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Geochemical characterization and petrogenetic evaluation of migmatites around Ganaja, Kogi state, Nigeria

Imasuen O. I. and Onyeobi T. U. S.

Geology Department, University of Benin, Benin City, Nigeria

ABSTRACT

A detailed geologic mapping of various rock types around Ganaja in Kogi State (Nigeria) was carried out on a scale of 1:25,000. The area lies between latitudes $7^0 42^I$ and $7^0 44^I$N; and between longitudes $6^0 42^I$ and $6^0 45^I$E covering about 29km^2. Field observations and a study of the rock samples collected indicate that the rocks belong to the migmatite – gneiss complex of the south-western Nigeria Basement Complex. The area is underlain predominantly by migmatite, augen gneiss, biotite gneiss as well as minor occurrences of pegmatite and quartzo – feldspathic veins. Petrographic analyses of the rock samples from this area show the migmatites to generally consist of quartz, feldspar (plagioclase, microcline and orthoclase), biotite and a few accessory minerals like epidote and zircon. The geochemical analysis data and petrographic details suggest an igneous parentage for the migmatites. However, with their uncomplicated mineralogical composition, these migmatites differ from those of the near-by north-eastern part of Lokoja which are of pelitic rock parentage. Consequently, it is suggested that a deformational episode occurred along with the metamorphism of the various rocks of the mapped area and its environs resulting in varied metamorphic derivatives ranging from the amphibolite facies to higher metamorphic facies condition. These migmatites may have been formed from the metamorphism and metasomatism of fractionated igneous bodies during tectonism. The segregation and migration of the melting minerals such as quartz and feldspar during regional metamorphism resulted in the banding of the leucosome and melanosome minerals. The outcrops and their associated foliation generally trend in NNE – SSW directions

Keywords: Ganaja migmatites, Geochemical, Metamorphism, Leucosome, Melanosome.

INTRODUCTION

The area studied is situated at the extreme eastern part of the south-western Nigeria Basement Complex. It is made up of Basement Complex rocks which include migmatite gneiss (augen gneiss or porphyroblastic granite and biotite gneiss) intruded by the NE-SW trending pegmatite dykes and covered by the Cretaceous – Recent coarse-medium grained sands to the East, forming the bank of River Niger.

Covering an area of about twenty-nine square kilometers (29km^2), the location is bordered by latitudes 7^o $42^/$ and 7^o $44^/$N and longitudes 6^o $42^/$ and 6^o $45^/$ E (see Figure1).

Rocks in the area had regionally been described in the past by previous workers;[1,2,3,4] This study presents the result of a detailed geological field mapping, petrographic, geochemical and mineralogical studies principally to establish the petrogenesis of the migmatites and the associated rocks in Ganaja and environs in Kogi State Nigeria.

