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Geology and Petrography of Schlieren cum Nebulites from Bauchi, Northeastern Nigeria

Yahuza I.[1*], Haruna A.I.[1] and Isah B.[2]
[1]Department of Applied Geology, Abubakar Tafawa Balewa University Bauchi, Nigeria
[2]Department of Geology, University of Jos, Nigeria
isahyahuza@gmail.com

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Abstract

Bauchi area is part of sheet 149NE which falls within the Northern Basement Complex of Nigeria. In this study, the area was mapped on a scale of 1:25,000. Samples were collected at the flanks of the outcrops, railway cuts, road cuts as well as blasting sites within the area. At each sampling point, two or more samples were collected based on morphological variations. The first and second order morphological classifications of migmatites as being metatexite or diatexite such as banded orthogneiss, stromatic, schlieren or nebulite were used as the guiding principle. This technique was repeated for the rest of the sampling points in the area covering about fifteen (15) different locations. A total of 10 representative samples were studied petrographically. Together with the field mapping and morphological features, it was observed that the area has five different lithologic units, viz: metasediment (quartzite), schlieren (melanocraticdiatexite), nebulites(Bauchite, quartz-diorite and granulitic granite) in a sequence ofprograde metamorphism where CO_2 (graphite) aids in supplying the temperature needed for the exceptional coarse grains features of the nebulites yet through rapid cooling.

Keywords: Quartzite, Shlieren, Nebulite, Prograde Metamorphism, Graphite.

Introduction

The rocks of this area were studied by Falconer[1], Bain[2], Oyawoye[3-5], Dada *et al.*[6] and Haruna[7]. This present work is aimed to investigate the rocks in the light of prograde metamorphism. The study area is located on sheet 149N.E. (Bauchi N.E.) which lies between latitudes $10^0$15'00" & 10^0 20'48.33" North of the Equator and longitudes $09^0$50' 00" & $09^0$55'00" East of the Greenwich Meridian. It covers a total land mass of about 95 square kilometers and is accessible through many roads (notably Bauchi-Gombe, Bauchi-Jos, Bauchi-Ningi & Bauchi-Dass Federal Highways) and other numerous footpaths. The area has medium-high level outcrops (500–680m) of Precambrian Basement rocks. Drainage pattern is dentriitic with smaller streams which meanders into the larger perennial rivers (Dindima to the south & Gubi to the north), which are also tributaries of the Gongola River[8].

Literature Review: Oyawoye[3] concluded that most of Nigeria was probably covered by sedimentary rocks which were metamorphosed to schists, quartzites, amphibolites and calcsilicates in the normal cycle of regional metamorphism during the Precambrian times. These are still found over most of the country where not obscured by Cretaceous sedimentary rock or completely granitized, as in the Bauchi District. In the Bauchi District, the metasedimentary rocks appear to have been converted to granulites with irregular masses of calcsilicate rocks. From these granulites, the evolution of the present Bauchi rocks began with the interstitial development of microcline and a corresponding decrease in the proportion of biotite. Most of the early components for the microcline are taken from the biotite and the downward migration of the basic material must have started very early. This process, if it could be called granitization, was controlled by the planes of schistocity and differential rates of development lead to the development of the lit-per-lit gneiss. As the process advanced, the intervening bands of granulite also succumbed to granitization and only short parallel streaks of biotite and few schlieren were left to indicate their former presence. Thus the biotite gneiss was evolved[3]. From here on, the course of granitization is reflected in the field mainly by textural changes. There is a marked and progressive, though not entirely gradual, disappearance of the original fine grained granular texture and the emergence of medium to coarse porphyroblastic aggregates[3]. King and De Swardt[9] remarked on a similar trend of development in the Osi area of Nigeria. Although the microcline porphyroblasts tend to grow with their longer axes in the plane of foliation of the rock, the general effect of their development is to obliterate the gneissose appearance and alter the rock progressively towards one of granitic aspect[3]. These transformations are believed to fall within the normal cycle of regional metamorphism and to have been under the temperature and pressure conditions equivalent to the amphibolite-granulite facies[3]. The intensity appears to be normally a function of depth though subject to many variables whose influences are not well known, among them: extraneous heat from consolidating abyssal magma, fluid emanation affecting change of temperature and or fluid pressure, stress and the bulk composition of the metamorphism[10]. Acting separately or in concert, these would tend to make the intensity of granitization completely varied, at a given plane in a plutonic series. Thus in Bauchi one is still able to observe the various stages of development from lit-per-lit gneiss to the Biotite-Hornblende Granite despite the deep erosion[3]. The principal stages in the development form aureoles around the core of Quartz-Diorite from where, it would appear to emanate heat and solution. The mineralogical changes show that the entire process is a metamorphic redistribution of rock components in an effort to reach a state of equilibrium under plutonic conditions[3]. And Soesoo and Bond[11] proposed that during melt segregation and transport the system is controlled by self-organized criticality that governs the topology of magmatic bodies from migmatitic leucosomes to pluton and batholiths.

Methodology

The method of mapping along profiles from one outcrop to another taking note of road and railway cuts as well as blasting sites that revealed sub-surface lithology was used in a systematic manner in the field in order to understand the geology of the area[12]. Structural measurements were taken using compass clinometer, while samples of fresh rocks units were taken at each location with coordinates, labeled using hammer, GPS and pens.

The first and second order morphological classifications of Sawyer[13] and Hasalova *et al.*[14] were used as the guiding principle. This technique was repeated for the rest of the sampling points in the study area covering about fifteen (15) different locations. A total of 29 samples were collected. The 29 samples collected were sorted and grouped into 5 on the basis of morphology. From each group, 2 representative samples (10 in total) were picked for petrographic analyses.

Petrographic analysis involves the description of a rock sample in thin section using the optical microscope in the lab. This is more detailed than the macroscopic study, which involves looking at the rock sample with naked eye or through a hand lens to observe the color, texture, mineralogy and composition[15]. The polished thin sections were prepared at Thin Section Laboratory of ATBU Bauchi, Nigeria from the 10 selected fresh samples for petrographic studies.

The thin section of each sample was viewed in two modes the first with the analyzer out to produce or give the Plane-Polarized Light (PPL). In this mode, properties such as color, pleochroism, form, cleavage, relief and alteration could be seen. After this, the same slide this time with the analyzer produced the Cross-Polarized Light (XPL). In this mode, mineral properties such as interference colors, extinction angle, twinning and birefringence could be observed[15].

Hence, the best slide pictures are taken using phone camera mounted on the microscope with the aid of an adopter. The data were then compared with the results of the field mapping, presented and discussed below.

Results and discussion

The selected samples from the field were coded thus: Melanocratic Diatexite (A1, A2), - schlieren; Bauchites (B1, 2; D1, 2, 3), Quartz Diorites (C, E1) and Granulitic Granite (E2) - nebulites. This section presents the results of the analyses which comprise the field relationship of the samples, their morphological classifications, and petrography followed by the geology of the area.

Field Relationship, Macroscopic and Microscopic Descriptions: Schlieren: Melanocratic Diatexite (A1, A2): Samples A1 and A2 were found coexisting together in the field (Figure-1a). Morphologically, they are classified as melanocratic diatexite – schlieren mignatite because of the presence of rafts and schollen of paleosome[13] from Gudum with a nebulitic migmatite (brown Bauchite) developing from it (Figure 1b). Under the microscope (Figure -1c,1d), Sample A1 shows low relief. Anhedralto subhedral crystals. No cleavage. No twining. Interference colours include pink, blue, and grey which disappears as the stage is rotated. Minerals of the Rock are Q = quartz P = plagioclase K = k-feldspar B = biotiteGrp = graphite.

While Sample A2 (Figure 2a),under the microscope shows medium relief, anhedral to subhedral crystals, no cleavage, Albite twining, brown and grey interference colour which disappears as the stage is rotated. However, the brown colour remains both under PPL and XPL (Figure-2b,2c) signifying clinopyroxene. Minerals of the Rock are: = quartz P = plagioclase K = k-feldspar B = biotite Grp = graphite Cpx = clinopyroxene.

