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Barchan Dunes of Wadi Khulays, Western Region of Saudi Arabia: Geomorphology and Sedimentology Relationships

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ABSTRACT. The barchan dunes of Wadi Khulays, western region of Saudi Arabia have been evaluated in terms of their geomorphological and sedimentological relationships. Statistically significant relationships (r = 0.63 to 0.99) have been found between barchan height and their morphology, movement and sedimentology. These relationships have been attributed, in the first place, to the effect of the wind regime and to the mechanism in which sand is transported and deposited over the surface of barchan dune. The planar surface of the dunefield, sand supply and local wind velocities are also considered to be very important. The analysis of the characteristics of barchan dunes morphology, movement and sedimentary materials are necessary to facilitate improved geomorphologic understanding. It also provides important information for controlling the growth and movement of dunes which might create, in arid environments, serious problems for the economic development of these areas.

Introduction

The Wadi Khulays area lies about 90 km north of Jeddah in the western region of Saudi Arabia (Fig. 1). The Wadi consists of several Wadies (i.e. vallies) which drain from the drainage basins of the western slopes of the Arabian Shield. They coalesce to form the Wadi plain of Khulays. The Wadi is presently used to be the major source of water and agricultural products supply for Jeddah. Figure (1) show the major landforms in the area of Wadi Khulays which include; plains, terraces, alluvial fans, and aeolian forms (Zaidi, 1984). These features are adjacent to other geomorphologic features such as escarpments, horsts, mountains, graben and plains which are the results of a long and complex denudational history (Zaidi, 1984). The aeolian landforms in the area are mainly depositional types such as sand dunes and sand sheets, and are developed mainly on deflated gravely alluvial plains surfaces in the western and southern part of the Wadi. The examined dunes are mainly of individual barchan type up to 5 m high, 35 m long of windward slope and 71 m wide (Table 1 and Figure 2). Generally, they show a gentle northwesterly windward slope (2º to 10º) and a steep southeasterly slipface slope (30º to 32º).

This dune form owes its presence to crossing of prevailing northwesterly wind with seasonal north-northeasterlies. The interdune areas are deflated, gravely surfaces and composed of coarse and angular fragments. Such areas with essentially limited loose sand are likely to posses barchans (Bagnold, 1941). Based on intensive observations and surveys, this paper presents some quantitative information on the relationships among variation in morphology, sedimentary characteristics of sand, and rate of movement for barchan dunes of Wadi Khulays. In addition, this study is important because it provides valuable information for the future study on dune movement in this region or in other arid environments.

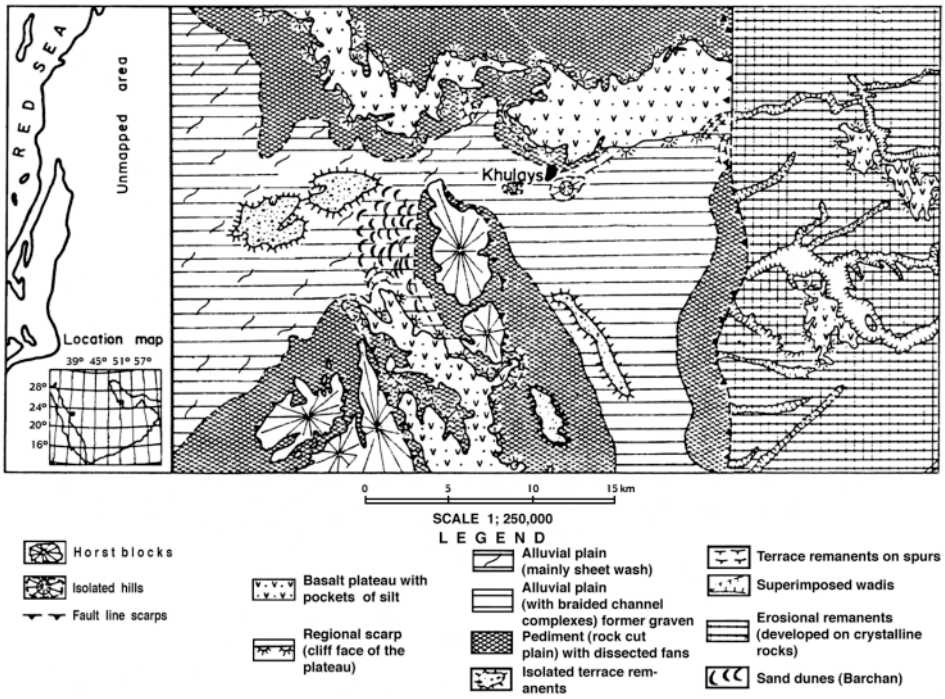

FIG. 1. General map showing main geomorphological features of the Wadi Khulays and the location of dunes examined in this study (after Zaidi, 1983).

