Article

Geochemical and Mineralogical Characteristics of Geophagic Materials from Kiambu, Kenya

JM Gichumbi 1, *, O Ombaka 1, JG Gichuki 2

1 Chuka University College, Chuka, Kenya
2 Chepkoilel University Colleges, Eldoret, Kenya

* Author to whom correspondence should be addressed; E-Mail: jsmwangi2003@yahoo.co.uk.

Article history: Received 13 August 2012, Received in revised form 5 September 2012, Accepted 6 September 2012, Published 7 September 2012.

Abstract: Geophagia is the deliberate consumption of soil and clay. The practice of geophagia is due to reasons of culture, medicinal, religious and mineral deficiency. Geophagy is widespread among pregnant and breast feeding women in sub-Saharan Africa and this is evidenced by the sale of geophagic materials in markets across Africa. This study is aimed at studying the geochemistry and mineralogy of geophagic samples sold in Kiambu County, Kenya. The geophagic samples were analyzed by atomic absorption spectrometry, X-ray fluorescence spectrometry, X-ray diffractometry, Fourier transform infrared spectrometry. The results obtained showed that the materials consist mainly of silica (SiO₂) and alumina (Al₂O₃). They also contain the elevated levels of iron oxides. The mineralogical analysis showed that quartz and kaolinite were the major phases.

Keywords: geophagy; pregnancy; geochemistry; mineralogy; atomic absorption spectrometry; X-ray fluorescence spectrometry; X-ray diffractometry; Fourier transform infrared spectrometry.

1. Introduction

Geophagia is a form of pica and is defined as the deliberate consumption of earthy substances including soil and clay [1]. It is widely practiced in Africa, America including USA, Asia including India and China, Australia and Europe. Geophagia is more commonly associated with women during pregnancy early childhood, mental retardation or psychiatric abnormalities and also in some cultural
Geophagia is as old as humankind and is more prevalent in some societies than others. According to Ekosse and Jumbam [2] in the 16th and 18th century geophagia was regarded as magical and superstitious, hence the desire for its prevention and therapy for those indulged in the habit.

There are three main reasons given for the practice of geophagia: women practicing geophagia believe geophagia enhances beauty, could be beneficial to pregnant women or even enhance fertility [1]. The practice is common in pregnant women in Nigeria and Cameroon and this is attributed to believe that eating clay is good for their unborn babies because it makes their babies smooth and beautiful [2].

There are three major hypotheses about the physiological causes of pica: hunger, micronutrient deficiency and protection from toxins and pathogens [3]. In Africa pregnant women consume soil because they believe it facilitates smooth delivery and enhance dark skin pigment for the baby. Other reasons advanced by pregnant women include simple craving due to their smell and texture, the soils ability to reduce the symptoms of morning sickness, hunger pangs and believe that soils can provide some micronutrients important for the fetus [4]. The currently available data, best supports the protection hypothesis as a cause of most type of pica, although some evidence suggests geophagy may occur during iron deficiencies.

The sale of geophagic materials is common in many societies. In Nigeria, clay is mined in large quantities and distributed for sale in markets all over West Africa [2]. In Kenya, geophagic materials are sold in open air markets. The geophagic materials sold in open air markets were found to contain high levels of silica.

This study is aimed at characterizing the geophagic materials consumed by pregnant women from five towns in Kiambu County, Kenya. The materials were collected from Gachie, Kiambu town, Githunguri, Kikuyu and Wangige towns. Despite the prevalence of geophagy among pregnant women in Kiambu, no studies have analyzed the chemical and mineralogical content of these materials.

2. Materials and Methods

2.1. Study Location and Sample Collection

Kiambu County, Kenya was chosen as an appropriate research site due to the prevalence of geophagic behavior among pregnant women. The geophagic materials were collected from open air markets and they are sold according to size, colour and purchasing power. A total of 20 samples were collected from the sampling sites.

2.2. Apparatus and Reagents
Digestion block, digestion tubes filter papers, analytical balance and plastic bottles were used. All the reagents were analytical grade and were standardized for respective metals. The reagents for digestion procedure were standardized.

Energy dispersive X-ray fluorescence (XRF) used PAN analytical Minipal QC model and atomic absorption spectrometry used 210 VGP ASS model. XRF was performed on pressed powder disks and involves no pretreatment other than simple crushing and milling procedures. The mineralogy of the geophagic samples was determined by PAN analytical X’celerator X-ray diffractometer (XRD) model and Fourier transform infrared (FTIR) used Shimadzu 800 instrument.

2.3. Sample Preparation and Pretreatment

The samples were dried in an oven at 105 °C and then placed in a dessicator to cool and weighed until a constant weight. The materials were then ground to uniform thickness.

