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Formation of desert pavements and the interpretation of lithic-strewn landscapes of the central Sahara

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ABSTRACT

This study focuses on two different but interlinked lines of evidence that critically examine land surface processes contributing to the formation of desert pavements in the central Sahara. (1) Soil pedostratigraphies from the Messak plateau (SW Libya) illustrate phases of land surface stability and instability that reflect humid and arid phases of Quaternary climate, respectively. (2) The density and morphologies of surface lithic scatters in the same region were re-examined, based on data previously published by Foley and Lahr (2015, PLoS ONE). This re-examination shows that many surface clasts previously interpreted as lithics are better interpreted as formed by *in situ* weathering and wind abrasion. Furthermore, weathering, abrasion and deflation are the major processes by which desert clasts are formed and concentrated on the land surface, not human agency. Erosional Quaternary periods allowed for the formation of condensed pedostratigraphies by which surface clasts and lithics were mixed and concentrated on the land surface. These two independent lines of evidence show that desert land surfaces do not reflect a single time period of formation, and that Quaternary desert pavements (including any lithics located thereon) evolved in response to subaerial weathering and erosion processes.

1. Introduction

Geomorphological processes are particularly active in regions that experience extreme climatic regimes and relatively rapid climate changes, including the central Sahara. Climate-driven weathering and subsequent sediment transport in this region throughout the Cenozoic has resulted in the formation of extensive weathered bedrock surfaces, on which small grain sizes have been lost by deflation or transported by episodic flash floods, leaving a hamada-like mantle of surficial clasts mainly of pebble and boulder sizes (Zerboni, 2008; Adelsberger and Smith, 2009; Zerboni et al., 2011; Fookes et al., 2013). Variations in aridity/humidity throughout the Quaternary, in particular, have resulted in episodic landslides (Busche, 2001; Lee et al., 2013), river/lake development (Cremaschi, 2001; Drake et al., 2008), ecosystem changes (Parker et al., 2008; Cremaschi et al., 2014), and responses to these changing conditions by human activity (Geyh and Thiedig, 2008; Mercuri, 2008; Cremaschi and Zerboni, 2009). One of the less considered effects of wet to dry Quaternary climatic transitions in desert regions is the weathering of exposed rocks and the formation of soils during wet periods, and their breakup and erosion as a consequence of enhanced wind activity in glacial/arid times. The main effect of the interplay between dust input, soil forming processes, and deflation is the formation of desert stone pavements (e.g., Watson and Nash, 1997; McFadden et al., 1998; Dietze et al., 2013; Goudie, 2013; Fuchs et al., 2015). The final stage in formation of a desert pavement is the creation of a layer of clasts, generally covered by a dark rock varnish and/or polished by wind. These clasts become embedded within the finer matrix of the topsoil, where present. According to the time of development of the surface, more than one clast layer or palaeosol can be found in the stratigraphy, buried by aeolian or colluvial sediments (Fuchs et al., 2015). Moreover, human groups extensively settled in deserts such as the Sahara, in particular during wetter interglacial phases of the Pleistocene (Jones and Brian, 2016), leaving behind them an impressive quantity of stone tools and débitage. The latter, especially those dating to the Pleistocene, can become part of the desert pavement surface. Key evidence for prehistoric human activity in the central Sahara region is therefore the presence of surficial lithic scatters (Adelsberger et al., 2013; Foley and Lahr, 2015). Lithics are defined as anthropogenically-formed stone materials, including stone tools and débitage. Lithics are a subset of all clasts present on the land surface, which mostly include clasts that have not been shaped by human activity but by subaerial weathering. The terms *lithics* and *clasts* are used herein according to these specific definitions.

Although many studies have been concerned with the Holocene

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archaeology and cultural anthropology of the central Sahara, particularly in the central Sahara (e.g., Cremaschi and di Lernia, 1998; Cremaschi and Zerboni, 2009; di Lernia et al., 2013; Cremaschi et al., 2014; Guagnin, 2014), fewer studies have examined the archaeology of earlier time periods across the region (e.g., Cancellieri and di Lernia, 2013; Drake et al., 2013; Cremaschi et al., 2014).

A recent study by Foley and Lahr (2015) presented evidence for high-density lithic scatters, based on observations from 50 randomly-sampled 1 x 1-m quadrats, from across the surface of a very small portion of the Messak plateau (SW Libya). Based on simple counting of the number of lithics from within these quadrats, Foley and Lahr calculated lithic density (expressed as number of lithics/m^2), and then extrapolated this figure across the wider region that had been previously surveyed (some > 400 km^2). They calculated an average density of 75 lithics/m^2 and thus 7.5×10^7 lithics/km^2 across the region as a whole which, they argued, is consistent with a 'modelled' value based on population density, length of time of occupation, number of flakes used, débitage production, and tool volume. However, they did not consider the geomorphological processes shaping the land surface in such an arid region, in the interpretation of this evidence.

In this paper, we revisit the relationship between geomorphological and anthropogenic processes in the morphology and concentration of clasts on desert pavements in the central Sahara. This paper (i) defines the main natural surface processes responsible for the formation of desert pavements based on published and new evidence from the Messak plateau region of southwest Libya, including soil pedosequences, and (ii) critically re-examines the methodology and results obtained, and the interpretation of the results, from this region by Foley and Lahr (2015), in the light of this new evidence and with reference to what is already known about the formation of desert pavements. Thus, our study sets the reanalysis of these previous data into a wider climatic, geomorphic and environmental context. This critical re-examination is needed because, in order to evaluate the formation of desert pavements, one must consider (i) the physical weathering and erosion processes that can substantially modify the morphology of any surface clasts, and (ii) the nature of macroscale landscape evolution over long time scales (< 500,000 years) which may substantially impact on the density of lithics recorded on the surface today, as well as the density of clasts in total.

