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Mineralogy and Geochemical Characteristics of Matamba Kaolin Deposit-Njombe Region South-Western Tanzania: Implications for Industrial Applications

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Abstract

Kaolin is a commercial clay material composed of hydrated aluminosilicate mineral kaolinite and used in various industrial applications such as ceramics, paper, paints, refractories, fiberglass, plastics, cosmetics and pharmaceuticals. It is formed as a result of strong chemical weathering of crystalline and feldspar-rich rocks or hydrothermal alteration of granitic rocks at relatively low temperature and pressure conditions. The kaolin deposit of Matamba originated from the weathering of leucogabbro rock during the development of the African land surface. In view of highlighted properties, the mineralogy and chemical characteristics of the Matamba kaolin deposit were investigated to determine its industrial applications. As part of the study approach, forty-six (46) samples were collected and analyzed for major oxides using X-ray fluorescence (XRF) and mineralogical composition using X-ray diffraction (XRD). The XRD results indicated that the Matamba kaolin is dominantly composed of kaolinite (10.1–100%) with other phases such as albite (1.2–56.8%), oligoclase (10.1–54.3%), quartz (1.2–33.9%), goethite (1.0–9.4%) and muscovite (1.1–29.5%). The dominant major oxides are SiO_2 (39.78–67.96 wt.%), Al_2O_3 (14.60–38.07 wt.%) and subordinate amounts of Fe_2O_3 (0.93–6.37 wt.%), MgO (1.42–4.74 wt.%), Na_2O (0.10–1.09 wt.%), K_2O (0.14–2.01 wt.%), CaO (0.08–0.99 wt.%), TiO_2 (0.07–1.66 wt.%), P_2O_5 (0.36–1.77 wt.%) and LOI (1.91–13.97 wt.%). These major oxides correlate with the mineralogical composition supporting kaolinite dominance. Consequently, compared with some industrial specifications, these results indicate that Matamba kaolin deposit may be useful for ceramic products, refractories such as fireclay crucibles and electrolytic production of aluminium and its alloys. However, it should be beneficiated and upgraded to improve some technical properties to qualify for other industrial applications.

Keywords: Matamba kaolin, Mineralogy, Geochemical characteristics, XRD, Industrial applications.

Introduction

The exploitation of kaolin is a financially sustainable and profit-making mining industry that contributes positively to the national economies of the world (Ekosse 2010). Kaolinite is one of the potential industrial minerals used in many industrial applications including ceramics (Murray 2002). Generally, kaolin deposits are formed from the transformation of aluminosilicate rocks such as granite, leucogabbroic or volcanic tuffs (Baioumy et al. 2012). They are formed where rocks are in contact with water, air or steam. However, the type of kaolin formed is principally controlled by the composition of the pre-existing rock mineralogy (Nyakairu et al. 2001). Kaolin is dominantly composed of kaolinite minerals and a small amount of minerals that constitute the kaolin group, namely halloysite, smectite, nacrite, palygorskite and dickite (Ekosse 2010, Bukalo et al. 2018). In addition, it contains a number of impurities such as quartz, tourmaline, carbonates and zircon which are commonly derived from the parent rock (Ekosse 2010). The quality of kaolin as an industrial raw material is controlled by mineralogy and geochemical characteristics (Ling et al. 2012, Mziray et al. 2022).

Tanzania is endowed with numerous kaolinite clay deposits in various places, formed during different alteration processes mainly by residual weathering and by hydrothermal influence on pre-existing aluminosilicate (mainly feldspars) rich rocks (Kimambo et al. 2014, Leger et al. 2015). Kaolin in Tanzania has been reported in different places including Matamba-Makete, Pugu-Dar es Salaam, Malangali-Iringa, Chimala-Mbeya, Chenzema-Morogoro, Kitahana-Kigoma, Luana-Njombe and Same-Kilimamjaro as shown in Figure 1 and of all, the Pugu kaolin is the only deposit that has been deeply explored to the resource level (Leger et al. 2015).

Globally, the demand for kaolin for industrial applications have increased significantly due to the growth of industrialization (Oyebanjo et al. 2020). Kaolin utilization in Tanzania is not a new venture and the need for this raw material has increased in refractories and their products have fetched great markets within and outside the country. Despite many occurrences in Tanzania, Matamba kaolin has not been sufficiently investigated in terms of its mineralogy and geochemical characteristics to ascertain its suitability for use as a raw material for industrial applications. This study used mineralogical and geochemical techniques to determine the suitability of the Matamba kaolin deposit as a raw material for industrial applications. These techniques have become successful and the results have been used to suggest a specific industrial use for Matamba and adjacent kaolin occurrences. Since little has been done for kaolin occurrences in the country, findings from this study can be used as a guide for various studies in similar deposits, especially in establishing their suitability for industrial applications.

Geology of the Study Area

The study area is located in the Palaeoproterozoic Ubendian Belt (Muhongo 2002), mostly composed of high-grade metamorphic rocks, gabbros, pellitic to semi-pellitic sediments, chert, quartzite, limestone, semi-calcareous sediments and granitic intrusives trending NW-SE of the craton (Boniface et al. 2012, Ngole et al. 2014, Tulibonywa et al. 2015, Mutasingwa et al. 2021). It is made up of several lithological and structurally distinct blocks or terranes and is well defined by the South-West margin of the Archean Tanzania craton (Mruma et al. 2003, Boniface et al. 2012, Ganbat et al. 2021). It is believed to be part of Neoarchean rocks that have been overprinted by younger metamorphic events which differ in lithology and experienced different metamorphic overprints during Proterozoic orogenic events (Kazimoto et al. 2015, Mutasingwa et al. 2021, Ganbat et al. 2021).

