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Geomorphology of the megadunes in the Badain Jaran Desert

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Abstract

The Badain Jaran Desert features the highest megadunes on Earth, and a unique megadune-lake alternation landscape. Based on field survey and interpretation of aerial photographs, this paper examines the general characteristics of the Badain Jaran megadunes, their morphometry and formation, as well as the formation of megadune-lake alternation landscape. It is suggested that the megadunes in the Badain Jaran Desert were developed in a low wind energy environment. The compound transverse megadunes, the dominant megadune type, have a similar wind regime to barchanoid dunes, and the compound star megadunes, which occur near the mountains, have a similar wind regime to star dunes. Similar to the barchanoid dunes, the height, base area and spacing of the compound transverse megadunes show reasonably good inter-correlation. The base area of the megadunes and the area of the leeward interdune lake basins are also inter-correlated. The alignment and spacing of the Badain Jaran megadunes implies that wind is the most important factor in their development; the morphology underneath the megadunes does not determine the general pattern of the megadunes as previously suggested. Repetitions of dune fixation and reactivation in the development process played an important role in increasing the megadunes' height, hence their size. The interdune lakes in the megadune area were mainly formed by talus springs and are only partly fed by atmospheric precipitation.

Keywords: Badain Jaran Desert; Megadunes; Morphometry; Dune formation

1. Introduction

The Badain Jaran Desert, part of the Alashan Desert, is the second largest dunefield in China. It features the highest megadunes on Earth (Breed et al., 1979; Zhu et al., 1980), beautiful interdune lakes and mysterious booming sands. Though it has been inhabited by Mongolian herdsmen for a long time, the Badain Jaran Desert did not receive much attention until the 1980s.

The Badian Jaran Desert is a little studied area in northwest China (Wang, 1990). Early work in the desert was conducted as part of expeditions to the Alashan Desert, such as those led by Scandinavian geologists (Hörner, 1936). They mainly surveyed the physiographic formations and the archeological relics in the marginal areas of the desert. Shortly after the reunification of China, several expeditions were organized to investigate the natural resources in the Alashan Desert. In 1957, the Chinese–Soviet Central Yellow River Complex Expedition studied the aeolian processes in the Alashan Desert, and in 1958, the Qinghai-Gansu Expedition of the Chinese Academy of Sciences explored the Alashan Desert. In 1959,

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Chinese and Soviet investigators began a 3-year Complex Sand Expedition in the region. The expeditions in 1950s and 1960s were mainly concerned with the natural conditions, utilization of the natural resources. Survey results on the vegetation, water resources and aeolian landforms were reported by Li (1962), Lou (1962), Yu (1962), Sun and Sun (1964) and Tan (1964). Several ideas were proposed on the formation of the megadunes in some local areas (Lou, 1962; Sun and Sun, 1964; Tan, 1964). Lou (1962) suggested two possible reasons why the megadunes were created. The first is that the pattern of the megadunes is controlled by underlying humps that were covered by drifting sand. The second is that the megadunes developed from the sand deposits that accumulated when the drifting sand was obstructed by local stone humping. Sun and Sun (1964) thought the megadunes were related to the morphology of the underlying formation that had been folded by tectonic movements. Tan (1964) pointed out that lacustrine deposits of the early Pleistocene occur underneath the megadunes. Old dunes, which were fixed by calcareous cementation, once existed over the lacustrine deposits. Drifting sand covered these old fixed dunes, resulting in the current megadunes.

After the 1970s, remote sensing technology was employed to recognize the general characteristics of the Badain Jaran Desert (Breed et al., 1979; Walker et al., 1987; Zhu et al., 1992; Guo et al., 2000). Breed et al. (1979) made a detailed report of the dune type, height, arrangement and spacing and their relation to the local wind regime based on the interpretation of landsat imagery. Chinese and German scientists made a comprehensive survey of the Badain Jaran Desert in 1988 and compiled a 1:500,000 map of the aeolian landforms, based on landsat TM imagery (Zhu et al., 1992). The map shows the types, distribution of the aeolian landforms, as well as the alignment, height and spacing of the megadunes.

The Badain Jaran Desert witnessed increasing interest from scientists in different fields after the 1990s. Several researchers studied the formation and geological evolution of the desert (Dong et al., 1995; Jakel, 1996; Yang, 2000; Yan et al., 2001). Dong et al. (1995) studied the climatic changes at the southern fringe of the Badain Jaran Desert since the Pleistocene. Jakel (1996) studied the origin and development of the desert. Yang (2000) reconstructed the change of landscape and precipitation in the desert over the last 30,000 years by dating the deposits in the megadunes. Other researchers studied the characteristics and formation of the sand dunes (Wang, 1990; Lu and Guo, 1995; Yang and Jiang, 1998; Yang et al., 1999; Yan et al., 2001). Wang (1990) proposed that the Badain Jaran Desert has been developing since the early Mid-Pleistocene. Due to climatic changes (glaciation–interglaciation), the sand dunes were subjected to alternations of fixation and reactivation, which ultimately resulted into the formation of megadunes. Yang and Jiang (1998), by measuring the morphmetric parameters of dunes, concluded that dunes in the Badain Jaran Desert became higher, more complex and stable from the northwest to the southeast. Yan et al. (2001) studied the megadunes by means of TL dating method and bedding occurrence of the dunes. They concluded that the formation and growth of megadunes in the Badain Jaran Desert were dependent on the sand supply, wind regime, underlying morphology and the shrub vegetation. Recently, Qu et al. (in press) studied the fractal behavior of the Badain Jaran megadunes. They found that the compound star megadunes have greater fractal dimension than star dunes. Hofmann (1996) studied the limnology and geochemistry of the lakes in the desert. Guo et al. (2000) detected the old drainage system across the Badain Jaran Desert that existed between the mid-Tertiary and pre-early mid-Pleistocene using the spaceborne radar images.

