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Geochemistry Characterization of Migmatites Around Nabardo-Toro Environs, North Eastern Nigeria

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Abstract

The geology of the Nabardo area comprises of migmatites that appears to have undergone varying degree of metamorphism and multiple phases of deformation. The geochemistry of these rock suites is analyzed using X-ray Fluorescent. A total of thirty (30) samples were analysed for major and trace elements. The geochemical data are plotted on major tectonic discrimination diagrams to distinguish the nature of original magma content. This paper aims at characterizing the three migmatites types of the Narbardo area. The metatexites are mostly calc-alkaline with some slightly theoleiitic. The plot of alumina saturation versus alkalinity (A/NK vs A/CNK) diagram (ASI) of Maniar and Piccoli classifies the diatexites as predominantly peraluminous which tends to indicate that they are sedimentary type (S-type) protolith, while those that shows metaluminous are indicating source from Igneous sources (I-type). The molecular plot of Al_2O_3/ (CaO + Na_2O + K_2O) versus SiO2 after White and Chappel, 1977 showing nebulite plotting in the I-type field implies that the original magma from which they were formed contained great amount of granitic or crustal material. Based on the geochemical plots and REE signatures, fractional crystallization alone cannot account for these migmatites but rather partial melting and metamorphic differentiation are the major source of these migmatites. They are formed by partial melting of mafic rich protolith that were formed during the Pan-African orogeny.

***Keywords**: Metatexite, diatexite, nebulite and partial melting*

I. INTRODUCTION

The use of geochemistry in geological mapping/investigation cannot be overemphasized as it concerns the quantities, distribution and circulation of chemical elements in the natural domains like soil, water, atmosphere, vegetation and rocks. In continuation of the research work within the study area, some rock samples were selected for geochemical studies after carrying out a detailed field mapping. The samples selected were fresh representative rocks that cover the geology of the whole study area. Tomoyuki et al, 2002 describes metatexite migmatites as layered migmatites that are made up of leucosome and melanosome with metamorphic fabrics, while diatexites are massive and more homogeneous type and has plutonic igneous textures. Diatexite is a migmatite in which the pre-migmatization structures are destroyed (Brown and Solar, 1998; Condie, 1989) and a homogenization and coarsening of texture occurs. Diatexites represents rocks in which the melt fraction was large as the melt fraction increases, the rheology of the whole becomes one of magma, and this allows large-scale material support (Condie, 1989; Sawyer, 1998). The nebulite occur in contact aureoles, but in regional migmatite terrain they tend to be restricted to area of low syn-anatectic strain. Because these migmatites contain a fraction of melt well above the 'melt connectivity threshold' defined by Rosenberg and Handy (2005), they are mechanically weak. Consequently, they would readily undergo bulk of flow if there was penetrative deformation and then the neosome would develop a foliation and compositional banding (Sawyer, 2009). For proper understanding of partial melting and processes of melt transport within the middle to lower continental crust, the study of migmatites in high temperature metamorphic terranes is key (Tomoyuki, 2002). This study is focused on investigation of the geochemical characters of rock units within the Nabardo area to infer the nature of the original protolith and original rock structure left during partial melting as well as characterize three migmatites (metatexites, diatexites and nebulite) types of the Nabardo area in terms of field occurrence, texture, mineralogy and geochemistry.

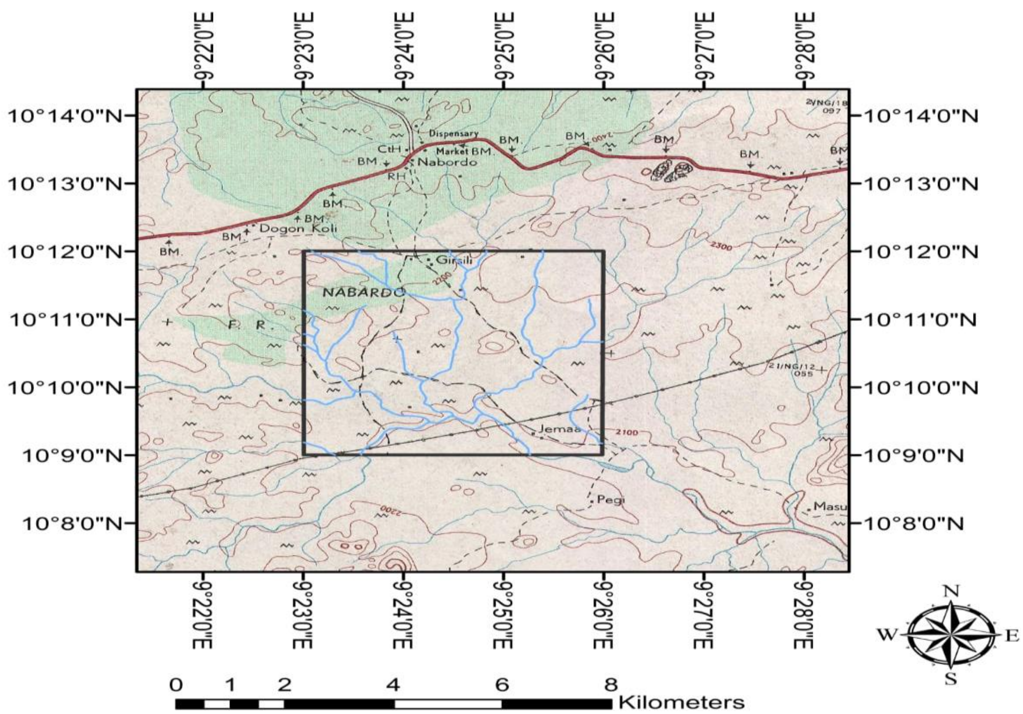

Fig.1. Location map of Nabarro and its environs

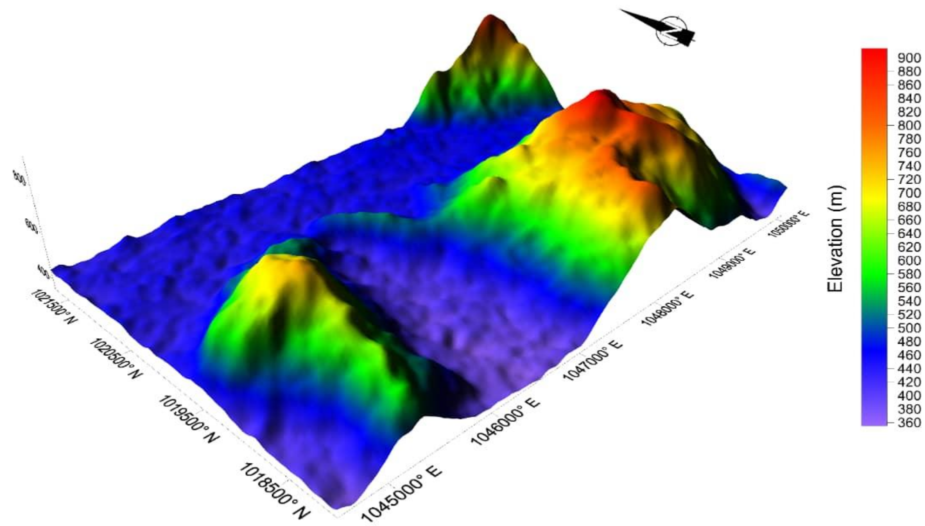

Fig. 2. Digital Elevation model of the study area

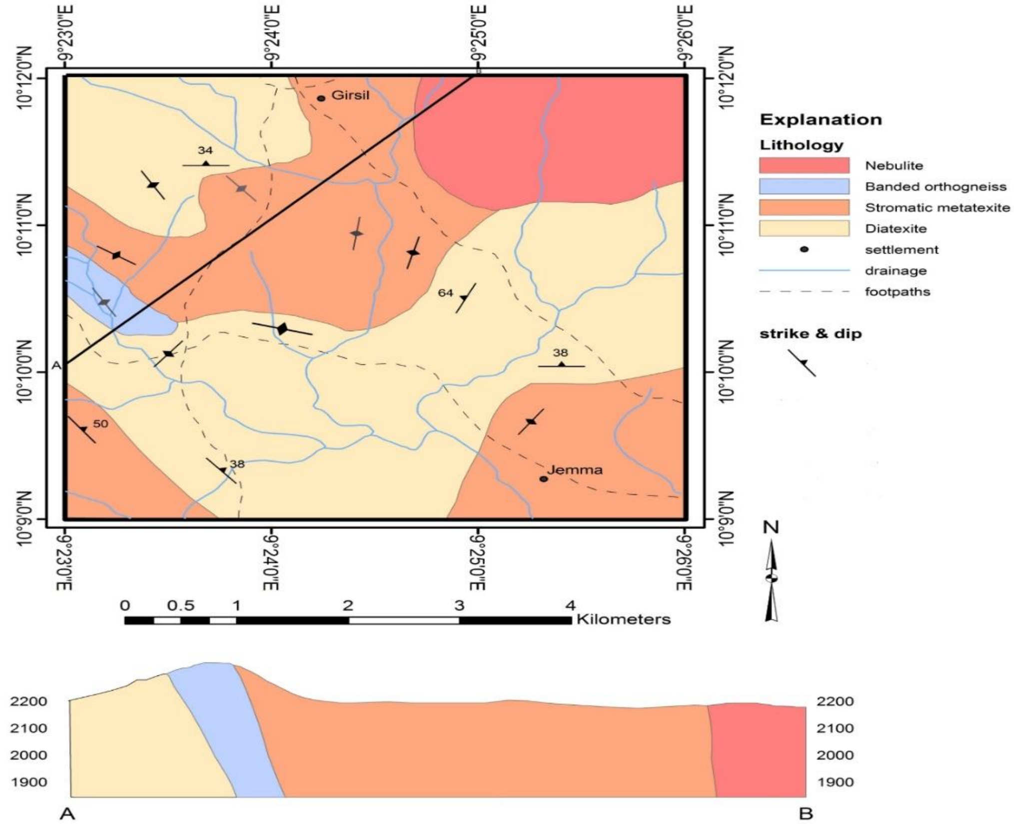

Fig. 3. Geological map of the study area

II. GEOLOGICAL BACKGROUND

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The study area is located on latitudes 10^0 9'00" N & 9^0 12'00" N and longitudes $9^0$23'00"E & $9^0$26'00" E (Fig.3) . It covers an area of approximately 42.55km^2 with an average elevation of 900m above sea level. The study area which is part of Sheet 148, Toro SE is entirely typical of the Nigerian Basement Complex The metamorphic rocks of northern Nigeria which underlie the greater part of the region consist mainly of Migmatitic Gneiss, Granite gneiss, mica schist and porphyritic granite. The migmatites therefore constitutes an important group of the metamorphic rocks of northern Nigeria. The metatexite migmatites can be distinctly identified as having a planar structure constituting several layers with separate layers having different mineralogy and texture. The metatexite migmatite formed from melt residuum separation at low degrees of partial melting and consequently, low melt fraction. (Milord, 2000). It is important to note that the formation of the diatexite migmatite is based on melt fraction being higher i.e., where the molten rock material has almost been changed entirely to melt (Milord, 2000). The increase in the melt fraction is as a result of an increase in metamorphic temperature, injection of another melt from a different source and the melt being redistributed within the melting layer. These reasons were reported by Brown, 1973, Greenfield et al., 1996 and Sawyer, 1998 respectively. Where the metasedimentary rocks melted sufficiently to undergo magma flow, but did not experience a significant melt-residuum separation, mesocratic diatexites were formed. The mesocratic diatexites goes into the magma separation and further give rise to melanocratic diatexites on one hand and leucocratic diatexites on the other hand. (Milord 2000). The migmatite gneiss is characterized by a variety of structures and textures. The well-foliated gneissic portion and the mafic component constitute the paleosome while the granitic and felsic component constitute the neosomes. The previous assume a general trend of NW/SE with few exceptions in NE/SW direction. It is pertinent to know also that almost E-W structures were also observed which forms relics of the older structure believed to have been affected by the eburnean (possibly) orogenic event.

