**[Supplementary material]**

# Land-use and cultivation in the *etaghas* of the Tadrart Acacus (south-west Libya): the dawn of Saharan agriculture?

Savino di Lernia[1,2], Isabella Massamba N'Siala[3], Anna Maria Mercuri[3] & Andrea Zerboni[4,*]

[1] *Dipartimento di Scienze dell'Antichità, Sapienza Università di Roma, Italy*

[2] *GAES, University of the Witwatersrand, South Africa*

[3] *Dipartimento di Scienze della Vita, Università di Modena e Reggio Emilia, Modena, Italy*

[4] *Dipartimento di Scienze della Terra 'A. Desio', Università degli Studi di Milano, Italy*

[*] *Author for correspondence:* ✉ *andrea.zerboni@unimi.it*

## Geographic, climatic and environmental settings of the Tadrart Acacus

The Tadrart Acacus massif is located in the Fezzan region of southwest Libya, between 26° and 24° latitude N. It covers an area of approximately 5000km$^2$ with a maximum elevation of 1410m asl in its western part (Perego *et al*. 2011; Zerboni *et al*. 2015). Geologically, this region belongs to the western fringe of the Murzuq Basin (El-ghali 2005), and the Tadrart Acacus consists of Lower Silurian to Lower Devonian shales and sandstones (Tanezzuft, Acacus and Tadrart Formations) gently tilted in shape of an E-NE merging cuesta. A tectonic-controlled drainage network dissects the cuesta; wadis are oversized in comparison with the present-day water discharge, and their dendritic to meandering pattern represents a Tertiary fossilised stream system (Zerboni *et al*. 2015).

During the Middle and Late Pleistocene interglacials and the Holocene (Cremaschi & Zerboni 2009; Zerboni *et al*. 2011; Gatto & Zerboni 2015; Cancellieri *et al*. 2016) the region enjoyed a period of wetter environmental conditions that can be traced by reconstructing palaeohydrological changes triggered by the expansion and withdrawal of the southwest African Monsoon.

In the Early-Middle Holocene, the area benefited from a period of high rainfall (Cremaschi 1998; Cremaschi & Zerboni 2009, 2011; Zerboni & Cremaschi 2012), which was interrupted by transitory dry spells (Cremaschi *et al*. 2014). Wet environmental conditions ceased because of the progressive reduction in the intensity of the African monsoon since *c*. 5500 cal. BP, while the onset of severe arid environmental conditions is dated to the second millennium BP (Cremaschi & Zerboni 2011). The present climate of the region is hyperarid caused by low altitude pressure and winds. Scarce meteorological data is recorded in the

region and the meteorological station closest to the Tadrart Acacus is in Ghat (24°59'N, 10°11'E, 561m asl): the mean annual temperature is approximately 25°C and the mean annual rainfall generally does not exceed 10mm (Walther & Lieth 1960). Local environments are hyperarid and shaped by the wind erosion and sedimentation; a poor plant cover dots the bed of the wadis, mostly consisting of *Acacia-Panicum* desert savannah (White 1983; Mercuri 2008).

**Materials and methods**

The geo-ethno-archaeological survey of the etaghas in the Tadrart Acacus was carried out during the 2008–2010 field missions of the Italian-Libyan Mission in the Acacus and Messak of Sapienza University of Rome and the Libyan Department of Archaeology. We undertook a survey of the etaghas after being informed upon the existence of this traditional subsistence technique integrating herding (di Lernia *et al*. 2012; Zerboni *et al*. 2013).

Areas potentially suitable for recession cultivation have been identified on the basis of remote sensing analyses of satellite imagery, surveyed in the field and cultivation and functional areas (e.g. residential, seeds separation and processing, straw accumulation) GPS-mapped with the help of local informants. During the fieldwork, we interviewed with the help of our informants Mohammed "Skorta" Hammadani and Ali Khalfalla all kel Tadrart families, trying to understand the techniques, the times and the social relevance of etaghas' exploitation. Our informants introduced us to all the kel Tadrart families living in the area. A total of nine families have been interviewed, using a standard *questionnaire* approved by the Libyan Department of Antiquities: only adult males (age >18) have been interviewed, and all gave their full consensus. Only occasionally, female members of the families have been allowed to give some information (mostly about water resources): as a whole, 29 men all belonging to the kel Tadrart supported this research (approximately ¼ of the Tadrart Acacus population).

