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Clay Minerals as Indicator of Phosphatogenesis: A Case Study of Sokoto Basin, Northwestern Nigeria

Onuigbo, E.N.* Okoro, A.U. Nwokeabia, C.N.
Department of Geological Sciences, Nnamdi Azikiwe University, P.M.B. 5025, Awka, Nigeria

Abstract
Phosphate deposits which occur in the Sokoto Basin of northwestern Nigeria is more pronounced in the shales of Dange Formation which recorded value ranges of 32- 36% P_2O_5. Minor occurrences were documented in shale of Dukamaje Formation and the limestone of Kalambaina Formation. However, non phosphatic siltstone, marl, shale and sandstone also occur. Clay mineral evaluation of the phosphatic and non phosphatic units was undertaken in order to study their relationship with phosphatogenesis. Result of analysis shows that the clay mineral distribution in the phosphate bearing sediments and non phosphatic units are consistently different. Kaolinite and hydrargillites are associated with phosphate bearing sediments whereas montmorillonite is typical of non phosphatic ones. The study of clay mineral distribution appears to be a good tool in phosphate exploration in an epicontinental inland basins.
Keywords: Phosphatogenesis, Clay mineral, Sokoto Basin, Kaolinite, Montmorillonite, Paleocene

1. Introduction

Sokoto Basin is the southern part of Lullemmeden Basin. The Lullemmeden Basin is a broader, sedimentary basin that covers northwestern Nigeria, most parts of Niger Republic, Benin Republic, Mali, Algeria and Libya (Obaje et al., 2013).

Sedimentary phosphate deposits occurrences in the Sokoto Basin has been reported (e.g Kogbe, 1976; Nwabufo- Ene, 1982, 1990a and b; Haynes and Nwabufo- Ene, 1990; Okosun, 1989, 1997; Etu- Efeotor, 1998; Ogunleye et al., 2002; Adekeye and Akande, 2004; Okosun and Alkali, 2013; Obaje et al., 2013, 2014a and b; Kolo, 2014). The phosphate occur mainly as nodules with few occurring as pellets in the southern part of the basin. The nodules are found either as thin nodular beds or dissemination in shales and siltstones and the mineralization is more prominent in the Dange Formation (Okosun and Alkali, 2013; Obaje et al., 2014a). The phosphatic nodular bed however, measure between 0.1 m and 0.3 m whereas the nodular dissemination may be up to 6 m in thickness. In the Dukamaje Formation, the thickness of the deposits ranges from 1- 5 m and the phosphatic nodules/pellets occur in different sizes of between 0.1 and 1 cm with varying concentration in different locations (Okosun, 1989; Etu- Efeotor, 1998; Ogunleye et al., 2002). These phosphate deposits show affinity to the phosphate deposits of Morocco, Niger, Jordan and Egypt which belong to the southern Tethyan phosphate province (Okosun and Alkali, 2013). Nwabufo- Ene (1982, 1990a and b) and Haynes and Nwabufo- Ene (1990) had ealier noted that Sokoto phosphatic sediments were derived from a north- south seaway (the Tethys) and are associated with sediments moved from east to west originating from the Chad Basin. Adekeye and Akande (2004) distinguished the phosphates into three microfacies; phosphatic mudstone, peloidal phosphatic wackestone/peloidal phosphatic packstone and oolitic phosphatic grainstone. They interpreted the microfacies as primary and secondary in origin and the primary accumulation of phosphorus- rich muds was attributed to deposition in a low energy reducing environment restricted to transgressive phases. The secondary enrichment of the phosphate was by winnowing and reworking during regression.

The phosphates were mostly deposited during early and middle Paleocene, and show features of an epicontinental setting. The deposition of the phosphates was particularly favoured by changing tectonism which modified the chemistry of the bottom waters. Sites of enhanced phosphate deposition corresponds to three major structural highs and six entrapment sub basins related to shoaling. The climate varied from humid to arid and semi- arid. Weathering, reworking and winnowing marked the subsequent phosphogenic history (Nwabufo- Ene, 1988).

Nwabufo- Ene (1989 a and b) noted the geological significance of clay minerals, Ca/ Mg ratio and carbonate substitution in phosphatogenesis of the Bende- Ameke area, southeastern Nigeria and Sokoto Basin.

