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Geology & Economic Potential of Migmatites Around ZumbulAnd Environs, DASS LGA Of Bauchi Sheet 149 SW North East Nigeria.

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Abstract
The study area Zumbul and its environs is part of Dass sheet 149-SW, Bauchi state, NothernEastern Nigeria. Bounded by Latitudes 10º00'10"N and 10º04'15"N and longitudes 9º22'30"E and 9º26'30"E. Detailed geological mapping of the research area was carry out to update the previous geology information of the study area, the field observation indicate four lithological unite of Migmatite: Diatexite, pegmatite, Stromatic and Banded orthogneiss. Biotite, muscovite, quartz, feldspar are the major minerals seen during petrographic studies, and the migmatite showed little fractionations as they formed from medium temperature minerals to low temperature (Andesine to Oligoclase) coinciding with anorthoclase and microcline mineral assemblages at the discontinuous series arm of the Bowen reaction series. In variations diagrams, the compositional trends for the analyzed sample are characterized by negative correlation between TiO_2, Fe_2O_3, MgO, CaO& P_2O_5 with increased SiO_2 but positive correlation between Na_2O, K_2O and Al_2O_3 with increasing SiO_2even though some erratic and scattered distribution are also observed. The tectonic classifications of different authors indicated that the migmatite are peraluminous and peralkaline. They formed under syn-collision to late orogenic and anorogenic tectonic settings.
Key words: *Diatexite, pegmatite, Stromatic, Banded Orthogneiss and Zumbul area.*

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I. Introduction

The study area Lukshi and its environs, lies between latitudes 10º00'10"N and 10º04'15"N and longitudes 9º22'30"E and 9º26'30"E, it is part of Dass sheet 149-SW . The study area is located within the Pan African Older Granite,the area is accessible through numerous interconnected foot paths and untarred roads linking all parts of the study area.The study is focused on studying the geology, petrography and geochemistry of Zumbul and its environs and also to deduce the geologic setting of the rock types. A total of ten 10 samples from strategic locations of different lithology were carefully selected and analyzed for major elements (oxide), trace elements as well as rare earth elements. In addition, four (4) major rock samples were studied petrographically. The petrographic studies will reveal the mineralogical composition, and the whole-rock geochemical studies will reveal the chemical composition of the samples, which together with the results from structural analysis data obtained will be used to give a better understanding of the geology, Petrography and Geochemistry of the study area.

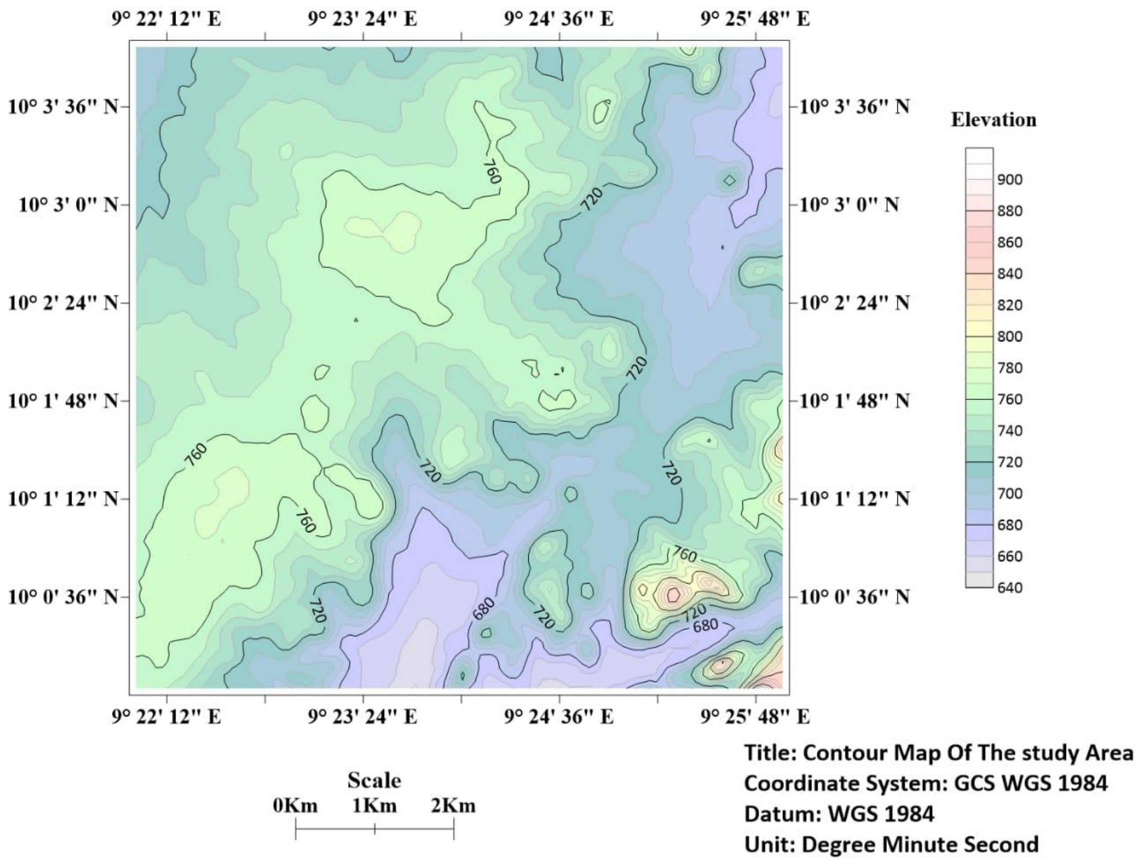


Figure1: Location map of the study area. (Source: Google earth)

