Postprint: Morphological Characteristics and Genesis of the Bailingdui Yardang Landforms in the Lop Nur Region, Xinjiang

Authors: Lin Guiquan, Lin Yongchong

Date: 2021-10-10T00:00:00+00:00

Abstract

Yardang landforms represent a weak link in aeolian geomorphology research, and significant breakthroughs from morphological description to quantitative investigation have yet to emerge, necessitating innovative studies integrated with new technological approaches. The Lop Nur region of Xinjiang is characterized by extreme aridity and intense wind erosion, with widely distributed yardangs developed during different periods, making it an ideal area for studying yardang morphological characteristics. Using Google Earth, morphological parameters including length and width were measured and analyzed for 1,000 individual yardangs across four sub-regions of the Bailongdui yardangs along the prevailing wind direction in the Lop Nur region of Xinjiang. The results indicate that while certain regional variations exist in morphological parameters such as length, width, and length-to-width ratio (R value) among the four sub-regions of the Bailongdui yardangs, they are generally similar overall. The mean yardang length is 63.42 m, with 65% concentrated between 25.00–75.00 m; the mean width is 13.97 m, with 80% distributed between 5.00–20.00 m; and the mean R value is 4.37, with 80% concentrated between 2.00–6.00. The mean R value of the Bailongdui yardangs is generally close to the R value of yardangs developed under specific wind field conditions (R=4.00). Therefore, regional wind erosion has shaped a relatively stable yardang morphology, which is essentially similar to that formed by wind erosion under specific conditions. Although wind dynamics constitute the primary shaping force for Bailongdui yardang morphology, factors such as stratigraphic lithology, surface salt crust, and extremely arid climate also exert important influences. The morphological variation characteristics of the Bailongdui yardangs can provide regional insights for a deeper understanding of yardang landform development processes.

Full Text

Preamble

Yardang landforms represent a relatively weak link in the study of aeolian geomorphology, with research progressing slowly from morphological description to quantitative analysis. Innovative investigations employing new technological approaches are urgently needed. The Lop Nur region of Xinjiang experiences an extremely arid climate with intense wind erosion, hosting extensively developed yardangs from different periods that make it an ideal area for studying yardang morphology. Using Google Earth imagery, we measured and analyzed morphological parameters including length and width for 1,000 individual yardangs in the Bailongdui Yardang area of Lop Nur along the prevailing wind direction. The results demonstrate that while certain regional variations exist in morphological parameters such as length, width, and length-width ratio (R value) across four subregions, the overall characteristics are similar. The yardangs exhibit a mean length of 63.42 m, with the majority falling between 25.00–75.00 m; the mean width is 13.97 m, concentrated in the 5.00–20.00 m range. The mean R value of Bailongdui Yardangs is approximately 4.00, with 80% distributed between 2.00–6.00, closely approaching the R value of yardangs developed under specific wind field conditions (R = 4.00). Therefore, regional wind erosion has shaped a relatively stable yardang morphology that essentially approximates the form created under particular wind erosion conditions. Although wind dynamics constitute the primary shaping force for Bailongdui Yardang morphology, factors such as stratigraphic lithology, surface salt crust, and extreme arid climate also exert important influences. The morphological variation characteristics of Bailongdui Yardangs provide regional insights for deepening our understanding of yardang development processes.

Keywords: yardang; morphology; genesis; Lop Nur

Yardangs are aeolian erosion landforms typically distributed along desert margins in arid regions with scarce precipitation, flat and exposed surfaces, and intense sand transport activity—conditions favorable for yardang development. China represents a primary distribution area for yardangs, particularly in Lop Nur and the Hami Basin of Xinjiang, as well as the Qaidam Basin, where yardang landforms are extensively developed. Understanding of yardangs has a long history, with early work focusing on morphological description, classifying them into forms such as long-ridge-shaped and streamlined configurations. Quantitative description primarily involves analyzing morphological parameters including length, width, height, and length-width ratio (R value), which varies significantly across different regions, ranging from 1.00 to 40.00. Due to the diversity and complexity of yardang morphology, fundamental morphological parameters reflecting the essential attributes of yardang landforms have yet to be extracted.