This paper deals with clay minerals as indicators of phosphate genesis.

2. Regional Tectonics and Stratigraphic Settings

The Sokoto Basin was probably formed as a result of the Mesozoic rifting and separation of Africa from America. Epeirogenic movements may have led to migration of the centre of the shallow, flat bottomed sedimentary basin (syneclise) of the Saharan platform as indicated by the displacement of marine sediments from the Chad Basin in the east during Cenomanian – Turonian times, to the Lullemmeden Basin in the west, during the Maastrichtian – Paleocene stages. Three phases of deposition have been recognized in the Lullemmeden Basin (Petters, 1977, 1978a and b, 1979a, Haynes and Ene- Nwabufo, 1998; Nwajide, 2013). These include the continental pre- Maastrichtian phase, the marine (in part) Maastrichtian- Paleocene phase and the upper Tertiary continental phase.

The Maastrichtian Rima Group (consisting of Taloka, Dukamaje and Wurno Formations) and the Paleocene Sokoto Group (Dange, Kalambaina and Gamba Formations) in the Sokoto region of northwestern Nigeria were laid down in and around the Saharan epeiric sea that flooded the central Saharan during Latest Cretaceous and Early Tertiary times (Petters, 1978a). An embayment of the Saharan sea extended into Sokoto in northwestern Nigeria.

Taloka Formation is the oldest stratigraphic unit in the Sokoto Basin and consists almost entirely of siltstones. Marine Dukamaje Shale is found between the Taloka Formation and Wurno Formation (consisting also of siltstones and similar to Taloka Formation). The Dange Formation of Paleocene age consisting of grey shale, marl and pale yellow calcareous shale overlies the Wurno Formation. The Dange Formation is overlain by Kalambaina Formation and the Gamba Formation (Fig. 1). The units were deposited during the Late Paleocene. Deposition during Late Tertiary was entirely continental. The Gwandu was deposited during Eocene.

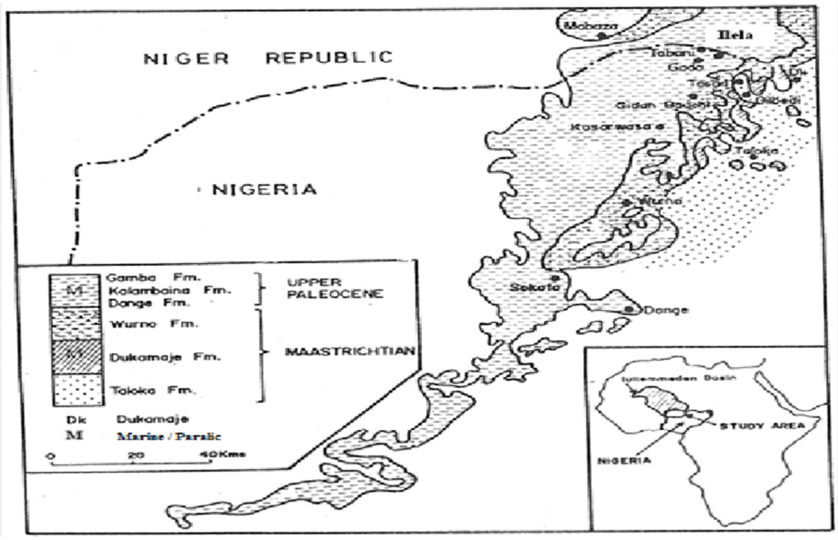

Fig. 1: Outcrop of marine and marginal marine sediments in southeastern Lullemmeden Basin (after Petters, 1977)

3. Methodology

Samples from sections and boreholes which penetrated the Taloka, Dukamaje, Wurno, Dange, Kalambaina and Gwandu Formations were collected. The boreholes were drilled by the Geological Survey of Nigeria and described as GSN BH 4501, 4503 and 2354 (Figs. 2, 3 and 4). Clay fractions (less than 0.002 mm) were then separated for analysis. The clay minerals were determined by X- Ray Diffraction Technique (XRD) and the result is given in Table 1.

