Aeolian microtextures in silica spheres induced in a wind tunnel experiment: Comparison with aeolian quartz

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A B S T R A C T

Microtextures in quartz attributed to aeolian transport, principally bulbous edges and abrasion fatigue have seldom been tested in the laboratory under controlled conditions. A wind tunnel experiment was conducted, using glass spheres (>70% SiO2) as a proxy for quartz, with the objective of determining the extent of mechanical damage to silica/glass transported in a mixture with quartz beach sand. The microspheres were microscopically imaged prior to transport in a wind tunnel, subjected at velocities ranging from 4 to 13 m/s in sequential runs of 10 min. The range in velocity is capable of lifting grains into the air column or saltating quartz grains and silica/glass spheres to produce mechanical impact, i.e. abrasion commonly experienced in aeolian transport. With increasing velocity silica/glass spheres, which displayed minor imperfections prior to transport, began to show significant grain damage exhibiting increasing depth into the silica/glass fabric – a result of mechanical contact – as well as increasing frequency of craters, dislodged plates and abrasion fatigue. While pits appear earlier in the experiment (8 m/s), dislodged plates and abrasion fatigue need a threshold velocity of near 10 m/s to become more frequent. Bulbous edges on the grain surface, often considered the hallmark of aeolian transport, are not seen in the grain population analyzed, possibly because of the initial near-perfect sphericity of the silica/glass spheres. The experiment proved that aeolian transport throughout short distances and during a relatively short period of time is enough to imprint significant abrasion marks in microspheres. In fact, the microtextures produced were fresh surfaces, fractures and abrasion that imprinted areas of different sizes. A comparison of microtextural imprints on silica/glass spheres relative to coastal dune sands was made to better understand energy thresholds required to achieve grain damage.

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1. Introduction

The use of scanning electron microscope (SEM) in sedimentary studies was proposed by Biederman (1962) and has been applied in the microtextural characterization of Aeolian grains in the past (Krinsley and Takahashi, 1962; Campbell, 1963; Krinsley and Donahue, 1968; Krinsley and Margolis, 1969; Fitzpatrick and Summerson, 1971; Nieter and Krinsley, 1976; Krinsley and Wellendorf, 1980; Lindé and Mycielska-Dowgiallo, 1980; Hanes, 1986; Willetts and Rice, 1986; Bela et al., 1995; Williams et al., 1998; Abu-Zeid et al., 2001; Mahaney et al., 2001; Lisá, 2004; Moral Cardona et al., 2005; Kenig, 2006; Morgan et al., 2008; Costa et al., 2009). Additionally, quartz grain SEM pictures were compiled as atlases by Gillott (1974), Krinsley and Doornkamp (1973), Le-Ribault (1977) and Mahaney (2002). The interpretation of quartz microtextural imprints has been applied to a wide range of sedimentological environments and even in forensic studies (e.g. Bull and Morgan, 2006; Pye, 2007) and have been used essentially as a complementary tool to provenance studies. With that purpose in mind it is essential to establish the relationship between microtextural peculiarities and sedimentary environments.

Krinsley and Takahashi (1962) compared SEM images of crushed quartz grains subjected to an air jet, ball mill and shaking table, and compared them with grains from modern beach and dune deposits to understand the transport history of the grains based in their surface morphology. Nieter and Krinsley (1976) analyzed and experimentally tested a population of loess grains from Long Island (New York) and concluded that silt-sized quartz is a powerful agent of abrasion and that short periods of time and gentle winds (10 mph=app. 4.5 m/s) can promote sufficient grain collisions to modify the surface of quartz grains.

