Petrographic Analysis of the Palaeocene-Eocene Phosphate-Bearing Rocks of Eastern Dahomey Basin, Southwestern Nigeria.

Timileyin Olanipekun (olanipekuntimileyin@gmail.com)
Ekiti State University
Anthony Bolarinwa
University of Ibadan

Article

Keywords: Phosphorites, Eastern Dahomey Basin, Petrography, Fluorapatite

Posted Date: October 7th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-88244/v1

Abstract

Phosphorus is ubiquitous for its essential function in plant growth. Phosphate-bearing rocks include phosphorites and rocks that host phosphate mineral. Phosphorites, rocks containing ≥18 % phosphorus-pentoxide (P2O5), are essential sources of phosphorus. Due to the vast application of phosphorites in the manufacture of fertilisers and industrial products, the study of phosphate bearing rocks is crucial. This article examines the mineral component and structure of phosphate-bearing rocks in the Eastern Dahomey Basin, Southwestern Nigeria. Eleven pulverised samples of phosphatic rocks were analysed, employing a microscope, for petrographic studies. Three major types of phosphorites exist in the Eastern Dahomey Basin: Granular (which are composed of oolitic and pelletal structures), Nodular (which comprises cylindrical, rectangular, ellipsoidal shapes), and the vesicular (which either have coarse or fine forms) varieties. The phosphorites contain fluorapatite (as the dominant mineral), calcite, quartz, and glauconite. Generally, the phosphorites are fossiliferous (lamellibranches, echinoderms, shell, and bone fragments are observable). The phosphatic limestones are micrite (allochems) hosting collophane (specks of fine-textured fluorapatite) and glauconite. While fluorapatite occurs in the phosphatic claystone, it is glauconitic, just as the gypsum. The results of the petrographic analysis indicated the influence of seawater in the deposition of the phosphate-bearing rocks in an oxic environment.

1. Introduction

Natural phosphorus, which is essential for plants' growth, can be derived from phosphorite. Phosphate-bearing rocks include phosphorites. Commonly, phosphorite contains phosphorus pentoxide (P_2O_5) in appreciable quantity. According to Nathan (1984), phosphorites (usually of the non-detrital sedimentary variety) have at least 18 percent (≥ 18%) phosphorus-pentoxide (P_2O_5). A substantial quantity of phosphorites is critical materials in the manufacture of fertilisers, animal feeds, and other industrial products (such as phosphoric acids, cleaning agents, cosmetic products, and paints).

Phosphorites, with a crustal abundance of 0.12%, can be found in these forms with their corresponding proportion in the world: marine sedimentary deposits (75%), igneous, metamorphic and weathered deposits (15–20%), and guano deposits, derived from biogenic sources (2–3%). However, the remaining (2–8%) are unaccounted for (McKelvey *et al.*, 1953; Jasinki, 2015; Abou El-Anwar et al., 2017). While about 200 minerals with 1% or more P_2O_5 content are known, apatite is dominant in phosphorite (Palache et al., 1951; Altschuler et al., 1958; Deer et al., 1962). Apatite has a chemical formula, $Ca_5 (PO_4, CO_3)_3$ (OH, F, Cl). Apatite can exist in these forms—due to anionic substitution for the carbonate component in apatite—which are denoted by the corresponding prefixes, in a manner that follows the chemical formula stated earlier: Hydroxyapatite, Fluorapatite, and Chlorapatite, however, if a carbonate mineral such as calcite substitutes (through a partial replacement of carbonate ions) for some phosphate components, carbonate-fluorapatite (known as francolite) is formed. Also, other minerals, among a plethora of varieties, that host phosphorus are brushite ($HCaP0_4 . 2H_20$), monetite ($HCaP0_4$), whitlockite ($3Ca_3(P0_4)_2$),

crandallite ($CaAl(P0_4)_2(OH).5H_20$), wavellite ($Al_3(OH)_3(P0_4)_2.5H_20$), taranakite ($K_2Al_6(P0_4)_6(OH)_2.18H_20$), millisite ($(Na, K) CaAl_6(P0_4)_4(OH)_5.3H_20$), variscite ($AlP0_4.2H_20$), and strengite ($FeP0_4.2H_20$).

