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Grain size distribution of different minerals in a sediment as a function of their specific density

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Abstract

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A beach sediment from Ameland, the Netherlands was divided into 9 grain size fractions. For each fraction the heavy minerals were separated subsequently and split in a number of magnetic fractions, roughly coinciding with particular minerals. All these fractions were weighed, and their mineral composition determined. The resulting grain size distribution for each different mineral turns out to be determined mainly by its specific density, and only to a minor degree by differences in the shape of grains.

Introduction

At the Kernfysisch Versneller Instituut (KVI), Groningen, a small program is devoted to the study of natural radioactivity. In addition to the investigation on radon concentrations in and around Dutch dwellings, which is part of the National research program SAWORA, samples of materials are studied by means of their emitted gamma-ray spectra. The discovery by Bonka (1980) that at some German North Sea islands the darker parts of the beach were related to higher than normal gamma-ray dose has led to a similar type of investigation in the Netherlands. At the beach of Ameland dark coloured spots were found and the study of some samples of this sand by gamma-ray spectroscopic methods showed an enhanced concentration of nuclei belonging to the decay series of thorium and uranium (Koopmans & Hofstee 1982). To study the origin of the enhanced concentrations several samples of 'dark' and 'normal' sand were studied in the laboratory. After drying, the samples were separated into different grain size fractions, which were again separated in fractions of different magnetic susceptibility in order to study the specific radioactivity as a function of grain size and magnetic susceptibility. Contrary to the ^{40}K activity, which is only slightly decreasing with decreasing grain size, both the activity of ^{232}Th and ^{238}U series increases exponentially with decreasing grain size (about three orders of magnitude when going from $250<Ø<300$ μ to $Ø<90$ μ). The study of the gamma-ray spectra for various magnetic fractions for the grain size $90<Ø<105$ μ showed strong fluctuations (two orders of magnitude) in the activities due to both the thorium and uranium series (Landeweer & Bergman 1985). Optical inspection of these fractions indicated that the magnetic separation had fairly closely followed the mineralogical composition of the sample, causing most minerals to be strongly concentrated in particular magnetic fractions. In this paper we report on the study of the grain size distribution of the different minerals from the dark sand (olive green-brownish) taken at Ameland near beach pole 19.

Sample preparation

13.489 kg of the dark sand was dry sieved for ten minutes in the following fractions:
<90, 90-105, 106-125, 126-150, 151-180, 181-212, 213-250, 251-300, and >300 μ.

Each of these fractions was weighed, resulting in the grain size distribution shown in Fig. 1; note the slightly bimodal character of this sample. The first maximum coincides with a maximum in the garnet population (16.3 wt.%), the second maximum corresponds to the light fraction which consists mainly of quartz (72.1 wt.%). The mineralogical composition of the dark sand is given in Table 1. Each of these different grain sizes, with the exception of the coarsest two, was separated by means of bromoform ($\varrho = 2.85 \times 10^3$ kg/m^3) in a heavy and light fraction. First the heavy fraction was weighed and the very minor magnetite component was removed by hand with a permanent magnet. Next the remaining fraction was divided into various magnetic fractions with a Frantz isodynamic separator. Some fractions contained relatively pure ilmenite, garnet or zircon, but most fractions were mixtures. The mineral composition of each magnetic fraction from each size fraction was weighed and its mineralogical composition was determined optically under a binocular as well as by estimates of mineral contents from Guinier X-ray films. All the contributions were summed up to give the mineral composition of each grain size sample. It should be mentioned that the values obtained are weight percentages, and as such not directly comparable to grain counts; in economic evaluations of black sand deposits, however, one is interested in wt.%, not in the number of grains. While studying the different mineral separates, the following qualitative observations were made:

- quartz is sub-angular to well-rounded.
- tourmaline crystals are rather elongated.
- epidote is well-rounded, oval shaped. Its X-ray pattern changes towards a more clino-zoisite pattern as one moves from finer to coarser fractions, where, in general, the 'epidote' is also paler green.

Table 1. Mineral composition of the dark sand.