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In microtextural studies of grains emplaced in aeolian environments (dunes), Abu-Zeid et al. (2001) examined quartz sand grains in desert dunes from Al Ain in the United Arab Emirates and revealed that a strong variability was observed displaying mechanically and chemically altered surface textures. The authors only identified the microtextures but were not able to conclude about the provenance of the grains based exclusively on their surface microscopic features. Costa et al. (2009) and Costa et al. (accepted for publication) used approximately 4000 quartz grains from tsunami deposits and present-day analogs (nearshore, beach, dune and alluvial samples) from a group of locations worldwide (Portugal, Indonesia and Scotland) to characterize grains laid down by tsunami waves and to establish, whenever possible, the provenance of such grains. Their results point to the difficulties of assigning general microtextural features to specific sedimentary environments, even though, in some cases, the results proved conclusive and established likely sources for quartz grains transported and deposited by tsunami waves. Furthermore, it was suggested that a short-lived event (e.g. tsunami) has the capacity to imprint the surface of the grains as demonstrated by Mahaney and Dohm (2011). Dune samples are characterized as having a balanced representation of the microtextures analyzed (fresh surfaces, percussion marks, angularity, dissolution and adhering particles). The application of grain surface microtextural studies was further used, for instance, in forecasting the microtextural characteristics that should be present in a tsunami grain in Mars or in Japan (associated with the March 2011 tsunami) (Mahaney et al., 2010; Mahaney and Dohm, 2011). Differences in fluid viscosity between the two media – water and wind – seem to produce different microtextures exclusive to the environment, with v-shaped percussion cracks exclusive to water and abrasion fatigue and bulbous edges to air.

Many wind tunnel experiments have tried to address several issues regarding physical and sedimentological features of aeolian transport (e.g. Bauer et al., 2004; Rasmussen et al., 2011), threshold velocities for particle entrainment under different moisture characteristics (e.g. Bauer et al., 2004; Han et al., 2009) or different particle sizes (e.g.: Kang et al., 2008; Li et al., 2008; Harikai et al., 2010).

Regarding imagery of grains, only the work by Yang et al. (2007) and Rasmussen et al. (2011) have used laser or SEM images to observe effects of wind tunnel aeolian transport. However, no one but Krinsley and Wellendorf (1980), Willetts and Rice (1986) and Lindé and Mycielska-Dowgiallo (1980) have studied the microtextural features in quartz grains after being submitted to a series of wind tunnel tests.

Willetts and Rice (1986) developed and filmed a wind tunnel experiment designed to observe particles colliding with the sediment bed. They collected important data about these collisions and were able to conclude that sediment bed activity caused by collision increases with particle sphericity.

Lindé and Mycielska-Dowgiallo (1980) prepared three experimental sets where quartz grains were subjected to different tests: (a) after grinding of quartz crystals in a rotating rock mill, (b) after a plus aqueous transportation of two durations (600 and 1000 h), and (c) after (a) plus aeolian transportation of three durations (5, 50 and 100 h). The sediment composition used was one mixture of sand from a Polish river and another from Polish dunes. The authors concluded that in the aeolian experiment the rounding of the corners of the grains was greater than in the aqueous experiment. Furthermore, there was deposition of grain fragments on the larger grains in the aeolian experiment. The presence of upturned plates as well as small molten and recrystallized quartz fragments was also noted. The aeolian grains from the experiment were better rounded and the authors attributed this fact to the higher impact energies and by the absence of a shock-absorbing water cushion around the grain.

The objective of this paper is to characterize the microtextural aeolian features of silica/glass (as an analog of quartz) grains using a wind tunnel experiment and to contribute to the determination of microtextural signature of dune grains.

2. The experiment

A wind tunnel experiment was conducted in Laboratório Nacional de Engenharia Civil (LNEC) is a Boundary Layer Wind Tunnel type with a test area 9 m long and a cross section of 2×3 m². It works by suction, admitting and discharging to the atmosphere, and is capable of generating winds up to 18 m/s. In this experiment the velocities varied between 4 m/s and 13 m/s.

The platform used consists of a 6 m-long×0.50 m-wide wooden structure, bordered by a 0.20 m-high vertical wall used to prevent salination beyond the transport path. This structure was situated at 0.10 m above the floor (Figs. 1 and 2).