Nebulites: Bauchites (B1, 2; D1, 2, 3): Being varieties of Bauchite, Samples B1, 2; D1, 2, 3 coexist together in the field (Figure 3a) except where the green variety has been covered or the brown variety has been removed either by erosion or mining activity.

Morphologically, they are nebulitic migmatites because of scattered ghost-like remnants of paleosome within a coarser-grained, diffuse mesocratic neosome[16] from Warinje (Figures -3b,7a), Inkil (Figure4a), Dumi (Figure-5a) and Wambai (Figure-6a). Under the microscope, there was high relief, subhedral to euhedral crystals, cleavage, calsbad twining, interference colours include green, greyand blue which disappear as the stage is rotated. However, the green colour remains both under PPL and XPL (Figures-3c, 3d; 4b, 4c; 5b, 5c; 6b, 6c; 7b, 7c). The green colour under PPL is for Fayalite, Orthopyroxene and Clinopyroxene which changed under XPL to blue, purple and blue wish grey respectively (Figures -3d,4c,5c,6c,7c). Minerals of the Rocks are:

Q = quartz, P = plagioclase, K = k-feldspar, Grp = raphite, Cpx = clinopyroxene, Opx = orthoproxene, F =fayalite.

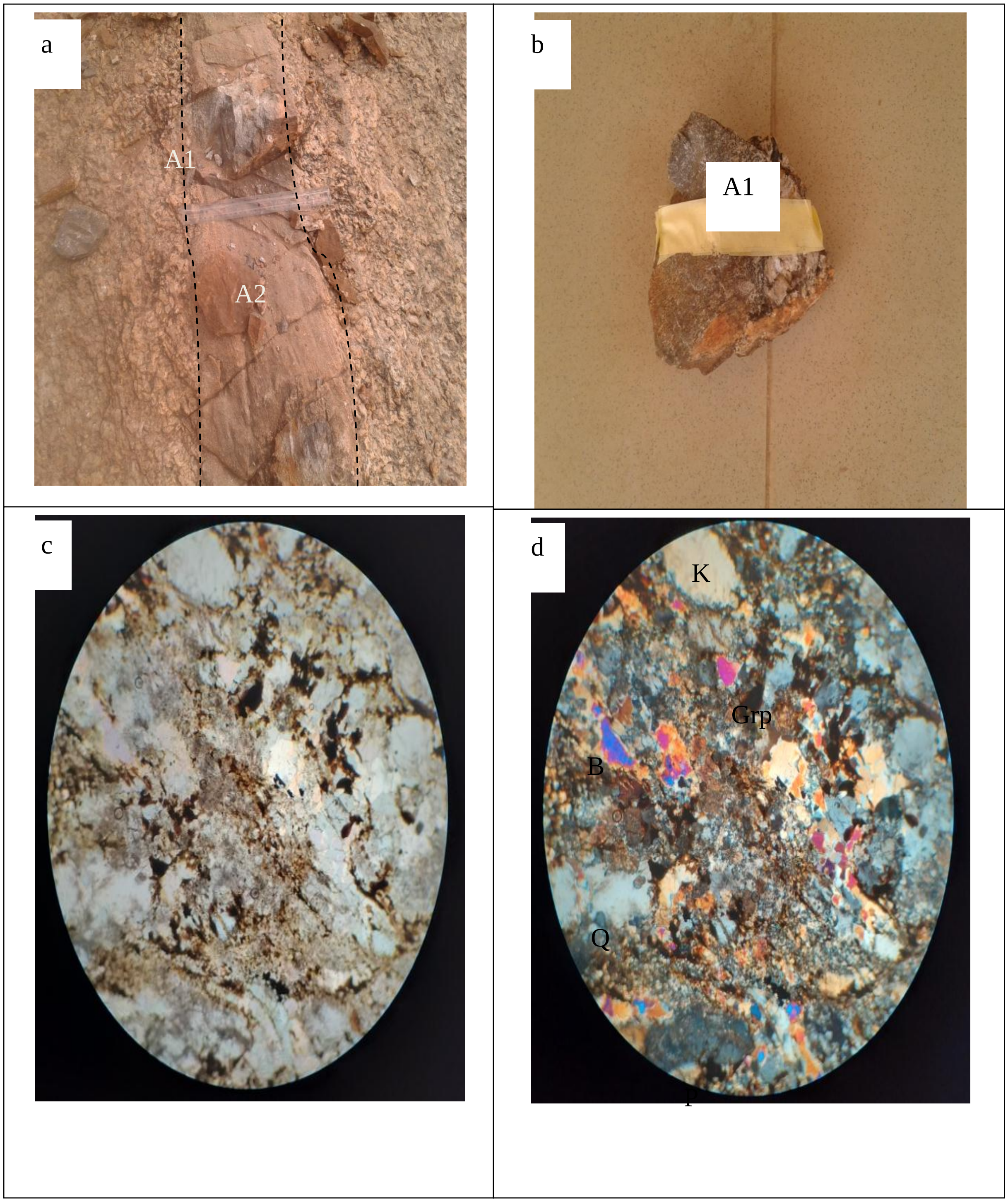

Figure-1a): Field occurrence of Shlieren (Samples A1 and A2) b) Hand Specimen of Schlieren (Sample A1) c-d) Schlieren (Sample A1) under PPL and XPL 12x.

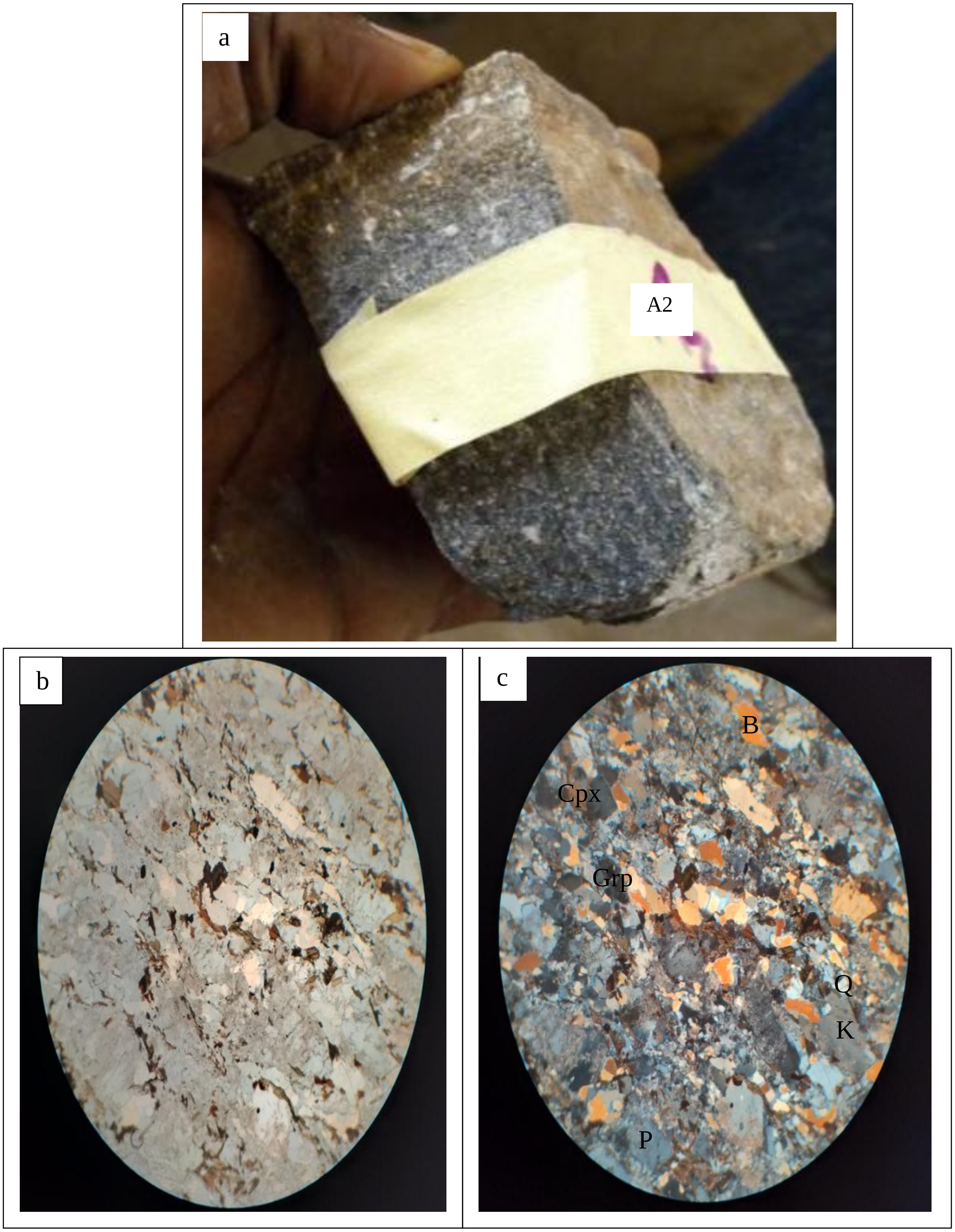

Figure-2: a) Hand Specimen of Schlieren (Sample A2) b-c) Schlieren (Sample A2) under PPL and XPL 12x.