Mineral	Weight %
light fraction	72.1
epidote	1.7
garnet	16.3
rutile	0.9
zircon	3.5
ilmenite	3.3
monazite	< 0.1
magnetite	0.1
tourmaline	0.2
others	1.9

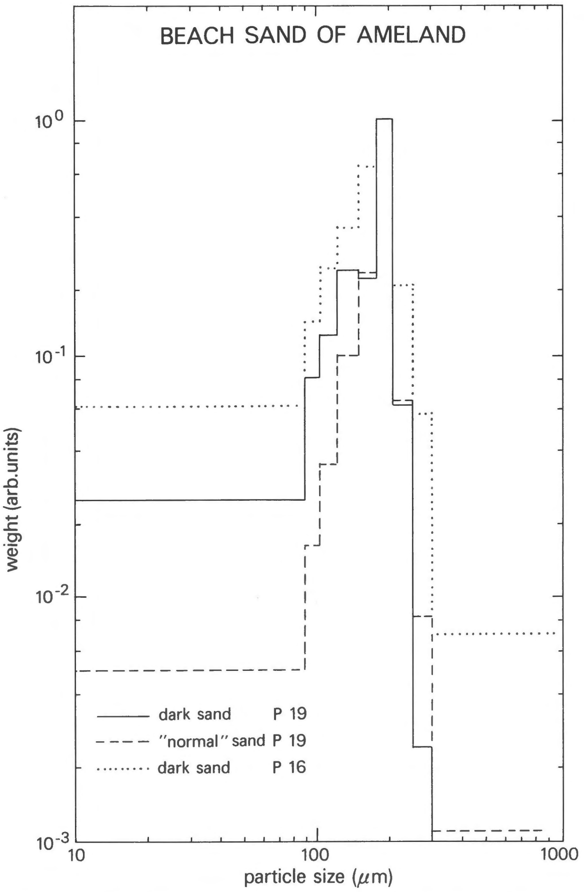

Fig. 1. Grain size distributions normalized to unity for size 180<Ø<212 for various samples of Ameland sediment. Note the bimodal character of the distributions for 'dark' sand.

– garnets range from sub-angular, equant grains to well-rounded. The percentage of pinkish garnets varies from close to 90% in the finest fractions to about 50% in the coarser fractions, the remainder of the garnets have a reddish color. Microprobe analyses of some selected pink and red garnets gave the following mean compositions: alm 75/ spess 3.5/ pyr 15/ gross 5.5 for pink garnets, and alm 69/ spess 3.5/ pyr 8.5/ gross 19 for red garnets. (alm=almandine, spess=spessartite, pyr=pyrope and gross=grossularite). The calculated densities are 4.16 for pink, and 4.11 for red garnets. It is surprising that even such a small difference in density causes already an observable shift in their hydrodynamic behaviour.

– rutiles are usually fairly rounded and somewhat elongated; knee-twins have only rarely been observed.

– zircons are well-rounded in the coarser fractions, only in the finest fractions elongated and idiomorphic zircons dominate.

– ilmenites are very well rounded; a determination of the specific density of ilmenites from the fraction 126-150 μ gives 4.59, from the fraction <90 μ the specific density is 4.68. (all densities are given in 10^3 kg/m^3).

– other minerals (anatase, hornblende, pyroxene, sphene, (aragonitic?) shell fragments) were occasionally observed, as were small micaschist fragments in the coarser fractions.

The grain-size distributions per mineral

Sedimentary geologists, to quote Rubey (1933), are familiar with the fact that heavy minerals tend to be concentrated within the finer grained

