

Geochemistry of Some Tertiary and Early Cretaceous Basaltic Exposures around Gulf of Suez (Emphasis on Significance of High Field Strength Elements and their Ratios), Egypt

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Abstract: The significance of Nb, Zr, Y, Ti, and REE and the use of their ratios in the Tertiary and Early Cretaceous basalts of Egypt have not been previously noted. The study deals with three basaltic occurrences around Gulf of Suez representing two episodes. Tertiary basalt of Abu Zenima and Ehamer areas show within plate continental/oceanic transition setting and tholeiitic. Early Cretaceous basalt of Abu Darag area are alkaline and within plate continental. In terms of high field strength elements and REE abundances and their ratios, some geochemical constraints has been revealed: 1- The Y/Nb, Zr/Y, Zr/Nb and LREE/HREE of Tertiary basalts are more comparable but differ than the Early Cretaceous one suggesting two mantle sources; 2- K_2O , Na_2O , Nb, Zr, La/Sm and LREE/HREE of the Early Cretaceous basalt are higher than those of Tertiary one suggesting enriched mantle source or small degree of partial melting at greater depth; 3- The chemical weathering has increased LOI, MgO and K_2O and decreased CaO from the marginal part of the Abu Darag basaltic dyke, upper part of Abu Zenima flow and Ehamer dyke, 4- The Early Cretaceous basalt shows a greater crustal contamination than Tertiary one as indicated from, higher K_2O/P_2O_5 , Rb and Th and Lower Zr/Nb, and TiO_2/P_2O_5 than Tertiary one.

Keywords: basalt, Tertiary, Cretaceous, high field strength elements, REE.

1. Introduction

The preliminary review of the Egyptian basaltic rocks indicates that, they have been situated in different tectonic environments and different episodes. The comparing their characteristics with world's basalts, caution must be taken in consideration as the present is the key of the past for Phanerozoic less than 600 Ma, i.e.: generation processes of basaltic magma may differ in the rates of formation than the present because the geothermal gradient in past (Archaean) are more steeper, the mantle compositions are changed with geological times and the crust thickness are increased with time [1]. The review of different basalt occurrences in Egypt resulted in the following geochemical characteristics, 1-The Tertiary basalts show tholeiitic/alkaline and oceanic/continental transitional characters for most occurrences in the northern part of Egypt [2]. Some Tertiary basalts show alkaline nature (e.g. The Bahariya basalts show alkaline and continental type and those of south Quseir is of low TiO_2 , alkaline and oceanic/continental setting). As well as the basalts of El Minya are of high TiO_2 and continental type. Stratigraphic and/or petrographic similarity of all Cairo-Suez basalts, Abu Zaabal and Qatrani tends to indicate only one phase of magmatic activity, emplaced along the faults that affected the area during the Oligocene [3]. 2-The Early Cretaceous basalts of Abu Darag areas is continental and alkaline [4], but the Early Triassic basalts of Farsh el Azraq and Wadi Iqna and middle Jurassic basalts of Wadi Abu Natash and Wadi Budra are mildly alkaline [5]. The basalt

ages are after [6]. [7] Give geological studies of some basalt in southwest Sinai.

HFSE include Nb, Ta, Y, Zr, P, Hf, Eu, Lu, Th, La, U, W. Zr is more incompatible than Ti [8]. Precise determination of these elements and their ratios provide sensitive signatures on characterizing mantle reservoir, crust genesis and subduction magmatism [9]. The present work is aimed to determine the significance of high field strength elements and their ratios for some basaltic rocks of different episodes around Gulf of Suez in Egypt (Fig. 1).



Figure 1: Location map of study basalt occurrences at Abu Zenima, Ehamer, and Abu Darag around Gulf of Suez.

2. Sampling and Analytical methods

2.1 Sampling

More than 30 thin sections have been selected from 300 hand specimens for petrographic investigation. 17 representative samples are subjected to XRF method for major and trace elements analysis. The REE of 4 samples are measured using ICP-OES method.

2.2 X-ray Fluorescence Analysis (XRF)

The XRF analysis was carried out at Central Laboratories Sector of the Egyptian Mineral Resources Authority, Ministry of Petroleum, Cairo, Egypt. 17 samples are selected for major and trace elements analysis. (5 from Abu Zenima basalt, 6 from Ehamer basalt and 6 from Abu Darag basalt). The powder (< 74µm) samples are subjected to XRF analysis using X-Ray fluorescence equipment PW 2404 with six analyzing crystals. Crystals (LIF-200), (LIF-220) were used for estimating Ca, Fe, K, Ti, Mn and other trace elements from Nickel to Uranium while crystal (TIAP) was used to determine Mg and Na. Crystal (Ge) was used for estimating P and crystal (PET) for determining Si and Al and PXL for determining sodium and magnesium. The concentration of the analyzed elements is determined by using software Super Q and Semi Q programs with accuracy 99.99% and confidence limit 96.7%. The estimation of the major and trace elements were done as powder pellets (Pellets method) which were prepared by pressing the powder of the sample in Aluminum Cup using Herzog presser and 10 ton pressure. On the other hand using fusion method in platinum crucible (Bead method) gives better results for light elements measurements, but owing to presence of phosphorus in phosphate and sulfur in sulphides in the sample which led to corrosion in platinum crucible, we used the pellet method as mentioned above.

2.3 ICP-OES Analysis

The REE analysis of the four basalt samples were performed using a simultaneous inductively coupled plasma emission spectrometer (720 ICP-OES) (Agilent technologies). Sample powders (0.5 gm.) were sealed in a Teflon cup and digested in 5 ml nitric acid, 3 ml per chloric acid and 15 ml hydrofluoric acid and put in hot plate for 4 hours till complete digestion, then add 5 ml of hydrochloric acid to give clear soluble solution. The techniques used (XRD and ICP-OES) are performed at Central Laboratories Sector of the Egyptian Mineral Resources Authority, Ministry of petroleum, Cairo, Egypt.