Megadunes are the most typical landforms in the Badain Jaran Desert. However, their formation, especially the formation of the megadune-lake alternations, is open to argument. Based on a field survey and interpretation of aerial photographs, this paper examines the general characteristics of the Badain Jaran megadunes, their morphometry and formation, as well as the formation of megadune-lake alternation landscape.

2. Physiographical setting

The Badain Jaran Desert lies in the northwest of the Alashan Highland in western Inner Mongolia of China, between 39° 20′ N and 42°N, and 99° 48′ E and 104° 14′ E (Yang, 2000), covering an area of 49,000 km^2 (Yan et al., 2001). The desert is bounded to the south by the Heli Mountains, the Beidai Mountains

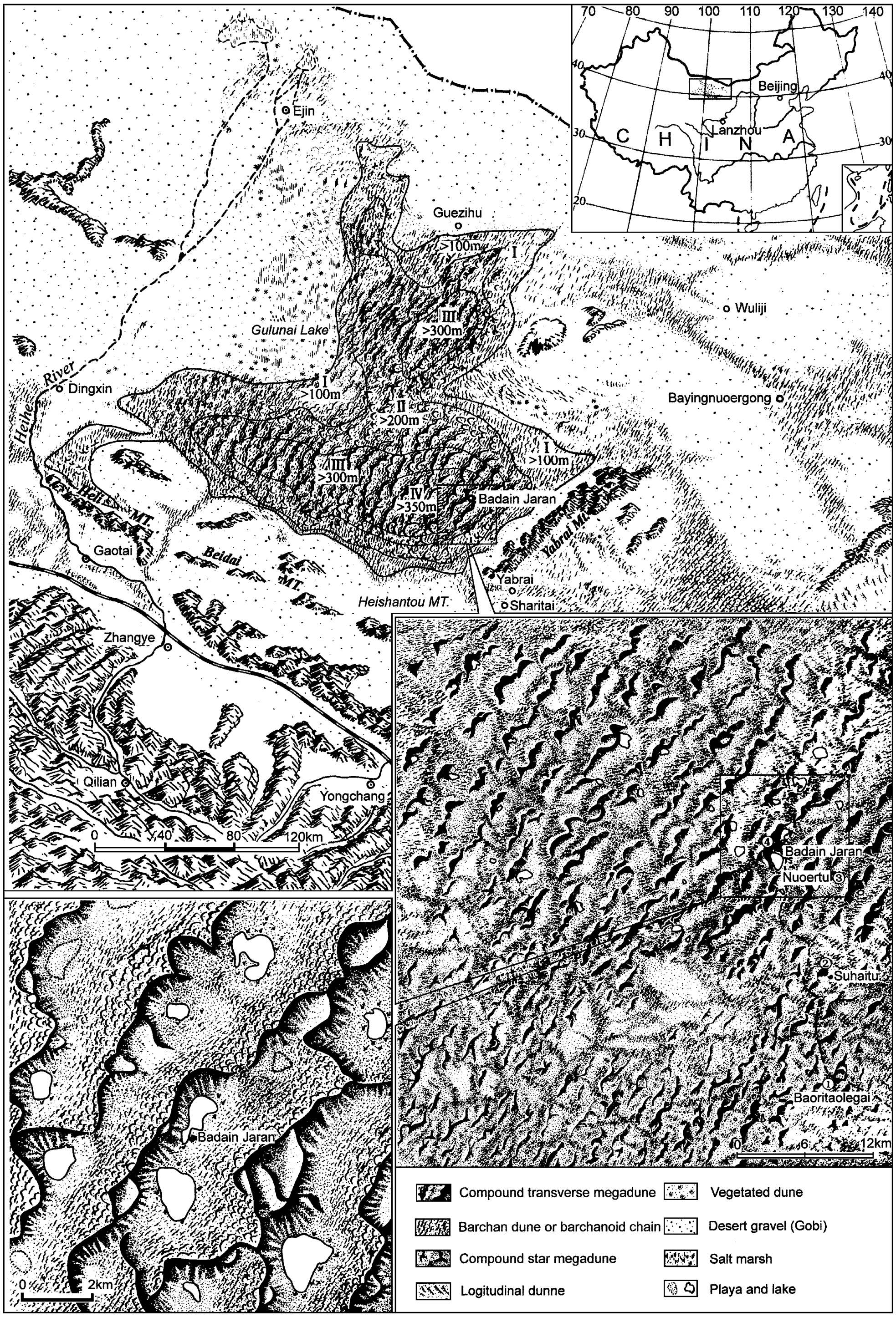

Fig. 1. Map of aeolian landforms in the Badain Jaran Desert.

and the Heishantou Mountains that separate it from the gobi of the Hexi Corridor. To the southeast, it is bounded by the Yabrai Mountains, which separate it from the Tengger Desert. To the west, it stretches down to the low and flat area of Gulunai grassland. To the north, it is bounded by the Guezihu wetland that merges with the black gobi and the plains of Mongolia (Fig. 1). Its elevation gradually decreases from approximately 1800 m in the southeast to 1000 m in the northwest. The Heihe River to the west is the only river near the desert.

The climate of the Badain Jaran Desert is of extreme continental type, with cold winters. The mean annual precipitation is less than 90 mm, mainly falling from June through August and decreasing from the southeast to the northwest (Fig. 2A). The annual potential evaporation is over 2500 mm, increasing from the south to north (Fig. 2B). The mean annual air temperature ranges from 9.5 to 10.3 °C, increasing from the south to the north as the elevation decreases (Fig. 2C). The mean annual wind speed ranges from 2.8 to 4.6 m s^{-1}, increasing from the south to north, with the strongest winds in April and May (Fig. 2D).