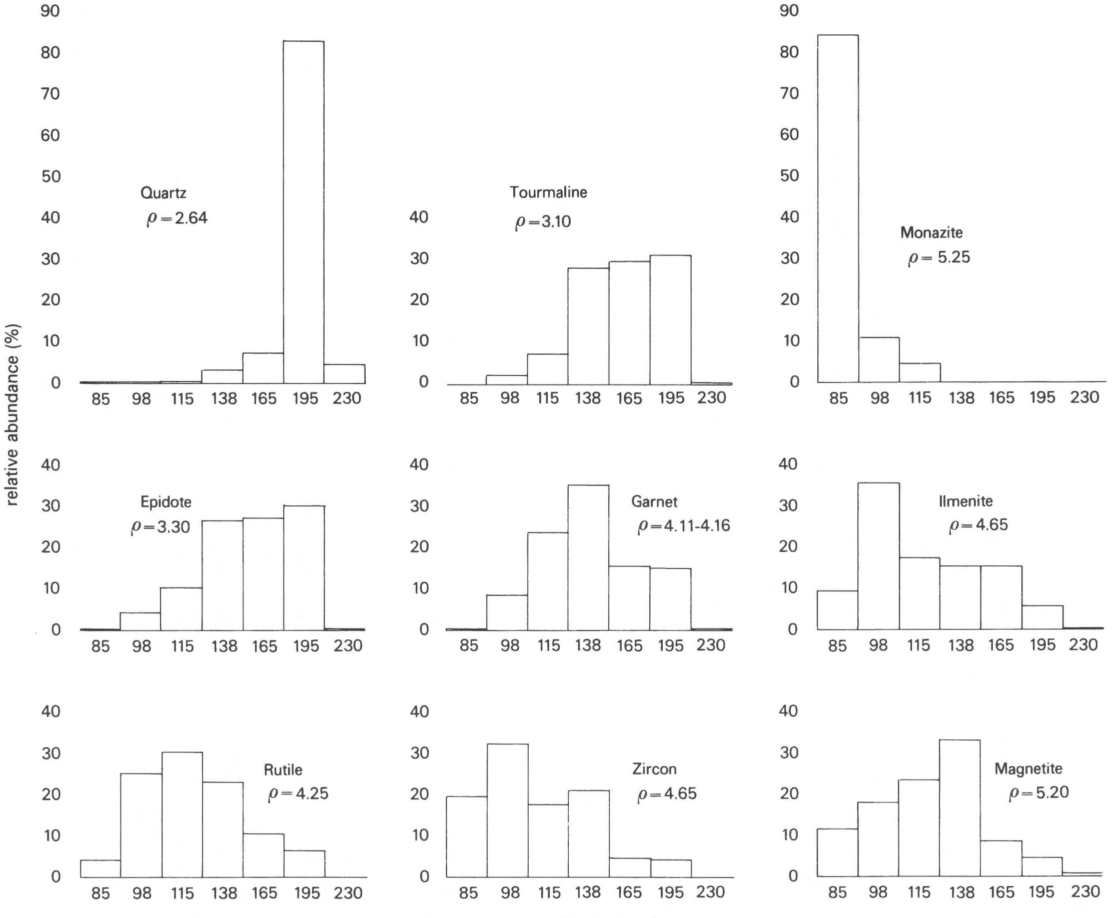

Fig. 2. Grain size distribution of individual minerals.

portions of sandstones and that this concentration is due largely to processes of sedimentation. This effect is demonstrated in Fig. 2, which shows the grain size distributions of quartz (=light fraction), tourmaline, epidote, garnet, rutile, zircon, ilmenite, monazite, and magnetite; the grain size classes are presented on Fig. 2 by their median values. It is evident from this figure that an increase of the density of a mineral shifts its average grain size towards a smaller size class. It should be mentioned that magnetite separation by permanent magnet turned out to be not very effective so the grain-size distribution of magnetite is given with much reserve. As observed by manually shaking the sand, magnetite has a tendency for clustering. This may result in an apparent larger grain size in the sieving procedure. Fig. 3 shows the average grain size of each mineral as a function of specific density. It is clear that this property is the dominant factor that determines which grain sizes for each mineral will be deposited side by side in the same sediment. A closer look at the fine structure of Fig. 3, however, reveals that shape also plays a role, because all elongated minerals fall in too small a size class with respect to their more spherical neighbours. This relation holds for tourmaline, to a lesser degree for epidote, slightly for rutile, whereas from optical observation it is clear that the size maximum for elongated, idiomorphic zircons would fall at a smaller size. Similarly the corresponding size maximum for well rounded zircons would fall at a larger size than the averaged zircon point on the graph of Fig. 3. It is clear that the hydrodynamic equivalent diameter for spherical particles is larger than the smallest axis of elongated grains, which determines the size class during sieving. The reverse is, of course, true for flat particles; significant amounts of mica flakes were only observed in the coarsest fractions.

