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CHARACTERIZATION OF CLAYS FOR MAKING CERAMIC POTS AND WATER FILTERS AT MUKONDENI VILLAGE, LIMPOPO PROVINCE, SOUTH AFRICA

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ABSTRACT

Clay is a raw material that has many uses across the different industries. The principal use of clay at Mukondeni Village is making of pots, which are based on traditional paintings of Venda and Tsonga people and are sold to tourists, businesses and local people. Although the knowledge of using raw clay for making of ceramic pots is known to many throughout the world; very little scientific studies have been conducted to establish the basic characteristics of clays for this purpose. The main aim of this study was to characterize the Mukondeni clay deposit based on its mineralogical, geochemical and physical properties. The mineralogical and chemical characteristics of the clays were determined using XRD and XRF, respectively. Atterberg limits tests were conducted in order to establish the physical properties of the clays. The XRD results indicated that the gritty reddish clay (RCSH) has the least amount of smectite (37.7%) while in smooth greenish (GCSH) and black (BCSH) it was found to be up to 55.69% and 55.08%, respectively. Although all clays indicated elevated SiO and Al_2O_3 concentration, the RCSH had the highest (66 % silica and 16.07% Al_2O_3) with the least LOI percentage (4.39%). On the other hand, the trace element results showed the clays to be having high concentration of Cr (±888.33 ppm), Ni (±343.30 ppm), V (±118.86 ppm) and Zn (±50.66 ppm). Among all the Mukondeni clays, the GCSH had the highest plastic index of 20; indicating that it is highly plastic than the RCSG (5) and the BCSH (6.3). It was found that the smectite content in both black and green clays are indicative of high plasticity, stickiness and low porosity compared to red clay. As a result, the two clays (black and green) were considered unsuitable for making ceramic pots and water filters since they have high potential of cracking during the drying up process. It was recommended that the potters mix the red clay with the other two clays to improve their molding and overall pots making properties.

Keywords: ceremic pots, water filters, smectite clay, characterization.

INTRODUCTION

Clay is an earthy substance containing a mixture of hydrous aluminium silicates, with residual fragments of other minerals and colloidal matter. It possesses property of plasticity when wet, but becomes permanently hard when fired at a high temperature (Heckroodt, 1991; Guggenheim and Martin, 1995 and Horm and Strydom, 1998). Clay can also be referred to as material comprising of finest fraction of sediment (Heckroodt, 1991, and Dies, 2003). The significance of clay as ceramic material and building materials was recognized since the ancient times. Currently, raw clay is finding a wide application in different industries such as ceramic, agriculture, steel, chemical, paper, metal production and electrical power generation, fillers; extenders and polymers, absorbents and adsorbents, filler extenders and thickeners, and construction; civil and mining and environmental applications (Horm and Strydom, 1998).

The people of Mukondeni Village in Limpopo Province of South Africa are generally very poor and unemployment is rife. The income generating activities at the village include agriculture carried out at small-scale level, brick-making, piggery and pottery making. The lack of job opportunities has resulted in the majority of the people relying on pottery work as a source of income. In trying to provide the members of the community with stable income, the ceramic water filters factory with the estimated monthly production of 800 to 1000 filters was established in the area.

Although the use of raw clay for pottery making has long history in the community of Mukondeni, its use in ceramic water filters requires that physical, geochemical and geotechnical properties of these materials be established to define the clay suitability for these purposes. The main aim of this study was to identify the different types of clays in the area and to carry out the mineralogical, geochemical and geotechnical evaluation of the clay for making ceramic water filters in the newly established factory at Mukondeni Village.

Regional geology

The study site lies within the Southern Marginal Zone (SMZ) of the Limpopo Belt. The approximately 60 km wide ENE-WSW trending SMZ consists of granulite faciessupracrustal gneisses of mafic, ultramafic and metapelitic composition, formally known as the Bandelierkop Formation, intermixed with volumetrically dominant tonalitic grey gneiss referred to as the Baviaanskloof Gneiss (Du Toit *et al.*, 1983). The Bandelierkop Formation is intruded by homogeneous igneous enderbites of the Matok Complex (Bohlender *et al.*, 1992). Metapeliticgranulites of the Bandelierkop Formation consist of quartz, plagioclase, hypersthene, garnet, biotite and cordierite, with less common perthitic K-feldspar, spinel, sillimanite and late kyanite (van

