Mineralogy and geochemical properties of dust storm in Sistan region and Khuzestan Province, Iran

Jamshid AHMADIAN, Mamoru MURATA, Maryam AMINOROAYAEI YAMINI, Hiroaki OZAWA, Takeshi KOZAI, Natsuko ADACHI and Hiroshi NISHIMURA

鳴門教育大学学校教育研究紀要

第 31 号

Bulletin of Center for Collaboration in Community
Naruto University of Education
No.31, Feb., 2017

原著論文

鳴門教育大学学校教育研究紀要　31，169－176

Mineralogy and geochemical properties of dust storm in Sistan region and Khuzestan Province, Iran

Jamshid AHMADIAN[1, 2], Mamoru MURATA[3], Maryam AMINOROAYAEI YAMINI[1], Hiroaki OZAWA[4], Takeshi KOZAI[3], Natsuko ADACHI[3] and Hiroshi NISHIMURA[3]

[1]Payame Noor University, PO BOX 19395-3697 Tehran, Iran
[2]Center for collaboration in community, Naruto University of Education, Naruto, Tokushima, 772-8502, Japan
[3]Naruto University of Education, Naruto, Tokushima, 772-8502, Japan
[4]Department of International Education, Naruto University of Education, Naruto 772-0022, Japan

Abstract：In recent years, dust storms coming from western neighboring countries are drastically increased dust storms and affecting western and eastern part of Iran. This phenomenon is caused a lot of environmental and socio-economic problems. Sistan is a region located in southeast Iran with extensive wind erosion. X-Ray Diffraction (XRD) analysis of airborne and soil dust samples from Sistan shows that the dust mineralogy is dominated mainly by quartz (30-40%), calcite (18-23%), muscovite (10-17%), plagioclase (9-12%), chlorite (~6%) and enstatite (~3%), with minor components of dolomite, microcline, halite and gypsum. X-Ray Fluorescence (XRF) analyses of all the samples indicate that the most important oxide compositions of the airborne and soil dust are SiO_2, CaO, Al_2O_3, Na_2O, MgO and Fe_2O_3, exhibiting similar percentages for both stations and soil samples. However Khuzestan Province is located in southwest Iran with sandy deserts. XRD result from Khuzestan show that mineralogical composition of these dust particles can be divided into three groups: (1) Carbonate group (calcite mineral), (2) Silicate group (quartz mineral) and (3) Clay group (Kaoline mineral). The most important minor phase is Gypsum. SEM studies indicate that these particles were found in rounded, irregular, prismatic and rhombic shapes. XRF and ICP analyses of the samples show that the most important oxide compositions of airborne dusts are SiO_2, Al_2O_3, Fe_2O_3, CaO and MgO. This research can be help to find the impact of geological units on the wind erosion lands for finding dust storm sources in the states of western and eastern parts of Iran.

Keywords：Aeolian dust, dust chemistry, mineralogical composition, Sistan, Khuzestan, Iran.

Ⅰ. Introduction

Mineral dust plays an important role in the optical, physical and chemical processes in the atmosphere, while dust deposition adds exogenous mineral and organic material to terrestrial surfaces, having a significant impact on the Earth's ecosystems and biogeochemical cycles (Lawrence and Neff, 2009). Dust particles are fine airborne soil and/or weathered or transported rock particles removed from the Earth's surface as a result of wind erosion under certain climatic, meteorological and soil conditions. The Earth's surface is composed of a large number of minerals, which occur in heterogeneous mixtures within rocks and weathering mantles. Analysis of the physical properties and chemical composition of dust aerosols is, therefore, important to determine aerosol sources, mixing processes and transport pathways (Bergametti *et al.*, 1989; McConnell *et al.*, 2008; Mishra and Tripathi, 2008). It is estimated that 1000-3000 Tg of mineral aerosols are emitted annually into the atmosphere over the globe (Jones *et al.*, 1995), which can be transported over long distances (*e.g.*, Prospero, 1999). The role of dust aerosols in atmospheric processes, i.e. Earth's radiation balance and cloud microphysics *etc*, strongly depends on a variety of physico-chemical parameters, size distribution, dust sources, atmospheric lifetime and mixing processes in the atmosphere (Frank *et al.*, 1996; Sokolik *et al.*, 1998; Rosenfeld *et al.*, 2008).

Southwestern and southeastern Iran is recognized as regions where dust storm generation is especially intense and characterized by a wide distribution of aeolian sediments (Zarasvandi *et al.*, 2011; Ahmady-Birgani *et al.*, 2015). Until recently, this has been related mostly to the wind action in response to the fluctuation in temperature and precipitation and the absence of vegetation in these regions (Ghahreman, 2003). However, with the intensive utilization of natural resources, urbanization, industrialization, armed conflicts, and other anthropogenic activities, land's surface disturbance became inevitable and the frequency, intensity, complexity, and duration of dust and sand storms have increased substantially, imposing heavy damages to the economy, society, and public health.

The main aims of this study are to examine airborne particulates at Sistan region and Khuzestan Province, two meteorological sites, in southeastern and southwestern Iran, respectively, and to assess their mineralogical-geochemical characteristics of airborne and soil dust properties. These observations should also provide information on the source materials of these atmospheric particulates.

