Acta Mineralogica-Petrographica, Szeged, XXVI/2, 171 — 186, 1984

CONTRIBUTIONS TO THE PETROCHEMISTRY AND GEOCHEMISTRY OF SOME QUATERNARY BASALTIC ROCKS, NORTHERN AND SOUTHERN YEMEN

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ABSTRACT

Petrochemical and geochemical characteristics of some basaltic rocks from Sirwah-Marib and Dhamar-Rad'a volcanic fields (Northern Yemen) as well as Shuqra volcanic field (Southern Yemen), all of Quaternary age are presented. The relation of major elements together with other petrochemical indices and normative minerals have been discussed and the chemical characterization of the examined basaltic rocks is elucidated. The distribution and behaviour of selected trace elements in the examined rocks are also studied.

INTRODUCTION

The present study deals with the petrochemistry and geochemistry of some basaltic rocks from Sirwah-Marib and Dhamar-Rad'a volcanic fields (Northern Yemen) of Quaternary age. These form two of three major recent volcanic fields in the Yemen Arab Republic (Northern Yemen), previously grouped by GEUKENS [1966] into:

1. Sana'a-Amran (Hamdan).
2. Sirwah-Marib.
3. Dhamar-Rad'a.

Comparison, on a chemical basis with Shuqra volcanic field (Southern Yemen, Yemen People's Republic) of Quaternary age has also been attempted *(Fig. 1)*. Also,

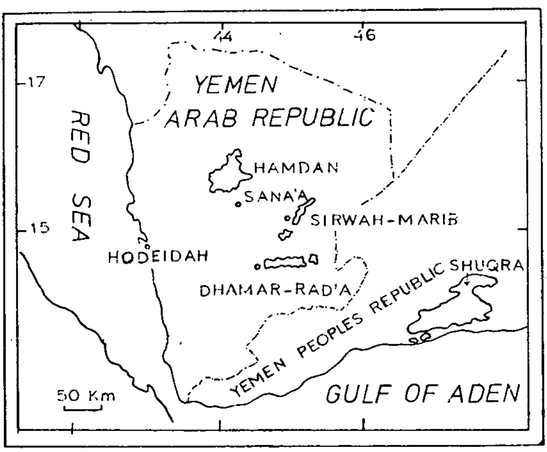

Fig. 1. Location map of Quaternary volcanics: Hamdan Sirwah-Marib and Dhamar Rad'a in Yemen Arab Republic and Shuqra in Yemen People's Republic

the only Egyptian olivine tholeiitic basalt from St. John's Island of Quaternary age has been compared with the Quaternary basaltic rocks of Yemen [EL-SHAZLY *et al.*, 1974, ABDEL-MONEM and HEIKAL, 1981]. However, few workers previously contributed to the chemistry of these volcanics, among whom may be mentioned SHUKRI and BASTA [1955], GEUKENS [1966], KABESH and GHOWEBA [1976], COX *et al.*, [1977], KABESH and HEGAB [1978], and KABESH *et al.*, [1980, 1981]. KABESH *et al.*, [1980] discussed some major and trace element relations of basaltic rocks which form part of the volcanics of Dhamar Rad'a. On the other hand, KABESH *et al.*, [1981] discussed some chemical features and the classification of Sirwah Marib basaltic rocks. However, no geochemical work is included in that study. COX *et al.*, [1977] advanced the general geology structure and petrography of part of Shuqra volcanic field. These authors (op. cit.) also mentioned data of major elements, normative values as well as some trace element abundances for 4 basaltic rock samples in Southern Yemen.

PETROCHEMISTRY

Major element data mentioned in the present study are essentially derived from previous studies of Dhamar-Rad'a volcanics (3 samples Table 1), [KABESH *et al.*, 1981], Sirwah-Marib basaltic rocks (12 samples Table 1), [KABESH *et al.*, 1981] while major element data of Shuqra volcanics, (4 samples, Table 1) are quoted from COX *et al.*, [1977] and 2 samples of St. John's Island (Egypt) after EL-SHAZLY *et al.*, [1974]. These data were recalculated and processed in the present work following several chemical parameters.

MAJOR ELEMENT CHEMISTRY

The chemistry of major elements is discussed through different variation diagrams.

Fig. 2 shows the relation between SiO_2 and FeO^*/MgO, all in weight percent. It is evident that all the examined basaltic rocks from Northern, Southern Yemen and St. John's Island (Egypt) plot within the field of tholeiite according to the classification of MIYASHIRO [1974].