Wind tunnel experiments demonstrate that homogeneous rock layers under specific wind field conditions develop relatively stable yardang morphology (R =

4.00), where airflow resistance is minimized and no significant lee-side vortices appear. Although long-term wind erosion reduces individual yardang size, their morphology remains unchanged, representing a stable yardang form. However, because yardang formation and development involve multiple environmental factors including wind force, stratigraphic lithology, climate, surface conditions, and tectonic movement, variations in the degree and manner of each factor' s influence result in morphological differences across regions. Consequently, studying yardang morphology, stratigraphic lithology, and climatic characteristics in different global regions contributes to further understanding of yardang genesis, development processes, and erosion mechanisms.

2 Data and Methods

2.1 Study Area

The Bailongdui Yardang is distributed in the Lop Nur region of eastern Tarim Basin, Xinjiang (40°26 24 -41°02 24 N, 90°56 24 -91°34 12 E). Lop Nur experiences a warm temperate continental extreme arid desert climate with a mean annual temperature of 11.8°C, extreme maximum temperature of 70.0°C, and extreme minimum temperature of -10.7°C. The region is extremely arid with annual precipitation below 20 mm and potential evaporation reaching 3,000 mm. Situated between the eastern Tianshan Mountains and the Altai Mountains, the area is influenced by the Mongolian-Siberian High, resulting in prevailing stable northeasterly winds near the surface. Strong eastward airflow occurs throughout the year, particularly in spring and summer, with mean wind speeds exceeding 2.5 $m \cdot s^{-1}$ and extreme maximum wind speeds of 40 $m \cdot s^{-1}$. The region experiences 18.6 days of strong winds annually, with frequent sand transport activity. This intense erosion has led to extensive yardang development across Lop Nur, including the Bailongdui, Longcheng, Sanlongsha, and Loulan area yardangs.

The Lop Nur region began subsiding at the end of the Triassic and became the convergence center of the Tarim Basin during the Pliocene, now covered by massive lacustrine-fluvial strata. Bailongdui Yardang developed on gray-white mudstone and sandstone from these lacustrine-fluvial sediments, which contain substantial gypsum and other rock salts. The Bailongdui Yardang area extends approximately 80 km in length and 20 km in width, with individual yardangs being relatively large (300–400 m long) and mostly distributed independently. Yardang bodies extend in a NE-SW direction, consistent with the prevailing wind direction, featuring steep windward slopes and gentle leeward slopes.

2.2 Data Sources and Measurement Methods

This study primarily utilized Google Earth imagery, which achieves 0.3 m resolution in the Bailongdui Yardang distribution area. Given the large size of individual Bailongdui Yardangs, Google Earth imagery provides sufficient resolution for measuring morphological parameters such as length and width. Additionally, most Bailongdui Yardangs exist in a completely separated state, facilitating

measurement of individual yardang dimensions. We selected four subregions along the prevailing wind direction to measure yardang morphological parameters [Figure 1: see original paper]. Each subregion comprised 250 yardangs, totaling 1,000 measured individuals. All measured yardangs were in an independent distribution state [Figure 2: see original paper]. We measured length, width, and orientation for each yardang [Figure 3: see original paper], with length defined as the maximum distance along the long axis and width as the maximum distance perpendicular to the long axis.

3 Results

3.1 Morphological Characteristics of Bailongdui Yardangs

The 1,000 yardangs measured across four subregions exhibit the characteristic of developing along the prevailing wind direction. Regional yardangs extend approximately NE 40°–50°, with each subregion showing distinct morphological features [Figure 2: see original paper]. In Subregion 1, yardang lengths range from 20.81–237.90 m (mean 97.11 m), widths from 5.00–30.00 m (mean 11.17 m), and R values from 1.10–16.70 (mean 5.35). In Subregion 2, lengths range from 8.92–135.48 m (mean 35.52 m), widths from 4.31–27.00 m (mean 10.19 m), and R values from 1.08–10.74 (mean 4.31). In Subregion 3, lengths range from 10.65–181.30 m (mean 56.28 m), widths from 5.00–20.00 m (mean 12.77 m), and R values from 2.03–10.00 (mean 4.64). In Subregion 4, lengths range from 5.35–388.91 m (mean 64.75 m), widths from 2.65–37.11 m (mean 15.73 m), and R values from 2.65–28.74 (mean 4.31).