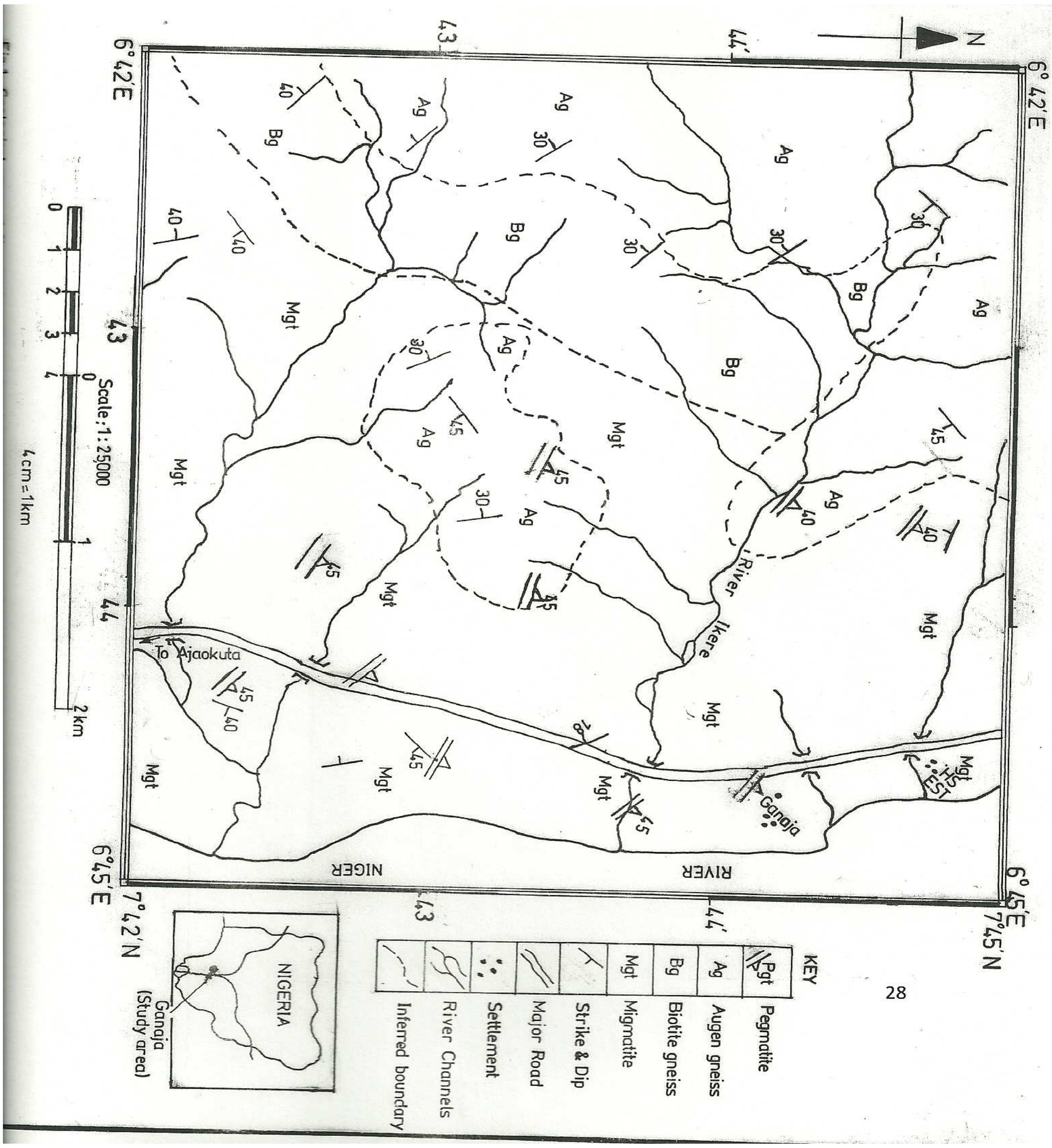

Figure 1. Location Map of Area of Investigation

Geology of the Nigerian Basement Complex

The Nigerian Basement Complex forms a part of the north – south trending orogenic belt which Grant[5], Ajibade and Wright[6] had shown to extend westward into the Benin Republic, Togo, Ghana; eastward into the Cameroon, and northward into Niger Republic. The crystalline rocks which are exposed today rest on a pre-Pan African old basement which is the sialic crust,[7].

The Nigerian Basement Complex consists of three broad lithological groups:

1. Polymetamorphic Migmatite-Gneiss complex which is composed largely of migmatite and gneisses of various compositions and amphibolites, the relics of metasedimentary rocks represented by medium to high grade calcareous pelitic and quartzitic rocks occurring within the migmatites and gneisses and they have been described as "Ancient Metasediments", Oyawoye[8]. Isotopic ages varying from Liberian to Pan – African have been obtained from the rocks.

2. Low grade sediment-dominated schists which form narrow belts in the western half of the country (Figure 2) have been described as "newer metasediments[9] and unmigmatized to slightly migmatized shists[10] The schist belts are believed to be relics of a supracrustal cover which was folded into the migmatite gneiss complex[11,12] which was intruded by Pan-African granitoids.

3. Syntectonic to late tectonic granitic rocks which cut both the migmatite gneiss complex and schist belts. The granitoids include rocks varying in composition from granite to tonalite and charnockite with smaller bodies of syenite and gabbro. Radiometric ages of the granitoids range from 750 – 500 Ma which lie within the Pan – African age spectrum. These pan-African granitoids are called older granites in Nigeria to distinguish them from the Mesozoic tin bearing granite complexes of central Nigeria which are referred to as the Younger granites (Figure 2). The regional rock in the mapped area is migmatite gneiss complex comprising relics of ancient metasedimentary sequences of biotite-gneiss, calc silicate rock, quartzite and quartz schist, all of which had been migmatised and strongly deformed. Migmatites in this area have also been described to vary in the degree of migmatization from one part of the migmatite gneiss complex to another, from outcrop and even within a single outcrop.

