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Mineralogy, Geochemistry and Health Impacts of Earth Materials Consumed by Humans in Vhembe District, Limpopo Province, South Africa

By

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[redacted]

Submitted on 19th April 2013

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DECLARATION

I, Abuh Momoh hereby declare that this thesis for the award of a Doctor of Philosophy Degree in Environmental Geology at the University of Venda, hereby submitted by me, has not previously been submitted for a Degree at this or any other University, and that it is my own work in design and execution and that all the reference materials contained therein have been duly acknowledged.

Student signature..... Date.....19.04.2013

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Co-supervisor signature..... Date.....19/4/13

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To my lovely children, Maryam Omaye Momoh, Mohammed Mansur Momoh, Mohammed Munir Momoh and my beloved wife Hadiza Momoh for their patience, love and inspiration.

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This work focuses on three main themes (clay mineralogy and geochemistry, bioaccessibility of essential nutrients and effects of eating Earth materials on human health), treated in five chapters. The first theme of the study assessed the prevalence of geophagic practice in the area. Issues examined were demography, rationale for eating Earth materials or dirt and distribution chain of consumed Earth material in the District. Purposive sampling was used to identify 438 women who practice geophagy in the area. Forty six point three percent of the women were married, 45.4% were single, 4.3% were divorced and 3.2% were widowed. The reasons they gave for geophagic practice are medicinal, quelling of nauseate feelings and control of early morning sickness in pregnancy. Clays and soft stone are the most preferred types of Earth material. Average daily ingestion rate for pregnant women was 90 g per day while non- pregnant women consume an average of 40 to 60 g on a daily basis.

Features of geophagic materials were assessed with a view to ascertain if these features could assist in the understanding of these geophagic materials to perform some of the functions that have been adjudged for human geophagic practice. Tests conducted include: colour, pH, electrical conductivity (EC), cation exchange capacity (CEC), textures and occurrence of beneficial bacteria in the samples. Colour ranged from red, yellow to dark grey through various shades of brown. The pH of the geophagic materials ranges from 4.30 to 7.90. The values obtained for EC ranges from 8.22 µS/cm to 652 µS/cm while CEC ranges from 3.74 meq/100g to 19.78 meq/100g. On the basis of texture, the consumed Earth materials were classified as clays, sandy clay loam and silty clay materials. Significant growths of filamentous bacteria (*Streptomycete*) were recorded in some geophagic materials from the District. Aggregates of grey, brown and whitish bacteria colonies were observed on the rim of the plates.

The third part of the study focused on an investigation of the potential of these geophagic materials to supplement the mineral nutrients of geophagists. The oral bioaccessibility using *in vitro* physiologically based extraction test (PBET) was used. A simplified, two-stage extraction simulating the human stomach (pH 1.2 – 1.7) and intestine (pH 6.3 – 6.5) was developed and applied to 30 geophagic samples. Extractants were analysed by inductively coupled plasma mass spectrometry (ICP-MS). The element concentrations extracted from geophagic materials within the human stomach and intestine respectively were on average 0.90 and 0.20 ppm Fe; 81.44 and 22.42 ppm Zn; 10.10 and 9.02 ppm Se; 1672.7 and 1900

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ppm Mn; 24.93 and 230.04 ppm Cu; 11.7[illegible]nd 11.72 ppm Co; 2.22 and 3.23 ppm As; 29.50 and 35.91 ppm V; 5.59 and 102.87 ppm Cr; 5.53 and 21.28 ppm Ni; 0.09 and 0.05 ppm Cd; 5.52 and 6.72 ppm Pb. Iron, Zn, Mn and Cd bioaccessibilities were found to be higher in the stomach while Cu, V, Cr, Ni, Hg and Pb bioaccessibilities were found to be higher in the intestinal phase. Bioaccessibilities of Se, Co and As were similar in the stomach and intestinal phases. The fourth aspect of this study focuses on the implications of eating Earth on human health in Vhembe District. Haemoglobin levels in blood of non-pregnant geophagic women were measured and identification of helminth ova in 30 geophagic samples and 3 non-geophagic samples were investigated to confirm the possible role of geophagy in causing iron deficiency anaemia and in the transmission of geohelminths (*Ascaris lumbricoides*, *Trichuris trichuria*, *Stongyloides stercoralis* and Hookworm). Sixty eight non-pregnant geophagic women between the ages of 18 and 49 and five non-pregnant women that do not practice geophagia between the ages of 18 and 45 (control group) were recruited into the study. Forty four percent of the geophagic women were diagnosed as anaemic and 56% were normal. All the women in the control group were normal. An *Ascaris lumbricoides* ovum was detected in sample 21 of the geophagic material.

The fifth aspect deals with determination of minerals in consumed Earth materials. Thirty five samples of consumed Earth materials and three non-geophagic clays were analysed for their mineralogical composition using x-ray diffractometer (XRD). The concentrations of major and trace elements were determined by means of x-ray fluorescence spectrometry (XRFS). The clay mineralogy showed that consumed Earth materials consist of kaolinite, smectite, muscovite, quartz, albite, orthoclase, goethite, hematite, microcline and anatase. Result of Tukey's post hoc test mineralogy showed that only kaolinite has a significant percentage with respect to all other minerals. The consumed Earth materials are richer in kaolinite (samples 1, 4, 7-9, 11-23, 24-30) with a lesser percentage of quartz than non-consumed Earth materials. Major element chemistry of the consumed Earth materials are enriched in Fe and Al and depleted in Ca, K and Mn. The chemical index of alteration (CIA, concentration of elements in soils and rocks) for the consumed Earth materials ranges from 17.09 – 99.07. Kaolin is the dominant mineral in the consumed Earth material; and because of its ability to coat and adhere to intestinal membrane of geophagist, this could suggest that pregnant women, lactating mothers and children indulge in geophagic practice to seek various forms of protection against gastrointestinal problems and toxins.

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The investigations contained in this thesis have given rise to five different articles of which four have been published and one is under review.

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LIST OF ACRONYMS, ABBREVIATIONS AND MEASUREMENTS

AAS	Atomic absorption spectroscopy
Al	Aluminium
Al_2O_3	Aluminium oxide
ANOVA	Analysis of variance
As	Arsenic
BAF	Bioaccessible fraction
C	Celsius
Ca	Calcium
$C_{bioaccessibility}$	Concentration of trace element from geophagic clays
CBC	Complete blood count
Cd	Cadmium
CEC	Cation exchange capacity
CIA	Chemical Index of Alteration
Cr	Chromium
C_{total}	Total concentration of element in geophagic clays
Cu	Copper
C_{1-3}	Control samples
CVAR	Cumulative variance explained
EC	Electrical conductivity

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EV	Eigen value
EVM	Expert Group on Vitamins and Minerals
F	Fluoride
Fe	Iron
Fe_2O_3	Iron oxide
Fig.	Figure
HIV	Human immunodeficiency virus
I	Iodide
ID	Index dose
IDoral	Oral index dose
IBM	International Business Machine
Kg	Kilogramme
LoD	Limit of detection
LOI	Loss on ignition
M	Molar
MAP	Maximum absorption potential
Max.	Maximum
Meq/100g	milli equivalent per 100 gramme
MDI	Mean daily intake
Mn	Manganese
MgO	Magnesium oxide
MnO	Manganese oxide
Mg/day	Milligram per day

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Min.	Minimum
N/A	Not available
N/R	No response
Na_2O	Sodium oxide
Ni	Nickel
NRC	National Research Council
NW	Northwest
OH	Hydroxyl radical
OLM	Ocular larval migraine
%	Percentage
Ø	Theta
Pb	Lead
PBET	Physiologically based extraction test
PCA	Principal component analysis
Pers. comm.	Personal communication
pH	Negative logarithm of hydrogen ion concentration
PHEs	Potentially harmful elements
PTEs	Potentially toxic elements
P_2O_5	Phosphorus oxide
R	Rand
RNI	Recommended nutrient intake
Se	Selenium
SEM	Scanning electron microscope

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Si	Silicon
SO_3	Sulphur oxide
SPSS	Statistical Package for the Social Sciences
SULs	Safe Upper Levels
TDI	Tolerable daily intake
UK	United Kingdom
U.S.A	United States of America
USEPA	United States Environmental Protection Agency
US$	United States Dollar
µS/cm	micro Siemens per centimetre
µg/l	micro gramme per litre
µg/d	micro gramme per day
VAR	Explained variance
VLM	Viscera larval migraine
W.H.O	World Health Organisation
WNW	West North West
XRD	X-ray diffraction
XRFS	X-ray fluorescence spectrometry
Zn	Zinc

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CHAPTER ONE

INTRODUCTION

1.1Background

Earth materials like clay, sands, wall scrapings, ant hills, termite mounds, alluvial sediments from floodplain of rivers and dried up pond sediments are deliberately consumed by human beings; such habit of eating Earth materials is referred to as geophagy or geophagia. It is a common and culturally sanctioned habit worldwide (Reid, 1992). The practice is as old as the evolution of animal kingdom but is most common in sub- Sahara Africa (Abrahams and Parsons, 1996).

At the turn of the nineteenth century, several explorers, anthropologists and colonial doctors reported the practice of geophagy in tropical countries (Abraham and Parsons, 1996). Also Alexander von Humboldt, during his South America travels recorded the eating of clay by Ottomac tribe along Orinoco valley in Venezuela (Keay et al., 1983). These people were involved in geophagic practice because of annual flooding of Orinoco River that curtailed local food supplies of fish and turtle. During this period, Humboldt recorded how five to six inch (12.5-15cm) diameter balls of mainly alluvial material were prepared and eaten by the Ottomac in large quantities within a day to lessen hunger with apparently no harmful effect on the health of the consumers (Abrahams and Parsons, 1996).

David Livingstone highlighted in his treatise, dated November 1870 on 'safura' the local name of earth eating which he observed in Zanzibar, Tanzania. These people became addicted to geophagy and were falling sick. Symptoms of the disease with safura are swollen feet, haggard appearance, and shortness of breath and weakness which led to death in some cases (Abrahams and Parsons, 1996).

In sub-Sahara Africa, many pregnant women, lactating mothers and children are involved in geophagic practice. This is as a result of inadequate essential elements (Fe, Zn, Cu, Mn, Se and Ca) necessary for formation of new tissues at foetal and maternal stages that is lacking in their normal diets (Kikouma et al., 2009). The additional need for these elements cannot be provided by food alone, nutrient supplementation is recommended by way of geophagic

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practice for proper healthy growth of the developing baby and mother (National Research Council, 1989). Few males on this continent are involved in geophagic practice.

The prevalence of geophagy among pregnant women in some African countries shows a distribution of 65% in Kenya, 46% in Ghana, 42% in Namibia and 28% in Tanzania (Kawai et al., 2009; Antelman et al., 2000; Luoba et al., 2004). These women eat several types of Earth materials ranging from hardened clay soil sold in shops and market places to those from the walls of houses or termite mounds (Luoba et al., 2004).

Notable examples also abound in the Middle East where Christians take soft whitish stones from Bethlehem grotto and rub them in water for nursing mothers to drink and in Pakistan where Muslims eat gray flat oblong cakes made from dust of the Prophet Mohammed tomb as a cure for all diseases (Hunter, 1993).

According to Aufreiter et al. (1997), the causative reasons for consumption of Earth materials are as follows; food and food detoxifier- In China, a country where traditional knowledge of famine foods has been transmitted between generations, soils were utilized during famine as food about forty years ago in 1957 (Aufreiter et al., 1997).

In 2002, food shortages were reported to be resulting in geophagia in Malawi. Many plants containing toxins were consumed during periods of food shortage, for example, the African famine food called the wild yam, *Discorea dumentorum pax.* It is detoxified through the use of clay (Abrahams, 2005). Mud cookies baked in the sun by Haitians in Port-au-Prince is one way that poor people reduce hunger as food prices soar (Wiley and Katz, 2008).

Native American populations have been reported to mix soil with acrid acorns tubers and bermes as a means of improving the taste of acorns meals. Also, the Aymara and Quechua people of the Andes Mountains of Bolivia and Peru still continue to eat wild potatoes by dipping them in thick slurry of clay that effectively adsorbs potentially toxic glycoalkaloids (Johns, 1986).

Psychiatric and psychological reasons: Soil is one of the non food items commonly sought by mentally retarded people because they cannot differentiate between food and non food items, but a study in the United States showed that individuals are often aggressive in seeking the non food item of their choice, and they are quite often deliberate about what they ingest (Danford et al., 1982). African American women consume holy clay tablets in order to derive

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psychological comfort and allay anxieties associated with ill health or pregnancy (Hunter et al., 1989; Geissler, 2000).

Cultural norm: Women of reproductive age from western Kenya consume soils from termite mounds that have symbolic significance because of their red colour (i.e. the colour of blood), intense taste, fertility, the use of their material for building dwellings and their location may be coincident with sites of burials or former habitation (Hunter and de Kleine, 1984; Geissler, 2000; Abrahams, 2005).

Pharmaceutical reasons: Modern societies also use kaolin and smectite clays to treat gastrointestinal disorders. In Nigeria, clays are mined from Paloecene shales at Uzalla for treating gastrodynia (stomach ache) and dysenteric ailments (Vermeer and Ferrel, 1985).

Physiological reasons: Eating of volcanic soils with high clay content, rich in high cation exchange capacity can release many elements under acid digestive conditions, these can significantly supplement intake of available Cu, Fe, Mn and Zn by some rural communities (Mills, 1996; Davies, 2008). Calcium and Fe are the two mineral nutrients that are frequently implicated in the physiological explanation for geophagy. Daily Ca needs for pregnant women increases from 800 - 1200 $mgday^{-1}$, primarily to provide the nutrient for foetal skeletal growth and development (Abrahams, 2005).

As a source of beneficial bacteria: Soils are deliberately consumed on the understanding that certain beneficial bacteria that are contained in it will help one's digestive system function properly by reducing the growth of harmful bacteria, assist in lactose digestion, help stimulate the immune system and improve the general health of geophagist (Gumbo, pers. comm.).

Three major hypotheses were put forward to explain geophagic practice: hunger, micronutrient deficiency and protection from toxins and pathogens (Wilson, 2003; Young et al., 2008). The hunger hypothesis holds that people consume Earth materials because they do not have anything else to eat (Laufer, 1930). The micronutrient deficiency hypothesis posits that people with micronutrient deficiencies eat Earth materials in order to increase micronutrient intake of Fe (Hunter, 1973). The practice of geophagy has been shown to supply 17% - 55% of recommended pregnancy supplementation of Ca, Mn, Zn, Fe, Cu, Mn, Se, K, Ni and Co (Brand et al., 2009; Hunter and de Kleine, 1984).

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The protection hypothesis states that geophagic practice is motivated by an attempt to mitigate the harmful effects of plant chemicals or microbes (Johns, 1986; Profet, 1992). It was proposed that geophagic soils protect by either adsorbing pathogens or toxins within the gut lumen or coating the surface of intestinal endothelium, thereby rendering it less permeable to toxins and pathogens (Young et al., 2010). Also, this hypothesis implies that pica (Latin word that describes the consumption of non-foodstuff objects) would be ingested during periods of rapid growth i.e. the times of greatest need for protection from toxins and microbes. Childhood and pregnancy are the periods when geophagic practice would occur most (Flaxman and Sherman, 2000). Pregnant women, whose immune systems are relatively weak, may also need protection from substances that would normally be harmless (Fessler, 2002).

Eating of Earth materials could lead to some serious health problems in man, like mechanical bowel disorder (Keay et al., 1982) and nutritional dwarfism (Prasad, 1991). Constipation: the reduction of the power of absorption of food materials by the body: severe abdominal pain, obstruction and perforation of the colon may result following the internal accumulation of soil (Abrahams, 2002).

von Garnier et al. (2008) reported a case of Cameroonian lady who had been eating kaolin for fifteen years and was anaemic. After one month of treatment by Fe replacement therapy, her anaemic condition was corrected and three months later had a haemoglobin level within the normal reference range (von Garnier et al., 2008). Geophagy is a major factor for transmission of *Ascaris lumbricoides, Trich*uris *trichiura* and other parasitic infections among children (Saathoff et al., 2000). Lead poisoning and other macro- element disorder could occur as a result of pica (Trivedi et al., 2005).

Simpson et al. (2000) warned against women eating soils that are enriched in Mg. High levels of Mg could be harmful to pregnant women and also to the unborn foetus. Researches based on chemical analysis of geophagic materials have not substantiated the nutritional hypothesis because they are limited to the determination of total element content without considering the extent to which these elements are biologically available (Wilson, 2003; Young et al. 2008; Young et al., 2010).

The focus of this study is to analyse the various forms of minerals and macronutrients in Earth materials with a view to test mineral nutrient supplementation and protection

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hypotheses in favour of this practice, and also to highlight some possible human health issues arising from consumption of Earth materials in Vhembe District of Limpopo Province.

1.2 Problem statement

There is an ongoing misunderstanding concerning the consumption of Earth materials (geophagy) globally. Some people are of the opinion that it is nutritionally beneficial, while others say it is harmful to one's health. The nutritional benefit has been speculated, because soils contain large quantities of macronutrients and micronutrients. Though, these nutrients are present in these materials, their level of bioavailability for human absorption is still largely unknown.

More so, quite a large number of women folk that are involved in geophagic practice across Vhembe District are not aware of the inherent dangers in the consumption of some of these Earth materials, because the constituents of these Earth materials are not yet fully characterised.

This study is aimed at mineralogical and geochemical characterisation of Earth materials that are consumed in Vhembe District as a basis for testing postulated hypotheses on the merits and demerits of the practice; and also to carry out a detailed microbiological examination of blood samples of geophagists to ascertain their health status and to highlight possible health impacts of such habit amongst women geophagists.

1.3 The study Area

1.3.1 Location

Vhembe District is located at the north-western tip of South Africa in Limpopo Province (Fig. 1.1). It lies approximately between latitudes 22° 08′ and 23° 24′and longitudes 28^{0} 54′ and 31^{0} 05′. The District is made up of the former Venda homeland and part of former Ganzakulu. There are four municipalities within the District; namely, Thulamela, Musina, Mutale and Makhado. It has a population of about 1.2 million people, of which 54% are female (Amidou, 2007). The District is labelled as the least urbanised Province in South Africa, with 90% of its population living in rural areas. The orders of increase in population size among the Municipalities are as follows: Musina, Mutale, Makhado and Thulamela.

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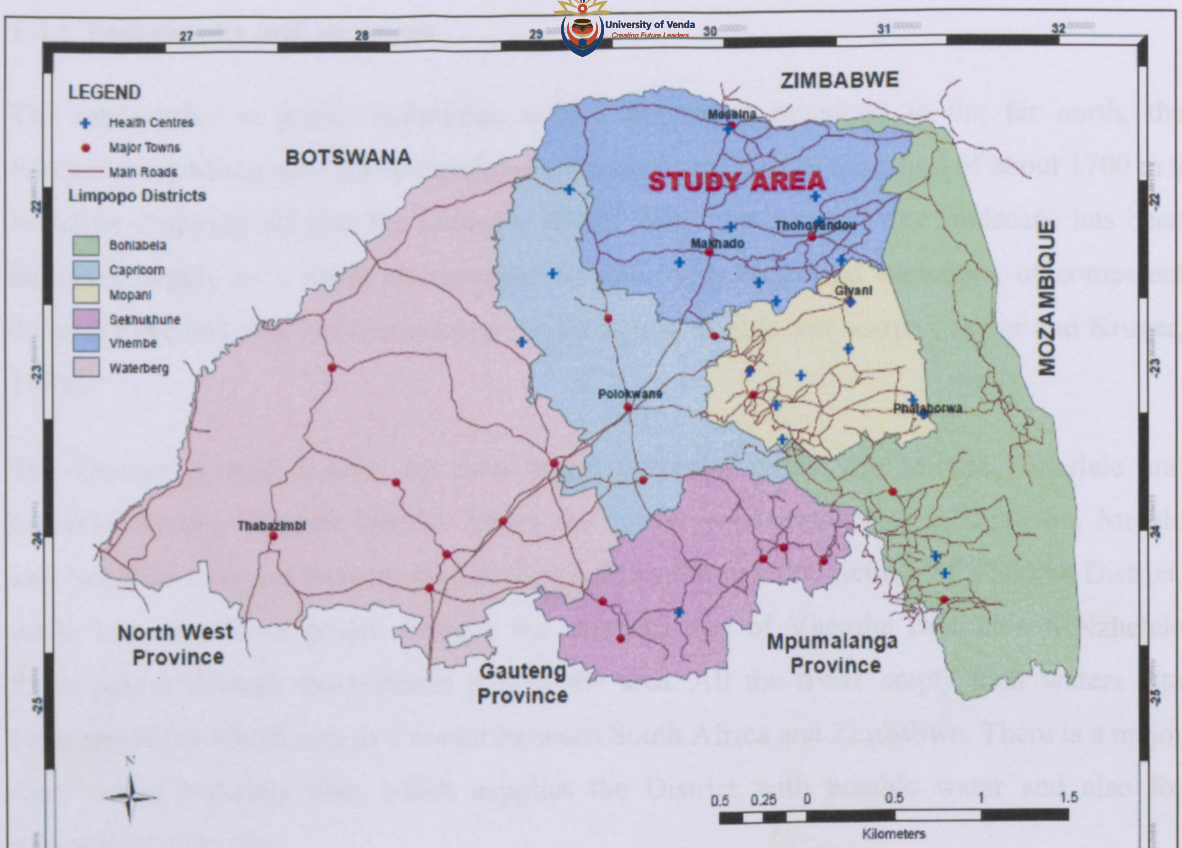

Figure 1.1: Location map of the study area (Source: Municipal Demarcation Board, 2006)

1.3.2 Climate

Vhembe District falls with in the sub-tropical type of climate, with rainfall ranging from 300-1000 mm per year (Munyati and Kabanda, 2009). Most of the rain falls in the summer months, between October and March. The mountainous areas receive enormous amounts of rainfall yearly with an average value of about 1329 mm (Marete, 2003). Annual evaporation increases gradually from 1400 mm in the west to 1900 mm in the east. Musina has the highest rate of evaporation in the District. The annual rate of evaporation of Musina is about 2700 mm (Marete, 2003).

Daily temperatures vary from mid 20's to mid 30's degrees with an average range of between 17° and 27°C in the summer and 4° to 20°C in the winter. Part of the District can be extremely hot during summer with temperatures as high as 45°C. The average seasonal humidity within the area is about 80% during summer, while during winter, it is about 38% (www.sa-venues.com/weather/limpopo.html).

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1.3.3 Topography and Drainage

The topography is gently undulating with a prominent mountain in the far north, the Soutpansberg Mountain. The Soutpansberg Mountain reaches an elevation of about 1700 m a sl before dropping off into the Limpopo River valley. The present day landscape has been moulded largely as a result of erosional forces, while faults and intrusions of competent dolerite dyke and sills have influenced the formation of hills and scarps (Taylor and Kruger, 1986).

The District is well drained by three major perennial rivers: the Mutale, Nzhelele and Luvuvhu Rivers. Vhembe District covers the convergence watersheds of Luvuvhu, Mutale and Nzhelele river catchments. Mutale River flows through the vicinity of Vhembe District, while Luvuvhu River passes through the southern part of Vhembe District and Nzhelele River passes through the northern part of the area. All the rivers empty their waters into Limpopo River which acts as a border between South Africa and Zimbabwe. There is a major dam, called Nzhelele dam which supplies the District with potable water and also for agricultural activities.

1.3.4 Soils and Vegetation

The area is mainly covered by soils derived from quartzite and sandstones which are generally shallow, gravely and well drained with low nutrient, and acidic in nature (Mucina and Rutherford, 2006). Soils of basaltic origin and diabase dykes are fine textured, clayey and of considerable thickness. Soils of Aeolian Kalahari are fine grained. The areas along the northern slope are devoid of soils; they are mainly made of rocks (Brandl, 2002). The general soil types within the District are sandy soils, shallow silty sands, loamy soils and clayey soils which are found within the river valleys.

Diverse plant communities are found within the area; of these species, forests of Lebombo ironwood are worthy of note. Several grasslands with scattered trees, baobab trees, short open woodland and bushes of different kinds cover the entire District. There are finger grasses, herbaceous plants, wooded plants, grasslands and farmlands within the area.

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1.3.5 Land use

The major land uses of the area are agriculture and mining activities. The sub-tropical climate that prevails over the area gives rise to conditions favourable for the cultivation of tea, coffee and tropical fruits. Sunflowers, cotton, maize and peanuts are grown on a large scale, while tropical fruits such as banana, pineapples, mangoes, pawpaw and oranges are cultivated as well. Livestock farming includes cattle ranching and game. The Kruger National Park lies within the area. Coal, magnesite and low grade Cu are currently being mined in the area around Tshikondeni and Musina, respectively.

1.4 Hypothesis

- Earth materials are consumed to satisfy nutritional deficiency and to protect geophagist against toxins and pathogenic infection.
- Geophagous women are more prone to iron deficiency anaemia and helminth infections than non- geophagous women.
- Consumed Earth materials possess antimicrobial properties for fighting against other pathogenic bacteria that cause infection amongst geophagists.

1.5 Objectives of the study

General objectives

This research is aimed at determining detailed mineralogy and chemical composition of consumed Earth materials in Vhembe District so as to ensure better understanding of the merits and demerits of the practice.

Specific objectives

- To assess the physicochemical properties (texture, flavour, colour, pH, cation exchange capacity, electrical conductivity) of Earth materials consumed by humans and to ascertain the ability of these materials to protect geophagists against pathogenic infections in Vhembe District of Limpopo Province.

- To ascertain the prevalence of geophagic practice, the presumed reasons for consumption and distribution chain of Earth materials in Vhembe District.

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- To assess the bioavailability of essential macro nutrients in Earth materials with a view to confirm the nutrient supplementation hypothesis.

- To determine the role of consumed Earth materials in the transmission of geohelminth infections amongst female geophagists in Vhembe District.

1.6 Research questions

To proffer solutions to the research problem and general objective, the following research questions have been formulated to guide the study.

- **Degree of practice**: What is the degree of practice of geophagia amongst the women folk in Vhembe District?
- **Nutrient supplementation**: Are there essential macro and micro nutrients in Earth materials for geophagists' uptake?
- **Protection against toxins and detoxification**: Do chemical composition of these materials parallel those of other geophagic materials that are used in other places to serve medicinal purposes?
- **Health impacts**: What are the likely health problems that will arise from consumption of Earth materials?
- **Chemical and mineralogical composition**: What is the nature (chemical and mineralogical composition) of Earth materials in the area?

1.7 Justification for the study

There is a dearth of scientific data on soils and other Earth materials that are consumed in Vhembe District in South Africa. As such the topic deserves considerable attention, in view of the generally heavy loading of toxic elements in soils over large areas of disperse metalliferous mineralization in the country and the large number of people who practice geophagy (Davies and Mundalamo, 2010). Currently, very serious attention has been devoted to the study of geophagy in medical, geological and social sciences because of health issues arising from this practice (Gumbo, pers. comm.).

To date, the extent of research on geophagy in Vhembe District is relatively scarce, the quantities of Earth materials that are consumed on a daily basis per female geophagist and the implications of these ingested Earth materials on the health of the geophagist are still

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unknown. There is the need to assess the role of ingested soil in either supplying mineral nutrients such as Zn, Fe, Cu, Se or potentially harmful elements (PHEs) such as Pb or radio-nuclides, to geophagists.

One of the communiqué issued at East and Southern Africa Medical Geology caucus in Nairobi in 1979, embodied in Article 7 of their resolutions was: "There is great need to generate baseline data as well as effectively monitor the flow of nutritional and toxic trace elements in the environment that led to human exposure through the consumption of food, soils and water, especially the elements As, Pb, F, I and Zn" (Davies, 2004).

Also, the World Health Organization made a clarion call on developing countries to generate high resolution geochemical data which are adequate for environmental and epidemiological studies particularly in urban areas where conflicts between rapid development and environmental sustainability are severe and where surface, groundwater and soils are increasingly becoming contaminated (WHO, 1998).

Dissanayake (2005) identified geophagy as a worldwide practice providing a direct link between environmental geochemistry and human health. He urged researchers to answer several questions, including: Why do humans eat Earth materials? Could it be that the inorganic nutrients in Earth materials supplement our dietary intake of essential trace elements? Does the ingestion of soil cause detoxification of noxious or unpalatable compounds present in the diet? Do these soil elements alleviate gastrointestinal ailments? (Ferrell, 2008).

In view of the above, the present study on mineralogy and geochemistry of Earth materials is being undertaken to test the mineral supplementation and protection of geophagist from toxins and pathogens. It will also provide a baseline study of Earth materials that are consumed in Vhembe District. This study will provide important data that will help the medical community address environmental health problems arising from consumption of Earth materials.

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1.8 Significance of the study

The study will assess the role of ingested soils in supplying mineral nutrients such as Fe, Zn, Cu, Se or PHEs such as Pb and radio-nuclides to humans bearing in mind the mineralized rocks and soils in South Africa. Such assessment would be of utmost importance for epidemiological and risk assessment studies.

The study will also clear doubts about geophagic practice and prescribe for geophagist in Vhembe District, ways of practicing geophagy without having deleterious effects on human health. The study will provide geochemical data in Vhembe District for further studies based on the recommendations of this research, and health service providers in Vhembe District will use the results of this study to advice female geophagists on the benefits and demerits of consuming certain Earth materials in the area.

1.9. Scope of work

The scope of this research included the following:

- Detailed mapping and evaluation of Earth material features in the entire study area.
- Detailed geochemical investigation of Earth materials to assess and interpret any hazardous pollutants present.
- Estimation of the volume of Earth materials that are consumed on daily basis.
- Assessment of any potential impacts of geophagic practice on human health.

1.10 Structure of the Dissertation

This dissertation is organized into eight chapters.

- Chapter one introduces the background of the study, the research problems, objectives, justification and the significance of the research.
- Chapter two deals with the literature on mineralogy and geochemistry, and the implications of consuming Earth materials from several parts of the world. It also reviews the geology of the entire Vhembe District by reviewing the different rock types in relation to the ones that are consumed in the area.
- Chapter three reports on geophagy among women in Vhembe District.

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- Chapter four reports physical features and occurrence of beneficial bacteria in edible clays from Vhembe District.
- Chapter five documents a report on geophagy, anaemia and geohelminth infection amongst non-pregnant geophagic women in the locality.
- Chapter six reports on oral bioaccessibility of trace elements in consumed Earth materials from the locality.
- Chapter seven presents the mineralogy and geochemistry of consumed Earth materials in the District.
- Chapter eight presents the general conclusion and recommendation for further research work.

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CHAPTER TWO

LITERATURE REVIEW

2.1 Preamble

Researches carried out by Jones and Hanson (1985); Kruelen, (1985); Krishnamani et al., (2000); Abrahams and Parsons, (1996); Young et al., (2010) revealed that geophagy is a common practice throughout the animal kingdom.

The extent of these researches on mineralogy and geochemistry of Earth materials is limited. The literature review seeks to examine the role played by the mineral and chemical constituent in Earth materials in protecting geophagist against toxins, supplementing mineral nutrient intake of geophagist and health impacts that are likely to arise if geophagy is undertaken through consumption of Earth materials that are enriched in potentially harmful elements (PHEs) and other radio-nuclides. The literature reviews were based on two major hypotheses of geophagic practice. These are protection and mineral nutrient supplementation hypotheses. Potential health impacts associated with geophagy are also included in the review.

2.2 Protection hypothesis

Johns (1986) conducted a study on detoxification and mineral supplementation as functions of geophagy on four different geophagic clays consumed by Indian people from Bolivia, Peru and Arizona. These clays were dominated by interstratified illite-smectite, sometimes with subsidiary amounts of other clay minerals like kaolinite and chlorite. He was of the opinion that geophagia removes toxins from foods, and that it would enable consumption of wild potato species; this was the main reason for geophagic practice in these localities.

Eating clay with potatoes is thought to be effective in eliminating the bitterness of food, and in preventing stomach pains and vomiting. All the clays were effective in adsorbing the glycoalkaloid tomatine over a range of simulated physiological conditions. Tomatine adsorbtion capacities of the clays were usually intermediate between those of pure smectite and kaolinite, but for one clay it was significantly higher than smectite.

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Another classic example of the use of geophagic clays as food detoxifier was given by Johns and Duquette (1991a) in their study on the use of acorns to make bread by Indians in California and by natives of Sardinia. The clays are mainly composed of kaolinite with little amount of smectite. These clays were mixed with acorn meal to make them more palatable by reducing their bitter taste. They found that the clays used were able to reduce the tannic acid content of the acorn meal by up to 77%, thus providing a basis for their consumption. The researchers concluded that the clay functions through enhancement of palatability rather than as a detoxification agent. In addition, they suggested that the heating involved in the baking of bread might further enhance the tannic acid adsorption of the clays and could contribute to the catalytic activity of clay in decomposing tannic acid.

Johns and Duquette (1991b) examined the mineralogical composition of several geophagic clays from various African countries and found that their clay mineral content was dominated by kaolinite. These clays were mainly used to alleviate diarrhoea and sickness during pregnancy. Vermeer and Ferrel (1985) analysed the mineralogy of commercial geophagic clay from Nigeria and found that this clay is similar to kaolinite-based western medicines that are marketed for the purpose of alleviating gastrointestinal upset.

Young et al. (2010) carried out a detailed characterization of physical, chemical and mineralogical properties of eleven Earth materials that are being consumed in Zanzibar, Tanzania. They found that the textures of these soils are extremely diverse ranging from sand to clay.

All clay fractions are dominated by a kaolin type mineral, either kaolinite, halloysite or a mixture of both. The dominant type of kaolin mineral in the Zanzibar geophagic soils could be kaolinite, halloysite or kaolinite/smectite. This mineralogical similarity is consistent with the protection hypothesis, given that kaolin minerals have long been used in pharmaceutical formulations to treat both the causes and symptoms of gastrointestinal distress (Vermeer and Ferrel, 1985; Carreto, 2002).

The beneficial role of the kaolin minerals is based upon their ability to coat and adhere to the gastric and intestinal mucus membrane, thus protecting against toxins, bacteria and viruses, and adsorbing excess water in the faeces (Allen and Leonard, 1985; Leonard et al., 1994; Theodoru et al., 1994; Gonzalez et al., 2004).

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According to Young et al. (2010) geophagic soils of Pemba Island are diverse in colour, texture, major element chemistry and clay mineral content. The trace element content of the soils, whether of biological or non biological significance is uniformly low and the extent of bioavailability of those that are present is uncertain. Kaolin is the dominant clay mineral and the palliative, protective and detoxifying properties of kaolin lend support to the hypothesis that geophagia is a protective behaviour.

2.3 Mineral nutrient supplementation hypothesis

Abrahams and Parsons (1997) analysed the chemical composition of three Earth materials from Thailand, Uganda and Zaire to test the mineral nutrient supplementation hypothesis. These Earth materials were all reported as having low organic matter contents (0.2 - 28%) and clay contents of 15 – 28%. The cation exchange capacity (CEC) of these geophagic materials ranged from 10.9 - 28.8 meq/100g. The reported pH (in water) values for these soils vary widely, 4.4 for the Thailand soil, 6.8 for the Uganda soil and 9.4 for the Zaire soil. The Zaire soil contains high values for sodium and magnesium extractable by 0.1M HCl (3140 and 4100 mg/Kg respectively, which suggest the presence of soluble salts.

Abrahams (1997) expanded his earlier work on chemical analysis of Earth materials from Uganda, by sampling additional thirteen samples of Earth materials that are being sold in the market as medicines, to test their potential as nutritional supplements. All the soils had a high clay content, usually >50% and a moderately acid (pH 5) except for four samples which had a pH of 7.

The mineralogy of the samples was dominated by kaolinite, the CEC of these materials mostly ranged from 20 – 30 cmol/kg. These values are very high for kaolinitic material. He suggested that this might be due to the presence of interstratified smectitic material and noted that 7 of the 13 soil samples contained small amounts (<5%) of interstratified kaolinite-smectite. He concluded on the basis of geochemical analysis of one soil that the daily consumption of 5 g of this material was capable of contributing 19 - 25% of the daily recommended nutrient intake (RNI) of Fe while the bioavailability of Fe in all other soils examined as assessed by 0.1M HCl extraction, was exceedingly low.

Geissler et al. (1997) studied the prevalence of geophagy among schoolchildren and pregnant women in western Kenya. Over 70% of schoolchildren in Nyanza Province were found to

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consume soil at an average rate of 30 g dai[illegible] The eaten soils are gotten from termite nests, the edges of paths and gullies, weathered stones and the walls of huts.

Geissler et al. (1998a) in furtherance of their work on geophagy, iron status and anaemia among primary school children in western Kenya found that an average of 28 g of soil was eaten daily by geophagous children, which for iron could in principle supply 32% of the RNI for girls and 42% of the RNI for boys between the ages of 10 - 18 years. They were unable to come to any conclusion as to whether geophagy was a cause or a consequence of the incidence of anaemia and iron depletion in this group of children.

The consumption of soil may induce Fe deficiency because it makes the mineral element less bioavailable, because other soil components may impair Fe uptake or metabolism. On the other hand it is possible that anaemia or iron deficiency may induce a craving for soil (Wilson, 2003).

Geissler et al. (1998b) showed that geophagy is common among pregnant women on the coast of Kenya with 50% of a sample population indulging in the practice. The average daily intake of soil was sufficient to supply about 14% of the recommended dietary allowance of Fe for pregnant women. They found that geophageous women tended to be more anaemic and suffer more from Fe deficiency than non geophagous individuals. No conclusion could be drawn from their studies as to the major cause of this ill health.

Wiley and Katz (1998) studied the practice of geophagy among pregnant women in tropical Africa and noted that it was related to the need for Ca, mainly for pregnant women in non-dairy persons where there was a special need for Ca supplementation. Clay consumption may reduce the discomfort and loss of nutrients experienced during the early stages of pregnancy.

Aufreiter et al. (1997) studied the chemistry and mineralogy of geophagic soils from Zimbabwe, North Carolina, U.S.A and Hunan Province, China. Soils from Zimbabwe were from termite mounds and contained kaolinite as the main clay mineral. The amounts of Ca, Mg, K and Na that could be extracted by weak acid (pH 2) treatment were low, as were the amounts of most other nutrient elements. The American samples were from a clay rich sub soil. They were all dominated by halloysite and contained low amounts of Ca. The Chinese samples were from an unknown site, but they are dominated by smectite. Filtrate after acid extraction procedure could be obtained from only one sample in which the concentrations of nutrient elements were relatively low. They concluded that the results were in consonance

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with the sole aim of the consumers. The soils from Zimbabwe were consumed primarily to alleviate incidence of diarrhoea, those of North Carolina, U.S.A was for multipurpose use - food, nutrient supplementation and psychological reasons; while the Chinese eat Earth materials as famine food.

Mahaney et al. (2000) studied the chemistry and mineralogy of soils consumed by humans in Indonesia. Three of these geophagic soils were compared with two controls that were not eaten. The soils were derived either from volcanic material of an andesitic composition or from weathered Neogene sediments. Soils were clay rich, usually containing over 70% clay and low in organic matter. Soil pH values varied from 6.0 – 8.1 for the non- eaten ones. Kaolinite and halloysite were major components of both the geophagic and control soils.

There were differences in chemical composition between the volcanic and sediment derived soils but few differences when comparing eaten and control soils within each group. Also, there was no difference in the capacity of the eaten soil and control soils to adsorb alkaloids. On the bases of Scanning Electron Microscope (SEM) examination of the sand fractions of the soils, they speculated that some of the mineral constituents may have a role in mineral or trace element supplementation, and that with the presence of marcasite, a sulphur bearing mineral may be important in treating endo-parasites.

2.4 Nutritional and health impacts

The impact of consuming Earth materials on human mineral nutrition and health are numerous. Johns (1986) records the important detoxification function of geophagy in the domestication of wild potato. Earth materials are consumed to treat gastrointestinal upsets such as dysentery and diarrhoea (Abrahams, 2005). Geophagy can equally supply Fe in amounts that can account for a major proportion of the recommended daily intake of Fe in some countries (Abrahams, 1997). An excessive intake of soil can potentially reduce the absorption of already bioavailable nutrients and death of an individual. Black slaves in the new world used to commit suicide by undertaking geophagy due to a firm belief that after death, they would return spiritually to their native home. It was reported that in 1687, approximately 50% of deaths among the slaves in Jamaica was attributable to this problem (Abraham, 2002). Very harsh measures which included the use of masks, iron gags and chaining to floors were introduced to try and control geophagy. One consequence of geophagia is that the amounts and balance of mineral nutrients within the individual will be

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affected. For example, Hooda et al. (2004) from their work on potential impact of soil ingestion on human mineral nutrition found out that instead of releasing mineral nutrients for potential absorption in the body (supplementation) the soils generally removed nutrients that were already bioavailable in the solution. The first group of tests, based on either the bulk soil nutrient contents or their partial extractions (Mahaney et al., 1996; Abrahams, 1997; Aufreiter et al., 1997) indicated that soil ingestion could release large amounts of nutrients for potential absorption in the body. Though, the total or partial extraction of soil nutrients does not provide conditions similar to those in the gastrointestinal tract where ingested soil can release mineral nutrients as well as act as a sink for them by retaining already available nutrients through adsorption. They affirmed that the use of strong or weak acids by previous workers to assess potential nutrient availability from soil ingestion was not reasonable, as such methods are effectively assuming that the soil cannot be a sink but only a source through dissolution and desorption reactions.

Recent methods developed by Ruby et al. (1996), Smith et al. (2000) represent a significant improvement compared to previously used procedures (Mahaney et al., 1996; Abrahams, 1997; Aufreiter et al., 1997). They concluded that despite soils being rich in mineral nutrients, soil ingestion, can potentially reduce the absorption of already bioavailable nutrients particularly micronutrients such as Fe, Cu and Zn exacerbating their deficiency among geophagists.

Gelfand et al. (1975) report on five cases of life-threatening hyperkalaemia caused by the absorption of large amounts of K from soils enriched in this element. Hypokalaemia and hypozincaemia have also been associated with geophagy (Abrahams, 2002; Ukaonu et al., 2003).

Davies and Mundalamo (2010) opined that eating of large quantities of soil by practicing geophagists expose them to potentially toxic trace elements in mineralized areas, that are associated with mineral extraction, or polluted urban environments, where levels of potentially toxic trace elements are high.

Growth retardation and delayed puberty is associated with Zn deficiency among geophagists in Turkey. Geophagy can be considered as an accelerating factor of Zn deficiency in people who have already a low Zn intake. In such cases, oral Zn treatment improves linear growth and sexual maturation in affected individuals. In terms of toxicity of elements via soil ingestion, most concern to date has been centred on Pb (Cavdar et al., 1980).

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In the mineralized mining province of Derbyshire (England), Barltrop et al. (1974) found that Pb contaminated soils may lead to increased absorption of the element in local village children aged 2 - 4 years, but to an extent that is unlikely to be of biological significance.

Further research in the same geographical area indicated that elevated levels of Pb are transferred to children by the soil dust-hand-mouth pathway, but this is not reflected in the blood Pb concentrations which are within normal UK ranges (Abrahams, 2002). The reason for this appears to be the chemical weathering of primary galena (PbS) to pyromorphite ($Pb_5(PO_4)_3Cl$), a stable soil-Pb mineral, with extremely low solubility that may contribute to low human bioavailability in these soils (Cotter-Howells and Thornton, 1991).

The potential hazard of Pb contaminated soil to geophagists has been emphasised not only in children, but also in adults (Abrahams, 2002). Children are of most concern, however with lead as neurotoxin being especially harmful to the developing brains and nervous systems of young people (Abrahams, 2002). Kutalek et al. (2010) suggested that geophagic soil samples can be highly contaminated with microbes and may contain high levels of Pb.

Kawai et al. (2009) examined the associations of geophagy with anaemia and helminth infection among 971 human immunodeficiency virus (HIV) positive pregnant women in Tanzania. They found that severe anaemia and red blood cell characteristics suggestive of Fe deficiency were strongly associated with the prevalence of geophagia. These authors (Kawai et al., 2009) further found that geophagia was associated with decreased haemoglobin concentration and a marginally increased risk of anaemia, and that soil consumption can physically damage the intestinal mucosa and reduce the absorption of nutrients. These possible mechanisms may explain the association between geophagy and the increased risk of anaemia in their study.

Ascaris lumbricoides infection was strongly associated with geophagy, but no significant associations were noted between geophagy and other helminth infections, including hookworm, *Trichuris trichiura* and *Strongyloides stercoralis* (Geissler et al., 1998a). *Ascaris lumbricoides* infection is less likely to cause anaemia or any other physiologic stimulus that may lead to craving, their cross-sectional association suggests that infection may be a consequence of soil consumption (Geissler et al., 1998a). According to Kawai et al. (2009) soil consumption is a common practice that is associated with an increased risk of anaemia and helminth infection among HIV infected pregnant women in Tanzania.

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Shinondo and Mwikuma (2009) from their work on geophagy, as a risk factor for helminth infections amongst pregnant women in Lusaka, Zambia found that, the types of soils ingested by geophagous pregnant women did not contain helminth ova. They emphasised the importance of a moist environment for geohelminth ova of *Ascaris lumbricoides* and *Trichuris trichuira* to survive and embryonate.

The soils ingested by the women were dried and some toasted, baked or smoked before ingestion, thereby rendering them unsuitable for the survival of ova, or the support of embryonated ova which are the infective stages. Unlike the conventional soil/clay consumption, geophagous people are very specific and particular about the type of soil they eat.

Shinondo and Mwikuma (2009) found that geophagical soils are commercially mined or excavated from known (and usually uncontaminated) sources at depth, rather than from the surface in Lusaka, Zambia. Parasitological findings from their work, proved that geophagy does not put pregnant women at risk for geohelminth infections (Shinondo and Mwikuma, 2009).

In Turkey, Fe deficiency anaemia has been linked to the consumption of clays (mainly sepiolite and montmorillonite) of high cation exchange capacity (Munnich et al., 1968), while in Jos-Plateau, Davies et al., (2008) have postulated that geophagy could be an important source of potentially harmful element (PHEs) since there is so much radiation counts of uranium and thorium in the Younger granite rocks of Nigeria. Geissler et al., (1998b; 1998c) has identified geophagy as a possible risk factor in the transmission of various geohelminth infections and also could be implicated in the development of Fe depletion and anaemia.

Further work by Saathoff et al. (2002) has identified geophagy as a risk factor for *Ascaris lumbricoides infection* and that it equally plays a role in the transmission of other parasitic infections like *toxocariasis* and *amoebiasis* amongst school children in Kwazulu Natal Province of South Africa.

Geopahgy can lead to *toxocaris* infection through the consumption of *Toxocara canis* (the common dog roundworm) or *T. canis* (cat roundworm) eggs. Following ingestion, the larvae are carried by the blood stream into different tissues and organs of the human host, causing a clinical syndrome of visceral larva migrans (VLM), characterized by inflammation and

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eosinophilic granulomas. The other common human syndrome is ocular larvae migrans (OLM) induced by larvae penetrating into the eye (Magnaval et al., 2001).

In Slovak Republic, subclinical *toxocarosis* was estimated at 13.65%. (Havasiova et al., 1993., while in Italy, *T canis* eggs were found in 30% of soil samples (Genchi, 1976), Toxocaral disease can manifest with mild symptoms, the greatest burden falls on young children most likely because of geophagy (Abrahams, 2002).

Studies conducted in the United States of America showed that geophagy in early childhood is related to elevated, extreme and diagnosable problems of bulimia nervosa in adolescents, which suggests that geophagy may be a symptom of a more general tendency to indiscriminate or uncontrolled eating behaviours (Selinus, 2005).

A cohort study conducted in western Kenya on the role of geophagy and other risk factors for helminthiasis in pregnant and lactating women showed that geophagy significantly increased the risk of infection with *Ascaris lumbricoides* after antihelminth treatment (Wong et al., 1988; Ziegler, 1997; Shinondo and Mwikuma, 2009). Ozumba and Ozumba (2002) have attributed mycobacterial infection among children in Nigeria to geophagic practice while Abbey and Lombard, (1973) revealed that excessive tooth wear is a consequence of human geophagia.

2.5. Clay mineralogy

Clay minerals are secondary minerals derived from chemical alteration of mainly feldspars and micas (Table 2.1). They form an integral part of geophagic materials. They consist of layered silicates arranged in tetrahedral and octahedral sheets (Fig. 2.1).

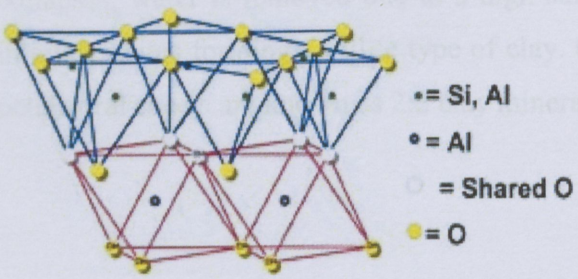

Figure 2.1: Single layered clay structure (Williams and Haydel, 2010)

These minerals consists of Si-O tetrahedra in which one silicon atom (Si^{4+}) is centred between four oxygen atoms, and Al-O octahedra in which one aluminium atom (Al^{3+}) is

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centred between six oxygen atoms ($-O^{2-}$) (O(H) molecules may also be included depending on mineral type). Clays that have one tetrahedral sheet and one octahedral sheet are known as 1:1 clay minerals. Examples are kaolin group – kaolinite, halloysite, dickite, nacrite (William and Haydel, 2010).

Clays that have two tetrahedral sheets and one octahedral sheet are known as 2:1 clay minerals. (Fig. 2.2)

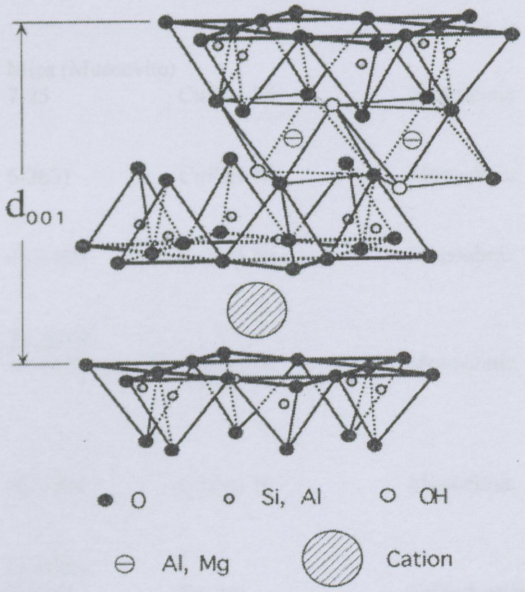

Figure 2.2: Double layered clay structure

Examples are smectite group – illite, smectite, montmorillonite. Within the smectite clays, cations are attracted to the negative surface of the silicate sheets, whereas anions are attracted to the positively charged sites where bonding takes place at the edges of the crystalline structure (Moore and Reynolds, 1997; Williams and Haydel, 2010). When the region collapses, water is removed due to a high surface charge attracting cations primarily K^+ to interlayer sites forming an illite type of clay. Clays that have two tetrahedral sheets and two octahedral sheets are known as 2:2 clay minerals e.g. chlorite.

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Table 2.1: Mineralogical data of diagnostic peaks for identification of minerals by XRD (After ICDD, 2001)

ICDD (2001)	*Radiation and filter*	*Crystal system*	*d-values (Å)*	*Intensity (%)*	*Miller indices*
Quartz					
46-1045	CuKα_1 Ge Mono	Hexagonal	4.26	16	(100)
			3.34	100	(101)
			1.82	13	(112)
Kaolinite					
29-1488	CuKα1 Ni	Monoclinic	7.1	100	(001)
			4.41	60b	(110)
			3.58	100	(002)
14-164	CuKα_1 Mono	Triclinic	7.17	100	(001)
			4.36	60	(110)
			3.57	80	(002)
Mica (Muscovite)					
7-25	CuKα1 Ni	Monoclinic	10.1	100	(001)
			4.49	90	(002)
			3.36	100	(003)
6-263)	CuKα1 Ni	Monoclinic	9.95	95	(002)
			3.32	100	(006)
			2.57	55	(224)
46-1409	CuKα1 Ni	Monoclinic	9.97	30	(002)
			3.32	100	(006)
			1.99	50	(224)
Smectite					
29-1499	CuKα1 Ni	Monoclinic	2.15	100	(001)
			4.45	55	(101)
			2.56	35	(107)
29-1498	CuKα1 Ni	Monoclinic	13.6	100	(001)
			4.46	60	(003)
			2.56	80	(100)
Goethite					
29-713	Co Kα	Orthorhombic	4.18	100	(110)
			2.69	35	(130)
			2.45	50	(111)
Feldspar(Microcline)					
19-932	CuKα_1 Mono	Triclinic	4.22	45	(201)
			3.29	50	(202)
			3.24	100	(040)
19-926	CuKα_1 Mono	Triclinic	4.22	100	(201)
			3.26	80	(130)
			3.25	100	(220)
Orthoclase					
31-966	CuKα_1 Mono	Monoclinic	4.22	70	(201)
			3.77	80	(130
			3.31	100	(220)

(Source: Ekosse and Jumbam, 2010)

2.6. Trace element geochemistry and human health

Two main groups of trace elements are of great importance to human health. Those that are essential to animal life like Fe, Mn, Cu, Zn, Cr, Mo, Se and F. The potentially harmful elements (PHEs) known to have adverse physiological significance at relatively low levels. These include As, Cd, Pb, Hg and some of the daughter products of U (Appleton et al., 1996). All trace elements are toxic if ingested or inhaled at sufficiently high levels for long enough period of time. Selenium, Fe, and Mo are examples of elements which show a relatively

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narrow concentration range in the order of microgram per litre (µg/l) between essential and toxic levels (Appleton, et al., 1996., Zhenli et al., 2005). A metal in trace amounts (smaller than 0.1% of the mass of the organism) is essential when an organism fails to grow or complete its life cycle in the absence of that metal. The same trace metal is toxic when concentrations exceed those required for correct nutritional response (Venogopal and Luckey, 1975). Researches concerning toxicity of trace metals follow the general trend that an under supply leads to a deficiency, sufficient supply results in optimum conditions, but an oversupply produces toxic effects, followed by lethality (Forstner and Witmann, 1981).

The rapid development and increase in mining and industrial activities have gradually redistributed many of the trace elements from the Earth's crust to the environment and has substantially raised the chances of human exposure to these elements through ingestion or skin contact (Okorie, 2010). There are several trace elements which are present in consumed Earth materials which are not needed for human growth, development and reproduction; and occur more or less constantly in living tissues. These elements are believed to be acquired by the body as environmental contaminants due to contact with the environment. Trace elements find their way into the human body by direct ingestion, absorption via air (inhaling) or drinking water or via food chain (inadvertent consumption). The most common PHEs listed by USEPA are As, Cd, Cr and Pb. These elements are not required by organisms at any concentration level (Dean et al., 2004).

The hazardous impacts of these elements are dependent upon the period of exposure, concentration and quantity of material used. The hazard imposed by PHEs within the consumed Earth materials is dependent on their availability for biological uptake. The degree to which a contaminant may dissociate from Earth materials and become available to human beings (bioaccessibility) is therefore a determining risk factor (Scott et al., 2004).

2.6.1 Sources of trace elements

Trace elements occur naturally in rocks, soils and ore in the form of minerals. There is a range of normal background values of these trace elements in soils, sediments, water and living organisms (Alloway and Ayres, 1997). The availability of these trace elements to terrestrial, aquatic and marine organisms is determined by the degree of solubilisation, release of elements from rock forming minerals, adsorption and precipitation reactions in soils and sediments. (Alloway and Ayres, 1997).

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2.6.2 Natural sources of trace elements

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The form in which trace elements occurs in rocks, soils, stream sediments or other Earth materials determines their chemical behaviour in response to the natural environment or to laboratory procedures. There are four main types of occurrence:

(a) As a major component of mineral such as Pb in anglesite ($PbSO_4$);

(b) As a trace constituent in the crystal structure of a well-crystallised mineral, such as Zn in magnetite;

(c) As a trace element in a poorly crystallised material, or occluded as a trace mineral in such a phase, or adsorbed on such a material and trapped by further precipitation, e.g. Co or Cu in Fe- Mn oxides;

(d) As a trace element adsorbed on the surface of a colloidal particle of Fe-Mn oxide or clay or organic material, or in exchange layer of a clay mineral.

Ore minerals undergo dissolution caused by chemical weathering leading to the release of metals or metalloids continuously into environment at various rates and concentrations from natural materials. When they get accumulated to a certain level on the Earth's surface, they can be released at a sufficient concentration to be considered pollutants such as As released from the weathering of arsenopyrite (Gerba, 1996).

Other processes which are important in relation to the behaviour of metals are those involving the translocation of soil constituent, leaching, eluviation, salinisation and calcification (Alloway, 1995).

Krauskopf (1967), Rose et al. (1997) and Alloway (1995) gave estimates of the level of concentrations of trace elements in igneous and sedimentary rocks also indicating common ore minerals and their associated metals (Table 2.2).

