

Minerals in Human Geophagic Soils from Selected Rural Communities in Gauteng and Limpopo Provinces in South Africa

Georges-Ivo E. Ekosse¹ and Larry C. Obi²

¹*Directorate of Research and Innovation, University of Venda, P/Bag X5050, Thohoyandou 0950, Limpopo Province, South Africa*

²*Division of Academic Affairs and Research, University of Fort Hare, Eastern Cape, South Africa*

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ABSTRACT Twelve representative human geophagic soil samples collected from selected rural communities in Gauteng and Limpopo Provinces, South Africa, were analyzed using X-ray diffractometry to identify, quantify and characterize their minerals constituents. Kaolinite, smectite, talc, muscovite, quartz, calcite, dolomite, microcline, goethite and hematite were the clay and non-clay minerals identified. Two most dominant minerals in the geophagic soil samples were quartz (35-52 wt%) and kaolinite (31- 53 wt%). Abundances for the other minerals were 8-27wt%. Based on the results, the clay minerals and mineral oxides could serve as elemental sources for supplementation of Al, Na, K, Ca, Mg, and Fe in the bodies of the geophagic individuals. There could however be influential factors such as the soil matrix itself, soil type, chemical form of the element, stomach and intestinal pH, and the soil to solution ratio, which could affect the elemental bio-accessibilities.

INTRODUCTION

Human geophagia, defined as the deliberate ingestion of earthy materials by humans (Abrahams and Parsons 1996), has been in practice for over two million years (Clark 1969), with documented records of the habit in Africa and Asia as far back as 5500 years (Abrahams 2005). Although practiced in several continents of the world (Veermeer and Frate 1979; Hunter and De Kleine 1984; Abrahams and Parsons 1997; Aufferiter et al. 1997; Grigsby et al. 1999; Woywodt and Kiss 2002; Höllriegel et al. 2007; Woode and Hackman-Duncan 2014), the habit is rooted and widely sustained in Africa and Asia (Hooda et al. 2003; Wilson 2003; Norman et al. 2015). Poverty and famine (Woywodt and Kiss 2002), nutritional, psychological, cultural and medical (Danford et al. 1982; Norman et al. 2015), social (Geissler et al. 1999), spiritual, religious and ritual (Hunter 1993) and physiological needs (Veermeer 1996) are some of the main reasons given for the continued sustenance of the practice.

Growing research and scientific interests regarding geophagia in Africa (Ekosse and Jum-

bam 2010), and in particular Southern Africa has concentrated on the habit from sociocultural (Songca et al. 2010), physicochemical (Ngole et al. 2010), chemical (Abrahams and Parsons 1997), microbiological (Abrahams 2002; Bisi-Johnson et al. 2010), hematological (Mogongoa et al. 2011), and health concerns (Brand et al. 2009). Remarkably lacking are detailed mineralogical studies of geophagic materials serving as a knowledge platform from which other geophagic research findings must build upon. This baseline knowledge deficiency is exacerbated by clear-cut demarcations of knowledge disciplines that have limited multi- and interdisciplinary collaboration.

With the emergence of medical geology, several facets of the discipline including mineralogy are being integrated into environmental and human health. It is, thus, imperative to mineralogically identify and characterize geophagic materials with the purpose of making available baseline information for further studies to be developed upon. In a previously documented study on geophagic practice in Limpopo Province, the focus was directed to urban and rural environments only (Ekosse et al. 2010), although the inhabitants of the Province are predominantly rural. Though Gauteng Province is heavily urbanized, there are conspicuous pockets of rural settlements especially towards its borders with Limpopo Province. This paper, therefore, aimed at generating baseline knowledge of human geophagia in the two provinces by identi-

Address for correspondence:

Georges-Ivo E. Ekosse

Professor

Directorate of Research and Innovation,

University of Venda, P/Bag X5050

Thohoyandou 0950, Limpopo

Province, South Africa

E-mail: ekosse@gmail.com

fying, quantifying and characterizing the different minerals contained in consumed soils from their selected rural communities.