The systematic survey of the archaeological evidence and rock art galleries in the vicinity of the etaghas was accomplished mapping and describing the distribution of Late and Final Pastoral to Garamantian archaeological findings and panels with rock art and Tifinagh inscriptions. The dating of surface contexts followed the criteria indicated in Cremaschi & di Lernia (1998). Ceramic decoration was attributed following Caneva (1987) and lithic tools and other stone materials described following Tixier (1963); phases of local human occupation during the Holocene are shown in Table S1 according to di Lernia (2017). The description and stylistic attribution of rock art panels refer to di Lernia & Gallinaro (2011);

the most recent artworks and Tifinagh inscriptions recorded according to Biagetti *et al*. (2012) and Gallinaro (2013).

Once identified, functional areas of selected etaghas have been sampled for laboratory analyses and excavations were performed in correspondence of the areas used for separating seeds and straw, and in the deposit found within a rockshelter used during the exploitation of the etaghas. Test trenches have been also excavated in the central part of the etaghas, in correspondence of areas used for cultivation. Plant macroremains have been observed under the stereomicroscope (×25) to check the presence of cereal grains in the sediment of trenches. Field description of deposits followed the internationally accepted guidelines proposed by FAO (2006). Undisturbed blocks were collected from the main deposits and soils for micromorphological analysis; thin sections were manufactured from oriented monoliths of soil according to the methods described in Murphy (1986). Preliminary micromorphological studies of sediment thin sections employed an optical petrographic microscope (Olympus BX41, with a digital camera Olympus E420); thin sections were observed under plane-polarized light (PPL), cross-polarized light (XPL) and incident oblique light. The terminology and concepts of Stoops (2003) was used for the description of thin sections, while interpretation was carried out mostly on the basis of the concepts of Stoops *at al*. (2018) and Nicosia & Stoops (2017).

Organic matter and charcoal-rich sediment samples have been collected for accelerator mass spectrometry (AMS) $^{14}C$ dating in order to obtain radiometric age determinations for the phase of etaghas exploitation. AMS radiocarbon dating results were calibrated (2σ calibration) with the OxCal v4.3 software (Bronk Ramsey & Lee 2013) using to the IntCal13 curve of Reimer *et al*. (2013).

**Table S1. Phases of human occupation in the Tadrart Acacus and surrounding regions (modified after di Lernia 2017).**

| | | Cultures | Uncalibrated chronology before present (BP) | Calibrated chronology | Calibrated chronology before present (cal BP) |
|---|---|---|---|---|---|
| **Prehistoric phases** | Pre-Pastoral | Early Acacus | 9800–8900 | 9300–7950 BC | 11 200–9900 |
| | | Late Acacus 1 | 8900–8500 | 8250–7500 BC | 10 200–9400 |
| | | Late Acacus 2 | 8500–7900 | 7600–6650 BC | 9500–8600 |
| | | Late Acacus 3 | 7900–7400 | 7050–6100 BC | 9000–8000 |
| | Pastoral | Early Pastoral 1 | 7400–6900 | 6400–5700 BC | 8300–7600 |
| | | Early Pastoral 2 | 6900–6400 | 5900–5300 BC | 7800–7200 |
| | | Middle Pastoral 1 | 6100–5500 | 5200–4250 BC | 7100–6200 |
| | | Middle Pastoral 2 | 5500–5000 | 4450–3700 BC | 6400–5600 |
| | | Late Pastoral 1 | 5000–4000 | 3950–2350 BC | 5900–4300 |
| | | Late Pastoral 2 | 4000–3300 | 2850–1500 BC | 4800–3400 |
| | | Final Pastoral | 3300–2700 | 1700–800 BC | 3700–2700 |
| | | Late Pastoral 1 | 5000–4000 | 3950–2350 BC | 5900–4300 |
| | | Late Pastoral 2 | 4000–3300 | 2850–1500 BC | 4800–3400 |
| **Protohistoric phases** | | Final Pastoral | 3300–2700 | 1700–800 BC | 3700–2700 |
| | Garamantian | Formative Garamantian | | 1000/850–400 BC | |
| | | Mature Garamantian | | 400–50 BC | |
| **Historical phases** | | Classic Garamantian | | 50 BC–AD 200 | |
| | | Late Garamantian | | AD 200–600 | |