Reenen *et al.*, 1990). The Formation are largely supracrustal gneisses that have undergone a considerable degree of anatexis, and are exposed in the area east and northeast of Bandelierkop, located 40 km south of Makhado Town. The Baviaanskloof Gneiss is greyish, migmatitic, tonalitic to trondhjemitic gneiss in which the granitic character is immediately apparent. Mineralogy is basically quartz, plagioclase, hornblende or biotite, and the rock is well banded and homogeneous in places whereas others are strongly heterogeneous (Anhaeusser, 1992; Brandl and Kroner, 1993). The contacts of this gneiss run parallel to the gneissic fabric, and anatectic leucocratic granite always occurs at the contact between this unit and the Bandelierkop Formation (Du Toit *et. al*., 1983).

Location of the study area

The study area is found at the far north of Limpopo province at Mukondeni Village situated between 30° 05′E to 30° 07′E and 23° 15′S to 23° 16′ S. The locality map of the study area is shown in Figure-1. It is located at about 30 km south east of Makhado Town and about 50 km south west of Thohoyandou Town.

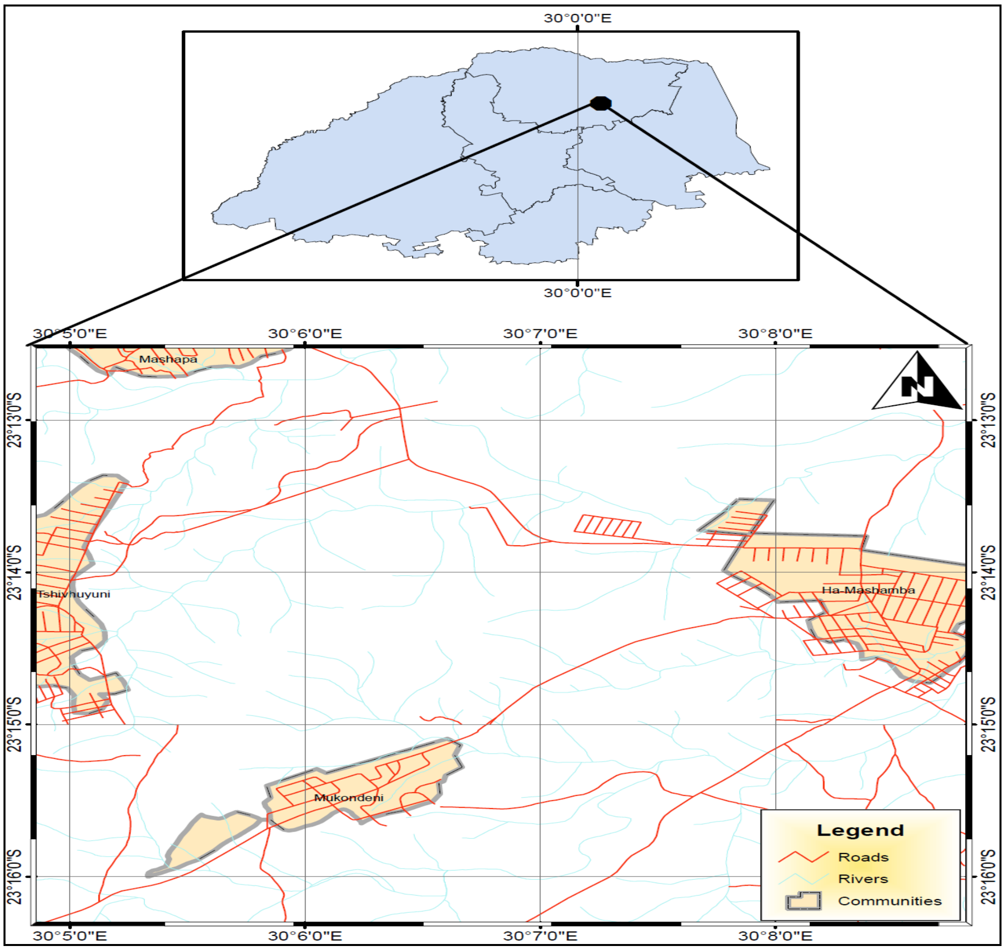

Figure-1. The geographical location of Mukondeni village.

