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Geochemical Analysis for Mineralisation Assessment of Zaranda Migmatite, from Interpretation of Trace Elements and Petrography

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Abstract: *The study was conducted on exposed rocks of Zaranda village of Bauchi state in Nigeria, which falls within latitudes **10°16'00" N** & **10°13'00"N** and longitudes **9°39'21"E** & **9°42'35"E**. Previous studies have identified the rocks as metatext, leucocratic & mesocratic, these rocks compose of quartz biotite, plagioclase, microcline, and garnet which are results of fractional crystallization and partial melting in some areas, this two mechanism of differentiation are both capable of segregating minerals, This research work uses trace elements and rare earth elements, previous literature, rock features, mode of rock emplacement, structures & minerals found in rock to determine whether or not economic mineralisation has taken place during the metamorphism/crystallisation of the rocks of the study area. Rock samples are generally low laying out crops, Geochemical data were analysed, and interpretation indicates rock samples are A-type granite, in peraluminus, calcic, and are emplaced by volcanic arc & syn-collitional. The research work concludes that the quartzite sample (S1) contains Gold, However, no fracture is observed on the rock sample compared to elsewhere where gold mining is taking place, sample metatexite S24 appears as anomalous granite while in addition has the same mineralogical composition as mineralised granite field of New England, with leucocratic sample number S3, S22, & 215, mesocratic S20, metatexite S16 The three microstructures myrmekite, perthite & antipatithe observed on the rock samples are not related to any mineralisation.*

Keywords: Mineralization, *metatexites, differentiation, plagioclase, myrmekite, crystallisation, granite, mesocratic.*

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1.0 Introduction

The study area is located In the northern Precambrian basement (Dada 2006; Oyawoye 1961; Rahaman 1978) , the area mainly comprises of pan-African migmatites and based on previous literature (Salisu *et al*., 2022; Yahuza *et al*., 2020). 15 samples of rocks have been subjected to geochemical and petrology studies after carrying out the sample sorting and geological mapping technique. The rock samples are found to contain high amounts of silicon oxides and and fewer concentrations of the major elemental oxides. However, the identified minerals include biotite, ilmenite, silimanite, garnet, quartz, and feldspar (plagioclase orthoclase). Microstructures were observed under cross- and plane-polarized light, indicating rock forms, resulting in partial melting of structures: melting of feldspar in quartz and vis-é-vis and cleavages in plagioclase feldspar. The paleosome appears finer and lighter in colour as observed in the field. The remains of metasedimentary rocks as evidenced by quartzite rock are observed at a point within the study area. The homogeneous and inhomogeneous migmatite into metatexite, mesocratic, and leucocratic diatexite are rich in sodium-plagioclase (Babale *et al*., 2022; Isah *et al*., 2020; Salisu *et al*., 2022; Yahuza *et al*., 2020).

The features to study in mineralisation include; the mode of rock emplacement, structures, minerals in rocks, and the presence of trace /rare earth elements. The rocks of the area have been subjected to the biological action of plant root penetration by cracking and physical –by the heating in the daytime by sun heat and cold in the night time making the rocks expand in the day time and contract in the night, thereby causing the rock to subsequently crack Trace or minor elements analysed included V, Cr, Cu, Sr, Zr, Ba, Zn, Ce, Pb, Bi, Ga, As, Y, Ir, Au, Ni, Rb, Mo, Co, Cd, Ru, Eu, Re, Nb, Ag, Ta, W, Hf, Yb, In, Se, U, Th, Sb, Ge, Sn with GCD kit/petrograph to determine whether or not the metatexite, mesocratic and leucocratic diatexite are mineralisation or otherwise.

The study highlights the need for a comprehensive understanding of the mineralisation potential within the Zaranda Migmatite region. It emphasizes the existing knowledge gap in terms of trace element analysis and petrography, which are essential for assessing the presence and distribution of valuable minerals. This knowledge gap underscores the significance of the study in bridging these analytical and interpretational aspects to contribute to a more informed assessment of mineralization in the Zaranda Migmatite area of Bauchi.

2.0 Materials and Method

2.1 Desk Study

The desk study involved extensive and in-depth studies of previously published and accessible unpublished works in the study area.

(a) Literature Review: a literature review of the Nigerian basement complex and its tectonic settings was carried out by studying both published and unpublished reports.
(b) Remote Sensing: interpretation through analysis of satellite images

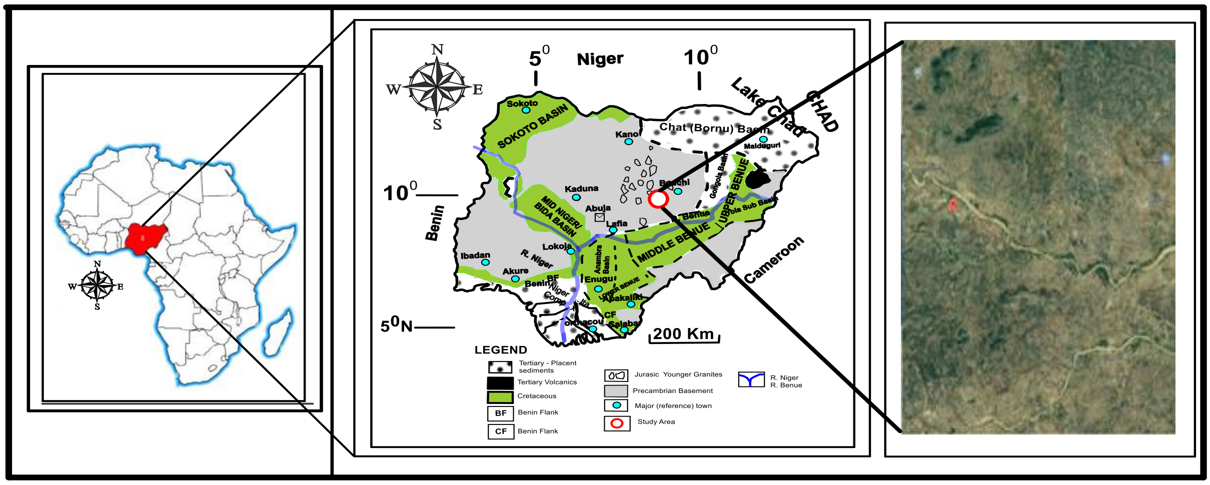


Fig. 1. Geological Map of Nigeria showing the study area (Modified after Obaje *et al.*, 2011; Aminu *et al.*, 2022a)

2.2. *Field Mapping*

The first step of the field mapping involved the reconnaissance survey which was carried out to have an overview of the geology of the area on a scale of 1:50,000. Areas of interest such as outcrop and river channels were delineated from the survey and mapped on the scale of 1:25,000

2.3 Field Equipment

These include measuring tape, Compass and clinometer, Hammer, Hand lence, Global Positioning System, field notebook, biro and sample bag etc.

