Acta Mineralogica-Petrographica, Szeged, XXVI/2, 221—233, 1984

LATE PRECAMBRIAN VOLCANISM IN GABAL ABU HAD, EASTERN DESERT — EGYPT: EVIDENCE FOR AN ISLAND—ARC ENVIRONMENT

MOHAMED A. HEIKAL and ABDEL-AAL M. AHMED

ABSTRACT

Gabal Abu Had represents one of the widely distributed localities of the Late Precambrian Dokhan Volcanics in Egypt. The Abu Had volcanics are characterized by predominance of pyroclastics similar in that character to modern volcanic arcs. Chemically, they belong to the calc-alkaline series which characterize volcanism in island-arcs and continental margins. An island-arc environment is suggested for the Dokhan volcanics of Gebel Abu Had based on major and immobile trace elements.

INTRODUCTION

The basement complex of Egypt covers an area of about 100.000 square kilometres among which the Dokhan volcanics occupy limited areas attaining about 10% of the basement outcrop [STERN, 1979]. The Dokhan Volcanics are best developed north of Latitude 26° in the Eastern Desert, particularly at Gabal Dokhan, from which they acquired their name *(Fig. 1)*. The Dokhan Volcanics represent the oldest unmetamorphosed volcanics in Egypt and are considered of Late Precambrian in age [EL SHAZLY *et al.*, 1973; STERN, 1979].

Gabal Abu Had represents one of the widely distributed localities of the Dokhan Volcanics in the Eastern Desert of Egypt where they form a greyish-black belt that extends in a NE—SW direction *(Fig. 1)*. The Abu Had volcanics frequently occurs in the form of successive sheets, mainly represented by lavas and pyroclastics with the latter as the most dominant varieties. The bulk composition of the lavas is mainly andesitic comprising augite — and quartz-bearing varieties. Rhyodacites are uncommonly observed. The pyroclastics are made up of dacitic and andesitic ashfall tuffs of relatively thick units. Ignimbritic rhyolites are recorded among the Abu Had rock association.

In the present study, field and geochemical features are used in an attempt to identify the tectonic environment in which Abu Had volcanics were formed. Field criteria are largerly based on those given by GARCIA [1978]. Chemical discrimination parameters proposed by recent workers are also applied, using major elements as well as immobile trace elements (Table 1) of the studied volcanics. *Fig. 2* shows the chemical identification of Abu Had volcanics according to their silica and alkali contents [MIDDLEMOST, 1980].

FIELD EVIDENCES

Continental and island arc volcanoes, particularly those in orogenic belts, are normally much more explosive than oceanic volcanoes [RITTMANN, 1962; RITTMANN and RITTMANN, 1976]. According to WILLIAMS and MCBIRNEY [1979] the continental

TABLE 1

Chemical analyses of Abu Had Volcanics

%	1*	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
SiO_2	69.54	63.82	63.03	58.78	58.40	58.19	57.91	57.73	57.61	57.60	57.58	72.24	66.43	64.84	63.15	62.38	61.98	60.79	59.21
TiO_2	0.30	0.52	0.34	0.33	0.92	0.64	0.68	0.62	0.32	0.52	0.60	0.27	0.60	0.26	0.52	0.26	0.20	0.80	0.26
Al_2O_3	14.38	14.42	14.61	16.33	16.33	15.82	16.33	16.93	16.28	16.42	16.98	13.31	15.31	14.88	14.19	15.63	16.09	15.49	15.73
Fe_2O_3	0.59	4.05	3.29	3.86	5.07	3.33	3.34	3.02	3.73	3.56	3.98	0.61	0.64	2.67	2.91	1.93	2.91	4.34	3.24
FeO	3.36	1.39	2.17	2.69	2.26	3.71	3.91	3.85	3.53	3.80	3.42	1.59	2.72	1.96	2.32	1.74	2.11	2.78	3.97
MnO	0.16	0.11	0.12	0.13	0.12	0.19	0.13	0.15	0.14	0.15	0.13	0.06	0.07	0.14	0.12	0.10	0.09	0.12	0.13
MgO	0.84	1.84	2.23	2.89	2.64	3.26	2.97	2.68	3.05	3.26	3.01	0.38	1.38	2.38	2.51	1.76	2.10	2.51	2.38
CaO	2.33	4.37	4.37	6.12	5.99	3.77	6.10	6.06	6.29	6.01	5.48	1.45	3.73	4.84	4.25	4.78	4.66	5.59	7.05
Na_2O	4.19	3.98	4.12	2.96	3.37	3.61	3.40	4.41	2.61	3.26	3.46	3.69	3.69	3.83	3.11	4.41	3.40	3.11	2.61
K_2O	3.69	3.94	2.23	3.21	1.96	2.69	1.80	0.97	2.30	1.93	1.85	4.82	3.28	2.83	4.59	2.16	3.83	2.82	2.37
P_2O_5	0.10	0.13	0.13	0.17	0.17	0.19	0.21	0.18	0.19	0.22	0.20	0.05	0.19	0.15	0.15	0.14	0.20	0.16	0.18
Loss on ignition	0.57	0.54	0.85	2.29	1.25	1.45	1.19	2.21	2.08	1.71	1.53	1.28	0.91	0.71	1.33	3.51	1.08	1.02	1.52
H_2O	0.12	0.93	0.98	0.26	0.18	0.18	0.11	0.15	0.06	0.18	0.18	0.17	0.08	0.15	0.17	0.20	0.37	0.12	0.37
Total	100.17	100.04	98.47	100.02	98.66	99.03	98.08	98.96	98.19	98.62	98.40	99.92	99.03	99.64	99.22	99.00	99.02	99.65	99.04
Trace elements (ppm)																			
Sr	100	500	500	200	100	150	100	300	150	100	100	n. d.	300	300	150	400	200	150	50
Ba	200	500	500	300	150	300	150	200	300	200	200	150	400	400	300	500	400	300	150
Zr	50	60	60	40	30	40	10	80	50	20	20	30	50	50	50	60	50	30	30
Nb	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
V	20	50	100	80	100	60	60	100	80	60	60	10	30	40	60	40	60	60	60
Cr	80	300	200	60	100	300	100	50	150	80	80	80	80	200	150	100	100	60	60
Co	3	10	20	20	20	10	20	3	5	10	10	n. d.**	3	6	10	3	6	10	20
Ni	n. d	40	50	5	30	10	20	5	5	20	20	3	10	20	40	20	30	20	10
Cu	10	20	30	20	20	30	50	10	10	40	30	5	20	20	30	20	80	50	30