Objectives

The primary objective of this paper is to identify and quantify the minerals contained in human geophagic soils from Gauteng and Limpopo Provinces, and infer on possible health implications.

MATERIAL AND METHODS

Randomly selected representative geophagic soil samples were collected from rural settlements between Pretoria (in Gauteng Province) (25°45' 12" S 28°11' 13" E) and Polokwane (in Limpopo Province) (23° 54' 44.1"S; 29° 27' 12.7" E). The geographic coordinates of the sources from where the twelve geophagic soil samples used in this study were collected, are given in Table 1. The samples were as representative as possible in terms of variety, and were in the state in which geophagic individuals normally ingest them.

Laboratory tests conducted on the geophagic soil samples were for color determination, minerals identification, quantification and characterization. Prior to analyses, the samples which were generally in fine powdery form were oven-dried at 105 °C. Aggregated soil particles were separated to single particles by gentle grinding using an agate mortar and pestle. With a spatula, the samples were mounted on white cardboard sheets provided by the Munsell Color Company Inc., Maryland, USA. The color descriptions of the geophagic soils, which comprised the hue, value/chroma and color of the mounted samples, were obtained by visually comparing them to colors of standard soils recorded in the Munsell Soil Color Book (Munsell Colour Book 2002). The hue = color, value = lightness of color, chroma = purity of color, and color is the description of the color-based on naturally occurring colors. An example of soil color for a moderate yellowish brown sample having the color 10YR/5/4 is interpreted as 10YR = yellow red value on the hue band; 5 = lightness value of the color; and 4 = the level of purity on the chroma band (Mpuchane et al. 2008).

Table 1: Geographic coordinates of sources and color of geophagic clayey soils obtained from selected rural settlements in Gauteng and Limpopo Provinces

<i>Sample number</i>	<i>Source</i>	<i>Geographic coordinates</i>	<i>Hue/value/Chroma</i>	<i>Color specification</i>
1	Shierlek (Bela – Bela)	24°53'06" S, 28°17'39" E	10R/4/6	Moderate reddish brown
2	Shierlek (Bela – Bela)	24°53'06" S, 28°17'39" E	10R/4/6	Moderate reddish brown
3	Plat River (18 km form Bela-Bela)	25°01'02" S, 28°10'16" E	10YR/6/6	Dark yellowish orange
4	Mashakane		10YR/5/4	Moderate yellowish brown
5	Settlers (anthill)	24°51'23" S, 28°32'04" E	5YR/4/4	Moderate brown
6	Settlers (trees)	24°51'23" S, 28°32'04" E	10YR/5/4	Moderate yellowish orange
7	Thabazimbi	24°35'24" S, 27°24'35" E	10YR/7/4	Grayish orange
8	Pienaars River (b/w Bela-Bela and Hamanskraal)	25°38'59" S, 28°20'17" E	10YR/7/4	Grayish orange
9	Jacob Zuma village (b/w Bela-Bela and Thabazimbi)		10YR/6/6	Dark yellowish orange
10	Emmarentia (b/w Bela-Bela and Thabazimbi)	25°57'15" S, 28°06'13" E	10YR/6/6	Dark yellowish orange
11	Mahalingwe (b/w Bela-Bela and Thabazimbi)	24°50'26" S, 28°02'53" E	10YR/6/6	Dark yellowish orange
12	Vingerkrwal (Mabola station b/w Bela-Bela and Thabazimbi)		10YR/5/4	Moderate yellowish brown