METHODS AND MATERIALS

Systematic soil auguring was conducted around the clay mining site at Mukondeni. This was done to intersect the different soil horizons in the area. The holes were drilled up to ± 5 m depth at 20 by 20 m grids. The texture and colour of the soil was used to distinguish between the different intersected soils horizons. Based on these criteria, three soil types/horizons were identified. These were (i) the gritty reddish type of clay detonated as RCSH, (ii) black fine and smooth clay denoted as BCSH, and (iii) the green type of clay also characterized by fine and smooth texture. Both the BCSH and the RCSH occur more prominently in the area; thus they are commonly used by potters in making pots and ceramic water filters.

A composite sample of each of the soil horizons intersected by the drill holes was collected and analyzed for their mineralogical, geochemical and geotechnical characteristics. This section is earmarked for the presentation of the methods, materials and procedures used in analyzing the soil samples in the laboratory.

XRD analysis of the samples

The samples were prepared for XRD analysis using a back loading preparation method. Analysis was

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done using a PANalyticalX'Pert Pro powder diffractometer equipped with X'Celerator detector and variable divergence- and receiving slits with Fe filtered Co-Kα radiation. The clay phases were identified using X'PertHighscore plus software. The relative phase amounts (w %) was estimated using the Rietveld method (Autoquan Program). Amorphous phases, if present were not taken into consideration in the quantification. The presence (or absence) of Smectite in samples showing a peak at around 14 Angstrom was confirmed by additional XRD analysis after exposing the samples to an ethylene glycol enriched atmosphere for 72 hours.

Major oxides and trace element analysis

The clay samples were prepared for direct analysis with PANanalytical Axios X-ray fluorescence spectrometer instrument. The sample preparation involved milling of clay samples to less than 75 μ fraction. The milled sample was then roasted at 1000 °C for at least 3 hours to oxidize iron (Fe^{2+}) and Sulfur (S), and to determine the Loss on Ignition (L.O.I) percentage.

The analysis of major oxides required that the glass disks are prepared through fusing 1 g roasted sample, 8 g (12-22) flux consisting of 35% alkali borate ($LiBO_2$) and 64.71% lithium tetra borate ($Li_2B_4O_7$) at 1050°C. The glass disks were then analyzed by XRF instrument equipped with a 4 kW Rhodium (Rh) tube. Trace element analysis was achieved by mixing 12 g milled sample and 3 g Hoechst wax. The mixture was then pressed into a powder briquette by a hydraulic press with the applied pressure of 25 ton.

Atterberg limits

Liquid limit test

The liquid limit can be generally defined as the moisture content at which soil begins to flow like a liquid material. It gives the moisture content at which the shear strength of the soil is approximately 2.5KN/m^2 (Das, 2006). The liquid limit property of clay was determined using liquid limit device (Casagrande), grooving tool, water bottle, mixing dishes, spatula, and the drying oven. The procedure for testing the liquid limit of the soil samples began with calibration and cleaning up of the Casagrande equipment. The calibration involved setting of the drop at a consistent height of 10 mm. Water was added on the dry sample in the dish to increase its moisture level. The moist sample was placed on the Casagrande's cup and smoothened to the maximum depth of 8 mm. The groove was cut at centre line of the sample in the cup and the device was cranked at 2 revolutions per second until the two halves of the soil pat come into clear contact of about 13 mm long at the bottom of the groove. The number of blows (N) that caused the closure was recorded. The sample in the pat was collected, weighed together with the can, labeled and dried in the oven at 110°C for more than six hours. The weight of the dried sample was also determined. The trial was repeated 3 times in different moisture content, producing successively lower numbers of blows to close the groove. These blows were between 25 to 30, 20 to 30 and 15 to 25. The number of blows (N) was plotted against the water content and the best-fit straight line through the plotted points was constructed for which the liquid limit was determined as the water content at 25 blows.

Plastic limit test

The plastic limit (PL) of soil is generally the water content at which the soil begins to crumble when rolled into a thread of 3 mm in diameter. This was tested by taking 3 ellipsoidal-shaped masses of the sample and rolling them using a plastic limit device with a calibrated opening of 3.18 mm until the soil crumbles. The crumbled soil was collected and weighed, dried and weighted again for water content determination. Prior to weighing the moist soil and the can, the mass of the can was determined separately. Three trials of the test were performed for each soil type.