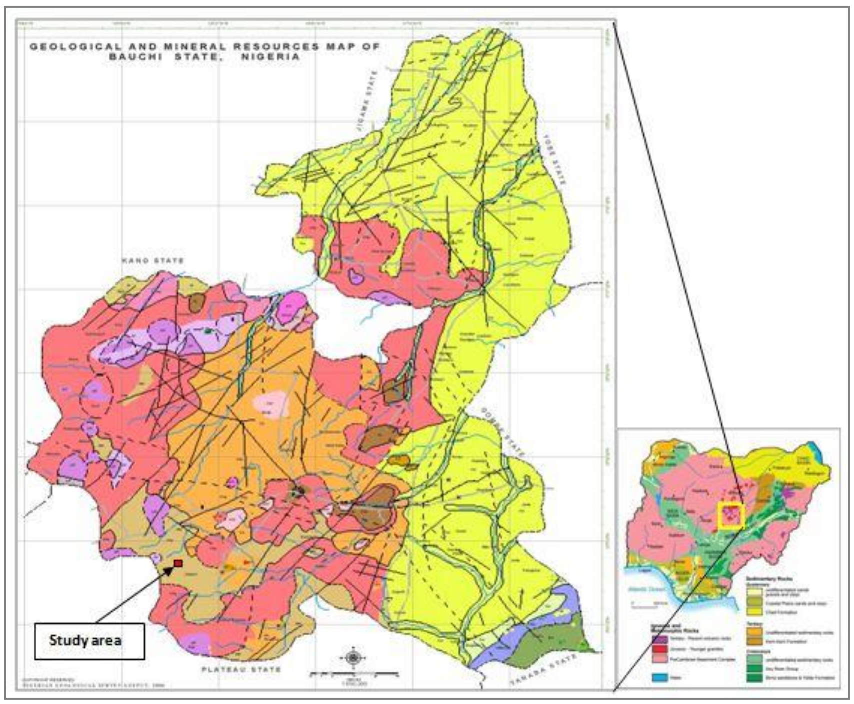


Fig.4. Geological map of Bauchi state showing the study area (source: NGSA)

III. METHODOLOGY

XRF method of geochemical analysis was used. The XRF is a method for measuring the thickness of coatings and for analyzing materials and can be used for the qualitative and quantitative determination of the elemental composition of a material sample. (Van Grieken (2013)). The samples are firstly crushed, to break down aggregates using a jaw crusher or any other suitable tool for size reduction. The particles are then air-dried in a clean place, then major and trace elements (including REEs) were determined by X-ray Fluorescence. For XRF measurements, a sample has to be additionally pulverized, homogenized and pressed into pellet with or without a binder. Usually chromatographic cellulose, boric acid or starch are used as a binder in a proportion

1:10 by weight (in some cases a liquid binder might be used). For the emission—transmission method usually a 150 or 200 mg pellet is prepared (25 mm diameter).

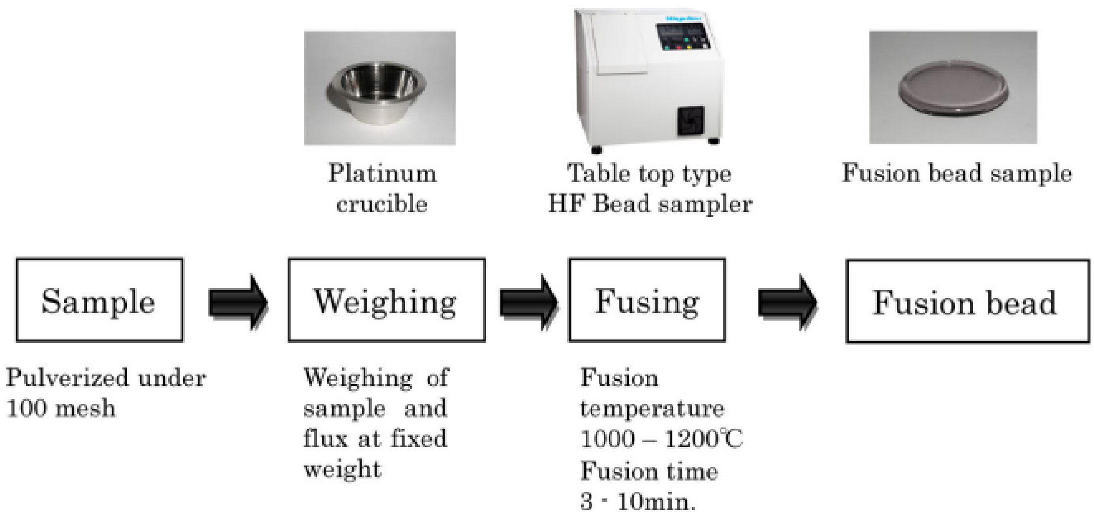


Fig. 5: XRF Sample preparation chart

IV RESULTS

Thirty (30) freshly representative rock samples were carefully selected from the study area and these were subjected to elemental analysis. These samples were sent to National Geosciences Research Laboratory (NGRL), Kaduna for sample preparation Most of the elements have concentration above the detection limit. The geochemical data presented in the table below showed that most of the major and trace elements detected have varied concentrations that were suitable for geochemical interpretations. The geochemical data was subjected to variation analysis using Petrograph software package and deductions were made based on the plots obtained. The rocks were established as migmatites and gneiss. With respect to field observation, petrographic study and fabrics, the lithologies encountered were further subdivided into three categories: *Metatexite-Diatexite and Nebulite*

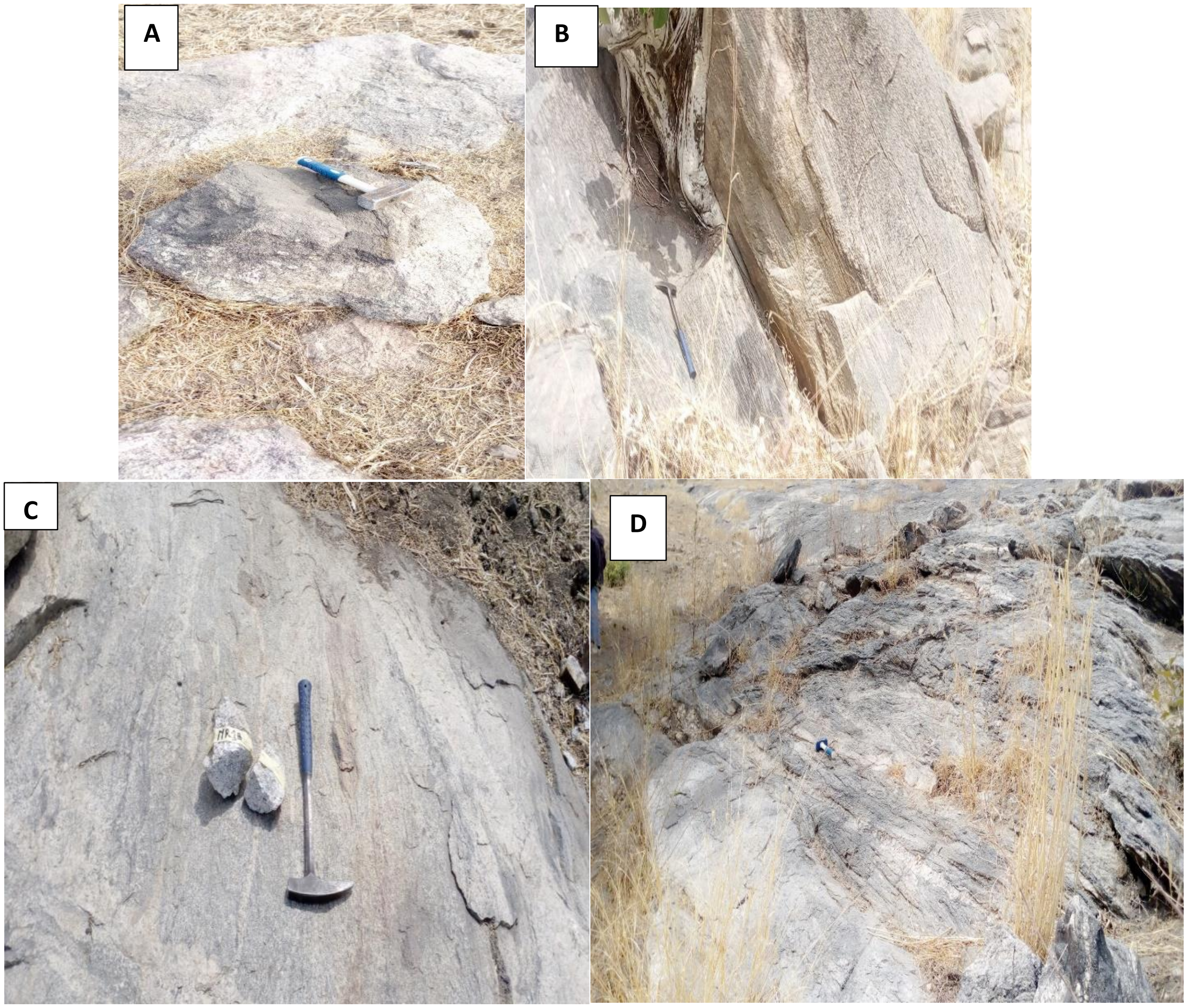


Plate 1

(a) Field occurrence of nebulite within the study area. (b) Field occurrence of Banded Orthogneiss (c) Field view of diatexite (d) Field view of metatexite.

