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Spatial distribution of dust deposition within a small drainage basin: Implications for loess deposits in the Negev Desert

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ABSTRACT

Loessial colluvial sediments and aeolian aprons are common deposits in the Negev Desert Highlands. In an attempt to monitor the amounts and distributional pattern of loess, monthly dust measurements were carried out during 2004 to 2006 in 10 cm diameter traps located at 18 stations along four slopes, north-facing, south-facing, east-facing and west-facing in a second-order drainage basin near Sede Boqer, Negev Desert Highlands, Israel. Annual total dust depositions ranged between 110 g and 178 g m^{-2} with an average of 151·1 g m^{-2}. The average annual dust deposition in the catchment was 23·5% higher than the average amount recorded at the hilltops (122·4 g m^{-2}) and may be a consequence of sheltering opportunities in the hilly topography. When analysed according to season and aspect, significantly higher monthly amounts were received during the wet rainy season of December to March (17·0 g m^{-2}), in comparison with the rest of the year (8·1 g m^{-2}). As for the aspect, while no significant differences characterized north-facing and south-facing slopes, east-facing slopes received significantly higher amounts (by 43·3%) than west-facing slopes, pointing to preferential dust deposition at the leeward slope. Concurring with the classical model that anticipates higher dust deposition at the leeside slope, but in disagreement with some reports published in the literature, the findings of this study were also supported by a field survey that showed preferential loess accumulation at the eastern and north-eastern aspects. These findings may shed light on distributional patterns of colluvial sediments and aeolian aprons in the Negev, on soil-forming processes and on past cycles of dust deposition.

Keywords Aeolian aprons, aeolian input, colluvial sediments, drainage basin, dust traps, leeward slopes.

INTRODUCTION

Loess deposits are a common feature in many parts of the world. Mainly composed of quartz grains of silt size (2 to 63 μm), they may stem from relatively heavy loads of silty dust (Pye, 1995; van Loon, 2006), originating from weathering of high mountain chains or derived from glacial deposits. Silty loess deposits may be found in front of glaciated areas in Europe and the USA (Mason, 2001; Antoine *et al.*, 2003; van Loon, 2006), at the footslopes of the Himalaya Mountains in China (Wright, 2001; Sun, 2002) or at desert margins, such as in the Negev (Yaalon & Ganor, 1979; Crouvi *et al.*, 2008; Enzel *et al.*, 2008), the Mojave (McFadden *et al.*, 1986), the Namib (Brunotte & Sander, 2000) and the Atacama (Eitel *et al.*, 2005). In many of these deserts, silt is carried by wind to the desert margins mainly from nearby inner desert sources like sand dunes or alluvial fans. These silty deposits (loess) may reach substantial depth, forming soils, colluvia and aeolian aprons (van Loon, 2006; Enzel *et al.*, 2008).

Loessial colluvial sediments, sometimes in the shape of gully-transected tongues, are a common feature in the Negev Desert Highlands, Israel. Deposited by wind and water, the colluvia consist of rock particles and soil minerals (Birkeland, 1974; Wieder *et al.*, 1985). Confined to the footslopes, gully-transected tongues are relatively common at the eastern and north-eastern aspects (Fig. 1A and B).

Aeolian aprons are less common in the Negev. Contrary to colluvia, aeolian aprons may be found at the upper slope sections, and as such may exhibit much more homogeneity in particle size distribution (PSD). While aeolian aprons may primarily reflect dust or sand deposition, colluvia also contain rock particles, reflecting the intensity of the *in situ* weathering and the efficiency with which the sediments are washed away from the upper slope sections to concentrate at the footslope. As a result of the complex interaction between all of these factors, judgment as to the origin of the materials deposited in colluvia based only on their volume is highly problematic.

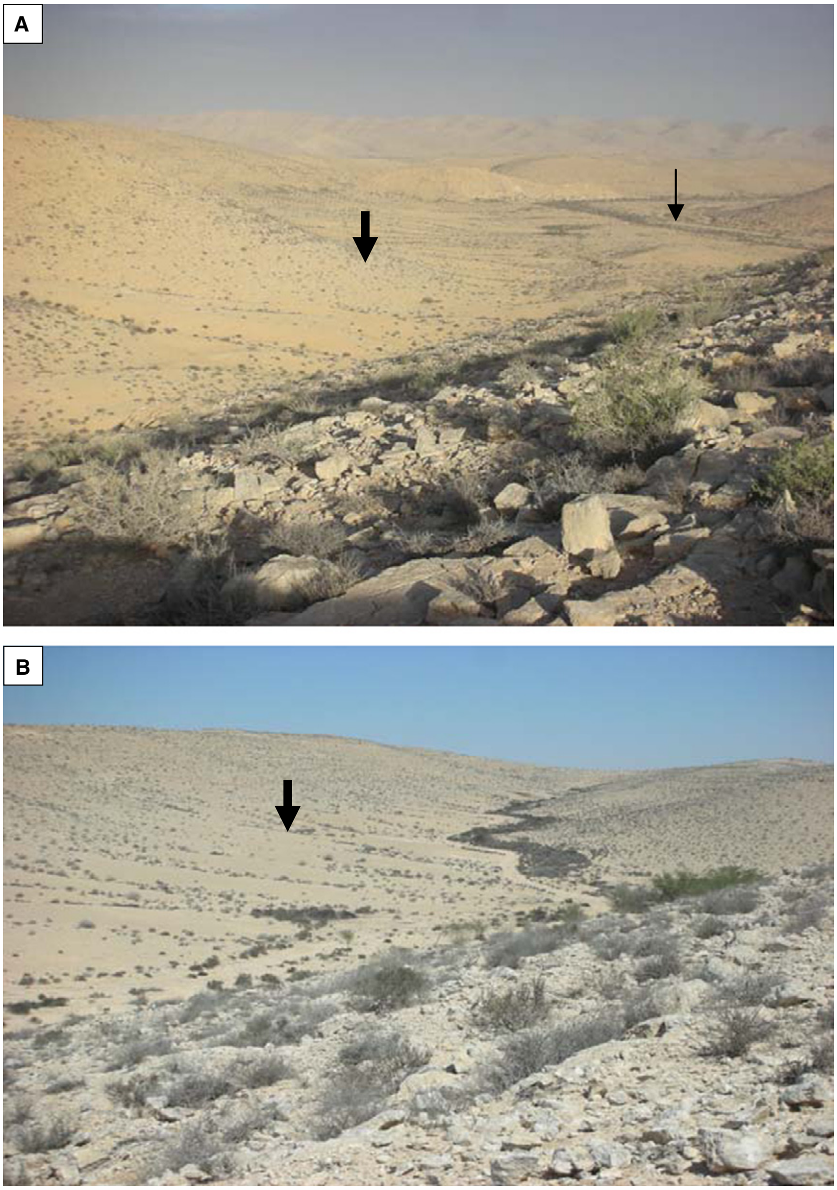

Fig. 1. Colluvial sediments (wide arrow) left of the wadi bed (narrow arrow) at the footslopes of the north-eastern aspect 0·3 km north of the present research site (A) and colluvial sediments (wide arrow) on the eastern aspect 0·1 km south of the research site (B). Shrubs at the front of the photographs are up to 50 to 60 cm tall.