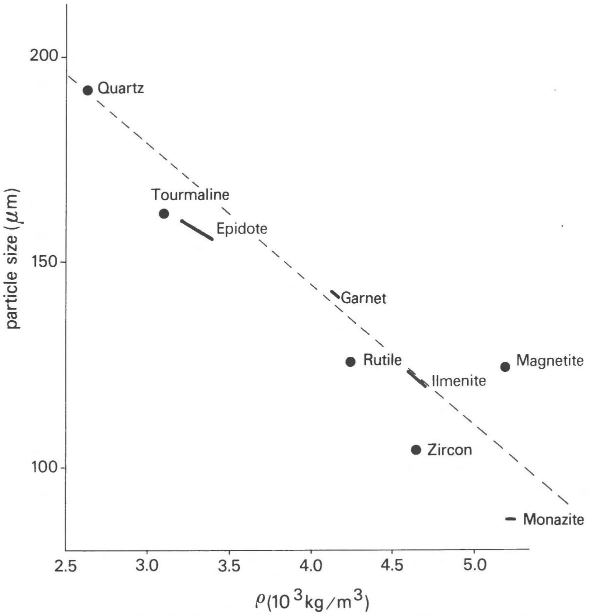

Fig. 3. Average grain size of individual minerals versus their specific density. The stippled line is drawn through the minerals that most closely approximate spheres. Diagonal symbols indicate a range in chemical compositions and densities for a given mineral, as well as the qualitative trend in the grain size distribution as a function of variable density of a mineral.

Some additional considerations

– It is clear that an exploitation of black sand deposits can profit greatly from a carefully chosen screening procedure. In the example from Ameland, wet sieving with sieves of .18 mm would reduce the amount of material to be processed in a mineral separation plant by 2/3 at a recovery loss of zircon of 4%, and a loss of rutile and ilmenite of 6% (compare Fig. 2). As mineral losses to tailings would probably be reduced when the amount of tailings would be reduced by 2/3, it is likely that the real recovery losses would be even less. This means that for similar black sand occurrences production might rise threefold for a given installed capacity of a mineral separation plant.

– Although sands will normally not contain as much heavy minerals as in the sample under consideration, it should be clear that a bimodal grain size distribution may in fact represent a unimodal distribution in terms of hydrodynamically equivalent grains. Bearing this in mind, a grain size distribution of a sediment should ideally be based not on all grains, but on grains of one mineral in the sediment only. In practice, however, the number of cases where the outcome is significantly different will be small.

– In principle, after correction for deviations of Stokes' law (Gibbs et al. 1971) one should be able to distinguish between water- and wind deposited sediments by looking at the average grain size of (at least) two minerals with different specific density. This can be done by applying Stokes' law for each different mineral, and solving for the density of the fluid. A similar approach has been proposed by Von Engelhardt (1939), who tried to distinguish between water- and wind laid sediments by using the ratio of the diameters of quartz and magnetite grains as a diagnostic feature. In practice this method meets with considerable problems, because the average grain size diameter for each mineral must be very accurately known (the mineral diameter occurs squared in Stokes' law), and secondly because deviations from Stokes' law have been quantitatively studied for water only, and not for air. The third, and most obvious reason is that actual particles are not ideal spheres.

Acknowledgments

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References

Bonka, H. 1980 Erhöhte natürliche Strahlenexposition durch Schwermineralanreicherungen an der Küste Norddeutschlands – Atomkernenergie-Kerntechnik 35: 5

Gibbs, R.J., Matthews, M.D., and Link, D.A. 1971 The relationship between sphere size and settling velocity – J. Sed. Pet. 41 no 1: 7-18

Koopmans G., and Hofstee, P. 1982 Verslag van het project over activiteitsmetingen van gips- en zandmonsters – KVI internal report i 8b (unpubl.)

Landeweer, G., and Bergman, R. 1985 Meting van de radioactiviteit van zandmonsters van Ameland – KVI internal report 106 i (unpubl.)

Rubey, W.W. 1933 The size-distribution of heavy minerals within a water-laid sandstone

Von Engelhardt, W. 1939 Die Unterscheidung wasser- und windsortierter Sande auf Grund der Korngrössenverteilung ihrer leichten und schweren Gemengteile – Chemie der Erde, Band 12, Heft 4: 445-465