

Mineralogical studies of tertiary shales from k-well Akiri field, Niger delta

Chikodili Judith Anameje ^{1,*}, Michael M. Inyang ², Igboke John Elebe ¹ and Sonia Shailong ¹

¹ Department of Geoscience, Federal Polytechnic of Oil and Gas Bonny, School of Applied Sciences, Bonny, Rivers State, Nigeria.

² Department of Geology, University Of Portharcourt, Faculty of Sciences, Port Hacourt, Rivers state, Nigeria.

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Abstract

Shale cuttings from the K-Well (Akiri) in the Niger Delta have been analysed for their mineralogical and geochemical compositions. Analysis of the 2m portion from the 2183, to 3,720m stratigraphic period was performed using X-ray diffraction, inductively coupled plasma optical emission (ICP-OES), and mass spectrometry (ICP-MS). Many types of clay minerals exist, although kaolinite and chlorite predominate. From 3250-3720m in altitude, the illite/smectite composition shifts from a phase with 32% illite layers to a phase with 82% illite layers. Shallow shales had a drop in kaolinite concentration (from 22-16%) whereas deep shales saw a decline (from 29-22%). Unlike chlorite and feldspar, whose abundance do not rise with depth, but quartz does. In all samples, calcite may be found in minute quantities. In this case, the pore water is the source of the potassium. Total organic carbon (TOC) readings obtained from the shale samples demonstrate a high concentration of organic matter in the rock.

Keywords: Mineralogy; Geochemical; Stratigraphy, Diffraction; Spectrometer

1. Introduction

Shales are clastic sedimentary rocks composed mostly of clay and silt, and they may be fine-grained, laminated, or fissile. The texture determines whether these rocks are clayey, silty, or sandy. Mineral make-up, cementing ingredients, organic matter, depositional setting, and strength are some of the other characteristics used to categorize shale. Shales have a high clay content (average of 57 percent), low strength (5-30 MPa), poor permeability (1×10^6 to 10^{12} m²/s), and are easily eroded by water (susceptible to hydration and swelling when in contact with water). Shales serve as source rocks for petroleum production and as seals in petroleum traps and reservoirs, making them vital to the petroleum industry. The pace of penetration is sluggish and the wellbore is unstable while drilling for oil or gas in shale formations. Drilling fluid, shale interactions and pressure differences between oil/gas wells and shale deposits are the main causes of these issues. Proper monitoring of the drilling fluid density and the use of potassium-base drilling fluid that is insensitive to shale hydration may help avoid or mitigate these issues. The Akata and Agbada Formations are marine/deltaic, plastic, and over-pressured shale beds that serve as both source rocks and seal rocks in the Niger Delta petroleum province.

Shale resource play has grown in significance in the hydrocarbon exploration process over time. Despite hundreds of well penetrations, knowledge of the factors influencing reservoir quality in shale formation is still in its infancy.

A key factor in calculating TOC (total organic carbon) levels is paleoredox. Thorium, vanadium, cobalt, uranium, and nickel are examples of redox-sensitive elements that may be taken into account when estimating the degree of anoxia during deposition. The relative friability of the mudstones may be determined since the inorganic geochemistry is closely related to mineralogy, which plays a vital impact in how easily the formation may fracture.

* Corresponding author: Chikodili Judith Anameje

2. Material and methods

Twenty-one core samples were retrieved from K-Well and analyzed for mineralogical components such as main oxides, trace elements, and rare earth elements as part of this study. Departments of Geology and Chemistry at Delta State University conducted the analyses; using:

- 20 samples from K-Well.
- XRD for Clay mineral identification. These preparation and analytical methods provide data for major elements, trace elements and rare-earth elements.

2.1. Samples

Twenty (20) samples of well cuttings were obtained from the Agbada Formation in the eastern region. Drilling at the Akiri field went through recent layers of the delta-plain to the Upper Oligocene parts of the delta at a depth of 3,753 m (11,260 ft).

2.2. X-Ray Diffraction

It is non-destructive and most effective with materials that are completely or partially crystalline. X-Ray Diffraction is usually abbreviated as XRD.

Because the material being studied is often finely ground to a uniform condition, the process is sometimes referred to as x-ray powder diffraction.

