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ENGINEERING GEOLOGY

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Clay minerals and their distinct properties

**Clay** refers to naturally occurring material composed primarily of fine-grained minerals, which is generally plastic at appropriate water contents and will harden when fired or dried. The minerals found in clay are generally silicates less than 2 microns (one millionth of a meter) in size, about the same size as a virus. Clays are very abundant at the earth's surface; they form rocks known as shales and are a major component in nearly all sedimentary rocks. The small size of the particles and their unique crystal structures give clay materials special properties, including cation exchange capabilities, plastic behaviour when wet, catalytic abilities, swelling behaviour, and low permeability.

**Clay minerals** are hydrous aluminium phyllosilicates, sometimes with variable amounts of iron, magnesium, alkali metals, alkaline earths, and other cations found on or near some planetary surfaces.

Clay minerals belong to the phyllosilicate family of minerals, which are characterized by their layered structures composed of polymeric sheets of silica tetrahedra attached with octahedral sheets. Research on clay minerals has received considerable attention because of their natural prevalence, reactivity, low cost, nonhazardous nature in handling, etc. Clay minerals have been widely investigated for their significance in various environmental, industrial, and geological settings.

Clays and clay minerals have been mined since the Stone Age; today they are among the most important minerals used by manufacturing and environmental industries.

Chemical And Physical Properties

* **Ion exchange**

Depending on deficiency in the positive or negative charge balance (locally or overall) of mineral structures, clay minerals are able to adsorb certain cations and anions and retain them around the outside of the structural unit in an exchangeable state, generally without affecting the basic silicate structure. These adsorbed ions are easily exchanged by other ions. The exchange reaction differs from simple sorption because it has a quantitative relationship between reacting ions. The range of the cation-exchange capacities of the clay minerals is given in the Table.

| **Cation-exchange capacities and specific surface areas of clay minerals** |
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| **mineral** | **cation-exchange capacity at pH 7 (milliequivalents per 100 grams)** | **specific surface area (square metres per gram)** |
| \*Upper limit of estimated values. |
| **kaolinite** | 3–15 | 5–40 |
| **halloysite (hydrated)** | 40–50 | 1,100\* |
| **illite** | 10–40 | 10–100 |
| **chlorite** | 10–40 | 10–55 |
| **vermiculite** | 100–150 | 760\* |
| **smectite** | 80–120 | 40–800 |
| **palygorskite-sepiolite** | 3–20 | 40–180 |
| **allophane** | 30–135 | 2,200\* |
| **imogolite** | 20–30 | 1,540\* |

The ion-exchange properties of the clay minerals are extremely important because they determine the physical characteristics and economic use of the minerals.

* **Clay-water relations**

Clay materials contain water in several forms. The water may be held in pores and may be removed by drying under ambient conditions. Water also may be adsorbed on the surface of clay mineral structures and in smectites, vermiculites, hydrated halloysite, sepiolite, and palygorskite; this water may occur in interlayer positions or within structural channels. Finally, the clay mineral structures contain hydroxyls that are lost as water at elevated temperatures.

* **Interactions with inorganic and organic compounds**

Smectite, vermiculite, and other expansible clay minerals can accommodate relatively large, inorganic cations between the layers. Because of this multivalency, the interlayer space is only partially occupied by such inorganic cations that are distributed in the space like islands. Hydroxy polymers of aluminum, iron, chromium, zinc, and titanium are known examples of the interlayering materials. Most of these are thermally stable and hold as pillars to allow a porous structure in the interlayer space. The resulting complexes, often called pillared clays, exhibit attractive properties as catalysts—namely, large surface area, high porosity, regulated pore size, and high solid acidity.

**Physical properties**

Clay mineral particles are commonly too small for measuring precise optical properties. Reported refractive indices of clay minerals generally fall within a relatively narrow range from 1.47 to 1.68. In general, iron-rich mineral species show high refractive indices, whereas the water-rich porous species have lower ones. Specific gravities of most clay minerals are within the range from 2 to 3.3. Their hardness generally falls below 21/2, except for antigorite, whose hardness is reported to be 21/2–31/2.