Phosphorites occur in some African basins. However, the most prolific basins for phosphate-rock mining are those in North Africa. The formation of Dahomey Basin's phosphorites dates from the Palaeocene to Eocene. The geological association subtlety varies in African basins. For example, the North African basins commonly have a thick bed of phosphorites interbedded by limestones and marls such as those reported in the Metaloui Basin, Tunisia (Garnit et al., 2017), in Tebessa region, Algeria (Rabah Kechiched et al., 2018). In West African basins, the phosphorites occur in sandstones as phospharenites. However, these phosphatic rocks are associated with sandy clays, limestones, dolomites, claystones, marls, and cherts (Pierre, 2014).

According to Whiteman (1982), the Dahomey Basin (Fig. 1) is a vast sedimentary basin on the Gulf of Guinea's continental margin. This trough extends 440 km from the Volta-Delta (Ghana) in the west to the Okitipupa-Ridge (Nigeria) – also known as Ilesha-Spur-in the east; its 224 km width spans from the Northern onshore margin (in Dahomey, Benin Republic) to the Bathymetric contour (Offshore Dahomey). In terms of structural configuration, the Dahomey Basin falls within the Romanche (South-eastern Ghana) and Chain (South-western Nigeria) Fracture Zones (Jones and Hockey, 1964; Gbadamosi, 2009). Consequently, different parts of the Dahomey Basin, with a similar lithostratigraphy, are found in Ghana, Togo, Benin Republic, and Nigeria.

Phosphate-bearing rocks exist in the Dahomey Basin's Nigerian section and are within the Ososun (spelt as Oshosun in some other literature) and Ilaro formations. The Ososun formation phosphorites are bioclastic, based on their composition of skeletal fragments that form bone beds within the formation (Abimbola et al., 2002; Adesanwo et al., 2010). In the Dahomey Basin, the phosphorites commonly occur as interbeds with limestone and very thin beds (laminae) of gypsum. In most cases, the overlying rock is a shale with some clays as surficial deposits (Antolino, 1968; Abimbola et al., 2002). Besides, phosphorites as intrapelites and intraclasts within cross-bedded grits—that is typical of the Ilaro formation— occur in Eastern Dahomey Basin, Southwestern Nigeria (Adesanwo et al., 2010).

While discussions about the Eastern Dahomey Basin's rock stratigraphy are extensive, little information (such as the Russ (1924) study of phosphorites' composition) exists about the petrographic description the phosphorites in this region. Under a thin section using a microscope, rocks' study offers insights about the mineral content and rocks' arrangement. Shreds of evidence from Adesanwo et al. (2010) provided some information about the mineral make-up and configuration of the phosphorites at Ososun. Notwithstanding, details about phosphatic rocks in other areas (such as Oja-Odan and Igbeme) within the basin want. This academic article examines the detailed petrography of phosphatic rocks in four locations within Southwestern Nigeria. Plus, it elucidates the mineralogical and palaeontological components for suggestive depositional conditions of these rocks.

Figure 1: Outcrop geology of Dahomey Basin showing stratigraphy (Kaki *et al*., 2013. 1 - Alluvium (Recent); 2 - Benin-Ijebu Formation (Pleistocene/Upper Miocene); 3 - Ososun Formation (Middle Eocene); 4 - Imo Shale (Lower Eocene/Paleocene); 5 - Araromi Shale and Turonian Sandstone/Afowo Formation (Upper Cretaceous); 6 - Pre-Cambrian Crystalline Basement; 7 - Core hole or water well; 8 - Dry well; 9 - Oil well; 10 - Faults; 11 -Water depth contour.

