Aeolian Research 20 (2016) 89–99

Contents lists available at ScienceDirect

Aeolian Research

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

Yardangs in the Qaidam Basin, northwestern China: Distribution and morphology

Jiyan Li [a,*], Zhibao Dong [b], Guangqiang Qian [b], Zhengcai Zhang [b], Wanyin Luo [b], Junfeng Lu [b], Meng Wang [b]

[a] Taiyuan Normal University, Jinzhong, Shanxi 030619, China

[b] Key Laboratory of Desert and Desertification, Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, No. 320, West Donggang Road, Lanzhou, Gansu 730000, China

ARTICLE INFO

Article history:
Received 17 April 2015
Revised 31 October 2015
Accepted 2 November 2015
Available online 6 January 2016

Keywords:
Yardangs
Aeolian erosion landforms
Dune fields
Aeolian geomorphology
Qaidam Basin

ABSTRACT

The northwestern Qaidam Basin exposes one of the largest and highest elevation yardang fields on Earth. The aim of the present study was to describe the distribution and morphology of these yardangs, and analyze the factors responsible for the distribution pattern of these aeolian landforms. The yardang fields are bounded by piedmont alluvial–diluvial fans from the mountain ranges surrounding the basin, except in the south, where they are bounded by dune fields, dry salt flats, lakes, and rivers. This distribution pattern can be attributed to regional tectogenesis and its corresponding environmental impacts. The morphology of the yardangs varies considerably in response to the diverse factors that control their formation and evolution. Long-ridge yardangs are mainly located in the northernmost part of the yardang field, and the long ridges are gradually dissected into smaller ridges in the downwind direction. Further downwind, the convergence of northerly and northwesterly winds and the effects of temporary runoff cause the ridges to gradually transition into mesa yardangs. Saw-toothed crests, and conical and pyramidal yardangs, occur in groups on folded brachyanticlinal structures. Typical whaleback yardangs are found in the southeast, at the northern margin of Dabuxun Lake. Morphological parameters vary among the yardang types. The orientation of the yardangs in the northernmost area is nearly N–S, with a transition towards NW–SE in the southernmost area in response to a change in the dominant wind direction that results from the orientations and positions of the mountain ranges that surround the basin.

1. Introduction

"Yardang" is a Turkmen word introduced to the English literature by a Swedish explorer (Hedin, 1903) to designate the streamlined, wind-eroded ridges that evolve from semi-consolidated lacustrine deposits in China's Taklimakan Desert. The widespread discovery of such streamlined ridges on Earth and other planets has led to expansion of the meaning to include streamlined landforms that evolved from consolidated bedrocks (McCauley et al., 1977b; Greeley and Iversen, 1987; Cooke et al., 1993; Lancaster, 1995; Goudie, 2007; Laity, 2009, 2011; Laity and Bridges, 2013). Though yardangs are found in most major deserts around the world, they nevertheless cover only a small percentage of the Earth's land surface. In the arid regions of North America, Australia, and Europe, yardangs are commonly small and limited in extent (Laity and Bridges, 2013). Several yardang fields are found in the western coastal desert of South America, with typical mega-yardangs about 10 km long eroded from bedrock (Inbar and Risso, 2001; Bailey et al., 2007; Goudie, 2007; de Silva et al., 2010). Yardang fields in Africa are mainly distributed in the Sahara and Namib Deserts (Stapff, 1887; Walther, 1891, 1912; El-Baz et al., 1979; Grolier et al., 1980; Bristow et al., 2009; Laity and Bridges, 2013). There are multiple, extensive yardang fields in Asia, including the northwestern arid regions of China (Kozlov, 1899; Hedin, 1903; Xia, 1987; Halimov and Fezer, 1989; Dong et al., 2011, 2012), the Lut Desert of Iran (Krinsley, 1970), Kuwait (Al-Dousari et al., 2009), and Saudi Arabia (Goudie, 2007). These yardangs are mainly distributed in hyper-arid regions, where annual precipitation is less than 50 mm and there is minimal vegetation cover. However, the yardangs in northeastern Spain (Gutiérrez-Elorza et al., 2002) and at Rogers Lake, California (Ward and Greeley, 1984) exist in a semiarid climate, and the yardangs in Hungary (Sebe et al., 2011) exist in a cold desert environment. The yardangs in these regions may also indicate the existence of an arid environment in the past, when they first