**References**

BIAGETTI, S., A. KACI, L. MORI & S. DI LERNIA. 2012. Writing the desert: the 'Tifinagh' rock inscriptions of the Tadrart Acacus (south-west Libya). *Azania* 47: 153–74. https://doi.org/10.1080/0067270X.2012.674323

BRONK RAMSEY, C. & S. LEE. 2013. Recent and planned developments of the program OxCal. *Radiocarbon* 55: 720–30. https://doi.org/10.1017/S0033822200057878

CANCELLIERI, M., M. CREMASCHI, A. ZERBONI & S. DI LERNIA. 2016. Climate, environment, and population dynamics in Pleistocene Sahara, in S.C. Jones & A.S. Brian (ed.) *Africa from MIS 6–2: population dynamics and paleoenvironments*: 123–45. Cham: Springer. https://doi.org/10.1007/978-94-017-7520-5_7

CANEVA, I. 1987. Pottery decoration in prehistoric Sahara and Upper Nile: a new perspective, in B.E. Barich (ed.) *Archaeology and environment in the Libyan Sahara: the excavations in the Tadrart Acacus, 1978–1983* (British Archaeological Reports International Series 368): 231–54. Oxford: British Archaeological Reports.

CREMASCHI, M. 1998. Late Quaternary geological evidence for environmental changes in south-western Fezzan (Libyan Sahara), in M. Cremaschi & S. di Lernia (ed.) *Wadi Teshuinat: palaeoenvironment and prehistory in south-western Fezzan (Libyan Sahara)* (Quaderni di Geodinamica Alpina e Quaternaria 7): 13–47. Roma-Milano: CNR.

CREMASCHI, M. & S. DI LERNIA. (ed.) 1998. *Wadi Teshuinat: palaeoenvironment and prehistory in south-western Fezzan (Libyan Sahara)* (Quaderni di Geodinamica Alpina e Quaternaria 7): Roma-Milano: CNR.

CREMASCHI, M. & A. ZERBONI. 2009. Early to Middle Holocene landscape exploitation in a drying environment: two case studies compared from the Central Sahara (SW Fezzan, Libya). *Comptes Rendus Geoscience* 341: 689–702. https://doi.org/10.1016/j.crte.2009.05.001

– 2011. Human communities in a drying landscape: Holocene climate change and cultural response in the central Sahara, in I.P. Martini & W. Chesworth (ed.) *Landscape and societies, selected cases*: 67–89. New York: Springer.

CREMASCHI, M., A. ZERBONI, A.M. MERCURI, L. OLMI, S. BIAGETTI & S. DI LERNIA. 2014. Takarkori rock shelter (SW Libya): an archive of Holocene climate and environmental changes in the central Sahara. *Quaternary Science Reviews* 101: 36–60. https://doi.org/10.1016/j.quascirev.2014.07.004

DI LERNIA, S. 2017. *Archeologia Africana: preistoria, storia antica e arte rupestre*. Roma: Carocci.

DI LERNIA, S. & M. GALLINARO, 2011. Working in a UNESCO WH site: problems and practices on the rock art of the Tadrart Acacus (SW Libya, central Sahara). *Journal of African Archaeology* 9: 159–75. https://doi.org/10.3213/2191-5784-10198

DI LERNIA, S., I. MASSAMBA N'SIALA & A. ZERBONI. 2012. "Saharan waterscapes": traditional knowledge and historical depth of water management in the Akakus Mts. (SW Libya), in T. Sternberg & L. Mol (ed.) *Changing deserts: integrating people and their environment*: 101–28. Cambridge: The White Horse.

EL-GHALI, M.A.K. 2005. Depositional environments and sequence stratigraphy of paralic glacial, paraglacial and postglacial Upper Ordovician siliciclastic deposits in the Murzuq Basin, SW Libya. *Sedimentary Geology* 177: 145–73. https://doi.org/10.1016/j.sedgeo.2005.02.006

FAO. 2006. *Guidelines for soil description, Fourth edition*. Rome: Food and Agriculture Organization of the United Nations.