4.0 Result

4.1 Lithostratigraphic successions in the boreholes

Boreholes drilled into the basin by Geological Survey Agency of Nigeria at Dange village about 30 kms from Sokoto denoted as BH no. 4501, BH no. 4503 and BH no. 2354 penetrated the Rima Group (consisting of the basal Taloka Formation overlain by the Dukamaja Formation and the Wurno Formation) and the Sokoto Group (the Dange, Kalambaina and Gamba Formations) and the Gwandu Formation (Figs. 2,3 and 4). Figure 5 summaries the lithostratigraphic units of the basin that were penetrated by the boreholes.

BH No 4501

The lithologic section of the borehole from the base consists of black shale of about 2.5 m thick sandwiched in between phosphatic and kaolinitic grey shale (Fig. 2). The general thickness of the units is about 22.5 m. They constitute the members of the Dange Formation. The Dange Formation is overlain by 8 m thick moderately phosphatic limestone of Kalambaina Formation which lies at the depth interval of between 15 m and 7m. Above the limestone and at the depth interval of between 7 m and surface, the reddish brown siltstone with clay bands which constitutes the Gwandu Formation occur.

The Depositional environment is interpreted to range from shallow marine from the base to continental at the top.

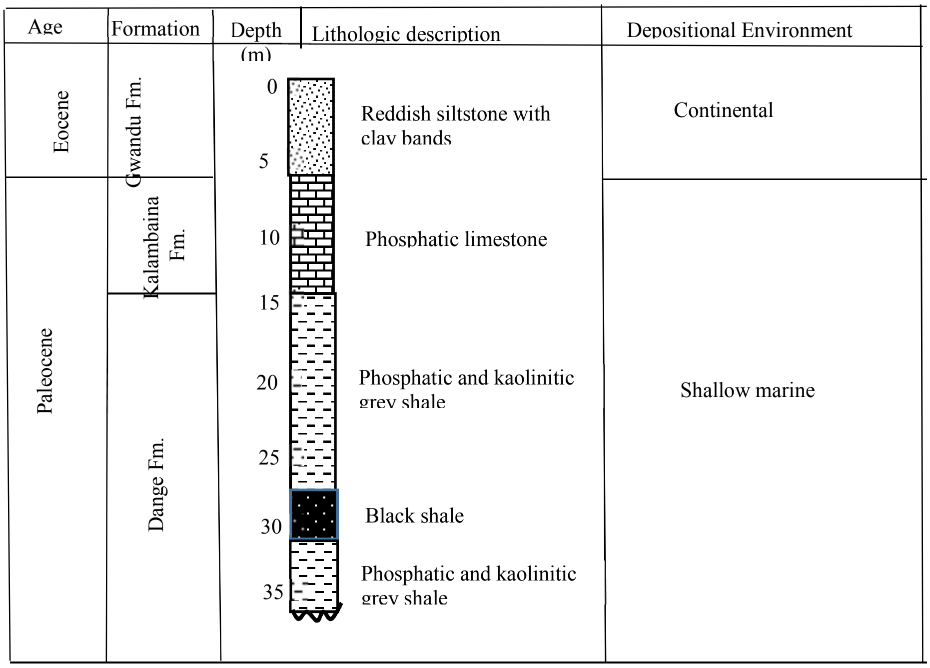

Fig. 2: Lithologic section of GSN Borehole no. 4501 at Dange Village about 30 kms from Sokoto

BH No 4503

The base consists of muddy siltstones which sandwiched the brownish yellow mudstone (generally 16.5 m thick) and lie at the depth interval of 17.5 m and below. The mudstone is about 7 m thick. The siltstones and the mudstone are interpreted as members of the Rima Group consisting predominantly of the Taloka and the Wurno Formations (Fig. 3).

Overlying the Rima Group (Wurno siltstone) at the depth interval of 17.5 m and 2.5 m is inter- bedding of phosphatic grey shales and non phophatic marl (about 0.85 m thick). The grey shale is thicker above the marl unit (11.75 m). These constitutes the Dange Formation. The topmost part (2.5 m to the surface) is the phosphatic limestone member of the Kalambaina Formation.

The depositional environment varied from marginal marine at the base to shallow marine (shelf) at the top.