* 1 Rhyodacite, 2—3 Quartz-andesites (Imperial Porphyry), 4—11 Andesites, 12 Ignimbritic rhyolite, 13—17 Dacite tuffs and 18—19 Andesitic tuffs.

** n. d. Not detected.

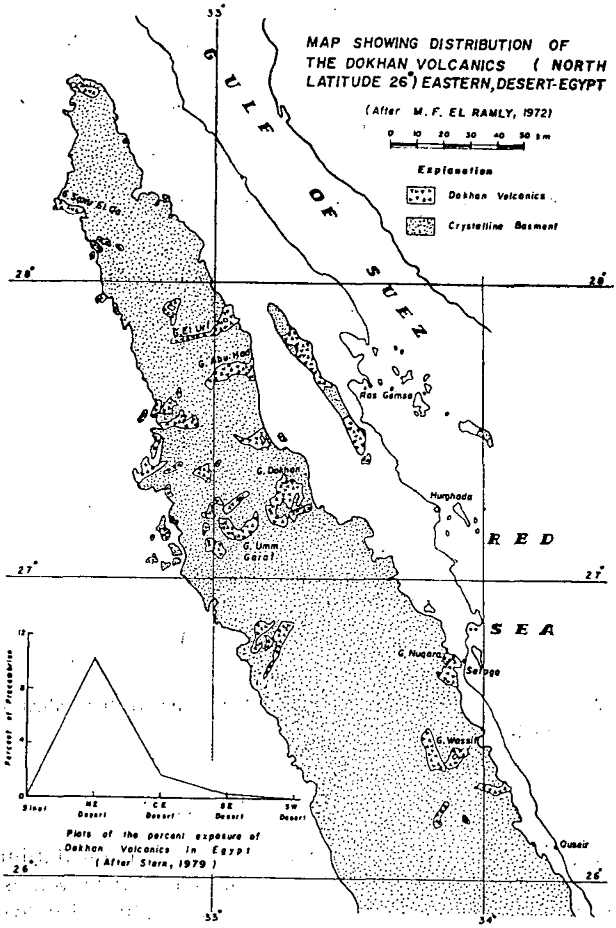

Fig. 1. Sketch of the northern part of the Eastern Desert of Egypt showing distribution of the Dokhan Volcanics and location of the investigated area.

and island arc volcanics have contributed 95% or more of all the pyroclastic deposits laid down during historic times. The important controlling factor for the predominance of pyroclastics within a volcanic sequence, is their tectonic setting without regard of magma type [GARCIA, 1978].

In Abu Had volcanics, pyroclastics (dacitic and andesitic tuffs) are predominant similar in that character to modern volcanic arcs. In general, the Egyptian Dokhan volcanics are characterised by abundance of explosive products [e. g. FRANCIS, 1972]. In addition, the upper part of Abu Had succession is interbedded with sediments of the Hammamat Group. The basal part of the Hammamat Group is mainly derived from the Dokhan volcanics [AKAAD and NOWEIR, 1980, p. 132]. GARCIA [1978] has reported that pyroclastic rocks in island arcs are interbedded with volcanoclastic sedimentary rocks derived from such arcs.

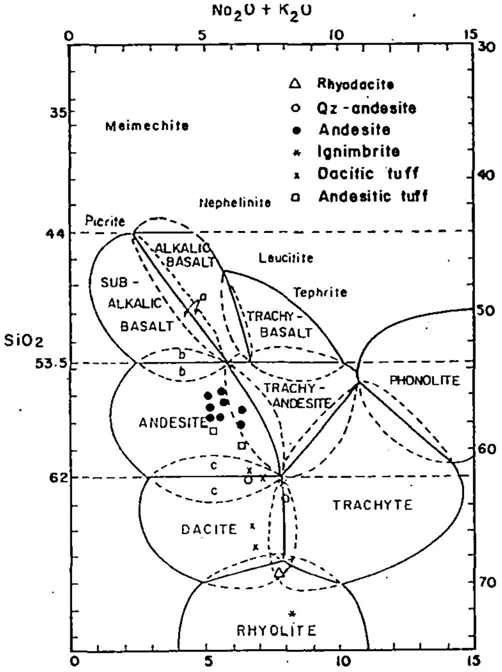

Fig. 2. Chemical classification of Abu Had volcanics according to their silica and alkali contents [Middlemost, 1980].

GEOCHEMICAL EVIDENCES

The following discussion and diagrams outline the chemical affinity of Abu Had volcanics and assess the possibility of using major elements as well as immobile trace elements in identifying the tectonic environment of the studied volcanics.