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Table 2.2: Mean heavy metal contents (mg/kg) of major rock types and their common ore minerals (Krauskopf, 1967; Rose et al., 1997; Alloway, 1995)

Heavy metals	*Earth's crust*	*Igneous rocks*			*Sedimentary rocks*			*Ore minerals*
		Ultra mafic	*Mafic*	*Granite*	*Limestone*	*Sandstone*	*Shales*	
Pd	14	14	3	24	5.7	10	23	Galena (PbS)
Zn	80	58	100	40	20	30	120	Sphalerite (ZnS)
Cu	50	15 (10-400)	90 (30-160)	15 (4-30)	5.5 (5-20)	15 (5-20)	60 (25-175)	Chalcopyrite $CuFeS_2$
As	1.5	1	1.5	1.5	1	1	13(1-900)	Arsenopyrite (FeAsS) (AsS) Realgar
Cr	100	1800 (1000-3400)	200 (40-600)	20 (2-90)	10 -	35 -	100 (26-100)	Chromite $FeCr_2O_4$

2.6.3 Anthropogenic sources of trace elements

Major anthropogenic sources of trace elements includes metalliferous mining and smelting, agricultural materials, sewage sludge, fossil fuels combustion, metallurgical industries, electronics, chemical and other manufacturing industries, waste disposal on the environment, warfare and military training (Alloway and Ayres, 1997; Fuge, 2005). Table 2.3 shows some of the industrial uses and anthropogenic sources of selected trace elements.

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Table 2.3: Industrial uses and anthropogenic uses of trace elements

Trace elements	*Industrial uses*
As	Pesticides/herbicides, glass and ceramic works, traditional medicine
Cd	Electroplating, storage batteries, stabilisers, solar cells, pigments, alloys for telegraph and telephone wires, photochemical and nuclear reactors.
Cr	Alloying additives to stainless steel, chrome plating, dyes, and pigments supplements in deficient pastures, intra uterine contraceptive devices.
Ni	Alloys for corrosion resistant equipment. Cooking utensils, coinage, heating elements, gas turbines, jet engines, electroplating, paints, pigments, batteries
Pb	Storage batteris, anti knock agent in petroleum/gasoline, paints, ammunition, glassware, ceramics, protection from radiation, bearing alloys, rubber industry, printing press
Zn	Galvanising of iron and steel for corrosion protection, alloys, vulcanisation of rubber, photocopying paper, paints and plastic industries, fertilizers and cosmetics

Source: After Alloway, 1995

2.7. Potentially harmful elements in Earth materials

A review of the occurrence in Earth materials, deficiency and toxicity of the most common potentially toxic elements (PTEs) in the environment is given below. Table 2.4, shows the toxicity of major toxic elements in geophagic clays.

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Table 2.4: Toxicity of major potentially toxic elements (PTEs) in Earth materials

PTE	Toxicity	Human toxicity	Zoo Toxicity	Phyto Toxicity
As	Various skin lesions appear (after several years of low arsenic exposure) hyper pigmentation, i.e dark spots, hypo pigmentation, i.e white spots and keratoses of the hands and feet. After a dozen or more years skin cancers are expected. Longer exposures may lead to cancers of the lungs, kidneys, liver and bladder	H	M	L
Cd	Nephropathy, pulmonary lesions and lung cancer	M	M	
Cr	Allergic contact dermatitis, possibly carcinogenic in some cases of workers being exposed, mostly because of Cr^{6+}	H	M	L
Cu	Copper is absorbed primarily from food. The toxicity for human is not very high.		H	M
Ni	The toxicity for humans is not very high, but it can cause respiratory diseases.			M
Pb	Lead can be very toxic for human health. For children: reduction in intellectual quotient, hyperactivity, hearing loss. For adults: increased blood pressure; liver, kidney and fertility damage	M	M	
Zn	Zinc deficiency may also be a problem for human health. At high doses Zinc may interfere with calcium metabolism and impair immune responses.			

Source: After Poggio et al., 2009; H = high; M = moderate; L = low.

2.7.1 Arsenic

Arsenic occurs in a wide variety of minerals mainly as AS_2O_3. It can be recovered from processing of ores containing Cu, Pb, and Zn, Ag and Au. It equally occurs in air ashes wherever coal is burnt. Natural release of arsenic on a global scale is estimated to be about 8 X 10^4 metric tons per year, whereas human activities account for about 24 X 10^4 metric tons of arsenic per year (Dara, 1993). Arsenic occurs in nature as arsenate (As^{5+}) and arsenite (As^{3-}). Arsenic may occur in Earth materials due to agricultural practices such as the

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applications of arsenic containing pesticides, herbicides and phosphate fertilizers raising concerns about the risks of arsenic to the environment and human health (Gregory et al., 1996; Feng et al., 2009).

As^{5+} and As^{3+} are the most common forms of As. In aerobic environment, As^{5+} is dominant, usually in the form of arsenate (AsO_4^{3-}) in various protonation states: H_3Aso_4, $H_2AsO_4^{3-}$, $HAsO^{2-}$, and AsO_4^{3-}. Arsenate and other anionic forms of As behave as chelates and can precipitate when metal cations are present (Bodek et al., 1998). As^{5+} is readily immobilized on soils and sediment particles by adsorption and co precipitation with oxides of Mn, Al and Fe under acidic and moderately reducing condition (Jung et al., 2009). Arsenate (As^{5+}) can also be mobilised under reducing conditions that encourage the formation of As^{3+}, under alkaline and saline conditions in the presence of other ions that compete for sorption sites and in the presence of organic compounds that form complexes with arsenic (Smith et al., 1995).

Elemental As and arsenine, AsH_3 may be present under extreme reducing conditions, sorption and co precipitation with hydrous Fe oxides are the most important removal mechanisms under most environmental conditions (Pierce and Moore, 1982; Krause and Ettel, 1989). Arsenic is a protoplasmic poison that affects the cardiovascular systems, gastro intestinal tract, kidney, nervous system, skin, blood and liver. Arsenic is stored mainly in the liver, kidney, lung and heart, arsenic readily crosses the placental barrier and causes foetal damage (Klassen, 1996). Anaemia, developmental disabilities, embryo toxicity, heart diseases, hyper pigmentation and peripheral neuropathies are some of typical human health effects that may be produced due to As toxicity (Asante-Duah, 1993). Small doses of inorganic arsenic induce mild vasodilatation, renal damage and encelophalopathy.

Long term exposure may cause myocardial damage, hypertension, milk and rose complexion (Klassen, 1996). The chronic ingestion of arsenic causes muscle weakness and aching, skin pigmentation (especially of the neck, eye lids, nipple and axillae), hyperkeratosis, oedema (Klasen, 1996).

Humans exposed to As containing dust may suffer non-allergic contact dermatitis and conjunctivitis, whereas continued ingestion of As containing Earth materials may cause perforation of nasal septum and cancer in humans, which will ultimately lead to death (Dara, 1993).

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Tolerable daily intake and MDI indicates the quantity of Earth materials a geophagist is expected to take in a day without running the risk of being harmed. These values have been used to assess the potential health risks to a geophagist. Arsenic is a non threshold carcinogen. Tolerable daily intake is inappropriate and as such an IDoral has been proposed of 0.3µgbw/day (Environment Agency, 2010). The oral index dose on assumed body weight of 10 kg geophagy is 3 µg/day and MDI 5µg/day based on 20 kg geophagy (Environment Agency, 2010).

2.7.2 Chromium

Chromium occurs as a yellow coloured dichromate salt under alkaline contion.. It is mined as chromate; $FeCr_2O_4$ (Smith et al., 1995). Major sources of Cr contamination include releases from electroplating processes and the disposal of Cr containing wastes (Smith et al., 1995). Chromium exists in the environment in two stable oxidation states, Cr^{6+} and Cr^{3+}, which have different toxicity and transport characteristics.

Chromium oxidation state of 6^+ is the form of Cr that is normally found in contaminated Earth materials (Cynthia and David, 1997). Hexavalent Cr, Cr^{6+} typically exists as the oxy-anion chromate (CrO_4) and dichromate (CrO_7^{2-}) precipitate readily in the presence of metal cations such as Ba^{2+}, Pb^{2+} and Ag^+.

Chromate and dichromate also adsorb on soil surfaces especially Fe_2O_3 and Al_2O_3. The hexavalent Cr has a high solubility in soils (pH > 8) and waters; it tends to be mobile in this environment. It is acutely toxic subject to biological uptake and also carcinogenic (Bienchi and Levi, 1987). Chronic exposure to hexavalent chromium is reported to induce renal failure, anaemia, haemolysis and liver failure.

Chromium oxidation state of 3^+ is the dominant form of chromium at low pH (< 4). Chromium in oxidation state of 3^+ has limited hydroxinite solubility and forms strong complexes with ions such NH_4^-, Cl^-, F^- CN^-, SO_4^- making it relatively immobile and less available for biological uptake. Cr^{3+} is an essential trace element to humans and shortages may cause heart failure, disruption of metabolism and diabetes. Uptake of excess Cr^{3+} can cause skin rashes (Okorie, 2010).

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The tolerable daily intake for Cr^{3+} based on a 10 kg geophagic baby is 50 µg/day for soluble compounds and 50 000 µg/day for metallic and insoluble compounds (Ljung et al., 2006). The mean daily intake for Cr^{3+} is 60.2 µg/day and 6.7 µg/day for Cr^{6+} (Nathanial et al., 2009).

2.7.3 Cadmium

Cadmium occurs naturally in the form of CdS or carbonates (Cd or $CdCO_3$). It is recovered as by product from mining of sulphide ores of Pb, Zn and Cu. Sources of Cd contamination include plating operations and the disposal of Cd containing wastes (Cynthia and David, 1997). The most common form of Cd include Cd^{2+}, $CdCN^-$ complexes or $Cd(OH)_2$ solid sludge (Smith et al., 1995).

The chemistry of Cd in Earth materials is controlled by the pH. Under acidic conditions, Cd solubility increases and very little of Cd is adsorped by soil colloids. At pH values greater than 6, Cd is absorbed by the soil solid phase or is precipitated and the concentration of Cd is greatly reduced.

Cadmium forms soluble complexes with inorganic and organic ligands, in particular chloride. The formation of these complexes will increase the mobility of Cd in Earth materials. Hydroxide and carbonate of Cd solids dominate at high pH (> 8). Cadmium will also precipitate in the presence of phosphate, arsenate, chromate and other anions.

Cadmium salts with low solubility includes cadmium phosphate ($Cd_3(PO_4)_2$, cadmium sulphide (CdS), cadmium hydroxide ($Cd(OH)_2$) and carbonate ($CdCO_3$). The solubility of these cadmium salts will increase with decreasing pH

When excess cadmium is ingested, it causes acute bronchitis and inflammation in the liver (McFarland, 1979). High blood pressure or hypertension has been attributed to Cd toxicity; some hypertensive patients have been found having elevated amounts of Cd in their kidneys and arterial walls (Venugopal, 1978; Ademoroti, 1996).

The tolerable daily intake for Cd based Earth materials on a geophagy 10 kg child is 5 µg/day (Ljung et al., 2006). Mean daily intake is 28.7 µg/day based on 20 kg body weight of geophagist (Nathaniel et al., 2009).

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2.7.4 Copper

Copper occurs naturally in the environment and is distributed through natural phenomena (wind blown dust, decaying vegetation and sea spray) and human activities (mining, metal production, wood production and phosphate fertilizer production and iron and steel production). Copper is mined as a primary ore product from Cu sulphide and oxide ores. Mining activities are the major source of Cu contamination. Copper can be found in many kinds of food, in drinking water and in air; as a result of we absorb some quantities of Cu each day by eating, drinking and breathing. The absorption of Cu is necessary, because it is a trace element that is essential for human health. Soil chemistry strongly influences the speciation of Cu. The cupric ion Cu^{2+} and hydroxide complexes, $CuOH^{+}$ and $Cu(OH)_2$ are also commonly present. When Cu ends up in soil, it strongly attaches to organic matter and minerals over a wide range of pH values (Ljung et al., 2006). Copper does not break down in the environment and because of that it can accumulate in plants and animals when it is found in soils. Copper can interrupt the activity in soil as it negatively influences the activity of microorganisms and earth worms.

In anaerobic environment, when sulphide is present, CuS(s) will form. The cupric ion (Cu^{2+}) is the most toxic species of Cu. A dietary intake of 2 to 3 mg of Cu is recommended for human adults. Copper is mainly absorbed from the duodenum in man and its retention depends upon the chemical form in which the metal is ingested. Ingestion of 15 to 75 mg of copper a day causes gastrointestinal disorders. Continuous ingestion of copper from food and water may cause chronic Cu poisoning and a disease called heptolenticular degeneration or Wilson's disease may develop (Dara, 1993). In addition excessive intake of Cu may cause hemolysis and nephrotoxic effects. Other conditions which manifest increased Cu contents in the liver include thalassema, cirrhosis, tuberculosis and carcinoma (Dara, 1993).

Impairment of the ability to absorb copper resulting in its deficiency is called Marike's disease (Krishan, 1995). Acute inhalation of copper dust or fumes at concentration of 0.075 – 0.12 mg/m^3 may cause metal fume fever with symptoms such as cough, chills and muscle ache (Yasir et al., 2009).

The tolerable daily intake for copper based on a 10 kg child is 1400 mg/day (Ljung et al., 2006) and for mean daily intake 1000 µg/day based on a 20 kg child (Nathanail et al., 2009).

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2.7.5 Lead

The primary sources of Pb contamination include metal smelting and processing, Pb battery manufacturing, pigment and chemical manufacturing and Pb contaminated wastes. Lead released to groundwater, surface water and land usually in the form of elemental Pb, Pb oxides and hydroxides and Pb metal oxyanions complexes (Smith et al., 1995).

Lead occurs most commonly with an oxidation state of 0 or +2. Pb^{2+} is the more common and reactive form of Pb and forms mono nuclear and polynuclear oxides and hydroxides. Under most conditions Pb^{2+} and lead hydroxyl complexes are the most stable forms of Pb (Bodek et al., 1988; Cynthia and David, 1997).

Low solubility compounds are formed by complexation with both inorganic ligands (Cl^-, CO_3^{2-}, SO_4^{2-}, PO_4^{3}) and organic ligands (humic, amino acids and ethylene di tetra acetic acid (EDTA) (Bodek et al., 1988).

Lead carbonate form above pH 6 and PbS is the most stable solid when high sulphide concentrations are present under reducing conditions. Most Pb that is released to the environment is retained in Earth materials (Evans, 1989). The primary processes influencing the fate of Pb in soil include adsorption, ion exchange, precipitation and complexation with sorbed organic matter. These processes limit the amount of Pb that can be transported into the surface water or groundwater. The overall human exposure to Pb is primarily from food. Lead has estimated daily intake ranges from 100 to over 500 µg of Pb (USEPA, 1979). The worldwide average for an adult is about 200 µg/day. The major routes of Pb absorption are the gastrointestinal tract and the respiratory system. Gastrointestinal absorption of Pb varies with age. Adults absorb approximately 10% of ingested Pb while children absorb upto 40%.

Lead can be very toxic to human health if large amount of the element is absorbed rapidly; a shock syndrome may develop due to loss of gastrointestinal fluids. An acute haemolytic crisis sometimes occurs and causes severe anaemia and heamoglobinuria. The kidneys are damaged and urinary changes are evident and death may occur in one or two days. Muscle weakness may develop due to acute Pb poisoning.

The haematological effect of chronic Pb intoxification is microcytic anaemia. The renal chronic toxicity occurs in two forms – a reversible renal tubular disorder and acute irreversible intestinal nephropathy (Goyer, 1985). Other signs and symptoms of plumbism are

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an ashen colour of the face and pallor of the eyes, appearance of premature aging with stooped posture, poor muscle tone, emaciation and a black or greyish so called lead line along the gingwall margin (Klassen, 1996).

According to Todd et al. (1996), Pb can be mobilized from skeleton and deform bones which affects pregnancy, lactation, menopause and produces hyper-metabolic states. Lead mobilization during pregnancy is hazardous to the foetus. In children, it reduces intelligent quotient, hyper-activity and hearing loss. The tolerable daily intake for lead based on 10 kg child is 36 µg/day (Ljung et al., 2006).

2.7.6 Nickel

Nickel exists in oxidation state of +2. It also exists as certain compounds in which the oxidation state of the metal is between -1 and +4. It is used in stainless steel production, nickel cadmium-batteries, alloys and electroplating. Nickel is resistant to corrosion by air and water under ambient conditions and combines readily with other metals including Cr, Cu, Fe and Zn to form alloys (Kabeta-Pendias and Mukherjee, 2007). Nickel contamination may occur from emissions of metal, mining, smelting and refining operations, nickel plating and alloy manufacturing, land disposal of sludges and disposal of effluents. Nickel is found in the environment combined primarily with O or S as oxides or sulphides. Nickel is an essential micronutrient for some microorganisms and animals but not to plants. It is associated with the synthesis of vitamin B_{12}. It is toxic at higher concentrations (Dara, 1993).

A recommended daily dietary intake of Ni is about 300 – 600 µg per day. Only 1 – 10% of the dietary ingested Ni is absorbed (Dara, 1993). Nickel is a potent skin sensitizer (able to cause allergic reaction in humans) as many as 1 - 4% of men and 8 – 20% of women in the general population may be Ni sensitive (Environmental Agency, 2010).

Direct contact of Ni leads to skin rash which is the most common type of reaction to nickel exposure (Russell, 2005). Ingestion of nickel can cause skin reactions in previously sensitised individuals. The other main concern for oral exposure to Ni is its developmental toxicity potential, which has been observed in experimental animal studies (Environmental Agency, 2010). Other toxic effects of nickel observed following ingestion include chronic bronchitis, emphysema, reduced vital capacity and asthma.

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Nickel is present in a number of enzymes in plants and microorganisms. In humans, Ni influences Fe absorption and metabolisms and may be an essential component of the haemopoetic process.

The tolerable daily intake for Ni based on a 10 kg child is 500 µg/day (Ljung et al., 2006) and for mean daily intake 130 µg/day based on a 20 kg child (Environmental Agency, 2010).

2.7.7 Zinc

Zinc does not occur naturally in elemental form. It is an essential trace element which is present in soil and can be toxic when exposure exceeds physiological needs. Zinc is mainly used as a corrosion resistant coating for iron and steel (Cynthia and David, 1997).

Zinc oxide is used in the manufacture of paints, rubber, ceramic and many other products. The main source of exposure to Zn is from food. There might be oral exposure arising from working in industries where Zn is used as source of raw materials.

Zinc usually occurs in the +2 oxidation state and forms complexes with a number of anions, amino acids and organic acids. Zinc is one of the most mobile potentially harmful elements in Earth materials. At higher pH values, Zn can form carbonate and hydroxide complexes which control its solubility. Adsorptions to sediments or suspended solids, including hydrous Fe and Mn oxides. Clay minerals and organic matter are the primary hosts of Zn in aquatic environments.

At high doses, Zn may interfere with Ca metabolism and impair immune responses. The tolerable daily intake for Zn based on a 10 kg child is 5000 µg/day (Ljung et al., 2006) and for mean daily intake 2700 µg/day based on 20 kg child (Nathanial et al., 2009).

2.7.8 Manganese

Manganese occurs naturally in the Earth's crust. Commonly occurring minerals which contain manganese include manganite and rhodonite. It is found in solution as Mn^{2+} ion, which may be stabilized by complexation to humic acids. Manganese is introduced into the environment through burning of coal (Krishan, 1995).

Manganese is used in the manufacture of steel and Mn alloys. Manganese is also used in drying compounds such as vanishes and oils. A daily allowance of 2.5 – 5 mg of Mn is

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recommended for humans. Manganese acts as a cofactor in enzymatic reactions such as phosphorylation, synthesis of fatty acids and cholesterol.

Elevated levels of Mn in humans can cause anaemia, impaired growth and skeletal abnormalities. Manganese is considered to be one of least PHEs.

Some typical health effects that may develop in humans include cirrhosis, influenza (metal fume fever) and bronchitis (Asante-Duah, 1993). Chronic exposure to manganese causes manganese psychosis which is an irreversible brain disease characterized by uncontrollable laughter, euphoria, sexual excitement followed by impotency and speech disability (Dara, 1993).

2.7.9 Cobalt

Cobalt occurs in association with other metals such as Ni, Mn and As. It is a constituent of minerals such as cobalite and smeltite. The concentration of Co in Earth materials (sands, clays, and rocks), water and animals is relatively small. Cobalt is used as a component of several alloys, which includes steelite that is used for making very hard cutting tools. Cobalt is used in electroplating to provide a hard surface that is resistant to oxidation and as a blue colourant in pottery enamel and glass.

There is very little information about environmental status of Co and its health hazards. Excessive amount of Co in humans can cause nausea, haematological disorder, diarrhoea, bone deformation and low blood pressure. It could also cause vomiting, vision impairment, heart problems and thyroid damage. Chronic exposure to Co at higher concentration produces goitre (Krishan, 1995).

2.7.10 Selenium

Selenium occurs in pure elemental form as Se, Se dust, hydrogen selenide (H_2S), selenium (IV) oxide (SeO_2). Severity of the toxic effect of Se depends on the chemical form in which it is ingested. The elemental Se is not toxic because it is insoluble. Selenium dust is dangerous to the lungs while SeO_2 is a problem in the industrial area because it causes localised irritation to the eyes and pulmonary oedema (Ademoroti, 1996). Its deficient concentration in food is 0.04 µg/g while the toxic concentration is 4 µg/g.

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A lethal dose of the metal in food is 0.1 – 1 ppm (Ademoroti, 1996). The early symptoms of acute toxic effects of Se are sore throat, fever, vomiting, irritation to eyes and nose, gastrointestinal irritation and drop in blood pressure.

2.7.9.1 Moderating property of selenium

Selenium has a moderating influence on the toxicity of other heavy metals like As. There is a strong interaction between Se and the metals. The toxic metals are strongly bound to Se and they are unable to form bonds with sulphur or nitrogen in the human body system. The toxicity of As, Hg, Cd are modified or counteracted by Se (Venogopal and Luckey, 1978)

2.8 Use of oral bioaccessibility to assess risk of potentially harmful elements (PHEs)

Oral bioaccessibility can be determined by either *in vivo* or an *in vitro* method. The *in vivo* method requires direct tests with human or suitable animal models as a surrogate for humans. The use of humans for bioaccessibility testing is not feasible on ethical grounds (Okorie, 2010).

The routine use of animals is also challenging in terms of cost, time, facilities and ethical issues (Sohel et al., 2007). On these bases, *in vitro* method of measuring oral bioaccessibility has been developed.

The principle underlying *in vitro* methods is that up take of a contaminant depends on the rate and extent of its dissolution in the gut (Sohel et al., 2007). There are different types of *in vitro* models. The *in vitro* bioaccessibility mimics the digestive systems of human by using reagents/enzymes.

The digestive systems of humans consist of the mouth, stomach and small intestine. The mouth compartment of the digestive system in most of the *in vitro* methods is omitted because of the short residence time the contaminant spends in the mouth. The stomach and the small intestine are therefore the major compartments of the system and where the contaminants spend most of the time, hence the definition of oral bioaccessibility as the fraction that is soluble in the gastrointestinal environment and available for absorption (Paustenbach, 2000).

The major problems facing *in vitro* method are the issues of validation, reproducibility and robustness for regulatory acceptance in risk assessment. At present, none of the *in vitro*

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methods has been approved by regulators in South Africa and other major countries like United Kingdom and Canada.

The physiologically based extraction test, which is batch based focuses on digestion characteristics as a method of separation, was used in this work. This method is still undergoing a unification process and it is anticipated that it should provide a standard method that will produce a conservative estimate of the oral bioaccessible fraction of trace elements from Earth materials, to be used in human health risk assessment.

In vitro bioaccessibility testing should be validated with *in vivo* method. No consumed Earth materials in South Africa have undergone *in vivo* testing; hence the true or acceptable bioaccessibility values of the trace elements in Earth material consumed in South Africa are still unknown.

Sialleli et al. (2010) used physiologically based extraction test to obtain information on potential human bioaccessibility of metals in urban soils from the city of Glasgow, UK. Chromium, Fe and Cu showed higher bioaccessibility under intestinal conditions, whilst Pb and Zn were markedly soluble in the stomach phase extractant.

Ljung et al. 2007 investigated the bioaccessibility of As, Cd, Cr, Ni and Pb in two particle size fractions (< 4mm and < 50μm) of playground soils from Uppsala, Sweden to assess the likely hazard arising from both deliberate and accidental ingestion of soil by children. Variations in bioaccessibility between the chemical elements were concluded to be attributable to differences in origin, sorption behaviour and pH dependence (Sialleli et al., 2010; Abraham, 2011).

A study conducted by Morman et al. (2009) to assess the bioaccessibility of As, Cd, Cr, Ni and Pb from background soils collected from a north south traverse across Canada and USA, revealed that the bioaccessible concentrations of Cd, Ni and Pb appeared to be controlled to some extent by the total soil concentrations of these chemical elements and in general the leachates results for the < 2mm size fraction were not substantially different from those ones determined from particle size of < 256μm.

Kikouma et al. (2009) found that Cu, Fe^{3+} and Zn were more efficiently released from edible clays in the low pH of a simulated gastric solution (pH approximate 1.8), although an exception was found for ferrous Fe where extractable concentrations were similar for both the stomach and intestinal phases (pH approximate 8.3).

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Hooda et al. (2004) determined the potential impact of geophagia on the bioaccessibility of selected macro nutrients (Ca and Mg) and micro-nutrients (Cu, Mn, Fe and Zn). They showed the sorption potential of soils in lowering the bioaccessibility of Fe and Zn. The calcareous soils investigated in Hooda et al's. 2004 study released significant amounts of bioaccessible Ca. Subsequent research reported by these authors again indicated that ingested soils can reduce the absorption of some mineral nutrients (Cu, Fe and Zn). Some soils may become a source of Ca, Mg and Mn. Though, it was not clear why similar soils should not release these three essential chemical elements (Hooda et al., 2004; Abrahams, 2011).

2.9. Solid phase partitioning

The manner in which an element is bound to the soil components or other environmental solids influences the mobility, bioavailability and toxicity of the element to organisms (Bacon and Davidson, 2008). Potentially harmful elements and their cations can occur in many geochemical forms; free or complexed ions in Earth materials solution, ions held to charged surfaces and metal hydroxides and carbonates (Rule, 1998).

Potentially harmful elements may be associated with Fe and Mn oxides, Al hydroxides can be bound within organic matter and also can be incorporated into sulphides and bound within lattice structure of soil.

Some potentially toxic elements are weakly bound to the solid phase hence have greater potential to be extracted i.e. available. The release of these PHEs from solid phase depends on the strength of the reagents used in the process. Normally reagents are targeted to remove the analyte of interest in the specific phase either by exchange processes or through dissolution of the target phase. The solid phase partitioning depends greatly on soil pH and organic matter content (Bacon, 2008).

2.10 Identified gaps in knowledge

Studies on geophagic practice as a tool for providing useful supplements of nutrient minerals and protection of geophagist against toxins and pathogens were based on total elemental and mineral analyses. These analyses may be form the determination of major nutrients, often with a variety of trace elements, many of which have no known physiological function. Such information is of no importance even when supplemented by analyses using sophisticated

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instrumental techniques, such as electron probe analysis of selected mineral grains or X-ray photoelectron spectroscopy (Wilson, 2003).

It is necessary to assess the potential bioavailability of the nutrient minerals in Earth materials under conditions approaching geophagist's digestive tract. Abrahams, (1997) and Aufreiter et al., (1997) did this by extracting with 0.1M HCl or with acid ammonium oxalate at pH 2. These analyses suggested that some geophagic materials are capable of supplying useful amounts of certain nutrient elements, particularly Ca and Fe but Smith et al., (2000) pointed out that these extractions do not take into account changes in Eh/pH conditions.

Smith et al. (2000) developed a PBET in their study of bioavailability of essential and toxic elements from geophagic materials consumed by humans in Uganda. This method simulated gastric solution under different redox conditions and involved a cocktail of pepsin, and various organic acids adjusted to pH 2 by using 1% HCl. Research by Smith et al. (2000) concluded that the geophagic materials in question could provide a major portion of the recommended nutrient intake of iron, but are inadequate as supplements for other nutrient elements.

There are scientific data to support the protection hypothesis, detoxification or the enhancement of palatability of foodstuffs containing undesirable elements like tannins, alleviation of gastrointestinal upsets such as diarrhoea and mineral nutrient supplementation-Fe, Ca, Se and Zn. These hypotheses would have been strengthened if mineralogy and geochemistry of the consumed Earth materials had been fully characterised.

More information is necessary with regard to (a) the nature of the constituent kaolin minerals by using recognized supplementary test like distinguishing halloysite from kaoloinite. This is done through the rapid formation of intercalation complex with forma-mide (Churchman et al., 1984); (b) the occurrence of interstratified kaoloinite-smectite, if this could be the reason for the high CECs of geophagic soils/clays and (c) the nature of the smectitic mineral particularly the occurrence and extent of inter-stratification with layer silicates or inter-layering with non exchangeable hydroxyl aluminium, as this relates to the ability of the clay to adsorb potential toxins.

The issue of mineral nutrient supplementation was based on total element geochemical analyses of geophagic materials. Only a reliable physiological based extraction test such as

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the one designed by Smith et al., (2000) would support any firm conclusions regarding the potentialities for mineral supplementation.

The amounts of Earth materials consumed need to be specified. Previous works have made calculations based on amounts reported from other studies, even if those works were conducted in another country several years ago (Hunter, 1973). These are gaps in knowledge which need to be urgently addressed to make the practice much safer to the practitioners.

In the light of the above, this study will use PBET to determine the bioavailability of essential trace elements in Earth materials that are being consumed in the study area by way of carrying out *in vivo* studies. Earth materials will be purchased from local stores in Vhembe District, markets and from geophagic mining sites for geophagist to take the amount they consume per meal, for the researcher to get accurate knowledge of the amount of Earth materials being consumed per day.

Earth materials are the world's oldest form of traditional medicines and it is still used in some continents till date to treat stomach upsets. Medicinal property of Earth material is shown in the stomach where clay minerals will release certain elements that they hold by cation exchange to adsorb pathogens and toxins in the gut lumen of the geophagist. Previous studies have been vague in the characterisation of their mineralogy. For example, halloysite and kaolinite are identified specifically as the main clay minerals in the Earth materials consumed by humans (Aufreiter et al., 1997; Mahaney et al., 2000), although Wilson, (2003) concluded that the identification of the clay minerals in these studies was ambiguous.

In this study, this researcher will use Churchman et al. (1984) criterion to distinguish halloysite from kaolinite through rapid formation of an intercalation complex with formamide. The protection hypothesis of Earth materials being consumed will be tested based on the types of clay minerals that are present in the materials. X–ray diffraction (XRD) analysis of these materials will reveal the various types of clay minerals that are present in the materials and through this, it will be possible to test the hypothesis that geophagia can protect human beings against toxins and pathogens.

In summary, microbiological examination of Earth materials and blood samples would be used as proxies in determining the association of geophagy with worm infection and anaemia, which are possible health impacts of geophagic practice. These tests will confirm the health

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status of geophagists if soil ingestion is of b[illegible] terms of nutrient supplementation, most especially for Fe.

2.11 Geology of Vhembe District

2.11.1 Geological evolution

Vhembe District lies within the Soutpansberg depositional basin, which was formed as an east-west trending half-graben along the Palala shear belt. This belt formed between two major crustal blocks, i.e. the Kaapvaal craton in the south and Limpopo belt in the north (Brandl, 1987). The basin rests unconformably on Archean granulite gneisses as well as on the Blouberg Formation and possibly also the Mogalakwena Formation of the Waterberg Group (Barker, 1979).

Deposition started with basaltic lavas and was followed by the deposition of sedimentary rocks. After an erosional period, pink massive quartzite was deposited; this covered a much larger area than original rift (Brandl, 1987). The eastern and most of the northern margin in the Soutpansberg rocks are unconformably overlain by rocks of the Karoo Supergroup. After sedimentation had ceased, the area was strongly block-faulted and then uniformly tilted to the north. During the last 60 million years, erosion formed the landscape as we see it today. The pink resistant quartzite was instrumental in shaping the present morphology (Brandl, 1987).

2.11.2 Local geology of the area

The entire Vhembe District is made up of a diverse group of rocks, ranging from igneous to metamorphic and sedimentary. The geology is typified by a succession of mudstone, sandstone, siltstone and shale horizons of Karoo sediments. At the base of this succession is the Archean granulite gneiss, which was overlain by pink massive quartzite before the deposition of the Karoo sediments.

There are series of dolerite dykes around the present day Tshikondeni coal mine, most of which are strongly discordant with the sedimentary succession (Taylor and Kruger, 1986). Also there are sills of diabase in the area; the sills were mainly emplaced along the interface of shale and competent quartzite. Some of the diabase intrusions are probably synchronous with Soutpansberg volcanism of basalts and basaltic andesites (Barker, 1979).

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2.11.3 Rock stratigraphic units

The Soutpansberg Group rocks gave rise to a mountainous wedge-shaped terrain, which extends from the Kruger National Park in the east, where it is 40 km wide, to Blouberg in the west. The Soutpansberg rocks rest unconformably on gneisses of the Limpopo Belt and Bandelierkop Complex. The Group represents a volcano-sedimentary succession which is subdivided into seven Formations (Fig. 2.1), namely, Tshifhefhe, Sibasa, Fundudzi, Wylie's Poort, Nzhelele, Stayt and Mabiligwe respectively (Brandl, 1987).

- ***Tshifhefhe Formation***

The Tshifhefhe Formation consists of basal discontinuous beds of only a few metres thick. It is made up of strongly epidotised clastic sediments, which includes shale, greywacke and conglomerate (Brandl, 1987).

- ***Sibasa Formation***

The Sibasa Formation is a dominantly volcanic succession with rare discontinuous intercalations of clastic sediments, having a maximum thickness of about 3000 m (Barker, 1979). The volcanics comprise of basalts, which were sub-aerially extruded, and minor pyroclastic rocks. The basalts are amygdaloidal, massive and generally epidotised (Barker, 1979). The clastic sediments which include quartzite, shale and minor conglomerate reach a maximum thickness of 400 m (Fig. 2.1).

- ***Fundudzi Formation***

This Formation is developed only in the eastern Soutpansberg and wedges out towards the west. It is up to 1900 m thick and consists mainly of arenaceous and argillaceous sediments with a few thin pyroclastic horizons. Near the top of the succession, about 50 m thick layers of epidotised basaltic lava are intercalated with the sediments (Barker, 1979; Brandl, 1999).

- ***Wylie's Poort Formation***

This is an entirely clastic succession, reaching a maximum thickness of 1500 m (Fig. 2.1). The Formation overlies, from east to west, progressively older units; its lower contact is interpreted to form a regional unconformity (Cheney et al., 1990; Brandl, 1999). Resistant pink quartzite and sandstone with minor pebble washes dominate the succession, with prominent agate conglomerate developed at the base (Brandl, 1999).

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- ***Nzhelele Formation***

This Formation consists of a 400 m thick volcanic assemblage (Musekwa Member) at the base, followed by red argillaceous and by arenaceous sediments. Maximum preserved thickness is of the order of 1000 m. The volcanics consist of basaltic lava and several thin, though fairly consistent horizons of pyroclastic rocks of which one is copper-bearing (Brandl, 1987).

- ***Stayt Formation***

Stayt Formation has a maximum thickness of 1800 m. Basaltic lava is developed at the base, followed by argillaceous sediments with thin interbeds of pyroclastic rocks. An agate conglomerate and a pink quartzite cap the sequence (Barker, 1979).

- ***Mabiligwe Formation***

This Formation has a thickness of about 50 m, which is entirely made up of a clastic succession with no development of any volcanics except for a thin tuffaceous horizon (Barker, 1979; Brandl, 1987).

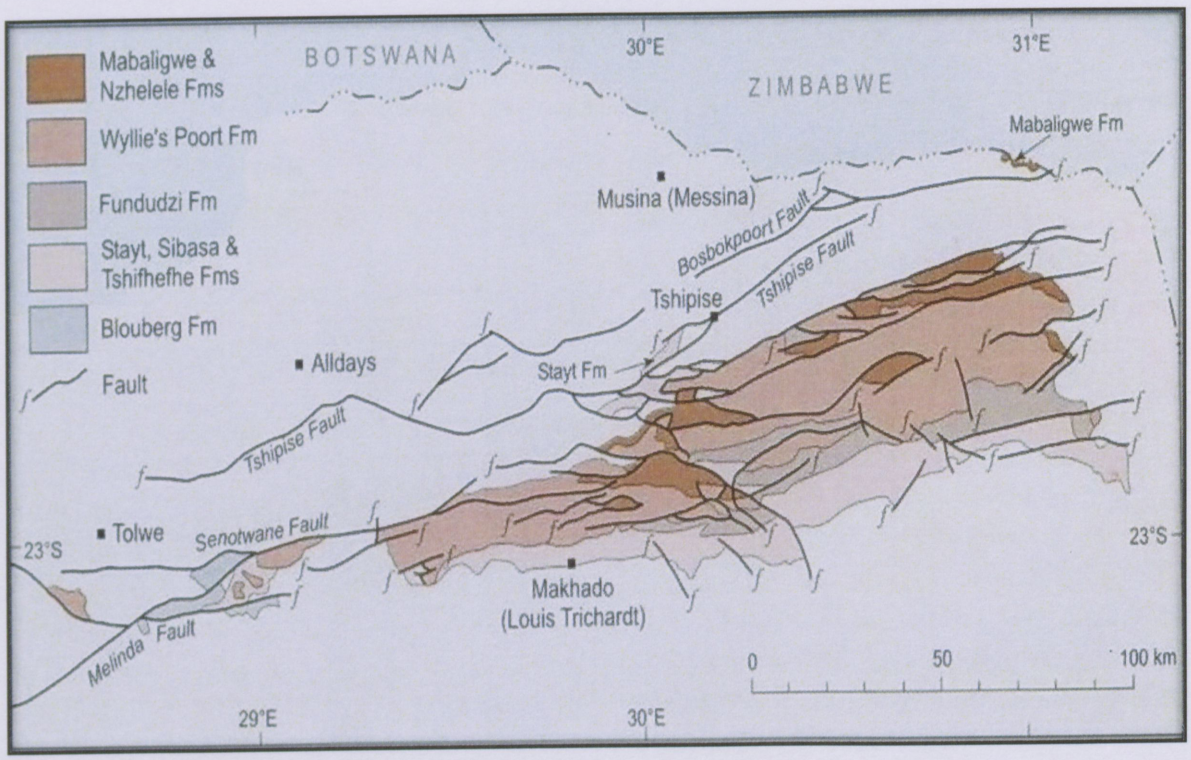

Figure 2.1: Stratigraphy and strucural setting of Soutpansberg (After Barker, 1983)

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2.11.4 Structural geology and Age

Two fault systems are recognized in the area, the most prominent one trending ENE (parallel to the regional strike) and the other one NW to WNW. The majority of the faults are believed to have been initiated in Pre Karoo or even during Soutpansberg times, with most of the structures having been reactivated in Post-Karoo times. The Soutpansberg rocks are unfoliated, but are strongly fractured in some places (Brandl, 1987).

Rb-Sr whole rock ages obtained from volcanic rocks which were hydrothermally altered suggest that Soutpansberg Group was deposited sometime between 1974 and 1800 million years (Barton, 1979; Brandl, 1987).

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GEOPHAGY AMONG WOMEN IN VHEMBE DISTRICT, LIMPOPO PROVINCE, SOUTH AFRICA

Abstract

This study was aimed at determining the spatial distribution, causative reasons for geophagic practice, types of Earth material eaten, and amount of Earth material consumed on daily basis, as well as demographic and socio-economic characteristics of female geophagists and distribution chain of geophagic materials in Vhembe District. Purposive sampling technique was used to identify 438 women in the area who were geophagic. A simple frequency, analytical tool was used to analyse the data obtained from the questionnaires administered on these women. Women within the age group of 16 to 45 years were the major consumer of Earth materials. Forty six point three percent of the women are married; 45.4% were single, 4.3% were divorced and 3.2% were widowed. Majority of the women had Grade 12 certificate. They were mainly engaged in waged labour, petty trading with very few of them in the civil service. The women were from all income groups in the District. The main reasons they gave for geophagic practice are medicinal, quelling of nauseate feelings, and for religious purposes. The preferred type of Earth material was soft stone (21.5%) and clay (20.5%). Preferences for these Earth materials were based on their colours, taste, flavours and texture. The mean daily intake of Earth material for pregnant women was 90 g, while mean daily intake for non-pregnant women ranged from 40 to 60 g. The geophagic materials were either bought in the local market or mined from the neighbourhoods. The study revealed high prevalence of geophagic practice amongst women of diverse ethnicity. Hunger was not considered as a major reason for geophagic practice in this locality.

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3.1. Introduction

Geophagy or geophagia is deliberate or inadvertent ingestion of Earth materials (clays, sands, ant hills, termite mounds and dried up pond sediments) by human beings and other members of the animal kingdom. The practice cuts across the globe, including Americas, the British Isles, Europe and Africa (Brand et al., 2009; Perridge et al., 2011). The habit is prevalent in sub-Sahara Africa and has also been documented in the following countries; South Africa, Swaziland; Nigeria, Zambia, Tanzania; Ghana; Uganda; Malawi; Zimbabwe and Cameroon (Abrahams, 1997; Nchito et al., 2004; Ekosse et al., 2010).

Human beings indulge in geophagic practice for wide varieties of reasons. Some of the reasons given for people's crave for Earth materials are the following: acting as an agent to counteract diarrhoea (Krishnamani and Mahaney, 2000); to supplement intake of available Cu, Ca, Zn and Mg by rural communities (Mills, 1996; Davies, 2008); to reduce abdominal pain caused by heart burn and nausea (Hunter and de Klein, 1984; Ekosse et al., 2011); in the treatment of dysentery and cholera amongst the Chagga women of Tanzania (Knudsen, 2002; Ngole et al., 2010).

According to Wilson (2003), three main reasons were advanced to explain geophagic practice; these are, hunger, micronutrient deficiency and protection from toxins and pathogens. Geophagic practice is motivated by an attempt to mitigate the harmful effects of plant chemicals or microbes (Johns, 1986., Profet, 1992). It was proposed that geophagic soils protect by either adsorbing pathogens or toxins within the gut lumen or coating the surface of intestinal endothelium thereby rendering it less permeable to toxins and pathogens (Young et al., 2010).

Childhood and pregnancy are the periods when geophagic practice would occur most (Flaxman and Sherman, 2000). Pregnant women, whose immune systems are low, may also need protection from substances that would normally be harmless (Fessler, 2002).

Eating of Earth materials (geophagy) could lead to some serious health problems in man, like mechanical bowel disorder and nutritional dwarfism (Keay et al., 1982). Severe abdominal pain, obstruction and perforation of the colon may result following the internal accumulation of soil (Abrahams, 2002).

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Geophagic behaviour has been widely reported in parts of South Africa namely; Thabo Mofutsanyane District, Free State; Eastern Cape Province; Qwa-Qwa and Manguang areas in Central South Africa (de Jager and Ekosse, 2011; Sumbele et al., 2011; Perridge et al., 2011). It has not yet been reported for Vhembe District in Limpopo Province of South Africa prior to this study.

3.2. Objectives of the study

The main objectives of this study were to determine the prevalence of geophagic practice amongst pregnant and non pregnant women in the area. The specific objectives were:

1. To decipher the various reasons for human beings to indulge in geophagic practice.
2. To ascertain the types, amount of Earth materials consumed and preferences for these Earth materials.
3. To determine the demographic and socio-economic characteristics of female geophagists in this locality.
4. To determine the distribution chain for these geophagic materials.

3.3. Subjects and methods

3.3.1. Study area and population

The study was conducted in four Municipalities, namely; Thulamela, Musina, Makhado and Mutale that make up the entire Vhembe District in Limpopo Province. Majority of the resident population are the Vendas, with other residents been Tsonga, Pedi, Zulus and Ndebele from Zimbabwe. The total population of the District is 1.2 million of whom women form about 55% (Amidou, 2007).

The study population was limited to female geophagists that attended local clinics and hospitals during the period of study. The heads, staff members and female geophagists were briefed about the objectives of the study. The participating women gave their consent before investigations were undertaken.

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Permission to conduct the study was granted by the Health, Safety and Research Ethics Committee, University of Venda (Appendix B) and Ethical Committee in the Health and Social Welfare Department of Limpopo Provincial Government (Appendix C).

3.3.2. Methods

A questionnaire was developed to obtain information from women geophagists in the District (Appendix A). The questionnaires were administered to the women in selected communities across the District. Information regarding spatial age distribution of geophagic women, extent and practices, demographic data of individuals who practice geophagia and their economic profiles were obtained. The questionnaire covered aspects of personal information on female geophagists, causative reasons and distribution chain of geophagic materials.

At recruitment, subjects were confirmed as geophagic practitioners by nurses attached to the Ante-natal care and Out Patient Consultation Units of the selected hospitals and clinics in the District.

Questionnaires were administered after the women had signed the consent form (Appendix D). After an introductory group discussion about human consumption of Earth materials by women as outline by Geissler et al., (1997), all recruited women were interviewed individually in a secluded area by a trained field assistant using the questionnaire. The interviews were conducted in the native languages (Venda, Sotho, Tsonga and Ndebele) of the District. After the interview, the women were asked to estimate their daily intake of the Earth material they consume, by picking an appropriate amount from Earth sample provided by the researcher. This was then weighed at the laboratory of the Department of Mining and Environmental Geology, University of Venda.

A total of 438 subjects were selected for the study and interviewed using the questionnaire. Purposive sampling technique was used to identify individuals who were geophagic in the selected hospitals and clinics for interview. This method of sampling is used in special situations where the sampling is done with a specific purpose in mind. The research is about the attitude of pregnant and non-pregnant women involved in the act of

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eating Earth materials. A simple statistical analytical tool, frequency of occurrence was used to interpret the data obtained from the questionnaires.

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3.4. Results

3.4.1 Demographic information of the respondents

The study participants were recruited from urban (settlement with high population density) and rural (an area with large amount of land with significantly lower populations than urban and suburban areas) sectors of Vhembe District in Limpopo Province of South Africa. Table 3.1 showed the demographic details of all the respondents in the sampled population. Of the 438 women that participated in the study, 45(10.3%) were from Sibasa, 6(1.4%) were from Malamulele, 124(28.3%) were from Thohoyandou, 89(20.3%) were from Makhado, 27(6.2%) were from Musina, 72(16.3%) were from Mutale, 47(10.7%) were from Elim, 25(5.7%) were from Tshakhuma and 3(0.7%) were from Dzanini.

Table 3.1: Demographic information of the respondents

Town	*Sex*	*Total Frequency*	*%*
Sibasa	F	45	10.3
Malamulele	F	6	1.4
Thohoyandou	F	124	28.3
Makhado	F	89	20.3
Musina	F	27	6.2
Mutale	F	72	16.3
Elim	F	47	10.7
Tshakhuma	F	25	5.7
Dzanini	F	3	0.7
Total		438	100

3.4.2 Population density of the respondents

This section presents information on the population density of the respondents. It indicated population of respondents from rural, urban and sub-urban areas. As shown in Table 3.2, 349(79.7%) of the respondents were from the rural population, 30(6.8%) were from the urban population, and 59(13.5%) from the sub-urban population (area with populations smaller than urban area).

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Table 3.2: Population density of the respondents

Town	*Rural*	*Urban*	*Sub-urban*	*Total frequency*	*%*
Sibasa	22	-	23	45	10.3
Malamulele	6	-	-	6	1.4
Thohoyandou	90	29	5	124	28.3
Makhado	88	1	-	89	20.3
Musina	8	-	19	27	6.2
Mutale	66	-	6	72	16.3
Elim	46	-	1	47	10.7
Tshakhuma	20	-	5	25	5.7
Dzanani	3	-	-	3	0.7
Total	349(79.7%)	30(6.8%)	59(13.5%)	438	100%

3.4.3 Tribe of the respondent

The tribe of each respondent is shown in Table 3.3. Three hundred and sixty two (82.6%) of the participants were Venda, 33(7.5%) were Tsonga, 19(4.3%) were Pedi, 2(0.5%) were Zulu, 8(1.8%) were Shona, 1(0.2%) were Xhosa, 4(0.9%) were Swati, 2(0.5%) were Sotho, while 1(0.2%) was Ndebele. Six respondents (1.4%) were from other countries (Nigeria, Ghana and Zimbabwe) resident in Vhembe District.

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Table 3.3: Tribe of the respondent

Tribes	*Sibasa*	*Malam*	*Thohoyandou*	*Makha*	*Masina*	*Mutale*	*Elim*	*Tshak*	*Dzana*	*Total Frequency*	*%*
Venda	41	1	111	79	14	69	19	25	3	362	82.6
Tsonga	2	4	3	1	4	2	17	-	-	33	7.5
Pedi	1	-	5	5	3	1	4	-	-	19	4.3
Zulu	1	1	-	-	-	-	-	-	-	2	0.5
Shona	-	-	1	2	4	-	1	-	-	8	1.8
Xhosa	-	-	-	1	-	-	-	-	-	1	0.2
Swati	-	-	4	-	-	-	-	-	-	4	0.9
Sotho	-	-	-	1	-	-	1	-	-	2	0.5
Ndebele	-	-	-	-	1	-	-	-	-	1	0.2
Foreigners	-	-	-	-	1	-	5	-	-	6	1.4
Total	45	6	124	89	27	72	47	25	3	438	100%

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3.4.4. Age, occupation and educational qualification of the respondents

The age, occupation and educational qualification of respondents are shown in Table 3.4. The number of participants with ages between1-9 was 1(0.2), those between ages 10-19 were 80(18.3%), those between ages 20-29, 186(42.5%), those between ages with 30-39 were 95(21.7%), those between 40-49, 46(10.5%), and 50-59, 17(3.9%), while participants age 60 and above were 5(1.1%) and 8(1.8%) are the respondents with no answer in this section. The next is the occupation category which showed that 159(36.3%) of respondents were students, 37(8.4%) were farmers, 93(21.2%) were wage laborers, 85(19.4%) were traders, 51(11.6%) were house wives, while 13(2.9%) represents others, a category of many occupation. The last column in this table is the educational qualification category which shows that 79(18.0%) were university graduates or under-graduates, 41(9.4%) were college graduates, 225(51.4%) were secondary school goers, 49(11.3%) were primary school children, while 34(7.8%) had no educational qualification. Ten respondents (2.3%) had no answer to the questions in this section.

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Table 3.4: Ages, occupation and educational qualification of the respondents

Respondents categories	*Age category*	*Total freq.*	*%*	*Respondents categories*	*Occupation category*	*Total Freq.*	*%*
Female	1-9	1	0.2	Female	School	159	36.3
Female	10-19	80	18.3	Female	Farming	37	8.4
Female	20-29	186	42.5	Female	Wage labor	93	21.2
Female	30-39	95	21.7	Female	Trading	85	19.4
Female	40-49	46	10.5	Female	At home	51	11.6
Female	50-59	17	3.9	Female	Other	13	2.9
Female	60/above	5	1.1				
Female	N/A	8	1.8				
Totals		438	100%			438	100%

Education level	*University*	*College*	*Secondary*	*Primary*	*None*	*N/A*	*Total freq.*	*%*
Total	79	41	225	49	34	10	438	75%
100%	18.0	9.4	51.4	11.2	7.8	2.3	438	100%

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3.4.5 Family economic performance

Information on family economic performance of the participants is shown in Table 3.5. The table shows that 252(57.5%) of the respondents were subsistence farmers, 83(18.3%) were middle income earners, 32(7.3%) were grant receivers, while 60(13.7%) were classed as affluent members of the District. Eleven (2.5%) were participants not willing to disclose their economic status.

Table 3.5: Family economic performance of the respondents

Family economic performance	*Total frequency*	*%*
Subsistence	252	57.5
Middle income	83	18.9
Grant	32	7.3
Affluent	60	13.7
N/A	11	2.5
Total	438	100%

3.4.6 Marital status of the respondents

Table 3.6 shows that 203(46.3%) of the participants were married, 199(45.4%) of the respondents were single, 19(4.3%) were divorced from their marriage, while 14(3.2%) were widowed.

Table 3.6: Marital status of the respondents

Marital status	*Total frequency*	*%*
Married	203	46.3
Single	199	45.4
Divorced	19	4.3
Widow	14	3.2
Total	438	100%

3.4.7 Number of previous pregnancy

The number of previous pregnancy of respondents is reflected in Table 3.7. The Table shows that 254(60%) of the participants had 1-3 previous pregnancies, 63(14.3%) of the respondents had 4-6 previous pregnancies, 3(0.7%) had 7-9 previous pregnancies and 1(0.2%) represents only 10-13 previous pregnancies. 112(25.6%) respondents had no

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record of previous pregnancy. 5(1.1%) of the participants provided no answer to this question.

Table 3.7: Number of previous pregnancies of the respondents

No. of pregnancy	*Total frequency*	*%*
1-3	254	60.0
4-6	63	14.3
7-9	3	0.7
10-13	1	0.2
None	112	25.6
N/R	5	1.1
Total	438	100%

3.4.8 Stage of pregnancy of the respondents

Information on stage of pregnancy of the respondents is shown in Table 3.8. The Table shows that 112(25.6%) of the respondents had never been pregnant, 96(21.9%) of the participants gave no answer, 116(26.5%) were less than a month pregnant, while those with pregnancy 2 months and above numbered 114(26.0%).

Table 3.8: Pregnancy stage of the respondents

Stage of pregnancy	*Total frequency*	*%*
None	112	25.6
N/R	96	21.9
Less than a month	116	26.5
2 months and above	114	26.0
Total	438	100%

3.4.9 Religion of the respondents

Religion of the respondents is presented in Table 3.9. The table shows that 409(93.3%) were Christian, 15(3.4%) of the respondents have no religion, 9(2.1%) practiced African Traditional Religion, while 5(1.1%) of the respondents provided no answer to this question.

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Table 3.9: Religion of the respondents

Religion	*Total frequency*	*%*
Christianity	409	93.3
None	15	3.4
African Tradition	9	2.1
N/A	5	1.1
Total	438	100%

3.4.10 Favourite food of the respondents

The favourite food of the respondent is presented in Table 3.10. Thirty nine (8.9%) of the respondents liked starchy food, 109(24.9%) liked pap (a smooth maize meal porridge), 27(6.2%) of the participants preferred vegetable, 43(9.8%) liked all types of food, 98(22.4%) of the participants favorite food was rice and meat, 7(1.6%) liked Earth material, 28(6.4%) said their best food was bread and tea, 21(4.8%) choosed snacks as their favourite food, 11(2.5%) liked potatoes and fish, 15(3.4%) liked egg and chips, 7(1.6%) liked the material from termite mounds, 17(3.9%) of the participants preferred cereals, while 8(1.8%) had no answer to the question in this section.

Table 3.10: Favourite food of the respondents

Type of food preferred	*Total frequency*	*%*
Starch food	39	8.9
Pap food	109	24.9
Vegetable	27	6.2
All types of food	43	9.8
Rice and meat	98	22.4
Anthills	7	1.6
Bread & tea	28	6.4
Snacks	21	4.8
Junk food (potatoes and fish)	11	2.5
Fatty food (egg and chips)	15	3.4
Termite mound	7	1.6
Cereals	17	3.9
N/A	8	1.8
Total	438	100%

3.4.11. Types of consumed Earth materials

Different types of Earth materials were being consumed by the respondents. From Table 3.11, 45(10.3%) consumed anthill, 94(21.5%) ate soft stone, 89(20.3%) consumed clay,

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33(7.5%) ate wall scraping, 70(16.0%) ate sand, 65(14.9%) ate termite mound, while 42(9.6%) gave no answer to the question in this section.

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Table 3.11: Different types of Earth material consumed by the respondents

Earth material	*Total frequency*	*%*
Anthill	45	10.3
Soft stone	94	21.5
Clay	89	20.3
Wall scraping	33	7.5
Sand	70	16.0
Termite mound	65	14.9
N/A	42	9.6
Total	438	100%

3.4.12. Volition to eat Earth material

This section presents information on respondents' perception towards their consumption of Earth materials, namely on whether it was done on their own volition or they were encouraged by someone. From Table 3.12, it is seen that 189(43.2%) of the participants were encouraged to eat Earth material by someone, while 244(55.7%) said they were not encouraged to eat earth and 5(1.1%) gave no answer to question in this section.

Table 3.12: Responses on encouragement to eat Earth material

Encouraged by someone to eat Earth material	*Total frequency*	*%*
Yes	189	43.2
No	244	55.7
N/A	5	1.1
Total	438	100%

3.4.13. Who Encouraged geophagists to eat Earth material?

This section presents information on how geophagists get encouragement to practice geophagy. Table 3.13 shows that 11(5.8%) of the participants were encouraged by friends, 8(4.2%) were encouraged by cousins, 46(24.3%) were encouraged by their mothers, 30(15.9%) of the respondents practice geophagy to quell early morning sickness during pregnancy, 9(4.8%) were encouraged by their sisters, 15(7.9%) got attracted to eating Earth materials due to the sweet smell it gives out when it rains, 36(19.1%) of the respondents were encouraged to eat Earth materials by their aunt's, 21(11.1%) were

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encouraged by both mothers and aunts, while 13(6.9%) gave no answer to questions in this section.

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Table 3.13: Who encouraged geophagists to eat Earth materials?

Yes, encouraged by:	*Total frequency*	*%*
Friends	11	5.8
Cousin	8	4.2
Mother	46	24.3
Pregnancy	30	15.9
Sister	9	4.8
Sweet smell of Earth	15	7.9
Aunt	36	19.1
Both mothers and Aunt	21	11.1
N/R	13	6.9
Total	189	100%

3.4.14 Respondents still consuming Earth material

Respondents that are still eating Earth material are shown in Table 3.14. It shows that 338(77.2%) of the respondents were still eating Earth materials, while 100(33.8%) of the respondents had stopped practicing geophagy. The reason they gave for stopping geophagia were, lack of apetite, counselling from medical personnel in their locality on dangers of eating Earth materials and old age.