Migrating dunes occupy over 80% of the Badain Jaran's total area. The primary dune types include vegetated dunes, barchan dunes, barchanoid chains and megadunes. The vegetated dunes occur near the edges of the desert generally and are less than 2 m in height. Towards the center of the desert, the vegetated dunes are gradually replaced by barchan dunes. The barchan dunes occur abundantly in the southwest (near Dingxin), in the east and southeast (near Yabrai Mountain).The barchan dunes typically are 2–4 m high; their windward slopes, which are up-convex in longitudinal profile, range from 5° to 20°. The slipfaces are oriented towards the SE (100° to 150°). Barchanoid chains mainly occur to the west of Guezihu and north of Gulunai. They are usually 5 to 20 m high and 50 to 300 m wide and extend 1 to 3 km, sometimes 5 km. Similar to the barchan dunes, the

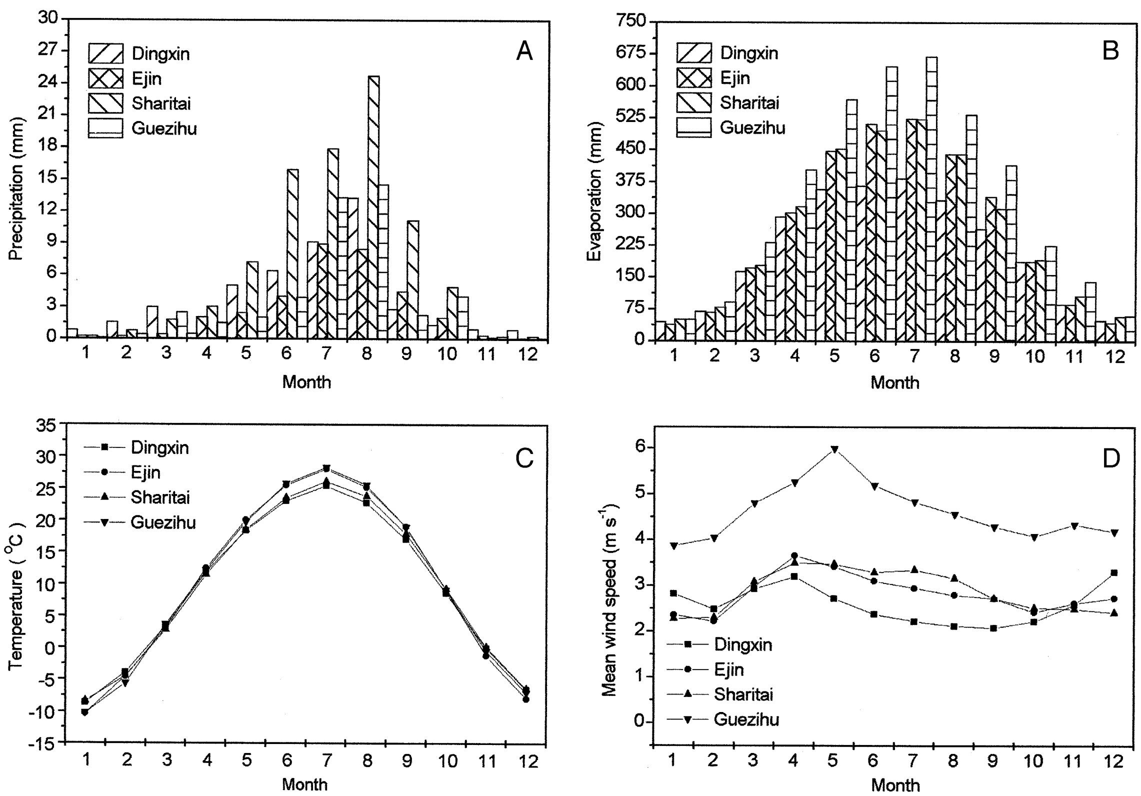

Fig. 2. The climatic elements around the Badain Jaran Desert.

barchanoid chains are oriented towards SE (100° to 150°). Star dunes appear in the south and east, near the mountains where the wind direction is complex. Linear dunes occur between barchanoid chains in the west. The majority of the desert is covered by megadunes, the dunes over 100 m high, which will be treated below.

3. Sand drift potential (*DP*)

The surface wind circulation over the Badain Jaran Desert is controlled primarily by the central Asiatic high-pressure cell in the winter and the thermal low-pressure cell that develops over the Indian subcontinent in the summer. During the winter, subsidence from the central Asiatic high tends to produce northerly to northwesterly winds across the deserts. During the spring the central Asiatic high weakens, its center shifts 10° westward, and a thermal low begins to develop over the Indian subcontinent. At this time, the Badain Jaran Desert lies in a zone between the high- and low-pressure cells, and also during this time, the highest drift potentials occur. In summer, low pressure dominates much of Asia, and the wind in the desert becomes weaker and more directionally unstable (Breed et al., 1979).

Sand drift potential (DP) was estimated using the method proposed by Fryberger (1979). Fig. 3 shows drift potentials based on meteorological data from four sites surrounding the Badain Jaran Desert. The available wind data for calculating DP for Dingxin, Ejin, Sharitai and Guezihu are from 1997 to 2001, 1996 to 2001, 1990 to 2001 and 1998 to 2001, respectively. The DP, resultant drift potentials (RDP), directional factor (RDP/DP) and resultant drift direction (RDD) in the northern site (Guezihu) are very different from the other three sites. We are not sure what makes the differences. It is possibly because that Guezihu is located in a corridor between mountains to the north and duefields to the south. The prevailing wind direction is parallel to the corridor. Except at Guezihu where