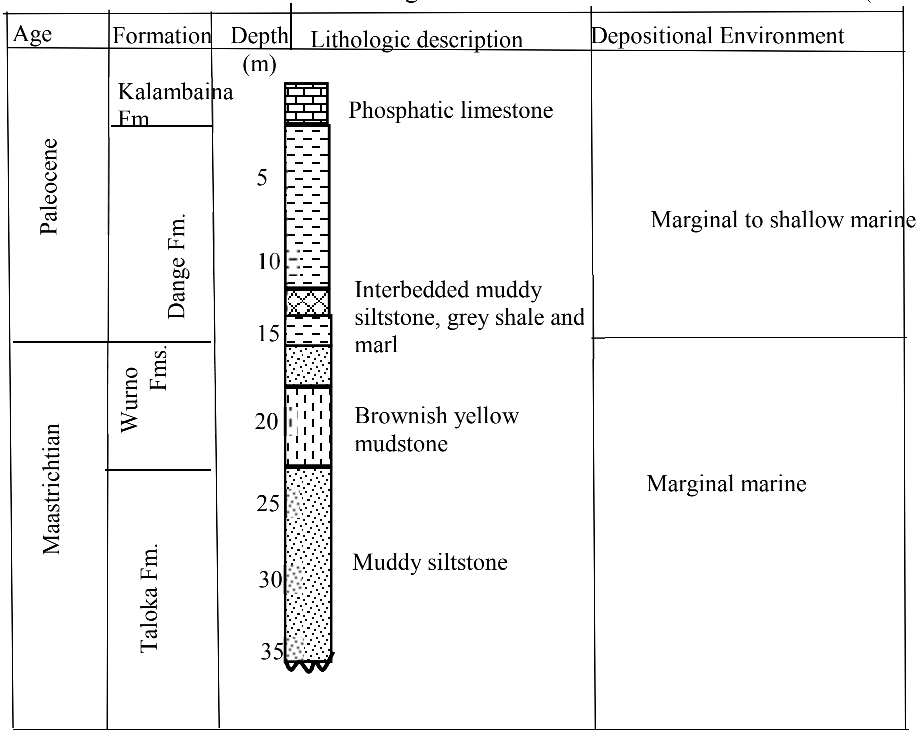

Fig. 3: Lithologic section of GSN Borehole no. 4503 at Dange Village about 30 kms from Sokoto

BH No. 2354

The base of the borehole consists of phosphatic grey shale of about 0.75 m thick at the depth of 18 m and below which constitutes the Dange Formation. The grey shale is overlain by 15 m thick phosphatic limestone and pale yellow shale of about 2.5 m thick of Kalambaina Formation (Fig. 4).

