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Full Length Research Paper

Traditional mining and mineralogy of geophagic clays from Limpopo and Free State provinces, South Africa

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This paper is based on responses to questionnaires administered to 226 representative geophagic adults in Limpopo (Polokwane and Sekhukhune) and Free State (Qwaqwa and Mangaung) Provinces in South Africa, and semi-quantitative mineral identification of 40 geophagic clay samples from the same areas. Geophagic clays consumed were whitish, yellowish, khaki and black; mined from hills and mountains, river beds, valleys, excavation sites and termitaria. Geophagic individuals from Free State preferred whitish geophagic clays; and sometimes khaki. Yellowish clays were preferred mostly by geophagic individuals from Limpopo. The clays are mined using selective digging, hand grabbing and picking techniques. The clays are processed through sieving, slurrying, grinding and pounding. Baking, burning and boiling are some beneficiation techniques used to render the clays more palatable and to reduce their microbial load. Mineral phases identified in the clay samples were quartz, kaolinite, mica, feldspar, smectite, goethite, calcite, and dolomite. The properties of kaolinite and smectite were found to have a dominant influence on the nature of geophagic clays and hence on the health of those who consumed the clays. Further details regarding the potential of geophagic clays to provide medicinal benefits to the consumer were examined in this study. Geophagic practice is very deep rooted, globally distributed, and has spanned over several centuries. Renewed interest and study by the scientific research community has continued to generate new knowledge on this somewhat enigmatic practice. Further efforts to address and regulate geophagic clay consumption should be strongly advocated.

Key words: Colour, heat treatment, kaolinite, pounding, sieving.

INTRODUCTION

Geophagia, the habit of deliberate consumption of earthy material (Dominy et al., 2004), has been reported to be in existence as early as the fourth century. It is practised in Africa (Mahaney et al., 2000), America including USA (Boyle and Mackay, 1999; Hunter, 1973; Vermeer and Dennis, 1979), Asia including India and China (Hunter, 1973; Utara, 2002), Australia (Reilly and Henry, 2000), and Europe (Woywodt and Kiss, 2002; Ziegler, 1997). Although this ageless habit has been proven archaeologically to be as old as *Homo sapiens*, it has nonetheless persisted over the centuries. Cultural and psychological reasons as well as medicinal, physiological and nutritional needs have been advanced to justify the practice (Callahan 2003; Geissler et al., 1998; Harvey et al., 2000; Hunter and de Kleine, 1984; Vermeer, 1966). Though formerly believed to be common among communities of low social status (Halsted, 1968), recent studies have indicated that pregnant females in affluent societies indulge in geophagic practice. It is most common in many indigenous communities especially in developing countries (Ngozi, 2008); and has also been linked to superstition (Halsted, 1968). In Southern Africa, women and children in both urban and rural settings are engaged in geophagia. South African urban women believe that the consumption of earthy material including soils and clays enhance their beauty (Woywodt and Kiss, 2002). Most of the earthy materials been consumed contain clay minerals.

Clay minerals are secondary minerals derived from chemical alteration of mostly feldspars and micas. These

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minerals are dominantly alumino silicates made up of tetrahedron and octahedron sheets constituting a unit cell. Their manner of auto-construction and habit form the unit cell characterized by layering yielding 1:1 and 2:1 classes of clay minerals. The 1:1 clays consist of tetrahedral and octahedral sheets forming kaolinite–serpentinite clay minerals and some of the members are kaolinite and halloysite. The 2:1 clay minerals have two tetrahedrally coordinated sheets of cations both sandwiching an octahedral sheet. This classification has six groups: pyrophyllite, talc, smectites, vermiculites, micas, and chlorites. Geophagic clays vary from one region to another. Preferences of choice of material include its colour, and texture. Materials consumed are usually clay, silty clay, silty clay loam and clay loamy in texture. In this study, the earthy materials studied will be called geophagic clays because of their clayey nature.

Although several communities in South Africa are geophagic, there is no documented research on how the geophagic clays are mined. Investigations on preferences of geophagic clays in South Africa in terms of colour, geomorphological source, feel, and mining techniques were not reported in the literature. Geophagic individuals tend to prepare geophagic clays in a variety of ways prior to consumption. The various methods of treatment of the clay are yet to be scientifically discussed. Moreover, studies on the mineral composition of geophagic clays have been given little attention and are sparsely reported in the scientific literature. This could partly be attributed to the late discovery of X-ray diffractometry (namely, in the 1930's); the primary tool used to elucidate the structure of clay minerals (Young et al., 2008). This paper's primary objective was therefore to investigate the traditional mining methods and mineralogy of geophagic clays from Free State and Limpopo Provinces in South Africa. These findings establish baseline knowledge on the characterisation of geophagic clays in South Africa based on observations of traditional mining, mineral identification and local beneficiation practices. There is renewed research effort on geophagia within the scientific community (Finkelman et al., 2005; Sheppard, 1998). Knowledge generated will hopefully contribute to expanding research findings on geophagia.

MATERIALS AND METHODS

Geophagic study sites and individuals

South Africa has nine provinces of which two are the Limpopo and Free State Provinces. This study chose the two provinces because of the large populations of people living in urban and rural settings, and because several communities within the settlements are known to be engaged in geophagic practice. In the Limpopo Province, Sekhukhune (24º 45´ 11.3″ S; 30º 00´ 36.2″ E), a rural settlement, and Polokwane (23º 54´ 44.1″ S; 29º 27´ 12.7″ E), an urban setting, were chosen for this study. In the Free State Province, Qwaqwa (28º 24´ 21.8″ S; 28º 57´ 10.3″ E), which is a rural settlement, and Mangaung (29º 12´ 65″ S; 26º 15´ 46″ E) which is an urban settlement, were selected as study sites.