Miyashiro [1974] has concluded that volcanic rocks of island arcs and active continental margins consist of three main rock series: calc-alkalic, tholeiitic, and alkalic. The alkalic series form only a very small part of these rocks. Such artificial distinction has the merit of permitting comparison with published data on modern examples where the temporal and spatial variation in island arcs and continental margins is defined mainly in terms of the calc-alkalic and tholeiitic series [Jakes and Gill, 1970; Jakes and White, 1972; Miyashiro, 1974; Stillman and Williams, 1978]. Miyashiro [1974] suggested that tholeiitic series could be defined by a slower rate of increase of SiO_2 content and higher enrichment of FeO* (total iron as FeO) and titanium with advancing fractional crystallization than the calc-alkaline series. The advance in fractional crystallization is measured by increase in FeO*/MgO ratio. *Fig. 3* shows that the main trend of evolution of Abu Had volcanics is calc-alkalic with slight tendency towards the tholeiitic trend.

The Abu Had volcanics show a K_2O to SiO_2 trend *(Fig. 4)* similar to that of the calc-alkaline rocks of the Cascades and Central Andes island arcs [Miyashiro, 1974]. The Halaban Group of Saudi Arabia (which is considered equivalent to the Egyptian Dokhan Volcanics) shows the same trend of Abu Had volcanics [Greenwood *et al.*, 1980, p. 16].

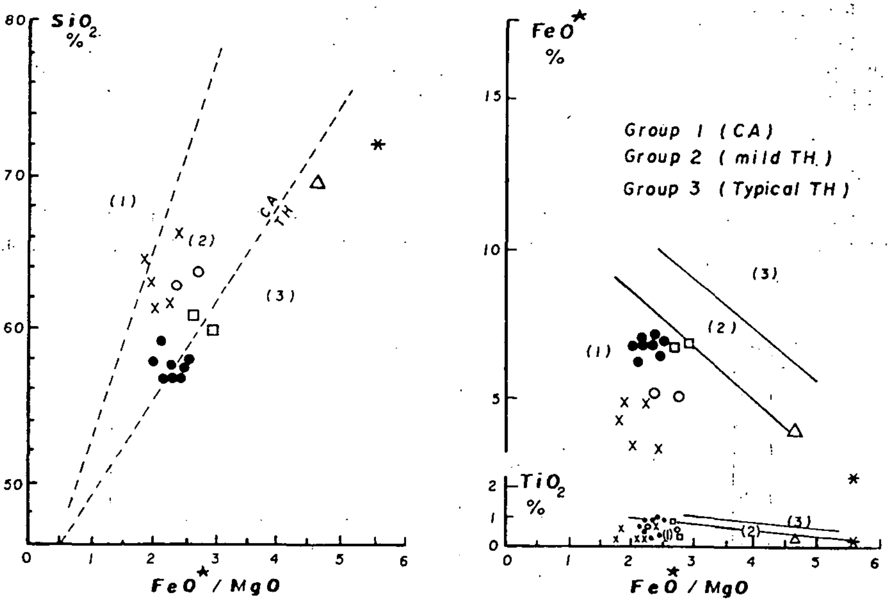

Fig. 3. Changes of SiO_2, FeO* and TiO_2 contents with FeO*/MgO ratio in Abu Had volcanics. Dividing lines are from MIYASHIRO [1973].
FeO*: total iron as FeO. Key for *Fig. 3* to *Fig. 8* as for *Fig. 2*.

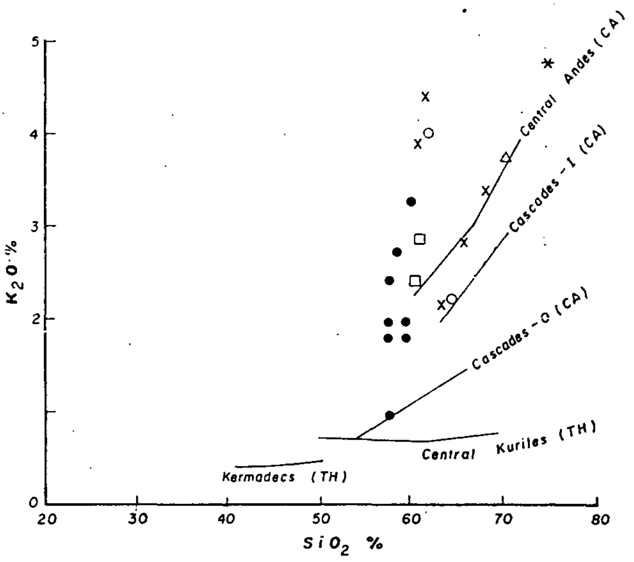

Fig. 4. Plot of K_2O against SiO_2 for Abu Had volcanics. Trend lines with names show average values for volcanic rocks in those volcanic arcs [MIYASHIRO, 1974].
Th: tholeiitic rocks, CA: calc-alkaline rocks, O: outer volcanic arcs, I: Inner volcanic arcs.

RITTMANN [1973], pointed out that lavas of all active volcanics can be divided into two well separated groups which reflect the tectonic situation of the volcanoes. This appears clearly in a diagram the coordinates of which are the value τ [GOTTINI, 1968] and the value σ (serial index of RITTMANN, 1957) being:

$\tau = Al_2O_3 - Na_2O/TiO_2$ (weight %)
$\sigma = (K_2O + Na_2O)^2/SiO_2 - 43$ (weight %).