Ⅱ. Study area

Dust storms have become a major environmental concern during the recently decades in the oil- and gas-rich Khuzestan, Sistan Provinces in Iran (Fig. 1). Sistan region is located in southeastern Iran, between latitudes 25° 4′ N and 31° 29′N and longitudes 55° 58′ E and 63° 20′ E and covers an area of 181,785 km^2. The Sistan region (Fig. 2) is a major dust source in southwest Asia (Goudie and Middleton, 2000), often producing intense dust storms that cover Sistan, and the southwest of Afghanistan and Pakistan (Alam *et al.*, 2011; Rashki *et al.*, 2012). Particles from dust storms might also cover farm and grasslands to result in damage to crops and fill the rivers and water channels with aeolian material. After the extreme drought of 1999, the dust activity over Sistan appears to be increasing in both frequency and severity. Over recent years, ten thousands of people have suffered from respiratory diseases and asthma during months of devastating dust storms in the Sistan basin, especially in the cities of Zabol and Zahak and the surrounding villages (Miri *et al.*, 2007). According to the Asthma Mortality Map of Iran, the rate of asthma in Sistan is, in general, higher than in other regions (Selinus *et al.*, 2010).

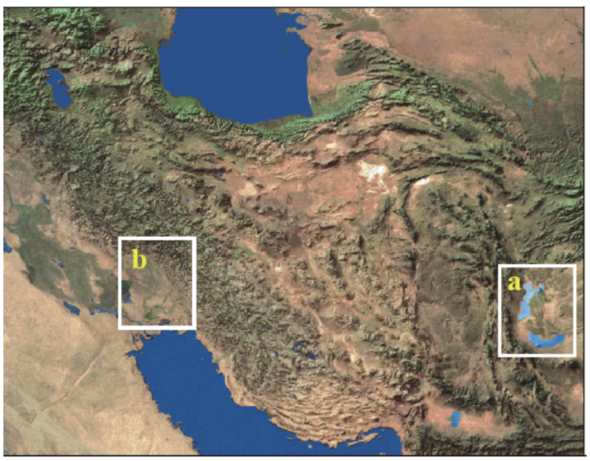

Fig. 1. Two prominent mineral dust sources in Iran. (a), Sistan region; (b), Khuzestan province.

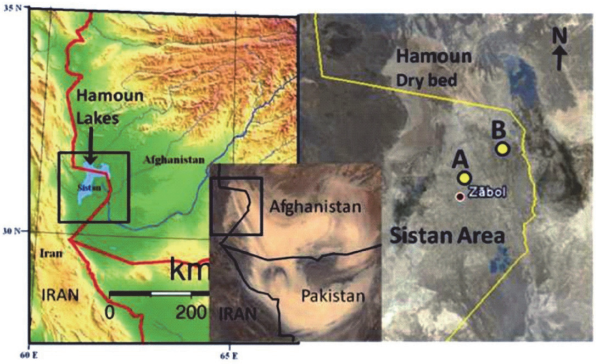

Fig. 2. Map of the study area showing the Sistan Basin, Hamoun lakes and the two measuring locations, A and B between Zabol city and the Hamoun dry-bed lakes.

Also Khuzestan Province lies between 47° 40′ E and 50° 33′ E longitude and 29° 57′ N and 33° 00′ N latitude and covers an area of 64,055 km^2(Fig. 3). Dust storms frequently occur in Khuzestan province mainly during summer, and intense dust storms are particularly associated with easterly-blowing winds (IRIMO Ahvaz, 2008). From March 2007 to June 2009, an average of 60 dust storm days per year has occurred in various cities of Khuzestan province (Zarasvandi, 2009). More than half of the number of dust storm days in 2007-2009 had maximum visibility of <1 km (IRIMO Ahvaz, 2008). Dust storms in Khuzestan likely emerge from sandy deserts, dried lakebeds, or chemically- and naturally-polluted regions in neighboring countries, are borne upwards and carried by winds to Iran (Zarasvandi, 2009). For example, airborne dusts travel daily eastward from Saudi Arabian and Iraqi deserts to southwestern and southern Iran (Raespour, 2008). Figure 4 Shows Khuzestan province on April, 2008.

Ⅲ. Mineralogy of dust storms particles

1. Mineralogy in Sistan region

Wind erosion and associated dust outflows is a common scenario in Sistan, which is considered as an active dust-storm region all year round, with higher intensity in summer (Jun-Aug). Middleton (1986) reported that over 30 intense dust storms per year originate from Sistan, more than any other area in southwest Asia. Especially during summer, when the Hamoun lakes are dry and the wind speed is at its maximum, Sistan becomes a major contributor of dust aerosols over southwest Asia and the northern Arabian Sea (Rashki *et al.*, 2012). Rashki *et al.* (2012) examined the climatology and meteorology over Sistan via observations from the nearby Zabol meteorological station, reporting that throughout the year the winds are northwesterly in direction with higher intensity during summer, while the sediment