3. Field Geology

3.1 Abu Zenima basaltic outcrop

The basaltic rocks near Abu Zenima city (Lat. 29° 4' 10"N and Long. 33° 5' 50"E) occurs as an inclined sheet (~20 m thick) (Fig.1), marked by three colors; black for the lower part, brownish for the middle and greenish for the top of the sheet due to the oxidation, carbonation and hydration of

sulphide and oxide minerals. The upper part is highly vesicular. The vesicles are filled with calcite, epidote and quartz and found as green amygdalae reaching in size up to 2 cm (Fig.2c). Cu sulphate and Cu carbonate is responsible for the green coloration of the upper part of the basaltic sheet. Iron hydroxide stained the middle part of the basaltic sheet by brownish color. The bottom part of the sheet is more or less fresh. Columnar joints are found, and partly weathered giving rounded blocks present as Paranoiac statues carved into the mountain (Fig 2d). The above description indicates that the basaltic sheet of Abu Zenima is subareal flow, covered unconformably by conglomerate beds of Nuchal Formation, and composed essentially of rounded fragments of limestone, sandstones, and cherts (Fig.2a), belonging to Miocene age. They are neither stained by reddish colors nor thermally affected. The basaltic sheet is underlain by marly sand bed of Eocene age with a small outcrop of a conglomerate bed of upper Eocene (the upper bed of Typa Formation) and stained by reddish and grayish colors (Fig.2b). The conglomerates are composed of reworked rounded polders of limestone. The polders are hard due to thermal effect and rich in Numulites and Discocyclina with microcrystalline matrix. [10] Write that, on the Sinai margin in the type section of Abu Zenima, the red beds are capped by a basalt flow, K/Ar dated at 22 Ma and Abu Zenima area comprises two main events of basaltic intrusions. i) Middle Jurassic basalts in Wadi Budra, (Lat.28° 4' N, Lon.33° 30' E); and, ii) Oligocene-Miocene rocks from Wadi Nukhul, (Lat.29°02' N, Long. 33° 16' E).

3.2 Ehamer basaltic outcrop

The basaltic rocks at Ehamer area, near Ain El Sokhna (Lat.29° 34' N and. 32° 22' E) is exposed as large mass (~300 m²) or plug, intruding the limestone strata. The rocks are black and fine- to medium grained. Cuboidal joints are pronounced and evolved to spheroidal blocks with weathered surface giving onion structure (Fig.2g). Rounded white xenoliths of carbonate minerals are found through the basalt plug (Fig.2f). The plug is dissected by thin basaltic dyke (~1 m thick), found as black ridge (Fig.2e). The country limestone is thermally metamorphosed to marble (calcitic type as determined by XRD and DTA analysis).

3.3 Abu Darag basaltic outcrop

The basaltic rocks at Abu Darag area (Lat.29° 24' N and Long. 32° 30' E) are found as thick dyke (~10 m width), trending northwest and intruding sandstone beds of upper Carboniferous-lower Permian, for about 300 m length. It is exposed as high ridge (~12 m height) (Fig.2 h). Their sides and country rocks are covered by black fragments of basalts. The intruded sandstone is stained by reddish brown color of iron oxides and weakly affected by thermal metamorphism. The basalt dyke margins are very fine-grained and vesicular.

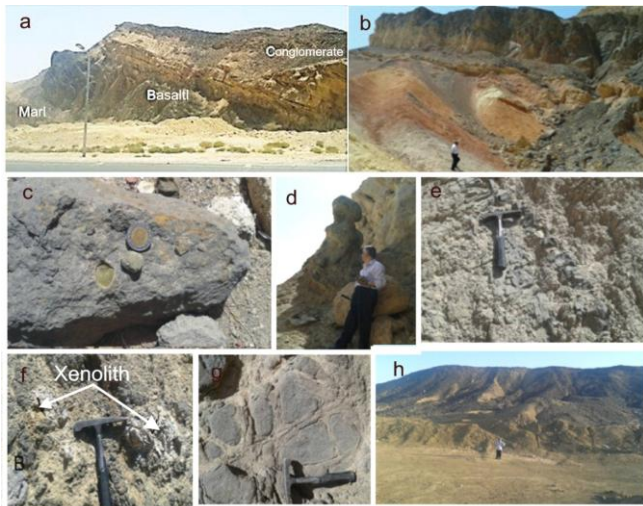


Figure 2: Field photos of, a) Abu Zenima basaltic sheet covered by conglomerate bed; b) Stained marly sand underlie basalt sheet; c) Rounded amygdale in basalt; d) Weathered basalt blocks as Paranoiac statues carved into the mountain; e) Ehamer plug dissected by thin basaltic dyke; f) White carbonate xenoliths in Ehamer basalt plug; g) Onion structure of Ehamer basalt showing spheroidal plucks; h) Thick basalt dyke at Abu Darag area.

4. Petrography

4.1 Abu Zenima basaltic sheet

The basalt rocks are composed essentially of plagioclase, pyroxene and olivine. Iron oxide is common accessory (~2%) but iddengesite, calcite and hydrous iron oxide are secondary minerals. High temperature SiO₂ polymorph (crystobalite) is determined by XRD. The rocks of the upper parts of the sheet are marked by numerous vugs and vesicles filled by quartz, calcite and copper minerals may be Cu sulphate and/or Cu carbonates, found as green patches in layering as a result of deposition from solution (Fig.3c, f). Some calcite filling vesicles encloses euhedral opaque crystal of columbite? (Fig. 3a, b). Plagioclase is found as lathes up to 0.5mm length, exhibiting normal and oscillatory zoning (Fig.3g). Lamellar and compound albite- carlsbad twinning are found. Plagioclase phenocrysts (An 50%) are common and some crystals penetrated by green patches of sulphate mineral along the twin planes and cracking. Most plagioclase phenocrysts are rimmed by thin mantle of albite. Olivine crystals are common as phenocrysts. The olivine phenocrysts in the upper parts of the sheet are smaller in size, strongly altered to red brown patches of iddengesite (Fig. 3c). Olivine crystals in the middle part of the basaltic sheet is weakly altered (Fig.3h, i) while that of the lower part is mostly fresh (Fig. 3j). Pyroxene is of diopside and augite in composition. Some show simple twinning (Fig.3k), and eight sided crystal, sometimes found in aggregate forming a glomeroporphyritic texture (Fig.3 l). Pyroxene crystals show pale brown tint with two sets of cleavage at 90° and enclose lathes of plagioclase in ophitic fashion (Fig.3d). Iron oxides are common, as black anhedral to subhedral grains up to 0.5 mm across. Chemical weathering resulted in producing solution rich in Fe, Mn, and Ca. Such solutions favored the leaching of Nb from the host basalt and redeposited in vugs and vesicles giving