Covering the platform, a mixture of approximately 66% of sand (beach face from Praia dos Salgados, Algarve, Portugal – selected because of sediment availability due to other on-going studies by the authors – with approximately 33% of silica/glass microspheres (Roadpaint 850-425 AC90; see Table 1 for details)), weighting a total of approximately 200 kg of sediment (i.e. sand + microspheres). Glass (> 70% SiO₂) microspheres were selected because their physical and mechanical features (i.e. hardness; specific weight and mean grain size) present many similarities with common quartz grains (Table 1) and from an economic point of view offer a competitive price. The sand was not washed with tap water and contained approximately 25% of carbonates (that were not removed). The sand was dried for 48 h at 60 °C and no cohesive forces were detected prior to the experiment. The median grain-size of the beach sand was 1.14 φ. The surface of the platform was covered by the sediment with a 0.05 m thickness and was flattened with an acrylic ruler and with a broom. A number of 2 cm³ receptors were placed at uniform distances of 1 m to allow recovery of grains traveling along the platform (Fig. 3). These receptors were positioned approximately 1

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**Fig. 1.** Schematic draw of the platform used during the wind tunnel experiment. Units are in cm.
to 2 mm above the sandy surface aiming to collect only grains transported by saltation. At the end of each run no obstacle forms were observed at the windward side of the receptors (transport by creep did not occur).

At the end of the 6 m-long platform a group of four 0.45 m-wide square boxes were placed at the floor level (i.e. 0.10 m below the base of the platform) therefore collecting grains dislocated along the platform and still under transport at its end. Initially a mesh (100 μm) was set up to retain all the grains that were not collected by the 4 square boxes located at the end of the platform. However, this mesh was removed because it caused constraints on air flux, decreasing velocities.

The removal of the mesh at the end of the platform may have affected average wind speed and vertical wind distribution in the early stages of the experiment when no sand movement was observed. Thus, it did not influence the results (i.e. microtextural imprints).

Seven 10-minute runs were conducted at increasing velocities (i.e. 4 m/s, 6 m/s, 7 m/s, 8 m/s, 10 m/s, 12 m/s and 13 m/s). All the runs were filmed with a fixed digital camera located at 2 m from the end of the platform, pointing in that direction. Photographs were also taken and an observer stayed within the wind tunnel channel to witness if any movement occurred. After each 10-minute run, samples were collected from each receptor (total 6) (Fig. 4). The water content for each specific run was calculated considering the difference between the wet and dry weights of a collected sample, after the sediment was dried at 100 °C for 12 h.

The samples from all runs were observed under a magnifying binocular lenses Leica EZ4 (300×) and the marks in the microspheres were noticeable when compared with the pre-experiment microspheres.

A minimum of 10 silica/glass microspheres were collected in each receptor after each run. Moreover, these grains were considered as representative to determine grain microscopic surface properties. Quartz and silica/glass microsphere grains were analyzed under the binocular microscope (Fig. 5) and prepared for SEM. This preparation involved sputter coating with Au to make the grains conductive. The grains were then taken to the SEM laboratory (Faculdade de Ciências da Universidade de Lisboa) and photographs were obtained using a JEOL JSM 5200 LV SEM (Fig. 6 — silica/glass microspheres that were imaged before the experiment).

### 3. Results

During the runs at 4 m/s, 6 m/s and 7 m/s it was not possible to detect any transport by rolling or saltation. After the 8 m/s run saltation occurred and it was intensified with the increase in velocity up to 13 m/s where significant sediment transport (suspension) occurred.

The water content influence was especially noticed in the initial threshold for saltation; contrary to the expected 7 m/s (e.g. Bagnold, 1941; Li et al., 2008) the saltation was only slightly initiated after 8 m/s. This was due to the fact that the wind tunnel is exposed to outdoor conditions which contributed to the results, because of the humidity registered in the day of the experiment (approximately 80%). The measurements of water content after each run revealed that initially (before the 1st run) the sediment exhibited 1.6% water content and samples became drier as the experiment occurred (value of 0.47% of sample weight at 13 m/s). However, at 8 m/s the water content measured was higher (2.59% of the sample weight) mainly as a result of weather influence at the specific day time while that run was being conducted. Although this is a relevant factor in terms of the establishment of the threshold of sand movement by wind it did not greatly interfere with the main goal of our experiment (i.e. the determination of microtextural imprints).

There were a small number of sedimentary structures detected at 12 m/s and 13 m/s and those were deflection and shadow structures. The total sand loss was not possible to quantify exactly due to the removal of the 100 μm mesh initially located at the end of the platform.

