

Aeolian origin of interdune lakes in the Badain Jaran Desert, China

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Received: 26 June 2015 / Accepted: 10 September 2015
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Abstract The coexistence of megadunes and interdune lakes is a unique landscape in the Badain Jaran Desert. Its formation mechanism is an open question. Two necessary conditions for a lake are water and basin. Different from various previous works focusing on water source, here, the lake basin origin is investigated. The chronological, geomorphological, and aerodynamic evidences support that the elongated lakes in the southeastern margin of the desert are aeolian lakes.

Keywords Megadune · Wind erosion · Blowout · Aeolian lake

The tallest terrestrial dune about 450 m high occurs in the Badain Jaran Desert, China (Dong et al. 2004; Yang et al. 2011). The modern wind regimes in the desert comprise intermediate and high energy wind environments. Three dominant winds are from northwest, northeast, and southwest, see Zhang et al. (2015) for more detailed information

about wind velocity and sand drift potential. The average annual precipitation over the period from 1980 to 2013 is less than 90 mm, whereas the annual potential evaporation is more than 2500 mm. The coexistence of megadunes and closed interdune lakes, mainly occurring in the southern part of the desert, is a well-known, attractive, and mysterious landscape. A very recent field survey showed that the numbers of permanent and seasonal lakes are 119 and 27, respectively (Zhang et al. 2012). Two types of lakes, namely, elongated and oval-shaped lakes, had been morphologically classified (Hofmann 1996). Elongated lakes are often shallow in depth (< 2 m) and small in area (< 0.2 km²). In contrast, oval-shaped lakes are deep and large. Their maximal depth and area can reach 15 m and 1.5 km². As pointed out in the review of Dong et al. (2013), the formation of these lakes is one of the three key issues being studied in the last two decades. A great number of hydrochemical, hydrogeological, and paleoclimatic works, e.g., (Chen et al. 2004; Ma and Edmunds 2006; Gates et al. 2008; Wu et al. 2014), were performed to find the source of water. But no lake has ever existed without a basin in which water accumulated (Reeves 1968). According to their basin origins, lakes can be classified as tectonic, fluvial, glacial lakes, etc (Reeves 1968; Cohen 2003). Aeolian lakes are a minor category on the global scale though they could be densely located in certain areas. The activities of wind erosion and dune migration can generate aeolian lakes by removal of clay and sand in dry beds or by blocking of drainage networks (Cohen 2003). Although all lakes in the Badain Jaran Desert were hypothesized as aeolian lakes in the “Encyclopedia of Chinese Lakes” (Wang and Dou 1998), the studies of lake basins are still lacking. Combining with field surveys and lots of progresses in this desert, here, we investigated the origin of lake basins with respect to sediment chronology, characteristics of interdune surface, and airflow pattern.

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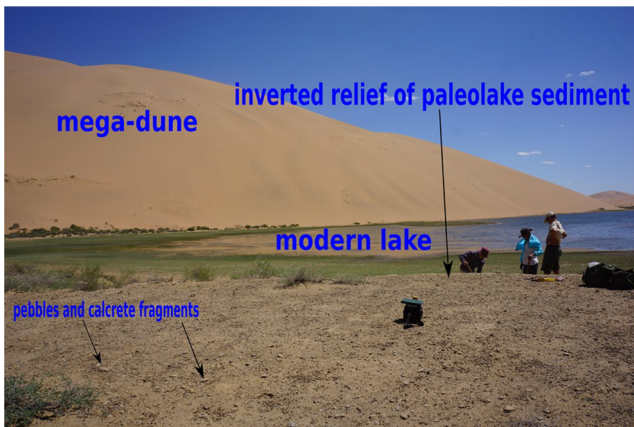


Fig. 1 A typical dune-lake landscape (Photograph by Si-Wen Liu)

For an individual megadune, the age of aeolian deposits commonly decreases with increasing height above the ground. The thermoluminescence and optically stimulated luminescence dating results indicated that megadunes began to form at 6.1×10^3 – 1.4×10^5 years BP at least and reached hundreds of meters high at 1.2×10^3 – 4.6×10^3 years BP (Yang et al. 2003; Bai et al. 2011; Liu et al. 2015). The short-lived isotopes have been introduced to date the lake sediments in the Badain Jaran Desert (Appleby 2008; Liu et al. 2012). The average sedimentation rates of Yindeertu ($39^\circ 51' 9''$ N, $102^\circ 26' 42''$ E) and Shuanghaizi ($39^\circ 43' 37''$ N, $102^\circ 19' 33''$ E) lake were derived to be 0.16cm/yr and 0.21cm/yr , respectively. For the lakes with the deposition depth < 1.5 m in the southeastern margin of the desert, their ages can be estimated to be less than 1000 years if a suitable value 0.18cm/year of the average sedimentation rate is selected. As a result, the time scales for the formations of megadunes and lakes are $10^3 - 10^5$ and 10^2 years BP. We can conclude that megadunes are generally older than the adjacent lakes based on the known chronological data of aeolian and lacustrine deposits.