amygdales of calcite enclosing some euhedral crystals of columbite. [11], write that, "The hydrothermal fluids are inferred to have been F- and CO₂ –rich with variable levels of Ca activity, and with *f*O₂ mainly between nickel-nickel oxide and magnetite –hematite buffers. This occurrence represents a new genesis for a columbite –group mineral. Columbite {(Fe, Mn)₂(Nb, Ta)₂O₆} is a typical product of the hydrothermal alteration of pyrochlore in many carbonatite, including calcitic and alkali carbonatite and also basaltic melts extract both Nb and Ta elements.

4.2 Ehamer

4.2.1 Basaltic Plug

The rocks are black to dark brownish grey, hard, and medium grained. They are composed essentially of olivine, pyroxene and plagioclase. Iron oxide as accessory and iddengesite is secondary. Olivine is found as small rounded grains and as coarse euhedral crystals up to 0.1 mm across. Olivine forms about 10% of the bulk composition of the rock. Pyroxene is common about 40 % and found as anhedral and euhedral grains with pale brownish tint. The extinction angles are about 35°. The crystals are weakly pleochroic and show cleavage in two directions at right angles. Pyroxene is of augite type as determined by XRD. Most grains enclose some plagioclase crystals in ophitic fashion (Fig.4c, d, e). Zoning is common. The core is calcic and the outer zones show oscillatory zonation. Plagioclase is found as tabular crystals up to 0.2mm width and 5 mm length (Fig.4a), forming about 45%. They form with pyroxene and olivine an intergranular texture (Fig.4b)). Most grains are fresh and show lamellar and compound albite-carlsbad twinning (Fig.4a). The extinction angle gives anorthite content of about 50% (i.e. anorthite and labradorite composition as indicated by XRD. The intruded country rock is limestone, thermally metamorphosed to calcite marble. The latter is hard, grey in color, and medium grained. It is composed of calcite grains. They found in mosaic aggregate as a result of thermal metamorphism by basaltic plug. Carbonate xenoliths within the basaltic plug are white, fine grained, massive and soft. They are composed essentially of fine grains (less than 0.01mm) with some rounded crystals of calcite (up to 1 mm across).

4.2.2 Phase (2) basaltic dyke (dissecting basaltic plug)

The rocks are black, hard and very fine grained and composed of olivine, pyroxene and plagioclase as essential mineral. Iron oxide is accessory. Iddengesite, chlorite, talc and antigorite are secondary. Plagioclase of the groundmass is very fine laths < 0.01 mm. Plagioclase phenocrysts found as lathes < 0.1mm in length. Some show zoning and compound twinning (Fig.4f, g). Pyroxene is found as phenocrysts up to 1mm and in aggregate forming glomeroporphyritic texture. The grains show two sets of cleavage and weak pleochroism from colorless to pale brownish yellow. Some pyroxene crystals show simple twinning and hourglass zoning. Olivine is found as euhedral phenocrysts, partly altered to talc, antigorite and iddengesite minerals as pseudomorph grains.

4.3 Abu Darag basaltic dyke

The basaltic rocks of Abu Darag dyke show some zonation (core and margin rocks). The core is hard, black, fine grained and massive. It is composed of olivine phenocrysts (up to 0.5 mm across) as fresh euhedral crystals. Some grains shows alteration to chlorite, antigorite and iddingsite along Y-cracks (Fig.4h, i). The olivine grains are set in a very fine grained groundmass of plagioclase laths <0.01 mm) and granules of iron oxide and pyroxene (Fig.4h, i). The plagioclase and pyroxene are of anorthite and augite respectively as determined by XRD. Some quartz xenoliths are recorded and surrounded by reaction zone of pyroxene granules (Fig.4j, k). The marginal basaltic rocks are brownish black in color and vuggy or vesiculated. Vugs or vesicles are empty and sometimes filled with calcite and /or quartz. Olivine is found as small grains, strongly altered to iddingsite and antigorite fibers set in a very fine to glassy groundmass. The latter is composed of pyroxene, fine lath of plagioclase and iron oxides. Quartz xenolith in the marginal rocks do not show reaction zones (Fig.4l). The country rocks are hard sandstone, composed of clear grains of rounded quartz cemented by clear calcite crystal and stained by reddish colors of iron oxides, suggesting weak thermal metamorphism.