### Table 1

<table>
<thead>
<tr>
<th>Beach grains and microspheres textural features.</th>
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<tr>
<td>Grain size (app.)</td>
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<td>-------------------</td>
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<tr>
<td>Glass microspheres</td>
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<tr>
<td>Beach sand (Salgados)</td>
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Fig. 2. Photo of experiment apparatus.

Fig. 3. Photo of receptor within the platform used for the wind tunnel experiment.

A — The two cm receptor within the sand carpet.

Fig. 4. Weight of samples collected after each run at the end receptor. It is noticeable the exponential increase of sand + microspheres transported across the 6 m-long platform.
However, the weight of sediment initially placed in the platform and the sediment removed from the platform at the end of the experiment allows an estimation of sediment loss of approximately 20 to 30 kg, i.e. 10% to 15% of the original sediment.

Fig. 4 presents the variation of weight detected in receptor 6 (the more distal receptor) and also shows the exponential increase in sediment collected with increase in velocity. In the receptors 1 to 5, located within the platform, it was possible to collect sediment samples after the 8 m/s run although in very small quantities (less than 1 g) (Figs. 5 and 6). Furthermore, more than 1 g of sediment samples was collected from these receptors only at 12 m/s and 13 m/s runs.

Fig. 7 exhibits a mosaic with 4 SEM images of silica/glass microspheres collected in receptor 6 after the run at 8 m/s where microtextural imprints (e.g. abrasion marks, craters) in the grains surface can be observed revealing the effects of grain collision during the 10-minute run. However, Fig. 7C displays one microsphere with no major microtextural mark in its surface. Furthermore, Fig. 8 compiles 4 SEM images obtained from samples collected in receptor 6 after the 10 m/s run, revealing an increase in the presence of abrasion marks, craters and the presence of a tectonic microfeature with conchoidal and linear fracturation. It was also observed the presence of many minor particles, which resulted from surface weathering, providing some coating to the microspheres. Moreover, Fig. 9 is a mosaic assembled with 4 SEM images obtained from samples collected in receptor 6 after the 12 m/s run. An increase in the presence of particles of different sizes (Fig. 9B, C, D) is observed when compared with previous wind tunnel runs. An increase in the number of abrasion marks and pits is also noted.

In Fig. 10, a mosaic is presented compiling 4 SEM images from samples collected in receptor 6 after the 13 m/s run. In this group of microspheres an increase is observed in percussion marks, a broken edge (Fig. 10D) and more extensive abrasion marks.

On the other hand, Fig. 11 presents the percentage of imprinted grains observed in the samples collected at the end receptor after each run. In this figure it is possible to observe that a linear increase in imprinted grains ($r^2 = 0.89$) is detected up to 12 m/s in successive runs. Furthermore, an increase in the number of imprinted grains is seen from 0% at 6 m/s (no movement) up to 60% at 13 m/s, thus demonstrating the direct correlation between wind velocity and microtextural imprints in the microspheres (used as analog for quartz grains). In Fig. 12, a chart demonstrating the variation of the percentage of imprinted grains along the platform during the 13 m/s run is
displayed. In this chart, there is a percentage increase between receptor 1, located at 1 m from the start point of the platform, with 45% of imprinted grains, and receptor 6, located at the end of the 6 m long platform, with 60% of imprinted grains. These values are somewhat hindered by the fact that the wind tunnel runs were conducted successively, thus the percentage of imprinted grains may be overestimated. The

Fig. 7. SEM silica/glass microspheres images obtained after a 10-minute run at 8 m/s. A — Abrasion mark noticed in the center of the grain; pits are also visible in the grain’s surface. B — Minor abrasion detected in the center of the grain. C — Microsphere with no visible microtextural imprint. D — Microspheres with minor shape imperfections but with strong microtextural imprints (e.g. abrasion marks and deep craters).

Fig. 8. SEM silica/glass microspheres images obtained after a 10-minute run at 10 m/s. A — Tectonic microfeature with deep crater irradiating energy that originated conchoidal and linear fracturation and the formation of steps. B — Microsphere covered with small particles and with its surface imprinted by abrasion marks and pits. C — Abrasion marks and presence of particles in the surface of the microsphere. D — Large microsphere with abrasion marks and the presence of particles in its surface.
samples collected (see weight data in Fig. 4) were analyzed morphoscopically and randomly at least 20 microspheres per sample were selected for SEM.