Fig. 5 shows GOTTINI—RITTMANN diagram on which the Abu Had volcanics plot exclusively in field B, designated by RITTMANN [1973] for volcanic rocks in orogenic belts and island arcs.

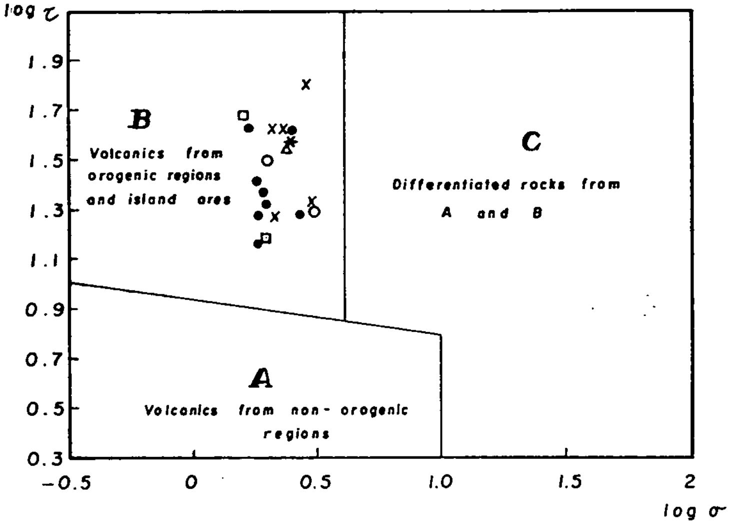

Fig. 5. Abu Had volcanics plotted in GOTTINI—RITTMANN diagram [RITTMANN, 1973]. Field A: Tholeiites, plateau basalts, alkali basalts, hawaiites. Field B: High-Al basalts, andesites, dacites, rhyodacites. Field C: Nephelinites, tephrites, trachytes, leucitites.

To determine the relation betwen the tectonic evironment and trace element contents, MIYASHIRO and SHIDO [1975] have constructed various diagrams using the trace element data for rocks in typical tectonic setting. *Fig. 6* shows a log V—log Cr diagram and SiO_2—log Cr diagram to discriminate between tholeiitic and calc-alkaline volcanic rock series. The Abu Had volcanics plot in the calc-alkaline field. *Fig. 7* shows the variation of chromium and nickel with increasing FeO*/MgO ratio in tholeiitic and calc-alkaline series of various tectonic setting. The studied volcanics fall in the field defined by MIYASHIRO and SHIDO for the volcanics of island arcs and active continental margins. The trace element data again reveal the calc-alkaline affinity of Abu Had volcanics.

According to MIYASHIRO [1973, p. 220] "the calc-alkalic trend, or at least the abundance of calc-alkalic rocks is characteristic of the volcanism in island arcs and continental margins, that is, in the covergent margins of plates". GARCIA [1978, p. 153] stated that the identification of a thick sequence of calc-alkaline volcanic rocks in the rock record strongly suggests the presence of a former volcanic arc.

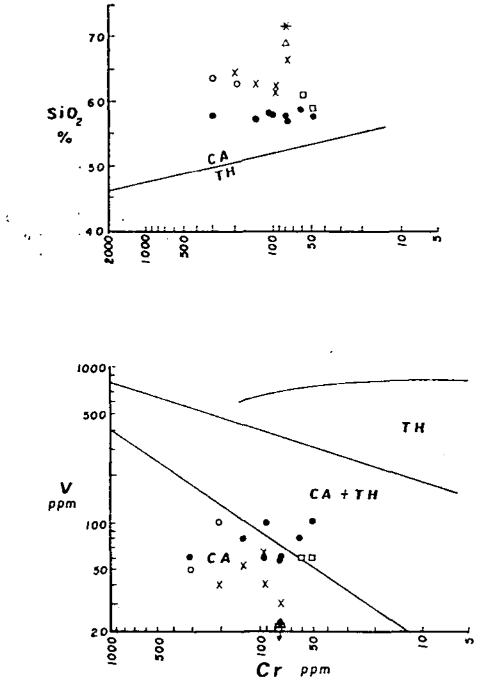

Fig. 6. Log V-log Cr and SiO_2—log Cr to discriminate between tholeiitic and calc-alkaline volcanic rocks of Abu Had [Miyashiro and Shido, 1975].

Accordingly, the calc-alkalic trend of Abu Had volcanics may indicate their evolution in the island arc or continental margin environments.

Recently, Ewart [1979, 1981] has reviewed the lava analyses from various modern geotectonic settings and gave average abundances of 30 minor and trace elements from the main volcanic environments. Ramsay *et al.*,[1981] used such data to plot the most important of these elements against SiO_2 for the following geotectonic settings:

1. Active continental margins (Western USA and Andean South America).
2. Anorogenic environments (Iceland, S. E. Queensland, and the Western Scotland-Northern Ireland province).
3. Oceanic islands (Galapagos, Hawaii, Canaries, and the Zephyr Shoal).
4. Primitive ensimatic island-arcs (Tonga-Kermadec and Lesser Antilles).

Fig. 8 shows that plots of Abu Had volcanics (except those of Cu) fall mainly in the field defined by Ramsay *et al.* [1981] after Ewart [1979, 1981] for immature island arcs. Whilst a few individual analyses may be incorrecrly allocated, the bulk of population lie in the island arcs field. Ramsay *et al.*, stated that the defined fields "are the fields of average values for defined SiO_2 ranges, and therefore indicate only typical concentrations of the relevant elements. The actual fields of individual points are, of course, larger".