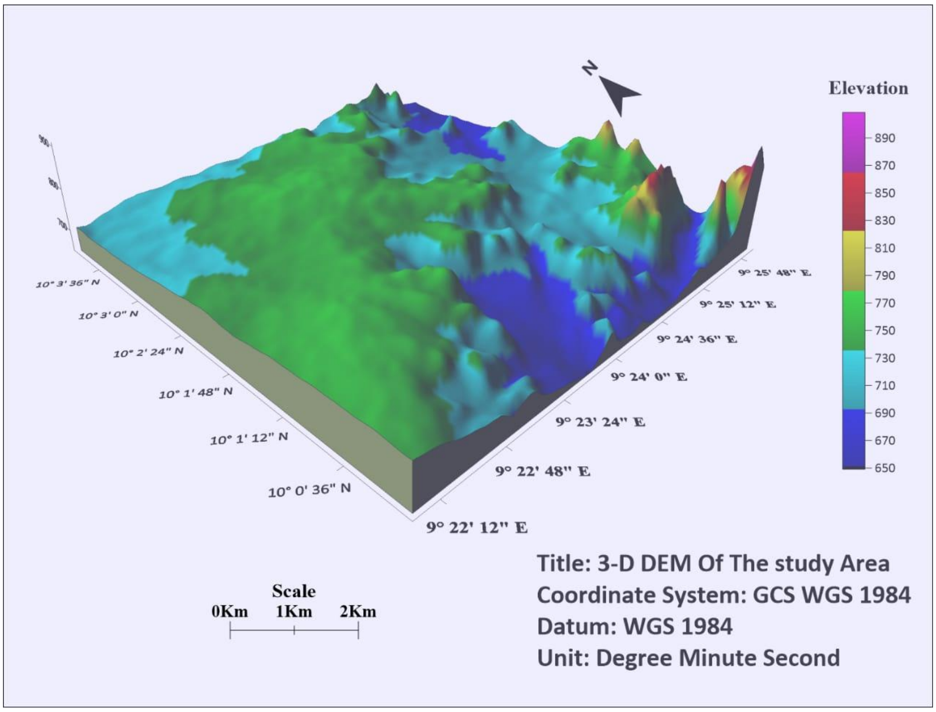


Figure 1: Digital Elevation map of study area (Source: Google earth)

II. Geological Background

The Jos-Bauchi transect is a representation of the Neoproterozoic (Pan-African) Belt of Northern Nigeria as it exposes high-grade metamorphic rocks of contrasted character depending on their distance from Neoproterozoic monzonitic plutons (Ferre and Caby, 2006).[5] [6] The Bauchi area provides evidence that high grade metamorphic conditions and anatexis are met by the combination of widespread regional amphibolites facies conditions and local contact metamorphism due to pluton emplacement. Hence most basement if not all of the study area shows the 550±100 Ma ages (Ferre and Caby, 2006)[5] [6].The Bauchi area has foliations running through it, these was deduced from field data, SLAB images and previous maps (Wright, 1971). It has in place biotite-muscovite granite which form elongated plutons parallel to the regional structures suggesting a syn-tectonic emplacement, and biotite- hornblende granites which have more rounded shapes molded by country rock structures in conformity envelopes, suggesting a late tectonic emplacement (Ferre *et al.*, 1998).[6]

A migmatite is a rock found in medium and high grade metamorphic areas that can be heterogeneous at the microscopic scale and consists of two, or more petrographically different parts, which are petrogenetically related to each other and to their protolith, through partial melting or segregation of the melt from the solid fraction (Sawyer 2008). The Migmatite was introduced as a new rocks formed where older foliated granite, was introduced by the younger granite by Sederholm (1907). While Edward Sawyer describes the Migmatite as a rock found in medium and high grade metamorphic areas that can be heterogeneous at the microscopic to macroscopic scale and that consist of two or more.

III. Methodology

To achieve the objective of this research, a set of materials and method were applied. The methodology adopted for data acquisition, analysis, processing and the procedures followed while planning and carrying out the geological, petrographic and geochemical investigations are described as follows. GPS, Compass clinometers, Geological hammer,Sample sack, Tape rule, Camera, Camera, Pen and Pencil and Paper tape.

Field Method

Mapping and Sample collection were carried out during the detail field work, observations of the different rock units were conducted to know the geology of the area at a scale of 1:25000. Representative surface rock samples were taken from each plutonic suite according to their mineralogical and lithological variations and areal coverage for petrography and whole rock geochemistry. A total of ten surface rock samples were collected from the study area and data were recorded based on the mineralogical compositions, texture and colour of the rocks with and without the aid of high magnification lens.

Laboratory Method;

Petrographic analysis: About ten selected samples were resized or reduced by cutting machine to a size of (10x5) cm2 and were sliced into two parts using rock cutter at thin section laboratory of geology Department, Abubakar Tafawa Balewa University Bauchi (one piece for thin section or rock geochemistry, and the remaining for reference and stored in laboratory).

The selected samples for thin sections were further resized by using secondary cutting machine. First the rock samples were cut and trimmed into rectangular slab. Further cutting was then followed till it reduced to the required size to be polished by polishing machine.

Thin sections were prepared at thin section laboratory of geology Department, Abubakar Tafawa Balewa University Bauchi. Transmitted light microscopy was used to identify mineralogical compositions, modal proportions and classifications, texture, grain size, alterations, micro structural features and etc.

Geochemical analysis: First the hand sample was cut down to a size for crushing. The samples were first dried in oven dry overnight and then crushed by primary and secondary crusher. Later they were homogenized, split and pulverized to minus 200mesh, which resulted in 100gram representative powder. Major, minor and trace elements concentration was analyzed using X- Ray Fluorescence (XRF) at the Gombe state university, department of geology central laboratory for whole rock analysis. A total of ten (10) representative samples selected from the study area were analyzed.