Questionnaire design and administration

Questionnaires were administered to adults engaged in geophagic practices from rural (Qwaqwa = 62 respondents and Sekhukhune = 54) and urban (Mangaung = 55 respondents and Polokwane = 55 respondents) settings in the two provinces. A combination of purposive and snowball sampling techniques were used to identify geophagic individuals from each of the study area to whom questionnaires were administered. Snowball technique was employed because of the reluctance of individuals revealing their geophagic habits. No more than five respondents were identified through any one initial subject. Purposive sampling was then used to identify another initial subject who formed the initial respondent through whom others were identified.

Observations of respondents on colour, softness and grittiness, mining methods, processing and benefication of geophagic clays were interpreted according to sources and settings from where the clays were sampled. Questions were directed at investigating where the preferred geophagic clay was found with details of the lithological setting. The respondents were also asked about the method of traditional mining practiced, the feel of the mined geophagic clay, its physical state during collection, and type of beneficiation. Descriptive statistics were employed to obtain the percentages and frequencies of variables used to gather data in the study.

Identification of minerals in geophagic clay samples

Forty representative geophagic clays were obtained from different localities in Mangaung (10 samples) and Qwaqwa (10 samples) in Free State Province and Polokwane (10 samples) and Sekhukhune (10 samples) in Limpopo Province; these were analysed for their mineral contents. Samples were air-dried and later ground into powder form. The powdered samples were loaded in sample holders and mounted in the Philips PW 3710 XRPD X-ray diffracttometer system for identification of mineral phases. The XRPD equipment, which operated at 40kV and 45 mA, had a Cu-K_α radiation and a graphite monochromator. A PW 1877 automated powder diffraction (APD) X'PERT Data Collector software package was employed to capture raw data and a Philips X'PERT Graphics and Identity software package was used for qualitative identification and semi quantitative analyses of the minerals from both the data and patterns obtained by scanning at a speed of $1^{o}2$□/min. Samples were scanned from $2^{o}2\theta$ to $70^{o}2\theta$. The results were compared with data and patterns available in the Mineral Powder Diffraction File data book (International Centre for Diffraction Data, 2001).

RESULTS

Questionnaire responses

Respondents indicated that reddish, yellowish, whitish, khaki, and blackish clays were the types of geophagic clays which were consumed by the people in the study areas (Figure 1). Most of the respondents from Free State Province (74% from Qwaqwa and 40% from Mangaung), and 36% of respondents from Polokwane preferred white geophagic clays. More respondents from Limpopo Province (25% from Polokwane and 20% from Sekhukhune) than those from Free State Province (10% from Qwaqwa and 5% from Mangaung) preferred yellowish geophagic clays. Whereas 30% of respondents from

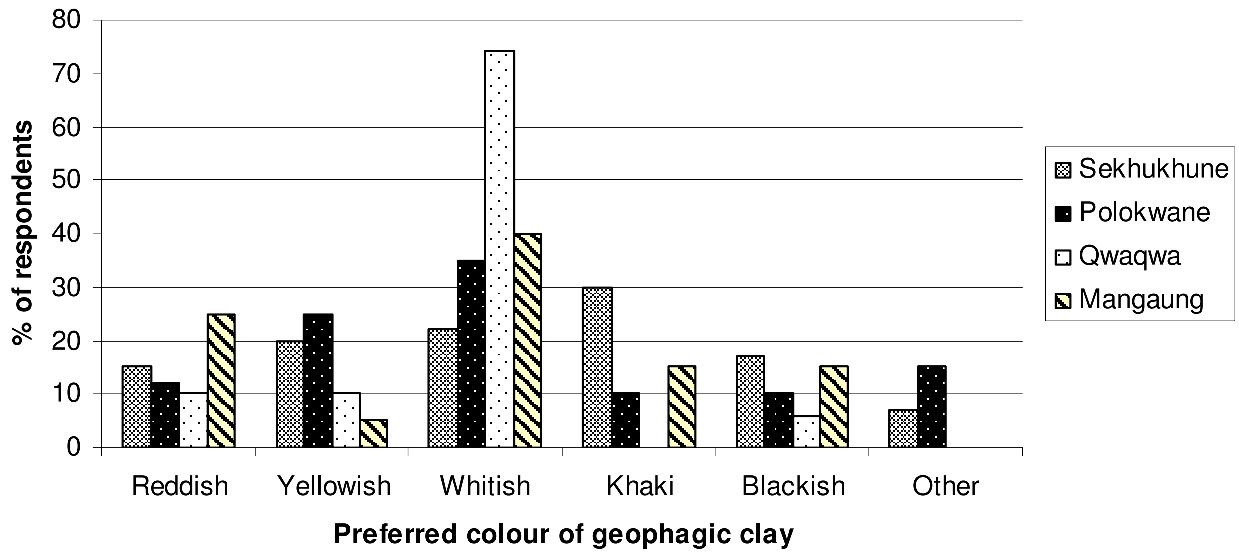

Figure 1. Preferred colour of geophagic clays consumed by respondents in the study sites.