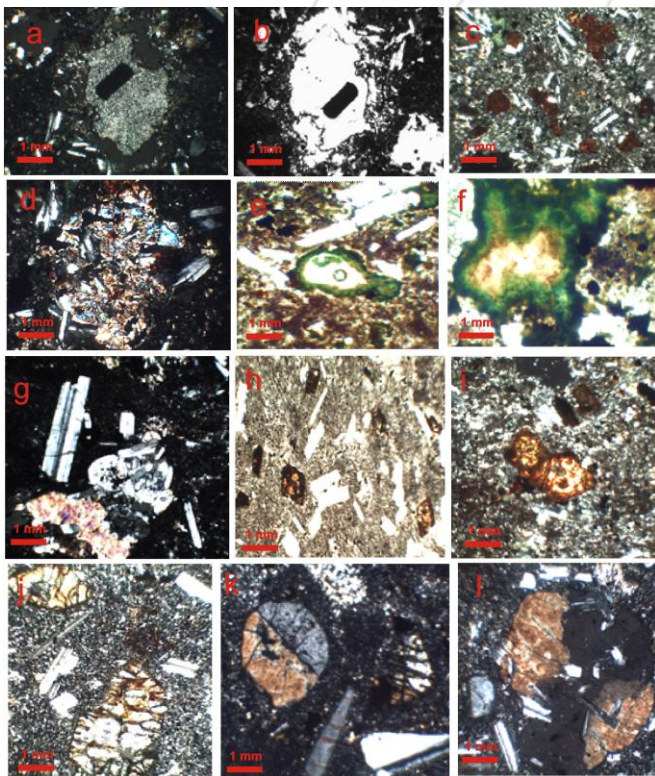


Figure 1: Photomicrographs of the study basaltic rocks of Abu Zenima, showing, a) A columbite crystal hosted in calcite filling vesicle under crossed polars; b) The same photo under ppl; c) Olivine crystal, completely altered to iddingsite; d) Augite phenocryst sieved by plagioclase lathes in ophitic fashion; e and f) Vesicles filled by zoned hydrothermal minerals of calcite core, Cu-sulphate and Fe-oxide mantle; g) Plagioclase phenocryst; h and i) Phenocrysts of olivine partly altered to iddingsite from the middle part of the basalt sheet; j) Fresh olivine phenocryst from the lower part of the basalt sheet; k) Augite phenocryst

,showing simple twinning; l) Augite in aggregate giving glomeropheric texture.

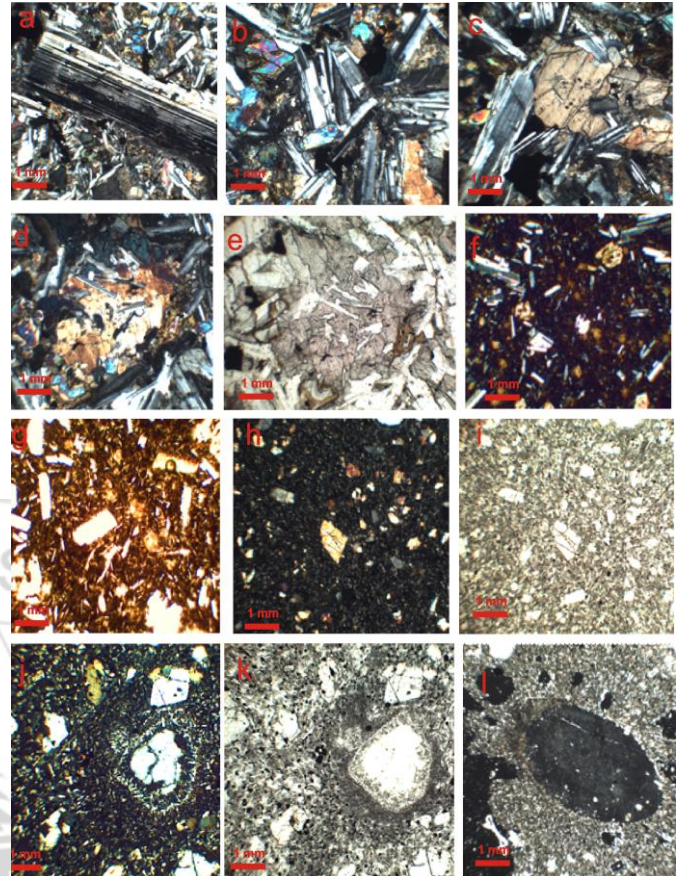


Figure 4: Photomicrographs of Ehamer and Abu Darag basalts, a) Plagioclase phenocrysts in basalt of Ehamer plug; b) Intergranular texture from Ehamer basalt plug; c, d, e) Augite phenocrysts enclosing plagioclase in ophitic texture from Ehamer basaltic plug; f, g) Fine grained porphyritic basalt with phenocrysts of plagioclase, olivine and pyroxene from the basalt dyke dissecting Ehamer basalt plug; h, i) Phenocrysts of olivine from Abu Darag basalt under C.N. and PPL.; j, k) Quartz xenoliths from the core of Abu Darag basalt dyke, showing reaction zone; l) Rounded quartz xenolith from the margin of Abu Darag basalt dyke without reaction zone.

5. Geochemistry

The major and trace elements analysis of 17 representative samples is presented in Table (1) together with REE analysis for 4 samples (Table 2).

5.1 Geochemistry of Abu Zenima basalts

The chemical analysis of the three parts of basaltic sheet is shown in Table 1. The basalts of the upper part are enriched in SiO₂, K₂O, LOI and Rb. The lower part of the basaltic sheet has high abundances of Al₂O₃, Na₂O, Cr, Ba and Th.

Table 1: Geochemical analysis of some Tertiary basalts at Abu Zenima and Ehamer and Early Cretaceous basalts at Abu Darag areas exposed around Gulf of Suez, Egypt

