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Research paper

Mineralogy, geochemistry and provenance of geophagic soils from Swaziland

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ABSTRACT

Geophagic soil samples from Swaziland were analyzed and characterized for their particle size, mineral content and geochemical composition. Texturally the samples were classified as silt loam except for two which were sandy loam. Minerals identified in the soils were dominantly quartz, and kaolinite, with plagioclase, microcline, muscovite, goethite and/or hematite, and illite-smectite. The SiO_2 and Al_2O_3 concentrations were supportive of quartz and kaolinite dominance in the samples. Depletion and enrichment of trace and rare earth elements in the geophagic materials compared to average upper continental crust (UC), average Post-Archaean Australian Shale (PAAS) and average Swazi Granite (SG) were indicative of sediment geochemical characteristics. Values for chemical index of alteration (CIA) (78.30–99.75) and chemical index of weathering (CIW) (84.54–99.95) suggested low amounts of essential constituents in the geophagic soils. Dental enamel damage, abrasion of the gastro intestinal tract and rupturing of the colon of geophagic practitioners in Swaziland are possible health concerns related to ingestion of these soils.

1. Introduction

Geophagia, the deliberate ingestion of earthy material (Abrahams, 1997; Abrahams and Parsons, 1997; Ekosse et al., 2010; Geissler et al., 1998; Wilson, 2003), by both animals and humans (Mahaney et al., 1993), is a complex phenomenon that has existed for many thousands of years (Ekosse and Jumbam, 2010; Lacey, 1990; Rowland, 2002) and continues to raise questions to researchers, policy makers and societies. It is widely practiced in almost all the continents of the world including Africa (Aufreiter et al., 1997; Woywodt and Kiss, 2002), North America (Aufreiter et al., 1997; Grigsby et al., 1999; Vermeer and Frate, 1979), Central America (Hunter and De Kleine, 1984); South America (Abrahams and Parsons, 1996), Asia (Aufreiter et al., 1997), and Europe and the Middle East (Höllriegel et al., 2007); and is not limited to age, gender or race (Geissler et al., 1998). However it is most commonly practiced by women of child bearing age in developing countries including those in Africa (Brand et al., 2010). Geophagia has been reported in Botswana, Cameroon, Ghana, Guinea, Ivory Coast, Kenya, Malawi, Nigeria, Senegal, Sierra Leone, Tanzania, Uganda, South Africa and Swaziland on the African continent (Abrahams and Parsons, 1997; Aufreiter et al., 1997; Ekosse et al., 2010; Geissler et al., 1998; Ngole et al., 2010; Odilon Kikouama et al., 2009; Smith et al., 2000).

Ingested materials are regarded as supplementary nutrients and minerals, and serve as homeopathic remedies for common ailments (Gomes and Silva, 2007; Halsted, 1968; Reilly and Henry, 2001). Women indulge in the practice because they believe in the relieving effects resulting from soil consumption, which include supplementation of minerals and nutrients and antacid, anti-emetic, and anti-diarrheal properties (Bisi-Johnson et al., 2010; Brand et al., 2010; Kawai et al., 2009). Geophagic materials are used orally to heal common ailments of the gastro intestinal tract (GIT) because they have medicinal properties (Carretero, 2002; Tateo et al., 2001). Earthy materials are also consumed to relieve hunger and/or added as an additional ingredient in the preparation of drinks and meals (Brand et al., 2010).

Ingesting soils has drawbacks which impact negatively on human health, including anemia, microbiological infections, helminthiasis, intestinal obstruction, dental abrasion and heavy metal poisoning (Geissler et al., 1998; Kawai et al., 2009). The drawbacks could also include the ambiguously debated and projected iron and zinc deficiencies (Halsted, 1968; Reid, 1992; Reilly and Henry, 2001; Trivedi et al., 2005). High levels of heavy metals at toxic quantities in the geophagic clayey soils may negatively influence human health (Ekosse and Jumbam, 2010). Large coarse sandy quartz particles in geophagic clayey soils could affect dental enamel and also lead to the possible rupturing of the Sigmoid colon due to the abrasive nature of the particles (Ngole et al., 2010).