In both liquid limits and plastic limit tests. Equation (1) was used in the determination of the percentage of water in the soil samples.

$$\text{Water content, w\%} = \left(\frac{W_2 - W_3}{W_3 - W_1}\right) \times 100 \qquad (1)$$

Where: W_1 is the mass of the Can, W_2 is the mass of the Can + Wet soil, and W_3 is the mass of the Can + Dry soil.

The difference between the liquid and the plastic limits was taken as the plasticity index of the soil. Equation (2) was used in the calculation of the soil plastic index.

$$\text{Plasticity Index (PL)} = LL - PL \qquad (2)$$

RESULTS

Mineralogy

The results obtained from the X-ray diffraction analysis is presented in Figure-2. A summary of the XRD results of the mineralogical analysis are presented in Table-1. The XRD results of the mineralogical analysis showed the mineralogical assemblages of the sample. The major minerals present have been indicated against the diagnostic peaks as shown in Figure-2. The clay samples showed that the main non-clay minerals are quartz, feldspars, hornblende and talc. The main clay mineral found in the three types of clay in the study area was Smectite. Plagioclase, talc and hornblende contents in RCSH recorded the highest concentration (25.36%, 6.89%, and 4.52%, respectively) than the other clay samples. However, Smectite content in this clay sample was the lowest with 37.7% than the two varieties (55.08% for BCSH and 55.69% for GCSH, respectively). Although quartz, feldspars, hornblende and talc are the main non-clay minerals, their composition is erratic in the different clay soils.

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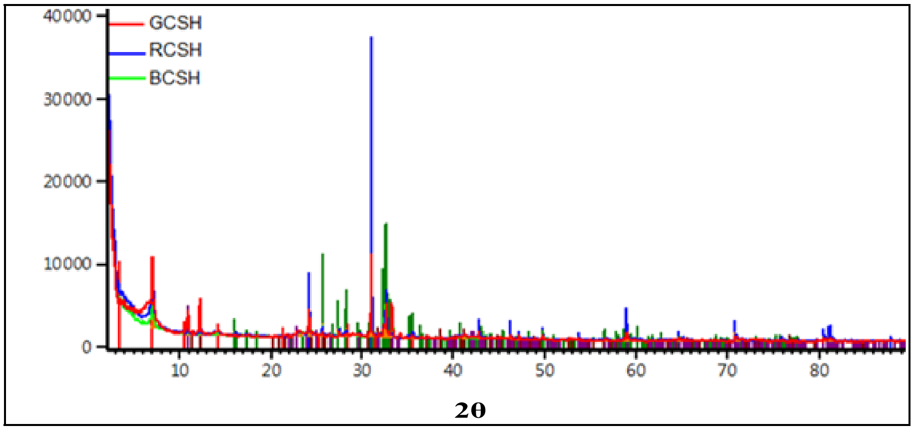

Figure-2. XRD difractograph of the mineral content of Mukondeni clay soils.
A = Albite, Q = Quartz, Ch = Chlorite.

Table-1. Calculated semi-quantitative percentages of clay minerals and the non-clay minerals.

Clay and non-clay minerals	Types of Clay					
	BCSH		GCSH		RCSH	
	Weight %	3 σ error	Weight %	3 σ error	Weight %	3 σ error
Hornblende	4.77	0.66	9.2	0.69	4.52	0.96
Plagioclase	15.91	1.29	8.79	1.53	25.36	1.62
Quartz	22.66	1.05	20.83	1.02	25.54	1.05
Talc	1.57	0.84	5.49	2.55	6.89	1.17
Smectite	55.08	1.95	55.69	2.1	37.7	1.59

Geochemistry

The chemical data presented in Table-2 revealed that SiO_2 contents range from 58.01% to 62.01% with an average of 62.01%, whereas Al_2O_3 contents vary between 14.19% and 16.07% with an average of 14.88%. The SiO_2 contents are mainly derived from quartz in sand and silt size fractions, whereas the main source of Al_2O_3 is the clay minerals and a small amount of feldspar minerals. Sample BCSH has low SiO_2 and Al_2O_3 contents (58.01 and 14.38%, respectively). The loss on ignition (LOI) value of different clay soils at Mukondeni was found to be 4.39 (RCSH), 7.71 (GCSH) and 12.47 (BCSH). LOI values are important in clays as they indicate the loss during firing (Johari *et al*., 2011).

