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Full Length Research Paper

Petrographic analysis for naming and classifying an igneous intrusive rock in the Lower Benue Trough

Michael A. Nwachukwu[1]*, Chukwuemeka Chinaka[1] and Maureen I. Nwachukwu[2]

[1]Department of Geosciences Federal University of Technology Owerri, Nigeria.
[2]GEOPROBE International Consultants Ltd Owerri, Nigeria.

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Absence of specific name and classification of the Isiagu intrusive rock and definition of its petrographic province became a challenge. To this effect, we collected rock samples at various depths from a deep quarry pit at Ishiagu and subjected the samples to both physical and optical analysis. This analysis was further tied to the basic principles of magma fractionation and crystallization. Physical analysis of hand specimens obtained at 0, 15, 30, 45, 60, 75 feet depths found the rock as hollo-crystalline, consisting of phenero-crystals. The texture is finer top-down, with mafic minerals increasing bottom-up, and felsic minerals greater top-down. This describes the intrusive as intermediate between felsic and mafic, rather than the use of basic and acidic in existing literature. Average specific gravity (SG) of the rock samples is 2.8, but the 45 ft sample has the highest SG of 3.0, and consists mainly of mafic minerals. Others have light to intermediate colours. A calcite vein of average width (30 cm) runs top-down of the intrusive body. This calcite (secondary mineral) is vitreous, colourless, has perfect cleavage, and hardness less than 4. From both physical and optical analysis, the major minerals of the Isiagu intrusive are in the order of abundance: Augite, Plagioclase, Quartz, Olivine, Hornblende, Biotite and Magnetite (main accessory). Plagioclase however is more abundant at depths ≥ 60 ft. The percentage concentrations of these minerals vary with depth and described the Isiagu intrusive as Olivine-diabase of Lacolith structure.

Key words: Olivine-diabase, intermediate intrusive, petrographic province, Isiagu.

INTRODUCTION

The study area (Ishiagu) lies in the sedimentary basin of Southern Nigeria (Figure 1). The sedimentary units in this area are generally cretaceous in age, and have long been studied by several workers (Reyment, 1965; Kogbe, 1975; Adegoke, 1969). Based on the findings of these workers, the study area is underlain by the Asu-River Group (Albian), and bordered on the south by the Eze-Aku shale (Figure 2). The Asu River group is the lowest (oldest) lithostratigraphic unit of the cretaceous age laid down within the Benue Trough. The Benue Trough originated from Early Cretaceous rifling of the central West African basement uplift. It forms a regional structure which is exposed from the northern frame of the Niger Delta and runs northeast for about I000 km to underneath Lake Chad, where it terminates (Figure 1). Regionally, the Benue Trough is part of an Early Cretaceous rift complex known as the West and Central African Rift System.

The Asu-River Group consists of largely brown sandy shale with fine grained micaceous sandstones. Both Reyment (1965) and Kogbe (1975) hold that the Asu-River Group shale grades into a subordinate sandstone facies. This is fine to medium grained, thinly bedded to massive, poorly sorted and grayish white to brown in fresh and weathered surfaces respectively. Whiteman (1972) showed that the Asu-River Group was intruded by minor basic and intermediate intrusive during the Santonian period which outcrop around Ishiagu. Hoque (1977) reported that the first depositional cycle of Albian to Santonian time was confined mainly to the Benue—

*Corresponding author. E-mail: geoprobe@clear.net.