On a local scale, the Matamba area is within the Quarter Degree Sheet (QDS) 246-Chimala in the Njombe Region mapped at a scale of 1:100,000. It is predominantly composed of leucogabbro, granite and Buanji quartzite as shown in Figure 2. The major geological structures at Matamba and adjacent areas include lineaments or faults, which are prominent and few dolerite dykes can be observed from the geological map of the study area. The mentioned structures show planar features with the same dip and strike and cut by pseudogranophyres bodies.

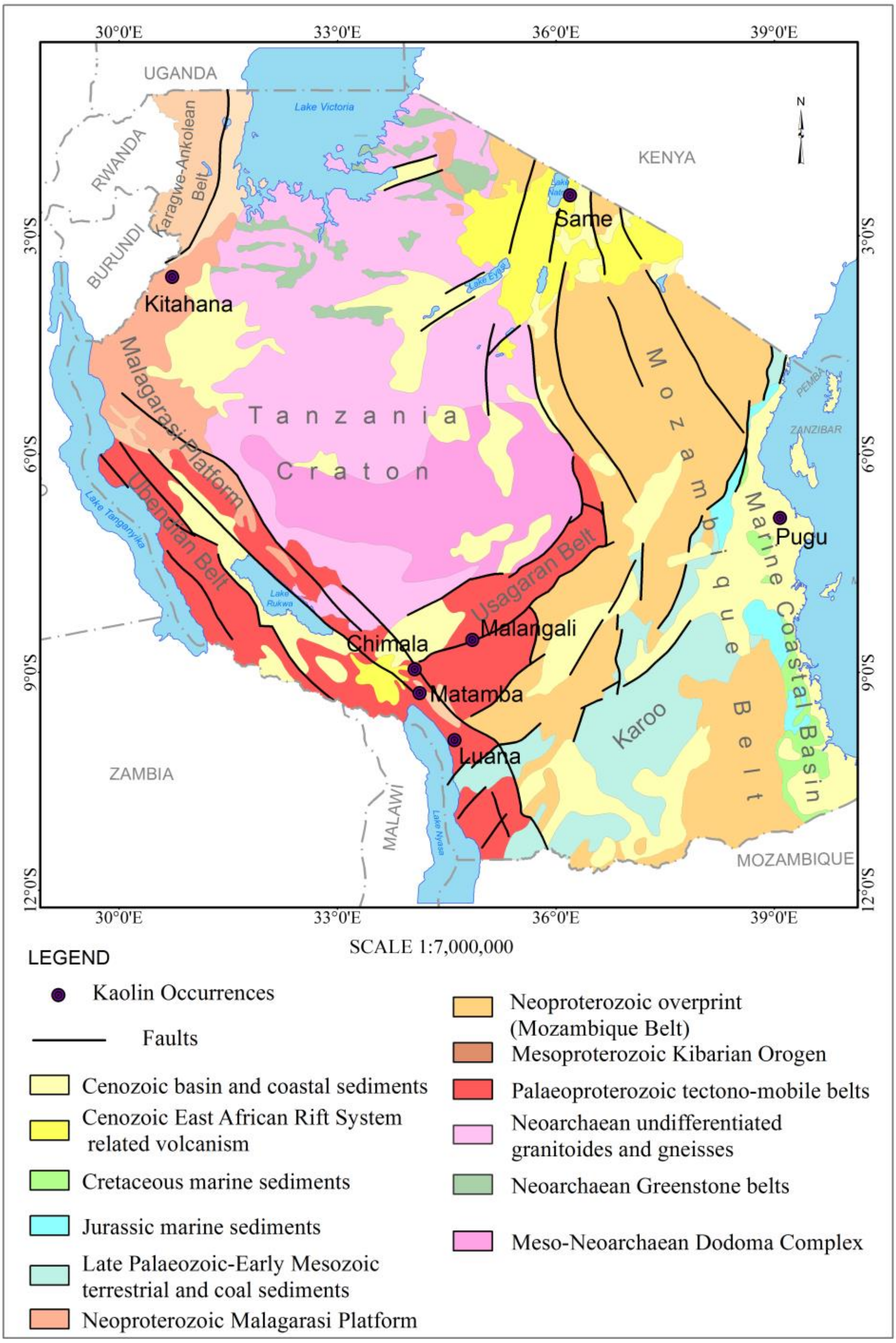

Figure 1: Geo-tectonic map of Tanzania showing kaolin occurrences (source Esri & USGS 2023).