Indeed, data concerning the spatial distribution of aeolian input in the Negev Highlands slopes is very scarce. It is primarily confined to dust measurements in set stations throughout the Negev, tens of kilometres apart (Ganor, 1975). Only limited attempts were made to study the spatial distribution of dust within the mountainous terrain of the Negev.

Such attempts were made by Goossens and Offer. Based on wind tunnel simulations, Goossens (1988) concluded that turbulence will be more effective in deposition of <30 μm grains, while a decrease in wind speed will primarily affect >30 μm grains. Subsequently, this author concluded that unlike sandy material (62 to 2000 μm), and in disagreement with classical literature (Russell, 1929; Simonson & Hutton, 1954; Lewis, 1960; Pye, 1984), the deposition of loessial (silty) material, 2 to 62 μm, will depend on wind turbulence. Accordingly, preferential deposition will take place in areas where the wind stream lines converge (and therefore carry a higher concentration of dust), while it will be low in the separation zone, such as at the leeward slope. Similar wind tunnel experiments were also reported by other scholars (Zufall *et al.*, 1999; Brenig & Offer, 2001; Parker & Kinnersley, 2004). As for the Negev, field measurements, reported by Goossens (2000) and Goossens & Offer (1990, 2005) and Offer & Goossens (1995), were interpreted to support their wind tunnel experiments.

Previous measurements included dust (Goossens & Offer, 1990; Offer & Goossens, 1995; Goossens, 2000) and measurements of the depth of the colluvial sediments and the aeolian aprons, i.e. loess accumulation (Goossens & Offer, 2005). However, while dust deposition was measured during one to 120 days only and confined to the dry period, conclusions regarding loess accumulation pose difficulties. Because loess accumulation is also the outcome of water transportation and is largely affected by surface heterogeneity (Yair & Lavee, 1985), it is safe to conclude that the thicker accumulation at the windward slope in comparison with the lee slope, as reported by Goossens & Offer (2005), does not solely reflect net aeolian deposition, as also acknowledged by the latter authors.

This study was designed to better understand the spatial distribution of dust by wind and to gain insight into the spatial distribution of the colluvial sediments along the hilly footslopes of the Negev Highlands. This study focused on a second-order drainage basin where long-term measurements of a range of physical variables were previously undertaken (Kidron *et al.*, 2000, 2011).

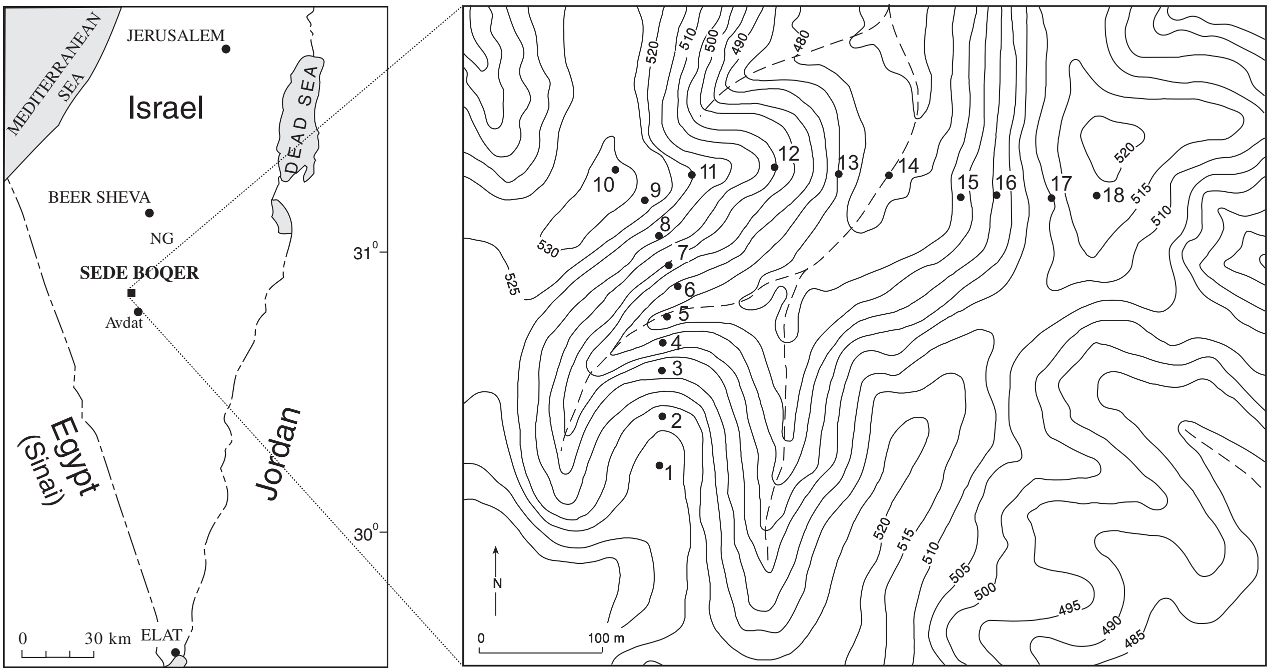

Fig. 2. Location and layout of research site. NG, Negev junction.

THE RESEARCH SITE AND METHODOLOGY

The research site is located near kibbutz Sede Boqer (SB) in the Negev Desert Highlands, Israel, *ca* 500 m above sea-level (Fig. 2). Rain precipitation is limited to the winter months (November to March) with an average annual precipitation of 95 mm (Rosenan & Gilad, 1985). The mean monthly temperatures vary from 9°C in January to 25°C in July (Rosenan & Gilad, 1985). Annual potential evaporation measured at Avdat (9 km south of SB) with a class A evaporation pan is *ca* 2600 mm (Evenari, 1981).

A second-order drainage basin, with relatively steep slopes, was chosen (Fig. 3A). The bedrock consists of Turonian limestone of three formations: Netzer, Shivta and Drorim, occupying, respectively, the upper, mid and lower slope sections (Arkin & Braun, 1965). Whereas the Netzer and Drorim Formations are strongly jointed limestone, characterized by patches of soil, massive and continuous bedrock characterize the Shivta Formation at the midslopes. Sparse vegetation, with 10 to 20% cover, characterizes the slopes, while the rock and stone surfaces are covered by lichens and cyanobacteria (Danin & Garty, 1983).

