Journal of African Earth Sciences 121 (2016) 56–61

Contents lists available at ScienceDirect

Journal of African Earth Sciences

journal homepage: www.elsevier.com/locate/jafrearsci

Inverted topography in the southeastern part of the Western Desert of Egypt

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ARTICLE INFO

Article history:
Received 5 January 2016
Received in revised form
20 May 2016
Accepted 23 May 2016
Available online 27 May 2016

Keywords:
Inverted topography
Western Desert
Nubia Formation
Nile

ABSTRACT

We present here a series of surficial geologic maps of 22,000 km^2 of the southeastern part of the Western Desert of Egypt showing 3084 bodies of wadi-floor sediment that have been inverted by erosion to form sinuous ridges capped by alluvial gravel, here described as "*inverted wadis*". These features represent fragments of one or more ancient drainage systems that developed at times when rainfall, and hence overland flow, was greater than it is today in this hyperarid region. While some of the inverted wadis were tributaries to a through-flowing river that followed the course of the modern Nile, others converge on what appear to have been internal closed basins west of the Nile.

Several components of this ancient drainage system have yielded artifacts assigned to an Acheulian lithic tradition, but there is not yet enough stratigraphic information available to enable us to relate this ancient drainage system to any of the proposed scenarios of Nile evolution.

1. Introduction

In this paper, we present a series of maps of features of inverted topography distributed across 22,000 km^2 in the Western Desert of SE Egypt.

The climate of SE Egypt today is hyperarid; Aswan receives ~3 mm of rain/yr, and Wadi Halfa <0.1 mm/yr. Among residents of Egyptian Nubia in 1964, when the Aswan Dam was closed and the Nubian villagers were moved from the reservoir area, few had witnessed rain in their lifetimes.

2. Regional geology

The drainage history of the eastern Sahara has been addressed by geologists and geographers at least since the time of Herodotus (summarized in Said, 1962, 1975; Williams and Williams, 1980; Embabi, 2004). We present here a series of maps, drawn from modern satellite imagery, that show fragments of fossil drainage networks, today preserved as sinuous ridges, elevated by a process of topographic inversion. These features are widespread across the deserts of Egypt. In this paper we focus on 22,000 km^2 in southeastern Egypt west of Lake Nasser, or Lake Nubia of Sudan, the reservoir impounded in 1964 behind the Aswan High Dam, or Sa'ad el A'ali. This part of SE Egypt is also known as the Selima Sand Sheet and the Toshka Plain (Fig. 1).

This region is underlain by unfossiliferous coarse-grained quartz sandstone assigned to the Nubia Formation (Issawi, 1973). Rocks of the Nubia Formation lie unconformably on crystalline basement rock, exposed at the 1st and 2nd cataracts of the Nile at Aswan and Wadi Halfa, and at isolated sites in the Western Desert. The Nubia Formation and/or its equivalents extends across much of North Africa as a time-transgressive basal sandstone/conglomerate, ranging in age from Permian to late Cretaceous. In the area described here, the Nubia Formation has been assigned to early Cretaceous time.

The Nubia Formation consists predominantly of strata of sandstones and conglomerates, much of which in SE Egypt is cemented by iron oxide. In some strata the iron-oxide cement is concentrated in discrete concretions; in other strata the concretions are consolidated into continuous beds of iron-oxide-cemented sandstone.

Weathering and erosion of the Nubia Formation preferentially removes the less-well-cemented components of the rock, leaving behind a lag concentrate of the more resistant, iron-oxide-cemented components. During periods of stream erosion and deposition, these resistant components have become concentrated in bodies of alluvial sediments on the floors of wadis.

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http://dx.doi.org/10.1016/j.jafrearsci.2016.05.020
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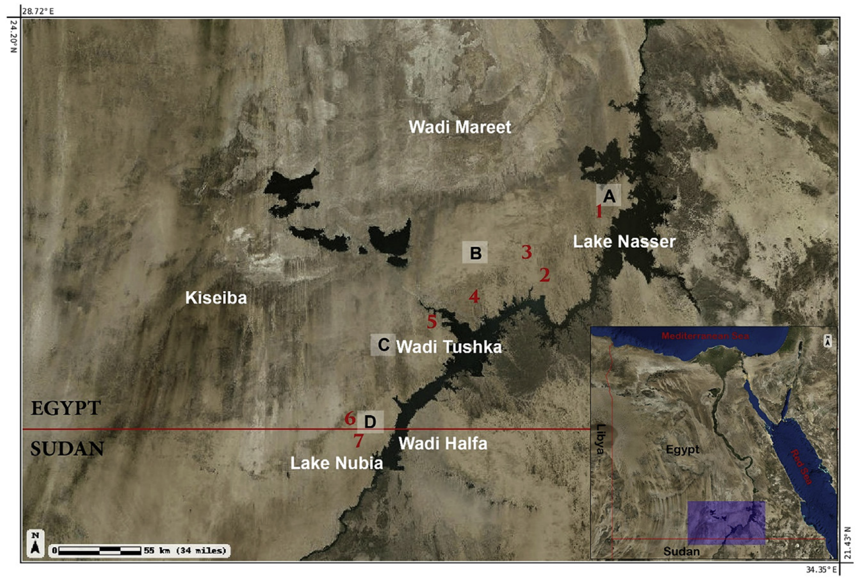

Fig. 1. Satellite image of the study area (obtained from ESRI satellite imagery for the world), showing the distribution of locations of inverted wadis and sites which were chosen for measurements.

