Current Research Thrusts into Clays and Clay Minerals in Africa

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Abstract

Clays and clay minerals are very important in several geochemical and mineralogical processes, and have very wide and varied industrial applications. This submission presents a bird's eye view on the geneses, mineralogy, geochemistry and applications of clays and clay minerals in Africa. Special emphasis was given to kaolins and their utilization, and geophagic clayey soils. The work elucidated on the geology, mineralogy, chemistry, technological properties and applications of these very important industrial minerals in Africa, thereby contributing to the Clays and Clay Minerals Body of Knowledge (CCMBK) globally, and advancing opportunities for sustainable developmental projects that local communities could possibly embark on. It concisely addressed clays as paleoenvironmental indicators; clay minerals geneses; mineralogical and chemical/geochemical characterization; physical and related properties; stable isotopes and dating; clays in medicine/pharmaceutics and geophagia; agricultural, environmental and industrial applications of clays; clays in soils; clay minerals mining/extraction; and clay minerals processing/beneficiation. The paper further projected the need for the formation of the African Clays Group (ACG) to promote CCMBK in the continent; and advanced collaboration pursuits with existing bodies such as the Geological Society of Africa, European Clays Group, the British Clay Group, Clays and Clay Minerals Society, Australian Clays Group among several others; and industries exploiting clays and clay minerals in the continent.

Keywords: *African clay group, genesis, geochemistry, geophagia, Industrial applications, mineralogy*

1. Introduction

Knowledge interests of researchers into the study of clays and clay minerals could have been engineered by the several applications in which these materials are employed. Though Georgius Agricola (1494-1555) proposed a definition for clay (Guggenheim and Martin, 1995), it was only agreed upon as, "a naturally occurring material composed primarily of fine-grained minerals, which is generally plastic at appropriate water contents and will harden with (sic) dried or fired" (Guggenheim and Martin, 1995) several hundred years later. Due to its inherent properties and characteristics, wide occurrences, and considerable accessibility to its being exploited, the material has over 100 documented applications (Murray, 2007), with its suitability to increasingly new industrial processes and products regularly being realized.

Many American, Asian and European countries gainfully exploit clays and clay minerals for economic benefit, as well as knowledge advancement. Over the years, clay and clay minerals exploitation and utilization in Western Europe and North America have emerged as a multi-million-dollar profit making venture (Ekosse, 2000; 2001; Murray (1991). Some of the raw materials used in these countries are imported from Africa. Certain African countries such as Botswana, Cameroon, Egypt, Nigeria, Senegal, South Africa, and Tanzania have equally recognized the economic potential of clays and clay minerals resources. Governments of these countries continue to make efforts in the diversification of their economies including the exploration and exploitation of clays and clay mineral resources; with a primary objective of creating employment in rural areas and reducing their dependence on economic trends set by Western Nations.

However, accurate and appropriate documentation of clay and clay minerals in Africa is scanty. Several non substantiated explanations have been advanced by researchers, government leaders, and investors as to why there is very considerable lack of research activities being conducted on clays and clay minerals in the continent. Considering the fact that there is an ever-increasing demand for the materials, it is imperative that basic and applied research are conducted aimed at filling in knowledge gaps of clays and clay minerals in Africa. Such research findings may not only be disseminated using appropriate platforms, but could equally be made available to government leaders for policy development and investors for exploitation. Job opportunities for graduates, skilled and unskilled personnel could be created.

This paper thus considers research thrusts into clays and clay minerals in Africa; with the primary objective of creating awareness of and encouraging research for the betterment of Africans through the exploitation of these materials. With emphasis on Africa, the document narrates concisely on clays and clay minerals classification; clay minerals geneses; clay minerals mining, processing and usage; African kaolins and their usage; and research thrusts with a bias towards IGCP 545 on clays and clay minerals in Africa. It is anticipated that if research efforts in the understanding of clays and clay minerals are augmented, these materials may contribute positively to knowledge expansion, and economies of several African countries.

