

XRD, SEM Characterisation and Economic Potentials of Volcaniclastic-Derived Clays from Ediki, Mungo Formation, SW Cameroon

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Abstract

The Cretaceous Mungo Formation in Ediki, situated in southwestern Cameroon, is characterised by sandstone, siltstone, and carbonates, overlain by pyroclastics and undifferentiated mafic rocks. Clayey occurrences are ubiquitously sandwiched within the sandstones. To determine the clay mineral diversity and commercial applicability, eleven clay samples were obtained through scooping and analysed by XRD and SEM methods. XRD results show kaolinite (NK1, NK2, NK4, NK6, NK7, NK8), halloysite (NK3, NK5, NK11), and illite (NK9) as major clay phases, while montmorillonite, feldspar, and quartz are associated with the clay. Magnetite, hematite, and ilmenite occur as impurities. Gibbsite is recorded in one sample (NK10). SEM reveals that the kaolinites are flat, plate-like, and lotus-like; halloysite is spongy, rod-like, and pseudo-spheroidal, while illite is scallop-shaped. The gibbsite sample is stalactitic. The clays are derived from the decomposition of the pyroclastics, ash, and ultramafic and mafic rocks. The iron oxide impurities are from mafic rocks, while quartz is derived from sandstone and siltstone. The occurrence of gibbsite indicates deep weathering in a warm, humid climate. Kaolinite and illite have potential use in ceramics, paper, and as components in cosmetics and toothpaste; montmorillonite and halloysite, as drilling fluids, catalysts, and adsorbents for environmental remediation, drug delivery, and to create stronger nanocomposites.

1. Introduction

Clay minerals are economically important as development minerals, especially in developing nations, by virtue of their wide applications in industry and pharmaceuticals and have been mined in world-class deposits such as Cornwall and Cape York Peninsula in England and Australia, respectively [1]. These minerals are hydrous aluminosilicates that have particle sizes less than 2 μm . They are mostly plate-like in shape and become plastic when wet but stone hard when dry. Their formation is usually through surface weathering, precipitation, low-temperature metamorphism, and diagenesis [2 – 4]. Their formation depends on climatic conditions and overall soil development [5], with rock composition also playing a crucial role [6]. Tropical conditions with high rainfall, warm temperatures, and high biological activity accelerate chemical weathering, which creates environments that typically produce clays like vermiculite, illite, kaolinite, halloysite, and montmorillonite, along with non-clay minerals such as gibbsite, hematite, and goethite.

Cameroon's geographical and geological setting favours widespread clay deposit formation [7 – 9]. Numerous deposits have been reported in many areas in Cameroon, with extensive characterisation of their nature and geochemical properties (e.g., [10, 11]). These materials have been valorised primarily for ceramic production, including bricks, tiles, and fine porcelain [12 – 14]. Southwestern Cameroon hosts ubiquitous clay occurrences that remain poorly investigated regarding their mineralogical characterisation. Previous work in the study area includes studies of kaolin profiles in the Mungo Formation [15] and characterisation of basement-derived clays in south-central Cameroon [10, 16]. This study aims to document the mineral assemblage of the Ediki clayey occurrences, construe their genesis,

and highlight potential industrial applications using X-ray diffractometry and scanning electron microscopy.

2. Study Site

2.1. Geographical situation

Ediki is a locality in Kumba 3 Sub-Division of the South West Region of Cameroon (Fig. 1(a-d)). It is bordered to the north by Mabonji, to the south by Mbalangi, to the east by the Mungo River, and to the west by Pete. The climate is tropical, with distinct rainy (April-September) and dry (October-March) seasons. The mean temperature is 25°C, with rainfall ranging from 2085 to 9086 mm and peaking in June and July [17, 18]. This high rainfall reflects Ediki's position in a hyper-humid coastal belt. The area is drained by the north-south flowing Mungo River and its dendritic tributaries. The topography is gentle, averaging 111 meters above sea level.

2.2. Geological setting of the study area

Geologically, Ediki forms part of the Cretaceous-Quaternary Douala sub-sedimentary basin, which is the northwestern extension of the west-central coastal province [19]. The local rocks belong to the Mungo Formation, which overlies the Mundeck Formation. The Mungo Formation comprises sandstone, shale, limestone, marl, silty clays, and siltstone. Clay occurrences are hosted within Upper Cretaceous (Turonian-Cenomanian) sandstones of this formation, which are overlain by recent pyroclastics and basaltic boulders. Within the study area, discontinuous shale outcrops appear along intermittent stream beds, while fossiliferous limestone occurs in central Ediki and along the Mungo riverbanks. Recent alluvium deposits towards the east, particularly along riverbanks, overlie isolated undifferentiated basaltic volcanic rocks. A hiatus separates these recent deposits from the underlying Mungo Formation transitional sequence of shale, limestone, and fine-grained sandstone characteristic of a low-energy coastal environment.

3. Methods

3.1. Sampling and Sample Preparation

Eleven clay samples were collected judgmentally from outcrops along the main road and railway cuttings. The selection criteria included colour variation, texture, clay horizon thickness, and the absence of visible contamination. The samples were collected vertically at intervals determined by outcrop extent. The clay occurrences sampled were closely associated with decomposed pyroclastics that overlay the cretaceous sandstones of the Mungo Formation of the Douala sub basin. The samples were then wrapped in labelled bags and transported to the Geology Laboratory of the University of Buea. At the laboratory, the samples were air-dried and crushed using an agate mortar and pestle. The crushed material was sieved and the clay fraction obtained after treatment in distilled water with caustic soda

added for effective particle separation to obtain the $< 2 \mu\text{m}$. Four hundred grams of each clay fraction were sent to the Department of Earth and Environmental Sciences at the Botswana International University of Science and Technology (BIUST) for XRD and SEM analyses.

3.2. X-ray Diffractometry (XRD) Analysis

No pre-treatment was applied to preserve all mineral phases within this size fraction. All the samples were subjected to ethylene glycol treatment for proper clay characterisation. Major mineral composition was determined semi-quantitatively on bulk fractions at the University of Botswana, Gaborone, using a Philips PW1710 X-ray diffractometer. The instrument utilized monochromatic Cu K α radiation and an automatic divergence slit at 40 kV and 35 nA. Randomly oriented powder samples were mounted in aluminium holders and scanned from 5° to 90° 2θ with a step size of 0.02° , a scan speed of $1.2^\circ/\text{min}$, and a 0.5 s count time. Minerals were identified via multiple peak matches using the MacDiff software and its integrated mineral database. Diffractograms were interpreted using X'PERT Data Collector software.