The experimental microtextural imprints were compared with quartz grains from 3 study sites from the Portuguese southern coast – Martinhal, Boca do Rio and Salgados – (Fig. 13) where 13 coastal dune

Fig. 9. SEM silica/glass microspheres images obtained after a 10 min run at 12 m/s. A – Surface of the microsphere with pits, abrasion marks and covered by many small particles. B – Microsphere surface covered with many particles of different sizes and some pits. C – Large pits and “coating” of particles observed in the surface of the silica/glass microsphere. D – The microsphere has its surface imprinted with percussion mark, pits and abrasion marks as well as a significant coating of particles.

Fig. 10. SEM silica/glass microspheres images obtained after a 10-minute run at 13 m/s. A – Surface of the microsphere covered with larger abrasion marks, deeper pits and coated with particles of different sizes. B – Percussion and abrasion marks are noticeable in the surface of the microsphere. C – Less intense abrasion patterns in the surface of the microsphere when compared with other images from this mosaic. D – Edge of the microsphere is broken; strong abrasion is visible, with considerable removal of the surface of the grain.
samples were collected and observed under the SEM (Fig. 14). Dune samples present typically bulbous edges, some dissolution, adhering particles and in some cases it is also possible to observe percussion marks. However, these features might be camouflaged due to the age of the dune (i.e. in a younger dune the presence of grains with fresh marks or sharp edges can be detected but with time the grains become rounder and dissolution features will be observed). A semi-quantitative approach to the microtextural classification (Costa et al., accepted for publication) of each grain was used, based upon the proportion of the grain surface occupied by each feature [0 (absent) to 5 (>75% of the grain surface)]. The angularity of the grains was classified from 0 to 5 (very rounded to very angular). Median values for each variable were calculated for each sample (Table 2). In this table, the microtextural quantification of 13 dune samples is presented and their median values stress the fact that dunes tend to exhibit low values of angularity and high values of dissolution and adhering particles. When comparing these results with the experimental data, one can observe that the roundness/angularity is a factor that is more time dependent, while abrasion, pits and percussion marks are present in both experimental and field data. However, in dune grains some mechanical imprints are sometimes covered by adhering particles or masked by dissolution (slower processes).

4. Discussion

The microtextural characterization of known dune grains was attempted in this study and results were in agreement with previous works by Nieter and Krinsley (1976), Lindé and Mycielska-Dowgiallo (1980), Pye and Tsoar (1990) and Mahaney (2002), allowing the description of coastal dunes with its generally common microtextural imprints (bulbous edges, rounded grains, dissolution features and abrasion marks).

Five types of microtextural features have been reported to be characteristic of aeolian quartz grains from modern deserts (Krinsley and Trusty, 1985):

(a) General rounding of edges, regardless of whether the grains have high or low sphericity.
(b) Upturned plates. These plates appear as more or less parallel ridges ranging in width from 0.5 to 10 μm and have been interpreted as resulting from breakage of quartz along cleavage planes in the quartz lattice.
(c) Equidimensional or elongate depressions, 20–250 μm in size, which occur predominantly on larger grains and which are caused by the development of conchoidal fractures during collisions. They are believed to develop as a result of direct impacts rather than glancing blows during saltation.
(d) Smooth surfaces which occur mainly on smaller grains (90–300 μm diameter), resulting from solution and precipitation of silica.
(e) Arcuate, circular, or polygonal fractures which are mostly found on smaller (90–150 μm) grains. These probably have several different origins, including the development of fractures during direct impacts, salt weathering, and chemical weathering.

A comparison between experimental data and field data demonstrates some constraints associated with limitations on the duration of the experiment, thus revealing that time plays a decisive role especially in the angularity/roundness microtextural signature — Krinsley and Wellendorf (1980) concluded that 25 mm would be sufficient to totally resurface a quartz grain in an experiment with winds of 8 m/s and sand grains of 500 μm in diameter.