Table 1: Presentation of geochemical result

(A) <u>Major Oxides in Wt% (Nd – Not detected)</u>

Sample ID	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	SrO	V_2O_5	Cr_2O_3	Eu_2O_3	CeO_2	I.O.I
NR1A	50.78	0.06	20.45	7.23	0.94	3.55	2.94	2.52	0.1	Nd	Nd	Nd	Nd	Nd	Nd	11
NR3B	59.07	0.91	16.59	11.32	0.85	4.03	3.18	2.25	0.04	Nd	Nd	Nd	Nd	Nd	Nd	1.7
NR5	63.34	0.43	16.44	10.89	0.51	2.32	2.04	1.97	0.1	Nd	Nd	Nd	Nd	Nd	Nd	1.9
NR7	94	0.2	4.79	0.24	0.06	0.013	0.02	0.04	0.01	Nd	Nd	Nd	Nd	Nd	Nd	0.6
NR9B	75.71	0.35	15.8	4.04	0.29	0.76	1.25	0.73	0.03	Nd	Nd	Nd	Nd	Nd	Nd	1
NR 11C	59.77	0.37	15.66	11.1	0.29	5.99	1.64	3.91	0.114	Nd	Nd	Nd	Nd	Nd	Nd	1
NR12	65.92	0.39	15.82	7.79	0.23	3.44	2.88	2.62	0.1	Nd	Nd	Nd	Nd	Nd	Nd	0.7
NR13	71.06	0.4	15.7	5.04	0.38	1.68	1.9	1.81	0.0061	Nd	Nd	Nd	Nd	Nd	Nd	1.9
NR 15A	86.64	0.31	6.9	2.16	0.44	0.29	0.38	0.5	0.081	Nd	Nd	Nd	Nd	Nd	Nd	2.1
NR9A	65.39	0.91	15.14	5.09	2.47	0.89	1.98	6.11	0.04	0.79	0.05	Nd	Nd	Nd	Nd	0.8
NR3A	59.37	1.32	14.22	7.42	4.15	2.11	2.43	5.26	0.08	0.71	0.05	Nd	Nd	Nd	Nd	2.5
NR4B	69.75	0.13	14.83	1.05	0.97	0.44	3.09	7.48	0.02	0.35	0.02	Nd	Nd	Nd	Nd	1.7
NR14 C	67.87	0.34	17	2.24	2.3	0.39	2.92	5.17	0.031	0.46	0.05	Nd	Nd	Nd	Nd	1

NR15C	65.76	0.48	18.51	2.28	1.69	0.54	2.13	7.32	0.054	0.83	Nd	Nd	Nd	Nd	Nd	0.3
NR 8	63.31	0.78	16.45	4.68	2.43	1.49	2.95	5.64	0.07	0.65	0.05	Nd	Nd	Nd	Nd	1.2
NR 10	56.87	1.36	15.7	7.6	3.82	1.42	2.66	5.94	0.08	0.95	0.06	Nd	Nd	Nd	Nd	3.1
NR 2	22.86	0.37	11.48	0.511	13.88	0.0005	0.0005	0.0005	0.0005	48.47	Nd	0.14	0.09	Nd	Nd	2.2
NR 14A	32.06	0.33	16.48	1.22	12.02	0.0005	0.6	0.1	0.02	34.99	Nd	0.0005	0.06	0.02	Nd	2.1
NR 9C	47.76	0.23	10.24	0.46	11.16	0.0005	0.63	0.12	0.0005	27.74	Nd	Nd	0.05	Nd	0.17	0.7
NR 16B	71.6	5	17.09	0.63	0.04	0.01	0.52	9.13	0.12	0.42	Nd	0.0005	0.011	Nd	Nd	0.4
NR 1B	72.03	0.0005	15.46	0.5	1.7	0.52	1.8	9.29	0.013	0.34	Nd	Nd	Nd	Nd	0.13	0.13
NR 2A	67.5	0.0005	16.86	0.32	1.08	0.3	2.44	10.38	0.054	0.39	Nd	Nd	Nd	Nd	Nd	0.6
NR 4	62.79	1.35	15.16	6.55	3.22	1.04	3.18	2.97	0.05	0.95	Nd	0.0005	0.05	Nd	Nd	2.6
NR 11A	64.93	0.39	17.12	2.92	2.39	1	3.12	5.07	0.07	0.47	0.034	Nd	Nd	Nd	Nd	2.3
NR6A	60.07	0.92	15.47	6.75	3.23	2.55	2.85	3.32	0.1	0.64	0.044	Nd	Nd	Nd	Nd	3.9
NR 16A	67.52	0.07	17.05	0.39	1.08	0.8	2.93	7.04	0.02	0.37	0.003	Nd	Nd	Nd	Nd	2.7
NR 16C	64.54	0.66	16.55	4.05	3.45	1.17	2.41	5.63	0.08	0.72	Nd	Nd	Nd	Nd	Nd	0.6
NR6B	70.02	0.13	14.83	1.05	0.97	0.44	3.09	7.48	0.02	0.35	Nd	Nd	Nd	Nd	Nd	1.7

NR 15B	63.01	1.4	15.16	6.55	3.21	1.04	3.18	3.01	0.05	0.95	Nd	0.0005	0.05	Nd	Nd	2.6
NR 16C	65.42	0.04	15.03	0.41	1.21	0.75	2.96	7.11	0.02	0.39	0.005	Nd	Nd	Nd	Nd	2.7

(B) Trace Elements in PPM (Ndd – Not detected)

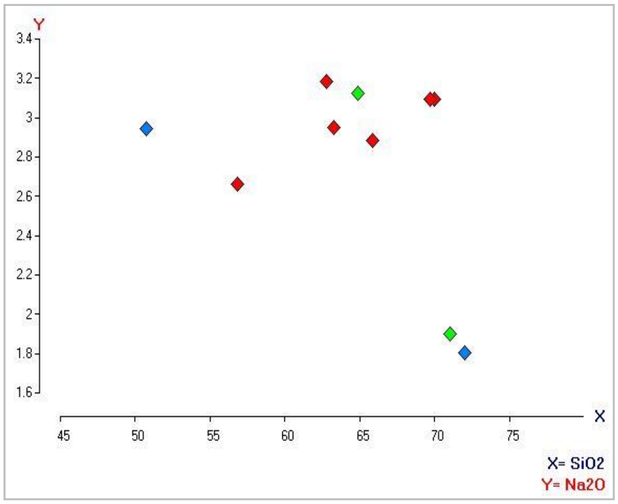
Sample ID	Pb	Zn	Cu	Ni	Cr	Co	Mn	V	Zr	Sn	Nb	Yb	Ba	Ga	Y	Th	Ag	Te	As	Eu	Nd	Ce
NR1A	Ndd	74.39	8.46	206.27	18.45	7.05	724.77	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd
NR3B	Ndd	83.59	39.74	38.35	44.64	11.15	336.29	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd
NR5	Ndd	94.58	27.17	8.85	10.26	15.12	401.1	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd
NR7	87.61	Ndd	17.78	81.13	83	2.43	42.01	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd
NR9B	Ndd	47.25	26.45	67.77	70.47	12.07	211.94	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd
NR 11C	Ndd	115.45	24.94	257.69	289.8	21.25	878.49	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd
NR12	Ndd	104.72	19.69	60.57	98.36	14.79	771.82	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd
NR13	Ndd	61.65	9.46	40.97	59.44	12.98	472.65	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd
NR 15A	Ndd	29.92	24.17	654.45	601.5	26.6	629.29	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd
NR9A	47.53	82.584	57.2	24.44	78	Ndd	Ndd	23.13	558.7	82.07	22.4	14.9	784	29.1	30	31.7	759	41.71	0.45	183	42.27	Ndd
NR3A	19.77	101.22	33.23	55.403	215.3	Ndd	Ndd	130.4	340.7	81.92	54.7	11.9	450	27.5	36.46	39.4	754	43.45	2.88	356	Ndd	Ndd
NR4B	40.85	15.746	7.909	20.825	92.3	Ndd	Ndd	Ndd	121.3	62.07	42.5	2.28	237	30.1	26.14	Ndd	624	9.083	Ndd	43.4	Ndd	53

