Interactive comment on "Study of Arabian Red Sea coastal soils as potential mineral dust sources" *by* P. Jish Prakash et al.

Anonymous Referee #1

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The study presents results from measurements of the mineral composition and other properties of soil, based on 13 samples at four locations in the Saudi Arabian coastal plane adjacent to the Red Sea. The region has been understudied so far, although it is an important source of wind blown dust with at least regional impact on human health, climate, and ecosystems. There is a great need for measurements of this kind, not just in the region studied here, but generally, to better understand the impact of dust aerosols as well as to have more data available, which can be used to evaluate and constrain dust aerosols in modeling studies. Thus, I very welcome this study with the new data. The manuscript is generally well written and well structured. Having said this, I see the potential for some improvement in the manuscript, which can be achieved by doing a minor revision. The study should be published after the recommendations have been taken into account.

The authors apply a variety of measurements techniques for studying the mineral properties of the collected soil samples. This is a good approach, since it allows to study the dust mineral properties from different viewpoints. It also reveals, though, that results from the different types of measurements can vary, allowing for ambiguity in the interpretation. This is most evident in the current study where the mineral composition is investigated for the same size range, i.e., < 38µm particle diameter. For instance, the results from the X-ray diffraction (XRD) analysis give a quartz fraction between about 20 and 40 % and a fraction of all the phyllosilicates of not more than 10%. In contrast, the single particle analysis, using computer controlled scanning electron microscopy, gives a quartz fraction of only up to about 10%, whereas the phyllosilicates have the largest fraction compared to the other minerals, partially more than 50 %. Which ones of the results from the two different measurement techniques are more reliable? The authors only report these contradicting results next to each other, but a discussion of the significant differences and how to interpret them is lacking. For instance, the possibility of the presence of phyllosilicates in the form amorphous material with poor crystallization is a known source for bias, when XRD analysis is used (*Leinen et al.*, 1994; *Formenti et al.*, 2008; *Kandler et al.*, 2009). Could using this method have caused an overestimation of the quartz fraction? Knowing the answers to such questions would be necessary for properly using the data to constrain or evaluate simulations with dust models.

I recommend following modifications for improving the manuscript:

1. **Section 3, "Sampling and analysis":** For each of the described measurement techniques applied in the study add information about known sources of bias.

Information about known sources of bias will be added to each of the described measurement techniques applied in the study as shown below.

Page 5, Line 23: Minerals with distinctive optical properties, including refractive indices, birefringence, extinction angles, pleochroism, and optical interference patterns, or those showing twinning, distinctive cleavage, and diagnostic extinction angles, can be readily be identified by optical microscopy (Kerr, 1959). Minerals readily identified in these samples by this method include quartz, various feldspars, amphiboles, pyroxenes, micas and carbonates, However, depending on the mineral type, particles <10 μm in diameter are often difficult to identify by this method, including clay minerals and other layered silicates. The method requires the samples preferably to be mounted in epoxy as a polished thin section. The method is biased towards easily identifiable and coarser minerals, especially those with twinning such as feldspars, and showing color and pleochroism such as hornblende and biotite. The method, although one of the most practical for qualitative mineral analysis, does require mineralogical expertise.

Page 5, Line 31: Powder XRD is particularly suited for fine-grained crystalline mineral mixtures, <10 µm in diameter. The procedure measures the crystallinity of a sample, i.e. excludes amorphous phases such as glass, partly crystalline layered silicates such as some clays, and hydroxides. If an amorphous phase is present, it will not be fingerprinted by XRD. The assessment of mineral content of a powder sample by the relative intensity ratio (RIR) method suggested by Chung (1974), and as applied in our measurements, does not account for amorphous content.

Page 6, Line 7: This analytical method disperses soil aggregates which are potential dust particles, so shifting the particle size distribution curves towards the smaller particle sizes. This may introduce a bias into the actual size distribution of wind generated dust particles in the field.

Page 6, Line 17: The elemental composition of dust *per se* does not provide adequate information on its mineral content. However, with *a priori* knowledge of the mineral composition of the samples, from optical and XRD measurements, "normative" mineral compositions can be calculated. This provides a method for inter-comparing chemically analyzed samples with each other.