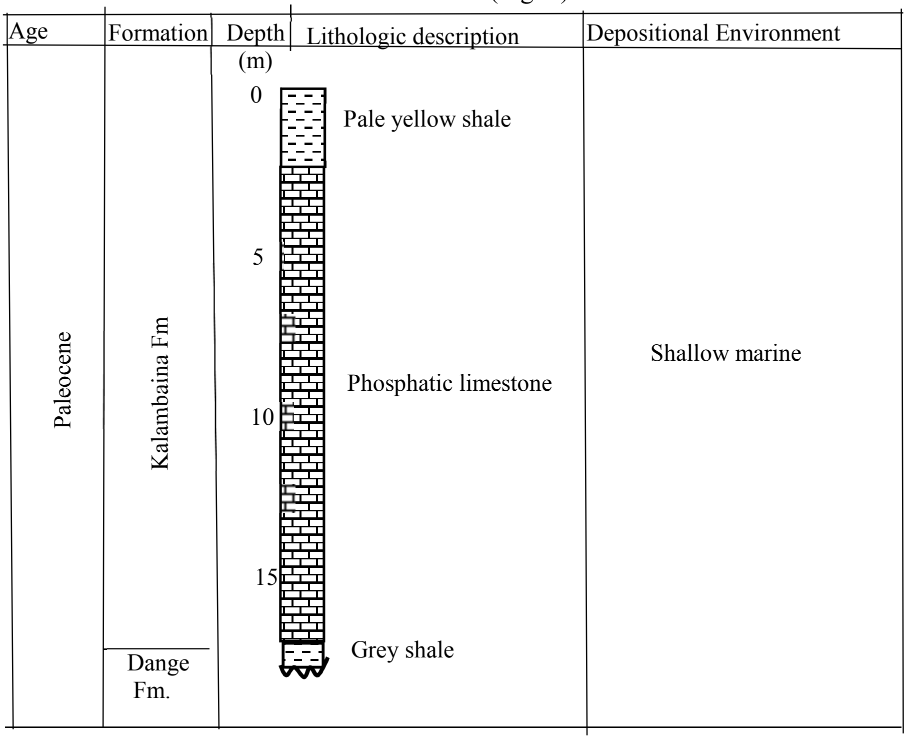

Fig. 4: Lithologic section of GSN Borehole no. 2354 at Dange Village about 30 kms from Sokoto

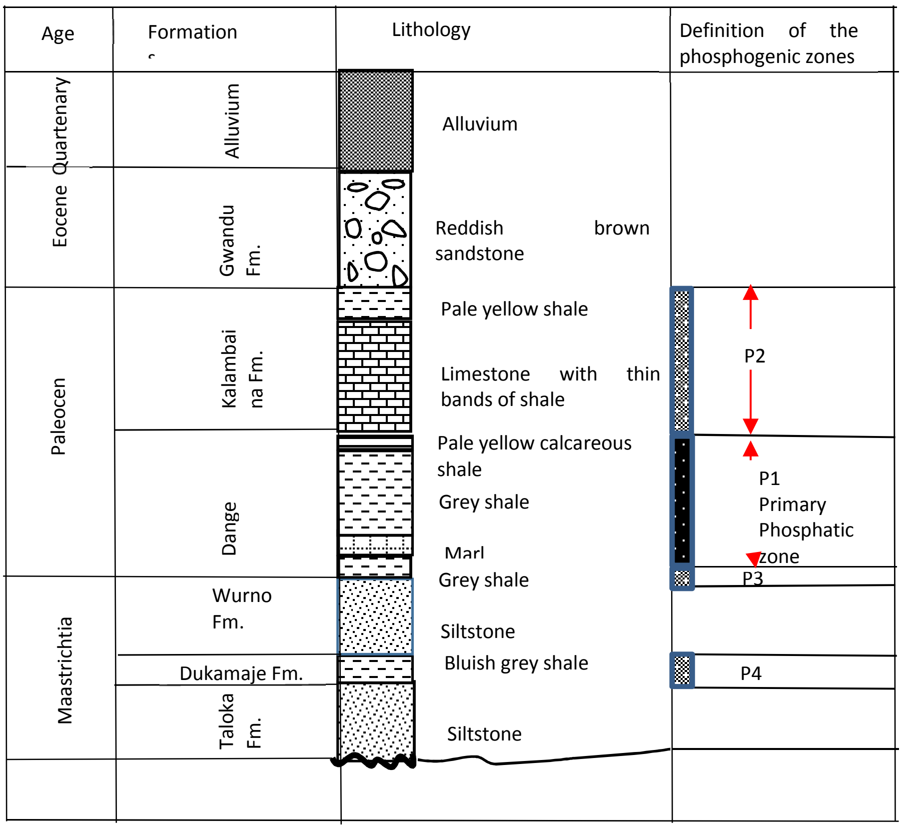

Fig. 5: The summarized stratigraphic successions penetrated by the boreholes at Dange Village showing the phosphogenic zones

Clay Mineral Analysis

The summary of result obtained from clay mineral analyses is shown in Table 1. The samples from the Taloka and Wurno Formations yielded mostly montmorillonite with some illite and chlorite. Zeolite (clinoptilolite) and cristobalite are also present. The Gwandu Formation has a similar clay mineral composition. The Dukamaje Formation has mostly kaolinite and surbodinate amounts of hydrargillite. Zeolite and glauconite are also present. The clay minerals in the Dange Formation (excluding the marl units) and the Kalambaina Formation are similar to the Dukamaje Formation. Kaolinite is most abundant in the Dange Formation.

The phosphorite concretions contain small amounts of glauconite, chlorite and leptochlorite.