2. Clays and clay minerals classification

Clay, used as a rock term, refers to a soft, loose, earthy material having particles with an average grain size of < 4 μm in the Wentworth grain size scale, or < 2 μm when referring to soils. Clay minerals form the greater portion of clays, but could also contain quartz, feldspar, carbonates, ferruginous material, and other non-clay materials. Clays are fine particles emanating from the decomposition of rocks under the influence of climate over time. Types of clays include Ball clay, China clay, Fire clay, Flint clay, and Kaolin which are dominated by kaolinite; Bentonite and Bleaching earth consisting mainly of montmorillonite; Common clays comprised of mixed layer of illite/smectite; Fuller's earth having montmorillonite, palygorskite, sepiolite and kaolinite; and Nanoclay dominated by montmorillonite. Clays and clay minerals are generally plastic (except for a few such as flint clay), and hardens on drying or firing; both are natural consisting mainly of phyllosilicates, though clay minerals could be synthetic and non phyllosilicate; and size is an important criterion in defining clays (Bergaya and Lagaly, 2006).

Clay minerals are hydrous layers of phyllosilicates consisting essentially of layers made of continuous tetrahedral silica and octahedral gibbsite sheets. The planar arrangements of the sheets and geometric positioning of the layers characterize the crystals and thus the categorization of mineral type. Classification of the clay minerals into eight groups is based on the layer type of ratio of octahedral: tetrahedral sheets, layer charge and the type of interlayer unit has been accepted and recognized. Further groupings have been categorized according to the type of octahedral sheet, the chemical composition and the geometry of the stacking sequence of the layers (Table 1) (Heckroodt, 1991). The most common clay minerals are kaolinite, halloysite, smectite (more specifically montmorillonite), and illite. Vermiculite, sepiolite and palygorskilte are relatively common.

Table 1: Classification of clay minerals

Group	Octahedral character	Species (Selected examples)
Serpentine – kaolin (1:1 Layer)	Tri	Amesite, berthierine, brindleyite, cronstedtite, fraiponite, kellyite, lizardite, nepouite
	Di	Dickite, planar halloysite, kaolinite, nacrite
	Di-Tri	Odinite
Pyrophyllite-Talc	Tri	Kerolite, pimelite, talc, willemsite
(2:1 Layer)	Di	Ferripyrophyllite, pyrophyllite
Smectite (2:1 Layer)	Di	Montmorillonite, beidellite, nontronite, volkhonskite Swinelordite (intermediate between di- and trioctahedral)
	Tri	Saponite, hectorite, sauconite, stevensite
Vermiculite	Tri	Trioctahedral vermiculite
(2:1 Layer)	Di	Dioctahedral vermiculite
Mica (2:1 Layer)	Di	Muscovite, paragonite, roscoelite, chernykhite, iIIite, phengite, alurgite,mariposite, glauconite, ce!adonite
	Tri	Phlogopite, biotite, annite, siderophyllite, lepidolite, zinnwaldite, laeniolite,ephesite, hendricksite, masutomilite
Brittle mica	Di	Margarite
(2:1 Layer)	Tri	Clintonite, bityite, anandite, kinoshitalite
Chlorite	Di	Donbassite
	Di-Tri	Cookeite, sudoite
	Tri	Clinochlore, charnosite, nimite, pennantite
Palygorskite-sepiolite		Palygorskite, yolomerite
(2:1 inverted ribbons)		Sepiolite, loughlinite, falcondoite

3. Clay minerals geneses

Clay minerals occur on the Earth's near surface resulting from several geologic processes including weathering, hydrothermal alteration, sedimentation, and diagenesis. From these geologic processes, the origin of clays and clay minerals could be neoformation/neomineralization, transformation, or inheritance (Eberl, 1984). Their origin is governed principally by protore rocks, climate, relief and time. Dependent on these factors, dominant clays and clay minerals based on abundance of occurrences: kaolinitic, bentonitic, palygorskitic, vermiculitic, and illitic sepiolitic clays are formed.

