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The geochemistry of gypsum occurrences in Nafada area, Northeastern Nigeria

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ABSTRACT

This present work attempts to study the geochemistry of gypsum deposits in the Cretaceous Fika shale of Nafada and environs. This is done in order to evaluate the quality of the gypsum deposit, determine their different forms and occurrences, as well as their suitability for various industrial applications. Geochemical results of 20 samples were obtained in the laboratory of Ashaka Cement Plc. The major and the minor oxides of the samples were known, also a petrographic analysis of the samples was carried out in the laboratory of the geology department of Abubakar Tafawa Balewa University, Bauchi to know the different characteristics of the different gypsum forms. This study can give an easy approach to different industrial applications of gypsum based on the geochemistry obtained and their characteristics. The gypsum in the study area has an average purity of 91.775 (wt%). A comparison was made between the gypsum in the study area and other foreign and local gypsum of pure quality. The results conform to the specifications of the British Industrial Standard and the Raw Material Research Development Council. The results of this work show that different gypsums in the study area have a different quality that can suit in for different industrial purposes, such as agriculture, pharmaceutical, ceramic, cement, and plaster.

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1. Introduction

Gypsum mineralization is one of the pivots for Nigeria's industrial revolution for a self-reliant and durable economy, especially in the building, agricultural, and construction industries (Haruna, 2005). The cement industries, as well as chemical, ceramic, pharmaceutical, paints, and many other industries in Nigeria need gypsum as one of the most important raw materials for their productions. However, prior to the 1990s, gypsum mineral has been imported from Spain and Morocco. Nigeria spent about N900 million annually on the importation of gypsum for its cement (Anonymous, 1996).

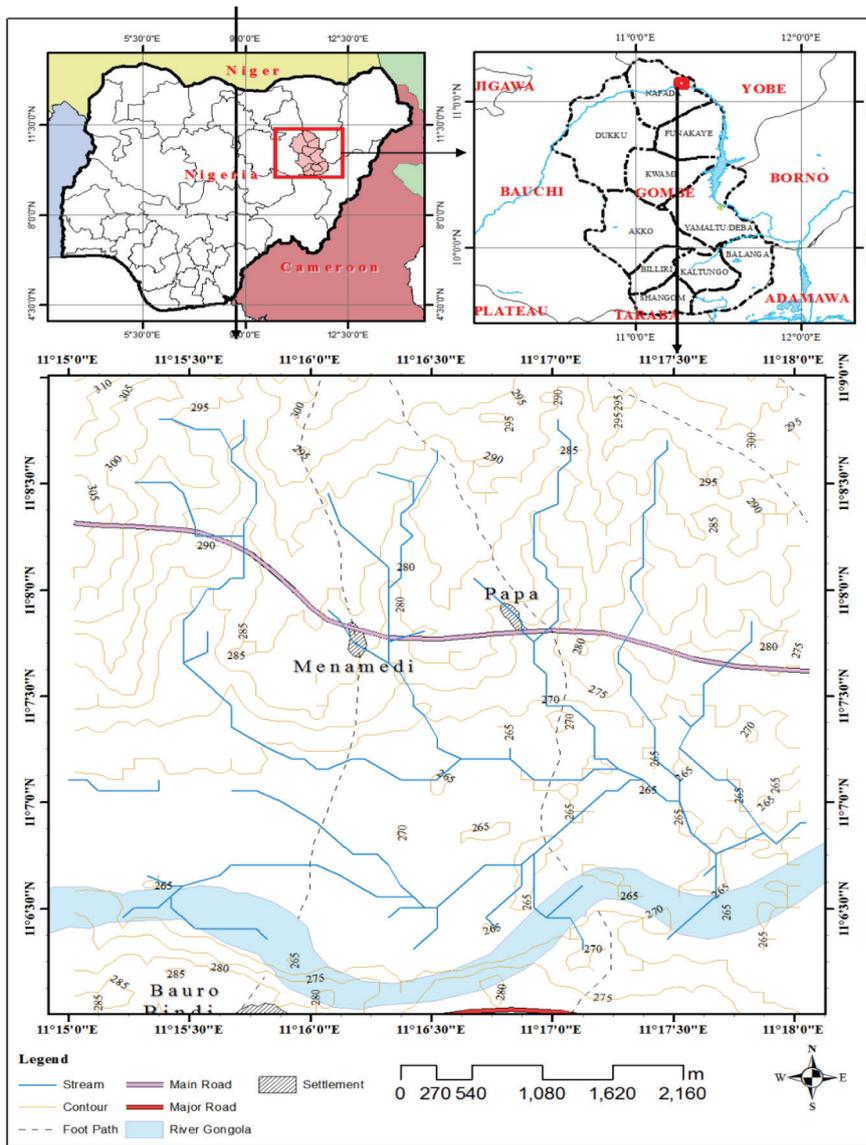
Gypsum is a hydrous calcium sulphate. Its chemical composition is expressed by the formula $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, which may be interpreted as calcium united with sulphuric acid and holding water of crystallization. The percentage of these materials by weight is calcium 32.5, sulphuric acid 46.6, and water 20.9. The mineral is not infrequently impure, as a result of other substances present during its formation or deposited subsequently in intimate relation with it. These impurities are usually organic matter, iron compounds, clayey material, and the carbonates of lime and magnesia. The color of gypsum, when reduced to powder

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is white. In its natural form, when pure, it is usually white and massive; and pearly or glistening when crystallized, and the crystalline form being transparent, sometimes to a remarkable degree. Gypsum is often gray, flesh-red, honey-yellow, ocher-yellow, or blue. As a result of impurities, it may be brown, red, or reddish-brown, and sometimes black. The hardness of gypsum varies from 1.5 to 2.0, the crystalline form being taken as the standard for the second degree in the scale of hardness of minerals. It can be scratched with the fingernail, which is the common test applied to distinguish it from other minerals that have a similar appearance. The specific gravity of gypsum is 2.3 at a temperature of 26°C, which is practically the ordinary temperature, one part of gypsum is soluble in 372 parts of water compared to 40 parts of common

salt that would dissolve in 100 parts of water. The presence of other salts in solution, as common salt, and especially potassium salts, increases the amount of gypsum which may be dissolved. When heated sufficiently, gypsum gives off its water of crystallization and becomes opaque, being altered to anhydrite. It does not dissolve in sulphuric acid, and when acted on by other acids does not effervesce or gelatinize. Rather it fuses, coloring the flame reddish yellow. When ignited at a temperature not exceeding 260°C, it will again combine with water and set.

Nafada and environs are located between latitude 11°06'N to 11°09'N and longitude 11°5'E to 11°18'E within the Gongola Arm of the Upper Benue Trough northeastern Nigeria. The study areas include Barwoinde located about 4 km southwest of Nafada,



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Fig. 1. Map of the study area.

Shole, Gadi, and Sudingo located about 10 km south of Nafada, Mada, and Papa mines located about 6 km northwest of Nafada town. These areas are generally flat-lying terrain and undulating in some areas. The area is generally surrounded by a sandstone ridge, the Dumbulwa-Bage High (Zaborski et al., 1997).

This present work is aimed at evaluating the quality of gypsum deposits in the Cretaceous Fika shale of Nafada and environs and assessing its suitability for different industrial uses.

2. Literature review

The Benue Trough of Nigeria is a rift basin that extends North-North-East for about 800 km in length and 150 km in width; its northern limit is the southern boundary of the Chad Basin (Fig. 3). The trough contains up to 6,000 m of Cretaceous to Tertiary sediments of which those predating the mid-Santonian have been compressively folded, faulted, and uplifted in several places. The Benue Trough is sectorially subdivided into a Southern, Central, and Northern portion (Fig. 3). Major localities (towns/settlements) that constitute the depocenters of the different portions have been well documented (Benkhelil, 1988; 1989; Obaje, 1999; Petters, 1980). Compressional folding during the mid-Santonian tectonic episode affected the whole of the Benue Trough and was quite intense, producing over 100 anticlines and synclines

(Benkhelil, 1988). The major deformational structures include the Abakaliki anticlinorium and the Afikpo syncline in the Southern Benue, the Giza anticline, Keana anticline, and the Obi syncline in the Central Benue, and the Lamurde anticline and the Dadiya syncline in the Northern Benue Trough. Following mid-Santonian tectonism and magmatism, the depositional axis in the Benue Trough was displaced westward resulting in strong subsidence of the Anambra Basin. The Anambra Basin largely contains sediments of Campanian–Maastrichtian to Eocene. It is logical to include the Anambra Basin in the Benue Trough, being a related structure that developed after the compressional stage (Akande and Erdtmann, 1998).