The phosphate bearing sediments (the stratigraphic units in Dukamaje, Dange and Kalambaina Formations) have clay mineral complexes consisting predominantly of kaolinite with some hydrargillite, zeolite and cristobalite. Chlorite and glauconite also occur in varying amounts. The Taloka, Wurno and some stratigraphic units of Dange, Kalambaina as well as the Gwandu Formations contain clay mineral complexes which are mostly montmorillonite, chlorite and zeolite. Cristobalite also occur. Hydrargillites and kaolinites were not recorded.

Table 1: Clay minerals identified in the various stratigraphic units of the Sokoto Basin

Formation	Lithology	Phosphate occurrences	Clay minerals
Gwandu	Reddish brown sandstone and mudstone	Not phosphatic	Montmorillonite, Zeolite, Chlorite and Cristobalite
Kalambaina	Pale yellow shale	Not phosphatic	Montmorillonite and Cristobalite
	Limestone with thin band of shale	Moderately phosphatic limestones	Kaolinite and Hydrargillite with Zeolite
Dange	Pale yellow calcareous shale	Phosphatic	Kaolinite and Hydrargillites
	Grey shale with marl band	Phosphatic shales; nodules up to 36% P_2O_5	Kaolinite, Chlorite, Glauconite, Zeolite, Hydrargillite and Cristobalite
	Marl	Not phosphatic	Montmorillonite with small amounts of Chlorite
	Grey shale	Phosphatic 10- 32% P_2O_5	Kaolinite and Hydrargillite
Wurno	Siltstone	Not phosphatic	Montmorillonite, Illite, Chlorite, Zeolite and Cristobalite
Dukamaje	Bluish grey shale	Slightly phosphatic less than 10% P_2O_5	Kaolinite, Chlorite, Hydrargillite and Glauconite
Taloka	Siltstone	Not phosphatic	Montmorillonite, Illite, Chlorite, Zeolite and Cristobalite

5. Discussion

Zann et al. (1988) recorded similar clay mineral distribution in the Enisey Mouth depression of Northern Siberia. Analysis of the clay fraction (less than 0.002 mm) of samples from the Upper Cretaceous deposits enabled the authors to reconstruct the paleoclimatic conditions that prevailed during the period of phosphate genesis. They concluded that phosphate bearing sediments have clay mineral complexes consisting predominantly of kaolinite with small but constant admixtures of hydrargillite. Non phosphatic deposits have mostly montmorillonite. According to the authors, such a distribution of clay minerals indicate the formation of phosphate bearing sequences during intense chemical weathering of the continental landmass, in association with warm and humid climatic conditions. Continental weathering has been noted as a factor that may directly control rates of phosphogenesis on shelves (e.g Barron and Frakes, 1990; Glenn and Arthur, 1990; Delaney and Filippelli, 1994; Ilyin, 1994) and that global warming at times of sea level rises led to enhanced chemical weathering of the hinterland, causing high supply of continental P to the shelves and increased phosphate formation (Soudry et al., 2006). Diverse kaolinite and chlorite bearing phyllosilicate assemblage has also been interpreted as being sourced from the continent (Dupuis et al., 2003; Ernst et al., 2006) and was likely induced by a sea level rise.

Nwabufo- Ene (1982, 1988) observed that the phosphates of the Sokoto Basin were deposited in an epicontinental inland sea. This is similar in many respects to the Enisey Mouth depression of Northern Siberia. The phosphate bearing sandy silty clayey Santonian and Maastrichtian sediments in the Enisey Mouth depression have similar clay mineral distribution (i.e kaolinite with small admixtures of hydrargillite) with the phosphorite horizons in the Sokoto Basin (the Dukamaje, Dange and Kalambaina Formations). The clay mineral distribution in the non phosphatic silty clayey Campanian sediments in the former area (montmorillonite etc) is similar to the clay mineral distribution in the non phosphatic Taloka, Wurno, parts of Dange and Kalambaina Formations as well as the Gwandu Formation. The paleoclimatic conditions in the two areas appear to be similar.

6. Conclusion

The clay mineral distribution in the phosphate bearing sediments and those that are not associated with phosphates are consistently different in the Sokoto Basin. Kaolinite and hydrargillite are indicative of phosphate bearing sediments whereas non phosphatic sediments are marked by montmorillonite. The study of clay mineral appear to be a good tool in exploring for phosphates in epicontinental inland basins.

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