IV. Result

The field occurrence and relationships of the various rock types observed during the field work were basically the signatures of their genesis/origin. Hand specimen of various rock types sampled at different locations were observed in the field and interpreted based on major rock forming minerals (mineralogy), colour, structures and textural characters.

Below is the geology map of the study area based on the field work conducted and sampling was on the bases of rock variation and association in the field (figure 3).

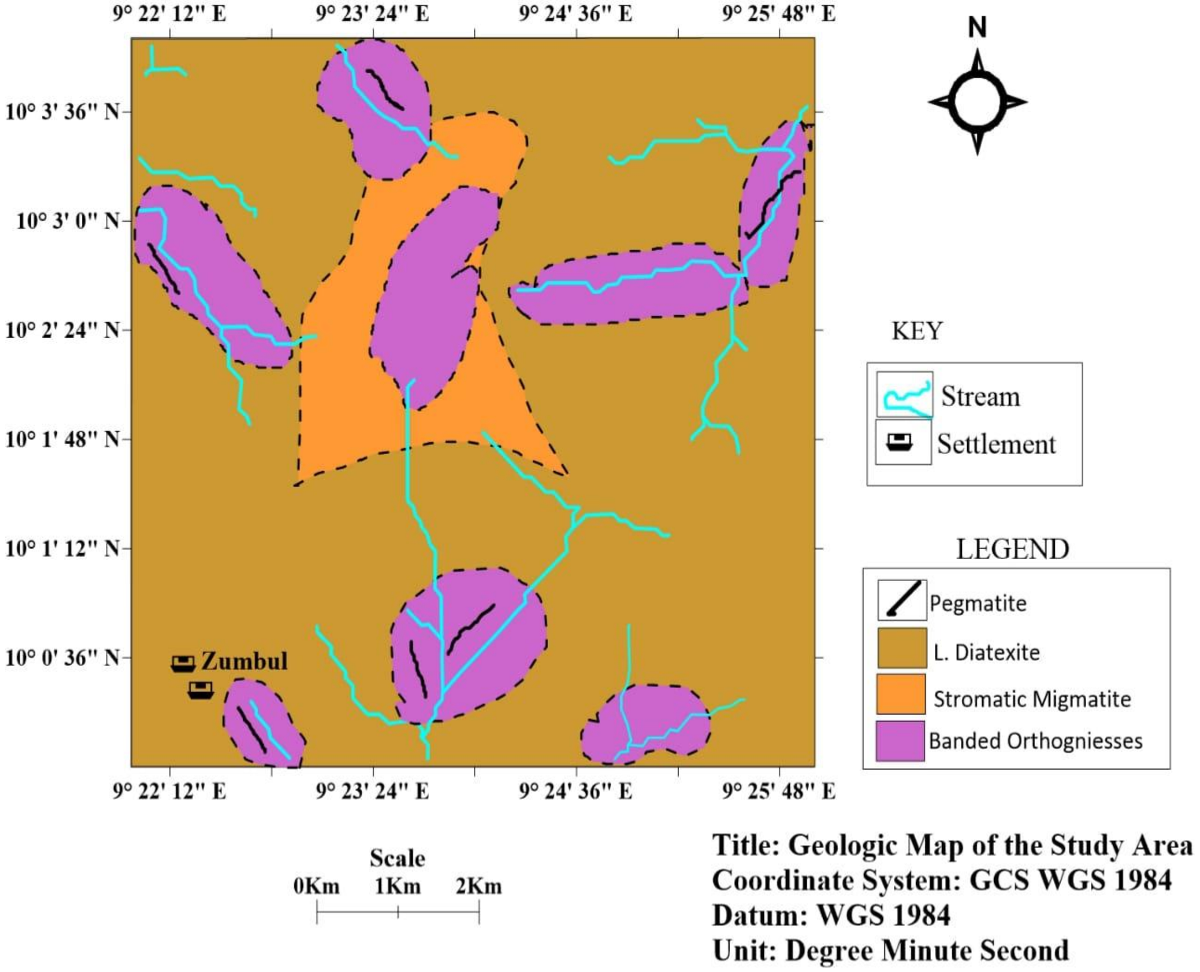


Figure 3: Geological map of the study area

Petrography
Pegmatite

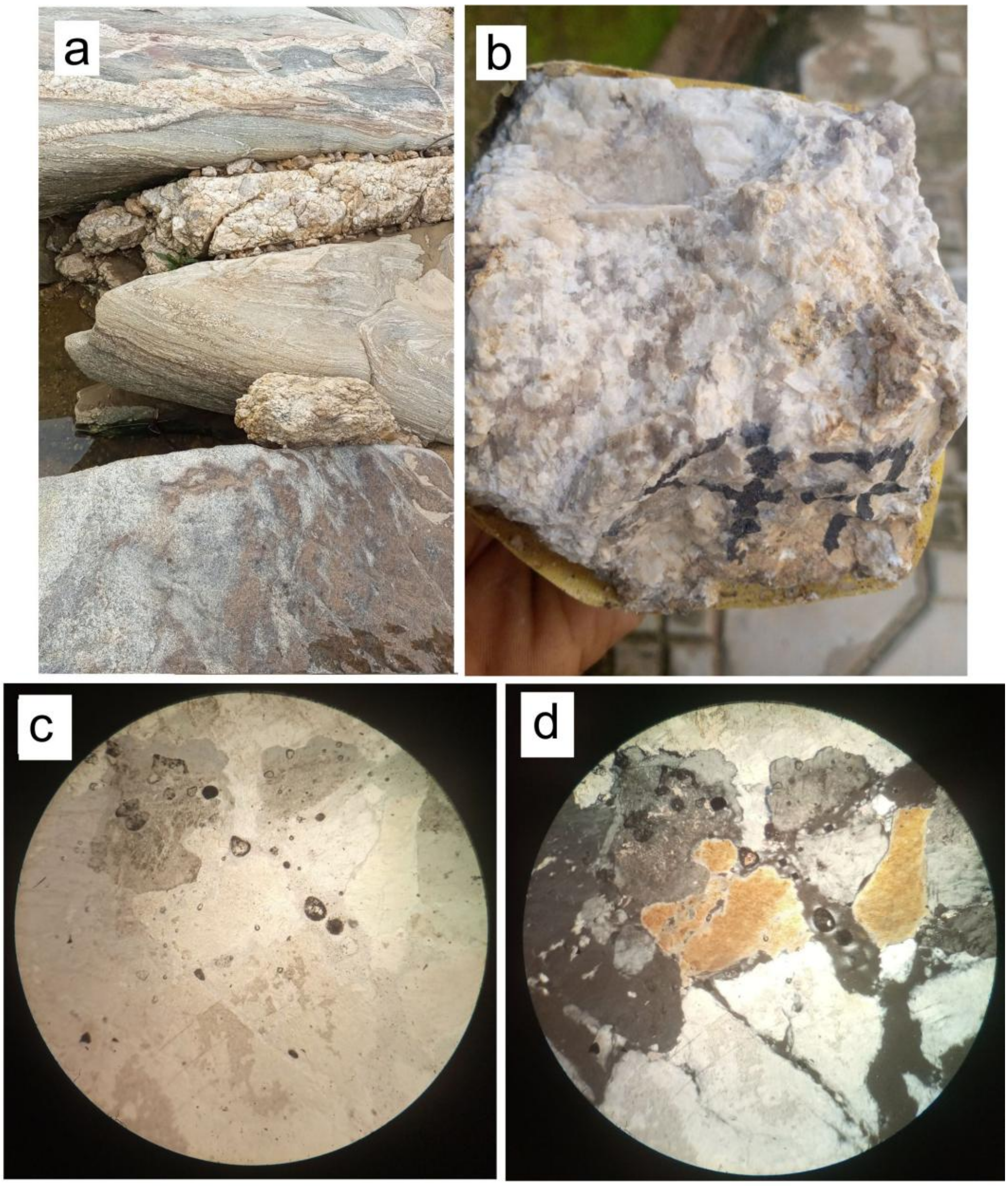


Plate I Pegmatite (a) Field view. (b) Hand Specimen. (c) PPL. (d) CPL

Table.1: *General optical Properties of pegmatite under Plane and Crossed Polarised Light*

	PPL	XPL
Quartz	1. Colourless 2. No relief	1. Wavy or undulatory extinction under cross polarized light
Biotite	1. coloured brown 2. High relief 3. One perfect cleavage	1. No twinning 2. Inclined extension angle
Opaqqu	Black opaque minerals	Black opaque minerals
Microcline	1.Colourless 2. Absent Cleavage 3. Low Relief	Light Yellow and Multiple Twinning

Diatexite: The Diatexites in the studyarea is the most widespread and abundant Morphologyin the study area. Theyunderwentatexturalhomogenization thathasdestroyedthepre-migmatizationstructures(e.g.,beddingandfoliation).Theyare highlycharacterizedbyobliterated foliations(PlateI).ThesefoldsareMagmaticfoldand havenorelationshiporassociationwithbeddingorlayeringoftheProtolith.Thediatexites found in the study area show a considerable range in morphology from mesocratic to melanocratic through to leucocratic diatexites .