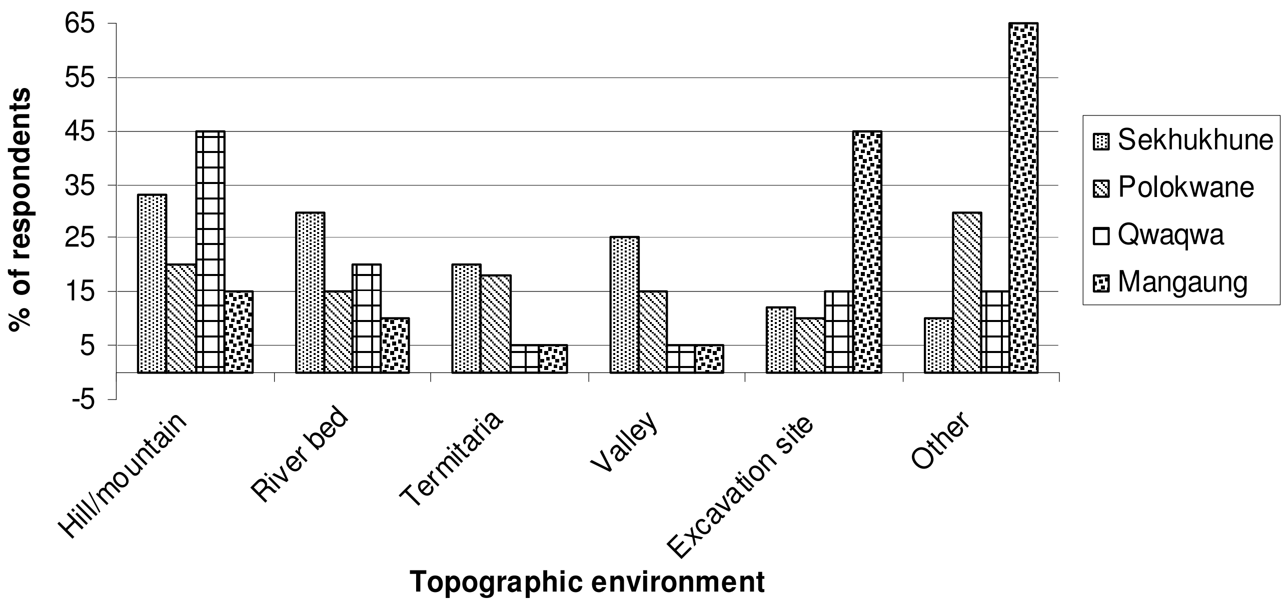

Figure 2. Type of geomorphological environment where geophagic clays are obtained in the study areas.

Sekhukhune liked khaki geophagic clays, 24% of respondents from Mangaung preferred reddish geophagic clays.

Respondents in rural environment (34% from Sekhukhune and 45% from Qwaqwa) collect their geophagic clays primarily from mountains and hills which are close to country rocks; whereas those in urban areas (38% from Polokwane and 65% from Mangaung) obtain theirs from other sources such as purchases from vendors (Figure 2). The vendors purchase the geophagic clays from traditional miners who live at the country sides in the two provinces. Some respondents also indicated that they obtained, to a considerable extent, their geophagic clays from river beds, termitaria, valleys and excavation sites (Figure 2). Respondents reported that geophagic clays were collected by employing one or more of the following traditional mining techniques: Digging, hand grabbing, scraping, and selective hand picking (Figure 3). Over 80% of respondents from both Qwaqwa and Mangaung indicated that their geophagic clays were traditionally mined using selective digging and hand grabbing techniques. Selective hand picking technique was mostly practised by respondents from Sekhukhune (40%) and Polokwane (38%) (Figure 3). According to the respondents, geophagic clays in the study areas were

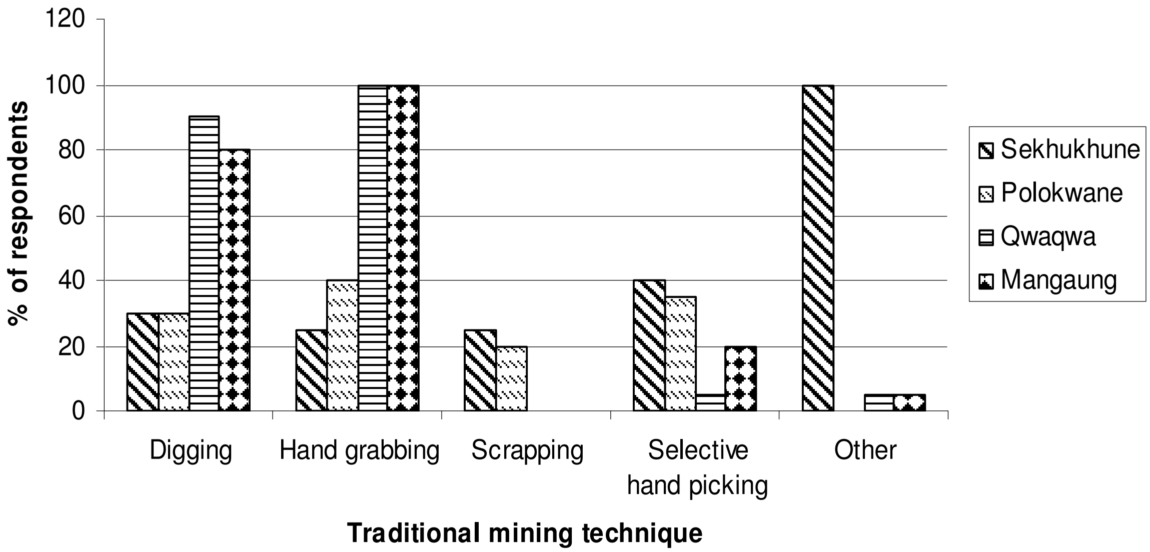

Figure 3. Type of traditional mining technique employed by residents in the study areas.

