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Geochemical Characteristics of Some Dykes around Sheikh Salem, Central Eastern Desert, Egypt.

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ABSTRACT

The area around Sheikh Salem is traversed by many dykes that extend for hundreds of meters to few kilometers; most of them have the NE trend. These dykes cut through the island arc metavolcanics and metagabbros, and are older than Sheikh Salem Younger Granite. The studied dykes are represented by basalts, basaltic andesites, andesites, dacites and rhyolites.

The present dykes, were evolved from primary medium to high-K calc-alkaline basaltic magma which undergone fractionation giving rise to intermediate and acidic varieties. Fractional crystallization seems to be the main role, yielding the more acidic types from the more basic parental melt.

The geochemical studies reveal that, the parent melt was enriched with LILE as well as HFSE, reflecting the role of subducted oceanic slab, and enriched sub-continental lithospheric mantle respectively, such geochemical characteristics indicate their eruption at active continental margin.

Key words: Dykes, Geochemistry, Pan African, Active continental margin, Sheikh Salem.

Introduction

A set of nearly parallel dykes cross the area around Sheikh Salem, which is covered mainly by metagabbros and represent the southern flank of the greatest metagabbro mass in the Southern Eastern Desert, extending from Wadi Mubarak to Wadi Dubr. The rocks in the area were studied by Amin et al., (1953), Amin, (1955), El-Ramly and Akaad, (1960), Akaad and Essawy (1964 & 1965), Essawy. (1967 & 1976), Hassan and Essawy (1977), Abu El-Leil, (1990), Mashaly, (1992) and Abu El-Ela, (1997). The gabbroic layered intrusion northwest of Mersa Alam is composed mainly of olivine gabbronorite, gabbronorite and gabbro. The intrusion was invaded by fine-grained gabbronorite dykes, as well as alkali basalt, trachy andesite and alkali rhyolite dykes. It was emplaced after the emplacement of the island arc metagabbro-diorite complex of Wadi Dabr and before the emplacement of the monzogranite pluton of Gabal Igla El Ahme, Abu Wl-Ela (1998). The metagabbros and diorites occurred near Marsa Alam (Wadi Dabr) in the Central Eastern Desert are represented by Rubshi Group and are suggested to be originated from subduction related magma and cut by rafts of dykes. Tawadros, (2012).

The present research is focused to clarify the geochemical characteristics of these dykes.

General geology and petrography

The area around Sheikh Salem is traversed by many dykes that extend for hundreds of meters to few kilometers; most of them have the NE trend. They are exposed in the northern and southern parts of the mapped area. (Fig.1). These dykes cut through the island arc metavolcanics and metagabbros, and older than Sheikh Salem younger granite.

In the Northern part of the area, the present dykes are: two basaltic dykes, trending N45^{o}E and N65^{o}E with average thickness of about ten meters and extend for 3-5 km. They are fragmented at the upper parts and show bifurcation and are dissected by minor faults. Two andesitic dykes are present in the eastern and in the middle parts of the mapped area trending N56^{o}E and N45^{o}E and extend for about 3 Km to 5 Km.

Acid dykes are represented in the area by rhyolitic dyke in the extreme eastern parts which trends N30^{o}E and dacitic dyke in the western parts trending N76^{o}E. In the Southern part of the area, the acidic dykes predominate than basic dykes and a set of parallel rhyolitic and dacitic dykes trending N65^{o}E is present near Idfu- Mersa Alam road and extend for about 3.5 Km.

Petrographically, the studied dykes are mainly basalts, basaltic andesites, andesites, dacites and rhyolites. Basaltic dykes are porphyritic basalts and diabase composed mainly of fresh plagioclase, pyroxenes, abundant iron oxides, and exhibit porphyritic texture with phenocrysts of labradorite, andesine and hornblende. Basaltic andesites and andesites are mainly porphyritic composed of andesine phenocrysts, hornblende, chlorite and iron oxides. Dacites are formed of plagioclase, potash feldspars, quartz and amphibole phenocrysts embedded in a

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finer grained groundmass. The plagioclase is characterized by albite twinning, quartz crystals are rounded with corroded boundaries due to the reaction with the groundmass, potash feldspars (sanidine) are less common. Rhyolites are composed of feldspars, quartz and hornblende, they exhibit spheriolitic texture through arrangement of the quartz crystals.

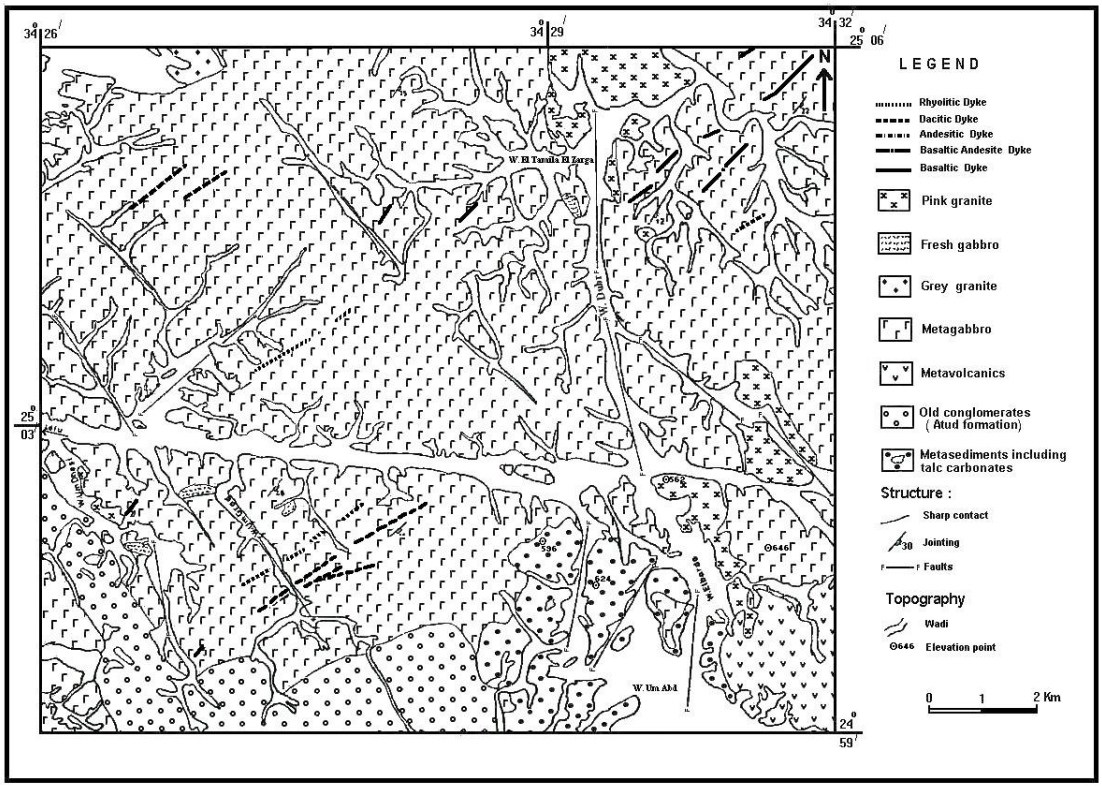

Fig. 1: Geological map of the area around Sheikh Salem.