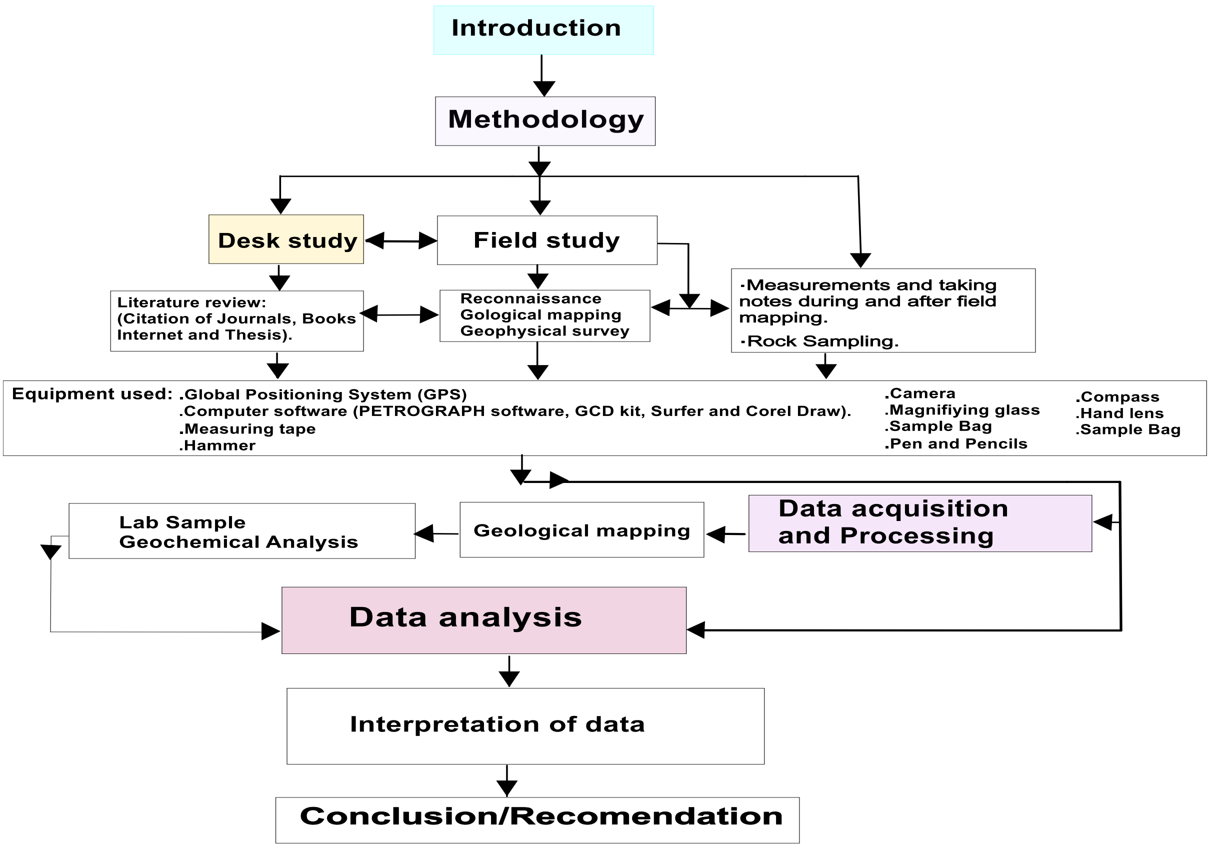


Fig. 2: Workflow chart adopted for this research, (Modified after Aminu *et al.*, 2022b)

2.3 Data collection

Samples were collected during field studies, which were sorted into groups and later three to four samples were selected to represent each of the groups, then samples were broken approximately 2cm to 3cm and labelled for pulverization and whole-rock geochemical analysis using x-ray fluorescent spectrometer at Nigerian geological survey agency, for major oxides and trace/minor elements. Results were used in plotting the iron and magnesium (AFM) diagram, Spider diagram, Hacker variation, feldspar plot, Total Alkali and tectonic discrimination diagram using GCD kit and PETROGRAPH software.

2.4 Sample preparation

Rock samples collected on the field at a noted coordinate, sampled were named with the use of masking tape and permanent marker, the sample is described in the field notebook for the geochemical analysis and petrographic studies with the use of thin section.

2.5 Geochemical analysis

Geological field mapping covering the whole study area was conducted, climbing the mostly low laying outcrops -taking notes and observing all rock exposures, important things done are; fresh sample collection, taken with point coordinates, -description of colour, textures and composition of rock samples is done on the field. This also includes the study of the lithology of rocks revealed in river channels. (Hugh Rollinson, 2021)

The sample name and description were recorded on the field notebook, and the labelled samples were taken to the laboratory in sample bags for geochemical and petrology analysis. Hugh Rollinson, (2021) and Sawyer, E. W., (2008) first and second-order classification principles used as a guide in classification of the rocks.

2.5 Geology of the study area

The study area (Fig. 1) is believed to be part of the older granite, the older granite is deep-seated its structures are concordant or semi-concordant with the preexisting rocks intruded in late Proterozoic to early Palezoic (Rahaman, 1988; Rahaman, 1978) age during the pan-African orogeny (Dada, 2006; Kröner & Mainz, 2005), the rock groups were formed as a result of granitisation which has reformed earlier rocks resulting in the formation migmatite and granitic rocks, the migmatites (Haruna, 2016)(Fig. 3) are classified into metateixite diatexite nebulite (Babale *et al*., 2022; Ferré & Caby, 2007; Yahuza *et al*., 2020).rocks migmatite rocks type form as a result of 1 partial melting, intrusion and metasomatism

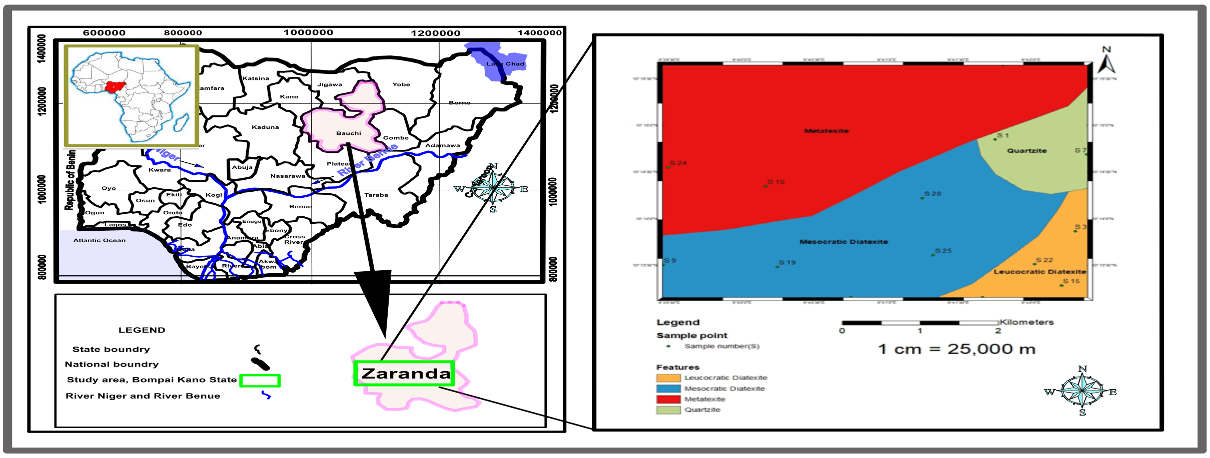


Fig. 3. The Geological map of the study area (Modified after Bertha *et al*., 2023: Mu'awiya *et al*., 2023: Abdulbariu *et al*., 2023).

