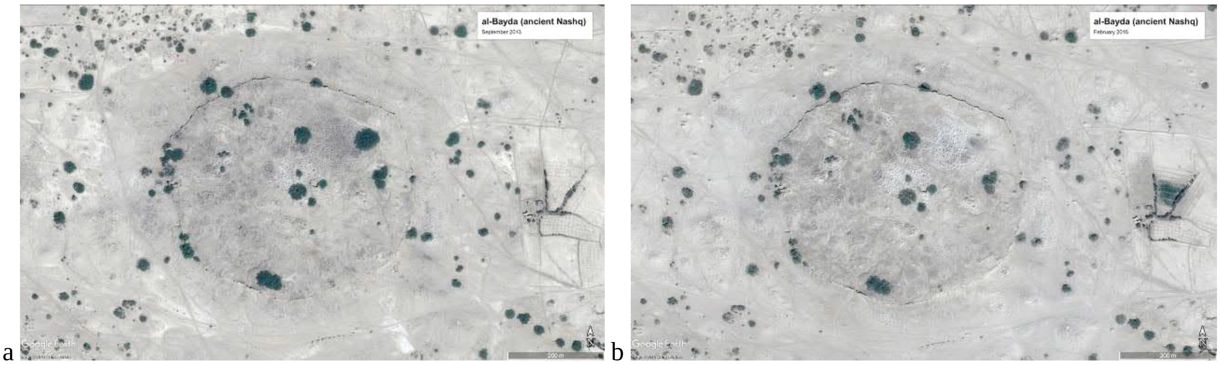

Fig. 7. a) Illegal excavations in al-Bayda even before 2013. b) After 2013 especially outside the settlement, excavations have been carried out (Google Earth Images © 2019 CNES / Airbus)

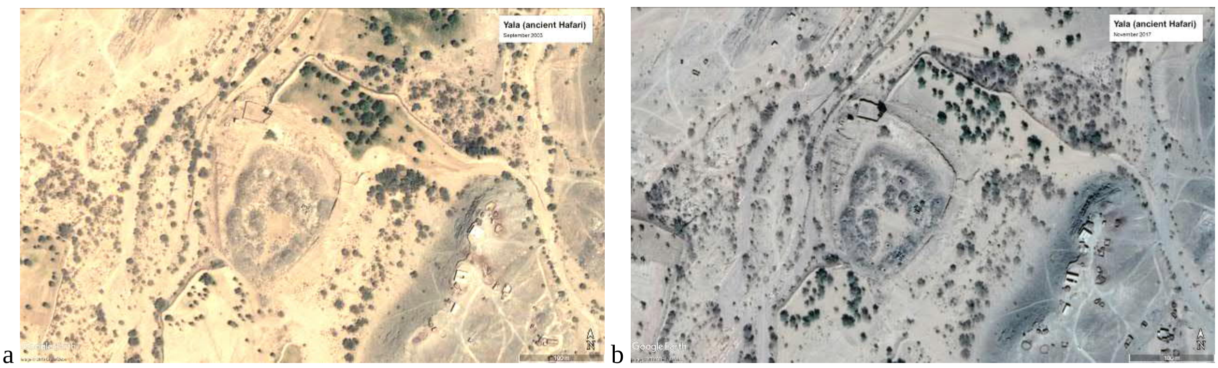

Fig. 8. a) In Yala only "House A" was excavated until 2003. b) Since 2003 several structures were illegaly unearthed (Google Earth Images © 2019 Digital Globe / CNES / Airbus)

Also in the Sabaean city complex of Yala (ancient Hafari) numerous looting holes can be observed. In the 1980s an archaeological excavation [de Maigret 1988] took place at the site. Only one building, the so-called “House A”, was excavated. This is clearly visible in the satellite image from 2003. After this time several uncontrolled and illegal digs were conducted and multiple structures unearthed (Fig. 8).

However, the monitoring of satellite images also reveals archaeological findings that have not yet been discovered or researched. This is especially true for Bronze Age tombs, which are easy to recognize in the satellite image due to their remarkable shape, but also for kites or entirely unexplored settlement sites, for example in al-Jawf region. These are recorded in AYDA with a short description, date of the satellite image and capture by remote sensing (Fig. 9). These sites have to be checked on site later and described in more detail.