Table-2. Major element composition of clays.

Type of Clay	Concentration of major elements (w%)															
	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Cr_2O_3	NiO	V_2O_5	ZrO_2	CuO	LOI	Total
BCSH	58.01	0.59	14.38	5.83	0.1	2.72	1.73	2.17	1.04	0.04	0.08	0.03	0.02	0.02	<0.01	12.47	99.23
RCSH	66	0.59	16.07	6.12	0.04	2.84	1.62	2.35	0.9	0.03	0.08	0.03	0.02	0.02	<0.01	4.39	101.11
GCSH	62.01	0.33	14.19	5.14	0.03	6.14	2.19	1.35	0.41	0.01	0.15	0.06	0.02	0.02	<0.01	7.71	99.75

Ch

Trace element composition

The concentrations of trace elements in the three types of clay found in the area were determined and the results of the analysis are presented in Table-3. The Mukondeni clay soils used to make ceramic water filter are in abundance of Ba (±450.53 ppm), Cr (±888.58 ppm), V (±118.91 ppm), Zn (±112.57 ppm) and Ni (±343.30 ppm).

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Table-3. The average elemental composition of the three clay soil of Mukondeni.

Type of Clay	Element concentrations (ppm)																	
	As	Cu	Ga	Mo	Nb	Ni	Pb	Rb	Y	Zn	Zr	Cl	Co	Cr	Sc	V	Cs	Ba
BCSH	15.01	43.43	18.56	1	5.66	278.01	16.75	58.49	14.37	61.83	136.9	7.58	40.46	675	16.37	102	34.91	557.57
RCSH	15.75	41.87	20.42	1	5.99	261.96	12.85	45.55	11.91	51.99	131.6	7.58	38.99	694	17.81	142.4	43.11	484.96
GCSH	11.97	20.55	16.88	1	3.9	489.93	9.09	22.31	7.2	38.18	69.22	7.58	38.62	1296	15.66	112.2	36.71	309.05

Atteberg limit results

The moisture content corresponding to the intersection of the flow curve with the 25 blows (along the x-axis) is the LL of the soil. The LL of the clays from the study area is presented in Figure-3.

The LL test showed that the three types of clay possess different physical properties. The LL value for black clay (BCSH) was found to be 29; while that of the green (GCSH) and red clays (RCSH) was 45.3 and 35.3 respectively (see Figure-3). The plastic limit of the red clay, green clay and the black clay were determined and found to be 29, 23 and 24, respectively. The plastic index for the three clay types denoted by BCSH, GCSH and RCSH were 6.3, 20 and 5, respectively. This gave an indication that BCSH and RCSH clays are characterized by more or less similar plasticity that is extremely lower than that of BCSH.

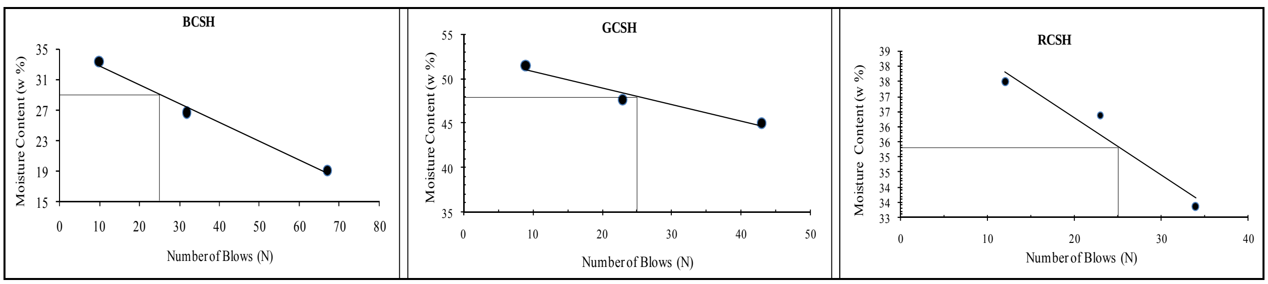

Figure-3. The flow curves of liquid limit for the clay soils of Mukondeni.