Kaolins could be primary (hydrothermal, residual or mixed hydrothermal and residual) or secondary (sedimentary) depending on their genesis. They are formed *in-situ*, by the alteration of feldspar-rich, Al-rich rocks such as granites and rhyolites; the parent minerals being feldspars (equation 1) and muscovite (equation 2).

$$2KAl_3Si_3O_{10}(OH)_2 + 2H^+ + 3H_2O \rightarrow 3Al_2Si_2O_5(OH)_4 + 2K \quad \text{(Eqn 1)}$$

K-feldspar → kaolinite

$$2KAlSi_3O_8 + 2H^+ + 9H_2O \rightarrow Al_2Si_2O_5(OH)_4 + 2K^+ + 4H_4SiO_4 \quad \text{(Eqn 2)}$$

muscovite → kaolinite

The alteration can be due to surface weathering, groundwater activity, or action of hydrothermal fluids. Secondary kaolin results from alteration of feldspathic arenites (arkose) emanating mostly from groundwater activity, erosion and transportation of the clay-size particles, which are mineralogically altered, and deposited, in lacustrine, paludal, deltaic and lagoonal environments.

Bentonitic clays are derived from the alteration of volcanic ash but could also result from transformation of feldspars, micas, various FeMg silicates and silication of detrital phylosilicates (Weaver, 1989). Bentonites are dominated by smectite (mainly montmorillonite) formed as depicted in equation 3. Deposition and formation occur in a low energy environment under temperate climatic conditions (low relief, low permeability, low temperature and low rainfall).

$$Mg^{2+} + 3NaAlSi_3O_8 + 4H_2O \rightarrow 2Na_{0.5}Al_{1.5}Mg_{0.5}Si_4O_{10}(OH)_2 + 2Na^+ + H_4SiO_4(aq) \quad \text{(Eqn 3)}$$

albite → montmorillonite

They were formed between Cretaceous and Miocene ages, although some deposits could be as old as Jurassic and others as recent as Pleistocene.

Vermiculite is hydrated magnesium iron aluminium silicate hydroxide ($(Mg,Fe,Al)_3(Al,Si)_4O10(OH)_2$-$4H_2O$). It is formed by the hydrothermal alteration of biotite and phlogopite. In soil mineralogy, the transformation of biotite to vermiculite with the release of K is considered the most important geochemical reaction occurring within the rhizosphere (Banfield *et. al*., 1999). This reaction makes K available to plants.

Illite ($K_{1-1.5}Al_4[Si_{7-6.5}Al_{1-1.5}O_{20}](OH)_4$;) is among hydromicas of which others include biotite, $K_2(Mg, Fe^{+2})_{6-4}(Fe^{+3},Al,Ti)_{0-2}[Si_{6-5}Al_{2-3}O_{20}](OH,F)_4$), and muscovite $K_2Al_4[Si_6Al_2O_{20}](OH,F)_4$ (Gallon, 1986). Illite is micaceous with similar chemical and mineralogical composition as muscovite, but slightly smaller in particle size. Differences of hydromicas and especially muscovite and illite occur in their physical properties such as their particle size. Illite is formed by the chemical alteration of K-feldspar, as shown in equation 4:

$$3KAlSi_3O_8 + 2H^+(aq) \rightleftharpoons KAl_3Si_3O_{10}(OH)_2 + 6SiO_2 + 2K^+ \quad \text{(Eqn 4)}$$

K-feldspar ⇌ illite

IIllitization is promoted by high concentration of K+ during digenesis. With increasing low temperatures and corresponding increase in argilization, K^+ is leached out and kaolinite formed. In sedimentary environments, illite is an important constituent in shales, mudstones and even limestones. The hydromicas occur in low to medium grade metamorphic and igneous rocks (Ekosse, 2005).

Palygorskite ($Mg_2Al_2Si_8O_{20}(OH)_2(OH_2)_4M^+.(H_2O)_4$), previously referred to as attapulgite or fuller's earth, is a rare, fibrous clay (Murray, 2000). Its genesis is associated with alkaline and hydrothermal alteration of magnesium-rich rocks (Singer, 1979). It is fibrous providing high surface area and porosity which provide excellent sorption and gelling properties (PIRSA Minerals, 2009). In 2001, South Africa and Senegal produced 155 000 tons of palygorskite (Harben, 2002).

4. Clay minerals mining, processing and usage

Clays and clay minerals are very unique industrial minerals due to a wide variety of inherent properties, including chemical inertness, desirable color, good covering or hiding power, softness and non-abrasive properties, and lower cost than competitive minerals (Murray and Keller, 1993; Murray 1986; Roskill, 2000). Clay minerals properties which serve as diagnostic evaluation indicators could be modified for optimum utilization. Controlling factors including mineral mining and processing, among other attributes such as mineral constitution of processed clay mineral product, and mineral chemistry influence their applications. The mining of clays and clay minerals is done usually by open cast. The mined mineral is then processed for suitable industrial applications. Konta (1995) has indicated that processing conditions of raw clays have a direct influence on desired industrial/technological properties.