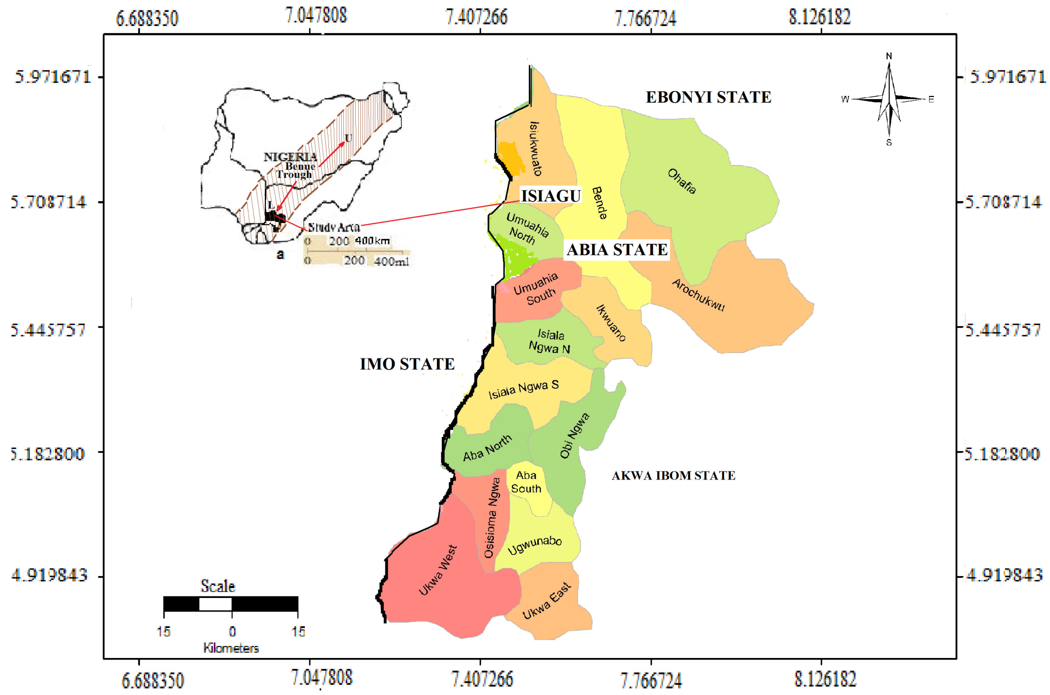

Figure 1. The study area.

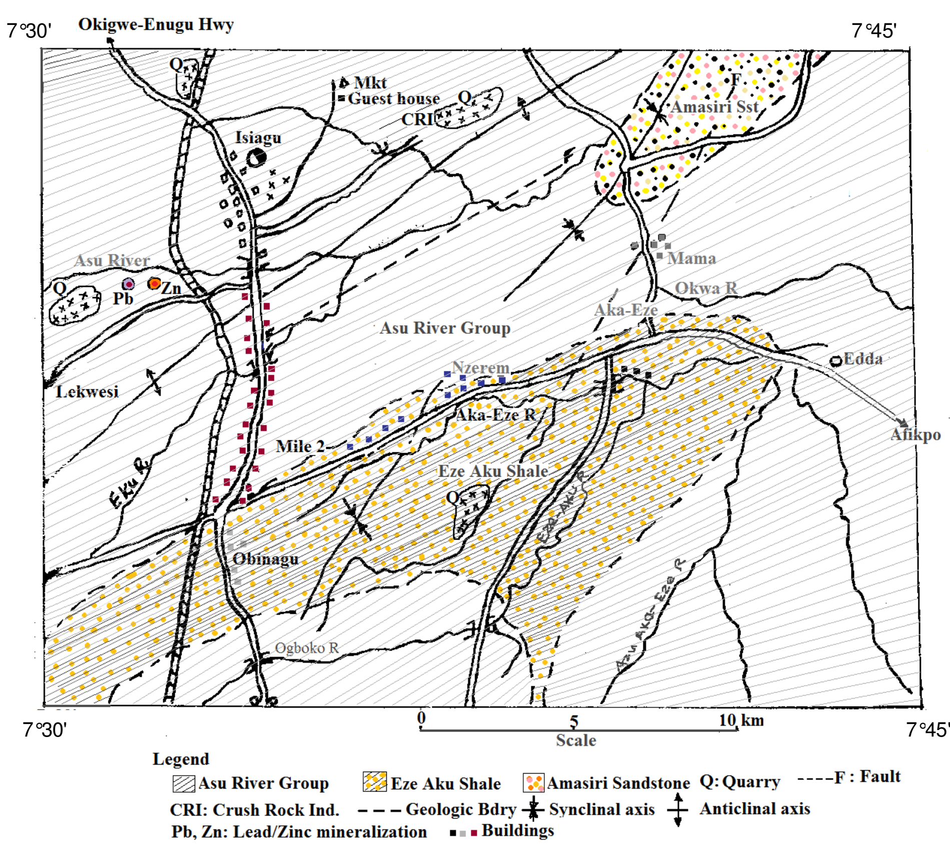

Figure 2. Geologic map of Isiagu showing the deep Crush Rock Industry quarry pit.

Abakaliki to Isiagu trough and the lithic fill is characterised by feldspathic sandstone, with Asu-River Group as the oldest sediments. According to Nwachukwu (1975), the Asu-River Group is overlain unconformable by the shale and sandstone units of Eze-Aku Formation (Turonian). The Eze-Aku shale consists of flaggy calcareous shale with bluish non calcareous to brownish and greyish shale and siltstones with thin sandstones (Whiteman, 1982). A minor sandstone unit in the area can be found at Amasiri.