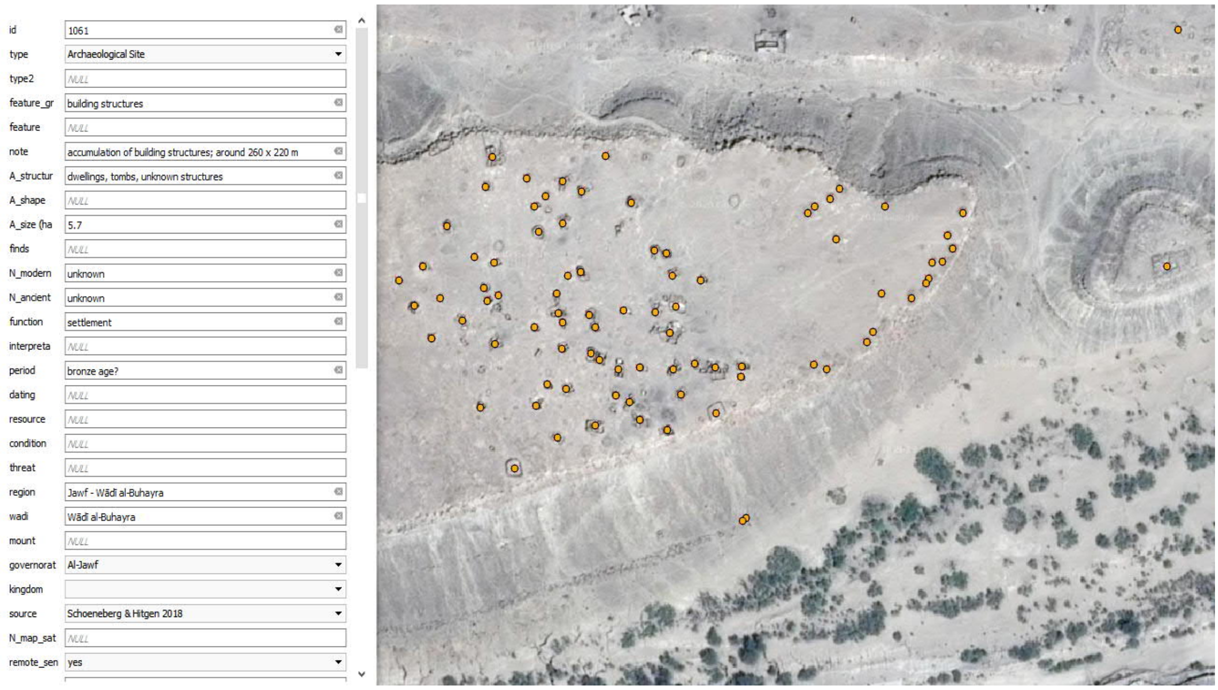

Fig. 9. Unknown settlement in Wadi al-Buhayra (al-Jawf region). Each structure gets an own ID in AYDA with a short description, coordinate assignment and source reference (Attribute Table © Josephine Schoeneberg / DAI, Satellite Image GIS Map data © 2015 Google)

CONCLUSION

AYDA is still *Work in Progress*. While digitization work is progressing well, the linking of the WebGIS with other databases is still to be done. In the end, the system should link every point in AYDA with a wide variety of information sources such as objects, excavation, photo and literature databases. AYDA will be available for selected scientists and cultural institutions. Together with the DAI, the Yemeni colleagues of the Antiquities Authority will keep the program up to date by entering new data and sites. The last-mentioned is necessary in order to enable an exact monitoring of the sites, to guarantee the basis for their preservation as well as a later possible development for the public. A complete release of the system to the public, however, can only take place to a limited extent, since the spreading of sensitive data, including exact coordinates if necessary, can lead to sites being targeted by potential robbers.

REFERENCES

Rebecca Banks, Michael Fradley, Jérémie Schiettecatte, and Andrea Zerbini. 2017. An integrated approach to surveying the archaeological landscapes of Yemen. Proceedings of the Seminar for Arabian Studies, 47, 9-24.