According to Murray (1986), there are three methods of mining and processing raw kaolins, and these are the dry process, wet process and combined dry and wet processes. These methods are also applied to other clays and clay minerals. The dry process method is considered to be relatively simple yielding a lower cost and lower quality product compared to the other two methods (Murray, 1986). Mined clay is transported to the processing plant where it is crushed and stored. Crude clay (20 – 25 wt % moisture) (Murray, 1986), must first be dried before being pulverized and air classified to separate fine from coarse particles. More often, in dry processing of clay, the properties of the crude are retained in the finished product. In wet processing, the mined clay is blunged, dispersed with chemicals, degritted for the removal of coarse particles, fractionated to achieve particle size objectives, and brightened by magnetic separation, ozonation, leaching or differential flocculation. Drying, sorting, bagging and loading of the processed clay (Murray, 1986) are the final stages before shipment.

Clays and clay minerals are utilized in several industrial applications (Table 2). These applications are based on type of clay mineral, mineral assemblage, particle size and distribution, color, physico-chemical and chemical properties of the clay. Key usages among several applications of clays and clay minerals include paper, paint, plastics, rubber, ceramics, agricultural, medicinal and therapeutic applications. Clays could be used as a carrier and extender for fertilizers and pesticides, animal feedstuffs, bitumen coated clay screeds, chemically processed clays, fire protection, friction lining, insulation material, lightweight concrete, packing material, refractory products, silicate bonded shapes and blocks, and plasters.

5. African kaolins and their usage

Over 250 kaolin deposits and occurrences in Africa recently studied (Ekosse, 2010) revealed kaolinite as the dominant kaolin mineral. The geneses of African kaolins are reported as primary, hydrothermal, residual, mixed and secondary (Ekosse, 2010). Fifty percent of the reported kaolins are of sedimentary origin, and 35 % are primary kaolins. Pimary kaolins are located mainly in Central and Southern Africa; and the hydrothermal kaolins are found dominantly in Central and West Africa. North African kaolins are mainly of secondary clays. Very substantial deposits and occurrences in Southern and West Africa are also secondary kaolins of sedimentary origin (Ekosse, 2010). Most of the sedimentary kaolins in the world are genetically associated with Cretaceous and Tertiary argillaceous sediments. Very substantial kaolin deposits occur close to the eastern coast of South American countries. Similar geological histories of Cretaceous and tertiary sediments and environments of deposition are shared near the eastern coast of South American countries and the coast of West African countries. Kaolin exploration in Africa should therefore focus on investigating cretaceous and tertiary argillaceous sediments. Precambrain and Permian argillaceous sediments have also been found to host kaolins of mineable quantities.

Advantages for kaolinite usage in industry include the following main reasons: high and stable brightness; fine grain size with controlled distribution range; easy to disperse; low 325 screen residue; strong covering power; good suspension, and excellent compatibility with other pigments and adhesives. It has the ability to be utilized for film formation, fibre extension, carrier, adsorbent and diluents (Ekosse, 2010). The main uses of the kaolins in Africa are for the manufacturing of ceramics and tiles, bricks, pottery, medicines, and as fillers. These applications are standard for kaolins from other parts of the world. Other important applications of African kaolins include absorbents, paints, paper, pesticides, rubber and refractory. One of the most important kaolin deposits in Africa is Pugu, Tanzania. The kaolinite sample from Pugu Kaolin is used as kaolinite reference (Kaolinite 1*Md*, 29-1488) for the mineral (Mineral Powder Diffraction File Data Book, 2001).

6. Research thrusts

Considering the fact that clays and clay minerals occur extensively in Africa, there is need for the continent to benefit from their abundances. Such benefits can be better achieved through directed research for development. One of such vehicles in place is the research project on clays and clay minerals in Africa.

6.1 The IGCP 545 on clays and clay minerals in Africa

The IGCP was launched in 1972 as the International Geological Correlation Program (IGCP) and later changed to International Geosciences Program involving UNESCO/IUGS/ and IGCP. It awards five (5) years funding to earth science related projects of multidisciplinary nature, and that involves collaboration between different countries.