Table 3.14: Eating of Earth material at present

Eating of earth material at present	*Total frequency*	*%*
Yes (Still eating Earth)	338	77.2
No (Stopped geophagy practice)	100	22.8
Total	438	100%

3.4.15 Benefits derived from eating Earth material

The benefits each of the respondents derived from eating Earth material are shown in Table 3.15. The table shows that 89(20.3%) enjoyed a 'pleasant' flavour from eating Earth material, 199(45.4%) enjoyed a soothing taste, 38(8.7%) of the respondents held that the brownish to reddish colour served as a potential source of Fe, 21(4.8%) of the respondents said that they derived nice feelings from it, 35(8.0%) of the respondents derived a sense of satisfaction, 17(3.9%) respondents said that it lessens the burden of

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hunger at times, 31(7.1%) of the respondents derived nice smell from it, while 8(1.8%) of the respondents gave no answer to the questions in this section.

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Table 3.15: Benefits for eating Earth material

Benefits for eating Earth material	*Total frequency*	*%*
Flavor	89	20.3
Taste	199	45.4
Colour	38	8.7
Nice feelings	21	4.8
Sense of satisfaction	35	8.0
Lessening of hunger	17	3.9
Smell	31	7.1
N/R	8	1.8
Total	438	100%

3.4.16 Possession of Earth material

Respondents who had with them a sample of the Earth material are shown in Table 3.16. One hundred and fifty seven (35.8%) of the respondents had a sizeable amount of Earth material in their bags, 261(59.6%) had no sample of Earth material with them during the period of the interview and 20(4.6%) of the respondents gave no answer to the questions in this section.

Table 3.16: Possession of Earth material

Sample of Earth material preferred	*Total frequency*	*%*
Yes (Possess Earth material)	157	35.8
No (Not in possession of Earth material)	261	59.6
N/R	20	4.6
Total	438	100%

3.4.17 Foods eaten at breakfast

Meals eaten by respondents at breakfast are presented in Table 3.17. Two hundred and forty one (55.0%) of the respondents ate bread and tea as their breakfast when they are not eating Earth material, 48(11.0%) of the respondents eat cereals, 98(22.4%) of the respondents eat pap, while 51(11.6%) of the respondents eat soft porridge.

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Table 3.17: Foods eaten at breakfast

Normal meal (breakfast)	*Total frequency*	*%*
Bread & tea	241	55.0
Cereals	48	11.0
Pap	98	22.4
Soft porridge	51	11.6
Total	438	100%

3.4.18. Foods eaten at lunch

What the respondents eat as lunch when they are not eating Earth material is reflected in Table 3.18. This Table shows that 56(12.8%) of the respondents ate rice as lunch, 63(14.4%) of the respondents ate bread, 24(5.5%) of the respondents ate chips and meat, 210(47.9%) of the respondents ate pap as their lunch, 48(11.0%) of the respondents ate snacks, 18(4.1%) of the respondents ate fruits as their lunch, 18(4.1%) of the respondents ate porridge, while 11(2.5%) of the respondents gave no answer to the questions in this section.

Table 3.18: Foods eaten at lunch

Normal meal (lunch)	*Total frequency*	*%*
Rice	56	12.8
Bread	63	14.4
Chip & meat	24	5.5
Pap	210	47.9
Snacks	48	11.0
Fruits	18	4.1
Porridge	18	4.1
N/R	11	2.5
Total	438	100%

3.4.19. Foods eaten at dinner

As shown in Table 3.19, 22(5.0%) of the women ate porridge at dinner, 34(7.8%) of the women ate bread as their dinner, 319(72.8%) of the women ate pap, 54(12.3%) of the women ate rice, while 9(2.1%) of the women gave no answer to the question in this section.

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Table 3.19: Foods eaten at dinner

Meal (dinner)	*Total Frequency*	*%*
Porridge	22	5.0
Bread	34	7.8
pap	319	72.8
Rice	54	12.3
N/R	9	2.1
Total	438	100

3.4.20. Number of times Earth materials were consumed

Number of times Earth material was consumed by respondents is shown in Table 3.20. One hundred and twenty five (28.5%) of the respondents ate Earth material once a day, 209(47.7%) of the respondents ate Earth material several times a day, 85(19.4%) of the respondents ate Earth material once in a while, 17(3.9%) of the respondents hardly ever ate Earth material, while 2(0.5%) of the respondents gave no answer to questions in this section.

Table 3.20: Number of times Earth materials were consumed

Time of consumption	*Total frequency*	*%*
Once a day	125	28.5
Several times a day	209	47.7
Once in a while	85	19.4
Hardly ever	17	3.9
N/R	2	0.5
Total	438	100%

3.4.21 Amount of Earth material consumed per day

The amount of Earth material consumed by the women varies from one consumer to another. As shown in Table 3.21, 45(10.3%) of the respondents ate from 10-30 g per day, 51(11.6%) of the respondents consume 30-50 g, 75(17.1%) of the respondents ate 50 g-70 g, 68(15.5%) of the respondents ate 70-90 g, 111(25%) of the respondents ate 90-110 g, while 88(29.1%) of the respondents ate 110 g and above.

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Table 3.21: Quantity of Earth material consumed

Normal meal (lunch)	*Total frequency*	*%*
10-30 g	45	10.3
30-50 g	51	11.6
50-70 g	75	17.1
70-90 g	68	15.5
90-110 g	111	25.3
110 g and above	88	20.1
Total	438	100%

3.4.22. Undesirable effects noticed after consumption

Responses from the women on any noticeable effects after consuming Earth material are shown in Table 3.22. Forty seven (10.7%) of the women said they felt some undesirable effects after consumption, while 391(89.3%) of the women said they do not notice any feelings after consumption of Earth material.

Table 3.22: Undesirable effects noticed after consumption

Notice of undesirable effects after eating the Earth material	*Total frequency*	*%*
Noticed certain feelings (abdominal pain) on consumption	47	10.7
No feelings on consumption	391	89.3
Total	438	100%

3.4.23. Unavailability of Earth material when it was needed

There are instances when Earth material was needed by the women but may not be available for consumption (Table 3.23). Three hundred and sixty eight (84.0%) of the respondents said there were instances when they wanted to consume Earth material but was not available; 57(13.0%) said they always have it at hand when the need for consumption arose; 13(3.0%) of the respondents gave no answer to the questions in this section.

Table 3.23: Availability of Earth material when needed

Wanted to eat Earth material but not available	*Total frequency*	*%*
Lacked Earth material atimes	368	84.0
Always have Earth material for consumption	57	13.0
N/R	13	3.0
Total	438	100%

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3.4.24 Description of feelings when Earth material was not available for consumption

Description of respondent's feelings when Earth material was not available for consumption is given in Table 3.24. One hundred and six (28.8%) of the respondents have a strong craving whenever the Earth material was not available for consumption, 51(13.9%) of the respondents had mild craving, 21(5.7%) of the respondents felt like vomiting, 29(7.9%) of the respondents remained normal, 39(10.6%) of the respondents salivate, 27(7.3%) of the respondents would be sweating, 20(5.4%) of the respondents felt severe hunger, 51(13.9%) of the respondents felt depressed, 13(3.5%) of the respondents got confused, while 11(3.0%) of the respondents gave no answer to the question in this section.

Table 3.24: Geophagists' feelings when they had no access to Earth material

Feelings	*Total frequency*	*%*
Strong craving	106	28.8
Mild craving	51	13.9
Vomit	21	5.7
Normal	39	7.9
Salivating	39	10.6
Sweating	39	7.3
Hungry	20	5.4
Depressed	51	13.9
Confused	13	3.5
N/R	11	3.0
Total	368	100

3.4.25. Period of consumption

According to respondents, crave for Earth material was not restricted to any particular time of the day (Table 3.25). Ninety two (21.0%) of the respondents said they consumed Earth material before regular meal, 81(18.5%) ate Earth material after regular meal, 48(11.0%) consumed Earth material as part of regular meal, while 217(49.5%) ate Earth material at other times.

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Table 3.25: Times of consuming Earh material

Time	*Total frequency*	*%*
Before regular meal	92	21.0
After regular meal	81	18.5
Part of regular meal	48	11.0
At other times	217	49.5
Total	438	100%

3.4.26. Method of consumption

Method of Earth material consumption is shown in Table 3.26. Eighty seven (19.9%) of the respondents consume Earth material in powdered form, 265(60.5%) of the respondents ate it as chunk, while 86(19.6%) of the respondents consume it as chunk and powder.

Table 3.26: Method of Earth material consumption

Mode of eating earth	*Total frequency*	*%*
Powder	87	19.9
Chunk	265	60.5
Chunk & powder	86	19.6
Total	438	100%

3.4.27 Ways of obtaining Earth material

Ways by which Earth material is acquired is given in Table 3.27. Fifteen (3.4%) of the respondents obtained their Earth materials from friends, 5(1.1%) of the respondents obtained theirs from the field, 193(44.1%) of the participants obtained theirs from homes, 78(17.8%) of the respondents obtained Earth materials from the market, while 147(33.6%) of the respondents obtained them from homes and market.

Table 3.27: Where Earth material was obtained

How Earth material is obtained	*Total frequency*	*%*
Friends	15	3.4
Field	5	1.1
Dwelling home	193	44.1
Market	78	17.8
Dwelling home and market	147	33.6
Total	438	100%

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3.4.28 Location of Earth material

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Information on the exact location of Earth material is presented in Table 3.28. This table shows that 172(39.3%) of the respondents got their Earth materials from surface of the earth, 17(3.9%) of the respondents got theirs from dried up ponds and stream sediments, 109(24.9%) of the respondents obtained theirs from termite mounds, while 73(16.7%) of the respondents got theirs from local shops. Fifty one (11.6%) of the respondents got theirs from retail outlets and 16(3.7%) of the respondents got theirs from wall scrapings.

Table 3.28: Nature of Earth materials

Where the Earth material is obtained	*Total frequency*	*%*
Ground and surface	172	39.3
Dried up pond and stream	17	3.9
Termite mound	109	24.9
Stores	73	16.7
Market	51	11.6
Wall scrapings	16	3.7
Total	438	100%

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3.4.29. Accessibility to Earth materials

The ease of accessibility of Earth materials to geophagists is presented in Table 3.29. Three hundred and seventy five (85.6%) of the respondents said they can afford to buy Earth material on their own, while 46(10.3%) of the respondents said they cannot afford it regularly. Nineteen (4.3%) of the respondents gave no answer in this section.

Table 3.29: Capability of affording Earth material on a regular basis

Capability to afford Earth material regularly	*Total frequency*	*%*
Yes	375	85.6
No	46	10.5
N/R	19	4.3
Total	438	100%

3.4.30. Religious support

The influence of religion affiliation on perspectives on geophagia by the participants is given in Table 3.30. One hundred and eighty nine (43.2%) of the participants said they have the support of their religion. Two hundred and one (45.9%) of the participants said

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they do not have the support of their religion, and 48(11.0%) gave no answer in this section.

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Table 3.30: Religious support of geophagists

Religious support	*Total frequency*	*%*
Yes	189	43.2
No	201	45.9
N/R	48	11.0
Total	438	100%

3.4.31 Husbands' thoughts about eating Earth material

The thoughts of geophagic practitioners' husbands on eating of Earth material is shown in Table 3.31. Seventy two (16.4%) of respondents husbands disagree with the eating of Earth material by their wives, 264(60.5%) of respondents husbands did not bother about their wives geophagia habit, 21(4.8%) of respondents husbands supported their wives' geophagic behaviour, while 29(6.6%) of respondents husbands were unaware that their wives eat Earth material while 51(11.6%) the respondents gave no answer to the questions in this section.

Table 3.31: Husbands' perspectives on eating of Earth material

Husband thoughts on eating Earth material	*Total frequency*	*%*
Disagree	72	16.4
Not bother	265	60.5
Agrees	21	4.8
He does not know	29	6.6
N/R	51	11.6
Total	438	100%

3.4.32 Husbands participation on eating Earth material

Table 3.32 shows that 27(6.2%) of the respondents' husband ate Earth material, while 340(77.6%) of the respondents said their husbands do not eat Earth materials. Seventy one (16.2%) of the respondents gave no answer to the question in this section.

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Table 3.32: Husbands' participation in eating of Earth material

Husbands' participation in eating Earth material	*Total frequency*	*%*
Yes	27	6.2
No	340	77.6
N/R	71	16.2
Total	438	100%

3.4.33 Knowledge of friends, relatives and associates who ate Earth material

Knowledge of friends, relatives and associates who ate Earth material is shown in Table 3.33. Four hundred and one (91.6%) of the respondents said they knew of friends, relatives and associates who also ate Earth material, while 20(4.6%) of the respondents said they were not aware of friends, relatives and associates who eat Earth materials while 27(6.2%) of the respondents gave no answer to question in this section.

Table 3.33 Knowledge of friends, relatives and associates eating Earth material

Knowledge of others who eat earth material	*Total frequency*	*%*
Yes	401	91.6
No	20	4.6
N/R	27	6.2
Total	438	100%

3.4.34 Relatives overseas

Relatives of respondents eating Earth materials are given in Table 3.34. Seventeen (3.9%) of the respondents said they have relatives overseas who also ate Earth material. Four hundred and ten (93.6%) of the respondents said they do not have relatives overseas who eat Earth materials. Twenty one (4.5%) of the respondents gave no answer to the question in this section.

Table 3.34: Relatives of geophagists' resident overseas

Relatives resident overseas	*Total frequency*	*%*
Yes	17	3.9
No	410	93.6
N/R	21	4.5
Total	438	100%

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3.4.35. Methods used in sending Earth materials to relatives overseas

Methods used in sending Earth materials to relatives overseas are shown in Table 3.35. Eleven (64.7%) of the respondents said they send Earth materials to their relatives overseas through post offices, while 6(35.3%) of the respondents said they send Earth materials to their relatives through friends.

Table 3.35: Methods used in sending Earth materials

Send through	*Total frequency*	*%*
Post Office	11	64.7
Friends	6	35.3
Total	17	100%

3.4.1. To what extent is geophagia practiced by the womenfolk in Vhembe District?

The research found that geophagia is not limited to any particular age group, but it was more common amongst pregnant and women of child bearing age. Elderly women in the District (> 50 years) were also involved in the practice but the amount of material consumed is low. They consume an average of 10 g of Earth material a day.

According to Abrahams and Parsons (1996), the practice is most common amongst the world's poorer-or more tribally-oriented people. This research found that the affluent members of the society in the locality were equally involved in geophagic practice. The difference lies in the choice of geophagic material and in the local town from which the Earth materials were obtained. The high income earners prefer clay sold in the local markets, while the low income earners prefer soft stones, termite mounds and anthills from the wild.

3.5. Discussion

The study confirms the results of several other studies on geophagic practice (e.g., Walker et al., 2005; Peter, 2011). The health personnel at the various clinics and referral hospitals in the area attested to the fact that geophagy is widely practiced in the entire Limpopo Province (Dr Nkuna, pers.comm.)

The results on the determination of population density in Vhembe District were found to agree with those from similar investigations in the rural, urban and sub-urban areas of

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Kenya (Luoba et al., 2004). Majority of those eating Earth materials were from rural and sub-urban areas and very few were from urban areas (Peter, 2011). The pattern of consumption of Earth materials among older and younger women is similar to that found in Bondo District, western Kenya and other parts of East Africa (Prince et al., 1999; Luoba et al., 2004). It has also been reported that no difference exists in earth eating habits of women from United States of America with women from Vhembe District (Smulian et al., 1995).

Geophagy was common among lactating and women of child bearing age (≤ 45 years). The practice is mostly associated with pregnant women as noted by previous studies which had similar findings (Woywodt and Kiss, 2002; Prince et al., 1999). This is further corroborated by earlier reports from East Africa (Geissler et al., 1998) where it appears to be widely accepted as a common practice in pregnancy (Hunter and de Kleine, 1984).

Geophagic practice has been attributed to poverty, and to be most common in people of low socio economic status (Abrahams and Parsons, 1996; Peter, 2011). The results from this study do not support this notion as geophagic habits have been found to prevail among individuals in the high income group in Vhembe District. A similar trend was noted in Swaziland (Peter, 2011).

Their level of education was low; the majority of respondents had Grade 6 and Grade 12 certificates. This level of education attracts low income and as such their purchasing power is very limited. There were few female geophagists with tertiary educational qualifications and very few did not have formal education. These findings are consistent with literatures from East Africa and other parts of Southern Africa (Young et al., 2010; Peter, 2011).

Majority of the women agreed that geophagy is mostly associated with pregnancy, especially during the second trimester. This is consistent with findings from similar researches (Luoba et al., 2004; Kawai et al., 2009). Dietary intakes of most women are mainly cereal based rich in carbohydrate. These foods may not be able to provide the much needed mineral supplements such Fe and Ca thus providing evidence for one of the reasons being advanced for geophagic practice.

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Research by Bopape et al. (2008) on the prevalence of anaemia and selected micronutrient status in pregnant teenagers of Polokwane Municipality in Limpopo Province, South Africa revealed that most of the pregnancies ended in miscarriages, still births or that the children may have died in their infancy as a result of poor dietary intake associated with poor food choices or inadequate pre-pregnancy nutrient stores in the body. The dietary habits of these pregnant teenagers are similar to habits of women and children in Bondo District, western Kenya where the diets are mainly cereal based with few animal products (Mwaniki et al., 2002).

There are various types of Earth materials in Vhembe District. These Earth materials are similar to those eaten by school children in parts of East Africa, Nigeria, Ghana and parts of southern Africa (Geissler et al., 1997; Luoba et al., 2004; Peter, 2011). Female geophagists in Vhembe District ate more frequently Earth materials from soft stone followed by clay and fine sand, compared to pregnant women in Western Kenya who ate more frequently materials from termite mounds. The coastal women from Kenya ate soft stone probably because of the scarcity of termite mounds in the coastal areas (Geissler et al., 1998; Luoba et al., 2004).

Soft stones were more frequently consumed by the Vhembe women because of its availability in virtually all the communities and when it rains, the sweet smell emanating from it attracts them to eat more of it.

The hypothesis that geophagy is practiced to supplement micronutrients suggests that colour (brownish-reddish hue indicative of iron in geophagic materials) may act as a primary or secondary stimulus in this respect (Wilson, 2003; Young et al., 2010). Consumed Earth materials in Vhembe District show a variety of colours, ranging from grey, yellow, white and pale brown. Findings from this study support those of similar studies where it was found that selection of geophagic soil was not entirely based on colour (Young et al., 2010; Ngole et al., 2010).

Female geophagists said that clay would have been preferable to soft stone because it lasts longer in the mouth and it has a soothing taste, but because it was sold in the local markets and shops at a high price of R1 to R3 (US$0.13 to US$0.38) for a lump and the young women cannot afford to go to markets where it is sold regularly. They had no option but to consume soft stones around their homes.

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The price the women paid for buying a lump of Earth material was similar to the price paid for similar quantity of Earth material sold in other parts of Southern Africa (Peter, 2011). Some female geophagists in the District ate termite mound and anthill. They said that these Earth materials are friable and dissolve very fast in the mouth when they are chewed.

A relatively small percentage of the women ate Earth materials from wall scrappings in the study area. This observation is similar to the findings of studies by Geissler et al., (1998) and Luoba et al., (2004).

In the present study most female geophagists tend to adopt the practice of geophagy on their own without any encouragement from relatives or friends. It could be a copied behaviour as suggested by Nchito et al., (2004). Female geophagists tend to have more relatives practicing geophagy than female non-geophagists. Mothers, cousins, sisters and aunts of female geophagists in this locality were all engaged in geophagy. Findings from this study are consistent with results obtained in Swaziland and Zambia on similar study groups (Nchito et al., 2004; Peter, 2011).

Majority of the women in the present study stated that they were still consuming Earth materials in the District. In some of the communities visited, Vendors of geophagic materials attested to the high prevalence of geophagic practice in the area. Consistent with previous studies conducted in South Africa, geophagic practice is deeply rooted among several communities and cultures, not only in Africa but in all continents of the world (Young et al., 2008; Ngole et al., 2010; Ekosse et al., 2011).

Several benefits were given for consuming Earth materials. The main ones were quelling nauseate feelings due to the soothing taste of the consumed materials, general craving due to odour the Earth materials emit when it rains, reddish brown colouration giving "blood" to women who said they had little blood, sense of satisfaction and lessening of hunger in some cases. These findings parallel earlier findings from studies in the Southern African region (Ekosse and Ngole, 2012) and other parts of the world where geophagy is practiced (Saathoff et al., 2002; Kawai et al., 2009).

Geophagy was more prevalent amongst women who crave for Earth material due to its sweet flavor and soothing taste. These properties probably help to quell nauseat feelings and early morning sickness during pregnancy. The findings of Luoba et al. (2004)

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support those of this study with reference to the brownish – reddish colour and sense of satisfaction as some of the reasons for geophagic practice.

Female geophagists who ate Earth materials several times a day were more in number than those who ate it once a day. There are few other female geophagists' individuals who ate Earth material once in a while, most especially during pregnancy and times when they were suffering from diarrhoea and dysentery. Peter (2011) stated that female geophagists from Manzini and Hhoho in Swaziland ate Earth materials more than once a day as compared to those women who ate Earth materials once in a day. The amount of Earth materials consumed on a daily basis was similar to what was reported by other researchers (Geissler et al., 1997; 1998; Luoba et al., 2004). Pregnant women from the coastal region of Kenya ate an average of 41.5 g on a daily basis. Women from Sierra Leone ate about 40 – 80 g. Ghanaian women consumed 30 g per day and women from western Kenya consumed between 20 – 108 g of Earth in a day (Geissler et al., 1997).

Majority of the women from Vhembe District of South Africa did not notice any undesirable feelings after consumption of Earth materials, unlike Luo women in western Kenya who said geophagia had negative consequences like abdominal pains, heart burns and that it could bring worms but did not consider these to be serious health problems (Prince et al., 1999). The women said that they were advised by medical doctors to drink a lot of milk each time they eat the Earth materials so that they could defecate easily.

A middle aged woman of 35 years of age residing in one of the communities said she was diagnosed of Fe deficiency anaemia during her second pregnancy. She was advised by doctors to stop eating Earth materials. Two months after ending of geophagic practice, her anaemic condition was cured. Similar condition of Fe deficiency anaemia had been reported in United States of America (U.S.A.) of a Cameroonian resident in the U.S.A (von Garnier et al., 2008)

Most female geophagists interviewed in this study described their feelings when they do not have access to Earth materials, as strong craving, salivating and tendency to vomit. Some women will go out of their homes and pick sands from the back of their houses to quench their desire for geophagy. Similar findings were reported by other researchers (Ekosse et al., 2010). According to Peter (2011), Swazis felt a very strong craving for Earth materials when they do not have access to them.

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Method by which Earth materials were consumed by the women subjects in this study was mainly as dry chunk and powder. According to de Jager and Ekosse (2011), traditional healers administer geophagic clays to their patients in wet or dry forms together with other medicinal herbs.

Geophagists obtain their Earth materials from different places. Women in Vhembe obtain theirs mainly from their surroundings and markets. Female geophagists from Kenya, Tanzania, Ghana and Cameroon select soils from termitaria, wall scrapings and anthills (Geissler et al., 1998; Luoba et al., 2004; Young et al., 2010; Perridge et al., 2011).

Some religious organizations in the District support their Faithful's practice of consuming Earth materials. The findings on the support of religion affiliation of participants are in agreement with those in the study by Peter (2011) which showed that some female geophagists from Hhoho in Swaziland that worshipped in Zion church consume soil as a way of prophecy.

Practitioners of African Traditional Religion use geophagic clays for performing rituals and to chase away bad luck amongst their followers (Peter, 2011). Prince et al. (1999) stated that a number of husbands of female geophagists in western Kenya ate soil to alleviate diarrhoea and dysentery. The findings on husbands' participation in the eating of Earth materials correspond with the views of these researchers. Geophagy is prevalent in Vhembe District as virtually 91% of the participants agreed that they had knowledge of other women who were engaged in geophagic practice. According to Abrahams and Parsons (1996), geophagia is widespread in sub-Sahara Africa, particularly among pregnant women. There was a huge diversity in ethnicity of women in geophagic practice across Vhembe District. Soil consumption was highest among the Venda's, compared to Pedis, Sothos, Zulus and Tswanas.

Very few of the participants had relatives overseas who ate Earth materials. Eating of Earth materials is widely practiced in almost all the continents of the world including Africa, North America, Central America, South America, Europe and the Middle East (Woywodt and Kiss, 2002; Ekosse and Ngole, 2012).

Relations of these women geophagists may have taken over geophagic practice to other parts of the globe in cases where the practice was not there before they migrated to such

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places. This contradicts the view of Lauer (1930) who concluded that geophagic practice is not universal as it is unknown in some countries such as Japan, Korea and parts of Africa.

These Earth materials are sent to relative overseas mainly through the post office while others send them through friends that travel to countries where their relatives live. Earth material known as 'sikor' (baked clay) consumed by pregnant Bangladeshi women residing in United Kingdom is normally imported into that country (UK) through the post office (Al-Ramali et al., 2010). This method of sending Earth materials to relatives overseas is similar to the method used by senders in Vhembe District.

One of the Earth material vendors at Taxi rank, Elim market, a lady from Zimbabwe said her products originate from Zimbabwe. She travels on a monthly basis to buy her stock from Zimbabwe and transports the consignment to Elim using public transport.

3.6. Conclusion

Geophagy is widely practiced amongst young and old women in Vhembe District. Pregnant women are the main consumers of Earth materials because of the role Earth materials plays in quelling nauseat feelings and early morning sickness during pregnancy. Other reasons they gave for the practice of geophagy were medicinal, religious purpose and sense of satisfaction. The economic performance of these women mainly fell under the subsistence category, though there are some affluent members of the society that are involved in geophagic practice. Major diet of the women is cereal based supplemented with animal products like beef and chicken. Types of Earth materials consumed vary from one locality to the other but the most preferred type of Earth material is clay sold in the local market. Their preference for clay is based on its odour, texture and soothing taste in the mouth. These features were the reasons the women gave for clay being the most preferred of all the consumed Earth materials. Hunger was not a major reason for geophagic behaviour and as such the hunger hypothesis for geophagic practice is rejected in the case of geophagia practiced in Vhembe. The women in the urban centre obtain their Earth material from local shops and other retail outlets. Those in rural areas obtain their Earth material from the wild.

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PHYSICOCHEMICAL FEATURES AND OCCURRENCE OF BENEFICIAL BACTERIA IN EDIBLE CLAYS FROM VHEMBE DISTRICT, LIMPOPO PROVINCE, SOUTH AFRICA

Abstract

The focus of this study was to assess the physical features of edible clays as criteria for selection of geophagic clays and to evaluate occurrence of beneficial bacteria in edible clays that will safeguard geophagic practitioners from other pathogenic bacteria. Colour was determined by use of Munsell colour chart. Textural classes were determined by percent dry weight of different size classes. The pH and electrical conductivity were determined using a bench field Crison multimeter. Starch casein agar was used to determine the presence of *Streptomycete*. The clays showed forms of colours ranging from reddish yellow to dark grey through pink to various shades of brown and yellow. The pH values of clay range from 4.30 to 7.90. Values obtained for electrical conductivity and cation exchange capacity were generally low. Texturally, the clays are mainly smooth to sandy clay loam and silty clay materials. Significant growth of filamentous bacteria was recorded in all the edible clays collected from the District. Aggregates of grey, brown, pink and white bacteria colonies were observed on the rim of the plates. Colonial growth patterns of concentric rings of spores and a characteristic musty odour typical of *Streptomycete* were observed. Diameter of the spores ranges from 4 mm to 5 mm. Their abundance (*Streptomycete*) could be of immense benefit to these women in the area of antibiotic strain producing activities of these bacteria in the geophagic clays. This study suggests that geophagic clays in this locality could perform the functions for which they were consumed. Further studies are required to determine the antibacterial activity of metabolites produced by the isolates.

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4.1. Introduction

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Earth materials such as soils, dried up pond sediments, anthills and termite mounds are deliberately or inadvertently consumed by human beings and other animals. Such habit of eating earth is referred to as geophagy, geophagia or pica. It is a common habit amongst pregnant women and children in sub-Sahara Africa (Abrahams, 2002). They indulge in geophagic practice because of the belief that clays are potential sources of beneficial bacteria and inadequate essential elements (Fe, Zn, Cu, Mn, Ca) necessary for formation of new tissues at foetal and maternal stages that is lacking in their normal diets (Kikouma et al., 2009).

The need for these elements cannot be provided by food alone. Nutrients supplementation is recommended by way of geophagic practice for healthy growth of the developing baby and mother (National Research Council, 1989; Dupin et al., 1992).

The practice has since spread all over the world and is common in many societies from Japan to South America (Abrahams, 2005). Women and children eat a wide variety of Earth materials which includes hardened clays sold in the local stores and market places, soils from termite mounds and anthills; but they prefer soft clay, free from sand. Geophagy can equally be explained by an instinctive response to the demands of the body (Aufreiter et al., 1997; Kikouma et al., 2009).

Clays are consumed on the understanding that certain beneficial bacteria that are contained in it will help ones digestive system function properly by reducing the growth of harmful bacteria, assist in lactose digestion, and improve the general health of the geophagist (Gumbo, pers. comm.).

According to Mahaney and Krishnamani (2003), several geophagic materials are not properly characterized in terms of their texture, pH, EC and CEC. Studies that dwell on the colours of geophagic materials include the work of Mahaney et al., (2000), who reported on geophagic materials that have pale yellow colour. The physicochemical characterization of geophagic clays could assist in the understanding of their real functions in the human body (Ngole et al., 2010).

Studies establishing a link between geophagy and beneficial bacteria amongst women and children in South Africa are relatively scarce. Also, the debate about micro-nutritional

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benefits or damages caused by geophagy is still open (Geissler et al., 1998). Several thousands of naturally occurring antibiotics have been isolated from bacteria (*actinomycetes*) that are contained in soils (Peela et al., 2005). The genus *Streptomycete* species produce about 75% of useful antibiotics (Miyadoh, 1993; Vijayakumar et al., 2010). Typical example is streptomycin, an active antibiotic against *Mycobacterium tuberculosis* isolated from soil. It has also been asserted that the increase in prevalence of allergic and autoimmune diseases that have been observed in affluent societies over the past few years is as a result of a decreasing human exposure to soil Mycobacterium (Abrahams, 2002).

4.2. Objective of the study

The main objective of this study was to assess the physical features and occurrence of beneficial bacteria in Earth materials that are being consumed in the area of study. The specific objectives were:

1. To identify Earth materials with appropriate physical features for consumption.
2. To determine the suitability of these Earth materials at performing some of the functions for which geophagy is practiced.
3. To correlate physical features of these Earth materials with other geophagic materials and recommend appropriate geophagic materials to practitioners.

4.3. Materials and methods

4.3.1. Sample collection

Clay samples were collected from designated geophagic mining sites (Fig. 4.1) in the District with the use of an alcohol-flamed hand trowel and some were bought from local stores and markets in the area.

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Figure 4.1: Termite mounds on a decayed vegetation in the locality.

At the mining sites, about 300 g of clay sample was collected in Ziploc bag and shipped to the laboratories of Environmental Geology and Microbiology Department, University of Venda, South Africa for analyses. A total of thirty five and three non-consumed (control samples) clay samples were collected from the entire area (Table 4.1).

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Table 4.1: Location and source of edible clay from Vhembe District

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Sample number	*Location*	*Source*	*Coordinates*
001	Louis Trichardt	Johannesburg	23° 01′ 39″S 29° 54′ 19″E
002	Makuya	Makuya	22° 53′ 57″S, 30° 02′ 37″E
003	Tshisaulu	Tshisaulu	22° 47′ 48″S, 30° 45′ 09″E
004	Tshisaulu	Tshisaulu	22° 48′ 15″S, 30° 44′ 18″E
005	Gaba	Gaba	22° 48′15″S, 30° 44′ 18″E
006	Mathasha	Mathasha	22° 53′ 52″S, 30 °31′ 35″E
007	Sibasa[a]	Johannesburg	22° 57′ 00″S, 30° 28′ 18″E
008	Thohoyandou[a]	Johannesburg	22° 59′ 39″S, 30° 26′ 47″E
009	Thohoyandou[b]	Johannesburg	22° 58′18″S, 30° 27′ 28″E
010	Thohoyandou[c]	Johannesburg	22° 58′ 18″S, 30° 27′ 27″E
011	Thohoyandou[d]	Johannesburg	22° 58′ 18″S, 30° 27′ 27″E
012	Thohoyandou[e]	Johannesburg	22° 58′ 18″S, 30° 27′ 28″E
013	Elim[a]	Johannesburg	23° 09′ 23″S, 30° 03′ 17″E
014	Elim[b]	Zimbabwe	23° 09′ 23″S, 30° 03′ 18″E
015	Sibasa[b]	Johannesburg	22° 56′ 58″S’ 30° 28′ 19″E
016	Thohoyandou[f]	Johannesburg	22° 58′ 18″S, 30° 27′ 28″E
017	Thohoyandou[g]	Johannesburg	22°58′ 18″S, 30° 27′ 28″E
018	Thohoyandou[h]	Johannesburg	22° 58′ 27″S, 30° 27′ 30″E
019	Thohoyandou[i]	Johannesburg	22° 58′ 27″S, 30° 28′ 30″E
020	Sibasa[c]	Johannesburg	22° 56′ 58″S, 30° 28′ 18″E
021	Shanyaba	Shayanba	22° 58′ 18.5″S, 30° 27′ 27.8″E
022	Elim market[b]	Zimbabwe	23° 09′ 23.3″S, 30° 03′ 18.6″E
023	Univen Recreation park	Univen	22° 58′ 29.7″S, 30° 26′ 45″E
024	Tshandama	Tshandama	22° 52′ 49.5″S, 30° 05′ 34.8″E
025	Riverside Residence	Univen	22° 58′ 27.4″S, 30° 27′ 01.9″E
026	Westgate Residence	Westgate Residence	22° 58′ 20.8″S, 30° 31′ 05.9″E
027	Russel shop Thohoyandou[f]	Johannesburg	22° 58′ 18.5″S, 30° 28′ 18″E
028	Fashionnworld shop Thohoyandou[g]	Johannesburg	22° 58′ 24.4″S, 30° 27′ 29.5″E
029	Pep shop Thohoyandou[h]	Johannesburg	22° 58′ 28.2″S, 30° 27′ 31.1″E
030	Pep shop Thohoyandou[i]	Johannesburg	22° 58′ 28.2″S, 30° 27′ 31″E
031	Makhado Biaba	Makhado Biaba	22° 53′ 50.6″S, 30° 02′ 49.1″E
031	Makhado Biaba	Makhado Biaba	22° 53′ 50.6″S, 30°02′ 49.1″E
032	Mamumohi[a]	Mamumohi[a]	22° 52′ 06.6″S, 30° 07′ 17.4″E
033	Mlgavhini	Mlgavhini	23° 09′ 23″S, 30° 03′ 17″E
034	Musina CBD	Zimbabwe	22° 20′ 43″S, 30° 02′ 25.1″E
035	Nance Field Musina	Tshipise	22° 19′ 44.7″S’ 30° 28′ 19″E
Control 1	Shayanba[b]	Shayanba[b]	22° 58′ 18.5″S, 30° 27′ 27.1″E
Control 2	Behind Univen Stadium	Univen	22° 58′ 29″S, 30° 27′ 00.5″E
Control 3	Mamumohi[b]	Mamumohi[b]	22° 52′08.6″S, 30° 07′ 17″E

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4.3.2. Sample analyses

4.3.2.1 Quality Assurance and Control

Quality was assured through the following procedure:

- **Analyses of Earth materials**

Earth materials are prone to yield inaccurate results due to errors in the course of preparing the samples for analyses. Sample preparation is the most critical part of the analyses because it is responsible for the most and hidden sources of error. It is at this stage that most errors influencing the reliability of final results may be introduced (Zoltan and Ralph, 2004).

Errors emanating from contamination of samples during preparatory stage could be due to equipment handling, use of reagents and the way samples are handled. Contaminations at this stage could be due to systematic or random introduction of non-negligible amounts of analyte during different steps of the analyses. Sample preparation depends solely on the intended measurement technique that will be used. There are several stages of sample preparation, for consumed earth materials such as anthills, clays, sands, termite mounds and dried up pond sediments, the stages includes drying the sample in air while they are still in the Kraft envelopes, disaggregation of samples, homogenization and milling with a machine and pestle to pass through 2 mm sieve and followed by a sub sampling process, taking the required quantity for analyses. It is at this various stages of sample preparation that contaminants are introduced into the sample.

Drying of samples prevent microbial action on the sample during storage and acquisition of a constant reference value by determining the dry weight as against the initial weight when sample was collected and it is still moist which is very difficult to determine, samples are crushed and mixed properly to obtain a representative sample and to increase the surface area of the sample.

Grinding/milling of sample generally reduces its size and may contaminate the sample by abrasion of the mortar or milling parts with certain hardness (Arabinda et al., 1995). In the course of sample preparation, it is mandatory to use reagents and vessels' made in porcelain glass, quartz, platinum or various plastics. Impurities in reagents are major sources of contaminations if they are added in large quantity.

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Sample dissolution is not achievable in one step using a single reagent. In practice, a number of steps and reagents are dictated by the matrix composition. The dissolution process can lead to volatilization of the analyte arising from high temperature or volatilization of chloride ions or nitrosyl chloride (NOCl) as in acid digestion, adsorption, and co-precipitation of the analyte with a precipitate formed by a matrix element within the reactive mixture (Okorie, 2010).

The matrix of a sample is responsible for the degree of difficulties encountered during analyses because it will impose constraints not only in the analyte determination but also during preparation steps (Hoenig, 2001).

- **Sample storage**

Sampling is the first and one of the most important steps in analyses and has the role of ensuring the representative of sample. A representative sample is one that is evenly distributed and is required for the analyses. One of the special problems of environmental analyses is that the quantity of original sample may be in kilogram or tonne range and out of this only a few milligrams can be put into the equipment for the actual analysis (Baffi et al., 2002).

Samples to be used for analyses should have the same mean chemical composition as the original sample, depending on the samples to be analysed and elements to be determined, the sampling tools, filtrations devices, storage and storage vessels have to be carefully chosen and clean to minimize risks of possible contamination (Zoltan and Ralph, 2004). All vessels to be used during sample collection and storage should be washed, rinsed and then soaked overnight in 1 - 10 volume analytical grade nitric acids. They should be rinsed in high purity deionised water before usage.

Sample collection and storage is associated with the risk of contamination especially when the sampling is to do with low concentration of the analyte losses by adsorption of metal ions on the vessel or on the suspended particles, the samples collected can be stored for a short time or refrigerated and for longer periods in a freezer. For the same purpose, aqueous solutions are generally acidified immediately after sampling generally at pH 1.5 with nitric acid (Merkert, 1995). This treatment is generally sufficient to prevent the adsorption of trace elements onto the walls of the vessel for relatively long term storage. Another means to avoid

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adsorption losses is immediate freezing of the sample collected and it's thawing just before measurements.

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- **Acid digestion**

Acid digestion or wet decomposition of sample is routinely employed for the determination of elements in solids in order to transfer the analytes into solution so that they can be introduced into the instrument like inductive couple plasma mass spectroscopy and atomic absorption spectroscopy in liquid form (Pranar and Shankeraman, 2007).

Acid digestion involves the use of acids and heat to destroy the organic matrix, carbonate bound fractions and sorbed fractions of a sample to liberate the metal content (Okorie, 2010) It measures the total or pseudo total (depending on the reagent used for the digestion) concentration of the metal present in the sample matrix. All chemicals used were of high analytical grade concentrated hydrochloric acid and concentrated nitric acid obtained from Lelhabile Scientific Services, Polokwane.

- **Geophagic samples**

Geophagic samples were air-dried while in the Kraft envelopes at the laboratory of Mining and Environmental Geology, University of Venda, until a constant weight was obtained for each sample. This was done, to remove moisture from the samples. The samples were then transferred into a clean milling pot.

- **Milling of sample**

Stainless steel RJM Mill was used for milling the samples into powdered form; the samples were milled to -80 mesh size fraction in order to ensure homogeneity of the grains. During grinding of the samples, cleaning of the milling pot was done after each sample was grounded using pure clean milky quartz and acetone to avoid cross contamination between any two samples. Milled samples were then transferred to clean Kraft sample bags and labelled accordingly.

4.3.2.1. Determination of colour

The colours of samples were determined by use of Munsell colour chart, which describes colours in the order of their hue (actual colour), values (degree of lightness) and chroma

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(strength of colour) (Young et al., 2010). Few grams of each sample was spread on a white paper, under a bright white light and the colour was compared to the colour chips in the Munsell soil colour charts. The closest colour chips that has resemblance of the colour of sample was selected as the sample colour.

4.3.2.3 Clay pH determination

Clay pH was determined by suspending 10g of clay in 10 ml of distilled water, agitating it for 30 minutes then letting it settle for 30 minutes and reading the solutions pH (Brightsman et al., 2008).

4.3.2.4. Electrical conductivity of samples

This was measured in the clay to water suspension after pH measurement using a bench field Crison multimeter with a sensitivity of ± 0.5, 0.2 µS/cm at 5mg/l ionic strength. The results were expressed in micro Siemens per centimeter (µS/cm).

4.3.2.5. Cation exchange capacity (CEC)

Cation exchange capacity of each sample was determined by weighing out 15 g of clay sample and placing it in polyethylene bottle, to which 25 ml of 1 mol ammonium acetate ($NHC_2H_3O_2$) solution was added. The mixture was shaken in a wrist shaker for 1 hour. The supernatant was filtered into 100 ml volumetric flask through filter size paper. Twenty milli litres of ethanol was added to the bottle containing the solids. The bottle was thoroughly shaken and allowing the solid material to settle down. The supernatant was filtered out into the initial used volumetric flask. The washing, shaking and filtering procedure was repeated twice. The solution was made up to 100 ml with distilled water. The concentrations of exchange cations (Na^+, Mg^{2+}, Ca^{2+} and K^+) in the final solution were determined by atomic absorption spectroscopy (AAS). The sum of the equivalents of the exchangeable cations was assumed to be the equivalent to the CEC.

4.3.2.6. Particle size distribution

Particle Size analyses were determined by the percent dry weight of three different size categories; clay (0.002 mm), silt (0.002-0.05 mm), and sand (0.05 mm) by dry filtering and

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weighing the sand fraction. The remaining silt and clay fractions were suspended in dilute sodium hexa-metaphosphate and sampled at a fixed depth and time to determine the clay content.

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4.3.2.7. Isolation and enumeration of actinomycetes

Isolation and enumeration of *actinomycetes* were performed by the soil dilution plate technique (Peela et al., 2005) using starch casein agar medium (g/l: starch 10, casein 0.3, KNO_3 2, K_2HPO_4 2, $MgSO_4.7H_20$ 0.05, $CaCO_3$ 0.02, $FeSO_4.7H_2O$ 0.01 and agar 15). The magnesium sulphate concentration was doubled to inhibit other bacterial and fungal growth. The inoculated plates were incubated at 37^0C for seven days. After incubation, the *actinomycetes* colonies were observed.

4.3.2.8 Statistical analyses

Data were analysed by means of a student t-test estimating differences between the values obtained for consumed clays and non consumed clays (control groups). Values were expressed as means and standard deviations. A *p- value* of < 0.05 was considered statistically significant.

4.4. Results

4.4.1. Clay colour

The clay samples were made up of four colour groups according to the Munsell colour chart (2000). These are yellowish (51.4%), brownish (37.1%), greyish (8.5%) and white (2.8%) respectively. Within these main groups of colours, other colours (reddish yellow, dark grey, light grey, pinkish, brownish yellow and light yellow) totalling eight in number were identified (Table 4.2). The colours of the control groups ranged from reddish yellow to dark red.

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Table 4.2: Description and colour of analysed edible clays from Vhembe District

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Sample number	*pH*	*Colour*	*Description*
001	5.08	Reddish yellow (7.5YR 6/6)	Clayey smooth material
002	6.59	Reddish brown (5 YR 4/4)	Fine termite mound
003	5.56	Light brown (7.5 YR 6/3)	Very fine clayey material
004	4.30	Reddish brown (7.5 YR 7/8)	Smooth clay material
005	5.70	Pink (5YR 7/8)	Fine clay
006	5.74	Dark grey	Fine clay with decomposed roots.
007	5.09	Pale brown (10 YR 7/4)	Very fine clay
008	6.10	Very light brown (10 YR 8/6)	Highly compact material
009	5.88	Reddish yellow (7.5 YR 6/6)	Smooth clayey material
010	5.92	Reddish yellow (7.5 6/6)	Fine textured material
011	7.20	Strong brown (7.5 YR 5/6)	Blocked compact material
012	4.97	Yellow (10 YR 7/6)	Coarse blocked material
013	5.44	Reddish yellow (7.5 YR 6/6)	Soft clay material
014	5.95	Reddish yellow (7.5 YR 7/6)	Fine clayey material
015	5.98	Reddish yellow (7.5 YR 7/8)	Smooth with decayed vegetation
016	5.99	Reddish yellow (5 YR 7/6)	Fine silty clay material
017	6.18	Yellow (10 YR 8/6)	Blocked greasy material
018	6.15	Reddish yellow (7.5 YR 6/6)	Light fine material
019	6.13	Reddish yellow (7.5 YR 6/6)	Fine clayey material.
020	6.17	Reddish yellow (7.5 YR 7/8)	Smooth material
021	5.08	Reddish yellow (7.5YR 8/6)	Fine textured clayey material
022	6.59	Pale yellow (2.5 Y 8/3)	Fine smooth material
023	5.56	Olive brown (2.5 Y 4/4)	Fine clayey material
024	4.30	Light yellowish brown (2.5 YR 6/3)	Friable smooth material
025	5.70	Olive brown(2.5Y 4/4)	Fine clayey material
026	5.74	Light olive brown 2.5Y 5/3	Fine clay with decomposed roots.
027	5.09	Reddish yellow (7.5 YR 7/6)	Very fine clay
028	6.10	Reddish yellow (7.5 YR 7/8)	Highly compact material
029	5.88	Reddish yellow (7.5 YR 7/6)	Smooth clayey material
030	5.92	Reddish yellow (7.5YR 8/6)	Fine textured material
031	7.20	Light grey (5 YR 7/1)	Shaly compact material
032	4.97	Grey (5YR 6/1)	Coarse blocked material
033	5.44	Reddish brown (5YR 4/3)	Soft clay material
034	5.95	Reddish yellow (7.5YR 6/8)	Fine clayey material
035	5.98	White (10YR 8/1)	Compact smooth material
C-1	5.99	Reddish yellow (7.5YR 8/6)	Fine textured clay material
C-2	6.18	Dark reddish (2.5YR 3/6)	Fine smooth material
C-3	6.15	Dark reddish brown (2.5 YR 2.5/4)	Fine sandy material

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4.4.2. pH of edible clays

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Clay pH ranges from 4.30 to 7.90 (Table 4.3). The clays were acidic to very weak acid with samples 11, 31 to 35 having very weak alkaline pH values.

Table 4.3: pH, Electrical conductivity and cation exchange capacity of edible clays from Vhembe District

Sample	*pH*	*EC (µS/cm)*	*CEC (meq/100g)*
1	5.08	24.5	8.53
2	6.59	23.7	13.91
3	5.56	20.5	5.3
4	4.3	46.8	9.65
5	5.7	8.22	8.67
6	5.74	10.2	4.04
7	5.09	18.84	16.84
8	6.1	17.42	7.79
9	5.88	19.49	8.78
10	5.92	16.36	9.56
11	7.2	20.1	13.48
12	4.97	14.78	11.64
13	5.44	25.8	3.74
14	5.95	8.26	9.39
15	5.98	35.3	7.65
16	5.99	25.89	9.88
17	6.18	13.23	12.35
18	6.15	17.42	11.36
19	6.13	16.83	4.51
20	6.17	19.9	10.02
21	6.5	90.4	15.73
22	5.08	30.6	14.23
23	4.3	60.1	9.45
24	4.82	70	6.31
25	5.96	40.1	8.67
26	6.45	167.3	14.8
27	6.79	49.9	11.91
28	6.61	72.5	9.49
29	6.65	56.2	9.58
30	6.67	58.9	19.78
31	7.45	107.2	14.56
32	7.15	223	13.45
33	7.89	116.2	11.36
34	7.67	60.3	10.23
35	7.9	652	14.53
Mean	6.11	64.52	10.6
SD	0.91	112.33	3.67
Minimum	4.3	8.22	3.74
Maximum	7.9	652	19.78
P	<0.02	<0.02	0.81
C-1	5.6	19.2	6.19
C-2	4.76	25.8	12.49
C-3	4.84	10.2	11.46
Mean	5.06	18.4	10.04
SD	0.46	7.8	3.37
Minimum	4.76	10.2	6.19
Maximum	5.6	25.8	12.49

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The control samples pH ranged from 4.5 to 5.6. They are generally acidic (Fig. 4.2). The difference in the values ($p < 0.02$) of the mean is statistically significant.

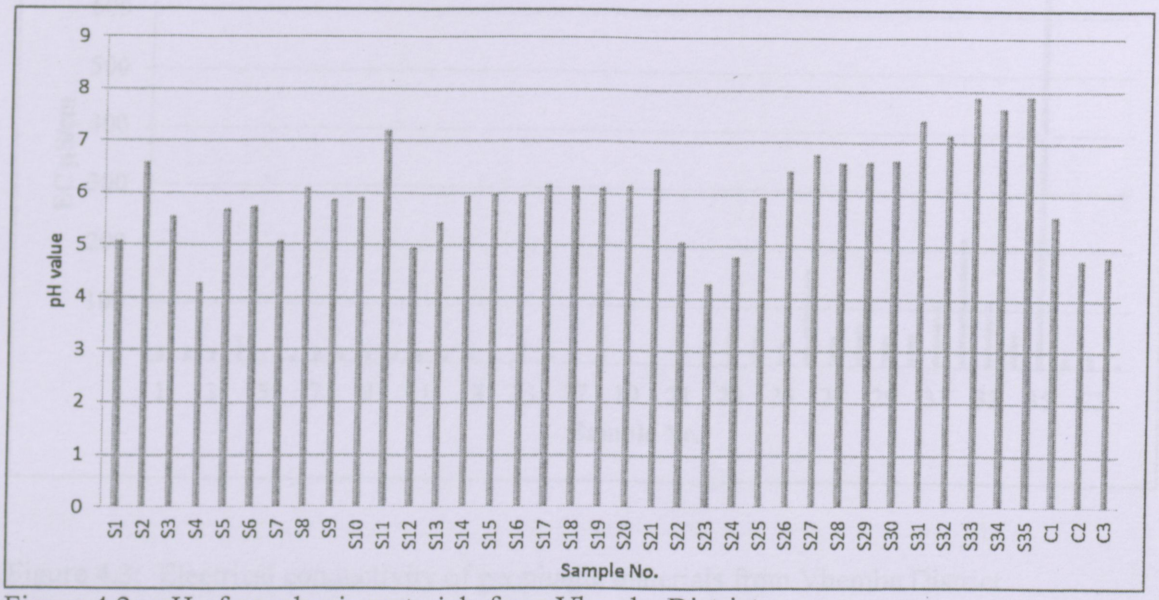

Figure 4.2: pH of geophagic materials from Vhembe District

4.4.3. Electrical conductivity (EC) of edible clays

The electrical conductivity values of edible clays ranges from 8.22 to 652 µS/cm (Table 4.3). Electrical conductivity gives an indication of dissolved salts in soils/clays. The values generally reflect the soluble salt content of the clays, thus, allowing simple interpretation of results. The edible clays (26,31, 32, 33 and 35) had higher values of EC (mean EC = 64.52 µS/cm) compared to control clays with a mean value of 18.4 µS/cm (Fig. 4.3). The difference in mean value is statistically significant ($p < 0.02$).

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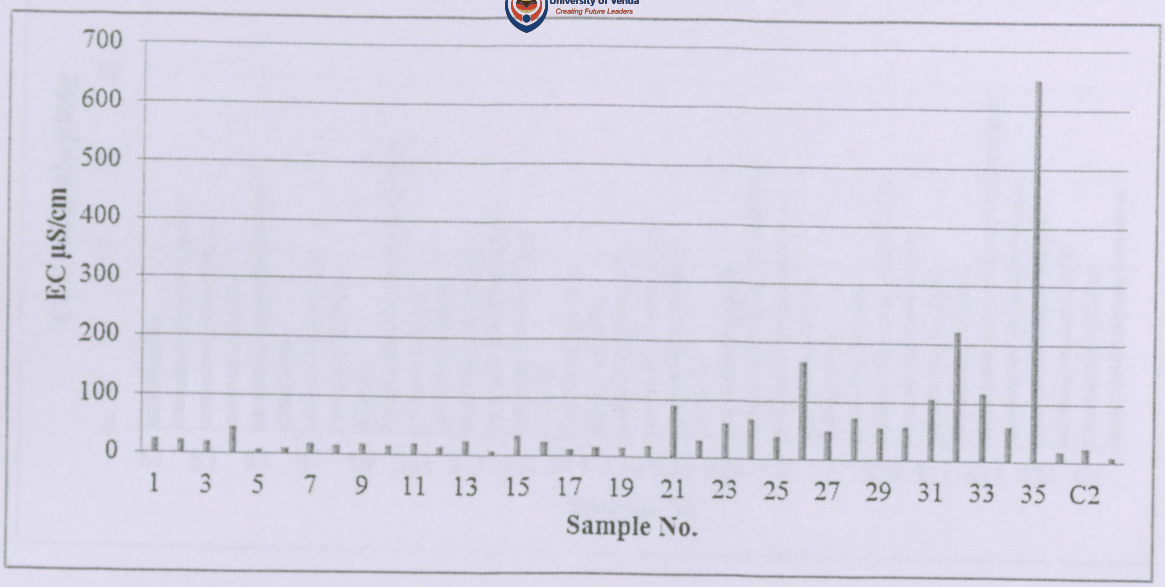

Figure 4.3: Electrical conductivity of geophagic materials from Vhembe District

4.4.4 Cation exchange capacity (CEC) of edible clays

The CEC for the edible clays ranges from 3.74 to 19.78 meq/100g (Table 4.3). The edible clays had a slightly higher values of CEC compared to control clays. The difference in the mean value ($p = 0.81$) is not statistically significant.

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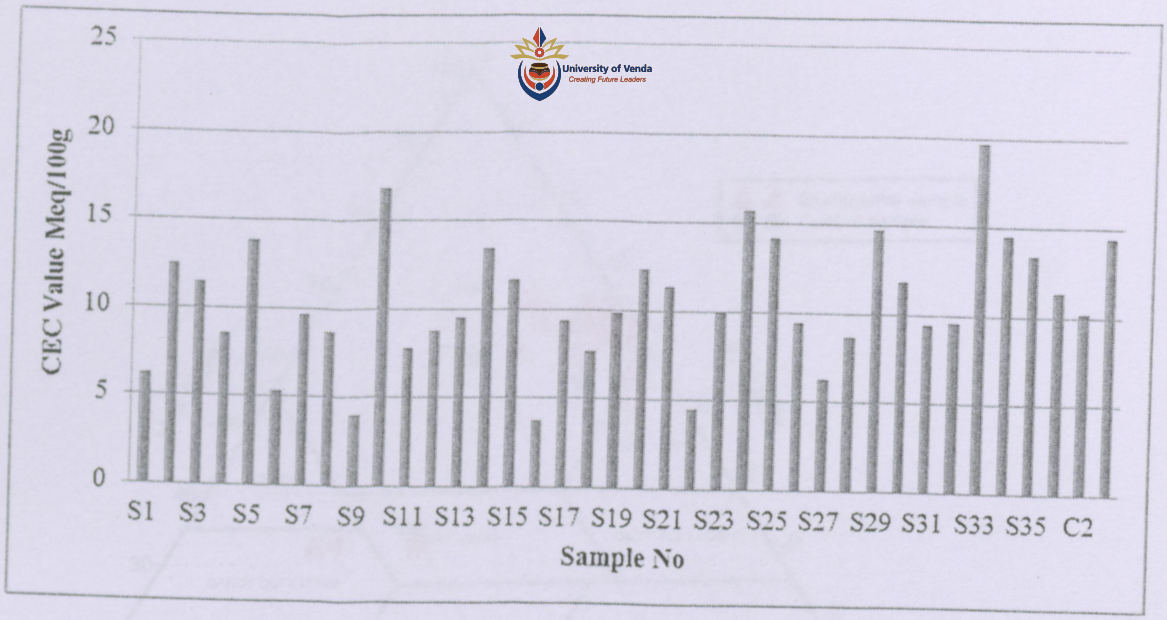

Figure 4.4: Cation exchange capacity of geophagic materials from Vhenbe District

4.4.5 Particle size distribution of edible clays

Textures are of different size classes with clay having the highest percentage of 85.71 %, clay loam had 8.57% and sandy clay loam had 5.7% % (Fig. 4.5). The sand content of the control samples was higher than those of the edible clays. The composition of the edible clays as depicted from textural classification in the triangular diagram was clays, clay loam and sandy clay loam while those of the control samples were clay and clay loam.