3.3. Scanning Electron Microscopy (SEM) Analysis

SEM imaging was performed using a Philips XL30 Environmental Scanning Electron Microscope equipped with an energy-dispersive spectrometer. The clay fraction of each sample was mounted on aluminium stubs with carbon-coated conductive glue, then viewed and photomicrographed. SEM was used solely to characterise particle morphology; no chemical analyses from EDS are reported here.

4. Results

4.1. XRD Analysis of Clay Mineral Fraction

XRD analyses identified kaolinite, halloysite, illite, gibbsite, montmorillonite, quartz, feldspar, ilmenite, magnetite, and hematite as the various mineral phases (Table 1). Kaolinite is the dominant clay mineral in the area, occurring as the predominant phase in six samples (NK1, NK2, NK4, NK6, NK7, NK8). Magnetite and hematite occur as traces in most samples except NK1 and NK3. Halloysite is the major mineral in three samples (NK3, NK5, NK11), while illite and gibbsite (non-clay mineral) dominate samples NK9 and NK10, respectively. Ilmenite occurs as traces in samples NK2, NK3, and NK9. Quartz is an insignificant phase, occurring in trace amounts in only two samples (NK3, NK10). Montmorillonite is also insignificant, appearing only in trace amounts in NK1. Feldspar, a non-clay mineral, appears in trace amounts in four samples (NK1, NK2, NK3, NK4).

Table 1
Mineral phases identified at the Ediki clayey occurrences by XRD analyses

SAMPLE GROUP	SAMPLE NUMBER / COORDINATES	COMPOUND NAME/DESCRIPTION	CHEMICAL FORMULA
KAOLINITE (Fig. 2)	NK1: 550901E 501049N	Montmorillonite-22A	$\text{Na}_{0.3}(\text{Al}, \text{Mg})_2 \text{Si}_4\text{O}_{10} (\text{OH})_2 \cdot 8\text{H}_2\text{O}$
		Iron (III) oxide	Fe_2O_3
		Halloysite (residual surrounding kaolinite peaks)	$\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot x\text{H}_2\text{O}$
		Kaolinite (major mineral with minimal halloysite and feldspar)	$\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$
	NK2 550974E 501243N	Magnetite	$\text{Fe}_{2.75}\text{Ti}_{0.25}\text{O}_4$
		Ilmenite	FeTiO_3
		Magnetite	Fe_3O_4
		Kaolinite (Prominent peaks)	$\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$
		Feldspar (at 20 theta)	$\text{K}_{0.47} \text{Na}_{0.43} \text{Ca}_{0.10} \text{Al}_{1.1} \text{Si}_{2.9} \text{O}_8$
	NK4 551404E 501427N	Magnetite	$\text{Fe}_{0.65}\text{Fe}_{1.81}\text{Mg}_{0.42}\text{Al}_{0.1}\text{Ti}_{0.03}\text{O}_4$
		Halloysite	$\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$
		Feldspar	
		Kaolinite (two highest peaks)	$\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$
		Iron (III) oxide	Fe_2O_3
	NK6 551587E 501820N	Iron (III) oxide (noisy peaks)	Fe_2O_3
		Magnetite (Noisy peaks)	Fe_3O_4
		Hematite (Noisy peaks)	Fe_2O_3
		Illite (small peaks in between)	$2\text{K}_2\text{O}_{0.3}\text{MgO} \cdot \text{Al}_2\text{O}_{3.24}\text{SiO}_{2.12} \text{H}_2\text{O}$
		Kaolinite (three major peaks)	$\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$

SAMPLE GROUP	SAMPLE NUMBER / COORDINATES	COMPOUND NAME/DESCRIPTION	CHEMICAL FORMULA
	NK7 551587E 501820N	Hematite (small noisy peaks)	Fe_2O_3
		Magnetite (Small noisy peaks)	$\text{Fe}_{2.946}\text{O}_4$
		Kaolinite (3 major peaks)	$\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$
		Feldspar (1st small peak)	
	NK8 551706E 501696N	Magnetite (Noisy peaks)	$\text{Fe}_{2.929}\text{O}_4$
		Halloysite (high peak at the end)	$\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$
		Feldspar (Noisy peaks)	$(\text{K}, \text{Na})(\text{Si}_3\text{Al})\text{O}_8$
		Illite (peak at 53.5)	$2\text{K}_2\text{O}_{0.3}\text{MgO} \cdot \text{Al}_2\text{O}_{3.24} \text{SiO}_{2.12} \text{H}_2\text{O}$
		Kaolinite (2 highest peaks)	$\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$
HALLOYSITE (Fig. 3)	NK3 551456E 501180N	Feldspar and quartz (smaller peaks)	$(\text{K}, \text{Na})(\text{Si}_3\text{Al})\text{O}_8, \text{SiO}_2$
		Halloysite (2 high peaks)	$\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$
		Illite (last peak)	$2\text{K}_2\text{O} \cdot 3\text{Mg} \cdot \text{Al}_2\text{O}_3 \cdot 24\text{SiO}_2 \cdot 12\text{H}_2\text{O}$
	NK5 551315E 501815N	Feldspar	$(\text{K}, \text{Na})(\text{Si}_3\text{Al})\text{O}_8$
		Halloysite (Highest peak)	$\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot x\text{H}_2\text{O}$
		Kaolinite (peak to its right)	$\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$
		Magnetite high	$\text{Fe}_{2.945}\text{O}_4$
		Iron (III) oxide	Fe_2O_3
	NK11 552289E 501140N	Hematite	Fe_2O_3
		Magnetite	Fe_3O_4
		Halloysite	$\text{Al}_2\text{O}_{3.2}\text{SiO}_2 \cdot x\text{H}_2\text{O}$
		Illite	$2\text{K}_2\text{O}_{0.3}\text{MgO} \cdot \text{Al}_2\text{O}_3 \cdot 24\text{SiO}_2 \cdot 12\text{H}_2\text{O}$