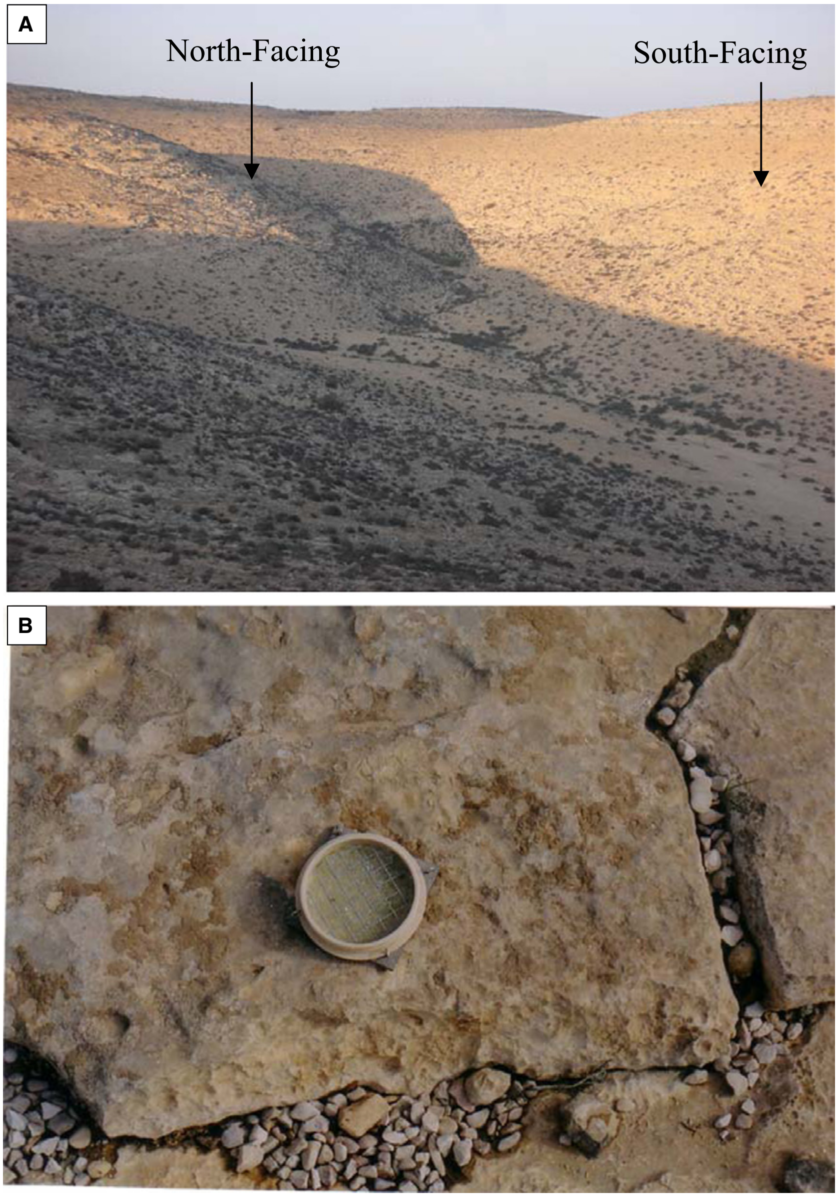

Fig. 3. General view of the drainage basin (taken from the top of the western aspect, *ca* 40 m above the wadi bed) (A) and view of the 10 cm diameter dust trap (B). Cracks were filled with pebbles to impede the entry of soil splash into the traps. Field of view is 1 km across.

Eighteen stations, 2 × 2 m each, were demarcated at the north-facing (NF), south-facing (SF), east-facing (EF) and west-facing (WF) slopes, and at the hilltops and wadi beds (Table 1). Traps, 10 cm in diameter with 1·5 cm high rims were installed within each station, parallel to the slope angle. The traps were put on a 10 × 10 × 1 cm wooden base that was screwed in its centre to the rock surface (in stations having rocks) or to *ca* 20 × 20 × 3 to 4 cm stones (in stations lacking rock outcrops such as the wadi beds). All soil patches within a 1 m radius from the trap were covered with pebbles to eliminate soil splash by raindrop impact.

The trap consisted of a roughed-Plexiglas bottom, 3 mm thick (with 2 mm high protrusions), underlying one layer of 3 mm diameter glass marbles. The rough Plexiglas ensured anchoring of the marbles at the 30° slope angles characterizing the research site. However, the Plexiglas was not capable of providing sufficient anchoring against the raindrop impact and the marbles tended to accumulate at the lower side of the trap. This drawback was solved with a 1 × 1 cm metal net, squeezed against the marbles, thus providing the additional anchorage needed during rainstorms. The trap was easily separated from its base, thus facilitating convenient dust collection (Fig. 3B).

Dust collection took place monthly. During collection, the glass marbles were put on a 2 mm mesh (to eliminate, as much as possible, contamination by organic matter such as branches and leaves) and rinsed with distilled water along with the metal net, the Plexiglas and the inside of the trap, into separated flasks. The flasks were taken to the laboratory, cleaned again of organic matter (that tends to float on the water surface), oven-dried at 105°C for 24 h and weighed. Dust measurements were carried out between June 2004 and May 2006.

In addition to dust, the hydrological rain, i.e. the rain incident on the sloping ground was measured with small orifice rain gauges, 30 cm above ground, located near each plot. With an orifice parallel to the slope, these rain gauges not only recorded the actual rain received at the ground (Sharon, 1980) but also reflected the wind flow during rain events (Sharon *et al.*, 2000). Thus, for instance, following rain that is carried by western wind, the rain gauge at the western aspect is expected to record more rain than a rain gauge at the wake of the wind flow at the eastern aspect. The meteorological (regional) rain was measured at a nearby station, 1·5 km away. The station also recorded the wind regimes.

Table 1. Properties of monitoring sites.

Station no.	Slope location	Abbreviated station: name and exposure	Geological formation	Elevation above m.s.l. (m)	Slope angle (°)
1	Top	Top N	Netzer	528	2
2	Upper	Up. N	Netzer	523	15
3	Mid	Mid N	Shivta	505	24
4	Bottom	Bot. N	Drorim	496	19
5	Wadi	Wadi N/S	Drorim	486	2
6	Bottom	Bot. S	Drorim	494	13
7	Mid	Mid S	Shivta	504	31
8	Mid-Upper	Mid-Up. S	Netzer	517	14
9	Upper	Up. S	Netzer	527	10
10	Top	Top S	Netzer	531	2
11	Upper	Up. E	Netzer	520	10
12	Mid	Mid E	Shivta	505	17
13	Bottom	Bot. E	Drorim	485	20
14	Wadi	Wadi E/W	Drorim	478	1
15	Bottom	Bot. W	Drorim	488	13
16	Mid	Mid W	Shivta	496	16
17	Upper	Up. W	Netzer	510	11
18	Top	Top W	Netzer	518	3

The letters N, S, E and W stand for the exposures north, south, east and west, respectively. Top S is a joint summit also for the eastern exposure.

Particle size distribution was executed to study dust texture. To determine the total amounts of sand and fines (silt and clay), all samples were mixed with 0·5% of sodium hexametaphosphate and treated with ultrasonic waves for 10 min to ensure silt and clay separation from one another and from the sand grains following the methods used by McTainsh *et al.* (1997) and Crouvi *et al.* (2008) and then wet-sieved through a 62 μm mesh. To calculate the total amounts of silt and clay, the silt and clay fraction of the sediments were then further analysed using a Sedigraph (5000ET; Micrometrics, Norcross, GA, USA). Owing to the small sample size, the summer amounts for both seasons were grouped for the Sedigraph analysis.