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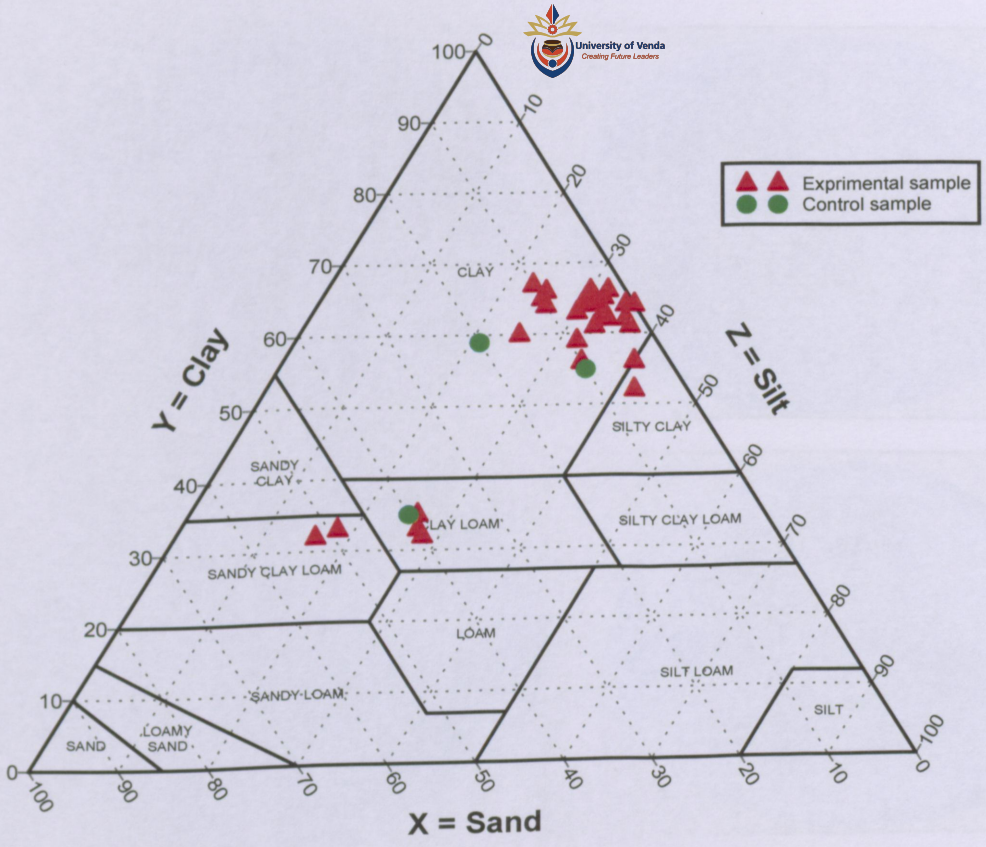

Figure 4.5: Textural triangle showing textures of edible clays and control samples from Vhembe District

4.4.6. Isolation of actinomycetes

All the isolates grew in a range of agar media showing morphology typical of *Streptomycete* (Anderson and Wellington, 2001; Oskay et al., 2004) The colours of the substrate mycelium and aerial spore mass varied from grey to milky white with some brownish stains of fungal growth. A total of four actinomycetes colonies which are whitish, grey, green and brown coloured filamentous colonies with various morphologies were isolated from edible clays (Fig. 4.6).

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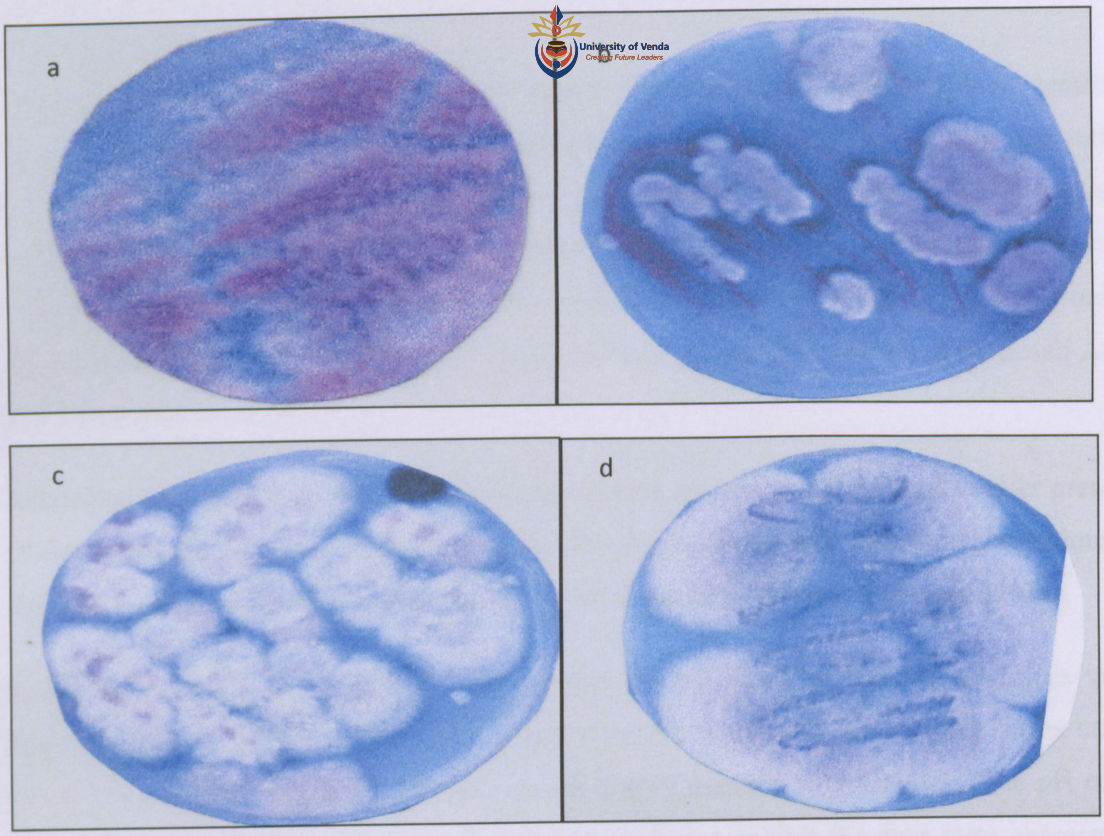

Figure 4.6: Filamentous coloured actinomycete colonies (a, b, c and d) growing on agar plates. All were isolated from edible clays in Vhembe District.

4.4.7. Do these geophagic materials conform to other geophagic materials that are used in other places against toxins and disease infection?

Geophagy is practised in order to elicit a healing response in humans through ingestion of available materials that may physically soothe an infected and inflamed gastrointestinal lining (Droy-Lefaix and Tateo, 2006; Williams and Haydel, 2010). Clays have also been used typically in mud spas (pelotherapy) to adsorb toxins from skin and provide heat to stimulate circulation for rheumatism treatment (Carretero et al., 2006; Gomez and Silva, 2007; Williams and Haydel, 2010). Clays provide inexpensive highly effective antimicrobials which could be used in the treatment of infections such as Superberg and Buruli Ulcer (Williams et al., 2008). The research found that there are beneficial bacteria (*Streptomycetes*) in edible clays from this locality. Antibacterial activity of this bacterium could guard against other pathogenic bacteria that may cause infections and diseases amongst geophagic practitioners.

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4.5. Discussion

The colours of edible clays are of various shades. One reason for human geophagic practice is mineral nutrient supplementation. It suggests that colour; particularly the common reddish hue indicative of Fe found in majority of the clays may act as a primary or secondary stimulus in this respect (Wilson, 2003; Young et al., 2010). The hue value is consistent with the hue value of samples described in the work of Ngole et al., (2010) which inferred the occurrence of goethite and hematite in the samples of geophagic materials from South Africa and Swaziland.

According to Fontes et al. (2005), reddish colouration of clays could be used to infer presence of Fe but not its quantities or bioavailability for geophagist uptake. Other notable colours of the edible clays are dark grey to shades of brown as noted by Diko and Ekosse, (2011).

Research by Omen et al. (2000) revealed that the pH value of the human saliva varies between 5 and 8. The pH values of the edible clays fall within the range of that of the human saliva. No chemical reaction can occur on the clayey material in the mouth. The pH of the edible clays are acidic to weakly acidic in nature, hence exhibit the sour taste character of acids (Abrahams and Parsons, 1997).

The use of clays to reduce excess salivation and nauseae during pregnancy is one of the reasons for human geophagy and this could be linked to the taste of soil, which in turn is related to the soil pH and dissolved salt content (Ngole et al., 2010). The acidity of the gastric juice in the stomach (pH of 2) could allow reactions to take place on the clay minerals and organic matter in the edible clays (Omen et al., 2000).

The residence time of ingested material in the stomach, being approximately 2 hours is inadequate for any reaction to occur in the stomach (Ngole et al., 2010). However, in the duodenum and small intestine portion of the gastrointestinal tract (pH 8) where absorption of nutrient takes place, some of the clay sized particles may undergo chemical reactions.

The edible clays had low amount of EC, showing that the dissolved salts in the clays were low. Research by Kotlyar et al. (1998), showed a relationship between flocculation, soil pH and salt content. Flocculation in edible clays may influence their ability to coat the intestinal mucosa and low salt content of geophagic samples is not likely to have any influence on the degree of flocculation that may occur (Ngole et al., 2010). The low salt content of geophagic

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samples reported by Ngole et al. (2010) in geophagic samples from Swaziland were similar to those reported in this study.

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The CEC values were similar to those reported by Abrahams and Parsons (1997) for Uganda geophagic clays, Ngole et al., (2010) for Swaziland geophagic soils but slightly lower than those reported for geophagic clays from Brazil. Also, Rateau et al. (1982) reported that clay fraction of ingested soil protects the gastrointestinal epithelium because it forms cross linkages with glycoprotein in the intestinal mucosa (Ngole et al., 2010). The edible clays from this locality exhibited similar traits with those clays from Uganda, Swaziland, and Brazil. They could equally adsorb toxins on the epithelial walls of the intestine and protect the intestine from diarrhoea causing toxins and other poisonous substances on the gut lumen. According to Williams and Haydel (2010), moderate ingestion of clays lacking high CEC could serve as a nutritional supplement for Fe, Cu, Ca, Zn and Mn.

Texturally, the geophagic materials are dominated by clay and it has been suggested that geophagic soils are selected because of their pleasant unctuous texture associated with clay richness (Wilson, 2003).

Edible clays are known to protect geophagist against gastrointestinal distress and detoxifying harmful pathogens and chemicals (Gonzalez et al., 2004; Young et al., 2010). Only 6 % of the entire samples have sandy clay loam and clay loam textures respectively. Selection of edible clays on the basis of overall clay mineral content is supported by this study and that of Diko and Ekosse, (2011), as against the work of Young et al., (2010) which does not support overall clay content as the basis for selection of geophagic samples.

According to Bisi-Johnson et al. (2010), there is some evidence that supports the usefulness of the commensally flora found in soil samples as vital in the establishment of healthy bacteria within the digestive tract. Edible clays could provide inexpensive, highly effective antimicrobials which could be used in the treatment of infections such as Superberg and Buruli ulcer (Williams et al., 2008). This study confirms the presence of beneficial bacteria (*Streptomycete*) in edible clays from this locality. This is supported by the work of Williams et al. (2008), on use of French green clays (rich in Fe-smectite) used clinically for healing Buruli ulcer, a necrotizing fasciitis (flesh-eating infection) caused by Mycobacterium ulcerans (Williams 2011).

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4.6 Conclusion

This study shows that the edible clays in this locality are of diverse colours ranging from grey, yellow, brown and reddish colouration. The reddish Earth materials are as a result of Fe content and these ones could supplement Fe need of the geophagists. Textures are mainly clay, with very few clay loam and sandy clay loam. The clay minerals in these clays could serve as a detoxifying agents and toxin absorbents on the gastrointestinal tract of geophagists. The acidic to weakly acidic nature of these edible clays could impart a sour taste, which enhance the counsumption of the clays by pregant women to control early morning sickness. Edible clays with high clay proportion and low CEC are suitable geophagic materials given their content of beneficial bacteria in this locality. The microbiology of these edible clays confirms the presence of beneficial bacteria (*Streptomycete*). Further studies are required to determine the antimicrobial activity of metabolites produced by the isolates, in order to know the specific type of antibiotics that could be produced from edible clays in this locality.

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GEOPHAGY, ANAEMIA AND GEOHELMINTH INFECTION AMONGST NON-PREGNANT WOMEN IN VHEMBE DISTRICT, LIMPOPO PROVINCE, SOUTH AFRICA

Abstract

Geophagy, the deliberate or inadvertent eating of Earth materials has been speculated to be associated with anaemia and geohelminth infections amongst its practitioners. This study focused on determination of haemoglobin levels in blood of geophagic women, an indication of anaemia and identification of helminth suum (eggs) as a possible route for transmission of helminth infections amongst non-pregant geophagic women. Haemoglobin level of blood was determined using Complete Blood Count (CBC) 5 Coulter Counter, and helminth ova were identified by floatation technique. Sixty eight non-pregnant geophagic women between the ages of 18 and 49, and 5 non-pregnant women between the ages of 18 and 45 (control group) were recruited for the study. Pregnant women were excluded from the study because they were potentially at risk with iron deficiency anaemia due to the developing foetus. Of the 68 non-pregnant geophagic women that were enrolled for the study, 9% of the women were diagnosed with severe anaemia, 35% were anaemic and 56% were normal. All the women in the control group had their haemoglobin level within the reference range and were normal. An ovum similar to *Ascaris lumbricoides* ovum was detected in one of the geophagic materials. Faecal droppings from human host or domestic animals within the locality that were infected with *A. lumbricoides* could serve as the source of helminth ova in the geophagic materials. Decreased haemoglobin level (anaemia) may be due to geophagy and poor availability of iron supplements in food. This study suggests that geophagy could be a causal factor for anaemia in this locality.

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5.1 Introduction

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The deliberate or involuntary ingestion of soils, anthills, clays, dried up pond sediments and termite mounds is referred to as geophagy, geophagia or pica. This habit has been in existence from historical times and it is widely practiced across the globe (Abrahams, 2005).

The rationale why soils are consumed could be very difficult to establish, but known causative reasons are as follows: food and food detoxifier (Johns, 1986; Aufreiter et al., 1997), as a source of pharmaceuticals (Vermeer and Ferrel, 1985), due to neuro–psychiatric and psychological reasons (Danford et al., 1982) and as a nutrient supplement (Davies, 2008).

In sub-Sahara Africa, geophagy concerns most pregnant women, lactating mothers and children. According to Chappius and Favier (1995) this is as a result of inadequate essential elements (Fe, Zn, Cu, Mn, Co, Ca) necessary for formation of new tissues at foetal and maternal stages that is lacking in their normal diets. The need for these elements cannot be provided by food alone; nutrient supplementation is recommended by way of geophagic practice (National Research Council, 1989; Dupin et al., 1992) for proper healthy growth of the developing baby and mother.

However, there are a number of medical problems that are associated with geophagic practice which include, Fe deficiency anaemia (Danford et al., 1982), mechanical bowel disorder (Keay et al., 1982), nutritional dwarfism and a potential route for transmission of pathogens (Magnaval et al., 2001).

Geissler et al. (1998a) have identified geophagy as a possible risk factor in the transmission of various geohelminth and other parasitic infections and has also been implicated in the development of Fe depletion and anaemia. Saathoff et al. (2002), has identified geophagy as a risk factor for *Ascaris lumbricoides* infection and noted that it plays a role in the transmission of other parasitic infections like *toxocaris* and *amoebiasis* amongst school children in Kwazulu Natal Province of South Africa. Hooda et al. (2004) were of the opinion that geophagia may be more common in groups of people that are at greatest risk of Fe deficiency due to poor diet compared to well nourished individuals.

Mokhobo's (1986) study involving patients in South Africa seems to support the theories that geophagia was a cause of Fe deficiency anaemia. Research undertaken by Munnich et al.

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(1968) using soil materials obtained in Turkey and the United States of America (USA) indicated that ingested clay materials can play a prominent role in the disease.

Nchito et al. (2004) undertook a controlled trial that investigated the effect of Fe-supplementation on Zambian school children where geophagy was prevalent. The authors could not support the hypothesis that geophagia is a result of hunger for this mineral nutrient, but instead supported the alternative hypothesis that soil consumption lowers Fe status by interfering with its absorption from the human gastro-intestinal tract.

Anaemia and Fe deficiency during pregnancy is a serious risk factor for maternal mortality, poor pregnancy outcomes, low birth weight and infant mortality in developing countries (Allen, 2000; Brabin et al., 2001; Merchant et al., 2004; Kawai et al., 2009).

According to Kawai et al. (2009) helminth infection affects over one billion people in tropical developing countries and contributes to severe morbidity. They noted that, women who practice geophagy may be particularly at risk of infection with *Ascaris lumbricoides, Strongyloides stercoralis* and *Trichuris trichuira* by ingesting eggs from contaminated soils.

Geohelminths are parasites in which at least one developmental stage (ova) requires period of development or incubation in the soil prior to being infective. Non-segmented round worms (*A. lumbricoides* and *S. stercoralis*), hookworms (*Nectar americanus* and *Ancylostoma duodenale*) and whipworm (*T. trichuria*) all constitute part of a group of helminths referred to as geohelminths (Sumbele et al. 2011). Occurrence of geohelminths in soils is normally linked to the sanitary conditions and habits of the people in the environment in which soils are found (Sumbele et al., 2011). The pathway by which humans get infected with these helminths could be by ingestion (*A. lumbricoides, T. trichuria*) or percutaneous (*S. stercoralis*) and others could be both ways (*A. duodenale* and *N. americanus* (Sumbele et al., 2011).

5.1. Objectives of the study

The general objective of this study was to determine the Fe level of non-pregnant geophagic women in the Vhembe District. Specific objectives were:

1. To identify the presence of helminth ova (if any) in geophagic materials consumed by female geophagists in the District.

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2. To establish any possible link between geophagy and anaemia amongst female geophagists in the area of study.

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5.2. Materials and methods

5.2.1. Study population

The research was conducted between September and October, 2011 in Vhembe District, South Africa. The District is predominantly rural, which reflects the notion about geophagic practice; which states that it is a habit that is mainly associated with people of low socio-economic status. The study population was limited to non-pregnant women attending out-patient consultation clinics and hospitals. Pregnant women were excluded from the study because they were potentially at risk of Fe deficiency anaemia due to the developing foetus. Some selected hospitals and rural clinics were visited and the objectives of the study were explained to them in a meeting with the heads, staff and nurses conducted in the local languages of Tshivenda, Tsotho and Xsonga. In the meeting, consent was obtained from all the patients (Appendix D). Only consenting individuals were interviewed and they were at liberty to withdraw at any stage of the study.

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5.2.2. Collection of blood samples and identification of ova

Five ml of blood was collected from consenting geophagists by a medical laboratory technician registered with the Health Professions Council of South Africa. Geophagists in the selected areas across the District identified the source of geophagic materials being consumed by the women (Fig. 3.2). Consumed Earth materials that were sold in local markets and retail outlets were purchased for the study (Fig. 3.3). These geophagic materials were used to identify ova of helminth (hookworm, *A. lumbricoides, T. trichuira* and *S. stercoralis*).

5.2.3. Experimental

5.2.3.1. Determination of haemoglobin

Haemoglobin content of the blood was measured using a complete blood count (CBC) 5 Coulter counter (Coulter Corp, Miami, FL). This test was used to determine the extent of Fe

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deficiency (anaemia). Anaemia was defined as haemoglobin <11.0 g/dl; severe anaemia as <8.5g/dl and >11 g/dl was taken to be normal haemoglobin human level (Massawe et al., 1999; Kawai et al., 2009).

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5.2.4. Microscopic identification of helminth ova in geophagic samples

5.2.4.1 Preparation of zinc sulphate solution

Three hundred grams of ZnSO4 was diluted with distilled water in a standard flask and thoroughly shaken. The mixture was made up to 1L mark in the flask.

5.2.4.2. Preparation of iodine solution

Ten grams of KI was added into 1 L of water and thoroughly shaken to dissolve completely. Then 10 ml of iodine was added to the mixture and mixed completely.

5.2.4.3. Determination of helminth suum in geophagic materials

Three grams of each powdered geophagic samples was placed in a tube and 15 ml of $ZnSO_4$ was added. The mixture was homogenised by stirring. The suspension was strained through a sieve of aperture of 80µ to remove coarse particles. Filtrate from the suspension was poured into a centrifuge tube and centrifuged at 13600 rpm for two minutes. The supernatant was decanted and resultant sediment from filtrate containing the suum was placed on the glass slide and few drops of iodine were added to stain the suum. The slide was covered with a cover slip and viewed at X10 magnification.

5.2.5. Data analyses and presentation

The data obtained were analysed using Statistical Package for Social Sciences (SPSS) version 16.0. The significance of the differences between the experimental and control groups was determined using one paired student's *t*-test.

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5.2.6. Ethical considerations

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The study protocol was approved by Health, Safety and Research Ethics Committee, University of Venda, South Africa (Appendix B). Permission was sought and granted by the Ethical Committee of Health and Social Welfare Department, Limpopo Provincial Government, South Africa (Appendix C). Signed consent was obtained from all study participants before collection of blood samples (Appendix D).

5.3. Results

Sixty eight non-pregnant geophagic women between the ages of 18 and 49 years and with a mean age of 25 years, and 5 non geophagic women between the ages of 18 and 45 years and having mean age of 26 years were enrolled in the study. Of the sixty eight non-pregnant women, 9% of the women were diagnosed with severe anaemia, 35% were anaemic, while 56% were normal (Table 5.1).

Table 5.1: Distribution pattern of haemoglobin level (anaemia) for experimental group

Reference value (g/dl)	*Frequency*	*Percentage (%)*	*Cumulative percentage*
< 8.5	6	9	9
< 10.99	24	35	44
> 11 g/dl	38	56	56
Total	68	100	100

The mean haemoglobin value for the experimental group was 11.34 g/dl±2.09 while the mean haemoglobin for the control group was 13.94g/dl±1.5g/dl (Table 5.2). There was significant ($t = 3.6$, $p = 0.0001$) difference between the two groups.

Table 5.2: Mean haemoglobin and standard deviation values of experimental group and control groups

Experimental group (n =68)		*Control group (n = 5)*		
Mean	*Standard deviation*	*Mean*	*Standard deviation*	*p –value*
11.34	2.09	13.94	1.5	0.0001*

*Statistically significant at ≥ 0.05

Four different types of geophagic materials were consumed by geophagists in the area. These are: (i) reddish brown termite mound found on bark of tree; (ii) yellowish silty sandy material

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found on horizon A soil profile; (iii) gray smooth natural clays; and (iv) whitish geophagic materials believed to be magnesite (mineralogical data not reported in this study).

Results of ova identification on 30 samples and 3 negative control samples (Table 5.3) showed that *A. lumbricoides ovum was* detected in sample 21.

Table 5.3: Geohelminth ovum in geophagic materials

Sample	*A. lumbricoides*	*T. trichuria*	*S. stercoralis*	*Hookworm*
1- 20	-	-	-	-
21	+	-	-	-
22 – 30	-	-	-	-
Negative control 1-3	-	-	-	-

The remaining 29 samples and 3 control samples were devoid of any helminth ova. The only sample with *A. lumbricoides* ova (Fig. 1) was sold in Mutale local market. The vendor of the geophagic materials obtained her supplies on weekly basis from an intermediary who in turn obtains her supplies from the miner.

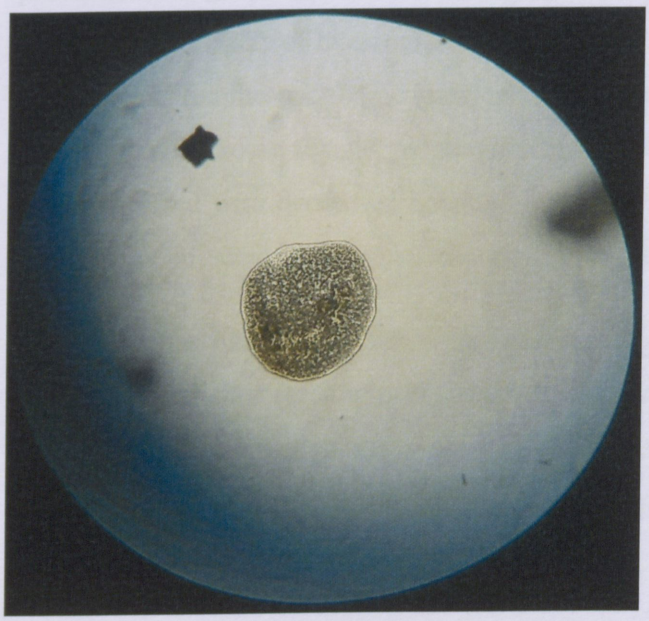

Figure 5.1: Embryonated Ascaris lumbricoides ovum.

5.3.1. What are the likely health problems that arise from consumption of Earth materials?

According to Ukaonu et al. (2003) geophagia could bind K in the intestine leading to severe hypokalemic myopathy. It may also cause a number of serious conditions such as heavy

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metal poisoning, hyperkalemia, iron and zinc deficiency, vitamin deficiency, intestinal obstruction or perforation, dental injuries and parasitic infestations (Dissanayake and Chandrajith, 2009). The research found that some non-pregnant geophagic women were diagnosed of anaemia and an *Ascaris* ovum (Fig 5.1) was detected in one geophagic material from Shayanba. During the field study, some geophagic practitioners were placed on admission for suffering from anaemia in some of the rural clinics due to craving for geophagic clay. Female geophagists eating an Earth material that was infested with Ascaris ovum are likely to be at risk of parasitic infections.

5.4. Discussion

Mean haemoglobin levels were low in female geophagists than in their non-geophagia practicing counterparts. This is consistent with previous studies on pica (a form of geophagy) in adults with Fe deficiency due to menorrhagia or pregnancy (Rector, 1989; Barton and Bertoli, 2010). Severe anaemia suggestive of Fe deficiency was associated with the prevalence of geophagy. These findings parallel those from the work of Raphuting et al., (2011) where results of haemoglobin levels for the control group were within reference range while levels for the geophagic group were decreased. The significant difference in the two results was that some female geophagists in Vhembe District were anaemic. Also, geophagia was associated with decreased haemoglobin concentration and a marginally risk of anaemia among HIV-infected women in Tanzania (Kawai et al., 2009).

Geophagia has been associated with Fe deficiency and anaemia, but no causal relationship has been established (Nyaruhucha, 2009; Raphuting et al., 2011). Other studies have reported geophagy to be associated with severe Fe deficiency anaemia in up to half of the people who practiced it (von Garnier et al., 2008; Kalanter-Zadeh et al. 2004). Conclusions drawn from these studies were supported by this present study.

Munoz et al. (1998) reported that occurrence of pica is not necessarily related to the severity of Fe deficiency anaemia. The control group in this study were neither anaemic nor Fe deficient and as such this study does not support the views of these investigators.

Geohelminth infection was linked to Fe deficiency anaemia among human immunodeficiency Virus (HIV) infected women who indulge in geophagia (Kawai et al., 2009; Bisi-Johnson et al., 2010). Anaemia resulting from geophagia, to which the craving for soil was attributed, is

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believed in some cases to have actually resulted from the worm infection encountered by ingestion of soil (Bisi-Johnson et al. 2010). This finding is not supported by the findings of present study or that of Bopape et al., (2008). The causes of Fe deficiency anaemia are known to be multi-factorial. These include; geophagy, inadequate intake of essential nutrients in diet and poor availability of Fe supplements in food (Odea, 2001; Bopape et al., 2008).

Some researchers have speculated geophagy to be a risk factor for soil transmitted helminth infection, exposure of individuals to parasites (Mokhobo, 1986; Kawai et al., 2009) and can contribute to the helminth load when soils with infective stages of parasites are consumed (Luoba et al., 2004; Peter, 2011). These observations were not consistent with findings in the present study, as no infective stages of parasites were identified in the geophagic materials.

Saathoof et al. (2002) and Glickman et al. (1999) found that geophagy is a risk factor for *A. lumbricoides* infection, and that it also plays a leading role in the transmission of other parasitic infections namely *toxocariasis* and *amoebiasis*. In this repect, results of this study differ from those of these authors as no well defined helminth ova could be extracted from the geophagic materials in this locality. In a related study by Sumbele et al., (2011) *A. lumbricoides*, *S. stercoralis*, *T. trichuria* and hookworm infection amongst geophagic individuals in the Eastern Cape Province of South Africa was linked to geophagy.

According to Shinondo and Mwikuma (2009), geophagy does not put pregnant women at risk for geohelminth infections because no ovum was isolated from the soils ingested by these women. Also, Kutalek et al. (2010) were of the opinion that geophagy is not a cause of adult helminth infection. Their finding is supported by this study as no geohelminth ova was identified in all the geophagic samples except one sample with an ovum, whose origin could be of environmental source (faecal droppings from pigs roaming in Shayanba community).

5.4.1 Limitations of this study

The major limitation of this study was inadequate number of control subjects (non geophagic women) equal to or close to the number of consenting subjects. Most women were not willing to participate in the study for fear of using their blood to determine their Human Immunodeficiency Virus (HIV) status. The study involved patients who had visited referral hospitals and clinics during the course of the study. Haemoglobin levels of other geophagic

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women who do not visit health facilities during the period of study were not determined in this study.

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5.5. Conclusions

This study has demonstrated that geophagy was associated with anaemia (decreased haemoglobin level) and not a probable mode for transmission of geohelminth infection (*A. lumbricoides*) amongst female geophagists in the Vhembe District. The single presence of geohelminth ova (*A. lumbricoides*) in geophagic materials could be due to the satisfactory sanitary state of the environment. There is need for health providers and social workers to educate the populace on dangers posed by eating Earth materials with high CEC as this could impede the uptake of soluble Fe, Mn and Cu leading to decreased haemoglobin level as reflected in this study. Some of the female geophagists with decreased haemoglobin level should be encouraged to eat iron rich foods to correct the decrease in haemoglobin level. The widely held view that geophagy is associated with anaemia is supported by this study.

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HUMAN BIOACCESSIBILITY OF TRACE ELEMENTS IN CONSUMED EARTH MATERIALS FROM VHEMBE DISTRICT, LIMPOPO PROVINCE, SOUTH AFRICA

Abstract

This study focuses on investigations of bioaccessible trace elements and potentially harmful elements (PHEs) following consumption of Earth materials by humans. Element associations are studied by application of factor analysis on the range of elements analysed. A two-stage physiologically based extraction test simulating the human stomach and intestine was used to estimate the human bioaccessibility of essential trace elements and PHEs in consumed Earth materials. Extracts from these Earth materials were analysed by inductively coupled plasma mass spectroscopy (ICP-MS). The mean concentrations of elements for the stomach and intestinal phases respectively, were as follows; Fe, 0.90 and 0.20 ppm; Zn, 81.44 and 22.42 ppm; Se, 10.10 and 9.02 ppm; Mn, 1672.7 and 1900 ppm; Cu, 24.93 and 230.04 ppm; Co, 11.73 and 11.72 ppm; As, 2.22 and 3.23 ppm; V, 29.50 and 35.91 ppm; Cr, 5.59 and 102.87 ppm; Ni, 5.53 and 21.28 ppm; Cd, 0.09 and 0.05 ppm; and Pb, 5.52 and 6.72 ppm. Iron and Zn showed higher bioaccessibility under gastric conditions whilst Cu, Mn, As, V and Ni were more bioaccessible in the intestinal phase. Concentrations of Se, Co, Cd, and Pb were the same in gastric and intestinal phases. Principal Component Analysis was used to study relationships amongst bioaccessible element concentrations. There were strong associations between Zn, Fe and Mn as essential trace elements, while the PHEs: Hg, Pb, Ni and V were found to be strongly associated with each other. Bioaccessible analyte concentrations were found to be correlated with pseudo-total analyte concentrations for all elements except Fe and Zn. The consumed Earth materials could contribute the daily recommended nutrient intake of Fe and a significant source of Zn, Mn and Cu for geophagic practitioners. Lead and As are the PHEs of greatest health concern in this locality.

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6.1. Introduction

Intentional or sometimes inadvertent consumption of Earth materials such as (clays, sands, dried up pond sediments, ant hills, termite mounds and wall scrapings) is referred to as geophagy or geophagia. It is a universal practice, but most common in sub-Sahara Africa and amongst rural black women of South America (Abraham, 2002).

Trace element is a chemical element that is needed in minute quantities for the proper growth, development and physiology of an organism (Bowen, 1996). All organisms require a specific intake level of essential trace elements for proper physiological functions. Deficient or excess levels of concentration for the essential elements can lead to adverse health effects and in certain cases death (Plant et al., 1996).

The practice of geophagy has been shown to supply 17% to 55% of recommended intake levels of Ca, Mg, Zn, Fe, Cu, Mn, Se, K and Co as supplementation for pregnant women (Hunter and de Kleine, 1984; Brand et al., 2009). In Ghana, Fe, Cu, Ca, Zn and Mn consumed in clays were in the range of 2 – 15% of recommended dietary allowances (Hunter, 1973).

One consequence of soil ingestion is that the amounts and balance of mineral nutrients within the individual will be affected. Clays, on entering the alimentary tract will first encounter the acidity of the stomach giving up the elements that they hold by cation exchange. Important amounts of mineral nutrients such as Cu, Fe, Mn and Zn can be supplied directly to geophagists via ingested soil (Johns and Duquette, 1991; Abrahams, 2002).

The ingestion of soil has been associated with inducing deficiencies of Fe, K and Zn in humans. Zinc deficiency has been reported in the mentally retarded and in various other societies/countries including Iran and Turkey and the aboriginal people of North West Australia (Danford et al., 1982; Cavdar et al., 1983; Abrahams, 2012).

Research by Hooda et al. (2004) on the potential impact of soil ingestion on human mineral nutrition revealed that the sorption potential of some consumed soils by geophagists lowers the bioaccessibility of Cu, Fe and Zn, although other materials were identified to be a source of Ca, Mg and Mn that humans could potentially utilise. Consumption of Earth materials having excessive trace elements may affect the health status of the geophagic individual. The

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constituents and the *in vivo* function of the materials being consumed should satisfy the needs of the consumer without being harmful (Brand et al., 2009).

Mascolo et al. (1999) warned earth eating women and children about the dangers of eating grey clays. These clays were observed to contain toxic trace elements such as As, Cd, Hg, Ti and Pb. These elements, when ingested, cause brain damage, as well as impair the red blood cells and kidneys. Metal toxicity due to geophagic practice by pregnant women may not only affect the consumer but also the unborn baby (Mascolo et al., 1999)

Lead poisoning and other toxic metal disorder could occur as a result of pica (abnormal ingestion of non-food substances). In regions associated with soils derived from the weathering of mineral deposits or mine wastes, high levels of PHEs such as Pb and radionuclide may be readily available (Trivedi et al., 2005; Ljung et al., 2006; Ferrel, 2008).

The bioaccessible fraction is the fraction that is mobilized from its matrix (e.g. dust, soils, water, food) in the human gastro-intestinal tract and becomes available for intestinal absorption (Oomen et al., 2006). The oral bioavailable fraction of a compound is the fraction that is available for systemic circulation (i.e. in the blood stream) and can exert adverse effects (Rousell et al., 2010).

Geochemists have developed PBET to estimate the bioavailability of potentially toxic elements following accidental or deliberate ingestion of contaminated soil, where data from suitable animal models is unavailable (Ruby et al., 1996; Sialelli et al., 2010). These tests involve treatment of a test portion of the soil with simulated gastro-intestinal tract fluids, at physiological temperature and pH.

The results from this procedure have shown good correlation with results obtained from animal studies for Pb and As. The procedure was later modified and simplified (Rodriguez et al., 1999; Cave et al., 2006).

Ljung et al. (2007) used the PBET to investigate the bioaccessibility of As, Cd, Cr, Ni and Pb in two particle size fractions (<4 mm and <50 μm) of play ground soils from Uppsala, Sweden to assess the likely hazard arising from both deliberate and accidental ingestion of soil by children (Sialelli et al., 2010).

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6.2. Objectives of the study

The main objective of this study was to determine the bioaccessibility of four key essential trace elements (Fe, Zn, Cu and Se) in consumed Earth materials. The presence of these trace elements in the readily available fraction for human adsorption may yield clues to the physiological reasons for consumption of Earth materials. The specific objectives of this study were:

1. To assess the concentration levels of any PHEs in Earth materials that is consumed by humans.
2. To ascertain if the Earth materials could supply the daily recommended nutrient intake of Fe to geophagists in this locality.

6.3. Materials and methods

6.3.1. Study site and sample collection

The study site, sample collection and preparation have already been described in section 4.3.1 and 4.3.2.1.

6.3.2. Sample analyses

Reagents

The reagents used were tri-sodium citrate (Analar R), DL malic acid (GPR), lactic acid syrup, sodium hydrogen carbonates (GPR), pancreatin, pepsin and 1,000 mg/l spectrosol stock solutions for calibration.

Solution A (stomach phase)

Two and half grams pepsin, 1 g tri-sodium citrate, 1 g DL malic acid and 840 µl lactic acid syrup were mixed, the mixture diluted with distilled water, acidified to pH 1.5 with HCl, and made up to 2 L in a standard flask.

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Solution B (intestinal phase)

Solution B was prepared from the stomach phase solution by the addition of 500 mg pancreatin per L of solution, and neutralized to pH 7 by the addition of 13 g of solid sodium hydrogen carbonate.

6.3.2.1. Physiologically based extraction procedures

Stomach phase

Zero point five grams of geophagic clay was weighed into a 50 ml screw cap Sarstedt tube and 10 ml of solution A was added. The mixture was shaken for 1h at 150 rpm and on an end over end shaker maintained at 37^0C. At that stage the pH of each soil suspension was checked (pH was maintained between 1.2 - 1.7) and the mixture was allowed to settle under gravity. A 5 ml aliquot of the supernatant was taken for analysis by ICP-MS with a disposable plastic syringe.

Intestinal phase

Zero point five grams of geophagic clay was placed in a 50 ml screw cap Sarstedt tube and treated with 10 ml of solution A by manually shaking the soil-fluid mixture in the screw cap. After 5-15 minutes, the mixture was neutralized and pancreatin added to bring the composition to that of intestinal solution. The bottle was shaken for 2h (150 rpm, 37^0C). The resultant pH of the suspension was adjusted to 6.3 by dropwise addition of 37% HCl as required. The mixture was again shaken on an end over end shaker maintained at 37^0C for 4h. The soil suspension was then removed and its pH measured (and recorded). The pH was maintained between 6.3 and 6.5 by addition of little drops of 37% HCl. Finally, 5 ml aliquot was removed for analysis as described in section 6.3.2.1.

6.3.3. Quality control

No certified reference material is available for these analytes extractable by physiologically based extraction procedures. The assessment to the accuracy of the PBET method was done using some of the geophagic samples that were digested in triplicate and analysed. The standard deviation was calculated from these results. Iron was used to test for the analytical precision and it indicated a low standard deviation ranging from 0.01 to 0.16 (Table 6.1).

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Table 6.1: Concentration of gastric phase extraction concentration (mg/l), mean and standard deviation for analytical precision determination

Sample ID	*Concentration of elements in extracted gastric phase (mg/l)*				
	Replicate1	*Replicate 2*	*Replicate 3*	*Mean*	*Standard deviation*
10	1.09	1.23	1.42	1.25	0.16
15	1.57	1.59	1.63	1.60	0.03
30	0.04	0.02	0.02	0.03	0.01

These values show that the analytical results were reproducible, and that element concentrations were close to their mean values.

De-ionised water prepared by cation exchange method was used as blank to zero the instrument and as solvent, in the analysis of all samples, to minimise contamination.

6.3.4. Determination of oral bioaccessibility

The oral bioaccessibility of trace elements from consumed Earth materials can be determined using the PBET method. The percentage bioaccessible fraction (% BAF) can be calculated using this equation:

$$\text{Bioaccessible fraction (\%)} = \frac{C_{\text{Bioaccessibility}}}{C_{\text{total}}} \times 100$$

Where $C_{\text{Bioaccessibility}}$ = Concentration of trace element released from soil (mg/kg) obtained via PBET stage I (stomach) or stage II (stomach + intestinal);

C_{total} = Total concentration of trace element in consumed Earth materials (mg/kg).

6.4. Statistical analysis

To study the associations among essential trace elements and PHEs in geophagic samples, correlation coefficient and PCA were calculated using IBM SPSS-19.0 statistical software. The Varimax method was chosen as the rotation method for PCA. Descriptive statistics of the samples analysed for the trace elements and PHEs are tabulated in Table 6.4.

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The results of oral bioaccessibility of trace elements from consumed Earth materials are shown in Tables 6.2 and 6.3.

Table 6.2: Results of simulation experiments for bioaccessible essential trace elements in gastric and intestinal phases (ppm).

	Stomach phase					*Intestinal phase*				
Sample	*Fe*	*Zn*	*Mn*	*Se*	*Cu*	*Fe*	*Zn*	*Mn*	*Se*	*Cu*
1	0.80	5.83	2484	8.42	21.92	0.46	8.79	3221	24.34	47.54
2	2.05	34.81	1485	28.15	17.93	0.55	56.39	1618	17.39	236.3
3	0.45	0	6.61	8.53	6.06	0.29	24.37	13.06	10.16	52.45
4	0.32	11.15	28.88	5.31	10.90	0.03	5.27	6.92	8.56	41.85
5	0.71	0	18.64	10.62	9.26	0.21	9.23	24.04	0	43.02
6	0.47	11.24	83.25	13.21	11.56	0.06	12.5	41.49	0	32.15
7	1.11	12.73	2607	0	26.30	0.38	11.13	2870	25.87	55.19
8	0.94	11.05	2316	41.51	16.08	0.14	6.67	1376	30.39	5156
9	1.34	14.98	2155	16.27	19.61	0.35	6.15	2842	9.85	76.51
10	1.10	30.64	2410	22.78	19.14	0.46	7.79	3644	0	55.94
11	1.24	142.7	2483	16.6	20.68	0.20	10.1	1727	11.68	61.98
12	1.34	22.05	2254	7.44	23.49	0.24	11.04	2944	0	61.93
13	1.28	198.2	2571	0	31.77	0.17	16.16	2284	15.45	57.16
14	0.93	66.09	2134	0	23.11	0.17	25.58	1812	15.08	53.73
15	1.55	53.72	2607	16.21	22.86	0.37	86.30	2919	0	91.48
16	9.52	1463	7139	0	55.8	0.54	17.9	3953	8.08	94.92
17	0.90	35.43	2351	19.87	27.76	0.51	8.71	3843	25.67	49
18	1.96	38.89	1982	1.41	28.30	0.67	29.61	2538	15.79	64.57
19	0.04	37.77	747	27.81	24.17	0.03	11.66	772.70	0	39.86
20	0.02	80.14	2383	3.76	38.67	0.02	8.04	3359	0	52.90
21	0.02	13.08	1472	0	38.97	0.02	213	6789	0	95.54
22	0.02	6.25	167.60	16.8	9.73	0.02	4.84	2264	0	59.81
23	0.02	66.08	1581	2.2	70.44	0.02	9.05	1107	1.83	35.55
24	0.02	0	173.30	1.42	20.97	0.02	5.20	274.4	12.76	46.40
25	0.02	35.75	672.60	0.32	40.15	0.02	6.64	480	6.4	35.16
26	0.02	0.887	754.10	0.96	34.38	0.02	3.64	55.96	8	111.90
27	0.02	9.01	334.20	7.56	21.11	0.02	8.26	641.4	6.77	11.17
28	0.02	11.06	993.40	9.80	2.93	0.02	22.02	1411	3.04	45.18
29	0.02	14.91	1986	16.21	25.92	0.02	7.69	1785	0	28.04
30	0.02	15.87	1804	0	28.03	0.02	19.16	386.8	13.58	8.04

All elements studied have a wide variation in their concentrations, with the greatest variations being shown by Zn, Mn and Cu (Table 6.2). The consumed Earth materials in the locality

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contain maximum concentrations for Fe, 2 ppm; Zn, 198 ppm; Mn, 2484 ppm; Se, 28.15 ppm; and Cu, 70.44 ppm. Bioaccessible analyte concentrations are presented in Figures 6.1 to 6.4. For Fe, concentrations in the intestinal phase in sample 4 and from samples 19 to 30 are not reflected because they were below the analytical LoD of 0.00011ppm, but concentrations were measurable in the remaining samples (Fig. 6.1)

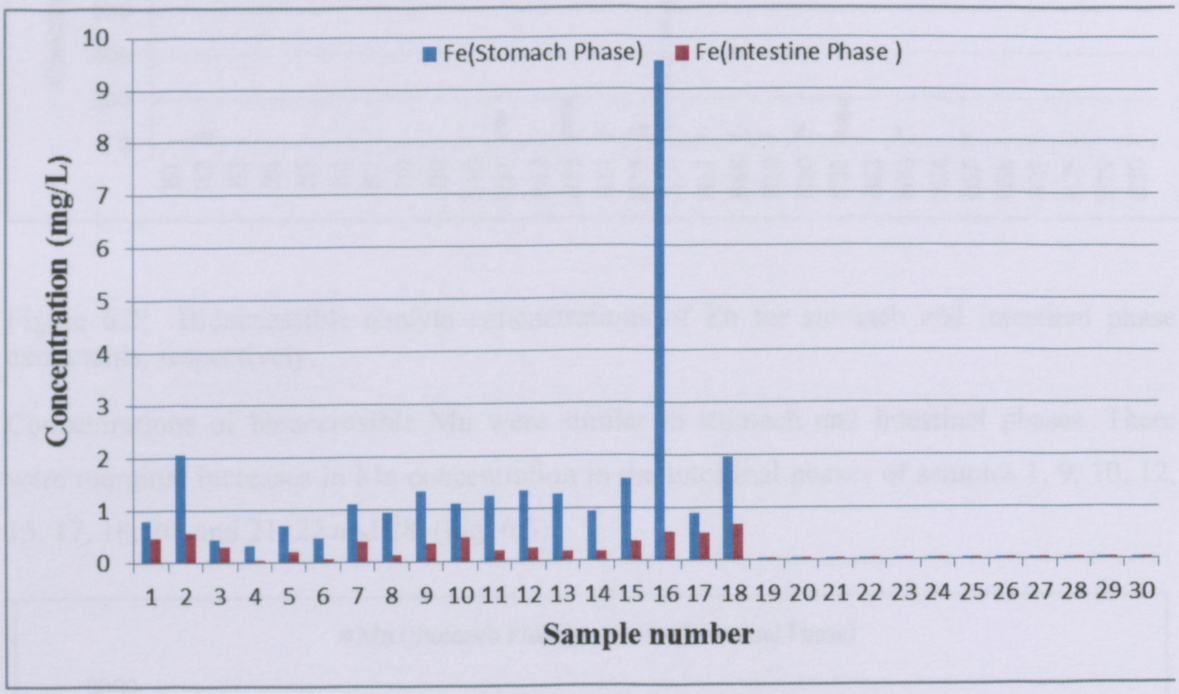

Figure 6.1: Bioaccessible analyte concentrations of Fe for stomach and intestinal phase extractants.

Concentration of bioaccessible Zn for stomach and intestinal phases were similar for samples 4 to 10, and samples 22 to 30. Intestinal phase extractants of samples 2, 3, 14, 15 and 21 were more visible compared to other geophagic samples from the locality. Sample 16 had the highest bioaccessible analyte concentration in the stomach phase (Fig. 6.2).

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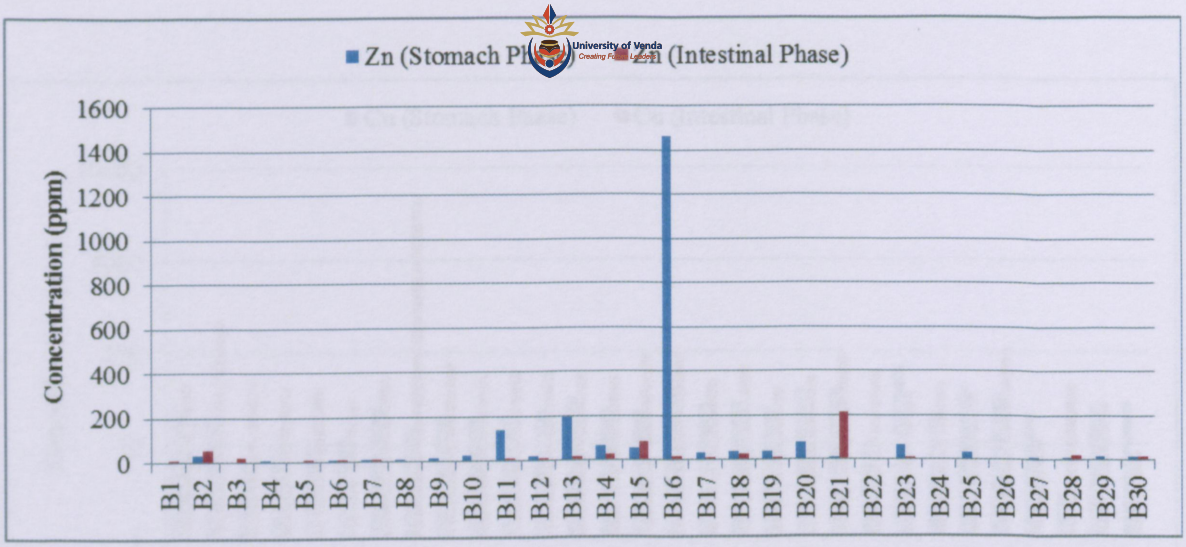

Figure 6.2: Bioaccessible analyte concnetrations of Zn for stomach and intestinal phase extractants, respectively.

Concentrations of bioaccessible Mn were similar in stomach and intestinal phases. There were marginal increases in Mn concentration in the intestinal phases of samples 1, 9, 10, 12, 15, 17, 18, 20, and 21, 22 and 28. (Fig. 6.3).

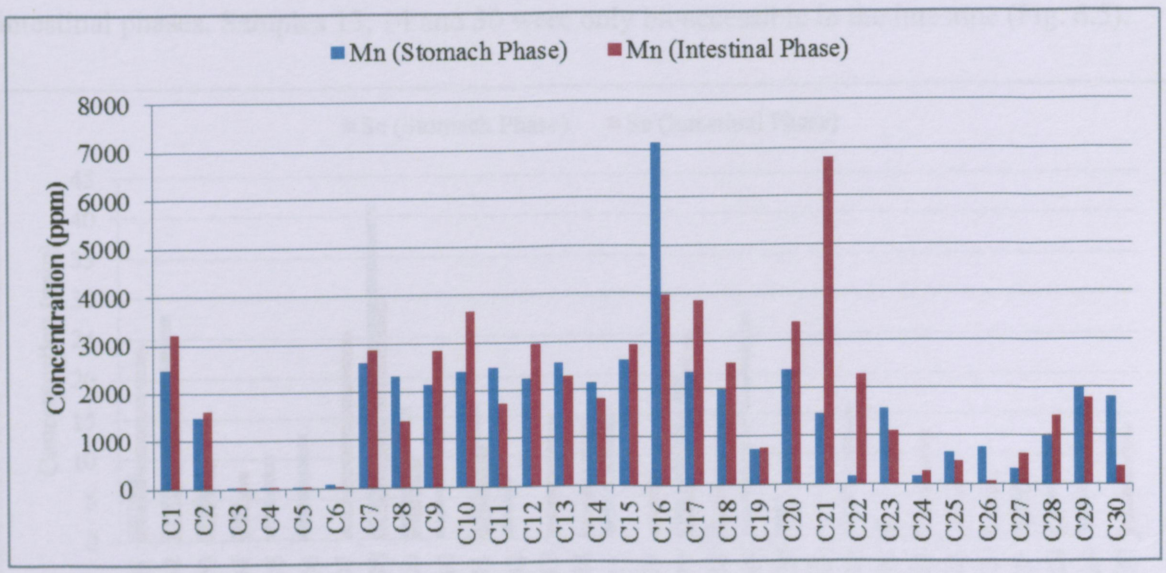

Figure 6.3: Bioaccessible analyte concentrations of Mn in stomach and intestinal phase extractants, respectively.

Copper bioaccessibility increased slightly in almost all the samples from stomach to intestinal phase except samples 23 and 30 (Fig. 6.4). The most outstanding sample from this locality was sample 8 where the intestinal phase was almost threefold than the stomach phase.

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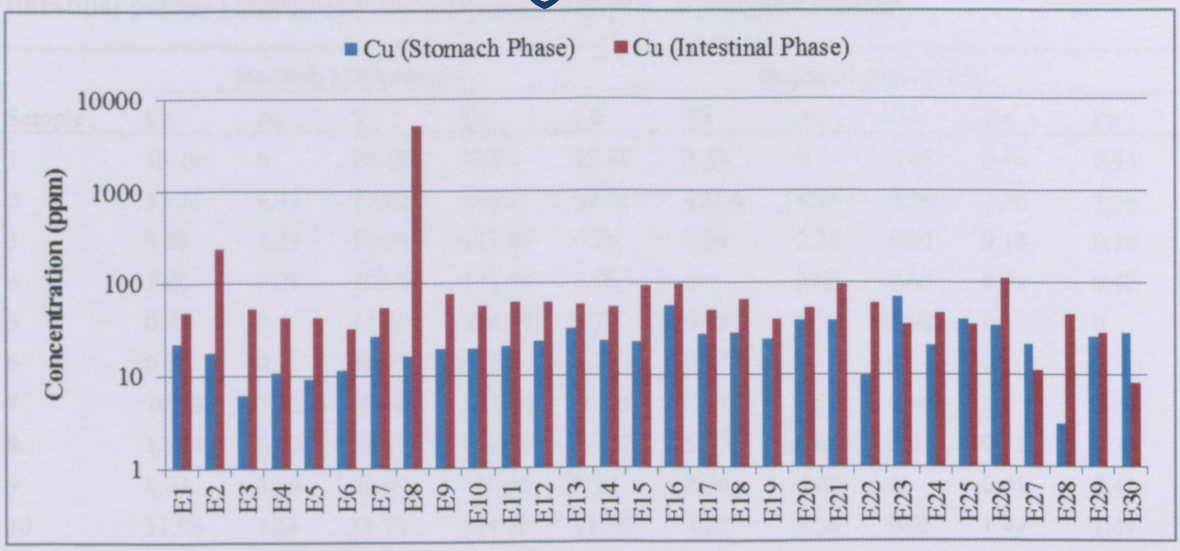

Figure 6.4: Bioaccessible analyte concentrations of Cu for stomach and intestinal phase extractants

Selenium was found to be completely non-bioaccessible for both phases in sample 21, while samples 5, 6, 12, 15, 20, 22 and 29 had no concentration of bioaccessible anlyte extraction for intestinal phases. Samples 13, 14 and 30 were only bioaccessible in the intestine (Fig. 6.5).

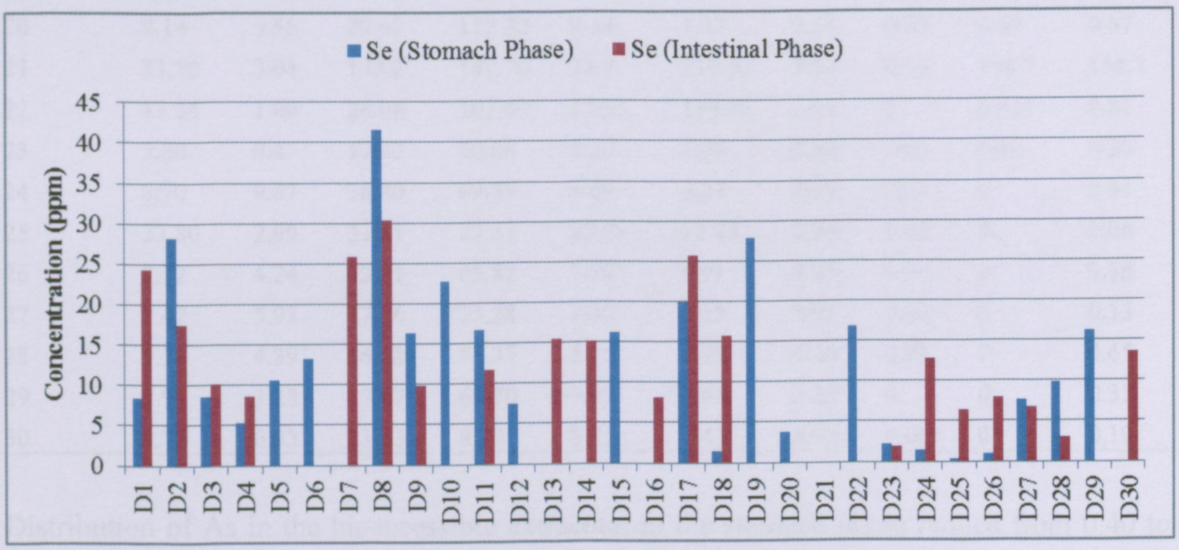

Figure 6.5: Bioaccessible analyte concentrations of Se for stomach and intestinal phase extractants, respectively.

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Table 6.3: Results of simulation experiments for bioaccessibility of PHEs in stomach and intestinal phases respectively for geophagic samples in Vhembe District.