The rounding of quartz grains has been significantly clarified by the precursory work of Twenhofel (1945) who concluded that wave traction transportation is not very, if at all, effective in producing rounding on sands of the specific gravity, solubility, and hardness of quartz on grains less than 1/4 mm in diameter and is not very effective on grains in the 1/4 to 1/2 mm size-range. It is considerably effective on grains in the 1/2 to 1 mm range, and increasingly effective with increasing grain size. Rounding by wave traction transportation is readily produced on minerals of high specific gravity, such as magnetite and zircon, to dimensions as small as 1/16 mm in diameter, and any rounding of sand grains by aqueous traction transportation requires travel of many thousands of miles. It is concluded that aeolian traction transportation is more effective in producing rounding than aqueous traction transportation for the same distance traveled, and that grains less than 1/4 mm in diameter of the hardness and specific gravity of quartz may be rounded in such transportation. Goudie and Watson (1981) examined fine and very fine sand grains in 108 desert dune sand samples from different parts of the world and found that well rounded grains are relatively rare (ca. 8% of grains examined). The same authors indicated that most quartz dune grains are not well rounded except where the sands have been recycled from older sedimentary units. In a more recent study, Kasper-Zubillaga (2009) compared SEM images of quartz grains from beach, coastal and desert dunes and concluded that in beach and dune environments there is an increase in rounded quartz grains from the beach towards the dune crest due to selective transport and abrasion associated with time and distance. Thus, there is good agreement with Beal and Shepard (1956) who observed coastal dune sands in several parts of the United States and Brazil and detected a higher degree of sphericity and roundness when compared with their parent beach sands.

It is clear that microtextural results from the wind tunnel experiment were predominantly abrasion surfaces and pits that increased with increasing wind velocity. The same pattern was detected by both Nieter and Krinsley (1976) who analyzed microtextural features in aeolian grains by silt abrasion and concluded that gentle winds (i.e.

Fig. 11. Percentage of imprinted grains collected at the end of the platform after each 10-minute run.

Fig. 12. Percentage of imprinted grains collected in each receptor after the 13 m/s run.
4.5 m/s) can promote surface changes in the grain population; and by Lindé and Mycielska-Dowgiallo (1980) who acknowledged that differences occurred between microtextures found on natural and experimental grains. However, similar microtexture assemblages prove that grains subjected to aeolian transport bear similar microfeatures to those produced in wind tunnel experiments.

Fig. 13. Map of locations where dune samples were collected in the Portuguese coast. A — Portugal. B — Algarve region. C — Martinhal area and dune sample used in this work. D — Boca do Rio area and dune samples used in this work. E — Lagoa dos Salgados area and dune samples used in this work.

Fig. 14. SEM images of quartz grains from Portuguese coastal dunes. A (Boca do Rio), B (Salgados) and C (Salgados) — Samples presenting typical dune microtextural signature with strong roundness, bulbous edges, strong dissolution, some percussion marks and the presence of numerous adhering particles. D — Younger dune from Martinhal, exhibiting almost absence of dissolution and coating.
Moreover, the latter authors also noted the presence of molten fragments, probably melted with abrasion becoming “attached” to a larger particle. These authors concluded that in the aeolian experiment, the rounding of the corners of the grains was greater than in the aqueous experiment. The aeolian grains from the experiment were better rounded and the authors attributed this fact to the higher impact energies and by the absence of a shock absorbing water cushion around the grain. Kuenen (1960) attributed the greater rounding of aeolian grains to the greater kinetic energy of windblown sand and the stronger abrasion by wind than by water transport, and also to the lesser air viscosity that “cushioned” the grains prior to impact. Although differences between desert and coastal dunes quartz grains exist, they are subjected to the same transport mechanism and therefore exhibit similar microtextural characteristics (e.g. Kuenen, 1960; Mahaney, 2002; Kasper-Zubillaga, 2009).

Marshall et al. (2012) demonstrated through aeolian simulation experiments that surface textures are a joint function of grain shape and grain speed. These authors recognized that, in some cases, texture types can be associated with specific aeolian regimes: Hertzian cracks, upturned plates, and blocky breakage typically occurring at expected energy levels. In fact, most of these textures can also be observed on natural grains. However, the study and interpretation of microtextures at lower wind-regimes requires a closer analysis to fully understand their origin. Our work contributes to this effort by recognizing microtextures produced on well-rounded grains. In agreement with Marshall et al. (2012) these textures have been observed previously in purely physical conditions and, therefore, do not appear to be an experimental artifact.