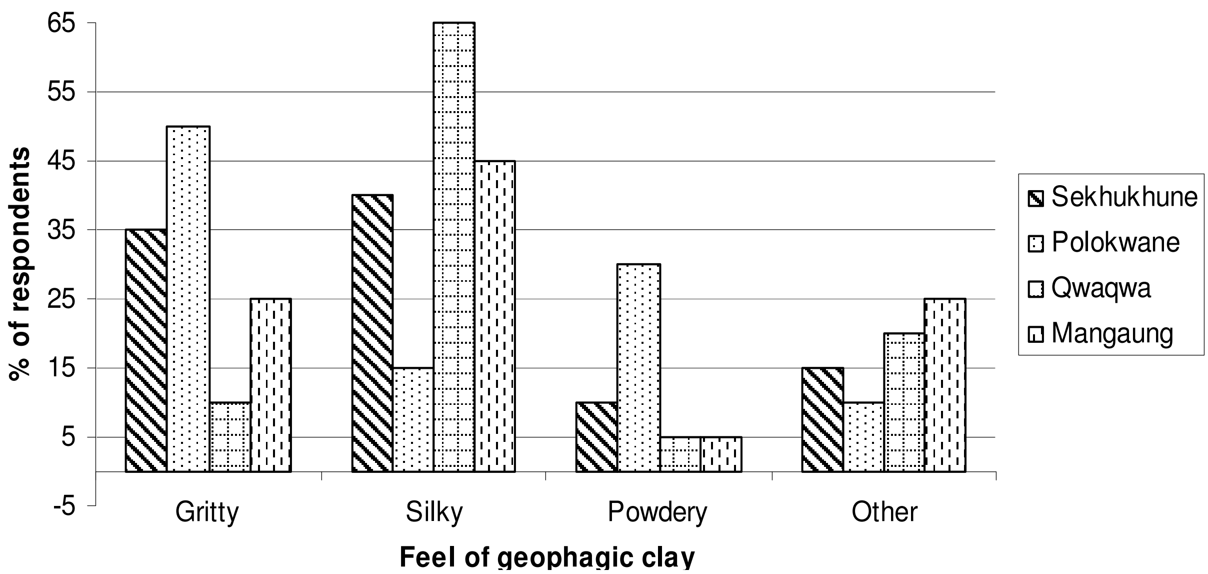

Figure 4. Textural feel of geophagic clays from the study areas.

generally gritty, silky and powdery (Figure 4). Geophagic clays from Limpopo Province were grittier and more powdery than those from Free State Province. On the contrary, Free State geophagic clays were silkier than those from the other province. Some of the respondents preferred geophagic clays which were soft, sticky and soapy. Most of the geophagic clays obtained in Free State were processed through sieving and slurrying, but in Limpopo Province and especially at Sekhukhune, the clays were processed by mainly pounding (Figure 5). Grinding was also employed as a form of processing particularly those from Limpopo Province. Geophagic clays from Limpopo Province were subjected to baking and burning as forms of heat treatment. Those from Free State Province were usually boiled. Also, in all the study areas, some of the respondents indicated that their clays were subjected to two or more forms of heating including baking, boiling and burning (Figure 6) as a form of sterilisation.

Mineral contents of geophagic clays

Minerals identified in geophagic clays from the study areas were quartz, SiO_2; kaolinite, $Al_2Si_2O_5(OH)_4$; mica (which included muscovite, illite, biotite, lepidolite and

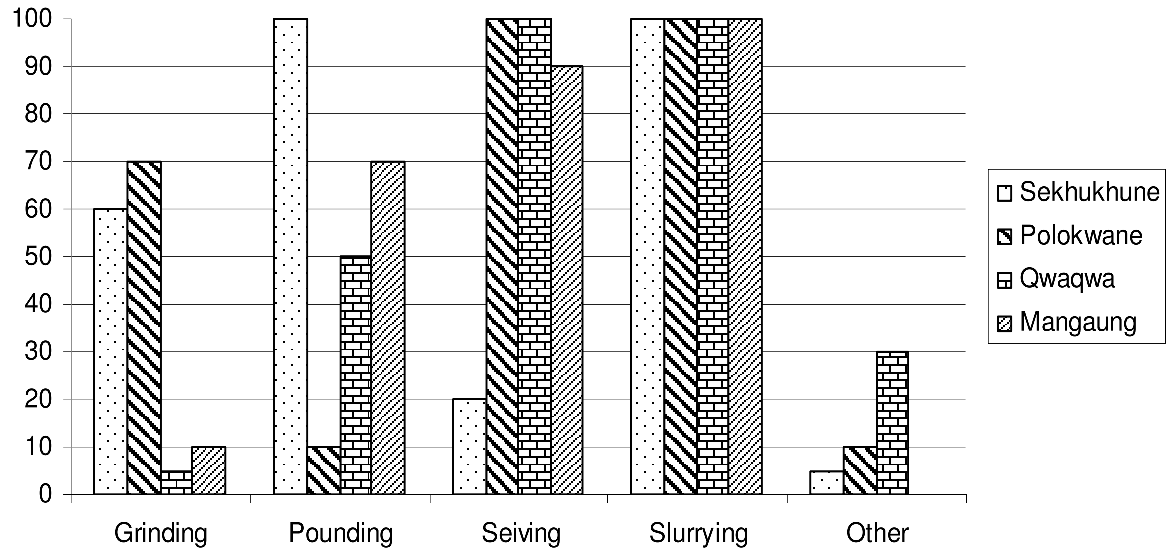

Figure 5. Type of processing of geophagic clays from the study areas.