	Stomach phase (ppm)				Intestinal phase (ppm)					
Sample	Co	As	V	Cr	Co	Ni	As	Cd	Hg	Pb
1	13.16	6	26.62	139.2	13.16	3.28	6	0.03	0.44	0.44
2	53.75	4.44	77.91	146.2	53.75	121.4	4.44	0.04	3.36	3.36
3	0.26	2.38	12.94	121.80	0.26	0.04	2.38	0.03	0.14	0.15
4	1.96	3.09	128.50	135.30	1.96	0	3.09	0.03	0.39	0.40
5	0.73	0	13.39	134.30	0.73	0.08	0	0.08	0	0
6	0.72	0	31.03	31.03	0.72	0.93	0	0	0	0
7	16.53	7.12	39.38	139.60	16.53	7.37	7.12	0.10	1.1	1.10
8	12.97	6.67	32.77	132.50	12.97	5.53	6.67	0.05	0.71	0.71
9	8.94	3.09	23.09	119.90	8.94	2.06	3.09	0	0.41	0.41
10	11.96	1.56	22.71	114.60	11.96	3.52	1.56	0.05	1.49	1.49
11	8.22	1.14	24.35	115.70	8.22	2.21	1.14	0.06	0.58	0.58
12	8.25	1.04	24.09	124.10	8.25	34.05	1.04	0	0.39	0.39
13	6.94	3.57	25.56	112.80	6.94	2.89	3.57	0	0.83	0.84
14	4.27	2.60	15.05	105.80	4.27	2.72	2.6	0	0.67	0.67
15	10.86	0	59.28	59.28	10.86	28.13	0	0.23	18.53	18.53
16	33.47	2.76	35.93	117.10	33.47	8.49	2.75	0	1.01	1.01
17	13.17	4.95	21.19	118.80	13.17	2.21	4.94	0	1.08	1.08
18	15.22	2.93	41.61	125.10	15.22	16	2.93	0	7.54	7.54
19	4.42	0.61	18.46	119	4.42	2.89	0.61	0	0.81	0.81
20	9.14	0.56	29.67	112.30	9.14	3.37	0.56	0.07	0.57	0.57
21	33.70	3.04	143.2	149.70	33.7	218.50	3.04	0.19	158.7	158.7
22	13.35	1.60	26.96	107.40	13.35	119.40	1.59	0	0.811	0.81
23	5.20	0.4	17.92	70.06	5.20	5.23	4.30	0.01	0.02	0.20
24	8.70	9.87	38.40	69.37	8.69	6.27	0.55	0.08	0	0.31
25	23.80	2.99	31.81	72.31	23.78	12.25	2.99	0.09	0	0.06
26	7.72	4.24	43.21	65.82	7.72	5.91	4.24	0.30	0	0.16
27	2.42	5.93	17.46	75.28	2.42	7.15	5.93	0.07	0	0.13
28	5.15	4.39	16.28	73.37	5.15	5.73	4.39	0.01	0	0.65
29	7.97	3.28	17.07	69.70	7.97	3.63	3.28	0	0	0.31
30	8.77	6.93	21.53	8.77	8.77	7.41	6.93	0.06	0	0.19

Distribution of As in the bioaccessible extractant in the stomach phase ranged from 0.40 to 6.67 ppm, while in the intestinal phase ranged from 0.55 to 0.67 ppm (Table 6.2). Cobalt ranged from 0.26 to 53.75 ppm in the stomach and intestinal phase respectively. Bioaccessibility of Co for the stomach and intestinal phase extractions were similar for most of the samples from the area of study (Fig. 6.6). Cadmium, Hg and Pb were not bioaccessible in the stomach phases

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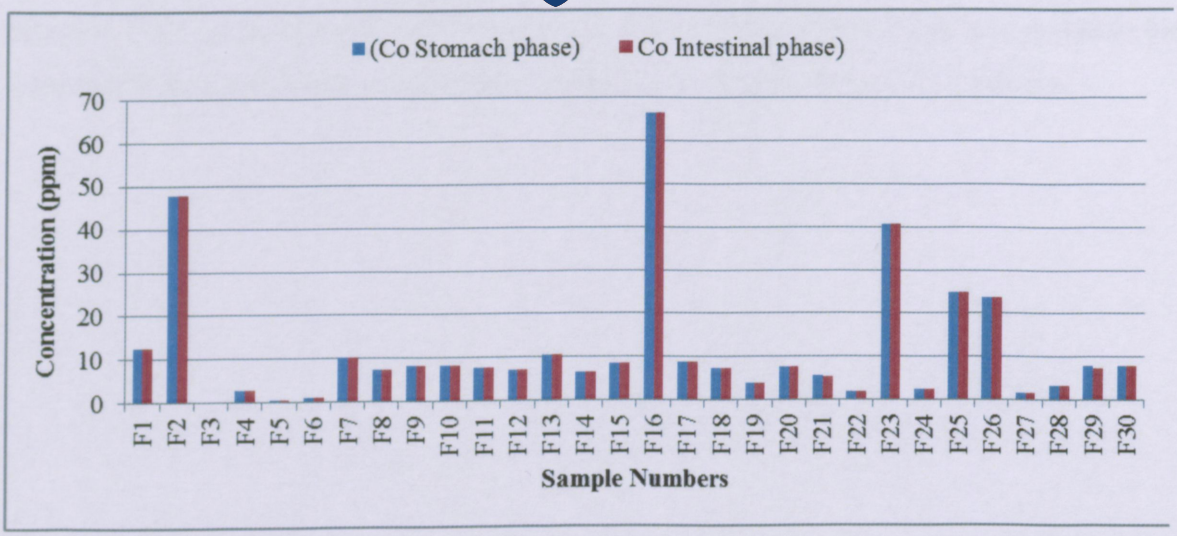

Figure 6.6: Bioaccessible analyte concentrations of Co for stomach and intestinal phase extractants, respectively.

Concentration of bioaccessible As were broadly similar in stomach and intestinal phases respectively for all the samples (Fig. 6.7). The trend could be due to variations in pH and CEC of the consumed Earth materials.

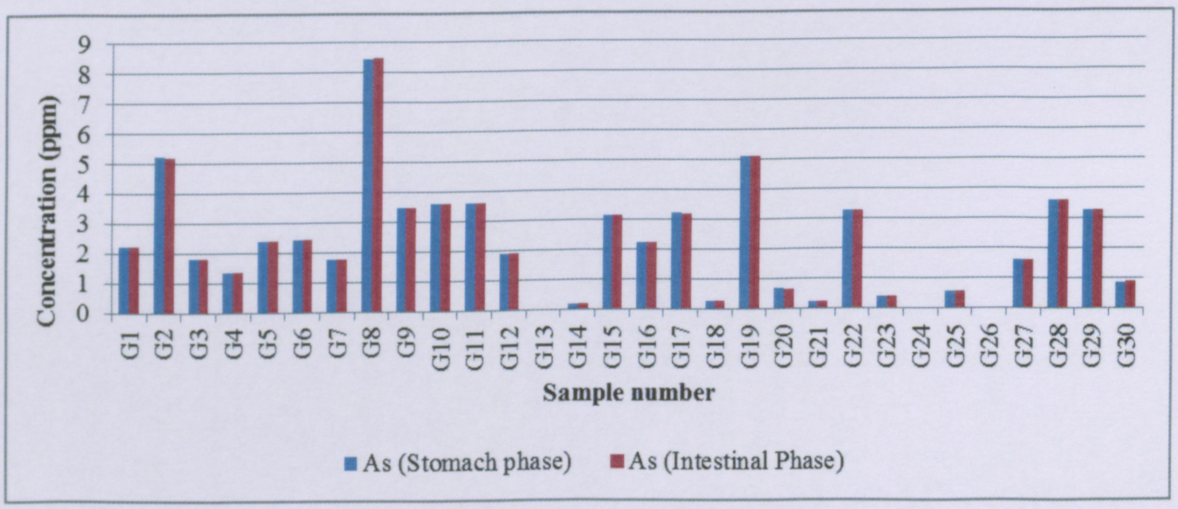

Figure 6.7: Bioaccessible analyte concentrations of As for stomach and intestinal phase extractants.

The summary data on bioaccessibility for the 30 samples are presented in Table 6.4. The bioaccessibility data in percent BAF shows the actual concentration of the element in the extract, and is related to the total concentration of the element.

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The minimum, maximum, mean metal concentration and % BAF (amount of element released from Earth materials in the human gastro-intestinal tract and becomes available for intestinal absorption) determined for each extraction stage are presented in Table 6.4.

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Table 6.4: Summary of stage related bioaccessibility

	Stage 1 Stomach phase (ppm)						*Stage 2 Intestinal phase (ppm)*						
Element	*%BAF*	*min.*	*max.*	*mean*	*median*	*S.D*	*%BAF*	*min.*	*max.*	*mean*	*Median*	*S.D*	*Det.Lim*
Fe	75	0.02	9.52	0.94	0.59	1.74	16	0.02	0.67	0.20	0.15	0.10	0.0001
Zn	84	0.00	1,463.00	81.44	15.42	264.50	23	3.64	213	22.42	9.66	12.78	0.0003
Se	-	0.00	41.51	10.10	7.99	10.46		0.00	30.90	9.02	8.04	9.10	0.002
Mn	90	6.61	7.13	1672.7	1893	1401.43	90	6.92	6789	1900	1756	876.17	0.003
Cu	56	2.93	70.44	24.93	22.98	14.09	95	8.04	5156	230.04	53.31	131.24	0.002
Co	44	0.15	66.35	11.73		15.04		0.26	53.75	11.72	8.73	11.40	0.002
As	95	0.00	8.47	2.22	2.04	1.91	80	0.00	9.87	3.23	3.01	2.46	0.003
V	20	3.74	83.39	29.50	26.25	16.46	24	12.94	143.20	35.91	26.09	30.55	0.0001
Cr	7	2.86	10.26	5.59	5.44	1.39	89	8.77	149.70	102.87	115.15	35.05	0.0002
Ni	10	0.00	39.67	5.33	2.76	8.14	38	0.00	218.50	21.28	5.38	47.69	0.0003
Cd	-	0.00	0.36	0.0.09	0.08	0.09		0.00	0.30	0.05	0.03	0.07	0.0001
Hg	-	0.00	47.45	4.08	2.89	8.56		0.00	158.70	6.65	0.50	28.93	0.0001
Pb	25	0.00	47.45	5.52	3.55	8.52	31	0.00	158.70	6.72	0.57	28.91	0.002

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Element concentrations extracted from geophagic materials within the simulated gastric and gastro-intestinal phases, respectively were, on average: 0.90 and 0.20 ppm Fe; 81.44 and 22.42 ppm Zn; 10.10 and 9.02 ppm Se; 1672.7 and 1900 ppm Mn; 24.93 and 230.04 ppm Cu; 11.73 and 11.72 ppm Co; 2.22 and 3.23 ppm As; 29.50 and 35.91 ppm V; 5.59 and 102.87 ppm Cr; 5.33 and 21.28 ppm Ni; 0.09 and 0.05 ppm Cd; and 5.52 and 6.72 ppm Pb.

Iron, Zn, Se,, Mn, Co and Cd gastric extractions showed a higher bioaccessibility than gastro-intestinal extractions; while Cu, As, V, Cr, Ni, Hg and Pb gastro-intestinal extractions showed a higher bioaccessibility than gastric extractions (Table 6.3). There was a high variation in metal bioaccessibility among the geophagic materials for the gastric extraction compared with the gastro-intestinal one (For Fe, 0.94 ± 1.74 for gastric extraction and 0.20 ± 0.20 for gastro-intestinal extraction). Selenium, Co and As solubilities were shown to be similar in the gastric and intestinal compartments. The bioaccessibility of essential elements increased in the order Fe < Se < Cu < Zn < Mn in both the gastric phase and gastro-intestinal phases. The difference in bioaccessibility between elements could be due to the differences in their behaviour.

Iron exhibits positive correlation matrix with all essential elements (Table 6.5). Iron and Mn were all positively correlated suggesting that they are similar in terms of their level of intake or involvement in similar physiological functions.

Table 6.5: Correlation matrix of the bioaccessible essential trace elements from stomach and intestinal phase extractant.

	Stomach phase					*Intestinal phase*				
	Fe	*Zn*	*Mn*	*Se*	*Cu*	*Fe 2*	*Zn 2*	*Mn 2*	*Se 2*	*Cu 2*
Fe	1.00									
Zn	0.94	1.00								
Mn	0.82	0.78	1.00							
Se	-0.07	-0.20	-0.06	1.00						
Cu	0.33	0.46	0.51	-0.42	1.00					
Fe 2	0.59	0.31	0.54	0.16	0.00	1.00				
Zn 2	0.00	-0.03	0.05	-0.11	0.14	0.02	1.00			
Mn 2	0.33	0.27	0.60	-0.03	0.31	0.41	0.58	1.00		
Se 2	0.13	-0.01	0.24	0.13	-0.06	0.43	-0.18	0.03	1.00	
Cu 2	0.01	-0.04	0.10	0.58	-0.12	-0.04	-0.06	-0.05	0.45	1.00

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Copper – Zn; Cu - Mn were weakly correlated with R^2 (correlation co-efficient) ranging between -0.03 to -0.12. According to Rousell et al. (2010), the observed relationships can be explained by the interactions of the metal with different soil compartments, i.e. cation exchange capacity of geophagic materials and soil pH.

For the toxic trace elements, the results obtained showed weak linear relationships between bioaccessibility values for stomach and intestinal phases (Table 6.6).

Table 6.6: Correlation matrix of the bioaccessible toxic trace elements from stomach and intestinal phase extractants

	Stomach phase						*Intestinal phase*			
	Co	*As*	*V*	*Cr*	*Co 2*	*Ni*	*As 2*	*Cd*	*Hg*	*Pb*
Co	1.00									
As	-0.01	1.00								
V	0.53	-0.04	1.00							
Cr	0.56	0.08	0.35	1.00						
Co 2	1.00	-0.01	0.53	0.56	1.00					
Ni	0.37	-0.11	0.12	0.03	0.37	1.00				
As 2	-0.01	1.00	-0.04	0.08	-0.01	-0.11	1.00			
Cd	0.31	0.13	0.26	0.19	0.31	0.13	0.13	1.00		
Hg	-0.11	0.10	-0.02	-0.32	-0.11	-0.11	0.10	0.06	1.00	
Pb	-0.16	0.03	-0.16	-0.46	-0.16	-0.06	0.03	0.01	0.94	1.00

The total concentrations for Co, As and Ni increased in the stomach phase. There was a decrease in the intestinal phase for the three elements. The coefficients of correlation (R^2) varied between -0.01 and 1.00. The correlation between As in the stomach and intestinal phase was strong, while correlation between Co stomach phase was -0.01. The bioaccessibility of elements could be affected by the physico-chemical parameters of geophagic materials (pH, organic matter, cation exchange capacity and electrical conductivity)

The results of varimax rotated factor loadings matrix and commonalities obtained from PCA for the trace elements studied are shown in Table 6.8 and 6.9 respectively. Principal component analysis is a statistical tool used to assess metal behaviour in Earth materials (Liu et al., 2003) and it is applied to detect the hidden structure and associations of elements in the data set, in an attempt to explain the influence of latent factors on the data distribution (Simeonov et al., 2000; Krishna et al., 2011). The rotated component matrix for the essential elements showed two components (Table 6.7).

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Table 6.7: Varimax rotated factor loadings matrix and communalities obtained from principal component analysis for essential elements in stomach and intestinal phases

Variables	*Comp. 1*	*Comp. 2*	*Communality*
Zn	0.945		0.879
Fe	0.937		0.902
Mn	0.759		0.576
Se		0.804	0.648
Cu		0.793	0.629
EV	2.35	1.284	
VAR (%)	46.993	25.677	
CVAR (%)	46.993	72.67	

Component I has a total variance of 46.99% and strong loadings of Zn, Fe and Mn. The second component account for 25.67% total variance and loadings on Se and Cu vary between 0.793 and 0.804. For the toxic trace elements, the rotated component matrix showed four components (Table 6.8).

Table 6.8: Varimax rotated factor loadings matrix and communalities obtained from principal component analysis for toxic elements in stomach and intestinal phases

Variables	*Comp. 1*	*Comp. 2*	*Comp. 3*	*Comp. 4*	*Communality*
Hg	0.971				0.947
Pb	0.967				0.942
Ni	0.81				0.799
V	0.668	0.415			0.619
Co 1		0.975			0.977
Co		0.975			0.977
As			0.95		0.905
As 1			0.947		0.901
Cd				-0.794	0.74
Cr				0.788	0.739
EV	3.14	2.24	1.85	1.31	
VAR (%)	31.42	22.44	18.53	13.08	
CVAR (%)	31.42	53.86	72.39	85.47	

Component I represents 31.42% of total variance. Mercury, Pb, Ni and V were the elements that are associated with geophagic materials in this group. Component II represents 22.44% of total variance with a load on cobalt in excess of 0.90; component III represents 18.53% of total variance. Geophagic materials in this group are enriched in As. Component IV represents 13.08% of total variance showing a strong negative loading of – 0.794 for Cd and a strong loading on Cr.

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6.5.1. Are there enough essential nutrients in Earth materials for uptake by the geophagists?

Iron is the mineral nutrient most prominent in the literature that discusses geophagia. According to Abrahams (pers. comm.), soils do have the potential to supply mineral nutrients, especially iron, where the ingestion of soil can account for a major proportion of RNI. But not all soils that are deliberately consumed by humans are enriched in mineral nutrients.

The research found that bioaccessible fraction of Fe was completely absent from simulated stomach and intestinal solutions of some geophagic materials. Majority of the women consume between 50 - 70 g of Earth material on daily basis, but the pregnant women consume more of the Earth material compared to non-pregnant women. Going by the reported rates of ingestion of some geophagic samples, geophagia practitioners could derive the recommended nutrient intake of Fe from samples 1, 2, 7, 9, 10, 15 to 18 respectively.

6.6 Discussion

The different trends in analyte bioaccessibility between simulated stomach and intestinal phases are due to pH and possible reactions of PHEs with soil matrix components and potential ligands in the extractant solutions. The increase in Cr bioaccessibility in the intestine may be due to the formation of soluble oxy-species stable at neutral, but not acidic, pH, in combination with the oxidation of Cr^{3+} to Cr^{6+} by MnO_3 species derived from the soil (Eary and Ral, 1987; Sialelli et al., 2010).

Smith et al. (2000) used a mixture of pepsin and organic acids in 1% HCl adjusted to pH 2 to determine whether selected geophagical clays could provide a major portion of the daily recommended quantity of Fe, but not for other elements. In this study, Fe, Zn, Se, Mn and Cu were the essential elements that were bioavailable for the geophagist uptake in some consumed Earth materials. On consumption of an average 40 g of some geophagic materials from this locality, 16 mg/d of Fe was found to be available and this is slightly above the RNI of Fe. In a related study, where 0.1 M HCl extraction of edible clays consumed by women in Belize was carried out by Hunter and de Klein (1984), it was realised that 26% of the total available Ca, 17% of Cu and 14% of Zn was bioavailable and could account for 5 – 18% of the RNI of the elements (Ferrel, 2008). The PBET method used in this study produced

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significant amounts of bioavailable essential trace elements and was similar to the acid extraction methods used by Hunter and de Kleine, (1984).

However, the bioavailability of elements extracted with a strong acid has been questioned by the realisation that elements mobilised in simulated stomach may precipitate or be adsorbed in the higher pH, generally reducing environments of the intestine (Ruby et al., 1996; Smith et al., 2000; Oomen et al., 2006; Ferrel, 2008).

A study of the bioaccessibility of soil contaminants to compare five *"in vitro"* digestion models revealed that a wide range of bioaccessible As, Cd and Pb in three contaminated soils had available percentage generally less than 50%, but values as high as 95% for As, 99% for Cd and 91% for Pb were observed. Differences were directly attributable to whether the extraction was simple or multiple, the pH employed, and the ratio of solid to solution (Oomen et al., 2002; Ferrel, 2008). In the present study, the available percentage was generally low for Pb, Ni, Cr, Co and the PHEs Hg and Cd were completely absent. Only arsenic attained some percentage in the gastric and intestinal phase extractant in most of the geophagic samples but it was completely absent in gastric and intestinal phases of samples 13, 15 and 16 respectvely.

According to Tateo et al. (2006) concentration of some transistion elements, such as V and Mo may remain very low in geophagic soils compared to the usual range found in mineral soils. Ekosse and Ngole (2012) also reported low concentration of V for geophagic soils from Swaziland. Geophagic soils from the Vhembe District have very low concentration of V which could not pose any risk to geophagic practitioners in the locality. Higher concentration of Cr was recently reported in a study in Swaziland by Ekosse and Ngole (2012). In this study, most of the Earth materials have very low Cr concentration in them.

Hooda et al. (2004) estimated potential bioavailability of Fe, Cu, Zn, Ca, Mg and Mn to humans. They indicated that the sorption potential of some geophagic soils lowers the bioaccessibility of Cu, Fe and Zn, although other materials were identified to be a source of Ca, Mg and Mn that humans could potentially utilise. The results of this study contradict observations of Hooda et al., (2004). These essential trace elements were readily bioaccessible for geophagists' uptake in some of the geophagic materials from Vhembe District. Previous studies observed high bioaccessibility of some trace elements in the stomach phase.

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Roussel et al. (2010) observed that Cd, Pb and Zn are more bioaccessible in the stomach with % BAF of 68, 62 and 47 respectively while Lamb et al., (2009) studying partitioning and bioaccessibility in uncontaminated soils found that Pb was more bioaccessible in the stomach with % BAF of over 80 while Cu, Zn and Cd were more in the intestinal phase.

Research by Turner and Ka-Hei (2007) observed more Cd and Zn in the stomach phase. Poggio et al. (2009) observed higher bioaccessibility of Pb and Zn in the stomach while Cu and Ni were in the intestinal phase. Okorie (2010) observed higher bioaccessibility of Pb and Zn in the intestinal phase than in the stomach phase for all the metals studied. Results of the present study show that Fe, Zn, Se, Mn and Cd were more bioaccessible in the stomach phase while Mn, Cu, Hg and As were more bioaccessible in the intestinal phase. Cobalt exhibited equal level of bioaccessibility with % BAF of 44.21 in the stomach and intestinal phases respectively.

Abrahams et al. (2012) reported Fe, Mn and the following PHEs; Pb, Co, Cr and Ni following ingestion of Calabar chalk in Nigeria. They indicated that consumption of an average 20 g/day of this geophagic material is not a significant source of mineral nutrients or PHEs to humans (Abrahams et al., 2012). The values presented for these elements in their research are in agreement with levels of some geophagic materials reported in the present study. Fraction of bioaccessible Fe was completely absent from simulated stomach and intestinal solutions of 12 geophagic materials from this study.

Some observations were made regarding the ability of these geophagic materials in supplying Co, Cr, Fe, Mn, Ni and Zn to female geophagists in this locality as reported by Abrahams et al., (pers. comm.).

- The maximum amount of soil consumed is 40 g/day.
- Absorption of mineral elements takes place in the small intestine of the gastro-intestinal tract. Amount of element in this phase was used for the calculation.
- All the six chemical elements solubilised in the simulated intestinal phase are absorbed by the geophagist (Abrahams et al., pers.comm).

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Table 6.9: Maximum absorption potential of five mineral elements following consumption of 40 g of Earth materials by female geophagists and a comparison with RNI for 15 - 18 year old female non-geophagists

	Co	*Cr*	*Fe*	*Mn*	*Zn*
MAP(mg/day)	9.37×10^2	8.22×10^2	16	1.52×10^4	1.79×10^3
RNI for 15-18 year female	_	50 – 200	14.8	_	_
SUL/GL	1.4	10	17	4	-

NB. RNI = Recommended nutrient intake, SUL/GL = Safe upper levels or Guidance levels.

Source: (After Abrahams et al., 2012)

The maximum absorption potential (MAP) data in Table 6.9 are compared against RNI values defined as the amount of a nutrient that is adequate for nearly all females of aged 15 – 18 and a population group typically associated with geophagy (Abrahams et al., 2012). No RNI is proposed for Co, Mn and Zn but the MAP observed for Fe is 16 mg/day for this mineral nutrient. This observation was based on the highest concentration of Fe that was bioavailable in the intestinal phase of gastro-intestinal tract where absorption takes place. The geophagic materials in this locality could contribute significant amount of Fe to the geophagists.

According to Davies (2008), geophagy could be an important source of potentially harmful elements to humans. The MAP of Co, Cr and Mn on consumption of 40 g/day of geophagic materials are above the Safe Upper Levels (SUL) or Guidance Levels (GLs) outlined in Table 6.7. This is contrary to the work of Diko and Ekosse, (2011) which showed that some geophagic soils from Cameroon and South Africa are depleted in Cr and Ni. The enrichment of PHEs in some mining environs in South Africa could be due to the heavy loading of toxic elements over large areas of disperse mineralisation in the country (Davies and Mundalamo, 2010). Al-Ramali et al. (2010) reported high concentrations of Pb, As and Cd in clay tablets sold in ethnic Bangladeshi shops in the United Kingdom (UK) and Bangladesh for human consumption. The present study reveals that the concentrations of Pb, Cr and Cd in geophagic material from Vhembe District are within SULs.

6.6. Conclusion

The findings of this study lead to the following conclusions. Iron, Zn, Se, Mn, Co and Cd were bioaccessible in the stomach phase, whilst Cu and Hg were bioaccessible in the

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intestinal phase. Principal Component Analysis indicated associations between Zn, Fe and Mn in the first component while the second component indicated associations between Se and Cu. Strong linear relationships were observed between concentrations extracted with PBET and total trace elements for Fe and Zn. The geophagic materials in this locality could contribute the daily RNI of Fe and could represent a significant source of the following mineral nutrients: Zn, Mn and Cu. In terms of human health, Pb and As are the PHEs of greatest concern in these geophagic materials, although the bioaccessible concentrations are generally low and within the SULs for human consumption.

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MINERALOGICAL AND GEOCHEMICAL CHARACTERISTICS OF CONSUMED EARTH MATERIALS FROM VHEMBE DISTRICT, LIMPOPO PROVINCE, SOUTH AFRICA

Abstract

This study was undertaken to assess mineralogical and geochemical features of geophagic materials from Vhembe District for human geophagic practice. Thirty five consumed Earth materials and two control samples were collected from local mining sites, retail outlets in shops and local markets in the area for analyses. The mineralogical characteristics of Earth materials were determined by X-ray diffraction (XRD) method. The concentrations of major and trace elements were determined by means of X-ray fluorescence spectrometry (XRFS). The results of mineralogical analyses indicate the following range in weight percent (wt. %) for each respective mineral in the sample: Kaolinite (14.88% to 77.35%); smectite (2.99% to 10.15%); muscovite (17.77% to 56.03%); quartz (4.50% to 49.40%); albite (4.99% to 9.38%); orthoclase (4.38% to 6.66%); goethite (1.86% to 11.21%); hematite (3.07% to 9.49%); microcline (4.95% to 6.04%) and anatase (1.01% to 4.13%). The average concentrations of Al_2O_3, Fe_2O_3 and TiO_2 were respectively 29.20%, 12.04% and 1.26% with low content of CaO (0.26%). Results of Tukey's post hoc test mineralogy showed that only kaolinite has a significant percentage with respect to all other minerals. Functional analysis revealed that the geophagic clays were enriched in oxides of Si, Al, and Fe; and depleted in oxides of Ca, K and Mn. Chemical index of alteration (CIA) values for the geophagic clay ranges from 17.09 – 99.07. The consumed Earth materials are made of variable minerals, with some having a mixture of kaolinite, smectite, microcline, muscovite, and others with a complex mixture of kaolinite, smectite, quartz or orthoclase. Qualitative description of XRD fitting pattern yielded results that were consistent with quantitative description. Kaolin is the dominant mineral of interest in the consumed Earth materials. Its calm soothing sour taste due to its weakly acidic nature, ability to coat and adhere to intestinal membrane of geophagists, could suggest that pregnant women, lactating mothers and children indulge in geophagic practice to alleviate gastrointestinal problems and protection against toxins.

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7.1. Introduction

Geophagy or geophagia is the deliberate consumption or involuntary ingestion of Earth materials such as clays, sands, anthills, termite mounds and sediments from dried up ponds. The practice is common amongst children, women of child bearing age and lactating mothers in Vhembe District of Limpopo Province. Research conducted by Jones and Hanson, (1985); Kruelen, (1985); Krishnamani and Mahaney, (2000); Young et al., (2010); revealed that geophagy is a common practice throughout the animal kingdom. This practice is found virtually in all continents of the globe, but most prevalent in sub-Sahara Africa (Abrahams, 2002; 2005; Wilson, 2003).

The postulated causative reasons for consumption of Earth materials are many, some of which include; as food detoxifier to counteract toxins and poisons (Houston et al., 2001; Shinondo and Mwikuma, 2009); for pharmaceutical reasons, e.g. kaopectate, a form of clay material, is used to treat diarrhoea and stomach upset (Vermeer and Ferrel, 1985); to supplement intake of available Cu, Fe and Mn by rural communities (Mills, 1996; Davies, 2008); to alleviate gastrointestinal disorders (Chandrajith et al., 2009). To date, there is so much confusion about the entire practice, though; it is thought to have both beneficial and harmful effects on man. The potential medical implications of the practice include excessive tooth wear, enamel damage and erosion of the mucosal surfaces of the stomach (Barker, 2005). Obstruction and perforation of the colon may result following the internal accumulation of soil (Abrahams, 2002).

Three major hypotheses were advanced for human geophagic practice: hunger, micronutrient deficiency and protection from toxins and pathogens (Wilson, 2003; Young et al., 2010). These hypotheses that were postulated in favour of geophagic practice reflect the nature, behaviour and properties of clay minerals in the geophagic materials; hence clay mineralogy could be a factor in the assessment of these hypotheses (Wilson, 2003).

According to Williams and Haydell (2010), ingestion of dried clay minerals or clay suspension is commonly used as a source of dietary elements and as an aloopathic treatment of gastro-intestinal illnesses, acute and chronic diarrhoea. In the acidic environment of the stomach, the clay minerals could bind to positively charged toxins and serve as detoxifying agents to reduce bioavailability interfering with gastrointestinal absorption of the toxin (Johns and Duqutte, 1991; Williams and Haydell, 2010).

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Due to the complex and poorly understood nature of geophagic practice, Dissanayake (2005) posed the following questions:

(i) Why do humans and animals consume soil?

(ii) Could it be that inorganic nutrients in soil supplement our dietary intake of essential trace elements?

(iii) Does the ingestion of soil cause detoxification of noxious or unpalatable compounds present in the diet?

(iv) Do these soil elements alleviate gastro intestinal ailments?

He urged researchers to carry out studies that could provide answers to some of these questions in order to evaluate the risks and benefits of geophagy (Dissanayake, 2005).

7.2. Objectives of the study

The main objectives of this study were to describe the mineralogical and geochemical characteristics of Earth materials eaten by humans in order to test protection hypothesis concerning human geophagic practice. The specific objectives were:

1. To determine if mineralogical and geochemical data could assist researchers in answering some of the questions on the reasons for eating Earth materials.
2. To ascertain whether Earth materials in the area are depleted or enriched in essential mineral supplements.
3. To establish mineralogical and geochemical differences between consumed Earth materials and non-consumed Earth materials.

7.3. Materials and methods

7.3.1. Sample collection

Thirty seven samples (thirty five geophagic and two control) were collected from local mining sites and retail outlets in local markets and shops across the entire District. These are Type A reddish brown termite mound found on bark of tree (Fig. 7.1)

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Figure 7.1: A typical Earth material mining site within the District

Type B is a yellowish silty sandy material found in horizon A soil profile (Fig. 7.2), and type C is grey smooth natural clays available in retail outlets sold in markets and shops in the area (Fig. 7.3). The clays are mined around Johannesburg and transported to other parts of South Africa.

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Figure 7.2: A geophagist collecting Earth material from preferred soil horizon

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Figure 7.3: Earth materials on display in a retail outlet in the area 2.5 cm

7.3.2. Sample preparation and analyses

Samples were air-dried, crushed and milled to < 2 mm size fraction for analyses. The mineralogy of consumed Earth materials was determined by X-ray diffraction (XRD) method. The powder was packed in a sample holder by back loading methods for determination of the mineral content of the whole consumed Earth materials. The XRD analyses of samples was performed in Geology Department, University of Pretoria, South Africa using a Pan analytical X'-Pert Pro Powder diffractometer with an X' Celerator position sensitive detector and variable divergence, and receiving slits with Fe filtered Co-K radiation. The phases were identified using X' Pert High score plus software. The relative phase amounts (weight %) was estimated using the Rietveld method (Autoquan programme). Identification of certain clay minerals required the use of supplementary treatments. Ethylene glycol tests were performed on selected samples to verify the presence of swelling clay minerals represented by smectite, while the presence of kaolinite was verified by treating selected samples to 550°C for 2.5 hours (Wilson, 1987). The samples were X-rayed in the range 2° to 89° 2Ø for total mineral content with a step size of 0.008°2Ø and measuring time of 4s/step. Major element and trace elements analyses were performed on the fused bead using the ARL 9400 XP x-ray fluorescence spectrometer. Samples were roasted at 1000 °C to determine loss on ignition value and after adding 1g of sample to 6g of $Li_2B_4O_7$ fused into a glass bead before determination of major and trace elements.

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Quality control of the preparation and instrumental performances were checked using a blank and certified reference material which were analysed with each batch of samples. A comparison between the certified values of the reference materials and those found in this study indicated that the recoveries were within a very close range.

7.3.3. Statistical analyses

Analysis of variance (ANOVA) test can be used to explain data variances in a sample population. Variance in data population is defined as the average of the square of a measure of deviation of the values to their mean. Analysis of variance is a statistical tool used for comparing sample means. Inferential statistics were used to analyse the data. Inferential statistics enable researcehers to infer characteristics for a large or total population from characteristics found using a smaller sample (Goon, 2011). Researches by Bluman (2004) showed that inferential statistics consist of generalising from samples to populations, performing estimations and hypothesis tests, determining relationships among variables and making predictions.

Application of multivariate statistical techniques such as cluster analysis (CA), factor analysis (FA) and principal component analysis (PCA) can lead to a better understanding of several variables in Earth materials. They also help to explain the correlation among a large number of closely related variables in terms of a small number of underlying factors without losing much information. These statistical tools, CA, PCA and FA enable the natural associations among samples and/or variables to be more clearly understood by unearthing the hiden underlying information (Elangban et al., 2012). According to Hare et al. (1998) factor analysis is an interdependent technique where all variables are simultaneously considered, each related to all others and still employing the concept of the individual variables and the linear composite of variables. There are two important factors in interpreting of results in factor analysis, namely, factor loadings and the Eigen value. Factor loadings are the correlations between factor scores and the original variables. Squared factor loadings indicate what percentage of the variance in an original variable is explained by a factor (Hare et al., 1998; Goon, 2011). The Eigen value is the column sum of the squared loadings for a factor. It represents the amount of variance accounted for by a factor.

Principal component analysis is a factor extraction method used to form uncorrelated linear combinations of the observed variables. Principal component analysis reduces a data set by

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explaining the correlations among a large number of variables in terms of a smaller number of underlying factors (principal components or PCs) and then applying Varimax rotation for finding more clearly defined factors called Varimax factors or VFs that facilitate interpretation of the data (Helena et al., 2000; Elangban, 2012) and bring forth the latent but important variables (Elangban, 2012). Principal component analysis enables the variance in the data to be accounted for as concisely as possible and identifying the most important variables in the data. Statistical analyses of mineralogical data were performed using ANOVA and Tukey test to obtain minerals with most significant level of concentration with respect to other minerals.

Multivariate statistical method was applied on major oxides data (wt %) in geophagic clays using IBM SPSS 19.0 statistical software. Varimax rotated factor analyses was performed on correlation matrix of rearranged data for 35 geophagic samples. The variance, cumulative and extraction sum of square loadings of the variables with Eigen values were computed. Rotation of the axis defined by factor analyses produced a new set of factors, each one involving primarily a subset of the original variables with little overlap as possible, so that the original variables were divided into groups. The factor analyses of the present dataset further sorted by the contribution of less significant variables (<0.4 factor score). A Varimax rotation (raw) of the different varifactors of Eigen value greater than 1, were further cleaned up by this technique (Akinyemi et al., 2011).

Liu et al. (2003) classified the factor loading as "strong," "moderate" and "weak" corresponding to absolute loading values of >0.75, 0.75-0.50 and 0.50-0.40, respectively. Factor and cluster analyses were combined to assess the degree of major component matrix dissolution and determination of chemical processes. Hierarchical agglomerative clustering was performed on data normalised to zero mean and unit variance using squared Euclidean distances as the measure of similarity (Massart et al., 1988). Ward's method was selected because it possesses a small space distorting effect, uses more information on cluster contents than other methods and has proven to be an extremely powerful grouping mechanism (Akinyemi et al., 2011).

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7.4.1. Mineralogical characteristics

The quantitative result of all the mineralogical characteristics of samples shows the following minerals and their respective concentrations (Table 7.1).

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Table 7.1: Results of mineralogical analyses (%) of geophagic samples from Vhembe District

Sample ID.	*Kaolinite*	*Smectite*	*Microcline*	*Muscovite*	*Albite*	*Anatase*	*Goethite*	*Hematite*	*Quartz*	*Orthoclase*	*Chlorite*	*Rutile*	*Titanite*	*Diopside*	*Calcite*	*Dolomite*	*Magnesite*
1	59.75	-	-	21.9	5.99	-	-	-	6.41	5.94							
2	35.29	-	-	-	-	1.01	11.21	3.07	49.42								
3	18.1	-	-	55.07	-	-	1.86	4.29	20.68								
4	77.35	-	-	-	-	4.13	-	-	18.53								
5	15.89	-	-	58	-		4.91	3.44	17.77								
6	14.88	-	-	56.03	-		4.14	9.49	15.46								
7	57.23	3.07	4.95	23.51	6.42				4.82								
8	55.09	3.92		28.26	7.19				5.54								
9	52.59	5.17		23.17	6.28				7.08	5.72							
10	49.86	9.39		22.42	5.28				6.62	6.44							
11	51.87	6.7		22.76	7.21				5.62	6.43							
12	54.71	6.17		20.55	7.33				5.11	6.15							
13	57.06	2.99		22.2	6.37				4.96	6.43							
14	53.26	8.81	5.54	21.31	4.99				6.09	-							
15	51.11	10.15		23.13	5.65				5.59	4.38							
16	52.87	9.94	6.04	20.35	5.58				5.21	-							
17	52.46	7.07		21.97	5.41				6.42	6.66							
18	56.77	7.44		17.77	6.95				5.63	5.44							
19	58.74			19.78	9.38				7.67	4.43							
20	57	5.08		19.2	9.1				4.5	5.13							
21	53.37			13.57	10.85				8.09	-							
22	75.05			3.28	-				9.32								

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23	65.92		-		9.25	9.29	15.53								
24	16.48		30.96		1.84	8.20	42.52								
25	64.28		-	3.32	9.71	8.32	14.36								
26	60.1		-	10.1		5.20	18.58	6.03							
27	66.67		13.79	7.88		-	9.14	-	2.52						
28	62.31	7.63	11.98	7.84		-	10.24	-	-						
29	62.76	7.12	11.73	7.62		-	7.25	-	-	3.52					
30	61.98	8.08	12.9	7.04		-	7.44	-	2.57	-					
31	-	18.33	42.72	-		2.44	26.65	6.85	-	-	2.97				
32	-	21.56	40.97	-	0.74	3.33	28.45	4.95	-	-					
33	-	19.68	37.52	-	-	9.55	22.15	6.24	-	4.84					
34	33.33	36.89	18.66	6.02	-	-	5.11								
35	-	11.79	-	-	-	-	0.34					0.36	4.21	83.3	
C-1	29.45	-	7.72	-	-	-	62.83					-	-	-	
C-2	65.65	-	-	-	8.88	7.78	17.70					-	-	-	

-, not detected

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The result revealed that the concentration of kaolinite ranges from 14.88% to 77.35%; muscovite (3.28% to 58%); smectite (2.99% to 36.89%); quartz (0.34% to 49.42%); albite (3.32% to 10.85%); orthoclase (4.38% to 6.66%); goethite (1.86% to 11.21%); hematite (2.44% to 9.55%); microcline (4.95% to 6.04%) and anatase (0.74 to 9.71%). Sample 35 had the following mineral concentrations: magnesite (83.3%); dolomite (4.21%); calcite (2.97%) and smectite (11.79%).

The kaolin content of most samples was greater than 50% (Fig. 7.4). The diffractogram (Appendix E) displays kaolinite as the predominant clay minerals. Each of the consumed Earth materials was accompanied by a certain fraction of quartz as reflected in the results of X-ray diffraction (Table 7.1).

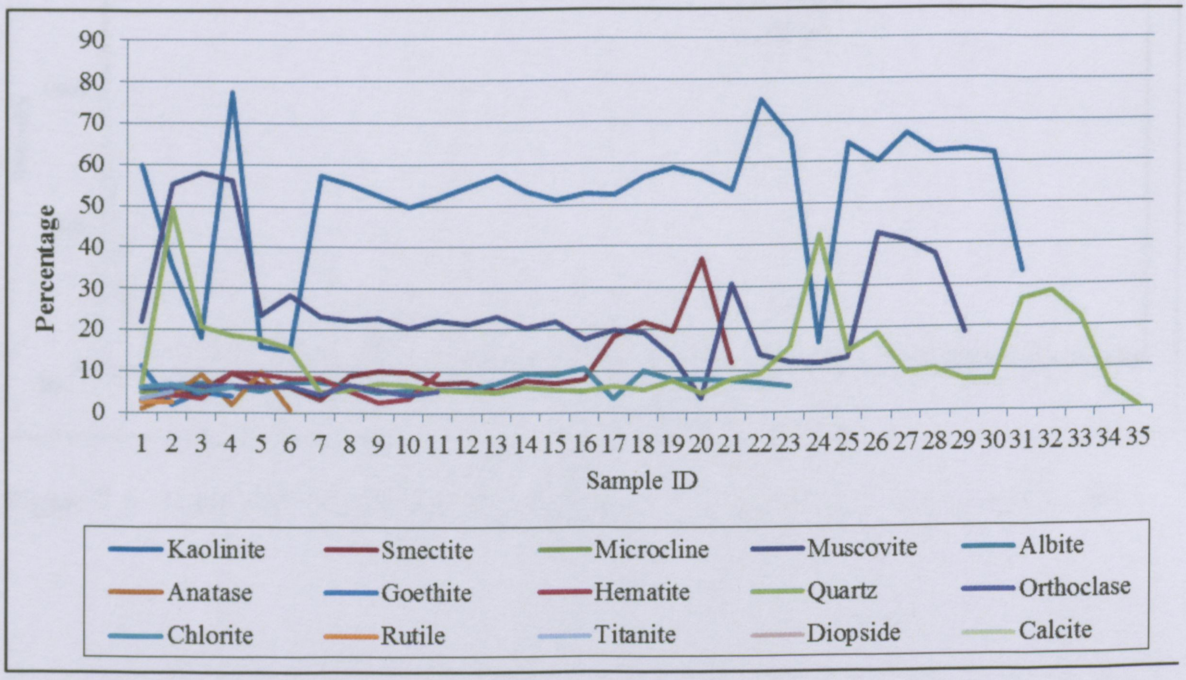

Figure 7.4: Plot illustrating clay mineralogy of the samples studied

Other detrital minerals such as albite and anatase were present in the samples, most especially samples 2 and 4 which had the presence of anatase in them. Muscovite was present in the entire sample except sample 2 which was muscovite free. Plagioclase albite was present in the entire sample except sample 2 to 6. Microcline was only noticeable in very few samples namely; 7, 14 and 16 respectively. Iron oxides, goethite and hematite were present in samples 2 to 6 respectively. Orthoclase was determined in all the samples except samples 2 to 8, 14 and 16 respectively. The most common clay mineral was kaolinite, closely accompanied by muscovite. The following samples; 3, 5 and 6 were deficient in kaolinite, but had higher

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percentage of muscovite closely accompanied by quartz. Smectite was present in virtually all the samples except samples 2 to 6 and sample 19. The percentage composition was less than 10% of the entire sample in which it was present. Sample 2 was a highly siliceous earthy material; samples 3, 5 and 6 were muscovite rich while the rest were kaolinitic in nature. Abundant quartz was identified by high peak intensities at 31^0 2Ø (Fig. 7.5) in sample 2, while significant amount of quartz in sample 3 was reflected in the peak intensities at 10^0 2Ø and 30^0 2Ø, respectively (Fig. 7.6).

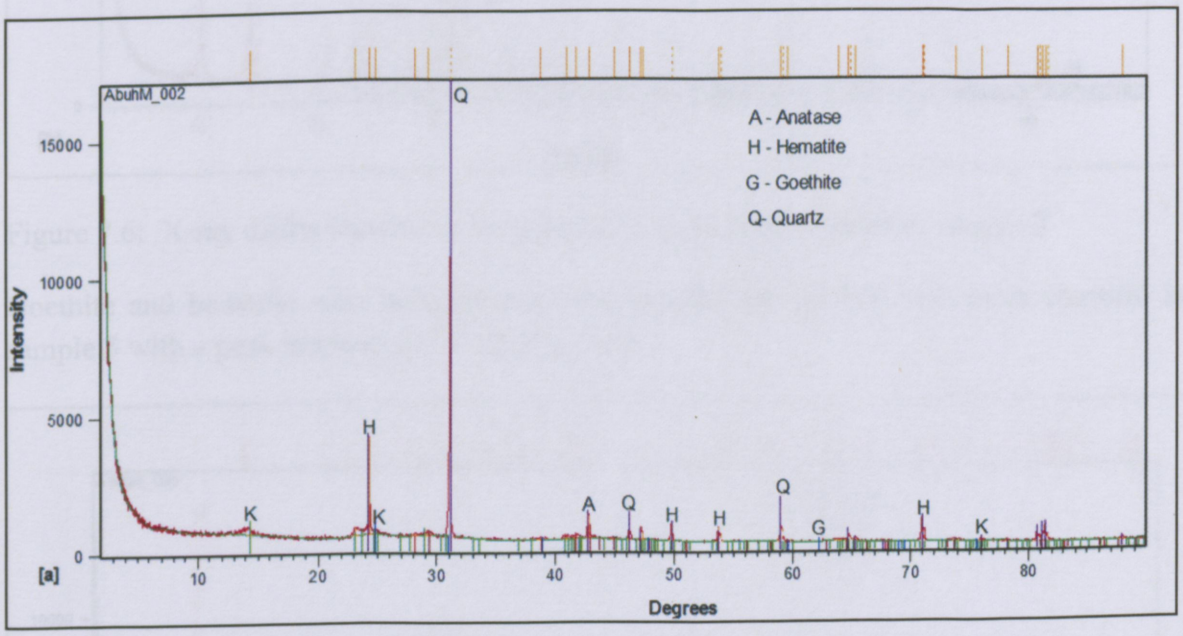

Figure 7.5: X-ray diffractogram showing variable clay mineralogy for geophagic sample 2

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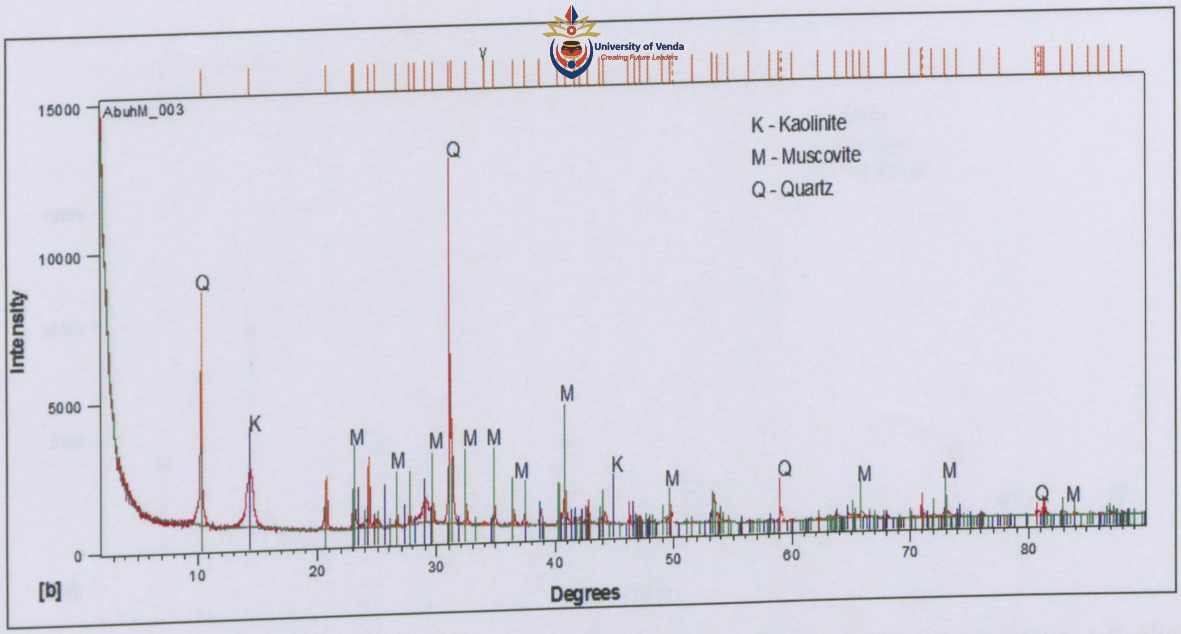

Figure 7.6: X-ray diffractogram showing quartz rich geophagic material, sample 3

Goethite and hematite were noticeable in few samples but goethite was more plentiful in sample 5 with a peak intensity at 54^0 2Ø (Fig. 7.7).

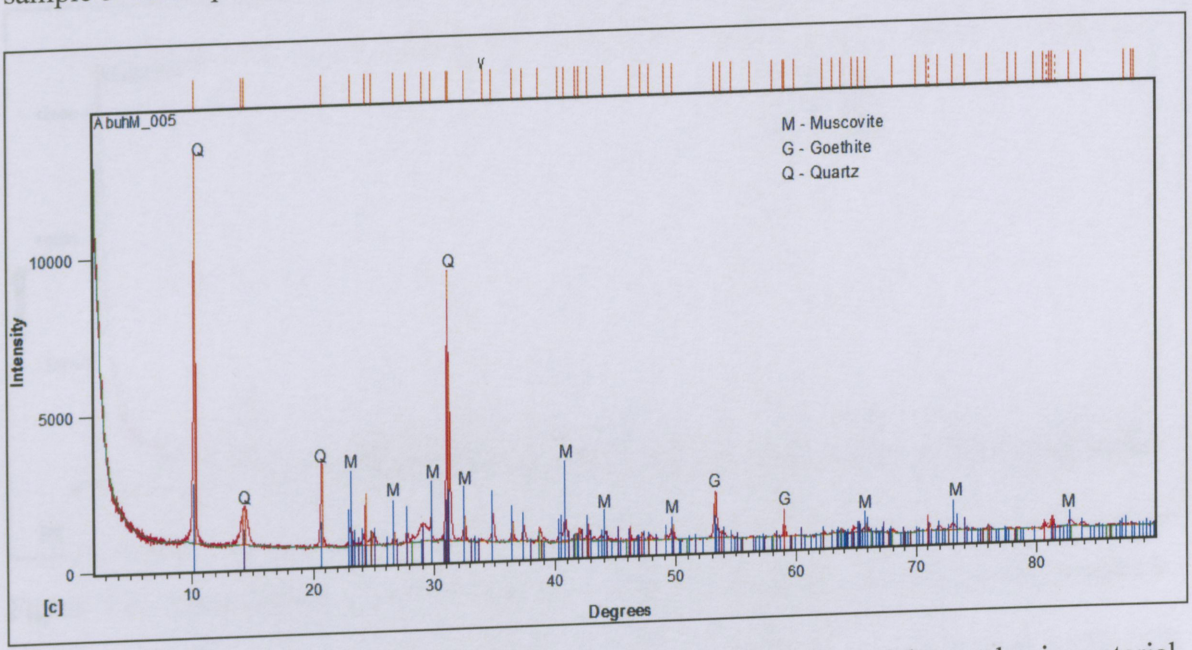

Figure 7.7: X-ray diffractogram showing goethite and muscovite rich geophagic material, sampe 5

Figures 7.8 and 7.9 respectively, show the variable nature of the clay mineralogy. Kaolinite was the predominant mineral of interest as reflected in the XRD pattern except in sample 2 in which quartz was the predominant mineral, with a very high peak intensity at 31^0 2Ø.

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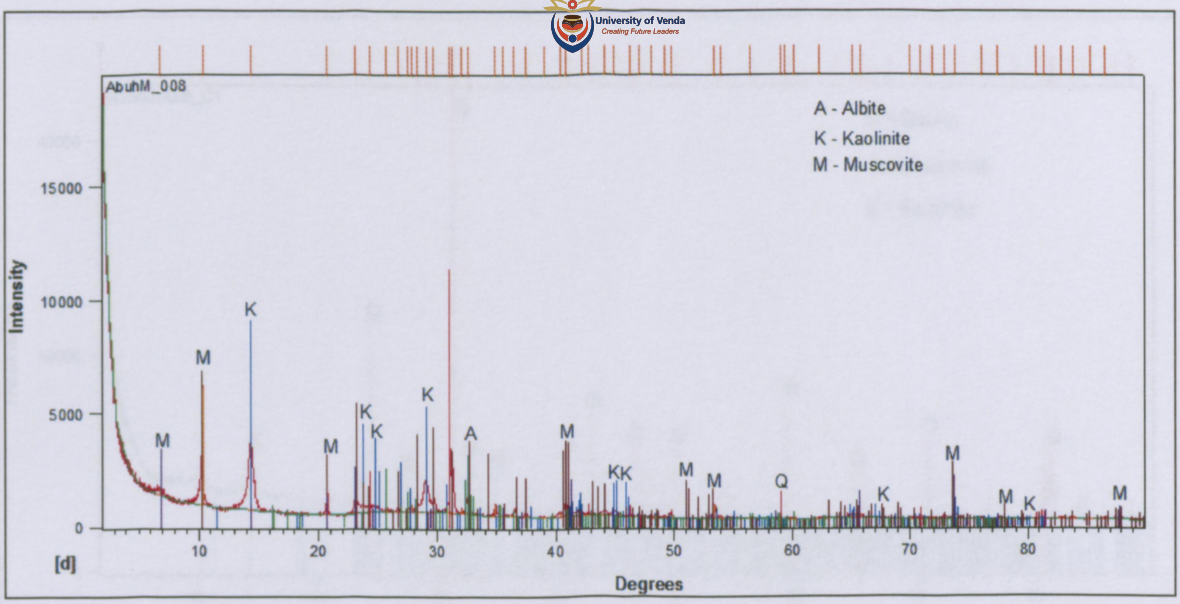

Figure 7.8: XRD pattern of geophagic material showing variable composition of clay minerals, sample 8

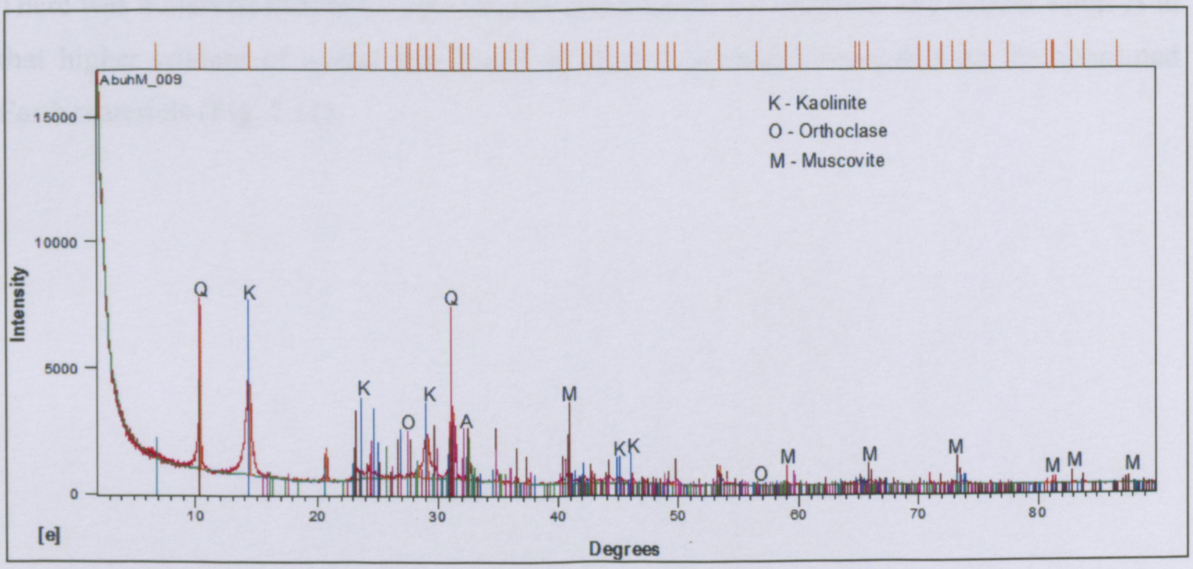

Figure 7.9: X-ray diffractogram showing dominant kaolinitic clay with muscovite, sample 9

In control sample 1, quartz was the predominant mineral (Fig. 7.10) accounting for 62.83% while in the second control sample kaolinite was the dominant mineral, closely followed by quartz.