Nwachukwu (1975) showed that lead-zinc mineralization occur only within the sedimentary rocks of the albian age (Asu-River Group). He was of the view that the mineralization occurs dominantly as an open fillings within steeply dipping fracture system.

On the origin of mineralization in Ishiagu, Ezepue and Odigi (1993) suggested a low temperature hydrothermal origin, with the anticlines which were transacted by north and north-west trending fractures serving as major controls for lead-zinc mineralization. The geologic history of Ishiagu and environs shows that during the Albian stage, majority of the argillaceous sediments in the area were laid down. Then the general topography (landscape) was more or less flat. However, the tectonic activities that occurred during the santonian age deformed these rocks and resulted in considerable folding of the sediments (Kogbe, 1975). There is igneous intrusion within Asu-River Group (Albian age). These igneous intrusions are therefore post Albian events (in accordance with the principle of cross-cutting relationship).

The intrusive are widely distributed from Ishiagu to beyond Zurak. But the more notable areas are Ishiagu, Lokpa in Okigwe area, Abakaliki, Lafia, Egbede Hills and Aghila area south of the belt. Etuk et al. (2008) described the Lokpaukwu–Uturu–Ishiagu magmatic belt of the Lower Benue Trough as an example of structurally controlled igneous intrusion. They believed that heat from the igneous intrusions raised the temperature of the source rocks above the liquid oil window limit, and thus inhibited the preservation of essential constituents of petroleum in the shale of the Lower Benue Trough.

The general relief of this study area is characterized by hills and valleys. Majority of the hills and valleys align in the NW-SE direction, and conform to orientation of the folds from the Santonian orogenic deformation. The characteristic dendritic drainage pattern of the argillaceous and other fine grained sediments is not uncommon with Ishiagu. The Ishiagu and environs are well drained with the general river flow trending NE-SW. Majority of the rivers return in the northern part and merge as tributaries to the Asu-River Group, while those of the south form tributaries to Eze-Aku River. In addition, the general surface water flow pattern conforms to the fold axes. Majority of the rivers in Ishiagu and environs align in this direction with the exception of those in the NW part which tend to flow in northwest-southwest direction, (Kogbe, 1975). Ishiagu is characterized by thick and dense vegetation typical of the tropical rainforest. The fine-grained soil; mostly clay, shale, silt and mixtures of these and sands support luxuriant plant growth. The presence of abundant trees, shrubs and grasses is responsible for the dense vegetation found in this area. The vegetation however is denser in the parts directly overlain by the Asu-River Group that is, mainly Ishiagu). Those in areas with Eze-Aku shale then grade after that of the Asu-River Group. The characteristic thick vegetation observed in the areas is overlain by the Asu River Group or close to it. It can be attributed to the close proximity of the Asu River group to the water table being the oldest lithostratigraphic unit of cretaceous age in the area. However, outstanding vegetation cover occurs along the river banks or old river valleys.

Review of igneous petrography

The difficulty of classifying rocks, applies more especially to the igneous group, because of the way in which the various types shade into one another. Even the same molten mass may differentiate into several species, showing not only differences of texture, but marked changes of chemical and mineralogical composition (Smith, (1997). Probably this is the major reason why the Isiagu and other isolated intrusive rocks in the lower Benue Trough has not been specifically named. They are generally classified as basic to intermediate intrusive (Reyment 1965; Kogbe 1975; Ofoegbu, 1988; Etuk et al., 2008; Maluski et al., 1995). It cannot be emphasized too often that the accurate mapping and description of the rock in the field is the basic starting point of the study of rocks. It is equally true that all conclusions or theories about the origin of rocks based upon laboratory investigations must be checked in the field and in hand specimen. Under the hand specimen examination, the important feature to be examined is the colour and texture of the rock. This is the degree of crystalline, and grain size or granularity, thus describing the rock as felsic or mafic. The intermediate then refers to igneous rocks that have mineral composition and characteristics between felsic and mafic, rather than basic and acidic used in old literature.