Fig. 3 shows the relation $FeO^* = FeO + 0.899 \times Fe_2O_3/MgO$ and FeO, all samples of Sirwah Marib and Dhamar Rad'a fall within field (3), tholeiitic basalt, while those of Shuqra and St. John's plot within field (2) mildly calc-alkalic rocks with the exception one sample from Shuqra which plots in the field calc-alkalic rocks. On the other hand, *Fig.* 4 shows the relation between FeO/MgO and TiO_2. It is evident from this figure that all the examined basaltic rocks from Northern and Southern Yemen plot within the field of tholeiitic basalt according to the classification of MIYASHIRO [1974] with the exception of one sample from St. John's Island falling in the field 1, calc-alkaline rocks.

MIYASHIRO (op. cit.) suggested that tholeiitic basaltic rocks are characterized by slower rate of increase of SiO_2 content and higher enrichement of FeO^* (total iron as FeO) and titanium with advancing fractional crystallization than the calc-alkaline basalt. The advance in fractional crsytallization is measured by increase in FeO/MgO.

On the basis of K_2O and Na_2O contents in the igneous rocks MIDDLEMOST [1975] classified the alkali rocks into four main types comprising Na-series, K-series, high K-series and phonolitic basalts. *Fig. 5* shows that the basaltic rocks of Sirwah—

TABLE 1

Chemical analyses of the investigated basaltic rocks Sirwah-Marib (Northern Yemen)

	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	46.90	47.30	50.50	43.10	50.90	44.40	44.40	43.50	46.20	46.10	45.60	45.50
Al_2O_3	15.90	15.80	13.90	16.50	14.10	16.40	16.40	16.50	16.13	16.12	16.20	16.20
Fe_2O_3	2.39	2.31	2.76	3.46	2.60	3.40	3.38	3.42	3.30	3.30	3.34	3.35
FeO	8.67	8.61	9.20	8.60	9.07	8.30	8.13	8.57	7.89	7.90	7.94	7.96
MgO	5.60	5.59	6.31	6.27	6.22	6.10	6.10	6.21	5.80	5.80	5.90	5.90
CaO	9.42	9.28	10.40	10.60	10.30	10.60	10.50	10.60	10.20	10.20	10.40	10.40
Na_2O	2.55	2.56	2.22	3.25	2.21	3.20	3.22	3.25	3.14	3.15	3.19	3.20
K_2O	3.87	3.87	1.11	2.86	1.13	2.53	2.52	2.79	2.17	2.18	2.22	2.23
MnO	0.18	0.18	0.17	0.34	0.17	0.30	0.30	0.35	0.29	0.30	0.30	0.30
TiO_2	3.21	3.17	2.09	3.35	2.08	3.27	3.26	3.34	3.30	3.30	3.31	3.32
P_2O_5	0.31	0.29	0.23	0.57	0.23	0.49	0.50	0.58	0.58	0.59	0.57	0.58
H_2O	0.82	0.87	0.79	0.89	0.79	0.93	0.94	0.85	0.94	0.94	0.93	0.96
Total	99.82	99.83	99.68	99.79	99.79	99.92	99.83	99.96	99.94	99.88	99.90	99.90
FeO/MgO	1.93	1.91	1.85	1.87	1.88	1.85	1.84	1.87	1.86	1.88	1.85	1.86
TiO_2/P_2O_5	10.35	10.93	9.09	6.23	9.04	6.67	6.52	5.76	5.69	5.59	5.81	5.72
K_2O+Na_2O	6.42	6.43	3.33	6.11	3.34	5.73	5.74	6.04	5.31	5.33	5.41	5.43
$\frac{K_2O \times 100}{K_2O+Na_2O}$	60.28	60.19	33.33	46.81	33.83	44.15	43.90	46.19	40.87	40.90	41.04	41.11
$\frac{K_2O+Na_2O \times 100}{K_2O+Na_2O+CaO}$	40.53	40.93	24.25	36.56	24.49	35.09	35.34	36.30	34.24	34.32	34.22	34.30

TABLE 1 (continued)