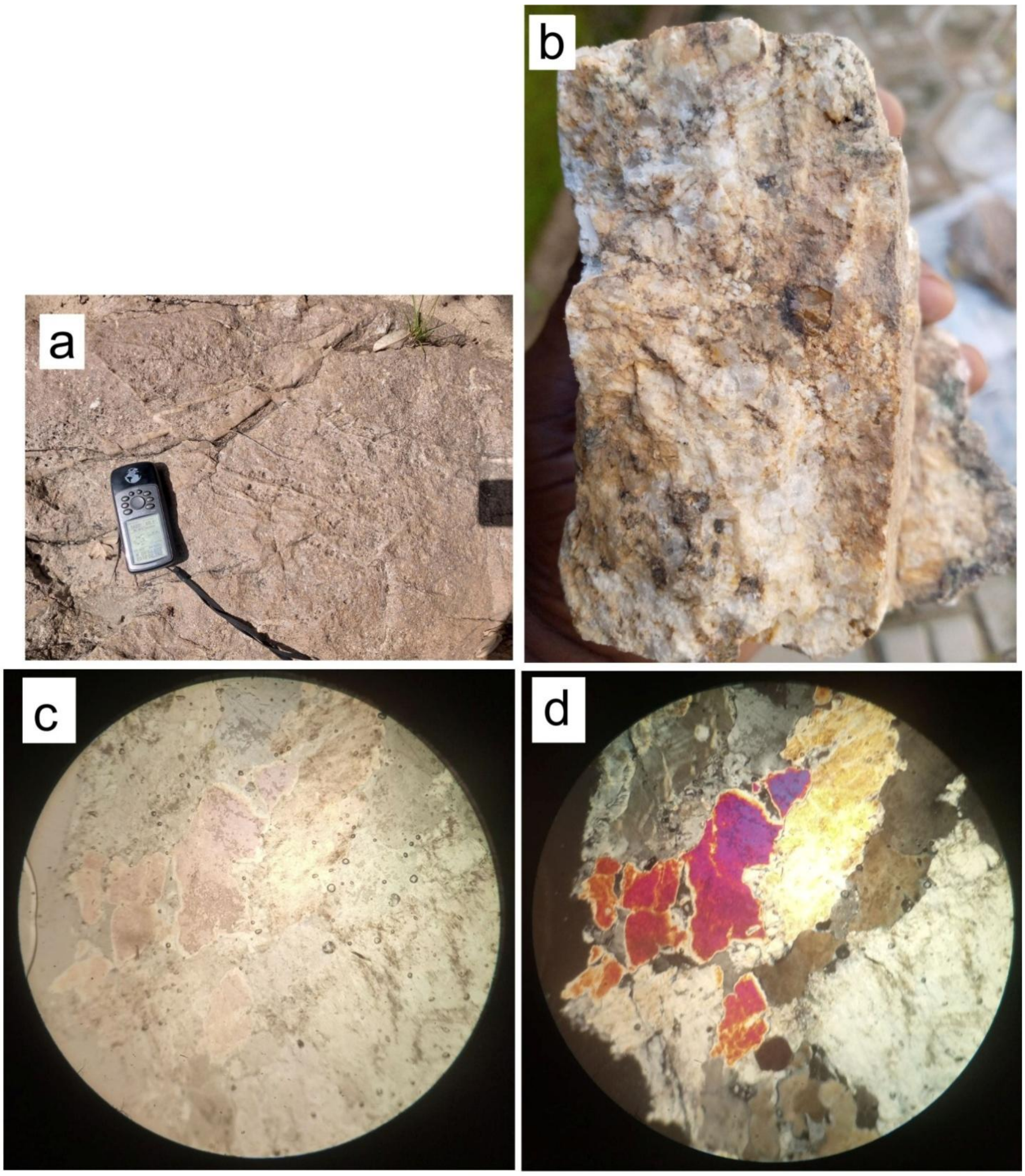


Plate II Leucocratic Ditexite (a) Field view. (b) Hand Specimen. (c) PPL. (d) CPL

Table.2: General optical Properties of the Leucocratic Diatexites under Plane and Crossed Polarised Light

	PPL		XPL	
Quartz	3.	Colourless	2.	Wavy or undulatory extinction under cross
	4.	No relief	polarized light	
Biotite	4.	coloured brown	3.	No twinning
	5.	High relief	4.	Inclined extension angle
	6.	One perfect cleavage		
Opaque	Black opaque minerals		Black opaque minerals	

Plagioclase	1. Perfect cleavage	Low birefringence color Undulatory extinction
Hornblade	Colourless High Relief	Pale Green

Plagioclase	2. Perfect cleavage	Grey in colour Undulatory extinction

Banded Orthogneiss: TheBanded Orthogneiss observed as boulder exposures in field. They are fine grained texture, and some samples retain low melt structure.
Morphologically, the samples were classified to be banded orthogneiss (Plate IV) due to presence of small volume of quartzo-feldspathic veins or leucosome band developed from the
hand specimen. Banded orthogneiss have both the leucosome and melanosome part
Minerals of the rocks are: Qtz=quartz, Bt=biotite, Pl=plagioclase

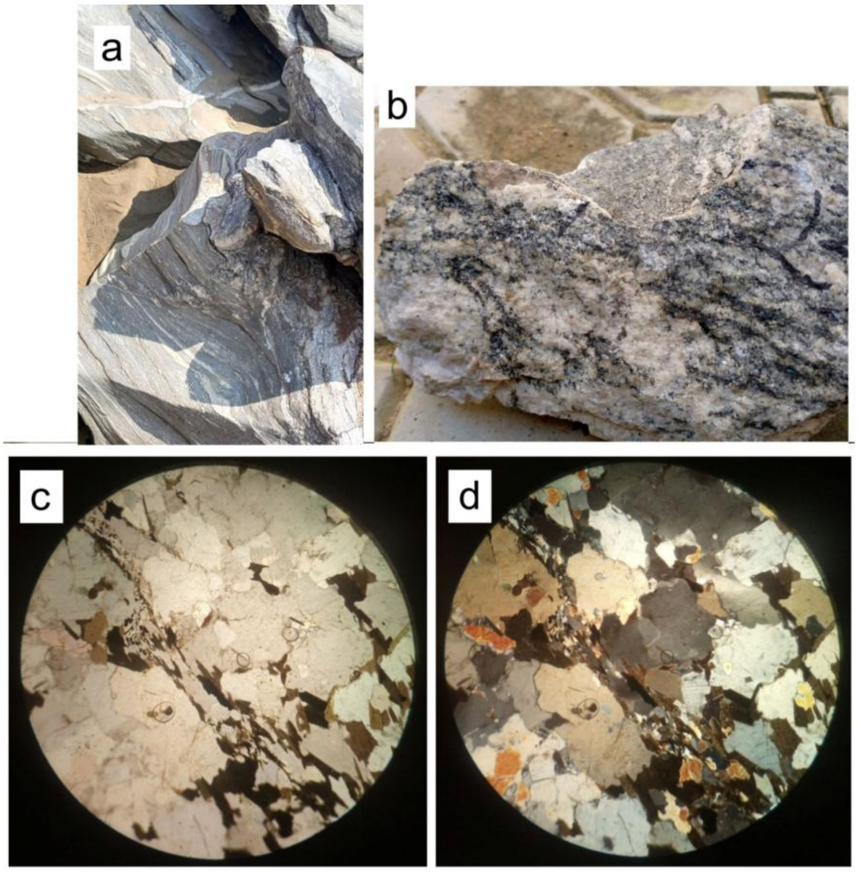


Plate IV Banded Orthgniess (a) Field view (b) Hand Specimen. (c) PPL. (d) CPL

Table.3: General optical Properties of the Banded Orthogneiss under Plane and Crossed Polarised Light

	PPL	XPL
Quartz	5. Colourless	3. Wavy or undulatory extinction under cross polarized light
Biotite	7. White yellowish 8. High relief 9. One perfect cleavage	5. No twinning 6. Inclined extension angle
Opaque	Black opaque minerals	Black opaque minerals
Plagioclase	3. Perfect cleavage	Grey in colour Undulatory extinction
Hornblende	Colourless	Brownish Green

Geochemistry:

The geochemical data for ten representative rocks samples from the study area are analyze to understand the elemental composition and deduce the tectonic history of the migmatite.

