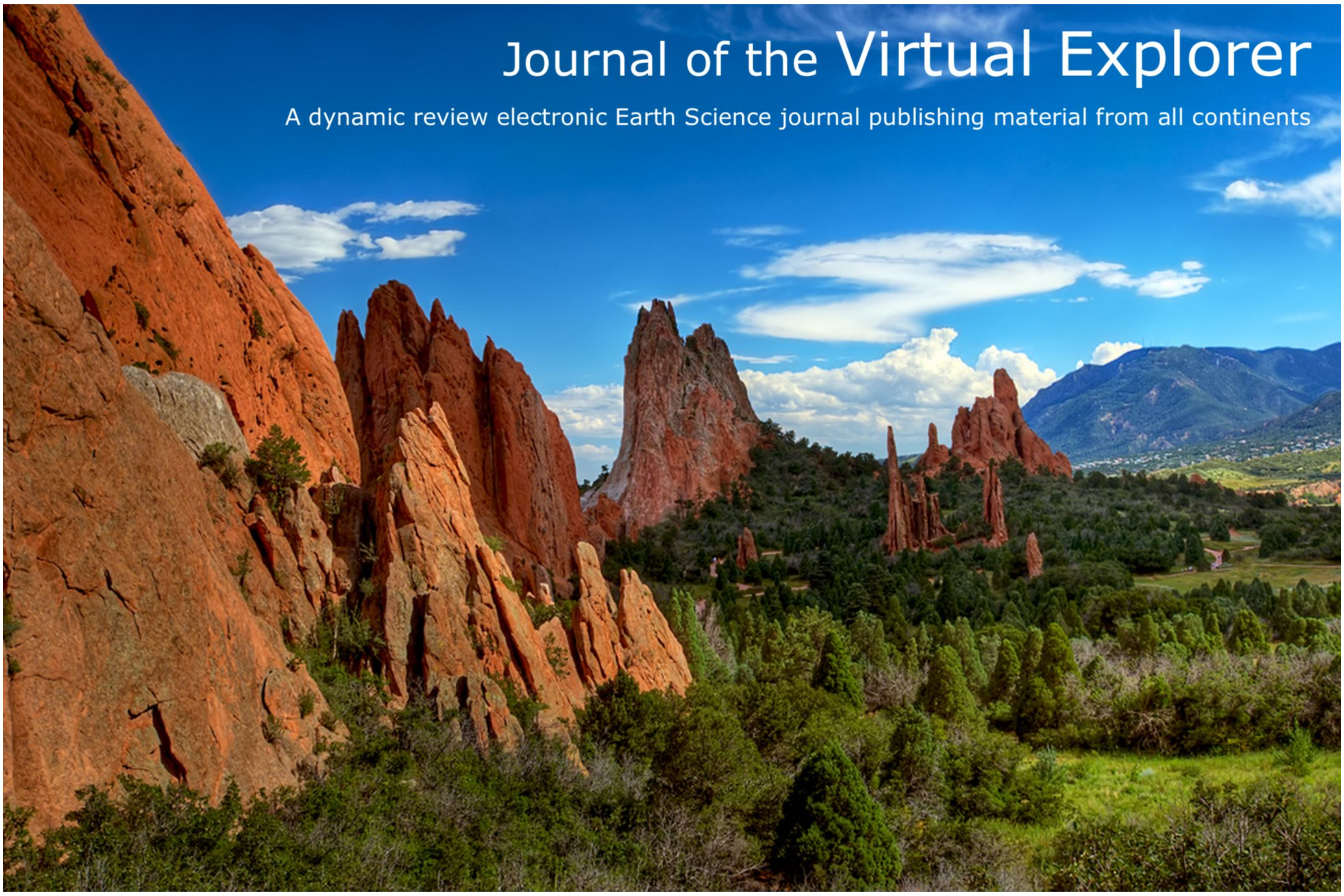

Petrography and Petrogenesis of Pre-Mesozoic rocks, Ago-Iwoye NE, SW Nigeria

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Abstract: Detailed geological mapping was carried out in a part of Ago-Iwoye NE with a view to identify the rock types and determine their origin. Petrographic and whole rock analysis of seven rock samples collected during the initial mapping exercise was done through thin sectioning, and X-ray fluorescence. Minerals were studied in cross and plane polarized light; their contact angle and boundary interaction were inferred in thin section. Normative mineralogy of the rocks was also determined using CIPW Norm.

The study area is underlain by both igneous and metamorphic rocks; the gneisses are migmatized and intruded by granitic rocks and pegmatite. The dominant minerals in thin section include quartz, biotite, muscovite and hornblende. Estimated mineral contact angle is ~56° and ~26° for hornblende-biotite and hornblende-muscovite, respectively. Mineral grain boundaries are planar and undulating in thin section.

The geochemical study revealed major oxides such as SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, K_2O and Na_2O. The highest estimated liquid temperature occurred in the gneisses with a value of ~1014°C, mean of ~862°C, range of ~281°C and water content of 1.6% which shows that the rocks are metamorphic in origin. The volume composition shows that quartz has the highest volume in all the seven samples with a percentage value of ~68%. Discriminant plots show that the granites are quartz-rich granitoid and granodiorite while the gneisses have high liquidus temperature; all the rocks samples record high alteration indices and are derived from passive and continental margins.

Rocks of the study area are Pan African granitoids emplaced into the polycyclic Pre-Cambrian migmatized complex host rock.

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Introduction

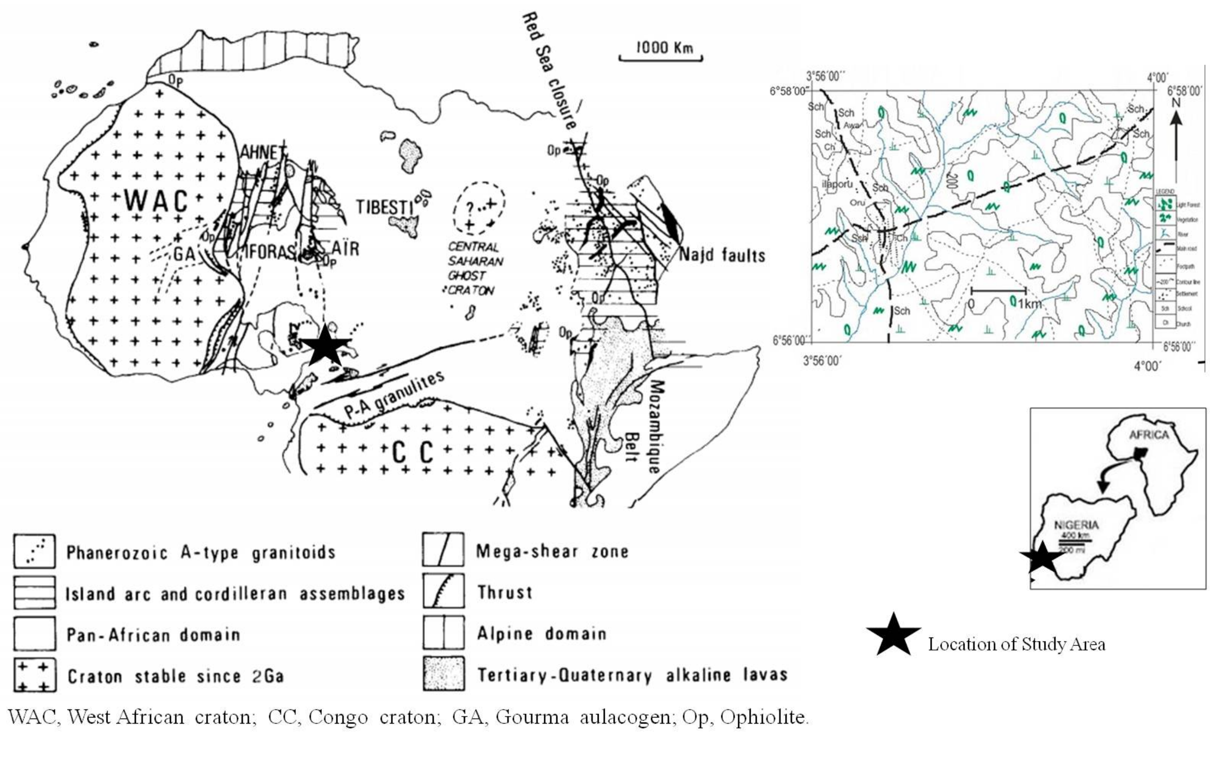
The pre Mesozoic rocks of the Nigerian Shield reside in the mobile belts that separate the West African craton from the Congo Craton (Kennedy, 1964, Caby & Boesse, 2001, Black, 1980, Rahaman, 1976). The shield is composed of a polycyclic basement and remnants of metamorphic cover sequences that represent a former ensialic domain, which was buried underneath pericratonic sediments, and subsequently reworked during the multistage Pan-African orogeny (Grant, 1978, Mullan, 1979, Caby, 1989).