Overall, Bailongdui Yardangs present relatively consistent morphological characteristics, with individuals extending in a NE-SW direction. Length, width, and R values are generally uniform, though some subregional differences exist [Figure 4: see original paper]. For the entire dataset: lengths range from 5.35–388.91 m (mean 63.42 m), with 65% concentrated between 25.00–75.00 m; widths range from 2.65–37.11 m (mean 13.97 m), with 80% between 5.00–20.00 m; R values range from 1.08–16.70 (mean 4.37), with 80% between 2.00–6.00. Compared with other yardangs in inland Asia, Bailongdui Yardangs are relatively large, similar in size to those in the Mangya, Dachaidan, and Golmud areas of the Qaidam Basin, larger than those in the lower reaches of the Kongque River and the Qiangqike Valley in Lop Nur, but smaller than those in the Lenghu and Chaerhan Salt Lake areas of the Qaidam Basin [15–16,18,22].

Global comparisons reveal that despite all being distributed in extremely arid regions, yardang morphology varies considerably worldwide, including long-ridge-shaped, streamlined, and boat-capsized forms, with R values ranging from 1.00–40.00. Most of these values differ from those of Bailongdui Yardangs . Wind tunnel experiments indicate that stable yardang morphology (R 4.00) forms under specific wind field conditions. This study selected independently distributed Bailongdui Yardangs for measurement, and overall, R values increase significantly with yardang length ($R^2 = 0.5641$) [Figure 5: see original paper], indicating that

longer yardangs become more elongated. However, no significant relationship exists between width and R value ($R^2 = 0.0400$) [Figure 6: see original paper].

3.2 Genesis Analysis of Bailongdui Yardangs

Yardangs primarily form through aeolian erosion, with wind serving as the main developmental force, though other factors may influence their evolution, including regional wind field characteristics (intensity, frequency, and direction), stratigraphic lithology, surface conditions (exposure and vegetation), climatic conditions (aridity), and regional tectonics. Among these, erosive force and yardang stratigraphic composition constitute the two primary factors. These elements collectively shape yardang morphology, though their degree and mode of action vary across regions, resulting in certain morphological differences.

Bailongdui possesses the fundamental conditions for yardang development. First, influenced by the Mongolian-Siberian High, the study area experiences prevailing northeasterly winds, with strong near-surface eastward airflow throughout the year, particularly in spring and summer, providing powerful wind erosion dynamics for yardang formation. Second, the entire study area consists primarily of lacustrine-fluvial deposits with broad lateral stratigraphic consistency, representing the common yardang-developing strata in the arid central Asian region. Third, Bailongdui Yardang lies in an extremely arid warm temperate desert climate zone with extremely scarce precipitation, intense evaporation, and complete absence of vegetation, creating ideal conditions for yardang development.

Field investigations and Google Earth image analysis reveal that yardangs in all four Bailongdui subregions exhibit consistent long-axis orientations in the NE-SW direction. The orientation of yardangs in this region is similar to those in other Lop Nur areas such as the lower Kongque River and Longcheng, consistent with the near-surface prevailing wind direction. Bailongdui Yardangs display typical aeolian erosion morphological characteristics: steep windward slopes, relatively gentle leeward slopes, and long axes extending along the prevailing wind direction [Figure 2: see original paper]. These yardangs maintain 基本一致的基本形态 regardless of individual size, approximating the stable yardang morphology formed under specific wind erosion conditions (R 4.00), indicating their formation through aeolian processes with wind erosion as the primary force.

Although wind dynamics represent the main erosive force for Bailongdui Yardang development and our measured yardangs are essentially in completely independent states (suggesting they may have experienced more complete development), certain differences exist between the measured R values (means of 4.31–5.35) and the stable yardang morphology under specific wind field conditions ($R = 4.00$). This indicates that other factors likely play a role in Bailongdui Yardang development. Field surveys reveal that gypsum and other rock salts are widespread in Bailongdui Yardang strata. In dry environments,

these crystalline salts are extremely hard and effectively resist wind erosion. Additionally, the yardang surface is bare and unvegetated, with a widespread hard salt crust that forms through surface processes: intense wind erosion causes salt-bearing rock layers to collapse and disperse around yardang bases; these salts dissolve under minimal precipitation and rapidly recrystallize at the surface; furthermore, extensive underground brine exists in the study area, and under high temperatures, intense evaporation transports brine to the surface through capillary action, crystallizing substantial salt and forming a crust. This salt crust creates a hard protective layer at yardang toes and surfaces, resisting wind erosion and influencing morphological development.