Whole-Rock Major, Minor and Trace Element

The rocks in the study area ranges their SiO_2 content from 46.3 wt% to 71.7 wt% and show variable range in concentration on their major, minor and trace element content.

In general, the rage of major, minor and trace element for the whole samples analyzed was described as follows SiO_2 values vary from 46.3 wt% to 71.7 wt%, TiO_2 ranges from 0.09-2.24%, Al_2O_3 from 10.1-13.7%, $Fe_3O_2$from 0.446-15.6, MnO from 0.027-0.274, MgO from 0.281-3.54, CaO from 0.780-13.6, Na_2O from 1.78-2.466, K_2O from 1.41-12.2, P_2O_5 from 1.71-2.08.

Table 5: Major element oxide data of whole rock samples from the study area (wt %)

Na2O	3.38	2.25	2.71	5.19	3	2.72	2.88	2.51	2.58	2.23
MgO	ND	0.581	ND	0.146	ND	0.096	ND	1.19	ND	ND
Al2O3	11.9	12.2	12	13.7	12.6	12.3	12.2	12.8	12.4	12
SiO2	74.1	59.8	72.2	69.8	72.5	71.2	71.8	60.6	71.7	70.7
P2O5	2.01	2.22	2.03	1.75	1.81	1.9	1.9	2.06	1.88	1.84
Cl	436	654	455	391	422	456	414	592	441	455
K2O	7.21	10.2	8.36	5.13	6.71	8.02	7.21	3.3	7.35	11.4
CaO	0.425	2.43	1.9	2.8	2.62	2.22	2.79	6.44	1.73	0.45
TiO2	0.0765	1.32	0.0614	0.144	0.0441	0.186	0.142	1.27	0.181	0.12
MnO	0.0116	0.128	0.0084	0.0165	0.0046	0.0103	0.011	0.118	0.0269	0.0268
Na2O	0.637	8.05	0.367	1.05	0.322	0.985	0.687	9.16	1.93	0.993

Table 6: Trace element data of whole rock samples (PPM)

S	954	921	ND	908	973	974	929	ND	ND	ND
Ar	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sc	ND	ND	ND	ND	ND	ND	ND	343	ND	ND
V	87.9	290	121	65.7	52.3	101	74.9	266	ND	49
Cr	ND	48.1	ND	ND	ND	ND	ND	29.4	ND	ND
Co	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ni	31.9	53.6	50.9	11.6	19.1	30.4	26.6	30.5	34	62.6
Cu	115	204	140	37.1	69.2	104	81.4	63.5	111	214
Zn	31.9	174	36.5	26.3	18.6	39.9	31.4	142	43.9	59.5
Ga	19.5	34	27.8	30.4	34.5	30.1	32.2	33.5	34.9	20.7
Ge	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
As	ND	3.39	3	ND	6.67	ND	ND	ND	2.84	11
Se	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Kr	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Rb	315	644	338	228	292	323	282	289	449	815
Sr	293	865	567	599	562	626	653	2310	468	116
Zr	28.2	692	103	115	105	95.3	89.3	316	63.1	13.8
Y	18.1	152	8.62	9.23	8.7	23.8	20.2	40.3	13.9	13.9
Nb	5.97	51.8	ND	9.32	ND	5.9	3.93	15.7	7.83	2.22

Characteristic of Major and Minor oxides

Harker variation diagrams are used to understand the processes occurring during the evolution of magmas. Major elements versus SiO_2 variatoin diagram (Harker diagram) are useful in petrological interpreation (Harker et al., 1996). In Harker variation diagram, as indicated on the (fig 10) below: MgO, FeO, CaO, TiO_2 decerases with incearse silica (SiO_2) even though some erratic and scattered distribution are also observed. There linear trend in most samples may indicate that the concentrations of most element are significantly changed form their primary abundance. K_2O, Na_2O and Al_2O_3 increase with increase in silica.

The compositional trends for the analyzed sample are characterized by a decrease of TiO_2, Fe_2O_3, MgO, CaO& P_2O_5 with increased SiO_2 whereas Na_2O, K_2O and Al_2O_3 increases with increasing $SiO_{2.}$

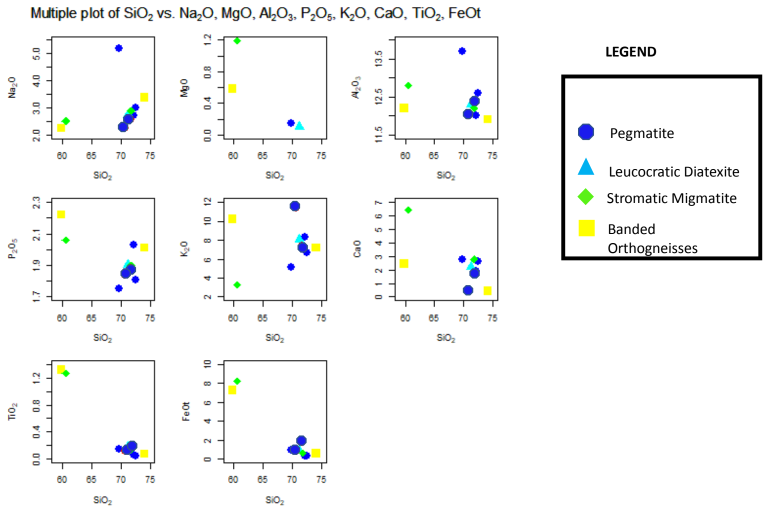


Figure 4: Multiple plot of SiO_2 vs Na_2O, MgO, Al_2O_3, P_2O_5, K_2O,CaO, TiO_2, FeOt

Trace Elements Geochemistry

Trace elements play significant roles in revealing the petrogenetic and evolutionary history of rocks. It has been observed that major element composition in rocks tend towards uniformity and it is only their trace element compositions and ratios that provide clues to their unique differences and petrogenesis.