The Pan African orogeny is multistage in nature as it involves the rejuvenation of older polyorogenic domain (Rahaman, 1988), and tectonometamorphic episodes in the whole of the Nigerian province. Ages include 640-620 Ma (Dada *et al.*, 1989, Dada & Respaut, 1989, Ferre *et al.*, 1998), 585 Ma, and 580 Ma (Tubosun *et al.*, 1984, Rahaman *et al.*, 1991). Structurally, the Nigerian shield is a southern continuation of the Touareg shield of central Sahara at the scale of Gondwana (Black *et al.*, 1994., Caby, 1989).

The rocks of the study area have been erroneously described as Precambrian to Pan African rocks from a polycyclic basement, because these rocks petrologically have some similarity with those previously described as the migmatized gneiss complex and other Pan African rocks. The understanding of the geology of the area has been based on regional studies and published maps by the Geological Survey of Nigeria. It is, however, important to provide information on the geology of rocks at a local scale.

The rationale for this research is to provide information on the petrology and genesis of the rocks of the area with a viewing to creating an archive of published information locally. In this paper, we aim to describe the composition of the rocks from field, thin section analyses, and also use chemistry to tie the genesis of the rock. We start by discussing the regional geology, petrographic description of the rocks, geochemical analysis and discriminants plots for genesis of the rock.

Figure 1. Geological Map of North-West-Africa



Geological Map of North-West Africa, with index map of the study area in square, inset of Africa and Nigeria in the left uppermost part of the map. (Modified after Black & Liegeois, 1993).

Local Setting

The study area is situated within the basement complex of south-western Nigeria within the coordinate of latitude N6°56'00" - 6°58'00" and longitude E3°56'00" - 4°00' over land area of approximately 10km^2. The climate is monsoonal type (Ojo, 1997), with double maxima rainfall peaking in June and September. The months of December and January are relatively dry. The average temperature is about 30°C throughout the year. Humidity is about fifty percent all year round. The climatic condition is reflected in the vegetation, which is lowland rain forest except where human interference has reduced it to secondary forest.

The rivers flows in NE-SW direction and their tributaries forms a dense sub-dendrite like pattern. The principal rivers appear to be controlled by the topography of the area, i.e. they flow in lowlands and specific channels. The leading river and their major tributaries are perennial while majority are active only during the wet season.

Regional Geology

Rahaman (1971), Oyawoye (1972), Cooray (1972), Elueze (1981), Caby (1981), Dada (1998, 1999) previously studied the general geology and geochronology of the basement rocks of Nigeria. The crystalline rocks in Nigeria are distributed in a circular area in the north central, a triangular area in the west which runs into the Benin Republic, and a rectangular area broken into three parts by sedimentary rocks on the eastern border of Nigeria with Cameroun Republic. The crystalline rocks are divided into three main groups: Basement complex, Younger granites and Tertiary to Recent volcanic. The Precambrian rocks of Nigeria, collectively known as the basement complex, occupy nearly half the total area of the country. The other half is covered by the Cretaceous and younger sedimentary rocks (Fig. 1).

Polycyclic Migmatite-Gneiss Complex (MGC)

Oyawoye (1965) recognized the following rock types as part of the MGC: banded gneisses, augen gneisses and pegmatites. Recent petrological division of the MGC includes: A grey foliated biotite acid or biotite hornblende quartz feldspathic gneiss of tonalitic to granodioritic composition, which is also known as the "grey gneiss" (Rahaman, 1981). Mafic and ultramafic components which when present, often outcrop as discontinuous boudinaged lenses or concordant sheets of amphibolites with minor amounts of biotite-rich ultramafic. Except where it constitutes the palaeosome to the migmatite, these are present in grossly subordinate amounts to the grey gneisses. Felsic components are a varied group of rocks consisting essentially of pegmatites, aplite, quartz-oligoclase veins, fine-grained granite gneiss, porphyritic granites etc. The three components may or may not be present together on a single outcrop. The migmatite-gneiss complexes are Archean (Dada *et al.*, 1989). Another important type of migmatite common in the Basement complex is the Agmatite, in which schistose or gneissic rocks (palaeosome) are dissected into irregular blocks by quartzo-feldspathic dykes and pegmatites (metasome) (Oyawoye, 1970).

Pan African Granitoid

The term "Pan African granitoid" covers group of rocks that include biotite and biotite-muscovite granites, syenites, charnokites, diorites, monzonites (Bauchite), serpentines, anorthosites, etc. Pan African as a name was introduced by Falconer (1911) to distinguish this rock type based on morphology and texture from Jurassic, anorogenic, peralkaline “Younger Granites” in north central Nigeria. The older granites, e.g. the coarse-grained biotite-hornblende granites, have concordant foliation with the MGC or schists (Oyawoye 1965) though they vary in composition, texture and colour.

Methods

Detailed geological mapping was done through traversing and positioning with the aid of a GPS. This was carried out in order to understand the geology of the area and determine the different rock types present. Petrographic analyses of selected rock samples were done. The samples were selected based on physical similarities and hand specimen mineralogical composition.

Seven samples (one pegmatite, two granites, and four gneisses) were collected for whole rock analyses. On petrological grounds, the best-preserved samples were selected for analyses and thin section preparation. Samples were crushed to powder form for whole rock analyses using a 9900 OASIS Integrated X-ray Analyzer at the Lafarge Cement WAPCO Nigeria laboratory. The result obtained from the XRF analysis was normalized using the CIPW Norm.