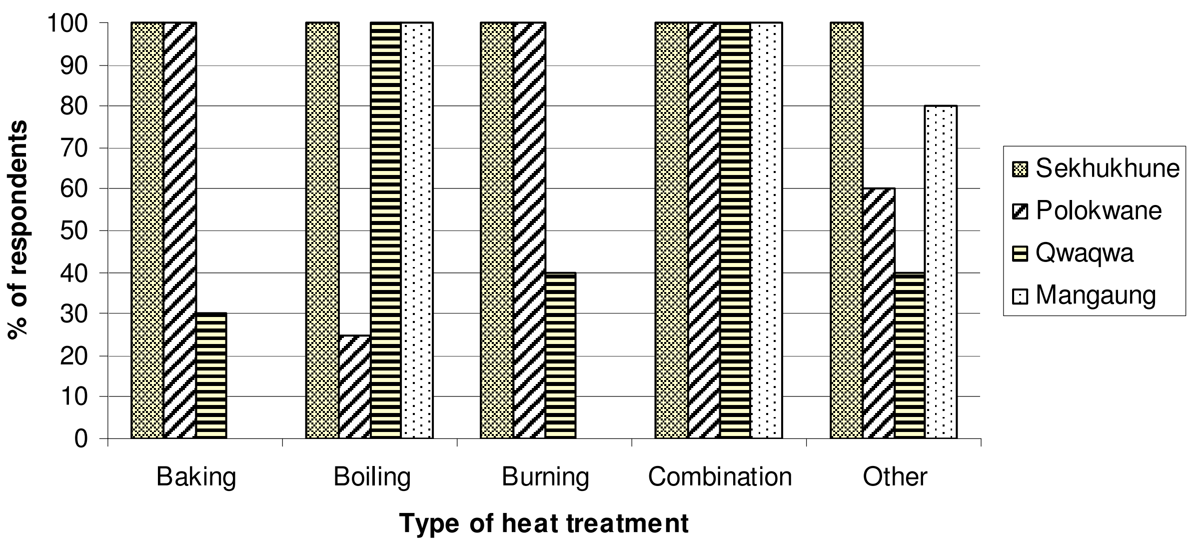

Figure 6. Type of heat treatment of geophagic clays from the study area.

chlorite); feldspar, $x\text{Al(Al,Si)}_3\text{O}_8$ (including orthoclase, microcline, plagioclase feldspar and feldspathoids); smectite, $(NaCa)(Al,Mg)_6(Si_4O_{10})_3(OH)_{6\text{-}n}H_2O$; goethite, FeO.OH; calcite, $CaCO_3$; and dolomite, $CaMgCO_3$. Quartz and kaolinite were the dominant minerals in all the samples. A representative X-ray powder diffractogram of a geophagic clay sample from Polokwane is presented in Figure 7. Samples from Free State were dominated by quartz, with a mean weight percentage of 74 (Figure 8). The lowest mean weight percentage for kaolinite was 5.1 for Qwaqwa and the highest was 23.7 for Polokwane; mica had mean weight percentages ranging from 6.3 for Mangaung to 41.5 for Polokwane; and feldspar had the lowest mean weight percentage of 0.8 for Mangaung and the highest weight percent of 10 for Polokwane (Figure 8).

Of the samples analysed from Sekhukhune, three contained smectite which constituted 61, 40 and 7 wt%, respectively (Table 1). Two of the samples from Plolokwane and four from Mangaung also contained smectite (Table 1). Of all the study areas, smectite was more common in samples from Qwaqwa than the others. However, the weight percentages of smectite in Sekhukhune geophagic clay samples were higher than those from Qwaqwa (Table 1). Goethite was identified in one sample from Sekhukhune, four samples from Qwaqwa and one sample from Mangaung (Table 1). Calcite was identified in at least one sample from each of the four study areas

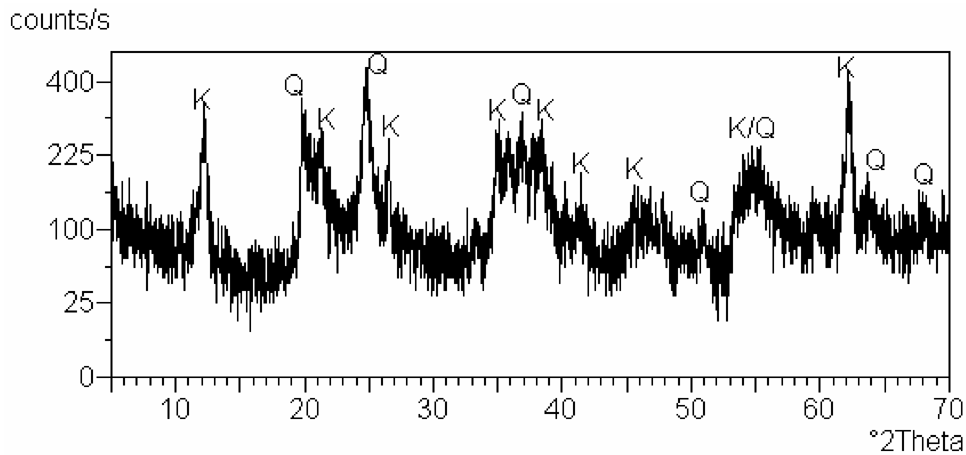

Figure 7. Representative X-ray powder diffractogram of a geophagic clay sample from Polokwane, Limpopo Province (note: K = kaolinite, Q = quartz).