The depocenters of the Southern Benue Trough comprise mainly the areas around Nkalagu and Abakaliki, while those of the Anambra Basin center around Enugu, Awka, and Okigwe. The Central Benue Trough comprises the area from Makurdi through Yandev, Lafia, Obi, Jangwa to Wukari. In the Yola Benue Trough, the depocenters comprise Pindiga, Gombe, Nafada, Ashaka (in the Gongola Arm) and Bambam, Tula, Jessu, Lakun, and Numan in the Yola Arm (Fig. 4).

3. Gypsum occurrences in Nigeria

The occurrence of gypsum within the Fika shale in the Gongola arm of the Upper Benue Trough was first reported by Carter et al. (1963) and later confirmed

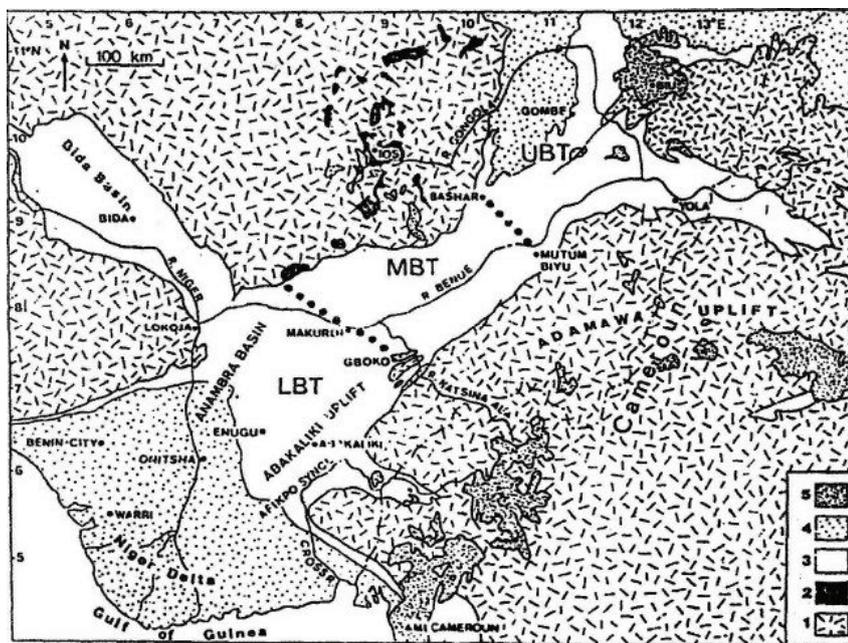


Fig. 2. Outline of the geological map of the Benue Trough and adjacent areas (after Zaborski, 1998). LBT Lower Benue Trough; MBT Middle Benue Trough; UBT Upper Benue Trough. (1) Precambrian. (2) Jurassic “Younger Granites.” (3) Cretaceous. (4) Post-cretaceous sediments. (5) Cenozoic recent basalts including those of Cameroon line.

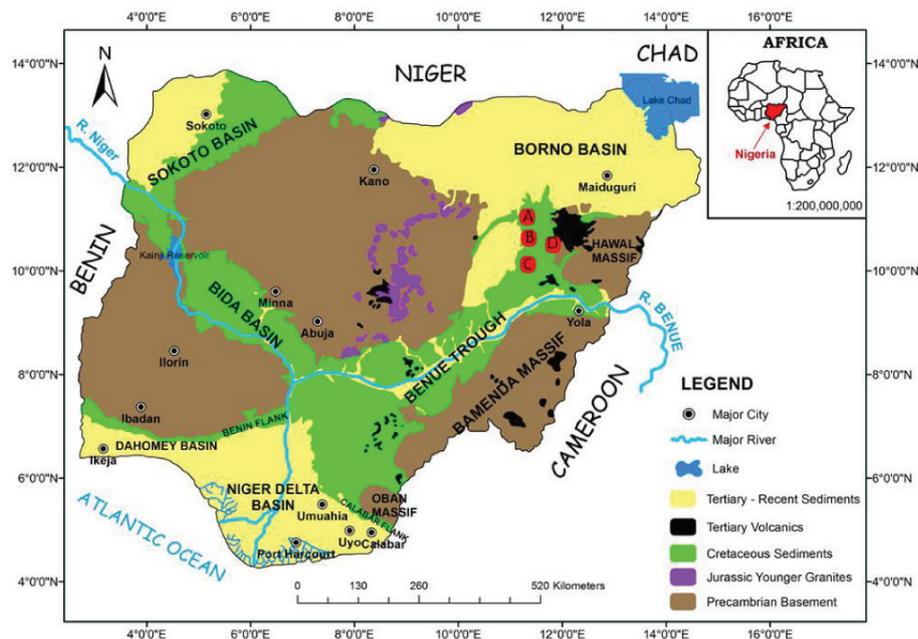


Fig. 3. Generalized geological map of Nigeria showing studied localities in the Northern Benue Trough. (A) Yaranduwa 3, Northern Benue Trough, (B) Yaranduwa 1, Northern Benue Trough, (C) Gombe Inlier, Gombe, Northern Benue Trough, (D) Sabon Gari, Northern Benue Trough (Uriah et al., 2018).

by Reyment (1965). Orazulike (1988) reported the occurrence of gypsum in Nafada and Bajoga areas. Barka (2011) also reported the occurrence of gypsum in Nafada area of Gombe State northeastern Nigeria. Ntekim (1999) and Mamman et al. (2007) also reported the occurrence of gypsum deposits in Guyuk and Cham in the Yola Arm of the Upper Benue Trough. The earliest work on evaporites in the Northeastern region was done by Haruna et al. (2007) in a geographical account of an early expedition into the areas of the Chad Basin and immediate environment. The author described two classes of evaporite mineral deposits namely;

(a) The magma salt (an admixture of sodium carbonate and bicarbonate, sodium sulphate and sodium chloride in concentrations of approximately equal magnitude)

(b) Magma natron (mainly sodium carbonate with a subordinate amount of sodium sulphate and sodium chloride). The earliest reconnaissance traverse of the area was made by Falconer (1911) during the mineral survey of northern Nigeria. Gypsum occurrence in Northeastern Nigeria was first reported by Carter et al. (1963) as occurring within a sequence of blue-black shales, containing few, thin, impersistent limestone beds, and occasional interbedding with thin siltstone beds and lava flows. Reyment (1965) confirmed this by reporting the Fika Formation as consisting of blue-black shales, occasionally gypsiferous with a thickness

exceeding 430 m. Maglione (1981) also confirmed the presence of gypsum mineralization in well-drained, well-aerated environments within the Nigerian sector of Chad Basin (part of which is the research area). Gypsum occurrence at Nafada and Bajoga areas was reported by Orazulike (1988). All these workers confirmed that the Fika shales are gypsiferous. Since then, not much work has been done in this area to determine the economic viability of the gypsum mineralization at various depths and in various places within the Chad Basin. Only the illegal miners patronize the gypsiferous areas. These areas are generally flat-lying terrain and undulating in some areas. The area is generally surrounded by a sandstone ridge, the DumbulwaBage High (Zaborski et al., 1997). Gypsiferous shales are reported from the upper Cretaceous Dukamaje Formation and the Paleocene Dange Formation in the Sokoto area. The 1.46 million tonne gypsum deposit at Wurno in Sokoto State is currently being mined by small-scale miners to supply the Sokoto cement plant. Other gypsum prospects are reported from Nafada and Bajoga in Gombe State, at Fika in Yobe State, and at Guyuk/Gwalura areas in Adamawa State (Ministry of Solid Minerals Development, 2000). Field occurrence of gypsum bodies in Nafada area shows discontinuous and displacive patterns of vertical to sub-vertical cross-cutting minor fractures within the Senonian Fika shale as thin lamina (1–6 cm), evident of diagenetic (secondary processes) origin.