The values from the XRF results were recalculated to total of 100%. The total may not exactly be 100% because of rounding error. The normative minerals were estimated based on the recalculated percentages of the oxides. The *Weight norm%* is the normative components of the minerals calculated weight percent. The *Volume% norm* was calculated in terms of the volume percentage in the normative rock, rather than their weight percentage. The *Fe^{3+}/ (total Fe) in rock* is the molar ratio of ferric iron to total iron in the rock composition used in the norm (specifically the rock in the corrected analysis). This ratio is a measure of the oxidation state of the rock, expressed out of 100%. The *Mg/ (Mg + total Fe) in rock*, is the molar ratio of Mg to the total of Mg and total of iron in the rock (specifically in the corrected analysis). It is a measure of the differentiation of an igneous rock. This ratio is independent of the degree of oxidation of the iron in the rock. The *Mg/(Mg + Fe^{2+}) in rock* is the molar ratio of Mg to the total of Mg and total of Fe^{2+} in the rock (specifically in the corrected analysis); it is also a measure of the differentiation of an igneous rock. *Ca/ (Ca + Na) in rocks and Ca/ (Ca + Na) in plagioclase* (albite and anorthite) are also measures of differentiation.

Differentiation index used in the normalization is the Thornton Tuttle differentiation which is the ratio of normative (quartz + albite + orthoclase + nephiline + Leucite + calcite + sodium + carbonate + sodium sulphate) to the weight total of the norm. The calculated density is the solid rock density calculated from the volume norm except for the exclusion of water in the norm (admittedly a substantial problem) while the calculated liquid density g/cc was determined assuming a dry magma and the crudely estimated liquid temp (Mc Birney, 1993). The calculated viscosity, dry, is the log base 10 of the liquid viscosity in Pascal seconds assuming a dry magma and a crudely estimated liquidus temp (Mc Birne, 1993) while the calculated viscosity wet, log_{10} of the liquid viscosity in Pascal seconds. Percentage water in the magma was estimated is from “Estimated water content” of Mc Birney, 1993.

Result and Discussion

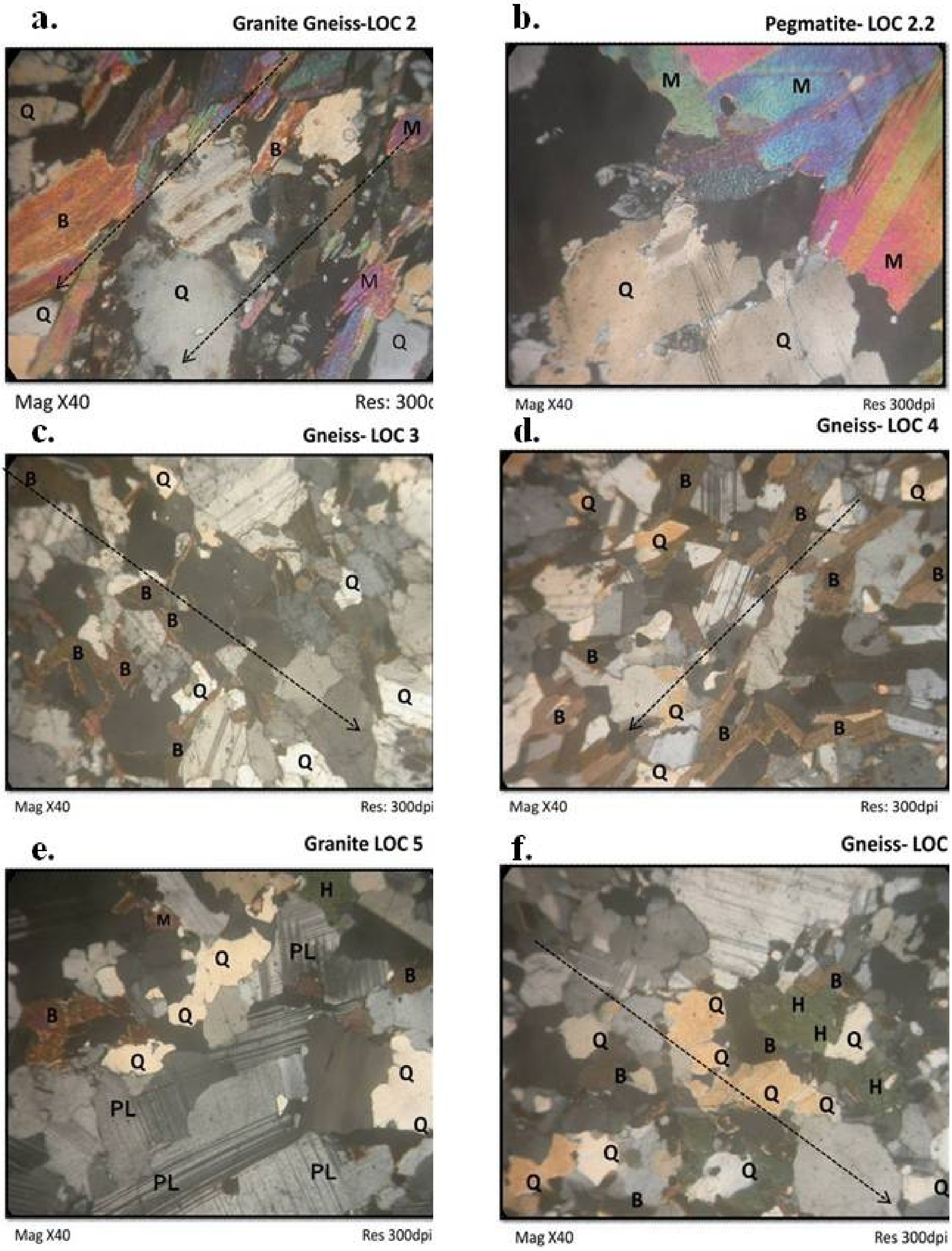
Petrographic description of rocks

Minerals in thin section include biotite, plagioclase, hornblende, muscovite, orthoclase, microcline, and quartz. The modal and average mineral percentages were estimated. The characteristic of the different minerals as observed in thin section are discussed as follows:-

The biotite shows grey to brown coloration, with subhedral to anhedral habit and no twining. Birefringence is 1st order and the mineral possess no extinction angles. Biotite forms interstitial lamellae with brown pleochroism. Commonly, an inner zone of deep green hornblende is surrounded by an outer biotite and quartz; this is shown in the digitized sketches of the slides in Appendix A.

The mineral quartz is colourless under the plane-polarized light, with no pleochroism, and twinning. The habit is subhedral to anhedral. Birefringence is also 1st order with extinction angle occurring at ~30°, 40° and 80°. The muscovite is colorless with no pleochroism and twinning. Habit is anhedral to subhedral. Birefringence is 3rd order with extinction angle at angle ~37°, 30° and 32°. The hornblende is deep green, pleochroic prismatic crystals in thin section with 1st order birefringence. Twining and extinction angle are totally absent.

Figure 2. Photomicrograph of samples



Photomicrograph of (a) granite sample at location 2 (b) pegmatite samples at location 2.2 (c) Migmatite samples at location 3 & (d) at location 4 (e) granite sample at location 5 (f) porphyroblastic granite sample in location 6. The arrows show the direction of inferred foliation.

The biotite-hornblende mineral association possesses dominant planar and undulating grain contact. The contact is oriented at different angles at distinct intervals. The hornblende is usually surrounded by biotite and quartz. The hornblende-muscovite grain contact is also planar and undulating at almost equal intervals (Table 1a & 1b, Appendix A). In all the samples, biotite and quartz dominate with biotite reaching ~ 60% of the whole rock.

The average planar grain contact for the biotite-hornblende is ~56°, with a maximum of 88° and minimum of 20° while that of the hornblende-muscovite is ~26° with a minimum and maximum of 20° and 30°.