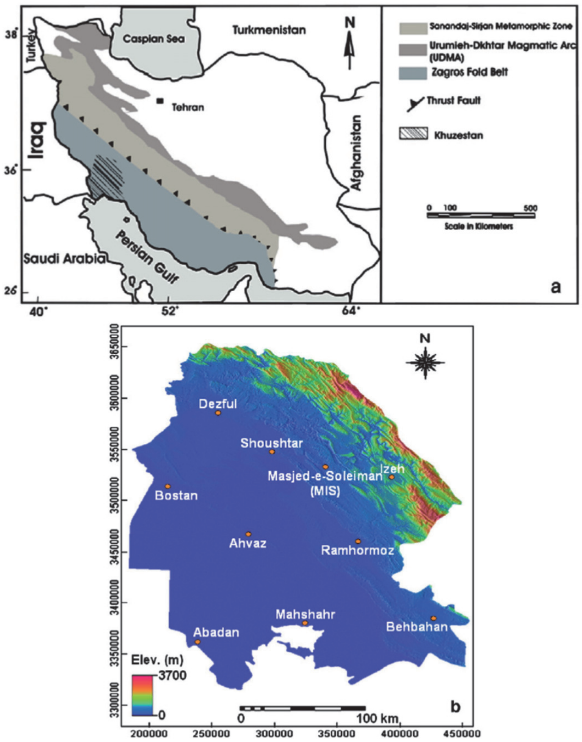

Fig. 3. Khuzestan province.
(a), location and regional geological setting in Iran; (b), digital elevation model and locations of the studied stations.

Fig. 4. Khuzestan province, April 19, 2008

loading depends mainly on the duration of dust torms and secondarily on wind speed and direction.

Rashki *et al.*, 2013, analyzed for samples collected during 15 events of intense dust storms at station A and on 9 days at station B, with their between distance being ~20 km. The dust samples were collected at 4 heights at station A and at 8 heights at station B. Except of the airborne dust samples, the mineralogy of soil samples collected at 16 locations is also analyzed and compared to those of airborne samples. Rashki *et al.*, 2013 reported large quantities of quartz-rich, feldspar- and mica-bearing silt, as well as mafic material from flood basalt sources and carbonate minerals from dolomites, are transported to the Hamoun wetlands in northern Sistan (Fig. 5). Due to droughts at Hamoun and large irrigation projects upstream on the river catchment, extensive desiccation has occurred in the wetlands resulting in large dry lake environments. These have produced large quantities of evaporite minerals to add to the alluvial silts, and the combination of these materials provides the provenance for the airborne dust.

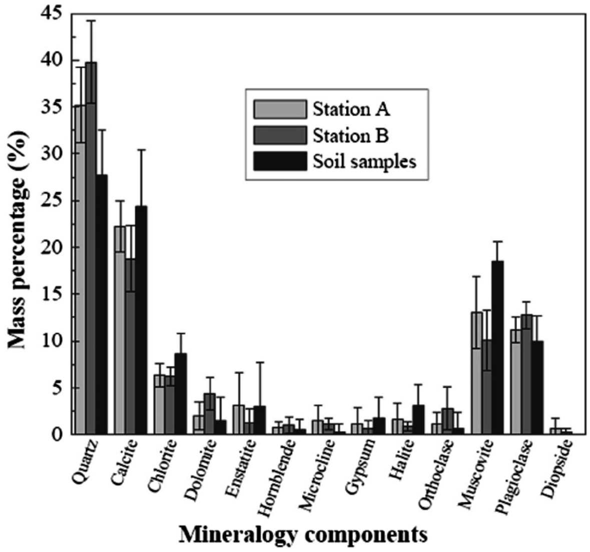

Fig. 5. Average mineralogy components for airborne dust samples in stations A and B and for soil samples obtained at various locations in Hamoun Basin (Rashki *et al.*, 2013). The vertical bars express one standard deviation from the mean.

2. Mineralogy in Khuzestan Province

During dust storm days in 2008 in different stations in Khuzestan, Zarasvandi *et al* (2011) collected nine samples of airborne dusts for XRD and SEM studies. Based on XRD analysis, samples of airborne dusts collected at mentioned stations (Abadan and Ahvaz cities) are composed of mostly of three mineral groups: carbonates (mainly calcite), silica (mainly quartz) and phyllosilicates (mainly kaolinite). However, the PM10 fraction usually has higher calcite and quartz content compared to the TSP and PM2.5 fractions. The abundance of calcite and quartz in most of the samples indicates detrital sedimentary origin for natural particles in airborne dusts in Khuzestan (Zarasvandi, 2009). The samples are characterized by multi-modal particle-size distributions and are comprised predominantly of angular to sub-rounded quartz particles. These can be the result of various types of dust concentrations during the storms in the study area, variable source sedimentary rocks and silt-size particles, and particle-size redistribution (Hladil *et al.*, 2008). The low reactivity of quartz with heavy metals suggests that its presence is not a factor in concentrating heavy metals in airborne dusts.

Several SEM images, taken with different magnifications of selected samples, show that spherical, irregular, long and prismatic, crystalline and rhombic twinning shapes are the most common shapes of dusts in the samples (Fig. 6). The SEM studies indicate that PM10 is the most frequent particulate size of Khuzestan airborne dusts. Spherical particles of b5 μm in PM2.5 are mainly clay aggregates (phyllosilicates), whereas large prismatic crystals of 20-40 μm are gypsum (sulfate). Regular crystals of 10-20 μm in PM10 samples are mainly calcite, whereas semi-spherical or irregular shapes of 10-20 μm in PM10 are quartz. SEM measurements indicate that the sizes of storm-generated dusts in Khuzestan vary between 20 and 50 μm (Zarasvandi *et al.*, 2011).