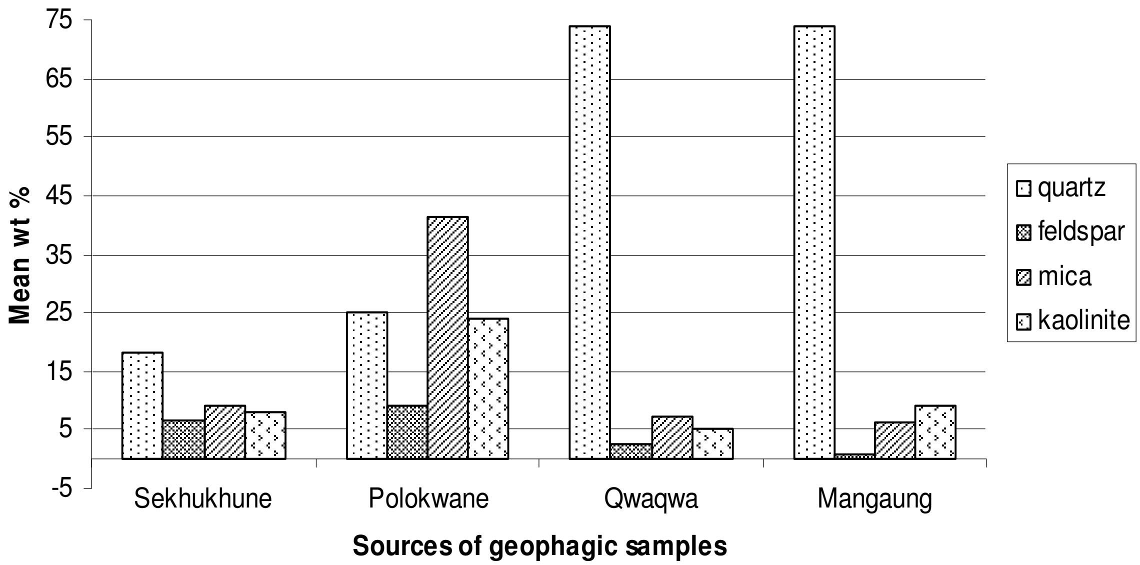

Figure 8. Mean wt % of quartz, feldspar, mica and kaolinite contained in geophagic clays from the study areas.

Table 1. Weight % of minerals contained in geophagic samples from Free State and Limpopo Provinces, South Africa.

Study area	Smectite (wt %)	Goethite (wt %)	Calcite (wt %)	Dolomite (wt %)
Sekhukhune	61, 40, 7	5	15, 10	11
Polokwane	7, 5	-	15, 5, 4	3, 27
Qwaqwa	7, 5, 3, 2 , 50	3, 3, 2, 3	14	-
Mangaung	2, 3, 2, 3	9	6, 20	84

with quantities varying as indicated in Table 1. Dolomite was identified in three samples from Limpopo Province, and one sample from Free State Province with very high weight percent. The weight percentages of these minerals in the samples are reported in Table 1.

DISCUSSION

Mineral contents and genesis of geophagic clays

As indicated in the mineralogical analysis results, geophagic clays from the two provinces contain kaolinite, illite, mica, quartz and feldspars. These mineral assemblages have also been reported for enzootic geophagic clays from Ivory Coast, Guinea and Senegal (Kikouama et al., 2009; Mahaney et al., 1993). Japanese macaques feed on geophagic soils that are rich in plagioclase and orthoclase feldspars and halloysite (a kaolin mineral) (Mahaney et al., 1993). Most geophagic clays contain kaolin (and especially kaolinite) and smectite (Wilson, 2003). This observation is substantiated in the findings of this study which reflect all the samples containing kaolinite with 35% of the samples having smectite.

Mineral genesis of geophagic clays consumed in Polokwane could be linked to the feldspars of Turfloop Granite and Zebediela kaolin; whereas those from Sekhukhune could possibly be associated to the micas in metamorphic rocks of the Limpopo Mobile Belt. The Turfloop Granite is the main geologic body at Polokwane area (Robb et al., 2006). Kaolinisation of the granite through mineral alteration of feldspar led to the formation of kaolinite (equation 1). The Zeibediela kaolin is a product of the residual weathering of a tuff-rich member of the Wolkberg Group (Horn and Strydom, 1998). The rocks of the Transvaal Supergroup which include dolomite, limestone, iron-formation, shale and quartzite (Goode, 2006) dominate the geologic terrain of Sekhukhune area. Muscovite contained in the rocks could have equally been transformed to kaolinite under favourable mineralogical conditions (equation 2).

$$\underset{\text{K-feldspar}}{2KAl_3Si_3O_{10}(OH)_2} + 2H^+ + 3H_2O \rightarrow \underset{\text{Kaolinite}}{3Al_2Si_2O_5(OH)_4} + 2K^+ \quad (1)$$

$$2KAlSi_3O_8 + 2H^+ + 9H_2O \rightarrow \underset{\text{Kaolinite}}{Al2Si2O5\,(OH)_4} + 2K^+ + 4H_4SiO_4 \quad (2)$$

The lithology of the Qwaqwa area is dominated by the Karoo Supergroup with the Drakensberg Mountain as the imposing topographic massif of the area (Free State CRDP, 2009). In the formation of the geophagic clays from Qwaqwa, plagioclase feldspars and olivine in the basalts of the Drakensberg Mountain were subjected to varying degrees of deuteric alteration which led to argilisation of the rocks and minerals to clay and clay minerals (Haskins and Bell, 1995). Muscovite and/or illite present could be indicative of its on-going conversion to kaolinite– the dominant clay mineral phase in the geophagic clay samples. Geophagic clays obtained close to country rocks, particularly at Qwaqwa, could also be inferred to have been formed through the alteration of feldspathic arenites, as indicated in equation 1. These arenites are derived from sediments of the Drakensberg Mountain Chain. Groundwater movement is considered to be integral to their formation (Murray, 1999; Ekosse, 2000; 2001). The geophagic clays were dominated by quartz grains which were physically weathered from the sand-stones in particular.

