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Petrological characteristics of some cretaceous igneous rocks, in Southwest of Gboko, Southern Benue Trough, Nigeria

Emmanuel Chigozie Ani and Ifeanyi Andrew Oha*

Department of Geology, Faculty of Physical Sciences, University of Nigeria, Nsukka, Enugu State, Nigeria.

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Detailed field geological mapping, outcrop petrography and thin-section microscopy are employed to delineate and describe igneous rocks, and to infer the tectono-magmatic and geochemical constraints affecting their emplacement in the Tse-Agberagba area, Southwest of Gboko, Southern Benue Trough. Magmatic activity, coupled with folding and deformation were the effects of the Santonian tectonic episode in the area. Petrological (outcrop and thin section) data on these rocks indicate that they are mainly dioritic and doleritic to basaltic on hand specimens. Thin-section microscopy reveals that the dioritic rocks are generally medium-grained and mesocratic, characterized by randomly oriented laths of plagioclase and hornblende. The doleritic rocks are generally melanocratic, fine-grained and porphyritic, and are characterized by randomly oriented microlites of plagioclase of labradorite composition, with olivine and augite in a groundmass of aphanitic plagioclase, olivine and nepheline. The rocks are characterized by sub-ophitic to intersertal relationships between plagioclase and clinopyroxene which develops calcite as an alteration product. The mineralogical assemblages in these rocks suggest crystallization from an alkali-enriched magma, in a divergent tectono-magmatic setting.

Key words: Southern Benue Trough, magmatism, dioritic, doleritic, alkali-enriched magma, divergent tectonic setting.

INTRODUCTION

Mineralogical assemblages provide definitive evidence of the geochemical composition and petrogenetic association of a given rock. This is because these minerals crystallize and form (in relation to one another) only when the appropriate tectono-magmatic and chemical conditions are favorable and in place for this to happen. Thin-section microscopy has always provided a useful preliminary way to study the mineral properties of rocks (Streckeisen, 1979; Mohammedyasin and Wudie, 2019). This study provides an insight into the tectonic and magmatic history of Late Cretaceous igneous rocks encountered in Pre-Santonian sedimentary deposits in the Southern Benue Trough.

The origin of the Benue Trough has been widely debated especially in relation to plate tectonics (Wright, 1976); rifting (Cratchley and Jones, 1965; King, 1950);

*Corresponding author. E-mail: ifeanyi.oha@unn.edu.ng.

wrenching (Benkhelil and Robineau, 1983; Benkhelil, 1986, 1989; Maurin et al., 1986). Intracontinental rifts are associated with igneous activity, emplacing igneous rocks as a result of asthenospheric uplift (mantle plumes), with attendant crustal stretching, thinning and block-faulting (Ofoegbu et al., 1990). Theories to account for the origin for the trough have stemmed mainly from petrological and geochemical studies on the igneous rocks within the trough. Burke et al. (1971, 1972) proposed a subduction origin for the igneous rocks in the trough, suggesting that the rocks are associated with compressional tectonism. Petrographic and geochemical data by other workers on these rocks however, show a predominantly alkaline character associated with an extensional, within-plate setting (Obiora and Umeji, 2004; Obiora, 2002; Obiora and Ugwuonah, 2008).

Igneous activity within the Benue Trough spanned the Cretaceous, having its greatest intensity during the Santonian and magmatism in the Gboko area has been found to be genetically related to the evolution of the southern part of the Benue Trough (Obiora and Charan, 2010). Major and trace element geochemical data by Najime (2014) on these rocks indicate the predominance of alkaline magmatism, with a continental tectonic setting in a spreading center related to orogenesis. The petrological characteristics of the igneous rocks presented in this paper expose the petrographic properties and mineralogical assemblages of these rocks; they are used to infer their origin, assessing the consistency of the results obtained by previous workers. Attempts are made to place rifting and magmatism in the area within the context of the wider models of tectonism in the region.

Regional setting

The Benue Trough of Nigeria is a rift basin in central West Africa that extends NNE–SSW for about 800 km in length and 150 km in width (Obaje, 2009).It is a major geological formation underlying a large part of Nigeria, extending laterally for about 150 km and stretching for over 1,000 km northeast from the Bight of Benin to the Chad Basin through the Gongola Rift, while branching into northern Cameroun through the Yola Rift. Other bifurcations of the Benue trough include the Mamfe Rift in southeastern Nigeria and southwestern Cameroun, and the Bida (Nupe) Basin in central Nigeria. Located at a major re-entrant into the West African continental margin, the Benue Trough is bordered to the southwest by the northern boundary of the Cenozoic Niger Delta miogeoclinal embankment. Although it extends transversely northeastward through the Nigerian Shield and seems to die out around the Zambuk Basement Ridge, its main negative Bouguer anomaly trend continues underneath the Bornu Basin (Cratchley and Jones, 1965; Ajakaiye and Burke, 1973). Geographically, it has been subdivided as “*Southern*”, “*Central*” and “*Northern*” replacing the former “*Lower*”, “*Middle*” and “*Upper*” subdivisions due to their stratigraphic ambiguity (Nwajide, 2013).