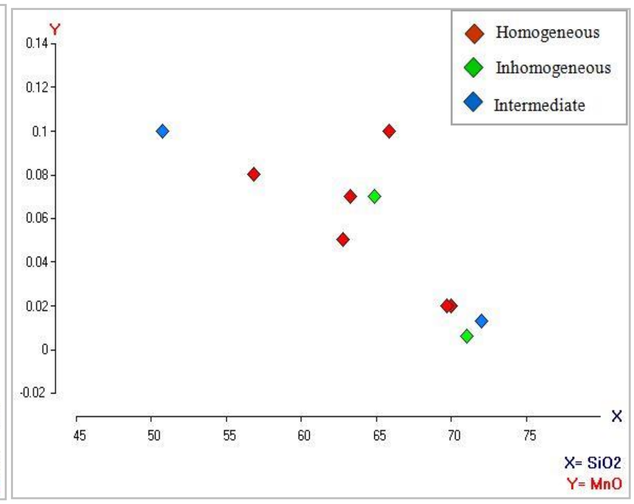
NR14C	49.57	47.719	24.76	23.733	117.8	Ndd	Ndd	Ndd	182	67.66	5.66	6.06	546	24.5	7.953	12.2	710	34.59	Ndd	91.6	Ndd	19.78
NR15C	86.71	51.896	Ndd	13.91	134.5	Ndd	Ndd	Ndd	106.1	151.2	13.1	6.5	Ndd	26.6	43.7	4.31	Ndd	Ndd	Ndd	216	Ndd	Ndd
NR 8	38.15	89.251	Ndd	22.554	83.34	Ndd	Ndd	53.5	343.5	79.79	26.9	17.6	626	33.2	29.53	27.5	730	35.17	0.53	225	25.38	Ndd
NR 10	15.69	128.29	49.53	21.297	71.23	Ndd	Ndd	83.02	623	83.41	31.2	19	876	29.9	37.56	11.3	807	Ndd	2.27	343	36.44	Ndd
NR 2	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd
NR 14A	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd
NR 9C	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd
NR 16B	67.58	6.4267	Ndd	14.067	Ndd	Ndd	Ndd	Ndd	Ndd	46.39	2.1	4.39	77.6	28.7	Ndd	Ndd	Ndd	Ndd	Ndd	8.2	Ndd	Ndd
NR 1B	91.35	6.5071	Ndd	25.383	104.5	Ndd	Ndd	Ndd	60.48	29.46	0.56	Ndd	Ndd	Ndd	13.54	Ndd	Ndd	Ndd	Ndd	75.3	Ndd	Ndd
NR 2A	49.29	Ndd	Ndd	28.605	151.7	Ndd	Ndd	Ndd	37.24	38.83	2.24	1.93	Ndd	6.77	10.55	Ndd	Ndd	Ndd	Ndd	20.7	Ndd	255
NR 4	37.69	116.65	48.65	65.776	Ndd	Ndd	Ndd	Ndd	Ndd	163.8	32.2	9.92	Ndd	24.9	35.44	51.5	Ndd	Ndd	1.59	233	198.6	Ndd
NR 11A	36.58	45.148	20.53	39.764	131	Ndd	Ndd	38.6	116.3	61.67	10.4	13.1	222	31.6	9.213	Ndd	638	34.52	Ndd	147	Ndd	Ndd
NR6A	21.35	132.23	55.76	Ndd	103.1	Ndd	Ndd	88.56	90.61	135.8	11.4	14.8	160	29.8	17.17	Ndd	Ndd	Ndd	0.61	340	Ndd	Ndd
NR 16A	58.58	13.094	Ndd	Ndd	62.88	Ndd	Ndd	Ndd	Ndd	27.49	3.01	0.88	Ndd	31.3	11.26	24.7	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd
NR 16C	38.34	84.271	132.7	25.855	111.4	Ndd	Ndd	Ndd	235.9	149.7	8.11	7.03	Ndd	27.5	14.33	15.6	Ndd	Ndd	0.61	220	Ndd	Ndd

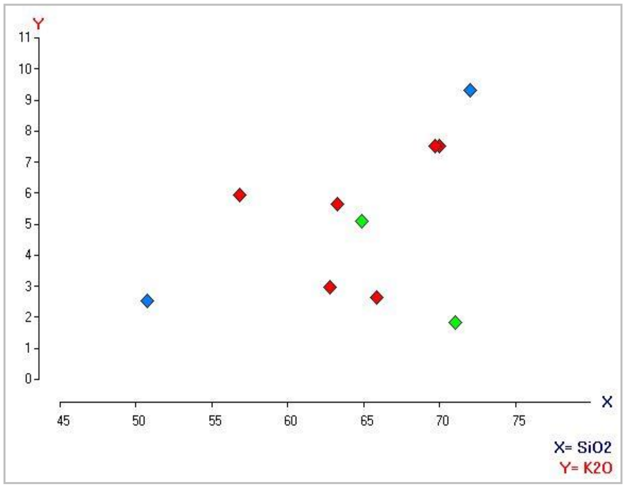
NR6B	40.85	15.746	7.909	20.825	92.3	Ndd	Ndd	Ndd	121.3	62.07	42.5	2.28	237	30.1	26.14	19.9	624	30.88	Ndd	43.4	Ndd	53
NR 15B	37.69	116.65	48.65	65.776	Ndd	Ndd	Ndd	Ndd	Ndd	163.8	32.2	9.92	Ndd	24.9	35.44	51.5	Ndd	Ndd	1.59	233	198.6	Ndd
NR 14B	58.58	12.693	Ndd	Ndd	62.95	Ndd	Ndd	Ndd	Ndd	26.62	3.01	0.88	Ndd	31.3	11.26	24.8	Ndd	Ndd	Ndd	Ndd	Ndd	Ndd

Diatexite

Variation Plots



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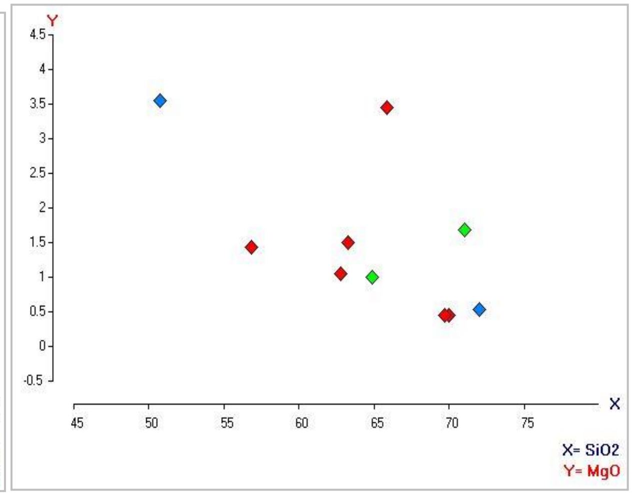
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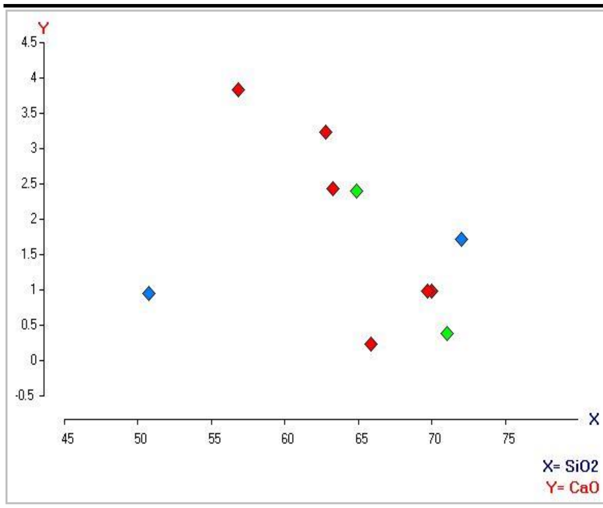
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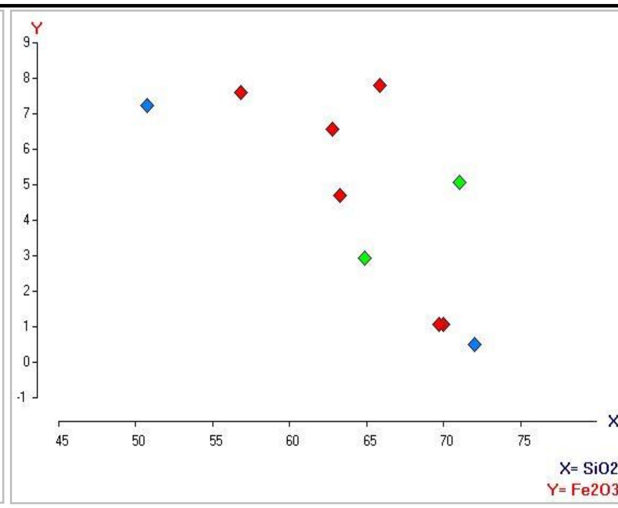
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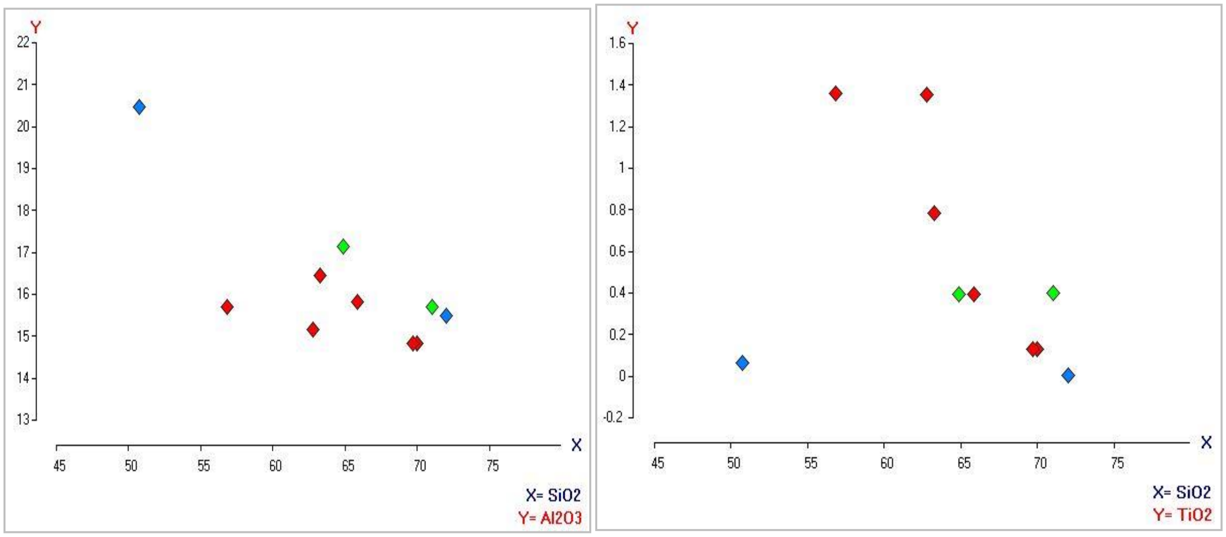


Figure 6: Variation plots of diatexites of the study area

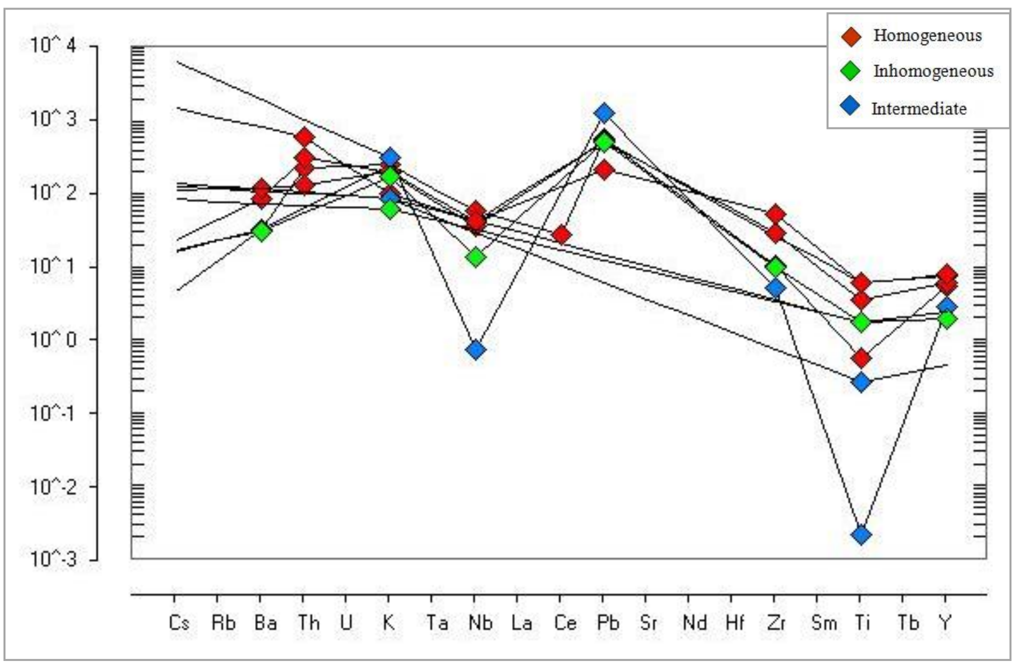


Figure 7: Spider plot – Primordial mantle-McDonough et al. (1982)