An *F*-test (*post hoc*, using Bonferroni) was executed to find significant differences ($P < 0{\cdot}05$). If significant, a paired *t*-test was executed to find significant differences between pairs of habitats. Two-way ANOVA was used to study the effect of aspect and season upon deposition.

RESULTS

Annual rain amounts as measured during 2004/2005 and 2005/2006 were 70·5 mm and 66·0 mm, respectively, lower than the long-term mean of 95 mm. The data show that most of the precipitation fell in between November and March (Fig. 4) as was also the case during the last 40 years. These months will be referred to, hereafter, as the 'wet season', whereas the remaining months will be referred to as the 'dry season'. As for the hydrological rain, significantly higher amounts characterized WF, while being significantly lower at EF. Both NF and SF yielded similar amounts to one another (Fig. 5).

The wind regimes during both wet and dry seasons are shown in Fig. 6. In both seasons, north-westerly and westerly winds prevailed, with north-westerly winds predominating during the dry season and westerly winds predominating during the wet season. The wet season was also characterized by winds with higher speed. Winds >9 m sec^{-1} were six to seven times more frequent during the wet season in comparison with the dry season. These winds comprised 1·9% and 1·2% of all winds during the wet season in comparison with only 0·14% and 0·32% during the dry season of 2004/2005 and 2005/2006, respectively.

Average monthly dust amounts, as obtained at all stations, are shown in Fig. 7. Overall, average annual deposition ranged between 110 g and 178 g m^{-2}, with the average deposition of all stations being 151·1 g m^{-2} and with the average annual deposition of the three hilltop stations being 122·4 g m^{-2}. When the PSD of the dust

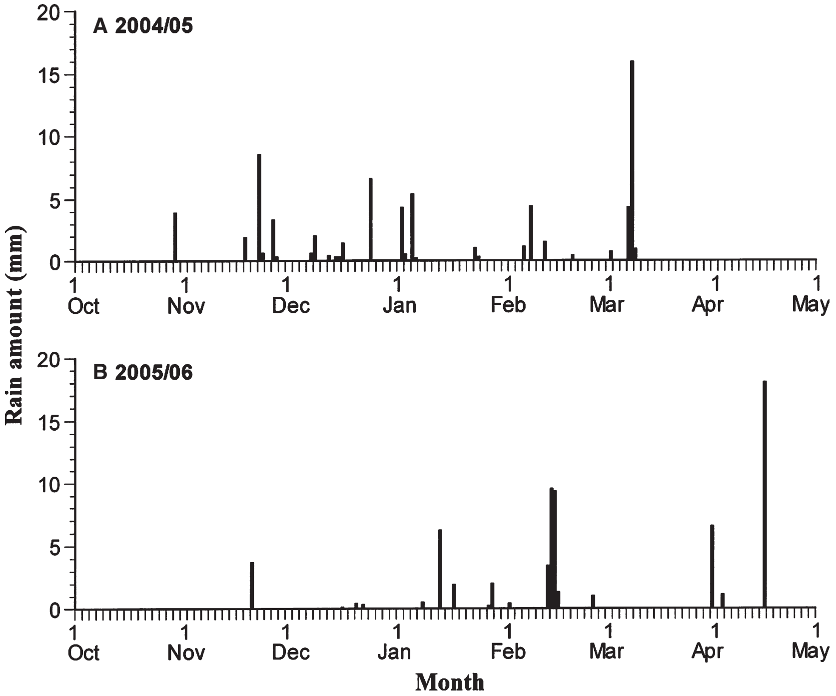

Fig. 4. Daily rain distribution during 2004/2005 (A) and 2005/2006 (B). Ticks on the *x*-axis are spaced at two-day intervals.

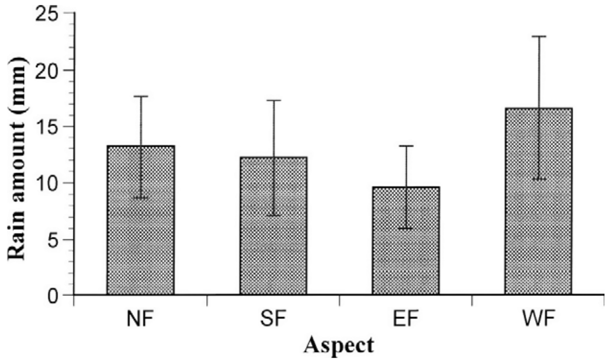

Fig. 5. The distribution of the hydrological rain at the four aspects during 2004 to 2006. Bars represent one SD.

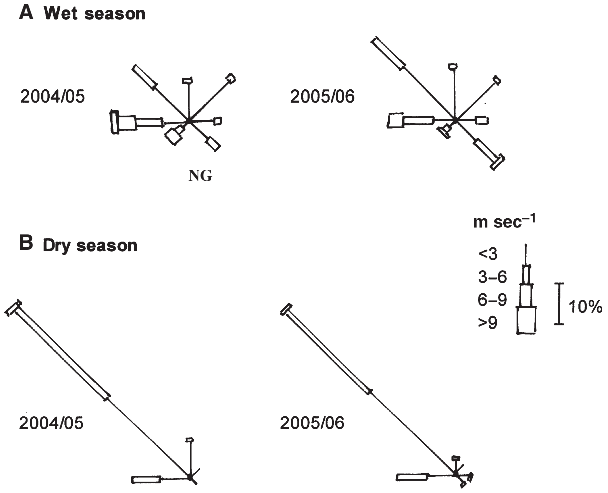

Fig. 6. Windrose during the wet (A) and the dry seasons (B) of 2004 to 2006. Wind data were taken from a meteorological station 1·5 km from the research site.

was examined, dust was mainly comprised of silt (70·2 to 73·7%) with only 13·3 to 16·9% and 13·0 to 15·5% of sand and clay, respectively (Table 2).

The data indicated a consistent trend: dust amounts at the EF stations exhibited the highest amounts, followed by stations at NF, SF and WF, with winter amounts being substantially higher (Fig. 8). The differences were clearer when grouped in accordance with aspect. While NF and SF exhibited similar amounts, higher amounts of dust characterized EF in comparison with WF and the hilltop, being 43·3% and 53·5% higher, respectively. As for the hilltop and wadi stations, higher amounts characterized the wadi stations, especially during the wet season, during which dust deposition at the wadi stations was 31·5% higher than those recorded at the hilltops (Fig. 9).

Indeed, when a two-way ANOVA was executed for all four aspects (Table 3A) or only for NF and SF (Table 3B), only season yielded a significant difference. Both season and aspect yielded a significant difference when a two-way ANOVA was executed on EF and WF (Table 3C), indicating that both season and aspect affect dust deposition at these aspects. As the interaction between aspect and season did not yield a significant difference, it can be concluded that both of these variables affected dust deposition independently. Although higher wind speed, and subsequently higher carrying capacity, may explain the higher dust amounts during the wet season (Dayan *et al.*, 2008; Enzel *et al.*, 2010), the wind regime may also dictate the preferential dust deposition. While no data regarding the near-ground wind regime at the different slopes were available, this was inferred from the hydrological rain, which exhibited higher amounts at WF in comparison with EF (Fig. 5), attesting to the wind-sheltered location of EF (leeside slope).