An underlying reason for geophagic practices being sustained in developing countries is that the geophagic materials are readily available at little or no cost. Geophagic materials have varied mineralogical and chemical compositions (Ferrell, 2008). The materials are usually soils, sediments that are clayey in particle size and contain at least one clay mineral as mineralogical constituent. The practice is common in developing countries particularly those in Southern Africa. Several communities in Southern Africa including Swaziland (Bisi-Johnson et al., 2010; Ekosse et al., 2010; Ngole et al., 2010) are widely involved in geophagia.

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There is however very limited documentation of the mineralogy and geochemistry of the geophagic soils which are being consumed.

This paper's primary objective is to examine the mineralogical chemical composition of geophagic soils from Swaziland where the habit is very deeply rooted, with the aim of inferring on possible human health implications. The results are believed to establish baseline mineralogical and chemical characterization of geophagic soils in Swaziland; and contribute to the global body of knowledge of geophagia. Knowledge generated will hopefully contribute to the renewed and recently rekindled research interests, and intellectual debates on geophagic practice within the broader scientific community (Finkelman et al., 2005).

2. Materials and methods

2.1. Sampling and samples

Samples of geophagic soils commonly ingested by individuals in the Middle Veldt Region of Swaziland were obtained from different areas and markets as indicated in Table 1. Twelve geophagic soil samples were obtained from the Middle Veldt Region of the country because majority of the country's inhabitants are located within this region (Africa Health Workforce Observatory, 2009). Moreover, preliminary investigations by the authors revealed that most of the geophagic individuals also reside in the Middle Veldt Region of the country and consume soils for reasons that include hunger, salivation, craving, detoxification, and medicinal and religious aspects. Apart from the areas of Mahlanya (26°30′0″S, 31°17′0″E) and Ezulwini (26°24′0″S, 31°10′0″E) geophagic soil samples collected in the field by the authors, the remaining representative samples were purchased from open markets in Mbabane. The vendors indicated that the samples were obtained from rivers and mountains in different specific locations (Table 1). The Mahlanya and Ezulwini traditional mining sites of the geophagic soils were shown to the authors by practicing geophagic individuals. Approximately 200 g of freshly exposed geophagic soils were collected from the two mining sites using a hand trowel. For samples obtained from vendors, the authors ensured that they were representative of the different geophagic soils available in the markets at Mbabane, based on color and feel.

2.2. Laboratory analysis

Laboratory tests conducted on the geophagic samples included color determination, particle size analysis, mineral identification and chemical composition. All the samples were oven-dried at 105 °C. Samples were, in general, in very fine powdery form. Some were lightly ground with mortar and pestle to break down coarse aggregates. With a spatula, the samples were mounted on white cardboard sheets provided by the Munsell Color Company Inc., MD 21218, USA (Mpuchane et al., 2008). The determined color properties, which comprised the hue, value/chroma of the mounted samples, were obtained by visual comparison with colors of standard soils recorded in the Munsell Soil Colour Book (1992).

Particle size distribution of the soils was determined using a Malvern Mastersizer 2000 fitted with Hydro 2000G dispersion unit. Samples were treated with 30% H_2O_2 and 10% HCl to remove organic matter and carbonates/iron oxides, respectively. The disaggregated samples were then homogenized and a suspension of each sample in $Na_4P_2O_7$ was then loaded into the laser particle analyzer. Scattered light data were recorded from 2000 to 5000 snapshots at 10 μs. A polydisperse mode of analysis and a refractive index of 1.533 with an adsorption of 0.1 were chosen. Size data collection was performed at constant obscuration in the range of 10–20% and interpreted with a texture Auto Lookup Software Package (TAL Version 4.2).