2.3.1. Sample solution for major oxides

A 0.1 g of dried and ground sample was weighed and transferred into 125 mL plastic container. A 1 mL aqua regia and 3 mL HF were then added and the mixture was left for at least 10 h for cold digestion to take place. Thereafter, 50 mL of saturated boric acid was added to the plastic container having cold digested sample solution and left for one hour. De-ionized double distilled water was used to top the solution to 100 mL.

2.3.2. Sample solution preparation for minor elements

Standard procedures for the preparation of stock solutions (1000 ppm) for Na, Ca, Fe, Zn, Mg, Pb and Cd were employed. The standard stock solutions were used to prepare serial dilutions for the determination of these elements in the sample using AAS.

2.4. Energy Dispersive X-Ray Florescence

X-ray fluorescence (XRF) spectrometer is an x-ray instrument used for routine, relatively non-destructive chemical analyses of materials such as rocks, minerals, sediments and fluids. It works on wavelength-dispersive spectroscopic principles that are similar to an electron microprobe. However, an XRF cannot generally make analyses at the small spot sizes typical of EPMA work (2-5 microns), so it is typically used for bulk analyses of larger fractions of geological materials. The relative ease and low cost of sample preparation, and the stability and ease of use of x-ray spectrometers make this one of the most widely used methods for analysis of major and trace elements in rocks, minerals, and sediment. The method is useful for elements with atomic number 11 and above. This technique reveals information about the chemical composition of a sample. It can be used for both qualitative and
quantitative analysis.

A 5 g of dried sample was pulverized into a fine powder of 100 micrometers. The fine powder was mixed with 10 g analytical grade starch and made into pellets using a pellet making machine. The pellets were then put into a XRF machine for analysis of elements.

2.5. X-Ray Diffraction

Representative sub samples of each of the samples collected were crushed to a fine powder with a mill. The powdered sample was then pressed into a shallow sample holder. Each sample was then scanned using a PAN analytical X’pert accelerator. The mineral peaks were identified by cross checking the d values, peak intensity and miller indices with the data reported by ICDD. Phase concentrations and identification were also identified using a PAN analytical software High score Plus.

2.6. Fourier Transform Infrared Spectroscopy

Infrared spectroscopy as an analytical tool presents a lot of advantages as it is accurate, inexpensive and reliable. Infrared spectroscopy has been utilized significantly in organic analysis; however, its application in quantitative and qualitative analysis of minerals is not widespread [5].

The vibration of atoms in molecules and crystals fall in the infrared range. The molecules vibrate after absorption of energy. Thus infrared analysis employs the group vibration concept to ascertain the presence or absence of various functional groups in the molecule. Certain chemical groups have characteristic absorption bands that are consistent among minerals containing groups. The spectra originate primarily from vibrational stretching and bending modes within molecules. Thus, infrared method is used as a fingerprint in the identification of molecular structure. The infrared spectra in this study were obtained in the range of 200-4000 cm\(^{-1}\), in reference to other researchers [5]. This is to ensure that the range covered includes most of the useful vibrations active in the infrared. Infrared method have been found to be versatile in that it can be used both as a source of the physical parameters for crystal lattice determinations and as a means of eliciting purely implied qualitative relationships between specimens.

The sample preparation procedure used was the one used by Ravisankar et al. [5] but with modifications. The sample was dried in an oven at 105 °C for around 12 h. The mineral sample of about 2 mg was then mixed with 40 mg of spectroscopic KBr in the ratio of 1:20 using a clean mortar and pestle to prepare a sample pellet. The ratio of sample to KBr was varied in the ratio 1:100 and 1:200 to avoid overlap of the peaks. Before mixing, necessary amount of KBr powder was dried at 120 °C for six hours in an oven to avoid the broad spectral peak due to free OH which would seriously affect the interpretation of the bound hydroxyls associated with the minerals. A pellet of about 1 mm
thickness and 13 mm in diameter is prepared by pressing. The prepared pellet is placed in a suitable sample holder immediately after preparation and introduced in the infrared beam for analysis.

3. Results and Discussion

3.1. Major Elements

The results for the elemental oxides represent a mean value for the samples from the same town and they are shown in Table 1. The samples from Githunguri had the highest silica content of 54.14% and Limuru samples had the lowest value with 46.12%. This shows that the main oxide present in geophagic samples is silica. The levels of $\text{Al}_2\text{O}_3$ were also elevated with values ranging from 11.27 to 27.1%, with Kikuyu having the highest levels. The values for $\text{Na}_2\text{O}$ and $\text{K}_2\text{O}$ were higher than those of $\text{CaO}$ and $\text{MgO}$ for all the samples.

