Earth-Science Reviews 121 (2013) 18–30

Contents lists available at SciVerse ScienceDirect

Earth-Science Reviews

journal homepage: www.elsevier.com/locate/earscirev

Grain size of fine-grained windblown sediment: A powerful proxy for process identification

Jef Vandenberghe *

Department of Earth Sciences, VU University Amsterdam, De Boelelaan 1085, 1081 HV Amsterdam, The Netherlands

A R T I C L E I N F O

Article history:
Received 13 July 2012
Accepted 5 March 2013
Available online 20 March 2013

Keywords:
Grain size
Eolian
Loess
Dust
Windblown

A B S T R A C T

Dust transport by the wind is not a uniform process but may occur in different modes according to source area conditions and transport height and distance. Subsequently, these differences are expressed in terms of grain-size and fluxes of the aeolian deposits. Transport distances may vary from several tens of meters to thousands of kilometers, while the height accordingly may vary from meters to more than thousand meters. A relation with grain-size distributions may be established on the base of type occurrences of different loess facies. Three main loess populations (and several subpopulations) of primary windblown origin may be defined according to their grain size (dominated by fine sand to very coarse silt, silt and very fine silt to clay, respectively). Each of them reflects a specific aeolian process and transport conditions. It follows that the grain-size distribution of a loess deposit is an excellent proxy for the reconstruction of aeolian processes and wind circulation patterns.

Apart from (primary) pure wind deposition loess may also be affected by (secondary) post-depositional processes. Examples are settling of loess particles in a lacustrine setting and reworking by rivers or surface runoff. Although the primary loess characteristics are maintained, reworking processes leave also their imprint in the grain-size distribution as a useful tool for secondary process identification.

Contents

1. Introduction

Traditionally, sediment transport by wind is subdivided in three basic categories: rolling over the surface, jumping over short distance near to the surface (saltation) and suspended in the air (in the clouds at variable heights above the surface). Sediment transport rate, height and distance are dependent on sediment availability, grain properties (density, size and shape) and wind strength. Wind strength is determined by the air circulation pattern and includes both horizontal velocity and turbulent movements. Sediment availability for wind transport is proportional to the degree of weathering (on a bedrock substratum) and the amount of unconsolidated sediment, and inversely proportional to surface roughness, intergranular cohesion, the amount of vegetation and the protection and weight of individual grains (Bagnold, 1941). The latter author also derived laws that

* Tel.: +31 205987368; fax: +31 23 5989941.
E-mail address: jef.vandenberghe@vu.nl.

0012-8252/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.earscirev.2013.03.001

describe the varying grain size that may be transported as a function of varying wind energy for specific particle and environmental parameters. In addition to factors mentioned before, sediment deposition is also dependent on the existence of suitable dust traps (Tsoar and Pye, 1987). According to Lehmkuhl (1997), loess accumulated in the central Asian mountains and Chinese Loess Plateau only in areas with steppe vegetation, which was constrained to annual precipitation amounts between 250 and 600 mm. In drier areas, vegetation was too sparse to bind loess while in wetter areas soil development was too extensive and vegetation too dense.

Rolling, or gliding, requires the relatively least energy or, in other words, the heaviest grains may be transported by this way. It is assumed that grains with a diameter of up to 6 times the diameter that allows saltation may be subjected to transport by rolling. Considering that sands with a grain diameter of up to 500 μm are commonly saltated, it may be derived that rolling grains may have diameters in the range of several mm. Transport capacity by rolling or gliding is, of course, dependent on the roughness and the slope of the rolling or gliding surface, the grain shape and the smoothness of the grain surface.

Winds that are able to remove grains may be of relatively short duration. For instance, it has been reported that, with favorable field conditions and grain properties, exceptionally strong winds, pebbles of a few mm or cm diameter may saltate up to c. 1 m or higher (e.g. De Ploey, 1977; Hall, 1989; Lewkowicz, 1998). For transport in suspension, grains have to be uplifted tens or hundreds of meters high which is only possible in turbulent air motion. Ultra-fine grains may be blown up to several km high, for instance by volcano outbursts or by strong turbulence (Pye and Zhou, 1989; Pye, 1995; Lehmkuhl, 1997).

Aeolian transport and sedimentation may be accompanied by other mechanisms of transport. Depositional mechanisms may occur simultaneously or successively. An example of simultaneous deposition is when aeolian sediment is deposited in a lake. In such a case, characteristics of aeolian transport are intermingled with characteristics of lacustrine settling or wave action (lacustro-aeolian deposition). Examples of successive processes of deposition are wind-transported sediments that are re-mobilized afterwards by surface runoff or rivers. Occasionally, sediments may be deposited and reworked by alternating wind and water. Such processes of fluvio-aeolian transport may also modify the grain-size distribution of the original aeolian sediment. In general, the characteristic aeolian grain size in all these cases may remain unchanged, or diluted, or changed in accordance with the energy conditions of the accompanying non-aeolian process and with possible admixture of sediment originating from the latter process.