The older granite is known to be deep-seated, an often concordant or semi-concordant intruded during the pan-African Orogeny of the late Proterozoic to early Paleozoic age. They are believed to have culminated from extensive granitisation which modified earlier rocks resulting in the formation of migmatites and widespread granitic rocks, of the Basement Complex, distinctions from the high-level, highly discordant tin-bearing granites (younger granite) of Northern Nigeria (Nanfa *et al*., 2022). Older granite rocks are subdivided into pre-, syntectonic, post-tectonic rocks and basic and intermediate rocks which cut across the migmatite-gneiss-quartzite complex and the schist belts. Older granite is the best representation of the Pan-African orogeny(Kröner and Mainz, 2005; Rahaman, 1978; Rahaman, 1988; Dada, 2006).

Oyawoye, 1961 concluded that the name Bauchite is used to denote a dark greenish fayalite-bearing rock of quartz syenite to andemallite (Oyawoye, 1961) exposures along Jos Bauchi consisting mainly anatectic metapelitic, gneisses, metatexites, sheets of diatexite (Ferré and Caby, 2007, Obaje, 2009) Older granite is found to be overlain by in Undeformed Acid and Basic Dykes, Younger granite basement areas and cretaceous sediments in the sedimentary basin areas.

The study area is covered by migmatites part of the older granite, exposed at some points and river channels were observed.

3.0 Results and Discussion

3.1 Petrographic analysis

Sample use in geochemical analysis has also been prepared for thin sections, for the petrographic studies with the use of a petrographic microscope.

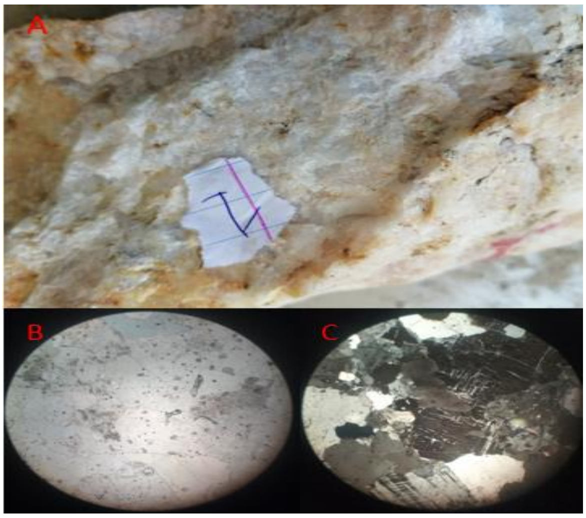


Fig. 4. Quartzite Rock sample at S1 A field rock sample B = under plain polarised light (PPL) C =under cross polarised light (XPL)*Quartzite*

Three different microstructures were observed under the microscopic studies plate 1 mymikite, perthite & antiperthite, the structures are all not related to mineralization elsewhere (Collins, 2013).

3.2 Geochemical Analysis

From Table 2 the point with the highest amount of Au is S25 but the samples lack joints which in this study point sample S1 (Quartzite) gives the threshold value of Au mineralisation. A total of about 36 minor or trace elements is identified all occurred less than 0.1 wt% in the rock sample that is, less than 1000 parts per million (ppm)

Table: I Microscopic analysis of quartzite sample

	Quartz (QTZ)	Biotite (BIO)	Plagioclase (PL)
COLOUR	Colourless	Pale to deep greenish brown	White to grey
RELIEF	Low relief	Moderate to high	Low to moderate
HABIT	anhedral	Tabular irregular	Tabular (anhedral and euhedral)
CLEAVAGE	none	Perfect cleavage	Perfect cleavage
PLEOCHOISM	none	pleochroic	none
INTERFEREN CE COLOUR	1^{st} order pale yellow	3^{rd} and 4^{th} order colour	1^{st} order
EXTINCTION	underuse	parallel	inclined

3.3 Microstructure Observed

Mykmatithie formation has been identified as a deformation precursors.

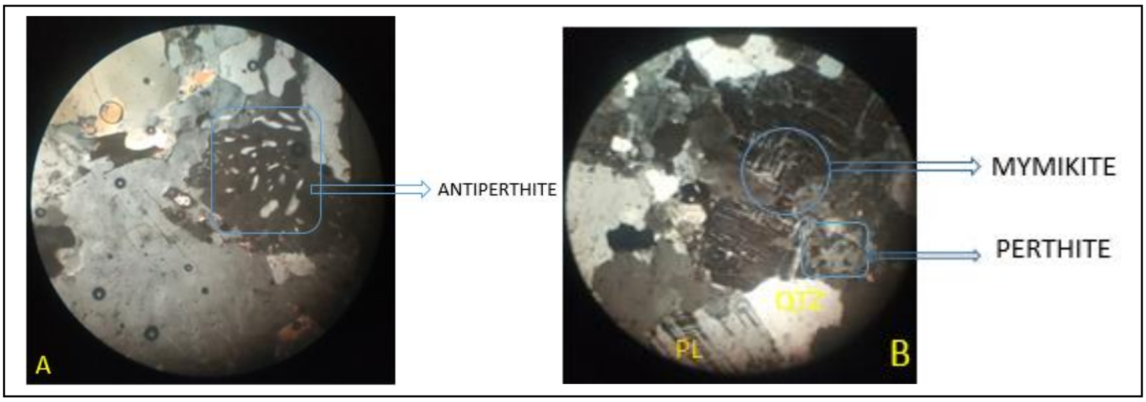


Plate 1: A Antiperthite structures on sample S14, B Mymikite perthite on sample S1, PL = plagioclase QTZ = quartz