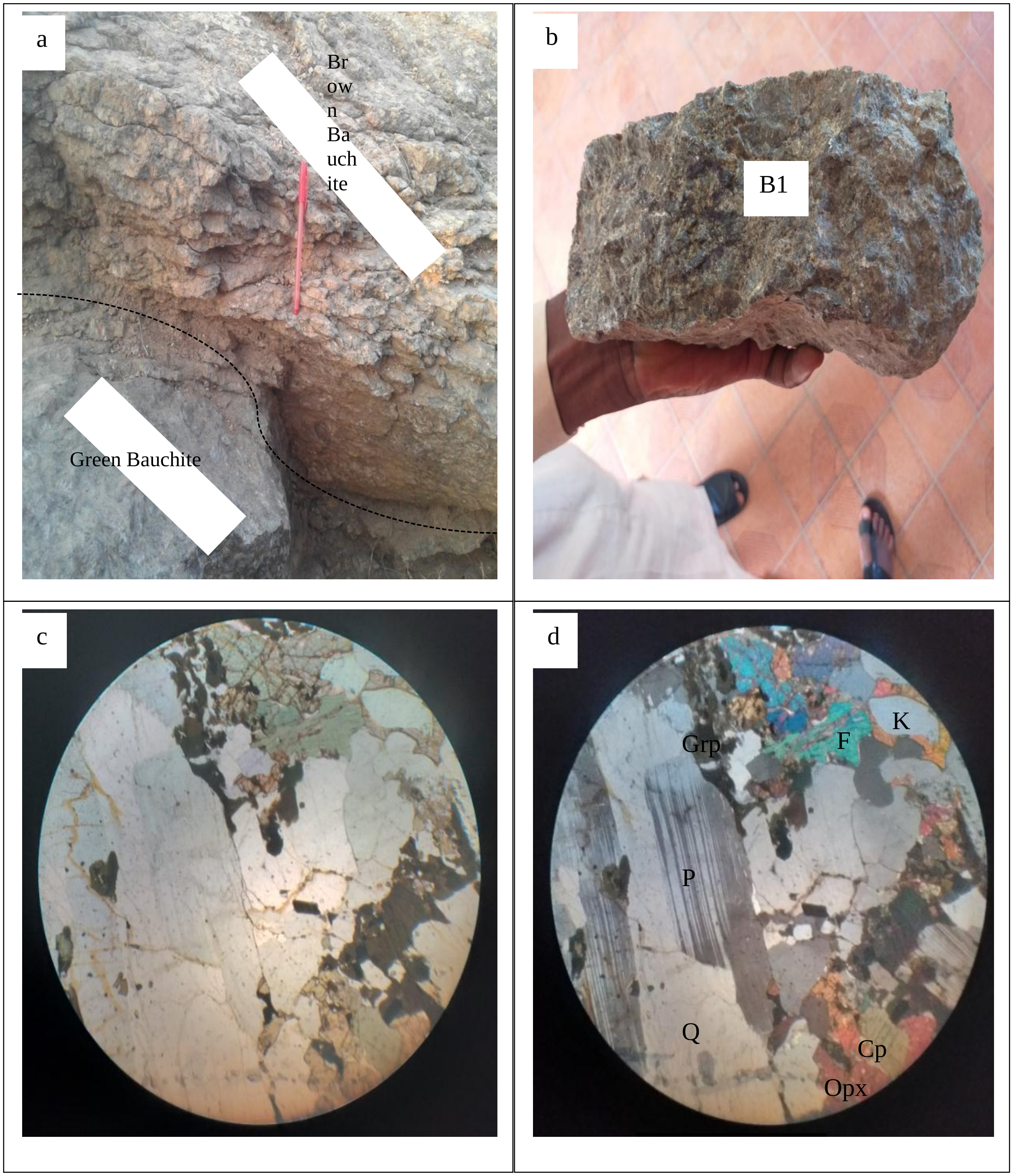

Figure-3: a) Field Occurrence of Nebulites – Bauchites (Samples B and D) b) Hand Specimen of Green Bauchite (Sample B1) c-d) Green Bauchite (Sample B1) under PPL and XPL 12x.

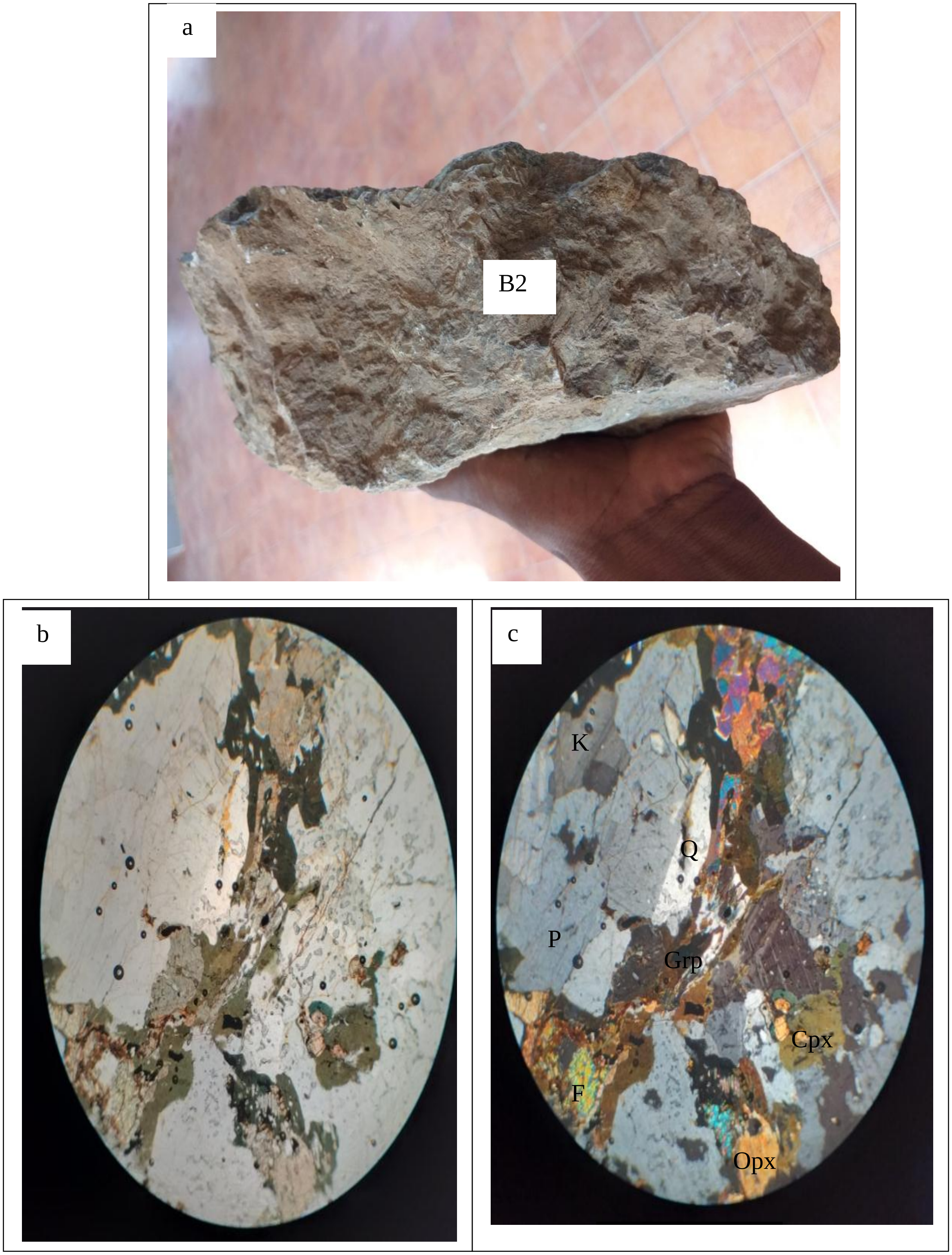

Figure-4: a) Hand Specimen of Green Bauchite (Sample B2) b-c) Green Bauchite (Sample B2) under PPL and XPL 12x.