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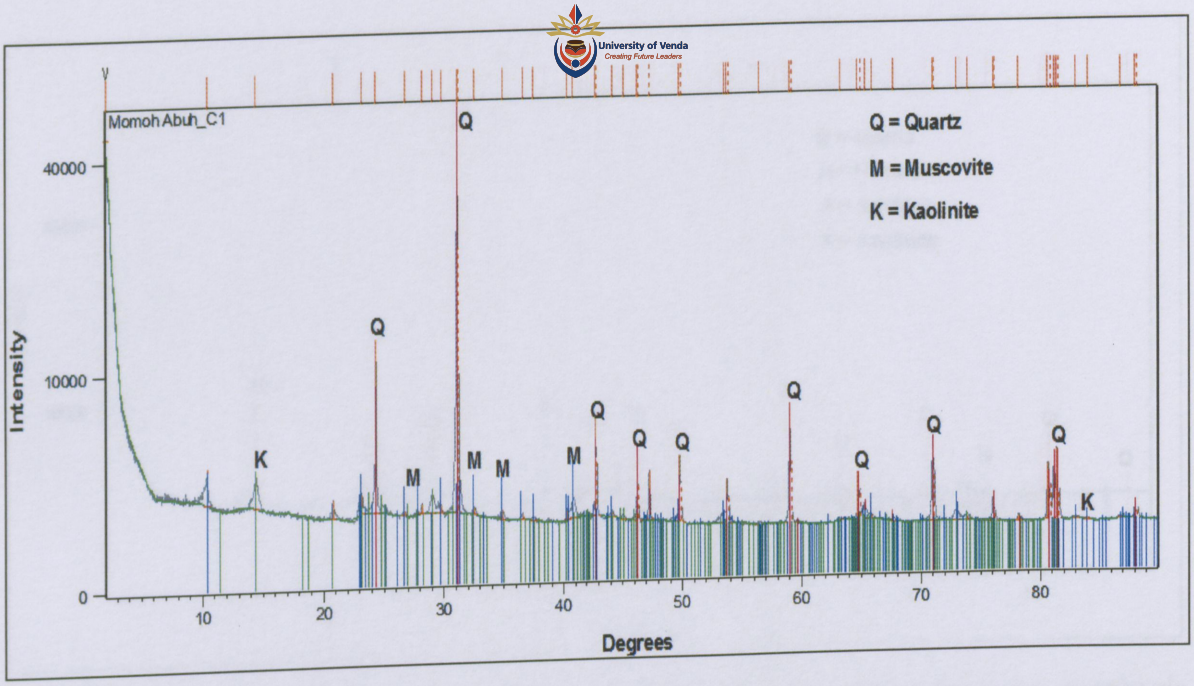

Figure 7.10: X-ray diffractogram of quartz dominated non-geophagic material, sample 1

There was a marked difference between the consumed Earth materials and control samples in that higher content of quartz was found in control samples compared with the consumed Earth materials (Fig. 7.11).

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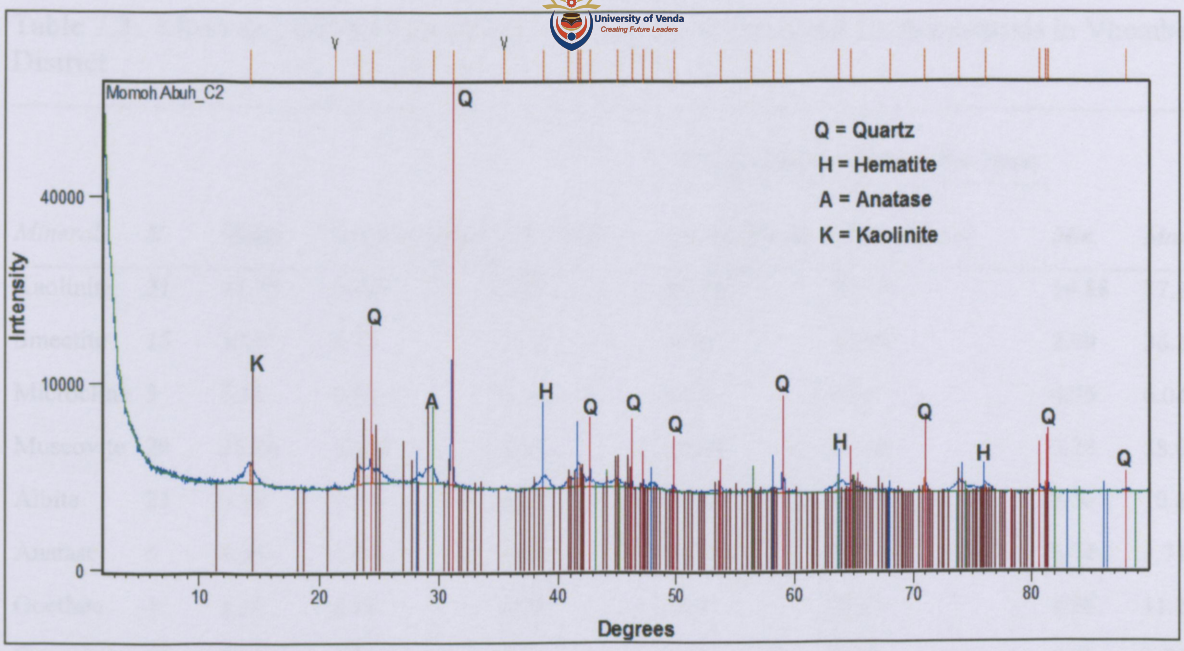

Figure 7.11: X-ray diffractogram showing variable quartz hematite in a non-geophagic sample 2

Mean and standard deviation for minerals in the analysed samples are shown in (Table 7.2). The Analysis of variance (ANOVA) test (Table 7.3) shows that the average percentage of minerals in the consumed Earth materials was highly significant ($P \leq 0.001$).

Tukey's post hoc test was therefore used to identify the homogeneous groups (pairs with no significant mean differences) among the minerals. Results of Tukey's post hoc test (Table 7. 4) showed that only kaolinite had a significant percentage with respect to all other minerals.

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Table 7.2: Mean and standard deviation for minerals in consumed Earth materials in Vhembe District

					95% Confidence Interval for Mean			
Minerals	*N*	*Mean*	*Std. Deviation*	*Std. Error*	*Lower Bound*	*Upper Bound*	*Min.*	*Max.*
Kaolinite	31	51.75	16.40	2.95	45.73	57.76	14.88	77.35
Smectite	15	12.17	8.70	2.25	7.35	16.99	2.99	36.89
Microcline	3	5.51	0.54	0.31	4.15	6.86	4.95	6.04
Muscovite	29	25.36	13.63	2.53	20.18	30.54	3.28	58.00
Albite	23	6.94	1.74	0.36	6.19	7.70	3.32	10.85
Anatase	6	4.44	4.08	1.66	0.1653	8.73	0.74	9.71
Goethite	4	5.53	4.00	2.00	-.84	11.90	1.86	11.21
Hematite	11	6.05	2.90	0.87	4.10	8.00	2.44	9.55
Quartz	35	12.40	10.82	1.82	8.69	16.13	0.34	49.42
Orthoclase	11	5.74	.80	0.24	5.19	6.28	4.38	6.66
Chlorite	4	6.02	0.79	0.40	4.76	7.28	4.95	6.85
Rutile	2	2.54	0.03	0.03	2.23	2.86	2.52	2.57
Titanite	2	4.18	0.93	0.66	-4.20	12.57	3.52	4.84
Total	176	19.02	19.50	1.47	16.12	21.93	.34	77.35

Table 7.3: Table of analysis of variance showing levels of significance

Tests of Between-Subjects Effects

Dependent Variable:Value

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	47950.07[a]	12	3995.84	35.00	.000
Intercept	9257.37	1	9257.37	81.09	.000
Treatment	47950.07	12	3995.84	35.00	.000
Error	18608.26	163	114.16		
Total	130279.53	176			
Corrected Total	66558.33	175			

a. R Squared = .720 (Adjusted R Squared = .700)

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Table 7.4: Values of homogeneous means of minerals using Tukey's test

		Subset for alpha = 0.05		
Minerals	N	1	2	3
Rutile	2	2.54		
Titanite	2	4.18	4.18	
Anatase	6	4.45	4.45	
Microcline	3	5.51	5.51	
Goethite	4	5.53	5.53	
Orthoclase	11	5.74	5.74	
Chlorite	4	6.02	6.02	
Hematite	11	6.06	6.06	
Albite	23	6.95	6.95	
Smectite	15	12.17	12.17	
Quartz	35	12.41	12.41	
Muscovite	29		25.36	
Kaolinite	31			51.72
Sig.		.95	.06	1.000

7.4.2. Major oxides geochemistry

The results of major oxides concentrations in geophagic clays and control samples are shown in Table 7.5. Mean contents of SiO_2, Al_2O_3 and FeO_3 in geophagic clays were 42.52%, 29.20% and 12.04% respectively.

Mean values of other oxides in geophagic clays from the area were as follows; TiO_2 1.26%; P_2O_5 0.09%; Na_2O 0.29%; MgO 2.47%; MnO 0.12%; SO_3 0.03%; K_20 4.20%; CaO 0.26% and LOI 7.8%. The mean value for Na_2O was twice the value for control sample. There was no significant ($t = 2.94$, $P = 0.06$) difference between the oxides of the two groups.

The concentration of the following oxides; MnO, NaO, P_2O_5, SO_3, CaO were less than 1%. Geophagic samples had lower mean concentration of SiO_2 and Fe_2O_3 than control samples. Average Al_2O_3 oxide concentration in geophagic samples was greater than the control samples by 26%. The non-geophagic samples were very siliceous compared to geophagic samples.

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Table 7.5: Mean and standard deviation of major element concentrations in geophagic and control samples from Vhembe District (wt %).

Sample	SiO_2	Al_2O_3	FeO_3	TiO_2	P_2O_5	Na_2O	*MgO*	*MnO*	SO_3	K_2O	*CaO*	*LOI*
1	39.14	32.03	10.56	0.83	0.06	0.37	1.17	0.13	0	4.73	0.12	10.05
2	42.48	21.83	23.98	3.34	0.15	0.1	0.45	0.19	0	1.04	0.87	5.31
3	39.65	25.76	16.32	2.24	0.05	0.07	1.41	0.02	0	9.27	0	5.18
4	31.81	24.49	27.17	3.08	0.16	0.03	0.67	0.07	0	0.05	0	12.18
5	40.85	27.24	14.70	1.93	0.04	0.12	1.10	0.01	0	8.39	0	5.67
6	34.81	23.03	23.47	3.54	0.15	0.09	0.85	0.03	0	8.49	0	5.53
7	39.05	33.55	9.27	0.72	0.06	0.44	2.02	0.11	0	4.11	0.17	10.46
8	39.21	32.86	9.67	0.67	0.04	0.42	2.32	0.13	0	4.75	0.19	9.70
9	39.62	31.79	10.29	0.81	0.06	0.38	2.02	0.15	0	5.03	0.09	9.62
10	38.68	31.89	9.68	0.77	0.05	0.35	1.90	0.12	0	4.81	0.08	11.47
11	38.37	30.56	11.19	0.77	0.06	0.48	2.28	0.17	0	5.19	0.19	10.51
12	39.14	33.68	9.50	0.73	0.05	0.49	1.72	0.14	0	4.26	0.11	10.52
13	39.06	33.57	9.12	0.7	0.06	0.5	2	0.1	0	4.28	0.16	10.4
14	39.17	32.21	9.97	0.72	0.05	0.45	1.91	0.14	0	4.74	0.1	10.38
15	38.54	31.68	10.25	0.74	0.06	0.45	1.93	0.13	0	4.79	0.13	11.11
16	43.34	28.42	11.78	1.43	0.07	0.29	1.19	0.30	0	3.58	0.14	9.28
17	38.98	33.68	8.27	0.66	0.04	0.42	1.99	0.10	0	4.48	0.06	11.28
18	38.87	32.27	9.87	0.12	0.76	0.53	1.73	0.12	0	4.33	0.15	11.13
19	39.7	32	9.77	0.77	0.05	0.45	1.81	0.16	0	4.70	0.11	10.28
20	38.14	32.72	10.30	0.83	0.07	0.43	1.59	0.12	0	3.99	0.16	11.39
21	50.57	34.48	7.42	0.48	0.08	0.40	1.10	0.12	0.13	4.62	0.33	1.20
22	52.16	38.02	5.67	0.86	0.04	0.12	0.01	0.02	0.11	2.57	0.15	1.10
23	37.22	31.07	26.97	3.24	0.19	0.01	0.01	0.37	0.20	0.16	0.14	1.30
24	56.44	23.73	9.68	1.31	0.02	0.09	1.21	0.03	0.02	7.07	0.02	1.52
25	39.27	30.54	25.26	2.82	0.20	0.11	0.01	0.28	0.23	2	0.5	1.63
26	42.58	29.35	22.08	2.59	0.19	0.29	0.43	0.26	0.21	0.68	0.94	1.22
27	50.78	36.49	6.51	0.47	0.04	0.39	0.65	0.09	0.14	3.97	0.23	1.43
28	51.23	35.29	6.77	0.50	0.04	0.39	0.84	0.10	0.12	4.26	0.24	1.50
29	50.58	35.96	6.86	0.48	0.03	0.39	0.80	0.09	0.12	4.2	0.25	1.53
30	50.62	35.89	6.98	0.48	0.06	0.39	0.78	0.09	0.1	4.1	0.28	1.60
31	58.98	19.91	8.47	1.07	0.01	0.32	2.12	0.05	0	5.35	0	4.56
32	60.31	19.05	9.35	1.74	0.17	0.01	3.62	0.22	0	4.94	0.37	1.28
33	51.38	17.77	17.04	2.37	0.10	0.09	2.15	0.07	0	4.39	0.84	4.52
34	49.8	28.99	6.49	0.49	0.05	0.63	1.37	0.09	0	3.87	0	9.08
35	7.72	0.40	0.83	0.07	0.01	0	39.29	0.02	0	0.06	1.88	49.76
Mean	45.52	29.2	12.04	1.26	0.09	0.29	2.47	0.12	0.03	4.20	0.26	7.84
SD	1.57	1.21	1.11	0.16	0.02	0.03	1.09	0.01	0.01	0.36	0.06	1.41
Cert Ref	65.8	14.67	3.75	0.68	0.28	3.57	2.3	0.06	0.01	4.56	2.5	1.32
Control 1	63.64	26.46	4.47	0.61	0.01	0.03	0.76	0.02	0.04	0.01	0.01	5.30
Control 2	38.31	30.35	26.09	3.16	0.21	0.04	0.01	0.03	0.04	0.27	0.23	1.78
Control 3	50.91	14.33	14.27	1.15	0.08	0.22	3.26	0.11	0	3.69	3.32	9.06
Mean	50.93	23.71	14.97	1.64	0.10	0.09	1.34	0.05	0.01	0.36	0.06	1.41
SD	12.66	8.35	10.82	1.34	0.10	0.10	1.7	0.04	0.02	2.05	1.85	3.64

LOI-loss on ignition, SD- standard deviation, C1-C3: Non geophagic control samples, Cert Ref – Certified reference

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7.4.2.1. Chemical alteration of geophagic clays

According to Nesbit and Young (1982), a good measure of the degree of weathering can be obtained by calculation of the chemical index of alteration (CIA) using molecular proportions.

$$CIA = [Al_2O_3/ (Al_2O_3 + CaO + Na_2O + K_20)] \times 100$$

To this end, the chemical index of alteration (CIA) was calculated for the geophagic clays from Vhembe District. The CIA values for geophagic clays ranges from 17.09 – 99.07, while those of control samples ranges from 98.25 – 99.81 (Table 7.6).

Table 7.6: Chemical Index of Alteration for geophagic clays and control samples from Vhembe District

			Group I from Dendrogram cluster analysis										
Site	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	Na_2O	MgO	MnO	SO_3	K_2O	CaO	LOI	CIA
Cly 29	50.58	35.96	6.86	0.48	0.03	0.39	0.8	0.09	0.12	4.20	0.25	1.53	88.14
Cly 30	50.62	35.89	6.98	0.48	0.06	0.39	0.78	0.09	0.10	4.10	0.28	1.60	88.27
Cly 27	50.78	36.49	6.51	0.47	0.04	0.39	0.65	0.09	0.14	3.97	0.23	1.43	88.83
Cly 28	51.23	35.29	6.77	0.5	0.04	0.39	0.84	0.10	0.12	4.26	0.24	1.50	87.83
Cly 21	50.57	34.48	7.42	0.48	0.08	0.40	1.10	0.12	0.13	4.62	0.33	1.20	86.56
Cly 22	52.16	38.02	5.67	0.86	0.04	0.12	0.01	0.02	0.11	2.57	0.15	1.10	93.05
Cly 31	58.98	19.91	8.47	1.07	0.01	0.32	2.12	0.05	0.00	5.35	0.00	4.56	77.83
Cly 33	51.38	17.77	17.04	2.37	0.10	0.09	2.15	0.07	0.00	4.39	0.84	4.52	76.96
			Group II from Dendrogram cluster analysis										
Site	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	Na_2O	MgO	MnO	SO_3	K_2O	CaO	LOI	CIA
Cly 1	39.14	32.03	10.56	0.83	0.06	0.37	1.17	0.13	0.00	4.73	0.12	10.05	85.99
Cly 2	42.48	21.83	23.98	3.34	0.15	0.10	0.45	0.19	0.00	1.04	0.87	5.31	91.57
Cly 3	39.65	25.76	16.32	2.24	0.05	0.07	1.41	0.02	0.00	9.27	0.00	5.18	73.09
Cly 4	31.81	24.49	27.17	3.08	0.16	0.03	0.67	0.07	0.00	0.05	0.15	12.18	99.07
Cly 5	40.85	27.24	14.7	1.93	0.04	0.12	1.10	0.01	0.00	8.39	0.00	5.67	76.20
Cly 6	34.81	23.03	23.47	3.54	0.15	0.09	0.85	0.03	0.00	8.49	0.00	5.53	72.86
Cly 7	39.05	33.55	9.27	0.72	0.06	0.44	2.02	0.11	0.00	4.11	0.17	10.46	87.67
Cly 8	39.21	32.86	9.67	0.67	0.04	0.42	2.32	0.13	0.00	4.75	0.19	9.70	85.98
Cly 9	39.62	31.79	10.29	0.81	0.06	0.38	2.02	0.15	0.00	5.03	0.09	9.62	85.25
Cly 10	38.68	31.89	9.68	0.77	0.05	0.35	1.90	0.12	0.00	4.81	0.08	11.47	85.89
Cly 11	38.37	30.56	11.19	0.77	0.06	0.48	2.28	0.17	0.00	5.19	0.19	10.51	83.91
Cly 12	39.14	33.68	9.50	0.73	0.05	0.49	1.72	0.14	0.00	4.26	0.11	10.52	87.39
Cly 13	39.06	33.57	9.12	0.70	0.06	0.50	2.00	0.10	0.00	4.28	0.16	10.40	87.17
Cly 14	39.17	32.21	9.97	0.72	0.05	0.45	1.97	0.14	0.00	4.74	0.10	10.38	85.89
Cly 15	38.54	31.68	10.25	0.74	0.06	0.45	1.93	0.13	0.00	4.79	0.13	11.11	85.51
Cly 16	43.34	28.42	11.78	1.43	0.07	0.29	1.19	0.10	0.00	4.48	0.06	11.28	87.16
Cly 17	38.98	33.68	8.27	0.66	0.04	0.42	1.99	0.10	0.00	4.48	0.06	11.28	87.16
Cly 18	38.87	32.27	9.87	0.12	0.76	0.53	1.73	0.12	0.00	4.33	0.15	11.13	86.56
Cly 19	39.70	32.00	9.77	0.77	0.05	0.45	1.81	0.16	0.00	4.70	0.11	10.28	85.88
Cly 20	38.14	32.72	10.30	0.83	0.07	0.43	1.59	0.12	0.00	3.99	0.16	11.39	87.72
Cly 23	37.22	31.07	26.97	3.24	0.19	0.01	0.01	0.37	0.20	0.16	0.14	1.30	99.01
Cly 25	39.27	30.54	25.26	2.82	0.20	0.11	0.01	0.28	0.23	2.00	0.50	1.63	92.13
Cly 26	42.58	29.35	22.08	2.59	0.19	0.29	0.43	0.26	0.21	0.68	0.94	1.22	93.89
Cly 34	49.80	28.99	6.49	0.49	0.05	0.63	1.37	0.09	0.00	3.87	0.00	9.08	86.56
Cly 35	7.72	0.40	0.83	0.07	0.01	0.00	39.29	0.02	0.00	0.06	1.88	49.76	17.09
Control 1	63.64	26.46	4.47	0.61	0.01	0.03	0.76	0.02	0.04	0.01	0.01	5.30	99.81
Control 2	38.31	30.35	26.09	3.16	0.21	0.04	0.01	0.03	0.04	0.27	0.23	1.78	98.25
Control 3	50.91	14.33	14.27	1.15	0.08	0.22	3.26	0.11	0	3.69	3.32	9.06	99.81

Cly – Clay samples

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Two major groups of geophagic clays emerged from dendrogram cluster analyses of geophagic clays. Those geophagic clays whose SiO_2 (wt %) relationship with CIA were greater than 50% represent moderate to high degree of weathered clays (Fig. 7.12),

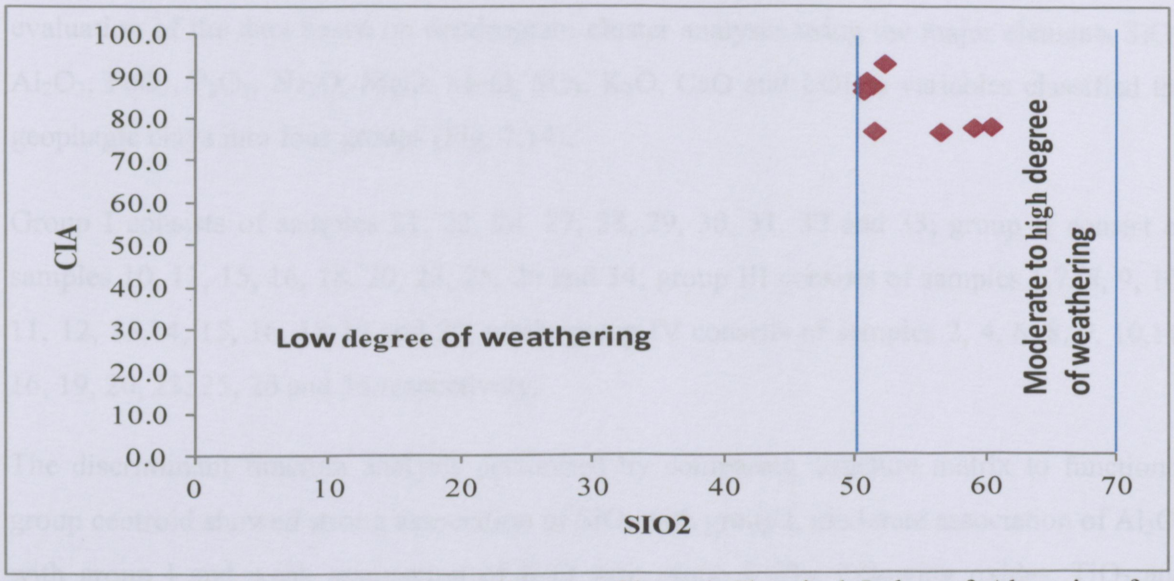

Figure 7.12: Relationship between SiO_2 (wt %) and Chemical Index of Alteration from Group I in the dendrogram cluster analysis of clay samples from Vhembe District

While those whose SiO_2 (wt %) relationship with CIA were less than 50% are referred to as clays of low degree of weathering (Fig. 7.13). Only one of the geophagic clay had a CIA value of less than 50%.

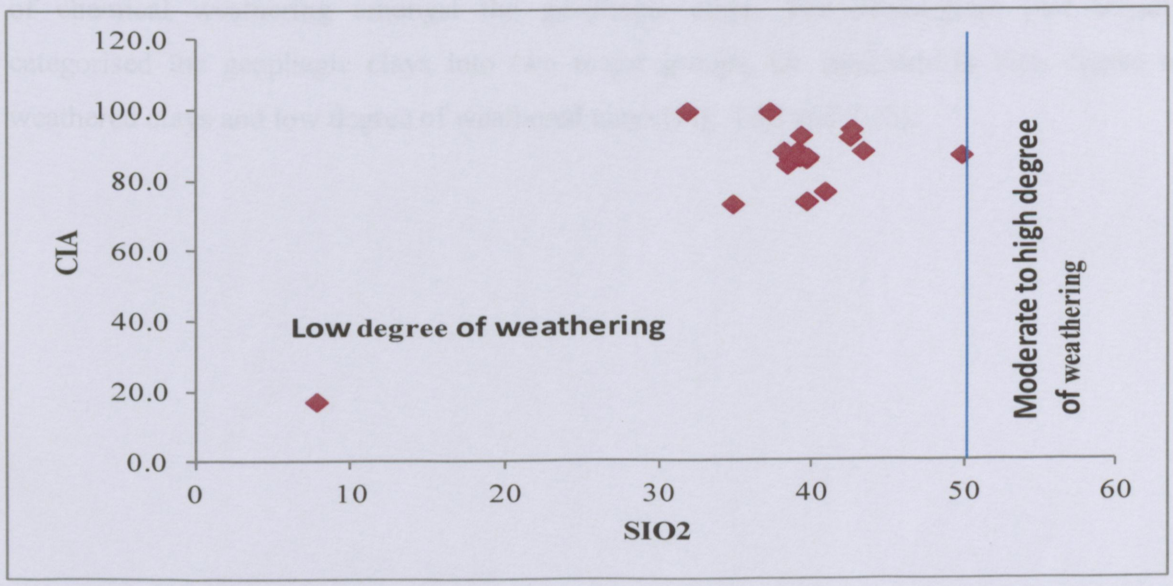

Figure 7.13: Relationship between SiO_2 (wt %) and Chemical Index of Alteration from Group II in the dendrogram cluster analysis of clay samples from Vhembe District

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7.4.2.2. Cluster analyses

The relationship among the geophagic clays obtained through cluster analyses made from dendrogram plots (distance cluster combination) is shown in Figure 7.14. Statistical evaluation of the data based on dendrogram cluster analyses using the major elements SiO_2, Al_2O_3, FeO_3, P_2O_5, Na_2O, MgO, MnO, SO_3, K_2O, CaO and LOI as variables classified the geophagic clays into four groups (Fig. 7.14).

Group I consists of samples 21, 22, 24, 27, 28, 29, 30, 31, 32 and 33; group II consist of samples 10, 11, 15, 16, 18, 20, 23, 25, 26 and 34; group III consists of samples 1,7, 8, 9, 10, 11, 12, 13,14, 15, 16, 18 19 and 20; while group IV consists of samples 2, 4, 6, 8, 9, 10,11, 16, 19, 20, 23, 25, 26 and 34 respectively.

The discriminant function analysis performed by comparing structure matrix to functional group centroid showed strong association of SiO_2 with group I, moderate association of Al_2O_3 with group I and weak association of K_2O with group I. The following oxides, TiO_2 and Fe_2O_3 showed strong association with group II. In group III, SO_3 showed strong association, while MnO showed moderate association with it. The groups were 100% different from each other in terms of element associations.

The dendrogram plot reflects a sequence in the association displaying the phase as a degree of chemical weathering amongst the geophagic clays. The dendrogram plot broadly categorised the geophagic clays into two major groups, i.e. moderate to high degree of weathered clays and low degree of weathered clays (Fig. 7.12 and 7.13).

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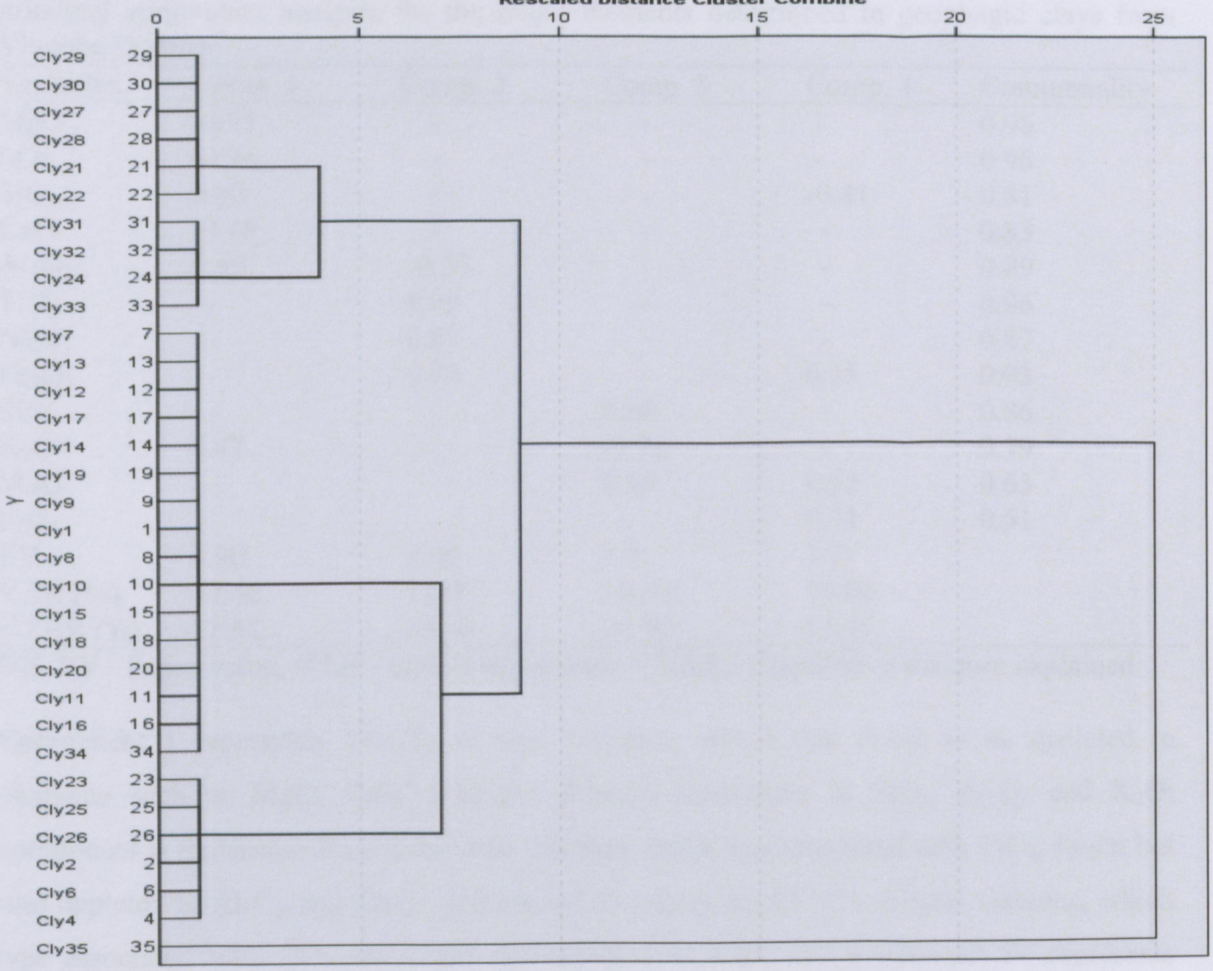

Figure 7.14: Dendrogram cluster analysis of clay samples using major elements reported as oxides (wt %) and loss on ignition as variables

7.4.2.3 Functional analysis

The functional analysis of the major elements reported as oxides using rotated component matrix showed 4 components (Table 7.7).

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Table 7.7: Varimax rotated factor loading matrix and communalities obtained from principal component analysis for the major elements determined in geophagic clays from Vhembe District

Variables	Comp. 1	Comp. 2	Comp. 3	Comp. 4	Communality
MgO	-0.95	-	-	-	0.96
LOI	-0.94	-	-	-	0.98
SiO_2	0.80	-	-	-0.41	0.81
CaO	-0.78	-	-	-	0.83
Al_2O_3	0.68	-0.57	-	-	0.89
TiO_2	-	0.90	-	-	0.96
Na_2O	-	0.87	-	-	0.87
Fe_2O_3	-	0.74	-	0.55	0.93
SO_3	-	-	0.89	-	0.86
K_2O	0.47	-	-0.70	-	0.79
MnO	-	-	0.56	0.52	0.63
P_2O_5	-	-	-	0.71	0.51
EV	3.90	2.60	1.9	1.6	
VAR (%)	32.40	22.00	16.00	13.00	
CVAR (%)	32.42	54.46	70.49	83.45	

NB. EV - Eigen value, VAR - explained variance, CVAR - Cumulative variance explained

Component 1 represents 39.82% of total variance, which was found to be depleted in elements such as MgO, CaO, LOI but showed enrichment in SiO_2, Al_2O_3 and K_2O; component II represents 26.36% of total variance which was associated with TiO_2, Fe_2O_3 but was depleted in Al_2O_3 and Na_2O; component III represents 19.17% of total variance, which was associated with SO_3 and MnO but depleted in K_2O; and component IV represents 15.57% of total variance, which was associated with Fe_2O_3, MnO and P_2O_5 and depleted in SiO_2. The depletion of MgO and CaO in component I and Al_2O_3 and Na_2O in component IV coincides with samples taken from termite mounds, anthills and horizon A of soil profiles.

Depletion of Al_2O_3 and Na_2O in component II coincides with termite mound and magnesite rich material and SiO_2 in component III coincides with samples from horizon A of soil profiles. Component IV that was deficient in SiO_2 coincides with magnesite. The depletion and enrichment trends could be correlated with the degree of weathering and origin of formation of geophagic clays.

7.4.3. Trace element geochemistry

Total trace element contents of the consumed Earth materials (Table 7.8) were within the range of values found for mineral soils reported by Mitchell (1964).

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Table 7.8: Trace element (ppm) analyses of Earth materials and control samples

Sample ID	Ba	Co	Cu	Cr	Mo	Ni	Pb	Th	V	Zn	As
1	140	45	30	0	3	43	44	14	46	125	0.01
2	26	38	114	0	2	53	19	1	182	28	0.03
3	298	0	0	397	3	31	4	10	206	0	0.04
4	26	2	52	0	1	67	0	2	575	39	0.02
5	949	0	28	334	5	30	5	78	164	0	0.03
6	26	8	59	137	5	23	18	5	507	19	0.02
7	173	47	37	0	3	53	17	4	50	138	0.01
8	202	33	4	0	3	51	32	2	48	131	0.01
9	26	0	49	0	5	53	29	4	68	90	0.04
10	160	35	17	0	3	47	57	15	34	121	0.03
11	137	3	16	0	3	49	51	8	49	138	0.04
12	157	0	1	0	3	55	46	10	43	139	0.03
13	166	0	10	0	2	46	6	11	50	139	0.05
14	183	0	10	0	3	50	20	9	55	132	0.33
15	202	33	4	0	3	51	32	2	48	131	0.23
16	26	18	28	0	5	51	14	7	79	84	0.22
17	160	35	17	0	3	47	57	15	34	121	0.15
18	137	3	16	0	3	49	51	8	49	138	0.02
19	123	0	22	0	4	43	26	10	47	138	0.33
20	60	0	31	0	2	57	18	10	45	151	0.21
21	553	13	23	84	1	28	17	13	81	102	2.24
22	297	11	5	45	1	16	66	98	78	69	3
23	106	127	259	242	4	111	7	15	602	88	3
24	1299	70	3	169	1	35	36	33	117	64	3
25	175	103	225	229	4	105	12	11	519	84	2.5
26	175	103	225	229	4	105	12	11	519	84	2.67
27	445	12	18	78	1	31	8	15	67	92	3
28	479	11	23	74	1	28	17	16	70	96	3
29	485	12	20	74	1	29	9	16	70	99	3
30	490	11	22	77	1	28	6	15	74	98	3
31	10.83	29.21	108.7	108.07	1	68.46	12.97	9.95	148.61	113.12	3
32	757.57	45.91	17.46	159.28	1	70.76	3	11.53	360.32	111.96	2.87
33	754.98	48.71	24.42	265.68	1.11	134.85	3	9.8	9.43	119.34	3
34	485.06	10.73	23.14	69.8	1	29.13	3	15.08	9.43	112.01	2.97
35	98.35	21.05	11.04	134.88	1	169.62	3	3	9.43	46.82	3
Mean	285.36	26.53	44.36	83.04	2.51	55.36	21.74	14.78	146.09	96.6	1.28
SD	292.68	32.1	64.92	108.63	1.39	33.04	18.54	19.39	178.33	41.28	1.41
Min. Soil cont.	100-6000	1-80	3-100	7-1000		7-800	3-120		12-800		1-80
C-1	666.48	25.63	11.42	56.63	1	11.31	4.21	3	79.98	43.27	3
C-2	151.78	102.58	253.57	203.91	3.57	91.3	3	13.67	569.03	85.84	3
C-3	551.08	28.21	24.45	94.23	1.26	74.04	3	7.71	179.54	88.27	3
Cert. Ref.	1400	65	20	55	1.2	34	53	42	65	48	3

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The mean concentrations of trace elements in the context of human nutrition were as follows: Co, 26.53 ppm; Cu, 44.36 ppm and Zn, 96.6 ppm. The mean concentrations of trace elements which are associated with toxicity were as follows: As, 1.28 ppm; Ni, 55.36 ppm; Pb, 21.74 ppm; Cr 83.04 ppm. Some of the consumed Earth materials (samples 22, 24 and 29) were enriched in radionuclides and rare earth elements (REE). The radionuclides and REE could be from weathered rocks in the vicinity of where these Earth materials were mined.

7.4.4. What is the nature (chemical and mineralogical composition) of Earth materials in the area?

The research found that the consumed Earth material varies from one sample to the other. Majority of the samples have over 51% by weight of kaolinite and a small amount of smectite and muscovite. Thirteen minerals were identified in the geophagic materials. Primary minerals were quartz, feldspar, muscovite and secondary minerals were kaolinite, smectite, goethite, chlorite, rutile, titanite and hematite. The dominant clay mineral (kaolinite) could have been altered from primary minerals, particularly feldspar (microcline) and mica (muscovite) as shown in equation 1 and 2.

$$2KAl_3Si_3O_{10}(OH)_2 + 2H^+ + 3H_2O \rightarrow 3Al_2Si_2O_5(OH)_4 + 2K^+ \quad \ldots\ldots\ldots(1)$$

Feldspar kaolinite

$$2KAlSi_3O_8 + 2H^+ + 9H_2O \rightarrow Al_2Si_2O_5(OH)_4 + 2K^+ \quad \ldots\ldots\ldots\ldots\ldots(2)$$

Feldspar Kaolinite

Another possible formation mechanism for kaolinite could be alteration of feldspathic arenites rich in quartz. This is as a result of the presence of quartz in some of the geophagic samples.

The research also found that oxides of Al, Si and Fe were the major ones, while oxides of Ca, Mn, Na, Ti and P were less significant. Earth materials in Group I (21, 22, 24, 27, 28, 30, 31 32 and 33) of the dendrogram plot which showed strong association with SiO_2 are likely to pose health risks to geophagists. According to Lohn et al. (2000), quartz particles in geophagic materials could scratch the walls of the intestines, eventually leading to perforation of the small intestines and the colon.

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7.5. Discussion

Virtually all the Earth materials studied were dominated by kaolinite, except one sample whose silica content was greater than kaolinite (Table 7.1). Johns and Duquette (1991) reported similar occurrence of kaolin in Earth materials consumed by women of child bearing age in California and Sardinia. Chandrajith et al. (2009) revealed that in humid tropical environments, smectite clays are present in partly weathered soil profile and degrade further to form kaolin. The higher content of kaolinite in analysed Earth materials of the area showed that they were highly weathered products. The mineralogical analyses as reported in this study also support the work of Diko and Ekosse, (2011), which showed kaolinite as the major phyllosilicate in geophagic samples from South Africa. The clays contain abundant kaolinite with subsidiary amounts of smectite (John and Duquette, 1991). These clays were able to reduce the tannic acid content of an acorn meal by up to 77%, thus providing a rationale for their consumption (Wilson, 2003).

This mineralogical characteristic was consistent with the protection hypothesis earlier advanced to account for human geophagic practice (Young et al., 2010). Kaolinite is used in production of pharmaceutical drugs such as kaopectate, which helps to cure or alleviate diarrhoea and gastrointestinal upsets (Vermeer and Ferrel, 1985; Wilson, 2003; Young et al., 2010). Kaolin has the ability to coat and adhere to the gastric and intestinal membrane, thus protecting against toxins and bacteria, and adsorbing excess water in the faeces (Gonzalez et al., 2004).

Another reason for human geophagic practice is that consumed Earth materials act as a natural antacid by reducing excess acidity in the digestive tract. This is dependent on the mineralogical characteristics of these materials and the pH values (Wilson, 2003). The pH values of the consumed Earth materials are weakly acidic to neutral and would impart a sour taste to Earth materials on consumption. The sour taste could be beneficial to pregnant women in reduction of nauseate feeling and prevention of excess salivation (Ngole et al., 2010).

Geophagic clays studied by Diko and Ekosse (2011) showed remarkable traces of goethite and hematite minerals, similar to the soils in this study, whose reddish colouration indicate the presence of goethite and hematite in them. However, the reddish colour may not be an indication of bioavailability of Fe to geophagists who may assume that they could

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supplement their Fe intake by consuming such earthy materials (Fontes et al., 2005; Ngole et al., 2010).

According to the work of Barker (2005), ingestion of siliceous Earth materials could damage the dental organ of geophagists and erode the mucosal surface of the stomach. Considering the health risks that are associated with geophagic practice, samples in Group I of the dendrogram plot if ingested, could pose danger to these geophagic women and children.

The geophagic clays have variable chemical compositions. There was no notable difference between total Na and P content of geophagic clays and control samples. This is consistent with the geophagic soils in Udawale National Park in Sri Lanka (Chandrajith et al., 2009).

Geophagic clays from Makuya, Tshisaulu, Biaba and Musina communities in the Vhembe District were deficient in Ca (< 0.2 % CaO). The geophagic clays were characterized by high Si, indicating a high amount of quartz, of which sand was the most significant fraction. According to Ngole et al. (2010) significant quantities of Si in geophagic clays may result in various medical conditions. These include dental enamel destruction and perforation of the sigmoid colon (Lohn et al., 2000).

The mean concentrations of the following oxides; K_2O and Na_2O were low in geophagic materials from the Vhembe District. This study confirms the results of several other studies carried out in Thailand, Zaire, Swaziland and Uganda (Abrahams and Parsons, 1997; Ngole et al., 2010; Ekosse and Ngole, 2012) which showed low values for oxides of K and Na in geophagic materials from these countries.

Ferric content of geophagic clays from this locality was higher than ferric content of other clays from Nigeria (Okunlola and Awoyemi, 2011). The geophagic clays were rich in Fe_2O_3 and were similar to geophagic soils from Zanzibar in Tanzania (Young et al., 2010).

Major oxides of Mn and P are variable in the geophagic clays. The values of the different oxides of Ti, K, Mn, P and S in each of the samples fell within the range of values reported in geophagic soils from Turkey, Swaziland, Mississippi, Georgia and Zanzibar (Young et al., 2010; Ngole et al., 2010). According to Ekosse and Ngole (2012), TiO_2 in geophagic soils could possibly be in the form of free Ti oxides and some may have substituted for Al in the octahedral sheet of kaolinite.

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High values of CIA (76-100) indicate intensive chemical weathering in the source areas, whereas low values (50 or less) indicates unweathered source areas (Islam and Rahman, 2009). These high values of CIA suggest low amounts of essential constituents (Ca, Mg, Fe and P) in geophagic materials (Ekosse and Ngole, 2012). The CIA of geophagic clays from this locality showed low and moderate to high degree of weathering, respectively. This is consistent with CIA values of shale from Surma Group in Bangladesh (Islam and Rahman, 2009). High values of CIA have been reported in geophagic soils from Swaziland (Ekosse and Ngole, 2012).

Very high values (>88) for CIA of geophagic soils from Democratic Republic of Congo (DRC), Cameroon and Nigeria confirmed extremely high degree of weathering compared to CIA Values of 45 - 55 which were indicative of no weathering (Depetris and Probst, 1998; Ekosse and Ngole, 2012). Chemical index of alteration (CIA) values for geophagic clays from this locality were consistent with CIA of geophagic clays from these countries except for one sample which has a very weak CIA value of less than 20. This could be due to environment of deposition of this geophagic clay in Vhembe District. The climate is sub tropical and is similar to the climatic condition of countries like Nigeria, Cameroon and DRC where the intensity of rainfall was very high.

The concentration of trace elements of biological significance in the Earth materials are high, unlike the geophagic soils from Zanzibar in Tanzania that are uniformly low when compared to the usual range found in all types of mineral soils (Young et al., 2010).

7.6. Conclusion

The consumed Earth materials in Vhembe District of Limpopo Province have over 50% by weight of kaolinite in each sample and a relatively small amount of smectite and muscovite. The plagioclase albite, anatase and orthoclase content is also low in the samples and only four of the samples have significant concentration of haematite and goethite. The mineralogical characteristics vary greatly from one sample to the other. The samples are mixtures of kaolinite, smectite microcline and muscovite rich, or kaolinite, smectite quartz, or orthoclase rich. These consumed Earth materials are weathered products which are leached from rocks under favourable (adequate amount of rainfall for weathering processes) weathering conditions.

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The dominant major oxides in the geophagic clays were Al_2O_3, SiO_2 and Fe_2O_3. Oxides of Ti, P, Na, Mn and Ca in the geophagic clays and control samples were less significant and variable in composition. Relationship between SiO_2 and CIA revealed that the geophagic clays were of low degree or moderate to high degree of weathering. Relative enrichment and depletion trends of major oxides in the geophagic clays could be due to the intensity of weathering and the environment where these geophagic clays were formed. Siliceous geophagic clays could be detrimental to the health of geophagists because of gradual wearing of the mucosal wall and perforation of the sigmoid colon. Geophagic clays in group I from the dendrogram cluster analyses are found to be very rich in quartz which could damage the dental enamel and rupture the colon of geophagists in this locality. Earth materials devoid of much silica are ideal for human consumption because the sour taste helps to quell nausea and excess salivation during pregnancy. This could be one of the reasons for human geophagic practice.

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GENERAL CONCLUSION AND RECOMMENDATION

8.1. Conclusions

This study has investigated the mineralogy, major and trace element chemistry of geophagic materials that are consumed by humans in the Vhembe District of South Africa. Determinations of the physicochemical properties, bacterial counts and detection, and measurement of the amount of helminth ovum, were focal points of the study. An investigation on the prevalence of geophagic practice amongst womenfolk was also carried out. To achieve the research objectives, the study was divided into three sub-themes. The first theme of the research dealt with the prevalence of geophagic practice in the area. The research revealed that geophagic practice is deeply rooted amongst the inhabitants of the area. Both young and old women were involved in the practice. Pregnant women are more involved in the practice than non-pregnant women. Craving for Earth material was the main reason for practicing geophagia. Hunger is not a major reason for geophagic practice in this locality. The choice of material is influenced by the income of the practitioners. The high income earners prefer clay sold in the local markets and shops, while the low income earners in the rural areas collect their Earth materials from the wild.

The second theme focussed on determination of the physical features of geophagic materials as a clue for unravelling the criteria for selection and functions of consumed clays. The geophagic clays are found to be acidic in nature. Textures are mainly clayey, with small amounts of clay loam and sandy clay loam. Cation exchange capacity is low and the colour ranges from brown, pale yellow and reddish to grey. Microbiological examination of the geophagic clays reveals the presence of beneficial bacteria (*Streptomycetes*) in some Earth materials.

The health impacts of consumed Earth materials by humans were assessed by determining the Fe status (haemoglobin value) of geophagists' women and identification of helminth ova in geophagic materials. The results indicated that some women were anaemic and an *Ascaris lumbricoides* ovum was detected in one of the geophagic materials. Geophagia could be linked to one of the causes of anaemia amongst female geophagists in Vhembe District. Physiologically based extraction test was also carried out on the geophagic materials to see if

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there are PHEs that could be bioaccessible for uptake by geophagists. Lead and As are the PHEs of great concern, though their impact is minimal because the bioaccessible concentrations are higher in the stomach phase than in the intestinal phase where absorption takes place.

The fourth experiment was on determination of essential trace element content and their bioaccessibility. The results obtained showed that Fe, Zn and Mn were more bioaccessible in the stomach phase than in the intestinal phase. Copper was more bioaccessible in the intestinal phase than in the stomach phase. Consumption of an average of 40 g of some geophagic materials on daily basis could provide the necessary recommended nutrient intake of 16%. Some of the geophagic materials were completely devoid of bioaccessible Fe.

The last theme was on the mineralogical and geochemical constituent of consumed Earth materials. The clay mineral content, major oxides and trace element contents were measured. Clay minerals were identified and their contents determined. The samples were rich in kaolinite, smectite, microcline, muscovite or kaolinite and smectite rich. Plagioclase, albite, anatase, hematite and goethite were found in minor amounts. Silica, Fe_2O_3 and Al_2O_3 were the most dominant oxides while CaO, MgO, MnO, K_2O, TiO_2 and P_2O_5 contents were very low. Chemical index of alteration values range from low to moderately high.

The research has provided the much needed answer for the reasons why humans indulge in geophagic practice in the Vhembe District, the role of consumed Earth materials in supplementing the mineral nutrients of geophagists. This study has also thrown light on the protection hypothesis of geophagia with the use of clay mineralogy. The dominant clay mineral in the consumed Earth material is kaolin. It has the potential to absorb toxins on the walls on the gastrointestinal tract of female geophagists. Occurrence of beneficial bacteria (*Streptomycete*) in geophagic clays could protect geophagists against other bacterial and pathogenic infections.

The widely held view that geophagy is practiced to alleviate the pangs of hunger is not corroborated in this study in the Vhembe District. The hunger hypothesis is rejected, as nobody in this District specifically mentioned hunger as the major reason for practicing geophagia.

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Geophagic materials should be carefully sourced from clean environment. Sanitary habits should be strictly adhered to by geophagists living at Shayanba and its environs, because of the possible infestation of geophagic materials with *Ascaris lumbricoides* ovum.

The results of this study can be used to develop a more appropriate scientific approach in the selection of geophagic materials for Vhembe District. Processing of these geophagic materials by pounding with pestle in local mortar, roasting, baking, smoking or sedimentation in water are recommended as a way of minimizing geohelminth infection, preventing obstruction and perforation of the colon.

8.2. Recommendations

The present study dealt with bioaccessibility of essential trace elements in geophagic materials for well being of geophagic practitioners. Isotope tracer studies on the blood samples of geophagist need to be considered in order to ascertain the exact amount of Fe and other essential nutrients that are released to the blood stream from geophagic materials. Research on the speciation of chemical elements in the simulated gastrointestinal systems should be carried out to unravel the particular species of elements that are absorbed into the human system. Further studies are required to determine the antimicrobial activity of metabolites produced by the isolates in some geophagic clay to identify the specific type of antibiotics that could be produced from some of the beneficial geophagic clays and fungal presence in one of the geophagic material for overall safety of the practitioners. Further studies are required to examine the association between geophagy and anaemia among geophagic practitioners in the Vhembe District.

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- Anaemia; Medical condition in which a person has too few red cells in their blood, making them to look pale and feel weak (Oxford English Dictionary).
- Anaemic: Person suffering from anaemia (Oxford English Dictionary).
- Ante-natal: Medical care given to pregnant women before delivery (Oxford English Dictionary).
- Anonymity: State of remaining unknown to most other people (Oxford English Dictionary).
- Bioavailable: Readily available fraction (sum of soluble and weakly adsorbed fractions) for animal uptake (Oxford English Dictionary).
- Clinic: Building where people go for medical treatment.
- Cohort: A group of people who share a common feature.
- Craving: Strong desire for something.
- Composite: Something made by putting together different parts of materials (Dictionary)
- Deficiency: State of not having enough that is essential.
- Dysentry: An infection of the bowels that causes severe diarrhoea with loss of blood (Dictionary).
- Detoxification: To remove harmful substances or poisons from the body.
- Epidemiological: Scientific study of the spread and control of diseases.
- Fertility: The state of being fertile.
- Geophagy: Deliberate soil consumption.
- Geophagous: Person that eats earth.
- Health: A state of complete physical, mental and social well being and not merely the absence of disease or infirmity.
- Hyperkalaemia: Excess of potassium in the blood stream.
- Hypozincaemia: Low amount of zinc in the blood stream.
- Hyptohesis: An idea that is based on a few known facts but that has not yet been proved to be true.
- In-vivo vitro: Taking place outside a living body in scientific apparatus.
- Mineralogy: Scientific study of essentials minerals.

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- Nutrient: A substance that is needed to keep a living thing alive and to help it to grow (Dictionary).
- Palatable: Having a pleasant or acceptable taste.
- Pathogens: A thing that causes disease.
- Palliative: Medicine that reduces pain without curing its cause.
- Pica: Eating of non-food substances.
- Plaque: An infectious disease that kills a lot of people.
- Physiological: Way in which a particular living thing functions.
- Pathways: A line along which certain things moves.
- Toxins: A poisonous substance.
- Questionnaire: A written list of questions that are answered by a number of people so that information can be collected from the answers.

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SCHOOL OF ENVIRONMENTAL SCIENCES
DEPARTMENT OF MINING AND ENVIRONMENTAL GEOLOGY

QUESTIONNAIRE DIRECTED TO GEOPHAGIST (PERSON WHO EATS EARTH MATERIALS IN VHEMBE DISTRICT OF LIMPOPO PROVINCE, SOUTH AFRICA.

Information for research on geophagic practice in Vhembe District is required. The practice in the District is widespread and ingested soils have important medical implications such as nutritional and protection against pathogens which remains to be confirmed and resolved till date.

Confidentiality is assured and your completion of this questionnaire is appreciated. Please fill in the space with details or put a cross in the relevant block. Kindly respond to all the questions. Where applicable mark more than one answer.

Personal Information

1. Name (Initials): .....

2. (i) Town, : .....
   (ii) Village: .....

3. Grid Reference / GPS Coordinates: (Lat.; Long.; Alt.) .....
   .....

4. Population: Size / Density: ..... Rural: .....
   Urban: ..... Suburban: .....

5. Tribe: ..... 6: Sex: M ( ) or F ( ) 7. Age: .....

8. Occupation: A. (i) School ..... (ii) Farming .....
   (iii) Waged labour/trading ..... (iv) At home/
   Housewife ..... (v) Other (give details).....
   .....

(For adults only): Have you been to school?
Yes ( ) No ( )
If yes, have you been to (i) Primary school? Yes ( ) No ( )

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(ii) Secondary school? Yes ( ) No ( )
(iii) University / college? Yes ( ) No ( )

9. Family level of economic performance (Subsistence economy, middle income, Affluent, etc.) : .....
Note: How do we assess this? Do we need some type of household income scale?

10. Marital status: .....11. : Number of previous pregnancies: .....

12. Stage of pregnancy (if applicable): .....13. : Religion .....

Causative Reason(s)

1. What type of food do you like best? .....

2. Do you eat any kind of earth material? (Explain earth material as soil, clay, Soft stone, wall scraping, sand, earth, termite mound / anthill, etc.) : Yes ( ) No ( )
3. Has anyone encouraged you to eat earth material? Yes ( ) No ( )
(ii) If yes, who? Mother ( ) Friend ( ) other (give details).....
.....

4. Why did they encourage you? .....

(i) Are you eating earth material at this period of time? Yes ( ) No ( )
(ii) If 'No', when was the last time you ate earth material? .....

5. (i) Do you like eating earth material? Yes ( ) No ( )
5. (ii) Why do you like eating this, or what benefits do you think you derive from it? (e.g. flavour, taste, colour, nice feeling in the hand or mouth, sense of satisfaction, lessening of hunger .....

6. Do you have with you (nearby) any sample of the earth material you prefer eating? Yes ( ) No ( )

7. Would you eat another kind of earth material if the one you prefer was not available?

8. What do you normally eat at meal times when not eating earth material ?

* Breakfast : .....

* Lunch : .....

* Dinner : .....

9. How often do you eat earth material? Once a day ( ) Several times a day ( ) Once in a while ( ) Hardly ever ( )

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10. How much do you take?

** The interviewer has a number of polythene bags containing varying amounts of earth material (in units of grams marked on the bag). The interviewee could then indicate by pointing at a certain bag.

11. Do you notice any undesirable effects after you consume this material?
Yes ( ) No ( )

12 Are there times when you want to take this material (the one you prefer) and it is not available? Yes ( ) No ( )

13. How can you describe your feelings if you do not have access to this material when you want to eat it? .....
What do you do then?.....

14. When do you consume the material?

Just before regular meal ( )
Just after regular meal ( )
As part of the regular meal ( )
At another time of the day ( ) give details .....

15. How do you consume the material?

Gnawing a chunk of the earth material ( )
Ingesting the earth material powder with water ( )
Ingesting the earth material powder without water ( )
Other ( ) give details .....

Distribution Chain of Geophagic Materials

1. How do you obtain the material you consume? From your home ( )
Market ( ) From Friends ( ) From Stores as a Pharmaceutical ( )
( )

2. Where do you obtain the material you consume? Directly from the ground surface ( ) from a deeper layer of earth material via a hole or cliff-face, etc. ( ) termite mound ( ) anthill ( ) mine ( ) dried-up stream ( ) scrapping wall of a building ( ) seaside ( ) other ( ) give details
.....

3. If you buy the earth material, can you afford to buy it regularly?
Yes ( ) No ( )

4. Do your religious beliefs support your eating of these materials? Yes ( )
No ( )

5. (i) What does your husband think about eating earth material?
.....

5. (ii) Has he ever eaten earth material as an adult? Yes ( ) No ( )

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6. Do you know any other people in South Africa who eat earth materials (your Children, other relatives, friends)? If so, can you give details .....
.....

7. Do you have relatives overseas to whom you sometimes send these materials?
Yes ( ) If so, where .....
No ( )

8. How do you send them these materials?

By post ( )

Via a friend ( )

Not applicable ( )

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APPENDIX B: ETHICAL CLEARANCE FROM UNIVERSITY OF VENDA

RESEARCH AND INNOVATION

OFFICE OF THE DIRECTOR

NAME OF RESEARCHER/INVESTIGATOR:

Prof. T.C Davies

PROJECT TITLE: Geophagy (deliberate soil consumption) in Limpopo Province, South Africa. A socio-economic, geochemical and microbiological study.