The Geochemical Characteristics of the studied dykes

Fourteen fresh homogenous samples representing the different varieties of basic, intermediate and acidic dykes were selected for chemical analyses. The analyses were performed by the XRF techniques. The obtained chemical analyses and the calculated molecular norms (Barth, 1962 and Hutchison, 1974, the Fe_2O_3/FeO ratios after Middlemost, 1989) are presented in Table (1).

Chemical Classification

The studied dykes are classified into basalt, basaltic andesites, andesite, dacite and rhyolite according to total alkalis – silica diagram, (LeBas et al., 1986), (Fig. 2) and on the Zr/Ti versus SiO_2 diagram after Winchester and Floyed, (1977), (Fig. 3). The present dykes are also classified based on normative colour index and the normative plagioclase composition according to Irvine and Baragar (1971), (Fig. 4), basalts, andesites, dacites and rhyolites plot in their equivalent fields, the basaltic andesite plot in both basaltic andesite and andesite fields.

Nature of the magma:

The nature of the parent magma of the studied dykes is classified as sub-alkaline magma according to the total alkalis - silica diagram after Irvine and Baragar (1971), (Fig. 5). The sub-alkaline magma is further classified on the AFM diagram, (Fig. 6), most of the dykes plot in the calc alkaline field defined by Irvine and Baragar (1971), as there is continuous enrichment in alkalis and depletion in total iron and Mg contents from mare basic varieties (basalt and basaltic andesite) through intermediate (andesite) to more acidic types (dacite and rhyolite.)

Table 1: Major oxides (Wt %), Trace elements (ppm) and Molecular Norms.

Rock type	Basalt		Basaltic andesite						Andesite	Dacite		Rhyolite		
Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SiO_2	47.8	49.17	52.47	52.71	52.94	53.48	53.8	55.18	57.27	67.55	68.28	75.79	76.02	76.72
TiO_2	2.37	2.91	1.19	2.16	1.28	1.21	1.76	1.5	1.29	0.5	0.41	0.03	0.05	0.21
Al_2O_3	17.17	14.77	19.29	15.58	16.66	16.8	18.17	16.77	16.94	15.03	16	13.32	13.47	11.56
Fe_2O_3	1.94	2.6	1.77	2.21	1.64	1.83	1.98	1.75	1.52	0.8	0.56	0.23	0.37	0.86
FeO	9.71	13	5.89	7.37	5.45	6.11	6.6	5.85	4.36	1.99	1.4	0.46	0.74	1.72
MnO	0.16	0.17	0.12	0.12	0.13	0.12	0.14	0.13	0.1	0.04	0.04	0.02	0.01	0.03
MgO	3.78	3.89	3.05	4.08	5.17	5.06	3.6	4.42	3.53	1.98	0.65	0.05	0.12	0.11
CaO	7.11	6.34	7.09	6.36	8.54	8.11	8.84	6.93	5.97	3.14	2.24	0.14	0.31	0.34
Na_2O	3.62	2.77	3.75	3.21	4.25	2.96	3.48	3.71	4.01	4.41	6.06	4.27	4.11	3.99
K_2O	0.96	1.2	0.67	1.32	0.64	1.29	0.18	1.16	1.24	2.16	1.5	4.14	3.68	4.22
P_2O_5	0.65	1.22	0.19	0.59	0.17	0.22	0.38	0.23	0.36	0.1	0.1	0.01	0.02	0.02
CO_2	1.34	0.31	0.97	0.78	0.38	0.38	0.09	0.45	0.72	0.13	0.22	0.03	0.02	0
H_2O	3.98	2.83	3.91	3.86	2.86	2.78	1.82	2.51	2.84	2.18	2.43	1.36	1.45	0.27
Ba	559	479	181	426	142	443	198	449	507	512	451	1013	962	621
Cr	45	50	19	98	142	95	18	145	68	40	1	1	1	12
Ni	23	27	22	47	25	36	19	23	50	23	3	8	7	18
Co	35	1	35	36	32	22	29	34	19	7	6	6	8	4
Pb	8	25	10	3	2	10	9	3	3	47	3	36	14	9
Rb	29	38	11	52	6	28	2	24	32	49	38	434	288	57
Sr	851	558	500	625	450	494	431	478	505	247	232	10	77	19
Y	15	29	12	14	19	17	16	21	17	14	17	109	93	13
Zr	113	242	75	116	74	68	83	74	74	36	52	233	175	55
Th	4	3	2	9	3	3	9	1	1	6	8	53	34	12
Zn	113	141	75	116	74	68	83	74	74	36	52	233	175	55
Cu	3	1	1	46	3	3	16	3	17	29	22	28	26	66
La	24	40	3	3	2	3	5	6	16	4	12	7	2	12
Ce	113	104	22	61	9	50	82	42	102	79	33	58	49	40
Nb	51	31	6	10	5	9	8	10	18	8	9	98	92	8
Q	1.88	5.37	7.74	8.75	1.22	5.8	7.46	6.91	11.33	22.27	20.39	32.62	34.74	33.52
Or	5.92	7.45	4.1	8.18	3.85	7.83	1.08	6.99	7.51	13.05	8.99	24.93	22.13	25.33
Ab	33.94	26.15	34.89	30.24	38.86	27.3	31.85	33.97	36.89	40.4	55.17	39.08	37.57	36.4
An	23.55	22.63	28.81	24.5	24.95	29.53	34.08	26.19	23.27	14.39	9.2	0.45	1.3	1.19
Di	0	0	0	0	11.7	6.29	6.02	3.55	0	0	0	0	0	0.31
Hy	22.01	26.58	15.38	19.22	14.51	18.08	13.86	16.74	14.14	7.51	3.11	0.69	1.19	2
Ol	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mt	2.12	2.86	1.92	2.42	1.75	1.97	2.11	1.87	1.63	0.85	0.59	0.25	0.39	0.91
Il	3.45	4.26	1.72	3.16	1.82	1.73	2.5	2.13	1.84	0.71	0.58	0.04	0.07	0.3
Ap	1.42	2.68	0.41	1.1	0.36	0.47	0.81	0.49	0.77	0.21	0.21	0.02	0.04	0.04
Cc	3.54	0.82	2.54	2.07	0.98	0.99	0.23	1.16	1.87	0.36	0.56	0.08	0.05	0

