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*Full Length Research Paper*

# Physicochemical and mineralogical considerations of Ediki sandstone-hosted kaolin occurrence, South West Cameroon

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**Field mapping, colour, particle size distribution, pH and x-ray diffraction studies were undertaken to elucidate the genesis of Ediki kaolin. The kaolin occurs within the Mungo formation of upper cretaceous age, ascribed to the Douala sedimentary basin. The kaolin profile consists of upward coarsening sandstone – siltstone – sandstone sequence with a gradient of 35 to 40°. Texturally, the kaolin is mainly silt loam with a constitution of sand (18.1 to 24 wt.%), silt (68 to 73.3 wt.%) and clay (7 to 13.5 wt.%). The pH of the sample is acidic with values ranging from 4.8 to 5. Kaolinite and quartz are the dominant mineralogical phases whereas, muscovite + microcline and illite + goethite occur as minor and trace phases respectively. High porosity and permeability of the sandstones favoured migration of fluids which enhanced the formation of secondary diagenetic minerals. The presence of detrital feldspars and mica grains in the sandstones, were favourable parent phases for kaolinite formation. Kaolinization was further enhanced by the hot humid tropical climate, acidic pH, fairly gentle relief (40°), low K and Na concentrations (inferred from the mineralogy), as well as the low energy depositional environment.**

**Key words:** Diagenesis, kaolinization, secondary kaolins, supergene enrichment, tropical climate.

## INTRODUCTION

The occurrence of different kaolin polytypes (Kaolinite, Dickite, nacrite and halloysite) has been reported in early mineralogical studies of sandstones (Hemingway and Brindlwy, 1948; Chukhrov, 1968). More recently, mineralogical and textural characterization, facilitated by improved instrumentation (x-ray diffraction and scanning electron microscopy) has been preferred over structural determination in petrographic studies of sandstone (Lanson et al., 2002; Ruiz Cruz, 2007). Lanson et al. (1995, 1996, 2002), Beaufort et al. (1998), Ruiz Cruz (2007) have linked both mineralogical and textural evolution of sandstones to temperature and or depth variation during diagenesis.

In addition to quartz and carbonate cementation, clay cementation is among the most damaging diagenetic processes for petrophysical properties of sandstones. Apart from chlorite, kaolin and illite are the most abundant authigenic clays (Lanson et al., 2002). However, despite the enormous wealth of literature on clay diagenesis in sandstones, there is no common consensus on reaction pathways leading to crystallization of these minerals. This paper attempts to elucidate on the geology and emplacement of Ediki kaolin from physic-chemical and mineralogical studies.

## STUDY AREA AND GEOLOGIC SETTING

Ediki is found in the South West Region of Cameroon, precisely between 4°28'N to 4°33'N and 9°25'E to 9°30'E (Figure 1). The area is drained by a fairly north – south trending River Mungo. The climate is tropical with mainly two distinct seasons; a rainy season between April and September and a dry season from October to March. During the dry season daily temperature rises above 25°C.