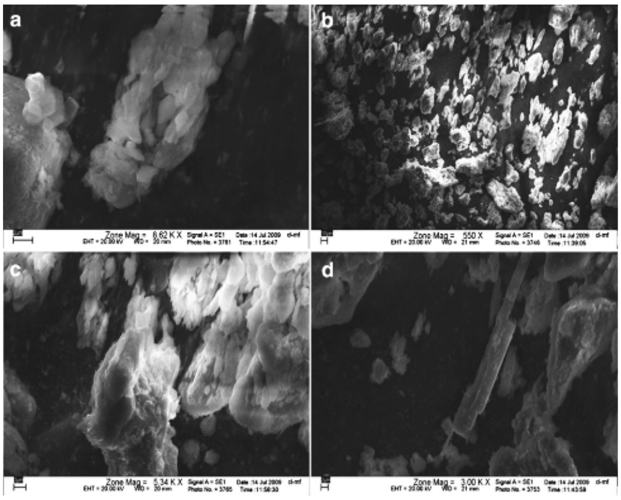

Fig. 6. SEM images of airborne dust particles in Khuzestan. (a), calcite; (b), quartz; (c), calcite and clay aggregates; (d), gypsum. Scale bar in each image is 2 μm except in (b) where it is 10 μm (Zarasvandi *et al*., 2011)

Ⅳ. Elemental composition of dust

1. Elemental composition in Sistan region

Knowledge of the chemical composition of airborne dust is necessary for clarifying the likely source regions and is important for quantitative climate modeling, in understanding possible effects on human health, precipitation, ocean biogeochemistry and weathering phenomena (Goudie and Middleton, 2006). The major-element and ion-chemistry analyses provide estimates of mineral components, which themselves may be hazardous to human health. In general, the analysis reveals that all samples at both stations from Sistan region contain major amounts of SiO_2, mainly in the mineral quartz, variable amounts of CaO in the mineral calcite, plagioclase feldspar and to a limited extent in dolomite, as well as substantial Al_2O_3 concentrations (Rashki *et al.*, 2013). More specifically, average major elements of airborne dust at both stations indicate a predominant SiO_2 mass component (46.8-47.8%) with significant CaO (12-12.2%) and Al_2O_3 (10.4-10.8%) contributions; a few percent of Na_2O (4.2-5.4%), MgO (4.3%) and total iron as Fe_2O_3 (3.8-4.1%), as well as trace amounts (<1%) of TiO_2, K_2O, P_2O_5 and MnO (Figs. 7a, b). When compared to various average shale analyses in the literature (Geosynclinal Average Shale and Platform Average Shale from Wedepohl, 1971; Average Shale from Clarke, 1924; North American Shale Composite from Gromet *et al.*, 1984), the Sistan dust is significantly depleted in SiO_2, Al_2O_3, K_2O and total Fe and significantly enriched in CaO, Na_2O and MgO. The MgO is largely contained in dolomite and, to a lesser extent, in clay minerals such as palygorskite and montmorillonite (Goudie and Middleton, 2000; Engelbrecht *et al.*, 2009). These components can be ascribed to the importance of evaporite minerals such as calcite, dolomite, halite and gypsum inferred to have come from the desiccation taking place in the Hamoun dust source region. Furthermore, the elevated values for the trace elements Cl, F and S (Rashki *et al.*, 2013) support the latter postulate as it would be expected from an evaporite-rich source for deflation of dust (e.g., Talbot and Allen, 1996). Similar to the present findings, Engelbrecht *et al.* (2009) determined a high fraction of SiO_2 in silt, less CaO in calcite and slightly more Al_2O_3 in clay minerals at the Khowst site. At both Afghanistan sites (Bagram and Khowst), the SiO_2 was dominant with fractions of about 50-55%, followed by Al_2O_3, CaO and MgO.

By comparing the major elements of different dust storms, some interesting relationships are revealed. More specifically, on days (*e.g.* 15/11/2009, 7/1/2010, 23/1/2010) (Fig. 7a) when airborne dust was relatively depleted in SiO_2, enhanced MgO and, particularly Na_2O values were recorded (Rashki *et*

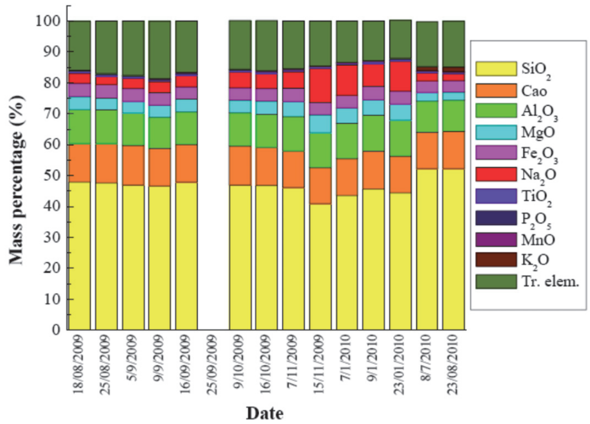

Fig. 7a. Major elements (oxides) for airborne dust samples obtained on different days at Station A from Sistan region by means of the XRF analysis (Rashki *et al.*, 2013).