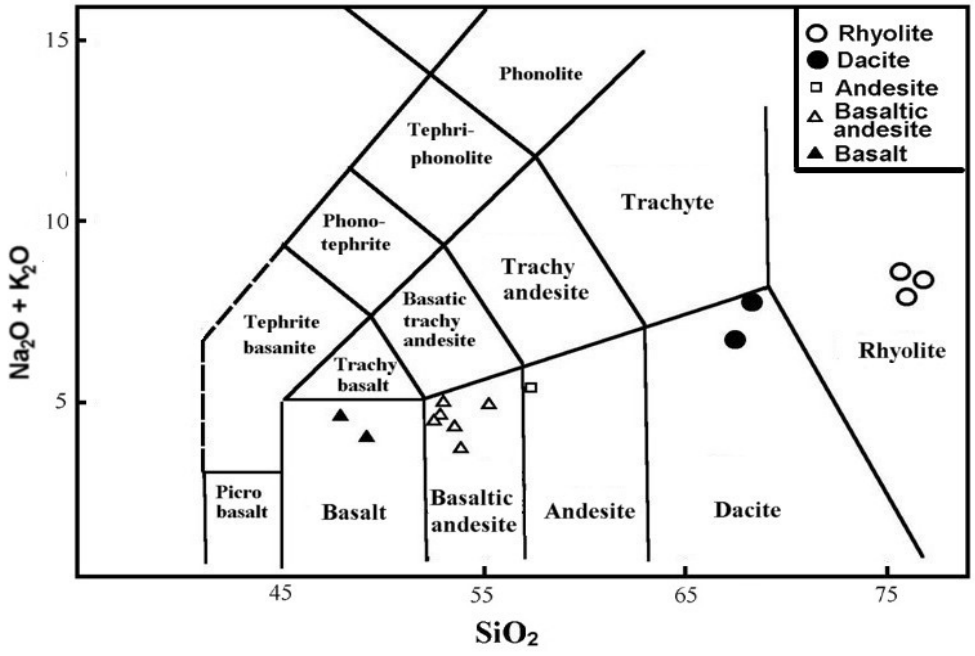

Fig. 2: Total alkali versus silica, (all in Wt %), classification diagram after Le Bas *et al*., (1986).

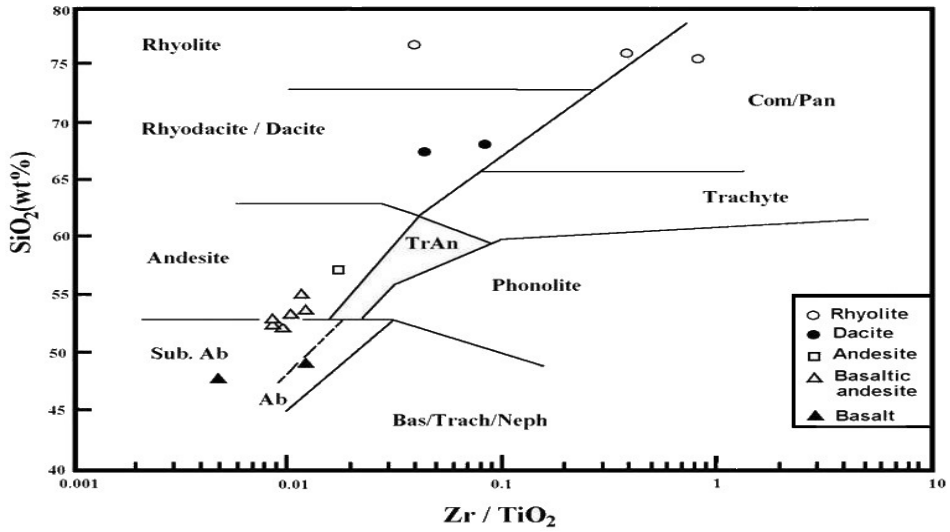

Fig. 3: Zr/Ti versus SiO_2 diagram after Winchester and Floyed, (1977).

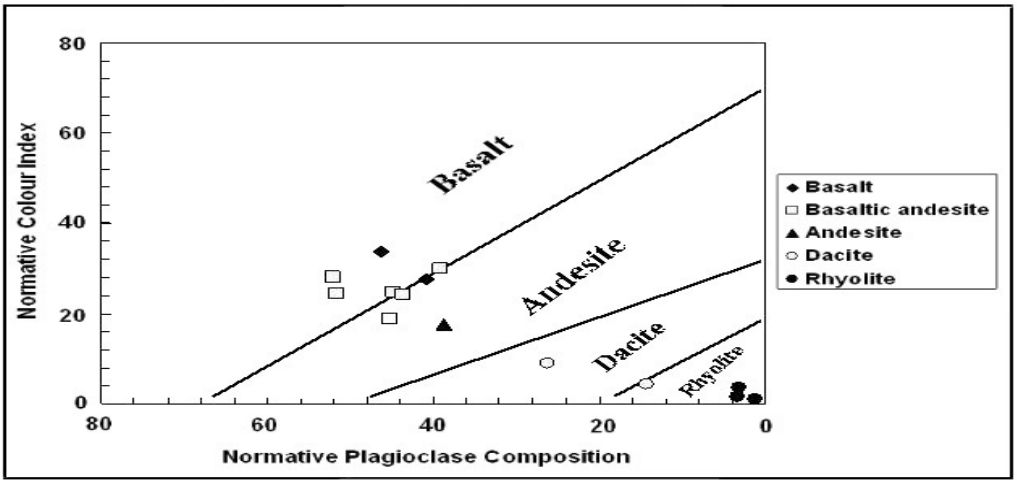

Fig.4: Normative colour index versus the normative plagioclase composition according to Irvine and Baragar, (1971).