PROJECT NO: SES/10/MEG/001

SUPERVISORS/ CO-RESEARCHERS/ CO-INVESTIGATORS

NAME	INSTITUTION & DEPARTMENT	ROLE
Prof. H. Akinsola	University of Venda, Public Health	Researcher
Mr. M. Abuh	University of Venda, Mining & Environmental Geology	Researcher
Mr. B. Iweriebor	University of Venda, Mining & Environmental Geology	Researcher

ISSUED BY:

UNIVERSITY OF VENDA, HEALTH, SAFETY AND RESEARCH ETHICS COMMITTEE

Date Considered: 26 May 2010

Decision by Ethical Clearance Committee Granted

Signature of Chairperson of the Committee: .....

Name of the Chairperson of the Committee: Prof. P.E. Lukhele-Olorunju

UNIVERSITY OF VENDA
PRIVATE BAG X5050, THOHOYANDOU, 0950. LIMPOPO PROVINCE. SOUTH AFRICA
TELEPHONE 015 962 8313 / 8484 / 8504. FAX 015 962 8439 / 4749
Email: research@univen.ac.za

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APPENDIX C: ETHICAL CLEARANCE FROM LIMPOPO PROVINCIAL GOVERNMENT

LIMPOPO
PROVINCIAL GOVERNMENT
REPUBLIC OF SOUTH AFRICA

DEPARTMENT OF HEALTH & SOCIAL DEVELOPMENT

Enquiries: Selamolela Donald
Ref: 4/2/2

03 November 2010
Prof T C Davies
Department of Mining and Environmental Geology
University of Venda
Private Bag x 5050
Thohoyandou
0950

Dear Sir

Re: Permission to conduct the study titled: Geophagy (Deliberate soil consumption) in Limpopo Province, South Africa. A socio-economic, geographical and microbiological study.

1. The above matter refers.
2. The permission to conduct the above mentioned is hereby granted.
3. Kindly be informed that:-
   - Further arrangement should be made with the targeted institutions.
   - In the course of your study there should not be any action that will disrupt the services
   - After completion of the study, a copy should be submitted to the Department to serve as a resource.
   - The researcher should be prepared to assist in the interpretation and implementation of study recommendation where possible.

Your cooperation will be highly appreciated.

Head of Department
Health and Social Development
Limpopo Province

Private Bag x 9302 Polokwane.
18 College Str. Polokwane 0700. Tel: (015) 293 6000 Fax: (015) 293 6211 Website: http/www.limpopo.gov.za

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APPENDIX D: INFORMED SIGNED CONSENT FORM

CONSENT FORM

The 'Geophagy Study Group' of the University of Venda, represented by Prof. T.C. Davies, ID No. 0199576, Prof. H. Akinshola, ID No. A0868996, Mr. B. Iweriebor, ID No. A4020672 and Mr. A. Momoh, ID No. A00162507 are pleased to meet you. This Group is undertaking a study on the merits and demerits of 'Geophgy' as practised in the Limpopo Province of South Africa. Geophagy is the habit of eating clay or earth, and it is practised widely in many parts of the world.

At the end of the study, we hope to come up with a documentation on how geophagy can be practiced safely, and its correlation with geohelminths and other possible negative health consequences.

You are please requested to answer willingly, some questions to enable us carry out this project. No harmful procedure is involved in this study. Only stool and possibly blood samples will be required from you after answering the questionnaire. No tests will be done on you.

For your kind gesture and time spent, we shall pay your return transport fare.

If you agree to participate in the study, please sign below:

Signature of Participant:..... Date:.....

Signature of Interviewer:..... Date:.....

Signature of Witness:..... Date:.....

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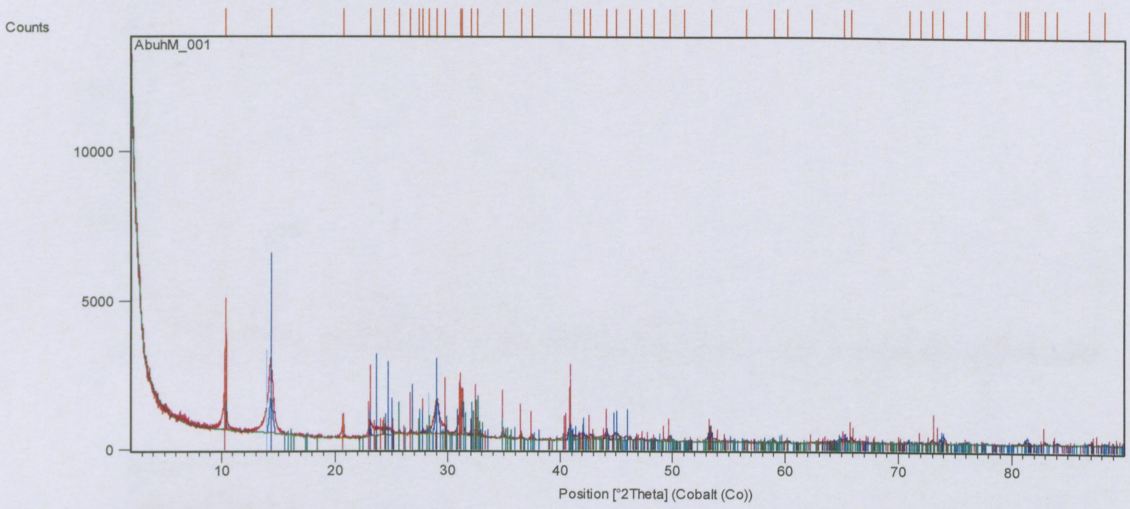
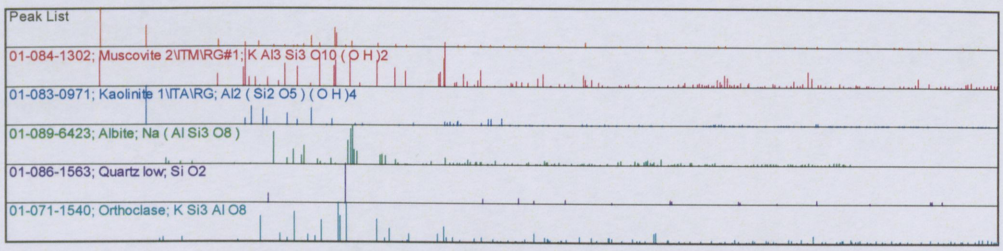
APPENDIX E: X-RAY DIFFRACTOGRAMS OF GEOPHAGIC CLAYS





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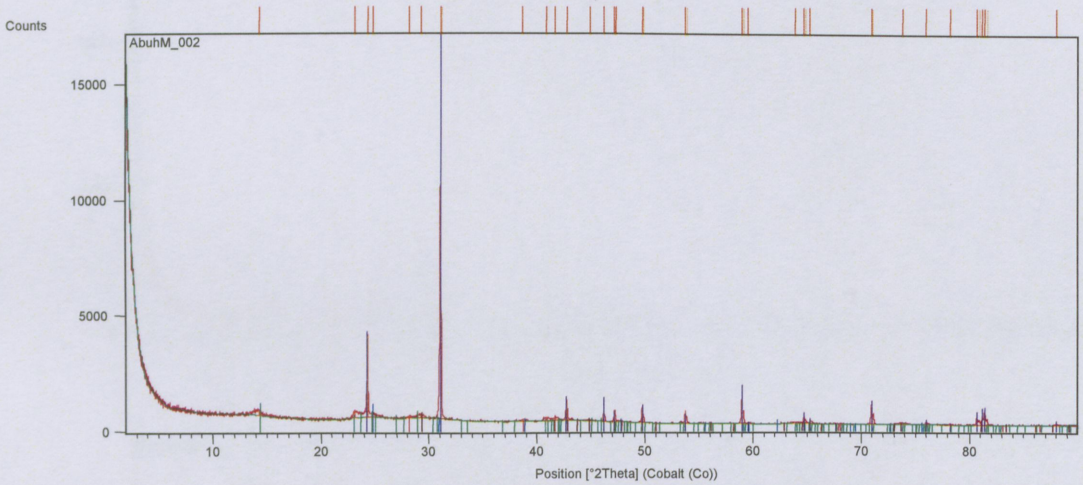

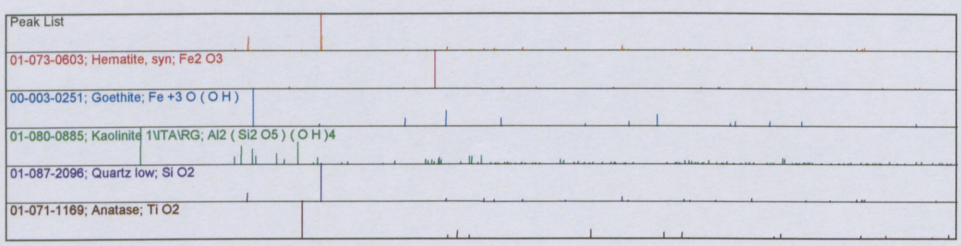

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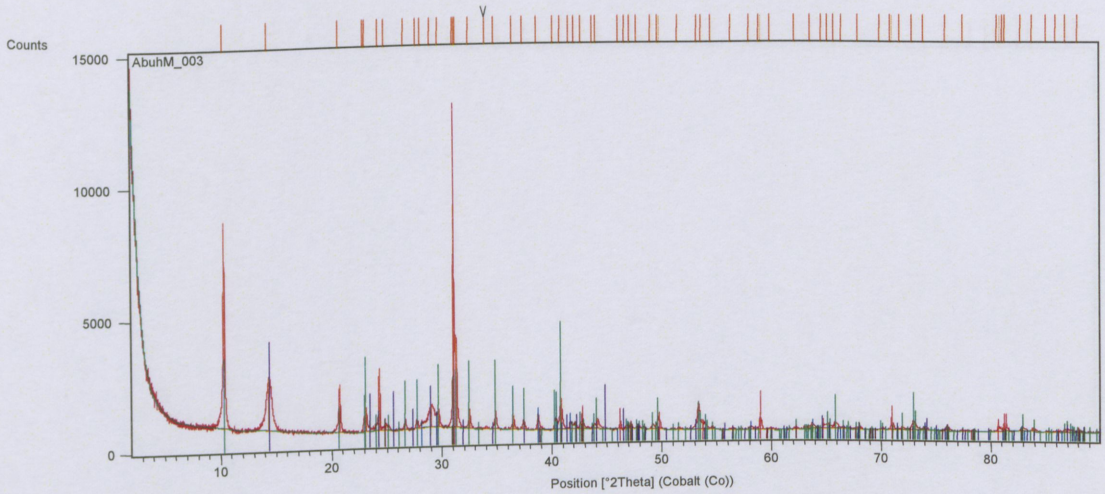

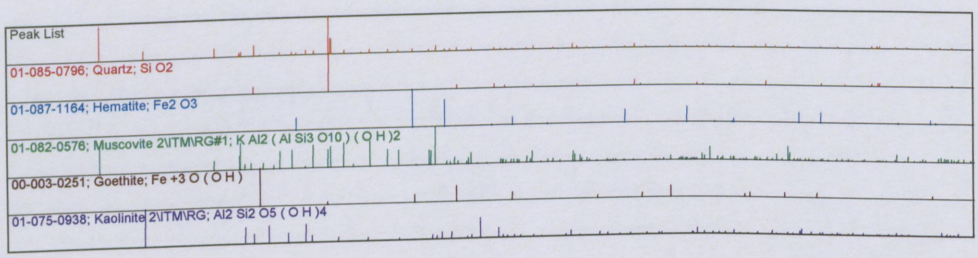

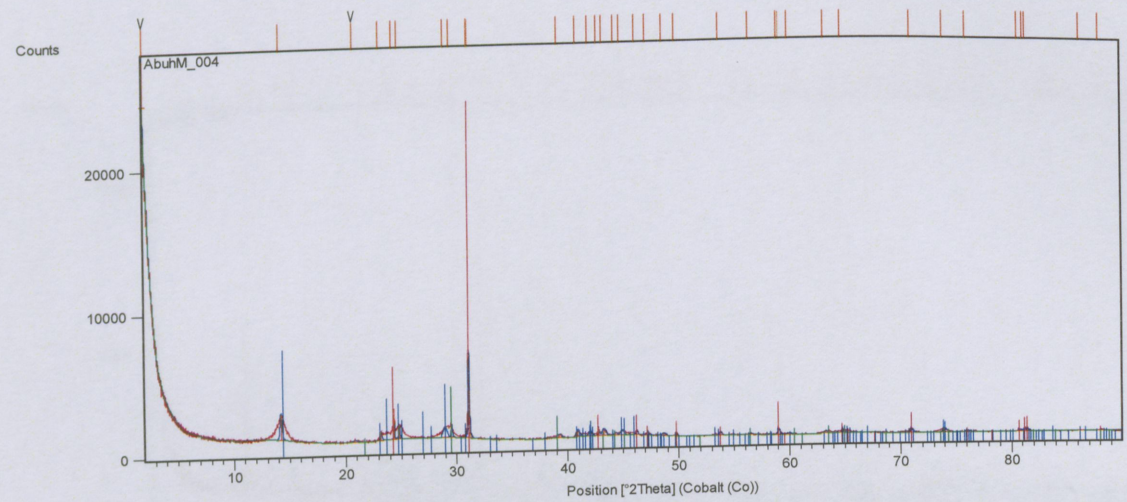

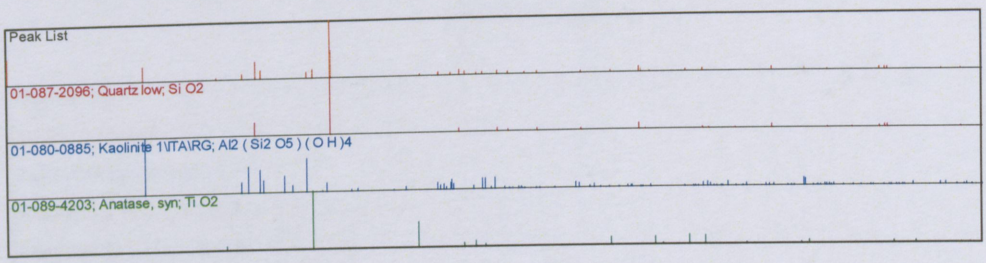

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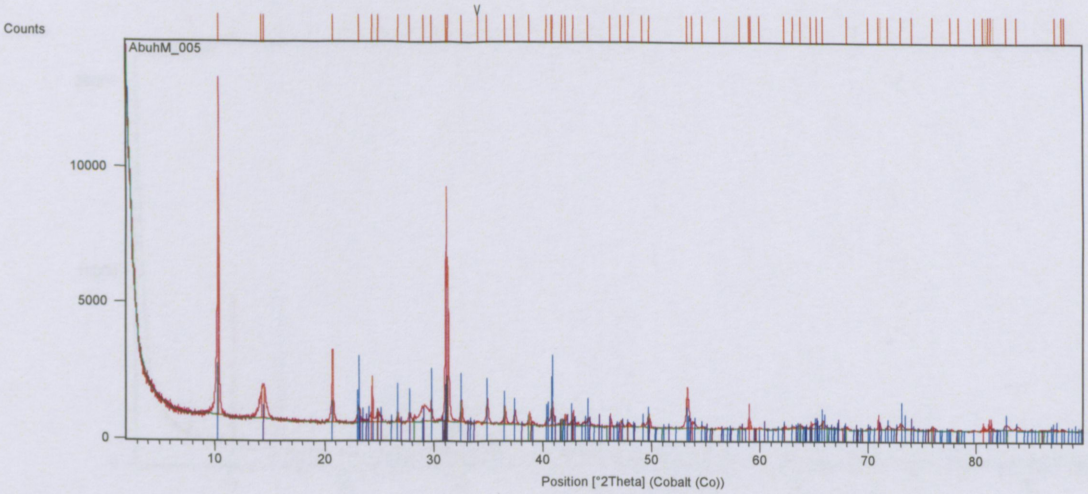

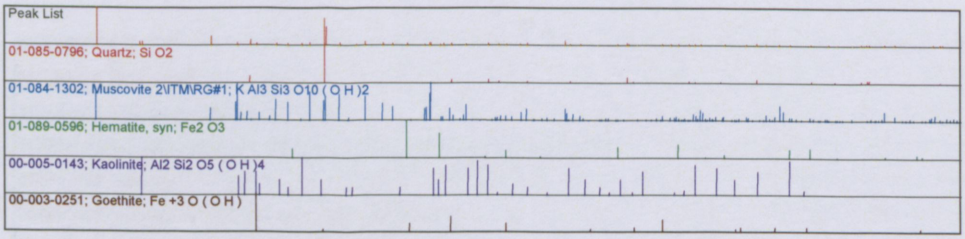

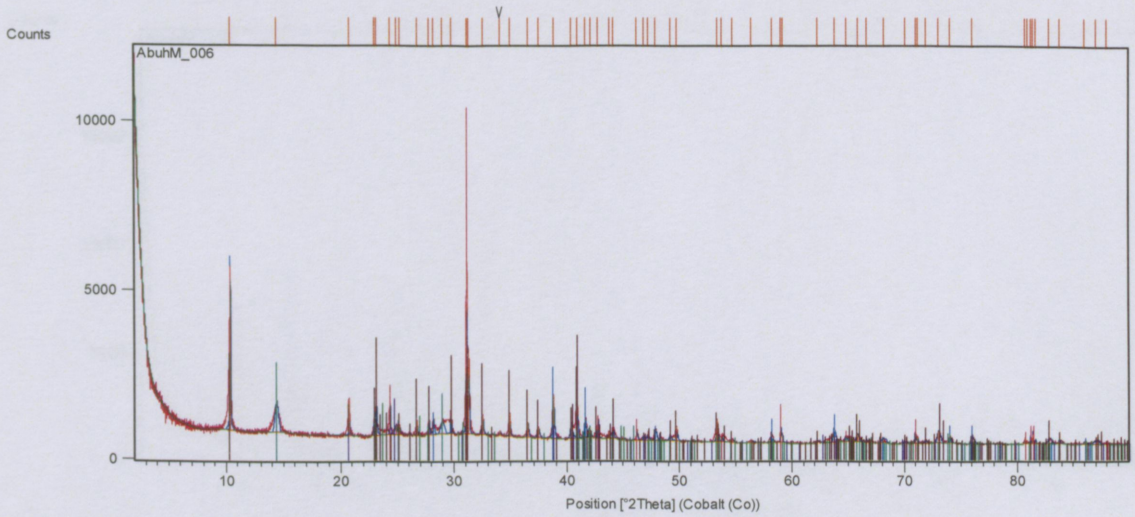

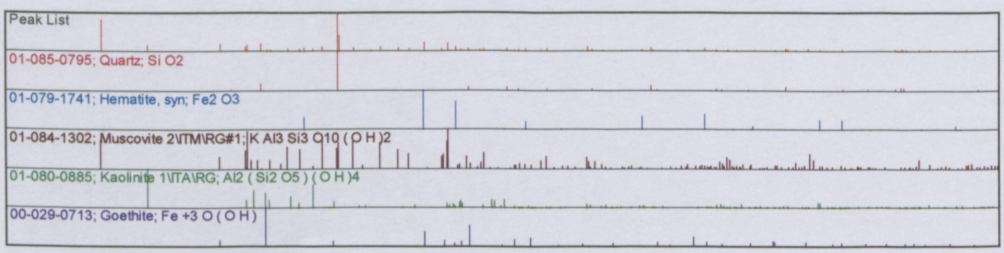

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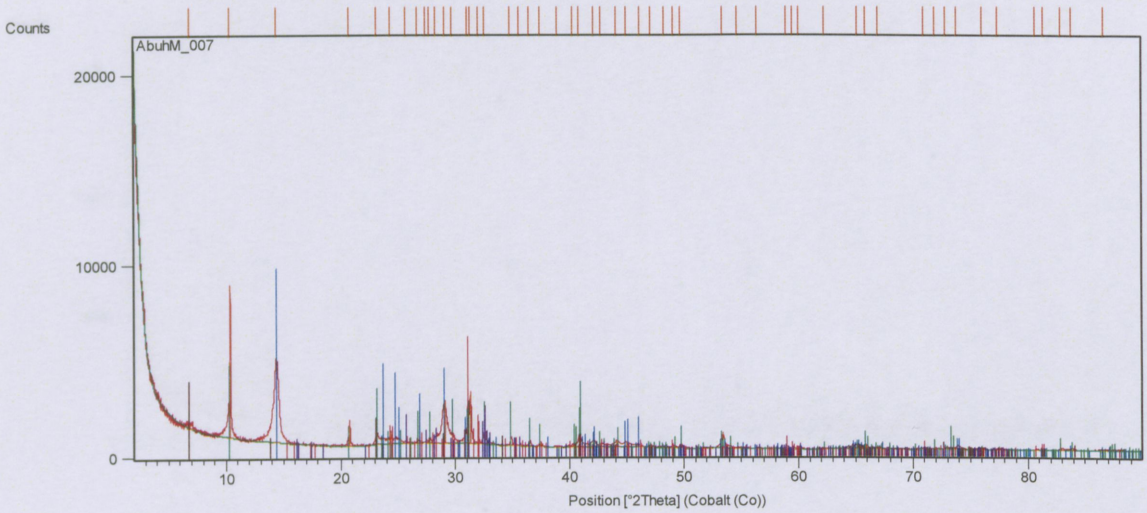

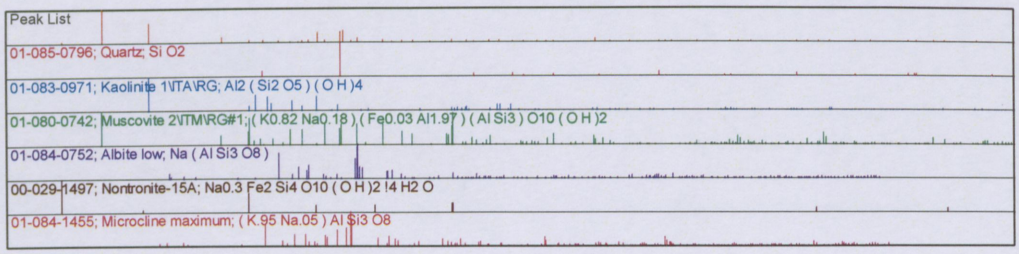

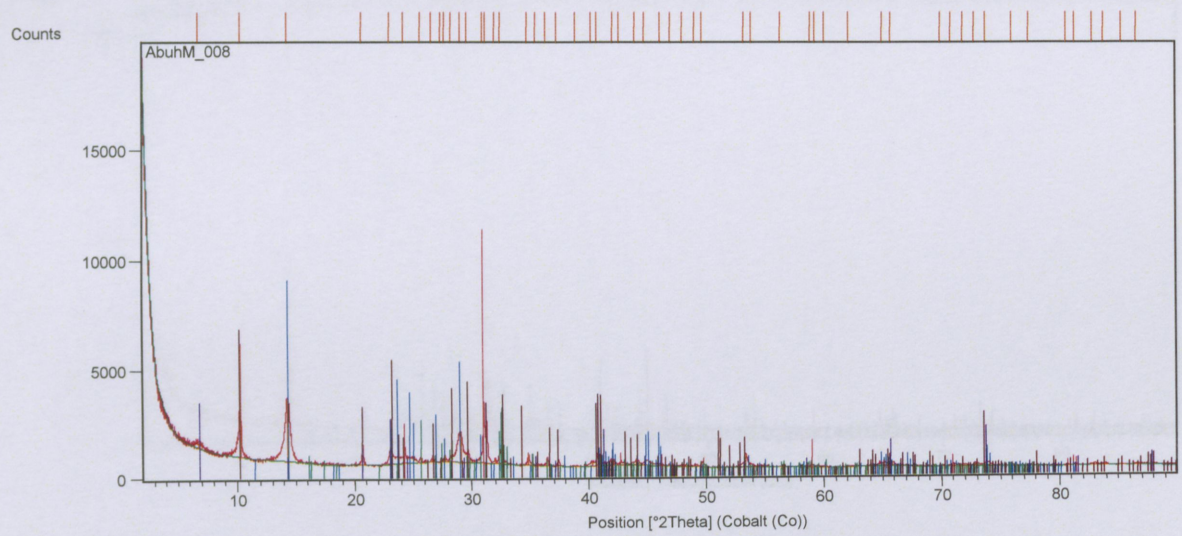

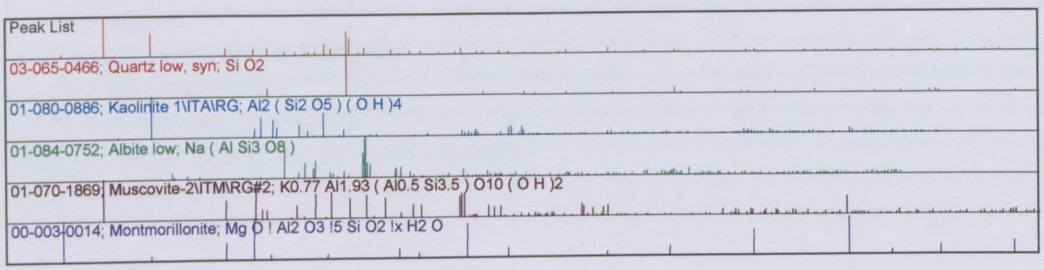

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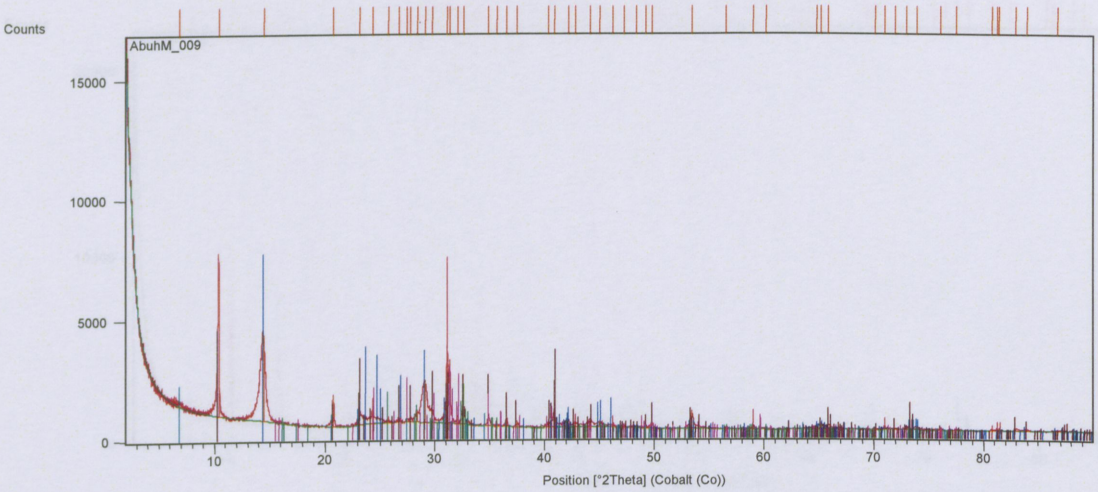

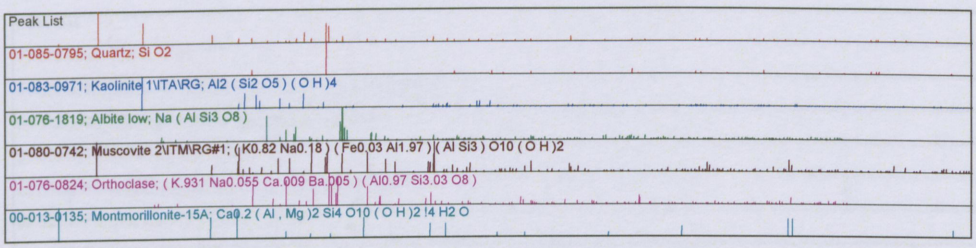

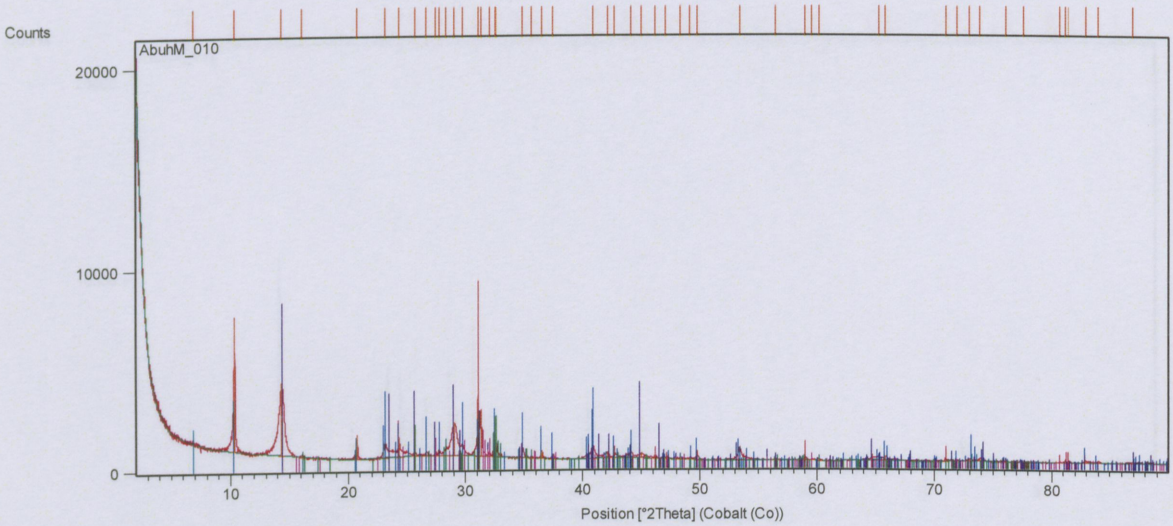

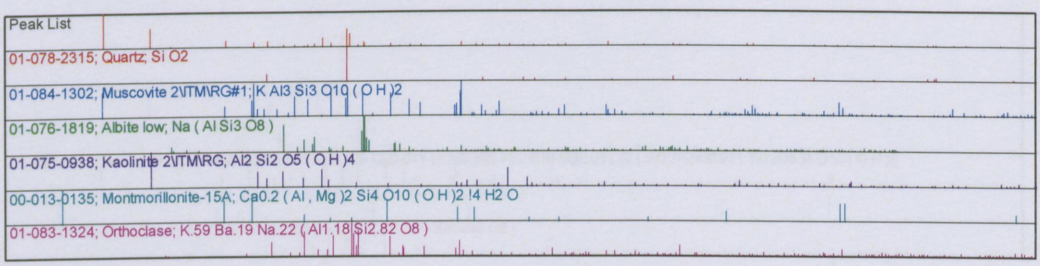

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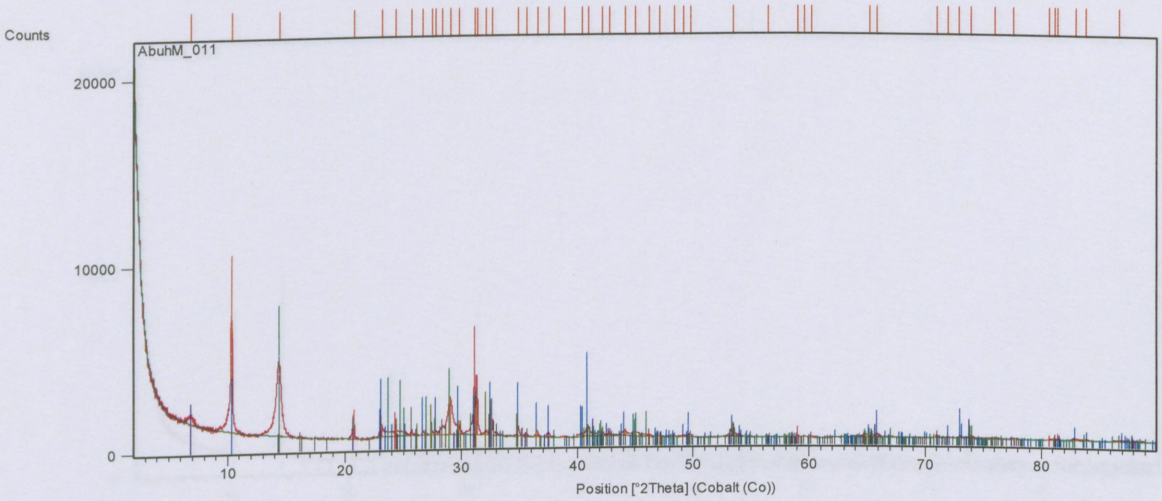

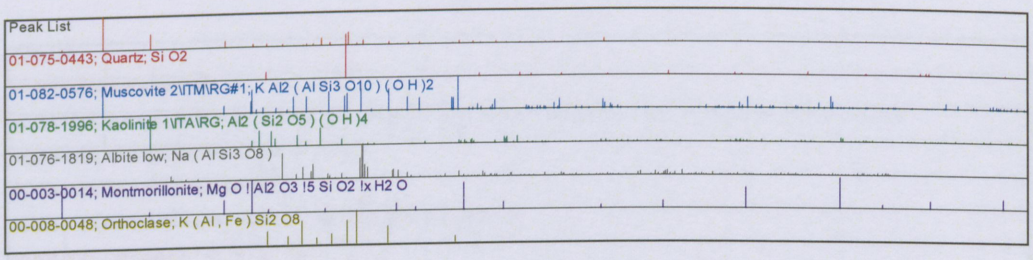

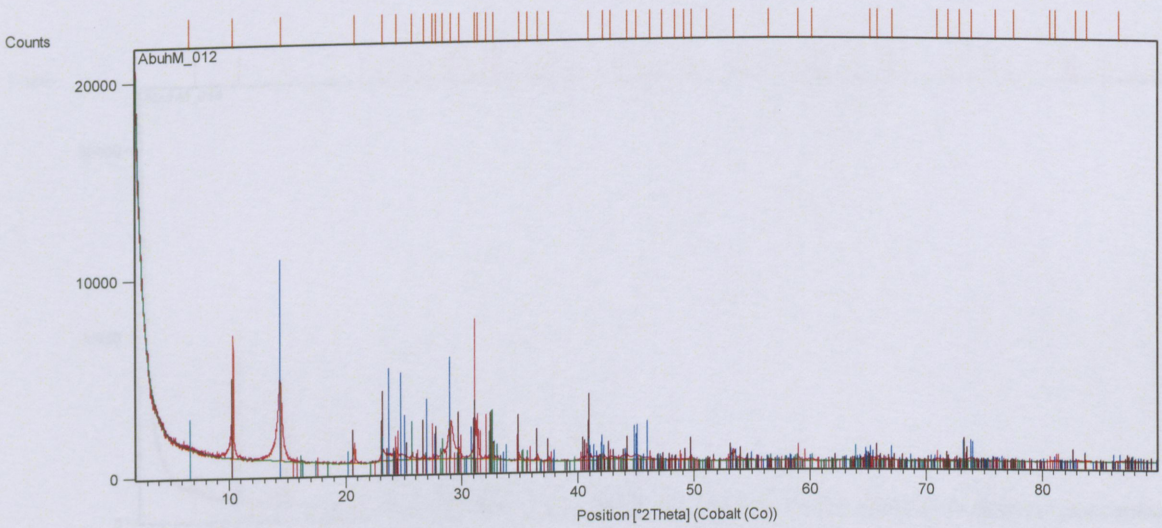

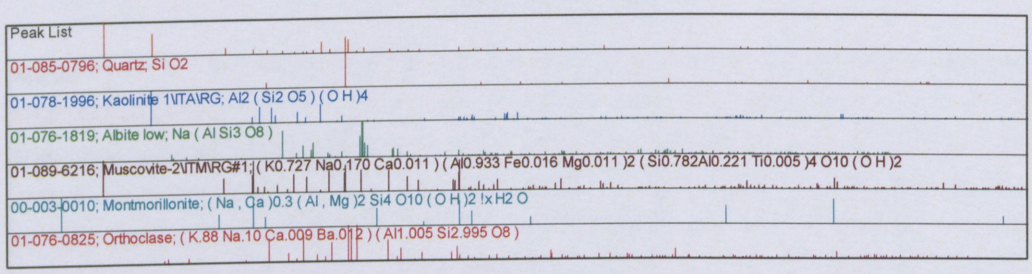

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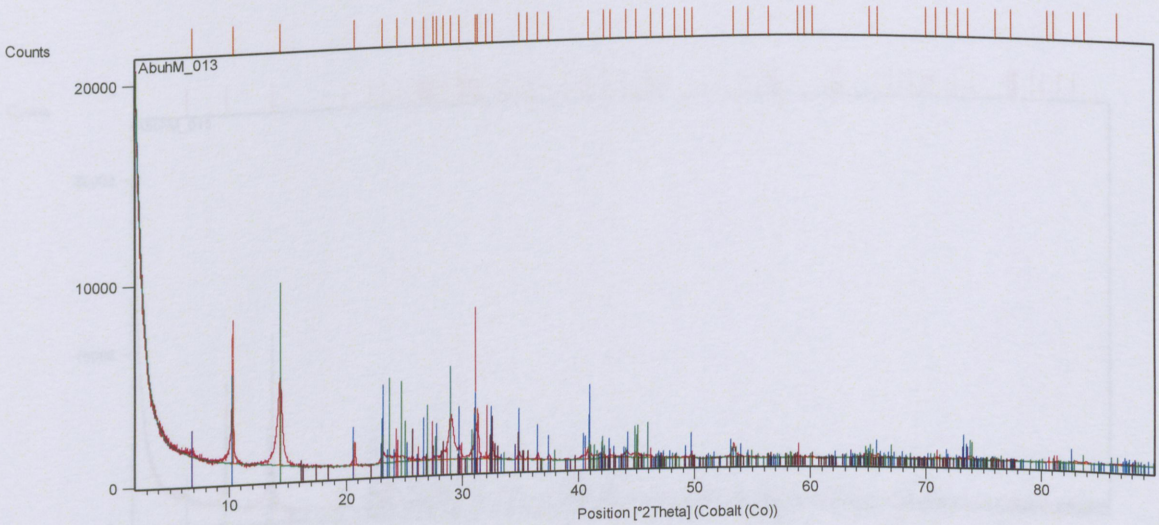

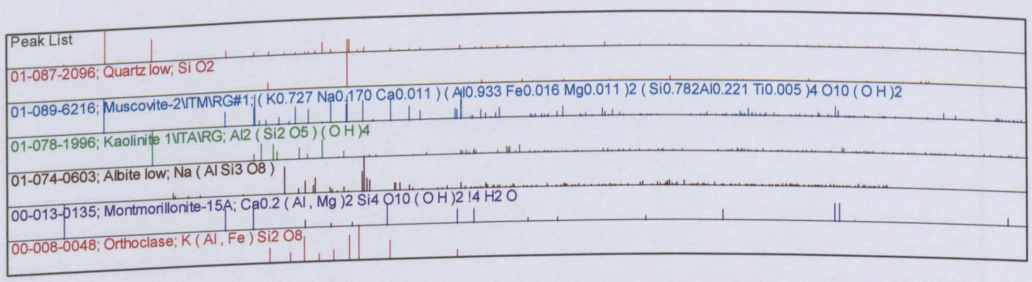

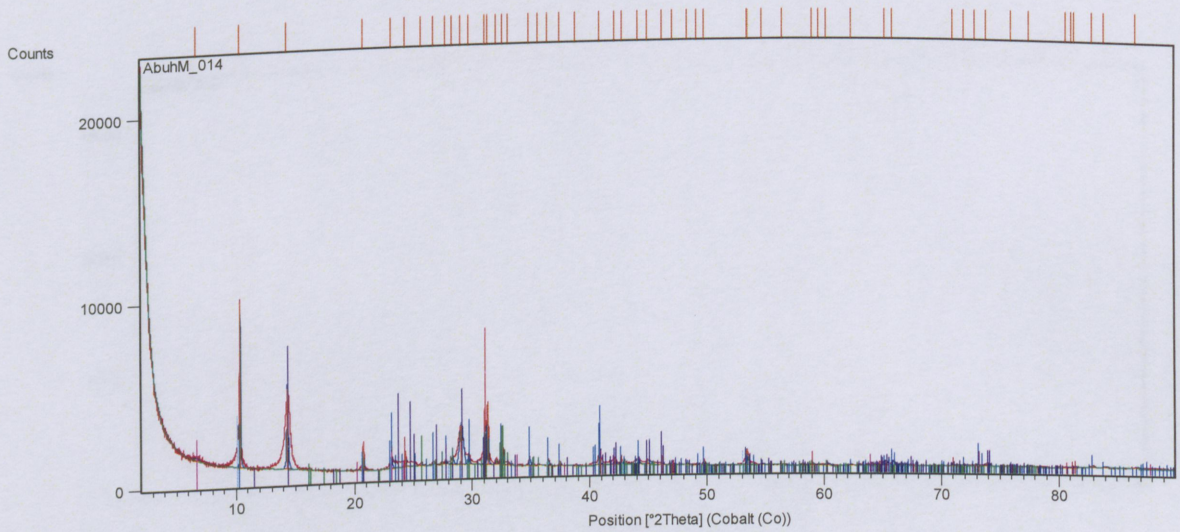

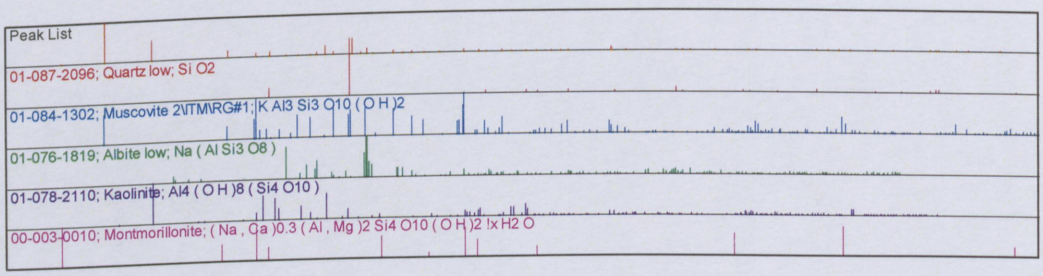

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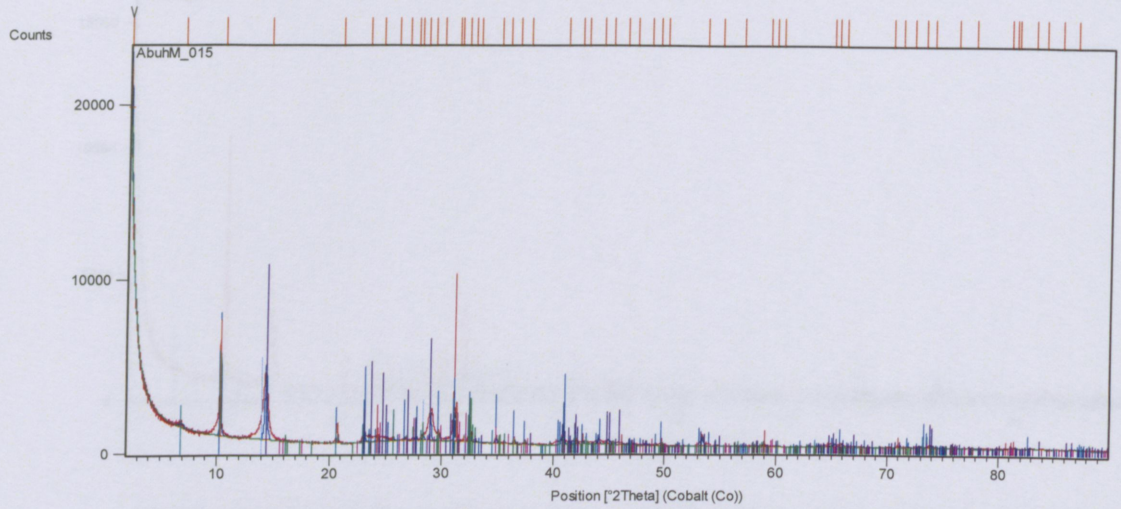

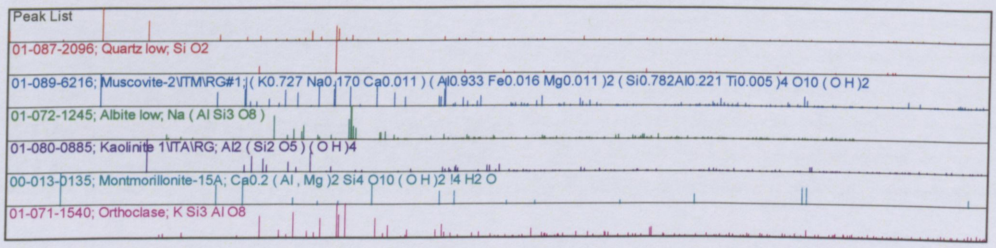

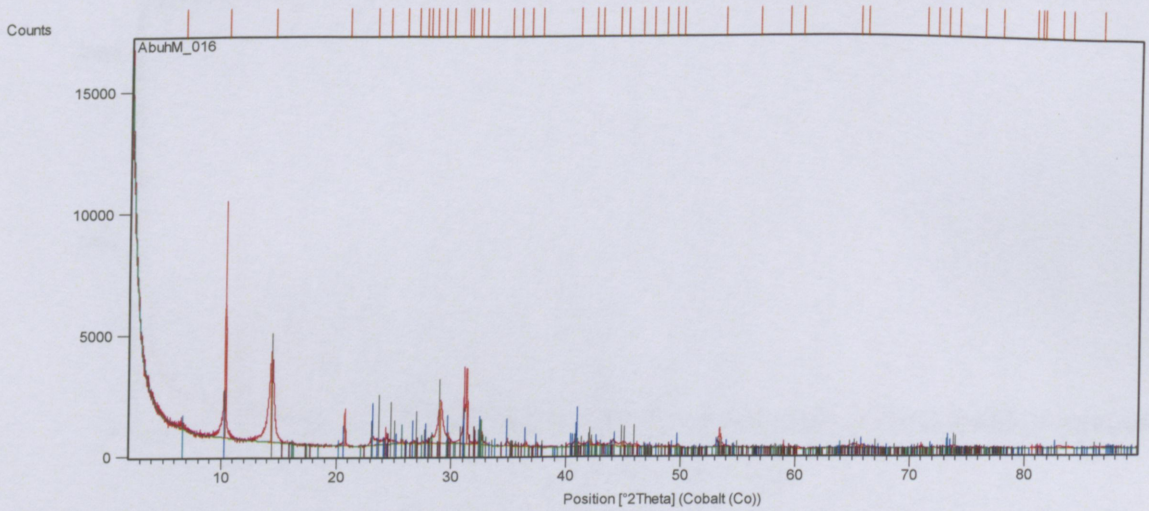

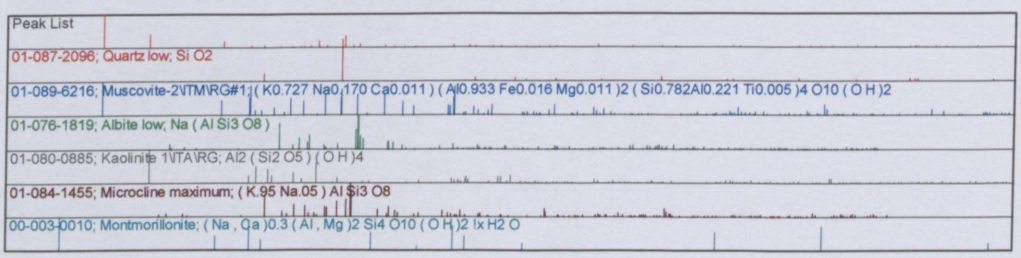

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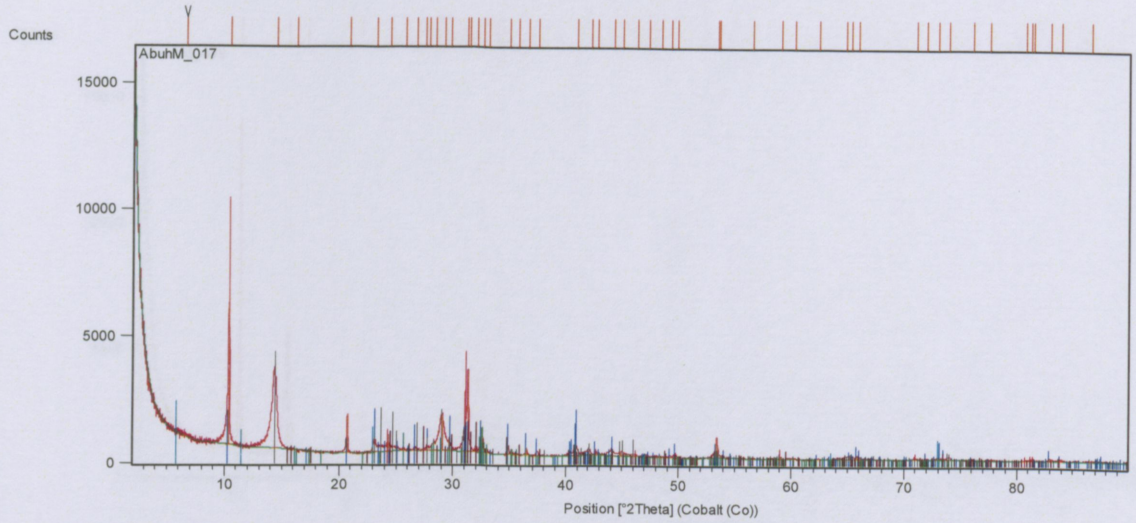

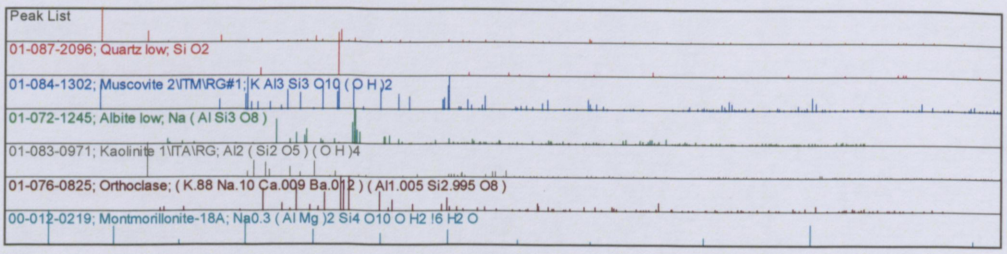

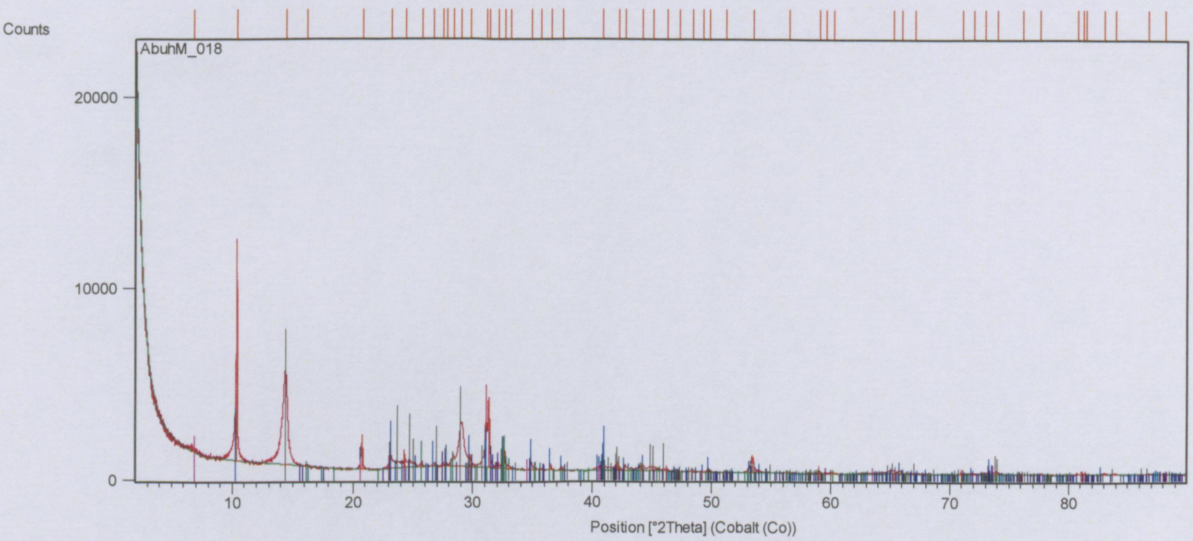

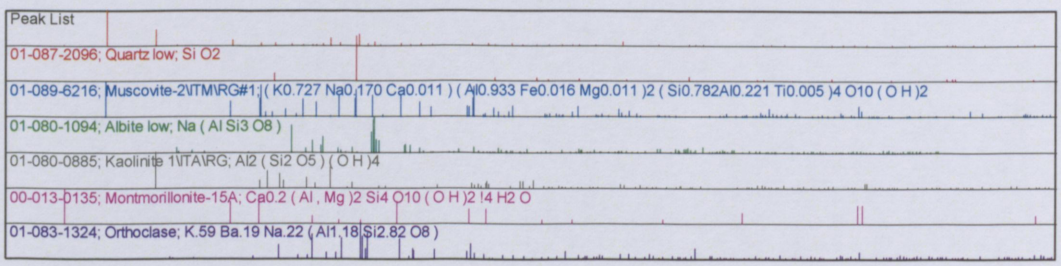

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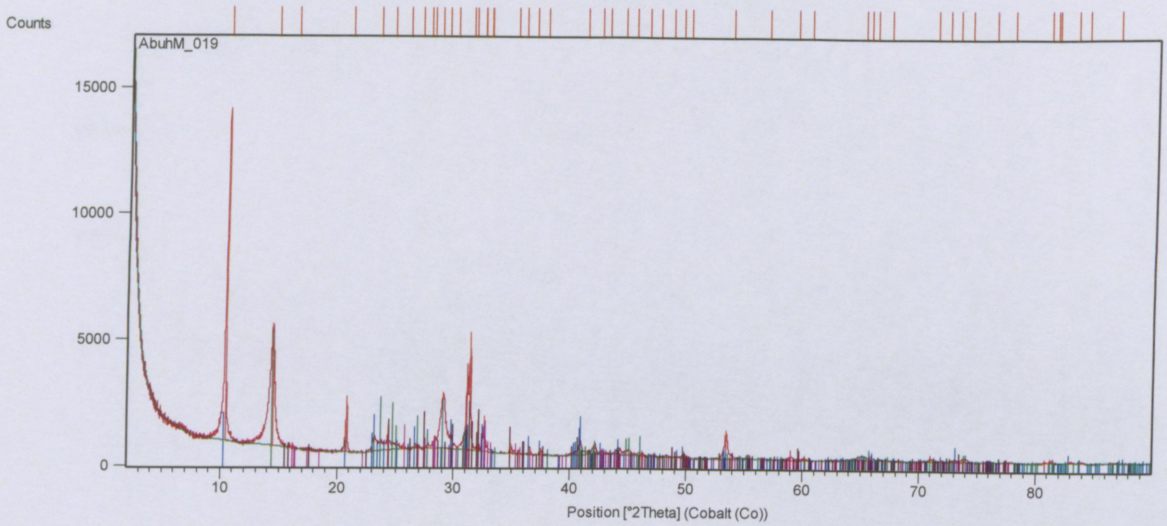