* Corresponding author at: No. 319, Daxue Street, Yuci Strict, Jinzhong City, Shanxi Province, 030619, China (New Campus of Taiyuan Normal University). Tel.: +86 139 1985 9405.

E-mail address: jyli@lzb.ac.cn (J. Li).

http://dx.doi.org/10.1016/j.aeolia.2015.11.002
1875-9637/

evolved. For this reason, yardangs have potential as (paleo) climate proxy indicators.

Stapff (1887) and Walther (1891, 1912) were among the first to describe yardangs, in the Namib Desert and Egypt, respectively. The investigations of Kozlov (1899) and Hedin (1903) were conducted in northwestern China. Bosworth (1922) compared the yardangs of northwestern Peru with inverted boat hulls. However, unlike the most common aeolian phenomena, such as sand and dust storms and dune migration, yardangs cause no significant harm to human lives and economic activities. Thus, it was not until the late 19th and early 20th century that they began to gain considerable attention from researchers. McCauley et al. (1977a) summarized the distribution of yardangs around the world. Yardangs have also been found on Mars (Ward, 1979; Bridges et al., 2010; Zimbelman and Griffin, 2010) and probably on Venus (Trego, 1990, 1992; Greeley et al., 1995), which suggested the universality of their formation mechanisms and provided a major impetus for studies of the aeolian processes that would lead to the evolution of yardang landforms and renewed investigations of terrestrial analogs for the extraterrestrial systems. Other field investigations of yardangs were conducted in Africa and northwestern China (Laity and Bridges, 2013). However, these investigations were localized and focused on morphological descriptions.

The aspect ratio (i.e., the length:width ratio) is an important morphological parameter of aeolian landforms, since it is a critical element for distinguishing yardangs from other hills or inselbergs (Grolier et al., 1980). The values of this ratio commonly average 3:1 or greater for yardangs (Laity, 2009). Based on the results of wind tunnel experiments, Ward and Greeley (1984) proposed that the ideal (mature) form of a yardang would have an aspect ratio of 4:1, independent of scale. Gutiérrez-Elorza et al. (2002) found a mean aspect ratio of 4.1:1 for yardangs in the Ebro Depression of northeastern Spain, which corroborated the hypothesis of an ideal aspect ratio proposed by Ward and Greeley based on evidence from field observations. However, field observations by other investigators contradicted this hypothesis. Researchers have reported mean aspect ratios of 1.5:1 in the Um Al-Rimam Depression of northern Kuwait (Al-Dousari et al., 2009), 1.8:1 in Mongolia (Ritley and Erdennebat, 2004), and 3:1 in the Western Desert of Egypt (Grolier et al., 1980). The aspect ratio of yardangs in coastal Peru range from 3:1 in the northern part of the extensive yardang field to 10:1 in the southern part (McCauley et al., 1977b). This suggests that whether or not an ideal form exists, that form will be modified by local factors such as the wind and water regimes, and the nature of the surface materials (e.g., unconsolidated sediments vs. bedrock).