The rocks identified from petrographic studies include the migmatized gneiss, granite and pegmatite. The migmatized gneiss is strongly foliated occurring as the parent rock type in the study area. It is composed of mafic minerals such as biotite and hornblende. The dark-colored host rocks (palaeosome) is intruded by veins of fine grained lighter rock consisting of quartz and feldspar (metasome). The metasome include granitic intrusion, pegmatite, and quartzo feldspathic veins. The term “migmatized” is used because of the field relationship of the palaeosome and the metasome especially the occurrence of granitic metasome in the metamorphosed parent rock. In this work, the migmatized gneiss is used to represent a group of rocks that includes granite gneiss, porphyroblastic granite, and banded gneiss. The banded gneiss contains mafic and felsic bands resulting from the segregation of minerals. The mafic bands are composed of biotite and hornblende while the felsic bands consist of quartz, muscovite, and feldspar minerals. The granite gneiss is metamorphosed granite rock that display subtle bands of mafic and felsic minerals. They contain minerals such as quartz, feldspar (microcline), mica (muscovite), and hornblende.

The pegmatite occurs both as outcrop and intrusions in other rock types. The composition of the pegmatite includes feldspar, muscovite, tourmaline, quartz, and occasionally biotite. Plagioclase feldspar is dominant with modal percentage estimated between 45-50% (fig.2). The minerals grains are large and phaneritic with size ranging from 2.2cm - 5cm. The pegmatite intrusions are simple pegmatites that occur as dykes in some of the other rock types. On the other hand, pegmatites outcrops are generally aphanitic with grains smaller than those seen in the intrusion. The pegmatite outcrop is restricted to the WNW part of the study area (fig.3) where it occurs in association with the biotite granite and the migmatized gneiss host rock.

The average modal percentage of minerals in the migmatized gneisses includes quartz~34%, biotite~20%, hornblende~11%, plagioclase~4%, microcline~6% and other minerals~8%. Inferred orientation of foliation is approximately N30°E and N45°W (fig.2) on the average when taken north of the 0 calibration of the microscope slide. The granites has average value of quartz~43%, biotite~20%, plagioclase~10%, microcline~03%, hornblende ~8% and other minerals ~16% while the average pegmatite is composed of quartz~38%, biotite~15%, muscovite ~30%, orthoclase~12% and other minerals~5%.

Whole Rock Analysis (Petrogenesis)

Major Oxide Geochemistry

The major oxides obtained from the XRF analysis include SiO_2, Al_2O_3, CaO, MgO, K_2O, and Fe_2O_3 (Table 2). The entire rock samples show high SiO_2 content, with the highest value recorded in the granitic rocks (Sample 1 in Table 2). The SiO_2 value ranges from 54.51- 81.58%, with the least value recorded in the non-granitic rocks. The other oxide with appreciable high value is alumina between 15.66 - 20.13%. All the other oxides Fe_2O_3, MgO, Na_2O, CaO and K_2O have values of <5% in all the samples.

The variation of the SiO_2 with other oxides is shown on the Harker diagram (Fig.4), there is little spread or scatter of the data points. Two kinds of population were observed, the greater and less than 75% SiO_2 variation with the other oxides. There is strong positive correlation between SiO_2 and CaO, Al_2O_3, MgO, Fe_2O_3 with coefficient of correlation, r of >0.81 while there is moderate correlation between the Na_2O, K_2O and SiO_2 with r-value of 0.5 and 0.66, respectively. Co-variation values of 30 and 43% shows that SiO_2 variation is unassociated with changes in Na_2O and K_2O, while values of 66% - 94% show that the oxides varies significantly with changes in SiO_2 content.

The normative mineral weight and volume percentage are shown in Tables 4 & 5; the major normative minerals include quartz, muscovite, hornblende, biotite, and plagioclase, while orthoclase, plagioclase, corundum, hypersthene and magnetite occur as accessory minerals.

Index of Weathering and Alteration

The CIA and CIW of 80.39% and 80.8% (Table 2) were the highest recorded in all the samples analyzed; these values were obtained from the granite sample at Location 1. All the rock types of the study area show a high degree of alteration and weathering. The least CIA and CIW values (Table 2) were recorded in the metamorphic rocks. The aluminum saturation index (ASI: molar Al_2O_3/ (CaO + Na_2O+K_2O)) (Zen, 1986) was used to distinguish between S- and I-type granites (Chappell, 1999). On the A/NK– A/CNK diagram (Fig. 5d), all the samples plotted in the peraluminous field (A/CNK >1). The SiO_2–A/CNK diagram (Clarke, 1992) shows that the samples are S-type granite with A/CNK >1.1 (Fig.5c).

Table 1. Optical properties of Minerals in the analyzed samples

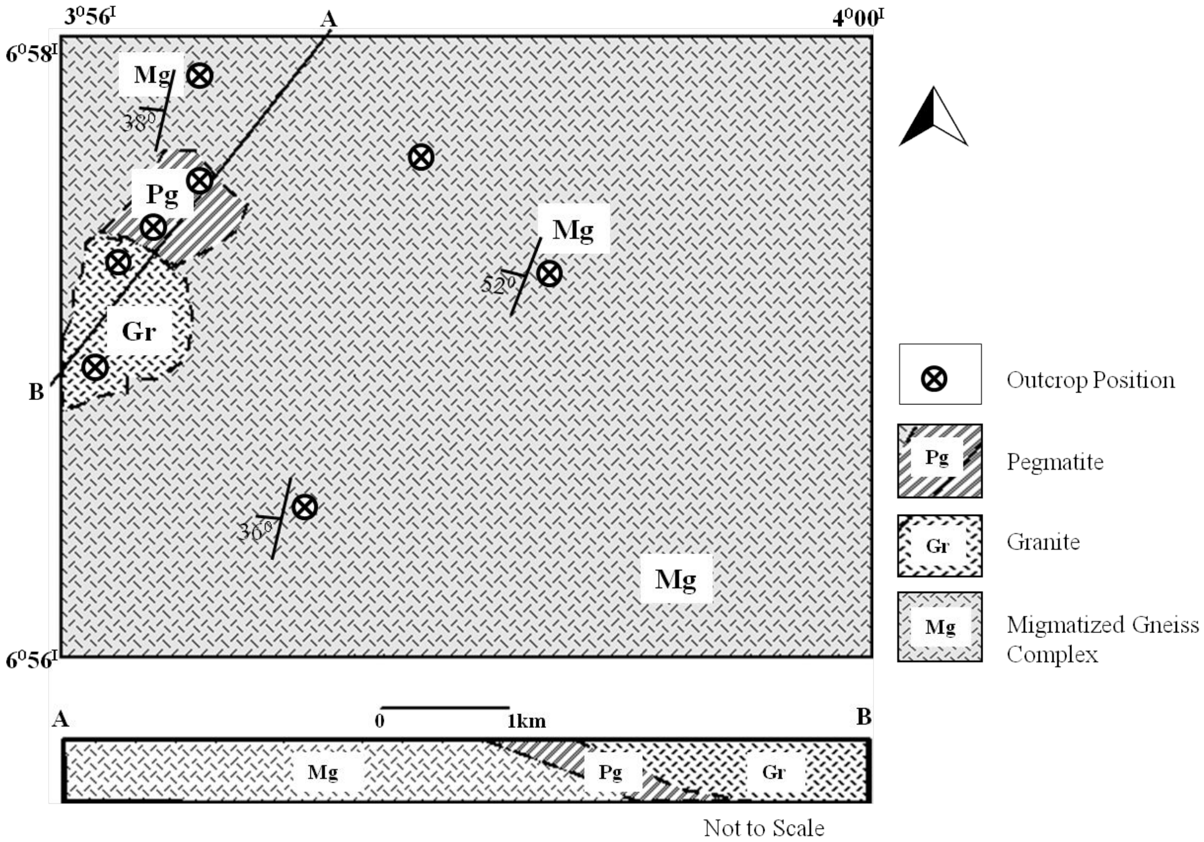
Quartz	**Colour**	**Pleo**	**Habit**	**Twinning**	**Bire**	**Ext. angle**
L1	Colourless	Abs	anhedral	Abs	1st order	32
L2	Colourless	Abs	anhedral	Abs	2nd order	36
L3	Colourless	Abs	anhedral	Abs	3rd order	42
Biotite						
L1	brown	Wk	subhedral	Nil	1st order	Nil
L2	brown	Wk	anhedral	Nil	1st order	Nil
L3	brown	Wk	anhedral	Nil	1st order	Nil
Muscovite						
L1	Colourless	Abs	anhedral	Nil	3rd order	35
L2	Colourless	Abs	anhedral	Nil	4th order	30
L3	Colourless	Abs	anhedral	Nil	5th order	33
Hornblende						
L1	green	Wk	anhedral	nil	1st order	nil
L2	green	Wk	anhedral	nil	2nd order	nil
L3	green	Wk	anhedral	nil	3rd order	nil