The Trough contains up to 6,000 m of Cretaceous sediments of which those predating the mid-Santonian have been folded, faulted, and uplifted in several places (Wright et al., 1985). Sedimentation in the southern to middle Benue Trough started with the marine Albian Arufu, Uomba, Gboko formations, generally referred to as the Asu River Group, which is composed of mainly limestones, shales, micaceous siltstones, mudstones and clays (Offodile, 1976). The Eze Aku Formation, a group of essentially calcareous shale, micaceous fine to medium grained friable sandstones and occasional beds of limestone (Reyment, 1965), constitutes the major outcropping geological formation (Anyiam et al., 2017). It is laterally equivalent to the Konshisha River Group (Figure 1), where they occur as dark grey fossiliferous limestone (mudstones and wackes) intercalating with grey shale and sandstones, dipping steeply westward in their exposures along the River Konshisha near Haan (Najime, 2011).

Over 120 igneous rock bodies have been referred to and described by various authors. Most of the rocks occur as intrusive rocks of basic to intermediate composition, with a few pyroclastic rocks and rare lava flows. Four major magmatic districts have been outlined for the igneous of the Southern Benue Rift by Obiora (2002). They include the area southwest of Gboko, the Ejekwe–Wanikande area, and the Abakaliki and Okigwe–Ishiagu districts, from the north to the south, ranging in age from Albian to Cenozoic. The igneous rock bodies southwest of Gboko as outlined by Obiora (2002) consist of subvolcanic intrusions of phonotephrites, phonolites and trachytes dated 86 Ma (Foyum Monzo-syenite), 61 Ma (Abata Syenite) and 59 Ma (Agila Syenite) (Umeji, 2000) where they are hosted by slates and shale of the Asu River and Eze-Aku Groups. Igneous activity within the study area is characterized by dome-shaped plutons, exposed by extensive surficial weathering and outcropping as small hills around towns north of Tse-Agberagba, southwest of Gboko, Benue State, Nigeria. These rocks are primarily dioritic; they intrude the overlying Konshisha River Group. They are doleritic to basaltic towards the east (Figure 1), intruding the underlying Asu River Group and exposed along the Koshisha River.

Three phases of magmatic activity have been outlined for the Gboko area and other parts of the Southern Benue Trough (Najime, 2014). The first phase spanned the Late Jurassic to the Early Albian (Najime, 2010; Najime et al., 2012) and was characterized by protrusions of dyke-like bodies into zones of weakness along up-doming areas in a north–south trend on the Afro-Brazilian plate. The Gboko Hills, Mount Ikyuen and the dyke-like swarms of rhyolites dated 113 ± 3 Ma (Umeji and Caen-