The textural features cast much light on the conditions under which igneous rocks consolidate from their parent magmas. They are controlled by the rate and order of crystallization, which depend in turn on the initial temperature. It also depends on the composition, gas content and viscosity of the magma and the pressure under which it solidifies. Based on the major- and trace-element geochemistry, Hezarkhani (2006) described fractional crystallization as the process that produces the present intrusive rocks. He used petrography and geochemistry to classify the Sungun intrusive rock as partly consisting of later diorite/granodiorite phase. His result indicates that the composition of various rocks can be explained by up to 24% fraction of ferromagnesian minerals such as pyroxene and amphibole. Barth (1965 and 1966) modified Bowen's original diagram to explain the order of crystallization as continuous and discontinuous series. Some igneous rocks are classed as holocrystalline if they are composed of crystals. Others such as obsidian consist entirely of glass and consequently are referred to as holo-hyaline. The rest include many lavas and shallow intrusive rocks containing both glass and crystals, and are said to be hypo-crystalline or merocrystalline. Extremely minute, incipient crystals are called microlites, provided they show birefringence. If they are even smaller, spherical, rod and hair-like isotropic forms, they are called crystallites.

Consider next the grain size or granularity. If most of the constituents are so small as not to be visible to the unaided eye, the rock is called aphanites. Its texture is said to be aphanitic or encrystalline. Rocks of coarser grain are classed as phanerites, and their texture are termed phaneritic or dyscrystalline. If the diameters of most of the crystals are less than 1mm, the grain is called fine, if they are between 1 mm and 5 mm, medium, if between 5 mm and 3 cm, coarse, and if more than 3cm, very coarse. The degree of crystallinity and granularity of an igneous rock reflects its history. Holocrystalline rocks of medium and coarse grain are mostly plutonic. The next step is to prepare thin section. This procedure, which is the main step or method on which most petrographic works are based, provides us with precise information regarding the mineralogy of the rock. It also provides information about the proportions of the various minerals and their texture, being as important as the mineralogy. Mineralogical compositions may be used as a method of classification of igneous rocks. It is on this that most of the classifications in general use depend. The simple classifications are qualitative in nature, while the various rock groups are being determined simply by the presence or absence of certain essential minerals. The more sophisticated classifications are of a quantitative nature and correspondingly more complex. The actual amounts of the various minerals present have to be determined. Often colour index is used in quantitative and semi quantitative classification to describe percentage of minerals by volume with density greater than 2.8, being mainly the dark minerals. Some old but very useful classification methods reviewed in this study include that of Nockolds (1978), Moorhouse (1959), and Grout (1932).

MATERIALS AND METHODS

Collection of rock samples

Fresh rock samples for this research were collected from quarry pit of the Crush Rock industry located at Amokwe village Isiagu. Here the intrusive was covered by a thin overburden of about 1 m, being mainly weathered rocks. The quarry is constructed in 15 ft bench levels, through which entry to the full depth (75 m) was possible. Six fresh rock samples were collected with the help of a semi-sledge hammer at 0, 15, 30, 45, 60, and 75 ft consistent with bench toes. Joints, cracks fractures and calcite veins at the quarry faces were examined. Samples were numbered according to their respective depths. Weathered samples were very much avoided to prevent alteration of results. Physical examination of the bulk samples and prepared hand specimen was conducted with the aid of hand lens. Mineral constituents were identifies primarily based on colour, crystal shape, lustre, hardness, streak, magnetism, and acid test. The Specific Gravity (S.G) of the fresh rock samples was determined using a lever balance. This was tested as follows:

Each of the fresh rock samples was weighed in air using the lever balance, and their weights recorded. The samples were each tied using a nylon thread and reweighed by immersion inside a 400 ml beaker. Beaker was filled almost to the brim with water, and the sample weight in water recorded. The difference between the weight in air and that in water for each of the samples was obtained. This was used to compute the specific gravity of each of the samples thus:

$$\text{Specific Gravity (S.G)} = \frac{\text{Weight in air}}{\text{Loss of weight}}$$

A total of 18 thin sections were prepared, making 3 thin sections from each of the classified depth samples. Equipments and materials for making the thin sections are as follows:

(i) Cutting and slicing machines.
(ii) Fresh rock samples (collected from Ishiagu intrusive).
(iii) Sheet of slide glass (about 7 cm by 2 cm with about 0.15 mm thickness).
(iv) Canada balsam.
(v) Emery cloth (sandpaper) and caborundum powder.
(vi) Spirit liquid
(vii) Water
(viii) Cover slip
(ix)Micrometer screw gauge