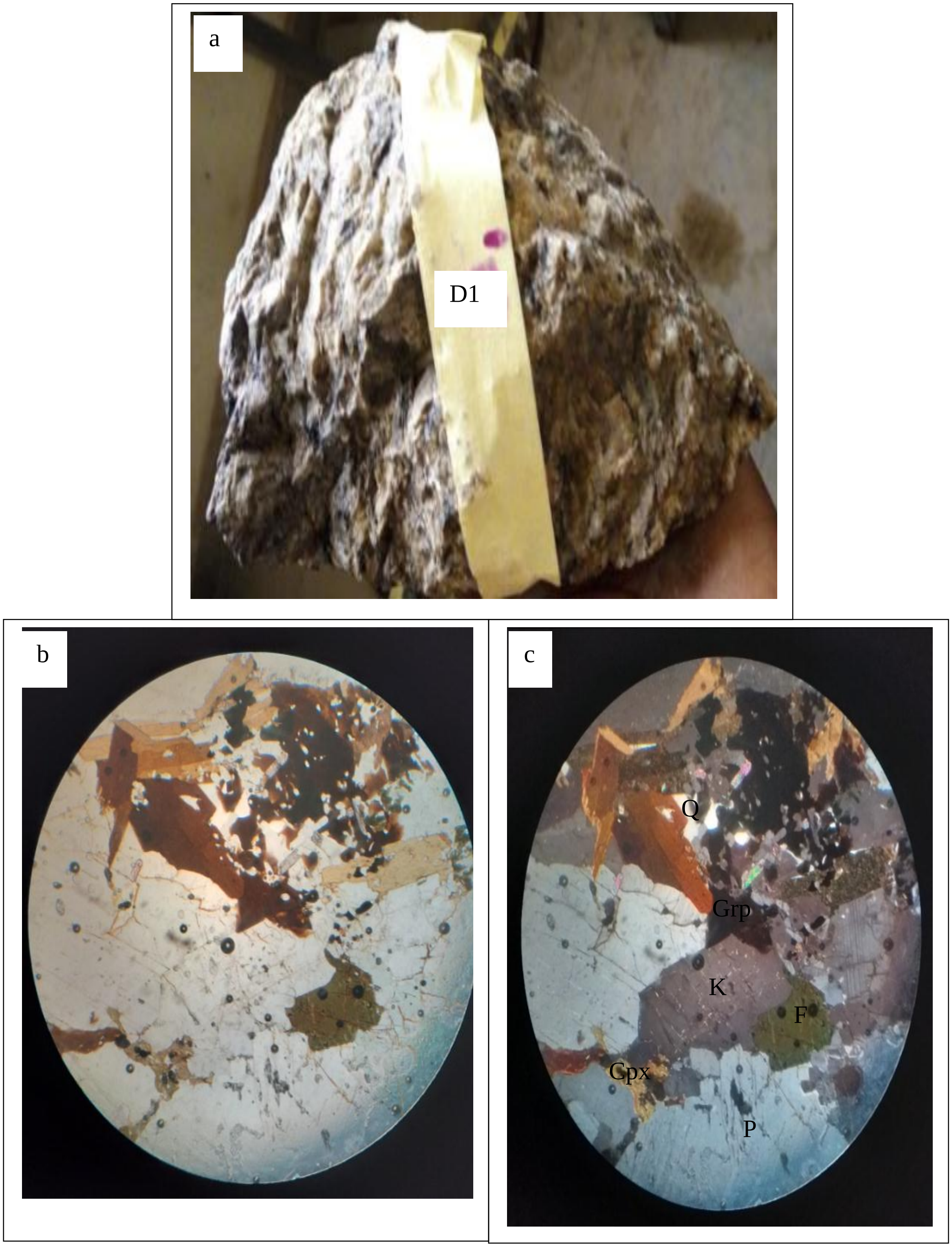

Figure-5: a) Hand Specimen of Brown Bauchite (Sample D1) b-c) Brown Bauchite (Sample D1) under PPL and XPL 12x.

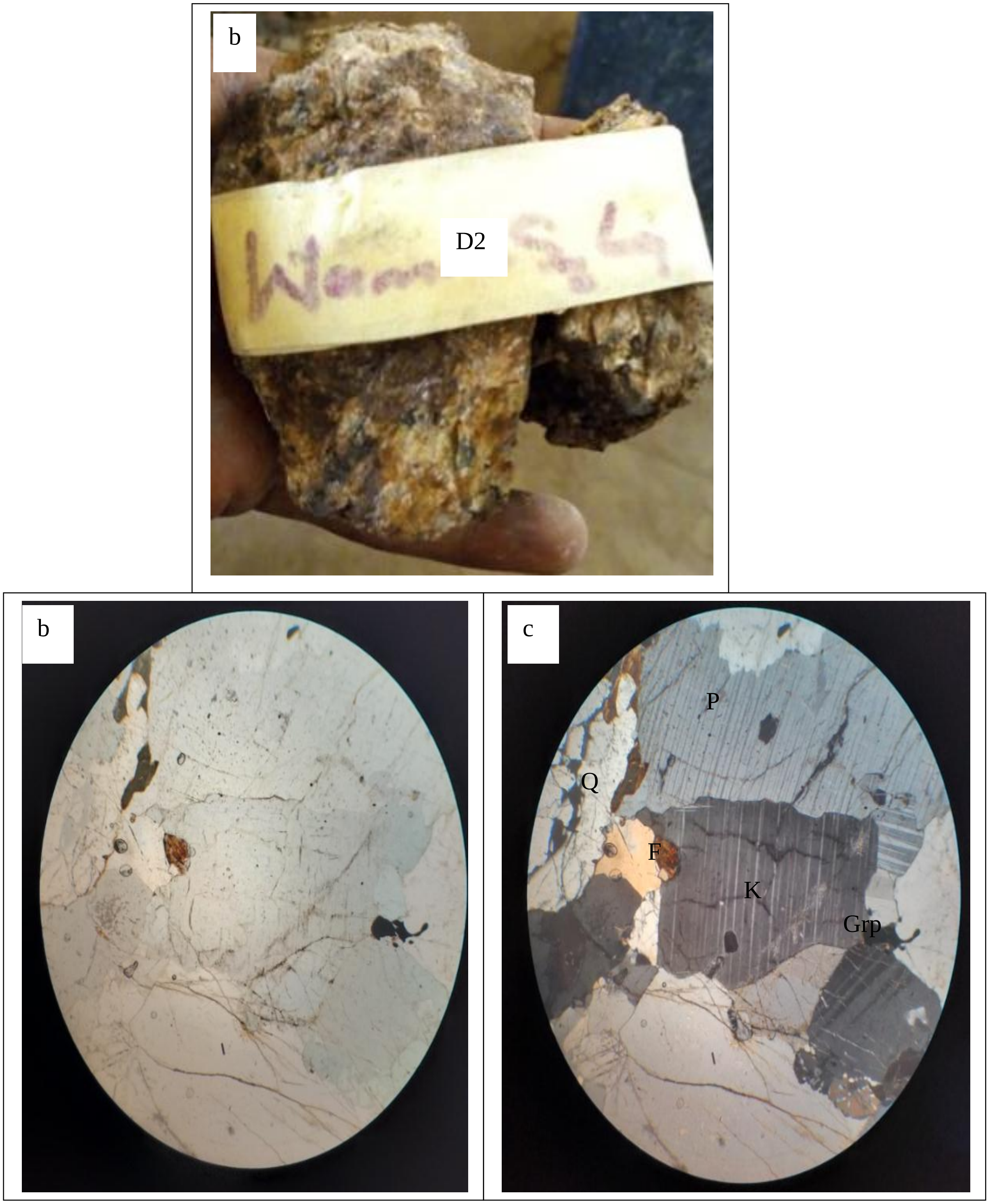

Figure-6: a) Hand Specimen of Brown Bauchite (Sample D2) b-c) Brown Bauchite (Sample D2) under PPL and XPL 12x.