Organic matter in soil samples was removed from the samples prior to mineralogical analysis. This was achieved by oxidation of samples with thirty percent H_2O_2 as described by Jackson (1979) and Bird and Chivas (1988). X-ray powder diffraction (XRPD) technique as described by Bish and Reynolds (1989), Moore and Reynolds (1997), and Ekosse (2005) was used to identify the minerals. In XRPD, diffraction peaks occur when the path of the diffracted X-rays is equal to an integer multiple of the path difference expressed by Bragg's equation (Eqn 1), given by:

$$n\lambda = 2d\sin\theta \quad (1)$$

Where, n is an integer, λ is the wavelength, d is the interatomic spacing, and θ is the diffraction angle. The samples, which constituted representative geophagic soils from the study areas were gently crushed in an agate mortar, milled and homogenized to fine powder at approximately 10 μm in size. Samples were mounted on sample holders with little pressure, using a blade to minimize preferred orientation of the particles (Hughes and Brown 1979; Cuadros and Linares 1995). The mounted samples were scanned from $2 - 75^\circ 2\theta$ Cu radiation at a speed of $0.02^\circ 2\theta$ steps size/0.5 sec, using a LYNXEYE detector and generator settings of 40 kV and 40mA. Diagnostic peaks for the identification of the minerals were interpreted by using the ICDD reference numbers, and the crystal system, d -values, peak intensity and Miller Indices of the minerals in the samples presented and cross checked with data reported in Joint Minerals Powder Diffraction File Data Book (International

Centre for Diffraction Data 2001). Mineral abundances were determined as semi-quantitative estimates, using relative peak heights or areas proportions (Brime 1985).

RESULTS

Out of the 12 geophagic soil samples, five had some form of brownish tainting, five had yellowish coloration, two were yellowish brown and two were greyish (Table 1). Ten minerals were identified in the samples of which, some were clay minerals and others were non-clay minerals.

The clay minerals with their main diagnostic peaks in $\text{\AA}$, included kaolinite (7.1, 4.41, 3.56), smectite (13.6, 4.46, 2.56), talc (9.34, 4.66, 3.11) and muscovite (9.91, 4.50, 2.56), and the non-clay minerals were quartz (4.25, 3.34, 1.82), calcite (3.04, 1.91, 1.87), dolomite (4.22, 3.26, 3.25), microcline (2.70, 2.52, 1.69), goethite and hematite as summarized in Table 2. Table 3 gives a summary of the minerals abundances of the identified minerals in the samples. Yellowish and brownish tainting in the geophagic soils were due to the Fe-rich minerals goethite and hematite detected by XRD though their concentrations in the samples were in general $< 5 \text{ wt}\%$. In terms of similarities, all the samples except for sample 10 were mineralogically dominated by both quartz and kaolinite.

Both, quartz and kaolinite, were the two most dominant minerals in the geophagic soils with their combined abundances between 73- 92 wt% except for sample 10 which was an outlier with 45 wt % (Fig. 1). Quartz was the only mineral

Table 2: Minerals identified by XRD in geophagic clayey soil samples from selected localities in Limpopo Province