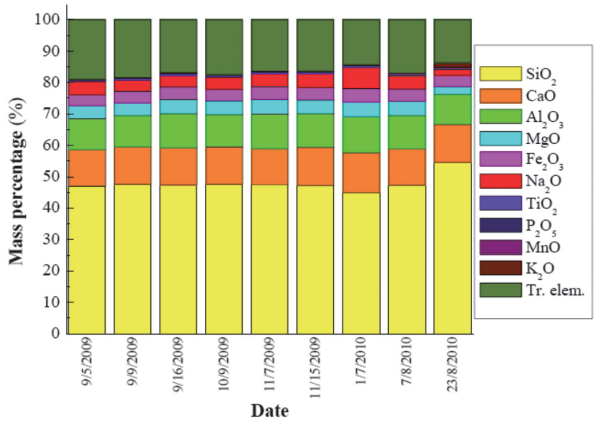

Fig. 7b. Same as in Figure 7a, but for the station B in Sistan region (Rashki *et al.*, 2013).

al., 2013). Conversely, when SiO_2 values were higher (*e.g.* 8/7/2010, 23/8/2010), both MgO and Na_2O contributions dropped. This suggests that certain intense dust storms were richer in evaporite source material (i.e., elevated MgO and Na_2O) coming from Hamoun dried lake beds, while others had more silica, reflecting weathered rock detritus from the Hirmand river and Afghanistan mountains. An explanation of these variable chemical compositions of dust samples is a real challenge, but it is postulated here that they may reflect local desiccation cycles and, possibly, even micro-climatic changes in the Hamoun-lakes dust source region. Excessive desiccation of the lakes would enhance potential evaporite minerals for deflation in drier periods, while in wetter periods, airborne dust would logically have been derived more from weathered fluvial detritus rich in SiO_2.

2. Elemental composition in Khuzestan

The dominant major oxides in Khuzestan airborne dusts are SiO_2 and Al_2O_3 (Zarasvandi *et al.*, 2011). The concentrations of these two major elements are similar to those of normal airborne dusts worldwide. The abundance of SiO_2 in Khuzestan airborne dusts is mainly due to quartz. The average concentration of SiO_2 in Khuzestan airborne dusts is less than the average value presented by Wu *et al.* (2009) for dust aerosols over the Eastern Pamirs. Major oxides in Khuzestan airborne dusts are more concentrated in coarse particles than in fine particles (TSPNPM10NPM2.5). The likely reason for this is transportation of minerals and altered indiscrete particles.

Nearly constant Ti/Nb ratios indicate a similar provenance for siliclastic rocks (Engelbrecht *et al.*, 2009b). Zarasvandi *et al.* (2011) shows all but one of the studied dust samples have Ti/Nb ratios of ~400 (excluding sample AH-1, mean= 402.5 and standard deviation= 41.9). Thus, most Khuzestan airborne dusts likely originate from essentially the same source area. Well mixing of dusts by winds is also a likely reason for the narrow variance of Ti/Nb ratios in Khuzestan airborne dust (cf. Crouvi *et al.*, 2010). In addition, because Rb commonly substitutes for K and because Ga commonly substitutes for Al in aluminosilicates, nearly constant ratios of either Rb/K or Ga/Al in airborne dusts indicate homogeneity of aluminosilicates in source areas of dusts (Engelbrecht *et al.*, 2009b). Zarasvandi *et al.* (2011) shows that, because the studied dust samples have nearly constant Ga/Al ratios of ~0.28 (mean= 0.28 and standard deviation= 0.04) and nearly constant Rb/K ratios of ~4 (mean= 4.04 and standard deviation= 0.98), aluminosilicates in the source areas of Khuzestan airborne dusts are roughly homogeneous.

Ratios of Si/Al in TSP and PM10 of dust samples are similar, probably due to the presence of silicate, tectosilicate, and aluminosilicate minerals in most size fractions of Khuzestan airborne dusts. Some element ratios (*e.g.*, Mg/Al, Ca/Al, and Fe/Al) in airborne dusts indicate contribution of clays to the chemical compositions of Khuzestan airborne dusts (Zarasvandi *et al.*, 2011). These geochemical characteristics are generally common to the TSP, PM10 and PM2.5 fractions of Khuzestan airborne dusts (Zarasvandi, 2009), suggesting that source materials of those dusts are similar, if not the same.

The chemical compositions of airborne dust samples in Khuzestan are similar to those in other parts of the world (Zarasvandi, 2009). Comparisons Fe/Al ratios in samples of airborne dusts in Khuzestan with those in other parts of the world indicate that this ratio is almost invariant and, thus, can be good source tracer for dust origin (Zarasvandi *et al.*, 2011). The Fe/Al ratio is not expected to change during transport, but its variations are mostly due to variations in clay mineral compositions (Goudie and Middleton, 2006). Ratios of Ca/Al show greater variations in TSP, PM10, and PM2.5 of Khuzestan airborne dusts. The Ca/Al ratios in all Khuzestan dust samples are relatively high, probably because the samples were all collected during summer or warm periods. Rainfall during summer facilitates separation of Ca-bearing compounds and, thus, concentration of salts in source deserts and enrichment of Ca in dusts (Wu *et al.*, 2009).