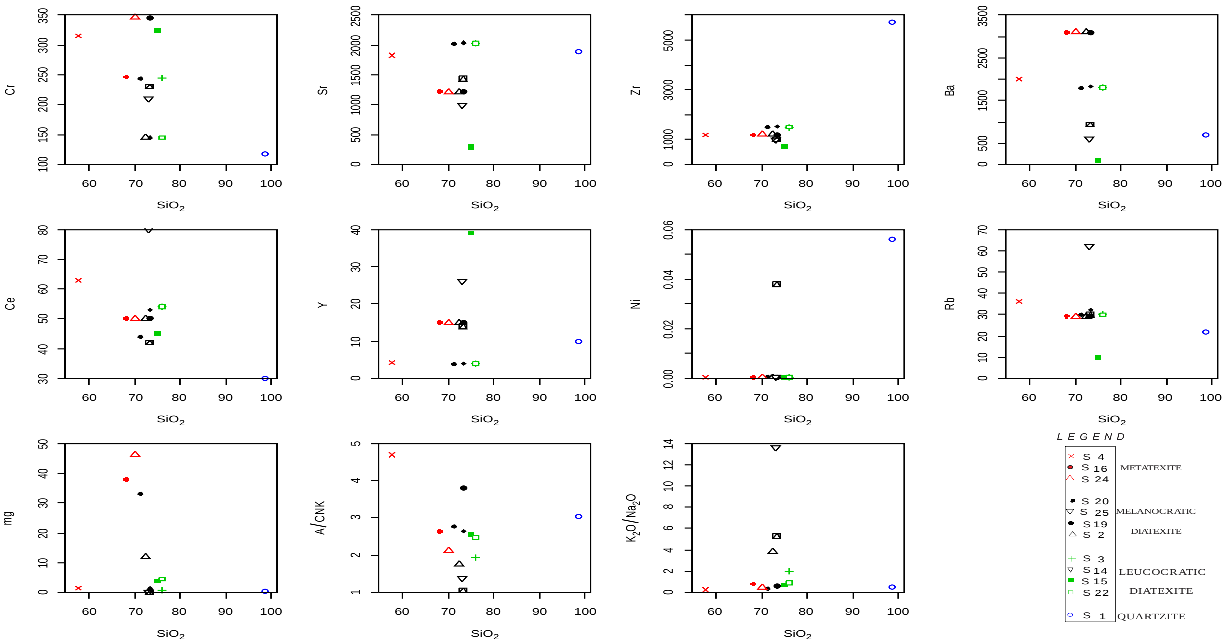


Fig. 5. Trace element against SiO_2

The variation of the trace elements (**Error! Reference source not found.**5), observed concerning the concentration of SiO_2 showed two features. 1 - Gives negative correlations of Ni, Zn, Y, Nb, and Zr with SiO_2, and

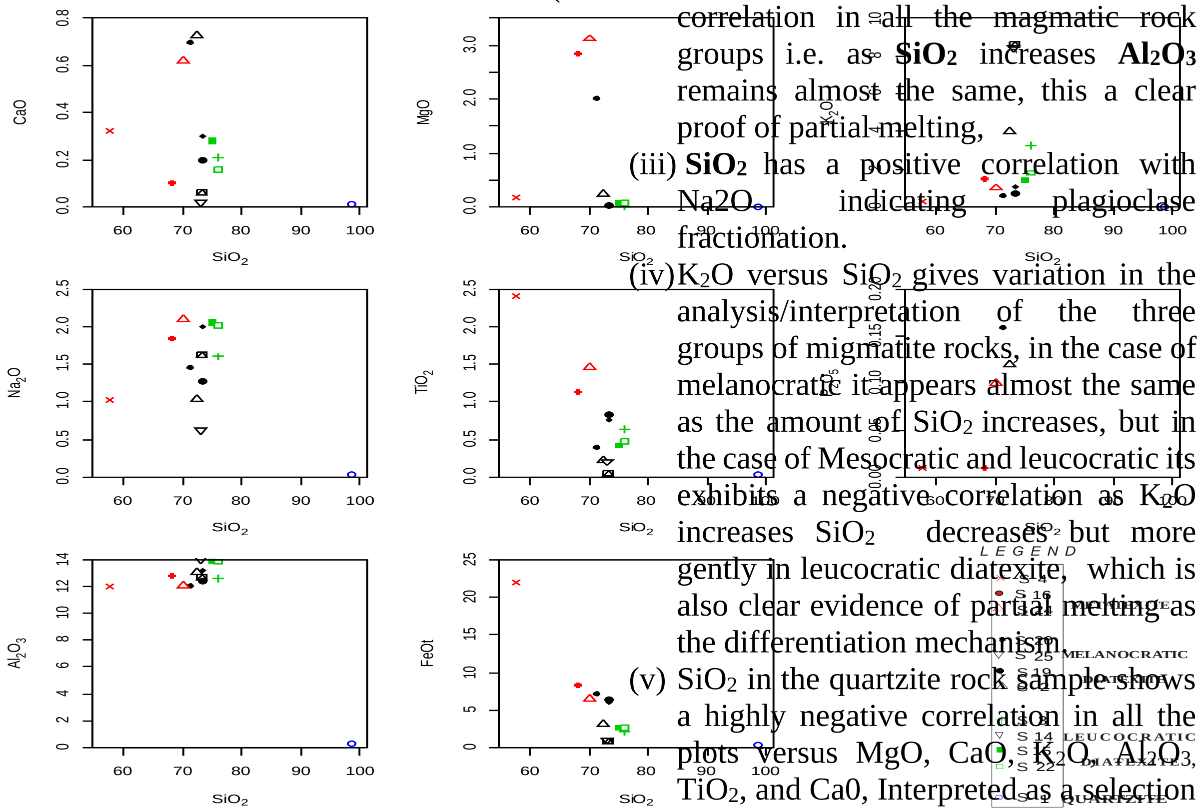
2 -Ni, Zn, Nb, Zr and Y behaved as compatible elements. While Rb, Th, Ba, K, and Pb behaved as incompatible elements.

3.4 Major Elements

In Harker variation diagrams of major oxides (Fig. 6), for most of the samples: MgO, Fe2O3, Al_2O_3, C_aO, P2O5 and TiO_2 decrease with increasing SiO_2, whereas Na_2O and K_2O increase with increasing SiO_2 contents even though some erratic and scattered distributions are also available. This is because MgO, C_aO, TiO2, Fe_2O_3 and Al_2O_3 take part in ferromagnesian minerals formation in the initial steps of crystallization, therefore, their concentration decreases with an increase in SiO_2 contents. SiO_2 has a positive correlation with Na_2O

indicating plagioclase fractionation. SiO_2 shows a good positive correlation with K_2O for most of the samples, supporting the role of fractional crystallization.

The interpretation of the major oxides (MgO, CaO, K_2O, Al_2O_3, TiO_2, and CaO) versus the SiO_2 (



) are as follows;

(i) MgO, TiO_2, Fe_2O_3 & MgO., Give a negative correlation in all the analysis/interpretation of the three (3) rock samples, as SiO_2 increases the MgO decreases this is a clear case of fractional crystallisation.

(ii) **Al_2O_3, CaO** versus **SiO_2** gives a positive correlation in all the magmatic rock groups i.e. as **SiO_2** increases **Al_2O_3** remains almost the same, this a clear proof of partial melting,

(iii) **SiO_2** has a positive correlation with Na2O, indicating plagioclase fractionation.

(iv) K_2O versus SiO_2 gives variation in the analysis/interpretation of the three groups of migmatite rocks, in the case of melanocratic it appears almost the same as the amount of SiO_2 increases, but in the case of Mesocratic and leucocratic its exhibits a negative correlation as K_2O increases SiO_2 decreases but more gently in leucocratic diatexite, which is also clear evidence of partial melting as the differentiation mechanism.