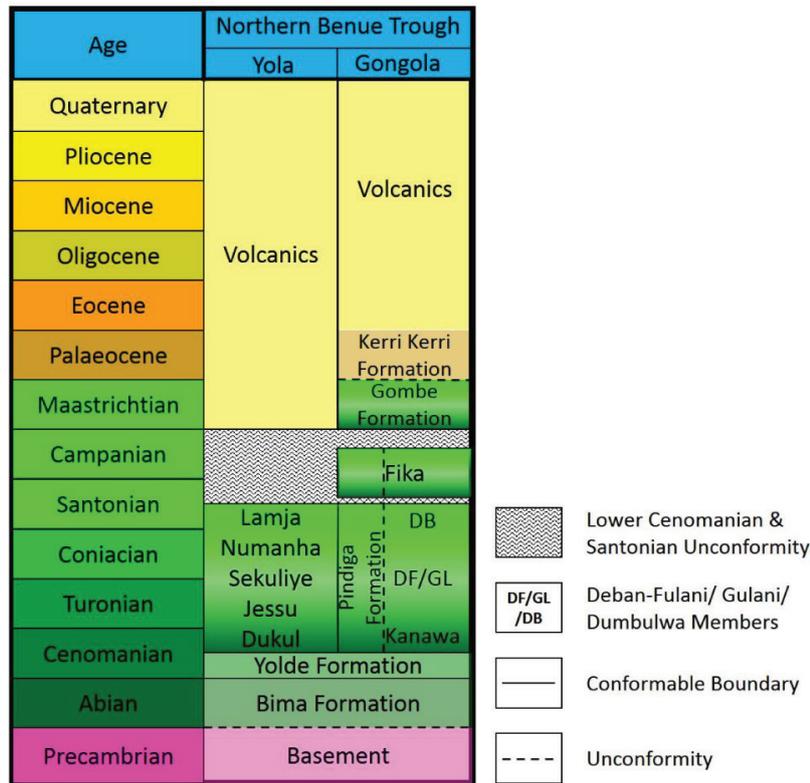


Fig. 4. Stratigraphy of the Benue Trough (Uriah et al., 2018).

The geochemistry of gypsum deposits within the Senonian Fika shale in Nafada and environs reveals that gypsum in the study area has a high percentage purity of 90.6–95.8 wt%. These results concur with the British Industrial Standard and Raw Material Research Development Council [British Industrial Specification (BIS), 1997; RMRDC, 2005] and Umeshwar (2005) indicating high grade gypsum form that is suitable for different industrial usage (Cement, agriculture, medical, pottery and ceramic, pharmaceutical, chemical, paints, building, and construction).

3.1. Fika shales

The name Fika shales was assigned by Racburn and Brynmor (1934) to the limestone—shale group which also includes the Gongila and Pindiga Formations of the present work. The Fika shales is a sequence of blue-black shales occasionally gypsiferous and containing one or two thin impersistent limestone beds (Carter et al., 1963). The Formation underlies a broad belt of the country in the north-western part of the Mutwe plain extending westwards to Fika and south-westwards to form the narrow outcrop which strikes southwards from Nafada. Although the beds are poorly exposed, sections are known from wells, boreholes, and stream channels (Carter et al., 1963). The shales contain abundant fish fossils and also

crocodile remains and chelonian fragments. The blue-black nature of shale may be indicative of attendant reducing conditions at the time of deposition of the unit. The blue-black shales were deposited during the middle Cretaceous world-wide marine transgression in both the Benue Trough and Chad Basin (Petters, 1978). These sediments feature sparse population of benthic foraminifera assemblages, as well as high organic matter content suggesting deposition under anoxic conditions (Petters 19820). However, the blackness of sediment can also be primarily due to the high abundance of pyrite and may not necessarily signal high organic content. Petters and Ekweozor (1982) analyzed many shale cuttings from the Fika shales and reported that they contain fluffy, biodegraded humic matter (nonfluorescent amorphous organic matter, humosapropelinite showing intergrowth of micrinite and framboidal pyrite in some places. This organic matter is inferred to have been derived mostly from an oxic paralic swamp or the lacustrine depositional environment. The relative abundance of arenaceous benthic foraminifera within Fika shales points to the prevalence of near-shore environment. Petters (1980) dated Fika Formation as Coniacian to early Maastrichtian. The Fika shales overlie the Gongila Formation and underlie the Gombe Sandstone in the Chad Basin.

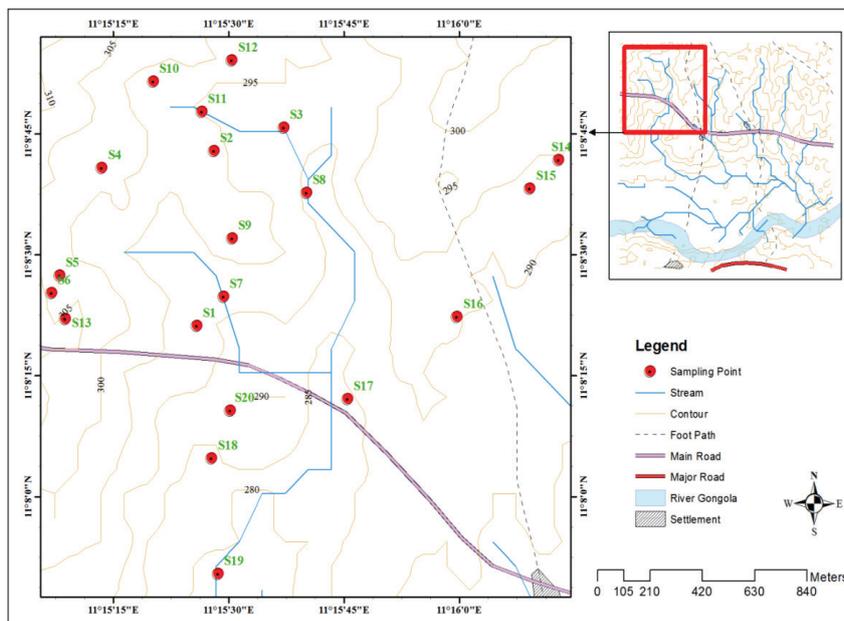


Fig. 5. Sampling location of the study area.

4. Field methods

The fieldwork was conducted in the month of March 2016. Two mining sites were visited namely, Barwoweinde and Mada around Menamedi and Papa. Twenty mining pits were sampled (Fig. 5). The mode of mining in all the mining sites was pitting (ranging from 12 to 18 m depth). While in the field, careful observation of different gypsum forms was done by observing the various carrier beds and the structural and textural characteristics of the samples collected. The carrier beds are mostly the Fika shale and mudstone. The following are the findings based on the fieldwork:

- (i) The gypsum changes in forms with depth
- (ii) The thickness and deformation of the gypsum forms increase with depth
- (iii) All the different gypsum forms at any depth have peculiar carrier beds.

5. Laboratory methods

Twenty samples were analyzed using X-ray fluorescence analytical technique at the laboratory of the Ashaka Cement Plc quality section. This was done to determine the chemistry in order to assess the quality of the gypsum.

5.1. Samples preparation for XRF analysis

The samples were cleaned, crushed, sieved, and weighted.

5.2. Procedures for XRF analysis

The powdered sample, 10 g was mixed with 1 g of stearic acid (binder) and thoroughly homogenized in an agate mortar. The mixture was then transferred into a 40 mm diameter hardened steel disc and pressed into a pellet at a pressure of 25 tons using hydraulic pressure press. The pellet was then used for X-ray fluorescence (XRF) analysis of the major elements.

During the XRF analysis, the rock samples were radiated with electrons or X-rays of sufficient energy. The X-rays were emitted at different wavelengths and intensities specific for the elemental composition of the different samples. Measurement of the intensity of secondary 2° characteristics radiation forms the basis for XRF. Fluorescent X-rays of different wavelengths are characteristic of activated elements emitted.