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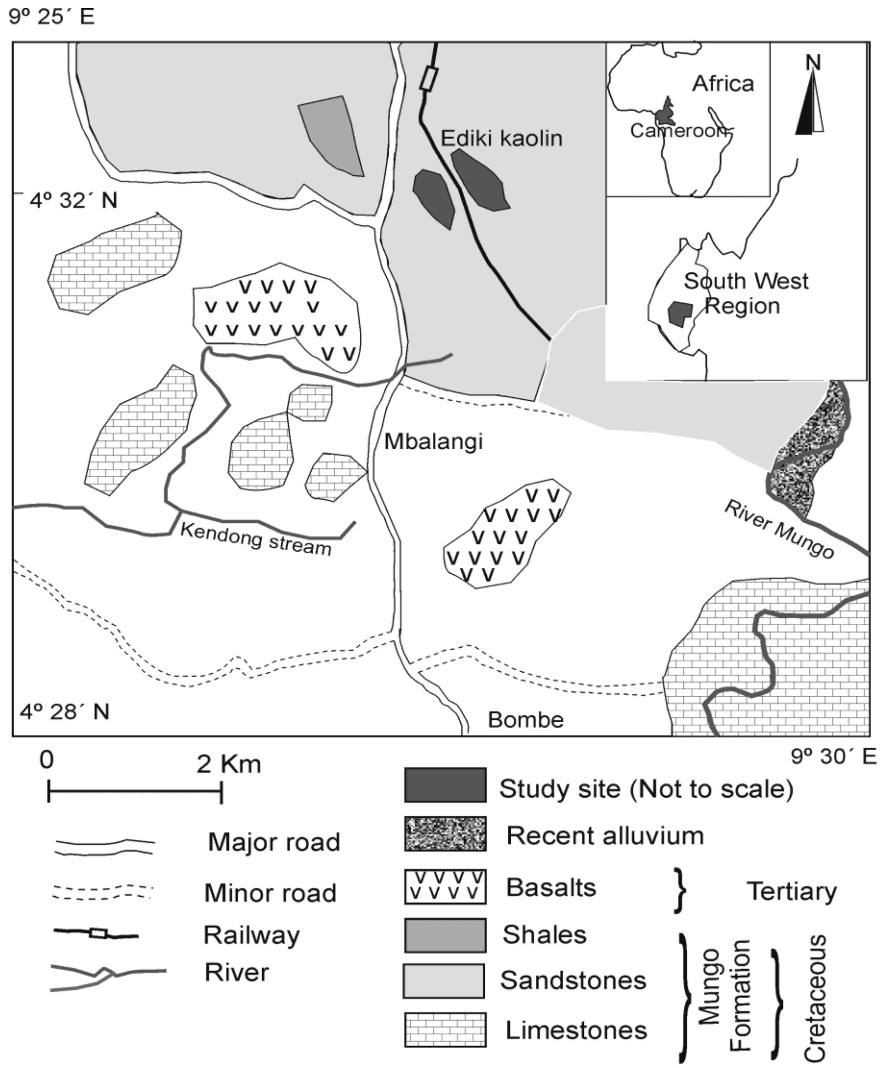


**Figure 1.** Location and geologic map of Ediki.

Rainfall in the area varies from 2085 to 9086 mm (Fonge et al., 2005), with peak values obtained in the months of June and July (Ayonghe et al., 2004).

The kaolin occurs within the Mungo formation of upper cretaceous age (Turonian – Cenomanian). Within the vicinity of Ediki Kaolin, occurrence a dominantly sandstone unit outcrops towards the north and northeast. Further north of the study area, isolated shaley units are exposed whereas towards the centre and southeast, a significant limestone deposit outcrops (Figure 1). Recent alluvium occurs towards the east particularly along the banks of River Mungo. Isolated basaltic rocks were exposed towards the north and centre of the study area. These tertiary basalts appeared to be undifferentiated. Stratigraphyically, the recent alluvium covered the undifferentiated basalts. A non-depositional unconformity separated the latter from the underlying Mungo formation transitional megasequence (consisting of shales, limestone and fine-grained sandstones characteristic of lacustrine environments) (Table 1). The absence of the Mundeck and Logbaba formations were considered to represent the non-depositional events. Precrambrian gneissic granites considered to be bedrocks in Ediki, did not outcrop within the vicinity of the kaolin occurence. No structural controls were equally identified in the area.

**Field observations**

A 20 m representative sediment profile was observed along a road cutting adjoining a rail way line. The profile consisted of upward coarsening kaolin bearing sandstone – siltstone – sandstone sequence (Figure 2). The footwall of this profile was not exposed however; the underlying kaolinitic sandstone unit appeared to be grading into siltstones at greater depths. This suggested a repetitive sandstone – siltstone – sandstone sequence with depth, indicative of differential energy of depositional environment and or degree of weathering. From field observations, a 7 m thick brown to yellowish, loosely packed coarse sand unit covered the top of the profile. This unit was capped by a shallow top soil with variable thickness (0.4 to ~ 1 m) across the length of the road cutting. The coarse sand was underlain by fine – grained, whitish sand and siltstones approximately 4 m thick. Below this unit was a thin lateritic crust (0.05 m) rich in iron oxides (goethite and/or hematite).