(v) SiO_2 in the quartzite rock sample shows a highly negative correlation in all the plots versus MgO, CaO, K_2O, Al_2O_3, TiO_2, and Ca0, Interpreted as a selection of melting of low-temperature minerals (quartz), Fig. segregation and crystallization in fractures

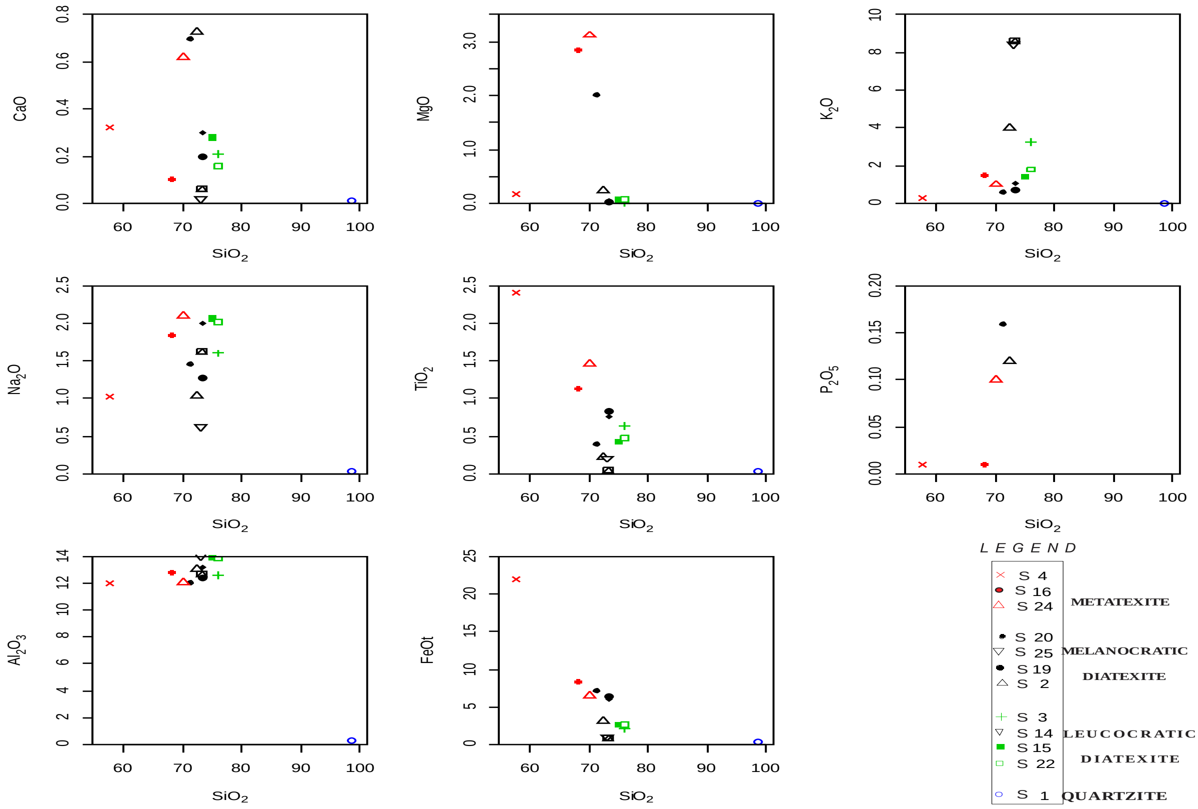


Fig. 6: Major oxides by the SiO2

3.5 Rock Age

The relative age, of rocks are relatively post-orogenic sampled in *3.6 Spider diagram*

Multi-element variation diagrams (

Fig. 8), the overall shape of the individual patterns of all rock types are similar. Broad ranges in

elements for the diatexite migmatites are interpreted due to K-feldspar-dominated fractional crystallization. Therefore, all samples from the study areas show marked

anomalies in Ti, Yb and U and positive anomalies for Nb, Rb, Ba, Th and Pb. Spider diagrams show similar characteristics to those of metatexite and diatexite indicating either the retention of plagioclase and accessory minerals in the source during partial melting or their separation during fractionation (

Fig. 8).

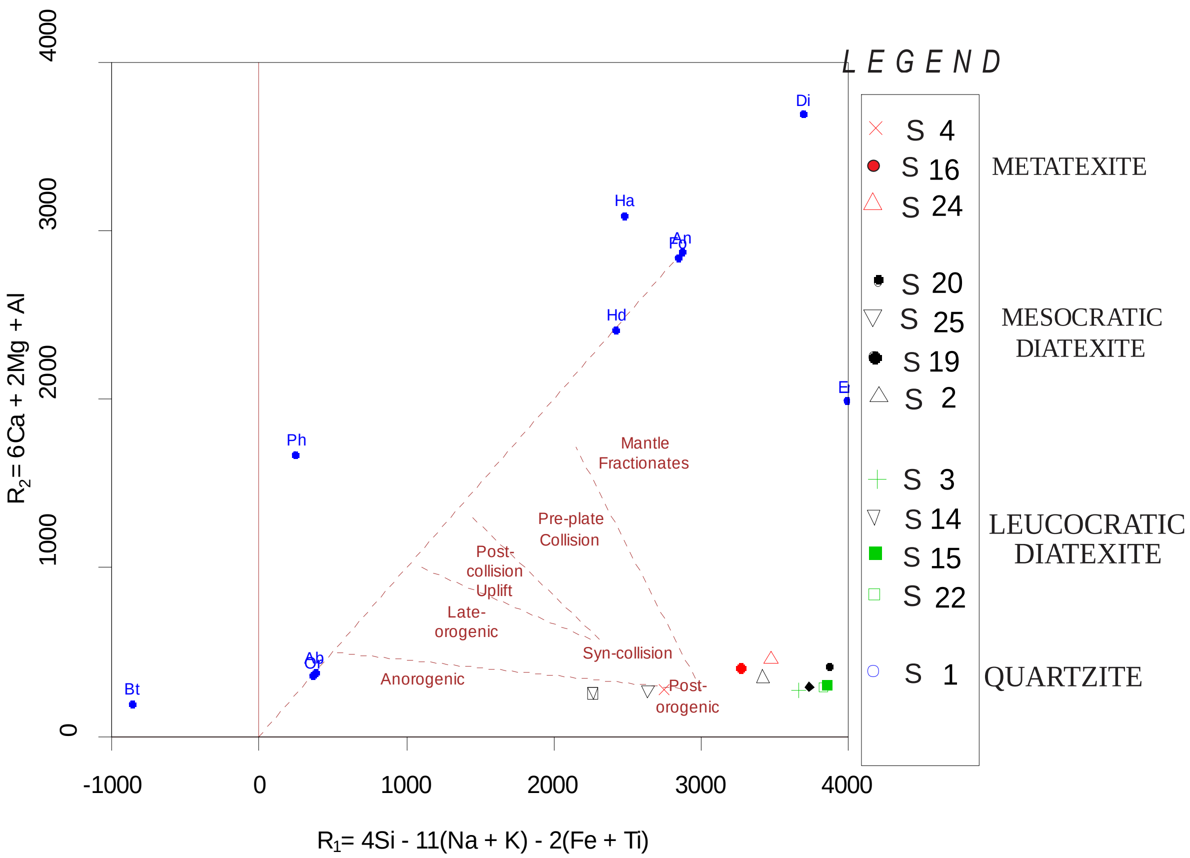


Fig. 7: Relative age of the rocks in the study area.