From these general considerations, it appears that grain size is a main element in characterizing the transport process. Similar considerations may be made for particle shape, but this grain parameter is frequently disregarded (Tysmans, 2008). Although the grain-size distribution of a sediment is a complex function of many variables, to reconstruct the different transport processes from the grain size distribution of the aeolian sediment is the challenge explored in this paper. In that respect, the specificity of a grain-size distribution for a corresponding transport and deposition process should be investigated. Such an attempt is certainly not new as sedimentologists as Folk (1966) and Doeglas (1968) attributed almost half a century ago, specific grain-size properties to aeolian deposits. However, technological constraints enabled only general interpretations on the sedimentary environment. Since some years methodological progress gave a new impetus on grain-size research in two ways. At first, laser-diffraction replaced the traditional dry and wet sieving and also the settling devices. It enables to determine the grain-size distribution of a sample with considerably more detail (especially in the fine-grained part of the distribution) and to carry out the analyses at a much larger speed than before (enabling to multiply the number of analyses hundred- or thousandfold) (e.g. McCave et al., 1986; Syvitski et al., 1991; Konert and Vandenberghe, 1997). Secondly, statistical techniques have been developed to separate different subpopulations in a bulk sample and to quantify both the modal size and proportion of each subpopulation. Examples are the end-member modeling with the EMMA-program (e.g. Weltje, 1997; Weltje and Prins, 2007) and Weibull distribution modeling (e.g. Sun et al., 2002).

The present overview is not intended to derive theoretical or experimentally-based relationships between processes and depositional conditions on the one hand, and grain-size properties on the other hand. Instead, the objective of this paper is to define the characteristic grain-size distribution of specific aeolian sediments and to attribute them to their respective processes and conditions of transport and deposition or re-deposition. This knowledge is of crucial significance in the reconstruction of palaeo-environments. Once such relationships are known and understood, it is possible to derive the depositional environment and sediment transport processes from the grain-size distribution. We limit the discussion to the grain size of fine-grained aeolian sediments and environments excluding, for instance, river dunes and coversands for which we refer, for instance, to Vandenberghe (1991), Kasse (2002) and Vandenberghe and Kasse (2008). Since we are focusing in this paper on the grain-size characteristics and related aeolian processes of dust, occasionally called ‘loess’, we keep off here any requirement of posterior diagenesis (opposed to Pecsi, 1990); similarly, we avoid discussions on the origin of loess (e.g. Smalley et al., 2011).

2. Approach and methodology

We selected a number of characteristic aeolian depositional (sub-) environments with their sedimentary records at sites where the depositional processes could be established with sufficient certainty. These sub-environments and processes have been characterized by the use of other information (e.g. sedimentary structures, geomorphological position, present-day measurements, etc.). In the first place, we look for specifying the purely aeolian transport processes and grain-size distributions. In the second place, we discuss environments that are more complex since the associated sediments, primarily supplied by wind, were prone to reworking during or after deposition by running or standing water.

Each grain-size population reflects a particular source sediment and/or a specific transport process with proper energy conditions. In general, climatic conditions play a most important role in the grain size of aeolian sediments. Aeolian grain-size distributions are directly determined by wind circulation patterns: both transport process and energy may be translated in terms of local or regional wind speed, while the wind direction links locations of provenance and depocentre. Apart from its direct role in ‘wet aeolian precipitation’, effective precipitation plays an indirect role by determining vegetation cover, soil formation and soil humidity that affect the sediment availability in the source area.

The data used in this paper are especially derived from research that was done at the VU University Amsterdam since the beginning of the 1980s in central and eastern Asia and northwestern and central Europe (Fig. 1) by Bokhorst, Huijzer, Nugteren, Prins, Vandenberghe and Vriend (references see below) and compared with other research. The samples from that research were prepared according to the methods described by Konert and Vandenberghe (1997). A few grams of sediment were pre-treated with H_2O_2 and HCl to remove organic matter and carbonates respectively. It means that the pure siliciclastic fraction is measured. Practically all our samples were analyzed with a laser particle sizer (most of them with the Fritsch Analysette 22, a limited number with the HELOS from SYMPATEC). A grain-size distribution shows up with 56 size classes in the range between 0.15 and 2000 μm. Only a few older analyses used in this paper were realized by the pipette method. Especially for very fine-grained particles, it is important to realize that there is sight discrepancy between the grain sizes measured by the laser method and by the traditional pipette method (Konert and