2. Methods And Materials

2.1 Sampling locations

Well-labelled samples from the field totalled eleven (Fig. 2). This work took place at the following localities in the Eastern Dahomey Basin, Southwestern Nigeria: Igbeme, Oja-Odan, Ososun, and Ebiti.

Igbeme is a village off the Ilaro-Oja-Odan-Benin-Republic-international-border expressway. An excavated site (latitude 06^0 56' 09.3" N and longitude 02^0 43' 57.2" E) exposes part of the Dahomey Basin's stratigraphy. Each sample obtained from this location were phosphatic shale, gypsum, and phosphatic limestone. More importantly, these samples were labelled to avoid mix-up during analysis.

Oja-Odan is about 20 km west of Ilaro (from the town's point of entry). Two sampled locations were: The Forest Reserve (a property of the Ogun State's Ministry of Environment - latitude 06^0 53' 22.3" N and longitude 02^0 49' 46.7" E) and a cocoa plantation (6^0 52' 25.2" N, 02^0 51' 26.6" E)—about 5 km northwest of the forest reserve—enclaved by maize and palm plantations at Abule Feyisetan. At these respective locations, one sample of phosphatic limestone was picked and appropriately labelled.

Ososun and Ebiti areas possess phosphorite exposures. Each sample of the nodular, granular, and vesicular forms of phosphorites was collected and labelled.

2.2 Rock thin section preparation

The thin section slides prepared for the petrographic analysis took place at the Department of Geology, University of Ibadan, Nigeria. Fresh field samples were washed with distilled water to remove all agglutinated sediments (like sands and clays). Airdrying of the samples took place for four weeks. The photographed air-dried samples (described as hand specimens in Fig. 3.1–3.3) exist for documentation and appropriate matching.

A Logitech sawing machine sized each of the eleven rock samples into smaller dimensions (about 3 cm by 3 cm). The rock samples were mounted by glazing, with an Araldite glue, on new thin section slides. After that, these mounted-rock-slides (m-r-s) underwent lapping. Lapping is vital in the thin section preparation of rock samples. Carborundum (silicon carbide) served as the active ingredient during lapping (a process of making the surface of the m-r-s hazy). It took a mean time of 5 min to lap each slide. The essence of this is to make the m-r-s transparent for light rays to pass through them.

2.3 Petrographic study

The minerals present in the rock were identified, as subject to what is contained in the slides, by their unique optical properties, under the petrographic microscope using both transmitted and reflected lights.

Finally, photomicrographs are obtainable using a camera attached to the petrographic microscope (magnification − 500 X). Furthermore, the photomicrographs were well labelled.

3. Results And Discussion

The photomicrographs (Figs. 3.1–3.4) represent the rock samples from the field. Phosphatic limestone is observable (Fig. 3.1). The phosphatic limestone at Igbeme is a micrite (calcite mud) (Fig. 3.1 A); it precipitated from seawater with little terrestrial influence during deposition. The phosphate mineral (fluorapatite) was identifiable as scattered specks of brown-coloured collophane (Fig. 3.1 A). The phosphatic limestones at Oja-Odan, unlike those at Igbeme, were fossiliferous. These limestones are allochems (lithoclasts) with peloids of quartz and glauconite (Fig. 3.1 B). Echinoderms and lamellibranches with shell and bone fragments are noticeable in thin sections. Gypsum is present in the phosphatic limestone taken at Igbeme (Fig. 3.2 D). Glauconite is present in the gypsum. The phosphatic shale was fossiliferous (Fig. 3.2 E) as it contains a fauna—that is insect-like in appearance.

Phosphatic claystone, glauconitic, contains fluorapatite granules with heavy impregnation by hematite (Fig. 3.2 F). The phosphatic claystone was non-fossiliferous.

The lithic fragments of different minerals such as calcite and quartz (white) and glauconite (green or greenish-brown) with fluorapatite and collophane (brown) make-up the micritic matrix (Fig. 3.1 B – C). The presence of glauconite signifies the deposition of phosphatic limestone in a marine environment and seawater influence in the claystone (Rabah Kechiched et al., 2018).