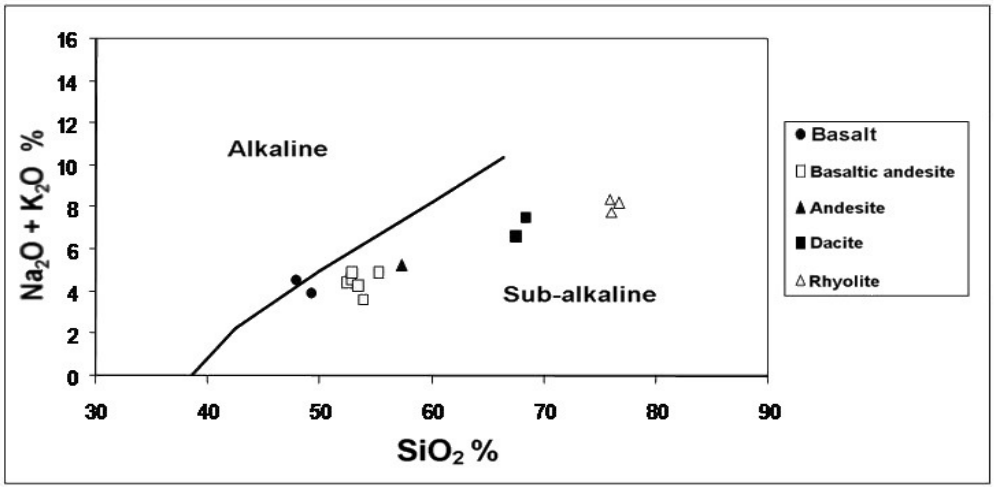

Fig. 5: Total alkalis - silica diagram after Irvine and Baraga, (1971).

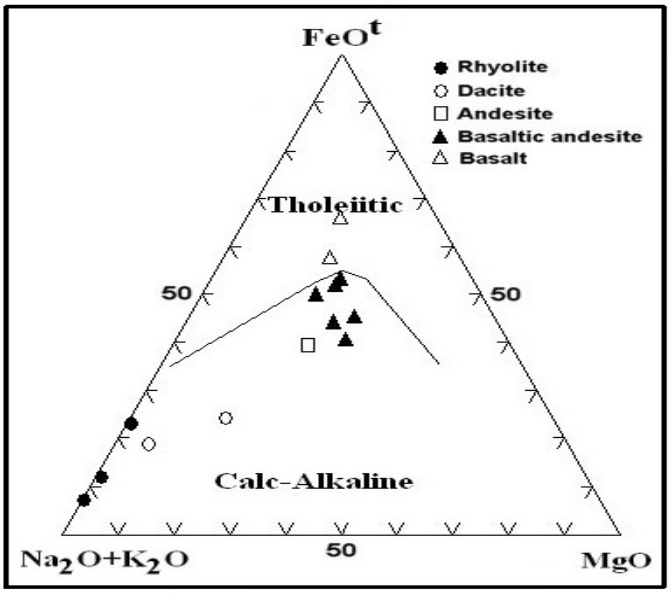

Fig. 6: AFM diagram, fields after Irvine and Baragar, (1971).

The basic and intermediate types of the present dykes are derived from medium-K rich magma according to K_2O versus SiO_2 diagram, (Le Maitre 1989), (Fig. 7), while rhyolites plot in the high-K calc-alkaline series, The medium-K calc-alkaline nature of the magma reflects the arc maturity as well as low to medium subduction rates, Kraus, *et al*., 2010.

Fractionation of the Magma

The fractionation trends of the parent magma show good coherence according to the Differentiation Index and the elements during the crystallization of the parent melt from basic to acidic phases, (Thoronton and Tuttle, 1960), Fig. (8). The content of the total alkali, Rb, Ba, Zr, Nb, and Y increase gradually with increasing the differentiation index from basalt, basaltic andesite to rhyolite. CaO, MgO, TiO_2, Sr, Cr, Ni, Co and Cu decrease with increasing differentiation index, La and Ce remain relatively more or less constant.

The concentration of the transition elements of the present dykes reflects the nature of fractionation of the parent melt from basic to acidic stages. According to Allegre *et al*., (1968), the contents of the transition elements are concentrated in mafic and solid phases and become impoverished in residual melts. Allegre and Minster, (1978), used Sc-Zn array of the transition elements normalized to chondrite values. The transition elements of the present dykes are normalized to chondrite (normalization values are after Wood *et al*., 1979 b) and plotted in Fig. (9). the resulted pattern shows W-shaped trend, exhibiting good successive parallelism from basalt, basaltic andesite to the more acidic members. Such parallelism indicates that during fractionation of the parental melt of the present dykes, the transition element contents gradually decrease and the troughs become deeper from basalts to rhyolites.

The deepening of the troughs correspond to Cr and Ni, with respect to other normalized elements, reflects the role of clinoyroxene and spinel for Cr and role of olivine for Ni.

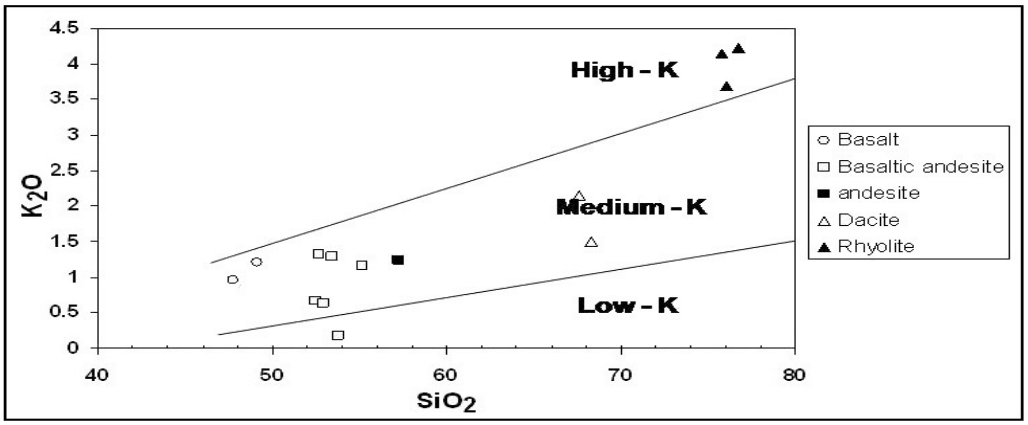

Fig. 7: SiO_2 Wt. % versus K_2O Wt. % for the studied dykes, boundaries after Le Maitre, (1989).