6. Petrographic analysis

Four different gypsum forms (alabaster, selenite, satin spar, and balatino) were studied in hand and thin section to assess their textures and textural evolution.

6.1. Sample preparation for thin section

Firstly, the sample to be used for the thin section was selected. In selection, finer grained samples were chosen so as to give more information of the rock rather than coarse-grained samples. Also, representative samples were taken such that all or almost all of the mineral assemblages for each rock type was reflected. After selecting the sample, it was then taken to the

laboratory where the following processes were conducted to produce thin sections:

Using rock cutting machine, the sample was chipped from the side of interest. The chipped sample was thinned gently by rubbing on a glass slab containing a mixture of water and carborundum powder. The glass slide was marked using a diamond pen and further dried together with the sample for 2–5 minutes at 60°C–70°C. A mixture of Araldite is used to gum the rock sample and glass slide. The sample was oven dried for 3–5 minutes after which it is subjected to further grinding and thinning on T/S machine and glass slab, respectively, until it achieves a thickness of 0.03 mm. Canada balsam is used to gum the sample slide with glass cover. The slide is washed, dried, and labeled to make it ready for further studies.

During the thin sectioning, the following precautions were taken:

I was careful enough not to break the glass slides when thinning and grinding on a glass slab. I also ensured to remove all air bubbles in the slide using forceps. In order not to affect important features of the section, I was careful in applying gum. Due to the fact that exposing the slide to extreme temperatures might induce cracking, I ensured that I avoid overheating the T/S slide.

7. Results and discussion

7.1. Petrography and geochemistry of gypsum forms

Hand specimen description was merged with the petrographic studies in order to determine their textural similarities and differences. The chemical composition of the gypsum forms also showed their level of similarities and differences. Four different gypsum forms are recognized on the basis of the difference in depth, carrier beds, and structures.

7.2. Petrography

Petrographic analysis was carried out for the entire samples collected from the study area in geology laboratory of Abubakar Tafawa Balewa University, Bauchi. The thin section was carefully observed through the microscope. The characteristics of the gypsum sample were observed both under the plane and crossed polarized light. The field observation and the lab studies were merged and it was deduced that four different gypsum forms are observed.

7.2.1. Alabaster gypsum form

This is exclusively massive gypsum. It is internally laminated but the laminations are thicker than that of the

Balatino laminated gypsum. It was found at a greater depth of 12–13 m within the highly deformed blue-black shales. It is very heavy and has irregular, rough texture from the outside surface. It is internally laminated and the laminations have a thickness of 3–4 mm. There are lots of blue-black shale fragments trapped between most of the internal gypsum laminations. The internal gypsum laminations appear undisturbed. It looks similar to selenite only that here there is no evidence of recrystallization in hand specimen. The internal laminations are thick, well developed, well preserved, and transparent. The petrographic studies of the Alabaster gypsum showed a marked similarity of that of the Balatino laminated gypsum. Under plane polarize light (Plate 1), the gypsum was colorless and the traces of cleavages were seen. Under cross polarize light (Plate 2); the gypsum appeared to be laminated with the limit of each lamina forming a mammillary structure. The mammillary structures displayed an offlap relationship. All the laminations have distinct, well developed, perfect cleavages which defined the direction of lamination.

7.2.2. Balatino laminated gypsum forms

They are finely bedded and the fine beds range in thickness from 1 to 3 mm. They occur within mudstone and the bedding plane between mudstone and shale. Sometimes particles of blue-black shale were seen between the thin gypsum beds. The surface of the Balatino laminated gypsum is transparent, smooth, and tabular. Some samples of this gypsum form showed evidence of dissolution from the edges of the lamination;

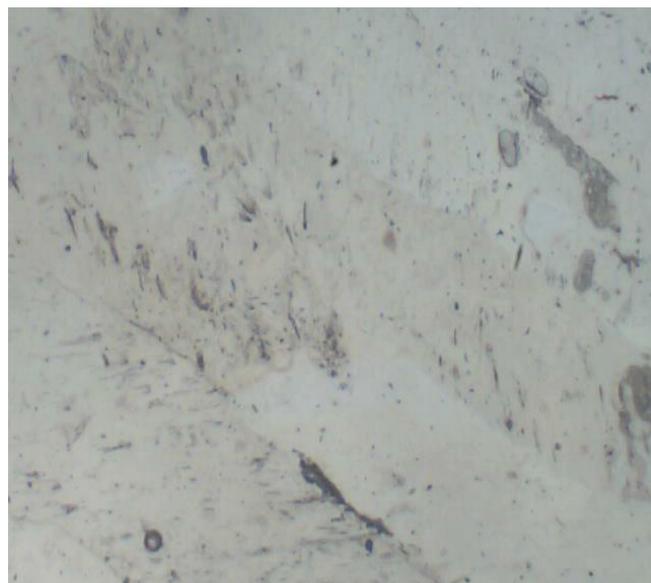


Plate 1. Photomicrograph of Nafada Gypsum (Alabaster). Plane Polarise light. Mg x40.

hence, such areas have slightly rough texture. They are found mainly in mudstone at the depth of 2–4 m with much pyramidal detrital gypsum around them within some of the pits. The individual lamina looks equal in size (mainly, 2 mm) and extend laterally conforming to the fine bedding of the shale and pseudo-bedding of the mudstone. Petrographically the Balatino laminated gypsum is colorless under plane polarized light (Plate 3) but the cleavages are very perfect and distinct. The direction of the cleavage follows the direction of thin lamination. Under cross-polarized light (Plate 4), the individual lamina showed an off-lapping relationship with each other. The limit of each lamina showed a kind of mammillary structure. The perfect cleavages are parallel to each other and conformed to the primary laminations. Each lamina showed white color with low relief under the cross-polarized light. The matrix of gypsum lamina showed inclined extinction as the stage is rotated.

7.2.3. Satin spar gypsum form

These are tabular beds of fibrous gypsum commonly parallel to subparallel to the beddings of the blue-black shales. The thickness ranges from 2 to 6 cm and consists of vertically arranged fibers or acicular crystals which are perpendicular to the bedding of the shale. This gypsum form still retained the traces of former laminations which appear as primary structures. The gypsum tabular thick bed alternates with black shale beds from depths of 4–8 m in the deeper parts of shales. The deeper the shale bed, the thicker the satin spar. This shows an obvious probable nucleation of fibrous crystals with depth due to overburden

pressure. At a greater depth of 9–11 m, the thick beds of satin spar are folded, which appeared to be due to nucleation of the fibrous crystals. Petrographic studies of the satin spar gypsum showed that under plane polarized light (Plate 5), the gypsum is colorless. Under cross polars (Plate 6) the cleavages are perfect, distinct, and seemed to define the direction of lamination on the matrix. These are the growth of parallel fibers of gypsum from anterior and posterior sides of the slide towards the center. These fibers are growing inclined to the lamina and the cleavage.

7.2.4. Selenite gypsum form

This consist of laterally continues beds of prismatic gypsum crystals that are arranged vertically or obliquely to the bedding planes of mudstones. The thickness of the selenite beds depends on the length of the vertically arranged crystals. The length of the crystals ranges from 2 to 3 cm. The selenite crystals are associated with minor fragments of pyramidal detrital gypsum and fragments of mudstone between the prismatic crystals. The bed of the selenite crystals shows traces of former lamination. Sometimes, the prismatic crystals are well developed to the extent that they persist through the former laminations without breaking. The surface of the selenite bed is irregular and rough and this could be due to leaching by ground water. It is found at the depth of 4–6 m within mudstone and gray shales in the mining pits. Petrographic studies of selenite indicated that under plane polarized light (Plate 7), the gypsum is colorless with traces of cleavage. Under cross polars (Plate 8), the matrix contains well developed, distinct, and perfect cleavage which is oriented in one direction

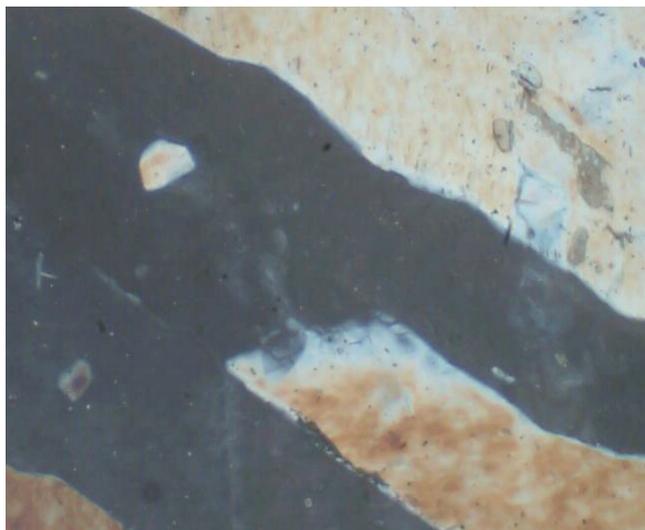


Plate 2. Photomicrograph of Nafada Gypsum (Alabaster). Cross Polarise light. Mg $\times 40$.