In detail, this paper (1) outlines the geology and geomorphology of the Messak plateau; and (2) presents new field evidence for the complex processes forming desert pavement in the region. (3) We then consider the data presented in Foley and Lahr's (2015) study, and re-calculate lithic density based on excluding those clasts which have been formed by natural – not anthropogenic – processes. (4) We then show that macroscale landscape evolution by deep and surface weathering, and subsequent deflation, can form a condensed stratigraphy which concentrates clasts (and any lithics) on the surface, which casts doubt on the value of calculations of lithic density. These geomorphological considerations are important if one is to accurately consider the impacts of past human activity on the regional landscape, and thus the wider context of the 'Palaeoanthropocene' of the central Sahara.

2. Geology, geomorphology and climate of the Messak plateau

The Messak plateau (~15,000 km^2) is a prominent topographic feature of the north-central Sahara, in SW Libya (Fig. 1). This plateau consists of two separate units (the Messak Settafet and the Messak Mellet) and is underlain by massive, east-dipping Cretaceous (Nubian) sandstones, which are occasionally interbedded with thinly-bedded shales and conglomerates (Cremaschi, 1998; El-Ghali, 2005). The western and northern edges of the plateau form a steep (300 m high) scarp in the Messak Mellet, which reaches maximum altitudes of ~1200 m asl. The remainder of the plateau dips shallowly (< 1°) eastwards, where the plateau contains evidence for both wholly relict and some contemporary landscape elements. Relict features include low-relief bedrock surfaces with high-density and relatively large blocky debris (hamadas) or with smaller rounded debris (serir); bedrock surfaces covered with patches of Neogene to Pleistocene rubified palaeosols (Zerboni et al., 2015a); a deeply incised dendritic fluvial network, today almost fossil, but in the Pleistocene able to form gravel mega-bars; a complex system of underground and surface solutional features (Perego et al., 2011); and Pleistocene fluvial terraces overlying bedrock surfaces in the lower-elevation east of the region (Perego et al., 2011; Zerboni et al., 2015a). The dendritic drainage system cutting the Messak plateau and forming stepped canyons probably evolved from the Tertiary (likely the Oligocene or Miocene), in response to wetter climate and regional uplift (Busche, 2010; Hounslow et al., 2017). After this initial phase, rivers were periodically reactivated during humid periods over millions of years, up to the early Holocene (Perego et al., 2011), contributing to removal of the pedogenic cover of the plateau. As a consequence, the headwater areas of most wadis have high denudation rates, exposing sandstone bedrock outcrops (Zerboni, 2008). Erosion in headwater areas can moreover be matched with alluvial megafans formed at plateau footslopes, as in the case of the Wadi Berjuj gravel-bearing alluvial fan (Perego et al., 2011). Parts of the ancestral regional drainage system and several gravel-bearing alluvial fans have been buried under dunes of the adjacent Murzuq sand sea (Perego et al., 2011). Significant regional land surface elements are shown in Fig. 2 and their distribution reported in the simplified geomorphological map (Fig. 1).

During the Quaternary, deep and thin paleosols formed on the Messak plateau, but these were partially or entirely removed by wind erosion during arid (glacial) phases (Trombino, 1998; Zerboni et al., 2011). However, this erosion or reworking was not spatially or temporally uniform. As a consequence, the surface of the plateau experienced differential accumulation of residual clasts that constitute the desert pavement (Fig. 2). The presence of a Mn-bearing rock varnish (Cremaschi, 1998; Zerboni, 2008) permits a remote sensing approach to define the occurrence of areas where surface stoniness and stability are highest (Zerboni, 2008; Zerboni et al., 2015a). The spectral band ratio 5/4 of Landsat TM and ETM + platforms provides a good index for varnished surfaces, giving the highest values where bare rock outcrops dominate. Holocene landscape elements include east-draining ephemeral wadi systems, which may include a mixture of fluvial gravels, aeolian reworked sands, shallow soils and Mn-bearing weathering surfaces. Isolated bedrock hilltops are also found across the plateau region and in association with all landscape elements. AMS-^{14}C dating has shown that rock varnish on surface boulders of the Messak plateau developed episodically throughout the Holocene in response to variations in humidity (Zerboni, 2008), and that black Mn-rich varnishes formed after the mid-Holocene climatic transition.

Climatically-driven weathering is the major control on the macroscale geomorphology of the northern and central Sahara regions (Wright, 2001; Zerboni, 2008; Perego et al., 2011). The major weathering processes are thermal heating and cooling on bare rock surfaces and boulders (Moores et al., 2008; Eppes et al., 2010; Dorn, 2011; Viles and Goudie, 2013); rare salt wedging and episodic freeze-thaw where moisture is present within rock fractures (Aref et al., 2002); and granular disintegration, which particularly affects sandstone (Labus and Bochen, 2012), the dominant lithology in this area. Mechanical abrasion by wind-blown sand also takes place, because of the availability of loose quartz sand and silt grains as weathering products (Wright, 2001), unstable and unvegetated land surfaces, and vigorous seasonal wind patterns, but its effects are hampered by surfaces affected by granular disintegration and mechanical weathering. These environmental conditions give rise to dust storms (Goudie and Middleton, 2001) and active sand dune migration (Al-Masrahy and Mountney, 2013). Associated with sediment transport is the formation of polished desert pavement surfaces (Zerboni, 2008; Adelsberger and Smith, 2009; Matmon et al., 2009), and boulder or rock surfaces with wind-abraded facets (ventifacts) (Wade, 1910; Desio, 1937; McCauley et al., 1980;