3. Caparation of the elemental compositions in Sistan region and Khuzestan province

Figure 8 summarizes the results of the elemental compositions determined by XRF analysis at Sistan region and Khuzestan province (Rashli *et al.*, 2013; Zarasvandi *et al.*, 2009) is also shown. The vertical bars express one

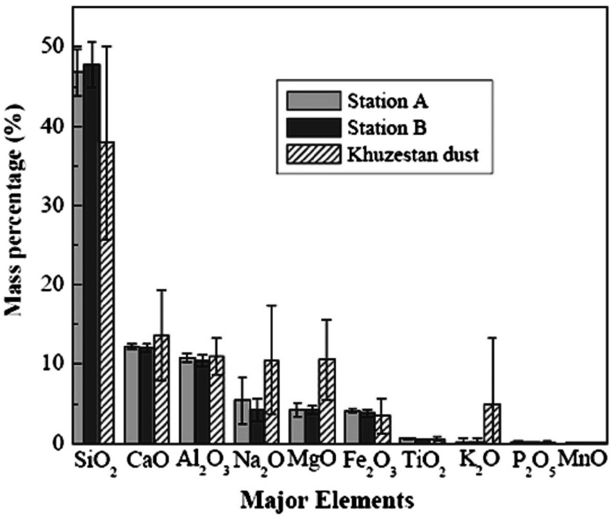

Fig. 8. Average X-ray fluorescence (XRF) results for major dust elements in stations A and B from Sistan region (Rashki *et al.*, 2013).
Similar results obtained in Khuzestan Province (Zarasvandi *et al.*, 2009) are also shown for comparison.

standard deviation from the mean. Concerning the major elemental oxides over Sistan region, both stations exhibit similar results, well within the standard deviations, suggesting that the transported dust over Sistan is locally or regionally produced with similarity in source region. In contrast, the mean elemental composition of airborne dust over Khuzestan province exhibits remarkable differences from that over Sistan, revealing various source regions and dust mineralogy. More specifically, the SiO_2 percentage is significantly lower and highly variable over Khuzestan, which is also characterized by higher contributions of Na_2O, MgO and K_2O compared to Sistan region. The dust storms over southwestern Iran may originate from local sources as well as being transported over medium- and long-ranges from different sources located in Iraq as well as in Arabian Peninsula. A comparative study of the mineralogy and elemental composition of airborne dust at several locations in Iraq, Kuwait and the Arabian Peninsula (Engelbrecht *et al.*, 2009a) has shown significantly variable contributions, suggesting differences in overall geology, lithology and mineralogy of these regions. In further contrast, airborne dust over Sistan seems to have its individual characteristics originating from local and well-defined sources.

Ⅴ. Health Effects of Dust Storm in Iran

1. Health Effects in Sistan region

Sistan region lies within a dry temperate zone with lowlands. It is an arid region with very low annual precipitation (61 mm), low air humidity, and frequent droughts and dry winds. Tens of thousands of people have been suffering through months of devastating sand storms in Sistan Basin, especially the cities Zabol and Zahak and surrounding villages. A severe sandy dust storm occurred in Zahak and its 80 villages on June 30, 2008 and resulted in closed schools and businesses. With the storm lasting about 5 days, more than 3,000 people suffering from allergy and respiratory diseases went to hospitals or health centers.

Miri *et al.* (2007) indicated that 132,000 people have been considered as patients suffering from respiratory diseases related to the dust storms. The health damages to the population were estimated at over US $66.7 million in the period 1999-2004. The information obtained from hospitals indicated that most of the patients who visited hospitals suffered from chronic obstructive pulmonary disease (COPD) and asthmatic diseases with the peak of incidence during the summer season (June, July and August) when the severest dust storms occur.

2. Health Effects in Khuzestan Province

Dust storms blow out of Iraq and Saudi Arabia over western and southwestern provinces of Iran causing severe health effects, especially in Khuzestan Province, southwestern Iran. Health effects of dust in Khuzestan Province include increasing asthma in some cities especially for people with chronic respiratory and cardiovascular diseases. Allergic diseases are more frequent in children and adolescence compared to other age groups. On June 16 and 17, 2008, 205 people went to hospital and 2 people perished due to respiratory poisoning of dust (Fazlollahi, 2008). Although the levels of chemical, mineral, and microbial contaminants are not very high, the contaminants could enter into the food chain and cause health problems; therefore more studies on contaminants in food and water resources in the region are required.

Ⅵ. Conclusions

To fully understand mineral dust characteristics and the potential impact to human health, dust mineralogy and geochemical properties were examined in the Sistan region and Khuzestan Province, southeastern and southwestern of Iran, respectively. The results showed that quartz, calcite, muscovite, plagioclase and chlorite are the main mineralogical components of the dust in Sistan. In contrast, significantly lower percentages for enstatite, halite, dolomite, microcline, gypsum, diopside, orthoclase and hornblende were found. On the other hand, SiO_2, CaO, Al_2O_3, Na_2O, MgO and Fe_2O_3 were the major elements characterizing the dust of Sistan region.