The values for $\text{FeO}_3$ ranged from 9.20 to 12.7% and the most iron rich samples were obtained from Kikuyu Town. The high levels of iron may explain why female populations are known to develop exceptional cravings for these materials during pregnancies, when they are more likely to be anemic. Further investigations are necessary to ascertain whether the Fe is released to the body system as believed by those who ingest the materials or whether the ingestion is causing iron deficiency as concluded in the works of Mogongoa et al. [1] and Hooda et al. [6].

Table 1. Bulk chemical (major element) analyses in geophagic samples from Kiambu open air markets

<table>
<thead>
<tr>
<th>Oxide</th>
<th>Gachie</th>
<th>Kambu Town</th>
<th>Githunguri</th>
<th>Kikuyu</th>
<th>Wangige</th>
<th>Limuru</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{SiO}_2$</td>
<td>53.03</td>
<td>51.65</td>
<td>54.14</td>
<td>46.18</td>
<td>47.10</td>
<td>46.12</td>
</tr>
<tr>
<td>$\text{Al}_2\text{O}_3$</td>
<td>11.27</td>
<td>13.68</td>
<td>14.87</td>
<td>27.1</td>
<td>17.15</td>
<td>18.14</td>
</tr>
<tr>
<td>$\text{CaO}$</td>
<td>0.72</td>
<td>0.76</td>
<td>0.75</td>
<td>0.31</td>
<td>0.42</td>
<td>0.46</td>
</tr>
<tr>
<td>$\text{MgO}$</td>
<td>0.42</td>
<td>0.54</td>
<td>0.60</td>
<td>0.28</td>
<td>0.40</td>
<td>0.34</td>
</tr>
<tr>
<td>$\text{Na}_2\text{O}$</td>
<td>2.98</td>
<td>2.77</td>
<td>2.68</td>
<td>2.22</td>
<td>3.95</td>
<td>2.65</td>
</tr>
<tr>
<td>$\text{K}_2\text{O}$</td>
<td>2.80</td>
<td>2.40</td>
<td>2.70</td>
<td>2.30</td>
<td>3.30</td>
<td>3.00</td>
</tr>
<tr>
<td>$\text{TiO}_2$</td>
<td>0.91</td>
<td>1.38</td>
<td>1.26</td>
<td>1.88</td>
<td>1.72</td>
<td>1.77</td>
</tr>
<tr>
<td>$\text{MnO}$</td>
<td>0.17</td>
<td>0.25</td>
<td>0.25</td>
<td>0.11</td>
<td>0.16</td>
<td>0.15</td>
</tr>
<tr>
<td>$\text{FeO}_3$</td>
<td>9.20</td>
<td>10.2</td>
<td>11.3</td>
<td>12.7</td>
<td>10.0</td>
<td>12.6</td>
</tr>
<tr>
<td>LOI</td>
<td>15.22</td>
<td>15.37</td>
<td>10.45</td>
<td>5.92</td>
<td>13.8</td>
<td>13.32</td>
</tr>
</tbody>
</table>

3.2. Trace Element Analysis

Trace element analyses of Cu, Zn, Cr, Pb, Sb, Co, Cd, Sr, B, V and Mo were analyzed (Table 2). The results were obtained from both AAS and XRF data. The energy dispersive XRF was used for
preliminary investigations and the qualitative analysis was done using AAS. The levels of Cu ranged from 4.0 to 9 ppm and the levels of Zn ranged from 27.5 to 58.0 ppm. These values are lower as compared to those reported by Ekosse and Jumbam [2] on geophagic clay samples from Cameroon and Nigeria.

The levels of Cr, Pb and Co were low ranging from 0.5 to 9.0, 0.68 to 1.54 and 1.5 to 5.5 ppm, respectively. Cadmium, boron and vanadium were not detected for all the samples. The levels of molybdenum ranged from 30 to 52.0 ppm. A representative XRF spectrum is shown in Fig. 1.