TABLE 1. Shape dimensions, grain size and movement of selected barchan dunes in Wadi Khulays.

Dune no.	H (m)	WI (m)	SI (m)	Hw (m)	Mz (ϕ)	σ (ϕ)	Dm (m/year)
1	3.0	28.0	5.4	35.0	1.31	0.58	11.0
2	3.8	35.0	7.0	39.3	1.28	0.52	10.7
3	4.8	31.0	8.7	41.5	1.51	0.79	14.3
4	1.5	18.0	2.4	22.5	1.33	0.81	16.5
5	2.4	16.0	4.2	25.7	1.51	0.94	15.6
6	1.7	17.0	3.4	23.2	1.35	0.83	16.2
7	3.1	21.0	5.2	32.2	1.66	0.65	11.4

TABLE 1. Contd.

Dune no.	H (m)	WI (m)	SI (m)	Hw (m)	Mz (ϕ)	σ (ϕ)	Dm (m/year)
8	4.9	29.0	8.9	43.0	1.63	0.73	9.7
9	2.1	17.0	3.7	24.3	1.74	0.61	15.0
10	4.3	31.0	8.2	42.0	1.85	0.61	10.3
11	5.2	27.0	9.7	71.7	1.93	0.62	9.5
12	5.0	28.0	8.5	16.6	1.33	0.66	16.3
13	3.2	27.0	5.7	41.5	1.32	0.70	11.0
14	5.8	30.5	10.8	55.2	1.85	0.67	9.6
15	4.5	29.0	8.3	43.7	1.78	0.59	10.0
16	2.9	20.0	5.0	32.5	1.43	0.75	14.8
17	2.7	20.0	5.3	32.3	1.33	0.65	15.0
18	3.3	24.0	6.5	43.2	1.53	0.71	10.8
19	2.5	19.0	5.2	18.5	1.46	0.58	15.3
20	4.7	27.0	8.5	47.8	1.74	0.63	10.2
21	3.2	24.0	5.7	36.5	1.68	0.58	10.4
22	2.7	21.0	5.2	37.2	1.79	0.55	15.2
Average	3.5	24.5	6.4	36.2	1.6	0.7	12.7
Range	1.7 - 5.8	16.0 - 35.0	2.4 - 10.8	16.6 - 55.2	1.28 - 1.93	0.52 - 0.94	9.5 - 16.3

H = dune height, WI = windward length, SI = slipface length, Hw = dune width, Dm = dune movement.

FIG. 2. Barchan dunes at Wadi Khulays.

Methods of Investigation

Several characteristics parameters were measured for selected 22 barchan dunes. The geometric parameters measured include dune height (H), windward length (WI), slip-face length (SI), dune with (Hw) which represented the distance between the two horns, and dune movement (Dm) - (Figure 3). All the measurements have been done by means of theodolite, stadia rod and measuring tape. The measurement of dunes movement has been done by fixed stadia rod in the base of the windward slope for each studied dune. Eleven months later, the distance between the stadia rod and the base of windward slope of the 22 barchan dunes were measured. In addition, a total of 22 sand samples were collected from the crest of each dune for determining sedimentary characteristics of the 22 barchan dunes. Sand samples were taken by pressing a plastic tube 3 cm in diameter. Special care was taken to ensure that the plastic tube had penetrated into a uniform depth of 3 cm. Approximately 25 g of each sample was sieved 30 min through a set of sieves at 0.25 phi intervals ranging from 0.0 to 4.25 using sieve shaker. Mean grain size (Mz) and sorting (σ) parameters were calculated using a FORTRAN program. Moment measures were used to obtain these parameters. Correlation coefficient was calculated to find the relationship between the parameters of barchan dunes morphology and their mean grain size and sorting characteristics.