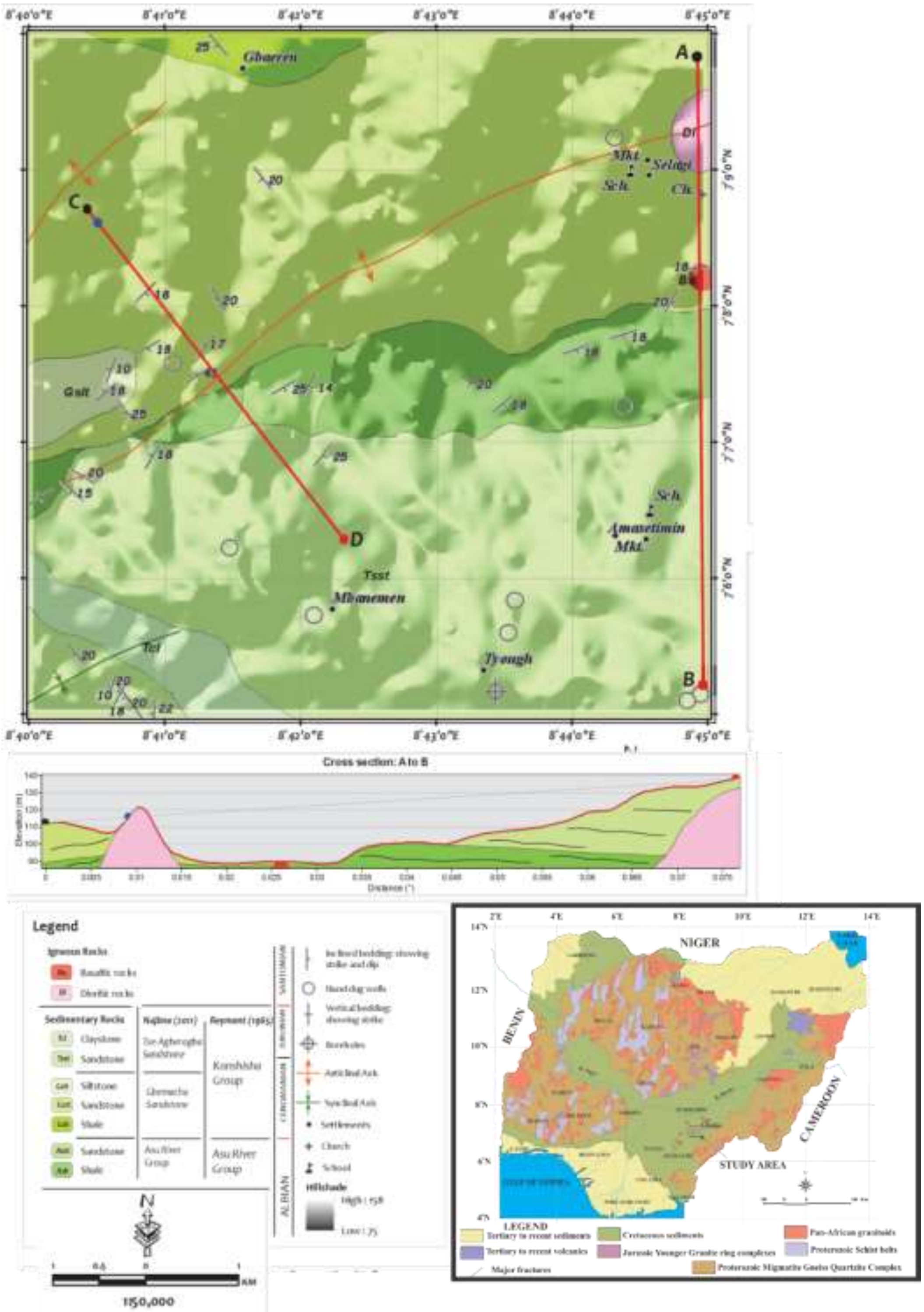

Figure 1. Geological Map of the study area with cross-section. Inset is geological map of Nigeria showing location of the study area.

Vachette, 1983) in the Gboko area, with the Wanikande Syenite dated 104 ± 4 Ma (Wright, 1989), belong to this phase. The second phase spanned the Middle Albian to Early Santonian, producing abundant intrusions and minor occurrences of tuffs and lavas interbedded with the Albian sediments (Wright, 1989). Basaltic rocks within Albian sediments occur along the River Mu north of Gbemacha and similar lavas occur between clastic alluvial fans and the shale and limestone of Albian age, along the River Konshisha northwest of Buabunde in the Gboko area (Najime, 2014). The third phase is of Santonian age, dated 81 to 83 Ma (Wright, 1989), and include the intrusives and volcanic flows around Ishiagu, Abakaliki, Lefin, the Egedde Hills, the Agila area and in the Gboko area as documented by Najime (2010), Najime et al. (2012) and Oha et al. (2016).

METHODOLOGY

Detailed field geological mapping was carried out on a scale of 1:25,000 and the igneous rocks within the study area were described on hand specimens; they were sampled and cut into thin section. They were studied using a polarizing microscope.

Field geological mapping

The studied area is bounded by latitudes 7°05' N and 7°10' N and longitudes 8°40' E and 8°45' E, in the Federal Surveys of Nigeria 1:100,000 (Sheet 271) map – Gboko, lying in the extreme northeastern end of the Southern Benue Trough, transitional into the Central Benue Trough. The area covers the region directly northeast of the Tse-Agberagba market to the southwest (Figure 1), the Mbanemen area in the south-central, the areas around Tyough and Amasetimin in the southeast, Gbaeren in the northwest and Selagi in the northeast, all within Konshisha Local Government area in Benue State. The area is underlain primarily by shale of the Asu River Group and unconformably overlying sandstones belonging to the Konshisha River Group (Reyment, 1965). They are folded into antiforms and synforms which trend in an essentially NE-SW direction.

In the northeastern region of the study area, stretching for about 750 m in diameter and over 170 m in height, the dioritic rocks intrude the sandstones, outcropping as a conical hill – the Selagi Hill, and occupying an axial position along the major anticline (Figure 1). The rocks are generally medium to coarse grained and mesocratic, containing abundant feldspars with randomly oriented laths of hornblende as the dominant visible mafic mineral. Exfoliation weathering is common and the rocks are jointed. Southward, in the Tyough area, these rocks are encountered in wells, occurring below the sandstones. At AEC/Tyough/02 they are porphyritic, containing lath shaped phenocrysts of hornblende about 3 cm long, embedded in a medium grained matrix of feldspars, and at AEC/Tyough/08, they are characterized by lesser hornblende and more feldspar contents. The doleritic rocks were encountered at AEC/Selagi/07along the Ngoo-Igbonde River where they discordantly intrude the sandstones. They are melanocratic, fine-grained, porphyritic and fractured (Figure 2d).

Petrography and thin-section microscopy

Dioritic rocks

In thin section the dioritic rocks are generally mesocratic, and medium to coarse grained, exhibiting porphyritic textures at AEC/Tyough/02 and AEC/Tyough/08. The rocks are characterized by randomly oriented plagioclase laths in sub-ophitic to intersertal relationships with clinopyroxenes, which produce calcite as an alteration product. The plagioclase crystals typically occur as combined Carlsbad-albite twins having average extinction angles of about 12° and 25°, corresponding to plagioclase of andesine composition (An_{46}), following the method of determining extinction angles of such plagioclase twins as outlined in Kerr (1959). Combined albite, Carlsbad and pericline twinning (Figure 5) was also observed in orthoclase phenocrysts at AEC/Tyough/08; it has extinction angles of between 11° and 26°, also corresponding to plagioclase of andesine composition, with the pericline twins being almost without inclination (0°), and also depicting an andesine composition (An_{42}) (Kerr, 1959).