Geochemical Classification of Analysed Sample

AFM Classification

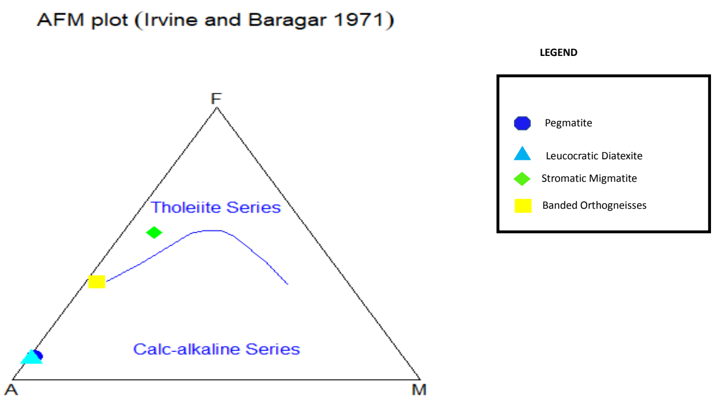
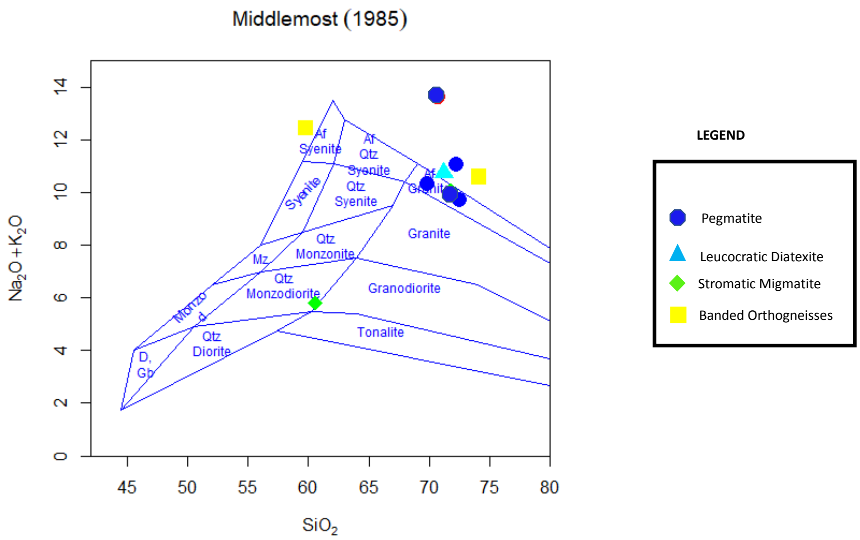


Figure 5: AFM plots showing the distribution of the rocks within the fields of tholeiite and calc-alkaline series after Irvine and Baragar (1971)[15]

As indicated from (Fig 6) the analysed sample falls within the calc-alkaline series while banded orthogneiss fall within the tholeiitic domain.

Those that plot in the field of calc-alkaline series owing to the fact that these rocks have high percentage of CaO and K2O relative to FeO*, and MgO and those that plot within the field of tholeiite series due to these rocks have high percentage of FeO*, and MgO relative to CaO and K2O.



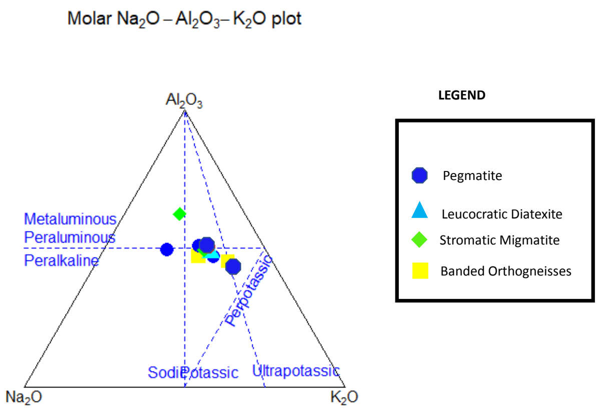


Figure 6: Molar Plot of Na_2O-K_2o-Al_2O_3

In the Molar Plot of Na_2O-K_2o-Al_2O_3, the granitoid rocks in the study area fall under peralkaline domain with the exception of Banded Orthogneiss have been at the peraluminous field, possibly indicating supracrustal origin (paragneisses) figure 9.

Feldspar Diagram

Figure 7 is a plagioclase feldspar plot, in which rocks in the study area were plotted in order to know a type of feldspars that are within rocks and the effects of temperature of crystallizations during the formation of the rocks by relating it to Bowen reaction series. The feldspar ternary plot of plagioclase show that the feldspars were formed during prograde metamorphism (fractional crystallization of magma), the time of cooling in which the granitoids fall within the domain of Andesine to Oligoclase plagioclase feldspars which are low temperature

mineral assemblages when compared on to Bowen reaction series where the results of feldspar plot showed relationship with the discontinuous series, this is why the rocks contained most of biotite, anorthoclase and microcline minerals.
In figure 7, the feldspar ternary was based on alkali feldspar, the result of the plot show that the alkali feldspars are Anorthoclase, Sanidine and Orthoclase, which confirmed the result of petrographic studies.

