

Impact of aeolian sediments on pedogenesis – examples from the fringe area of the Saharan desert

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Abstract

A series of soils was studied along a moisture gradient from the centre to the outer fringe area of the Saharan desert. The contribution of added aeolian material to the soils in general decreases along the moisture gradient but shows differences from the trend according to the age of the soils and the underlying rocks. The impact of the pedogenetic processes of soil horizon formation, accumulation of organic matter, carbonatisation, texture development and development of mineral assemblage is discussed. Also related consequences like changes in water storage capacity and ped formation are discussed according to their impact on pedogenesis. In general the impact on pedogenesis is not only a function of the amount of added materials, it differs also according to the properties of the specific soil material from a certain rock and the stage of soil development.

Key Words

Aeolian materials, pedogenesis, organic matter, carbonatisation, texture development

Introduction

All deserts are known as important source regions for aeolian dust. Early studies (Yaalon & Ganor, 1973; Péwé, 1982; Ganor & Mamane, 1982) resulted in estimates of 250 Mio. to more than 700 Mio. tons loss of materials per year (Figure 1). The deposition of aeolian dust is widely recognized as an important modifying part of soils. The rates of dust deposition observed across the globe vary from almost 0 to greater than $450 \text{ g m}^{-2} \text{ yr}^{-1}$ (Lawrence & Neff 2009). Sites receiving dust deposition can be differentiated into categories based on the amount of aeolian additions; soils developed from autochthonous materials with some aeolian additions, soils developed from autochthonous materials with aeolian additions as a major part, soils developed from aeolian materials on autochthonous rocks. The latter will be formed at deposition rates of about 10 g m^{-2} or more per year (Yaalon, 1987).

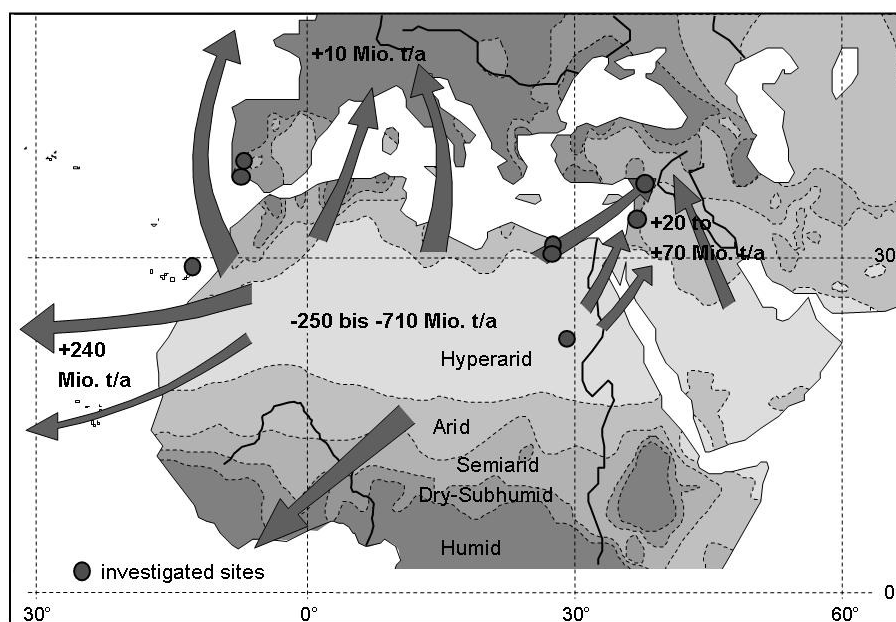


Figure 1. Transport trajectories of dust from the Saharan desert (according to Yaalon & Ganor, 1973; Péwé, 1982; Ganor & Mamane, 1982) and investigation sites.

Whereas pedogenesis is well described for soils derived from pure aeolian deposits (e.g. loess), information

about the effects of aeolian additions on soil formation for soils developed mainly from autochthonous materials containing only traces or minor parts of aeolian materials are still rare. Much progress has been made for the identification of aeolian additions. After more or less early qualitative descriptions, the analysis of oxygen isotopes in quartz grains (e.g. Jackson *et al.* 1971) and other mineralogical methods resulted in a broad knowledge about the fact of aeolian additions and possible source regions, but those studies seldom reflect the effect on pedogenesis.