	Dhamar-Rad'a (Northern Yemen)			Shuqra (Southern Yemen)				St. John's Island	
	13	14	15	16	17	18	19	20	21
SiO_2	46.63	47.73	49.90	47.39	45.63	44.42	44.35	47.52	48.44
Al_2O_3	14.39	13.86	14.78	16.80	17.58	16.16	15.07	15.94	13.56
Fe_2O_3	3.25	4.93	3.62	1.09	4.64	1.99	2.52	2.32	1.56
FeO	10.17	10.61	9.11	8.52	5.37	7.63	8.25	8.95	8.24
MnO	0.14	0.19	0.18	0.18	0.17	0.16	0.18	0.17	0.20
TiO_2	2.11	1.99	2.56	2.03	2.32	2.31	2.07	1.40	1.12
MgO	7.09	7.70	6.35	6.72	7.17	9.79	11.71	7.39	8.76
CaO	9.81	8.93	9.74	9.10	9.50	11.08	10.91	10.72	12.33
Na_2O	2.96	2.51	2.21	3.97	4.04	3.28	3.01	3.27	2.50
K_2O	0.49	0.30	0.25	1.15	1.46	1.10	1.02	0.27	0.27
P_2O_5	0.36	0.27	0.36	0.57	0.66	0.40	0.57	0.87	0.37
H_2O	1.95	0.85	0.99	2.76	1.37	0.78	1.12	1.42	1.74
Total	99.35	100.07	100.05	100.28	99.91	99.09	100.06	100.24	99.09
FeO*/MgO	1.84	1.95	1.94	1.41	1.33	0.96	0.90	1.49	1.10
TiO_2/P_2O_5	5.86	7.37	7.11	3.56	3.51	4.77	3.63	1.61	3.03
K_2O+Na_2O	3.45	2.81	2.46	5.12	5.50	4.38	4.03	3.54	2.77
$\frac{K_2O \times 100}{K_2O+Na_2O}$	14.20	10.67	10.16	22.46	26.54	25.11	25.31	7.62	9.75
$\frac{K_2O+Na_2O \times 100}{Na_2O+K_2O+CaO}$	26.02	23.93	20.16	36.00	36.67	28.33	26.97	24.82	18.34

$FeO^* = FeO + 0.899 \times Fe_2O_3$.

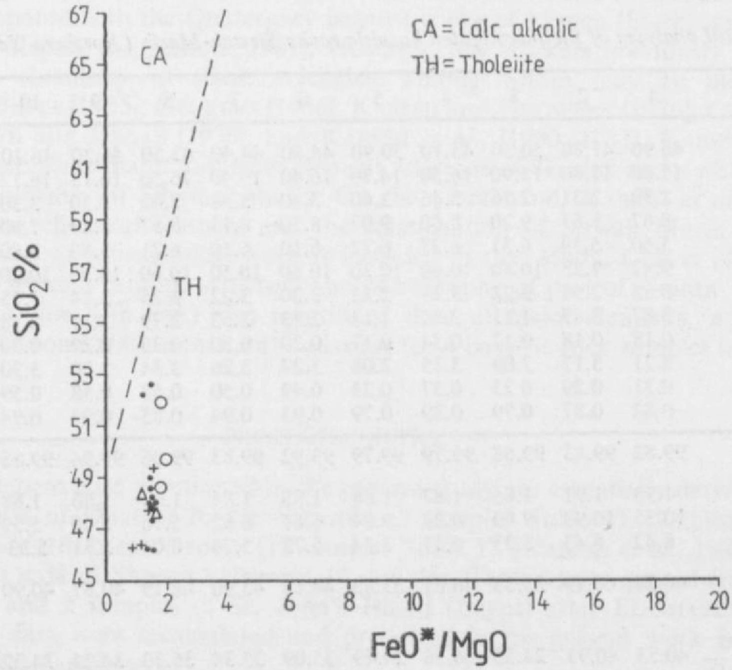

Fig. 2. Variation of SiO_2 *vs* FeO*/MgO after MIYASHIRO [1974].
● Sirwah-Marib
○ Dhamar Rad'a
+ Shuqra
△ St. John's Island