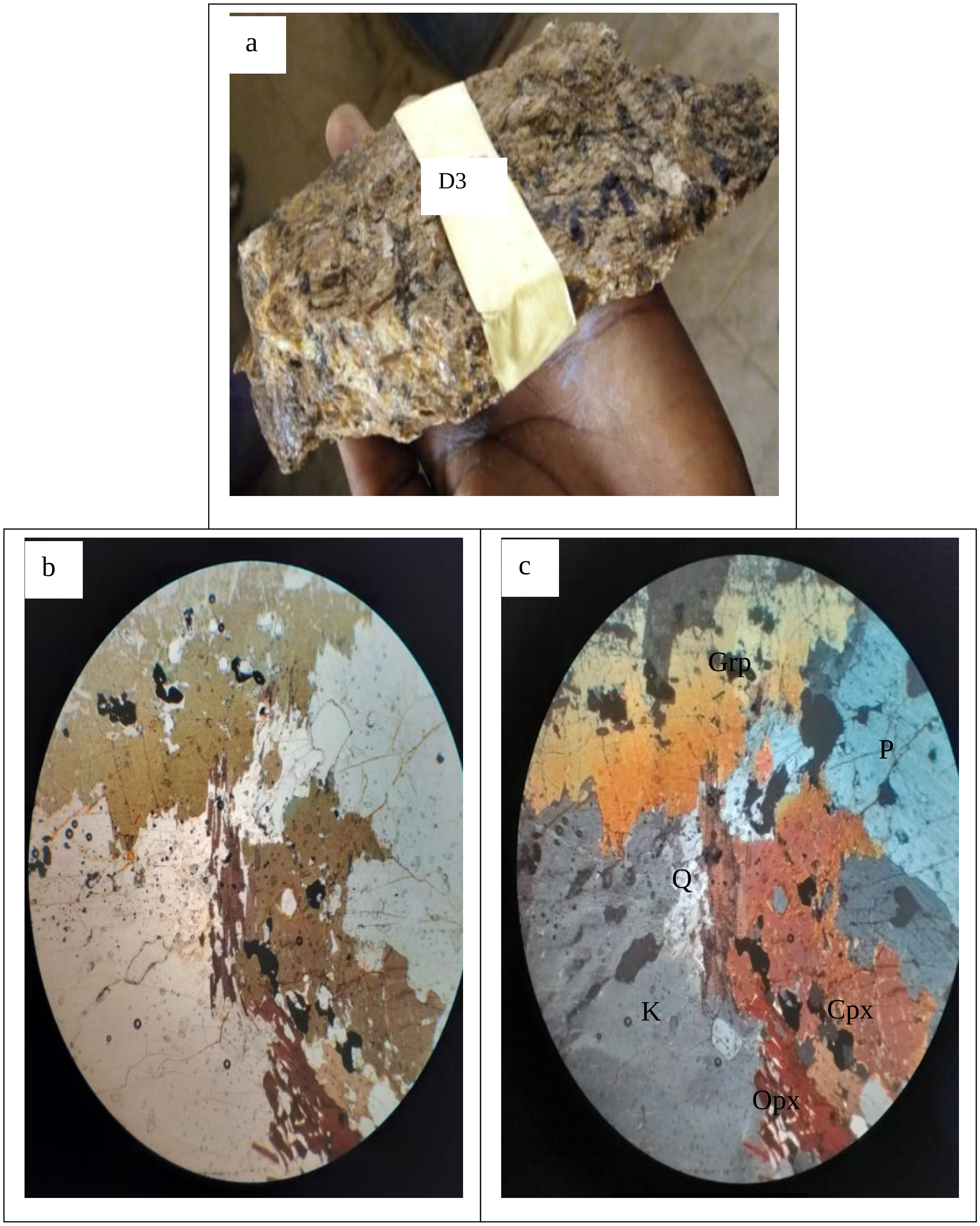

Figure-7: a) Hand Specimen of Brown Bauchite (Sample D3) b-c) Brown Bauchite (Sample D3) under PPL and XPL 12x.

Quartz Diorites (C and E1): The coarse grained quartz-diorite (Figure-8b) was sandwiched in Bauchite at a blasting site around Federal Low-cost and the medium grained (Figure 9a) at Dumi overlaid by granulitic granite (Sample E2 (Figure-10a)). Morphologically, they are also nebulitic migmatite because of scattered ghost-like remnants of paleosome within a coarser-grained, diffuse mesocratic neosome[13]. Under the microscope, both show high relief, subhedral to euhedral crystals, cleavage, Albite twining. Interference colours include green, greyand blue which disappear as the stage is rotated. However, the green colour remains indicating Hypersthene (Figures -8c, 8d; 9b,9c). Minerals of the Rocks are: Q = quartz, P = plagioclase, K = k-feldspar, Gp = graphite, B = biotite, Cp = clinopyroxene, H = Hypersthene Il = Ilminite.