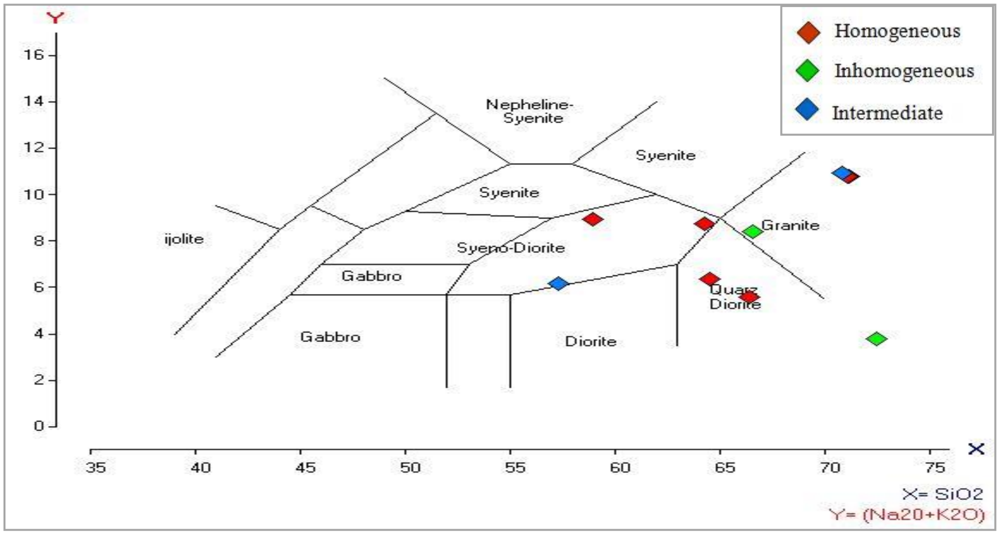


Figure 8: Total Alkali vs Silica (TAS) plot after Cox – Bell-Pank, 1979.

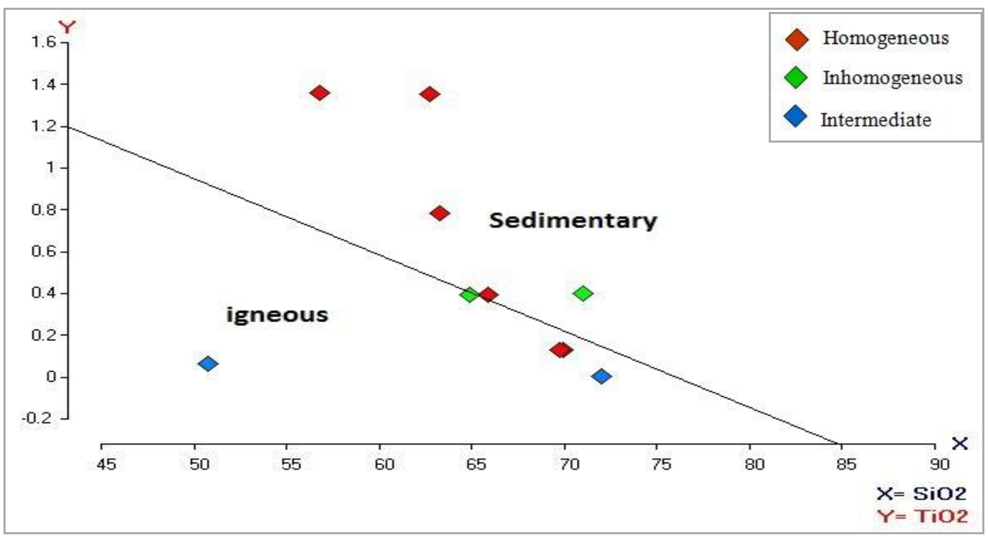


Figure 9: TiO_2 – SiO_2 discrimination diagram showing the plots of (Tarney, 1977).

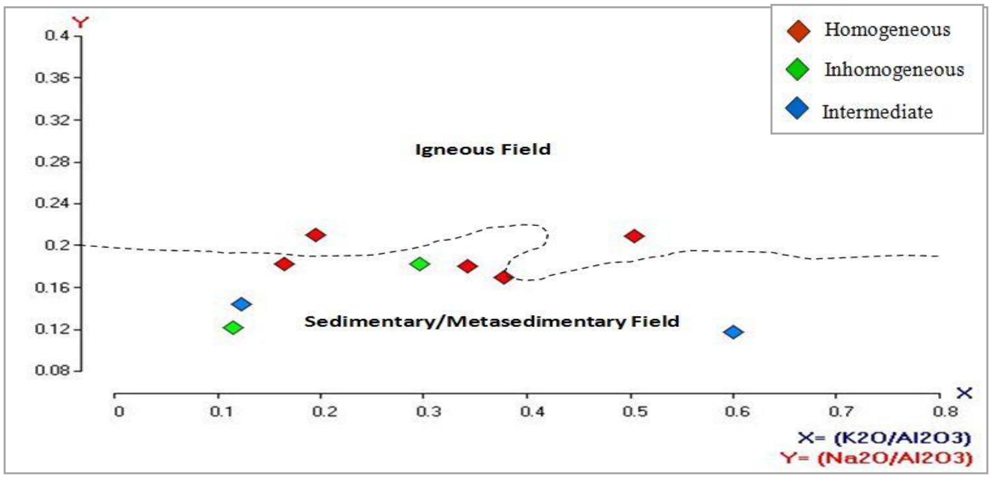


Figure 10: Petrogenetic plot of Na_2O/Al_2O_3 vs. K_20/ Al_2O_3 after Garrels

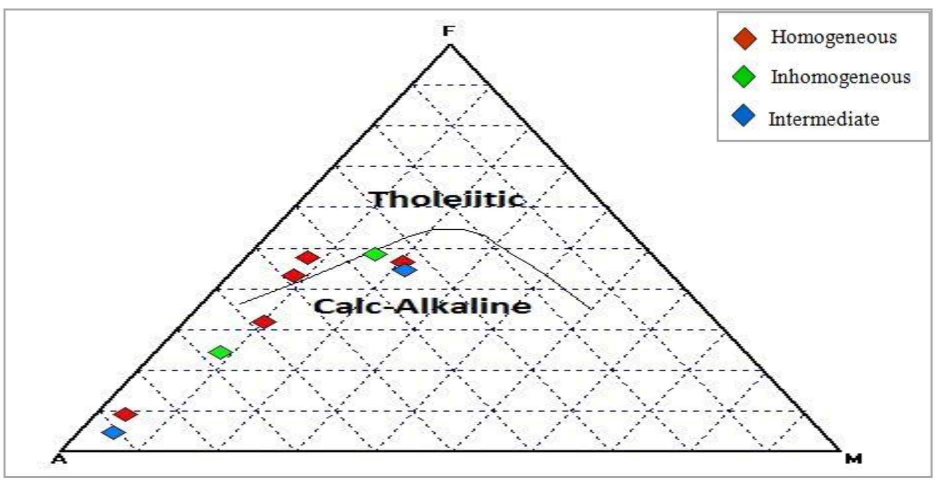


Figure 11: AFM diagram after Irvine Baragar, 1971 and Mackenzie (1971)

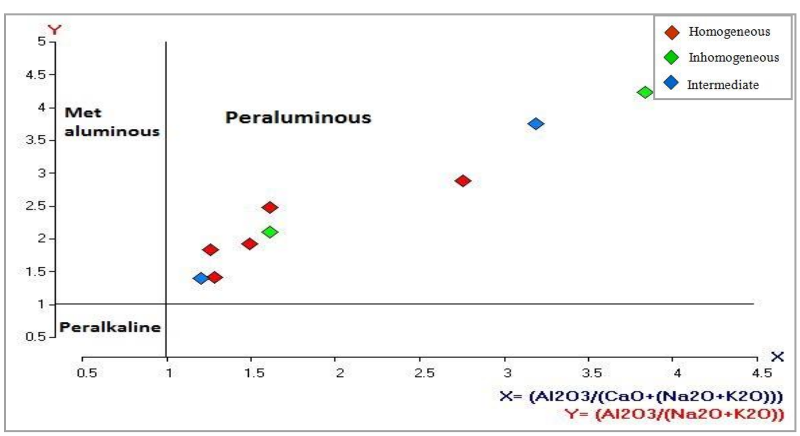
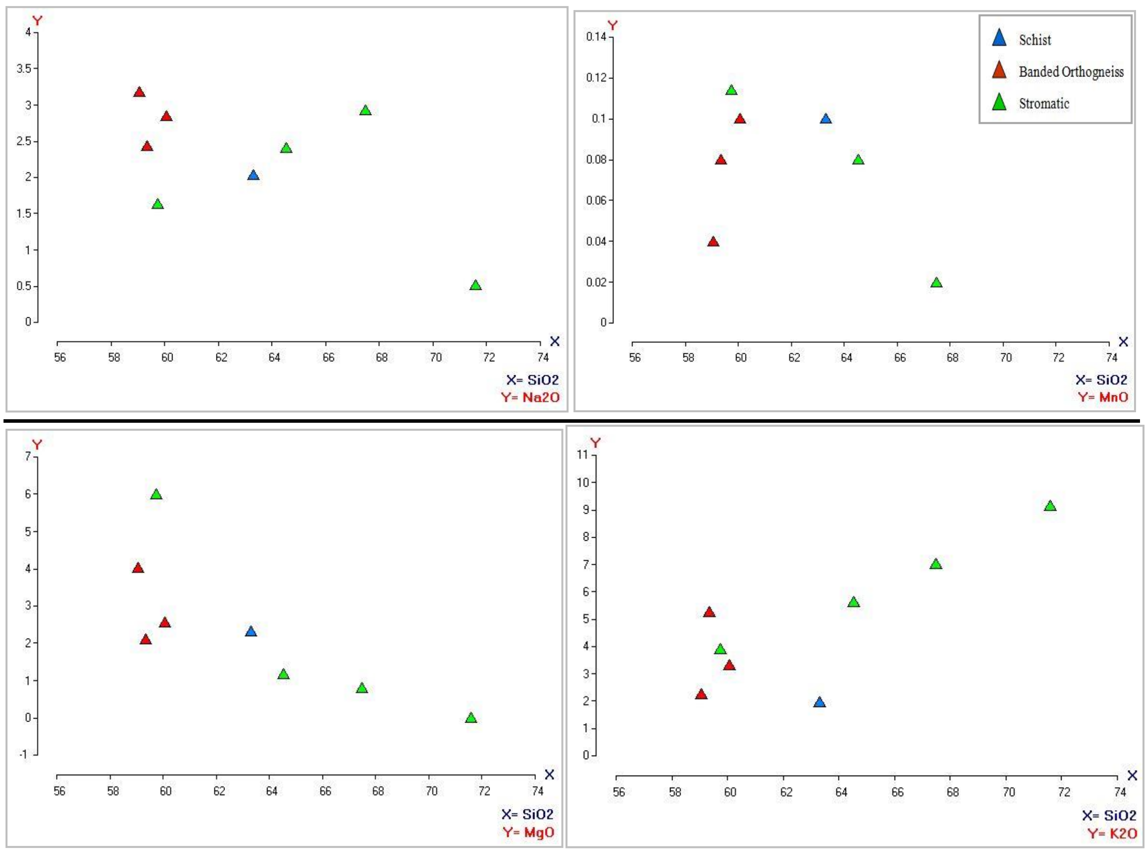