DISCUSSIONS

The three types of clay soils of Mukondeni fall into the smectite group with high swelling and shrinking potential. Silica (SiO) was found to be the highest component of the Mukondeni clay soils. According to Jahari *et al.* (2011), silica in clay soil exists as free form silica and as compound silica such as in kaolinite ($Al_2Si_2O_5(OH)_4$). The red colour of RCSH can be attributed to presence of a slightly high iron oxide (±6.12%). The black colour characterizing the BCSH suggests that these materials comprise of high organic matters. This was supported by the fact that this material had a relatively high LOI (12.47%). However, LOI of clay soil can be generally high since higher temperature turn to drive off structural water of clays (Konare *et al.,* 2010). In addition, one of the findings of this study is that Cr, V, Zn and Ni were constantly high in all soils. This can be due to the fact that metals such as Ti, V, Mn, Fe, Co, Ni, Cu, Zn and Pb sorbs to smectite easily (Siegel, 2002).

The most important property of clay soils that determines their uses for ceramic purposes is their plasticity property. This property allows the ceramist to create different shapes that have the ability of maintaining their forms before being fired (Dies, 2003). This property of soil (Clay soil) can be influenced largely by their chemical composition and the nature of aggregate they contain. Some chlorite species can improve the plasticity of clay while others turn to reduce the soil plasticity. On the other hand, soils such as glauconite sands that are characterized by much less content of fines possess elevated plasticity property. Comparatively, soil containing greater than 95% kaolinate clay remains non-plastic (Guggenheim and Martin, 1995). In all types of clays, smectite is generally sticky with high plasticity and strength in both dry and wet state. As a result, it is the most preferred material used in the making of ceramic pots (Vitelli, 1999).

Most often potters have the tendency of choosing their clay on the basis of easy to work, easily obtainable and because it requires minimum firing time and fuel (Vitelli, 1999). Although the type of clay found in Mukondeni is generally smectite, the potters prefer mixing the black (BSCH) and red (RSCH) when preparing the material for making ceramic pots. This might be influenced by the fact that the red clay is grittier and less sticky than the smooth black clay.

High smectite content in black (55.08%) and green (55.69%) clays indicates that these materials are highly plastic and sticky than red clay with smectite content of 37.7% (see Figure-4). The indications that red clay is more porous than the black and green clays were given by the gritty feeling they possess.

Due to the fact that plasticity and porosity are a function of the particle sizes of the material. The finer the clays, the more plastic and less porous they are. In view of this, both black and green clays are characterized by relatively high PI than red clay as shown in Figure-4. They are therefore less porous than the red clay.

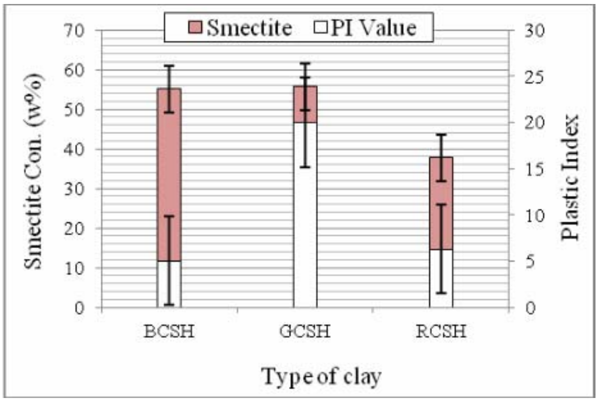

Figure-4. Comparison of the soil plastic index values and their smectite concentrations.

The plasticity and high PI of BSCH and GCSH clays raise serious concerns due to the fact that clays that exhibit these properties often crack when drying up.

CONCLUSIONS

The clay soils at Mukondeni village are identified by their different colours (red, green and black) and varying geotechnical properties such as texture and plasticity. In terms of mineral composition, these clays are all dominated by smectite.

The elevated plastic index characterizing both the black and green clays indicates that they can crack easily during the burning of the pottery products. The reduced smectite concentration and plastic index values in red clay make it less plastic, less sticky with poor molding property.

In view of this, it is recommended that in making ceramic pots and water filters, the red clay should be mixed with the other two clays (i.e., black and green). This will improve the molding property of red clay while reducing the stickiness of both green and/or black clay comprising of high percentage of smectite.

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