Preparation of thin sections

Each fresh rock sample was cut perfectly to a square shape of the required thickness of about 1.0 cm with the help of the cutting machine. The specimen is reduced perfectly flat with emery cloth (Sand paper) and caborundum powder to a thin sheet with thickness of about 0.04 mm measured with the micrometer screw gauge. Boiled Canada balsam was placed on top of the flattened specimen. The arrangement is covered with a cover slip and left for 24 h, after which it is washed, cleaned with spirit, and later with water. This method of thin section preparation was used on all the six fresh rock samples, and a total of 18 thin sections were prepared from the samples. Among these 18 thin sections, 3 thin section slides were prepared from one fresh rock sample for at least full representation of all the constituent minerals. In each set of 3 thin sections of a sample, 2 thin sections were covered with Canada balsam to aid proper microscopic examinations, whereas one was left uncovered for a staining test if need be. In all, 12 thin section slides were covered, and 6 left uncovered with Canada balsam. The Twelve covered thin section slides (2 slides from each rock sample) were subjected to microscopic examinations. Greggory Bottley Reflected Light Polarizing Petrographic microscope was used with magnification 10×, and the analysis was accomplished by use of the microscope analyzer in, and analyzer out.

Table 1. Specific gravity of rock samples at respective depths.

Samples	Depth	Specific gravity
1	0.00	2.70
2	15.00	2.77
3	30.00	2.68
4	45.00x	3.00
5	45.00	2.19
6	60.00	2.75
7	75.00	2.85

Table 2. Optical responses of the associated minerals in thin sections

Name of mineral	Seen with the analyzer out	With the analyzer in
Quartz	Mineral is transparent and clear, has no cleavage traces	Cream colour
Plagioclase	This mineral is cloudy with 2 faint cleavage directions	Grey colour, with stripes and twinning
Biotite	Colour is brown based, which changes on rotation of stage. One developed cleavage.	Mine becomes darker in colour.
Honblende	Mineral changes colour from brown to green. on rotation of the stage. Shows 2 good cleavages directions.	Dull orange colour.
Augite	Mineral has a steady brownish colour, with 2 cleavage directions that are at right angles	Mineral colour changes from brown to grey on rotation of stage.
Olivine	Mineral is colourless, stands out in the thin section. No good cleavage, but traversed by dark curving cracks.	Mineral shows brilliant blue colour.
Magnetite (Accessory)	Mineral is dark and opaque	Constant dark
Calcite (Secondary)	Mineral is colourless, with perfect cleavage	Uniform cream

RESULTS AND DISCUSSION

Physical study of the hand specimens

The fresh rock samples megascopically showed the following characteristics – black, dark green, dark grey, and mottled black and white colours, with fine, medium to coarse textures. They are holocrystalline (consist of crystals) and generally phanerocrystalline consist of grain sizes coarse enough to be identified with the necked eye. They consist of yellowish or golden crystals suspected to be pyrite (accessory). Some of the rock samples contain a segregated portion consisting of calcite. This is suspected to be a secondary mineralization along fracture or cavities resulting from hydrothermal crystallization. The calcite mineral was confirmed by an acid test. The light coloured crystals are the felsic minerals like the quartz, feldspars and muscovite (white mica). While the dark, dark greyish and greenish crystals are the mafic minerals like the biotite, amphiboles, pyroxene and olivine. The 45 ft sample has the highest SG of 3.0, and consists mainly of mafic minerals (Table 1)

$$\text{Average S.G} = \frac{2.70 + 2.77 + 2.68 + 3.00 + 2.19 + 2.75 + 2.95}{7} = 2.85$$

Optical analysis

The analytical procedure is as shown in Table 2, and the optical views are as presented in Figures 3 to 5. The common rock forming minerals were identified by their properties: Pleochroism, color, optical forms and cleavage as shown in the sections drawn from the microscopic views. Two thin sections were selected out of the three made from each depth replicate sample. The combined optical views of the two selected slides of each depth sample were presented to double-check the analytical results (Figure 6). Analytical results indicate that percentage of high temperature minerals increase