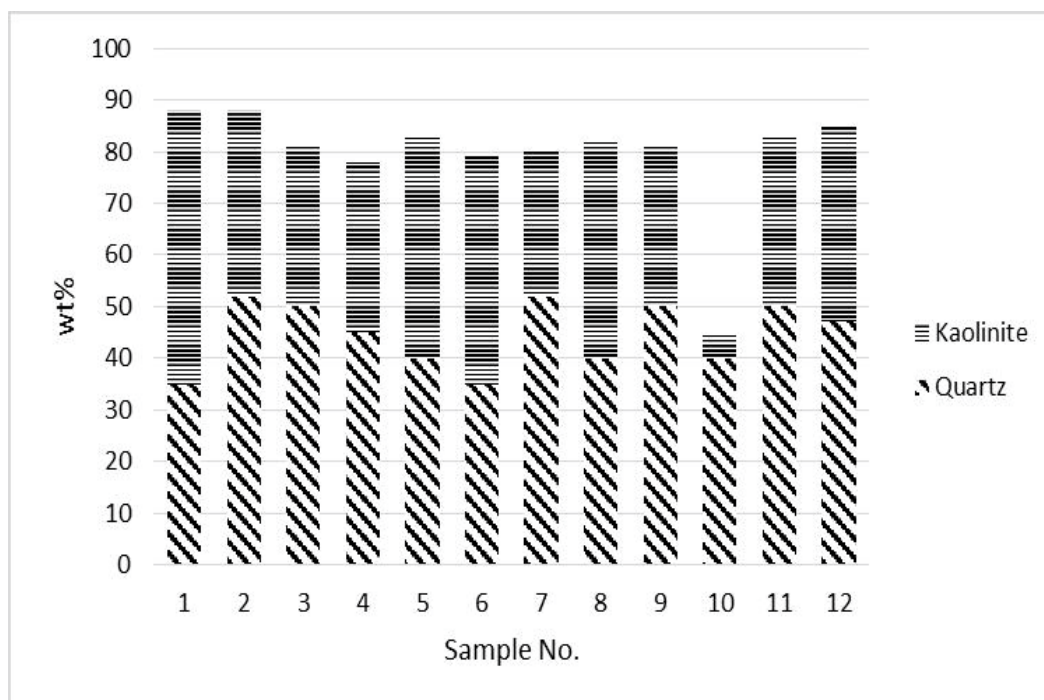
Name of mineral	Chemical name	Chemical formula	Main diagnostic peaks (d $\text{\AA}$)
<i>Clay Minerals</i>			
Kaolinite	Aluminum silicate hydroxide	$\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$	7.1, 4.41, 3.56
Smectite			
(Na montmorillonite)	Hydrated sodium calcium	$(\text{Na,Ca})(\text{Al,Mg})_6$	13.6, 4.46, 2.56
Talc	Aluminum silicate	$(\text{Si}_4\text{O}_{10})_3(\text{OH})_{6-n}\text{H}_2\text{O}$	
Mica (muscovite)	Magnesium silicate hydroxide	$\text{Mg}_3\text{Si}_3\text{O}_{10}(\text{OH})_2$	9.34, 4.66, 3.11
	Potassium magnesium aluminum	$\text{KMgAlSi}_4\text{O}_{10}(\text{OH})_2$	9.91, 4.50, 2.56
<i>Non Clay Minerals</i>			
Quartz	Silicate hydroxide		
Calcite	Silicon dioxide	SiO_2	4.25, 3.34, 1.82
Dolomite	Calcium carbonate	CaCO_3	3.04, 1.91, 1.87
Feldspar (Microcline)	Calcium magnesium carbonate	$\text{CaMg}(\text{CO}_3)_2$	2.89, 2.19, 1.79
Hematite	Potassium aluminum silicate	KAlSi_3O_8	4.22, 3.26, 3.25
	Iron oxide	Fe_2O_3	2.70, 2.52, 1.69

Table 3: Results in wt% of semi quantitative analysis of minerals identified in geophagic soil samples

<i>b</i>	<i>Calcite</i>	<i>Dolomite</i>	<i>Goethite / Hematite</i>	<i>Microcline</i>	<i>Quartz</i>	<i>Kaolinite</i>	<i>Muscovite</i>	<i>Talc</i>	<i>Smectite</i>
1	4	-	3	-	35	53	3	-	2
2	-	-	4	1	52	36	3	-	4
3	3	5	3	5	50	31	1	-	2
4	-	-	3	5	45	33	14	-	-
5	-	-	2	12	40	43	-	-	3
6	-	-	3	3	35	44	15	-	-
7	-	-	5	5	52	28	10	-	-
8	-	-	2	-	40	42	-	2	4
9	-	-	4	10	50	31	2	-	3
10	-	-	-	4	40	5	-	50	1
11	-	-	1	16	50	33	-	-	-
12	-	-	-	7	47	38	4	-	4

identified in all the samples with its abundances being 35-52 wt%. Five of the samples consisted of ≥ 50 wt% quartz each, followed by others with 45wt % and 40wt %. All the samples contained kaolinite with its abundances ranging from 31-53wt %; except for sample 10 with only 5wt % of the mineral. Abundances for all the other miner-

als in the different samples were between 8-27wt% (Fig. 2). Calcium bearing minerals were not detected in the samples except for samples 1 and 3, where their abundances were very low (3-5wt %) (Table 3). The abundances of the clay minerals in the samples were 33 (sample 11) - 59wt % (sample 6) (Fig. 3).