SAMPLE GROUP	SAMPLE NUMBER / COORDINATES	COMPOUND NAME/DESCRIPTION	CHEMICAL FORMULA
ILLITE (Fig. 4)	NK9 552403E 501630N	Magnetite	Fe_3O_4
		Halloysite	$\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$
		Feldspar	$(\text{K}, \text{Na})(\text{Si}_3\text{Al})\text{O}_8$
		Illite (Prominent peaks)	$\text{KAl}_2(\text{Si}_3\text{AlO}_{10})(\text{OH})_2$
		ilmenite	FeTiO_3
GIBBSITE (Fig. 4)	NK10 552036E 500491N	Magnetite (Noisy peaks)	Fe_3O_4
		Iron-magnesium compounds (noisy peaks)	$\text{Mg}_{0.208}\text{Fe}_{0.955}\text{Ti}_{0.833}\text{O}_3$
		Quartz (peak just before gibbsite)	SiO_2
		Gibbsite (Highest peak)	$\text{Al}(\text{OH})_3$
		Halloysite (Next peaks in height)	$\text{Al}_2\text{O}_3 2\text{SiO}_2 \cdot x \text{H}_2\text{O}$

These mineral phases can be grouped into four dominant categories: kaolinite, halloysite, illite, and gibbsite. The kaolinite group shows several associations: NK1, NK4, and NK8 contain kaolinite with halloysite, montmorillonite, feldspar, and magnetite; NK2 and NK7 have kaolinite with feldspar, magnetite, and ilmenite; NK6 contains kaolinite with illite and magnetite. Kaolinite peak intensities range from approximately 80 to over 150 counts, with halloysite and feldspar peaks in these samples below 50 counts.

As seen in Table 1, the halloysite group includes NK3, NK5, and NK11 (Fig. 3), with halloysite peaks exceeding 150 counts. NK5 shows halloysite with kaolinite and magnetite; NK11 contains halloysite with illite, magnetite, and hematite; NK3 includes halloysite with feldspar, ilmenite, and quartz.

The illite phase is represented by sample NK9, showing illite with halloysite, magnetite, and feldspar. The gibbsite phase is sample NK10, containing gibbsite with quartz, halloysite, and magnetite (Fig. 4). Illite XRD counts exceed 80, while gibbsite counts exceed 150.

4.2. Clay Structure and Morphology

4.2.1. Kaolinite Structure and Morphology

Kaolinite has a 1:1 layer structure with Al^{3+} in octahedral sites and Si^{4+} in tetrahedral sites (Fig. 5). The electrically neutral layers are held together by hydrogen bonding between basal oxygens and adjacent hydroxyl groups. This structure in its form limits isomorphous substitution, resulting in a nearly fixed chemical formula of $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$.

Kaolinite in these samples displays various morphologies (Fig. 6). NK1 and NK2 show flat, plate-like crystals, while NK4, NK6, and NK7 exhibit aggregated pseudo-hexagonal, stacked crystal flakes. NK6 and NK8 contain loose pseudo-vermiform flakes. Most kaolinite particles lack parallel orientation and show face-to-edge fluctuations (NK1, NK2, NK7). This platelet morphology contributes to the material's plasticity, which is important for ceramic applications.

4.2.2. Halloysite Structure and Morphology

Halloysite has a layered structure like kaolinite but with water molecules separating the 1:1 layer (Fig. 5). This higher water content makes it less stable, allowing transformation to kaolinite over time. SEM images reveal distinct halloysite morphologies, which are varied in the Ediki area (Fig. 7). NK3 shows spongy hydroid shapes, NK5 exhibits loosely stacked pseudo-spheroidal platelets, and NK11 reveals rod-like or tubular structures. This tubular morphology is particularly interesting for nanotechnology applications such as nano containers.

4.2.3. Illite and Gibbsite Structure and Morphology

The illite sample (NK9) displays scalloped edges, loose platelets with irregular elongated spines, and a cornflake texture with tightly packed crystals. The gibbsite sample (NK10) shows a typical crystalline structure with stalactite-like aggregates (Fig. 8).

5. Discussion

5.1. Genetic Significance of Ediki

Clays generally form through silicate mineral instability, particularly feldspars, occurring in supergene weathering crusts, soils, continental and marine deposits, volcanic deposits, geothermal fields, altered wallrock, and low-grade metamorphic rocks [2]. Their formation depends on climate-rock interactions, which directly influence clay properties. Clay deposits are classified as primary (formed in situ) or secondary (sedimentary origin). Ideal conditions for kaolinitic clay formation include high rainfall, warm temperatures, lush vegetation, low relief, and high groundwater tables [20, 21]. Field observations at Ediki show gradational contacts between clay concentrations and the overlying laterite cover and the pyroclastics, with clays near presumed volcanic parent rocks and pyroclastics. This supports in-situ formation through decomposition of the dominant pyroclastic deposits rather than the allochthonous hypothesis. The XRD analysis confirms kaolinite, halloysite, illite, and gibbsite as main constituents, with montmorillonite, feldspar, and iron oxides as accessories like other deposits in the coastal regions of Cameroon [15]. The Ediki clays likely formed from weathering of Mount Cameroon volcanic and

volcaniclastic rocks, including basalts and ankaramite. They differ from Cretaceous kaolins of the Douala Sub-Basin, which contain kaolinite, smectite, and illite as major phases [22].

The clays are of supergene origin due to the absence of hydrothermal indicator minerals like pyrite that would suggest limited hydrothermal influence in contrast to the hydrothermally influenced deposits like Balengou n[23]. The parent rocks that decomposed are the same as those of other clay deposits along the Cameroon Volcanic Line [11, 24]. However, Ediki clays differ from northern Cameroon's quartz-rich smectitic clays formed under Sudano-Sahelian conditions [25]. Traces of montmorillonite in the clay materials from Ediki indicate chemical decomposition of volcanic ash rich in plagioclase feldspar. Halloysite typically forms from ultramafic rocks, volcanic glass, and pumice, often alongside kaolinite [20, 26]. Illite within the Ediki deposit is derived from kaolinite chemical alteration under deep burial conditions through loss of interlayer water. The iron oxides point to a volcanic protolith, like clays reported from Mount Bana [27].

Gibbsite and illite in the Ediki area are likely formed at different depths, with gibbsite at shallow levels and illite at greater depths. Gibbsite forms through prolonged tropical weathering of aluminium-bearing minerals like feldspars [28]. Its presence indicates advanced weathering where silicon has been removed from kaolinite or halloysite, typically occurring in ferrosols where intense weathering prevents neo-feldspar formation [29].

The Ediki clay assemblage shows both similarities and differences with other Cameroonian deposits. Unlike smectite-rich northern clays [25, 30], Ediki clays are dominated by kaolinite-halloysite with very minor smectite content. They share similarities with other volcaniclastic-derived clays along the CVL [11] but differ from hydrothermally influenced Balengou deposits [23]. This mineralogical diversity across Cameroon reflects variations in parent rock composition and weathering conditions.