** samples	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Major Oxides (Wt %)																	
SiO ₂	48.34	50.1	47.7	46.15	48.1	47.89	49.23	50.67	44.86	46.8	48.63	43.55	45	47.39	45.85	47.5	49.44
TiO ₂	2.27	2.1	2.48	2.71	2.5	2.74	2.51	2.9	3.17	2.9	2.76	2.25	2.06	1.92	2.52	2.32	2.11
Al ₂ O ₃	11.36	11.2	13.61	13.85	13.7	14.63	14.5	14.33	12.28	12	11.74	12.66	12.6	12.33	12.16	11.9	11.72
Fe ₂ O ₃	13.21	13.1	12.86	12.98	13.1	13.22	13.06	12.92	14.66	14.5	14.22	13.97	13.9	13.16	10.25	10.06	9.87
MnO	0.02	0.01	0.01	0.03	0.02	0.04	0.03	0.02	0.03	0.02	0.01	0.04	0.03	0.02	0.03	0.02	0.01
MgO	6.23	6.26	6.19	6.4	6.21	6.73	6.56	6.39	8.91	8.8	8.55	9.95	9.7	9.45	11.46	11.26	11.02
CaO	11.75	11.4	12.1	13.25	12.65	10.52	10.39	10.21	9.8	9.6	9.39	11.02	10.9	10.62	9.2	8.97	8.74
Na ₂ O	1.89	1.71	1.92	2.19	1.98	2.18	1.96	1.87	1.71	1.52	1.27	2.72	2.56	2.36	2.77	2.7	2.49
K ₂ O	1.9	1.74	0.63	0.87	0.56	0.87	0.78	0.58	0.93	0.69	0.48	1.51	1.13	1.12	1.42	1.21	1.02
P ₂ O ₅	0.41	0.25	0.86	0.47	0.36	0.48	0.38	0.27	0.39	0.28	0.16	0.59	0.53	0.31	0.5	0.4	0.29
LOI	2.85	2.06	0.75	0.89	0.78	0.45	0.26	0.18	2.98	2.74	2.51	1.52	1.2	1.03	3.58	3.27	3.03
Total	98.31	98.18	98.47	98.89	99.38	98.84	98.85	99.74	98.76	99.14	99.23	98.23	98.45	98.57	98.29	98.38	98.71
Trace Elements (ppm) and chemical ratios																	
V	345.5	363.8	401.8	388.2	371	381.7	338.8	379.5	443.7	469.8	439.8	275.5	281.5	278.1	326.2	319	321.5
Cr	98.6	104.1	152.2	160.2	479	109.8	81.7	101.9	95.7	92.6	92.9	587	667	576.9	270.8	557	562.7
Ni	45.7	46.5	154	155.4	57.4	55.7	52.1	53.4	67.5	56.4	65.1	331.9	332	330.5	421.1	414	417.6
Cu	24.1	25.1	45.69	48.3	43	47.4	44.9	45.7	78.4	69.7	76.5	87.7	84.2	85.8	89.9	83.3	86.2
Zn	103.9	138.9	150.3	149.7	136	193.5	194.8	190.8	108.3	97.8	106.2	127.8	128	128.3	142.9	136	138.4
Co	57	57.5	66.01	66.6	64	63.4	57.8	61.6	71	70.2	68.8	75.5	72.8	74.1	68.4	64	65.9
Ga	24.2	24.4	25.05	24.7	25	26.6	25.8	25.8	26.3	25.4	25.5	23.6	23.4	22.5	24.6	24	24.8
Rb	36	31.8	19.13	19	18	22.6	21.5	21.3	22.9	23.9	21.4	35.9	35.1	34.7	35	34	34.3
Sr	606.6	616	670.6	669.1	530.7	566.3	530.7	595.8	584.8	564	577.2	728.7	717	721.2	735.4	706	719.7
Y	32.4	33	31.91	31.6	30.3	33.2	28.9	31.4	32.6	34	29.7	29	28	28.3	31.4	29	30.2
Zr	207.9	219.2	237.7	237.1	230	224.2	206.4	220.8	237.5	248	234.3	259.8	255	256.4	272.5	260	265.5
Nb	17.3	19.2	20.5	21.1	20	20.5	18.4	21.6	21.7	21.4	22.8	45.7	44.5	46.2	49	45.4	47.8
Ba	537.4	638	763.4	709	1238	683.8	678.3	723.5	578	646	589.4	718.2	773	745.8	792.6	823	810.4
La	28.6	16.4	20.27	20.5	10.2	14	13.4	15.8	14	22	16.3	42.9	28.4	34.6	45.6	50.6	47.7
Ta	2.4	2.3	2.4	2.5	2.3	2.4	2.2	2.2	2.6	2.4	2.2	2.6	2.7	2.5	2.4	2.3	2.3
Pb	3.2	2.9	6.51	4.3	3	12.4	10.5	11.7	4.5	4.1	4.1	6.7	4.3	5.8	5.6	5	5.4
Th	4.9	12.7	10.5	11.5	16.2	10.5	11.2	8.7	10.4	11.1	8.9	21.2	15.2	18.3	24.5	15	19.8
Y/Nb	1.87	1.72	1.56	1.5	1.52	1.62	1.57	1.45	1.5	1.59	1.3	0.63	0.63	0.61	0.64	0.64	0.63
Zr/Y	6.42	6.64	7.45	7.5	7.59	6.75	7.14	7.03	7.29	7.29	7.89	8.96	9.11	9.06	8.68	8.97	8.79
Zr/Nb	12.02	11.42	11.6	11.24	11.5	10.94	11.22	10.22	10.94	11.59	10.28	5.68	5.73	5.55	5.56	5.73	5.55
Fe ₂ O ₃ /MgO	2.12	2.09	2.08	2.03	2.11	1.96	1.99	2.02	1.65	1.65	1.66	1.4	1.43	1.39	0.89	0.89	0.9
K ₂ O/P ₂ O ₅	4.63	6.96	0.73	1.85	1.56	1.81	2.05	2.15	2.38	2.46	3	2.56	2.13	3.61	2.84	3.025	3.52
TiO ₂ /P ₂ O ₅	5.54	8.4	2.88	5.77	6.94	5.71	6.61	10.74	8.13	10.36	17.25	3.81	3.89	6.19	5.04	5.8	7.28

**1, 2 top Abu Zenima, 3, 4 middle Zenima, 5 bottom Zenima, 6, 7, 8 Plug Ehamer, 9,,10, 11Ehamer dyke 12, 13, 14 core Abu Darag and 15, 16, 17 Margin Abu Darag.