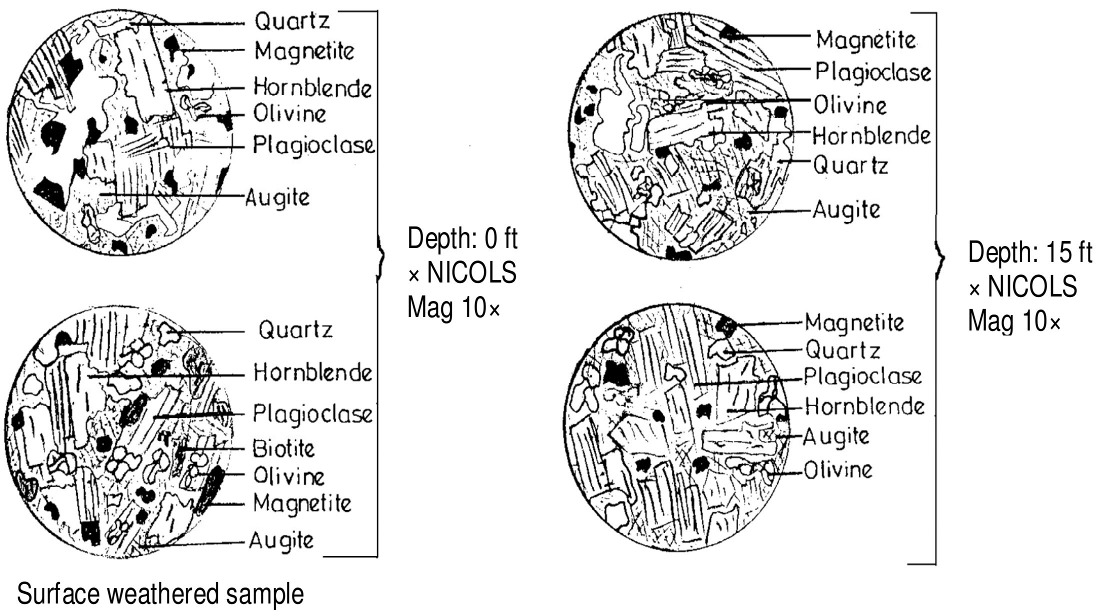

Figure 3. Analytical structure of optical view at depth 0 to 15 ft.

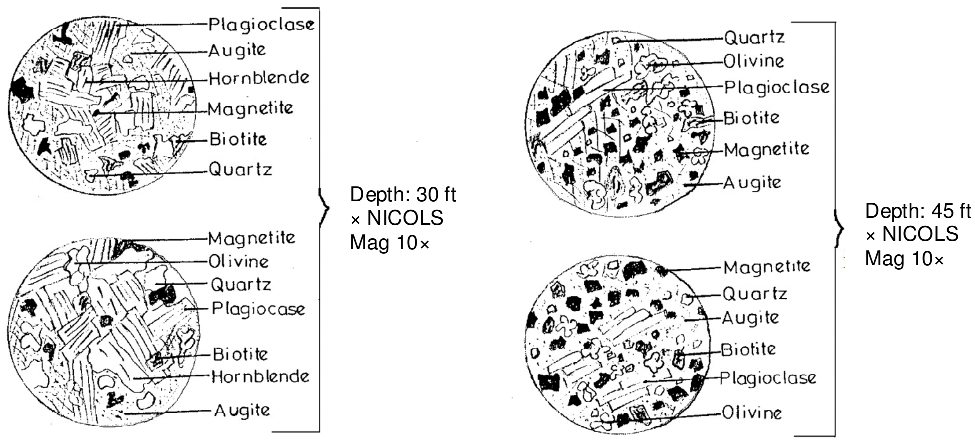

Figure 4. Analytical structure of optical view at depth 30 to 45 ft.

with depth, and that of low temperature minerals decrease with depth (Tables 3a to f). The result has provided evidence to the rock color being darker towards surface, since the high temperature minerals crystallize first, and are of lighter colour.

Classification

Physical analysis has satisfied the conditions spelt out for diabasic rock (Johannson, 1934), with respect to colour, texture, and specific gravity. Going by optical analysis and as provided by Morehouse (1959), this rock could be quartz-diabase. This is because the rock has mafic minerals within 40 to 70% and quartz over 5% of felsic minerals. But holding the views of Grout (1939), the optical analysis best satisfies the condition given for Olivine diabase. This is because the rock contains basic plagioclase over 95% of the total feldspar. It contains mafic minerals between 40 to 90%, and shows the presence of olivine (2 to 10%) most importantly. This has therefore influenced the Isiagu intrusive rock name as Olivine diabase. The rock is therefore described as intermediate between felsic and mafic rather than use basic and acidic as common in old literature. According to Smith (1997), typical specimens of olivine diabase may contain plagioclase (50 to 60%), with minor olivine (3 up to 12% in Olivine diabase), magnetite (2%) and ilmenite

