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Cover Page Footnote

We would like to thank Dr. Anne Cafer of the University of Mississippi Department of Sociology & Anthropology and Dr. Mary Willis of the University of Nebraska-Lincoln Department of Nutrition for acquiring our samples. We would also like to thank the staff at the Mississippi State University Institute for Imaging and Analytical Techniques for their help gathering and interpreting the data. Finally, we would like to thank Dr. James Cizdziel at the University of Mississippi Department of Chemistry and Biochemistry and Dr. Carolyn Freiwald at the at the Department of Sociology and Anthropology for supporting and guiding this research project.

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Abstract

Trace elements in three edible clay samples from an open-air market in Kitwe, Zambia were analyzed for heavy metals using a scanning electron microscope coupled with an energy-dispersive spectrometer. The ingestion of clays has been observed throughout history but persists in many rural countries that lack sufficient access to proper medical care. In many African countries, women have been observed eating clay during pregnancy to reduce nausea or meet their recommended intake of iron. Similar studies identified harmful heavy metals in the makeup of the edible clays, however, the results of this analysis elemental analysis coupled with the SEM for the three samples did not show toxic concentrations of lead, mercury, or arsenic. Although eating soil can damage tooth enamel, inhibit digestion of important nutrients, and put people at risk of biological infections, the elements found in these three samples should not lead to health issues resulting from heavy metal poisoning.

Acknowledgements

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Introduction

Geophagy, or ingesting soil, has been observed in many cultures from Bangladesh to Mississippi, as well as in non-human primates (Al-Rmalli, Jenkins, Watts & Haris, 2010; Nuwer, 2016; Reynolds et al., 2015). The tradition or cultural phenomena of clay eating has been frequently observed in pregnant women since it is believed to have a variety of health benefits (Nkansah, Korankye, & Darko, 2016; Mukasa-Tebandeke et al. 2015; Mwalongo & Mohammed 2013; Odongo, Moturi, & Mbuthia, 2016; Olantunji, Olajide-Kayode, & Abimbola, 2014; Pereira, Enders, Iop, Mello, & Flores, 2018). It is believed to help with the effects of morning sickness, such as nausea, or provide nutrients that are vital for biological functions for both the fetus and mother, such as iron, calcium, and B12 (Nkansah et al. 2016; Mukasa-Tebandeke et al. 2015; Mwalongo & Mohammed 2013; Odongo et al. 2016; Olatunji et al. 2014). In many African countries, clay is sold as an edible good in open air markets, but this phenomenon is not limited to Africa (Nkansah et al. 2016; Mukasa-Tebandeke et al. 2015; Mwalongo & Mohammed 2013; Odongo et al. 2016; Olatunji et al. 2014). Clay that is advertised as an edible health supplement can be found online, or even in stores that market to certain immigrant populations, and has persisted throughout history in the United States (Al-Rmalli et al. 2010; Nuwer, 2016). However, most studies have shown that the edible clays contain dangerous elements such as lead, mercury, and arsenic (Al-Rmalli et al. 2010; Nkansah et al. 2016; Mukasa-Tebandeke et al. 2015; Mwalongo & Mohammed 2013; Odongo et al. 2016; Olatunji et al. 2014, Pereira et al. 2018; Reyes-Gutiérrez, Romero-Guzmán, Cabral-Prieto, & Rodríguez-Castillo, 2008). These elements may be naturally occurring or the result of pollution from mining. Elemental analysis of edible clay samples from Nigeria, Kenya, Tanzania, Uganda, Ghana, and Bangladesh sold for human consumption all contained higher than recommended levels of heavy metals (Al-Rmalli et al. 2010; Nkansah et al. 2016; Mukasa-Tebandeke et al. 2015; Mwalongo & Mohammed 2013; Odongo et al. 2016; Olatunji et al. 2014). For example, in Ghana the average measured concentration of lead found in clays sold for consumption was between 500-600 micrograms per day with the recommended level being approximately 150 micrograms per day (Nkansah et al. 2016). Doctors do not recommend eating any amount of soil from any location due to risk of parasitic or other microbial infections, digestive issues, and risk of bioaccumulation of hazardous elements like mercury or lead (Al-Rmalli et al. 2010; Nkansah et al. 2016; Mwalongo & Mohammed 2013; Odongo et al. 2016; Olatunji et al. 2014, Pereira et al. 2018; Reyes-Gutiérrez et al. 2008).