3.1 Granular phosphorite

The granular phosphorites (GP) are predominant in both Ososun and Ebiti areas (Fig. 3.3 G). The term granular, commonly used in the description of sedimentary rocks composed of granules, signify minerals with 4 mm or smaller grain sizes. As observed in the microphotograph (Fig. 3.3 G), high to low spherically rounded granules (with oolitic and pelletal structures), subangular to angular grains, and clasts of fluorapatite exist with opaline silica and calcite (that form the micritic matrix). The motley of different grain types indicates high-level turbidity (responsible for the mixing of the grains) in the transport of the phosphatic grains to the site of deposition. Turbulent currents lead to the formation of clasts during the fracturing of the grains. The granular phosphorites are bioclastic (Abimbola et al., 2002; Adesanwo et al., 2010). The rock is light-brown in colour due to iron stains, and it weathers into dirty white (Russ, 1924). Carbonaceous matter encrustation, which is dark, in colour is present. Also observed in the GP were fossils such as lamellibranches and brachiopod shells.

3.2 Nodular phosphorite

The nodular phosphorites (NP) lie at both Ososun (Fig. 3.4 J) and Ebiti (Fig. 3.4 K) areas. They were coarser than the granular type. The nodular phosphorites were in either perfect or imperfect ellipsoidal, spherical, cylindrical, and rectangular forms with a pebble-conglomeratic appearance. In addition to that, nodular phosphorites were dead-whitish or creamy in colour (hand specimen). Fluorapatite appears as a yellowish-brown or brown-coloured nodule which are enmeshed in sparite and glauconite. Their diameters could be as wide as 5 cm. Most of the NP were flat—and they had pitted surfaces. Minute lamellibranch, through borings, were responsible for these (Russ, 1924). Compositionally, the nodular phosphorites are similar to the granular type. The matrix consists of aluminium phosphates.

3.3 Vesicular phosphorite

As the name implies, the vesicular phosphorites (VP) possess vesicles, which are either filled or empty. Two varieties exist, namely: the fine and the coarse. The fine vesicular phosphorite, a weathered derivative of the granular phosphorite, resides at the boundary between Ososun and Ebiti areas (Fig. 3.3 H). Their textures are similar to pumice. Granules of apatite that dissipated during the GP's precipitation led to the formation of the calcined bone or pumice-like structure (Russ, 1924). Replacement reaction in the apatite granules (dark brown) is responsible for the VP's reticulating appearance of iron and alumina (light brown).

Similarly, the coarse vesicular phosphorite lies at the boundary between Ososun and Ebiti (Fig. 3.3 I). The coarse-type is the altered derivative of the nodular phosphorite. The replacement of calcium ions in Ca-phosphate by iron and aluminium ions in clayey soils or claystones potentially forms wavellite. Ooids are present; the brown concentric rings depict their presence. The addition of iron affects the redox state of the deposited phosphorite. The colouration of the rock towards green suggests a reducing or euxinic environment of deposition.

4. Conclusion

The collophane (or specks of fluorapatite) found in the Igbeme and Oja-Odan regions indicates a favourable redox condition for the exchange between the phosphate (in the overlying Ososun and Ebiti phosphorites) and carbonate (in the underlying Igbeme and Oja-Odan limestones) as a result of leaching. The presence of glauconites in the phosphate-bearing rocks (Nodular, granular, and vesicular (fine and coarse) phosphorites, limestones, and claystone) suggests that the environment of deposition as near-shore marine. In the phosphatic claystone, the presence of ferric oxide (reddish brown) indicates a redox condition towards an oxic (oxidising) environment of deposition.