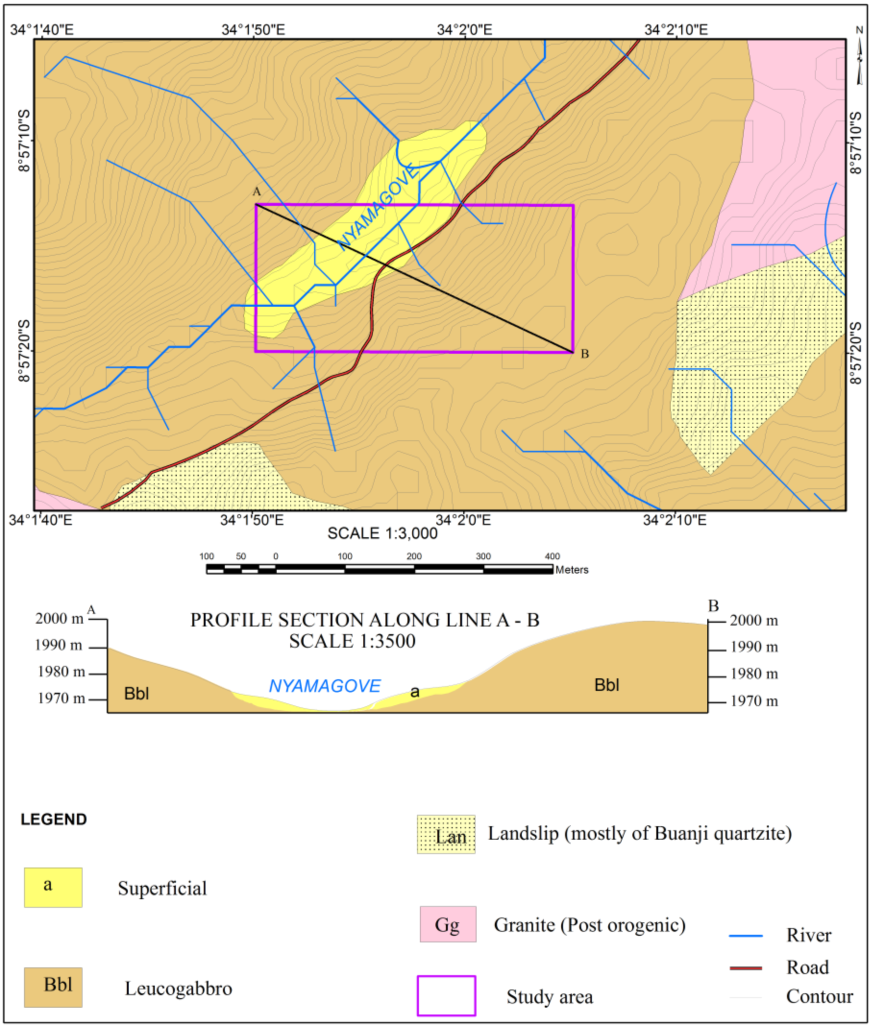

Figure 1: Geological map of the study area showing distributions of different rocks in the area (The map was modified from Ngole et al. 2014).

Materials and Methods

Systematic field sampling was carried out by hand auger (rounded steel pipes) during fieldwork. The collected samples from the Matamba study area were analyzed for mineralogy by X-Ray Diffractometry (XRD), major and trace elements by X-Ray Fluorescence (XRF) at the Geological Survey of Tanzania (GST) Laboratory and the Department of Geosciences at the University of Dar es Salaam. The XRD is good in accuracy, effectiveness, fast and reliable method in phase identification and quantification of bulk minerals present in clay materials (Ali et al. 2022). XRF spectrometry was used for major and trace elements determination because of its great accuracy, precision and clarity of emission spectrum in chemical composition investigation (Oyedotun 2018).

Sampling, sample preparation, and analyses

A total of forty-six (46) representative kaolin samples were collected by hand auger (rounded steel pipes) which press on the ground at different depths (1 m to 4 m maximum) depending on the hardness of saprolites/saprock and the existing escarpment/cliffs. The spacing interval of the collected samples was 50 m, while the line spacing was 100 m. The hand auger was attached to the clear surface and forced into the ground by 10 kg hummer to take a sample. After reaching the desired depth, the sample in the hand auger was carefully emptied onto the plastic sheet spread near the auger drill hole. The samples on the plastic sheet were packed in the calico bags whereby each sample taken was weighing at least 2 kg. The hand auger was cleaned before another sample taken.

Mineral compositions were determined with an automated XRD machine (Olympus BTX-III and Bruker AXS Phaser A26-X1-A2B0D2C) made in Germany with Cu anode wavelength of 1.540598 Å Cu-Ka1, scan type coupled two thetas of incidence and X-ray generator of 30 kV with 10.0 mA. This method is fast and accurate in mineral determination. The quantitative mineralogical composition was calculated taking into account the results of qualitative mineralogy from microscopy observations and processed images by Match3 software. Chemical analyses were performed by NEX CG-Rigaku X-Ray Fluorescence machine Miniplay 4 Energy Dispersive 12-position sample system with a detection limit of 0.01 wt.%.

Results and Discussion

Mineralogy of the Matamba kaolin deposit

The mineralogical compositions of forty-six (46) analysed samples from the study area are presented in Table 1 and Figure 3. The quantitative XRD analysis results indicated that, the kaolin of Matamba is composed of kaolinite ($Al_2Si_2O_5(OH)_4$), albite ($NaAlSi_3O_8$), oligoclase (Na, Ca)((Al, Si)$_4O_8$), quartz (SiO_2), goethite (Fe(OH)O) and muscovite ($KAl_2(AlSi_3O_{10})$ $(OH)_2$. Kaolinite is the dominant mineral with an average amount of 78.3% for the whole deposit.

The X-ray patterns of the studied samples collected within the study area in the region between 2°–60° revealed the predominance of kaolinite (21.6–100%) over other minerals entailing albite (1.2–56.8%), oligoclase (10.1–54.3%), quartz (1.2–33.9%), goethite (1.0–9.4%) and muscovite (1.1–29.5%) (Table 1; Figures 4 to 6).

In general, MTR02, MT03, MTR04, MTR05, MT08, MTR10, MT11, MT16, MT17, MT18, MT34, MT35, MT37 and MT42 samples exhibited > 75 wt.% values of kaolinite. According to Kogel et al. (2006) classification, these grades are pointing to the kaolinite rocks category. Noteworthy, sample MTR 09 was practically pure kaolinite (100 wt.%). The presence of the highest percentage kaolinite suggests the chemical decomposition of the iron-bearing ferromagnesium minerals such as biotite and the proportions of the various minerals are very minimal within the study area.

Kaolin deposit which comprises kaolinite as a dominant mineral has unique property such as crystalline morphology, natural whiteness, particle size, softness and chemical stability (Nouri and Masoumi 2020) and deposit containing >75% kaolinite is considered as high-grade (Awad et al. 2018, Mesele et al. 2021). In this regard, the Matamba kaolin deposit falls under the high-grade deposit.

The total amount of kaolinite mineral plays a significant role in the grade of kaolin and industrial use (Ekosse 2010). However, the quality changes from one deposit to another depending on the source rock and its nature of weathering (Nouri and Masoumi 2020, Obiri 2022). Matamba kaolin deposit contains an average amount of 78.3% for the whole deposit which is classified as high grade.