DISCUSSION

Average monthly dust deposition during the wet season was approximately twice the amount of dust deposited during the dry season. The higher amounts obtained during the wet months should not be surprising given the higher occurrence (six to seven-fold) of >9 m sec^{-1} winds during the wet season in comparison with the dry season; this was verified by long-term measurements. According to Bitan & Rubin (1991), winter winds may reach an hourly average of up to 13·3 to 14·4 m sec^{-1} in comparison with only 9·7 to 10·8 m sec^{-1} for the rest of the year. Given the higher erosivity of high-speed winds (Goossens, 1988), larger amounts of dust are expected. Indeed, westerly and south-westerly winds were of the highest velocity during the current research, in agreement with previous reports (Nativ *et al.*, 1985; Bitan & Rubin, 1991; Enzel *et al.*, 2010). These winds provide most of the dust settled in Israel (Enzel *et al.*, 2010), which mainly stems from northern Sinai (coarse silt) and the Sahara (clay and very fine silt) (Ganor *et al.*, 1991; Crouvi *et al.*, 2008; Dayan *et al.*, 2008).

For the most part, these high-velocity winds are linked to East Mediterranean (EM) cyclones which provide most of the precipitation to the Negev (Kidron & Pick, 2000; Enzel *et al.*, 2008).

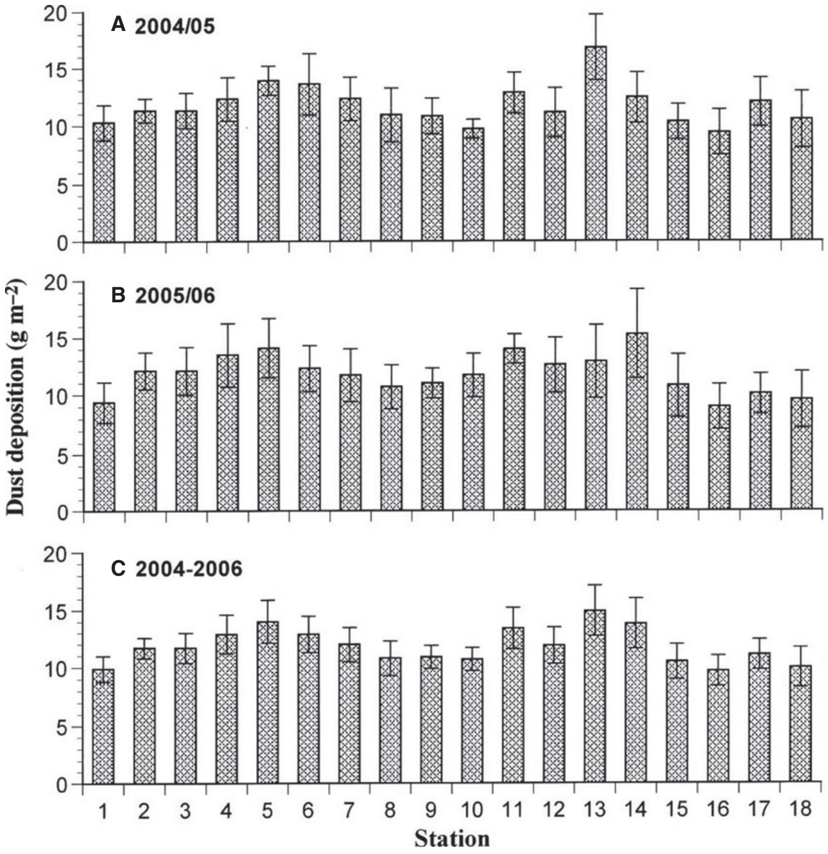

Fig. 7. Average monthly amounts of dust deposition for (A) 2004/2005, (B) 2005/2006 and (C) 2004 to 2006. Bars represent one SD.

Table 2. The average seasonal and annual percentage of fines (silt and clay) in dust during both years of measurements.

	East-facing			West-facing			Total		
Source	Fines	Silt	Clay	Fines	Silt	Clay	Fines	Silt	Clay
Wet season	85·7 (1·3)	70·2	15·5	86·7 (1·1)	73·7	13·0	86·2 (0·7)	72·0 (2·5)	14·3 (1·8)
Dry season	83·2 (1·3)	–	–	83·1 (1·3)	–	–	83·2 (0·1)	71·2	12·0

Values in parenthesis indicate one SD.

These winds are also the main carrier of dust to the Negev (Dayan *et al.*, 2008; Enzel *et al.*, 2008). Apparently, as evidenced by the high amounts of hydrological rain and the low amount of dust recorded at WF, the amount of dust carried by the raindrops was small, although dust may serve as nuclei for raindrops (Levin *et al.*, 1996). However, although the amount of dust carried by the raindrops may be small, dust is principally carried by the high-velocity westerly and south-westerly winds that develop in front of the cold front of the EM cyclones, just prior to the rain event (Enzel *et al.*, 2008). Passing over the northern Sahara and northern Sinai-western Negev sand dunes, these winds are responsible for dune mobilization, sand abrasion and, subsequently, silt production (Whalley *et al.*, 1987; Enzel *et al.*, 2008) along with dust transport and deposition (Dayan *et al.*, 2008). The findings of the present study indicate that the dust will preferentially settle at wind-sheltered sites, such as at the lee slopes, thus showing a close link to the wind regime. The link between the wind regime and dust deposition is reflected by the higher amounts of dust received at EF, i.e. at the leeward slope (as can be deduced from the much lower hydrological rain received at EF in comparison with WF). On

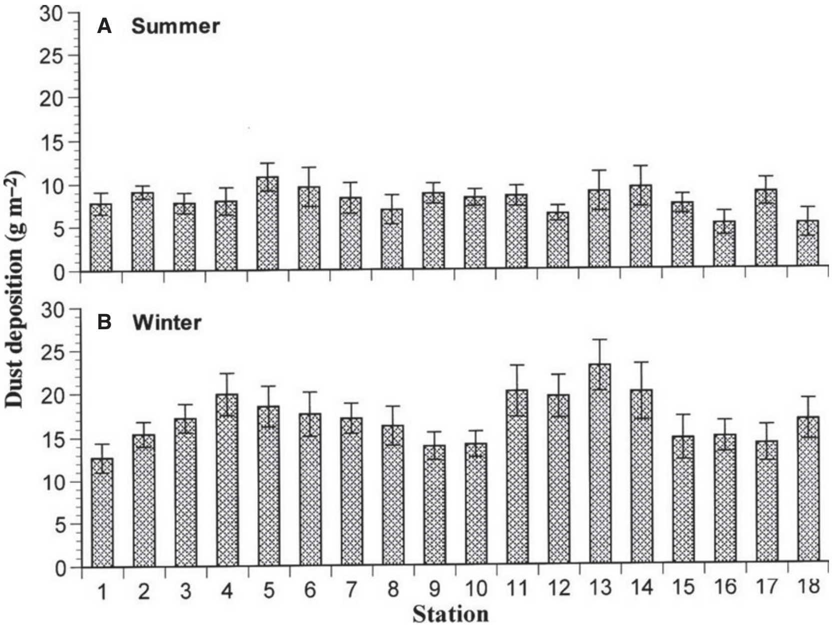

Fig. 8. Average monthly amount as obtained for (A) summer (April to October) and (B) winter (November to March) during 2004 to 2006. Bars represent one SD.