Declarations

Acknowledgments

Quite some persons played critical roles in the success of this work. Special thanks go to Mr. Femi Okunola—other staff—of the Nigerian Geological Survey Agency, Dr. S.O. Ipinniwa, and Dr. Oluwole Oyedeji for the exclusive information that aided the understanding of the study terrain. The authors recognise the technologists' assistance, Messrs. Mafoluku, and Uwaje, in the thin section preparation. An immense appreciation goes to Dr. Segun Akinyemi (Ekiti State University) for the manuscript's review.

References

1. Abimbola, A.F, Ojo, A.M, Okunlola, O.A, and Oguntoyinbo, F.I. (2002). Agrogeological studies of limestone, phosphate, and gypsum occurrences in the Dahomey Basin, Southwestern Nigeria, in relation to Soil Acidity Amelioration. *Nigerian Journal of Science*, vol. 36, pp. 119–128
2. Abou El-Anwar, E.A., Mekky, H.S., Abd El Rahim, S.H., Aita, S.K. (2017). Mineralogical, geochemical characteristics and origin of Late Cretaceous phosphorite in Duwi Formation (Geble Duwi Mine), Red Sea region, Egypt. *Egyptian Journal of Petroleum*, vol. 26, pp. 157–169, doi:http://dx.doi.org/10.1016/j.ejpe.2016.01.004
3. Adesanwo, O.O, Dunlevey, J.N, Adetunji, M.T, Adesanwo, J.K, Diatta.S, and Osiname, O.A. (2010). Geochemistry and mineralogy of Ogun phosphate rock. *African Journal of Environmental Science and Technology*, vol. *4*, no. 10, pp. 698–708
4. Altschuler, Z. S. Clarke, R. S., Jr., and Young, E. J. (1958). Geochemistry of uranium in apatite and phosphorite. *U.S. Geol. Survey Prof. Paper 314-D*, pp. 45–90
5. Antolino, P. (1968). Eocene Phosphate in the Dahomey Basin. Geological Survey of Nigeria.
6. Deer, W. A., Howie, R. A., and Zussman, J. (1962). Rock-forming minerals. In *Non-silicates*. John Wiley & Sons, New York. vol. 5, 371 p
7. Garnit, H., Bouhlel, S., and Jarvis, I. (2017). Geochemistry and depositional environment of Palaeocene - Eocene phosphorites: Metlaoui Group, Tunisia. *Journal of African Earth Sciences*, vol. 134, pp. 704–736
8. Gbadamosi, H.B. (2009). Geological modelling of Dahomey and Liberian basins. Texas A & M University, M.Sc. Thesis, Unpublished, 95 p
9. Jasinski, S. (2015). Phosphate rock. Minerals book (year 2015), *United States Geological Survey*.
10. Jones H.A. and Hockey, R.D. (1964). The geology of part of South-Western Nigeria. *Geol. Surv. Niger.* Bull. 31, 101 p
11. McKelvey, V. E. (1953). Domestic phosphate deposits. In W. H. Pierre (Ed.), *Soil and fertilizer phosphorus in crop nutrition*. New York, Academic Press, Agronomy Monographs. vol. 4, pp. 347–376
12. Nathan, Y. (1984). The mineralogy and geochemistry of phosphorites. In J. Nriagu, & P. Moore, *Phosphate minerals*, pp. 275–291, doi:10.1007/978-3-642-61736-2_8
13. Palache, C.B, Berman, H., and Frondel, C. (1951). The system of mineralogy: John Wiley and Sons, London. Vol. II, 7th ed., pp. 946–951

14. Pierre, J. P. (2014). Phosphate deposits of the Senegal-Mauritania-Guinea Basin (West Africa): A review. *"SYMPHOS 2013", 2nd International Symposium on International and Technology in the Phosphate Industry*, pp. 27–36
15. Rabah Kechiched, Rabah Laouar, Olivier Bruguier, Sihem Salmi-Laouar, Laszlo Kocsis, Delphine Bosch, Adif Foufou, Ouafi Ameur-Zaimeche, Hamza Larit. (2018). "Glauconite-bearing sedimentary phosphorites from the Tebessa region (Eastern Algeria): Evidence of REE enrichment and geochemical constraints on their origin." *Journal of African Earth Sciences*, vol. 145, pp. 190–200
16. Russ, W. (1924). Phosphate deposits of Abeokuta province. *Geological Survey of Nigeria: Nigerian government*, Bull. 7, pp. 9–39
17. Whiteman, A. (1982). Nigeria: its petroleum geology, resources, and potential. Graham and Trotman, London, 381 p