Results and Discussion

The results of the relationship between the parameters of barchan dunes morphology, rate of dunes movement and mean grain size and sorting of sand are listed in Table 1 and their relationships are depicted in Figure 4. Figures (4A and 4B) show positive correlation between dune heights and windward lengths and dune widths. As the height of the barchan dunes increases, windward length and dune width increase as well. Naturally, the growth of a barchan dune depends on how much sand it gains or loses. The wind, mainly unidirectional regime, transports the sand from the interdune area of the windward side. As this process continues the barchan dune grows in height as well as in length and width. Our field observations has indicated that the sand deposits tend to diverge on the windward side of a barchan and this process in turn will increase the width of the barchan dune. However, barchan dune size and form are also influenced by other factors such as wind velocity, variability of wind direction, grain size saturation of the interdune sandflow, interdue aerodynamic roughness (Howard *et al.*, 1978). In addition, the distance between the two horns, i.e. dune width increases with the increase of dune height. This correlation can be attributed to the mechanism in which sand grains transport and deposit over the barchan dune surface. Wind tends to transport sand near the foot of the windward side which is nearly horizontal and directed from the centerline outward to the horn. Near the centerline of the dune, the sand transport is directed in almost straight line from the windward foot to the highest portion of the crest (Hatenrath, 1967). As long as sand supply and a nearly constant direction of wind regime continue the barchan will grow progressively including the width of their horn or distance between horn to horn. Field observations show that barchan dune horns are more elongated in one direction than another. This has been noticed during a short period of wind