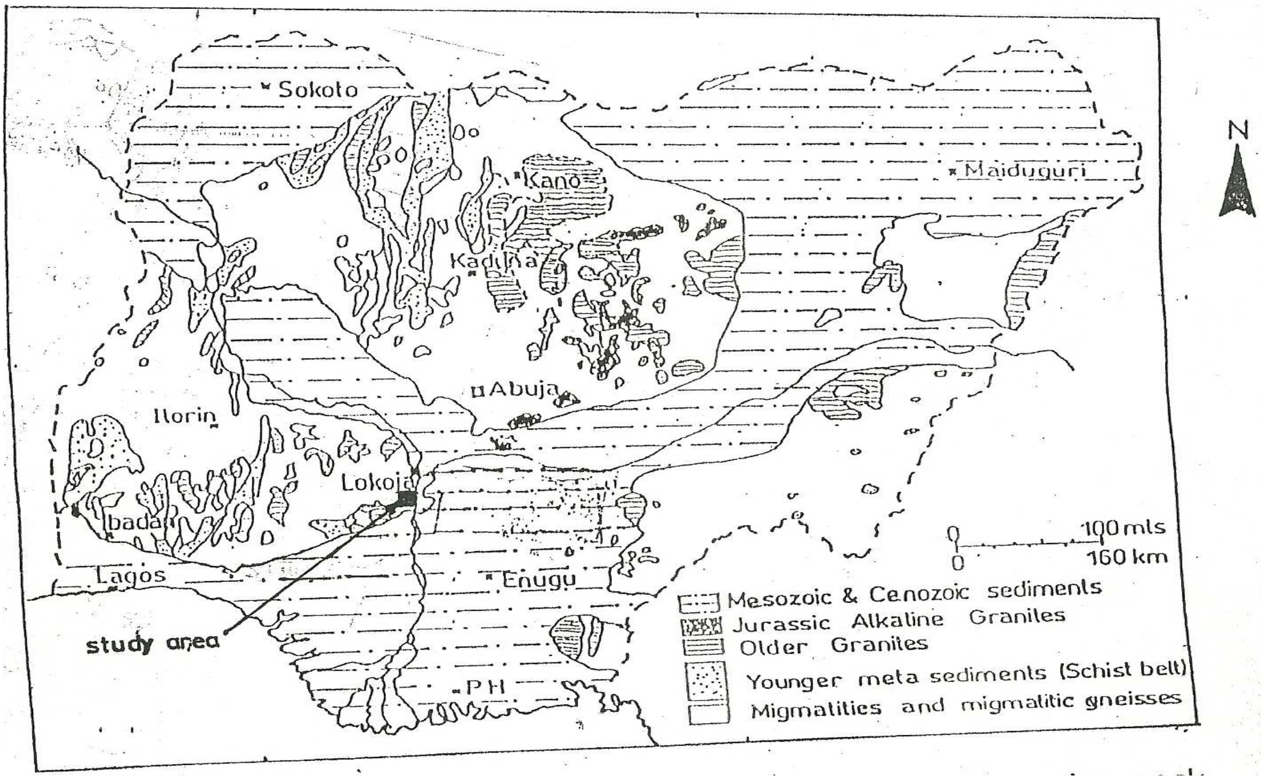

Figure 2. Geological map of Nigeria showing the three major rock units in the Basement Complex as well as the Jurassic granites which intruded the Basement (modified after Oyawoye[8])

Odigi[13] has indicated that the migmatitic gneisses in the Okene – Lokoja area are meta-igneous rocks which show mildly alkaline characteristics and are calc-alkaline in nature suggesting they were derived from an ensialic calc-alkaline magma.

Field occurrences

The major rock types that occur in this area are migmatites, augen gneiss and biotite gneiss while there are minor occurrences of rock types like pegmatites, and quartzo-feldspathic veins.