When surface microtextures are analyzed in combination with the roundness and angularity of the grains, it can contribute to the establishment of the relative age of an aeolian system. This information might prove valuable for assessing wind frequencies and intensities responsible for Quaternary and modern aeolian deposits (Marshall et al., 2012). However, present-day studies of abrasion textures rely largely on experimental data which may somewhat constrain conclusions. Nevertheless, in this study the microtextures recognized in the silica/glass microspheres were recognized and compared with microtextures observed in present-day coastal dune samples.

The SEM images of silica/glass microspheres presented in this study reveal a similar pattern with particle coatings noticeable after 8 m/s (initiation of particle movement), and increasing after 10 m/s although no bulbous edges were observed. This fact is due to the limited time of the experiment (70 min at different low wind velocities; i.e. max. 13 m/s). In fact, according to Krinsley and Wellendorf (1980) quartz grains (ca. 500 μm) abraded at a velocity of 8 m/s for 180 min were analyzed at the SEM and 80% of them presented surface microtextural marks (i.e. abrasion marks). Furthermore no significant rounding was described, hence implying that more time (> 3 h) would be needed to make the grains more rounded. The conclusions described above are in agreement with our results. Furthermore, the results of our work also support the findings of Willetts and Rice (1986) who plotted aeolian transport rate against point velocity and observed a transition between different transport mechanisms; the quartz sand being dislodged predominantly by wind at low transport rates, but at higher transport rates by a collision mechanism. This collision mechanism (grain flow) is the result of the flow of concentrated grain dispersion in a flowing fluid medium (Hsu, 2004); as Bagnold (1962) stated a granular mass cannot flow without some degree of dispersion (normal to the flow direction of the grains) which is the result of the tangential force caused by the effective weight of the grains when colliding against each other. The results observed in this paper indicate an increase of percussion and abrasion marks with increasing velocities, hence with stronger collisions between grains.

Aerolian-induced microtextures in quartz have only rarely (e.g. Krinsley and Wellendorf, 1980) been produced by simulation in controlled wind tunnel experiments. Abrasion tests, run at progressively increasing velocities, provide only provisional damage to silica/glass spheres transported over a short distance (6.0 m). If subjected to further multiple runs in the tunnel presumably greater damage would be seen in the array of imaged microtextures which in this experiment represent the initial state of grain fractography achieved by short-distance saltation and grain collision – silica/glass sphere → beach quartz – in the wind stream. Because the transported grains have similar specific gravities – 2.65 g/cm³ for quartz, –2.4 g/cm³ for silica/glass – quartz grains have slightly higher mass, and hence, kinetic energy to achieve grain damage. However, the difference in specific gravity is not seen to influence the degree of damage observed on the silica/glass spheres.

### 5. Conclusions

A wind tunnel experiment was carried out in order to identify microscopic imprints in the surface of silica/glass microspheres (used as analogs to quartz grains). A mixture of present-day beach sand with perfect circular silica/glass microspheres was subjected to a set of 10 min runs, each at different velocities (from 4 m/s to 13 m/s). In this experiment the threshold velocity to initiate movement of particles was 8 m/s; however this value was conditioned by the high humidity measured during the day of the experiment. Thus, a new experiment under dry conditions should be attempted in order to test our hypothesis.

Grains and microspheres were collected after each run and later observed on the SEM. The results suggest that although the microspheres were subject to short periods of collision, these were sufficient to leave microtextural imprints visible in the SEM photos and a similar pattern should be expected for quartz grains.
The damage inflicted on the silica/glass spheres increases with the frequency of occurrence of the microtextures observed, all increasing with velocity, and comparing closely with the range of microfeatures observed on quartz recovered from aeolian deposits worldwide.

Present-day coastal dunes tend to present bulbous edges, higher roundness, and strong dissolution and, in cases, coating with adhering particles. The experimental data compare well with coastal dune samples but it is important to note that time plays a decisive role in the frequency of occurrence of the microtextures observed, all increasing in terms of grain shape modification, thus bulbous edges and better roundness were not observed in the experimental data mainly because of the relatively short period of observation during the wind tunnel experiment.

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