The rocks are characterized by abundant hornblende crystals which are generally pleochroic from light to dark brown, undergoing oblique extinctions with maximum extinction angles of about 11° – 15°. They are lath-shaped and elongate in longitudinal sections and hexagonal in basal sections. Nepheline is present as phenocrysts with basal sections having a hexagonal to sub-hexagonal outline (Figures 3b, 4 and 5). They commonly display 1st order grey interference colors and parallel extinctions. Aegerine-augite is present as phenocrysts in the rocks from the Selagi Hill, having subhedral octagonal outlines, high relief and bi-directional cleavages at 87° and 93°. Magnetite is present as an accessory mineral present in the groundmass. Table 1 is a summary of the modal percentages of the mineral constituents of these rocks.

Doleritic rocks

The doleritic rocks are melanocratic, fine grained and porphyritic (Figure 6a), with grain sizes in the range of 0.5- 1 mm for the groundmass, and up to 2 mm in the phenocrysts. They are randomly oriented anhedral to subhedralmicrolites of plagioclase, with extinction angles of about 37°. They correspond to the anorthite composition of labradorite (An_{60}); they occur with orthoclase (twinned according to the Carlsbad Law), olivine and augite in a groundmass of aphanitic calcic plagioclase, olivine and nepheline. Olivine occurs as small hexagonal crystals in plane polarized light, which are typically iddingsitized, giving the outer iron-rich areas a typical brownish-red color distinguishable from their central pale to colorless regions. Euhedral calcite is present as an alteration product developed from intersertalaugite between the ca-plagioclase phenocrysts. Magnetite occurs both in the groundmass and as phenocrysts, characterized by a mottled metallic luster in reflected light **(**Figure 6c). Modal percentages of the minerals present are olivine (35%) + orthoclase (20%) + ca-plagioclase (15%) + augite (5%) + nepheline (5%) + magnetite (20%).

RESULTS AND DISCUSSION

The petrological characteristics of the igneous rocks in the study area indicate that they are doleritic and dioritic. The presence of feldspathoids (e.g. nepheline) in the dioritic rocks, and the presence of clinopyroxene and olivine in the groundmass of the doleritic rocks suggest an alkaline affinity for these rocks. This mineralogical assemblage suggests that they are co-genetic and likely derived from differentiation of an alkaline olivine-basalt magma, generating through variable low degrees of partial melting of an enriched upper mantle following asthenospheric uplift (mantle plumes) (Obiora and Charan, 2011). General alteration into calcite in these

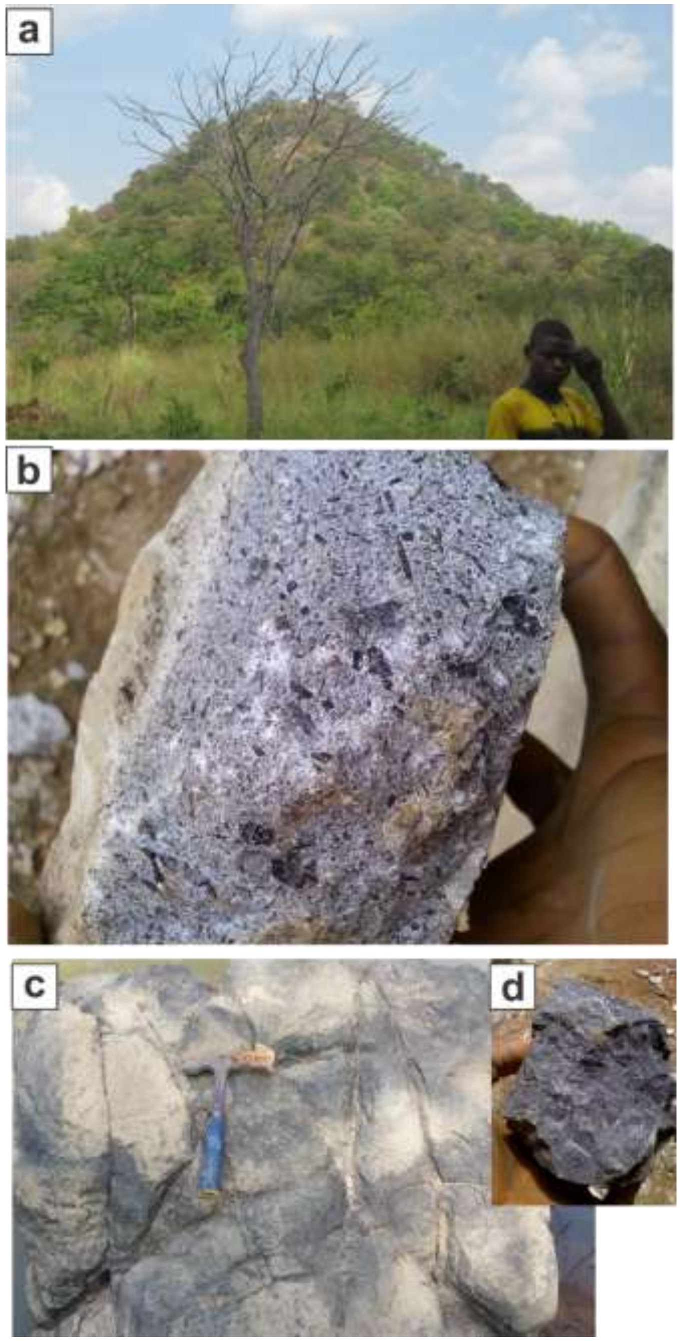

Figure 2. (a) Outline of the dioritic Selagi Hill. (b) dioritic rocks from wells at AEC/Tyough/02 (c) The doleritic rock at AEC/Selagi/07. (d) close view of doleritic rock in (c).

rocks can be attributed to the effects of a CO_2 -rich hydrous phase possibly related to calcium-rich saline groundwater pressed out of calcareous marine sediments in the area during burial (Obiora and Charan, 2010).