Table 1b. Mineral Contact Relationship

	Biotite-Hornblende	**contact angle**		**Hornblende-muscovite**	**contact angle**
L4	planar	080°	L4	undulating	
L5	planar	0°	L4	planar	30°
L5	undulating		L5	undulating	
L5	undulating		L6	planar	28°
L6	planar	60°	L6	planar	20°
L6	planar	58°	L6	undulating	
L6	undulating				
L6	undulating				
L6	planar	38°			
L7	planar	88°			
L7	undulating				
L7	planar	35°			

	Biotite-Hornblende	contact angle		Hornblende-muscovite	contact angle
L7	planar	15°			
L7	planar	50°			

Figure 3. Geological map of the study area from petrographic description of rock samples.



The non metamorphic rocks are restricted to the western part of the study area

Table 2. Geochemical results of Major oxides in samples analyzed in the study area

	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	Na_2O	K_2O	A/CNK	A/NK	CIA (%)	CIW (%)
1	1.44	81.58	15.66	0.34	1.25	0.1	2.28	4.1	6.58	80.39	80.8
2	5.08	65.05	17.74	3.68	2.32	0.12	1	2.86	15.84	74.1	74.48
3	6.12	58.53	17.66	5.24	3.19	0.12	1.21	2.37	13.28	70.33	70.67
4	1.37	78.47	15.73	0.27	1.21	0.11	5.78	2.17	2.67	68.42	68.75
5	4.63	65.2	16.43	4.91	2.81	0.1	1.75	2.54	8.88	71.72	72.03
6	1.42	75.84	17.46	0.74	1.22	0.13	3.35	3.56	5.02	78.09	78.54
7	6.1	54.51	20.13	4.72	2.57	0.14	1.67	2.54	11.12	71.79	72.15

Table 3. Qualitative Analysis Of Mineral

	granite (1)	pegmatite(2)	migmatite(3)	migmatite(4)	granite(5)	gneiss(6)	migmatite(7)
Fe^{3+}/(Total Fe) in rock	30	29.9	29.98	29.75	29.98	29.64	30.08
Mg/(Mg+Total Fe) in rock	88.13	55.55	54.68	89.91	53.16	76.5	51.89
Mg/(Mg+Fe^{2+}) in rock	91.39	64.06	63.28	92.69	61.85	82.23	60.67
Mg/(Mg+Fe^{2+}) in silicates	93.11	69.38	68.68	94.15	67.35	85.43	66.28
Ca/(Ca+Na) in rock	88.84	95.9	96.57	87.31	96.24	85.79	96.01
Ca/(Ca+Na) in plagioclase	89.61	96.41	96.79	88.9	96.8	87.26	96.44
Differentiation Index	90.05	85.67	83.17	92.78	84.44	89.02	83.17
Calculated density, g/cc	2.76	2.83	2.86	2.7	2.84	2.77	2.86
Calculated liquid density, g/cc	2.37	2.49	2.54	2.37	2.49	2.39	2.54
Calculated viscosity, dry, Pas	1.53	0.88	0.67	1.25	0.83	1.28	0.6
Calculated viscosity, wet, Pas	1	0.72	0.58	0.87	0.68	0.91	0.54
Estimated liquidus temp., °C	672.96	871.57	960.17	732.72	878.57	741.66	1013.98
Estimated H_2O content, wt. %	5.25	3.03	2.12	4.58	2.96	4.48	1.63

Table 4. Volume compositions for normative minerals

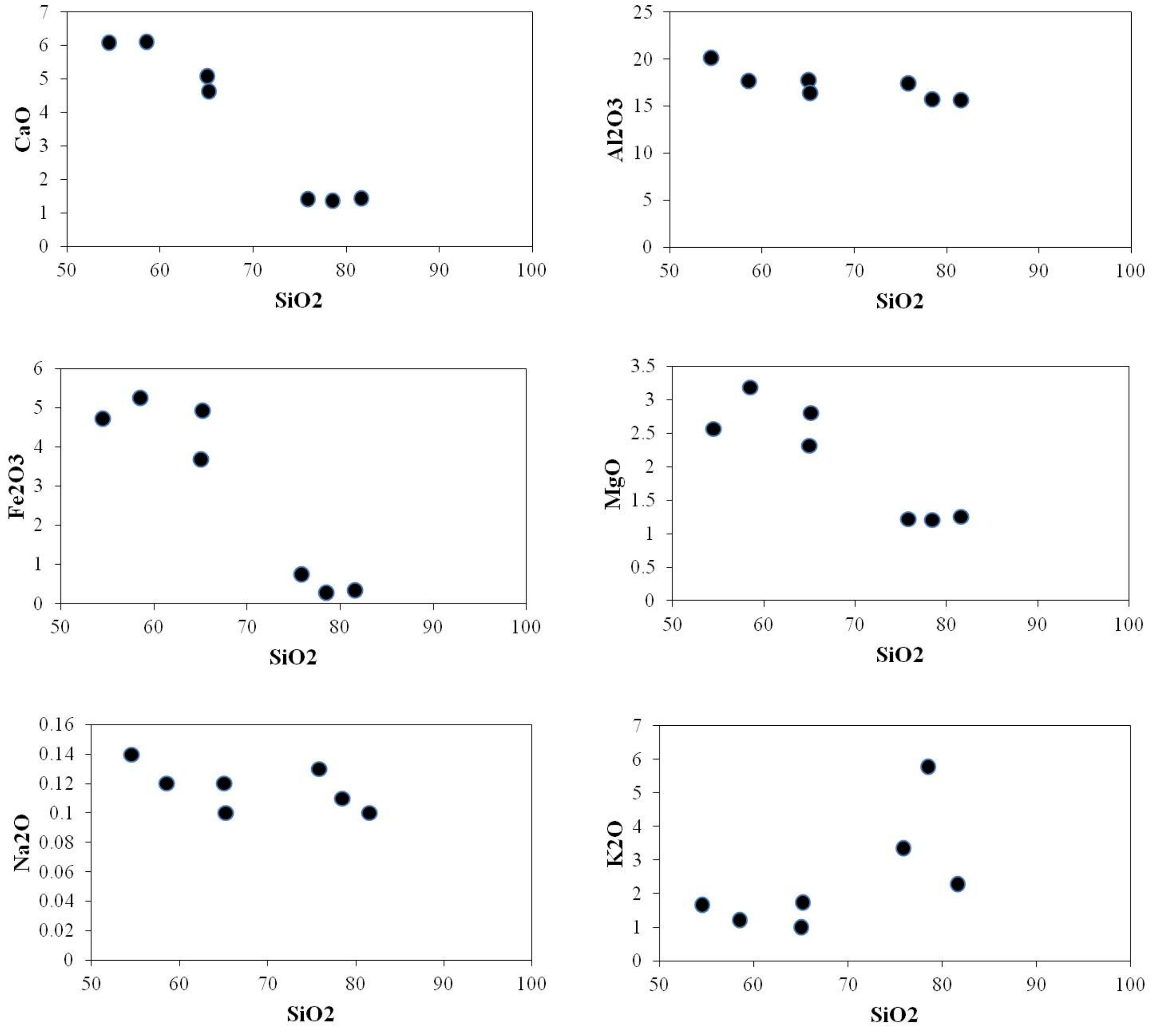
Sample	Quartz	Plagioclase	Orthoclase	Corundum	Hypersthene	Magnetite	Others	Total
1	68.16	7.75	14.14	7.04	2.81	0.07	0.02	100
2	50.47	28.3	6.9	5.44	7.93	0.92	0.04	100
3	39.05	35.41	8.71	3.95	11.5	1.36	0.02	100
4	50.48	7.27	35.03	4.5	2.63	0.06	0.03	100
5	46.92	25.52	12	4.46	9.85	1.22	0.04	100
6	59.59	8.07	21.36	7.68	3.1	0.17	0.04	100
7	34.46	36.37	12.34	5.65	9.87	1.27	0.04	100