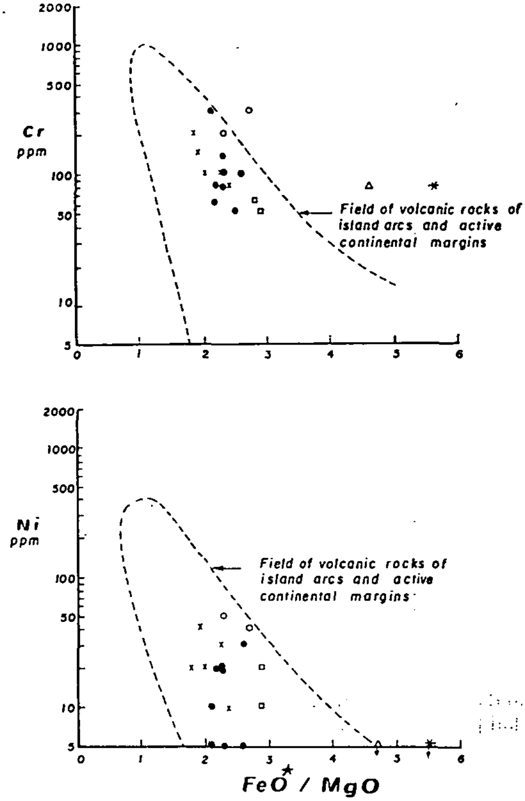

Fig. 7. Variation of Cr and Ni with FeO*/MgO for Abu Had volcanics [Miyashiro and Shido, 1975].

Table 2 compares some chemical features of Abu Had volcanics and those of rocks of different tectonic settings. Chemistry of the Dokhan volcanics, at the type locality, Gabal Dokhan — Egypt as well as that of the Helaban Group of Saudi Arabia are also given. The chemical data of Abu Had volcanics generally resemble data for the island arc calc-alkaline series. The same tectonic setting had been suggested for volcanics of Gabal Dokhan [Basta *et al.*, 1980], as well as for the Halaban Group of Saudi Arabia which is considered to be equivalent for the Egyptian Dokhan volcanics [Greenwood *et al.*, 1980].

DISCUSSION

The crystalline rocks of the Eastern Desert of Egypt (including the Dokhan Volcanics) form a part of the Arabian Nubian Shield which includes the crystalline basement of western Saudi Arabia, the Egyptian Eastern Desert and the northeastern Sudan. In turn, the Arabian-Nubian Shield forms a part of a widespread, U-shaped non-cratonic belt of rocks covering a significant portion of Africa *(Fig. 9)*. This belt is considered to be developed during the Pan-African orogeny [Kennedy, 1964]

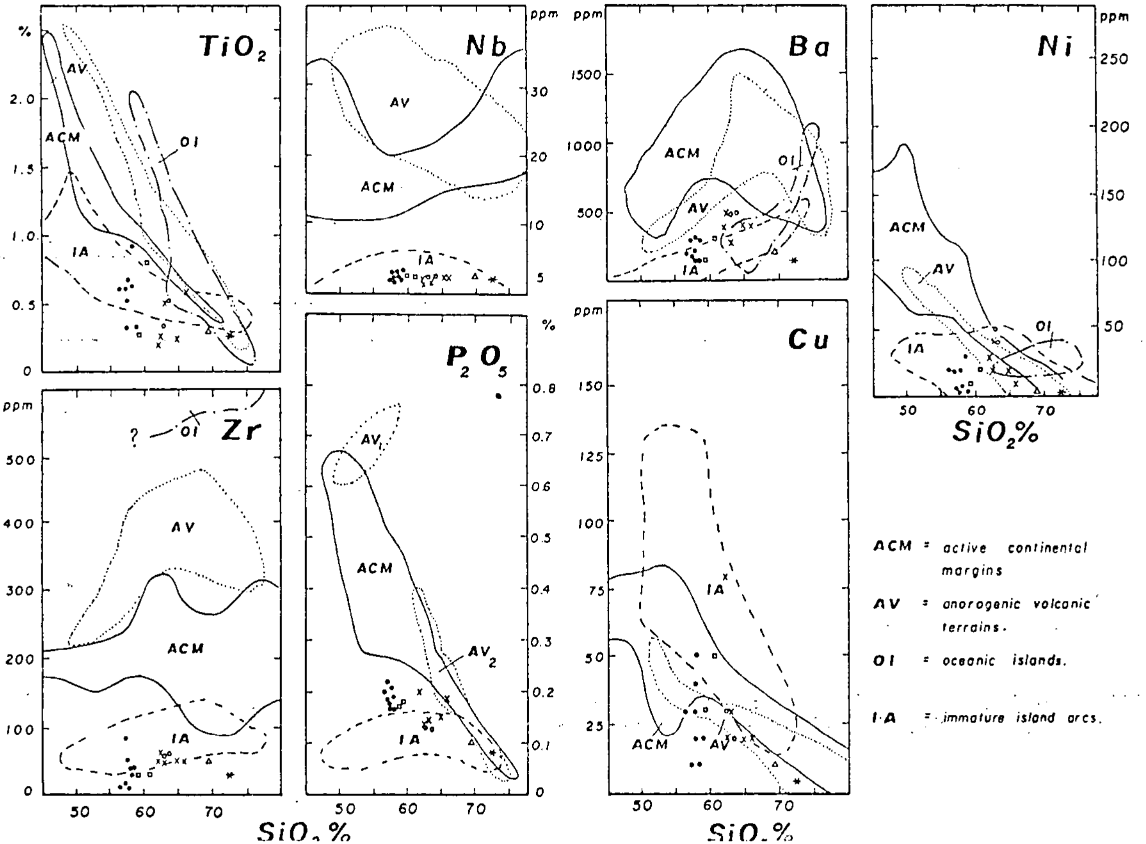

Fig. 8. Abundances of TiO_2, Zr, Nb, P_2O_5, Ba, Ni and Cu in Abu Had volcanics, compared with average fields of magmas from various modern geotectonic environments. [defined by RAMSAY *et. al.*, 1981 after EWART, 1979 and 1981].