Underlying this unit was a 2 to 3 m thick, highly weathered grey to greenish sandstone unit with a gradient of 35 to 40°. These weathered sandstones were considered host rocks of Ediki kaolin. The impermeable kaolin – bearing sandstone layer, prevented subsequent percolation of groundwater through the profile, thus

**Table 1.** Regional stratigraphy of Ediki.

| Eon | Era | Period | Formation | Lithology |
|---|---|---|---|---|
| Phanerozoic | Cainozoic | Recent | - | Alluvium |
| | | Tertiary | - | Undifferentiated basalts |
| | | | **Non-depositional unconformity** | |
| | Mesozoic | Cretaceous | Mungo formation | Transitional mega-sequence of sandstones shales and calcareous limestones characteristic of deltaic and /or lacustrine environment |
| | | | **Non-depositional unconformity** | |
| | | | Precambrian basement (Gneissic granites) | |

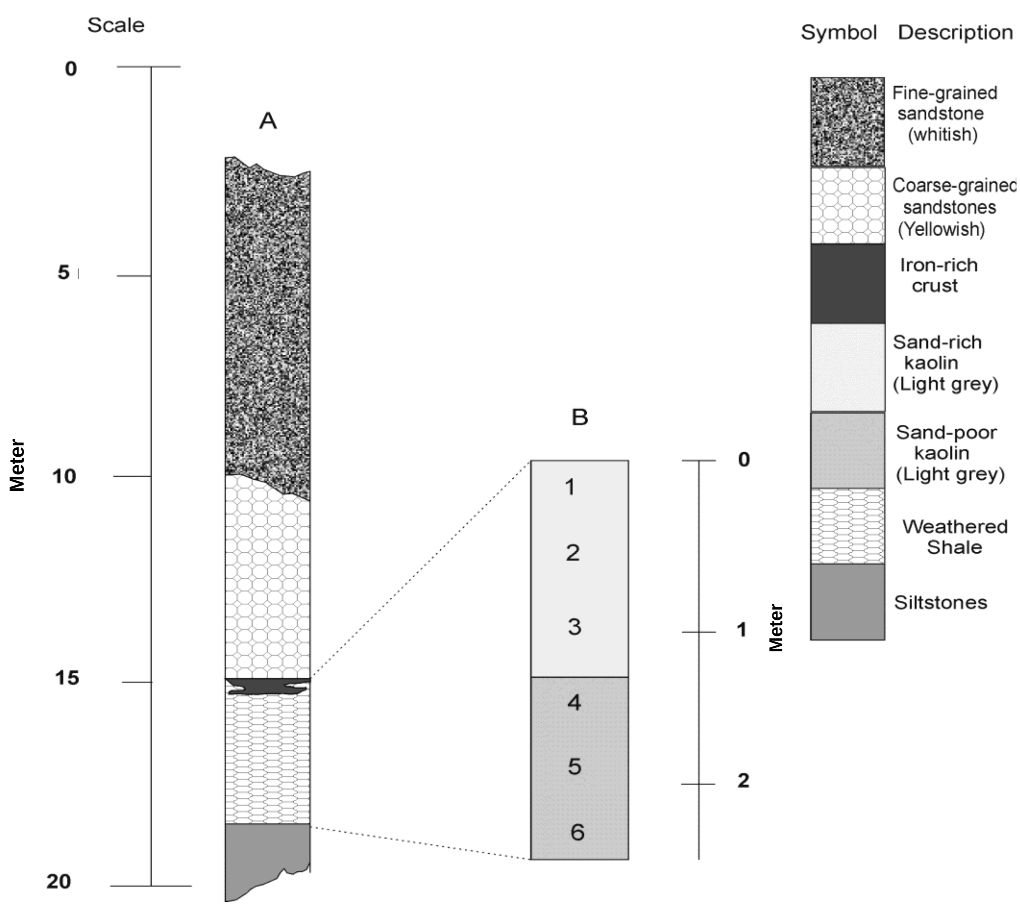


**Figure 2.** Lithostratigraphy of representative profile at Ediki kaolin occurrence.

concentrating the depleted iron oxides from overlying siltstone unit as the observed lateritic crust. Two kaolin facies were identified; a comparatively sand – poor kaolin (ED 3, 4, 5, 6, 9 and 10) and an overlying sand – rich kaolin (ED 1, 2, 7 & 8). The sand – rich kaolin occurred directly below the iron – rich lamina whereas the sand – poor kaolin appeared massive and extended towards the footwall grading into siltstones.