Figure 12: $Al_2O_3/(CaO + Na_2O + K_2O)$ versus $Al_2O_3/Na_2O + K_2O$ plot showing the dominantly Peraluminous nature of the rocks (after Maniar and Piccoli, 1989)

Metatexite.

Variation Plots



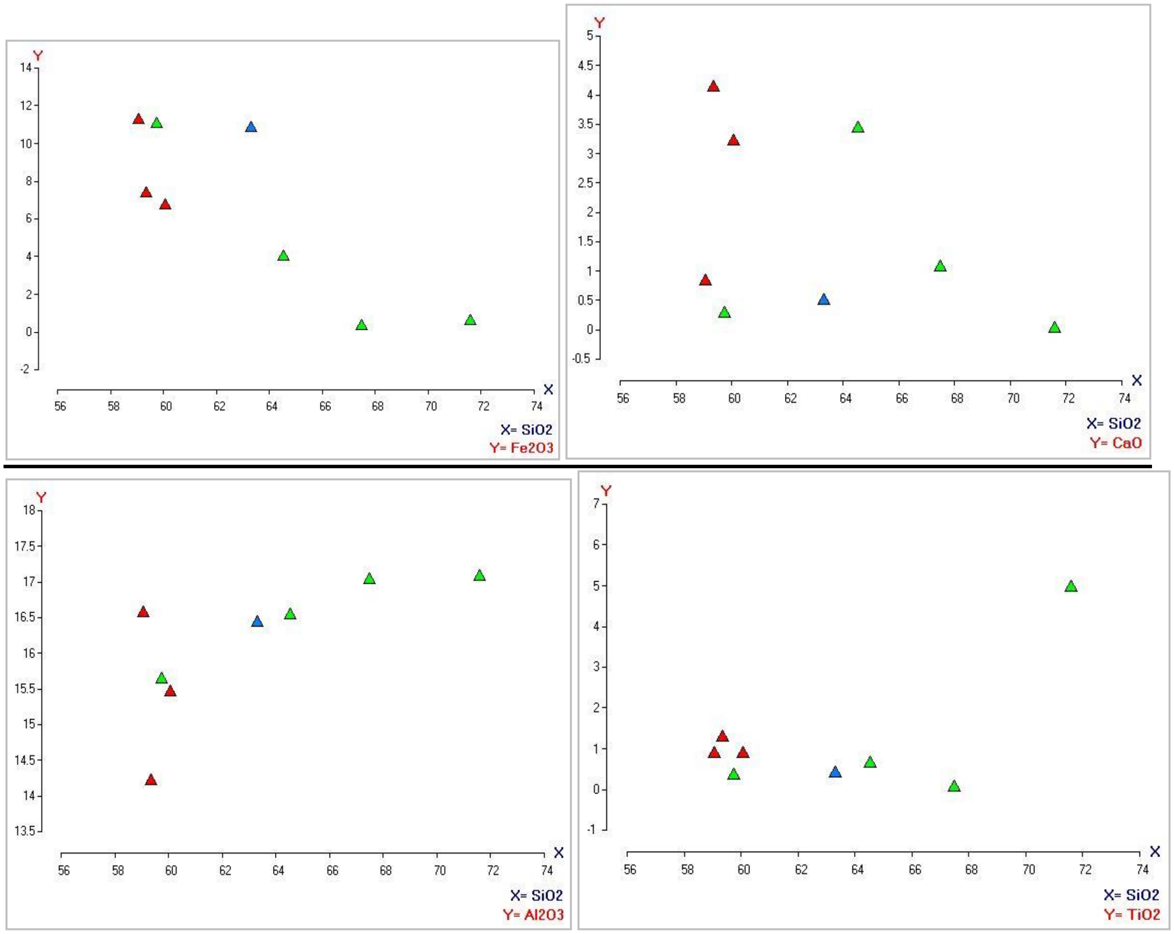


Figure 13: Variation plots of metatexites in the study area

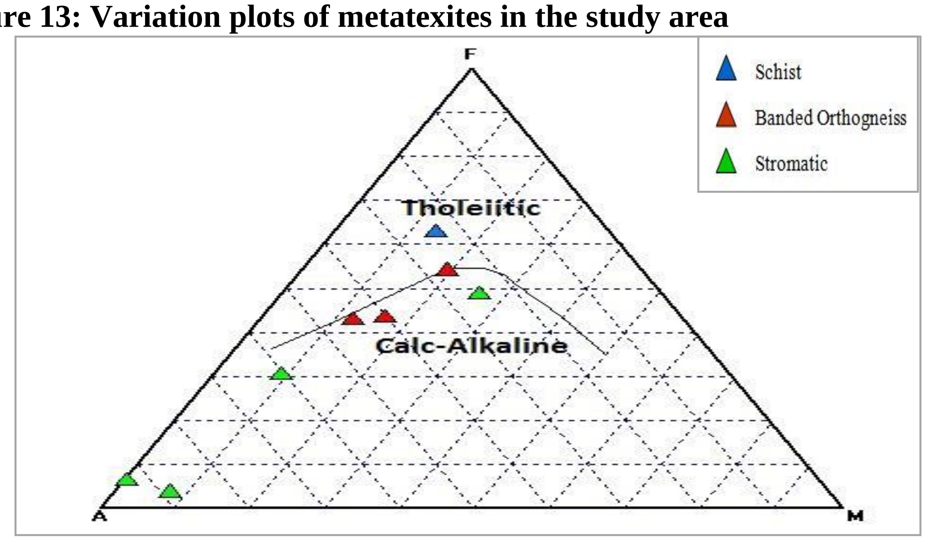


Figure 14: AFM diagram after Irvine Baragar, 1971

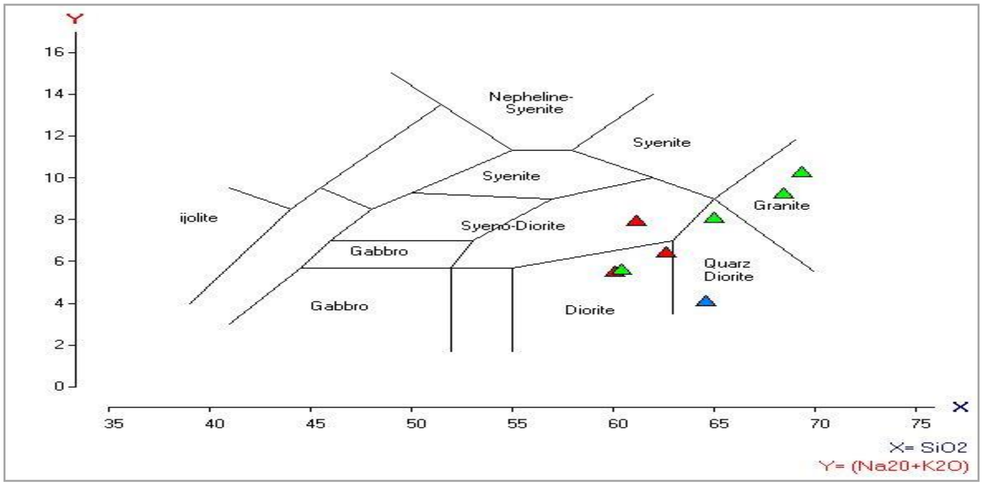


Figure 15: Total Alkali vs Silica (TAS) plot after Cox – Bell-Pank, 1979

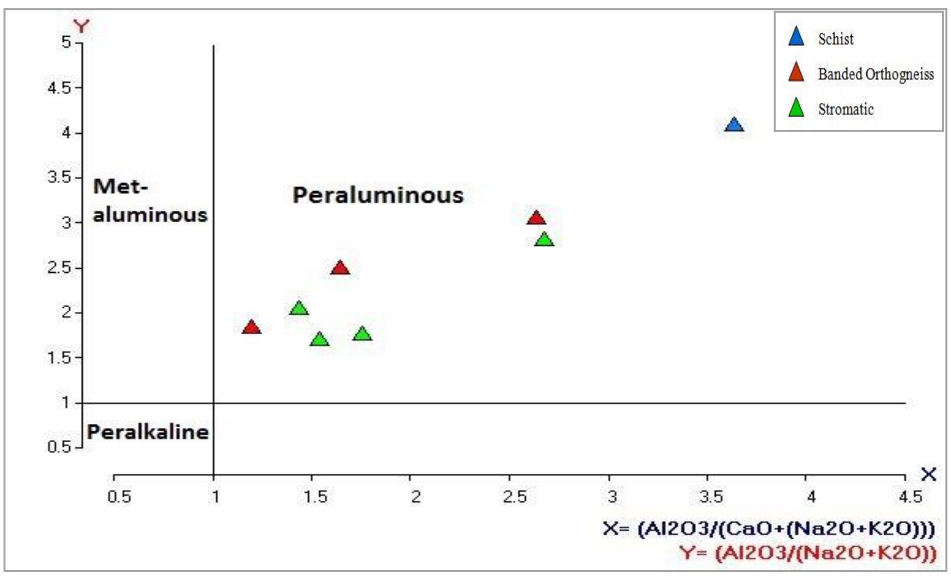


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Figure 16: Al_2O_3/(CaO + Na_2O + K_2O) versus Al_2O_3/Na_2O + K_2O plot showing the dominantly Peraluminous nature of the rocks (after Maniar and Piccoli, 1989)