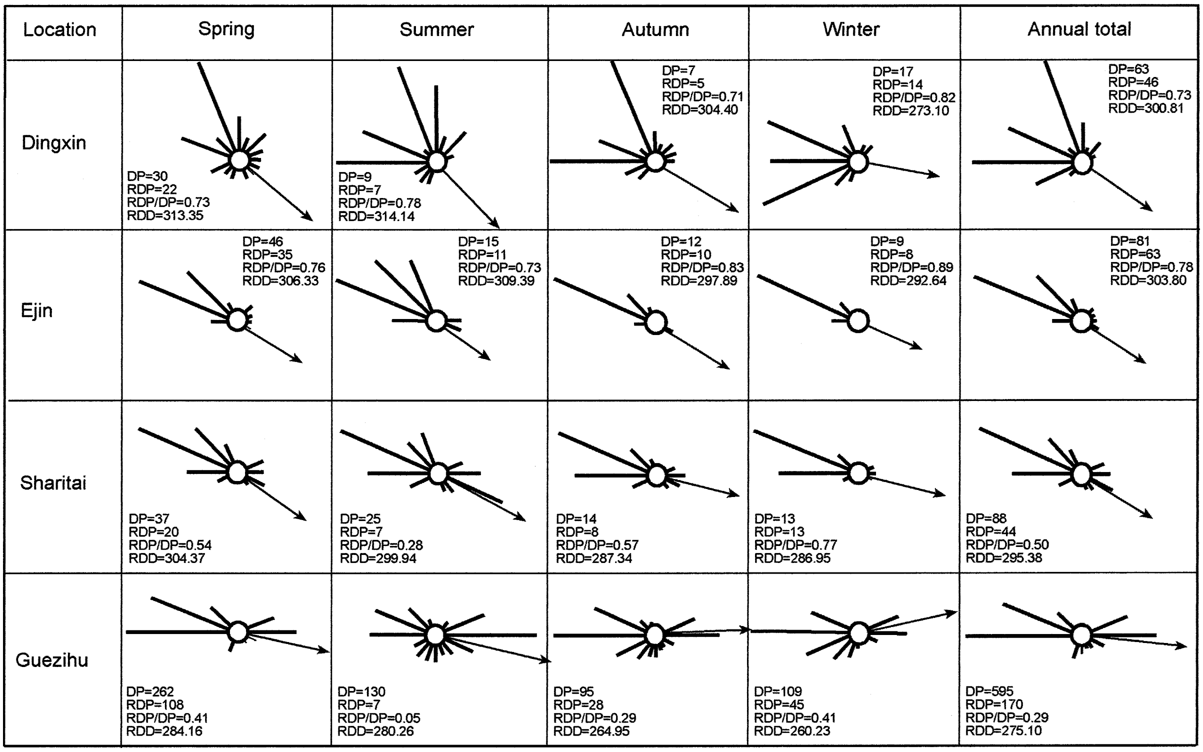

Fig. 3. The sand drift potential in the Badain Jaran Desert (the wind velocity is in knot).

DP is very high (595 VU), the Badain Jaran Desert generally has low wind energy environments, the annual DP ranging from 63 to 88 VU. Spring has the greatest DP, followed by the summer. Autumn has the lowest DP. The resultant drift directions are generally towards the southeast. The directional factor varies from 0.29 to 0.78. The summer usually has the lowest RDP/DP ratio, implying the most variable wind direction. The southwest site, Dingxin has an acute bimodal wind regime; the north site, Guezihu has an obtuse bimodal wind regime, while the northwest site, Ejin, and the southeast site, Sharitai have narrow or wide unimodal wind regimes.

4. Sediments constituting the megadunes

Sand supply provides the material basis for the megadunes in the Badain Jaran Desert. Petrov (1966) suggested that outcropping Cretaceous sandstone and extensive Quaternary and modern alluvial-lacustrine sediments of the Heihe drainage system are the sources of the sand in the Alashan Desert, including the Badain Jaran. Field investigations, interpretation of aerial photographs and drilling records indicate that there are extensive thick alluvial-lacustrine deposits around the Baidain Jaran Desert (Yan et al., 2001). In the west and northwest of the Baidain Jaran, the alluvial-lacustrine deposits date back to the Brunhes normal epoch (730,000 years BP) reached thickness of 300 m (Cai, 1986). Before the last glaciation, the Heihe alluvial fan reached the east of the Gulunai grassland and are extended 10–15 km south of the Guezihu wetland to form the Badain Jaran lake (Yan et al., 2001). Guo et al. (2000) suggested there used to be a drainage system crossing the Badain Jaran Desert from the mid-Tertiary to the early Pleistocene period. The ^{14}C dating indicated that the area of Juyan Hai, the terminal lake of the Heihe River, which is a playa at present, extended over 800 km^2 3000 years ago (Zhu, 1983).

The megadune sand is composed mainly of medium, fine and very fine sands (Table 1). Fine sand accounts for 50% to 92%, medium sand accounts for 3% to 23% and very fine sand accounts for 2.5% to 39%, varying with the sampling position on a megadune and location of the dune. The mean grain size generally ranges from 0.18 to 0.25 mm. The sand on the windward slope is the coarsest, followed by the slipfaces and interdunes. The finest sand occurs on the small dunes superimposed on a megadune. The grain size distribution of the sediments constituting the megadunes is similar to that of the alluvial-lacustrine deposits of the Gulunai grassland and the Guezihu wetland though the distribution curves of the later are more flat. This implies that the Heihe drainage system should be the main sand source for the Badain Jaran Desert. Of course, it is more reliable to detect the source area of the sand based on mineralogical composition. The Heihe River originates in the Qianlian Mountains, with a total length of 821 km and a watershed area of 128,000 km^2. In the lower reach, the Heihe River forms a fluvial fan of about 31,000 km^2. (Sun and Zeng, 1997). At present, it transports about 600 million tons of sediments a year to the lower reach. In humid periods in the past, when the water supply was greater, the flooding area and the sediment output in the lower reach were much greater. For example, Yang (2000) found four humid

