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Abrasion resistance of muscovite in aeolian and subaqueous transport experiments

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ABSTRACT

Complementary aeolian and subaqueous transport experiments showed a trend in muscovite abrasion that may be useful for identifying ancient sandstones as aeolian or subaqueous in origin. We found that our experimental aeolian processes pulverized the micas quickly, while our subaqueous processes did not. In a pair of abrasion resistance experiments conducted with micaceous quartz sand, it was found that large muscovite grains were (1) reduced by aeolian processes to less than 500 μm in just 4 days, and (2) preserved by subaqueous processes to 610 ± 90 μm even after 356 days. At 20 days of aeolian transport no loose micas could be found even under the microscope, but after a year of subaqueous transport loose muscovite grains could still be seen with the naked eye. Thus, the occurrence and character of micas in a sandstone, particularly muscovite, may be helpful in determining the ancient depositional process.

1. Introduction

In the study of cross-bed forming transport processes, grain abrasion resistance can shed light on depositional environment. Muscovite is a common detrital mineral found in sandstones (Tucker, 1981; Pettijohn et al., 1973; Moorhouse, 1959); It is soft (Mohs 2–2.5) yet chemically stable. Although several abrasion experiments have been conducted with quartz (Lindé and Mycielska-Dowgiałło, 1980; Krinsley and Wellendorf, 1980; Nieter and Krinsley, 1976) and a handful of other minerals (Thiel, 1940; Marsland and Woodruff, 1937), no previous data has been published on mica abrasion resistance. Micas are usually absent in wind-deposited sands (Hallam, 1981; Mader, 1983; Moorhouse, 1959), and, in our field work, we have observed trace micas (biotite and phlogopite) only in active aeolian dunes in the immediate proximity of primary igneous sources (<10 km). On the other hand, micas are often associated with subaqueous, especially fluvial and deltaic, deposits (Graf et al., 2015; Garzanti et al., 2010; Hoang et al., 2010; Mader, 1983) and are commonly found in the littoral zone (Garzanti et al., 2013; Harris et al., 1993; Roehler, 1993; Weaver, 1989). Therefore, a pair of experiments were devised to observe and compare the abrasion resistance of muscovite in both aeolian and subaqueous processes.

2. Material and methods

2.1. Sand description

An ideal micaceous sand was developed for the abrasion experiments. The initial sediment (taken from the Sandhills in the Upper Coastal Plain region of South Carolina) was a muscovite-granule-rich, poorly sorted, sub-angular, fine to very coarse quartz sand. Small quantities of ironstone fragments and various feldspars were also present, and many grains were coated in a thin layer of clay. To better approximate a near-surface aeolian grain-size distribution, and to improve clarity in the subaqueous environment, loose fines were decanted off. Decanting the clay- and silt-sized muscovite grains was also desirable, since only the largest crystals were of interest. The resulting sediment was a moderate-poorly sorted micaceous quartz sand, with a mean muscovite long axis of 1800 ± 500 μm, with some individual flakes reaching 4 mm in diameter.

2.2. Aeolian methods

A cylindrical wind chamber was conceived using a 4 L, wide-mouth glass pickle jar. A brushless 20-A DC motor, operated through an electronic speed controller and servo tester, was mounted to the lid with the output shaft inserted into the container through the lid, and a plastic model airplane propeller attached to the end (see Fig. 1). The air speed was carefully adjusted until the simultaneous activity of all three modes of

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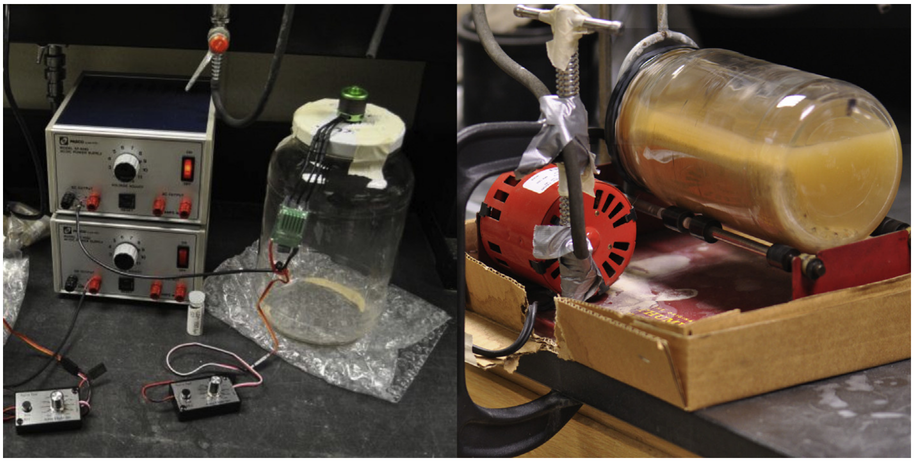