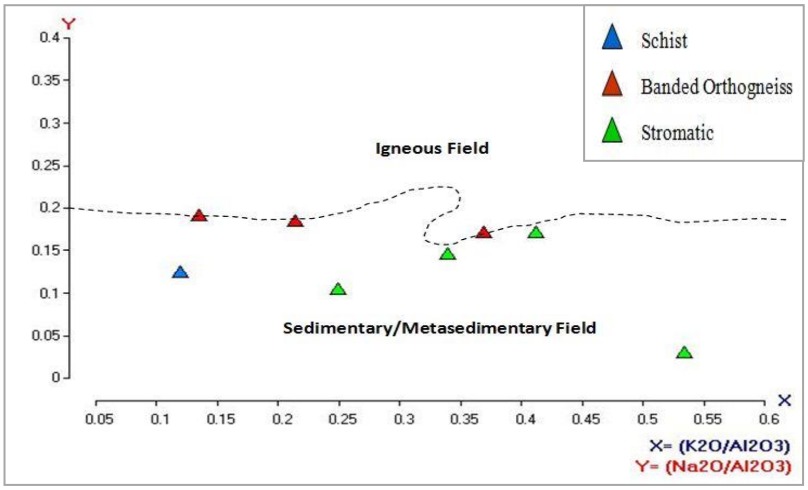


Figure 17: Petrogenetic plot of Na_2O/Al_2O_3 vs. K_20/ Al_2O_3 after Garrels and Mackenzie (1971).

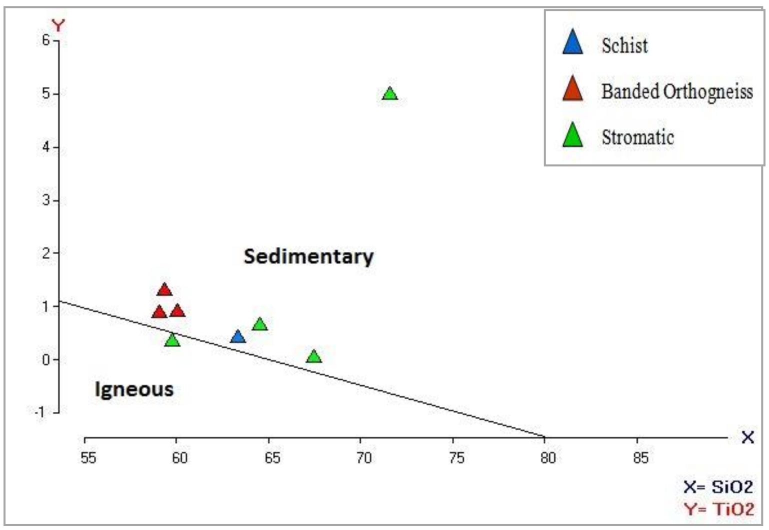


Figure 18 :A TiO_2 – SiO_2 discrimination diagram showing the plots of the metatexites samples, (Tarney, 1977).

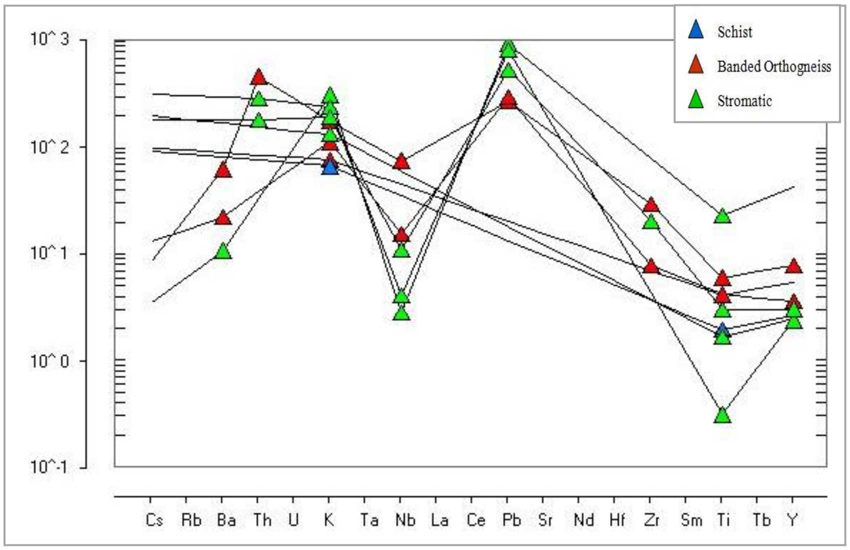
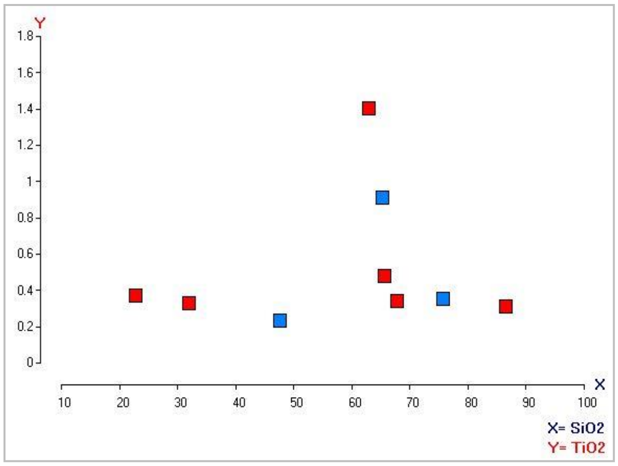
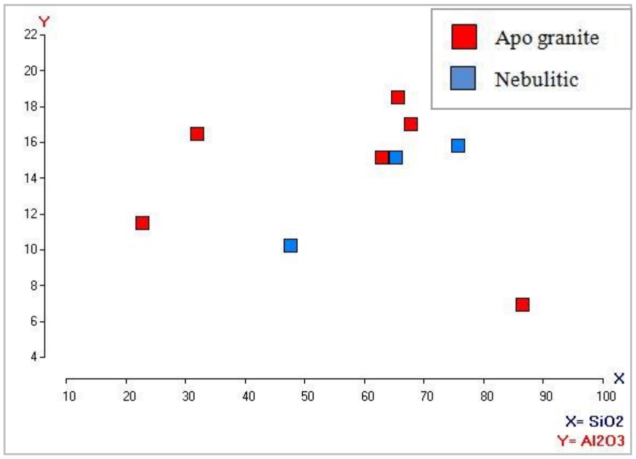


Figure 19: Spider plot – Primordial mantle-McDonough et al. (1982)

NEBULITES





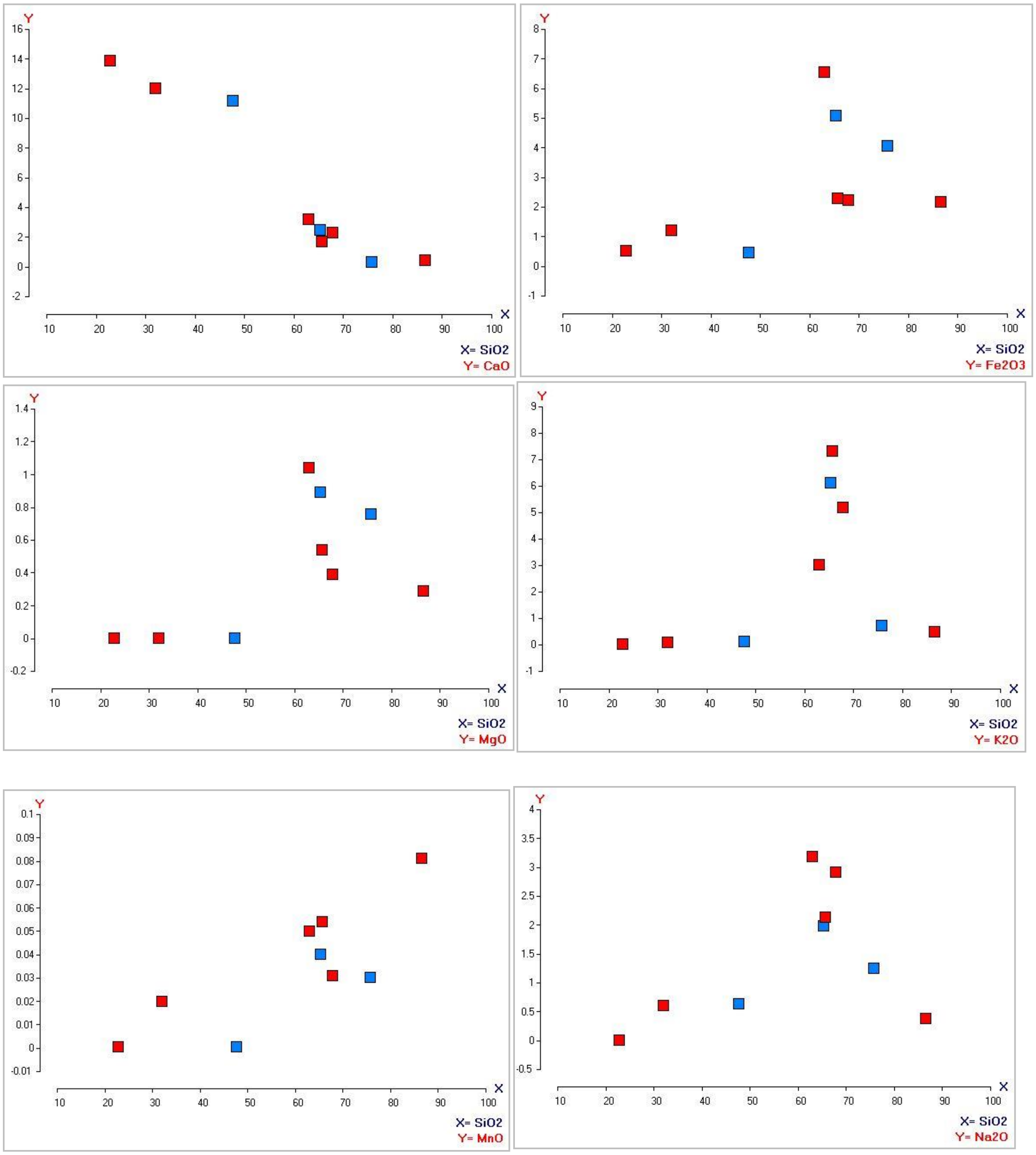


Figure 20: Variation plots of Nebulites in the study area.