Table 1
Typical grain size distribution of the sediments in the Badain Jaran Desert (%)

Sampling location	Medium sand (0.500–0.250 mm)	Fine sand (0.250–0.125 mm)	Very fine sand (0.125–0.063 mm)	Silt (0.063–0.004 mm)
Interdune, Baoritaolegai	7.39	89.04	2.75	0.82
Slipface, Baoritaolegai	5.26	91.12	2.53	1.10
Slipface, Suhaitu	20.21	63.88	15.22	0.30
Slipface, Nuoritu	14.42	56.77	24.74	1.71
Windward slope, Badain Jaran	4.77	92.08	3.17	
Superimposed dune, Suhaitu	2.98	51.66	39.33	6.03
Megadune crest, Yikeliaobao	17.77	52.00	29.90	0.33
Windward slope, Yikeliaobao	22.93	49.87	23.77	3.43
Lacustrine deposits, Guezihu	16.41	48.26	30.67	4.66
Lacustrine deposits, Gulinai	20.80	33.10	43.57	2.53

periods in the Badain Jaran Desert in the last 30,000 years.

5. Morphometry of the megadunes

Fig. 4 shows the megadunes in the Badain Jaran Desert. The aerial photograph was taken in 1960. Fig. 5 is a close-up of the lake of Badain Jaran taken in 1999. It can be seen that the landscape did not experience obvious changes over the latest 40 years. This is because the formation of general structure of the dunefield took a very long time. It is estimated that over 60% of the desert is occupied by megadunes. General height of the megadunes ranges from approximately 150 to 350 m; the highest dune is over 400 m high. Fig. 1 indicates that the height of the megadunes differs from place to place. The highest megadunes occurs in the south, along 40 °N. The megadunes over 300 m high account for 42.1%, those between 200 and 300 m account for 38.2% and those less than 200 m account for 19.7%. There are two primary types of megadunes: compound transverse and compound star megadunes. Compound transverse megadunes, the dominant type, account for over 95% of the total area covered by megadunes. The compound star megadunes, which generally have three slipfaces, are found in the southeast and east of the desert where the wind direction is variable due to the influence of the mountains.

The compound transverse megadunes are generally 0.6 to 3 km wide and extend 5 to 10 km in the NE30° to NE40° direction. Their spacing is usually 1 to 5 km. The windward slope is usually gentle, 1 to 3 km long and divided into two sections. The lower 3/4 section shows an inclination of 10° to 15° while the upper 1/4 section is steeper, 24° to 27°. The slipfaces are steep, 28° to 35°, up to 40°. Barchan dunes and barchanoid chains superimpose on the windward slope. Most superimposed dunes are aligned in the same direction as the megadune. However, on some megadunes, the alignment of the superimposed dunes deviates from that of the megadune, even perpendicular to it in some cases. The superimposed dunes on the lower 3/4

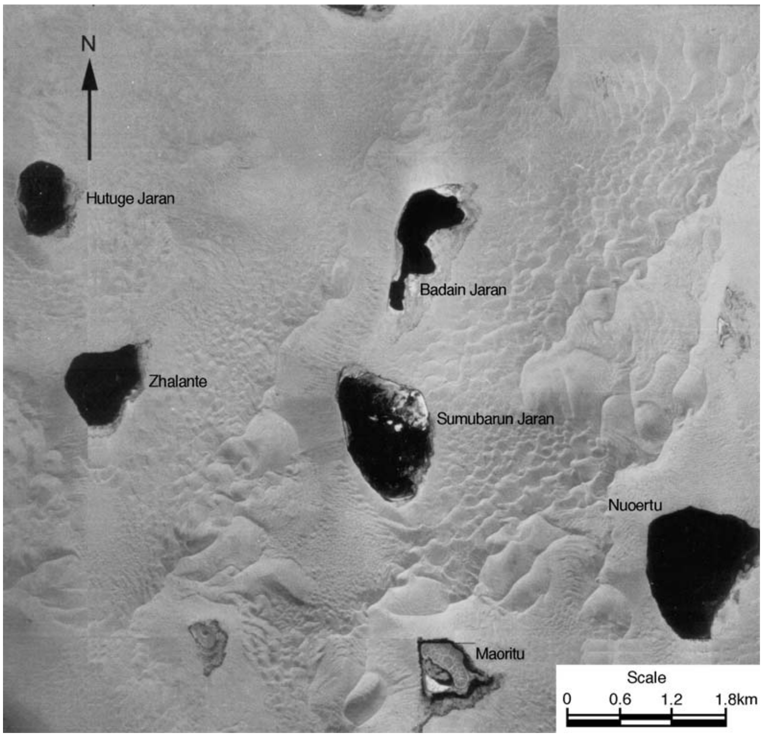

Fig. 4. Megadunes and lakes in the Badain Jaran Desert (aerial photograph taken in 1960; center: 102.42°E, 39.81°N).

Fig. 5. Picture of the Badain Jaran (taken in 1999, viewed from the northwest).

section of the windward slope are smaller, usually only several meters high, while those on the upper 1/4 section are larger, 10 to 40 m high. Calcrete development indicates that the lower 3/4 of the slope can be considered as an old, stable slope while the upper 1/4 is the new, active slope. In the old dune slope the calcrete layers are 2 to 10 mm thick and well developed along the cross beddings so that the cross beddings of the old dune are easily recognized. In the new, active slope, only a few calcareous root tubes are preserved. A 1- to 2-mm thick coarse sand layer appears between the old and new slopes.