Qualitative and semi quantitative mineralogical analyses were done using X-ray diffractometry as described by Bish and Reynolds (1989), Council for Geosciences (2011), and Moore and Reynolds (1997). Representative bulk samples were crushed, milled and homogenized to fine powder at approximately 10–15 μm in size. Sub-samples were back-loaded into shallow sample holders against rough filter paper in order to ensure random orientation, and scanned from 2 to 70° 2θ with CuKα radiation (40 kV and 40 mA), using a 0.02° 2θ scanning step and 0.5 s counting time per step, with a LYNXEYE detector. Minerals were identified with data reported in the ICDD (2001) database. Phase concentrations were determined as semi quantitative estimates, using relative peak heights/areas proportions (Brime, 1985).

Samples were analyzed for major oxides (SiO_2, TiO_2, Al_2O_3, Fe_2O_3(t), MnO, MgO, CaO, Na_2O, K_2O, P_2O_5 and Cr_2O_3) using fusion beads and for trace elements concentrations (As, Ba, Bi, Br, Ce, Co, Cr, Cs, Cu, Ga, Ge, Hf, La, Mo, Nb, Nd, Ni, Pb, Rb, Sc, Se, Sm, Sr, Ta, Th, Tl, U, V, W, Y, Yb, Zn, Zr), using pressed powder pellets with a PANalytical Axios WDXRF spectrometer according to the method described by the Council for Geosciences (2011), and Fitton (1997). The ground samples with grain size <75 μm were calcined at 1000 °C for 3 h to determine the loss of ignition (L.O.I.) and oxidize Fe^{2+} and S. One gram of calcined sample and 9 g of flux consisting of 34% $LiBO_2$ and 66% $Li_2B_4O_7$ were fused at 1050 °C to form stable glass beads. For trace element analysis 12 g of milled sample and 3 g Hoechst wax were mixed and pressed into powder briquette by hydraulic press with an applied pressure of 25 ton.

To better characterize the geophagic materials, the chemical index of alteration (CIA, $[Al_2O_3/(Al_2O_3+CaO+Na_2O+K_2O)]\times100$) and chemical index of weathering (CIW, $[Al_2O_3/(Al_2O_3+CaO+Na_2O)]\times100$) (Harnois, 1988), values were calculated. In the CIA index the CaO is incorporated in the silicate structure (Nesbitt and Young, 1982). The primary provenance of the geophagic materials was inferred from TiO_2 vs Al_2O_3 segregation diagram for granite, rhyolite and basalt (Ekosse, 2001).

Table 1
Source, geographic coordinates and color of geophagic soil samples from Swaziland.

Sample number	Source of samples according to vendors	Hue, value and chroma of samples	Color of samples
SZ28	Mahlanya[a]	10R5/6	Dull brown
SZ29	Mbekelweni	10YR7/4	Dull yellow orange
SZ30	Mphembekati	5YR5/8	Yellowish red
SZ31	Nsingweni	10YR8/3	Light yellow orange
SZ32	Ezulwini[a]	5Y8/2	Light gray
SZ33	Mbekelweni	2.5YR5/8	Bright reddish brown
SZ34	Nsingweni	10Y8/1	Light gray
SZ35	Elangeni mountain	10YR7/4	Very pale brown
SZ36	Lusushwana river	10YR7/8	Yellow
SZ37	Lusushwana River	2.5YR8/1	White
SZ38	Elangeni Mountain	7.5YR8/1	White
SZ39	Manzini-Mbabane roadside	10R4/8	Red

The Hue, value, chroma, and color of the geophagic clayey soil samples were determined using the method in the Munsell Soil Colour Book (1992).
[a] Samples collected from exposed roadcut by authors.

3. Results and discussion

3.1. General observations, particle sizes and their classification

Five different color varieties were observed in geophagic samples from Swaziland (Table 1). The colors were reflective of possible tinting by goethite and hematite. Considering that the colors of the geophagic samples were light, only very small quantities of the color imparting minerals were assumed to be present. Most of the samples felt gritty, although three (SZ32, SZ34, and SZ37) were either soapy or silky. Using the United States Department of Agriculture (1996) textural classification (clay = <2 μm, silt = 2 μm–50 μm, sand = 50 μm–2000 μm), the ranges