In the Wanakande area (approximately 50km southwest of Gboko), Benkhelil (1987) documented the occurrence of numerous intrusive bodies which formed scattered outcrops along the trend of the Workum Hill. The rock types range from basic to intermediate intrusive and consist of syenite, diorite, monzonite and gabbro, with minor dolerite and trachyte which altogether occur as discordant intrusive stocks and swarms of small sized sills. The diorites around Wanikande are similar to those of southwest of Gboko; they occur as small intrusive bodies which are generally greenish and consist of weakly zoned oligoclase and brown-green amphibole,

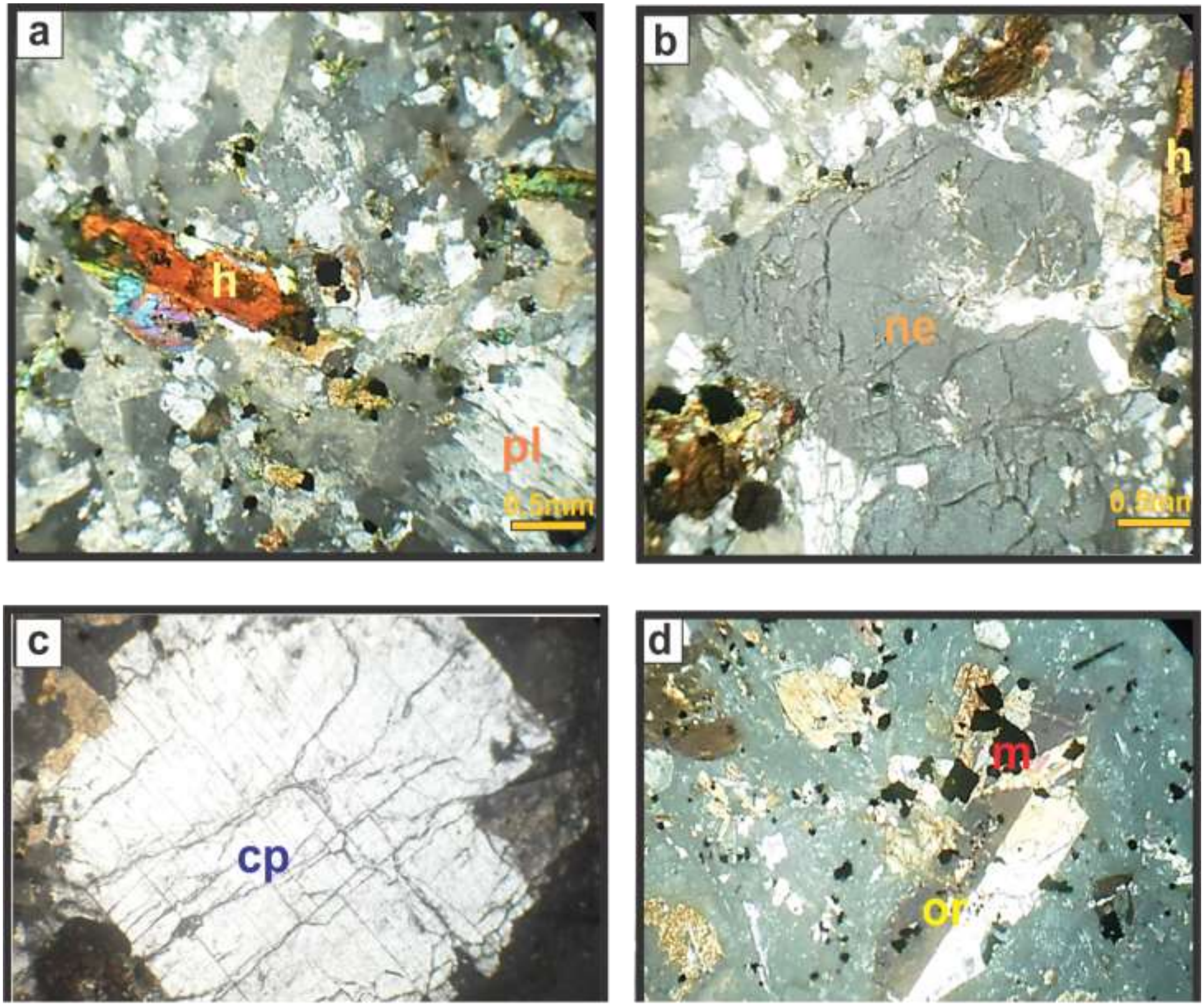

Figure 3. Photomicrographs of the rocks from the dioritic Selagi Hill; (a) Hornblende *(h)*phenocryst in plagioclase *(pl)* groundmass. (b) Nepheline*(ne)* and hornblende *(h)* crystals in a plagioclase groundmass. (c) Phenocryst of aegirine-augite*(cp).* (d) Orthoclase phenocryst *(or)* with accessory magnetite *(m).*