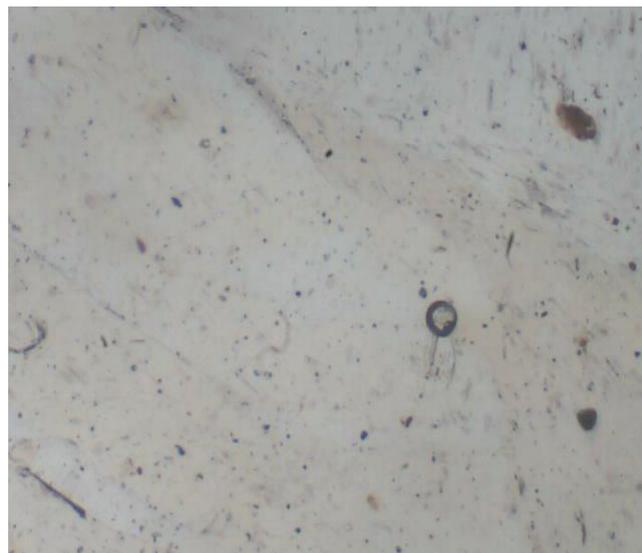


Plate 3. Photomicrograph of Nafada Gypsum (Balatino). Plane Polarise light. Mg $\times 40$.

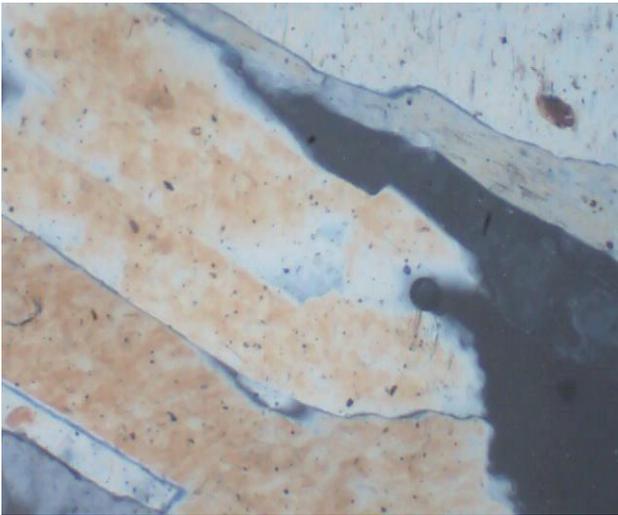


Plate 4. Photomicrograph of Nafada Gypsum (Balatino). Cross Polarise light. Mg $\times 40$.

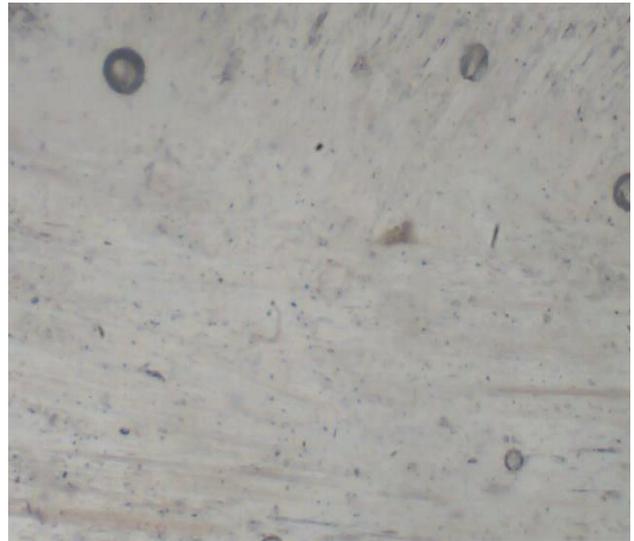


Plate 5. Photomicrograph of Nafada Gypsum (Satin spar). Plane Polarise light. Mg $\times 40$.

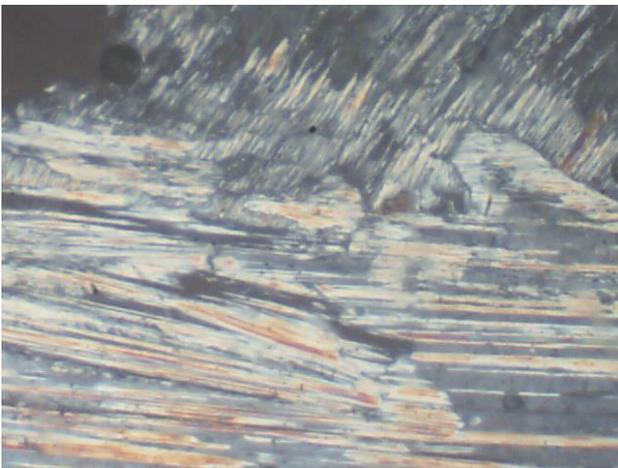


Plate 6. M Photomicrograph of Nafada Gypsum (Satin spar). Cross Polarise light. Mg $\times 40$.

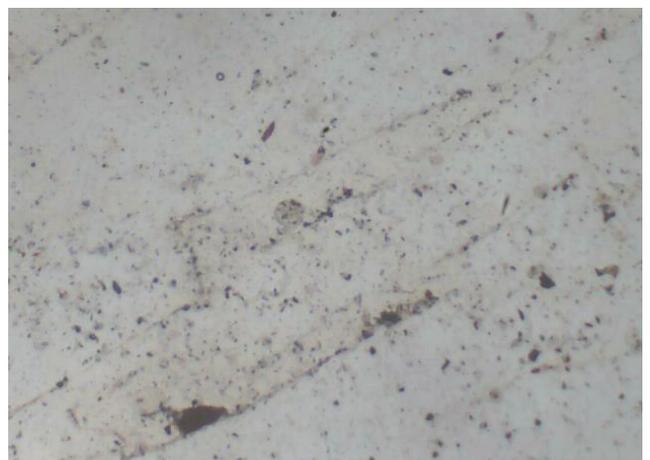


Plate 7. Photomicrograph of Nafada Gypsum (Selenite). Plane Polarise light. Mg $\times 40$.

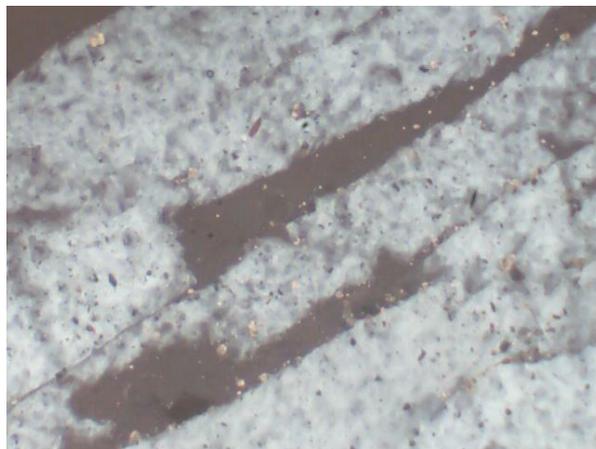


Plate 8. Photomicrograph of Nafada Gypsum (Selenite). Cross Polarise light. Mg $\times 40$.

showing the direction of lamination as well as the bedding. The prismatic selenite crystals grow perpendicular to the cleavage and the lamination.