The majority of compound star megadunes have two arms (Fig. 6), a main arm and a secondary arm, which form three slipfaces, two facing SE and one facing NE. The main arm is longer (200 to 3000 m long) and aligned in the same direction as the compound transverse megadunes, while the secondary arm is shorter (1/3 to 1/4 of the main arm) and extends in the SE direction, approximately perpendicular to the main arm. The compound star megadunes appear either in-group or isolated. Barchan dunes, barchanoid chains and star dunes superimpose on the windward slopes of both the main arm and secondary arm. The alignment of the superimposed transverse dunes is variable. They are either parallel or oblique to the arms (Fig. 6). Barchan dunes and barchanoid chains are developed between the compound star megadunes. Approaching the mountains, the compound star megadunes are gradually replaced by star dunes.

The morphometric parameters of several megadunes were measured on the 1:50,000 aerial photographs. Fig. 7 indicates that inter-correlations exist between the height, base area and spacing of the megadunes (Fig. 7A–C).

Megadune-lake alternation is common in the Badain Jaran Desert. There are more than 140 lakes

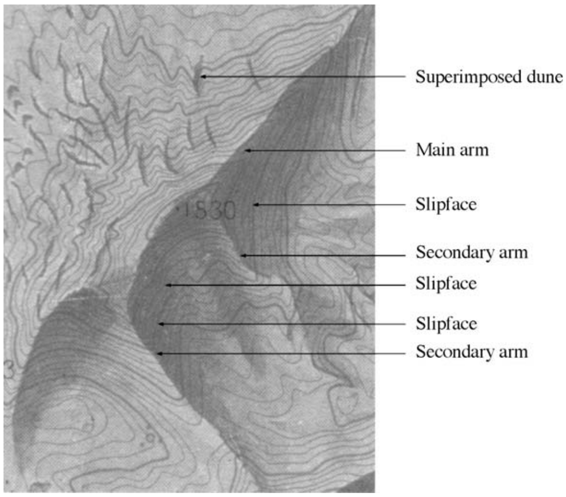

Fig. 6. Typical compound star megadune in the Badain Jaran Desert.

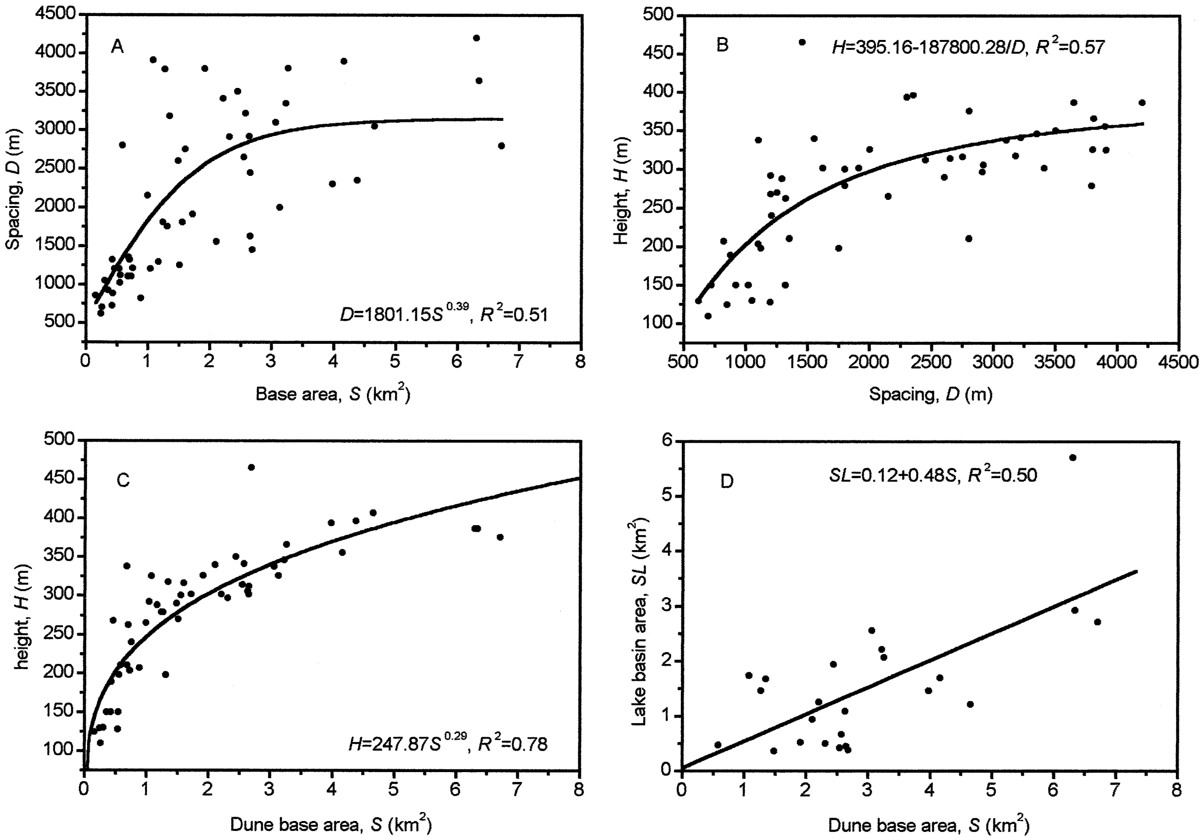

Fig. 7. Relationship between the morphometric parameters of the megadunes.