Table1: Mineralogical composition (wt.%) of clay materials of the representative samples from Matamba

Sample ID	Kaolinite wt. %	Albite wt. %	Quartz wt. %	Muscovite wt. %	Goethite wt. %	Oligoclase wt. %
MT 01	53.2	17.1	-	2.4	2.0	25.3
MTR 02	81.6	-	-	13.8	4.6	-
MT 03	86.4	-	3.2	2.1	1.2	-
MTR 05	94.7	-	-	2.9	2.4	-
MT 07	25.9	-	-	19.8	-	54.3
MT 08	93.8	-	-	3.3	2.9	-
MTR 04	83.5	1.8	2.9	1.4	9.4	1.0
MTR 09	100	-	-	-	-	-
MTR 10	95.1	-	-	3.0	1.9	-
MT 09	74.3	13.1	1.8	5.7	2.3	2.8
MT 10	75.9	5.4	2.0	8.4	1.9	3.4
MT 11	78.3	3.4	4.6	10.0	3.7	-
MT 12	76.1	16.0	1.3	3.4	1.0	2.2
MT 13	21.6	15.0	33.9	25.3	4.2	-
MT 14	63.7	5.8	-	15.2	5.2	10.1
MT 15	73.9	4.2	2.1	18.4	1.4	-
MT 16	84.5	2.1	-	10.4	3.0	-
MT 17	80.1	3.7	6.9	8.3	1.0	-
MT 18	79.3	8.1	1.8	9.2	1.2	-
MT 19	56.1	39.2	2.8	0.9	1.0	-
MT 20	72.6	17.2	5.3	2.8	2.1	-
MT 21	81.0	6.1	1.3	2.4	5.7	3.5
MT 22	80.1	11.2	0.6	1.0	7.1	-
MT 23	79.6	13.1	0.9	5.0	1.8	-
MT 24	63.6	20.3	1.6	7.8	1.2	3.5
MT 25	56.4	28.2	0.2	9.2	3.7	2.3
MT 26	62.9	26.3	1.6	3.8	1.5	3.9
MT 34	92.8	-	-	-	4.3	2.9
MT 35	84.6	10.0	-	4.4	1.0	-
MT 37	79.7	11.1	0..2	6.0	3.0	-
MT 42	97.1	-	-	1.1	1.8	-

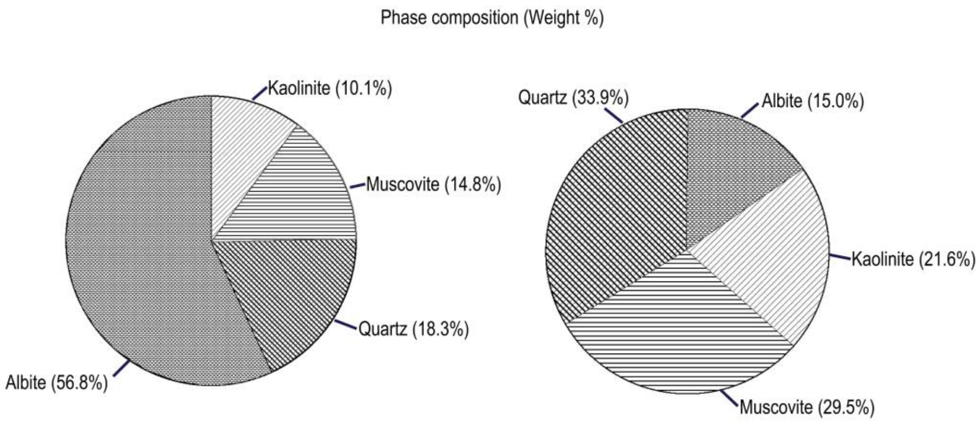

Figure 3: Phase composition (wt%) of the two representative samples calculated by the Reference Intensity Ratio (RIR) method showing the amount of kaolinite, albite, quartz and muscovite.

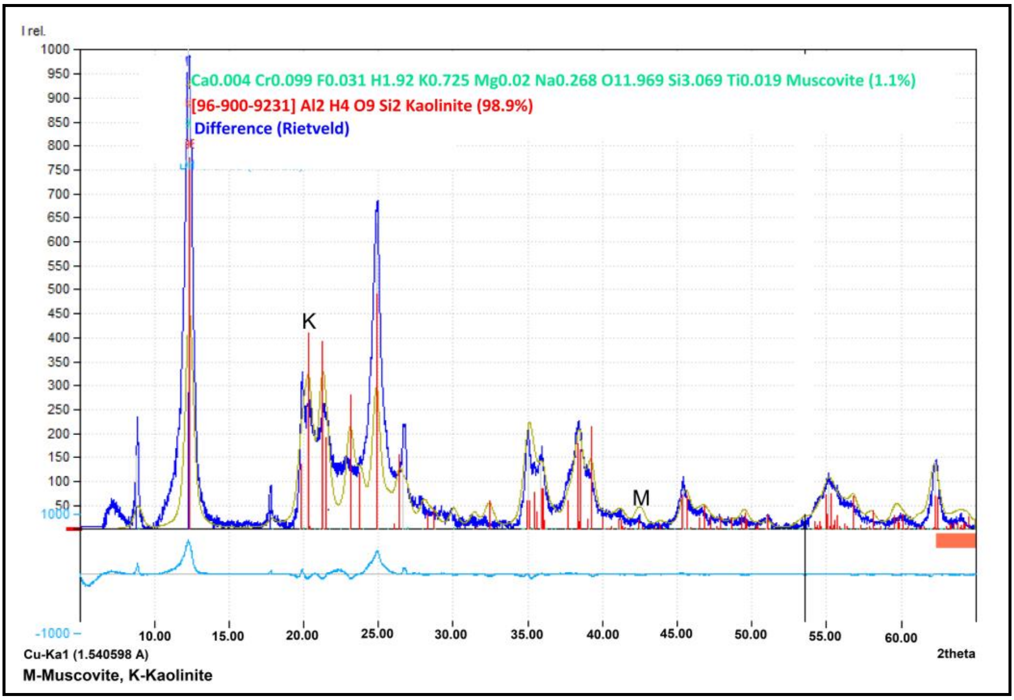

Figure 4: Representative X-ray diffractogram of the kaolin from the Matamba deposit showing kaolinite and muscovite minerals.