7.3. Geochemistry

The results of the XRF studies are summarized in Tables 1 and 2, all the information and findings in Tables 1 and 2 are plotted in Figs. 1–4:

8. Tabular presentation of results and parameters

The below Tables 3 and 4 show the four different gypsum forms identified in the field and the laboratory. Their various purities by wt% are determined from the XRF analysis, the average weight of all the gypsum forms is known as 94.135 for the Alabaster forms, 91.31 for the Selenite form, 90.065 for the satin spar form, and 91.575 for the Balatino forms. The average purity of the entire gypsum forms from the study area is given as 91.775.

The moisture content is a key parameter in determining the purity of gypsum, the minimum water content for a pure gypsum is 18 and the maximum is 20. The studied gypsum in the area has an average moisture content of 18.746 in wt%.

Different parameters were also tested against the various gypsum forms. The bar chart represents various gypsum forms plotted against their purity, while the line graphs represent different samples plotted

against different parameters, such as the lime content (CaO), SO₃, and water content. All these parameters determined the purity of the gypsum in the study area.

9. Comparison

Comparison is made (Table 6) between the gypsum in the study area and other gypsum from foreign countries (Morocco and Spain) (Fig. 10) and the local gypsum in other part of the country (Yobe, Benue, and Sokoto) (Fig. 11). The data that were used to compare the results were sourced from Haruna (2005). The result of the geochemistry of the gypsum in the study area has an average purity of 91.775 compared to that of Morocco and Spain with 95.90 and 94.70, respectively. The result was also compared to that of Yobe, Benue, and Sokoto, which has an average purity of 93.40, 89.30, and 42.40, respectively. The comparison is made in form of the bar charts shown in Figs. 6 and 7 below:

10. Discussion of results

The result of the analyzed samples is presented in Tables 1 and 2. The concentration of the various oxide composition of Nafada gypsum shows that SiO₂ ranges from 1.9% to 2.3%, Al₂O₃ from 0.1% to 0.3%, Fe₂O₃ from 0.09% to 0.12%, CaO from 30.9% to 32.3%, MgO from 1.10% to 1.13%, SO₃ from 38.9% to 43.0%, K₂O from 0.04% to 0.05%, and Na₂O from 0.070% to 0.074%.

Table 1. Oxide composition (wt%) of gypsum.

Parameters (wt%)	Samples									
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
SiO ₂	2.164	2.261	2.229	2.187	1.935	2.247	2.300	2.163	1.968	2.218
Al ₂ O ₃	0.274	0.275	0.257	0.236	0.153	0.262	0.281	0.281	0.145	0.245
Fe ₂ O ₃	0.095	0.132	0.115	0.110	0.092	0.119	0.132	0.100	0.100	0.116
CaO	32.313	32.057	30.936	31.916	32.950	31.826	32.014	33.371	32.011	30.881
MgO	1.108	1.131	1.136	1.128	1.101	1.126	1.132	1.108	1.103	1.132
SO ₃	43.022	40.202	41.286	42.389	42.546	42.284	40.099	42.000	42.503	40.341
K ₂ O	0.045	0.050	0.048	0.052	0.041	0.048	0.054	0.048	0.046	0.048
Na ₂ O	0.070	0.073	0.071	0.072	0.071	0.073	0.072	0.074	0.072	0.072
P ₂ O ₅	0.024	0.014	0.013	0.013	0.019	0.019	0.027	0.016	0.013	0.022
Mn ₂ O ₃	0.036	0.035	0.032	0.034	0.032	0.032	0.037	0.033	0.034	0.027
TiO ₂	0.023	0.024	0.016	0.030	0.024	0.033	0.023	0.021	0.035	0.021
Cl	0.012	0.002	-0.006	-0.006	-0.006	0.003	0.009	-0.006	-0.005	-0.003
Cr ₂ O ₃	0.008	-0.004	0.000	0.000	0.003	-0.002	-0.005	-0.006	0.006	0.007
SrO	0.042	0.039	0.035	0.041	0.041	0.039	0.041	0.039	0.039	0.043
Sum of Conc.	78.091	78.180	78.078	78.090	77.889	77.985	78.084	78.147	77.948	78.053
Purity	94.245	92.250	91.314	93.380	94.641	93.138	91.057	95.271	93.640	90.275
Combined water	18.910	19.991	19.092	19.075	19.145	19.028	18.944	19.900	19.126	19.053

Table 2. Oxide composition (wt%) of gypsum cont.

Parameters (wt %)	Sample									
	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
SiO ₂	2.256	2.329	2.254	2.209	1.974	2.258	2.338	2.336	2.189	1.987
Al ₂ O ₃	0.267	0.302	0.268	0.287	0.154	0.270	0.290	0.296	0.292	0.149
Fe ₂ O ₃	0.120	0.137	0.114	0.097	0.094	0.119	0.121	0.137	0.102	0.094
CaO	31.938	32.075	31.981	32.335	32.131	31.792	30.989	30.060	30.378	32.078
MgO	1.132	1.132	1.136	1.116	1.104	1.136	1.135	1.134	1.106	1.104
SO ₃	40.292	42.084	42.316	41.981	41.478	40.279	41.180	40.097	38.999	42.502
K ₂ O	0.051	0.054	0.048	0.051	0.041	0.051	0.054	0.053	0.048	0.045
Na ₂ O	0.070	0.072	0.071	0.071	0.073	0.071	0.071	0.072	0.071	0.070
P ₂ O ₅	0.015	0.025	0.017	0.024	0.013	0.011	0.030	0.017	0.021	0.018
Mn ₂ O ₃	0.030	0.034	0.032	0.034	0.030	0.027	0.037	0.034	0.29	0.032
TiO ₂	0.016	0.022	0.031	0.027	0.019	0.031	0.025	0.032	0.038	0.039
Cl	-0.006	0.009	-0.005	0.001	-0.005	-0.006	0.012	-0.006	0.003	-0.003
Cr ₂ O ₃	0.002	-0.003	-0.002	0.004	0.010	0.004	0.005	-0.005	-0.007	-0.002
SrO	0.039	0.041	0.040	0.039	0.042	0.038	0.044	0.039	0.040	0.039
Sum of Conc.	78.126	78.184	78.188	78.148	78.050	77.976	78.177	78.185	78.184	78.028
Purity	90.261	89.097	92.339	93.207	90.724	91.096	90.150	88.101	87.276	93.706
Combined water	18.031	18.938	18.042	18.891	17.115	19.025	17.981	17.944	17.899	19.126

Table 3. Gypsum forms and their average purity.

Sample no	Gypsum form	CaSO ₄ ·2H ₂ O content in wt (%)	Average weight in wt (%)	Average weight for the entire area wt (%)
1		94.245		
4		93.38		
5	Alabaster	94.641	94.135	
6		93.138		
8		95.271		
2		92.25		
9		93.64		
10	Selenite	90.275	91.31	
12		89.097		
13		92.339		91.775
11		90.261		
16		91.096		
17		90.15		
19	Satin spar	87.276	90.065	
18		88.101		
20		93.706		
15		90.724		
14	Balatino	93.207	91.575	
7		91.057		
3		91.314		

Table 4. Gypsum forms and their average moisture content.