Migmatites are the most wide spread rock type in the area and form the country rock in which all other rocks occur. They are well exposed with mostly flat lying outcrop as well as seen in cuts across river and stream channels as highly weathered rocks. They are segregated into the leucosome and melanosome bands which generally trend in a N-S direction. The leucocratic band contains more than 70% of quartz giving it a light appearance and lesser amounts of ferromagnesian minerals of mostly equigranular coarse to medium-grained granitic texture. The ferromagnesian minerals usually biotite or hornblende are common in the veins.

Plate 1. Polymictic migmatitic body with an augen shape body of plastically deformed gneiss

Migmatites underlie about 50% to the east of the mapped area (Figure 1) and usually have sharp contacts with rafts of biotite and augen gneiss (plate 1). The trends of the fold axis are mostly east west with the plunging of the lineation usually to the north reflecting the degree of deformation and plasticity.

The augen gneisses occur as isolated hills underlying about 40% of the mapped area. Due to intense weathering activities they are wildly exposed and range from a height of about 200m at the western boundary to about 500m towards the south-eastern part of the mapped area. Texturally, the augen gneiss is composed of quartzo-feldspathic coarse-grained minerals within the ferromagnesian melanocratic matrix giving it a typical inequigranular appearance. The mineral lineation usually strikes in a NE-SW direction while the augen gneisses have contacts with migmatites and biotite gneisses in the area (plate 1). The augen gneisses usually form elongated N-S trending ridge at the western boundary and are widely scattered throughout the mapped area, many of which occur as boulders.

The biotite gneisses form contacts with the augen gneiss bodies and migmatite usually at the western part of the study area. They are occurrences of isolated conical hills around the augen gneiss bodies forming the remaining 10% of the rock types in the mapped area. The biotite gneisses are usually granitic in composition with biotite and hornblende forming the greater portion of the melanocratic component.

They have fairly regular banding resulting from mineral segregation in which predominantly dark bands vary in thickness from a few mm to several cm. Local banding may be absent in which case the dark mineral tends to form streaky or lensoid aggregates aligned to form a rough foliation.

Pegmatite is one of the minor rock types which occur as dykes and veins cutting across the migmatite gneiss complex (plate 3). They have an average strike of 45^0 NW-SE and are exposed along stream channels and road cuts as well as areas of well exposed outcrops of migmatite bodies with an average width ranging from a few centimeters to a couple of metres. The pegmatites are coarse grained and are made up mainly of quartz (30%), feldspars (36%) and biotite (32%). Hornblende and other minerals occur as accessory. Quartz and quartzo-feldspathic veins are closely related to the pegmatite in space at some localities. They constitute the core of zoned pegmatite in migmatites. Thick concordant and usually closely joined veins are frequent. The mechanical weathering of quartz vein obviously in the lateritic crust is common in the mapped area.

Plate 2. A sharp contact between augen body (RS) and biotite gneiss body (LS)

Plate 3. A pegmatite dyke cutting across a massive augen gneiss body; geological hammer lies on the pegmatite dyke

Plate 4. Highly jointed augen body

Structural features and tectonism

Field observations indicate that the basement rocks have been subjected to many periods of deformation. The migmatite gneiss in the study area had undergone extensive migmatisation which may have nearly obscured and obliterated many of the earlier structures hence preventing comprehensive measurement and further interpretation of the structural evolution of the area.

However, the extent or degree of tectonism is expressed in the occurrence and the magnitude of metamorphism and metamorphic structures of the area such as foliation, minor faults, joints and fractures. There is the presence of deformed minerals and tectonic brecciation of some of the crystals like tourmaline, feldspar and quartz in pegmatite which is a tectonic imprint in the area. There is also banding exhibited by the migmatite bodies (plate 1). The dominant structural trend of foliation, dykes e.t.c in the area is northwest as displayed by the strike of foliation, banding and faults (Figure 1). The same direction also controls the elongation of the pegmatites.

Foliation is a continuous or discontinuous layer structure in metamorphic rocks formed by the segregation of different minerals or by alternation of bands of different textures. In Nigeria most migmatites recognized so far appear to have formed through partial melting though metasomatic addition of Na^+, K^+ and B^{3+} appears to have also taken place particularly in the agmatite types[14]. Injection of granitic magma driven along foliation plane is thought to have triggered anatexis that formed migmatites of pan African age in NW and SE Nigeria[15,16]. In this area of study, the structure has probably developed as a result of tectonic differentiation and metamorphic segregation. The preferred orientation of the foliation is dominantly in the NW-SE trend which is indicative of the pan African orogeny.