Electromagnetic radiation, or X-rays, are created when a material is struck by an electron beam and the electrons rapidly decelerate. Conventional diffraction uses an X-ray tube set up such that when electrons hit a target, they emit X-rays of predetermined wavelengths that may be further filtered to produce radiation of a single wavelength that can be directed at the sample in the diffractometer. X-rays have a wavelength between 0.05 and 0.25 nm. Crystallographic planes diffract X-rays when they reach the proper angle because the sample is rotated in the beam. The fundamental principle of all X-ray diffraction (XRD) research and interpretation is known as Bragg's Law, and it relates the X-ray wavelength to the angle of diffraction and the distinctive lattice (or d) spacing of the material under investigation [1]. The samples' clay minerals were identified by XRD examination as Kaolinite, Illite, and Montmorillonite; these findings concur with IR.

3. Results and discussion

3.1. Mineralogy

The use of X-ray analysis may be a simple method for identifying the mineralogical composition of shales.

Studies on the mineral composition of Tertiary subsurface sediments in the Niger Delta have shown that the main clay minerals are smectite, kaolinite, mixed-layer illite/smectite, and illite, with minor amounts of chlorite. The mineralogical compositions of clays from the recent delta are comparable. The Tertiary volcanics and Cretaceous sediments of the Benue Trough, as well as rivers that drain the Oban and Bamenda Massifs, have all contributed to the eastern Niger Delta's sedimentary layer. The weathering of the North, Central, and Southwest Nigerian Basement and the Cretaceous sediments that are drained by the Niger and Benue River systems are two sources of sediments that contribute to the creation of the sediments in the central and western Delta. Different clay-mineral assemblages may be found in the sequences from the western, central, and eastern Niger Delta. These variations are hypothesized to be influenced by geothermal gradients, deposition settings, source materials, pore-water chemistry, and basin tectonics. This research employs twenty clay-mineral assemblages from the Akiri well as potential criterion samples. The presence of hydrocarbons in the well under investigation and the mineralogy of clay may be linked.

3.2. Mineralogical Variation

In order to get a rough idea of how much clay minerals there are, there are easy methods to do so. They include peak area measurements and measurements of how high the reflections are above the background using the various correction factors used in this investigation [2, 3]. Brief descriptions of the minerals found in the clay fraction and in the complete rock samples by means of X-ray diffraction examinations are provided below.

The quantitative mineralogy of the depth interval between 2,183 and 3,720m is shown in Tables 1 Figure 1 displays X-ray diffractograms of the 2m fractions from samples with lengths of 2,183m, 2,853m, and 3,720m.

Table 1 Semi-quantitative estimate of clay mineral abundance (%) of < 2 µm size fraction in the Akiri-1 well

Approx Depth (m)	Smectite	I/S	Illite	Kaolinite	Chlorite
2,183	15	16	6	22	23
2,353	17	17	7	21	18
2,520	18	15	7	23	21
2,686	15	20	7	23	23
2,853	14	15	7	17	28
3,020	13	15	4	17	18
3,153	15	19	8	15	23
3,386	13	16	9	16	26
3,553	15	12	6	29	24
3,720	15	19	10	20	20

Kaolinite and chlorite are the most prevalent minerals in the shale at all depths, as can be observed from (Table 1). For the 2 m fraction, the percentage of illite layers in the illite/smectite was calculated. Plotting the findings as a function of depth is shown in (table2). Fig. 2. From 32 percent in the shallow samples that were tested to roughly 82 percent in the sample from 3,720 m, the percentage of illite layers rises. Illite and smectite are randomly interstratified in samples from shallow depths, but ordered interstratification is seen in samples at depths below 2,686. The depth dependence of the shale's chlorite concentration is seen in Fig. 2. Chlorite has a highly erratic fluctuation with depth that cannot be explained by the gain in illite layers caused by the illite/smectite.

Kaolinite is found in all samples, but it is only consistent up to a depth of 2,686 meters. Below that point, it declines and then suddenly increases as you go deeper Fig. 2.

The reduction at 2,686 m is related to the initial loss of smectite and suggests that kaolinite was removed during catalysis.

Table1 displays the relative fraction of smectite in the investigated shale samples, and Fig. 2 illustrates how the smectite concentration varies with depth. Smectite gradually rises between 2,183 and 2,520 meters in depth, after which it gradually falls and stays constant. Smectite loss occurs at the stratigraphic depth range when hydrocarbon occurs.