XRD analyses from Khuzestan Province show that minerals present in airborne dusts in Khuzestan can be divided into three groups: (1) carbonates (mainly calcite); (2) silica (mainly quartz); and (3) clays (mainly kaolinite). Gypsum is a significant minor mineral component of Khuzestan airborne dusts. SEM studies show that Khuzestan airborne dusts (a) have various shapes depending on mineral composition and (b) vary in size from 2 to 44 μm regardless of their mineral composition. XRF and ICP-MS analyses show that chemical composition of Khuzestan storm-generated dusts is similar to some other airborne dusts in the world. The significant major oxides in Khuzestan airborne dusts are SiO_2, Al_2O_3, Fe_2O_3, CaO and MgO.

A comparative study of the mineralogy and elemental composition of Khuzestan airborne dusts and Sistan region has shown significantly variable contributions in Khuzestan province, suggesting differences in overall geology, lithology and mineralogy of these regions. In further contrast, airborne dust over Sistan seems to have its individual characteristics originating from local and well-defined sources.

Acknowledgments

We are indebted to Dr. Yamashita, President of Naruto University of Education and Dr. Rostami, President of Payame Noor University for inviting the first author as a Foreign Visiting Researcher to conduct the joint research study in the period from April to September, 2016. And Dr. Karimi, vice president in research of Payame Noor University also served us valuable support and contribution to this study. The study was partly supported by JSPS KAKENHI Grant (No. 15H02915).

Refrences

Ahmady-Birgani, H., Mirnejad, H., Feiznia, S. and McQueen K.G. (2015), Mineralogy and geochemistry of atmospheric particulates in western Iran. Atmospheric Environment, 119, pp.262-272

Alam, K., Qureshi, S. and Blaschke, T. (2011), Monitoring Spatio-temporal aerosol patterns over Pakistan based on MODIS, TOMS and MISR satellite data and a HYSPLIT model. Atmospheric Environment, 45, pp.4641-4651.

Bergametti, G., Gomes, L., Coudé-Gaussen, G., Rognon, P. and Le Coustumer, M.-N. (1989), African dust observed over Canary Islands: Source-regions identification and transport pattern for some summer situations. Journal of Geophysical Research, 94(D12), pp.14855-14864.

Clarke, F. W. (1924), Bulletin of U.S. Geological Survey, 700, 29p.

Crouvi, O., Amit, R., Enzel, Y. and Gillespie, A.R. (2010), Active sand seas and the formation of desert loess. Quaternary Science Reviews, 29, pp.2087-2098.

Dhondia J. and Diermanse, F. (2006), Integrated Water Resources Management for the Sistan Closed Inland Delta, Iran. Annex F-FFS Manual. Delft Hydraulics. http://www.wldelft.nl/cons/area/rbm/wrp1/pdf/annex_f.pdf. Retrieved on 19 April 2009.

Engelbrecht, J.P., McDonald, E.V., Gillies, J.A., Jayanty, R.K.M., Casuccio, G. and Gertler, A.W. (2009a), Characterizing mineral dusts and other aerosols from the Middle East — Part 1: Ambient sampling. Inhalation Toxicology, 21, pp.297-326.

Engelbrecht, J.P., McDonald, E.V., Gillies, J.A., Jayanty, R.K.M., Casuccio, G. and Gertler, A.W. (2009b), Characterizing mineral dusts and other aerosols from the Middle East — part 2: grab samples and re-suspensions. Inhalation Toxicology, 21, pp327-336.

Esmaili, O., Tajrishy, M. and Daneshkar Arasteh P. (2006), Results of 50 year ground- based measurements in comparison with satellite remote sensing of two prominent dust emission sources located in Iran. Proceedings of SPIE Europe Conference on Remote Sensing of Clouds and the Atmosphere XI, Stockholm, Sweden. 6362, pp1-12.

Fazlollahi, M.R. (2008), Member of Asthma and Allergic Diseases Committee of Iran, Interview with Mehr News, 10 July 2008 (In Persian).

Frank, J.D., Gregory, R.C., Yang, Z., *et al.* (1996), Role of mineral aerosol as a reactive surface in the global troposphere. Journal of Geophysical Research, 101 (D17), pp22869-22889.

Ghahreman, A .(2003), Flora of Iran (Vol.1-23). University of Tehran Press.

Goudie, A.S. and Middleton, N.J. (2000), Dust storms in south west Asia. Acta Universitatis Carolinae, Supplement, pp73-83.

Goudie, A.S. and Midelton, N.J. (2006), Desert dust in the global system, Springer.

Gromet, L P, Dymek, R.F., Haskin, L.A., and Korotev, R.L. (1984), The "North American shale composite": Its compilation, major and trace element characteristics. Geochimica et Cosmochimica Acta, 48, pp2469-2482.

Hladil, J., Strnad, L., Salek, M., Jankovska, V., Simandl, P., Schwarz, J., Smolik, J., Lisa, L., Koptikova, L., Rohovec, J., Bohmova, V., Langrova, A., Kocianova, M., Melicher, R. and Adamovic, J. (2008), An anomalous atmospheric dust deposition event over Central Europe, 24 March 2007, and fingerprinting of the SE Ukrainian source. Bulletin of Geosciences, 38, pp175-206.