Table 2: Clay minerals applications

Applications	Kaolin	Bentonite	Palygorskite	Sepiolite	Applications	Kaolin	Bentonite	Palygorskite	Sepiolite
Abrasive wheel bonding	x				Metal drawing lubricants			x	x
Absorbents		x			Nanoclays		x		
Adhesives		x			Organoclays		x		
Adhesives and Caulks	x		x	x	Pharmaceuticals	x	x	x	x
Aerosols		x			Paint	x	x	x	x
Agricultural carriers			x	x	Paper	x	x		
Alum	x				Pencil Leads	x	x		
Animal feed binders		x	x	x	Percolation adsorbents			x	x
Anti-caking agents			x	x	Pillared clays		x		
Barrier clays		x			Plaster	x			
Bleaching earths		x	x	x	Plasticizers		x		
Cat litter		x	x	x	Plastics	x			
Catalysts	x	x			Polishing compounds	x		x	x
Catalyst supports			x	x	Reinforcing filters			x	x
Cement	x	x			Refractories		x		
Ceramics	x	x	x	x	Roofing granules	x			
Cosmetics	x	x	x	x	Rubber	x			
Crayons		x			Rubber filler		x		
Crayons and Chalk	x				Sealants	x	x		
De-inking newsprint		x			Seed growth		x		
Deodorizers		x			Sizing	x			
Dessicants		x			Slurry trench stabilization		x		
Detergents		x			Soaps and Detergents	x			
Drillig muds		x			Soil stsbilization		x		
Drilling fluids			x	x	Suspension aids		x		
Emulsion stabilizers		x			Tanning leather	x			
Enamels	x				Tape joint compounds		x	x	x
Fertilizer carrier		x			Water clarification		x		
Fertilizers	x				Wax emulsion stabilizer			x	x
Fiberglass	x				Welding and Road coating	x			
Liquid suspension fertilizers			x	x	Wire coating	x			
Medicines	x	x	x	x					

The IGCP 545 project was approved by the IGCP Scientific Board during its 35th Session from 14 – 16 February 2007 in Paris, France. This project focuses on clays and clay minerals in Africa.

In terms of research, the applications of clays and clay minerals include a wide variety of aspects that cut across several disciplines and professions including the making of plates, purifying of wine, moulding of many gadgets, soap tablets, paper, plastics, paints, and fertilizers. The variety of ways in which clays are used necessitates investigation which is why the project on clay and clay minerals in Africa was designed. The conceived project studies the Geneses and Paleoenvironmental Considerations, Mineralogy, Geochemistry and Applications of Clays and Clay Minerals in Africa because there is no proper documentation of clays and Clay Minerals in Africa. This project provides a unique contribution to Clays and clay minerals body of knowledge and presents an opportunity to advance expansion on sustainable developmental projects involving clays that local communities could embark. The broad aims of the project 'Clay and Clay minerals in Africa' (IGCP 545) addresses the following:

(1) To show where possible, relationships between various mineral occurrences and geological, structural, geographical and other controls that might have influenced the formation of the clays and clay minerals deposits and occurrences.
(2) To summarise basic geology, geochemistry and mineralogy, thereby reducing the risks associated with green fields investigations.
(3) To contribute to the application of clays and clay minerals in the understanding of paleoenvironments.
(4) To assist in optimal utilisation of clays and clay mineral resources.
(5) To contribute to the development of services to a growing African clays for industrial product manufacturing industry.
(6) To contribute to knowledge transfers.

Under these objectives, key areas to be investigated include: Paleoenvironments; Clay minerals genesis; Mineralogical characterization; Chemical/geochemical characterization; Physical and related properties; Stable isotopes and dating; Clays in medicine/pharmaceutics/microbiological characterization; Agricultural, environmental and industrial applications of clays; Clays in soils; Clay minerals processing/beneficiation; Clay minerals mining/extraction; and any others relevant areas of research interests. Studies on Geophagia fall under the main area of Clays in medicine/pharmaceutics/microbiological characterization.