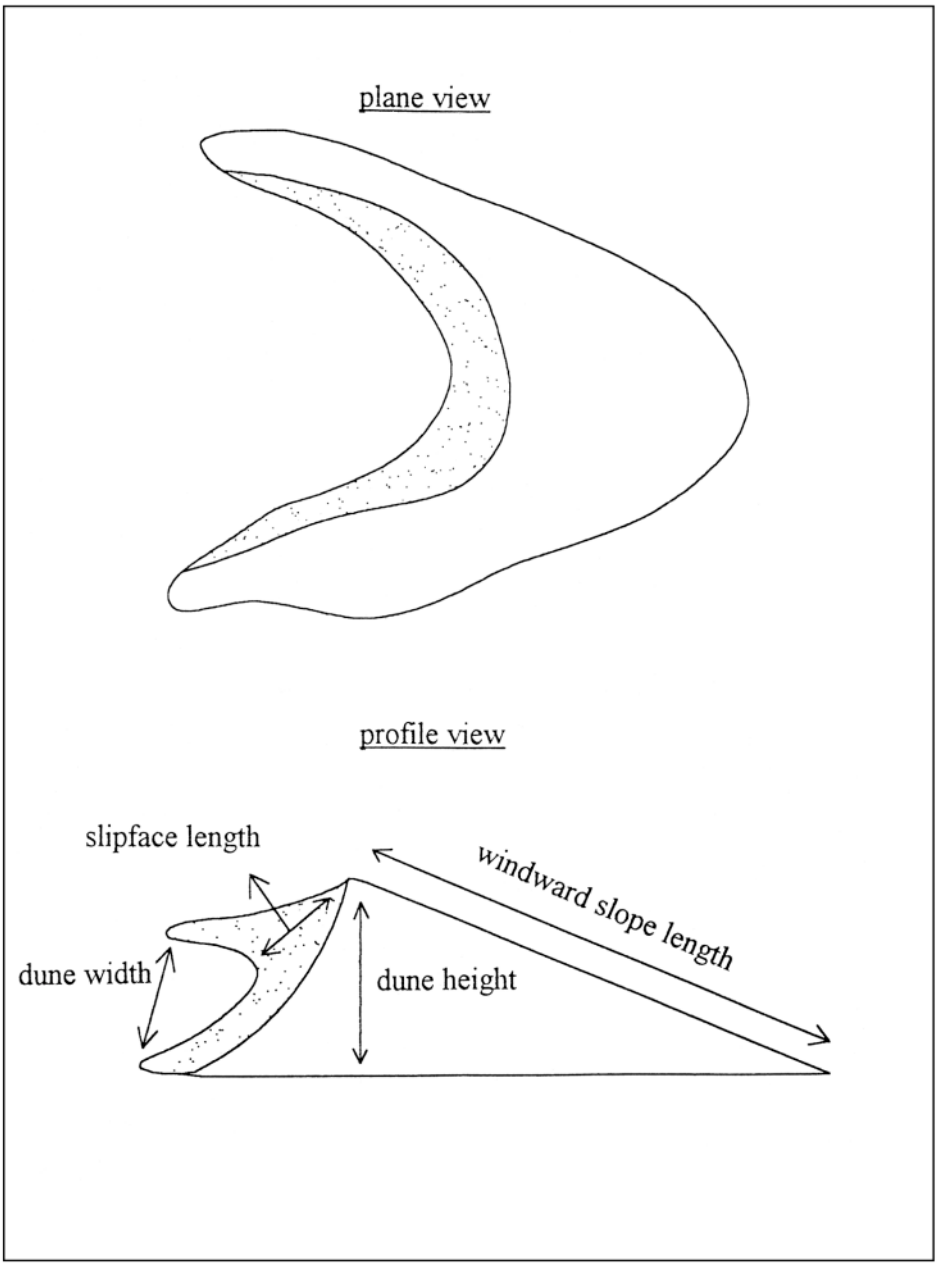

FIG. 3. A sketch shows the geometric parameters of a barchan dune.