Table 2 Percentage of illite layers in illite/smectite type interstratification in Akiri-1 well

Depth (m)	% Illites	Type of interstratifications
2183	-	-
2353	-	-
2520	32	Random
2686	46	Ordered
2853	58	Ordered
3020	65	Ordered
3153	70	Ordered
3386	78	Ordered
3553	80	Ordered
3720	82	Ordered

The clay dehydration zone and the presence of hydrocarbons coexist with the reduction in the smectite component. This outcome is in line with Bruce [4] observations and conclusions. He demonstrated the connection between hydrocarbon migration, accumulation, and the change of smectite into illite in clay.

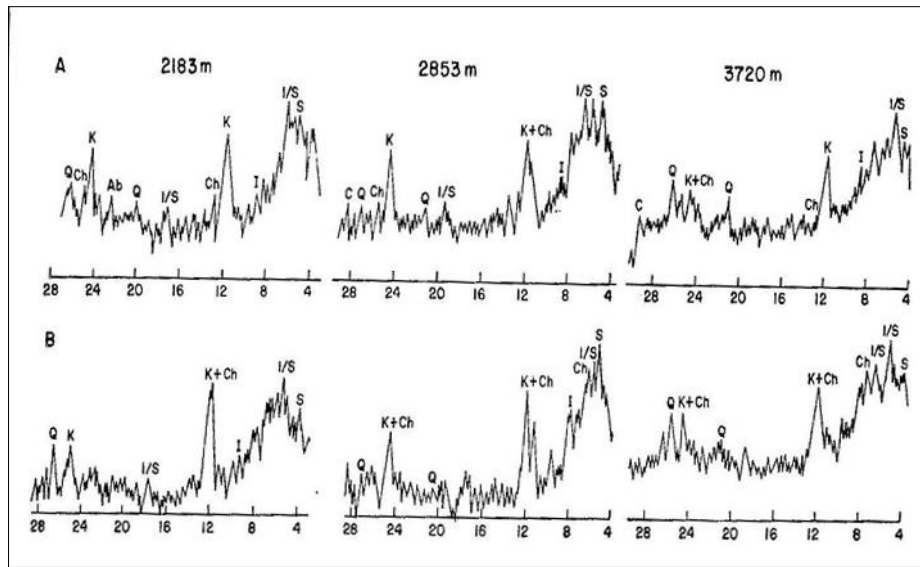


Figure 1 X-ray patterns of (<2μm) size fraction of shale from depths of 2,183, 2,853 and 3,720m. Q: quartz. C: Calcite. Ch: Chlorite. K: Kaolinite. I/S: illite/smectite. I: illite. Ab: Albite. A: untreated. B: solvated with ethylene glycol

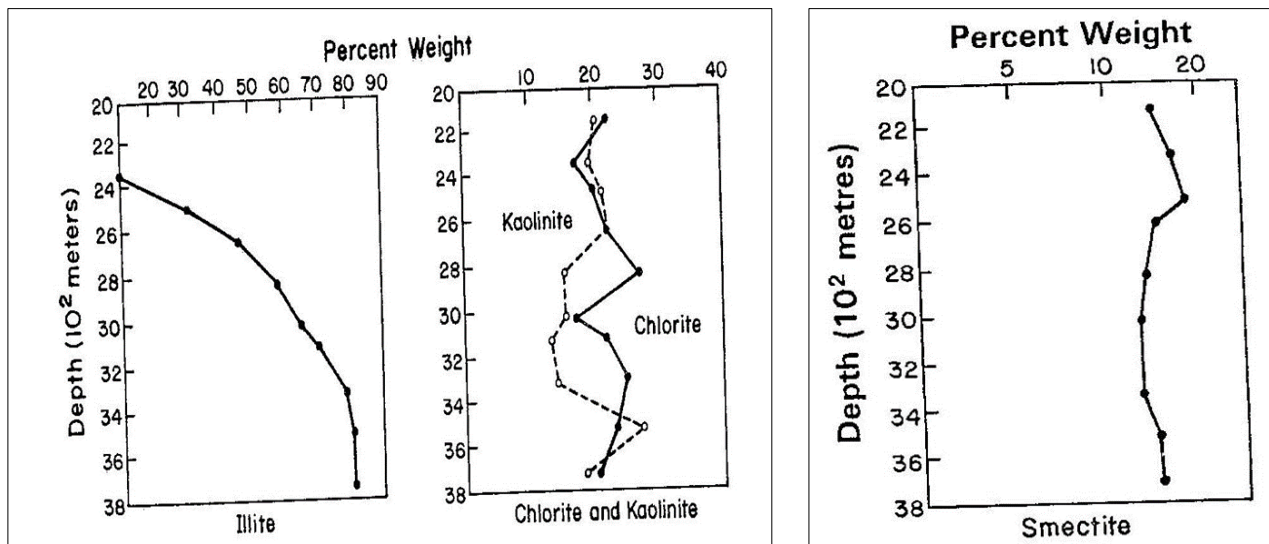


Figure 2 Variation of clay minerals: smectite, illite, kaolinite and chlorite in Akiri-1