Table 2: Rare earth elements analysis of some Tertiary basalts at Abu Zenima (Z) and Ehamer (E) and Early Cretaceous basalts at Abu Darag (D) areas exposed around Gulf of Suez, Egypt

	Z middle	E plug	D core	D margin
LREE	Tertiary basalt		Early Cretaceous basalt	
Ce	30.1	30	43	42.8
Eu	2.3	2.4	-	-
Gd	13.1	14.5	11	10.6
Nd	203	214	138	137
Pr	13.5	12.5	12	11.4
Sm	3.9	4.1	1	1.8
Σ LREE	265.9	277.5	205	203.6
Tb	0.55	0.95	0.8	0.78
Yb	3	3.6	-	-
Dy	2.6	2.5	1.3	1.2
Er	6.6	7.2	2	2.1
ΣHREE	12.75	14.25	4.1	4.08
LREE/HREE	20.85	19.47	50	49.9
La/Sm	5.2	10.6	28.4	28.1

The middle part of the sheet has high concentrations of V, Ni, Co, Zr, Cu, TiO₂, Zn and Pb. The variation of elements concentrations in the different parts of the basaltic sheet reflects clearly the effect of fractionation, weathering, contamination and rate of cooling. The upper part of the flow is rapidly cooled and form glassy skin preventing the escaping of the gasses and consequently resulted in large vesicles (filled with secondary minerals, giving amygdales). The upper part has been partly weathered together with the glassy skin. Glassy basaltic part represents the original basaltic melt .The chemical weathering was so strong or active as the rock of the upper part was vesicular. These processes resulted in increasing the water content, hydrous iron oxides and leaching of some mobile elements as Ca, Mn, Cu, Pb and Ba. The fractionation is reflected in increasing the concentration of SiO₂ and Fe₂O₃ in the upper part of flow .The lower part of the basaltic sheet was cooled rapidly and the melt become relatively viscous inhibiting olivine to settle

down to the bottom. This is resulted in concentration of the olivine minerals in the middle zone. Therefore the abundances of Ni are high in this zone as this element is highly partition in the olivine. The enrichment of Fe₂O₃ and Cr in the lower zone may be due to the settling down of the heavy minerals as chromite and /or magnetite when the melt was mobile in the early stage of flow. The abundances of Zr, Nb, Y and Ta in the three zones are more or less similar due to their incompatibility (i.e. not affected neither by fractionation nor weathering). The middle zone is rich in Cu, Pb, and Zn. This may be attributed to the process of secondary enrichment of sulphides. The chemical weathering of the upper part of the Abu Zenima basalt flow has added MgO, LOI and K₂O and removed CaO, resulting in strongly modified major element compositions. However, the more immobile trace elements remain largely unaltered (Table 1).

5.2 Geochemistry of Ehamer basaltic plug and basaltic dykes

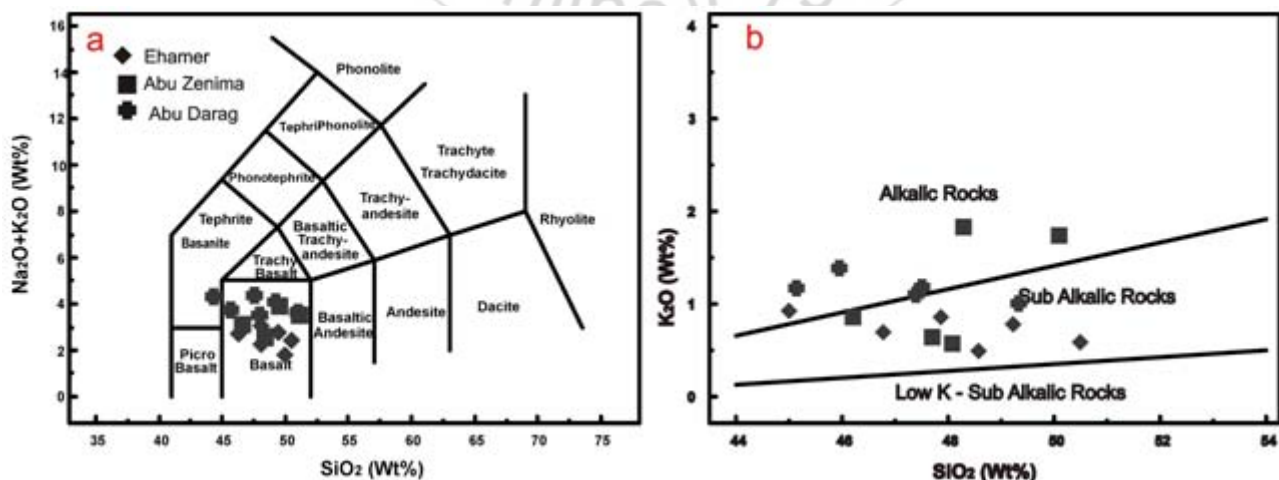
The basalt of Ehamer is found as plug, dissected by thin basaltic dykes. The chemical analysis of both phases indicate that , the plug is marked by high concentration of SiO₂, Al₂O₃,CaO, Na₂O,Zn, while the basaltic dyke is rich in TiO₂, Fe₂O₃ ,MgO, LOI ,V , Ni, Co and Zr. The two phases has the same element ratios (Y/Nb, Zr/Y, Zr/Nb) suggesting the same mantle source in spite of the differences in the degree of fractionation of both phases. The dyke was intruded through the deep seated joints dissecting the basaltic plug as a result of shrinkage after solidification. Then the basaltic rocks of dyke may be affected by action of meteoric water penetrated through the margins and micro joints. This resulted in high concentration of hydrous minerals and increasing in LOI(Table 1).The basaltic rocks of dyke represent weak fractionation as compared with the host basaltic plug indicated from the high concentration of Ni, TiO₂, V, Cr and MgO and lower abundances in K₂O and Si₂O. The chemical weathering has added MgO and K₂O and removed CaO from basaltic dike resulting in strongly modified major element compositions. However, the more immobile trace elements remain largely unaltered (Table 1). This accords [12].

5.3 Geochemistry of Abu Darag basaltic dyke

The chemical analysis of basaltic rocks of both margin and core reveals that the marginal basaltic rocks have high concentrations of SiO₂, TiO₂, MgO, Ni, V, and LOI. The contamination from the country sandstone rock as well as the variation in fractionation from the margin to the core play an important part in the variation of some compatible elements giving high concentration of SiO₂ in the marginal rocks as well as hydrous minerals filling the vesicles and high abundances of Ni, TiO₂ and V .The chemical weathering has increased LOI, MgO and Fe₂O and removed part of CaO from the marginal part of the basaltic dyke.