Materials and Methods

Soils along a moisture gradient have been studied in Southern Egypt (on gneiss; P = <2 mm, T = 23°C), North West Egypt (on limestone, P = 40-130 mm, T = 20-21°C), Lanzarote/Canary Islands (on basaltic pyroclastics of different ages; P = 150-200 mm, T = 16-18°C), Israel (paleosols within basalt layers and recent soils on basaltic pyroclastics; P = 460-900 mm, T = 15-23°C), Southern Portugal (on limestone; P = 520-630 mm, T = 17-18°C) and Turkey (on serpentinite; P = 1090 mm, T = 15°C). A full description of the sites, soil data and methods used can be found in Jahn (1995).

Results

The investigated sites show very different signs of aeolian activity (Table 1). In all soils significant additions of aeolian material occur but decrease more or less along the moisture gradient. The site in the central part of the Saharan desert (S-Egypt) lost a huge amount of during the Pleistocene weathered material. The recent soil is mostly built up by locally redistributed material (developed from gneiss) and drifting sand of the adjacent occurring sandstone area. Drifting sand is also a significant contribution of the soils at the inner desert fringe in NW-Egypt. In all other soils the major aeolian contribution consists of far transported dust (almost silty).

Table 1. Investigated sites, autochthonous rock, time of soil formation and reconstructed aeolian additions.

Sites	Autochthonous rock	Estimated time of soil formation (ca. yr)	Origin of soil mass in % of total soil mass (fine earth)		
			Locally redistributed	Local drifting sand	Far transported dust
S-Egypt					
AH-2, -4, -7	Gneiss	?	65, 76, 66	20, 18, 25	--
NW-Egypt					
P43, 24	Limestone	50,000	--	30, 39	60, 41
Lanzarote					
IV _B -101, -303	Basaltic Pyroclastics	250	--	?	4, 4
IV _A -605, -660	Basaltic Pyroclastics	6,000	--	?	15, 22
III-502, -510	Basaltic Pyroclastics	40,000	--	?	43, 25
III-570	Basalt	40,000	--	?	66
Israel					
Shipon	Basaltic Pyroclastics	20,000	--	?	2
1055	Basalt	30,000	--	?	2
1052 (Paleosol)	Basalt	150,000	--	?	17
Portugal					
Rod, Mol, Min, Gui, Bor	Limestone	200,000	--	3, 9, 8, 5, ?	12, 16, 20, 13, 10
Turkey					
P161	Serpentinite	15,000	--	1	2

Development of horizons

Aeolian activity in desert areas results in at least the development of two specific topsoil horizons (examples from Egypt). Many soils show due to wind erosion at the surface an enrichment of varnished and/or wind-shaped coarse rock fragments. Also the soil surface is mostly covered with a mm to some cm thick layer of well sorted aeolian sand. Below this sandy layer mostly a platy structured silty horizon with vesicular shaped coarse pores is developed (desert pan).

In the 250 year old Regosols from blackish basaltic pyroclastics of Lanzarote we could also observe a coarser grained upper layer and below the development of a brownish coloured horizon which contains mainly imported dust which was leached down from the surface. Quartz, kaolinite, illite and Fe-oxides of higher crystallinity qualify this fine material clearly as imported.

In well rubeficated limestone soils (examples from S-Portugal) with low organic matter content often a more

brownish and silty A and B horizon can be observed in comparison to the soil material at the base of a profile or in between the rock fragments of a BC horizon.

Accumulation of organic matter

Dust samples often contain some percent of organic matter in the form of fragmented litter. Since very young soils in semiarid climates are not mature enough to support a plant cover (the Regosols in Lanzarote show only the growth of lichen at the surface layer), this imported organic matter is an important step for development of a pool of organic matter. To store this imported organic material it is important that the topsoil is coarse grained and the aeolian material can be washed down by the scarce rain events. This imported organic matter may also increase the biological activity in the soil with the consequence of increasing the CO₂ content in the soil air and soil solution. This is an important prerequisite to enforce chemical weathering and to increase CaCO₃ solubility.