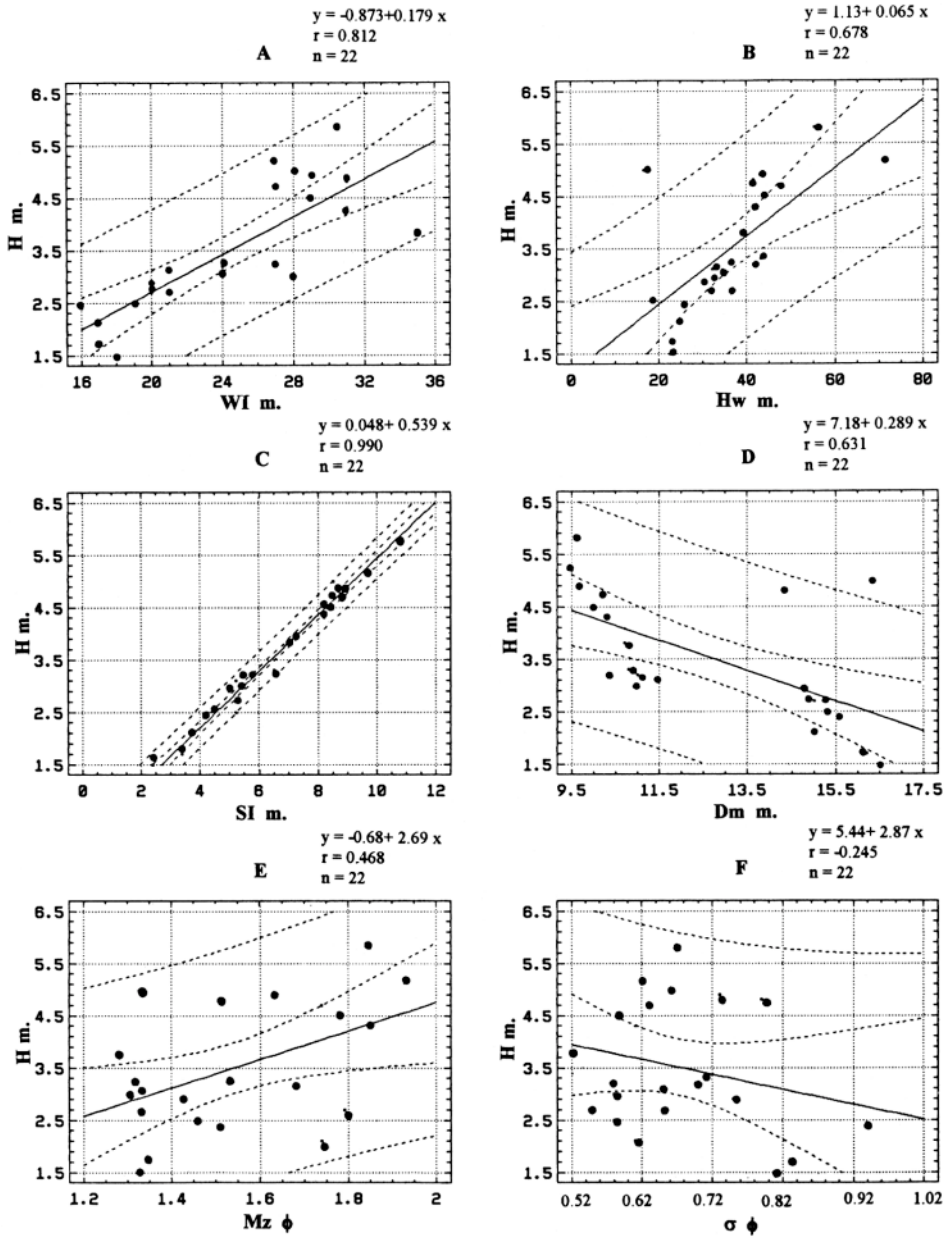

FIG. 4. (A) Relationship between dune height and dune windward length, (B) dune height and dune width, (C) dune height and slipface length, (D) dune height and dune movement, (E) dune height and mean grain size, and (F) dune height and sorting.

storm (the northwesterly winds during summer months) in which the observed barchan dune shows a pronounced elongation of its western horn. This can be explained by an asymmetry in the wind pattern. This phenomenon has been observed in barchan field in different areas (e.g. Holm, 1960; McKee, 1966; Norris, 1966; Lancaster, 1982; Sagga, 1986; Embabi and Ashour, 1993). However, some researchers attributed this to a slope in the dune field surface (Long and Sharp, 1964; Lettau and Lettau, 1969). This case is not supported in this study because the barchan dunes field is located on a planar surface.

A positive relationship was observed between barchan dune heights and slipface lengths (Fig. 4C). As barchan dunes height increases, there is a tendency for the slipface length to increase. This process can be explained by the fact that, as the barchan dune height increases, sand deposits on the crest roll down from the slipface by the influence of gravity to maintain the dune geometry. As this process continues the length of the slipface increases and the avalanched sand moves a few centimeters over the ground to leeward. Consequently, the barchan dune moves progressively in the downwind direction.

Figure (4D) shows a negative relationship between the barchan dune height and its rate of movement. As the barchan dune height decreases, the rate of its movement increases. In fact, the rate of barchan dune advance is dependent upon the size of the dunes, the velocity, direction and frequency of wind, and the supply of sand (Bagnold, 1941; Kerr and Nigra, 1952; Amstutz and Chico, 1958; Finkel, 1959; Hastenrath, 1967; Lancaster, 1982; Shehata *et al.*, 1992). Many researchers have observed that the size of a barchan dune is largely a function of its rate of movement. It has frequently been observed that the speed of movement of the barchan is greater for the smaller dunes and less for the larger ones (Bagnold, 1941; Finkel, 1959; Long and Sharp, 1964; Norris, 1966; Sharp, 1966; Hastenrath, 1967; Embabi, 1970; Fryberger *et al.*, 1984; Lancaster, 1983; Watson, 1985; Shehata *et al.*, 1992; Embabi and Ashour, 1993). The barchan dunes of Wadi Khulays show a rate of movement that varies between 9.5 m to 16.3 m with an average of 12.7 m during a period of 11 months. On the contrary, Watson (1985) found very weak correlation between dune height and the rate of movement in some dune fields in the eastern region of Saudi Arabia. He attributed that to the irregular topography of the area and the local crowding of the dunes. The location of the dunefield in Wadi Khulays on a planar surface with no significant local relief and completely absent of vegetation, accelerate the advancement of the barchan dunes in the downwind direction. In addition, the aeolian deposits on the sheet wash plain and in the Wadi plain to the north of dunefield are considered to be the sand supply for the barchan dunes.