Anthony R. Beck. 2006. Google Earth and World Wind: remote sensing for the masses? Antiquity 80, 308.
Robert H. Bewley, Andrew I. Wilson, David Kennedy, David Mattingly, Rebecca Banks, Michael Bishop, Jennie Bradbury, Emma Cunliffe, Michael Fradley, Richard Jennings, Robyn Mason, Luise Rayne, Martin Sterry, Nichole Sheldrick, and Andrea Zerbini. 2015. Endangered Archaeology in the Middle East and North Africa: Introducing the EAMENA project. In Stefano Campana & R. Scorpigno (eds.). Proccedings of the 43rd Annual Conference on Computer Applications and Quantitative methods (Oxford Archaeopress 2015) 919-932.
Ueli Brunner, Iris Gerlach, and Sarah Japp. Unpublished. Desert Kite Survey Marib.
Daniel A. Contreras and Neil Brodie. 2010. The Utility of Publicly-Available Satellite Imagery for Investigating Looting of Archaeological Sites in Jordan. Journal of Field Archaeology 35, 101-114.
Ricardo Eichmann and Holger Hitgen. 2003. Marib, Hauptstadt des sabäischen Reiches. In Iris Gerlach. 25 Jahre Ausgrabungen und Forschungen im Jemen - 1978-2003. Hefte zur Kulturgeschichte des Jemen 1, Sanaa, 52-61.
Martin J. F. Fowler. 2010. Satellite imagery and archaeology. In David C. Cowley, Robin A. Standring and Matthew J. Abicht (eds.). Landscapes Through the Lens: Aerial Photographs and Historic Enviroment. Occasional Publication of the Aerial Archaeology Research Group No. 2, Oxford, 99-110.
Iris Gerlach 2003/2004. Die archäologisch-bauhistorischen Untersuchungen des Deutschen Archäologischen Instituts in der sabäischen Stadtanlage und Oase von Sirwah (Jemen/Provinz Mārib). Nürnberger Blätter zur Archäologie 20, 37–56.
Iris Gerlach, Mike Schnelle, and Christian Weiss. 2011. Die Restaurierung der Pfeilerpropyla des Almaqah-Tempels von Sirwah (Jemen). In Martin Müller, Thomas Otten & Ulrike Wulf-Rheidt (eds.). Schutzbauten und Rekonstruktionen in der Archäologie. Von der Ausgrabung zur Präsentation. Xanten, 21.-23. Oktober 2009. Xantener Berichte 19, Mainz am Rhein, 223-243.
David Kennedy and Michael C. Bishop. 2011. Google earth and the archaeology of Saudi Arabia. A case study from the Jeddah area. Journal of Archaeological Science 38, 1284-1293. DOI:10.1016/j.jas.2011.01.003.
Lamya Khalidi. 2017. The Destruction of Yemen and Its Cultural Heritage. Int. J. Middle East Stud. 49, 735-738. DOI: https://doi.org/10.1017/S0020743817000691.
Rosa Lasaponara and Nicola Masini. 2011. Satellite Remote Sensing in Archaeology: past, present and future. Journal of Archaeological Science, 38, 1995–2002. DOI:10.1016/j.jas.2011.02.002.
Alessandro de Maigret. 1988. The Sabaean archaeological complex in the Wādī Yalā (eastern Ḥawlān ạ-Ṭiyāl, Yemen Arab Republic). A preliminary report. Reports and memoires, Istituto Italiano per il Medio ed Estremo Oriente 21, Rome.
Alessandro de Maigret and Christian Robin. 1993. Le temple de Nakrah à Yathill (aujourd'hui Baraqish), Yémen. Résultats des deux premières campagnes de fouilles de la mission italienne. Comptes rendus des séances - Académie des inscriptions & belles-lettres, 427–496.
Sarah H. Parcak. 2009. Satellite Remote Sensing for Archaeology, London.
Sarah H. Parcak, David Gathings, Chase Childs, Greg Mumford, and Eric Cline. 2016. Satellite evidence of archaeological site looting in Egypt: 2002–2013. Antiquity 90, 188–205. DOI: https://doi.org/10.15184/aqy.2016.1.
Tilok Thakuria, Tosabanta Padhan, Rabindra Kumar Mohanty, and Monica L. Smith. 2013. Google Earth as an Archaeologcial Tool in the Developing World. An Example from India. The SAA Archaeological Record 13, 20-24.
David C. Thomas, Fiona J. Kidd, Suzanna Nikolovski, and Claudia Zipfel. 2008. The Archaeological Sites of Afghanistan in Google Earth. AARGnews 37, 22-30.
UNESCO. 2016. Satellite-Based Damage Assessment of Cultural Heritage Sites. 2015 Summary Report of Iraq, Nepal, Syria & Yemen.
Jason Ur. 2006. Google Earth and archaeology. The SAA Archaeological Record 6, 35-38.
Burkhard Vogt. 2005. Beyond Archaeology - The Ongoing Conservation of the Great Dam of Marib. In Alexander Sedov & I. M. Smilianskaia (eds.). Arabia Vitalis. Studies on the Arab Orient, Islam and Ancient Arabia in Honour of V. V. Naumkin, Moscow, 401-408.
Burkhard Vogt. 2007. Der aktuelle Forschungsstand zum Großen Damm von Marib, Jemen, nach der Winterkampagne 2005/2006. Zeitschrift für Archäologie Außereuropäischer Kulturen 2, 121-141.
Keith N. Wilkinson, Anthony R. Beck, and Graham Philip. 2006. Satellite imagery as a resource in the prospection for archaeological sites in cental Syria. Geoarchaeology 21, 735-750. DOI: https://doi.org/10.1002/gea.20136.

Imprint:
Proceedings of the 23rd International Conference on Cultural Heritage and New Technologies 2018.
CHNT 23, 2018 (Vienna 2019). http://www.chnt.at/proceedings-chnt-23/
ISBN 978-3-200-06576-5

Editor/Publisher: Museen der Stadt Wien – Stadtarchäologie
Editorial Team: Wolfgang Börner, Susanne Uhlirz
The editor's office is not responsible for the linguistic correctness of the manuscripts.
Authors are responsible for the contents and copyrights of the illustrations/photographs.