5.2. Commercial Applicability of the Ediki Clay

The economic value of clay is infrequently determined by its bulk chemical composition alone; rather, it is a direct function of its mineralogical structure and physicochemical properties. Kaolinites have a 1:1 layer structure that does not expand, making it physically stable and resistant to high temperatures. The Ediki clay assemblage, characterised by dominant kaolinite and halloysite with subsidiary illite, trace quartz and feldspar, and very low montmorillonite content, presents several industrial opportunities. The economic application of the Ediki clay will be enhanced through further use of chemical characterisation methods including XRF and geotechnical characterisation to determine the Atterberg's limits, shear strength index, volume change potential, hydraulic conductivity, and the natural moisture content to definitively determine the economic value. The XRD and SEM results permits a preliminary economic assessment of the Ediki deposit and paves the way for further research and resource definition.

5.3.1. Suitability for Ceramics

Clays have extensive industrial applications, including building bricks, water filters, rubber, pharmaceuticals, and personal care products. Kaolinite-rich clays are the most abundant and widely used worldwide. Ediki's kaolinite is suitable for ceramic fabrication due to its strength, plasticity, and refractoriness. The specific mineral association at Ediki, mainly kaolinite, halloysite, illite, and gibbsite with trace quartz, is appropriate for ceramic applications. Kaolinite provides essential strength, plasticity, and refractoriness. Illite promotes vitrification, which densifies final products. Quartz prevents cracking, shrinking, and warping while providing a uniform shape during sintering at 850–1050°C for fired bricks and tiles [31], with small amounts also improving water absorption properties. The very low smectite (montmorillonite) content is advantageous for ceramic building materials, as high smectite content can cause excessive shrinkage and cracking.

5.3.2. Potential for Nanotechnology (Halloysite)

Beyond traditional uses, clays are increasingly employed in advanced materials and composites, including engineered ceramics, lightweight aggregates, hybrid metallo-ceramic composites, geopolymers, adsorbents, and pharmaceutical carriers [32]. Halloysite, a kaolin-group mineral, is primarily used in ceramics, but its applications in other industries are expanding due to unique properties [26]. Its suitability for nanotechnology depends on purity and the properties of its nano-sized tubular structure. Naturally occurring halloysite holds promise in nanotechnology due to unique physicochemical properties derived from its tubular morphology. With low global reserves, natural halloysite offers an economical alternative to synthetic nanomaterials. The association of halloysite with kaolinite at Ediki enhances the economic prospects of these materials.

5.3.3. Other Potential Uses

Montmorillonite, though present only in trace amounts in one sample, has diverse applications, including oil drilling muds, soil additives for water retention, petroleum refining catalysts [33], pharmaceuticals, animal feed, desiccants, cosmetics, paper, and food industries. However, its trace occurrence at Ediki suggests these applications would require blending with higher-grade material. Gibbsite, though not a clay mineral, influences soil management in the area. It contributes to soil aggregate stability, reducing erosion susceptibility, and strongly adsorbs phosphorus, which can limit plant availability. Gibbsite also promotes soil particle flocculation, influencing soil structure and water movement.

6. Conclusions

1. The Ediki area contains sandstones, siltstone, basalts, and recent pyroclastics of the Mungo Formation, with shale and limestone along riverbanks. Field observations support in-situ clay formation through intense tropical weathering of pyroclastics and undifferentiated mafic to ultramafic rocks.
2. XRD reveals Ediki clays are predominantly kaolinite, halloysite, and illite. Kaolinite dominates six samples (NK1, NK2, NK4, NK6, NK7, NK8), halloysite dominates three (NK3, NK5, NK11), illite

dominates NK9, and gibbsite dominates NK10. Minor components include trace montmorillonite (NK1 only), ilmenite, magnetite, hematite, quartz, and feldspar.

3. The mineral assemblage indicates formation through intense tropical weathering of pyroclastics, basalts, and associated volcanoclastic rocks. The presence of gibbsite signifies advanced leaching under warm, humid conditions. The absence of hydrothermal indicator minerals suggests supergene weathering without significant hydrothermal influence.
4. Kaolinite and halloysite are valuable for ceramics and pottery. Very low smectite content benefits ceramic applications. Tubular halloysite suggests the potential for higher-value applications in nanotechnology, adsorbents, and advanced composites. The overall assemblage is suitable for traditional ceramic building materials.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests

Author Contribution

Enerst Tata: conceptualization, methodology, data curation, and writing of original draft. Ateh K. Ijunghi: visualization, writing- review & editing, validation. Cheo E. Suh and Elisha M. Shemang: Review & editing, validation of manuscript.

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Data Availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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Figures