The three Zambian samples were purchased at a market in Kitwe, which is in the Copperbelt Province in northern Zambia. Each sample differed in color, texture, and consistency. There was no other information collected about the source or preparation of the clays. The purpose of these analyses was to determine the potential health benefits and risks using a scanning electron microscope (SEM) with an energy-dispersive spectrometer (EDS) and analytical software to interpret results (“Equipment,” 2018; “Energy Dispersive X-Ray Spectroscopy,” 2019). Our study found no toxic levels of heavy metals in these particular samples.

Methods

Samples were prepared at the University of Mississippi anthropology lab where the clay samples were ground and pulverized with a mortar and pestle and dried under a fume hood with a calcium chloride desiccant. Clay sample 1 was light grey and difficult to chip into pieces, but pulverized easily into a fine dust. Clay sample 2 was a pale orange color and easier to break up, and had a sticky, damp consistency. Clay sample 3 was a light brown color and the easiest to break apart, but very dry and grainy. The workstation and mortar and pestle were sterilized between samples with isopropyl alcohol, and new gloves were worn with each sampling to avoid samples cross contamination.

The samples were processed at the Mississippi State University Institute for Imaging and Analytical Technologies in collaboration with Orion Rivers. In this paper, we present results from sample imaging using the EOL JSM-6500F field emission scanning electron microscope (SEM) coupled with an energy-dispersive spectrometer (EDS).

Samples were prepared for processing on the scanning electron microscope by placing a dusting of each sample on small metal stubs with double-sided carbon tape on the flat head of the sample holder. The sample holder was then placed into an EMS 150 T ES coater, which used a charged plasma environment to stamp a thin, 30 nanometer layer of platinum on the samples mounted on the metal stubs. The SEM bombards the sample with electrons to image the sample. The attached EDS then interprets the unique readings that backscattered electrons create to identify elements in a sample and displays the information using INCAEnergy+ software. Three different scans, trials A, B, and C, were taken of each sample from different portions of the stub to get the most accurate results based on clay composition.

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Results

The original images produced by INCAEnergy+ were the spectra results coupled with a table of elemental composition based on weight percent and atomic percent. Table 1 is a comparison of all of the average weight percentages of the elements identified in the three samples from the three unique scans done by the EDS referred to as trials A, B, and C. Just the spectrum from trial A of each of the three samples can be found below in figures 1, 2 and 3. Each of the samples contained similar elements, including oxygen (O), aluminum (Al), silicon (Si), and iron (Fe), as well as potassium (K) and titanium (Ti) in small amounts. Heavy metals such as lead (Pb), mercury (Hg), arsenic (As) were not identified in any of the samples. Each of the clays displayed slightly different concentrations of elements.

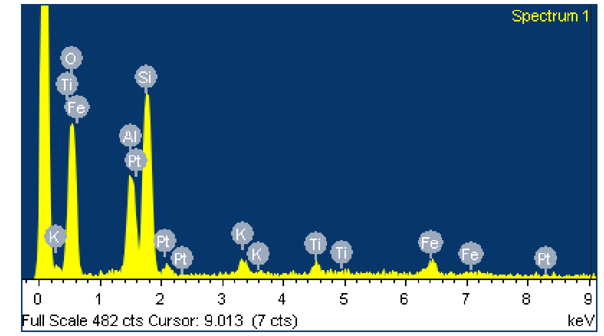

Figure 1: Sample 1 trial A EDS results in a spectrum format. The elements can be identified by the INCAEnergy+ software from unique patterns detected by the EDS.

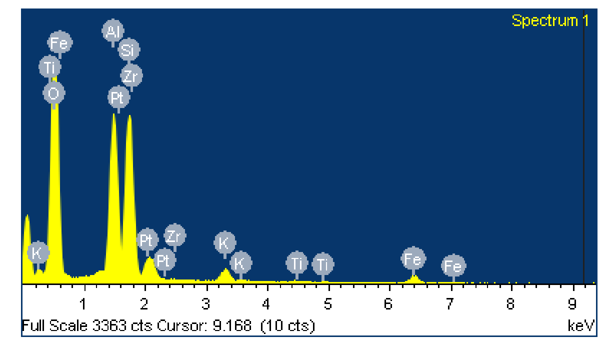

Figure 2: Sample 2 trial A EDS results. The peak for platinum is easily mistaken for zirconium, but it is a false positive.

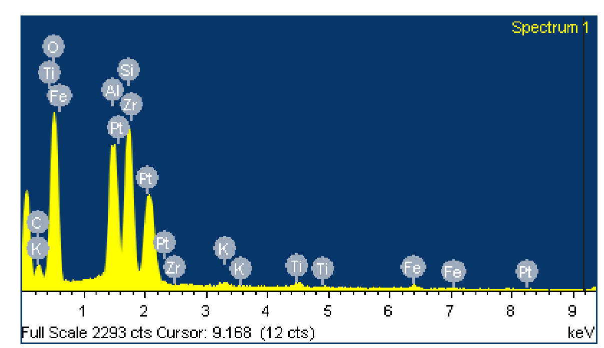

Figure 3: Sample 3 trial A EDS results. The same zirconium error in figure 2 can be seen above mingled among peaks identified as platinum.