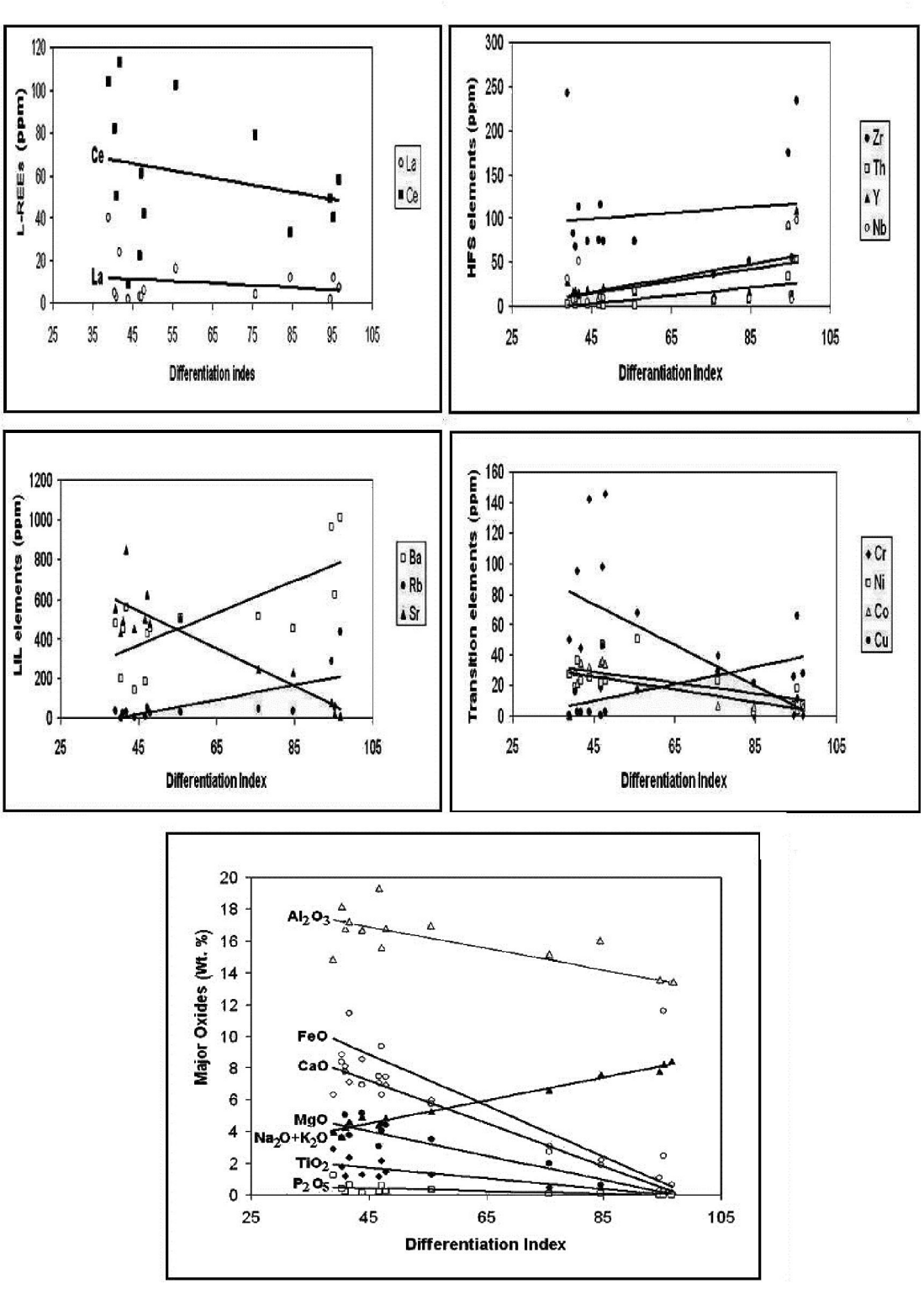

Fig. 8: The differentiation Index versus major and trace elements (Thoronton and Tuttle, 1960).

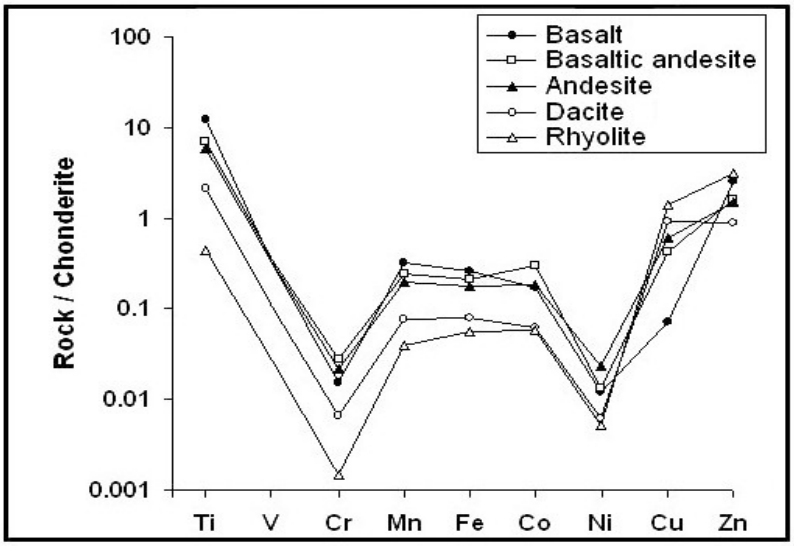

Fig. 9: Transition elements normalized to chondrite (normalization values are after Wood *et al*., 1979 b).

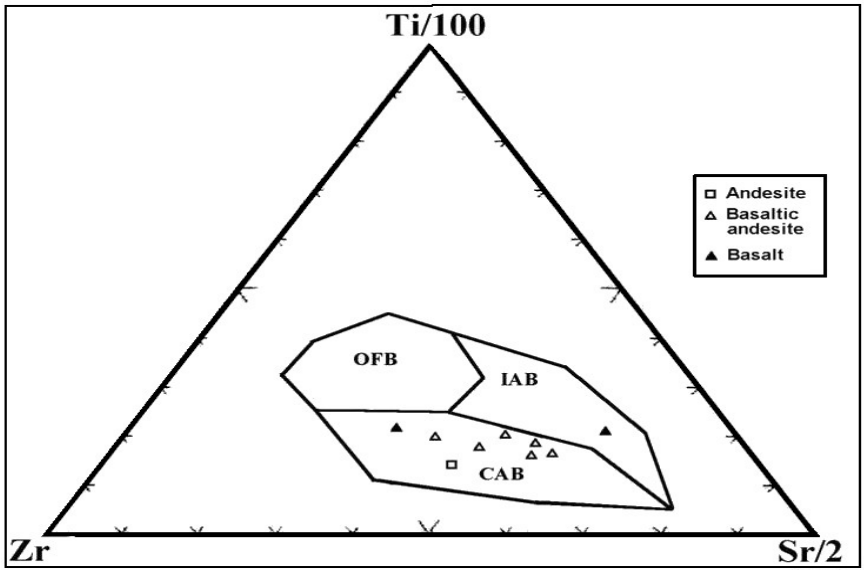

Fig. 10: Ti – Zr – Sr ternary diagram after Pearce and Cann (1973).