6. Nomenclature, Magma Type and Tectonic Setting

The plotting of samples on the binary diagram SiO₂ versus total alkalis [13] (Fig.5a), all samples fall in the field of basalt. The plotting on the SiO₂-K₂O diagram of [14] (Fig.5b) shows that, the Mesozoic basalts are fall on the field of alkali rocks while Tertiary basalts fall on the field of sub alkaline except one sample from the top of the basaltic flow of Abu Zenima suggesting some weathering and fractionation of the flow. The plotting on the ternary diagram TiO₂-P₂O₅-K₂O of [15] (Fig5d.) show that, Tertiary basalts are plotted in the oceanic and continental fields, while Mesozoic falls in the continental field .The oceanic affinity of Tertiary basalt may be due to thinner crust of north Egypt) .The plot on the ternary Ti/100 -Zr -Y^{x3} diagram of [16] (Figs 5 e) indicate that, both Early Cretaceous and Tertiary basalt fall in the field of within plate. The plot on the binary diagram Y versus Cr (Fig.5c) of [17] indicate that the Tertiary and Early Cretaceous basalts fall in the field of within plate, The plotting on the ternary diagram 2Nb-Y-Zr/4 of [18] (Fig.5f) indicate that the Early Cretaceous basalt of Abu Darag fall in the field of within plate alkali basalt field, while Tertiary basalts are plotted in the field of within plate tholeiitic and alkali.



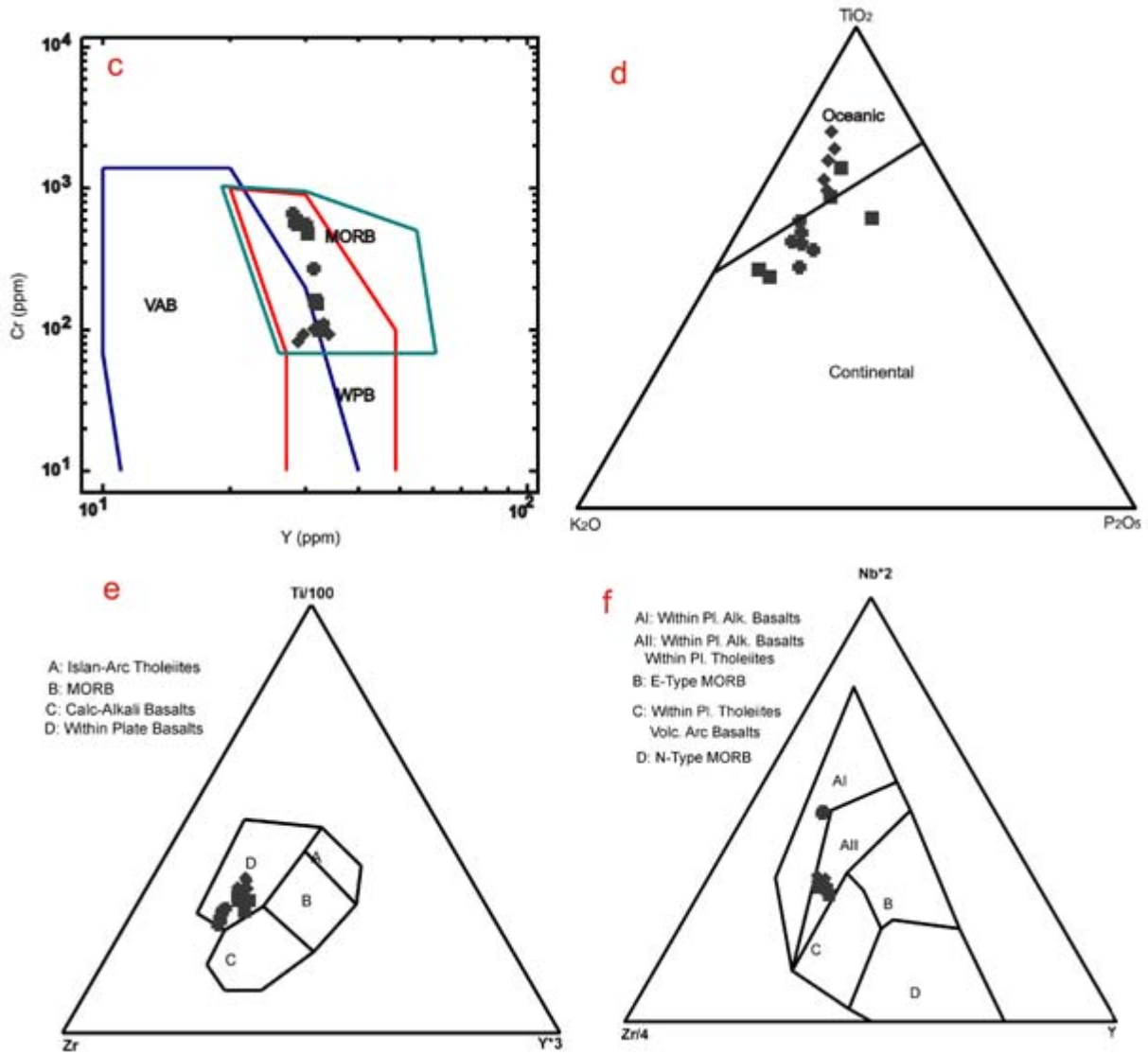


Figure 5: a) SiO₂–alkali diagram of Le Bas et al., (1986); b) SiO₂–K₂O diagram of Middlemost (1975); c) Y–Cr diagram of Pearce (1982); d) TiO₂–K₂O–P₂O₅ diagram of Pearce, et al., 1975); and e) Ti–Zr–Y diagram of Pearce and Can (1973); and f) Nb–Zr–Y diagram of Meschede (1986).