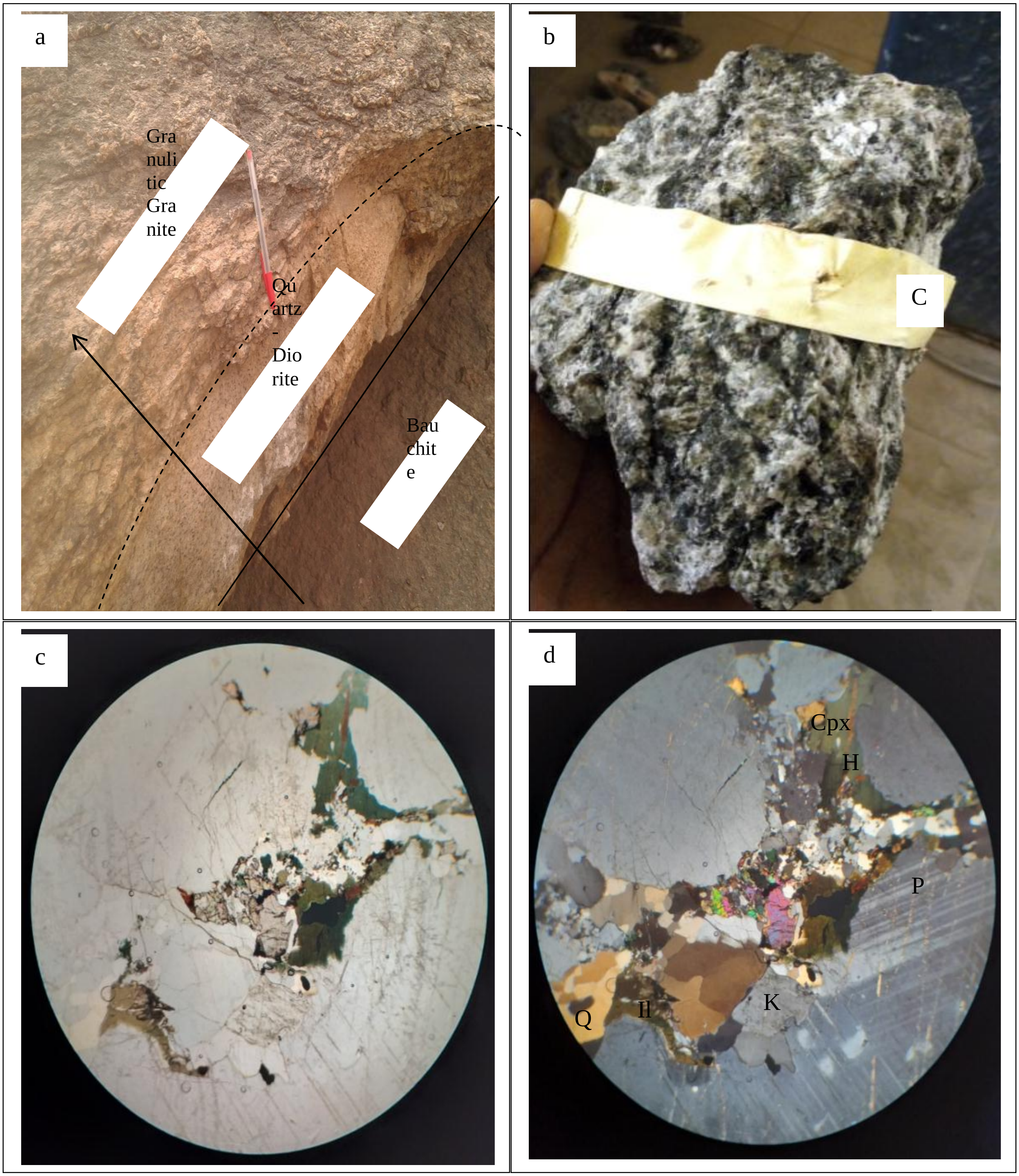

Figure-8: a) Field Occurrence of Nebulites – Quartz-Diorite and Granulitic Granite (Samples E1 and E2) b) Hand Sample of Coarse Grained Quartz-Diorite (Sample C) c-d) Coarse Grained Quartz-Diorite under PPL and XPL 12x.

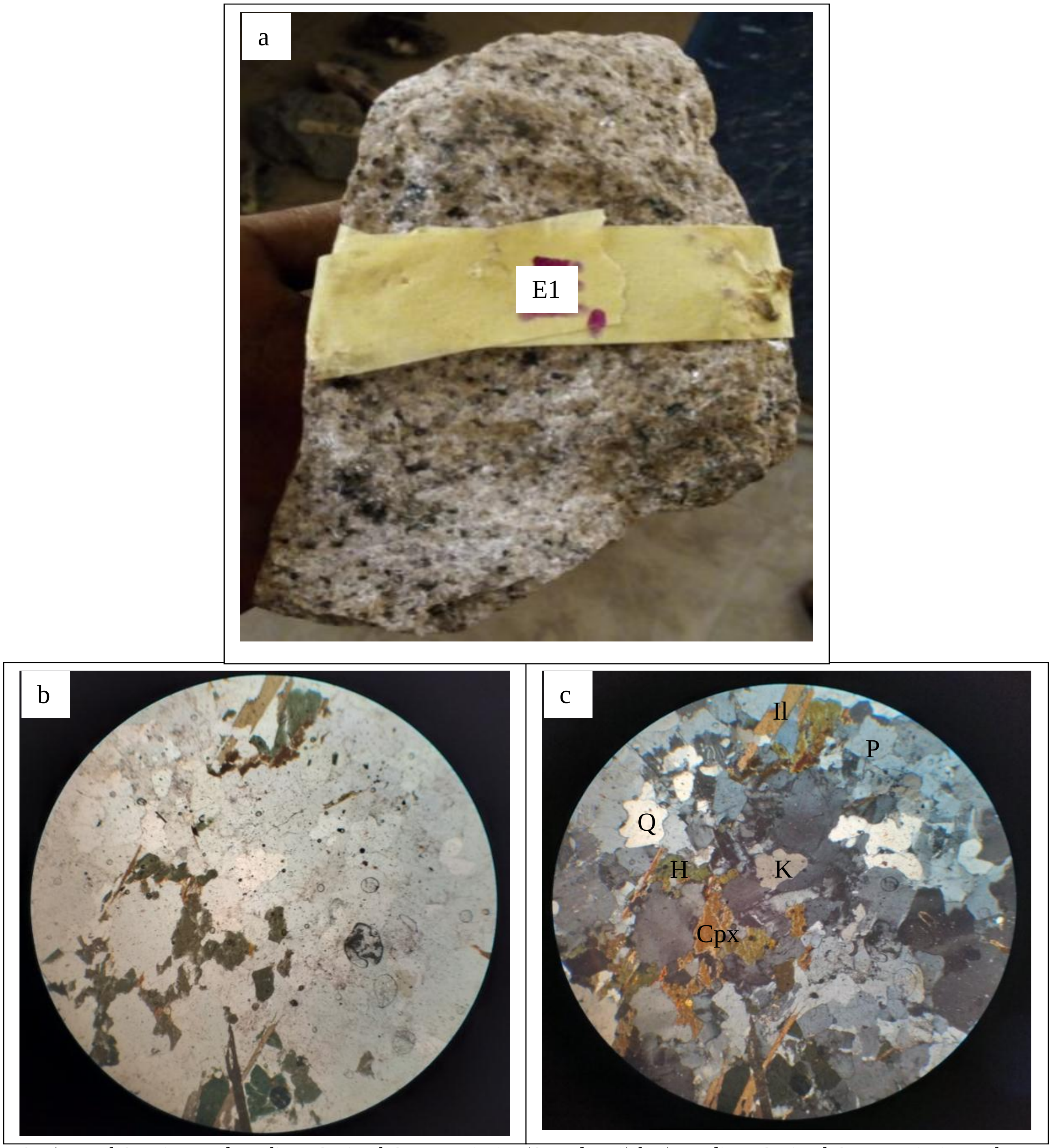

Figure-9: a) Hand Specimen of Medium Grained Quartz-Diorite (Sample E1) b-c) Medium Grained Quartz-Diorite under PPL and XPL 12 x.

Granulitic Granite (E2): The granulitic granite (sample E2) coexists together with quartz-diorite in the field. They usually appear overlying Bauchite (Figure-8a). Morphologically, it is equally a nebulitic migmatite because the neosome developed a foliation and a compositional banding[16] (Figure-10a). Under the microscope, granulitic granite shows high relief, subhedral to euhedral crystals, cleavage, Albite twining. Interference colours include brown and grey which disappears as the stage is rotated. However, the brown colour under PPL turns dark brown under XPL indicating Ilminite (Figure -10b,10c). Minerals of the Rock are: Q = quartz P = plagioclase K = k-feldspar Il = Ilmenite.