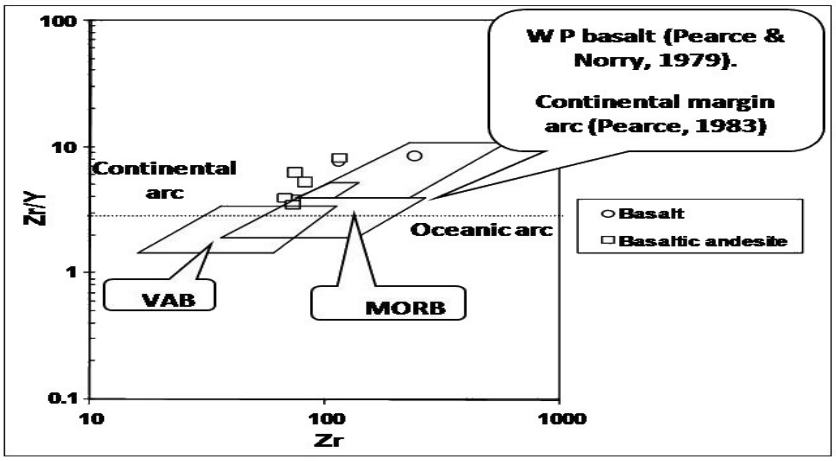

Fig. 11: Zr/Y versus Zr, boundaries after Pearce and Norry, (1979) and Pearce, (1983).

Tectonic setting

Pearce and Cann (1973), differentiated between ocean floor basalts, island arc basalts and calc alkaline basalts based on the ternary relation between Ti, Zr and Sr, (Fig. 10). The studied basic dykes plot in the calc-alkaline field.

Pearce and Norry (1979) used Zr/Y against Zr to discriminate between ocean island arc basalts, MORB and within plate basalts, Fig. (11), Pearce (1983), stated that "a more effective discrimination is done by Zr/Y ratio versus Zr (in Pearce and Norry, 1979) to explain the geochemical difference between MORB, ocean arcs and within plate ocean islands; however, it also produces a very effective discrimination between ocean arcs and active continental margin". Such discrimination is based on Zr/Y as a measure of within plate enrichment, and the within plate and active continental margin could be derived from the same enriched sources as the latter differing only in the contribution of the subduction component. Figure (12) represents the diagram of Pearce (1983), showing the plot of studied basalts and basaltic andesite dykes in the field of continental arc basalts.

In volcanic arc basalts, the chromium concentration is relatively low compared to other basalt types, as Cr is compatible in minerals such as olivine, pyroxenes and spinel in the basaltic melts, the low levels of Cr is either a function of mantle melting which is different from that of MORB or due to difference in fractionation history (Pearce and Gale, 1977, Garcia, 1978, Bloxham and Lewis, 1972 and Pearce 1982). Y is also depleted in island arc basalts relative to other basalts. The analyzed basalt and basaltic andesite dykes fall in the volcanic arc field in the Cr-Y diagram (after Pearce, 1982), (Fig. 12).

The studied basalts and basaltic andesite dykes are orogenic basalts according to the ternary relation FeO, MgO and Al_2O_3, (Pearce *et al*., 1977). The ternary relation discriminates between MORB, ocean island basalts, continental basalts, spreading center island and orogenic basalts, (Fig 13).

The relation between Ba and La differentiates between orogenic andesites (have a Ba/La ratio between 80 and 15), E-MORB and N-MORB (lies between 15 – 11 and 11 – 4 respectively), (Gill 1981). The earth's bulk Ba/La ratio is 11 (Anders, 1977), The E-MORB and N-MORB are from Wood *et al*., (1979 a & b). The studied andesitic dykes plot in the orogenic medium-K field of the Ba/La diagram, Fig. (14).

The present basaltic dykes are normalized to MORB (normalization values and ordering of elements are after Pearce, 1983). The present normalized basaltic pattern is compared with Andean type (Ewart, 1982), island arc calc-alkaline (Sun, 1980), island arc tholeiitic (Hawkesworh *et al*., 1977), and within plate alkaline (Thorpe *et al*., 1984), Figure. (15). The pattern of basaltic dykes shows an overall enrichment reflecting the role of sub-continental lithosphere and subducted slab respectively, such pattern is characteristic to those of active continental margins especially that of Andean range.

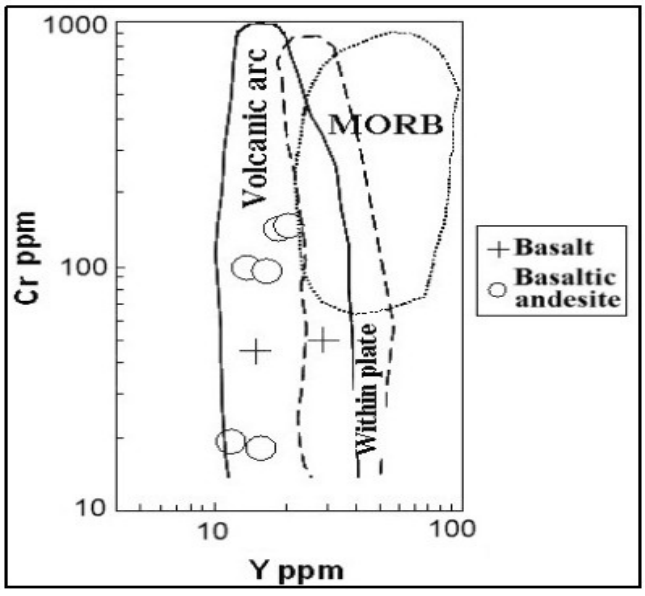

Fig. 12: Cr versus Y diagram, boundaries after Pearce, (1982).