TABLE 2

Comparison of major element chemistry of continental tholeiite, abyssal tholeiite behind the arc tholeiite, island-arc tholeiite, and Island-arc calc-alkaline volcanic rocks with Halaban Group of Saudi Arabia, Dokhan Volcanics (G. Dokhan-Egypt) and Abu Had Volcanics

	Continental tholeiite[1]	Abyssal tholeiite[1]	Behind the arc tholeiilite[1]	Island-arc tholeiite[1] series	Island-arc calc-alkaline series[1]	Halaban Group Saudi Arabia[2]		G. Dokhan Volcanics (Egypt)[3]		Abu Had Volcanics	
						Range	Median	Range	Avg.	Range	Avg.
SiO_2	51.5	47—62	48—50	45—70	50—66	57—76	68	54—70	61	57.6—72.2	61.6
TiO_2	1.2	1—2	1—2	0.5—1	0.2—1	0.3—1.4	0.5	0.3—1.5	1.0	0.2—0.9	0.5
Al_2O_3	16.3	14—15	14—17	14—17.5	16—18	12—18	14	13—17	15	13.3—17.0	15.6
Na_2O	2.5	2.5—3	1—3.5	2—3	2.9—5	1.0—5.4	4.3	1.6—5.7	3.7	2.6—4.4	3.5
K_2O	0.86	0.1—0.2	0.2—0.6	0.5	1—2.7	1.0—5.6	3.2	1—5	1.7	1.8—4.8	2.8
Na_2O/K_2O	3	10—15	6—10	4—6	1.3	0.2—5.6	1.6	0.7—4.4	1.6	0.7—4.6	1.5

1. Compiled by GREENWOOD *et al.*, [1980] after COATS [1968], MANSON [1968], JAKES and WHITE [1972], ANHAEUSSER [1973] and ROGERS *et al.*, [1974]
2. GREENWOOD *et al.*, [1980]
3. BASTA *et al.*, [198—]

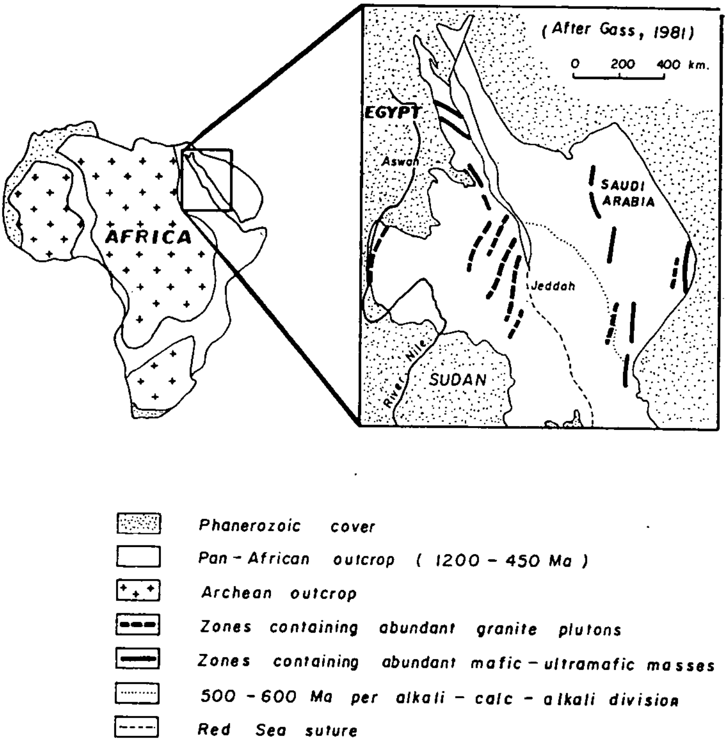

Fig. 9. Regional sketch map of the Arabian—Nubian Shield showing the disposition of mafic-ultramafic complexes (marking the approximate position of arc sutures) and linear granitic zones (possible arc axes). The Red Sea has been closed to a pre-Miocene position. The map of Africa shows outcrop areas of dominantly Pan-African age rocks whichs tend to encircle older cratonic rocks of Africa.

which has an age ranges of 1200—450 Ma [Gass, 1977, 1981; Kröner, 1979; International Geological Correlation Program (IGCP) Project 164, Saudi Arabia, 1979].

The origin of the Pan-African orogeny of the Arabian-Nubian Shield is controversial. Some authors suggest that this part of the Pan-African represents an Archean crust that was remobilized during the Pan-African orogeny (1200—450 Ma). This hypothesis requires the presence of continental (sialic) material older than the Pan-African orogeny [Hume, 1934; Clifford, 1968; Akaad and Noweir, 1980].