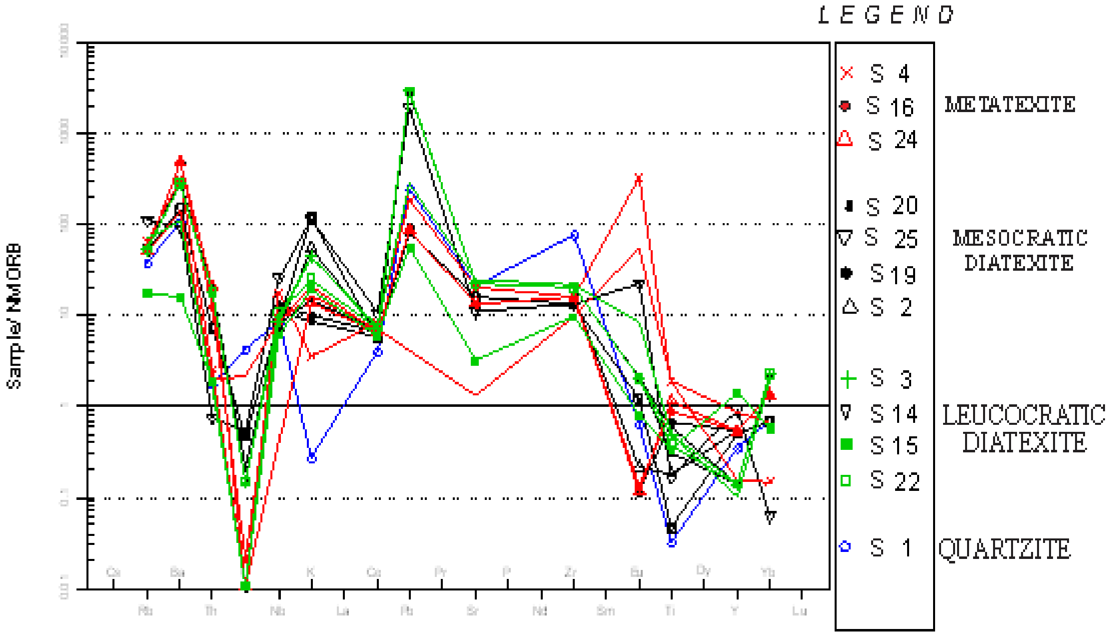


Fig. 8: Spider diagram

A high field element is depleted, large iron lexophile elements are enriched clear evidence of crustal contamination and or fractional crystallization

3.7 AFM diagram

Rock samples are mostly tholeiitic, a composition that describes the evolution of a mafic, with high magnesium and iron which has fractionally crystallised to become felsic, having low magnesium and iron.

An exception is rock samples S 3 and S 24 are calc-alkaline rocks which are rich in magnesium and calcium oxide, this composition makes the major earth's crust, here it is indicating crustal contamination during the process of metamorphism.

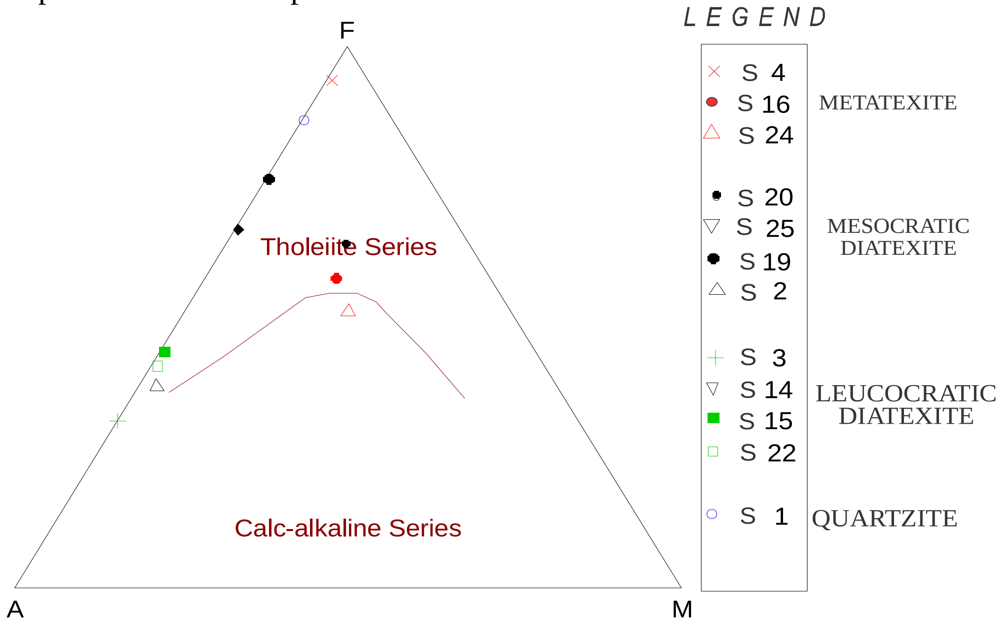


Fig. 9: AFM diagram

An exception is rock samples S 3 and S 24 are calc-alkaline rocks which are rich in magnesium and calcium oxide, this composition makes the major earth's crust, here it is indicating crustal contamination during the process of metamorphism.

3.8 Tectonic discrimination

Tectonic discrimination (Fig. **10**10) using major elements indicates rocks are mostly ferroan (Fig. **10** 10) except for three samples S24, S16 and S20 which contain high amounts of magnesium

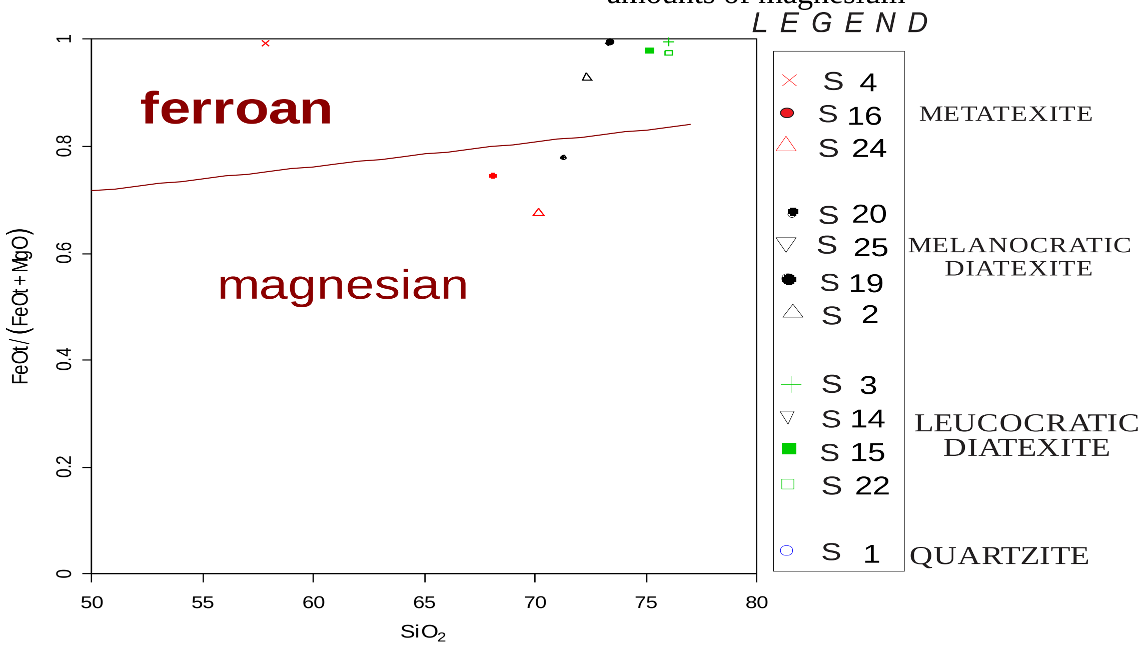


Fig. 10: Tectonic discrimination plot

3.9 *Source discrimination*

This indicates the rock samples are originally sedimentary, from which they are metamorphosed (Fig. 11)