GALLINARO, M. 2013. Saharan rock art: local dynamics and wider perspectives. *Art* 2: 350–82. https://doi.org/10.3390/arts2040350

GATTO, M.C. & A. ZERBONI. 2015. Holocene supra-regional environmental changes as trigger for major socio-cultural processes in Northeastern Africa and the Sahara. *African Archaeological Review* 32: 301–33. https://doi.org/10.1007/s10437-015-9191-x

MERCURI, A.M. 2008. Plant exploitation and ethnopalynological evidence from the Wadi Teshuinat area (Tadrart Acacus, Libyan Sahara). *Journal of Archaeological Science* 35: 1619–42. https://doi.org/10.1016/j.jas.2007.11.003

MURPHY, C.P. 1986. *Thin section preparation of soils and sediments*. Berkhamsted: AB Academic.

NICOSIA, C. & G. STOOPS. (ed.) 2017. *Archaeological soil and sediments micromorphology*. Hoboken (NJ): John Wiley & Sons. https://doi.org/10.1002/9781118941065

PEREGO, A., A. ZERBONI & M. CREMASCHI. 2011. The geomorphological map of the Messak Settafet and Mellet (Central Sahara, SW Libya). *Journal of Maps* 7: 464–75. https://doi.org/10.4113/jom.2011.1207

REIMER, P.J. *et al*. 2013. IntCal13 and Marine13 radiocarbon age calibration curves 0–50 000 Years cal BP. *Radiocarbon* 55: 1869–87. https://doi.org/10.2458/azu_js_rc.55.16947

STOOPS, G. 2003. *Guidelines for analysis and description of soil and regolith thin sections*. Madison (WI): Soil Science Society of America.

STOOPS, G., V. MARCELINO & F. MEES. 2018. *Interpretation of micromorphological features of soils and regoliths. Second edition*. Amsterdam: Elsevier. https://doi.org/10.1016/B978-0-444-63522-8.00001-2

TIXIER, J. 1963. *Typologie de l'Epipaléolithique du Maghreb: memoires du centre de recherches anthropologiques, préhistoriques et ethnographiques*. Alger & Paris: A.M.G.

WALTHER, H. & H. LIETH. 1960. Klimadiagramm. Weltatlas. Jena: G. Fisher.

WHITE, F. 1983. *The vegetation of Africa*. Paris: UNESCO.

ZERBONI, A. & M. CREMASCHI. 2012. Il significato paleoclimatico dei carbonati continentali olocenici centro-sahariani: memoria delle forzanti orbitali e di eventi climatici rapidi, in Accademia Nazionale dei Lincei (ed.) *Clima del Mediterraneo negli ultimi 12 mila anni. In ricordo di Ardito Desio nel decennale della morte, (XXIX Giornata dell'Ambiente, Roma, 17 Ottobre 2011)* (Atti dei Convegni Lincei 267): 97–106. Roma: Scienze e Lettere Editore Commerciale.

ZERBONI, A., L. TROMBINO & M. CREMASCHI. 2011. Micromorphological approach to polycyclic pedogenesis on the Messak Settafet plateau (central Sahara): formative processes and palaeoenvironmental significance. *Geomorphology* 125: 319–35. https://doi.org/10.1016/j.geomorph.2010.10.015

ZERBONI, A., I. MASSAMBA N'SIALA, S. BIAGETTI & S. DI LERNIA. 2013. Burning without slashing: cultural and environmental implications of a traditional charcoal making technology in the central Sahara. *Journal of Arid Environments* 98: 126–31. https://doi.org/10.1016/j.jaridenv.2013.08.008

ZERBONI, A., A. PEREGO & M. CREMASCHI. 2015. Geomorphological map of the Tadrart Acacus massif and the Erg Uan Kasa (Libyan central Sahara). *Journal of Maps* 11: 772–87. https://doi.org/10.1080/17445647.2014.955891

ZERBONI, A., L. MORI, G. BOSI, F. BULDRINI, A. BERNASCONI, M.C. GATTO & A.M. MERCURI. 2017. Domestic firing activities and fuel consumption in a Saharan oases: micromorphological and archaeobotanical evidence from Fewet (Central Sahara, SW Libya). *Journal of Arid Environments* 144: 123–38. https://doi.org/10.1016/j.jaridenv.2017.03.012