Page 7, Line 10: Due to the attenuation of the electron beam as it impinges the particle surface and loss of energy, the analysis is physically limited to an electron interaction volume of 2–5 µm below the mineral surface, depending on the primary beam voltage and the mineral density (Goldstein et al., 2003). Most of the investigated mineral dust particles have coatings of clay minerals and oxides, which results in an overestimation of the amounts of these minerals when analyzed by CCSEM (Engelbrecht et al., 2009a;Engelbrecht et al., 2016;Engelbrecht et al., 2009b).

2. **Sections 4.3 – 4.5, Figures 3 – 6:** Explicitly state both in the text and in the figures (at the axes or in the captions) the percentages of what variables are shown. Are these the

percentages of mass, volume, or number of particles? I suppose it is the mass fraction in the case of the XRD analysis. It is not clear to me in the cases of the other methods.

We agree to explicitly state both in the text and in the figures (in the captions) the percentages of variables in section 4.3-4.5 and Figures 3-6.

Section 4.3, Page 8, Line 9: XRD analysis of the thirteen, D<38µm sieved samples from the Red Sea coastal plain (Fig. 3) confirmed variable mass percentages of quartz (19 – 44%) and feldspars (plagioclase, K-feldspar) (31 – 48%), as well as of amphibole (and pyroxene) (4 – 31%), lesser amounts of calcite (0.4 – 6.2%), dolomite (1.9 – 6.6%), clays and chlorite (smectite, illite, palygorskite, kaolinite) (3.3 – 8.3%), with traces of gypsum (0 – 0.6%) and halite (0.2 – 4.8%).

Section 4.4, Page 8, Line 23 : The sedimentary samples all contain major mass percentages of SiO_2, varying between 63% and 78% in the thirteen samples, mostly as the mineral quartz, and lesser mass percentages of Al_2O_3 (3.7 – 7.3 %) CaO (0.9 – 1.7 %), Na_2O (1.2 – 2.0 %), and K_2O (0.9 – 1.6 %), in plagioclase and potassium feldspars. SiO_2 together with Al_2O_3, Fe_2O_3 (6.5 – 11 %), TiO_2 (1.2 – 2.5 %), MnO (0.1– 0.2 %) MgO (2.3 – 3.1 %), and some K_2O (0.9 – 1.6 %) is also contained in the previously identified amphiboles, clays and micas. Small amounts of CaO (0.9 – 1.7%) are contained in gypsum and calcite, and together with MgO (2.3 – 3.1%), in dolomite.

Section 4.5, Page 9, Line 13: For the total data set, the samples in the 0.5 – 38 µm size range contain about 0.1 – 10.2% quartz, 5 – 54% feldspar, 45 – 72% clay minerals, as major components with lesser amounts of calcite (0.9 – 7.4 %), dolomite (0 –0.8 %), gypsum (0 –1.5 %), and iron oxides (0.2 –12.4 %).

Figure 3: Normalized mineral compositions by percentage of mass [quartz (19 – 44%), feldspars (plagioclase, K-feldspar) (31 – 48%), amphibole and pyroxene (4 – 31%), calcite (0.4 – 6.2%), dolomite (1.9 – 6.6%), clays and chlorite (smectite, illite, palygorskite, kaolinite) (3.3 – 8.3%), gypsum (0 – 0.6%) and halite (0.2 – 4.8%)] of thirteen D < 38µm

sieved soil samples collected at four localities along the Red Sea coastal area, as measured by X-ray diffraction (XRD).

Figure 4: Compositional plot showing major oxides percentages by mass [SiO_2 (63 – 78%), TiO_2 (1.2 – 2.5 %), Al_2O_3 (3.7 – 7.3 %), Fe_2O_3 (6.5 – 11 %), MgO (2.3 – 3.1 %), CaO (0.9 – 1.7 %), Na_2O (1.2 – 2.0 %), K2O (0.9 – 1.6 %)] from ICP-OES analysis of < 38 µm sieved soils.