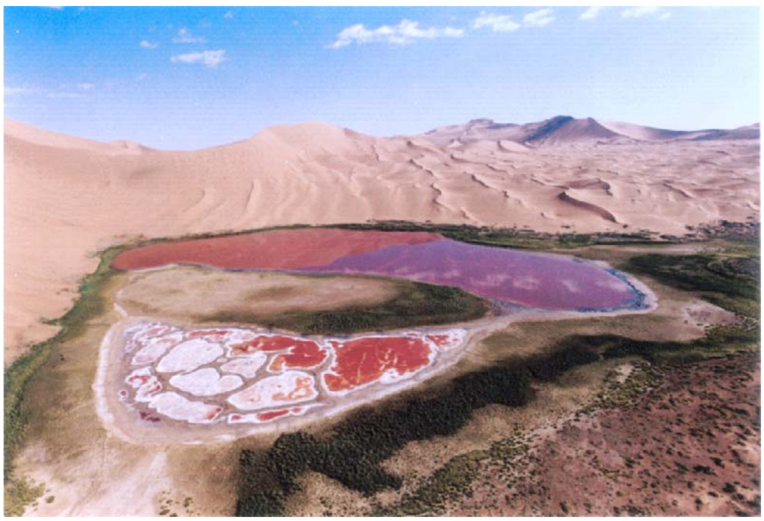

Fig. 8. Typical landscape of a lake surrounded by meadow, shrub and fixed dunes.

in the desert. The lakes mainly occur in the southeast. In fact, the desert got its name from the lakes. In the Mongolian language, "Badain" means "mysterious" or "from the heaven", and "Jaran" means "lake". As time went on, several lakes became salinized playas or wetlands due to the high evaporation. Some of them even became covered by sand dunes. There are two types of lakes with regard to their morphometry (Hofmann, 1996). Elongated shallow lakes appear in the compound star megadune area in the southeastern margin of the desert. Their depth is less than 2 m, and their size less than 0.2 km^2. Oval-shaped, deep lakes prevail in the compound transverse megadune area. Their maximum depth reaches 15 m, and their maximum size attains 1.5 km^2. The lake water is saline. The shallow lakes at the southeastern margin of the desert have a low salt concentration, less than 20 g/l, while the others show higher salt concentrations, up to 334 g/l. Most lakes are surrounded by meadow or shrubs about 1 m high (Fig. 8). Subsaline and fresh water allows the development of fixed dunes. These dunes are replaced by semi-fixed and migrating dunes as the distance to the lake increases. In several saline lakes, small travertine islands, with fresh spring water, are found. The areas of the interdune lakes or basins are controlled by the scale of the megadunes. Fig. 7D shows that the base area of the megadunes and those of the interdune basins are linearly related.

6. Formation of the megadunes

To date, there is no satisfactory explanation for the formation of the megadunes in the Badain Jaran Desert though several attempts have been made. The focus of argument is about the relief properties underneath the megadunes. A reasonable explanation of the formation of megadunes in the Badain Jaran Desert must answer four key questions: Why is the arrangement of megadunes so well organized? How can the megadunes reach such great heights? Why are the highest megadunes located near the mountains? Why are the interdune lakes concentrated in the area of the highest megadunes?

The types, alignment, patterns and distribution of the megadunes show that they are primarily the products of wind action. The orderly spacing and alignment in most of the Badain Jaran dune field is typical for aeolian dunes (Breed et al., 1979; Pye and Tsoar, 1990; Lancaster, 1995; Livingstone and Warren, 1996). The characteristics of the wind regime, especially directional variability, have frequently been regarded as the major factor determining dune type (Lancaster, 1995). Fryberger (1979) found that the directional variability of the wind, which was characterized by the RDP/DP ratio increases from the environments of barchanoid (transverse) dunes to those of star dunes. Barchanoid dunes occur in areas where RDP/DP is over 0.50, often of moderate or high wind energy. Star dunes occur in areas of complex wind regimes with RDP/DP less than 0.35. Lancaster's (1989) work in the Namib Sand Sea confirms Fryberger's hypothesis. The formation of compound transverse megadunes and transverse dunes should show similarities although those dunes are not identical. The sites surrounding the Badain Jaran Desert, except Guezihu, have a RDP/DP over 0.50. Thus, the compound transverse megadunes in the Badain Jaran are formed in a wind regime showing a directional variability similar to that of transverse dunes as suggested by Fryberger (1979), Pye and Tsoar (1990), Lancaster (1995), and Livingstone and Warren (1996). The resultant drift direction RDD of the surrounding sites except Guezihu generally is almost perpendicular to the alignment of the compound transverse megadunes. Wind direction variability near the mountains in the southeast and east is complex, because the westerly winds are blocked by the mountains. Detailed data of the wind regime are not available yet, however, the southeast site, Sharitai, which has a wide unidirectional wind regime, does not represent the wind regime of the compound star megadune area because it is located southeast of the mountains. Influenced by the latter, wind regimes at the southeast and northwest side notably differ. The directional variability of the wind regime for compound star megadunes and star dunes should be similar because these dunes all developed near the mountains. The correlations between the morphometric parameters of the compound transverse megadunes, shown in Fig. 7, suggest that these megadunes share the basic properties of well-developed single sand dunes.

It has taken a long time for the megadunes to reach such great heights. The higher the dunes, the more time is required. The lower area in the west of the Badain Jaran Desert belongs to the flood plains of the Heihe River so that the development of the dunes might have been influenced by flooding processes. The more distant to the Heihe River, the higher the dunes become and the less they have been influenced by flooding. Alternating fixation and reactivation as a result of climatic changes is an important factor in the growth of the megadunes. Vegetation and calcareous cementation were the primary agents causing dune fixation. In the Badain Jaran Desert, drifting sands are moving from the northwest to the southeast (Yan et al., 2001). In humid periods, when precipitation increased and vegetation grew well, the calcium carbonate in the sand was dissolved and reprecipitated to bind the grains, or bleached to form illuvial calcareous cementation horizons that fixed the sand. This inhibited the dunes from further wind action. During the dry periods, the sands drifting from the northwest covered the old fixed dunes and formed new dunes that became fixed during the next humid period. Thus, the magadunes were created due to the progressive coverage of old dunes by new active dunes. Yang (2000) found four calcareous cementation horizons in a megadune in the southeast of the Badain Jaran Desert. The lowest horizon he found was 0.3–0.4 m thick and was dated 31.75 ka BP, the second horizon was 0.2 m thick and was dated 19.1 ka BP, the third horizon was 0.1–0.2 m thick and was dated 9.435 ka BP, and the uppermost horizon was 0.02–0.08 m thick and was dated 2.02 ka BP. Hence, in the latest 30,000 years, the megadune experienced four fixation–reactivation alternations. Yan et al. (2001) found six fixation–reactivation alternations in another megadune over the last 60,000 years. Though the number and age of the horizons may differ from dune to dune, fixation–reactivation seems to have played an important role in increasing the height of the megadunes. The calcareous cementation horizons appear on both the windward and leeward slopes of the megadunes. The leeward slopes with the higher SE inclination, over 40°, are attributed to the calcrete.