In summary, Bailongdui Yardangs primarily formed through aeolian erosion, with other factors such as stratigraphic lithology, surface salt crust, and extreme arid climate also influencing morphological development to varying degrees.

4 Conclusions

This study measured and analyzed length, width, and length-width ratio (R value) morphological parameters of 1,000 yardang individuals across four subregions in the Bailongdui area of Lop Nur using Google Earth imagery, yielding the following conclusions:

1) Bailongdui Yardang individuals are relatively large, with length, width, and R value morphological parameters being generally similar across the four subregions. The mean yardang length is 63.42 m, concentrated in the 25.00–75.00 m range; the mean width is 13.97 m, concentrated in the 5.00–20.00 m range; and the mean R value is 4.37, concentrated in the 2.00–6.00 range. A significant correlation exists between length and width ($R^2 = 0.5425$). As yardang length increases, morphology becomes more elongated.

2) Although certain intraregional morphological differences exist in Bailongdui Yardangs, wind erosion has generally shaped a relatively stable yardang morphology that approximates the form created under specific wind erosion conditions.

3) Bailongdui Yardang development is influenced not only by wind dynamics but also by other factors including stratigraphic lithology, surface salt crust, and regional extreme arid climate, all of which affect yardang morphological development.

References

[1] Goudie A S. Mega yardangs: A global analysis[J]. Geography Compass, 2007, 1(1): 65-81. [2] Ward A W. Yardangs on Mars: Evidence of recent wind erosion[J]. Journal of Geophysical Research, 1979, 84(B14): 8147-8166. [3] Zimbelman J R, Griffin L J. HiRISE images of yardangs and sinuous ridges in the lower member of the Medusae Fossae Formation, Mars[J]. Icarus, 2010, 205(1):

198-210. [4] Trego K D. Yardang identification in Magellan imagery of Venus[J]. Earth, Moon, and Planets, 1992, 58(3): 289-290. [5] Ding Z J, Zhao J N, Wang J, et al. Yardangs on earth and implications to Mars: A review[J]. Geomorphology, 2020, 364: 107230, doi: 10.1016/j.geomorph.2020.107230. [6] Ban Gu, Yan Shigu. History of the Han Dynasty[M]. Beijing: Zhonghua Book Company, 2000: 62-64. [7] Gabriel A. The southern Lut and Iranian Baluchistan[J]. Geographical Journal, 1938, 92: 193-210. [8] Bagnold R A. An expedition to the GilfKebir and Uweinat, 1938[J]. Geographical Journal, 1939, 93: 281-313. [9] Huang Wenbi. Archaeology of Lop Nur, Xinjiang[M]. Beijing: Peking University Press, 1948: 75-77. [10] Masibroda V Y. The aeolian relief of the Turfan Depression and the western Bei Shanasa reflection of local atmospheric circulation[J]. Izvestia Akad Nauk Serya Geograf, 1952(2): 25-35. [11] Hedin S. Central Asia and Tibet[M]. New York: Scribners, 1903. [12] Stapff F M. Karte des unteren Khuisebtals[J]. Petermanns Geographische Mitteilungen, 1887, 33: 202-214. [13] Walther J. Die denudation in der Wùste undihre geologische Bedeutung[J]. Abhandlungen Sachsische Gesellschaft Wissenshaft, 1891, 16: 345-570. [14] Ward A W, Greeley R. Evolution of the yardangs at Rogers Lake, California[J]. Bulletin of Geological Society of America, 1984, 95: 829-837. [15] Liu Hongying, Dong Zhibao. Morphological characteristics and genetic analysis of yardangs in Qaidam Basin, China[J]. Journal of Desert Research, 2019, 39(3): 214-220. [16] Xia Xuncheng. Climatic characteristics of Lop Nur area[C]//Lop Nur Scientific Expedition Team of Xinjiang Branch, Chinese Academy of Sciences. Scientific Investigation and Study of Lop Nur. Beijing: Science Press, 1987: 118-131. [17] Ma Chunmei, Wang Fubao, Cao Qiongying, et al. Climate and environment before and after medieval warm period in Lop Nur area, Xinjiang[J]. Chinese Science Bulletin, 2008, 53(16): 1942-1952. [18] Song Haoze. Study of morphological parameters of yardangs and their changes[D]. Beijing: University of Chinese Academy of Science, 2019. [19] Gutierrz Elorza M, Desir G, Gutierrez Santolalla F. Yardangs in the semiarid central sector of the Ebro Depression (NE Spain)[J]. Geomorphology, 2002, 44: 155-170. [20] Lin Yongchong, Mu Guijin, Qin Xiaoguang, et al. Erosion characteristics of yardangs at Loulan Area, Xinjiang, China[J]. Journal of Desert Research, 2017, 37(1): 33-39. [21] Lin Yongchong, Mu Guijin, Qin Xiaoguang, et al. Weathering impact on the development of yardang landforms in Loulan region[J]. Arid Land Geography, 2018, 41(6): 1278-1284. [22] Mainguet M. Le Bourkou aspects dunmodele eolien[J]. Annales de Geographie, 1968, 77: 58-66. [23] McCauley J F, Grolier M J, Breed C S. Yardands[C]//Doehring D O. Geomorphology in Arid Regions. New York: State University of New York, 1977: 233-269. [24] Cooke R U, Warren A, Andrew S G. Desert geomorphology[M]. London: UCL Press, 1993. [25] Brookes I A. Geomorphic indicators of Holocene winds in Egypt western desert[J]. Geomorphology, 2003, 56(1/2): 155-156. [26] Laity J. Deserts and desert environments[M]. Chichester: Wiley Blackwell, 2008. [27] Laity J. Landforms of Aeolian erosion[C]//Abrahams A D, Parsons A J. Geomorphology of Desert Environments. London: Chapman and Hall, 1994. [28] Breed C S, McCauley J F, Whiteny M I, et al. Wind erosion in drylands[C]//Thomas D S C. Arid Zone Geomorphology: Process, Form and Changes in Drylands. Chich-