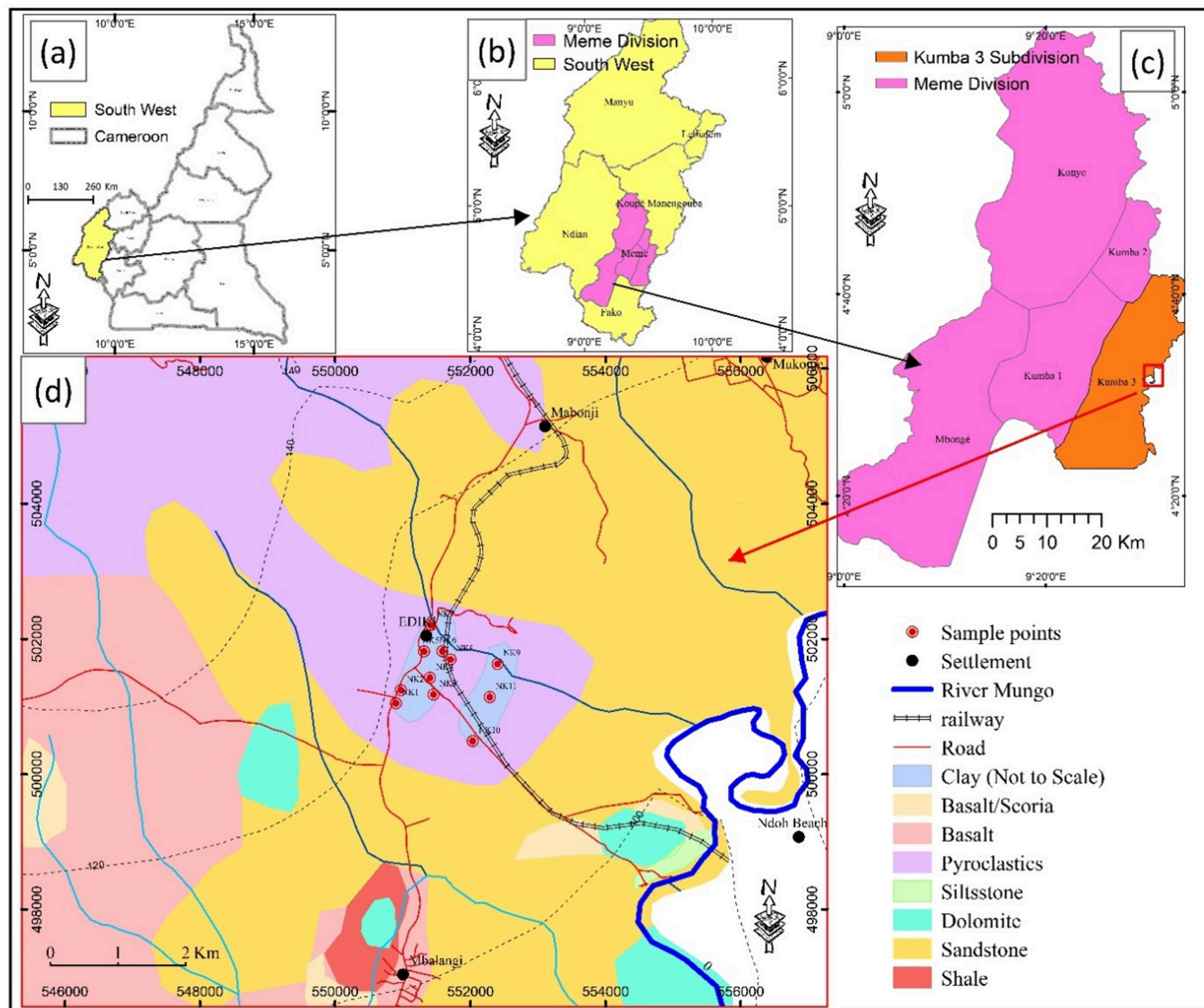


Figure 1

Location map of the study area: (a) South West Region in Cameroon; (b) Meme Division in the South West Region; (c) Meme Division with Kumba 3 Sub-Division highlighted with the study area in a red rectangle; (d) The geology of Ediki and environs with clayey occurrences (not to scale) at the center

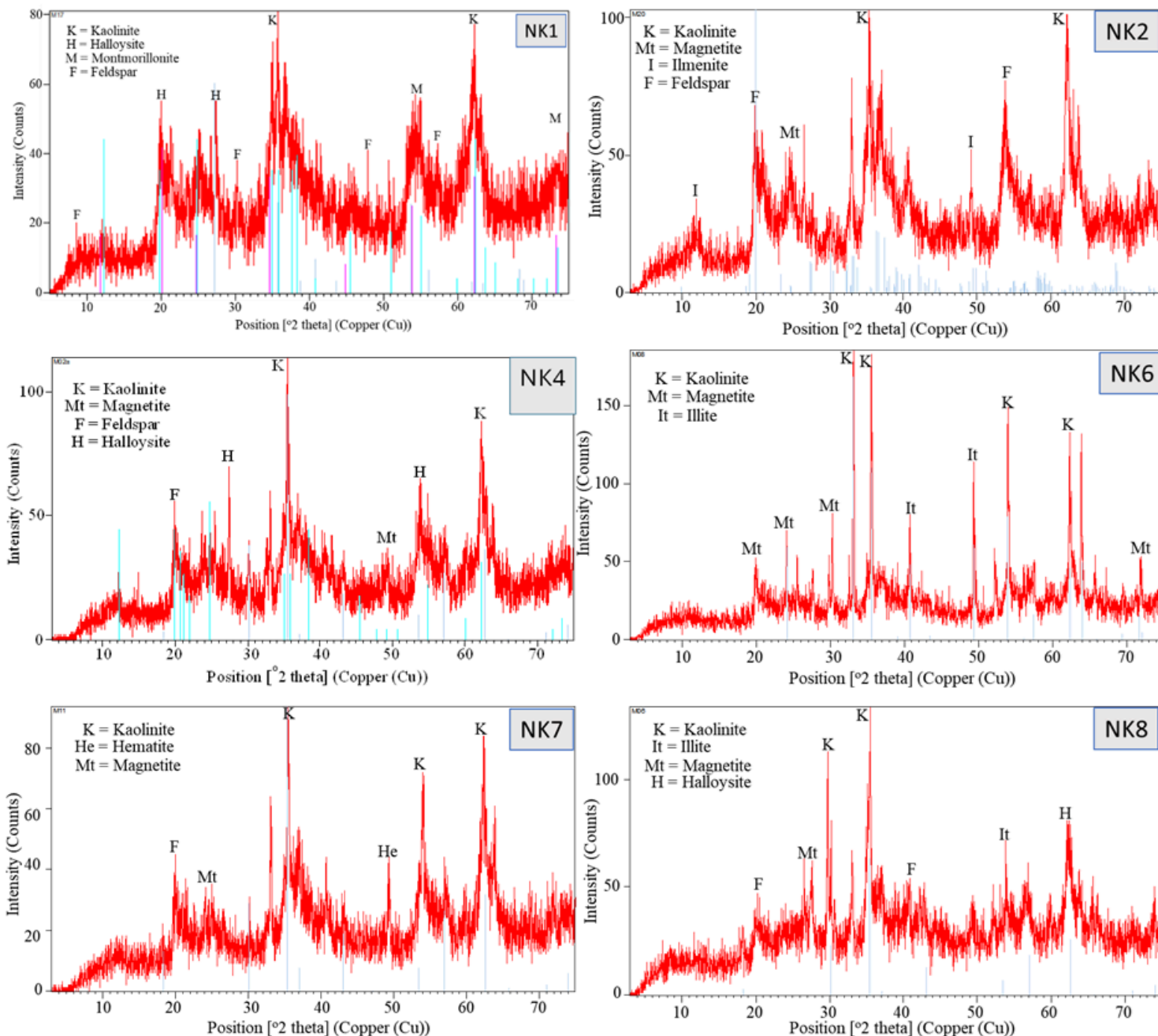


Figure 2

XRD patterns of kaolinite-dominant phases identified at Ediki (NK1: K $\pm$ H $\pm$ F; NK2: K $\pm$ F $\pm$ Mt $\pm$ I; NK4: K $\pm$ H $\pm$ F $\pm$ Mt; NK6: K $\pm$ It $\pm$ Mt; NK7: K $\pm$ He $\pm$ He $\pm$ F and NK8: K $\pm$ It $\pm$ Mt $\pm$ F)