This shows (Fig. 11) rocks are initially sedimentary (paleosome, Haruna, 2016) rocks which are metamorphosed to migmatite (neosome)

3.10 *Mineralization potential*

Rocks are minerals

12, sample S3 S15, S22, S19 & S24 in addition S16 and S24 appear to fall on the anomalous on the Ba-Sr-Rb ternary diagram.

12) , migmatites of the study area are depleted in Ca and fall in the field along the Na and K, similar pattern reported for Sn-

In Ba-Rd-Sr Rocks samples are positioned along Ba-Sr deleted in Rb, As indicated in Na-K-Ca ternary diagram (

mineralized granite from New England (Sharma *et al*., 2019).

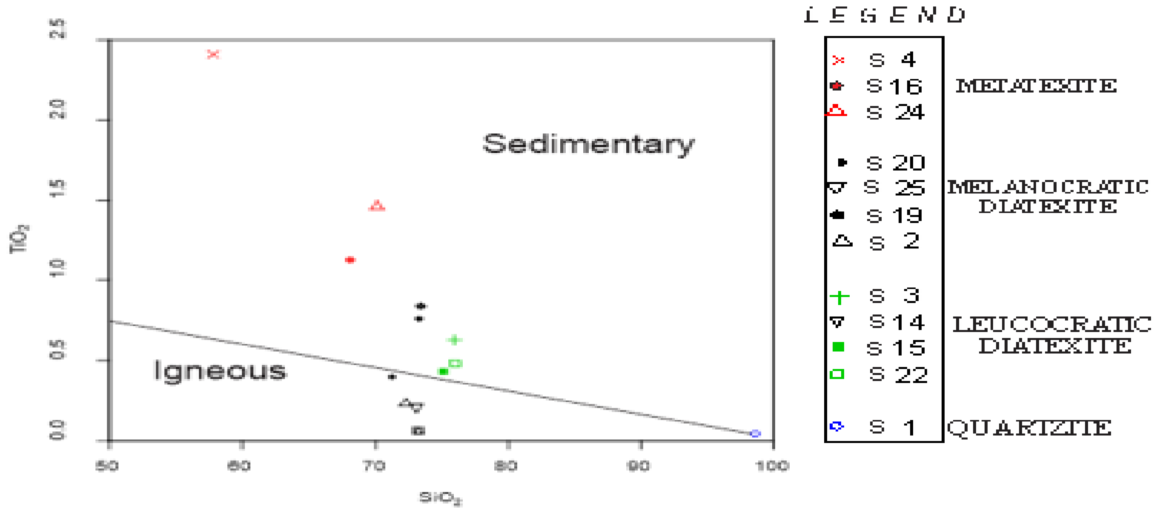


Fig. 11: Discrimination plots of TiO2 versus SiO$_2$

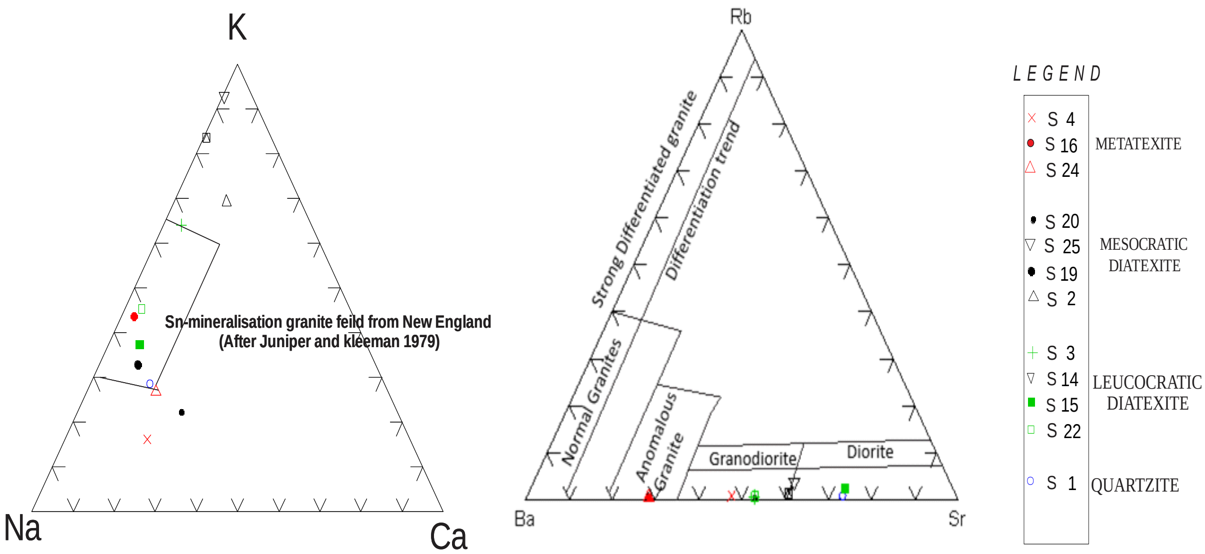


Fig. 12: Ternary plots for Na-K-Ca and Ba-Rb-Sr rock samples occupy the same position with some mineralised rock in New England, and anomalous granite respectively

