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AEROSOL–SOIL FRACTIONATION FOR NAMIB DESERT SAMPLES

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Abstract—Four soil samples, collected in the central Namib Desert, were fractionated by dry sieving and aerosol generation into 16 size fractions in the range 0.15–300 μm diameter. The mass-size function of each soil and the dust (mineral aerosol) generated from the soil were studied. Due to the preferential lifting of smaller soil particles by the air stream, the soil underwent strong physical fractionation resulting in the bulk of the dust being found in the range of 1.3–10.3 μm, whereas the bulk of the soil was found in the range 63–300 μm. The concentrations of 11 elements in eight soil size fractions (from <45 to >300 μm) obtained by dry sieving were measured by X-ray fluorescence analysis while the concentration for these elements in eight size ranges (from <0.15 to >10.3 μm) obtained by aerosol generation were determined by particle-induced X-ray emission. The concentrations of the elements Al, Si, K, Rb and Sr were found to vary by less than a factor of two throughout the particle size range studied. However, the concentration of the elements Ca, Ti, Mn, Fe, Y and Zr increased when the particle size decreased below 150 μm to reach a maximum around 63–45 μm and then to decrease. The concentrations of the elements in the generated aerosol particles were found to be more similar to those in the bulk soil than any particular size fraction. For the aerosol size fraction, elemental enrichment factors were calculated with respect to the composition of average crustal rock, average soil, the bulk Namib soil and the small size fraction of the Namib soil. For several elements, the enrichment factors varied quite significantly, depending on the choice of the reference material. The elemental ratios in the mineral aerosol were also compared to those in the atmospheric aerosol from the Namib Desert. It was confirmed that there is a marine contribution for S, Cl and Sr in the Namib natural aerosol. The composition of the mineral aerosol generated in this study should be useful in source apportionment studies for the Namib Desert and surrounding regions.

Key word index: Aerosols, desert, Namib, fractionation, X-ray analysis.

INTRODUCTION

Deflation of soils at the Earth's surface constitutes an important source of wind-blown dust. The annual production of dust is estimated to be of the order of 250×10^6 tons on a global basis (Prospero *et al.*, 1983), although widely differing estimates have been suggested. The main source areas of the wind-blown dust are the arid and seasonally arid regions of the world (Prospero, 1981). The dust produced in the arid regions is fed in the wind systems and transported over large distances. Such dust has been found in places as remote as Antarctica (Maenhaut *et al.*, 1979; Tuncel *et al.*, 1989).

The annual production of airborne dust from the Sahara and its pathways are fairly well understood. However, the production of dust from deserts in the Southern Hemisphere (Namib and Kalahari Deserts) is less well studied. The data available shows that, along the Atlantic coast, there is a dramatic fall in the amount of mineral dust present in the air across the Equator in the southeast trade winds as the influence of the North African desert falls off. Thus, the desert regions of southern Africa are not a massive source of mineral aerosol for the ocean (Chester *et al.*, 1984). Mineral dust from these areas is oriented in a northwest direction due to the southeasterly trade winds (Schütz, 1980).

Because of the rapid fallout of large size particles, the composition of the airborne dust might not reflect that of the soil from which it was generated. This necessitates the study of the chemical composition of dust as related to that of the soil.

The enrichment of elements in an aerosol sample can be inferred from size distributions and enrichment

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factors. The composition of average crustal rock or average soil is generally used for enrichment factor calculations. According to Rahn (1976), none of these is a satisfactory reference material because crustal rock is not easily weathered and soil may differ in its composition from the aerosol. Thus, there is a need to search for a suitable reference material.

Comparison of natural background aerosol in a remote continental area, where pollution sources are minimal, with aerosols artificially generated from the main source contributing to the aerosol in that area, might give an insight into the soil–aerosol fractionation effects.

In this study the mass-size function and the size distribution of the chemical composition of four Namib soils, as well as the aerosols generated from these soils, were studied. Several reference materials for the calculation of the enrichment factors were compared. Also, the aerosols generated from these soils were compared to the natural aerosol of the Namib Desert (Annegarn *et al.*, 1983) and to the composition of the aerosol in several remote areas (Lawson and Winchester, 1979). The suitability of the crustal elements in mineral aerosol for source apportionment studies is discussed.

EXPERIMENTAL

The soils in the vicinity of Gobabeb

The soil samples were collected near the Namib Research Institute at Gobabeb, situated in the middle of the Namib Desert, in central Namibia, on the Kuiseb river bed, at 23° 45′S 15° 03′E. This site is 100 km away from the nearest town, Walvis Bay (population 25,000). Vehicle movements in the direct vicinity of the station were limited to 2–4 per day.