Jointing in the area is generally a localized feature with multi-directional trends suggesting several phases of deformation. There were set of cross cutting joints observed in the study area which is an indication of complex tectonism (plate 4). The joints trend mostly NE though some were open joints due to weathering. However, the joints are parallel to each other indicating their cogenetic relationship (common origin). Therefore, the forces or deformational episodes that led to their formation were the same.

MATERIALS AND METHODS

The field work started with a reconnaissance survey of the area especially the access roads, drainage channels, types of settlements and also taking note of the minor and major outcrops. This was followed by the detailed geological mapping involving the traverse method of field mapping, collection of representative rock samples from outcrops, road cuts e.t.c.

Strikes and dips of outcrops, structures were taken with compass clinometers and their location recorded with the global positioning system (GPS). The rock samples collected were described megascopically (in hand specimen) in the field and then prepared for thin sections in the laboratory. Each rock sample that was studied under the microscope was first cut into a thin section with the rock cutting machine and mounted on glass slide with Canada balsam.

Table 1. Modal Composition of Ganaja rocks compared with other similar rock types

MINERAL	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	SAMPLE 6	SAMPLE 7	SAMPLE 8	SAMPLE 9
Quartz	20	40	30	20	35	10	30	39	30
plagiolase	20	40	40	20	26	16	35	12	12
Microcline	40	-	16	10	-	-	28	43	39
Orthoclase	15	5	5	20	8	-	-	-	-
Biotite	2	10	5	15	15	8	2	5	5
Muscovite	-	-	-	-	-	-	-	-	13
Epiodote	1	2	1	10	-	2	-	-	-
Zircon	-	-	1	-	3	3	-	-	-
Opaque	2	3	2	3	4	4	-	-	-
Hornblende	-	-	-	2	10	53	5	-	-
Actinolite	-	-	-	-	-	13	-	-	-
Sphene	-	-	-	-	3	-	-	-	-
Accessories	-	-	-	-	-	-	-	1	1

Sample 1-4:- Average modal composition for Gneisses from Ganaga Area (this Work)
Sample 5 - Average modal composition of Migmatite Gneiss from Okene – Lokoja areas Odigi[13]
Sample 6 - Average modal composition of Amphibolite from Okene – Lokoja area Odigi[13]
Sample 7 -Average modal composition of Gneisses from North West Ekido, SE Lokoja Imasuen et al[17]
Sample 8 -Average modal composition of Augen Gneiss from Igbeti, SW Nigeria Imeokparia and Emofurieta[18]
Sample 9 -Average modal composition of Banded Gneiss from Igbeti, SW Nigeria Imeokparia and Emofurieta[18]

For the geochemical analysis, ten elements were determined using the Atomic Absorption Spectrometer (AAS). The elements include Mg, Ca, K, Fe, Mn, Na, Ni, Si, Al and Cu. The model of AAS used is the Perkin Elmer analyst 200 spectrometer Standard solutions were prepared accurately from the stock standard of 1000ppm by using the serial dilution formulate $C_1V_1 = C_2V_2$ from which the machine was calibrated to 2, 4 and 6ppm respectively.

RESULTS AND DISCUSSION

Microscope and petrographic description

Examination of the rock sample in thin section revealed that the major constituent minerals of the gneisses, pegmatites, migmatites and aplyte dyke are feldspar, biotite, quartz and opaque minerals. These minerals were observed to be made up of different proportions in the rock samples as shown in Table 1.

In Table 1 the average modal compositions of Ganaja rocks are compared with the composition of similar rock types from other locations. The plagioclase feldspar in the rock samples from the area of study generally appears colourless under plane polarized light but it is pleochroic going from light to dark grey as the stage is rotated. It shows albite twinning with parallel extinction. The form varies from anhedral, subhedral to euhedral with a cleavage that ranges from perfect to imperfect. Some plagioclase have minor inclusions of quartz with subhedral form. Biotite is brownish under plane polarized light with a slight pleochroism and a wavy extinction at a small angle of $2\text{-}3^0$. Some of the biotite crystals are tabular in habit with most forms euhedral to subhedral. There were inclusions of hornblende and euhedral opaque minerals.