Table 2. Average trace chemical (minor element) analyses of geophagic samples from open air markets in Kiambu, Kenya

<table>
<thead>
<tr>
<th>Towns</th>
<th>Cu</th>
<th>Zn</th>
<th>Cr</th>
<th>Pb</th>
<th>Sb</th>
<th>Co</th>
<th>Cd</th>
<th>Sr</th>
<th>B</th>
<th>V</th>
<th>Mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gachie</td>
<td>9.0</td>
<td>27.5</td>
<td>9.0</td>
<td>0.83</td>
<td>ND</td>
<td>5.5</td>
<td>ND</td>
<td>9.5</td>
<td>ND</td>
<td>ND</td>
<td>34.5</td>
</tr>
<tr>
<td>Kiambu Town</td>
<td>4.0</td>
<td>39.0</td>
<td>7.0</td>
<td>0.68</td>
<td>54.5</td>
<td>4.0</td>
<td>ND</td>
<td>5.0</td>
<td>ND</td>
<td>ND</td>
<td>30</td>
</tr>
<tr>
<td>Githunguri</td>
<td>8.0</td>
<td>46.0</td>
<td>6.0</td>
<td>0.73</td>
<td>56.5</td>
<td>3.5</td>
<td>ND</td>
<td>5.5</td>
<td>ND</td>
<td>ND</td>
<td>43.5</td>
</tr>
<tr>
<td>Kikuyu</td>
<td>5.0</td>
<td>58.0</td>
<td>0.5</td>
<td>1.54</td>
<td>116.0</td>
<td>3.0</td>
<td>ND</td>
<td>11.0</td>
<td>ND</td>
<td>ND</td>
<td>52</td>
</tr>
<tr>
<td>Wangige</td>
<td>6.5</td>
<td>48.0</td>
<td>4.0</td>
<td>0.72</td>
<td>50.5</td>
<td>2.5</td>
<td>ND</td>
<td>6.5</td>
<td>ND</td>
<td>ND</td>
<td>30.5</td>
</tr>
<tr>
<td>Limuru</td>
<td>6.0</td>
<td>28.5</td>
<td>3.5</td>
<td>0.69</td>
<td>54.0</td>
<td>1.5</td>
<td>ND</td>
<td>7.0</td>
<td>ND</td>
<td>ND</td>
<td>35.5</td>
</tr>
</tbody>
</table>

Notes: ND = not detected.

3.3. Mineralogical Analysis

The mineralogical analysis was done using XRD and Fourier transform infrared.

3.3.1. XRD

The minerals identified included quartz, tectoaluminosilicate, sanidine, orthoclase calcite, goethite, hematite, kaolinite, halloysite, gibbsite and smectite. Quartz and kaolinite were the dominant phases present in the samples. This agrees with the findings of other researchers [7]. The presence of high levels of kaolin supports the protection hypothesis, but the elevated levels of iron containing minerals may support the micronutrient deficiency.
3.3.2. FTIR

The absorption frequencies of the peaks in the spectra of each site in wave number unit were compared to the observed frequencies in available literature. The minerals identified were in agreement to those identified by XRD.

Quartz presence was inferred by the observation of the absorption bands appearing at or around 455-450, 510-505, 695-690, 775-780 and 800-895 cm\(^{-1}\) [5, 8-12].

The pattern of quartz absorption can be explained by ascribing the 455 cm\(^{-1}\) region to Si-O asymmetrical vibrations. The bands in the region 690 cm\(^{-1}\) can be attributed to Si-O symmetrical bending vibrations and the bands in the region 780 cm\(^{-1}\) (Si-O symmetrical stretching vibrations) and 800 cm\(^{-1}\) (Si-O symmetrical stretching vibrations).

The presence of potassic feldspar (KAlSi\(_3\)O\(_8\)), sanidine and orthoclase was inferred from the absorption peaks. The infrared absorption peaks appearing at 410-405, 540-535 and 630-625 cm\(^{-1}\) were assigned to feldspar absorption. This is in agreement with other researchers [5,12]. The peaks in the range of 540-535 cm\(^{-1}\) can be attributed to Si-O asymmetrical bending vibrations and 630-625 cm\(^{-1}\) is due to Al-O-coordination vibrations in feldspars [5].

The presence of kaolinite mineral (Al\(_2\)Si\(_2\)O\(_5\)(OH)\(_4\)), which is a product of chemical weathering.
of feldspars. The presence of kaolinite is confirmed by the presence of absorption bands at 3690, 3620, 1030 and 475 cm\(^{-1}\) [13,14]. Kaolinite has been found to show a characteristic absorption band in the range 3700-3600 cm\(^{-1}\). These absorbances correspond to stretching vibrations of inner surface OHs 3696 cm\(^{-1}\) and inner OH 3620 cm\(^{-1}\).

The presence of calcite (calcium carbonate) is confirmed by the presence of the absorption peaks at 875-870 and 1440-1435 cm\(^{-1}\). This is in agreement with many works [5,8,10]. A representative IR spectrum is shown in Fig. 2.

![Figure 2. A representative IR spectrum.](image)

4. Conclusions

The geophagic materials from Kiambu were studied and it was found that the materials consist of mainly silica and alumina. The mineralogical analysis showed that quartz and kaolinite were the major phases present.

References