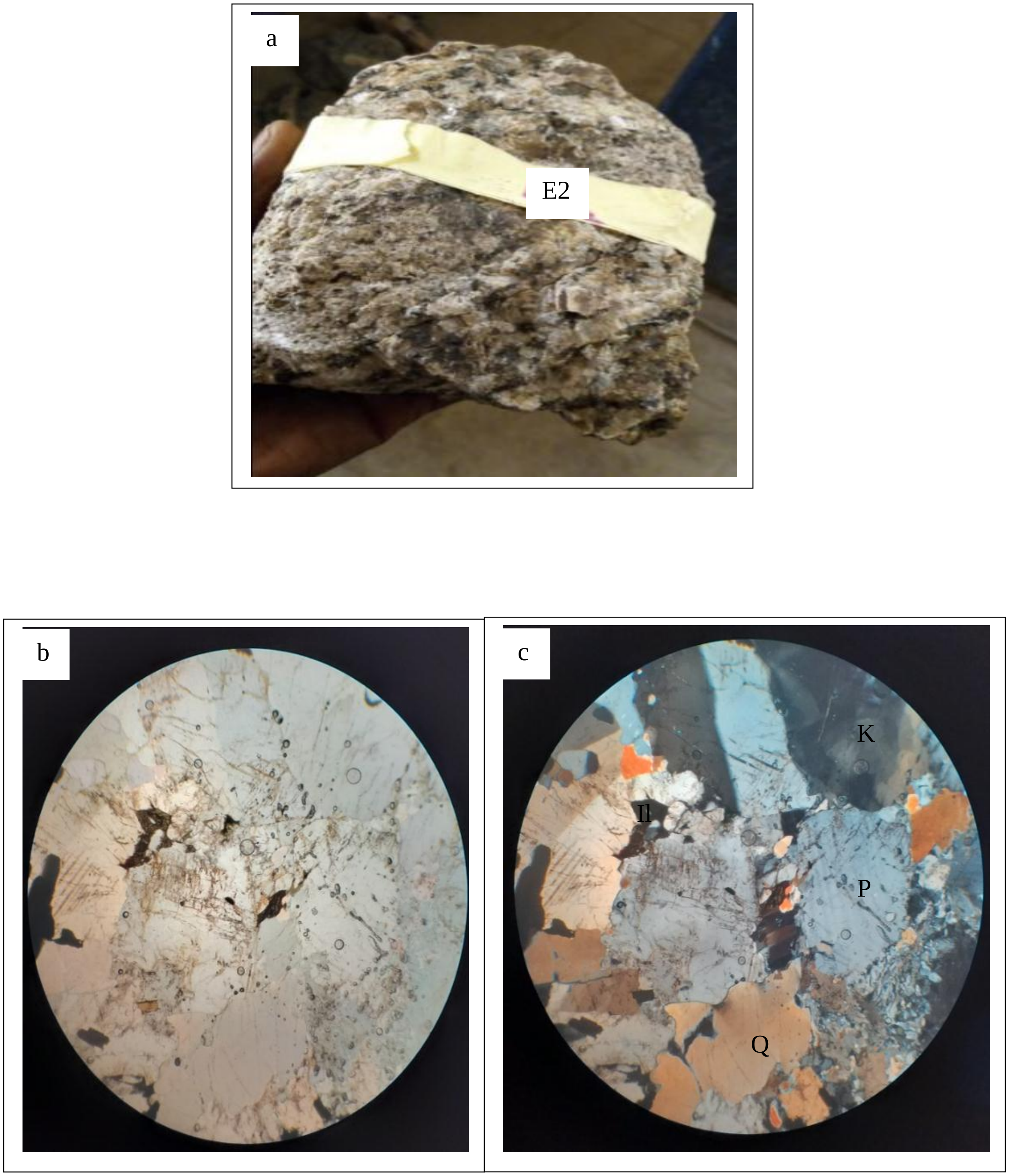

Figure-10: a) Hand Specimen of Granulitic Granite (Sample E2) b-c) Granulitic Granite under PPL and XPL 12x

Geology of the Area: The oldest rock in the area is quartzite (Figure 12a), though other metasediments such as granulite, amphibolite and calcsilicate rocks are evident in the surrounding areas which were interpreted to be part of this regional metamorphic process[2,3].This is followed by schlieren (melanocratic diatexite migmatite), then nebulites (Bauchites, quartz-diorites and granulitic granite as the youngest rock unit). The rocks are classified in Table-1 modified from information by Oyawoye[3].

Microstructure: *Myrmekite*.

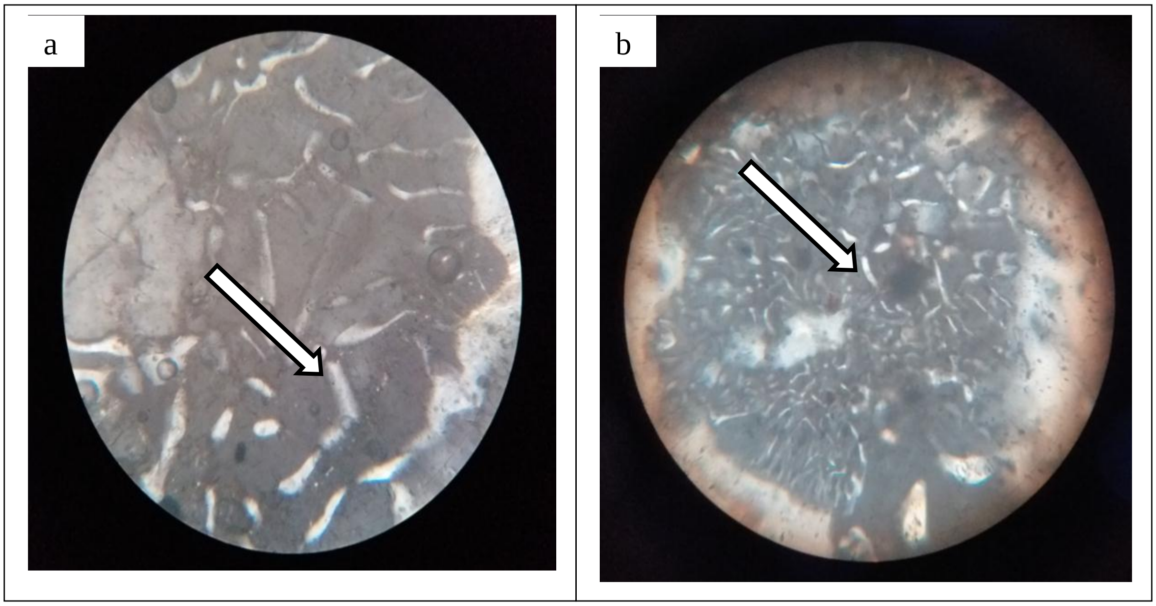

Figure-11: Myrmekiteina) Brown Bauchite (Sample D3) b) Medium Grained Quartz-Diorite (Sample E1) PPL 120x.

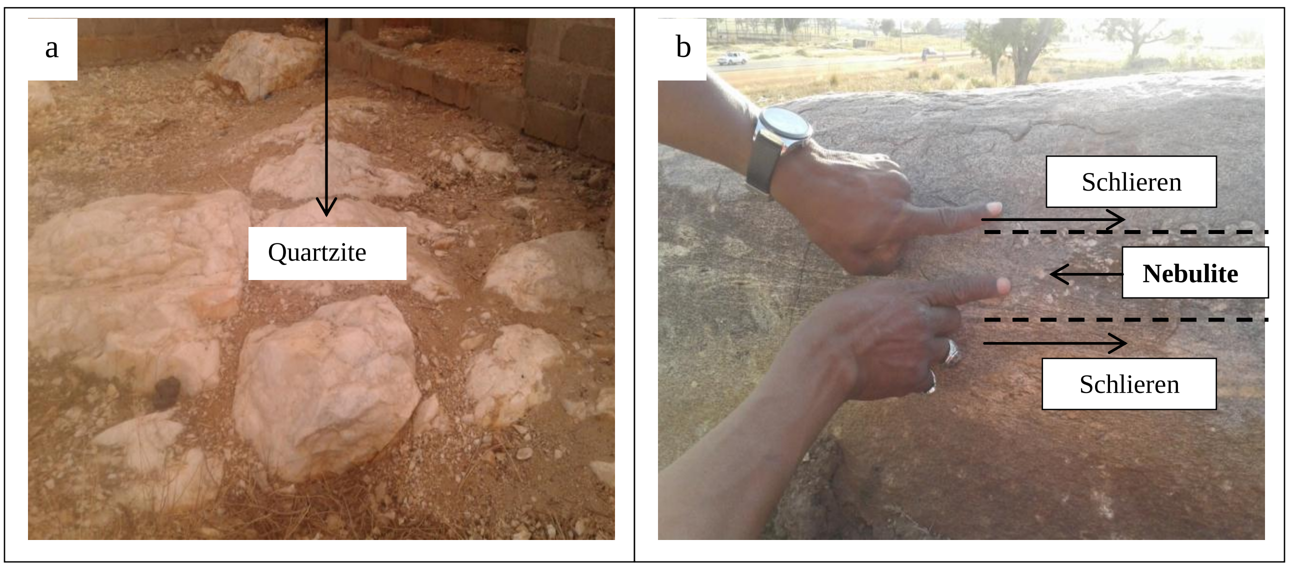

Figure-12: a) In-situ Quartzite within the Study Area b) Nebulite (Bauchite) Developing from Schlieren Migmatite.

Table-1: Rocks Classification in order of Probable Age.