Table 5. Weight percentage composition of the normative minerals

Sample	Quartz	Plagioclase	Orthoclase	Corundum	Hypersthene	Magnetite	others	Total
1	67.23	7.92	13.47	10.42	3.42	0.14	0.02	103
2	44.74	26.09	5.91	7.25	9.13	1.59	0.04	95
3	33.21	31.31	7.15	5.04	12.71	2.28	0.02	92
4	50.95	7.6	34.16	6.83	3.26	0.12	0.04	103
5	41.87	23.68	10.34	5.98	11.46	2.13	0.04	96

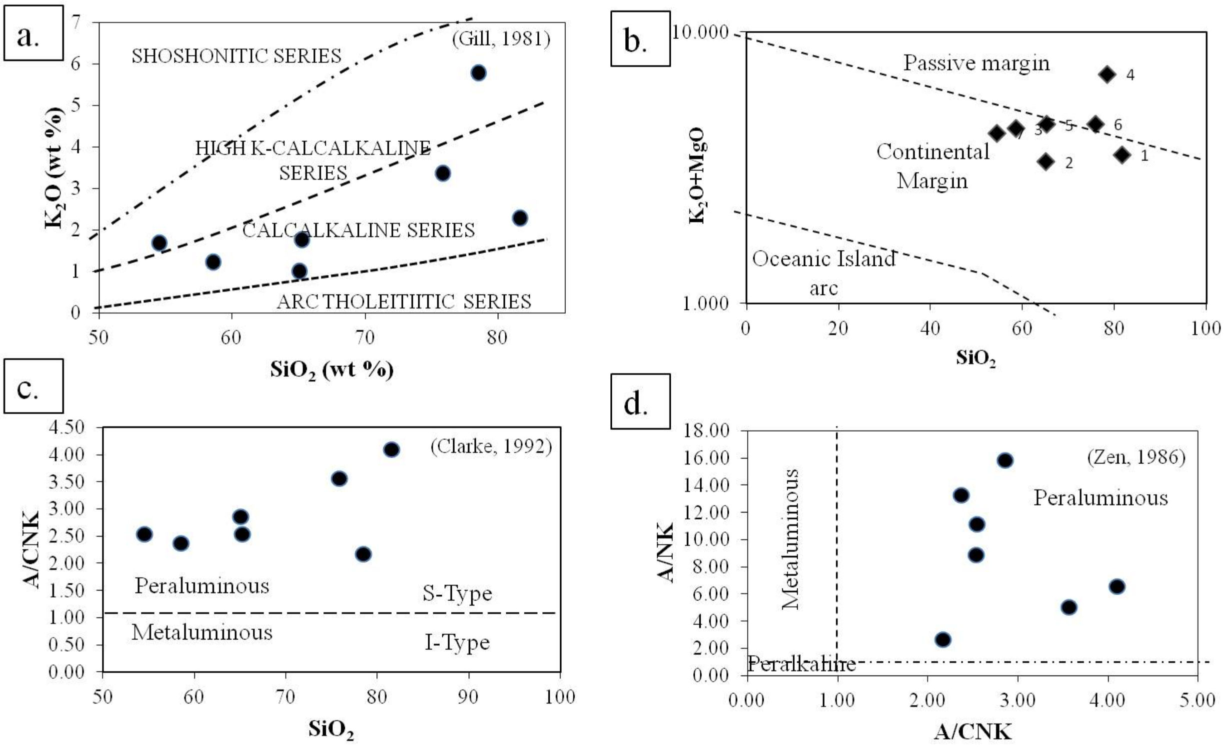
Sample	Quartz	Plagio-clase	Ortho-clase	Corun-dum	Hyper-sthene	Magnetite	others	Total
6	57.18	8.01	19.8	11.06	3.72	0.32	0.04	100
7	28.54	31.32	9.87	7.03	10.68	2.06	0.04	90

Figure 4. Harker diagram



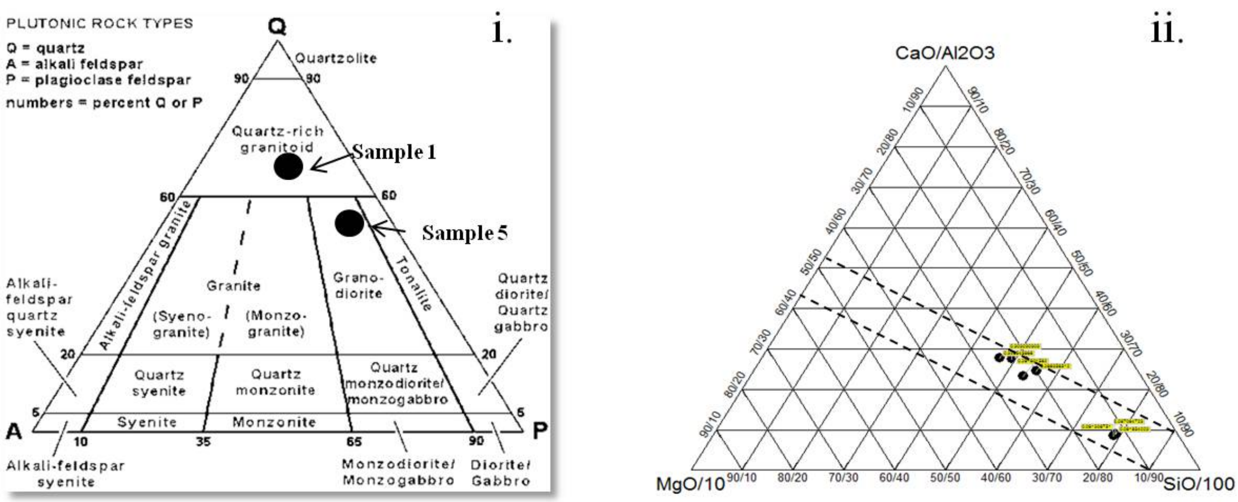
Harker diagram for oxides interrelationship, variation of SiO_2 with the other oxides. There is ‘r’ of 0.97, 0.81, 0.94, 0.9, 0.5 and 0.66 between SiO_2 and CaO, Al_2O_3, Fe_2O_3, MgO, Na_2O and K_2O, respectively. Covariation,’r^2’ is highest between SiO_2 and CaO.