## METHODS

Sampling technique was judgmental (Tan, 1996). The number of

**Table 2.** Particle size distribution, Hue, value, chroma, colour and pH of representative kaolin samples from Ediki.

| Sample | PSD wt. (%) | | | Texture | Hue/value/ chroma | Colour | pH |
|---|---|---|---|---|---|---|---|
| | Sand | Silt | Clay | | | | |
| ED1 | 24 | 69 | 7 | Silt loam | 10Y/8/2 | Light grey | 4.9 |
| ED2 | 21.4 | 70 | 8.6 | Silt loam | 10Y/8/2 | Light grey | 4.9 |
| ED3 | 18.7 | 71.6 | 9.7 | Silt loam | 10Y/8/2 | Light grey | 4.9 |
| ED4 | 18.1 | 73.3 | 8.6 | Silt loam | 5GY/8/1 | Light grey | 5.0 |
| ED5 | 18 | 68 | 14 | Silt loam | 5GY/8/1 | Light grey | 4.7 |
| ED6 | 20 | 69 | 11 | Silt loam | 5GY/8/1 | Light grey | 4.8 |

samples and sampling distance was a function of availability of outcrop as well as size and orientation of the kaolin occurrences (Ekosse, 2000, 2001; Giovanna et al., 2005).

Samples were obtained with the aid of an auger, machete and shovel. Colour was determined using Munsell Soil Colour Book (1995). For colour determination, the raw samples were aerated for 24 h. With a spatula, clayey aggregates were mounted on white cardboard sheets. The hue/value/chroma and color of the mounted samples were obtained by visually comparing them to those of standard soils recorded in the Munsell Soil Colour Book.

Particle size and PSD were determined by laser diffraction technique using a Malvern Mastersizer Hydro 2000 Mu (A) following methods discussed in Fitzsimmons et al. (2009). 10 g of samples was used for the analysis. Samples were subjected to minimal processing (crushing). Water was added to the samples at a gentle rate, and the samples were then swirled gently in beakers prior to analysis. This method of preparation was adopted in order to minimize disaggregation so as to accurately analyze the diameters of grains with intact coatings and mud aggregates. Samples were scanned from 0.02 to 2000 µm.

Hydrogen ion concentration (pH – $H_20$) was determined with a pH meter (Hi 9321 Micro Processor) following protocol by Tan (1996). Commercial buffer solutions of pH 7.0 and 4.0 were used for calibration of the pH meter. 10 ml of distilled water was mixed with 5 g of pre-weighed sample in a beaker at a ratio of 1:2 (Tan, 1996). The mixture was stirred for 15 min and the pH of the supernatant measured once the pH meter stabilized. Measurements were made twice and the average recorded for each sample. The temperature of the soil solution at the time of the analysis was recorded as well.

Powder x–ray diffraction (XRD) for bulk kaolin was carried out using a Philips PW 1710 XRD unit operated at 40 kV and 30 mA, with a Cu-Kα radiation. Clay slurries were mixed with a few drops of epoxy glue and allowed to dry overnight in an oven. The dried samples were gently crushed in an agate mortar to a fine texture. Samples were mounted on sample holders with little pressure, using a blade to minimize preferred orientation of the kaolinite particles (Hughes and Brown, 1979; Cuadros and Linares, 1995). Samples were scanned for from 3°2θ to 60°2θ at a counting time of 1 s and their defractograms recorded. A graphite monochromator with a PW 1877 Automated Power Diffraction, X'PERT Data Collector software package was employed for qualitative identification of the minerals. Interpreted results were compared with data and patterns available in the Mineral Powder Diffraction File data book and the search manual issued by the International Center for Powder Diffraction Data (ICDD, 2002).

## RESULTS

### Physical and chemical properties

The results of physic-chemical properties are summarised on Table 2. The kaolin was light grey in colour with only slight variation in intensity of hue, value, and chroma along the profile. This variation was attributed to degree of weathering and moisture content of the kaolin. A cumulative PSD of representative kaolin samples is presented on Figure 3. Texturally, the kaolin samples were silt loam with a significantly low percentage of clay (< 15 %). The pH was acidic, ranging from 4.7 to 5.0.