3.3. Clay and Clay Minerals

Soft, loosely bonded, fine-grained rocky or earthy substance made mostly of clay particles (with a diameter of less than 0.005 mm). Unlike peat, muck, certain soils, etc., which include enormous amounts of organic/natural ingredients, clays are often inorganic according to the traditional definition of mineral. Soil, ceramic clays, clay shales, glacial clays (including a considerable volume of detrital and transportable clays), and members of the mineral group feldspar (the "mother of clay") are eroded and weathered over long periods of time to generate clay particles. The hydrolysis process that occurs during weathering distorts the feldspar concentration, leading to the development of clay minerals including kaolinites (the principal minerals in kaolin clays) and smectite (the primary minerals in bentonite clays). Even when present in trace amounts, quartz (SiO₂), metal oxides (Al₂O₃, MgO etc.), and organic materials may be incorporated into clay with one or more clay minerals. [5, 6].

3.4. Clay Minerals

Clay minerals are distinctive earth minerals because they form in an environment near the planet's surface (the surface where the outer crust of the object comes into contact with the atmosphere) that contains varying concentrations of ions such as iron, magnesium, alkali metals, alkaline earth metals, and other cations. Diagenetic and hydrothermal modification of rocks in the presence of water creates these, which are considered vital components of soil [7]. Shale, mudstone, and siltstone are all examples of fine-grained sedimentary rocks that often include them. Due to the existence of an imbalanced electrical charge on their surface, clay minerals are able to absorb and store water and dissolved plant nutrients that would otherwise be lost through erosion from other minerals [8]. The majority of clay minerals are hydrous aluminosilicates or hydrous aluminum phyllosilicates since water is required for their production. Clay minerals are formed when rock is chemically weathered [7, 9].

Clay minerals have a chemical and structural composition with the fundamental minerals that form the bulk of the Earth's crust in igneous and metamorphic rocks. Conditions in the environment may undergo changes. Some of the more robust primary minerals, such as quartz, mica, and feldspar, may be preserved in soils, whereas the more fragile pyroxenes and amphiboles are broken down by weathering to generate secondary minerals.

Secondary minerals arise when the structure of a primary mineral is altered (incongruent reaction) or when the dissolved elements of a primary mineral are precipitated (neof ormation) to create a new, more stable crystal structure (congruent reaction). It is likely that these secondary minerals are classified as phyllosilicates due to their platy or flaky structure with uneven edges (Greek: phyllon, leaf), and because one of their most fundamental basic structural units is an extended SiO_4 tetrahedra sheet [10].

3.5. The Importance of Clay Minerals

Clay minerals may be employed as stratigraphic markers as well as environmental indicators of deposition and temperature for the formation of hydrocarbons. The kind of clay present in shale is determined by its source and diagenetic history. Early mineral changes in the depositional environment had a significant impact on clay mineralogy [11].

4. Conclusion

Clay minerals are important indications of their source regions and deposition basins. They provide evidence of the history of transformation and the quantity of chemical energy that went into their birth, has pointed out that climate has a major impact on the development of clay minerals. Due to the potential for environments to have significant effect on mineral suites through early mineral transformation in the basin of deposition, care is warranted when using clay for environmental study. The depositional basins have different compositions of exchangeable cations. Since smectite is converted to illite and other clays throughout diagenesis and tectonics, the quantity of provenance information in old shales is diminished.

The initial chemical composition of the shales in this stratigraphic stratum probably did not change much during the course of its depositional history, with the exception, maybe, of the K_2O concentration. Potassium plays a crucial role in the transformation of smectite into illite. It is hypothesized that the potassium required for this transformation has been delivered via the pore water from sources external to the rock, rather than resulting from the breakdown of potassium feldspar. Results of analyses indicate that potassium is sufficiently dispersed in deep shales for this conversion to take place.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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