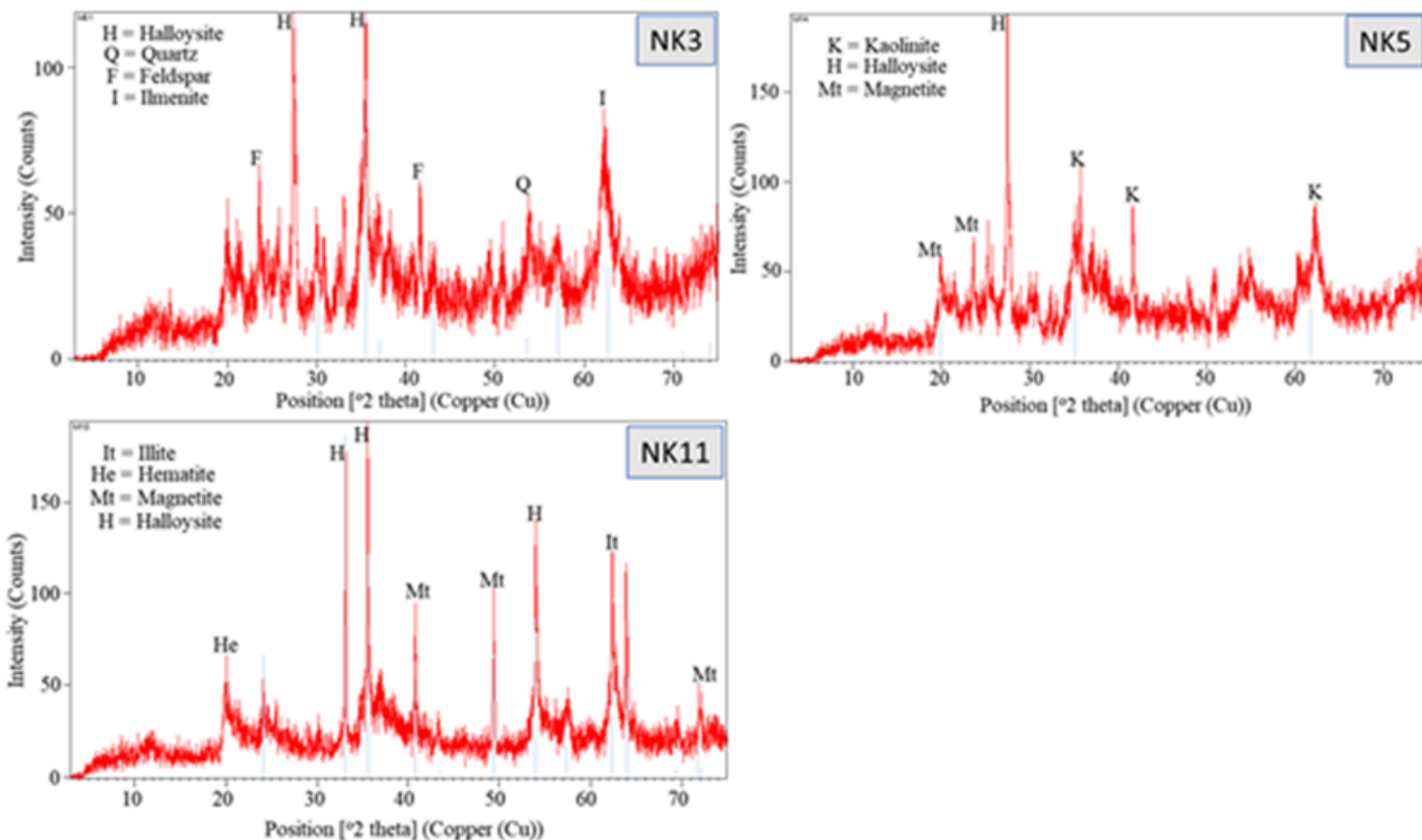


Figure 3

XRD patterns of the dominant halloysite clay mineral identified (NK3: H + I + F $\pm$ Q; NK5: H + K $\pm$ Mt and NK11: H $\pm$ Mt $\pm$ He)

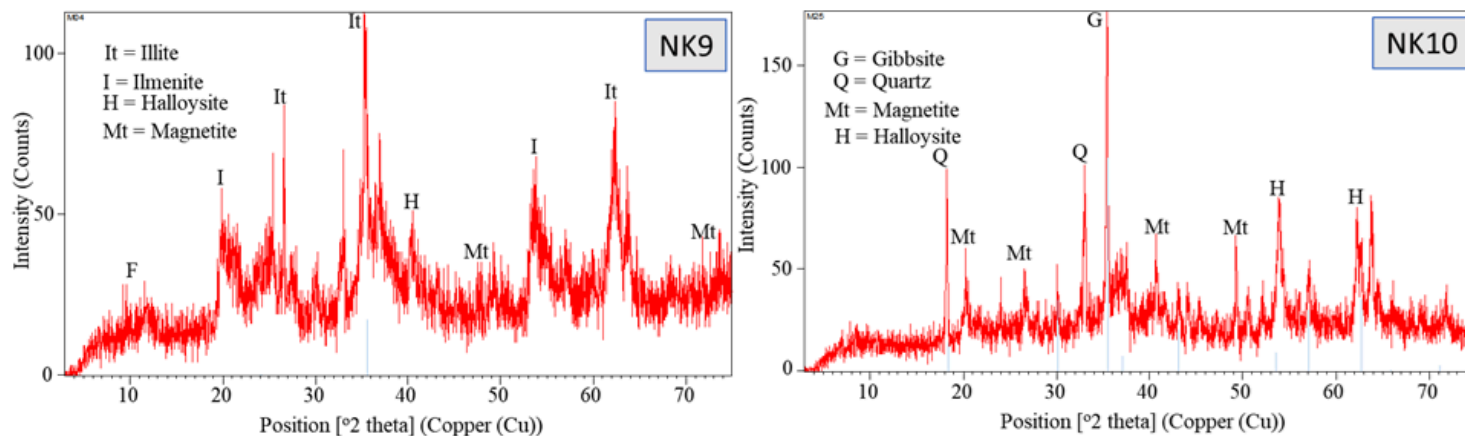


Figure 4

XRD patterns of illite (NK9: It $\pm$ H $\pm$ I $\pm$ F $\pm$ Mt) and gibbsite (NK10: G $\pm$ Q $\pm$ H $\pm$ Mt) clay phases identified at Ediki