Figure 1 gives a typical dune-lake landscape where the bare surface of lake shore is covered by coarse sand grains and pebbles ranging 1–5 mm in size or calcrete fragments, and the remanent former lacustrine deposits in the lake basin display as an inverted relief. The surface layer of interdune area is commonly characterized by coarser and poorly sorted sediments throughout the desert. Such a grain size composition, greatly different from that of megadunes, clearly tells us that the interdune area is subject to wind erosion. In fact, the interdune surface is not always flat. Blowouts changing from several to dozens of centimeters in depth can be seen everywhere. They can even develop on a preexisting lacustrine deposit tightly surrounded by dunes. Two primary types of blowouts are saucer and trough. The basins of elongated lakes are nothing but the large trough blowouts with steeper lateral slopes.

Generally speaking, the flow pattern and velocity field will change when a wind comes across an obstruction in all spacial scales from a small sand grain to a huge mountain. The dominant megadune types in the Badain Jaran Desert are the large compound barchanoid chains and the compound star dunes (Walker and Olsen 1987; Dong et al. 2004; Yang et al. 2011). The flow pattern around a star dune has been successfully revealed through field monitoring, wind tunnel experiment, and numerical simulation (Lancaster 1989; Zhang et al. 2000; Liu et al. 2011). As shown in Fig. 2, two permanent lakes (lake A and lake B) and a non-standard compound star dune with two larger primary arms (arm A and arm B) and two smaller subsidiary arms (arm C and arm D) coexist at Baoritaolegai ($39^\circ 36' 23.26''$ N, $102^\circ 29' 12.79''$ E). The crests of primary arms oriented NW-SE are sharp and sinuous. Following previous results (Zhang et al. 2000), the flow pattern near the ground is schematically drawn by small arrows in Fig. 2. Lake A and lake B are just located in the acceleration zones of the wind.

In consequence, the formation mechanism for elongated lake basins is that the compound star dune firstly strengthens the wind at its primary arm end, and then the corresponding interdune surfaces are being eroded to form trough blowouts until the water table is reached. Although the dynamic factor is wind, the shape and depth of lake should be controlled by dune if this mode is valid. We made a statistic of the morphometric parameters of megadunes and elongated lakes. The topographical data were freely downloaded from the satellite database of Google Earth. The values of peak height h and arm length s of megadunes, and length a and width b of elongated lake basins are listed in Table 1. For megadunes, there is a good linear relation between h and s ,

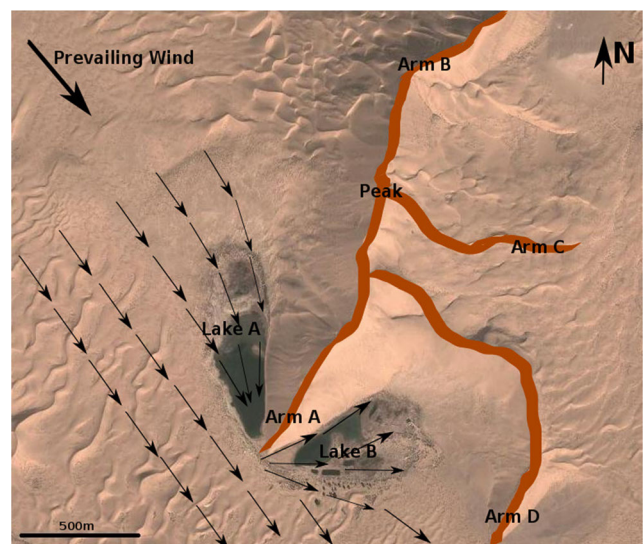


Fig. 2 The airflows in the zones of two elongated lakes are accelerated by a compound star dune at Baoritaolegai

Table 1 Geometric parameters of megadunes and basins of elongated lakes, h peak height, s arm length, a lake length, b lake width