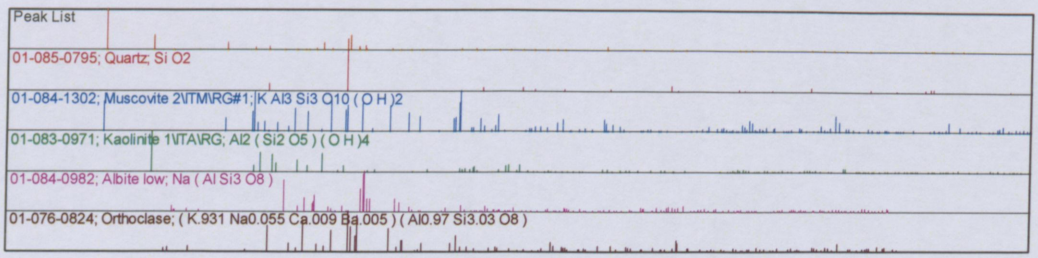

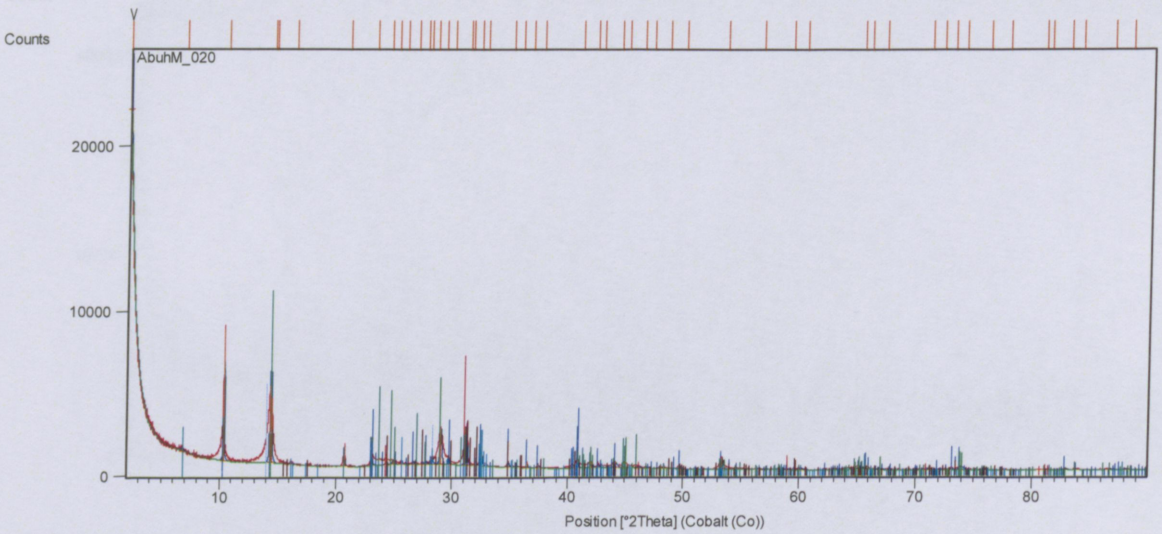

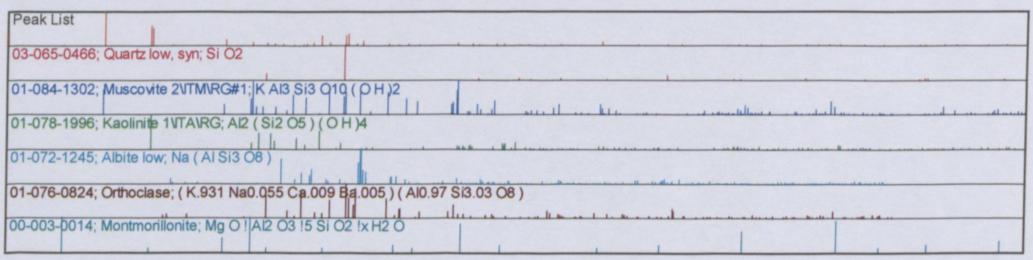

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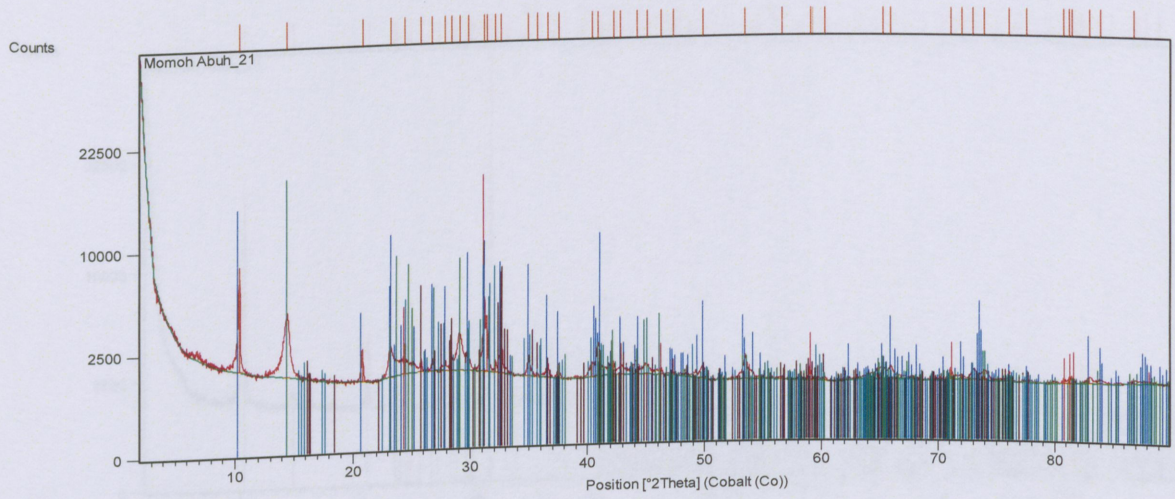



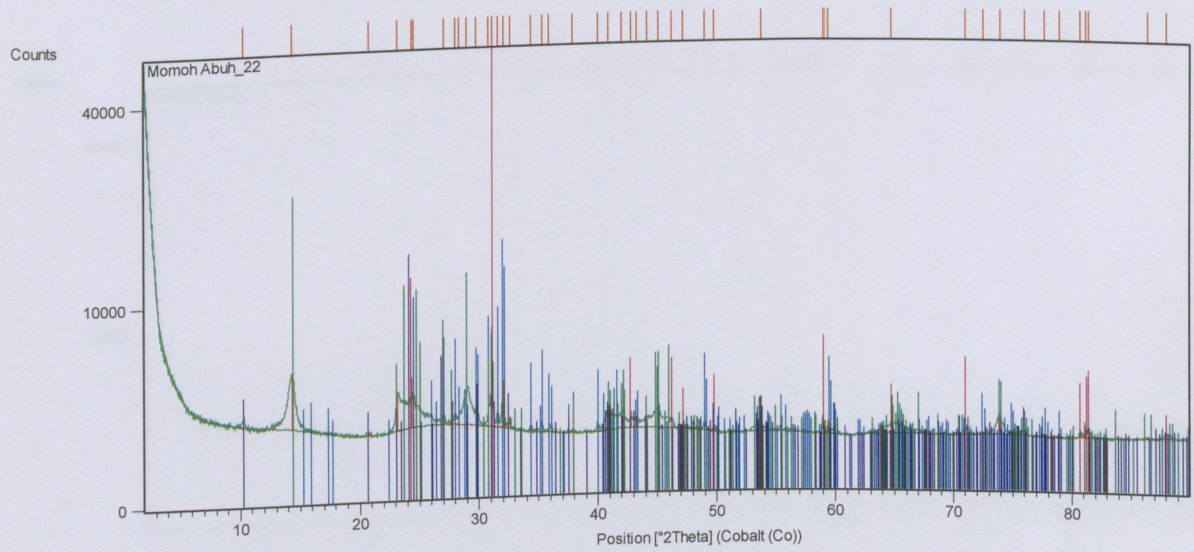

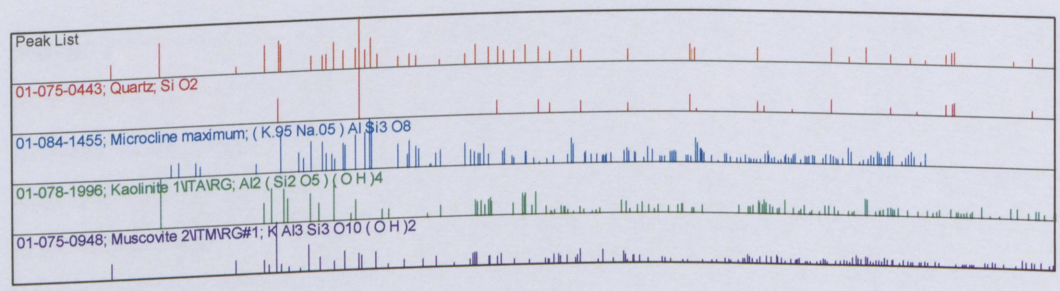

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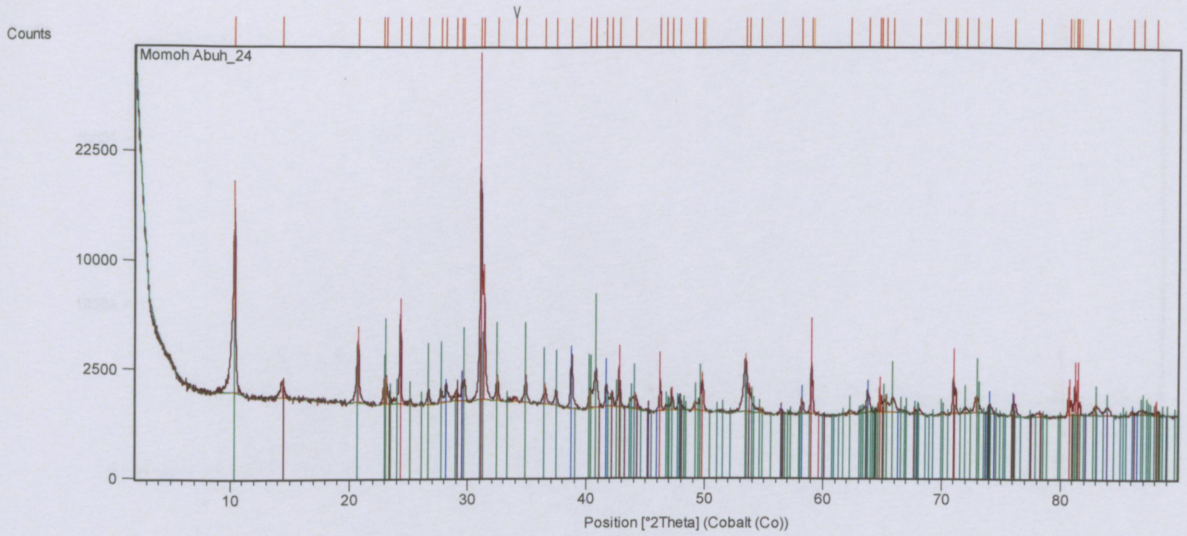

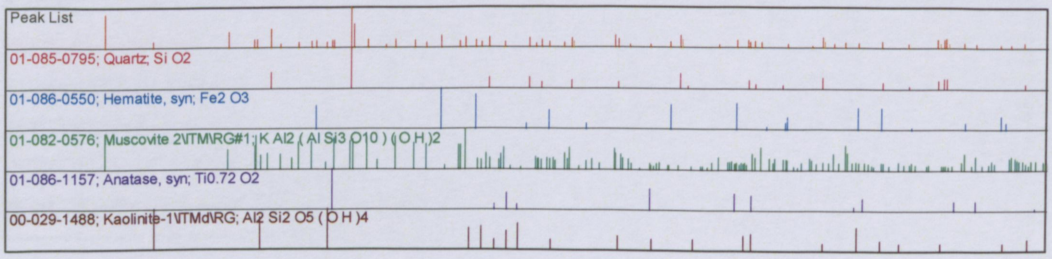

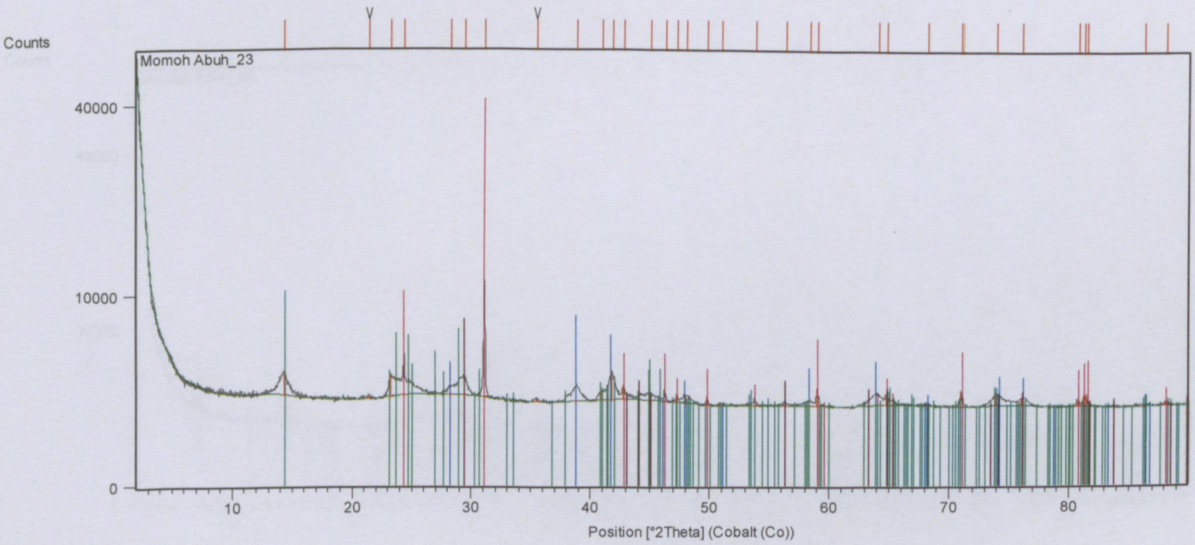

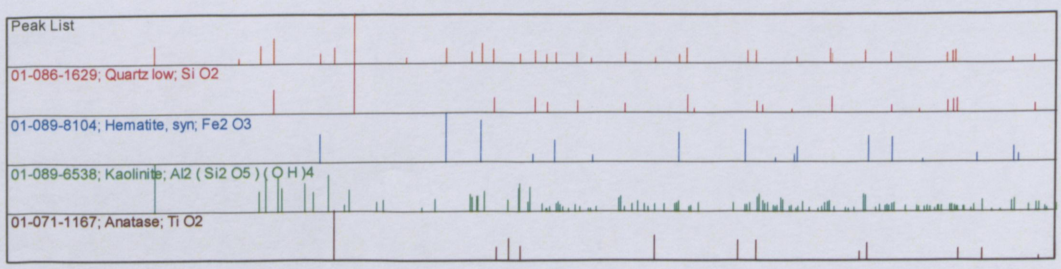

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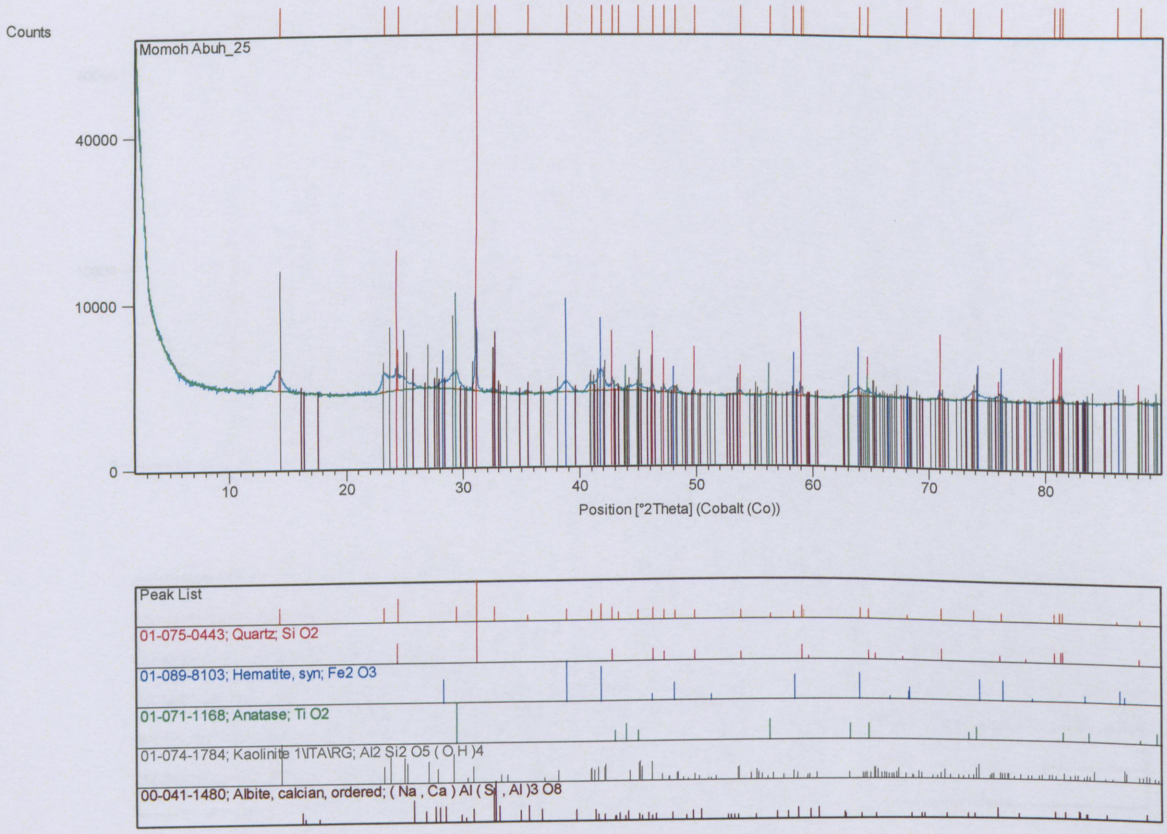

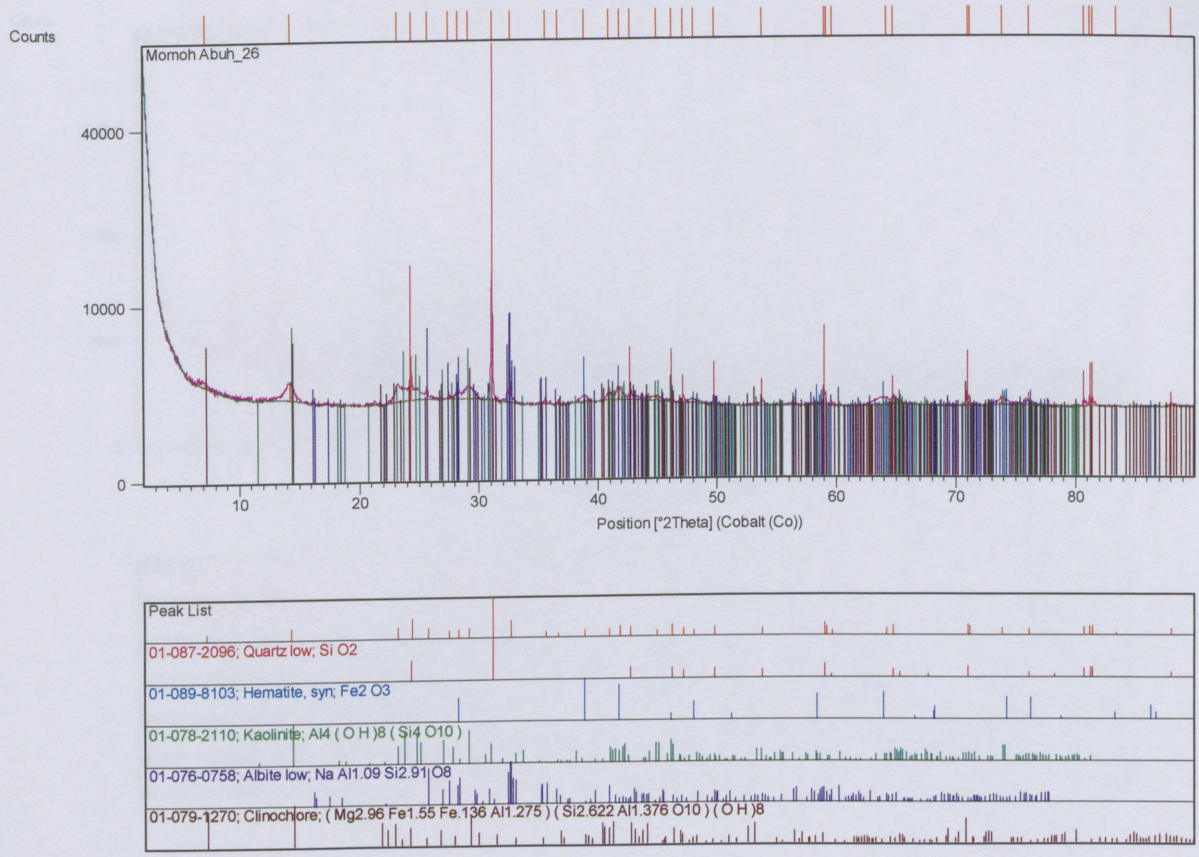

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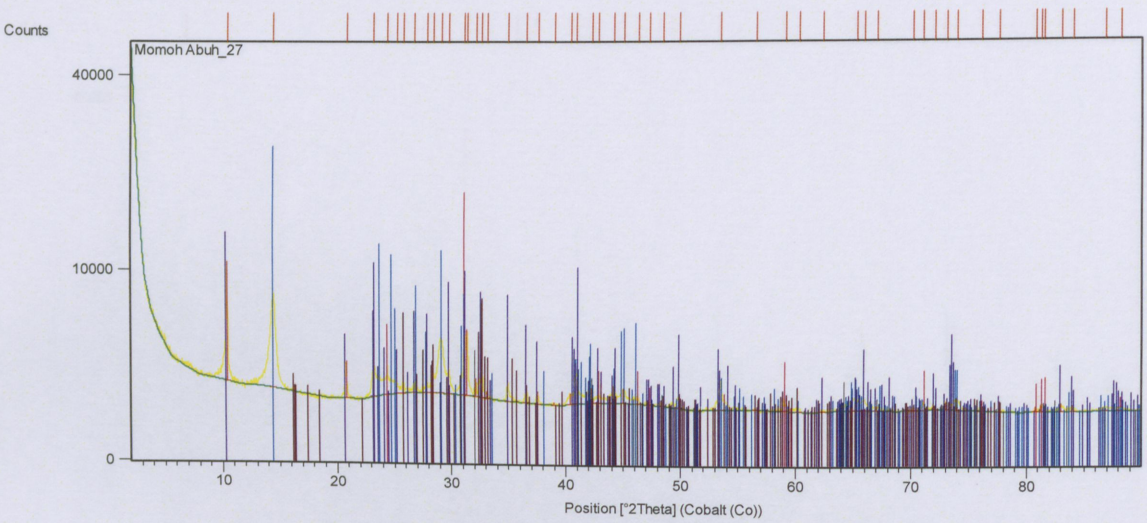

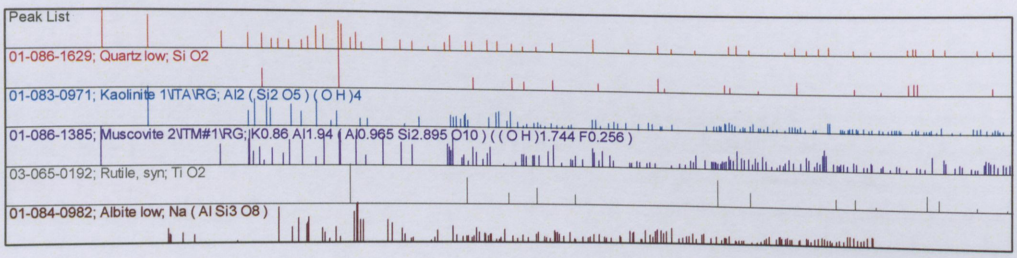

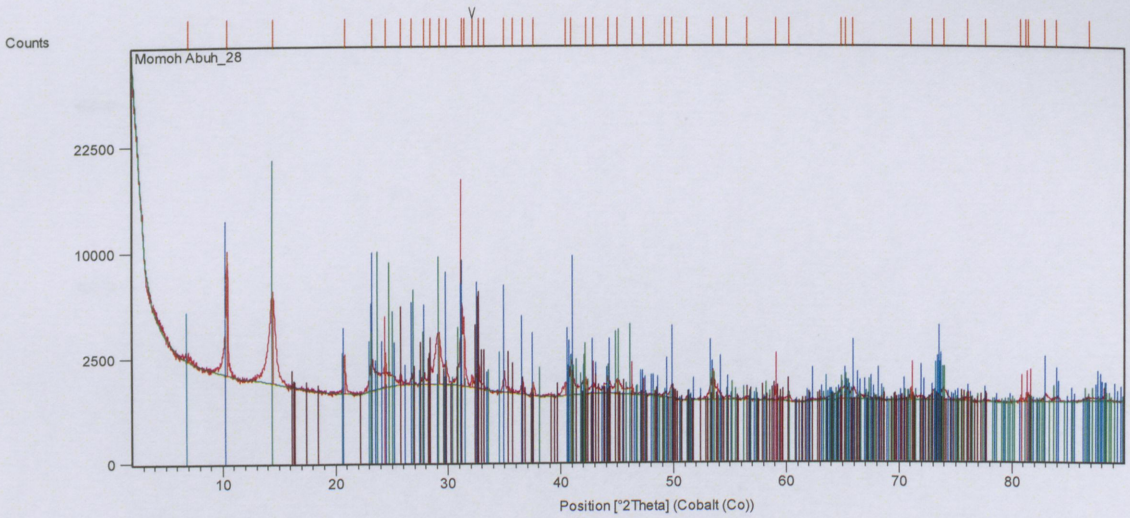

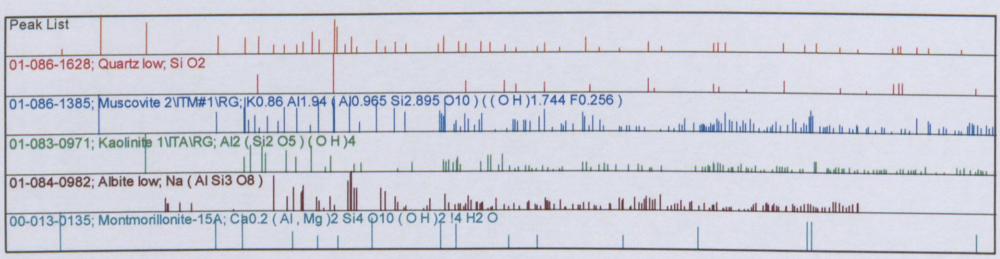

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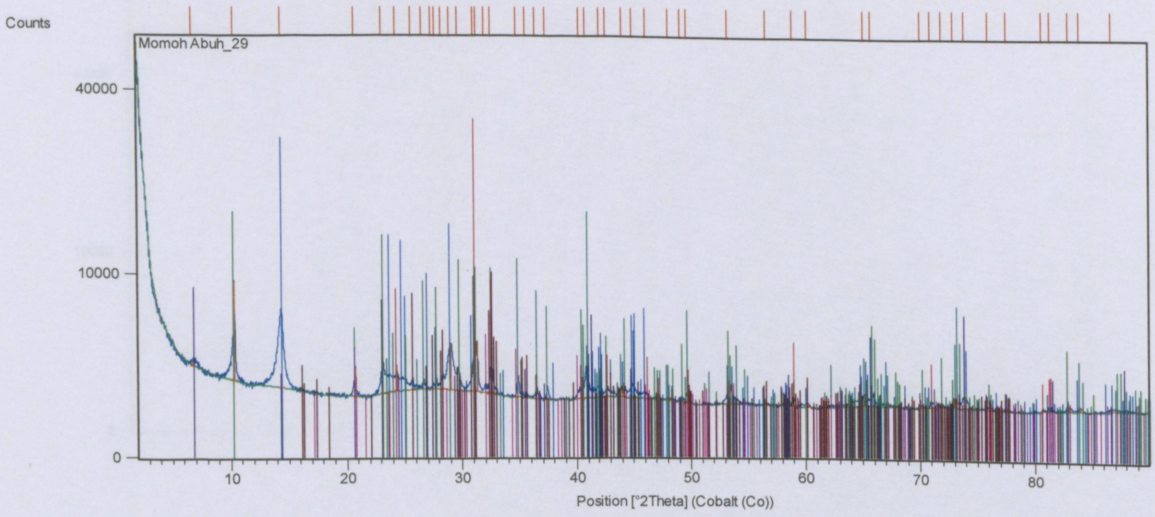

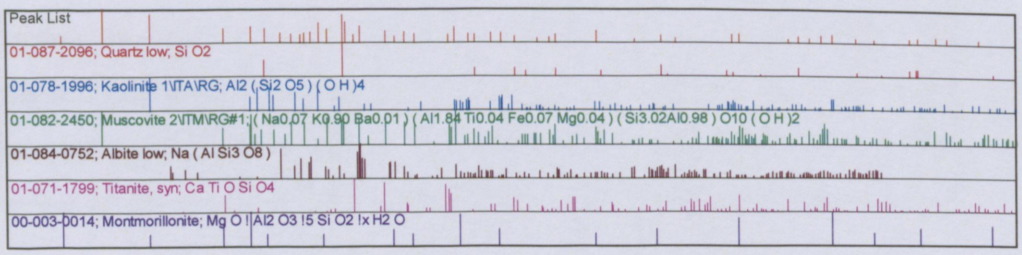

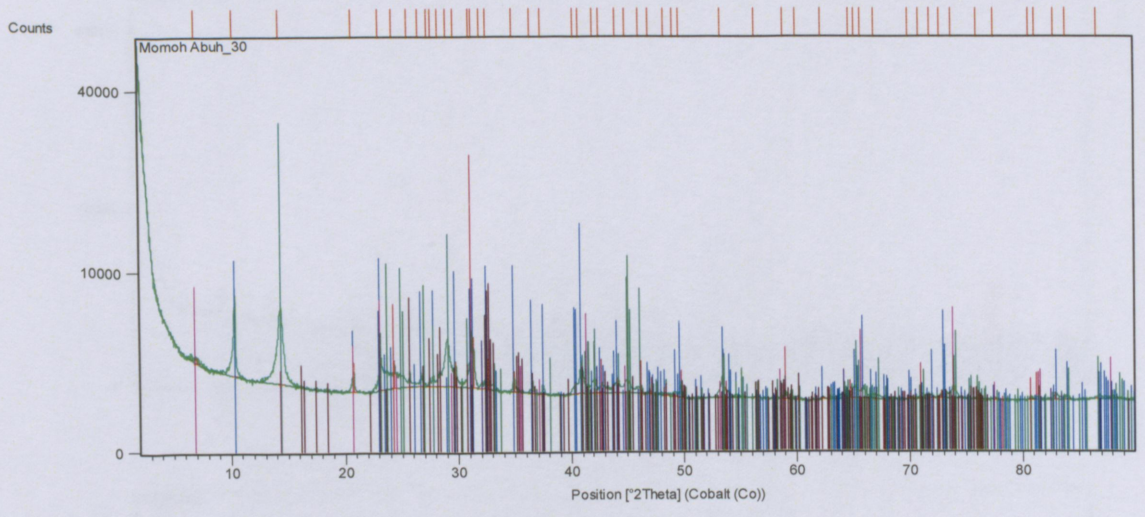

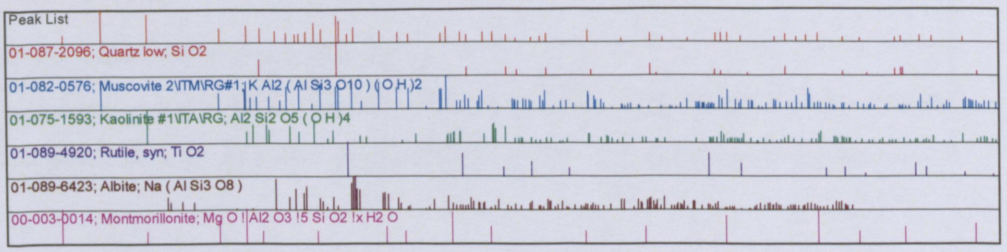

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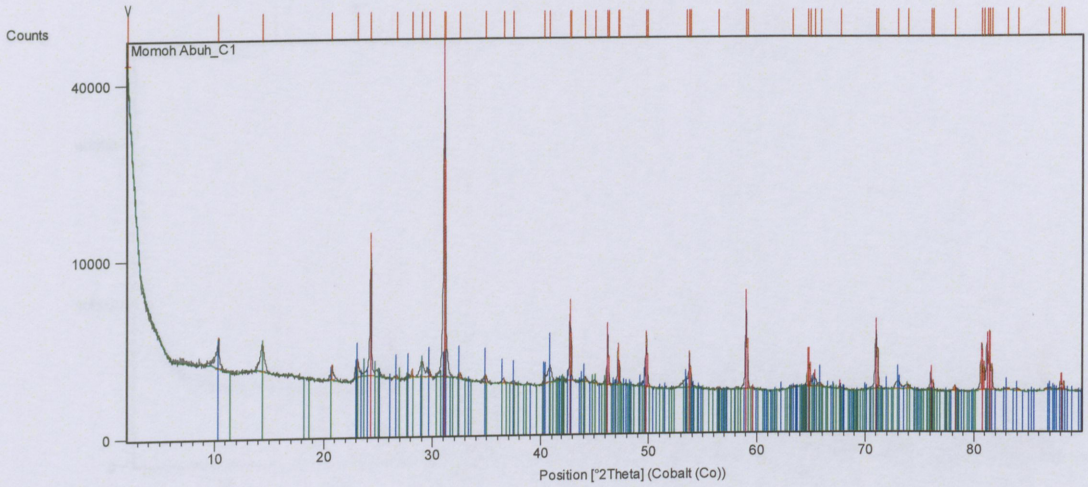

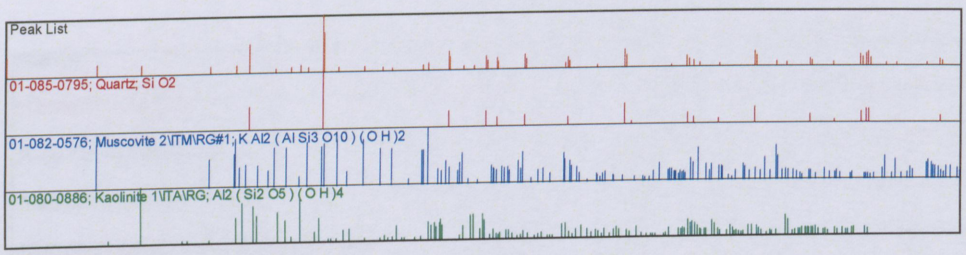

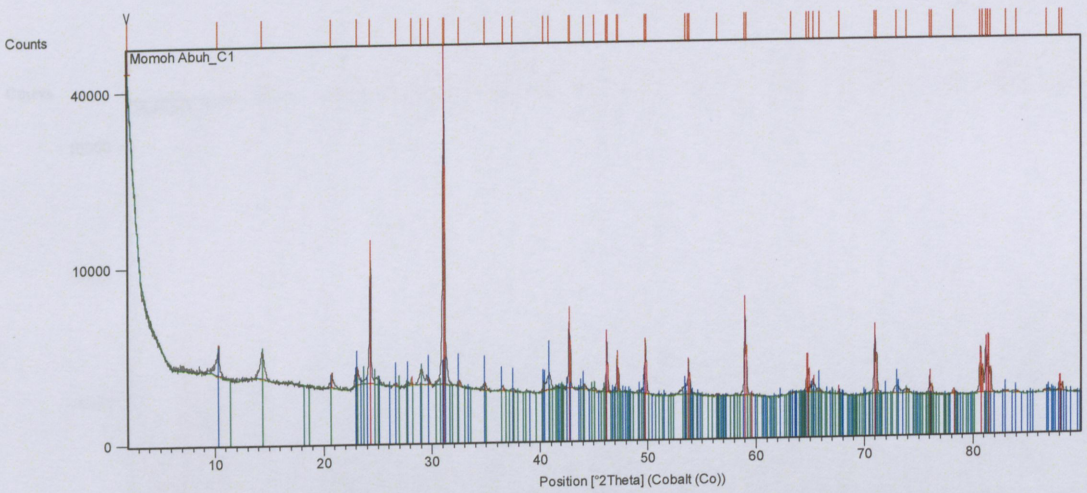

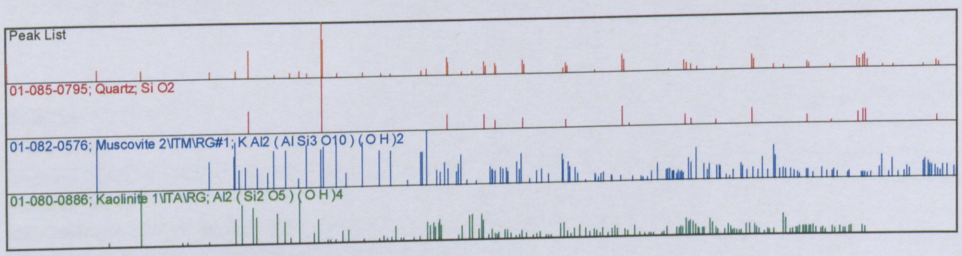

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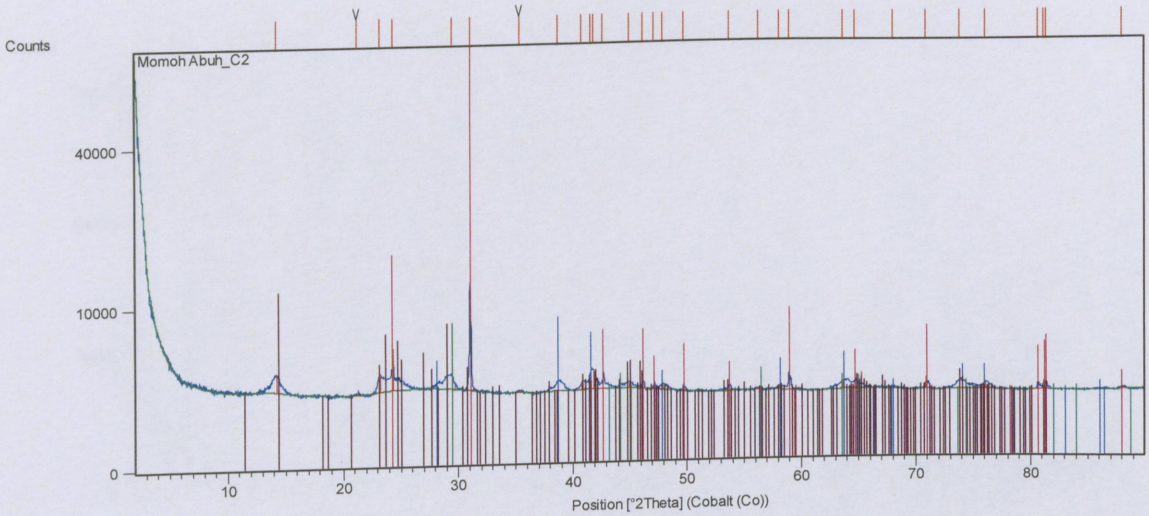

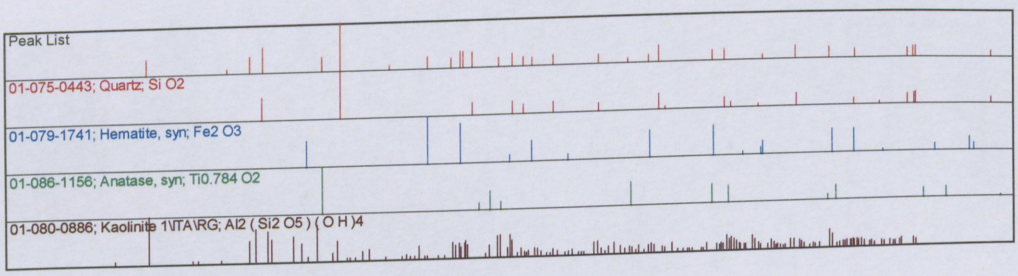

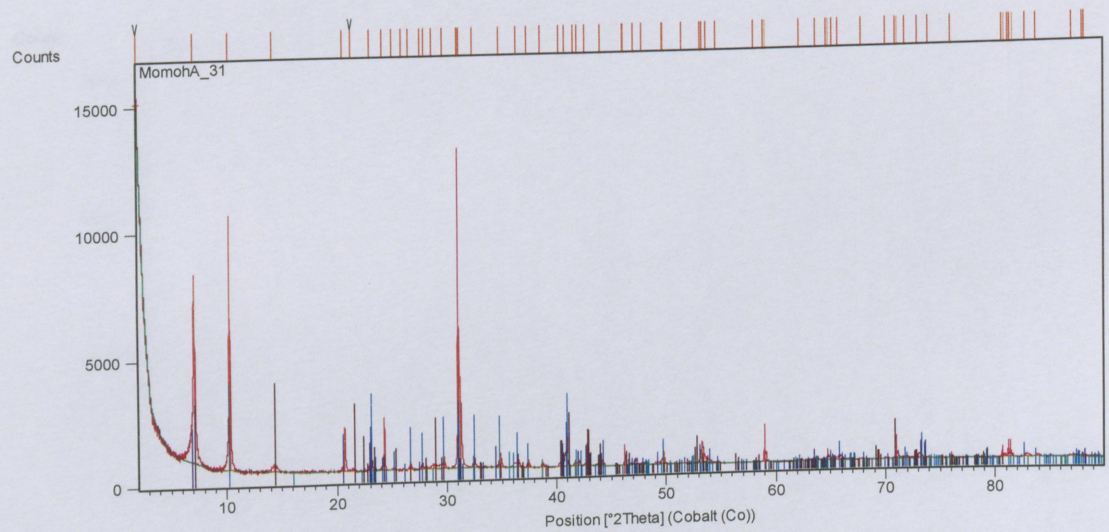

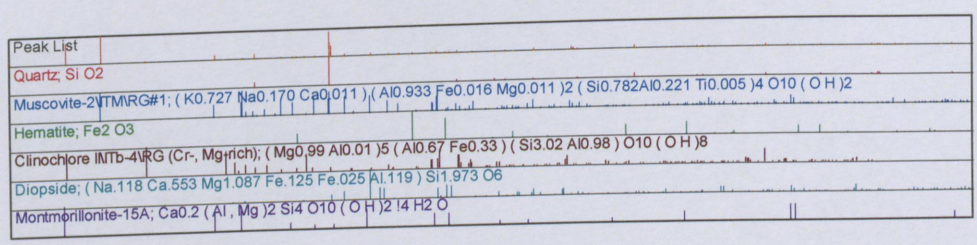

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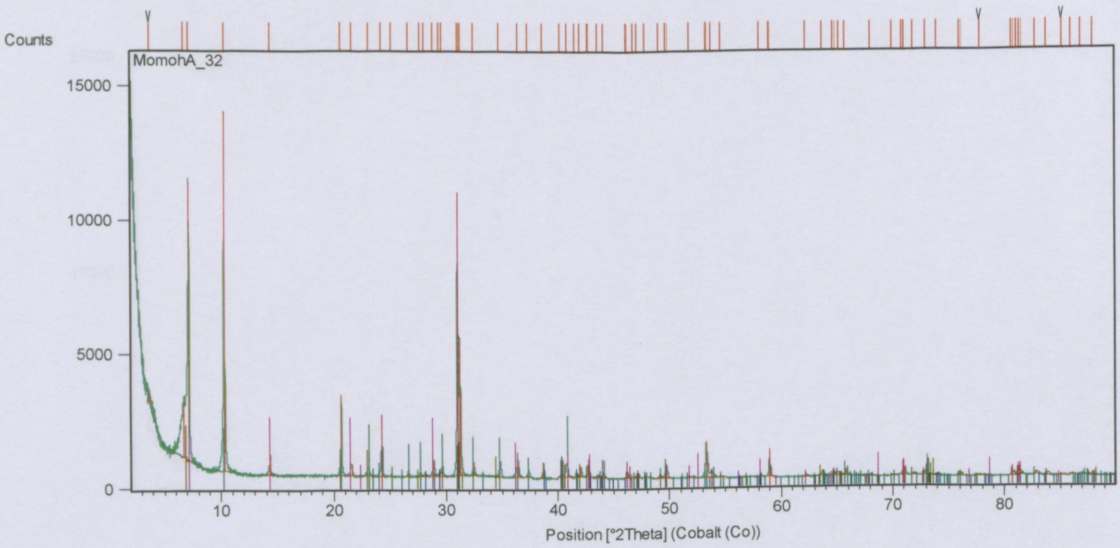

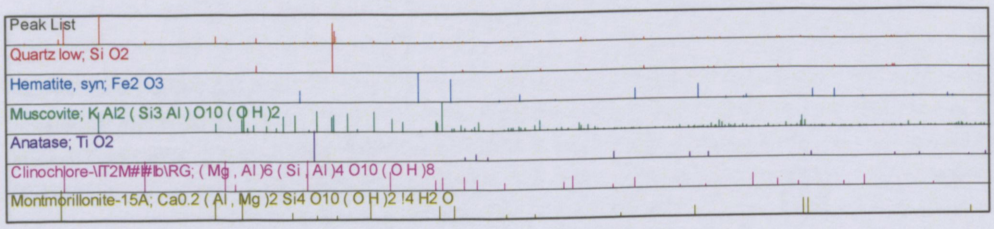

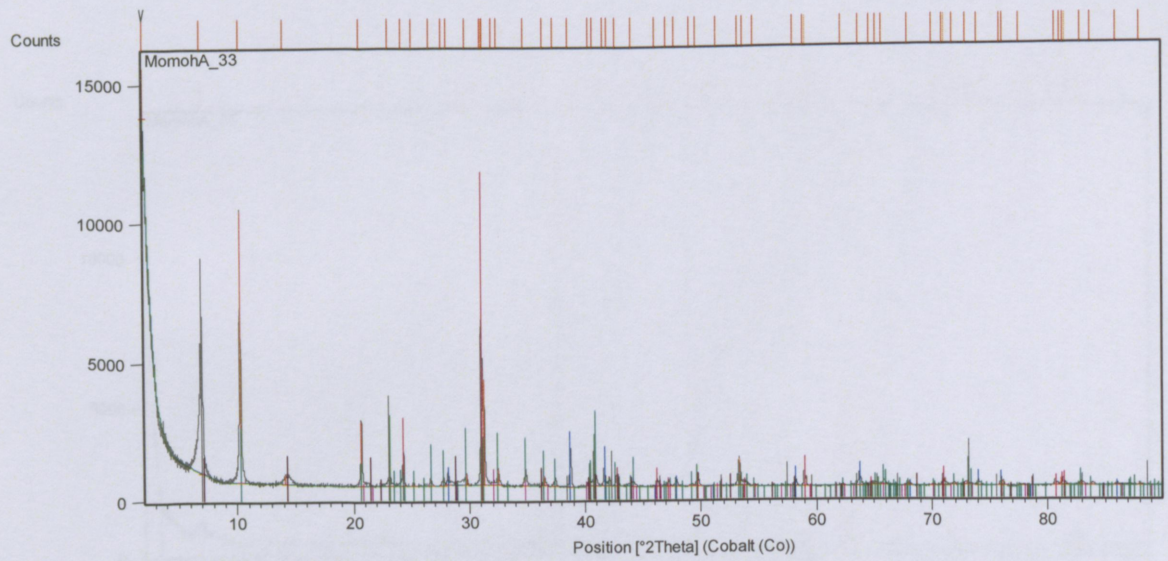

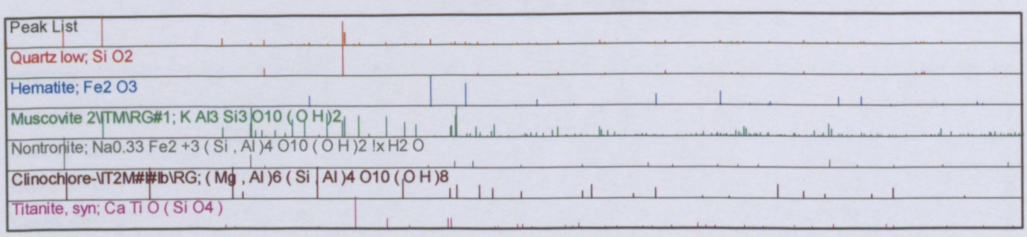

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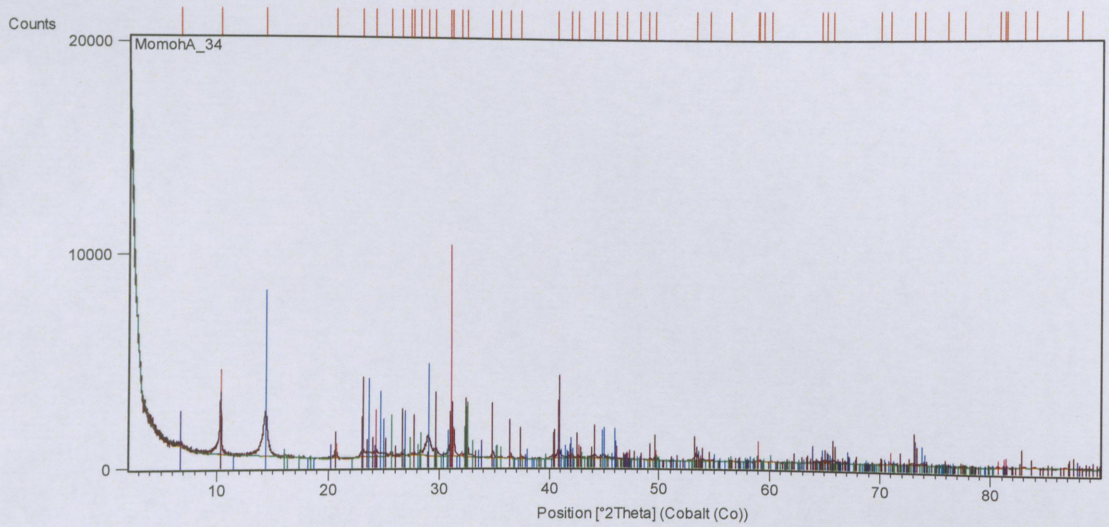

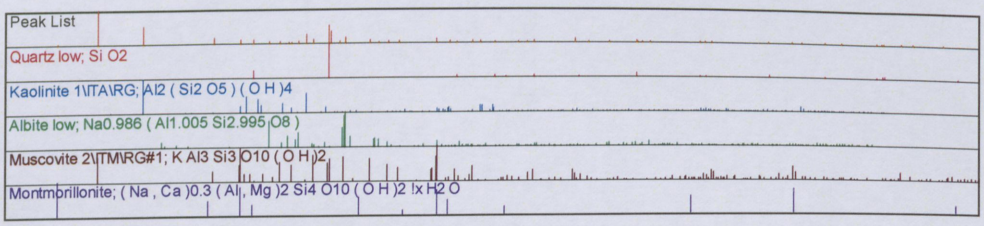

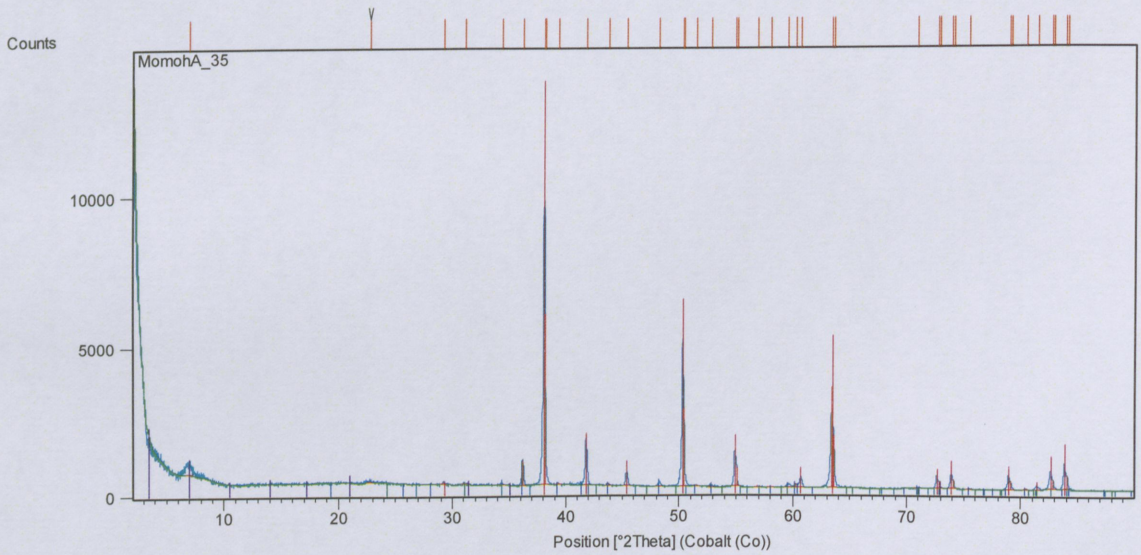

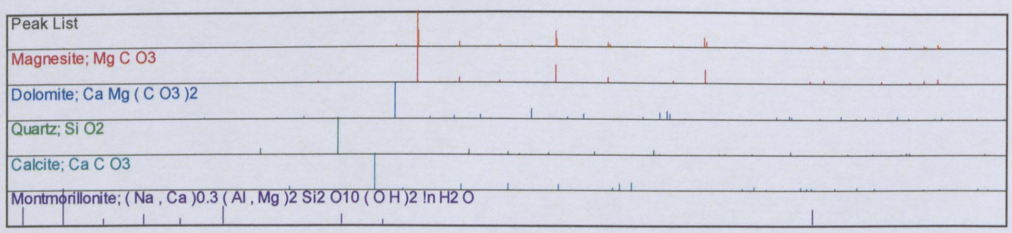

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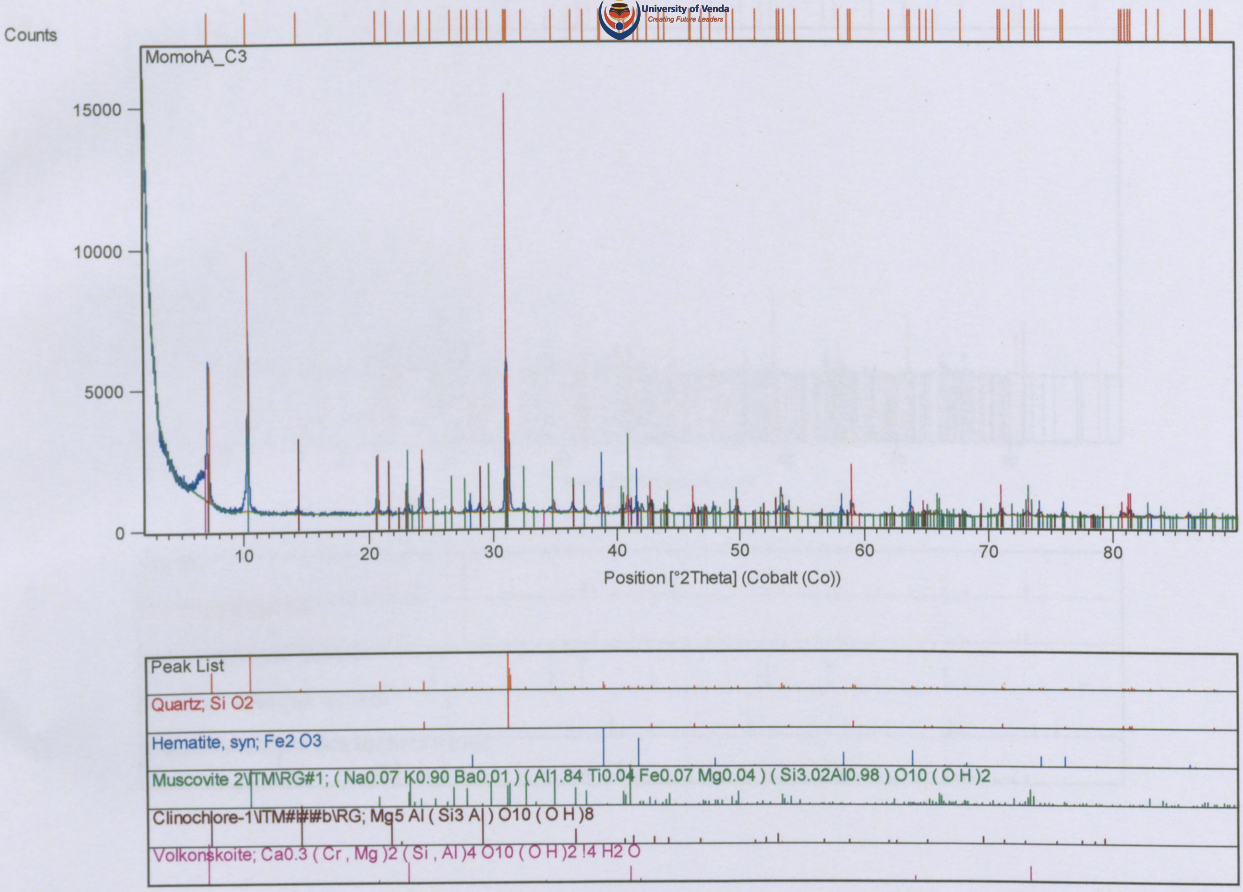

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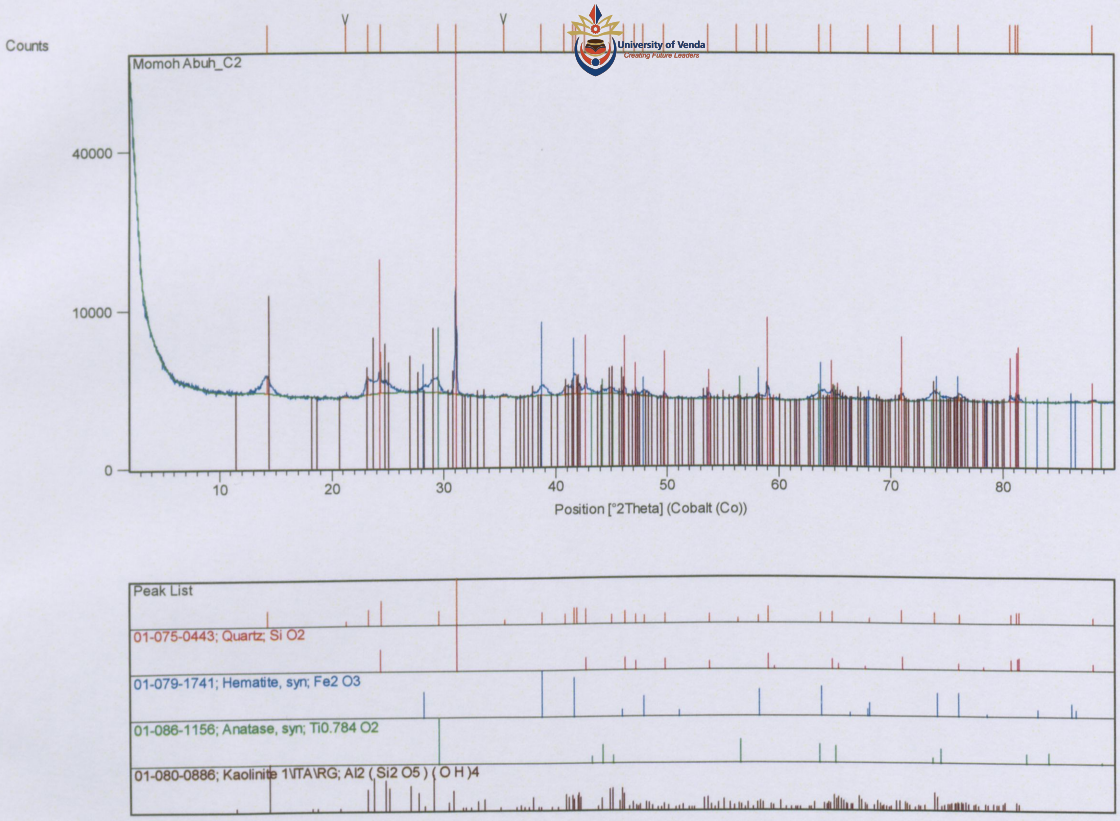

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