Quartz appeared colourless under plane polarized light with a low relief and varied from white to blue colour, under crossed nicols. There was no visible twinning although the form is irregular from anhedral to subhedral.

Table 2. Average chemical compositions of Ganaja rock compared with other similar rock types

oxides	Composition (wt %)						
	Sample I	Sample II	Sample III	Sample IV	Sample V	Sample VI	Sample VII
SiO_2	80.21	78.31	62.69	60.05	58.50	69.63	67.00
Al_2O_3	14.02	15.25	19.03	27.74	15.80	15.51	14.47
MgO	4.32	4.99	0.11	0.24	4.57	0.67	2.40
CaO	0.27	0.29	1.26	0.04	6.51	2.96	3.41
MnO	0.05	0.07	0.05	-	4.57	0.06	0.10
Na_2O	0.03	0.03	4.76	1.29	3.06	3.79	2.88
K_2O	0.01	0.01	2.69	1.52	2.22	2.23	4.29
Fe_2O_3	0.04	0.03	2.69	9.14	6.50	1.12	1.45
FeO	-	-	2.17	-	-	1.96	2.94
P_2O_5	-	-	0.18	-	0.25	0.3	0.10
CuO	-	0.01	-	-	-	-	-
NiO	-	0.01	-	-	-	-	-
LoI	0.30	0.10	-	-	-	-	0.80

Sample I = Average chemical composition of migmatite gneiss from Ganaja (this work)
Sample II = Average chemical composition of gneiss from Ganaja (this work)
Sample III = Average chemical composition of Hornblende biotite Gneiss from Agada, S, E Lokoja. Imasuen et al[17]
Sample IV = Average chemical composition of Porphyroblastic Gneiss from N.W Ekido, S. E Lokoja Imasuen et al[17]
Sample V = Major Oxide composition of average crust (Fairbridge 1972)
Sample VI = Average chemical composition of PreCambrian Gneiss Igbeti Area S.W Nigeria Imeokparia and Emofurieta[18]
Sample VII= Average chemical composition of Iseyin banded Gneiss Rahaman[10]

Opaques were observed as dark coloured minerals with parallel cleavage and high relief. There was no twinning but they have some quartz inclusions.

Epidote was observed as colourless to pale green under plane polarized light. It was slightly pleochroic and exhibited prismatic elongate crystal with pseudo hexagonal cross section.

The microcline is colourless in thin section but may appear cloudy due to alteration. The crystal forms are subhedral to anhedral and they have parallel cleavage. They also have extinction with angles ranging from 5^0 to 15^0. They exhibited polysynthetic twinning corresponding to albite and pericline laws. Orthoclase appears colourless in thin section although turbid in some sections because of incipient alteration at boundaries with quartz. They display subhedral and anhedral crystals in phenocrysts with a perfect cleavage parallel to (001) the relief was low with extinction angles ranging from 5^0 to 12^0. It shows Carlsbad twinning. Most of the thin sections generally show differentiation into leucosome and melanosome bands which is usually common in migmatites. The leucosome bands are made up of quartz, oligoclase, alkali feldspar and subordinate amount of hornblende in the augen gneisses; while the melanosome bands consist of plagioclase feldspar, biotite and green hornblende. The quartz which was in relatively high proportion (20-40%) occurs in two generations. They early quartz forms rounded inclusions in oligoclase crystals and tend to be interstitial in the quartz feldspar mosaic (otherwise called mymerrkitised quartz). A later generation forms large compound crystals that appear to have been super imposed on the general fabric. Alteration of biotite is common as some rocks show biotite bands with porphyroblastic quartz in a finer matrix. The green hornblende is associated with biotite in the melanocratic bands.

Chemical analytical results and discussion

The results of the chemical analysis for the migmatite rock samples from Ganaja area compared with similar rock types from other areas are shown in Table 2. The analytical values for the Ganaja rock samples compare favourably with those of similar rock types from other areas.