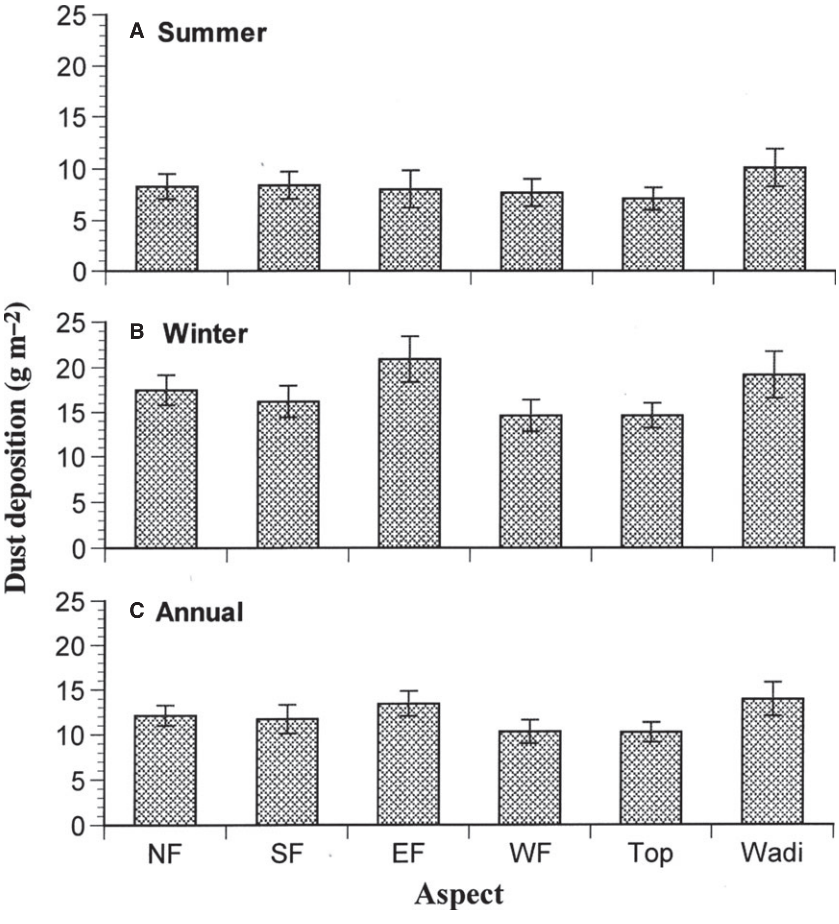

Fig. 9. Average monthly amount of dust deposited at the northern aspect (stations 2 to 4), southern aspect (stations 6 to 9), eastern aspect (stations 11 to 13), western aspect (stations 15 to 17) and at hilltops (stations 1, 10 and 18), and wadi beds (stations 5 and 14) during summer (A), winter (B) and all year (C).

Table 3. Two-way ANOVA for dust deposition in relation to aspect and season of: (A) the four aspects (north, south, east and west); (B) the northern and southern aspect; and (C) the eastern and western aspect.

(A)

	Season	
Aspect	Winter	Summer
North		
M	17·48	8·28
SD	(2·32)	(0·68)
N	6·00	6·00
South		
M	16·20	8·41
SD	(1·83)	(1·10)
N	8·00	8·00
East		
M	19·12	8·00
SD	(5·67)	(1·74)
N	6·00	6·00
West		
M	14·52	7·17
SD	(1·09)	(1·96)
N	6·00	6·00

Source of variation	SS	df	*F*	*P*-value
Aspect	2·28	1	0·90	0·354
Season	494·70	1	193·90	<0·001
Aspect × season	3·42	1	1·34	0·258
Error	61·20	24	–	–
Total	560·00	27	–	–

(B)

Source of variation	SS	df	*F*	*P*-value
Aspect	44·28	1	4·41	0·049
Season	511·50	1	51·00	<0·001
Aspect × season	21·28	1	2·12	0·161
Error	200·80	20	–	–
Total	777·90	23	–	–

(C)

Source of variation	SS	df	*F*	*P*-value
Aspect	48·20	3	2·70	0·057
Season	1005·60	1	168·80	<0·001
Aspect × season	26·98	3	1·51	0·225
Error	262·10	44	–	–
Total	1339·50	51	–	–

M, mean; SD, one standard deviation; *N*, number of observations; SS, sum of squares; df, degree of freedom; *F*, F-test.

the other hand, the channelling effect of the west–east-trending wadi, i.e. the re-direction of the wind along the wadi bed (Weigel & Rotach, 2004), is reflected by the similar rain amounts that were recorded at NF and SF. Contrary to urban environments (Oke, 1978), the channelling effect did not result in accelerated wind speeds (Kidron *et al.*, 2000). It may, however, explain the similar amounts of dust received at both slopes.

In comparison with the hilltops, the wadi bed and all the slope stations showed preferential deposition, in agreement with the lower wind velocities that were recorded at the slopes and the wadi beds (Kidron *et al.*, 2000). When calculated in accordance with topography, the average annual amount across all slopes was 151·1 g m^{-2}, i.e. 23·5% higher than that obtained at the hilltops. East-facing slopes received the highest amount of 186·3 g m^{-2} (when calculated according to a planar surface), i.e. 52·2% higher than the dust amount received at the hilltops, of 122·4 g m^{-2}. These amounts measured in this study were lower than the amounts monitored by other authors, of *ca* 200 to 250 g m^{-2}, which may be explained by the use of wet traps in other studies (Ganor, 1975; Goossens & Offer, 1990; Ganor & Foner, 1996). Wet traps may primarily reflect all dust particles crossing (but not necessarily settling on) a certain surface area (represented by the trap). Alternatively, the current use of dry and low-rim traps might more closely (but not entirely) reflect net deposition, i.e. dust particles most likely to accumulate within a certain surface area (trap).

It would be expected that the higher amounts of dust recorded at EF would be reflected in the landscape, for example, at areas having relatively homogenous surfaces that would not have complex wind–water interactions. For such a pattern to be preserved, it should be assumed that past wind flow trajectories, responsible for long-term patterns of dust deposition, were similar to the current trajectories.