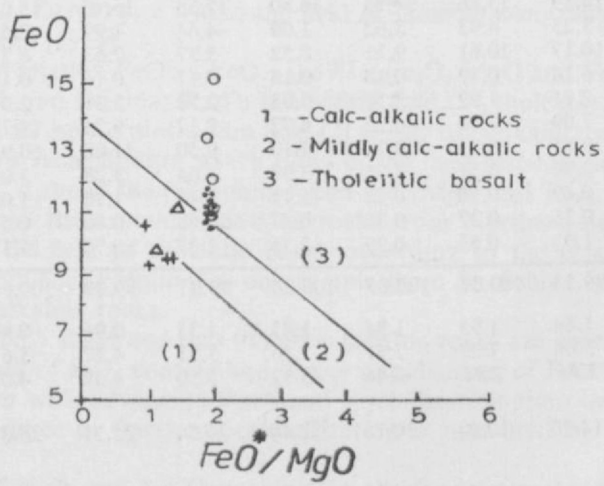

Fig. 3. Variation of FeO % *vs* FeO*/MgO after MIYASHIRO [1974]. Symbols as in *Fig. 2.*
$FeO^* = FeO + 0.899\ Fe_2O_3$
⊙ superimposed two or three points.

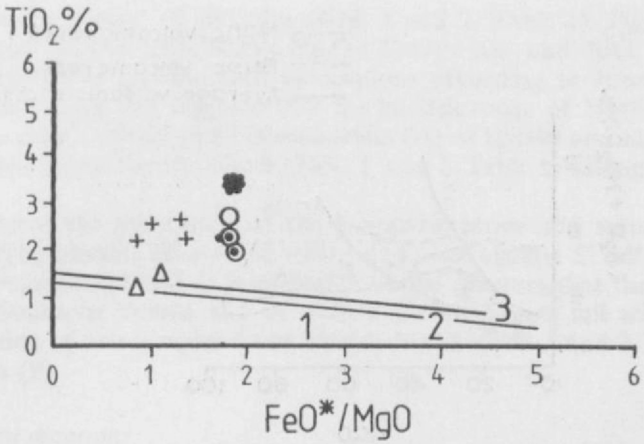

Fig. 4. Variation of TiO_2 *vs* FeO*/MgO after MIYASHIRO [1974]. Symbols as in *Fig. 2.*
1. Calc-alkalic rocks
2. Mildly calc-alkalic rocks
3. Tholeiitic basalt

⊙ superimposed two points

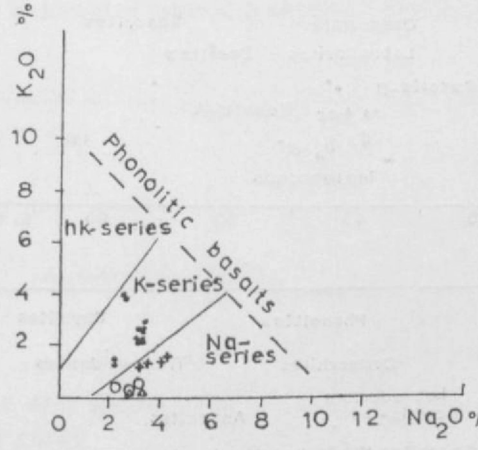

Fig. 5. K_2O—Na_2O diagram [MIDDLEMOST, 1975]. Symbols as in *Fig. 2.*

Marib plot within the K-series while those of Dhamar-Rad'a, Shuqra and St. John's Island fall within the Na-series.

An evidence of possible alkali metasomatism is shown by plotting total alkalies (Na_2O+K_2O) against alkali index $(K_2O/Na_2O+K_2O)\times100$ in *Fig.* 6) advanced by HUGHES [1973]. In the diagram three main field are present comprising mafic and felsic volcanics in addition to an igneous field which is characterized by typical values of alkalies.

The diagram shows that the basaltic rocks of Dhamar-Rad'a, Shuqra as well as those of St. John's Island fall within the field of mafic volcanics. The mafic volcanics possess low values of alkalies (2.46—5.54) and alkali index (7.62—26.54). On the

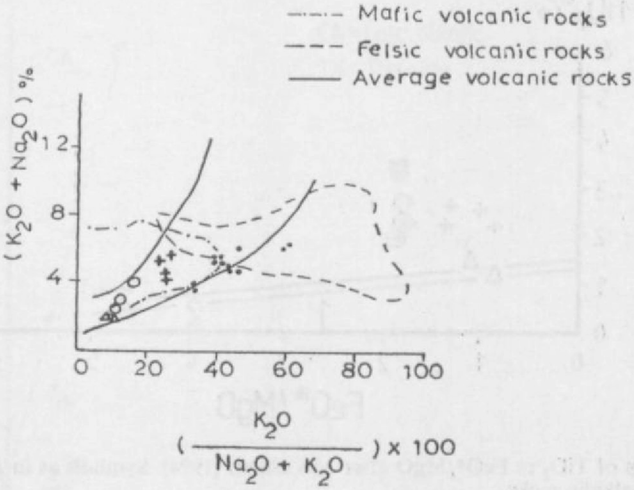

Fig. 6. Variation of K_2O+Na_2O (%) *vs* K_2O/K_2O+Na_2O after HUGHES. [1973]. Symbols as in *Fig. 2.*