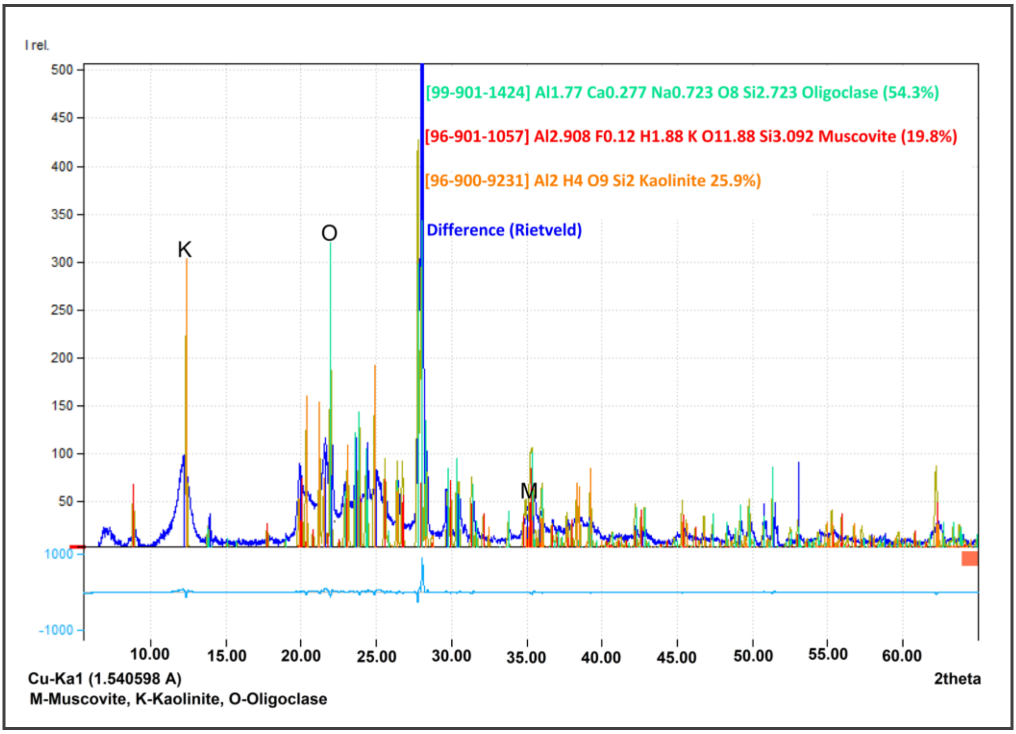

Figure 5: Representative X-ray diffractogram of the kaolin from the Matamba deposit showing kaolinite, oligoclase and muscovite minerals.

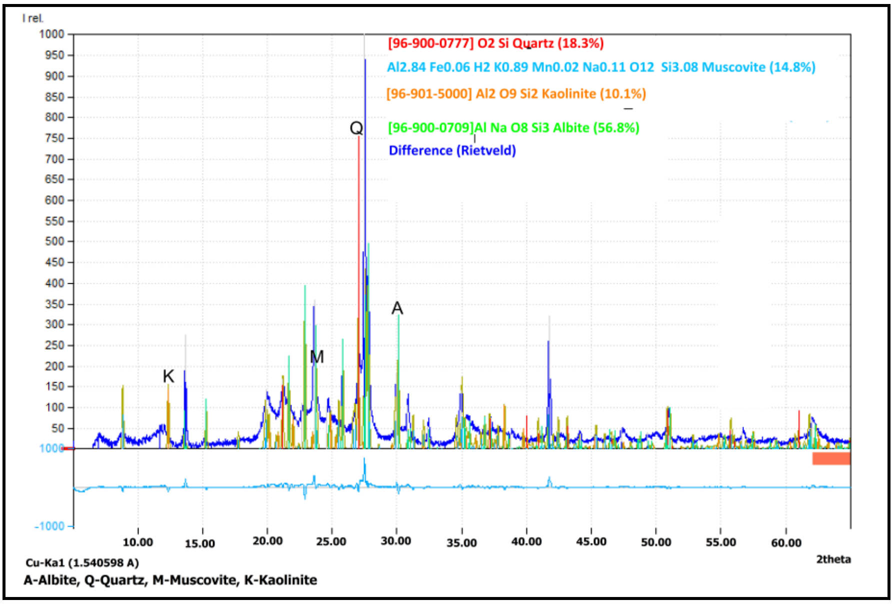

Figure 6: Representative X-ray diffractogram of the kaolin from the Matamba deposit showing kaolinite, albite, quartz and muscovite minerals.