Jalali, N. and Davoudi, M.H. (2008), Inspecting the origins and causes of the dust storms in the Southwest and West parts of Iran and the regions affected. Internal reports of Soil Conservation and Watershed Management Research Institute (SCWMRI), Iran.

Jones, P., Charlson, R. and Rodhe, H. (1995), *In* Aerosols in Climate Change 1994. Houghton, J.T. *et al.* (Eds.), Cambridge University Press, New York.

Lawrence, C.R. and Neff, J.C. (2009), The contemporary physical and chemical flux of Aeolian dust: A synthesis of direct measurements of dust deposition. Chemical Geology, 267, pp46-63.

McConnell, C.L., Highwood, E.J., Coe, H., Formenti, P., Anderson, B., Osborne, S., Nava, S., Desboeufs, K., Chen, G. and Harrison, M.A.J. (2008), Seasonal variations of the physical and optical characteristics of Saharan dust: Results from the Dust Outflow and Deposition to the Ocean (DODO) experiment. Journal of Geophysical Research, 113(D14S05), <doi: 10.1029/2007JD009606>.

Middleton, N. J. (1986), Dust storms in the Middle East. Journal of Arid Environments, 10, pp83-96.

Miri, A., Ahmadi, H. Ekhtesasi, M. R., Panjehkeh, N. and Ghanbari, A. (2009), Environmental and socioeconomic impacts of dust storms in Sistan Region, Iran. International Journal of Environmental Studies, 66, pp343-355.

Miri, A., Ahmadi, H., Ghanbari, A., Moghaddamnia, A. (2007), Dust Storms Impacts on Air Pollution and Public Health under Hot and Dry Climate. International Journal of Energy and Environments. 2, 1.

Mishra, S.K. and Tripathi, S.N. (2008), Modeling optical properties of mineral dust over the Indian Desert. Journal of Geophysical Research, 113(D23201), <doi:10.1029/2008 JD010048>.

Prospero, J. M. (1999), Long term measurements of the transport of African mineral dust to the south-eastern United States: Implications for regional air quality. Journal of Geophysical Research, 104, pp5917-15927.

Raespour, K.(2008), Statistical and synoptical analysis of dust phenomena in Khuzestan phenomena. MSc thesis, Sistan and Balouchestan University, 166p.

Rashki, A., Kaskaoutis, D.G., Rautenbach, C.J.deW., Eriksson, P.G., Giang, M. and Gupta, P. (2012), Dust storms and their horizontal dust loading in the Sistan region, Iran. Aeolian Research, <doi:10.1016/j.aeolia.2011.12.001>.

Rashki, A., Eriksson, P.G., Rautenbach, C.J.deW., Kaskaoutis, D.G., Grote, W. and Dykstra, J. (2013), Assessment of chemical and mineralogical characteristics of airborne dust in the Sistan region, Iran. Chemosphere, 90, pp227-236.

Rosenfeld, D., Lohmann, U., Raga, G. B., O'Dowd, C. D., Kulmala, M., Fuzzi, S., Reissell, A. and Andreae, M. O. (2008), Flood or Drought: How do aerosols affect precipitation? Science, 321, 1309, <DOI: 10.1126/science. 1160606>.

Selinus, O., Finkelman, R.B. and Centeno, J.A. (2010), Medical Geology: A regional synthesis. Springer, 391p.

Sokolik, I.N., Toon, O.B. and Bergstrom, R.W. (1998), Modeling the radiative characteristics of airborne mineral aerosols at infrared wavelengths. Journal of Geophysical Research- Atmospheres, 103 (D8), pp8813-8826.

Talbot, M.R. and Allen, P.A. (1996), Lakes: Processes, Facies and Stratigraphy. *In* Sedimentary Environments, Reading, H.G. (ed), Blackwell, Oxford, pp83-124.

Walter, M. and Wilkerson, D. (1991), Dust and Sand Forecasting in Iraq and Adjoining Countries. Technical Report, Air Weather Service, Scott AFB (AWS/XTX), IL 62225-5008.

Wedepohl, K.H. (1971), Environmental influences on the chemical composition of shales and clays. *In* Physics and Chemistry of the Earth, Ahrens, L.H., Press, F., Runcorn, S.K. and Urey, H.C. (Eds.), Pergamon, Oxford, UK, pp307-331.

Wu, G., Xu, B., Zhang, C., Gao, S. and Yao, T. (2009), Geochemistry of dust aerosol over the Eastern Pamirs. Geochimica et Cosmochimica Acta, 73, pp977-989.

Zarasvandi, A., Carranza, E.J.M., Moore, F. and Rastmanesh, F. (2011), Spatio-temporal occurrences and mineralogical-geochemical characteristics of airborne dusts in Khuzestan Province (southwestern Iran). Journal of Geochemical Exploration, 111, pp138-151.

Zarasvandi, A. (2009), Environmental impacts of dust storms in the Khuzestan province, Environmental Protection Agency (EPA) of Khuzestan province, Internal Report, 375p.

Zarasvandi, A. and Mokhtari, B. (2008), A Scientific Overview of the 50th Dusty Days in Khuzestan, Unpublished Data. http://www.tabnak.ir/pages/?cid=13646. Retrieved on 10 July 2008 (In Persian).