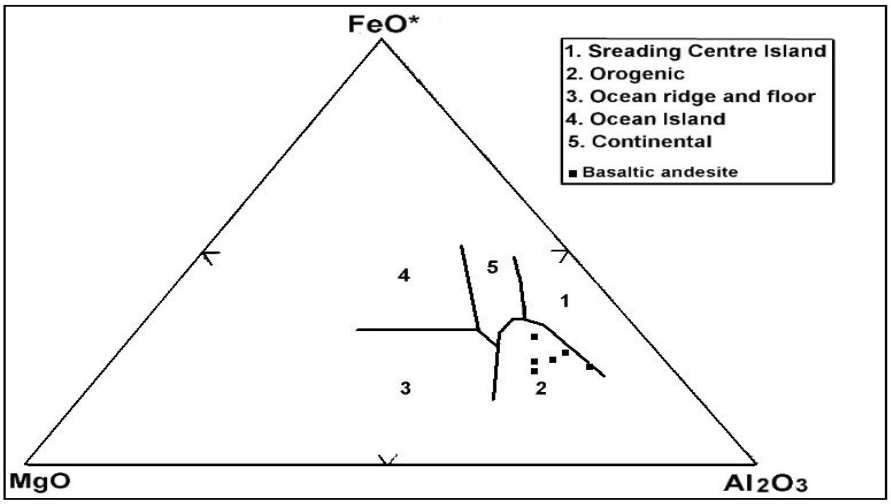

Fig. 13: FeO* (total iron as ferrous), MgO and Al_2O_3 ternary diagram after Pearce *et al*., (1977).

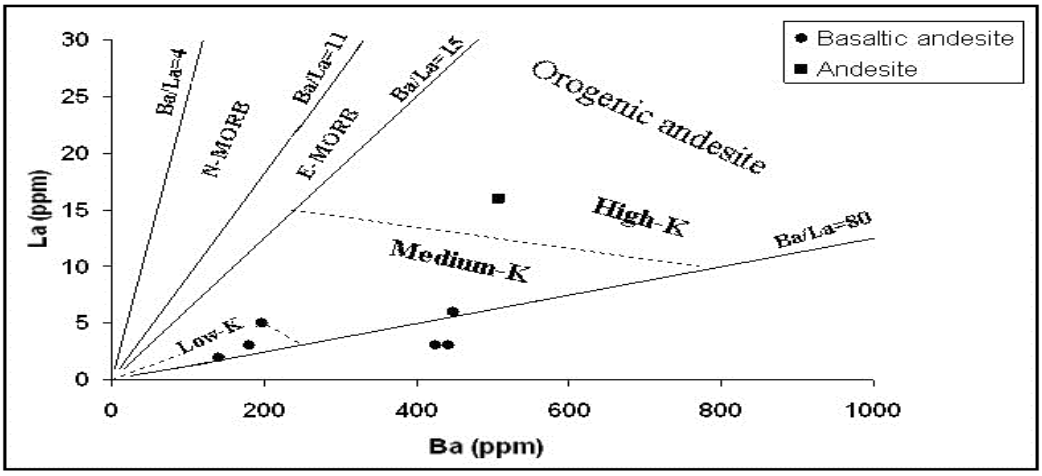

Fig. 14: La versus Ba discrimination diagram, Gill (1981).

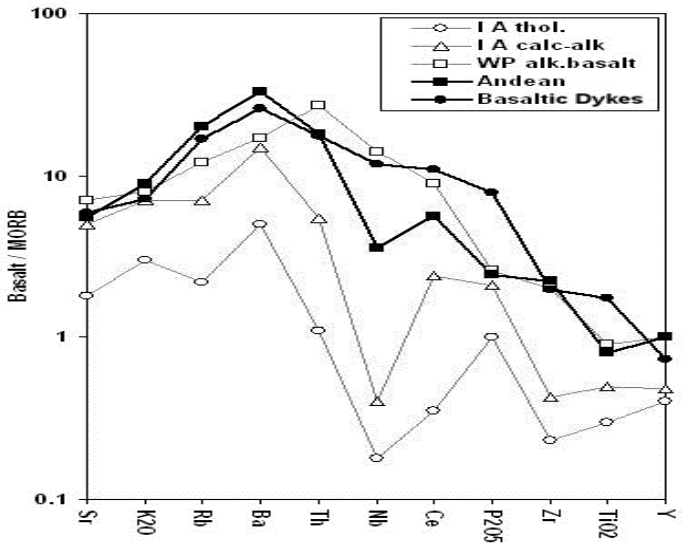

Fig. 15: The studied basaltic dykes normalized to MORB (normalization values and ordering of elements are after Pearce, 1983), compared with island arc calc-alkaline basalt, island arc tholeiitic basalt and within plate alkaline basalt.

The role of both subduction zone component and the within plate component is also recognized on the, MORB normalized basaltic andesite and andesitic dykes patterns, (normalizing values are after Pearce, 1983). The basaltic andesite normalized pattern is compared with Andean basaltic andesite, (Ewart, 1982), North volcanic zones of Andes (Marriner and Milward, 1984), Central volcanic zone of Andes (Thorpe *et al*., 1984) and South-west Pacific (Ewart, 1982), (Fig. 16). While the andesite normalized pattern is compared with island arc andesite, Andean andesite and anorogenic andesites (data from Ewart, 1982), (Fig. 17). Both basaltic andesite and andesitic patterns are more akin to those erupted at active continental margin of Andean type.

The thickness of the continental crust affects the contents of transition elements (Zn, Ni, Cr, Co, Cu and Ti) as their contents increase with increasing the continental crust thickness, Bailey (1981). The transition elements of the present andesitic dykes are normalized to low-K oceanic island arcs, and compared with Andean continental arc (thick continental crust) and continental island arcs (thin continental crust), and ocean island arcs, (Fig. 18). The present andesitic dykes are erupted through subduction under a thick continental crust.

The present dacites and rhyolites MORB normalized patterns show enrichment in both LIL and HFS elements except for P and Ti with respect to MORB, these anomalies characterize the orogenic dacites and rhyolites. The within plate acidic rocks are enriched in Rb, Th and Nb and depleted in Sr, Ba, P and Ti. The present dacites and rhyolites MORB normalized patterns, (normalization values and ordering of elements are after Pearce, 1983), are compared with continental margin arcs rhyolites (Ewart, 1979), oceanic island arc rhyolites (Weaver *et al*., 1979) and within plate rhyolites (MacDonald *et al*., 1987), (Fig. 19). The present MORB normalized acidic rocks are close to those erupted in active continental margin arcs.