Figure 5: CCSEM based individual particle analysis for 0.5 – 38 µm chemical set, with the chemical bins labeled as minerals by mass percentage [Si-rich, Quartz (0.1 – 10.2 %), K Feldspar (2.7 –15.6 %), Ca Feldspar (1.1 – 25 %); Na Feldspar (1.5 – 13.4 %); Si-Al, Clays (44.7 – 72.1 %); Si-Mg (0 – 3.7 %); Ca-Mg, Dolomite (0 – 0.8 %); Ca-Si (0.6 – 6.4 %); Ca-S, Gypsum (0 – 1.5 %); Ca-rich, Calcite (0.9 – 7.4 %); Fe-rich, Hematite (0.2 – 12.4 %); Salts (0 – 2.2 %); C-rich (0 – 5.5 %) and Miscellaneous (0 – 5.9 %)]

Figure 6: CCSEM based individual particle analysis for 0.5 – 2.5 µm (fine) subset, with the chemical bins labeled as minerals by mass percentage [Si-rich, Quartz (2.1 – 4.9 %), K Feldspar (3.8 –9.0 %), Na Feldspar (3.8 – 12.9 %); Ca Feldspar (1.4 – 7.7 %); Si-Al, Clays (39.2 – 70.7 %); Si-Mg (0.2 – 1.7 %); Ca-Mg, Dolomite (0 – 0.7 %); Ca-Si (0.3 – 1.5 %); Ca-S, Gypsum (0.1 – 1.7 %); Ca-rich, Calcite (0.6 – 4.1 %); Fe-rich, Hematite (3.2 – 24.1 %); Salts (0.1 – 1.6 %); C-rich (0.4 – 10.5 %) and Miscellaneous (1.2 – 10.1 %)].

3. **Section 5, “Discussion and Conclusions”:** Add a discussion of differences in the results from the different measurement techniques and how these differences should be interpreted. How should the data be used, when they are applied in modeling studies?

Discussion of differences in the results from the different measurement techniques will be added and interpreted as follows.

Page 9, line 32: The application of a range of techniques for the analysis of properties of soil samples allows for a better understanding of mineral dust. However, the different analytical methods often provide different results, as seen by comparing the XRD, electron microscopy and chemistry of the soils. In this study, the results from the XRD analysis gives a quartz percentage of between about 19 and 44 % and sheet silicates (clays, micas) of between 3 and about 8%. In contrast, the single particle analysis by CCSEM gives a quartz fraction of only up to about 10%, whereas the sheet silicates always have the largest mineral percentage, of up to about 72%. This can lead to ambiguity in the interpretation of the mineralogical composition of the samples. This is evident even where the mineral composition is investigated for the same size range, i.e. < 38µm particle diameter. Biases in XRD results can be related to the presence of partly amorphous sheet silicates with poor crystallization (*Leinen et al.*, 1994; *Formenti et al.*, 2008; *Kandler et al.*, 2009) and a subsequent overestimation of the quartz fractions. Knowing the answers to such questions would be necessary for properly using the data to constrain or evaluate simulations with dust models. Similarly, the individual particle analysis by CCSEM provides an overestimation of the clay fraction which can be attributed to surface coatings on the quartz and its underestimation (Engelbrecht et al., 2009a, b;Engelbrecht et al., 2016). What is of importance when considering the application of these results in models, health studies, and remote sensing, is not only the mineralogical composition of the dust, but also their mineralogical interrelationships such as mineral clusters, mineral coatings, and intergrowths.

4. **Section 4.1, Page 7, line 32:** Regarding the statement about the satellite images, I suppose this refers to the two references (Jiang et al. and Kalenderski et al.) that are mentioned elsewhere in the manuscript. Please explicitly reference the two papers once more at the end of the sentence.

Two references (Jiang et al., 2009 and Kalenderski et al., 2013) will be added in the text as shown below:

Page 7, Line 32, Section 4.1: However, the satellite images (Jiang et al., 2009 and Kalenderski et al., 2013) show that these coastal dust sources are activated quite frequently.

References:

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