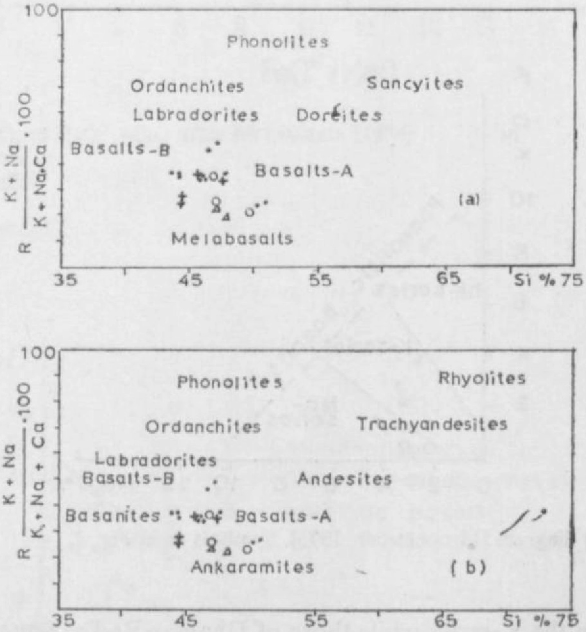

Fig. 7. a) Si—R diagram of the magmatic series: *A* saturated and *B* unsaturated after JUNG and BROUSSE [1966].
b) Si—R diagram of the magmatic series: *A* saturated and *B* unsaturated after VATIN—PERIGNON [1968]. Symbols an in *Fig. 2.*

other hand, the basaltic rocks of Sirwah-Marib show a wide range both in the total alkalies (3.33—6.43) and the alkali index (33.33—60.28). Consequently these basalts fall partly within the mafic volcanics, partly within the felsic volcanics and partly within the average igneous rocks. However, the two samples falling within the felsic volcanics show the highest alkali index (Nos. 1 and 2, Table 1). *Fig. 7a* shows the relation between $(K_2O+Na_2O/K_2O+Na_2O+CaO)\times 100$ and SiO_2 which distinguishes several types of igneous rock associations according to JUNG and BROUSSE [1962]. It is clear from the diagram that the basaltic rocks of Northern, Southern Yemen and St. John's Island plot between series (A) of basalts and metabasalts with only two samples from Sirwah-Marib (Nos. 1 and 2, Table 1) falling near series (B) of basalts.

Fig. 7b shows the separation of the magmatic series into saturated (A) and unsaturated (B) by plotting $(K+Na/K+Na+Ca)\times 100$ against Si (all in weight percent), (VATIN-PERIGNON, 1968). It is evident from the diagram that the basaltic rocks of Northern, Southern Yemen and St. John's Island (Egypt) fall within series (A) with the exception of two samples from Sirwah-Marib (Nos. 1 and 2, Table 1) which plot near series (B).

Alkali-silica diagram:

This diagram *Fig. 8* has been established to distinguish alkalic and tholeiitic rocks as shown by MACDONALD [1968] dividing line with IRVINE and BARAGAR's curve [1971]. In this method Na_2O+K_2O are plotted against SiO_2 (all in weight percent). According to the diagram the basaltic rocks of Dhamar-Rad'a and St. John's Island fall within the sub-alkaline field because of the absence of normative nepheline, those of Shuqra fall close to the alkaline field with the exception of two samples (Nos. 3 and 4, Table 2) devoid of normative nepheline and falling within the subalkaline field.