Carbonatisation

Dust samples contain, depending on the source region, carbonates (e.g. Lanzarote 18.5 %) and are on the one side a potential source for carbonatisation and on the other hand a buffer substance to inhibit weathering. The soils in S-Egypt contain 16-143 kg m⁻² carbonates, far too much to explain the necessary Ca amounts by weathering e.g. plagioclases. Rough estimates make it probable to assume that about 20 % of Ca of the carbonates comes from plagioclases and therefore about 80 % should be imported.

In Lanzarote we could observe that only the dust samples and the younger soils contain carbonates in the form of pure CaCO₃ whereas in the older soils calcite is Mg substituted. This observation leads to the assumption that under the given climatical conditions only the first step of carbonatisation is initiated by the import of carbonates whereas in later stages (with increasing water holding capacity of soils) the dissolution of imported carbonates, weathering of the autochthonous parent material and (re)precipitation of carbonates occur. Therefore the very strong carbonatisation of the soils of the eastern Canary Islands should be based on two different sources of Ca. The data for the soils from more humid regions give no indications of carbonatisation processes or estimates of whether imported dust was carbonatic or not.

Texture development

Aeolian contributions may influence the texture development progressive as well as regressive from coarse to fine grained. In the coarse grained younger soils from pyroclastics the finer additions accelerate development of loamy texture classes (Figure 2). On the other side in more strongly developed soils from easy weatherable materials (basaltic pyroclastics, basalt, lime stone, serpentinite) the aeolian additions prevent at least the top soils becoming as clayey as the subsoils.

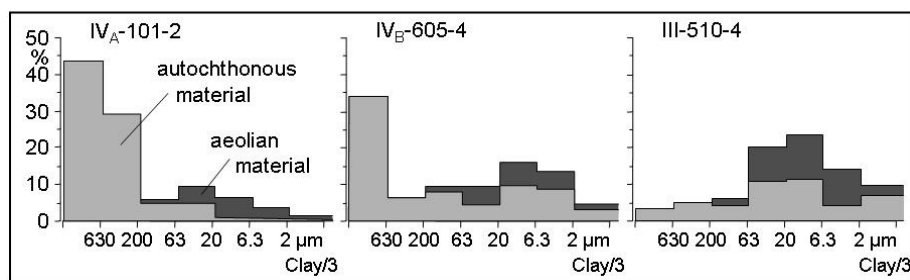


Figure 2. Reconstructed grain size distribution of autochthonous material (from pyroclastics) and of aeolian addition in different old horizons from Lanzarote.

Textures strongly influences the pore size distribution so the water and air regime of a soil will also be affected and in consequence most pedogenetic processes. Therefore in coarse grained soils aeolian additions increase water storage capacity, enables better plant growth in semiarid areas, increase litter fall and biological activity (see above) and also increase transformation processes for organic matter. In clayey soils the upper part is mostly more loamy developed under the influence of aeolian additions. Since aeolian additions are mostly dominated by non-swelling/-shrinking minerals, in the case of smectitic weathering of the autochthonous parent material (e.g. from basalt or serpentinite) the formation of peds is inhibited in the upper part. Often signs of stagnant conditions (Mn-coatings) can be observed in the transition zone of loamy and clayey horizons, even under semiarid to dry-subhumid conditions.

Development of mineral assemblage

Main constituents of aeolian sediments are quartz, illite and kaolinite. For soils developed from quartz-free autochthonous rocks, (beside other marker minerals) quartz is often used to quantify the influence of aeolian additions. Quartz grains occur in such cases usually as wind shaped grains of silt and fine sand size. In soils from rocks tending to form smectitic clay, from top to the bottom usually decreasing contents of illite and kaolinite can be found. Since the residuum of limestones is mostly also of a kaolinitic-illitic nature in such cases no diversification of clay assemblage is obvious.

Conclusion

Aeolian materials added to soils from an autochthonous rock may change soil forming processes in different ways. The size of impact is not only a function of the amount of added materials, it differs also according to the properties of the specific soil material from a certain rock and the stage of soil development. The impact on pedogenesis is generally stronger in younger soils than in older ones. The impact is also stronger in soils on rocks which are easy weatherable, like basaltic materials and serpentinite, than in soils on sedimentary rocks.

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