The soil of the Namib Desert in the vicinity of Gobabeb has been fully described by Schulze (1969), Goudie (1972), Scholz (1972) and Tyson and Seely (1980). South of Gobabeb extends a vast sea of sand dunes. According to Besler and Marker (1979), these sand dunes originate from the weathering of the underlining sandstone. The sand of the dunes has a brownish colour, lighter near the coast, and a reddish brown colour predominating towards the interior. The main minerals constituting the light-coloured dune sand are feldspar and quartz with secondary mineral constituents of monazite, staurolite and chlorite. The dark dune sand has garnet, monazite, opaque ore minerals and feldspar as main constituents, and chlorite, zircon, epidote, staurolite, tourmaline and ilmenite as minor constituents.

The plains between the dune ridges are covered with a reddish grey dense limestone crust containing large pebbles in its upper portion and covered with quartz gravels. The reddish grey crust contain 41.5% $CaCO_3$.

On the plains north of the Kuiseb River, two principal soil types can be distinguished. These are the syrosems or raw mineral soils and a soil with limestone or gypsum crusts.

Along both banks of the Kuiseb River, flood-loams with a dirty brown colour occur. These flood-loams contain gypsum and are also rich in NaCl. The composition of the flood-loams reflects the influence of the different areas inundated by different floods.

Because of the gypsum and the calcite crusts, surface Namib soil is known to contain a high calcium content. Analysis by XRF of about 200 surface soil samples from the Namib showed an average calcium content of 2%, which is almost twice as high as the world's average (Evens, 1978).

Soil sample collection

Four soil samples were collected. Sample 1 is from one of the numerous sand dunes (20 km south of Gobabeb), which covers the base plain south of the Kuiseb River, towards South Africa. Sample 2 is from the base between the dunes in that area. Sample 3 is from the Kuiseb river bed, which is dry except for one average precipitation event per year: the sample can be considered as an average for the region. Sample 4 is from the plain north of Gobabeb, which stretches out to Angola.

All samples were collected with a plastic scoop and stored in plastic bags.

Soil sample preparation and analysis

Each of the four Namib soil samples was fractionated by dry sieving to give size fractions of diameter >300, 300–250, 250–200, 200–150, 150–100, 100–63, 63–45 and <45 μm, i.e each sample set consisted of the bulk soil and these eight fractions (subsamples). From each subsample as well as from the bulk soil, an aliquot of about 0.03 g was mixed with 10 ml of bidistilled water and ground for 2 min with a McCrone Micronizing mill using corundum grinding elements. Three millilitres of the resulting slurry was pipetted on a Mylar film glued to a Teflon ring, which fitted the sample holder, and dried in an oven at 60 °C for about 8 h. Thus, intermediately thick samples were obtained. This method of sample preparation was introduced by Van Grieken *et al.* (1979). Three targets were prepared from each soil fraction. These targets were analysed by means of energy-dispersive X-ray fluorescence spectrometry (EDXRF). The EDXRF spectrometer used was a Tracor X-ray TX 5000 unit (Tracor X-ray Mountain View, CA, U.S.A.), which is a microcomputer-based energy-dispersive spectrometer with a rhodium X-ray tube. Two experimental set-ups were used to acquire the spectra for the light and heavy elements. For the light elements (Mg–Cl), an accelerating voltage of 15 kV and a 0.1 mA tube current with a cellulose filter were used, while for the heavy elements (K–Zr), a 35 kV accelerating voltage, a 0.35 mA tube current and a thin rhodium filter were used.

Spectrum evaluation and quantification were performed by means of the AXIL-QXAS software package (He, 1991).

Aerosol generation and analysis

A 1 kg aliquot from each soil was placed in a plexi-glass chamber, the design of which is shown in Fig. 1. The plexi-glass chamber was placed in a laminar flow clean air hood. A stream of filtered air was blown over the soil sample, at a velocity of about 10 $m\,s^{-1}$, by a fan fixed at the rear of the chamber. The chamber was divided into three, incompletely separated compartments by two layers of plexi-glass. The soil was placed in the lower compartment. The layers above this compartment provide some sort of a cut-off: very large particles will settle before they reach the upper compartment. At the top of the chamber, the dust (mineral aerosol) generated by the air is collected by sucking the air through an impactor using a vacuum pump. The impactor was a PIXE International (Tallahassee, FL, U.S.A), Model I-1 inertia cascade impactor. This impactor, when operated at 1 ℓ min^{-1}, fractionates the aerosol into size fractions of >16 16–8, 8–4, 4–2, 2–1, 1–0.5 and 0.5–0.25 μm equivalen aerodynamic diameter (EAD) for stages 7–1, respectively The collection surface was KIMFOL polycarbonate film o 1.5 μm thickness. It was coated with vaseline for stages 7– and with paraffin for stage 1. In addition a back-up filte collected particles of less than 0.25 μm. Fourteen impacto samples were collected from these soils. The collection tim ranged from 30 s to 2 min depending on the type of the soi Dust is easily generated from soils rich in small particles.