ester: John Wiley, 1997: 437-464. [29] Halimov M, Fezer F. 8 yardangs types in Central Asia[J]. Zeitschrift Fur Geomorphologie, 1989, 33(2): 205-217. [30] Goudie A S, Stockes S, Cook J, et al. Yardang landforms from Kharga Oasis, south western Egypt[J]. Zeitschrift Fur Geomorphologie, 1999, 116(S1): 97-112. [31] Kate R, Odontuya E. Yardangs and dome dunes northeast of Tavan Har, Gobi, Mongolia[J]. GSA Abstracts with Programs, 2004, 36(4): 33-36. [32] Dong Z B, Lü P, Lu J F, et al. Geomorphology and origin of Yardangs in the Kumtagh Desert, northwest China[J]. Geomorphology, 2012, 139-140, 145-154. [33] Yang Yi, Wang Rujian, Liu Jian, et al. Regional dust activity history during the past 45 ka reflected by sensitive grain size components in Lop Nur, Xinjiang[J]. Earth Science Frontiers, 2015, 22(5): 247-258. [34] Xia Xuncheng. Summary of scientific investigation in Lop Nur, Xinjiang[J]. Arid Zone Research, 1985, 2(1): 4-8. [35] Niu Qinghe, Qu Jianjun, Li Xiaoze, et al. Review and prospect of yardang landforms research[J]. Advances in Earth Science, 2011, 26(5): 516-527. [36] Li Jiyan, Dong Zhibao. Morphological parameters of yardangs in southeastern Qaidam Basin[J]. Bulletin of Soil and Water Conservation, 2011, 31(4): 122-125. [37] Song Haoze, Mu Guijin, Lin Yongchong, et al. Influence of common pedestal of Yardangs on the morphological measurement[J]. Arid Land Geography, 2020, 43(1): 48-55. [38] Hu Chengqing. Yardang geometries and control factors in the Qaidam based on multi source remote sensing images[D]. Hangzhou: Zhejiang University, 2017: 9-10. [39] Breed C S, McCauley J F, Whitney M I. Wind erosion forms[C]//Thomas D S G. Arid Zone Geomorphology. London: Belhaven Press, 1989: 284-307. [40] Bailey J E, Self S, Wooller L K, et al. Discrimination of fluvial and eolian features on large ignimbrite sheets around La Pacana Caldera, Chile, using Landsat and SRTM dervied DEM[J]. Remote Sensing of Environment, 2007, 108(1): 24-41.

Note: Figure translations are in progress. See original paper for figures.