	Rock Type	Description
6	Granulitic Granite	Youngest
5	Medium Grained Quartz Diorite (charnockitic)	Nebulitic Migmatites
4	Coarse Grained Quartz Diorite (charnockitic)	NebuliticMigmatites
3	Fayalite-Quartz Monzonite	Nebulitic Migmatites
2	Diatexite Migmatite	Melanocratic
1	Metasediments: Arkosic Quartzite	Oldest

Deformation Model

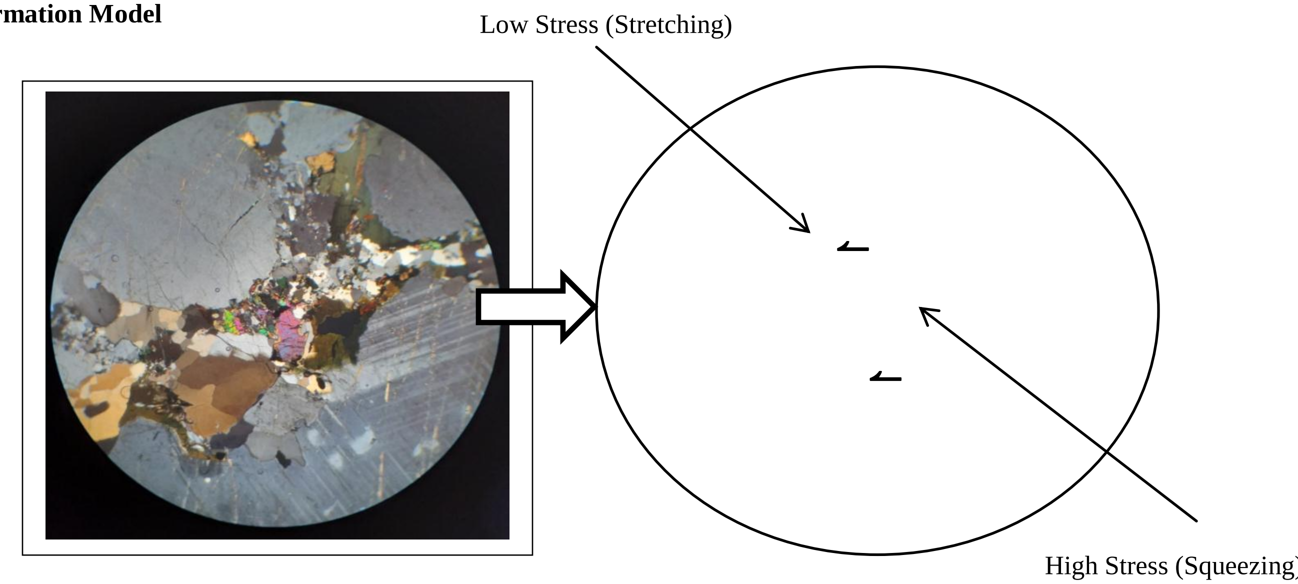

Figure-13 Evidence of Shearing

Discussion of the Results: Five (5) principal rocks are distinguishable in the study area: i. Granulitic Granite (Youngest), ii. Quartz-Diorites (nebulitic), iii. Bauchites (nebulitic), iv. Diatexite (schlieren), v. Metasediment (Oldest).

In most cases, the contact between the rocks is transitional. Interestingly, there was both fractionation which led to the formation of the Bauchite (nebulite) and exsolution which resulted in the formation of quartz-diorite and the granulitic granite (nebulites) without which Bauchite will not have been formed. Furthermore, the schlieren melanocratic diatexite is the only one among the various rock units capable of forming Bauchite. This section presents the discussions of the morphological and petrographic results of these rocks and they were compared with the results reported by other authors.

Morphological Features: The quartzite is white to grey in colour (Figure-12a). It was found at only one location within the study area around Fadaman Mada. This is one of the metasediments that constitute the Bauchi rocks as reported by Oyawoye[3] and Bain[2]. The schlieren – melanocratic diatexite (Figures-1,2) has pale some as rafts and schollen. The nebulitic migmatites comprise Bauchites, quartz diorites and garnulitic granite because the neosome developed a foliation and a compositional banding. The Bauchites are grouped into two, green (Figures-3a,4a) and brown (Figures-5a,6a,7a) which are very coarse grained. They mark the beginning of fractionation and crystallization (Figure-12b). The Bauchites were first studied by Falconer[1], then Bain[2] and Oyawoye[3-5] who named that so in 1965. The Quartz-Diorite (Figures-8b,9a) tends to be lighter than Bauchite due to higher silica content. Both Oyawoye[3] and Bain[2] identified the Quartz-Diorite but did not acknowledge the medium grained variety and also mistook the granulitic granite (Figure-10a) which is medium grained as biotite-hornblende granite.

Petrographic Features: The presence of pyroxenes in almost all of the samples signifies a granulite facies terrain[17]. Most of the twinings in the petrographic slides are not for albite rather they are for either Labradorite or Bytownite. This is further confirmed by the presence of the pyroxenes which only exist at same temperature with either of the two. The opaque mineral (Figures-1d,3c,4c,5c,6c,7c) is graphite (CO_2) sourced both from the mantle and at the surface from the existing carbonate rocks since we are dealing with a collisionalzone where all the rocks were once sedimentary. The CO_2 heats up the system enough to form very coarse grains through metamorphic process (carbonic dehydration)[18]. The fractures connecting the opaque minerals in the plates signifies penetration of the CO_2 and their orientation in same direction means the stress was regional not magmatic.

Microstructure: Myrmekite was observed in both Bauchite and quartz-diorite – nebulites (Figure-11a,11b). But interestingly, the one in the Bauchite (Sample D3 (Figure-11a)) seems to have more calcic than sodic plagioclase suggesting a metamorphic type because only Labradorite or Bytownite can exist at same temperature with pyroxenes. While the one in quartz-diorite (Sample E1 (Figure-11b)) can safely be said to be of igneous type because it seems to have more sodic than calcic plagioclase, almost entirely Albite which exists with biotite. Again, the myrmekite in the Bauchite appears to be coarser in grains than the one in the quartz-diorite. These distinctions have not been made by the previous authors[2,3].

Furthermore, shearing is evident in coarse grained quartz-diorite – nebuilite (Sample C (Figure-13)). The model established that the central part is the high stress portion while the flanks are the low stress regions. This is why the minerals squeezed themselves to occupy the little available space. The movement is horizontal reflecting a strike-slip displacement (half arrows). This further suggests that the area was once affected by some sorts of shear stress. This is important because if shearing can be detected even at a micro level, mineralization is possible since it will create differential stress where minerals can occupy.

Conclusion

An intensive fieldwork was carried out. 29 fresh samples were collected based on morphological variations as being metatexite or diatexite. The samples were then grouped accordingly into 5 groups (schlieren- melanocratic diatexite; nebulite – Bauchites, quartz-diorite and granulitic granite). 10 representative samples were selected from these groups. Petrographic slides were prepared at Thin Section Laboratory of ATBU Bauchi, Nigeria. The slides were studied and analyzed using microscope both under plane- and cross polarized lights (PPL & XPL) and a clear shot was taken. From the field and laboratory results, the following conclusions may be drawn: i. That the Bauchite (a nebulite) crystalized from the melanocratic diatexite (a schlieren). This is evident in their field occurrence at Gudum Hill and presence of high temperature minerals (othorpyroxene, clinopyroxene, iliminite and calcic plagioclase) as well as from the presence of schollen of melanocratic diatexite within the Bauchite. The temperature was aided by CO_2 (graphite) which enables the grains to grow very coarse yet through rapid cooling. ii. The brown Bauchite (a nebulite) differs from the green Bauchite due to silicification. This is evident from their field occurrence notably at Warinje and Wambai Hills. iii. The quartz-diorite (a nebulite as well) was exsolved from the excess melt of silica and K-feldsparin order to allow the system to form the Bauchiteas evident in their field occurrence notably at Dumi Hill, presence of hypersthene and higher silica contents. It is petrographically the same, but texturally medium and coarse grained from Dumi and Federal Low-cost respectively. iv. Finally, the granulitic granite occurs in the field overlying both the quartz-diorite and Bauchite – nebulites at Dumi Hill representing the final stage of the entire process.

These suggest that there is a morphological and petrographic continuity from schlieren (melanocratic diatexite) through Bauchites to granulitic granite (nebulite) which can never be established just from laboratory analyses without blending them to the field relationships.

Recommendation: Based on the results obtained from the field and laboratory analyses carried out, the following recommendations are made: i. It is clear that there was never a time when there was a pool of magma. Hence, detailed study into the origin, migration and deposition of the magma that formed these rocks of variable compositions should be carried out. ii. Further study into the economic potentials of the area should be carried out as there are both microscopic and macroscopic evidences of shearing.

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