Chemical composition of Matamba kaolin deposit

The summary of the chemical analysis of representative samples from the Matamba kaolin deposit is presented in Table 2. This analysis reveals major oxides and trace elements that suggest a dominance of the kaolin group of minerals with significant amounts of SiO_2 and Al_2O_3. Matamba kaolin deposit contains SiO_2 (39.78–67.96 wt.%), Al_2O_3 (14.60–38.07 wt.%), Fe_2O_3 (0.93–6.37 wt.%), MgO (1.42–4.74 wt.%), Na_2O (0.10–1.09 wt.%), K_2O (0.14–2.01 wt.%), CaO (0.08–0.99 wt.%), TiO_2 (0.07–1.66 wt.%), P_2O_5 (0.36–1.77 wt.%) with LOI (1.91–13.97 wt.%). The most abundant oxides in increasing amount are SiO_2 and Al_2O_3 as shown in Figure 7 whereas Fe_2O_3, TiO_2, MgO, CaO, Na_2O and K_2O occur in small amounts. The predominance of SiO_2 and Al_2O_3 is mainly due to the presence of quartz and kaolinite. The concentration patterns in the kaolin samples have the following order: $SiO_2 > Al_2O_3 > Fe_2O_3 >$ MgO $> K_2O > P_2O_5 > TiO_2 > Na_2O >$ CaO (Table 2).

The study by Murray (2007) indicated that, the kaolin deposit characterized by Fe_2O_3 content $\geq$ 5% would fire red, whereas those containing Fe_2O_3 ranging between 1 and 5%, would acquire a light brown colour. However, Fe_2O_3 content is not the only factor responsible for the colouration and can be reduced through beneficiation processes. Matamba kaolin has relatively high $Fe_2O_3 >$ 1% in most of the studied samples which suggests a light to red colour of the fired products. The presence of the low amount of alkali and titanium makes the kaolin deposit relatively good in quality (Mesele et al. 2021) and the Matamba kaolin deposit falls in this category with average titanium and alkali concentration of Ti 0.67 wt.%, Ca 0.42 wt.%, Na 0.52 wt.% and K 0.60 wt.%, suitable for industrial applications. Samples that have a percentage of $Al_2O_3 \geq$25 wt.% with a low Fe content and alkali elements might be suitable for refractories (Nkalih et al. 2018).

Elements such as K, Ca and Na are very mobile, whereas Al is usually immobile. As a result, the mobility of K, Na and Ca tends to increase the degree of chemical weathering during weathering process (Obiri 2022). The content of alkaline oxides (K_2O and Na_2O) is relatively low for Matamba kaolin, indicating a low percentage of flux minerals and this will result in an increase in sintering temperatures.

Table 2: Chemical compositions (wt%) of kaolin samples from Matamba

Sample ID	SiO_2	Fe_2O_3	Al_2O_3	CaO	K_2O	Na_2O	TiO_2	P_2O_5	SO_3	MgO	L.O. I
MT01	57.26	2.43	24.37	0.37	0.35	0.20	0.20	0.59	0.57	1.57	12.09
MT02	56.18	4.55	20.62	0.21	0.55	0.35	0.48	0.74	0.71	2.33	13.18
MT03	57.13	4.48	21.81	0.21	0.76	0.10	0.49	0.53	0.49	1.51	12.40
MT04	63.01	4.06	15.22	0.27	0.94	0.13	0.48	0.78	0.74	2.28	10.85
MT05	61.62	3.73	22.50	0.10	0.25	0.18	0.36	0.72	0.69	1.81	8.03
MT06	41.49	3.65	34.50	0.35	0.84	0.14	0.40	0.68	0.63	2.79	13.97
MT07	57.81	1.79	26.70	1.82	0.31	0.06	0.07	0.65	0.67	2.50	7.32
MT08	51.43	2.99	26.26	0.34	0.80	0.70	0.38	0.72	0.66	2.82	11.09
MT09	54.42	3.64	26.42	1.34	0.49	0.15	0.17	0.53	0.54	2.01	9.24
MT10	46.66	0.93	32.61	0.23	0.24	0.30	0.07	0.71	0.64	2.21	13.96
MT11	47.65	3.13	30.51	0.27	0.53	0.96	0.44	0.63	0.60	2.56	13.20
MT12	43.85	2.52	34.60	0.16	0.32	0.24	0.13	0.54	0.55	1.79	13.72
MT13	67.92	2.39	14.60	0.19	1.47	0.12	0.15	0.69	0.63	1.94	9.60
MT14	41.38	4.86	33.54	0.23	1.29	0.84	0.42	1.63	0.71	1.80	13.16
MT15	48.39	4.10	28.28	0.39	0.87	0.17	0.43	0.57	0.53	1.73	12.86
MT16	46.74	2.61	31.58	0.14	0.21	0.62	0.28	0.55	0.52	1.42	13.53
MT17	42.19	3.07	36.83	0.14	0.35	0.91	0.41	0.56	0.53	1.69	13.76
MT18	42.22	3.64	34.23	0.11	0.51	0.28	0.35	0.57	0.53	1.58	13.73
MT19	60.57	3.84	21.90	0.08	0.77	1.03	0.43	1.35	0.56	1.57	7.77
MT20	52.98	2.94	25.95	0.22	2.01	0.86	0.41	1.61	0.64	1.59	10.24
MT21	55.03	5.58	22.36	0.18	0.73	0.14	0.49	0.55	0.51	1.76	12.12
MT22	42.41	4.15	34.88	0.30	0.56	0.29	0.31	0.53	0.49	2.12	12.64
MT23	45.23	3.40	32.04	0.10	0.32	0.81	0.40	0.68	0.60	1.95	13.08
MT24	51.09	4.07	26.45	0.13	0.61	1.01	0.53	0.54	0.50	2.07	12.87
MT25	41.12	4.00	34.77	0.30	0.53	0.90	0.47	1.22	0.70	3.77	13.13
MT26	39.78	3.64	30.61	0.36	1.29	0.87	0.41	1.53	0.71	4.40	13.76
MT27	50.28	4.49	22.56	0.35	0.92	0.61	0.56	1.77	0.76	3.99	12.20
MT28	46.90	6.37	25.37	0.30	0.60	1.03	0.79	0.46	0.65	4.53	11.81
MT29	40.04	5.50	30.43	0.30	0.52	0.74	0.64	0.49	0.65	4.09	13.93
MT30	43.81	4.36	32.90	0.32	0.45	0.68	0.51	0.41	0.61	3.20	12.55
MT31	52.71	3.21	24.19	0.36	0.72	0.91	0.43	1.20	0.86	4.20	10.65
MT32	42.28	1.82	38.07	0.27	0.49	0.10	0.17	0.35	0.70	3.68	10.44
MT33	49.21	4.19	25.60	0.37	0.99	0.34	0.47	1.56	0.88	3.11	12.50
MT34	42.98	2.50	35.10	0.36	0.43	0.15	0.18	0.45	0.84	4.02	13.16
MT36	46.70	4.92	27.60	0.31	0.38	0.17	0.53	0.50	0.89	4.25	12.84
MT37	62.69	0.99	20.91	2.48	0.22	0.15	0.07	0.39	0.92	2.91	6.53
MTR01	55.79	1.26	25.32	2.14	0.39	0.62	0.10	0.36	0.87	3.76	7.40
MTR02	54.10	1.44	24.23	0.56	0.24	0.40	0.18	0.45	1.08	3.20	12.89
MTR03	56.34	2.56	24.28	0.29	0.14	0.81	0.19	0.37	0.78	3.71	11.20
MTR04	41.78	14.22	20.73	0.42	0.49	1.09	1.66	0.58	0.98	4.74	13.46
MTR05	47.77	1.83	34.32	0.32	0.31	0.16	0.13	0.38	0.73	3.57	10.28
MTR06	48.70	1.89	33.77	0.28	0.29	0.58	0.19	0.38	0.87	3.47	9.96
MTR09	48.53	0.75	31.26	0.38	0.22	0.70	0.11	0.37	0.80	3.58	12.92
MTR10	49.00	2.30	28.46	0.23	0.31	0.41	0.15	0.37	0.85	3.29	13.69
MTR12	67.96	3.51	16.13	0.51	1.22	0.92	0.18	1.72	0.98	4.27	1.91
MT 35	44.46	5.16	28.89	0.24	0.50	1.02	0.60	0.49	0.77	3.62	13.39