On the other hand, some authors suggest a plate-tectonic model suggesting that the continental crust of the Arabian-Nubian shield evolved in an oceanic environment within the Upper Proterozoic. According to Gass [1981], subduction occurred some 1200 Ma ago between converging plates of oceanic lithosphere. During this process oceanic crust of back-arc basins or marginal seas may have been consumed along predominantly westerly-inclined Benioff zones [Garson and Shalaby, 1976] and obducted fragments of this crust are now found as well preserved or partly dismembered ophiolite complexes in western Arabian and from northern Ethiopia to Egypt *(Fig. 9)* [Bakor *et al.*, 1976; Garson and Shalaby, 1976; Neary *et al.*, 1976; Gass, 1977; Frisch and Al-Shanti, 1977; El Shazly and Engel, 1978; El Sharkawy and El Bayoumi, 1979; Shanti and Roobol, 1979]. Finally, when subduction ceased, about 500 Ma ago, the whole region had developed a continental character [GASS, 1981]. The final stages of cratonization are marked by change from calc-alkaline to peralkaline magmatism, occurred earlier in some areas than in others. The line drawn on *Fig. 9* is that of STOESSER and ELLIOT [1979], and separates 500—600 Ma Arabian peralkaline (to the east) from calc-alkaline products (to the west).

In conclusion, the geological and geochemical features of Abu Had volcanics correlated with other features mentioned in this study strongly suggest the island-arc environment in which the studied volcanics were formed. Worthy of remark, such ensimatic island-arc cratonization model is faced by some difficulties. HASHAD and HASSAN [1979] stated that "It may perhaps be more reasonable to see the shield development in terms of an Andean type setting". The same tectonic setting was proposed by KRÖNER [1979]. Further geological, geochemical and geophysical studies of the Egyptian basement complex may reveal its proper tectonic setting.

REFERENCES

AKAAD, M. K. and NOWEIR, A. M. [1980]: Geology and lithostratigraphy of the Arabian Desert Orogenic belt of Egypt between latitudes 25°35′ and 26°30′ N. In: Evolution and Mineralization of the Arabian Nubian Shield. Inst. Applied Geol., King Abdulaziz Univ., Jeddah, Bull. 3 4 (ed. COORAY, P. G. and TAHOUN, S. A.), Pergamon Press, Oxford, 127—135.

ANHAEUSSER, C. R. [1973]: The evolution of the early Precambrian crust of southern Africa. Royal Soc. London Philos. Trans., **A 272**, 359—388.

BAKOR, A. R., GASS, I. G. and NEARY, C. R. [1976]: Jabal Al Wask: An Eocambrian, back-arc ophiolite in NW Saudi Arabia. Earth Planet. Sci. Lett., **30**, 1—9.

BASTA, E. Z., KOTB, H. and AWADALLAH, M. F. [1980]: Petrochemical and geochemical characteristics of the Dokhan Formation at the type locality, Jabal Dokhan, Eastern Desert, Egypt. In: Evolution and Mineralization of the Arabian-Nubian Shield. Inst. Applied. Geol., King Abdulaziz Univ., Jeddah, Bull. **3**, 4, (ed. AL-SHANTI, A.), Pergamon Press, Oxford, 122—140.

CLIFFORD, T. N. [1968]: Radiometric dating and the pre-Silurian geology of Africa, In: Radiometric Dating for geologists (eds. HAMILTON, E. I. and FARQUAHAR, R. M.), J. Wiley — Interscience, 299—416.

COAST, R. R. [1968]: Basaltic andesites, in: Basalts, Vol. II, (eds. HESS, H. H. and POLDERVAART, A.), John Wiley and Sons, New York, 689—736.

EL RAMLY, M. F. [1972]: A new geological map for the basement rocks in the Eastern and Southwestern Deserts of Egypt. Annal. Geol. Surv. Egypt, II. 1—18.

EL SHARKAWY, M. A. and EL BAYOUMI [1979]: The ophiolites of Wadi Ghadir Area Eastern Desert, Egypt. Annal. Geol. Surv. Egypt **IX**, 125—135.

EL SHAZLY, E. M. and ENGEL, A. E. J. [1978]: Proterozoic rifting and refractionation of northeast Africa (Abstr.) Precambrian Res., **6**, A20.

EL SHAZLY, E. M., HASHAD, A. H., SAYYAH, T. A. and BASSYUNI, F. A. [1973]: Geochronology of Abu Swayel area, South Eastern Desert. Egypt. J. Geol., **17**, 1—18.

EWART, A. [1979]: A review of the mineralogy and chemistry of the Tertiary-Recent dacitic, latitic, rhyolitic and related salic volcanic rocks. In: Trondhjemites dacites and related rocks (ed. BARKER, F.) Elsevier, Amsterdam, 13—121.

EWART, A. [1981]: The mineralogy and petrology of Tertiary-Recent orogenic volcanic rocks: with special reference to the andesitic-basaltic compositional range. In: Andesites (ed. THORPE, J.), Elsevier, Amsterdam.

FRANCIS, M. [1972]: Geology of the basement complex in the north Eastern Desert between latitudes 27°30′ and 28°00′ N. Annal. Geol. Surv. Egypt **II**, 161—180.

FRISCH, W. and AL-SHANTI, A. [1977]: Ophiolite belts and the collision of island arcs in the Arabian Shield. Tectonophysics **43**, 293—306.

GARCIA, M. O. [1978]: Criteria for the identification of ancient volcanic arcs. Earth Sci. Rev., **14**, 147—165.

GARSON, M. S. and SHALABY, I. M. [1976]: Precambrian-Lower Paleozoic plate tectonics and metallogenesis in the Red Sea region. Geol. Assoc. Canada Spec. paper **14**, 573—596.

GASS, I. G. [1977]: The evolution of the Pan-African crystalline basement in NE Africa and Arabia. J. Geol. Soc. London **134**, 129—138.