In China, several yardang fields are found in the northwestern arid regions, such as the Lop Nur region east of the Taklimakan Desert, the Wu'erhe region in the northwestern part of the Gurbantunggut Desert, and in the northwestern part of the Qaidam Basin. The Qaidam Basin has the largest yardang area in China (3.88×10^4 km^2; Dong et al., 2011, 2012; Kapp et al., 2011; Rohrmann et al., 2013). For at least 2000 years ago, Chinese historians and geographers have begun to investigate the yardangs in the Lop Nur region and tried to explain how they formed (Xia, 1987). The work of Hedin (1903) was of tremendous significance, and first introduced the terminology. Hedin described the yardangs of the Lop Nur region and attributed their formation to running water in the initial stages, followed by modification by the wind as they matured. Xia (1987) clarified the distribution and development processes of yardangs in the Lop Nur region. By providing field evidence, he determined that fluvial erosion played an important role in the formation of yardangs. Dong et al. (2012) studied the factors controlling the evolution of yardangs in the Kumtagh Desert, and proposed a more comprehensive evolution sequence. In summary, Dong et al. believed that the development of yardangs in the Kumtagh Desert can be divided into four stages based on varied controlling factors and morphological characteristics in different stages.

Even though the yardangs of the Qaidam Basin represent the largest yardang area in China, there have been few studies of these structures. Fan (1962) investigated the geomorphology of the northwestern Qaidam Basin and classified the yardangs in this region into three types: "pyramids", "long ridges" and "streamlined whalebacks". Based on this work, Halimov and Fezer (1989) further subdivided the yardangs of the Qaidam Basin into eight types. In addition to the three above mentioned types, they defined "mesa", "saw-toothed crest", "cone", "hogback" and "low, streamlined whaleback" types. They also proposed a new evolutionary sequence for the yardangs in the Qaidam Basin based on the dominant controlling factor in different stages. However, the work of Fan (1962) was in the Lenghu area at the northern end of the basin, and Halimov and Fezer (1989) studied the area between Lenghu and Iqe (see Fig. 1 for the locality), so these studies only covered part of the basin. With the help of high-resolution remote-sensing images, we have built on this research to provide a more complete description of the distribution and morphology of yardangs throughout the basin and have attempted to explain the distribution and evolution of these aeolian structures in the context of the regional tectogenesis that has occurred.

2. Physiographic settings and methods

2.1. Geographical and geological settings

The Qaidam Basin is the largest intermontane basin at the northeastern end of Tibetan Plateau and is enclosed by four mountain belts, the Kunlun Mountains in the south and west, the Altyn Tagh Mountains in the northwest, the Qilian Mountains in the northeast, and Ela Shan Mountain in the east, covering an area of 12×10^4 km^2 (Figs. 1 and 2). The interior of the basin is at an average elevation of 3000 m a.s.l., while the surrounding mountains reach elevations of 4000–5000 m a.s.l. The basin is characterized by a hyper-arid climate, with mean annual precipitation ranging from 100 mm in the southeastern to less than 20 mm in the northwestern, and the potential mean annual evaporation can be 100 times higher than precipitation. Another outstanding character for Qaidam Basin climate is the frequent occurrence of sand–dust storms, especially during March to May. The Altyn Tagh Mountains are much lower in elevation (4000 m a.s.l.) than the other peripheral mountains (5000 m a.s.l.), i.e. the mountains tend to be taller and have fewer passes through which the wind can travel in the south than in the north. Therefore, strong northerly and northwesterly winds from the Tarim Basin can pass through low areas of the Altyn Tagh Mountains and enter the Qaidam Basin as an extremely dry foehn (Halimov and Fezer, 1989; Wang et al., 2005). This dry foehn moves from northwest to southeast in the basin, and the wind direction becomes more westerly as the wind passes through the basin under the influence of the basin-bounding mountain ranges in the south, which divert the wind towards the southeast (Fig. 1). The physical environment and the formation and evolution of landscapes in the basin are all likely to have been determined by the characteristics of the peripheral mountain ranges, such as how they direct the flow of the drainage system towards the center of the basin, the presence of wetter low-lying lands in the southeastern part of the basin, the ring of piedmont alluvial–diluvial fans and oases surrounding the basin, and the presence of massive salt lakes in the center and southeast of the basin (Fig. 1).

Qaidam Basin is a tectonically controlled depression (Fig. 2). It has been a closed inland basin since the Paleogene and accumu-