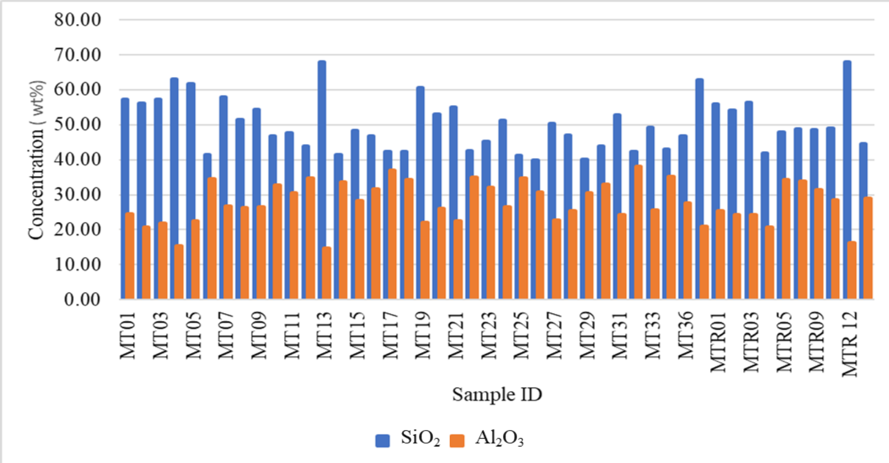

Figure 72: A bar chart of SiO_2 and Al_2O_3 concentration (wt%) of the representative samples from the Matamba kaolin deposit.

Comparison with other deposits

The Kaolinite content of any kaolin deposit plays a significant role in its grade and industrial uses (Ekosse 2010). However, the quality changes from one deposit to another depending on the source rock and its nature of weathering (Nouri and Masoumi 2020, Obiri 2022). About 78% of Matamba kaolin deposit can be classified as high-grade based on its kaolinite content. This deposit has characteristics similar to some of the world-class deposits from Venezuela, Southern Jordan, Buwambo-central Uganda, Georgia-USA and Northern Brazil especially their kaolinite content (Hernández et al. 2019, Gougazeh and Buhl 2010, Nyakairu et al. 2001, Pruett 2016) as shown in Table 3.

Buwambo kaolin deposit in Central Uganda contains 74–93 wt.% of kaolinite and falls under high-grade category (Nyakairu et al. 2001) whereas Venezuela kaolin deposit contains greater than 75% kaolinite (Hernández et al. 2019). In addition, the kaolin deposit of Southern Jordan is composed of kaolinite, quartz and muscovite which are the same as the mineralogical composition of the Matamba kaolin deposit.

The values of chemical composition for SiO_2 and Al_2O_3 from Matamba are almost similar to kaolin deposits from Venezuela, Central Uganda, Southern Jordan, Georgia UK, Ethiopia and composition data of kaolinite from other previous research works as shown in Table 4. As a result, the chemical composition of the Matamba kaolin deposit meets the requirement of various industrial applications and can be used in ceramic products, refractories such as fireclay crucibles and electrolytic production of aluminium and its alloys as shown in Table 5.

Table 3: Matamba kaolinite composition (wt. %) as compares with other deposits in the world and suitable industrial application

Country	Kaolinite wt.%	Industrial applications
Matamba-Tanzania	21–100	Ceramic products, refractories, paper filling and coating
Venezuela	47–99	
Central Uganda	74–93	
Southern Jordan	66–77	
Georgia, USA	89–97	
Northern Brazil	43–99	

Source: Hernández et al. (2019), Gougazeh and Buhl (2010), Nyakairu et al. 2001 and Pruett (2016).