### Mineralogy

Table 3 summarizes the mineralogy of representative bulk kaolin samples from Ediki as determined by XRPD. In all samples, kaolinite and quartz were the dominant phases (Figure 4). Muscovite and microcline were minor phases whereas; goethite, hematite and illite were present in trace amounts. No variation in kaolinite content with depth was observed; however illite was mostly identified in samples ED 5 and ED 6 at the bottom of the profile (~ 17 to 18 m deep). The mineralogy further suggests high $SiO_2$ + $Al_2O_3$ and low K, Na and Ca content.

The following d-spacings were assigned to kaolinite; 7.18, 7.12, 4.48, 4.35, 4.21, 3.56 and 2.56 Ǻ. The 111 kaolinite peak was absent in all samples whereas the appearance of both 020 and 110 kaolinite peaks were observed only in ED 1, 2, 9 and 10. The peak at °2θ angle of 44.1 was assigned to both kaolinite and anatase whereas that at 42.0 and 42.77° was assigned to quartz + goethite (Figure 4). The most intense quartz peaks were observed at 24° (4.24 Ǻ) and 31° (3.34 Ǻ). Muscovite was identified at 10.2° (9.98 Ǻ), 20.6° (5.0 Ǻ) and 29.7° (3.48 Ǻ) whereas the peaks at 35.2° (2.95 Ǻ) and 35.9° (2.89 Ǻ) were assigned to both illite and muscovite. A weak ilmenite peak corresponding to 2.76 Ǻ was observed at 37.8° whereas strong microcline peak (3.23 and 3.24 Ǻ) was observed at 32°.