Figures

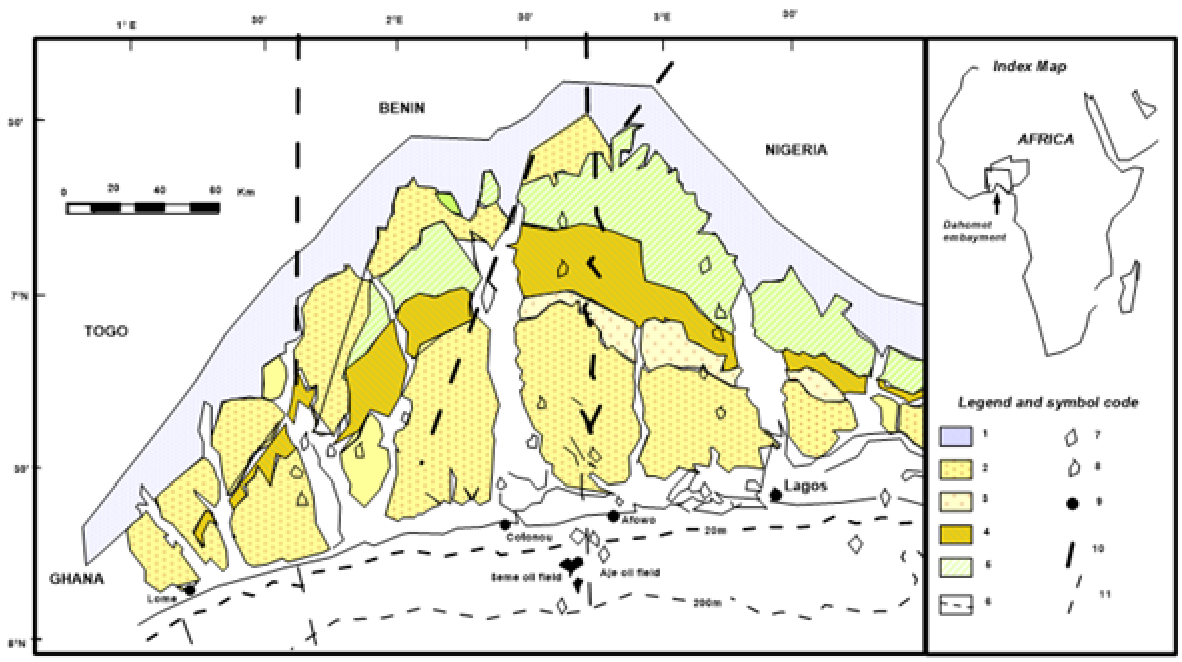

Figure 1

Outcrop geology of Dahomey Basin showing stratigraphy (Kaki et al., 2013. 1 - Alluvium (Recent); 2 - Benin-Ijebu Formation (Pleistocene/Upper Miocene); 3 - Ososun Formation (Middle Eocene); 4 - Imo Shale (Lower Eocene/Paleocene); 5 - Araromi Shale and Turonian Sandstone/Afowo Formation (Upper Cretaceous); 6 - Pre-Cambrian Crystalline Basement; 7 - Core hole or water well; 8 - Dry well; 9 - Oil well; 10 - Faults; 11 -Water depth contour.