Activities and milestones for the clays and clay minerals project cover:

(1) The organization of workshops on the development of research topics under the research themes established through different research theme leaders,
(2) Creating a website for the project
(3) Carrying out field trips
(4) Organizing Short courses
(5) Organizing workshops and conferences under the auspices of African Clays Research Group (ACRG) aimed at promoting Clays and Clay Minerals Body of Knowledge (CCMBK).
(6) Publication of research findings
(7) Organizing workshop of the African Clays Group
(8) Collaborative work on books to be written : Clays and Clay Minerals in Africa; Human and Enzootic Geophagia
(9) Organizing workshop for the linking of clays and clay minerals in Africa to others clay minerals groups
(10) Training of postgraduate students
(11) Organizing workshop on Project review
(12) Advancing recommendations and way forward

Though the project is in place, research activities have been slow to come by; and several possible reasons have been advanced to explain the tardiness. Explanations which are briefly discussed dwell on Institutions, laboratories and instrumentation; collaboration; and the Diaspora question.

6.2 Institutions, laboratories and instrumentation

A recent study by Matike et al. (2010) revealed that many universities in Africa offered earth and environmental sciences, and related programs. Among these, 71%, 47%, and 17% of the universities had offerings in geology, environmental sciences and earth sciences respectively. Fifty five percent of the universities offering earth and environmental sciences, and related courses were in Southern Africa, 32% in West Africa, 8% in East Africa and 5% Central Africa. In Southern Africa, Botswana, South Africa, Zambia, Zimbabwe, Malawi, Namibia, Mozambique, Tanzania and Swaziland had universities offering earth and environmental sciences. Fifty eight percent of the universities in Southern Africa with earth and environmental sciences offerings were located in South Africa. Seventy two percent of the universities within West Africa with earth and environmental sciences offerings were in Nigeria; followed by Ghana, Senegal and Sierra Leone. In East Africa, Kenya, Rwanda and Uganda were dominant. Cameroon, Democratic Republic of Congo and Congo in Central Africa also had earth and environmental sciences offerings with 60 % of the institutions found in Cameroon

Most of the universities offering earth and environmental sciences, and related programs in Africa are poorly equipped for research into clays and clay minerals. Principal equipment and instruments for the study of clays and clay minerals include X-ray diffractometer (XRD), X-ray fluorescence (XRF) spectrometer, scanning and transmission electron microscopes (SEM and TEM), Fourier transform infra red (FTIR) spectrophotometer, Inductively coupled plasma mass spectrometer (ICP-MS), particle size analyzer (PSA), differential thermal analyzer and differential scanning calorimeter (DTA and DSC), and graphite and flame atomic absorption spectrometer (GAAS and FAAS). Instrumentation for Oxygen and hydrogen isotopes analyses and dating, Electron Microprobe, Other laboratory facilities utilized in the study of clays and clay minerals are for Minerals Processing, Minerals Beneficiation, Metal Speciation, and Physico-chemical characterization. Unfortunately only 21 % of the universities in Africa have these equipment and instruments; with most of them located in South Africa and Botswana. In all the regions of the continent, universities in South Africa were the most equipped for the study of clays and clay minerals. Relatively modest equipment and instrumentation were found in Kenya and Nigeria (Matike et al., 2010).

Apart from instrumentation, political instability is a nagging factor negatively affecting earth and environmental science programs in the East, West and Central African regions (Schlüter, 2010). In as much as there is concerted efforts to advance research initiatives in the continent, the lack of equipment and appropriate laboratory facilities impacts negatively on research thrusts on clays and clay minerals and their outcomes. Though clays and clay minerals are most studied within Earth and Environmental Science programs of tertiary institutions, there are several related aspects that could be researched in other Life, Mathematical, Physical, and Health Sciences; Engineering, Education, Humanities, and Sociology disciplines. It may be worthwhile for researchers in the continent to be engaged in multi-, trans, inter and intra- disciplinary research activities embodying all aspects of clays and clay minerals.

6.3 Collaborations and the Diaspora question

The state of scientific development of countries is assessed by: its number of scientists, and contributions to body of scientific knowledge (Research and Publications); as well as strong reflections of national positive economic indicators such as patents, research, invention, health and well being, wealth and availability of affordable essential services.