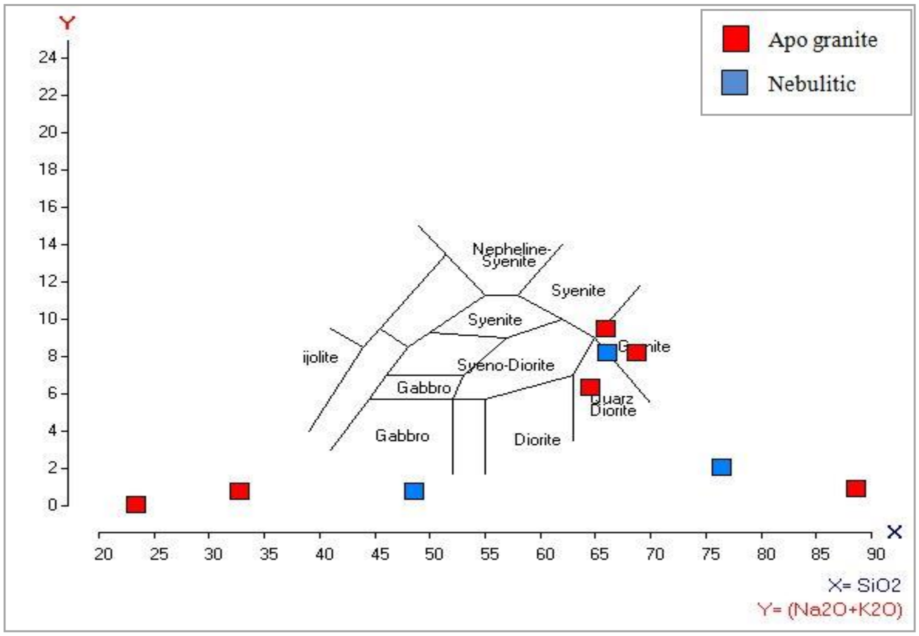


Figure 21: Total Alkali vs Silica (TAS) plot after Cox – Bell-Pank, 1979

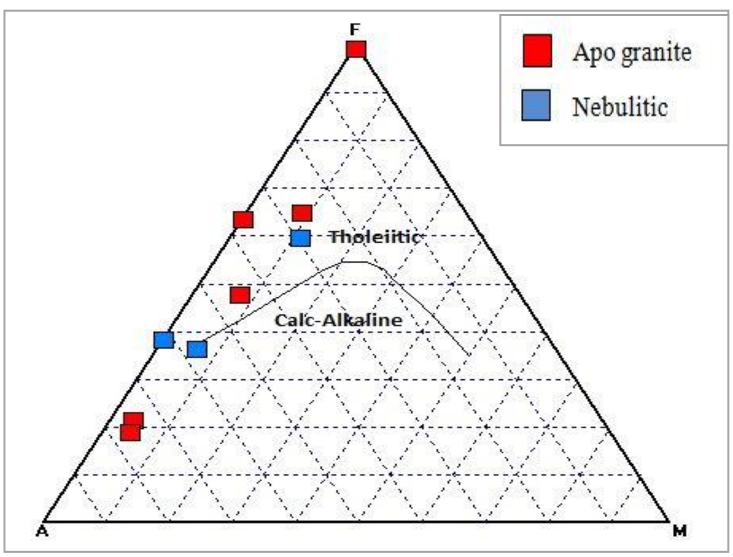


Figure 22: AFM diagram after Irvine Baragar, 1971

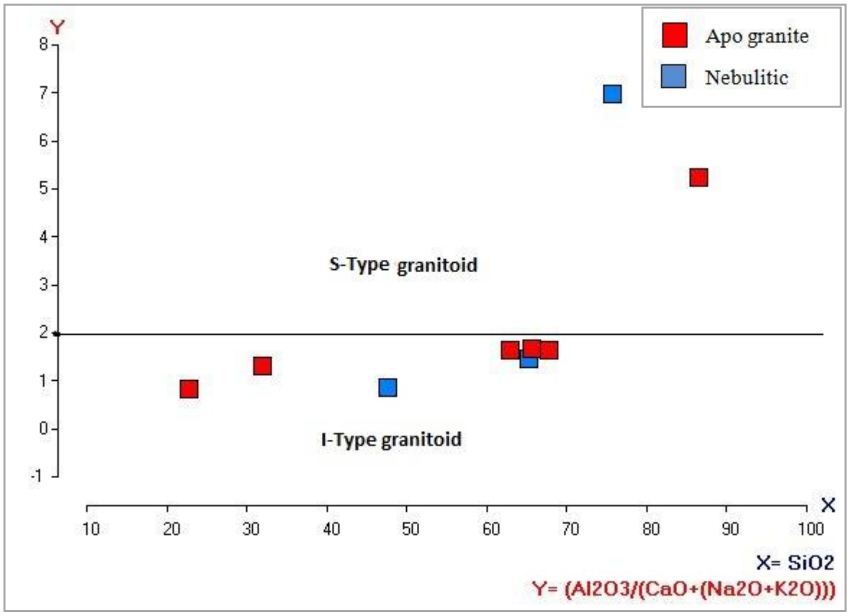


Figure 23: Classification into S type and I type granitiod after White and Chappel, 1977

V DISCUSSION

Migmatitic assemblages can be grouped in to metatexites, diatexites and nebulites on the basis of their field appearances (Sawyer 1987). The Metatexite is migmatite that preserves coherent, pre-partial melting structures in the palaeosome and residuum,whereas diatexite has disaggregated and lost structural coherency. The neosome is variable in appearance, it includes leucosome and melanosome in varying proportions.

Whole-rock geochemical examination have been determined on the representative rock groups of the study area. Major and trace elements results of these groups is given in (table A and B). From the major oxides presented in the table 1above, the granitoids shows a moderately high SiO_2 in the range of 56.87 – 94.0 wt% while alumina (Al_2O_3) has values ranging from 4.79 – 15.7 wt%. Fe_2O_3 shows a moderate value ranging from 0.24 – 7.6 wt% while those of MgO ranges from 0.013 – 1.68 wt%. The data also reveal that soda, Na_2O varies between 0.02 and 2.66 wt % while potash, K_2O ranges from 0.04 to 5.94 wt %.

The variation diagrams (figure 6,13 and 20) of the migmatites (diatexite, metatexite and nebulites) show random fractionation trend with the rocks, TiO_2, Al_2O_3, Fe_2O_3, K_2O, CaO and P_2O_5 decreasing with increase in SiO_2, while MgO and Na_2O are showing positive correlation, where SiO_2 increases their concentrations. These inter play between positive and negative trend in the variation diagram shows that there is no any specific trend of magma fractionation but rather a local fractionation with individual rocks that are showing negative correlation. In general, the rocks are showing differentiation as more SiO_2 is added to the system there by favoring the formation of more felsic rocks as partial melting increases. The AFM diagrams (figure 11,14 and 22) after Irvine Baragar, 1971, which is useful in discriminating between the tholeiitic and Calc-alkaline suites reveals that majority of the samples in diatexites and metatexites have a Calc-alkaline affinity as they plotted in the Calc-alkaline field which is an indication of enrichment in silica and alkalies (Miyashiro, 1974) while others are iron enriched in Theoleiitic field in nebulites. In determining the provenance of these rock types, the results of these samples were subjected to a petrogenetic plot after Garrels and Mackenzie (1971). The plot of Na_2O/Al_2O_3 vs K_2O/Al_2O_3 (figure 10 and 17) divides the samples into two petrogenetic sources. All the samples plotted in the Sedimentary/Metasedimentary field confirming their sedimentary protolith while those in the igneous field confirms the igneous protolith. The plot of alumina saturation versus alkalinity (A/NK vs A/CNK) diagram (ASI) of Maniar and Piccoli (1989) classifies the diatexites and metatexites as peraluminous (Figure 12 and 16) which tends to suggest that these migmatites are S-type. To corroborate the classification of diatexites, and migmatites as peraluminous, the plot of SiO_2 vs TiO_2 (figure 9 and 18) after Tarney 1977 still confirms that majority of the migmatites are from sedimentary protolith or rich in crustal materials. The migmatites rocks of the study area show typical Archean Chondrite normalized REE distribution patterns, (figure 7 and 19) after McDonough 1989, all the diatexites and metatexites rocks show uniform pattern on spider plots, they show negative Ti and negligible negative Nb anomaly. The slight variation could be due to contamination during formation and P-T conditions during melt generation. In Total Alkali Silica plot (TAS), (figure 8,15 and 21) after Cox et al., 1979, all the samples plotted in the granite-Quartz diorite field shows a protolith with appreciable amount of silica content. The molecular plot of Al_2O_3/ (CaO + Na_2O + K_2O) versus SiO_2 after White and Chappel, 1977 (figure 23) showing majorly the nebulite plotting in the I-type field implies that the original magma from which the nebulites were formed contained great amount of granitic or crustal material.

VI CONCLUSION

The metatexites, diatexites, and nebulitic migmatites are the major rock types of the study area. Metasediments (schists and quartzites) are believed to be the parent rocks. As melting sets-in, the low fraction melt leads to the formation of metatexite, whereas the high melt fraction forms the diatexite migmatites. The samples showed distinctive morphological, mineralogical, and geochemical continuity sequence of formation as a result of mineral differentiation from each sample and partial melting. Based on the geochemical plots and REE signatures, fractional crystallization alone cannot account for these migmatites but rather partial melting and metamorphic differentiation are the major source of these migmatites. They are formed by partial melting of mafic rich protolith that were formed during the Pan-African orogeny. The behavioral trends of the rock groups and the variation of trace elements relative to compatibility show that the rock types are co-genetic and affected by the same geologic processes.

Acknowledgement

The author wishes to express his profound gratitude to Prof. Ahmad Isah Haruna, Head of Department, Applied Geology Department, Abubakar Tafawa Balewa University, Bauchi, Nigeria, for his support and thorough supervision during this research exercise. His appreciation know no bound to the entire members of staff and colleagues during and after the field work. This publication is derived from part of his postgraduate thesis.

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