The range of SiO_2 values for the migmatite gneiss between 78 and 80% while Al_2O_3 varies from 14 to 16% CaO values are generally low about 0.30% while MgO values vary between 4.32 and 5.00%.

However, the presence of plagioclase feldspar in the migmatite (Table 1) accounts for the significant content of Al_2O_3 and CaO in the samples.

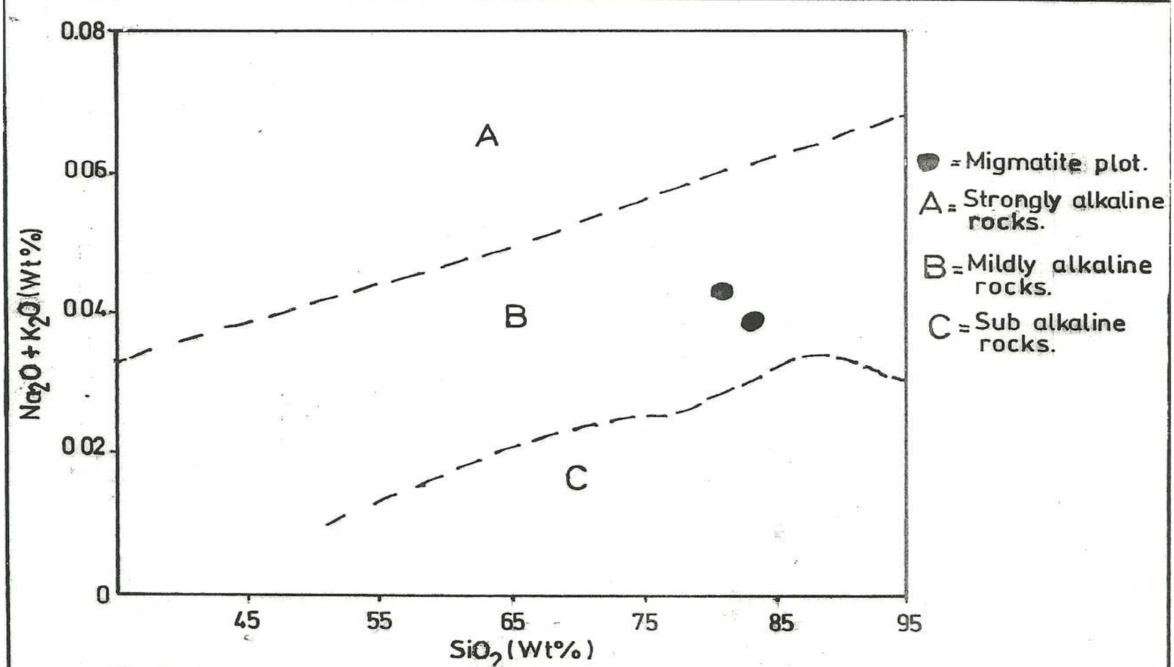

Fig.3. Plot of $Na_2O + K_2O$ versus SiO_2 of Migmatitic rocks from Ganaja area.
(Modified after MacDonald and Katsura 1954).