One of the more useful diagrams for identifying the source environment of basalts has been variably called a spider diagram (Fig. 6). From it, the study Tertiary and Early Cretaceous basalts show patterns more or less comparable to that of avg. continental crust of [19] but lower in Rb and K and higher in Nd, Nb, Ti, Y, Th and Tb (Fig 6a). The study basalts are higher in Th, Nd and lower in Sm and Nb than the avg. oceanic island basalt of [20] (Fig, 6b) and higher more than 10 times in Rb, Ba, Th, La, Nb, Nd and comparable in Ti, Yb, Tb, Y with respect to MORB of [21] (Fig.6d). Also the study basalts are higher more than 10 times than the chondrite composition of [22], (Fig. 6c).

La/Sm and FeO/MgO of the study Tertiary and Early Cretaceous basalts show negative correlation, suggesting that the sources that are most enriched in incompatible trace elements are depleted in FeO relative to MgO [23].

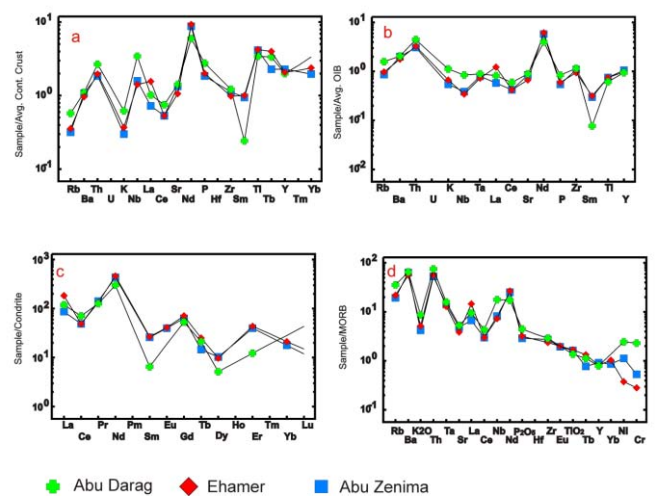


Figure 6: a) normalized basalt samples to avg. continental crust of Weaver and Tarney (1984); b) samples to avg, oceanic island basalt of Sun (1980); c) samples to chondrite of Sun and McDonough (1989), and d) samples to MORB of Bevins et al., (1984)

7. Discussion and Conclusions

Three basaltic occurrences around Gulf of Suez representing two volcanic events. Those near Abu Zenima city (east Gulf of Suez) and Ehamer area (west Gulf of Suez) are of Tertiary age, within plate continental to oceanic type and tholeiitic nature. The third occurrence at Abu Darag area (west Gulf of Suez) is of Mesozoic (Early Cretaceous), within plate continental type and shows alkaline nature. The basalts show some degrees of crustal contamination, crystal fractionation and weathering.

The evolution of the mantle, crustal thickness, depth and degree of partial melting can often be constrained by studying the abundances of high field strength elements Nb, Zr, Ti, Y and REE and their ratios, Zr/Nb, Zr/Y, Y/Nb and Zr/Ti and LREE/HREE [24]. The abundances of Zr and Nb are apparently unaffected by sea-water alteration and thus the Zr/Nb ratio is potentially a more useful measure of depletion than ratios involving K and Rb, which are very sensitive to sea-water alteration [25]. If a basalt has only undergone fractional crystallization of olivine, then the abundance of FeO in the basalt reflects the FeO/MgO ratio of the mantle source, the degree of melting, and the pressure at which melting occurs [23].

In terms of high field strength elements and REE abundances and their ratios, some geochemical constraints has been revealed and summarized as follow:

The Tertiary basalts of both Abu Zenima (top , middle and bottom parts of the basalt flow) and Ehamer basalts (plug and dyke) have Y/Nb, Zr/Y, Zr/Nb ratios are more correlated to each other in spite of contamination , weathering and fractionation. This suggest the same mantle source ;2- The LREE / HREE ratio of Tertiary basalt are similar but lower than that of Abu Darag Early Cretaceous basalt . [26] found that the high field strength element ratios remain unmodified for basalts of the same mantle source;3- Abu Darag basalt is enriched in incompatible elements and depleted in Fe O relative to MgO as a result of fractional crystallization of olivine, this accords [23]; 4- The higher abundances of K₂O, Na₂O, Nb and Zr and higher LREE/HREE ratio of the Early Cretaceous basalt of Abu Darag than those of the Tertiary basalt of Abu Zenima and Ehamer (Table 1) indicate with unravel enriched mantle source and alkali nature of Abu Darag basalt[27] . The continental crust of Egypt is thinner in the northern part [3].This may explain the oceanic affinity of some Tertiary basalt in the northern part of Egypt and may be related to Red Sea opening, 5-The chemical weathering has increased LOI, MgO and K₂O and decreased CaO from the marginal part of Abu Darag basaltic dyke, upper part of Abu Zenima flow and Ehamer dyke, resulting in modified major element compositions. However, the more immobile trace elements remain largely unaltered (Table 1).This accords [12]. 6-The Early Cretaceous basalt of Abu Darag shows a great crustal contamination than Tertiary basalts of Abu Zenima and Ehamer as indicated from, a)higher K₂O/P₂O₅ of Abu Darag basalt(2.84) than that of Abu Zenima and Ehamer basalts(avg. 2.33) ;b) Lower Zr/Nb (5.63) of Abu Darag

basalt than that of Tertiary basalt of Abu Zenima and Ehamer ((11.17), c) lower TiO₂/ P₂O₅ of early Cretaceous basalt (5.09);than that of Tertiary basalt (7.9) .d) higher Rb and Th of Abu Darag basalt than Abu Zenima and Ehamer Tertiary basalt. This accord [28], 7- Early Cretaceous basalt of Abu Darag is marked by numerous olivine phenocrysts in a groundmass of pyroxene, plagioclase and iron oxides, while Tertiary basalt of Abu Zenima and Ehamer has olivine, pyroxene and plagioclase phenocrysts.

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