A very comprehensive and detailed account of the past wind trajectories and loess accumulation in the Negev was recently provided (Crouvi *et al.*, 2008; Enzel *et al.*, 2008). Based on an analysis of the past palaeogeography, the wind regime and the loess properties, Enzel *et al.* (2008) assert that all evidence points to the Sahara (in general) and the northern Sinai (in particular) as the main source of loess. According to Enzel *et al.* (2010), past wind trajectories were similar to the current wind trajectories,

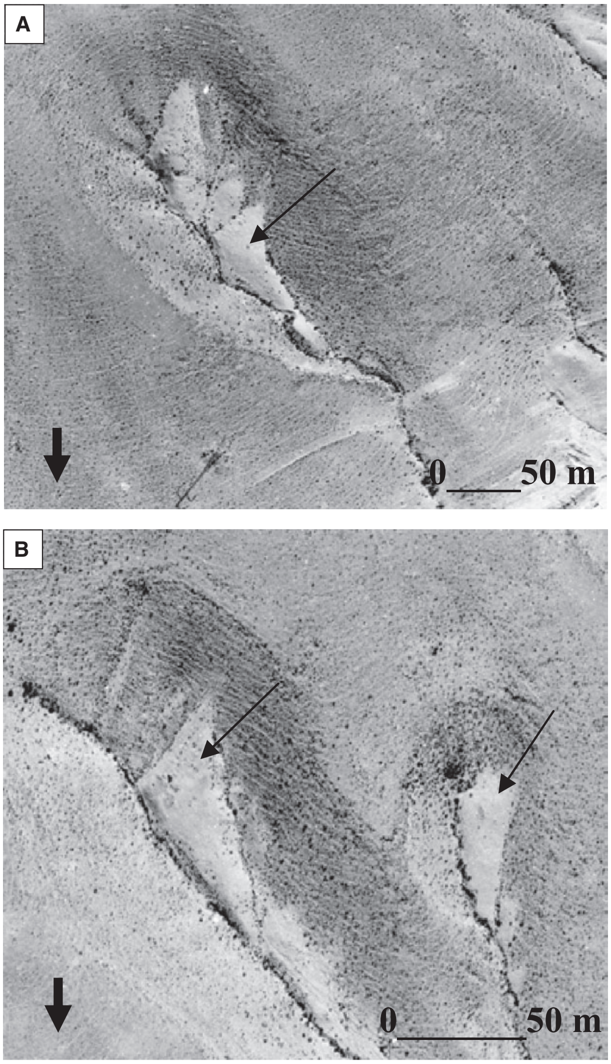

Fig. 10. Aerial photographs (A) and (B) showing aeolian aprons (indicated by thin arrows) near the Negev junction (NG). Thick arrows point towards the North.

implying a similar wind regime and subsequently similar patterns of deposition.

However, surface heterogeneity, as is the case in SB and in Avdat (where Goossens and Offer conducted their measurements), may blur depositional patterns. This heterogeneity may result from the variable responsiveness of the surface to runoff. While readily taking place on massive rock surfaces, runoff generation is hindered by jointed limestone (Yair & Lavee, 1985). This complex interaction between aeolian deposition and runoff may overshadow aeolian depositional patterns. Therefore, it was assumed that homogeneous slopes, such as those at the northern Negev, may better reflect net aeolian deposition. To this end, a survey was conducted at the Negev junction (referred to herein as NG), 20 km north of the present research site (see Fig. 2). The area consists of mixed layers of Eocene chalk and flint.

Aerial photographs and ground photographs at NG are shown in Figs 10 and 11, respectively. Pale yellowish sediments are clearly visible. These yellowish sediments tend to accumulate close to the hill divide and therefore can be defined as aeolian aprons. As in the other areas in the northern Negev (not shown), aeolian aprons are confined to the eastern or north-eastern aspects. Located near the hill divide, water erosivity is apparently low, suggesting that these sediments are originally wind-deposited, with minimal involvement of colluvial processes.

This interpretation was supported by the PSD at NG. Particle size distribution (PSD) at NG revealed a close resemblance (although with a higher fraction of coarse silt) to the dust captured in SB, supporting an aeolian origin for the aprons (Fig. 12). The coarse silt at NG may stem from high magnitude cyclones and associated loess deposits characterizing the late Pleistocene, during which the majority of loess accumulated in the Negev (Enzel *et al.*, 2008; Roskin *et al.*, 2014). Furthermore, the better sorted grains of the sediments may point to a closer source, possibly the Sinai dune field, as the main source of loess deposits in the Negev. Consistent with the results herein, these findings point to preferential deposition of the loess at the east-facing and north-east-facing slopes.

Subsequently, the data herein differ from those of Goossens & Offer (1990, 2005), Goossens (2000) and Offer & Goossens (1995), regarding the preferential deposition of dust at the windward (principally at the concave slope section) aspect. The differences in field data may stem from the use of wet traps (Goossens & Offer, 1990; Offer & Goossens, 1995), which tend to trap all particles crossing the actual surface area occupied by the trap. As for net accumulation, while Goossens & Offer (2005) concluded, based on the volume of loess deposition around a hill, that preferential net accumulation takes place at the windward slopes (among other places), total dust deposition during this study points to preferential net accumulation at the leeside slope.

It should, however, be noted that all studies, including the current study, may have drawbacks. Following high-depth rain events in the winter, some of the water spilled over the sampler rims, as indeed noted in the field. Trap efficiency also increases at lower wind speeds (Hall