GASS, I. G. [1981]: Pan-African (Upper Proterozoic) plate tectonics of the Arabian-Nubian Shield. In: Precambrian plate tectonics, (ed. KRÖNER, A.) Elsevier, Amsterdam, 387—405.
GOTTINI, V. [1968]: The TiO_2 frequency in volcanic rocks. Geol. Rundsch., **57**, 930—935.
GREENWOOD, W. R., ANDERSON, R. E., FLECK, R. J. and ROBERTS, R. J. [1980]: Precambrian geologic history and plate tectonic evolution of the Arabian Shield. Saudi Arabian Dir. Gen. Miner. Resour., Bull. **24**, 35.
HASHAD, A. H. and HASSAN, M. A. [1979]: On the validity of an ensimatic island-arc cratonization model to the evolution of the Egyptian Shield. Annal Geol. Surv. Egypt **IX**, 70—80.
HUME, W. F. [1934]: Geology of Egypt, Vol. II. The fundamental pre-Cambrian rocks of Egypt and the Sudan. Part I The Metamorphic rocks. Egypt, Surv. Dept., Cairo.
JAKES, P. and GILL, J. [1970]: Rare earth elements and the island arc tholeiitic series. Earth. Planet. Sci. Lett., **9**, 17—28.
JAKES, P. and WHITE, A. J. R. [1972]: Major and trace element abundances in volcanic rocks of orvgenic areas. Geol. Soc. Am., Buil., **83**, 29—40.
KENNEDY, W. Q. [1964]: The structural differentiation of Africa in the Pan-African (±500 m. y.) tectonic episode. Univ. Leeds. Res Inst. Afr. Geol., Dept. Earth Sci., Annu. Rep. Sci. Results **8**, 48—49.
KRÖNER, A. [1979]: Pan African plate tectonics and its repercussions on the crust of northeast Africa. Geol. Rund., **68**, 2, 565—583.
MANSON, V. [1968]: Geochemistry of basaltic rocks: Major elements, In: Basalts, V. I., (eds. HESS. H. H. and POLDERVAART, A.), John Wiley and Sons, New York, 215—269.
MIDDLEMOST, E. A. K. [1980]: A contribution to the nomenclature and classification of volcanic rocks. Geol. Mag., **117**, 51—57.
MIYASHIRO, A. [1973]: The Troodos ophiolitic complex was probably formed in an island arc. Earth Planet. Sci. Lett., **19**, 218—224.
MIYASHIRO, A. [1974]: Volcanic rock series in island arcs and active continental margins. Am. J. Sci., **274**, 321—355.
MIYASHIRO, A. and SHIDO, F. [1975]: Tholeiitic and calc-alkalic series in relation to the behaviours of titanium, vanadium, chromium and nickel. Am. J. Sci., **275**, 265—277.
NEARY, C. R., GASS, I. G. and CAVANACH, B. J. [1976]: Granitic association of north-eastern Sudan. Geol. Soc. Am. Bull., **87**, 1501—1513.
RAMSAY, C. R., BASAHEL, A. N. and JACKSON, N. J. [1981]: Petrography, geochemistry and origin of the volcano-sedimentary succession between Jabal Ibrahim and Al-Aqiq, Saudi Arabia. Fac. Earth Sci., King Abdulaziz Univ., Bull., **4**, 1—24.
RITTMANN, A. [1957]: On the serial character of igneous rocks. Egyptian J. Geol., **1**, pp. 23—48.
RITTMANN, A. [1962]: Volcanoes and their activity. John Wiley and Sons, New York, 305 pp.
RITTMANN, A. [1973]: Stable mineral assemblages of igneous rocks. Spinger-Verlag, Berlin.
RITTMANN, A. and RITTMAN, L. [1976]: Volcanoes. G. P. Putnam's Sons, New York, N. Y., 97 pp.
ROGERS, J. J. W., BURCHFIEL, B. C., ABBOTT, E. W., ANEPOHL, J. K., EWING, A. H., KOEHNKEN, P. J., NOVITSKY-EVANS, M. and TALUKDAR, S. C. [1974]: Paleozoic and lower Mesozoic volcanism and continental growth in the western United States: Geol. Soc. America Bull., **85**, 1913—1924.
SHANTI, M. and ROOBOL, M. J. [1979]: A late Proterozoic ophiolite complex at Jabal Ess in northern Saudi Arabia. Nature **279**, 488—491.
STERN, R. J. [1979]: Late Precambrian ensimatic volcanism in the Central Eastern Desert of Egypt. Unpub. Ph. D. Thesis, California Univ., San Diego.
STILLMAN, C. J. and WILLIAMS, C. T. [1978]: Geochemistry and tectonic setting of some Upper Ordovician volcanic rocks in east and southeast Ireland. Earth Planet. Sci. Lett., **41**, 288—310.
STOESSER, D. B. and ELLIOT, J. E. [1979]: Post-orogenic peralkaline and calc-alkaline granites and associated mineralization of the Arabian Shield, Kingdom of Saudi Arabia. USGS Saudi Arabia Project Rep. SA (IR) **265**, 1—42.
WILLIAMS, H. and MCBIRNEY, A. R. [1979]: Volcanology, Freeman, Cooper and Co., San Francisco

Manuscript received, 12. October, 1983

MOHAMED A. HEIKAL
Geology Department,
Al-Azhar University,
Cairo, Egypt.
ABDEL-AAL M. AHMED
Geological Survey of
Egypt, Cairo.