withbiotite, titanomagnetite and opaques as assessories (Benkhelil, 1987). Alkaline rock suites and tholeiites are characteristic of rocks formed in regions of extension (divergence zones) or anorogenic settings, commonly within continental or oceanic plates such as in rifting centers (Bonin, 1986). The observed alkaline affinity of these rocks suggests that they are products of extensional tectonism. It is consistent with an active rifting model (Wilson and Guiraud, 1992; Obiora and Charan, 2011; Najime, 2014) and corroborates the results obtained by previous workers in the area and that of the Benue Trough as an *aulacogen*(a failed rift).

Conclusion

The geology of the rocks around Tse-Agberagba area documents a classic case of the tectono-magmatic evolution of the Gboko area which presents a unique picture of the structural and magmatic trends in the basement rocks underlying the Lower Benue Trough, as well as the intrusive rocks contained in the overlying

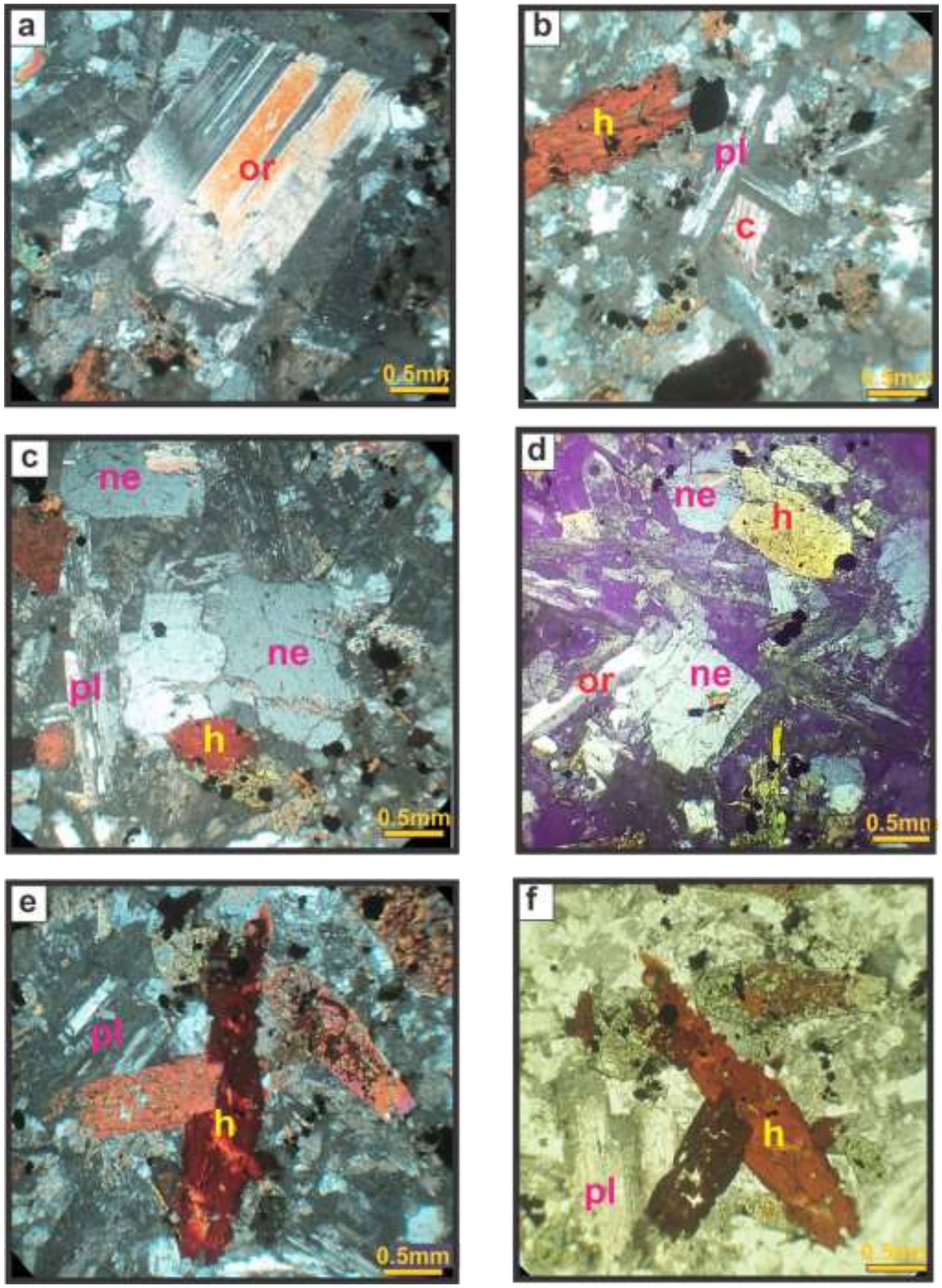

Figure 4. Photomicrographs of the dioritic rocks from AEC/Tyough/02. (a) Combined Carlsbad-albite twinning in orthoclase *(or).* (b) Calcite *(c)* developed from intersertal clinopyroxene between randomly oriented plagioclase *(pl)* crystals. (c) Nepheline*(ne)* and hornblende *(h)* phenocrysts in plagioclase groundmass (d) Hornblende *(h),* nepheline*(ne)*phenocrysts in a groundmass of plagioclase and orthoclase *(or).* Randomly oriented hornblende *(h)* crystals with ca-plagioclase *(pl)* in the groundmass in (e) crossed polar and (f) plane polar.