## DISCUSSION

### Physico-chemical and mineralogical controls on kaolinization

The physical and chemical conditions under which the

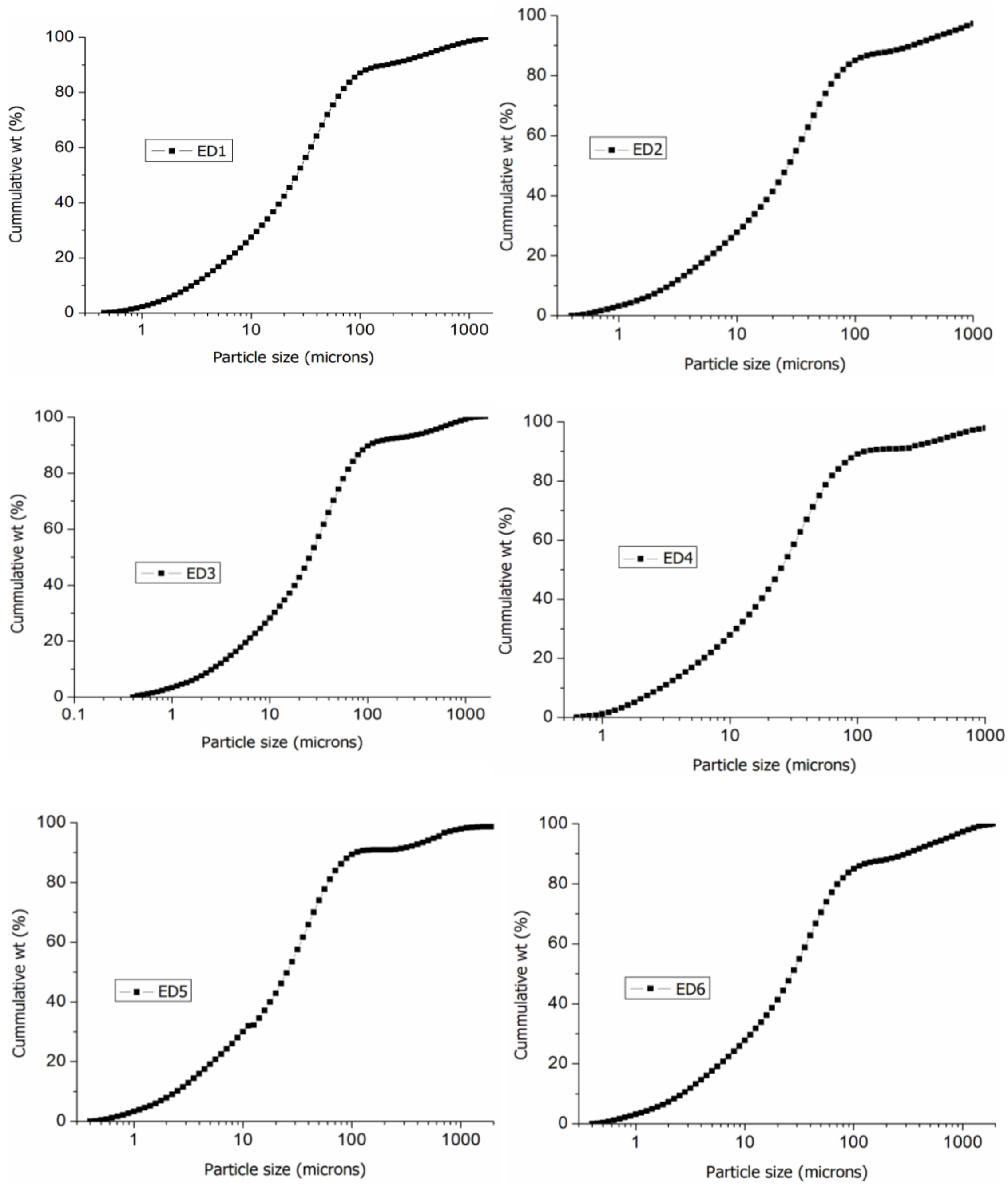


**Figure 3.** Cumulative particle size distribution of representative samples from Ediki Kaolin ocurrence.

**Table 3.** Bulk rock mineralogy of representative samples from Ediki.

| Sample | Kaolinite | Muscovite | Quartz | Goethite | Illite | Microcline | Hematite |
|---|---|---|---|---|---|---|---|
| ED1 | +++ | ++ | +++ | ++ | – | ++ | + |
| ED2 | +++ | ++ | +++ | + | + | ++ | + |
| ED3 | +++ | ++ | +++ | + | – | + | – |
| ED4 | +++ | ++ | +++ | + | + | + | – |
| ED5 | +++ | ++ | +++ | + | + | ++ | – |
| ED6 | +++ | ++ | +++ | + | + | + | + |

Major mineral phase (+++), minor mineral phase (++), trace mineral phase (+), not detected (–).

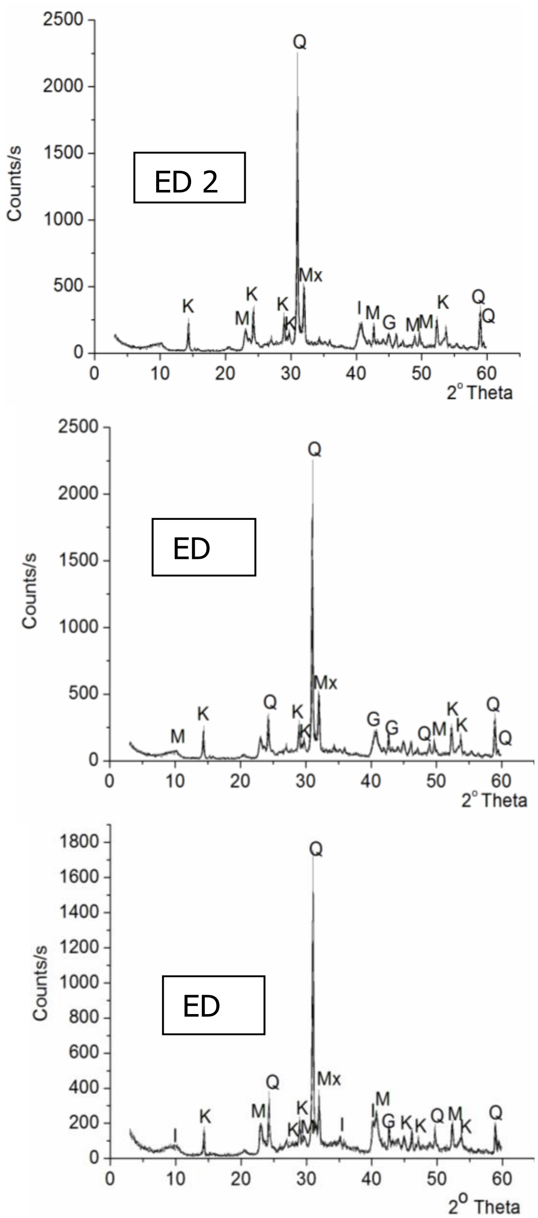


**Figure 4.** X-ray diffractogram of representative samples from Ediki kaolin occurrence (K, kaolinite; M, muscovite; Q, quartz; I, illite; G, goethite; Mx, microcline).