Table 4: Chemical composition of Matamba kaolin as compared with other deposits worldwide

Compounds	Matamba kaolin	Venezuela kaolin	Central Uganda kaolin	Southern Jordan kaolin	Georgia, UK kaolin	Ethiopia
SiO_2	39.78-67.96	34.34-70.05	39.15-52.37	38.50-60.36	40.9-79.9	41.9-73.1
Al_2O_3	14.60-38.07	11.15-40.89	33.41-37.92	25.74-36.83	12.7-43.7	19.95-29.0
Fe_2O_3	0.93-6.37	0.34-7.76	0.18-0.61	1.20-2.12	0.12-43.7	1.72-4.94
CaO	0.08-0.99	0.01-0.03	0	0.10-0.16	0-0.02	0.22-1.12
Na_2O	0.10-1.09	0.01-0.18	0.02-0.06	0.05-0.09	0-0.07	0.87-4.68
K_2O	0.14-2.01	0.01-2.06	0.49-1.09	0.17-0.61	0-0.39	1.9-5.75
TiO_2	0.07-1.66	0.03-2.05	0.02-0.12	1.17-1.64	0.53-2.77	0.38-0.99
MgO	1.42-4.74	0-0.48	0.33-0.37	0.08-0.14	0.03-0.29	0.10-0.60
LOI	1.91-13.97	7.13-14.39	11.77-13.65	9.21-13.00	5.6-14.3	5.08-16.35

Source: Hernández et al. (2019), Nyakairu et al. (2001), Gougazeh and Buhl (2010), Pruett 2016 and Mesele et al. (2021).

Table 5: Comparison of the elemental composition of Matamba kaolin with some industrial chemical specifications and applications (wt.%)

Compounds	Matamba kaolin	Paper coating	Paper filler	Ceramics	Refractory bricks	Pharmaceuticals & cosmetics
SiO_2	39.78-67.96	45-47	46-48	48-50	51.0-70.0	44.6-46.4
Al_2O_3	14.60-38.07	37-38	37-38	36-37	25.0-44.0	38.1-39.5
Fe_2O_3	0.93-6.37	0.5-1.0	0.5-1.0	0.6-1.0	0.2-0.7	0.1-0.2
CaO	0.08-0.99	-	-	-	0.1-0.2	0.1-0.2
Na_2O	0.10-1.09	-	-	-	0.8-3.5	0-0.1
K_2O	0.14-2.01	-	-	-	-	0-0.2
TiO_2	0.07-1.66	0.5-1.3	0.04-1.5	0.02-0.1	-	0-1.4
LOI	1.91-13.97	13.9-14.3	12.3-13.7	11.2-12.5	11.0-13.0	13.8-13.9

Source: Bello et al. (2017), Nkoumbou et al. (2009) and Adegbuyi et al. (2015).

Quality of Matamba kaolin deposit and possible industrial applications

The quality and grade of economical kaolin deposits are mainly determined on the basis of kaolinite content and its degree of structural disorder, as well as quartz and Fe-Ti mineral impurities (Abubakar et al. 2014, Obiri 2022). The presence of different internal structures and compositions makes kaolin suitable for various industrial applications (Masele 2021). The mineralogy and chemical characteristics of kaolin deposit usually determine its industrial uses and lead to extensive industrial applications as filler, extender, paper coater, ceramic raw materials, refractories and cement production (Abubakar et al. 2014, Kotal and Bhowmick 2015, Lima et al. 2017).

According to Ekosse (2010), the total amount of kaolinite plays a significant role in the grade and the quality of kaolin. A deposit containing >75% kaolinite is considered as high-grade kaolin (Awad et al. 2018). For the kaolin to be used in the ceramics industry should meet the following requirements: Fe_2O_3 lower than 1.5%, loss on ignition lower than 12%, Al_2O_3 25-45%, SiO_2 maximum 55%, CaO less than 1% and kaolinite >75% (Savic et al. 2014). For the production of refractory materials such as crucibles, it requires a high content of aluminium oxide >30% which is necessary for increasing the refractory and mechanical resistance. In addition, kaolin can be used in the electrolytic production of aluminium and its alloys with the requirement of higher than 30% Al_2O_3 and (Fe_2O_3 +TiO_2) less than 15% (Jock et al. 2013). Matamba kaolin deposit meets the requirements of some industrial applications and can be used in ceramic products, refractories such as fireclay crucibles and electrolytic production of aluminium and its alloys. However, this deposit should be beneficiated and upgraded to improve the technical properties of the products to meet international specifications and for other industrial applications.

Conclusion and Recommendations

The mineralogy of the Matamba kaolin deposit shows the presence of kaolinite as the dominant mineral, associated with albite, quartz, oligoclase, goethite and muscovite. The chemical composition results reveal major oxides and trace elements that are classified in kaolin minerals and dominated by SiO_2, Al_2O_3 and loss on ignition. Matamba kaolin deposit contains SiO_2 (39.78–67.96 wt.%), Al_2O_3 (14.60–38.07 wt.%), Fe_2O_3 (0.93–6.37 wt.%), MgO (1.42–4.74 wt.%), Na_2O (0.10–1.09 wt.%), K_2O (0.14–2.01 wt.%), CaO (0.08–0.99 wt.%), TiO_2 (0.07–1.66 wt.%), P_2O_5 (0.36–1.77 wt.%) with LOI (1.91–13.97 wt.%). Matamba kaolin deposit remains to be the best because of its high content of kaolinite > 75% as compared to Pugu and Same kaolin, both have <75 % kaolinite content. This makes the Matamba kaolinite suitable for various applications including ceramics production, refractories such as fireclay crucibles and electrolytic production of aluminium and its alloys. However, in order to meet international specifications and for diverse industrial applications, it needs to be beneficiated and upgraded to improve some technical properties and their products. In addition, a detailed study of the Matamba kaolin physical properties and its treatment is recommended to meet the universal industrial applications of kaolin as an important raw material.

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