Figure 5. SiO_2–K_2O diagram



(a) The SiO_2–K_2O diagram, all the samples falls in the field of High k-Calcalkaline and Calcalkaline Series (b) The rock are continental and passive margin igneous and metamorphic rocks on the plot of K_2O+MgO vs SiO_2 (Bhatia, 1983) (c) All the sample falls in the field of S-type granites, even the metamorphosed gneisses on the SiO_2–A/CNK diagram, where A/CNK = molar $Al_2O_3/(CaO + Na_2O+K_2O)$, aluminium saturation index (ASI). (d) The rock are peraluminous on the A/CNK–A/NK diagram where A/NK = molar $Al_2O_3/(Na_2O+K_2O)$, corroborating the high corundum content of Table 4 & 5.

Figure 6. QAP



(i) QAP (Streckeisen, 1976) for the two igneous samples (Sample 1 & 5), Sample 1 plot in the field of quartz-rich granitoid while Sample 5 is a granodiorite (ii) Accessing the alteration of magmatic rock, all the sample falls in the field of altered rocks corroborating the alteration indices of Table 2.

Qualitative Analysis

The amount of Fe^{3+} in all the samples is approximately 30%, Mg is highest in Samples 1 (granite) and 6 (gneiss), while there is a high ratio of Ca/Ca+Na and plagioclase in all the rock samples. The highest differentiation index is recorded in one of the gneisses. This may reflect re-crystallization and development of newer minerals. Calculated density of rock varies from 2.70 to 2.86 g/cc (Table 3). High density is unrelated to the estimated water content. The sample with density of 2.70 g/cc has water content of 4.58 while that of 2.86 has density of 1.63%. Estimated water content of all the gneisses is 3.2% in contrast with the granites with higher content of 5.25%. The estimated liquid temperature ranges 732°C - 1013.98°C in the gneisses with mean of 862.13°C, highest estimated liquidus is 1014°C (Table 3).

Ternary and Discriminant Diagrams

The QAP diagram (Streckeisen, 1976) was used to characterize the specific modal percentages of the constituents of the rock samples, especially in samples 1 and 5 that were classified as igneous rocks on the field and during petrographic studies. For the two granitic samples, Sample 1 plotted in the field of quartz-rich granitoid (Fig. 6i) while Sample 5 fell in the field of granodiorite. The latter has a very high percentage of plagioclase in thin section (Fig. 2e) and from geochemical analyses (Table 4 & 5). The ternary plot for the whole rock compositional field demonstrates the affinity and concentration of the mineral content of the rock and also the compositional variation of minerals.

The degree of alteration of the sample was further assessed using the ternary plot of CaO/Al_2O_3-MgO/10-SiO_2/100 (Davies *et al.*, 1978). All samples plotting outside the line are unaltered or marginally altered magmatic rocks. In the study area, all the samples plotted within the lines, corroborating the high CIA and CIW (Table 2) values. Alteration of the rocks is attributed to any of weathering, melting, metamorphism, or re-crystallization.

The high corundum content suggests high alumina content as seen in Table 2, various alumina contents can yield any of peralkaline, metaluminous and peraluminous rock. The plot of SiO_2–A/CNK diagram shows that all the samples are S-type granites including the metamorphosed gneisses. I-type granites have been previously described not to have undergone any surface weathering processes. On the other hand, S-type granites are products of partial melting of metasedimentary rocks (Chappell & White, 1974). Two of the samples plotted in the field of passive margin derived rocks on the K_2O +MgO vs. SiO_2 (Bhatia, 1983). The other samples fall in the field of continental margin derived rocks.

Discussion

The rocks of the study area display characteristics features of Pan African and the MGC rocks of Nigeria. Field observation suggests that these rocks have undergone a high degree of alteration especially surface weathering, which implies that they are not I-type of granitic rocks (Chappell & White, 1974). The penetrative foliation of some of the gneisses resulted from the magmatic segregation of the mafic and felsic content of the rocks. Assuming foliation and other metamorphic fabrics, sample 1, 2 & 5 are categorized as igneous rocks.

The metamorphosed rocks display different kinds of foliation from slightly foliated rocks (granite gneiss), to strongly aligned porphyries in the porphyroblastic gneiss, and strongly foliated banded gneiss. These are metamorphic fabrics diagnostic of the migmatized basement complex rocks of Nigeria.

The granitic rocks plotted as quartz-rich granitoid and granodiorite on the QAP diagram. The older granite suites include such rocks as granodiorite, syenite, monzonite, charnockite, and other granites. The preponderance of the plagioclase among the feldspars as observed in thin section and XRF analysis confirmed the naming of this rock as granodiorite. The quartz-rich granitoid also has the highest quartz and SiO_2 content both in thin section and from geochemical analyses.

High alumina content is consistent with the chemistry of Pan African rocks, which implied that the rocks of the study area are peraluminous and S-type granitic rocks. This high calc-alkaline content corroborates the description of Falconer, 1911, Burke *et al.*, 1976, Turner, 1983, Odigi *et al.*, 1993, Dada *et al.*, 1995, Oyinloye, 1998 on other parts of the basement complex terrain of Nigeria. The high hypersthene content of the granites suggests they are charnokite affinities.

Conclusion

The rocks of the study area belong to the south western basement complex terrain of Nigeria. It is underlain by migmatite gneiss (porphyroblastic gneiss, banded gneiss and granite gneiss), granites (quartz-rich granitoid and granodiorite) and pegmatite. The dominant mineral assemblages from petrographic studies include quartz, muscovite, hornblende, biotite and other accessory minerals which exhibit different optical properties. The biotite-hornblende mineral possesses dominant planar grain contact oriented at different angles and the undulating contact at irregular intervals in thin section. The hornblende-muscovite contact has equal proportion of planar and undulating contact.

Major oxides analyzed for include CaO, SiO_2, Al_2O_3, Fe_2O_3, MgO, Na_2O, and K_2O. The compositional study revealed that the rocks have high alumina content. There is strong to moderate correlation between the percentages of SiO_2 and other oxides. Indices of alteration suggest intense weathering and other magmatic alteration processes which may include partial melting and recrystallization during metamorphism. The gneisses have high liquidus temperature common to metamorphic rocks.

The granitic rocks are characteristic Pan African rocks suggesting they were emplaced into the migmatized host rock (Precambrian) approximately +550 Ma years. Emplacement of newer magmatic bodies into the host rocks suggest different phases of deformation and alteration of the magmatic content. Until now, erosion has altered the rocks of the area into its present state.

