WIND ACTION

M. Frechen
Centre for Environmental Change and Quaternary Research, GEMRU, Cheltenham, United Kingdom

Keywords: aeolian processes, loess, wind activity, dunes, aeolianite, natural hazards, saltation, deserts, paleoclimatology

Contents

Summary

Wind action has a major morphological and geological impact on the surface and environment of Earth. In the near and mid-term future, it is very likely that stronger wind activity owing to the enhanced greenhouse effect and climate change will result in more surface alteration and sediment mobilization. Natural hazards from wind and storm activity cause significant economic loss through damage to buildings, plants, soil erosion, and desertification. Air pollution is transported by wind and can lead to the contamination of food and water. There are also economic benefits through wind activity, such as the accumulation of fertile loess soils, airborne nutrients to soils, and wind energy. Global and regional wind systems based on the specific meteorological conditions are responsible for sediment transport in semi-arid and arid areas.

The aim of this article is to provide a summary of wind action in general, and of the dust and sand forming processes, as well as the variety of transport modes and its deposits. The two most prominent wind blown sediments—loess and sand—are discussed in detail. Loess is a typical silt-rich sediment mainly formed by glacial action combined with fluvial/glaciofluvial activity or in desert margins. Aeolian sand deposits are formed and accumulated in many semi-arid and arid environments and along coastal regions resulting in different morphological landforms like sand seas or different kind of dune-types. The importance of aeolian deposits as terrestrial climate archives are summarized for the loess/palaeosol record of Central Europe and the carbonate-rich aeolianites from the Mediterranean coastal plain of Israel. More information on this is presented in Appendix 1.

1. Introduction

"Wind" is a synonym for "air in motion" and occurs under many different meteorological conditions and environments. Air expands during warming up by solar radiation and rises up higher in the atmosphere owing to decreased density, which is proportional with the decrease of barometric pressure resulting in a low-pressure area. Cooler air flows into such a "Low"; this is called wind. Local winds occur owing to temperature differences between land and sea or between mountains and valleys, whereas global wind systems are driven by the solar radiation and the rotation of Earth. Violent storms can cause natural hazards with significant negative economic consequences for humanity, like damage to buildings, agriculture, or forestry, as well as floods along the coasts. However, there are also economic benefits related to wind activity, for example wind energy and the accumulation of fertile loess soils. At present, and in the geological past, wind activity has had major morphological impacts on the surface of the planet. Mobilization, transport, and accumulation of dust and sand play an essential role in landscape alteration and hence significantly influence the geo- and biosphere. The form and size of dunes, one of the most typical aeolian landforms, can vary within and between sand seas, through the interaction and variation of sand supply, the vegetation cover, and the wind regime. Wind ripples are the smallest bedform unit and can occur on any larger-scale aeolian bedform.

Aeolian deposits cover more than 20% of the continental surface.

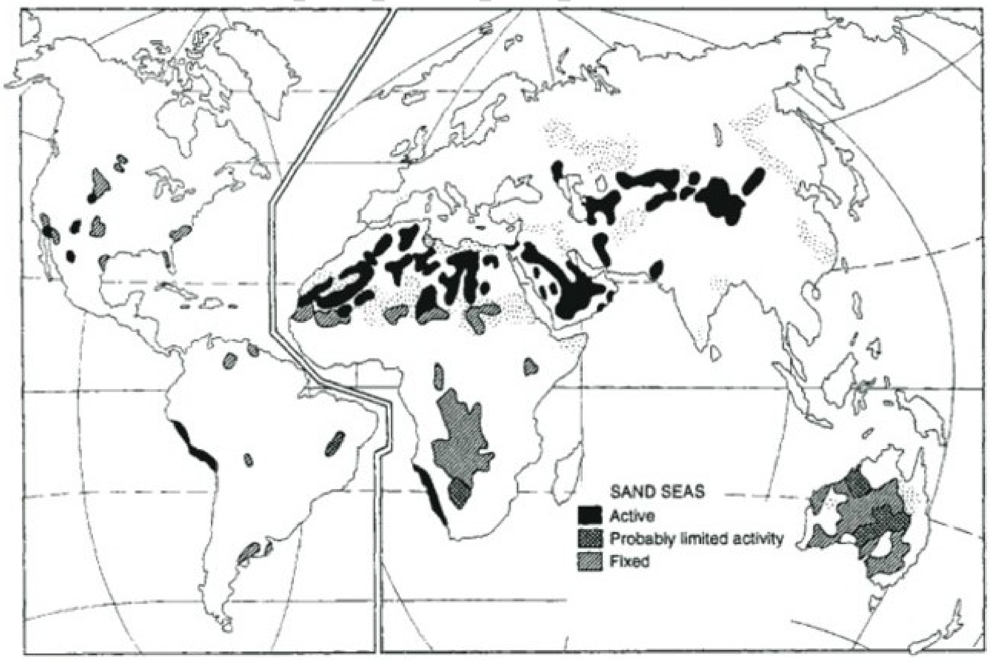

Figure 1. Global distribution of sand, dune sands and aeolianites.