**Fig. 1. Combined quartz and kaolinite abundances in geophagic soil samples**

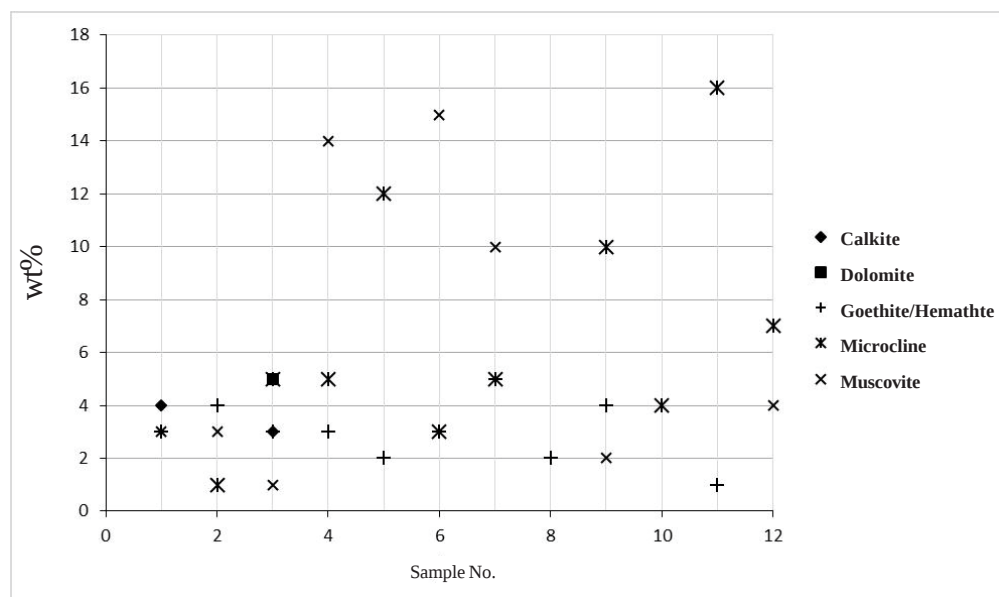


Fig. 2. Abundances of calcite, dolomite, goethite/hematite, microcline and muscovite in geophagic soil samples:

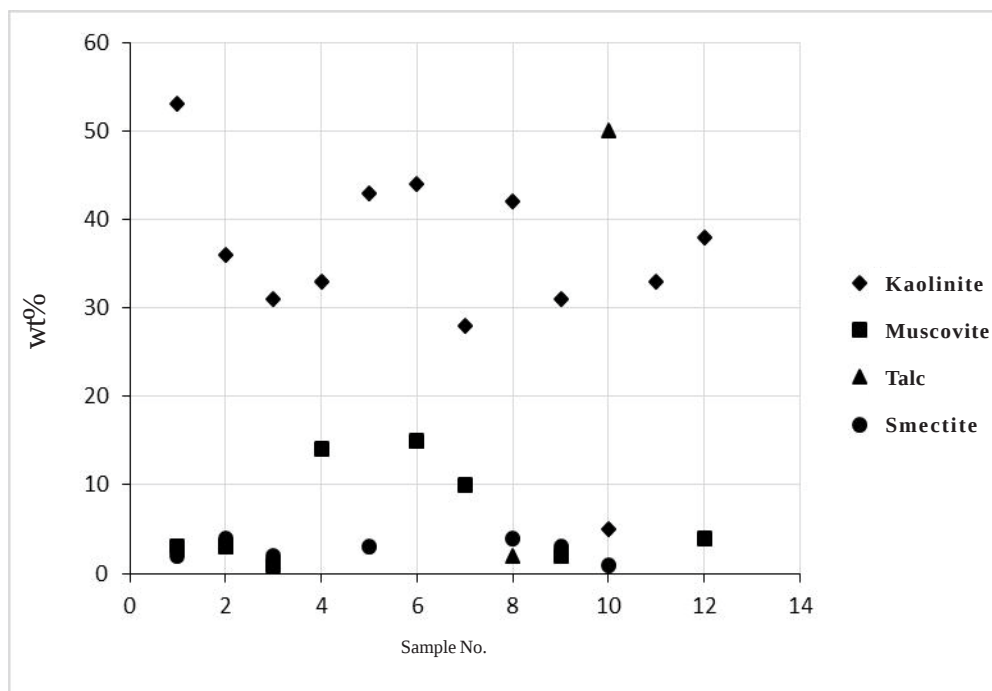


Fig. 3. Abundances of clay minerals in geophagic soil samples:

DISCUSSION

Geophagic practice has been demonstrated and reported to supply a good quantity of recommended supplementation of Ca, Mg, Fe and K (Hunter and De Kleine 1984; Brand et al. 2009). Based on the chemical compositions of the minerals identified in the geophagic soil samples, the soils could serve as sources for the following elemental supplementation to geophagic individuals:

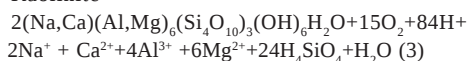
- ♦ Al from kaolinite, smectite and microcline
- ♦ Na from smectite
- ♦ Ca from smectite, calcite and dolomite
- ♦ Mg from smectite, talc, muscovite and dolomite
- ♦ K from muscovite, and microcline
- ♦ Fe from goethite and hematite

These elements are the most abundant in soils with mean concentrations on the earth's crust in gKg^{-1} as follows: Al (82), Na-K (24), Ca (42), Mg (20), and Fe (56) (Ochiai 1977). Though the elements may be present in the geophagic soils, their bio-accessibilities are governed by the soil matrix itself, soil type, chemical form of the element, stomach and intestinal pH, and the soil to solution ratio (Kutalek et al. 2010; Ngole et al. 2012).

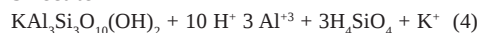
The acidity of the human stomach is high, having a pH of 2 (Omen et al. 2000). At this pH, depending on residence time of the geophagic soils in the stomach (Ngole et al. 2010), clay minerals and oxides could be broken down, releasing ions which are nutrient supplementations to the body. Geophagic soil could contribute Al to the body through the breakdown of the Al containing minerals as depicted in equations 2 to 5. The human body contains 50 - 150 mg of Al of which, most is in the lungs, brain, kidneys, liver, and thyroid. Excess Al is eliminated from the body as a component in feces, urine and sweat (Haas 2012).



Kaolinite



Smectite



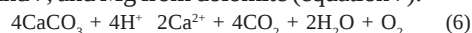
Muscovite



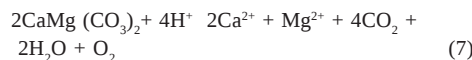
Microcline

There are several known sources of Na, of which NaCl (salt) is the main one, through which

it is obtained in the body. In this study, only smectite was identified to contain it as shown in equation 3. In the United States of America (USA), the daily intake of Na is 2-3 fold, and K, Ca and Mg are remarkably lower than the dietary reference intake (Krappanen et al. 2005), whereas in South Africa, intake of K has been reported to be lower than recommended (Charlton et al. 2005). Sodium regulates body fluids and increase blood pressure. Potassium works on balancing body fluids and reducing blood pressure. With low dietary levels of K, geophagic individuals could have their K intake augmented through consumption of K rich soils. Calcium, which could be obtained from dairy products, fish and vegetables, is needed for bones, teeth and blood clotting. Dairy products and vegetables are equally sources of Mg, which is responsible for the toning of muscles and activating enzymes. Diets of individuals in South Africa most likely contain insufficient Ca (Hough 2012). In the consumed soils, Ca is released from smectite, dolomite and calcite as shown in equations 3, 6 and 7, and Mg from dolomite (equation 7).