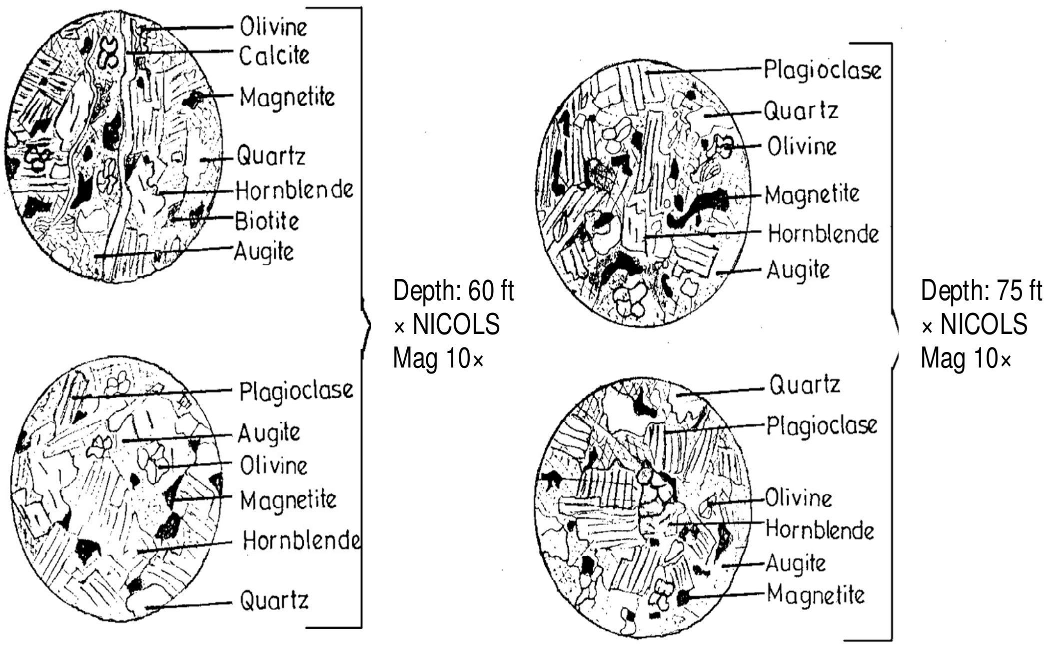

Figure 5. Analytical structure of optical view at depth 60 to 75 ft.