Vast deposits of aeolian loess, a silt-rich sediment, occurs throughout the Northern Hemisphere and also in Argentina and New Zealand in the Southern Hemisphere. In China and in Central Asia, loess deposits have a thickness of more than 300 m. The loess (loess record), ocean sediments (marine record), and the ice caps (ice-core record) provide the most complete and detailed climate archives of the past two million years, the Quaternary. Furthermore, these records and proxy data will allow the modeling of the natural future climate change superimposed by any artificial climate change caused by humanity.

Airborne dust may derive from a number of sources, including desiccated soils in all climates, cosmic dust, sea salt, volcanic dust, and smoke particles from fire. Although desiccated sediments can produce soil-derived atmospheric dust in any environment, the main dust and sand sources are located in semi-arid and arid regions, such as the Sahara and Namib in Africa, or the Taklamakan in Central Asia. The dominant mineral in most desert dust is quartz; other minerals include feldspars, calcite, dolomite, micas, chlorite, clay minerals, gypsum, amorphous inorganic material, and organic material depending on the source rock and the climatic conditions. Dust or sand are also found around ice caps and along extended river systems, indicating major accumulation periods during glaciations. Dunes also occur on the crests of barrier islands and beaches in a variety of climates. See *Sedimentary Rocks* and *Quaternary*.

2. Evidence of Wind Activity in the Geological Past

In the history of Earth, as on other solid planets like Venus and Mars, wind activity has played a major role in modifying the surface and landscape, resulting in deflation and the accumulation of thick sedimentary deposits. Since the Palaeozoic, the evidence for wind activity, like remains of wind-blown sediment, is very obvious. In North America, remains of Early Palaeozoic dunes have been described in detail. The interpretation of Palaeozoic loess-like sediments and loess from Siberia and from South America, respectively, are still under discussion. Typical and excellent examples of aeolian sediments, hence wind activity, are the cross-bedded Permian (Permian is the geological epoch at the end of the Palaeozoic between 285 to 225 m yrs BP) sandstone and part of the “Buntsandstein” formation, the earliest formation of the Mesozoic, in Central Europe and North America. In England, remains of barchan-like dunes were found in Permian deposits indicating northwesterly winds at that time. Remains of dunes are also described from the Colorado Plateau in North America from Triassic sandstone (Trias is the geological epoch at the beginning of the Mesozoic between 225 and 195 m yrs BP), from the Botucatu desert in Argentina (Mesozoic), or from Tertiary (the geological time epoch between 65 and 2 m yrs BP) deposits in the West Ural, Russia. Pleistocene aeolian deposits have been described from all continents, e.g. the Mediterranean coast of North Africa and the Levant. Late Glacial and Holocene dunes are found along modern deserts and along major river systems, like those of the Mississippi in North America, the Paraña in South America, the Rhine and Danube in Europe, or the large Yenisei and Ob river systems in Siberia, the Amu Darya in Central Asia, or the Yellow river in China. In the deep-sea record, the aeolian sedimentary input and accumulation is continuous ranging from the Mesozoic to the present and hence resulting in high resolution climate archives for most of the Tertiary and Quaternary.

3. Dust Transporting Wind Systems

Wind is a particularly effective medium for sediment transport under different meteorological conditions, as evidenced by recent sand movements in massive dune fields in semi-arid and arid environments of all continents. The fine-grained material, the dust, is raised high into the atmosphere by turbulent mixing and may be transported over thousand of kilometres by global wind systems or jet streams.

Dust storms. The highest frequencies of global dust storms occur in semi-arid and arid regions in Asia (Figure 2). The Seistan basin in Iran has more than 80 dust days per year. Along the flood plains of the river Amu Darya in Uzbekistan and Tadjikistan, an average of 108 dust days per year is likely. Other significant dust areas occur in the Karakum desert, the steppes of Kazakhstan, the regions of Almaty, the Altai, and the area between the Caspian and Black Seas.