sedimentary fill. Field mapping and petrographic studies confirm the existence of dioritic and doleritic mineralogical assemblages, which form prominent topographic features at outcrop scale and manifest as elevated conical hills with smaller slightly elevated basaltic masses to the south. The petrographic

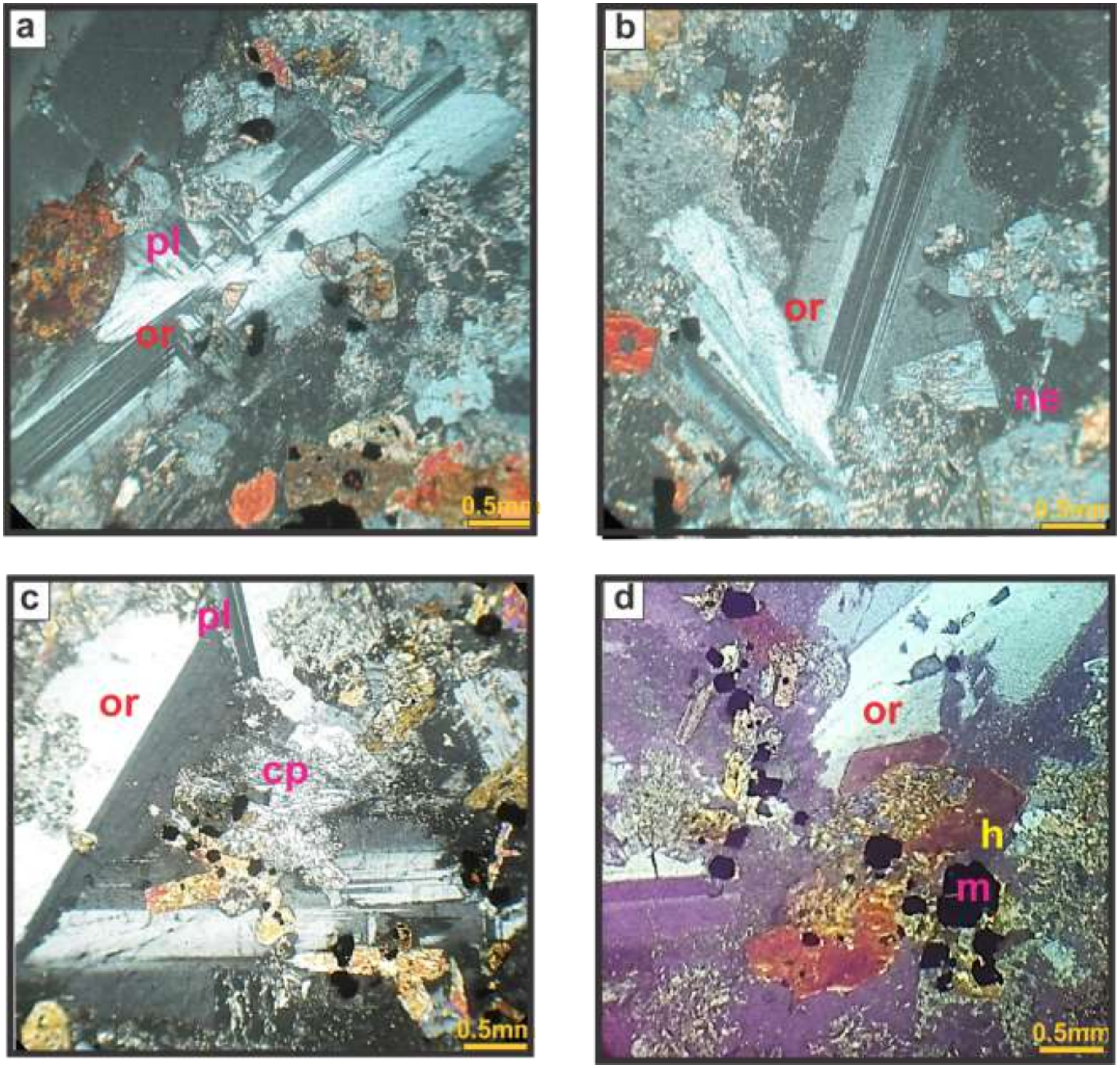

Figure 5. Photomicrographs of the dioritic rocks from AEC/Tyough/08. (a) Pericline twinning in orthoclase *(or)*phenocrysts (b) Combined Carlsbad-albite twinning in orthoclase *(or)*phenocrysts with nepheline*(ne)* in the groundmass. (c) Intersertal clinopyroxene*(cp)* between randomly oriented orthoclase *(or)* crystals. (d) Accessory magnetite *(m)* and hornblende crystals. Intersertal clinopyroxenes are developed between randomly oriented orthoclase *(or).*

characteristics of these rocks are consistent with the findings in other parts of the trough which suggest crystallization from an alkali-enriched magma in a divergent tectonic setting.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Table 1. Summary of the modal percentages for the mineral constituents in the dioritic rocks.