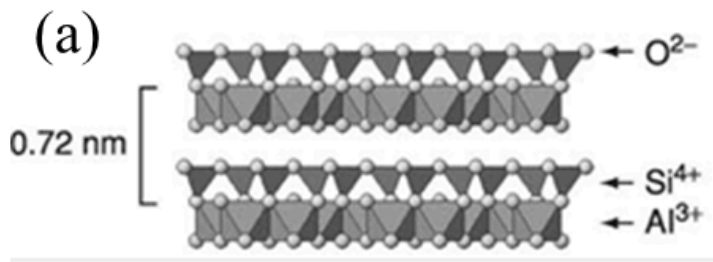
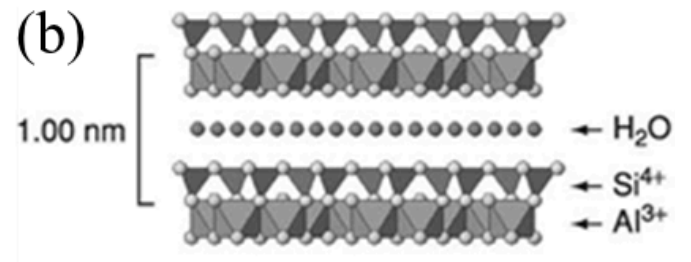
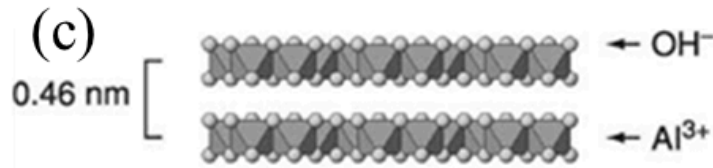


Figure 5

Morphological structures of (a) kaolinite, (b) halloysite, and (c) gibbsite adapted from Shulze (2005)

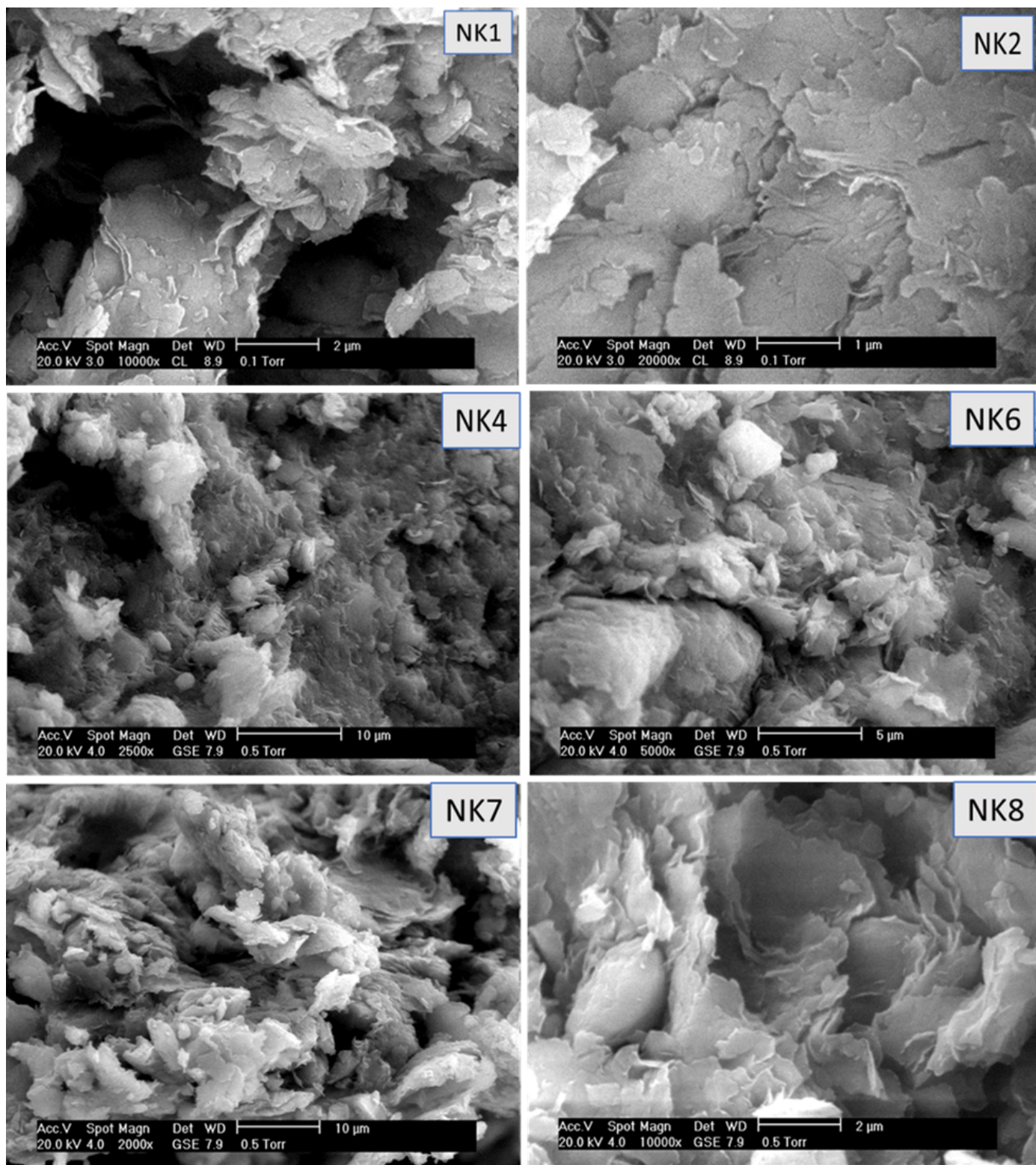


Figure 6

SEM images of the kaolinite dominant types: flat, plate-like (NK1 and NK2); pseudo-hexagonal, tightly packed kaolinite plates and flakes (NK4); fine platy particles and wavy flakes of kaolinites (NK6); tightly packed, well- or ill-formed tiny kaolinites (NK7); and pseudo-vermiform loose lotus-like flakes or onion skin texture (NK8)