Calcite

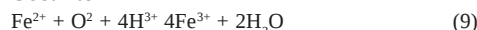


Dolomite

Iron from goethite and hematite is released in its ionic state before being integrated into forming complex compounds as demonstrated in equations 8 and 9. The average human being contains 60-70 ppm of Fe in complex forms bound to protein as porphyrin, hemoglobin, myoglobin, transferrin, ferritin, and hemosiderin. It is absorbed throughout the gastrointestinal tract (GIT) and excreted through the skin, and GI and urinary tracts (Sizer and Whitney 2000; Mpu-chane et al. 2010). Low values of Fe in the geophagic soils could make very little contribution to body Fe intake. Nevertheless, Mathee et al. (2014) confirmed the association between geophagia practice and depressed hemoglobin levels.



Goethite



Talc, which was present in only two of the samples, is very rarely found in geophagic soils. Most geophagic soils contain secondary argillaceous minerals and are generally associated with sedimentary environments. Though a clay min-

eral, talc is formed through metamorphic processes rendering it difficult to be easily broken down. It is most likely that there may be no changes to its chemical constituents when ingested.

Concentrations of trace elements in geophagic soils, not within the scope of this study, could also be contributive to nutrient supplementation (Ekosse and Jumbam 2010), though their consumption could lead to various life-threatening diseases (Woode and Hackman-Duncan 2014). Apart from being sources of nutrient supplementation, geophagic soils also have medicinal values (Mpuchane 2010). Geophagic soils are generally composed of kaolin of which kaolinite is the dominant clay mineral, and others being palygorskite, and montmorillonite (usually from bentonite) (Ekosse et al. 2008). Kaolin and bentonite are widely used as modern day digestive aids and for detoxification, as an active ingredient in several anti-diarrheal drugs and for the relief of pyralism (Odilon Kikouama 2009). The studied geophagic soils are rich in kaolinite and thus, have the potential to provide medicinal benefits to the consumer.

Main mineralogical drawback in geophagic practice that could affect human health is the presence of quartz in the soils. Quartz particles are hard, coarse and angular with a strong potential to damage dental enamel, the main inorganic component of the human tooth, made primarily of hydroxylapatite ($\text{Ca}_5(\text{PO}_4)_3(\text{OH})$) (a calcium phosphate mineral), through grinding, cracking, splitting and breakage during mastication of geophagic soils (King et al. 1999; Ekosse et al. 2011; Ngole and Ekosse 2012). Due to its resistance to chemical alteration, quartz could scratch the walls of the GIT eventually leading to perforation of the intestines (Lohn et al. 2000), and cause soil peritonitis due to perforation of the Sigmoid colon (Woywodt and Kiss 1999).

CONCLUSION

This study revealed that geophagic soils from rural settlements in Gauteng and Limpopo Provinces were yellowish and brownish with no striking color variation. Kaolinite, smectite, talc and muscovite were clay minerals contained in the geophagic soils, and the non-clay minerals were quartz, calcite, dolomite, microcline, goethite and hematite. Quartz and kaolinite amounted to between 73-92wt% in the samples. The chemical

structures of the different minerals identified in the soils presented Al, Na, K, Ca, Mg, and Fe as possible nutrient supplements in the bodies of geophagic individuals. Influential factors could unfortunately affect the elemental bio-accessibilities. Key mineralogical drawback in the composition of the soils is quartz, which exploits its resistance to chemical alteration, and its particle size and shape, to negatively impact the health of the geophagic individual.

RECOMMENDATIONS

Geophagic soils should be beneficated by reduction of quartz content.

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