	Andesine	Orthoclase	Hornblende	Clinopyroxene	Nepheline	Magnetite	Calcite
Selagi Hill	25	20	20	10	15	7	3
AEC/Tyough/02	20	20	30	10	10	5	5
AEC/Tyough/08	25	30	15	18	5	5	2

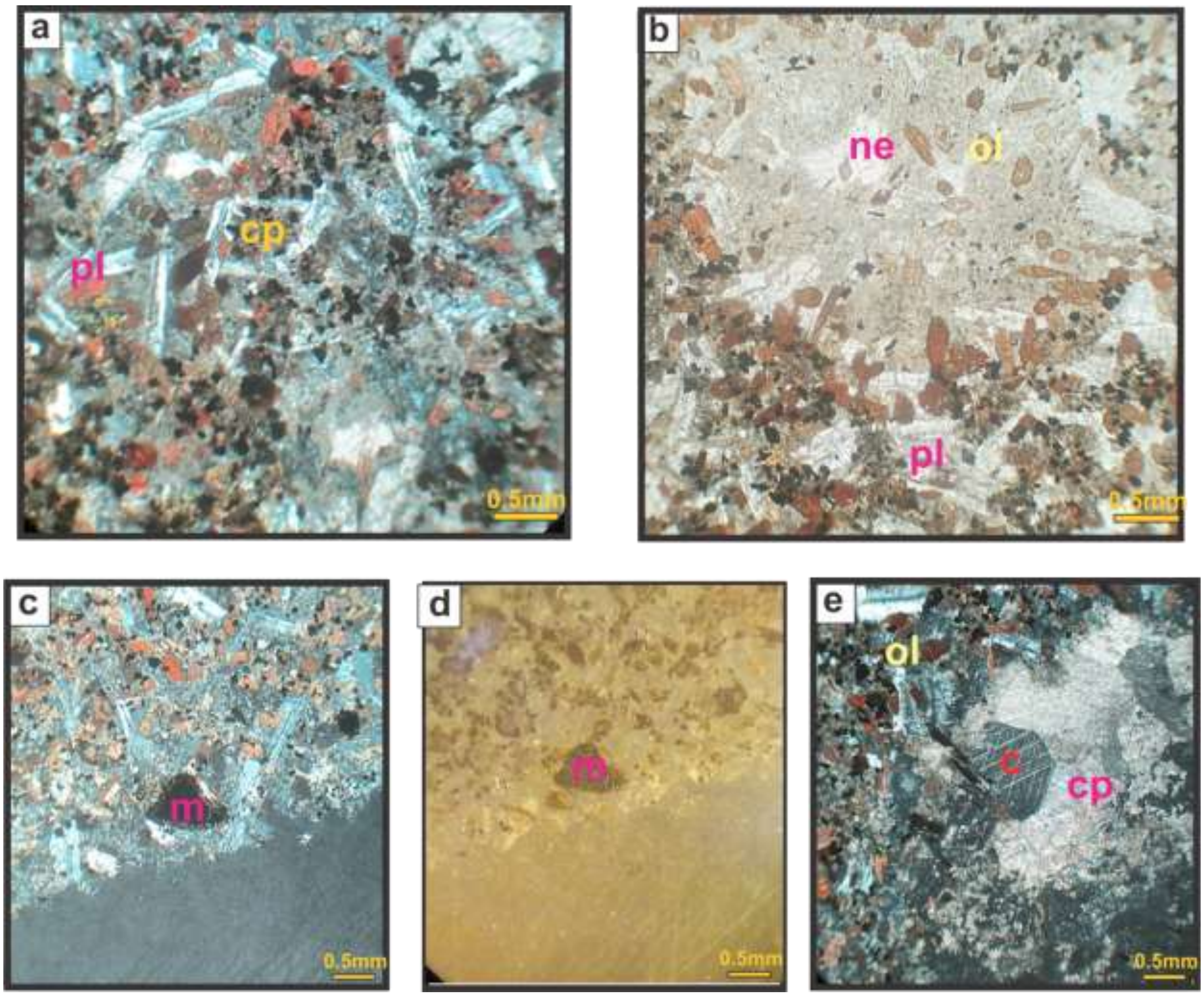

Figure 6. Photomicrographs of the doleritic rock from AEC/Selagi/07. (a) Randomly oriented calcic-plagioclase *(pl)* and intersertal clinopyroxene*(cp)*. (b) Iddingsitized olivine *(ol)* crystals embedded in a groundmass of nepheline*(ne)* and ca-plagioclase. Note their brown rims and clearer inner regions. (c) Accessory magnetite in crossed polar and in (d) reflected light showing its metallic luster. (e) Euhedral calcite developed from the adjacent clinopyroxene*(cp)*. Orthoclase *(or)* phenocrysts are also present.

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