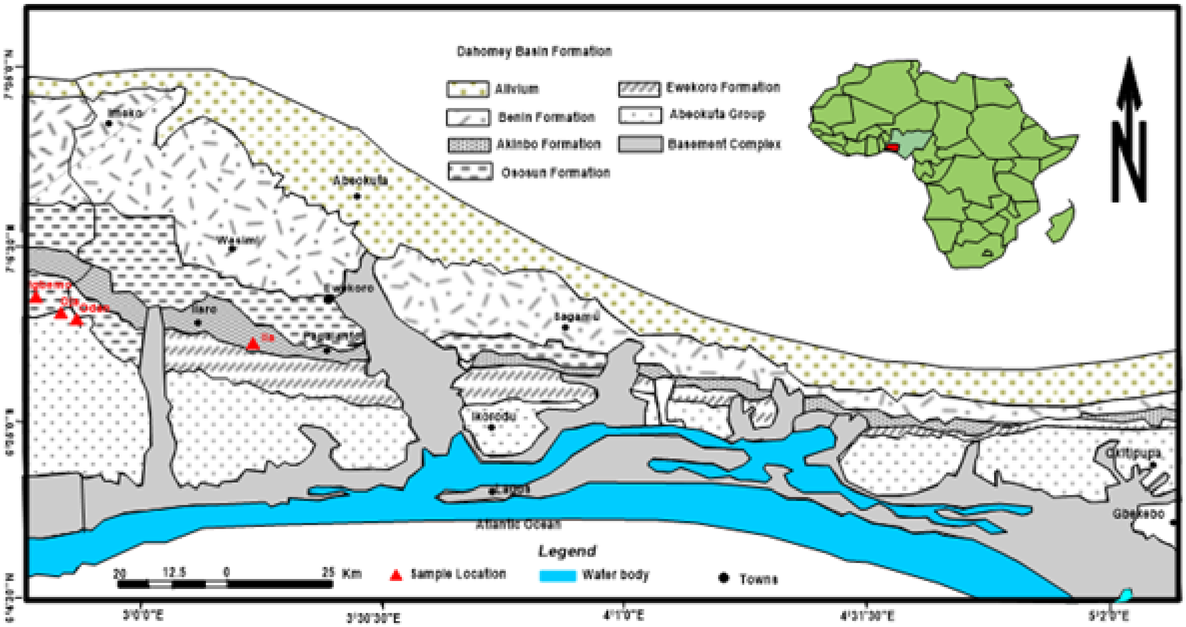

Figure 2

Geological map of the Eastern Dahomey Basin, Southwestern Nigeria, showing the sampled points (After Olatinsu et al., 2017).