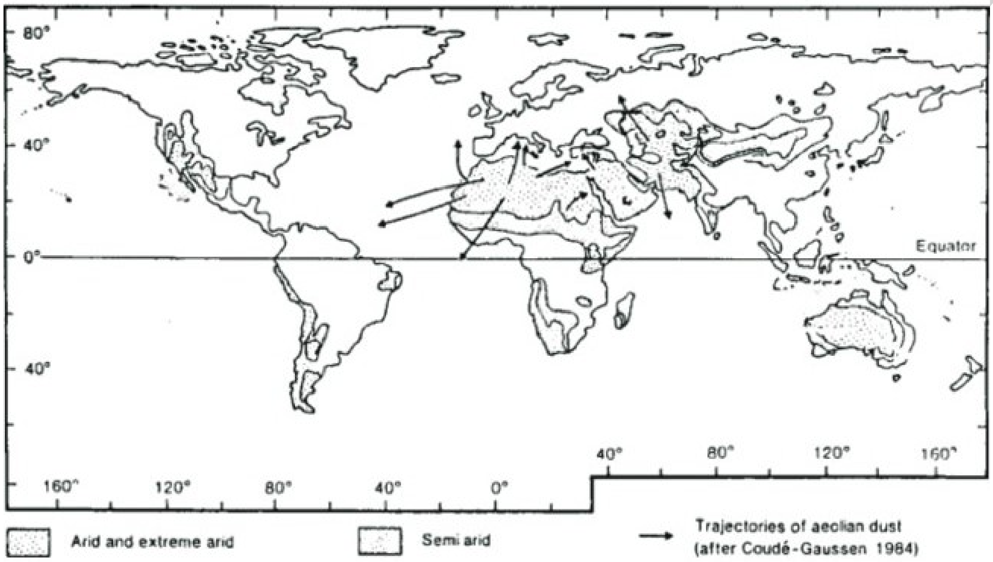

Figure 2. Global dust production and accumulation.

On the Indian subcontinent, the plains of the upper river Indus and the Thar desert are centres of major dust storm activity. In China, the Taklamakan desert and the Kansu area are the most active regions. The Gobi desert in southern Mongolia averages more than 30 dust storm days per year.

In the Middle East, the alluvial plains of Lower Mesopotamia and the desert areas of Syria, Jordan, and northern Saudi Arabia experience the highest dust frequencies.

In Africa, areas with annual dust frequencies of 10–25 days per year are located in southern Mauritania, northern Mali, central and southern Algeria, northern Libya, and northern Sudan.

In North America, dust storms occur on the Great Plains and in northern Mexico, exceeding five dust days per year. In Australia, an average of more than five dust storms per year are recorded for the Simpson desert.

Dust transporting wind systems. Dust-transporting wind systems range in size from small dust devils of 1–2 m diameter to tornadoes, the latter forming in association with advancing thunderstorm fronts. In Arabia, down-draught “haboobs” are violent dust storms generated by outflow of cold air from a cumulonimbus cloud and maintained by the resulting horizontal density gradient. The leading edges of these storms have the appearance of solid walls of dust ranging from 300 to 3000 m height in the atmosphere. In Sudan, in the Khartoum area, down-draught haboobs have a velocity of approximately 50 km/h and last on average between 30 minutes and one hour. They develop during summer, when warm monsoon and cooler more northerly air converge over Sudan and form a zone of meteorological instability.

In the Persian Gulf, the “Shamal” is a persistent wind blowing from the north between late May and early July in response to the development of a monsoon low over the northwest Indian sub-continent. The meteorological situation results in strong surface winds from northern directions, causing frequent dust storms in Iraq and Kuwait. These dust storms are associated with steep pressure gradients and low-level troughs. The dust haze is carried across the Arabian Gulf to Bahrain, the United Arab Emirates, and Qatar. In Iraq, the Mesopotamian plain, the southern deserts of Barah, and the area around Baghdad are significantly affected by these violent winds. Most Shamal dust storms do not exceed 1 km in height. Strong dust winds are restricted to low surface levels, where the wind velocities reach up to 45 km/h. Maximum velocities of 80 km/h have been measured at a height of 350 m above surface.

In Israel, the wind normally blows from a southwesterly direction. However, periodically easterly dust storms occur when a trough extends over the Red Sea towards the Eastern Mediterranean coast and a ridge of high pressure forms over Turkey, Syria, and northern Saudi Arabia. This meteorological situation mainly occurs in winter when anticyclonic conditions exist over Central and East Europe and the movement of mid-latitude depressions across the southern Mediterranean is temporarily suppressed. Then, large amounts of sand and dust are transported in the northern Negev of Israel, with wind velocities reaching about 60 km/h.