The occurrence of the highest megadunes (relative height) near the mountains is attributed to two reasons. First, the base level of the dunes is higher near the mountains. Secondly, the wind (NW) has been fairly constant during the formation of the Badain Jaran Desert (Wang, 1990; Yan et al., 2001). Thus, the sands blown from the northwest were blocked in the area near the mountains.

The interdune lakes are an important aid in reconstructing the genesis of the megadunes because the highest megadunes always occur near the interdune lakes. This is because the megadune area near the mountains is located near the zone of the talus springs. Fig. 9 shows the typical zonality of the hydrological phenomena in the inland basins of the arid regions in China (Zhao, 1985). The deserts in the arid regions of China are usually surrounded by high mountains that provide the water. Water collected from the mountains flows under the gravel deposits on the slope as concealed ground water and exits at lower elevations where the deposits become fine-grained and the water flow is blocked. The amount of emerging ground water in the Tarim Basin (in the south of the Xinjiang Autonomous Region), Jungger Basin (in the north of the Xinjiang Autonomous Region) and Hexi Corridor is sufficient to form oases. There are many oases in the basins because the snow and ice cover on the surrounding mountains provides lots of water. Similarly, many springs occur south of 40°N on the talus of the Heishantou, Beidai and Yabrai Mountains. At some places, the springs create lakes. Hofmann (1996)

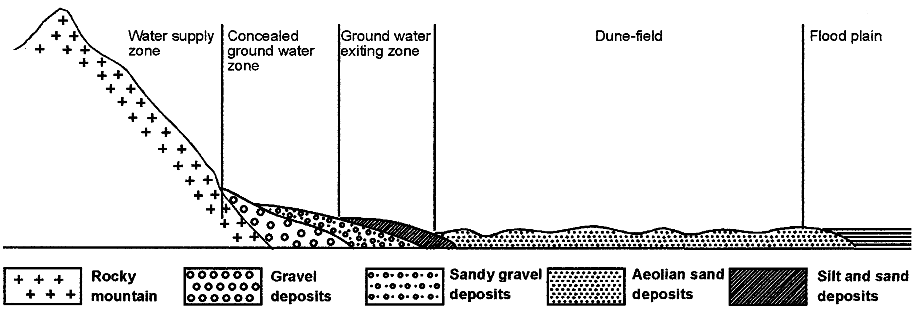

Fig. 9. Typical zonality of the hydrological phenomena in the inland basins of the arid regions in China (Modified after Zhao, 1985).

observed that many lakes show a sharp decrease in conductivity near the bottom, indicating sublacustrine inflow of low salinized water. This suggests that the groundwater in the megadune area belongs to an artesian aquifer within a large basin structure because the region belongs to the relatively stable Alashan fault block. However, unlike the mountains surrounding the Tarim Basin, Jungger Basin and Hexi Corridor, the mountains to the south, southeast and east of the Badain Jaran Desert cannot supply enough water to form oases. However, they do supply enough water, especially in the wet periods, to maintain the interdune lakes in the megadune area. Wang (1990) suggested that the outlines of the interdune lakes and, hence, the megadunes were controlled by the underlying topography and the lakes fed by atmospheric precipitation. He estimated that, in the Badain Jaran Desert, a 16-km^2 watershed area could deliver the equivalent of 800-mm water in a 1-km^2 interdune lake. However, the potential evaporation (about 3300 mm) exceeds the amount precipitation by a factor of 4. Wang's suggestion also cannot explain why the interdune lakes are limited to a west–east zone north of the mountains. To maintain the lakes, the water supply must at least balance the potential evaporation. If we accept that interdune lakes are formed by talus springs, the water of the interdune lakes should originate from the area south of the megadunes, about 6500 km^2 in size. Mean annual precipitation of the four sites around the Badain Jaran Desert is about 50 mm. The amount of water collected annually for the interdune lakes is estimated at 3.25×10^6 m^3, which can balance the potential evaporation of 98 km^2 water area, or 98 interdune lakes of 1 km^2 in size. This, of course, is only a very rough estimate, neglecting the conversion efficiency of atmospheric precipitation to ground water. However, it shows that it is more likely that the interdune lakes have been formed by the talus springs than when they have been controlled by the topography. If this is true, subsurface topography plays a less important role than previously thought.

7. Conclusions

Morphometry and formation of the megadunes in the Badain Jaran Desert were studied by means of field survey and aerial photographs. The megadune area is characterized by low a wind energy environment. Two main types of megadunes occur in the Badain Jaran Desert: compound transverse megadunes, which developed in a wind regime with a directional variability similar to that of transverse (barchanoid) dunes, and compound star megadunes, which developed near the mountains where directional variability of the wind is complex. Compound star megadunes and star dunes are created in a similar wind regime. The primary factor responsible for the formation of the megadunes is the wind action, not the underlying morphology as suggested by several researchers. Alternations of dune fixation and dune reactivation explain the excessive height of many of the megadunes. The special distribution of the highest megadunes is determined by sand movement, from the northwest to the southeast. The interdune lakes are formed by the talus springs and are only partly fed by atmospheric precipitation in the megadune area.

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