**Size and shape**

These two properties of clay minerals have been determined by electron micrographs. Well-crystallized kaolinite occurs as well-formed, six-sided flakes, frequently with a prominent elongation in one direction. Halloysite commonly occurs as tubular units with an outside diameter ranging from 0.04 to 0.15 micrometre.

**High-temperature reactions**

When heated at temperatures beyond dehydroxylation, the clay mineral structure may be destroyed or simply modified, depending on the composition and structure of the substance. In the presence of fluxes, such as iron or potassium, fusion may rapidly follow dehydroxylation. In the absence of such components, particularly for aluminous dioctahedral minerals, a succession of new phases may be formed at increasing temperatures prior to fusion. Information concerning high-temperature reactions is important for ceramic science and industry.

Solubility

The solubility of the clay minerals in acids varies with the nature of the acid and its concentration, the acid-to-clay ratio, the temperature, the duration of treatment, and the chemical composition of the clay mineral attacked. In general, ferromagnesian clay minerals are more soluble in acids than their aluminian counterparts. Incongruent dissolutions may result from reactions in a low-acid-concentration medium where the acid first attacks the adsorbed or interlayer cations and then the components of the octahedral sheet of the clay mineral structure. When an acid of higher concentration is used, such stepwise reactions may not be recognizable, and the dissolution appears to be congruent. One of the important factors controlling the rate of dissolution is the concentration in the aquatic medium of the elements extracted from the clay mineral. Higher concentration of an element in the solution hinders to a greater degree the extractions of the element.

**OTHER PROPERTIES;**

* Clays form flat hexagonal sheets similar to the micas.
* Clay minerals are common weathering products (including weathering of feldspar) and low-temperature hydrothermal alteration products.
* Clay minerals are very common in soils, in fine-grained sedimentary rocks such as shale, mudstone, and siltstone and in fine-grained metamorphic slate and phyllite.
* Clay minerals are usually (but not necessarily) ultrafine-grained (normally considered to be less than 2 micrometres in size on standard particle size classifications) and so may require special analytical techniques for their identification and study. These include x-ray

diffraction, electron diffraction methods, various spectroscopic methods such as Mössbauer spectroscopy, infrared spectroscopy, Raman spectroscopy, and SEM-EDS or automated mineralogy processes. These methods can be augmented by polarized light microscopy, a traditional technique establishing fundamental occurrences or petrologic relationships.

**Geology of Nigeria**

The basement complex is one of the three major litho-petrological components that make up the geology of Nigeria. The Nigerian basement complex forms a part of the Pan-African mobile belt and lies between the West African and Congo Cratons and south of the Tuareg Shield. It is intruded by the Mesozoic calc-alkaline ring complexes (Younger Granites) of the Jos Plateau and is unconformably overlain by Cretaceous and younger sediments. The Nigerian basement was affected by the 600 Ma Pan-African orogeny and it occupies the reactivated region which resulted from plate collision between the passive continental margin of the West African craton and the active Pharusian continental margin. The basement rocks are believed to be the results of at least four major orogenic cycles of deformation, metamorphism and remobilization corresponding to the Liberian (2,700 Ma), the Eburnean (2,000 Ma), the Kibaran (1,100 Ma), and the Pan-African cycles (600 Ma). Nigeria is situated within the Pan African mobile belt and sandwiched between the West African Craton to the west, the Taureq Shield to the north and the Congo Craton to the southeast. About half of the total area of Nigeria landmass is underlain by rocks of the Precambrian age known in the country as the Basement Complex. The remaining half is covered by Cretaceous to Quaternary sediments and volcanics. The basement complex is divided into two provinces: The Western Province and the Eastern province. The Western Province is approximately west of longitude 8⁰E, typified by N-S to NNE-SSW trending schist belts separated from one another by migmatites, gneisses and granites. This trend is believed to be the result of Pan African orogeny involving collision between the West African Craton and the Pan African mobile terrain with and eastward dipping subduction zone. The schist belts are differently interpreted as small ocean basins, infilled rift structures or synclinal remnants of an extensive supracrustal cover. The Eastern Province lies approximately east of longitude 8⁰E and is more nearly NE-SW. When followed eastward into Cameroon, the trend changes to ENE-WSW (e.g. Ngaoundere mylonite zone and the schist belts near Batare). The Eastern Province comprises mainly migmatites, gneisses and large masses of Pan-African granitoids (Older Granites) intruded in Jos plateau, by Jurassic peralkaline granites. Except for smaller schist occurrences around Madagali (Hawal Massif), Toungo and Gayam (Adamawa Massif) and Oban Massif in southeast, the Eastern Province is marked by the absence of major schist belts.