Three distinct wind systems are responsible for transporting dust across West Africa:

- In the north-west Sahara, dust is transported in the shallow Trade Wind layer from the Atlas Mountains in Morocco and the coastal plain in a direction almost parallel to the coast. The low-level winds carry dust to a height of 500 to 1500 m. Most of the dust is deposited in a zone extending in westerly directions from the African coast to the Canary Islands and the Cape Verde Islands.
- Frequent dust storms occur in the southern Sahara and Sahel during the northern hemisphere summer. There are periodic events of dust-laden air over the eastern Atlantic. The dust is raised into the atmosphere by strong winds associated with squall lines, which cross the Sahel from east to west. These meteorological conditions are caused by the Inter Tropical Convergence Zone (ITCZ), which lies

across the northern Sahel and separates hot and dry Saharan air from moist, tropical air to the south.

- During the Northern Hemisphere winter, the ITCZ moves southwards and lies approximately over southern Nigeria resulting in frequent dust and sandstorms there.

Minor dust transporting wind systems, e.g. the “Sirocco” originating in North Africa, transport dust into Southern Europe.

The most common synoptic situation producing strong winds in the desert of the North American South-West occurs in late winter and spring when the Pacific High is located near its southernmost position and when a deep low-pressure cell is centred over Nevada. This situation produces a steep east-west pressure gradient and gives rise to strong southwesterly winds. These so-called “Santa Anna winds” originate over the deserts of Nevada and eastern California and blow across the Los Angeles basin towards the Californian channel islands with wind velocities of approximately 50 km/h. These haboob-type violent winds develop in summer, when warm subtropical oceanic air from the Gulf of Mexico and from California converge over the region, creating a meteorological instability.

-
-
-

Bibliography

Derbyshire E. (ed.) (1995a). Aeolian sediments in the Quaternary record. *Quaternary Science Reviews*, Vol. **14**, Oxford. [Basic source].

Derbyshire E. (ed.) (1995b). Wind blown sediments in the Quaternary record. *Quaternary Proceedings*, Vol. **4**. [Basic source II].

Goudie A. S., Livingstone I., and Stokes S. (eds.) (1999). Aeolian Environments, Sediments and Landforms. John Wiley, 336 pp. [Comprehensive guide to sediments and processes].

Pye K. (1987). *Aeolian Dust and Dust Deposits*, 334 pp. London: Academic Press. [Respected, standard textbook, extensive bibliography].

Selley R. C. (2000). *Applied Sedimentology*, 521 pp. San Diego: Academic Press. [This monograph deals with various aspects of sedimentation in different environments including wind processes].

Thomas D .S. G. (ed.) (1997). *Arid Zone Geomorphology*, 713 pp. Chichester: John Wiley. [This modern monograph deals with the formation of desert relief including the role of wind].

Biographical Sketch

Manfred Frechen worked in 1978-1987 Dipl.-Geol., Geology and Palaeontology, University of Cologne on Diplom thesis: Volcanological interpretation of Palaeozoic pillow volcano complexes in the

Ostsauerland area, Germany. He was employed during 1987-1990 in University of Köln working on PhD thesis: Thermoluminescence dating of loess from the Middle Rhine Area [in German]. He held this academic positions:

1987 Research graduate ("Fluvial dynamics during the Lower Quarternary") funded by the German Science Foundation, University of Cologne

1988-89 Scholarship of the University of Cologne, several months research visits at Godwin Laboratory, Cambridge, U.K. (Prof. Dr. N.J.Shackleton), Institute of Earth Studies, Aberystwyth, U.K. (Dr. A.G. Wintle), Institut Inorganique et Chimie Nucléaire, Louvain-la-Neuve, Belgium (Prof. Dr. R. Debuyst)

1990-92 Research Associate ("Quaternary of the Eifel Area") funded by the German Science Foundation, University of Cologne

1993-95 Research Associate and Assistant of the Director of the Department of Quaternary Geology (Prof. Dr. W. Boenigk), University of Cologne

1996-97 Habilitation grant of the German Science Foundation

1996-97 Research Officer at the Department of Geography and Geology in Cheltenham

1998-99 Senior Research Fellow at the centre for Environmental Change and Quaternary Research in Cheltenham

2000-2001 Professorship in Soil Sciences at the University of Regensburg, Germany His main professional interests are volcanic rocks, Quaternary geology, pedology, dating of loess series and Quaternary sediments.