Mining and beneficiation

Colour and mining

Geophagists are very specific regarding the colour of clay selected for mining and consumption. White geophagic clays contain kaolin and smectite (Kikouama et al., 2009), while yellowish geophagic clays contain goethite. Soft and white and/or khaki geophagic clays preferred by most of the respondents in the four study areas are dominated by kaolinite and/or smectite; and may also contain calcite, dolomite, talc, and micas such as mus-covite and illite. Pregnant geophagic women in Kenya prefer yellowish geophagic material dug from excavation sites (Ngozi, 2008). The yellowish and reddish clays contain Fe, which could possibly be the reason why geophagic individuals consume them as a source of Fe supplement (Abrahams and Parsons, 1997). Through low scale selective traditional mining techniques, miners seek for whitish, khaki and yellowish geophagic clays with kaolinite, smectite and/or goethite contents.

Geomorphological environment

Some of the respondents obtain their geophagic clays from excavation sites where there could be road and road related construction projects, and building structures being erected. Excavation activities have loosened the geophagic clays from the parent sedimentary rocks and soils. Geophagic clays in these excavation sites have freshly exposed surfaces which are easily identified; and are relatively easier to mine compared to clays in unexposed surfaces. In a number of cases, respondents in this study indicated obtaining geophagic clays from termitaria. The consumption of geophagic clays from termitaria has also been observed among elephant populations (Ruggiero and Fay, 1994). Many sub-Saharan African types of clays from termitaria have been found to be rich in Ca and Fe (Allport, 2002; Hunter, 1993). There were geophagic individuals in the study areas who fed on clays from river beds. In Kenya, soft geophagic clays ingested by school children are obtained from river beds (Geissler at al., 1998). Unfortunately, these clays are usually loaded with water borne bacteria and pathogens.

Mining techniques

In the study areas, mining of geophagic clays is done at very small scale and is mainly for subsistence, except where the miners are geophagic and prefer to harvest the clays they consume by themselves. Mining sites of geophagic clays at Limpopo and Free State provinces in South Africa are usually close to human settlements. Proximity to their homes is an integral factor in the transportation of the mined clays to the houses of miners and

/or vendors where they are stored. The miners use very basic tools in mining the clays. Depending on the location of the geophagic clay to be mined and the type of mining activity, basic tools employed include hoes, spades, shovels, forks, pickaxes, machetes, crowbars and cutlasses. These tools are also used by traditional potters of sub-Sahara Africa (Gosselain, 1999). Some of the miners use very unconventional tools such as dry sharpened sticks, broken bottles and edges of used cans. Forks, pickaxes and crowbars are used for digging; and hoes, spades and cutlasses are used for scrapping. The shovel is used to gather the dug and scrapped geophagic clay. Where there are visible impurities and visually undesirable earthy material, selective hand grabbing is used to sort the geophagic clay from the ore. Mining of the geophagic clays is achieved through surface collection, pit extraction or gallery; these techniques are similar to those used by potters in Africa (Gosselain and Smith, 2005).

Textural feel

Consumers of geophagic clays in the study areas prefer those that are soft, silky and powdery. Geophagic clays that are gritty contain silt and fine sand particles of quartz and feldspars which may negatively affect dental enamel of geophagic individuals. Quartz has a higher degree of hardness (7 on Mohr scale) than dental enamel (5), which is hydroxyl apatite ($Ca_5(PO_4)_3(OH)$). Quartz particles through mastication are able to grind, crack and break dental enamel (King et al., 1999). Another malignant effect of quartz particles in geophagic clays is their ability to erode gastro-intestinal lining of geophagic individuals with the possibility of perforating the Sigmoid colon (Woywodt and Kiss, 1999). In overcoming the above cited problems of geophagic clays imparted by grittiness, coarse grained fine sand and silt particles could be fractionated away from desirable clay size particles. This beneficiation exercise can be carried out through the application of Stoke's Law of sedimentation of particles (Anastacio et al., 2005; Tateo et al., 2006).

Processing

Pounding, sieving, slurrying and grinding are different methods respondents indicated that are used for the processing of geophagic clays from the study sites. Pounding of geophagic clay is done with a stone, wooden mortar and pestle or wooden hammer in a stone by potters in some parts of sub Sahara Africa (Gosselain and Smith, 2005). Pounding is often followed by sieving of the clays to separate coarse large fine sand and silt particles from the clay size particles. Grinding is another processing technique which aggregates geophagic clay particles to almost same size. Primates also grind their geophagic clays before consumption (Mahaney et al., 1993). Grinding increases the clay pH, and assists in the ingesting process. Though grinding caters for problems due to coarseness and largeness of particles, its drawback lies in rendering toxic elements contained in the geophagic clays readily available for absorption. Geophagic clay slurries have been used to investigate clay behaviour in the human alimentary system (Stokes, 2006). The slurrying of geophagic clays also concentrates on fine particles and reduces organic matter content.

Heat treatment

Boiling, baking and burning are the various forms of heat treatment in which geophagic clays are subjected to. Geoghagic individuals from the study areas indicate that heat treatment is used to improve the palatability of geophagic clays. Heat applied through baking and burning reduces the moisture content of geophagic clays, making them assume a powdery chunky nature preferred by some geophagic individuals. Applying heat to geophagic clays enhances desirable colours. Khakhi, whitish and greyish clays are calcined; rendering their colours richer and brighter. Yellowish clays when heated change to brick red due to the transformation of goethite to haematite (Equation 3; Frost et al., 2003). The alteration process is characterised by the removal of OH and stripping of some of the O, enabling the (100), (010) and (001) directions in goethite become the (001), (110) and (111) directions in trigonal hematite cell (Oëzdemir and Dunlop, 2000).

$$\underset{\text{Goethite}}{2FeO(OH)} \rightarrow \underset{\text{haematite}}{Fe_2O_3} + H_2O \qquad (3)$$

Heat treatment generally reduces the microbes, bacteria and other pathogens. The effort may minimise and possibly eliminate poikilothermic micro-organisms and those that thrive in ambient temperatures are present in geophagic clays. Pyrothermic micro-organisms may likely persist in the clays.