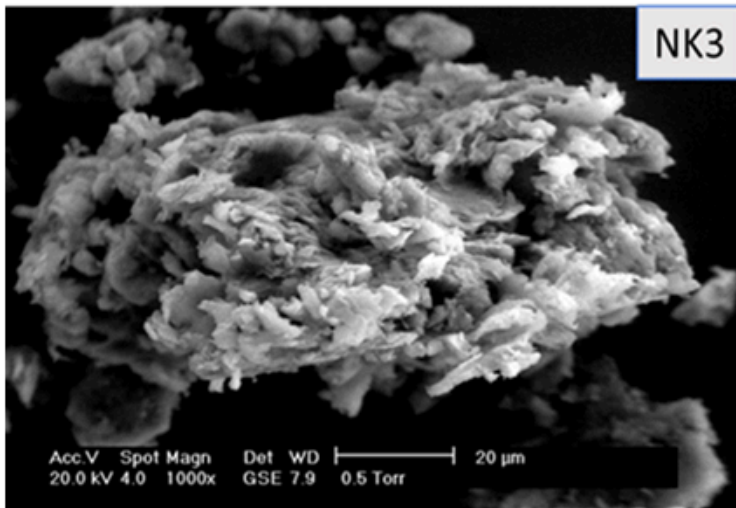
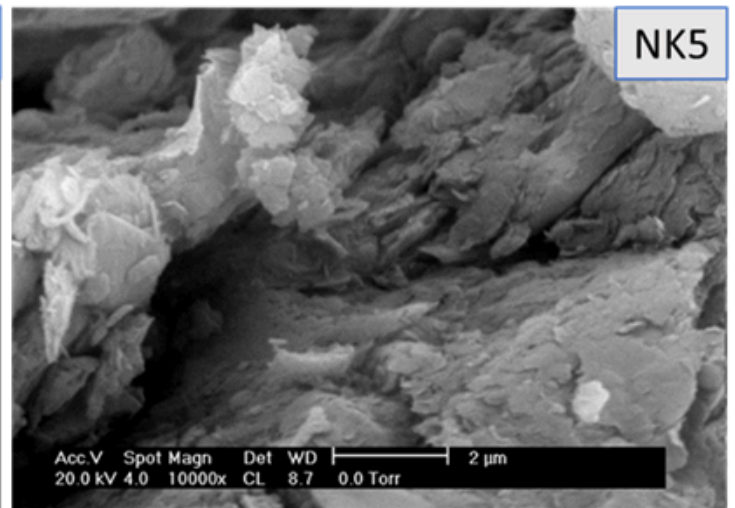
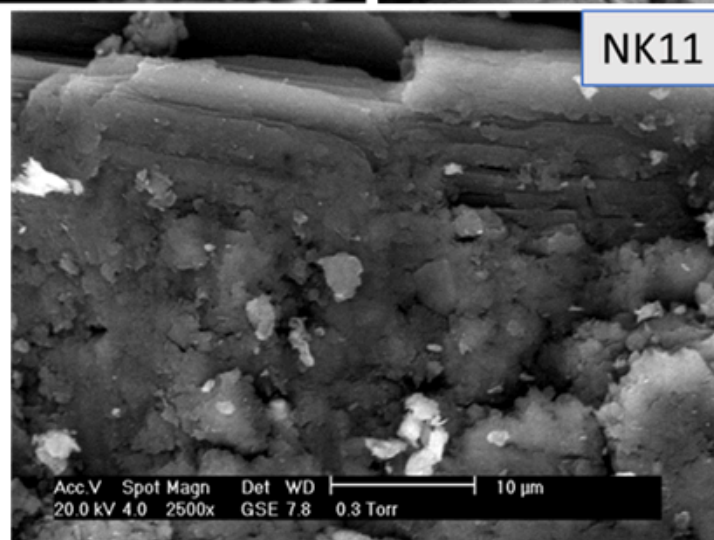


Figure 7

SEM images of halloysite showing spongy hydroid shapes (NK3), loosely stacked pseudo-spheroidal shapes (NK5), and rodlike tubes (NK11)

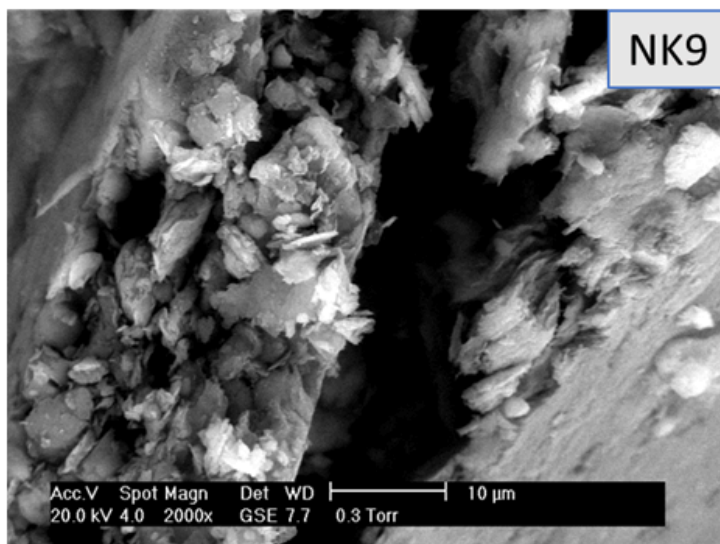
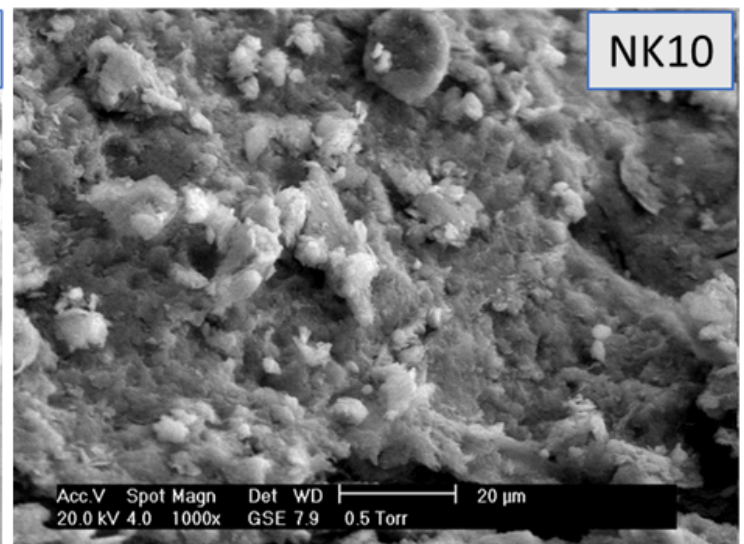


Figure 8

Scallop SEM of illite (NK9) and stalactitic aggregates of gibbsite (NK10) samples