**Nigerian Basement Complex**

Nigeria is almost equally divided between crystalline basement rocks and Cretaceous to Quaternary sediments and volcanics. The basement complex is commonly described under three lithologic groups:

* A migmatite gneiss complex (MGC),
* The schist belts
* Older Granites suites

The Cretaceous to Recent sediments are preserved in structurally controlled basins (Benue, Bida, Niger Delta, Dahomey, Sokoto and Chad).

The Migmatite gneiss complexes are believed to be the oldest rocks of the Nigeria Basement Complex. Much of the complex is believed to be reworked older crust (probably Liberian in age) which has been further reworked by later orogenies like the Eburnean (2000 + 200 Ma) and the Pan African (600+150 Ma) with addition of the granitoids and the schist belts. Although evidence of sedimentation and deformation during Kibaran (1300-1100 Ma) has been recognised, no magmatic event of this age has been recorded. The Kibaran was followed by ages ranging from 900-450 Ma representing the imprint of the Pan African event which gave rise to migmatite, gneisses, Older Granite intrusives and similar lithologic units. The middle and late Paleozoic age is not represented by any magmatic or sedimentation event. The Mesozoic is marked by uplift and intrusion of a series of anorogenic, alkaline, shallow sub-volcanic intrusive known as the Younger Granites which fall within a N-S narrow belt in the western part of the Eastern Province and extends north ward into Niger Republic. The middle Cretaceous marked the beginning of sedimentation following the development of early rifts that were initiated in early Jurassic. Marine transgression marked by the growth of transcontinental seas and epirogenic movements resulted in the formation and infilling of the many basins flanking the basement highs. Periodic sedimentation continued through the Tertiary and Quaternary .

**Mineral belts**

Mineral belts in Nigeria are divided into the Pan African mineral belts and the Mesozoic to Cenozoic belts. The Pan African Mineralisation belts include the Gold schist belts, the Chromite belt and the Sn-Ta Pegmatite belt all in the Western Province of the Nigerian Basement Complex. The Mesozoic-Cenozoic belts are the Younger Granite Sn-Nb Belt and the Benue Trough Pb-Zn in the Eastern province of the Nigeria Basement Complex. It should be stated here that Mineral belts as use in this work does not mean the same thing as metallogenic province, as the belts are relatively small and the deposits in each, not necessarily formed by the same geologic processes or the same metallogenic event. Thus the mineral belts are simply linear geologic features in which small and mostly low grade epigenetic and/or syngenetic mineral occurrences and deposits of a particular paragenesis are found.

Here is the list of the most frequent mineral resources in Nigeria, and the states where they usually can be found:

* Bitumen – Lagos, Edo, Ondo, Ogun.
* Coal – Ondo, Enugu.
* Oil and gas – Akwa Ibom, Abia, Bayelsa, Edo, Delta, Rivers, Imo.
* Gold – Edo, Ebonyi, Kaduna, Ijesha, Oyo.
* Iron ore – Benue, Anambra, Kogi State, Kwara, Delta State.
* Lead and zinc – Ebonyi, Benue, Ogoja, Kano.
* Salt – Akwa Ibom, Abia, Ebonyi, Cross River.
* Tin – Jos, Bauchi.