Human health considerations

The use of clays for different purposes is related to their physical and chemical properties which are imparted by the arrangement of the alumino silicates and other ions dominating their mineral structures (Ekosse, 2005; Ekosse and Mulaba, 2008). Clay properties also influence the density of their negative charges (Cara et al., 2000). The small size of the clay minerals particles such as kaolinite and smectite (< 2 µm in diameter) accords it large surface areas over which adsorption of cations and micro organisms could occur (Alexander, 1977). This property enables clay minerals to create a surficial coating on the stomach with inferred pharmacological implications. Reactions such as isomorphic substitution occur in the octahedral sheet because it is usually 67% filled providing vacant sites for other ionic reactions. Calcium and Mg from dolomite, calcite, smectite, talc and Fe from goethite and hematite could be supplied from the geophagic clays and absorbed as possible nutritional supplements (Abrahams and Parsons, 1997; Kaolin in news, 2005). There are however continuous contentious scienti-fic debates on the association of Fe and anaemia in geophagic individuals (Boyle and Mackay, 1999; Brand et al., 2009).

The studied geophagic clays have varied mineralogical composition which impact on their properties and influence human health when consumed. Geophagic clays rich in smectite and kaolinite are the most widely used traditionally as medicinal clays. Smectitic clays are natural intestinal detoxifier with the ability to absorb toxins such as heavy metals, free radicals and pesticides from the gastrointestinal tract (Eyton's Earth, 2007; Johns and Duquette, 1991; Mineral clay, 2008) and are used to relieve constipation, allergies, diarrhoea, indigestion and intestinal ulcers. Kaolinitic clays, commonly packaged as keopectate, are used as antidiarrhoeal medicine because of their ability to absorb water from human digestive tract. The geophagic clays from both the Free State and Limpopo Provinces in South Africa are rich in kaolinite and to a lesser extent smectite; and thus have the potential to provide medicinal benefits to the consumer.

The major mineral phase in the studied geophagic clays is quartz which cannot be easily altered. Angular quartz particles could be abrasive to the human gastro-intestinal tract. Geophagic clays could also have elements, including some heavy metals, such as Pb, Hg and Cr, which may impact negatively on human health. The clays, may, in addition carry micro organisms and geohelminths which could invade and infest the gastro-intestinal system of consumers. Other negative effects from the consumption of geophagic clays could include increase in the gastro-intestinal pH and the binding of plant toxins and pathogens. The blackish clays in this study may have a higher content of organic matter, and possibly Mn. The high content of organic matter in blackish clays may harbour a wide range of microbes, bacteria and geohelmiths, which could pose various health threats to their consumers.

Conclusion

Responses from geophagic individuals in Free State and Limpopo Provinces have been used to elucidate traditional mining and material selectivity of geophagic clays in the two provinces. Most of the geophagic individuals from Free State Province preferred whitish geophagic clays. Khaki clays were also preferred, perhaps as substitute for whitish clays. More geophagic individuals from Limpopo Province preferred yellowish geophagic clays when compared to those from the Free State Province. Very basic inexpensive tools are used to easily mine geophagic clays from excavation sites, and termitaria. Some of the clays were obtained from river beds, mountains, hills, and valleys. Selective digging and hand grabbing techniques are employed by over 80% of respondents from Free State Province; and selective hand picking technique is practised by respondents from Limpopo Province. Most of the geophagic clays from Free State Province were processed through sieving and slurrying, and those from Limpopo Province mainly by grinding and pounding. Geophagic clays from Limpopo Province were subjected to baking and burning and those from Free State Province, to boiling; although a combination of two or more forms of treatment is also used.

X-ray diffraction analysis of geophagic clays from the study areas in the two provinces depict quartz as the dominating non-clay mineral phase present in all the samples, with very high quantities in samples from Qwaqwa and Mangaung. Kaolinite was the most abundant clay mineral phase found in all the samples with higher percentage from Polokwane. Smectite was also identified in a large number of samples. Small quantities of goethite, calcite, feldspar and mica were also identified in some of the samples. These mineral assemblages are in general present in most clay that is consumed. Although the consumption of clayey materials has been considered to be geophagia, this appellation is too general as it includes soils, stones, rocks, and any other earthy substance. To this effect, suggestion is been made to refer the consumption of geophagic clays as *argillophagia*. In conditions where one or more kaolin minerals are the dominant earthy material being consumed, the term *kaolinophagia* could be applied.

Geophagic practice is very old, deeply rooted in several human populations all over the world, and cannot be stopped. There is thus need for concerted efforts to regulate the quality of geophagic clays. National statutory bodies, inter-governmental agencies and organisations should work collaboratively to educate geophagists on beneficiation methods that are safe and that would lead to an improvement of the quality of geophagic clays. Key health concerns should address the reduction and/or elimination of microbial, bacterial and pathogen loads in the geophagic clays to levels fit for human consumption. Minerals of recognised benefit to humans are mainly kaolinite and smectite, and perhaps calcite and goethite. Selective beneficiation exercise such as reduction and/or removal of sand and silt particles from the geophagic clays could be conducted to remove non-beneficial minerals.

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