No.	Location	h (m)	s (km)	a (m)	b (m)
1-a	(39° 33' 9.91" N, 102° 21' 36.20" E)	284	1.57	706	212
1-b	(39° 33' 9.91" N, 102° 21' 36.20" E)	284	1.57	800	253
2-a	(39° 33' 22.19" N, 102° 20' 24.44" E)	84	0.74	278	105
2-b	(39° 33' 22.19" N, 102° 20' 24.44" E)	84	0.74	684	285
3-a	(39° 33' 55.68" N, 102° 19' 39.14" E)	302	1.55	861	180
3-b	(39° 33' 55.68" N, 102° 19' 39.14" E)	302	1.55	920	170
4-a	(39° 34' 13.03" N, 102° 14' 30.11" E)	263	1.51	755	184
4-b	(39° 34' 13.03" N, 102° 14' 30.11" E)	263	1.51	584	168
5	(39° 34' 58.97" N, 102° 16' 38.35" E)	231	1.60	1575	466
6	(39° 35' 19.01" N, 102° 23' 10.64" E)	216	1.25	710	266
7	(39° 35' 58.88" N, 102° 28' 27.99" E)	145	0.98	580	248
8	(39° 36' 3.05" N, 102° 26' 2.95" E)	152	1.02	117	70
9	(39° 36' 9.32" N, 102° 25' 25.39" E)	150	0.98	181	71
10-a	(39° 36' 35.48" N, 102° 29' 9.00" E)	186	1.19	1258	477
10-b	(39° 36' 35.48" N, 102° 29' 9.00" E)	186	1.19	695	338

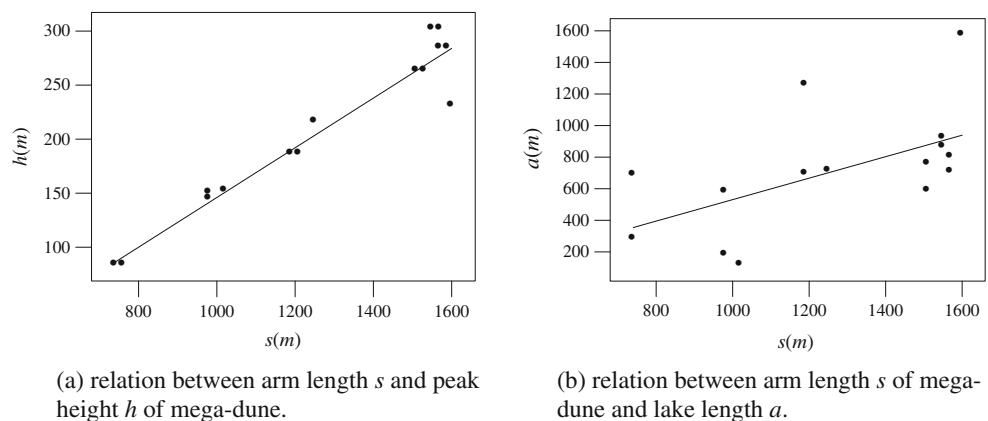
see Fig. 3a. So only one parameter, say arm length s , was chosen to represent the effect of dunes. Since two or more lakes with different spatial scales can occur near one star dune, the points in Fig. 3b look disperse. The positive correlation between a and s confirms that the mode proposed here can perfectly interpret the aeolian origin of elongated lake basins associated with compound star dunes.

As for the oval-shaped lakes distributed in the corridors of large compound barchanoid chains, it is uncertain whether the hypothesis of aeolian origin is suitable or not. The wind records of five locations in one summer showed that the resultant sand drift potentials on the surrounding dunes do not direct to the centric lake at Dashazao (39° 66' 6.30" N, 102° 8' 53.81" E) (Zhang et al. 2013). We also found that wind erosion is really occurring in the interdune corridors during a very recent field survey in August 2014. It is possible that the basins of oval-shaped lakes also are

blowouts. However, the maximum water depth of Nuertu lake (39° 46' 17.70" N, 102°27' 49.40" E) is about 15.9 m (Wu et al. 2014), and there is the continuous deposition of modern lake with the depth of 8.6 m at Western Nuertu lake (40° 1' 33.66" N, 101° 44' 12.67" E) (Guo et al. 2014). The global aeolian lakes in arid regions seldom have so large depth scales of water and deposition (Cohen 2003). Therefore, more works are required to determine the origin of this type of lake basins.

In summary, the origin of lake basins was investigated from the chronological, geomorphological, and aerodynamic viewpoints. It is shown that the megadunes are generally formed before the interdune lakes, the lake basins possess the typical characteristics of wind erosion, and the airflows in the zones of lake basins are accelerated by the megadunes. It is concluded that the elongated interdune lakes are of aeolian origin.

Fig. 3 Morphometric relations of megadunes and elongated lakes



(a) relation between arm length s and peak height h of mega-dune.

(b) relation between arm length s of mega-dune and lake length a .

Acknowledgments This research was supported by Natural Science Foundation of China projects (Nos. 41571006, 41290252, 41272191), the cooperation project of Hebei Academy of Sciences and the Chinese Academy of Sciences (No. 15001019), and Key Laboratory of Salt Lake Resources and Chemistry project (No. KLSLRC-KF-13-DX-3).

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