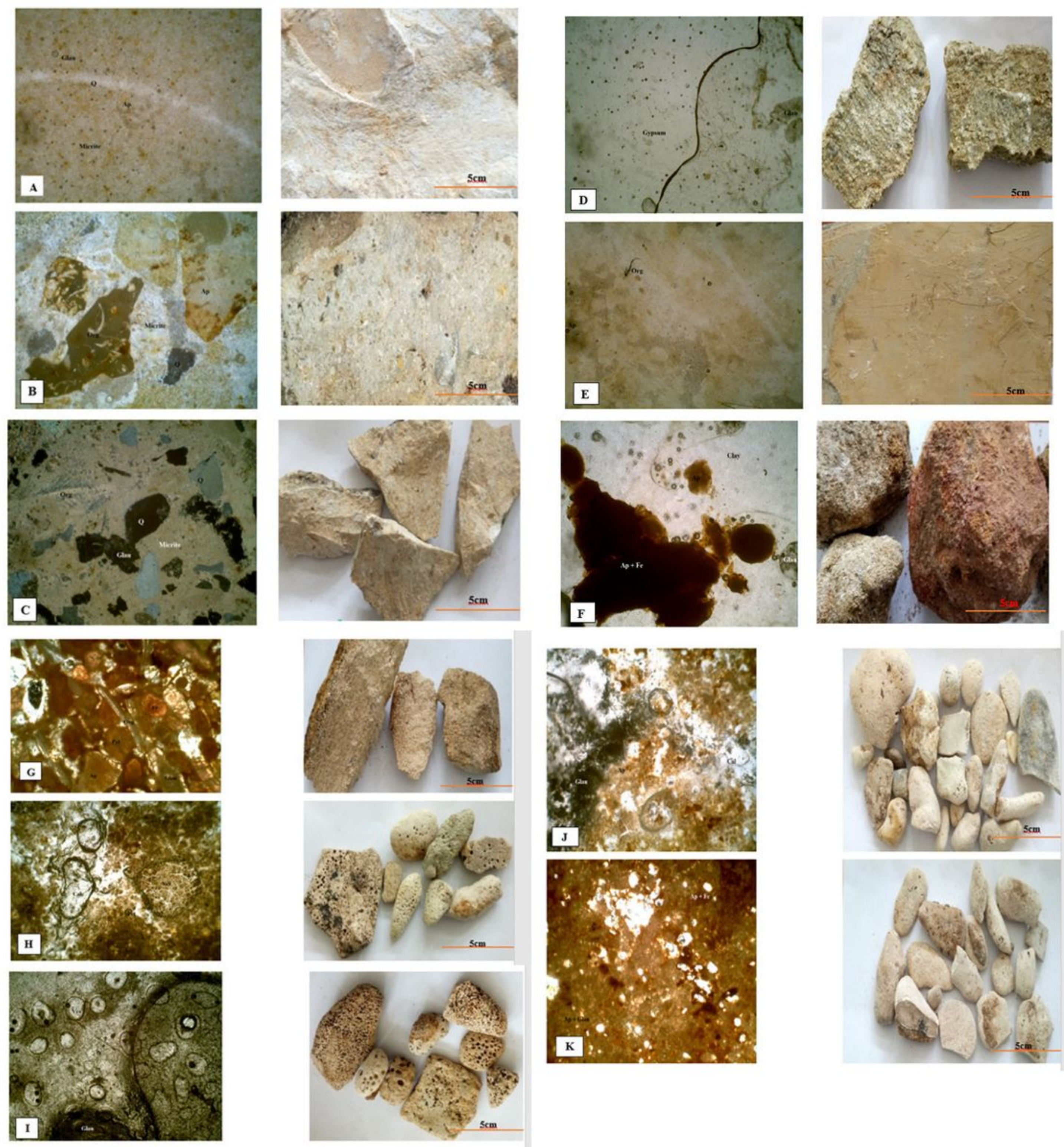

Figure 3

Photomicrographs and hand specimens of Phosphatic limestone at different locations in Eastern Dahomey Basin, Southwestern Nigeria. A- Igbeme, B- Oja-Odan (Forest reserve), C- Oja-Odan (Cocoa-Plantation). Q – quartz, Glau – Glauconite, Ap – Apatite, Org – Fossils. Photomicrographs and hand specimens of Lithologies in Eastern Dahomey Basin, Southwestern Nigeria. D - Gypsum at Igbeme, E - Phosphatic shale at Igbeme, F - Phosphatic claystone at Ebiti. Glau – Glauconite, Ap – Apatite, Fe –

Haematite, Org – Fossils. Photomicrographs and hand specimens of Lithologies in Eastern Dahomey Basin, Southwestern Nigeria. G – Granular phosphorite at Ososun and Ebiti, H – Fine vesicular phosphorite at Ososun-Ebiti boundary, and I – Coarse vesicular phosphorite at Ososun-Ebiti boundary. Glau – Glauconite, Ap – Apatite, Ves - Vesicles Fe – Haematite, Pel – Pelloid, Org – Fossils, Cal - Calcite. Photomicrographs and hand specimens of Lithologies in Eastern Dahomey Basin, Southwestern Nigeria. J – Nodular phosphorite at, Ososun K – Nodular phosphorite at Ebiti. Glau – Glauconite, Ap – Apatite, Cal - Calcite.