Table 2. major oxides trace/minor elements geochemical result

	Quartzite		Metatexite			Mesocratic diatexite				Leucocratic diatexite		
ID	**S 1**	**S 4**	**S 16B**	**S 24**	**S 2**	**S 19**	**S 25**	**S 20**	**S 3**	**S 15**	**S 22**	**S 14**
SiO2	98.61	57.81	68.11	70.11	72.32	73.4	73.1	71.21	76	75.14	76	73.24
CaO	0.01	0.32	0.1	0.62	0.73	0.2	0.02	0.7	0.21	0.28	0.16	0.06
MgO	0.001	0.18	2.84	3.12	0.24	0.03	ND	2.02	0.01	0.06	0.07	ND
SO3	ND	0.06	1.24	0.13	0.03	0.02	ND	0.11	ND	ND	ND	ND
K2O	0.02	0.26	1.51	1	4	0.73	8.45	0.62	3.24	1.4	1.81	8.6
Na2O	0.04	1.03	1.84	2.1	1.04	1.28	0.62	1.46	1.6	2.06	2.02	1.62
TiO2	0.04	2.41	1.13	1.46	0.23	0.84	0.21	0.4	0.63	0.43	0.48	0.06
MnO	0.001	0.32	0.21	0.03	0.06	0.19	0.004	0.03	0.08	0.03	0.02	ND
P2O5	ND	0.01	0.01	0.1	0.12	ND	ND	0.16	ND	ND	ND	ND
Fe2O3	0.43	24.39	9.21	7.18	3.46	7.07	1.16	8	2.4	3.01	3.01	1.06
Al2O3	0.32	12	12.82	12.06	13.01	12.4	14	12.12	12.6	13.84	13.81	12.7
H2O+	0.74	2.02	2	2.12	2.64	2.6	2.16	2.21	1.7	2.01	1.6	2
V	201.01	660	501.5	601	401	601	420	482	4,182	603	386	510
Cr	118.02	316	246.19	346.29	145.29	346.3	210.4	245	245	325	145	230.2
Cu	480	380	354	334	334	334	280	334	330	290	310	310
Sr	1,890	1,830	1,220	1,220	1,220	1,220	1,000	2,031	2,030	290	2,030	1,440
Zr	5,720	1,200	1,200	1,200	1,200	1,200	1,000	1,520	1,500	720	1,500	1,000
Ba	680	2,010	3,100	3,100	3,100	3,100	600	1,810	1,800	100	1,800	930
Zn	100	370	97	97	97	97	160	56	560	60	560	40
Ce	30	63	50	50	50	50	80	44	54	45	54	42
Pb	75	56.09	26	26	26	26	580	867	867.5	17	867	25
Bi	0.344	5	0.099	0.099	0.099	0.099	3.98	0.873	0.871	0.219	0.873	1.89
Ga	34.02	5.09	39	39	39	39	6	42	22	17.4	12	32
As	22	3	7.02	7.02	7.02	7.02	0.46	17.3	17.2	7	17	15
Y	10	4.3	15	15	15	15	26	3.92	3.9	39.1	3.9	14
Ni	0.056	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	0.038
Rb	21.6	36	29	29	29	29	62	30	30.4	9.84	30	30
Mo	15	0.009	32.01	32.01	32.01	32.01	0.008	81	83	14	83	48
Ir	5.1	2.02	20	20	20	20	3.8	6.07	6.09	3.1	6.09	3.1

Au	0.67	0.2	0.22	0.22	0.22	0.22	1.6	0.468	0.448	0.014	0.488	0.224

	Quartzite		**Metatexite**			**Mesocratic diatexite**				**Leucocratic diatexite**		
ID	**S 1**	**S 4**	**S 16B**	**S 24**	**S 2**	**S 19**	**S 25**	**S 20**	**S 3**	**S 15**	**S 22**	**S 14**
Co	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	0.998	0.21	0.213	0.01	0.21	0.02
Cd	0.09	0.005	0.034	0.034	0.034	0.034	<0.001	1.094	1.192	<0.001	1.094	0.998
Ru	0.032	1.23	0.005	0.006	0.015	0.006	0.98	0.001	0.001	<0.001	<0.001	0.002
Eu	0.65	340	0.14	0.12	0.22	0.12	23	2.06	2.06	0.82	2.06	1.24
Re	160	<0.001	170	180	180.5	180	0.004	36	36.02	101	34	120
Nb	20.22	42	20.22	40/10	17.02	30	60	25.87	20.35	14.3	24.87	20.12
Ag	0.6	0.54	0.11	0.41	0.41	0.41	1.12	0.09	0.09	0.67	0.09	1.12
Ta	70.2	55	42.1	42.1	42.1	42.1	101	60	64.2	63	64	36
W	12	5.06	0.891	0.891	0.891	0.891	5.62	1.46	1.46	13.3	1.46	0.96
Hf	39.45	24	33	33	33	33	28	21	21	16	21	20
Yb	2.14	0.46	4.14	4.04	4.04	4.04	0.19	6.9	6.9	1.76	6.9	2.11
In	9.72	2.23	2.1	2.1	2.1	2.1	2.8	0.09	0.09	3	0.09	1.9
Se	0.2	0.28	<0.001	0.001	<0.001	0.001	0.22	0.012	0.012	0.28	0.012	0.21
U	0.201	<0.001	0.001	<0.001	<0.001	<0.001	0.025	0.007	0.007	<0.001	0.007	0.022
Th	0.21	0.31	1.5	2.5	2.5	2.5	0.09	2.2	2.2	0.22	2.2	0.86
Sb	8.01	3.3	7.03	7	7.03	7	2.24	14	14	12	14	6.13
Ge	14.01	4.36	24	24	20	24	18.8	40	41	14	40	4
Sn	61.22	19.88	21.06	30.26	31.06	30.26	47.03	21.12	19.12	9.88	20.12	17.03
Apatite	0	0.02	0.02	0.24	0.28	0	0	0.38	0	0	0	0
Chromite	0.03	0.07	0.05	0.07	0.03	0.07	0.05	0.05	0.05	0.07	0.03	0.05
Zircon	1.15	0.24	0.24	0.24	0.24	0.24	0.2	0.31	0.3	0.14	0.3	0.2
Ilmenite	−0.02	0.64	0.41	0.01	0.11	0.36	−0.02	0.03	0.14	0.02	0.02	−0.03
Sphene	0.11	0	0	0	0	0	0	0	0	0	0	0
Orthoclase	0.12	1.54	8.92	5.91	23.64	4.31	49.93	3.66	19.15	8.27	10.7	50.82
Albite	0.34	8.72	15.57	17.77	8.8	10.83	5.25	12.35	13.54	17.43	17.09	13.71
Anothite	0.63	2.51	1.45	3.44	3.85	2.01	0.54	3.44	2.05	1.5	1.8	0.94
Corundum	0	9.1	7.63	6.26	5.56	8.77	3.64	7.79	5.71	8.39	7.87	0.38

Hematite	0.43	24.39	9.21	7.18	3.46	7.07	1.16	8	2.4	3.01	3.01	1.06
Hypersthene	0	0.45	7.07	7.77	0.6	0.07	0	5.03	0.02	0.15	0.17	0
Quartz	97.62	49.39	46.69	47.85	48.86	62.17	36.86	55.75	53.29	57.01	56.34	30.43
Rutile	0	2.07	0.91	1.45	0.17	0.65	0.22	0.39	0.56	0.42	0.47	0.08

4.0 Conclusion

This conclusion is based on; 1. The geochemical data, 2. On-field information acquired & previous literature, 3. Analyses of the results of trace/minor elements, and 4. Geochemical plots and field

- SiO_2 against trace elements indicates fractionation.
- There is a small amount of Au considered to be a background value however S25 with no fractures
- Rocks with the same mineral composition as S1, S3, S15, S16, S22 & S24 should be studied further for having qualities of a mineralized rock
- S16 and S24 appear anomalous granite and fall on the mineralise position of New England and are therefore suspected to be mineralise rocks

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