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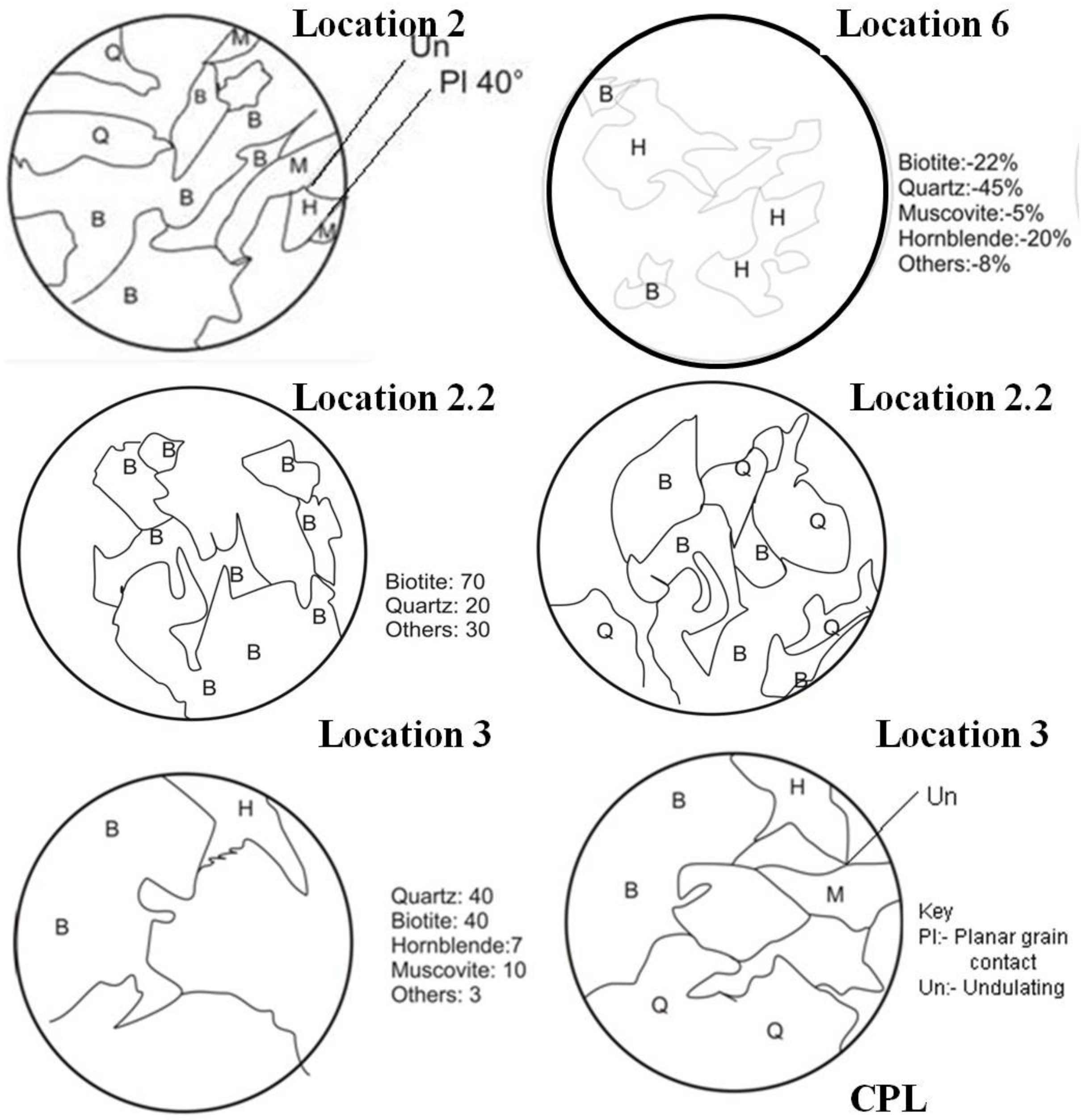
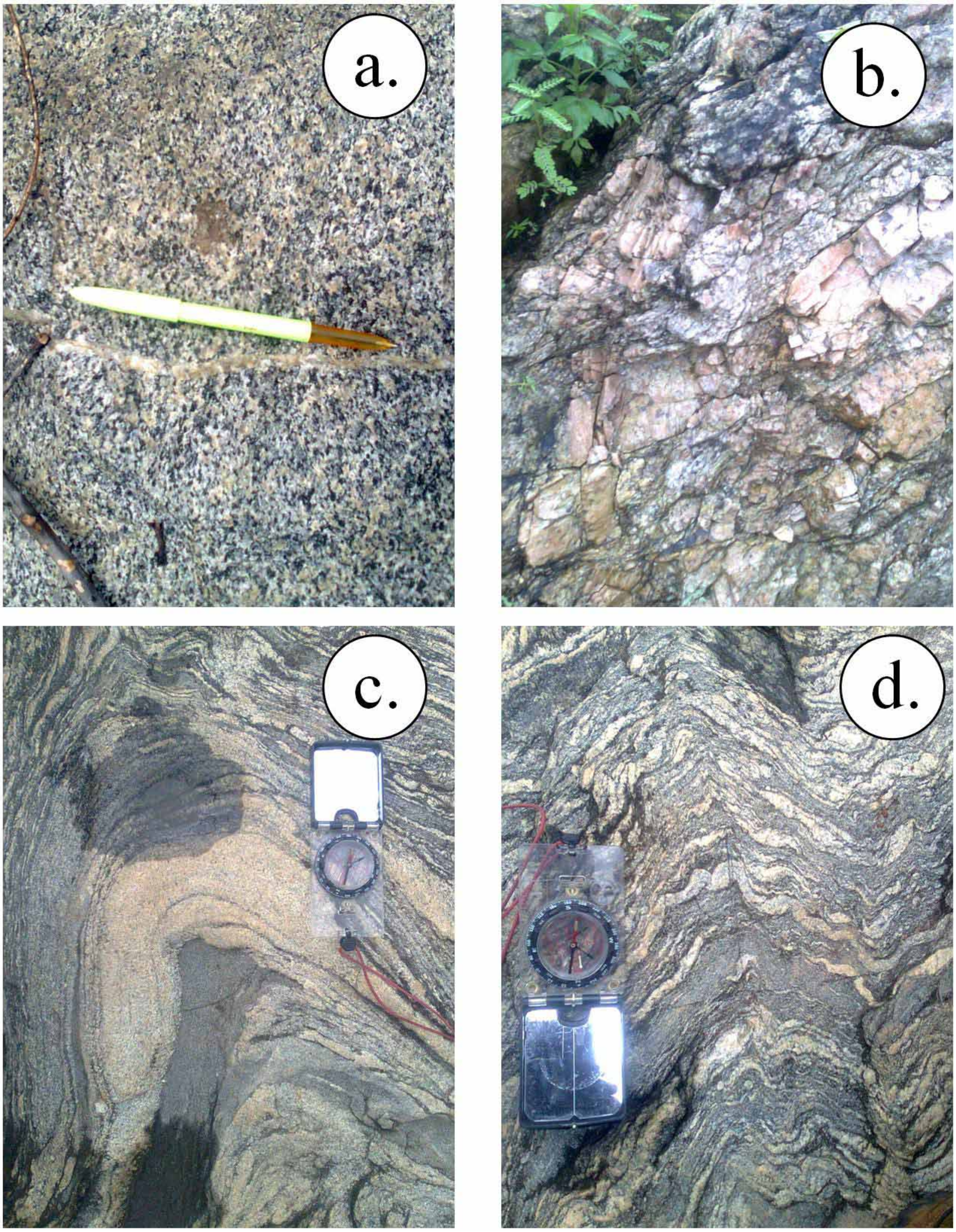
A. Figure 7

Figure 7. Digitized sketches of the slides



B. Figure 8

Figure 8. Location photographs



(a) Quartzo-feldspathic vein in granite at Location 5. (b) Pegmatica at Locaion 2. (c) Folded foliation in banded gneiss at Location 4. (d) Part of the migmatized gneiss at Location 3.