3. The process of topographic inversion

Topographic inversion occurs when and where rock materials that are more resistant to erosion than underlying or adjacent bedrock accumulate in low places of a landscape, and then become inverted as erosion lowers the landscape around them.

Eruption of lava during a period of regional erosional lowering may fill low places in a landscape (basins, stream valleys) with masses of resistant lava, which are then inverted as that regional lowering proceeds. But inversion of topography as a consequence of the accumulation in low places of the landscape of resistant sedimentary materials requires a multi-stage process, in which an erosional regime (to incise the wadis) is replaced by a depositional regime (to fill the wadi floors with sediment) which is superseded by another erosional regime (to achieve the inversion). Examples of topographic inversion have been described from many parts of the world.

Inverted topography has been recorded in several localities around the world, including parts of Africa (e.g., King, 1942; Butzer and Hansen, 1968; Brookes, 2003; Giegengack, 1968; Haynes, 1980; Aref, 2003; Embabi, 2004), the Arabian Peninsula (e.g., Miller, 1937; Holm, 1960; Maizels, 1983, 1987, 1990), several locations in Australia (e.g., Mann and Horowitz, 1979; Pain and Ollier, 1995), Utah (Williams et al., 2007), and in the Kumtag desert in China (Wang et al., 2015).

The majority of features of inverted relief in Arabia, Africa, Australia, Utah, and China are likely the result of preservation of the fluvial channel floors through cementation (e.g., Pain and Ollier, 1995; Williams et al., 2007; Giegengack, 1968; Maizels, 1983, 1987, 1990; Wang et al., 2015). Examples of surface armoring are poorly documented in the literature and this mechanism appears to be a complementary process to achieve induration of the fluvial sediments (e.g., Giegengack, 1968; Maizels and McBean, 1990; Pain and Ollier, 1995). In addition, inversion of lava flows in stream valleys has been documented around the world (Pain and Ollier, 1995).

Whatever the mechanism which led to development of the inverted topography, the delineation of an inverted valley occurs by fluvial erosion and/or aeolian deflation, as in different localities in Western Desert of Egypt (Giegengack, 1968; Aref et al., 2002; Aref, 2003; Brookes, 2003), the Arabian Peninsula (Holm, 1960; Maizels, 1983, 1987), the Atacama Desert (Morgan et al., 2014), and in the Kutmag desert in China (Wang et al., 2015).

Since wadi-floor sediments consist of the most resistant components of the Nubia Formation, they have offered more resistance to stream erosion at times when stream regimen, driven by one or another external factor, has changed from alluviation to erosion. Under those circumstances, bodies of wadi-floor sediment have been left standing as sinuous ridges as the less resistant sandstone was lowered around them.

4. Distribution of features of inverted topography in SE Egypt

Examples of inverted topography are distributed across many different physiographic environments in Egypt.

Low places along the Sinn-el-Kiddab escarpment became sites of discharge of carbonate-laden groundwater at times in the past when rainfall more plentiful than today supported rapid groundwater flow through cavernous carbonate bedrock. At points of spring discharge, the loss of dissolved CO_2 led to the precipitation of vast bodies of $CaCO_3$, or spring travertine, at and adjacent to points of discharge. Regional erosion, both by wind and by infrequent flash floods in later more arid periods, differentially eroded limestone bedrock, leaving the more resistant travertine standing as giant spring deposits, conspicuous features in the landscape, as at Refuf Pass, Bulaq, and el-Midauwara (e.g. Caton-Thompson, 1952; Smith, 2012).

Broad, shallow, wind-eroded basins at the major oases in the Western Desert became extensive shallow lakes at times in the past when rainfall was greater than it is today. Groundwater was added to those lakes as water under artesian pressure rose through the floors of those lakes as individual springs. Resistant minerals that precipitated at those spring orifices were left as positive topographic features when wind erosion in more arid times continued to lower the floor of the basin. Thus, conical mounds ~10 m high, typically described as "spring mounds" (Frizano, 1996; Smith, 2012; Haynes, 1985; Nicoll, 1998, 2004) are widely distributed across fossil-lake basins in the Western Desert. These features developed