A positive relationship has been found between the barchan dune heights and the mean sand grain sizes (Fig. 4E). As the barchan dune height increases, there is a tendency for the mean size to be finer. This results confirms Bagnold (1941) findings that large dunes consists of finer sands than small ones. The increase of barchan dune height means an increase in the windward slope and this sort of geometry effect the mechanism of sand transportation over the dune. It is well established that the coarse grains

are too heavy to climb up the steeper slope, and thus they tend to accumulate on the base of the slope as a lag deposit. In contrast, finer grains can be transported over a steeper slope. The mean grain size of the barchan dunes sand in Wadi Khulays is in the range of 1.28 to 1.93 phi (medium sand). Sand of a very similar mean grain size has been reported on barchan dune crests in different deserts (Amstutz and Chico, 1958; Hastenrath, 1967; Ahlbrandt, 1979; Watson, 1986; Sagga, 1986 and 1991).

Figure (4F) shows no significant relationship between the barchan dune heights and the sorting of sand deposits. This may be attributed to the strong fluctuation in wind velocity which leads to deposition of very find sand (3.0 to 4.0 phi) and silt (4.25 phi, coarse silt) on the barchan crest surface. This very fine sand material, once deposited, is difficult to erode by higher wind velocities if it is protected by the overlying or adjacent coarse grains. Therefore, as more fine material, silt, is added from suspension as a 'grain fall' population, the sediment of the barchan tends to become less well sorted. In contrast, if sand is transported by strong persistent and non gusty winds, this will produce extremely well-sorted sand (Marrs and Goylord, 1982). The sorting of barchan sand is in the range of 0.38 to 0.93 phi (sorted to moderately sorted). Similar sorting values have been found by researcher in other different deserts (Ahlbrandt, 1970; Binda, 1985; Sagga, 1986, 1990, and 1991).

Conclusion

The present study has discussed the various aspects of barchan dunes geomorphology and sedimentology characteristics in the Wadi Khulays, western region of Saudi Arabia. Statistically significant relationships (r = 0.63-0.99) have been found between barchan dune heights and their morphology (dune height, windward length, slipface length, and dune width), rate of movement, and the characteristics of mean grain size and sorting of their sand. The analysis of these factors reveals that the geomorphology of barchan dunes may be interpreted, in the first place, by the effect of the wind regime (prevailing northwesterly with seasonal north-northeasterlies) and by the mechanism in which sand grains are transported and deposited over the surface of barchan dunes. In addition, sand supply, the planar surface of the dunefield and local wind velocity are generally considered the most important factors in controlling the morphology, movement and sedimentology of barchan dunes. The results of this study can provide vital information for the further study of dune movement in this region or any arid area.

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الكثبان الهلالية في وادي خليص ، المنطقة الغربية للمملكة العربية السعودية : العلاقات الجيومورفولوجية والرسوبية

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قسم الجغرافيا ، كلية الآداب والعلوم الإنسانية ، جامعة الملك عبد العزيز
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المستخلص . تمت دراسة الكثبان الهلالية بوادي خليص بالمنطقة الغربية من المملكة العربية السعودية من ناحية العلاقات الجيومورفولوجية والرسوبية . تم إيجاد علاقات ارتباطية (ر = 0.63 – 0.99) بين ارتفاع الكثبان الهلالية وأشكالها ومعدلات زحفها وخصائصها الترسيبية . ولقد تم تفسير هذه العوامل ، في المقام الأول ، إلى نظام الرياح والكيفية التي تم بها نقل وترسيب الرمل فوق سطح الكثيب الهلالي . كما يعتبر كل من استواء سطح حقل الكثبان ومناطق إمدادات الرمل وسرعة الرياح المحلية من الأمور الهامة التي تفسر كثير من العلاقات الارتباطية السابقة الذكر . وتعتبر دراسة وتحليل خصائص الكثبان الهلالية من حيث المواد الترسيبية وأشكالها ومعدلات زحفها من الأمور الهامة التي تساعد في زيادة الحصيلة الجيومورفولوجية في هذه الأمور . وسوف تمدنا هذه النتائج بمعلومات هامة نستطيع من خلالها إيجاد أفضل الطرق للتحكم في نمو وزحف الكثبان التي تسبب العديد من المشاكل الخطيرة التي تهدد التنمية الاقتصادية في المناطق الجافة .