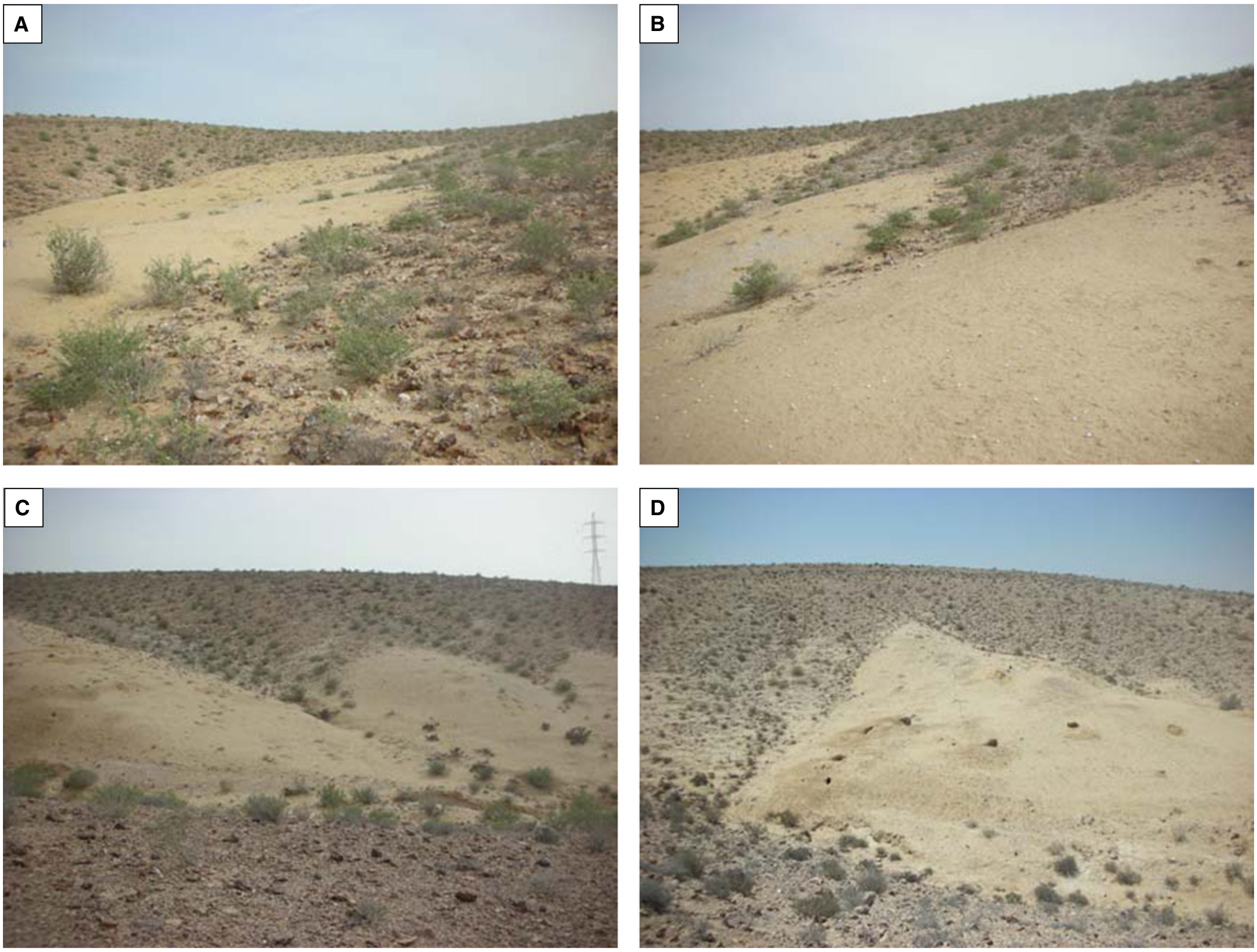

Fig. 11. Aeolian aprons at the Negev junction as photographed from the ground. Shrubs at the front of the photographs are up to 70 cm tall.

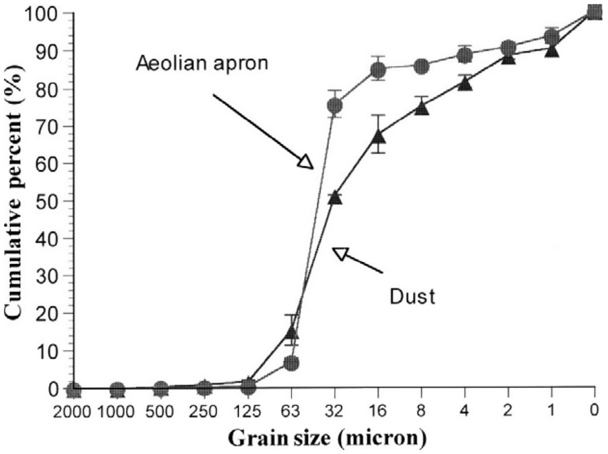

Fig. 12. Cumulative grain-size distribution of dust in Sede Boqer in comparison with the aeolian aprons at the Negev junction. Bars indicate one SD.

& Upton, 1988; Sow *et al.*, 2006) and this may result in preferential deposition at the leeside slopes (with lower wind speeds). Furthermore, the proximity and steepness of the opposite slopes may bias the results, because the leeside slopes may affect the wind regime at the windward slopes. Also, monthly deposition may not necessarily reflect net accumulation. Nevertheless, as observed during a rain event, the mineral grains tended to concentrate at the bottom of the trap and no visible loss was observed, implying only negligible loss of minerals during high-depth rain events. As for the trap efficiency, the conclusion of the present authors regarding preferential accumulation at the leeside slopes is supported by the lower gustiness that is expected to take place at these slopes. It is also supported by the above-mentioned field survey.

The present authors would like to argue that the higher trapping efficiency of the dry traps at low wind velocities cannot be regarded as a drawback, but rather may reflect the core principal of the classical model that anticipates higher dust accumulations at leeside slopes where wind velocity is low. It is argued that natural surfaces, especially in a desert such as the Negev, are characterized by very high cover of rock particles (cobbles, pebbles and stones; for details, see text and fig. 2 in Kidron & Starinsky, 2011). These rock particles serve as natural dry traps and, as such, are subjected to the very same 'limitations', i.e. high trapping efficiency at low-velocity winds. It is further argued that for a deposited dust grain to be re-lifted, higher energies (i.e. higher wind speeds) are necessary, which are most likely to take place at the windward slopes. Higher speeds at the windward slopes may result in turn accumulation of dust at the windward slopes, and in high net accumulation at the leeward slopes. As for biased results following slope proximity and steepness, no preferential accumulation was noted next to steep slopes as verified by the loess deposits next to SB or by the present field survey at NG that showed preferential leeside accumulation also on low-angle and distanced slopes (Figs 1, 11 and 12).

The current findings, coupled with a field survey at NG, provide extra credence to the classical model (Souster *et al.*, 1977; Brunotte, 1979; McDonald & Busacca, 1990; Arno *et al.*, 1998; Renssen *et al.*, 2007) whereby preferential dust deposition takes place at the leeward slopes. The findings of preferential accumulation at the leeward slopes are in agreement with field measurements at a loessial region in China (Hoffmann *et al.*, 2008) and also in agreement with field surveys that show preferential loess deposits in the leeside slopes of northern France (Antoine *et al.*, 2003).

Because soil forming processes are highly impacted by parent material and aspect, knowledge regarding the depositional patterns is very important. The data herein show that, in agreement with other publications (Li *et al.*, 1988; Pye, 1995), the hilly terrain promotes dust deposition in comparison with a flat area, and that in comparison with the hilltops, slopes and wadi beds accumulate higher amounts of dust. Thus, in addition to its role in concentrating runoff and impeding evaporation (Kidron & Zohar, 2010), the high trapping efficiency of the wadi provides preferential growth conditions for plants. Similarly, by creating preferential loci for dust deposition, both wadis and slopes act to intensify dust accumulation and consequently soil formation.

The present data highlight the role of seasonality in dust deposition and support the spatial distribution of the colluvial sediments and the aeolian aprons in the Negev. The current depositional patterns may facilitate the use of loess deposits as indicators for the possible source, environmental conditions and palaeo-cycles of dust deposition (Kohfeld & Harrison, 2003) responsible for loess accumulation also in other parts of the world (Mason *et al.*, 1999; Mason, 2001).

CONCLUSIONS

Research was carried out over a two-year period (2004 to 2006) during which monthly dust deposition was measured at 18 stations along four slopes, north-facing, south-facing, east-facing and west-facing in a second-order drainage basin near Sede Boqer, Negev Desert Highlands. Average annual dust deposition was 151·1 g m^{-2}. This deposition was 23·5% higher than the average amount recorded at the hilltops (122·4 g m^{-2}), due to the sheltering properties of the hilly topography. Significantly higher monthly amounts were received during the wet rainy season of December to March (17·0 g m^{-2}), in comparison with the rest of the year (8·1 g m^{-2}). While no significant differences characterized north-facing and south-facing, east-facing in the leeward side of the wind received significantly higher amounts (43·3% higher) than west-facing, in agreement with the classical model, but in disagreement with some reports published in the literature. The findings of this study were supported by a field survey that showed preferential loess accumulation at the eastern and north-eastern aspects. The current findings may explain spatial distributional patterns of loess accumulation and aeolian aprons in the Negev. These findings may also have important implications for soil-forming processes and past cycles of dust deposition.

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