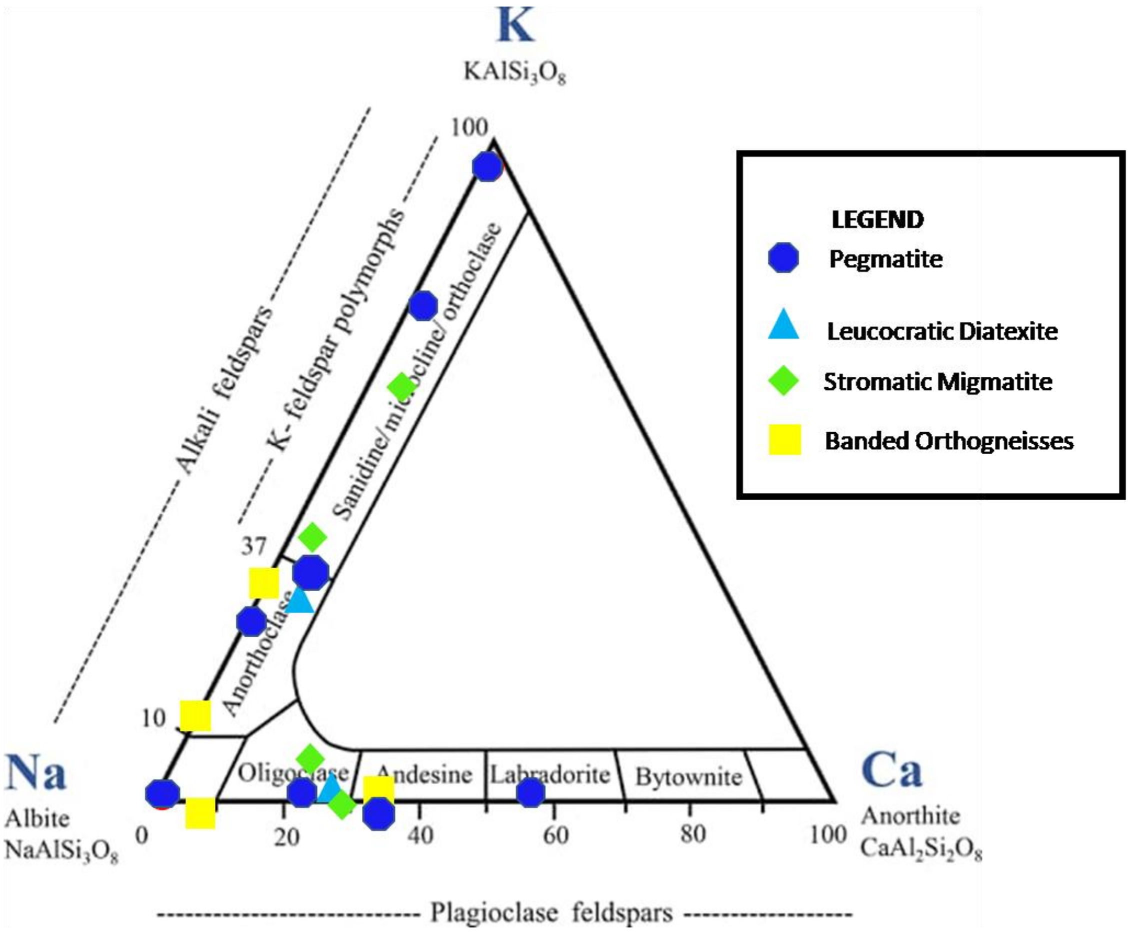


Figure7: (a) Plagioclase feldspar ternary plot

Tectonic Setting
The geochemical data were plotted on various major tectonic discrimination diagrams. On the Rb vs Y + Nb and Nb vs Y tectonic discrimination diagram, all the sample were grouped within the Syn-collisional and Volcanic Arc Granite domain (figure 11).

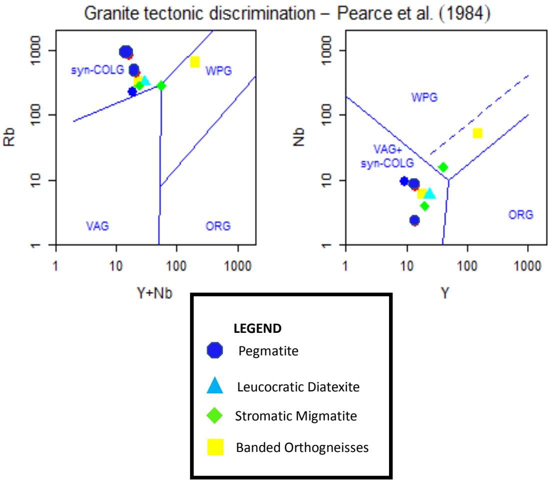


Figure 8: Plots of the analysed rocks on the tectonic discrimination diagram (a) Rb vs (Y+Nb) (b) Nb vs Y of Pearce et al (1984).[12][13]

V. Discussion

Detailed geological mapping was conducted in the study area and it reveals that the granitoids are migmatites and younger granites. The migmatites have graded from fine to medium grained, colours ranges from mesocratic to leucocratic with some displaying banding and mineral partings. Biotite, muscovite, quartz, feldspar are the major minerals seen during petrographic studies. Geochemical and petrographic studies reveal that the rocks have granite to quartz rich-monzonite origin and tectonically were formed under syn-collision to late collision settings.

VI. Conclusion

Conclusions

From the research conducted in the study area and different interpretation methods were used the following conclusions were drawn:

I. The rocks in the study area are migmatite specifically banded orthogneiss, pegmatite,diatexite.

II. The dominant minerals are quartz, biotite, feldspar and orthopyroxene

III. Various classification plots used showed that the migmatite rocks are granite, quartz rich-monzonite, calc-alkaline.

IV. The tectonic classifications of different authors indicated that the migmatite are peraluminous and peralkaline. They formed under syn-collision to late orogenic and anorogenic tectonic settings.

V. The migmatite showed little fractionations as they formed from medium temperature minerals to low temperature (Andesine to Oligoclase) coinciding with anorthoclase and microcline mineral assemblages at the discontinuous series arm of the Bowen reaction series.

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