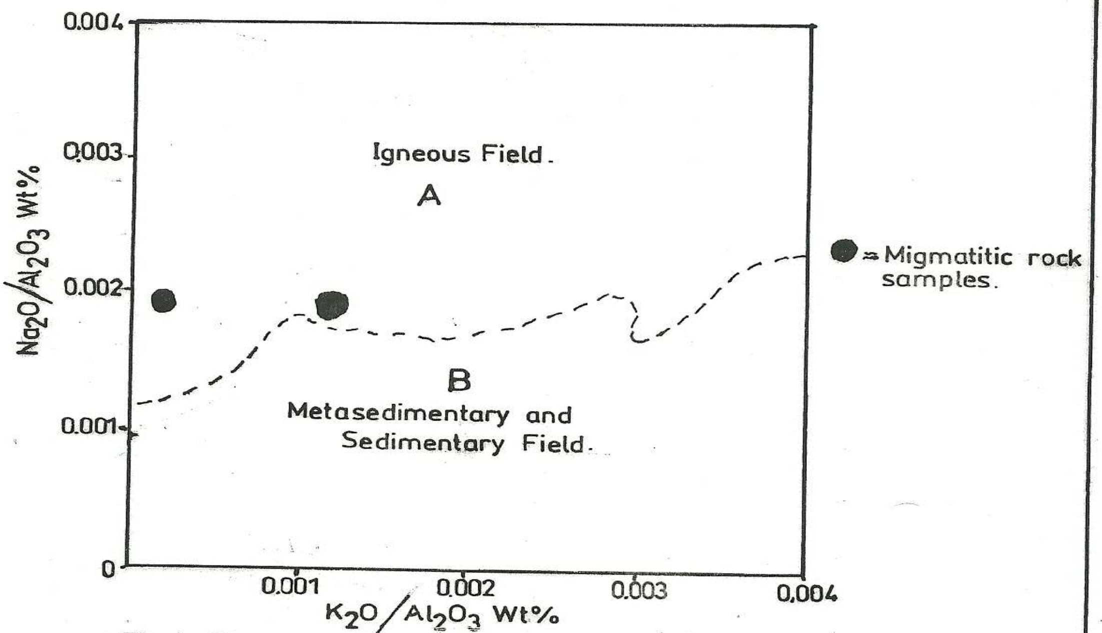

Fig.4. Plot of Na_2O/Al_2O_3 versus K_2O/Al_2O_3 of Migmatitic rocks in Ganaja area.
(Modified after Garrels and MacKenzie 1971).

The MacDonald and Katsura[19] diagrams of $Na_2O + K_2O$ (wt%) versus SiO_2 (wt%) is used to discriminate rocks of high alumina, alkaline and tholeitic compositions. Values on the plot for sample from Ganaja area show that the migmatites are mildly alkaline with high content of SiO_2 (Figure 3).

Using the Na_2O/Al_2O_3 versus K_2O/Al_2O_3 diagram developed by Garrels and Mackenzie[20], the values for the Ganaja migmatite rock plot within the igneous field (Figure 4) indicating that they are probably of igneous origin.

The migmatites represent metamorphosed products of fractionated igneous bodies as suggested by Odigi[13]. The relatively high MgO values and NiO values in the rock samples from the area of study (Table 2) probably indicate the presence of olivine in the primitive magma. The low K_2O contents of the analyzed samples are unlikely to reflect original igneous chemistry and possibly suggest evidence for metasomatism. These migmatitic rocks could approximate to low temperature melting compositions at high PH_2O- in 0-ab-or-H_2O and hence may be products of hydrous igneous fractionation process at high pressures[7].

CONCLUSION

The major rock types within the mapped area are migmatite, augen gneiss biotite gneiss, minor pegmatite and aplite dykes. The gneisses (augen porphyroblastic granite biotite gneiss) are the oldest rocks in the area and are probably products of an early orogenic event. While the pegmatites represent the youngest rock in the area occupying the fracture and available openings in the country rocks.

The area is suggested to be part of a metamorphic terrain of the south western basement complex of Nigeria. Formation of the different rock types in the area is most probably connected to the past tectonic events that affected the area and has greatly influenced the structural and textural features of the rocks.

Based on previous work and as indicative in this work the area has undergone at least two tectonic processes since the rocks are shown to have been invariably metamorphosed. Structures in the area have dominant NW-SE trend directions which correspond to the predominant stress direction that represents the imprints of the pan-African orogeny. The mineralogical and geochemical analytical data from this area of study compare favourably with similar rock types from other areas; however they suggest the migmatitic rock to be of igneous origin. They are characterized by the cal-alkaline composition from the Fe_2O_3 and Mgo content which were formed from the partial melting of the igneous rock parentage. Pressures resulting in textural modification predicted metamorphic conditions and Mn, Na, Ca, K, Fe, Mg, Al, and Si pseudo sections are compatible with partial melting and local segregation of melt into quartz – plagioclase to or at a low angle to schistocity. The most important melt compositional variations in prediction are tied to the modeled water content because water acts as flux for quartz- plagioclase melting which produces a rapid increase in silica (SiO_2) in the melt. In this investigation only slight discrepancies between melt compositional prediction and observed leucosome compositions are noticed for SiO_2, Al_2O_3 and Na_2O. However, significant discrepancies which are evident for K_2O, CaO may be products of leucosome modification process such as fractional crystallization with melt escape and/or back reactions between melt and country rock.

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