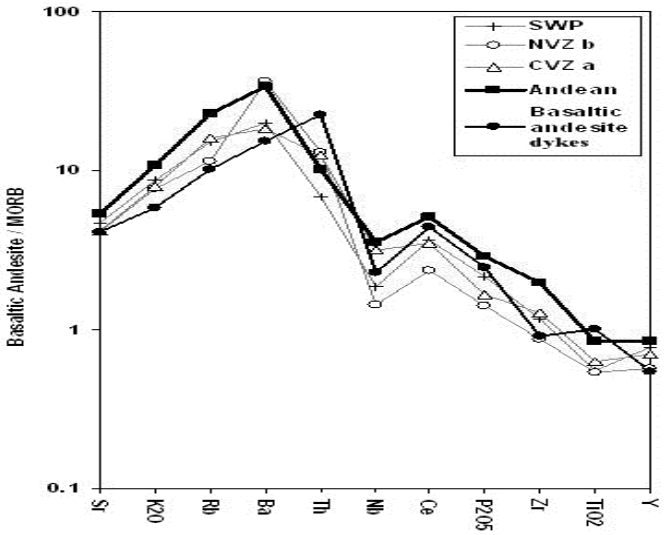

Fig. 16: MORB normalized basaltic andesitic dykes (normalizing values are after Pearce, 1983) compared with Andean basaltic andesite, North volcanic zones of Andes, Central volcanic zone of Andes and South-west Pacific basaltic andesite.

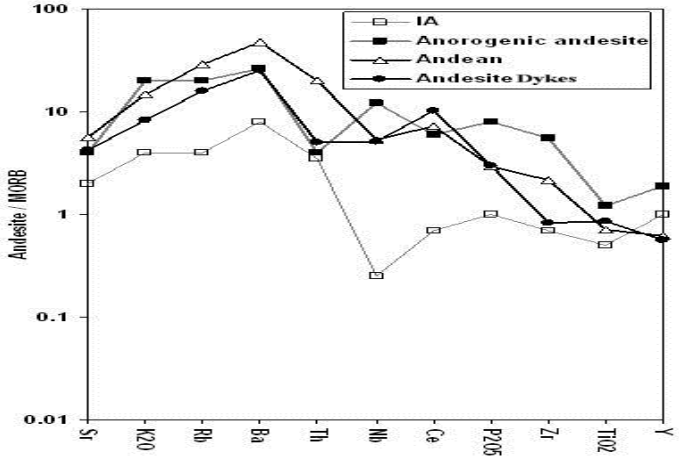

Fig. 17: MORB normalized andesitic dykes (normalizing values are after Pearce, 1983), compared with island arc andesite, Andean andesite and anorogenic andesites.

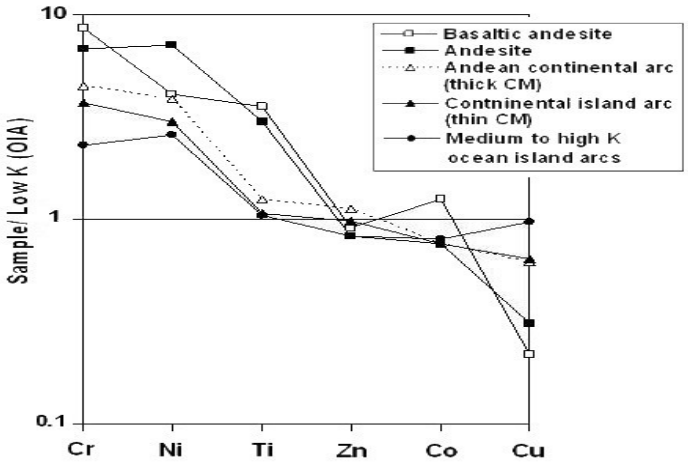

Fig. 18: The transition elements of the present intermediate rocks normalized to low-K oceanic island arcs compared with Andean continental arc (thick continental crust), continental island arcs (thin continental crust), and ocean island arcs. Data and normalizing values are after Bailey (1981).

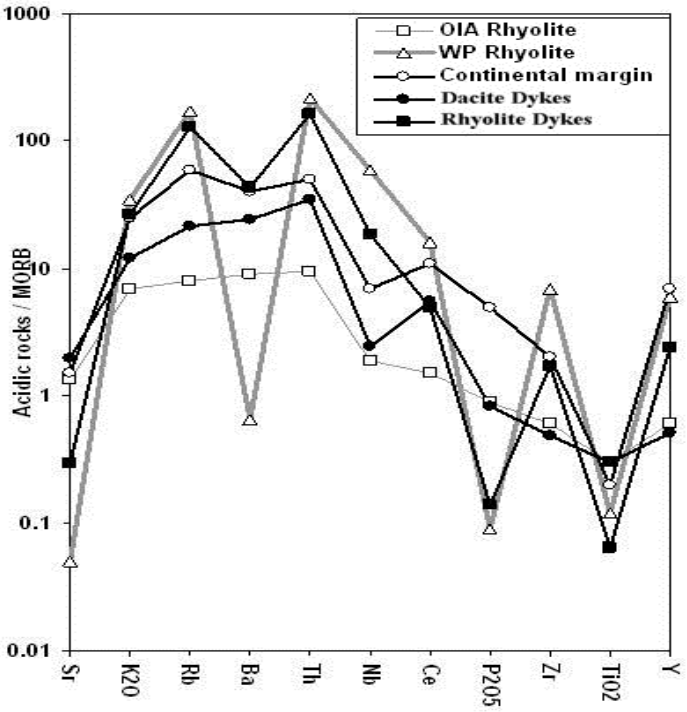

Fig. 19: MORB normalized dacitic and rhyolitic dykes, (normalization values and ordering of elements are after Pearce, 1983), compared with continental margin arcs, oceanic island arc rhyolites, within plate rhyolites.

Discussion and conclusion

The present dykes at Idfu – Marsa Alam Road are represented by basic, intermediate and acidic varieties, evolved from primary calc-alkaline basaltic magma which undergone fractionation giving rise to intermediate and acidic varieties. Tectonically, the present volcanic dykes erupted at active continental margin regime more akin to that of Andean type.

Fractional crystallization played the main role, yielding to the eruption of the more acidic types from the basic parental melt.This is indicated from the inter elements variation diagrams as well as from the chondrite normalized transition elements, which showed a successive parallel patterns from basalt, to the more acidic members, the successive depletion in Cr reflects the role of clinopyroxene and spinel, while, the successive depletion in Ni reflects the role of olivine.

The active continental margin as a tectonic setting for the present dykes is indicated from the enrichment of the parent magma with LILE reflecting the role of the subducted oceanic slab component. On the other hand,

the produced magma was enriched with HFSE reflecting the role of the enriched sub-continental lithospheric mantle or the so called within plate components. The medium-K calc-alkaline nature of the magma reflects the arc maturity as well as low to medium subduction rates, Kraus, *et al*., 2010.

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