kaolin minerals form are relatively low pressures and temperatures. Solubilities of the several chemical species are pH dependent (Chamley, 1989). The pH values of the natural waters normally lie between 4 and 9 corresponding to the solubilities of silica, the alkalis and alkaline earth elements. On the contrary, alumina remains insoluble within same range. Thus, kaolinite is easily formed and is widespread in soils developed under hot-wet, tropical climates (Ruiz Cruz, 2007). The characteristic porosity and permeability of the Ediki sandstones (inferred from silt loam texture with low clay content), favoured the migration of fluids which enhanced the formation of secondary diagenetic minerals.

The most common parent materials from which kaolin develop are feldspars and muscovite. The transformation of k-feldspar into kaolin minerals occurs according to the equation:

$$2KAlSi_3O_8 + 3H_2O \rightarrow Al_2Si_2O_5(OH)_4 + 4SiO_2 + 2K(OH) \quad (1)$$
Feldspar kaolinite

The sandstones contain, in addition to quartz, some detrital feldspars and mica grains, which are favourable parent phases for kaolinite formation. However, the absence of the 111 kaolinite peaks and concomitant presence of well resolved quartz peaks at 3.34 and 4.24 Å infers partial or incomplete kaolinization processes, low to moderate degrees of kaolinite crystallinity as well as significant quartz contamination (Lanson et al., 2002; Ruiz Cruz, 2007).

## Diagenetic evolution of kaolin

In sandstones, three major types of diagenetic kaolin are recognized: Kaolin replacing detrital mica, vermiform kaolin and blocky kaolin. Crystallization at the expense of detrital mica is obvious for the first kaolin type, because of petrographic relations between ‘‘expanded’’ mica flakes and authigenic kaolin growing in-between (Ehrenberg et al., 1993; McAulay et al., 1993). In contrast, the crystallization conditions of the latter two morphological types are controversial. The following hypothesis explains the crystallization of kaolin at the expense of both plagioclases and K-feldspars.

According to the hypothesis, kaolin crystallization is promoted at shallow burial depth by fluids of meteoric origin that flush the formation either during early diagenesis or after structural inversion (Lanson et al., 2002). As a consequence of feldspar dissolution, kaolin precipitates according to Equation 1. If meteoric fluids are responsible for this reaction, a constant supply of protons and removal of $K^+$ cations require the system to be open to precipitate significant amounts of kaolin (Lanson et al., 2002). This interpretation has long been supported by mineralogical models of mineral diagenesis which indicate that, in arkosic sandstones, the kaolin stability domain is restricted to low temperature (< 80°C) and shallow burial depths (Lanson et al., 2002; Ruiz Cruz, 2007). At temperatures of ~120 to 140°C, (corresponding to ~ 3.5 km deep), kaolin is supposed to react with the remaining K-feldspar to precipitate illite. Given the shallow depth of Ediki sandstone unit the equatorial climate experienced in the region is considered to have raised the temperature well enough for kaolinization and only slightly for illitization. According to the ‘‘meteoric-water flushing’’ model, several crystallization episodes must be invoked to account for the different kaolin morphologies observed in sandstone.

## Conclusion

This study presented an overview of diagenetic evolution of Ediki kaolins from physicochemical and mineralogical study. The kaolin is light grey in colour and textural classified as silt loam. The pH is acidic and suitable for the solubility and leaching of alkali and alkaline earth elements. Kaolinite and quartz are the dominant mineralogy. Inclusive of favourable pH, kaolin emplacement was enhanced by the tropical climate, porous and permeable nature of the sandstones as well as its shallow depth. The fairly gentle relief (35 to 40°) of the host rock helped preserved the kaolin matrix formed.

## ACKNOWLEDGEMENT

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