Fig. 1. (left) Aeolian apparatus, and (right) subaqueous apparatus.

transport, namely suspension, saltation and traction (rolling/impelling), demonstrated that the migrating dune closely approximated natural aeolian processes (Bagnold, 1954). To measure the sand speed, a foil ball, similar in diameter to the median grain size of the sand, was introduced and its revolutions about the circumference of the jar were counted for 30 s. This corresponded to a sand travel speed of about 5.1 kph, and was used in every trial. Two trials were run simultaneously in separate jars with identical configurations in order to accommodate trials of extended length. Ten samples of sand, approximately 5 g each, were circulated for various intervals for up to 20 days. After circulation, each sample was placed into a small dish that was divided into three equal sections. The long axes of the three largest muscovite grains from each section (totaling nine grains for each sample) were measured using a petrographic microscope. Equivalent transport distances were calculated. In addition, thin sections were made of the original sample as well as the 4-h, 16-h, 4-day, and 20-day samples.

2.3. Subaqueous methods

Subaqueous dune transport was simulated with a simple rock-tumbler assembly (see Fig. 1). The apparatus resembled a motorized version of a classic angle of repose demonstration described by Allen (1985, 35). Approximately 600 g of the prepared sand was placed in a 1.5 L glass jar and filled with tap water, leaving a small air gap. When placed on the assembly, the jar's lateral rotation caused continuous transverse grain avalanching, and thereby sustained a submerged dune on the rising slope. A sand speed of 0.87 kph was calculated by dividing the inner circumference of the jar by its period. Thirteen samples of the sediment, approximately 10 g each, were removed at various intervals up to 1 year in duration and equivalent transport distances were calculated. Since the muscovite grains were much more abundant than in the aeolian trials, it was not necessary to analyze all of them. Thus, only the 18 largest muscovite grains (twice as many as from the aeolian samples) were selected from each sample by hand, and their long axes were measured under a petrographic microscope. In addition, a thin section of the 203-day sample was made.

3. Results

3.1. Aeolian results

Muscovite flakes became significantly smaller and less frequent as aeolian transport duration increased. Mean long axis diameter dropped sharply in the first 24 h, from 1800 µm to about 365 µm. Muscovite grains greater than 500 µm could not be found under the microscope after just 96 h of circulation, and only grains smaller than 250 µm were seen after 192 h with the exception of one outlier. This corresponds to an 89% size reduction after 480 h, or 2442 km of transport. The trend of ln(*long axis*) vs ln(*transport time*) appears to approximate a second-degree polynomial regression, however the data spread is too large for a reliable fit. Thus, a box plot summarizes the overall trend (see Fig. 2). The apparent increases in average size (2- to 4-h, 8- to 16- and 24-h) and the large outlier at 4 h reflect the limitations of selective sampling. Despite this, the data shows clear trends of rapid decrease in both grain size and variability. Also, the trial duration was not long enough for the rotating sand to frost the glass on the inside of the jar. It is important to note that no loose micas at all were found in the 480-h thin section; the only surviving muscovite grains were those wedged into crevices in the quartz grains (see Fig. 3).

3.2. Subaqueous results

Even after 365 days of continuous subaqueous transport, muscovite flecks were still visible to the naked eye, though greatly reduced in size and abundance. The sample taken nine days earlier had a mean long axis of 610 ± 90 µm, corresponding to a 66% size reduction over a distance of 7450 km (see Fig. 4). In this sample, muscovite occurrence was less than half that of the original sand, but loose mica grains could still be found (refer to Fig. 3). Like the aeolian experiment, ln(*long axis*) vs ln(*transport time*) may approximate a second-degree polynomial regression, but the data spread precludes a reliable fit. A second box plot summarizes the trends in the subaqueous experiment (see Fig. 4). Again, the apparent increase in average size between 165-h and some of the later points is a direct result of the sampling method; Since the initial sand contained a variety of mica sizes, distribution of the very largest micas among small samples should be non uniform. This is also highlighted by the outliers. Overall, the plot clearly shows that micas tend to persist for long periods of transport. Throughout the experiment it was observed that many muscovite flakes buoyed up into the water upon reaching the bottom of the lee slope, becoming temporarily separated from the sand before settling back into circulation.

4. Discussion

Despite variability due to sampling bias, these results clearly demonstrate diverging trends. If the first 8 h of the aeolian experiment are taken together, then a steady and rapid decline in grain