Sample no	Gypsum form	Moisture content in wt (%)	Average moisture in wt (%)
1		18.910	
4		19.075	
5	Alabaster	19.145	19.212
6		19.028	
8		19.900	
2		19.991	
9		19.126	
10	Selenite	19.053	18.864
12		18.938	
13		18.042	
11		18.031	
16		19.025	
17		17.981	
19	Satin spar	17.899	18.395
18		17.944	
20		19.126	
15		17.115	
14	Balatino	18.891	18.511
7		18.944	
3		19.092	

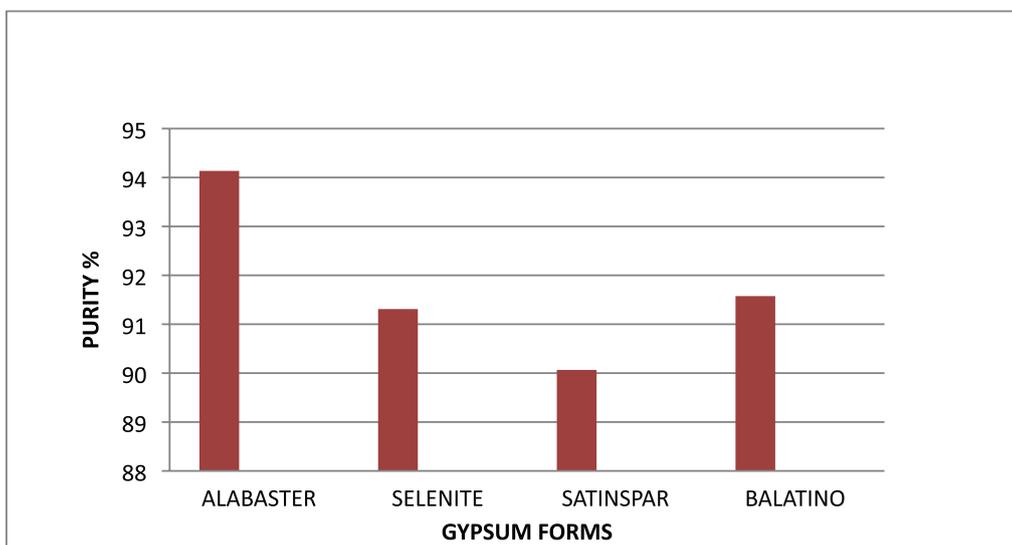


Fig. 6. Graph of average purity against gypsum forms.

According to BIS specification, gypsum with a moisture content of 20.9 weight percentage (wt%) is regarded as pure gypsum. Those with low moisture content are regarded as impure, while those with no moisture content have been transformed from gypsum to anhydrite. The studied Nafada gypsum has an

average moisture content of 18.75 weight percentage (Table 5) which is slightly below that of pure gypsum, while the average purity of the Nafada gypsum is 91.78%. From this result, it can be deduced that the studied gypsum contains little amounts of other compounds; hence, making them of good quality.

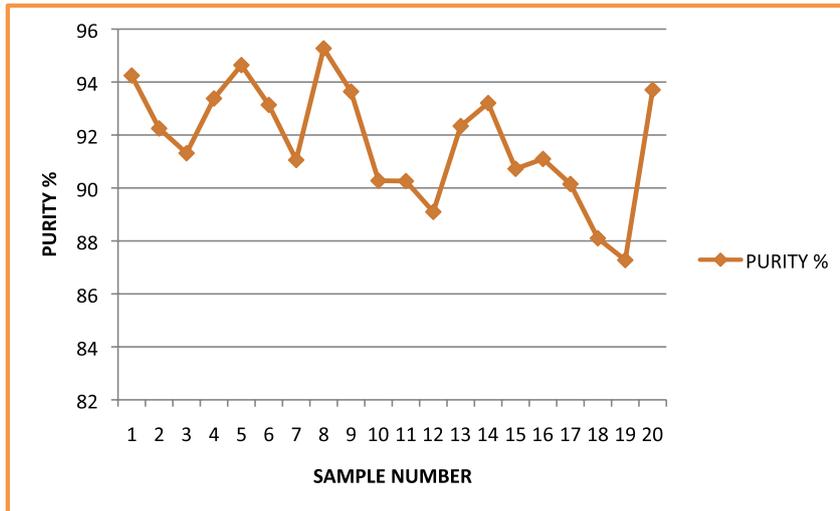


Fig. 7. Graph of purity of all samples.

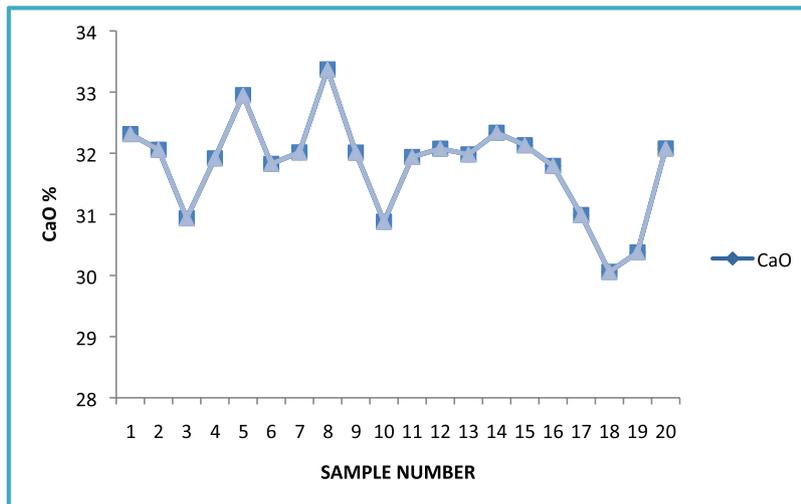


Fig. 8. Graph of lime content.

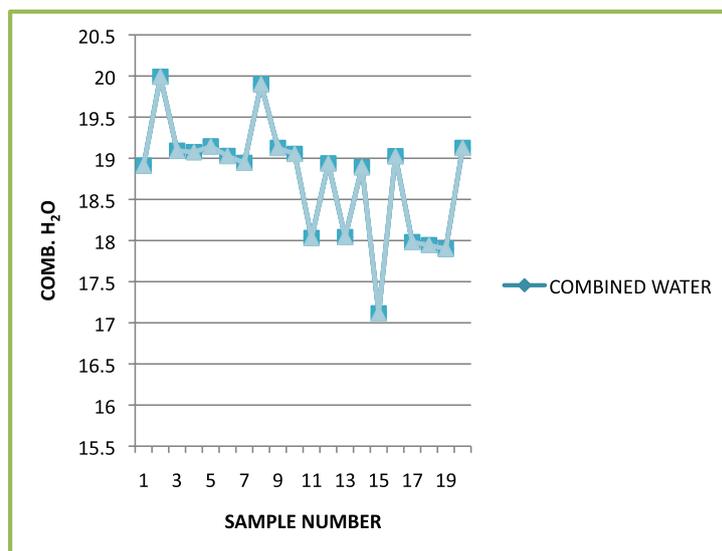


Fig. 9. Graph of combined water of the samples.

Table 5. Quality assessment parameters in the studied Nafada gypsum.

Sample no	Combined water	SO ₃	CaO	Purity
1	18.910	43.022	32.313	94.245
2	19.991	40.202	32.057	92.250
3	19.092	41.286	30.936	91.314
4	19.075	42.389	31.916	93.380
5	19.145	42.546	32.950	94.641
6	19.028	42.284	31.826	93.138
7	18.944	40.099	32.014	91.057
8	19.900	42.000	33.371	95.271
9	19.126	42.503	32.011	93.640
10	19.053	40.341	30.881	90.275
11	18.031	40.292	31.938	90.261
12	18.938	42.084	32.075	89.097
13	18.042	42.316	31.981	92.339
14	18.891	41.981	32.335	93.207
15	17.115	41.478	32.131	90.724
16	19.025	40.279	31.792	91.096
17	17.981	41.180	30.989	90.150
18	17.944	40.097	30.060	88.101
19	17.899	38.999	30.378	87.276
20	19.126	42.502	32.078	93.706

Table 6. Comparison of local and foreign gypsum [Source: Haruna (2005)].

Foreign gypsum	CaSO ₄ .2H ₂ O (wt%)	Moisture content	Local gypsum	CaSO ₄ .2H ₂ O (wt%)	Moisture content
Morocco	93.40	15.67	Yobe	93.40	15.00
Spain	94.70	18.38	Benue	89.30	18.52
			Sokoto	42.40	9.78

According to the British Industrial Standard and Raw Material Research Development Council (BIS, 1997; RMRDC, 2005), gypsum is graded into four

- High grades (88%–100%)
- Medium grades (65%–87%)
- Low grades (50%–60%)
- Anhydrides (less than 50%)

The purity of gypsum in Nafada ranges from 87% to 95% which is suitable both for agricultural and industrial uses.

Comparison of the studied gypsum characteristics to the BIS reveals that the studied gypsum conforms to the BIS specification for various industries, except that of the surgical and pharmaceutical industry which requires a minimum of 96.0% CaSO₄.2H₂O.