The materialization of improved positive economic indicators were the primary concern of UNO through the UN Secretary General's Task Force 10 on Science, Technology and Innovation (STI) which was put in place to effectively facilitate the promotion of science and technology for research and development) (S &T for R & D) towards the realization of the millennium development goals (MDGs). This has led governments to shift their national development strategies from Natural Resources to Knowledge based economy developed from research and innovation for better living. Unfortunately most African countries are yet to expand their clay and clay minerals knowledge; a vital knowledge based pathway for the economic advancement of a nation. Several African countries are thus lagging due to acute shortage of researchers partly as a result of continental brain drain. There remains much to be desired in terms of collaboration among researchers in Africa. Advances in communication technology, cheaper cost of travel, and researchers seeking to work with the best of their peers are key drivers of collaboration. However researchers in some African countries have engaged themselves in collaborative research for the generation of knowledge.

Africa is one of the continents most hit by brain drain. In 1999, there were > 300 000 African scientists in Diaspora (Meyer and Brown 1999); and the number must have since increased. The migration of talented African scientists creates economic, intellectual, technological and strategic vacuums that, remain extremely difficult to fill, and leads to continental dependence on foreign technical assistance. With ever increasing rate of departure of African researchers for greener pastures, role models for junior scientists in the continent are lacking. Appropriate academic, research and institutional forums for training and guiding of graduate students in clay and clay minerals are insufficient. In overcoming the impediment, deals could be worked out in which African researchers in Diaspora could be co-supervisors, and their laboratories and research centres in host countries utilized.

Opportunities for joint scientific research projects could be gainfully exploited. Outcomes from such collaborative endeavors will be beneficial to the researchers through co-authored publications, and to the institutions and countries involved – a win-win situation. Opportunities could further be stretched involving combined research efforts of governments, industries and clay and clay minerals researchers both in Diaspora and those in the continent. Through combined research efforts, the continent could embrace a new identity and emerge strong internationally in clay and clay minerals commodities and knowledge. The outcome of such research could further lead to obtaining patents, specialized investments, and products being processed into finished, affordable and marketable clay commodities.

The Africa Union (AU) recognizes that Africa Diaspora has skills and expertise required for development initiatives and programs on the continent. The African Diaspora could be involved in the continent's S&T plan of action by providing human and technical resources, lobbying governments, institutions and foundations for support, being represented in government structures, providing policy and technical advice, and participating in networks which are beneficial to communities and nations. With a bias towards clays and clay minerals, continental researchers could team up with those in Diaspora for the generation of knowledge worthy of contribution to the Clays and Clay Minerals Body of Knowledge. Efforts have been put in place to establish a databank of colleagues researching in clays and clay minerals in the continent; with the primary objective of promoting networks and collaborations. Appendix A is a document being circulated to gather information which will constitute the basis of reference data for researchers in clays and clay minerals.

6.4 Future trends into clays and clay minerals in Africa

An overview of themes of recent clay conferences could be indicative of future research trends in the study of clays and clay minerals. These include clays interface and life's origin; clay engineering, ceramics, geology, geochemistry, mineralogy, crystallography, clays and climate change, clays and nano- science, clays and the environment, clays and human health, soils and sediments, instrumentation and techniques applied to clays, among others. Through networking, researchers should be able to seek funding from various funding agencies and government departments which will enable them carry out their research activities.

7. Conclusions

Although the exploitation of mineral resources is widely carried out in the continent, clays and clay minerals have not been the focus of minerals exploitation. Mining outcomes of the 2002 world summit on sustainable development (WSSD) held in Johannesburg, spelt that mining benefits should be directed at poverty eradication; changing unsustainable patterns of consumption and production; and the implementation of initiatives for sustainable development, among others. One of the prime ways of promoting sustainable development could be through directed research led by African scholars in knowledge generation related to clay and clay minerals in the continent.

Africa has witnessed the migration of its researchers largely due to the presence of non competitive working conditions in the continent, including very inadequate investment in S&T for R&D. The continent is focused on stretching its meager resources to cover several competing projects of paramount interest. That notwithstanding there is diverse types of deposits and occurrences of clays and clay minerals in the continent which call for basic and applied research. An immediate and vigorous response intervention is required from stakeholders including researchers, governments, industries, national and international corporations, organizations and agencies. Collaboration and networking of researchers engaged in the study of clays and clay minerals should be encouraged and implemented by relevant organized bodies of knowledge and institutions.

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