Element	Sample 1 (wt%)	Sample 2 (wt%)	Sample 3 (wt%)
Carbon (C)	n/a	n/a	13.7 ±5.22
Oxygen (O)	48.17 ±5.26	50.6 ±5.01	30.9 ±5.16
Aluminum (Al)	8.16 ±2.32	13.2 ±1.95	22.7 ±0.909
Silicon (Si)	19.5 ±2.08	16.4 ±2.46	13.3 ±1.78
Potassium (K)	1.84 ±0.777	2.25 ±0.365	0.667 ±0.104
Titanium (Ti)	1.62 ±1.18	0.48 ±0.818	0.657 ±0.168
Iron (Fe)	3.99 ±4.28	4.833 ±0.640	1.98 ±1.98
Platinum (Pt)	7.04 ±5.88	7.943 ±2.70	16.0 ±6.04

Table 1: Average weight percentage for each of the most abundant elements found in clay samples 1, 2, and 3. The standard deviation is indicated by the ± value after the average weight percent.

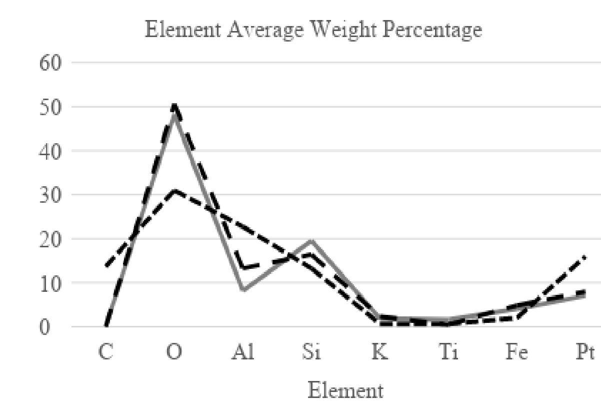

Figure 4: Elemental weight percent values for the three clays: Sample 1 is indicated by the solid line. Sample 2 is indicated by the line with longer dashes. Sample 3 is indicated by the line made of smaller dashes.

Discussion

Figure 1 depicts the spectrum from

trial A for clay sample 1 and the average weight percent of the elements from trials A, B, and C can be found in the second column of table 1. Clay sample 1 contained more Si and Ti than the other two clay samples. However, clay sample 1 also contained the least amount of Al, as seen in table 1. Clay sample 2, the orange-colored clay, contained the most Fe, Al, and K of all three clay samples (figure 2). The amount of Fe found in clay sample 2 could account for the vibrant orange color of the clay. Clay sample 3 (figure 3) contained a consistent amount of carbon (C) in each sample; the other two samples only showed a C reading once (clay sample 2) or twice (clay sample 1), so the C was excluded from their total average weight percent calculations. The sample of clay 3 also contained significantly more Pt, which could be an error due to stamping, although it is possible that the element was present in the clay itself. In Table 1, C was excluded for samples 1 and 2 and Zr (trials B and C) and Au (trial A) are excluded. These exclusions were necessary because the elements did not appear in every trial or were false positives that did not represent the sample. There was a large variance in standard deviation, which could be due to the grainy composition of the dirt or unevenness of the sample on the carbon tape.

Some elements, like zirconium (Zr) and gold (Au), are visible in the spectral data, but were present in insufficient quantities to be included in the results. This is because the peaks for Zr and Au are similar to peaks exhibited by other elements, such as the platinum used to coat the samples to avoid image distortion. The platinum prevents electron charges from the sample that would result in white splotches and make the image difficult to interpret. Although heavy metals were not detected in these samples, this could be due to the limit of detection for the EDS, which is typically 0.1 wt% or 1000 ppm.

Conclusion

Consumption of clay, or “dirt eating” is a practice in many cultures, especially by women to avoid iron or calcium deficiencies during pregnancy. However, it is common for the clay to contain dangerous levels of arsenic or lead that can be hazardous to the health of both the mother and the fetus.

The results for the Copperbelt Region Zambian clay samples show no detectable amounts of heavy metals or other hazardous elements in the clay samples, including Pb, Hg, and As. However, the ingestion of high amounts of Al or Si, as well as the risk of biological or parasitic infection, also are potential hazards. In addition, bioaccumulation of unsafe elements or compounds still may present health hazards when present in trace amounts.

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