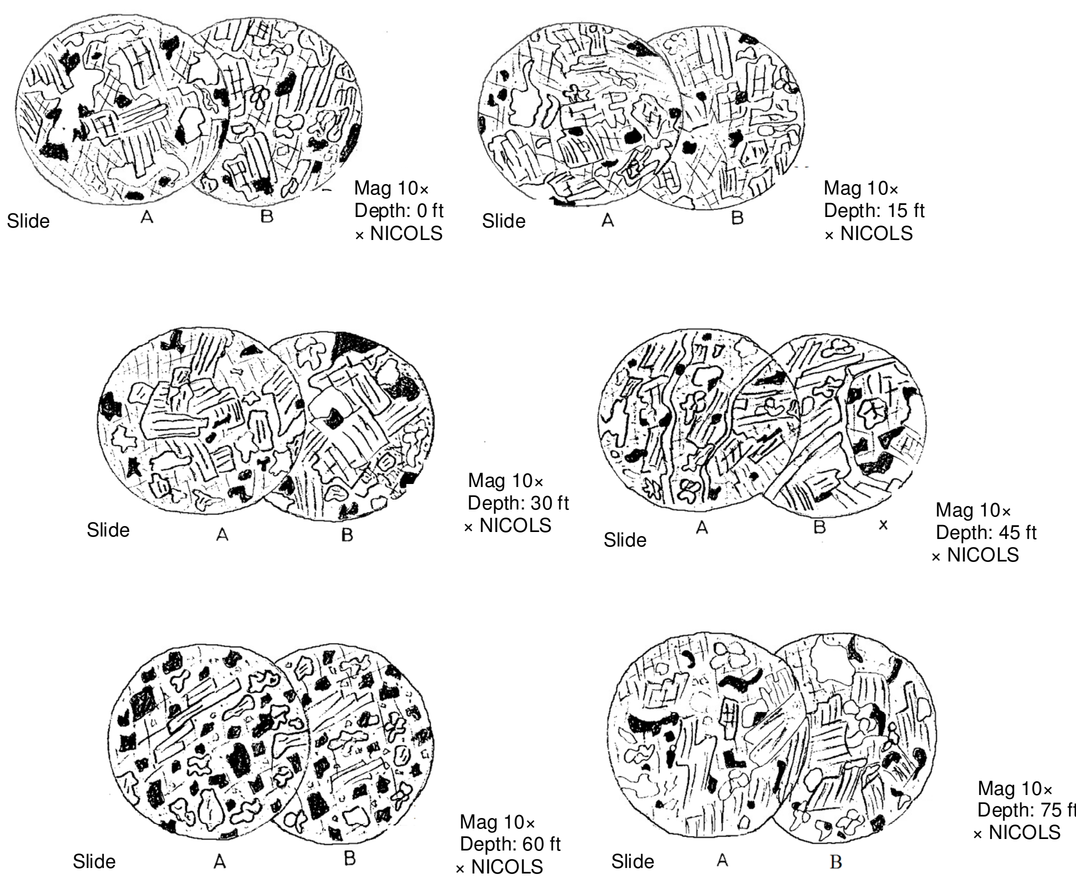

Figure 6. Combined optical views of two slides of each depth sample to double-check optical views and the analytical results. A= Primary sample; B= Replicate

Table 3a. Result of optical analysis for sample number 1

Sample No.	Sample depth (ft)	Minerals found	% Estimate
1	0 (surface Sample)	Quartz	6
		Magnetite	6
		Biotite	6
		Plagioclase	35
		Augite	40
		Olivine	2
		Honblende	5

Table 3b. Result of optical analysis for sample number 2

Sample No.	Sample depth (ft)	Minerals found	% Estimate
2	15	Quartz	6
		Magnetite	8
		Plagioclase	37
		Augite	42
		Olivine	4
		Honblende	3

Table 3c. Result of optical analysis for sample number 3

Sample No.	Sample depth (ft)	Minerals found	% Estimate
3	30	Quartz	6
		Magnetite	7
		Plagioclase	32
		Augite	42
		Honblende	2
		Biotite	5
		Olivine	6

Table 3d. Result of optical analysis for sample number 4

Sample No.	Sample depth (ft)	Minerals found	% Estimate
4	45	Quartz	2
		Magnetite	7
		Plagioclase	30
		Augite	46
		Olivine	10
		Biotite	5

(2%). Accessory and alteration minerals include hornblende, biotite, apatite, pyrrhotite, chalcopyrite, serpentine, and chlorite. The texture is termed “diabasic” and is typical of diabase. This diabasic texture is also termed “interstitial”. The feldspar is high in anorthite (as opposed to albite), the calcium end member of the plagioclase. Lewis (2008) described the petrology of Newark igneous rocks observed that Olivine occurs somewhat sparingly in the denser contact facies, and is very abundant only in the Olivine-diabase ledge.

Table 3e. Result of optical analysis for sample number 5.

Sample No.	Sample depth (ft)	Minerals found	% Estimate
5	60	Quartz	5
		Magnetite	5
		Plagioclase	43
		Augite	29
		Olivine	6
		Honblende	2
		Biotite	3
		Calcite	7

Table 3 f. Result of optical analysis for sample number 6

Sample No.	Sample depth (ft)	Minerals found	% Estimate
6	75	Quartz	5
		Magnetite	7
		Plagioclase	52
		Augite	30
		Olivine	5
		Honblende	1

According to him, the range in mineral composition of the intrusive would be designated in the older terminology by the names quartz-diabase, diabase, and olivine diabase. The prefixes quartz and olivine denotes special richness in these minerals in the most acidic and most basic portions of intrusive rock respectively.

Conclusion

This research has shown the Isiagu intrusive rock is of Olivine-diabase, with some hybrid body suspected to have resulted from later recrystalization of mafic components. Physical analysis of hand specimens obtained at 0, 15, 30, 45, 60, 75 ft depths found the rock as hollo-crystalline, consisting of phenero-crystals. Average specific gravity (SG) of the rock samples is 2.8, but the 45 ft sample has the highest SG of 3.0, and consists mainly of mafic minerals. The study has added clear picture on the petrogenesis of the intrusive. The coarsening upward texture of the rock significantly confirms gradual crystallization of the magma in a discontinuous manner. The intrusive bodies have dome-like shape arching the overlying sediments, and can be described as massive laccoliths. It is being speculated that the mode of crystallization changed at some stage, as shown by some darker rock samples at near surface depths. Several types of field evidence indicate that the Isiagu intrusion was emplaced at a shallow depth. These include zero to thin overburden rock, well-developed laccoliths structure with fine-grained boulders, and the abundance of round vesicles in some parts of the upper boulders. These characteristics appear similar to that described by White (2007) for the Graveyard point intrusive of Snake River Plain. Future studies on other intrusive bodies near Isiagu are recommended for comparative analysis. Such studies will explain if the associated intrusive rocks of the lower Benue Trough belong to one petrographic province. Petrographic photomicrographs may be added to support illustrations.

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