The studied gypsum has an average of 91.78% CaSO₄.2H₂O.

11. Industrial application

The BIS specification for cement is 70%–75% and 80%–85% CaSO₄.2H₂O for export quality, 0.6% (max) K₂O + Na₂O, and 3.0% (max) of MgO. The studied gypsum with an average of 91.78% (max) CaSO₄.2H₂O, 0.12% K₂O + Na₂O, and 1.12% MgO has met the BIS required standard limit. BIS specification for ammonium sulphate fertilizer is 85%–90% (min) CaSO₄.2H₂O, 6.0% (max) SiO₂, 1.0% (max) Fe₂O₃/Al₂O₃, and 1.5% (max) MgO. With 91.78% (max) CaSO₄.2H₂O, 2.19% SiO₂, 0.45% Fe₂O₃/Al₂O₃, and 1.12% MgO, the studied gypsum is within the BIS required specification for ammonium sulphate fertilizer production. Pottery has

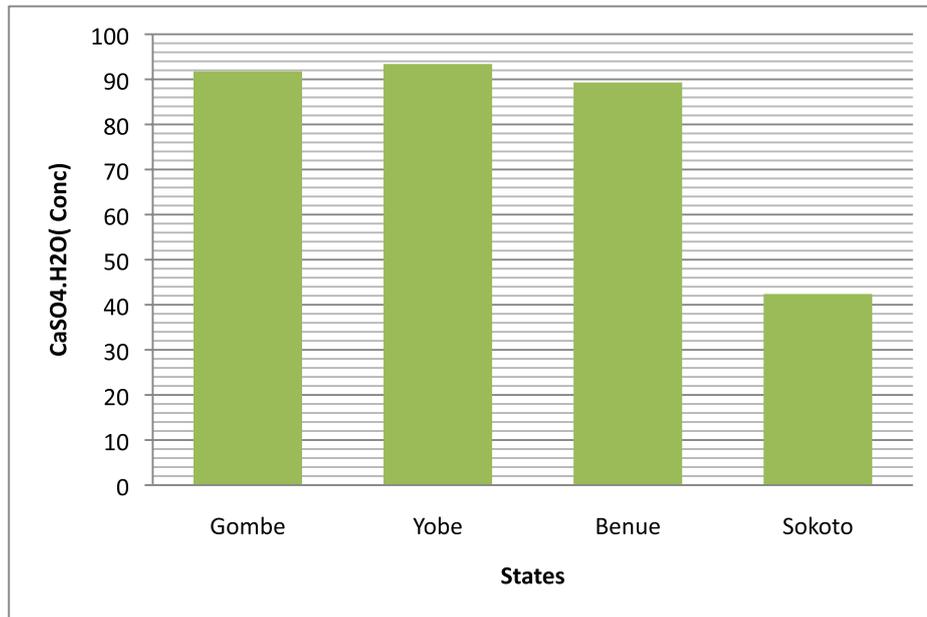


Fig. 10. Graph of comparison between gypsum locally and the study area. Note: Gombe = Nafada.

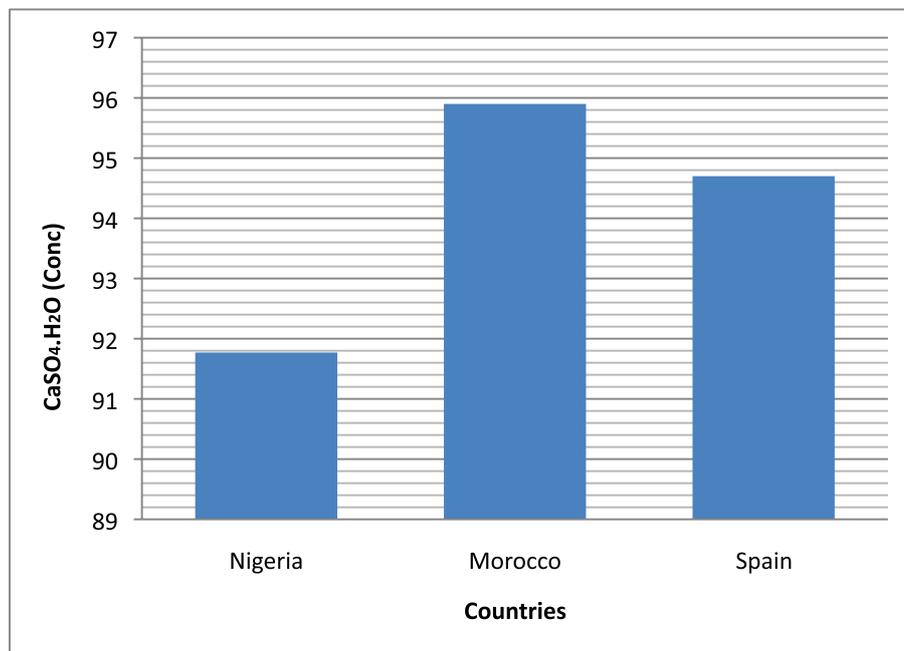


Fig. 11. Graph of comparison between gypsum internationally and the study area. Note: Nigeria = Nafada.

BIS specification of 85% (min) $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, 1.0% (max) $\text{Fe}_2\text{O}_3/\text{Al}_2\text{O}_3$, and 1.5% (max) MgO , while the studied gypsum has 91.78% $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, average (table) 0.45% $\text{Fe}_2\text{O}_3/\text{Al}_2\text{O}_3$, and 1.12% MgO ; hence is within the specified BIS requirement. Cosmetics manufacture has BIS specification of 75.25% (min) $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, 3.0% (max) SiO_2 , and the studied gypsum has 91.78% $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, 2.19% SiO_2 can be used for cosmetic manufacture. The studied gypsum with 93.0% $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ is within the specification for materials needed in the building, chemical and paint industries, and for soil amendment.

Similarly, according to BIS specification, gypsum with a moisture content of 20.9 weight percentage (wt%) is regarded as pure gypsum. Those with low moisture content are regarded as impure, while those with no moisture content have been transformed from gypsum to anhydrite. The studied Nafada gypsum has an average moisture content of 18.74 weight percentage (Table 4) which is slightly below that of pure gypsum, while the average purity of the Nafada gypsum is 91.78%. From this result, it can be deduced that the studied gypsum contain little

amounts of other compounds; hence, making them of good quality.

12. Summary

The chemical composition of the gypsum forms showed that all the gypsum forms are high-grade gypsum because they contained over 70% $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$. Economically, they are good gypsum raw materials but the Alabaster being the heaviest, is the most suitable for cement works. Balatino, selenite, satin spar, and alabaster could serve as good raw materials for the chemical industries, especially in the manufacture of fertilizer. The pure Balatino laminated gypsum is the best for the pharmaceutical, ceramic, paint, and paper industries because it makes a very good, plaster of Paris (POP) (Calcined gypsum) because of its pure quality.

All the gypsum forms are suitable for the chemical industry because the average $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ content is over 70%. The Pharmaceutical companies need very clean, undeformed gypsum to produce high-quality POP. The Balatino laminated gypsum is suitable because it contains an appreciable quantity of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$. It is clean and transparent as such it would be very good for making POP for medicine, as well as for ceramics, paint, and paper industries. A comparison of chemical composition of alabaster gypsum from the study area (Nafada), Benue and Sokoto gypsum revealed that the gypsum in Nafada is the best in quality for cement works because it is the heaviest (91.78 wt%), followed by Benue gypsum (89.3 wt%) and the lightest is the Sokoto gypsum (42.4 wt%).

13. Conclusion

This research shows that the study area has four different forms of gypsum, the balatino, the alabaster, the selenite, and the satin spar which varies in their characteristics. These gypsum forms vary in their depth ranging from 13 to 18 m. The geochemistry of these gypsum forms reveals that the gypsum is pure and can be used for different industrial applications, such as pharmaceuticals, ceramic, cement manufacture, agricultural purposes, and POP.

14. Recommendations

Based on the research and the information gotten from this work, I can recommend the following:

- i) Geophysical survey should be conducted in order to delineate the deposit in the area more

- ii) The government should invest more in a modern exploration of gypsum in the area so as to boost the economy of the country

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