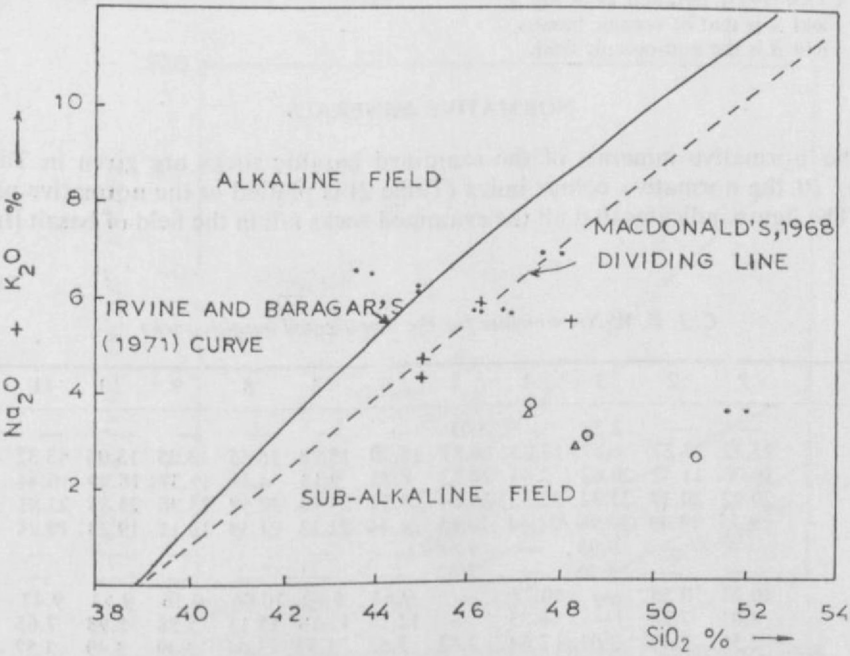

Fig. 8. Alkalies-silica diagram. Dashed line is MacDonald's [1968] dividing line for Hawaiian tholeiitic and alkaline rocks. The solid curve is the line proposed by IRVINE and BARAGAR [1971] to divide the alkaline and sub-alkaline compositions. Symbols as in *Fig. 2*.

Fig. 9 plot for the examined basalts using P_2O_5; TiO_2 and K_2O (all in weight percent) discrimination diagram of PEARCE and CANN, [1973]. The diagram shows that the basaltic rocks of Northern, Southern Yemen and St. John's Island (Egypt) plot within the field of non-oceanic basalts with the exception two samples from Dhamar-Rad'a falling in the field of oceanic basalts.

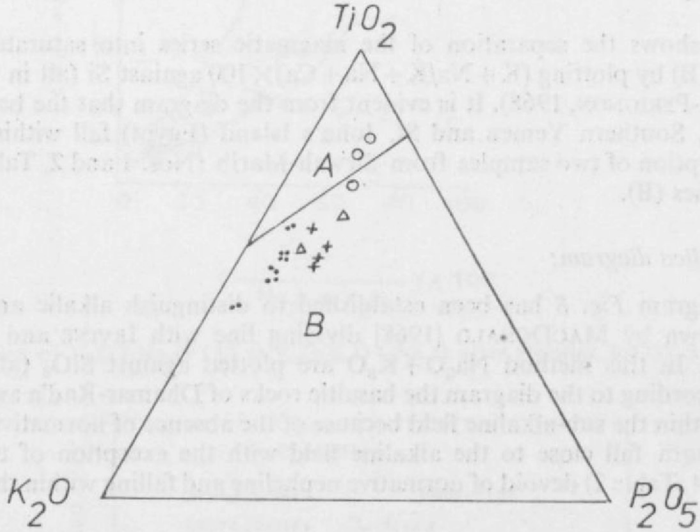

Fig. 9. TiO_2—P_2O_5—K_2O triangular diagram showing the plots for the basalts after PEARCE and CANN [1973]. Symbols as in *Fig. 2*.
Field *A* is that of oceanic basalts.
Field *B* is the non-oceanic field.

NORMATIVE MINERALS

The normative minerals of the examined basaltic rocks are given in Table 2 In *Fig. 10* the normative colour index (Table 2) is plotted *vs* the normative plagioclase. The figure indicates that all the examined rocks fall in the field of basalt [IRVINE

TABLE 2

C. I. P. W-Norm values for the investigated basaltic rocks

	1	2	3	4	5	6	7	8	9	10	11	12
Q	—	—	2.35	—	3.01	—	—	—	—	—	—	
Or	23.32	23.27	6.87	17.23	6.87	15.20	15.28	16.65	13.05	13.06	13.32	13.33
Ab	10.00	11.42	20.62	2.44	20.32	8.83	9.13	4.41	19.37	18.99	16.44	16.24
An	20.92	20.57	25.34	22.32	26.04	23.32	23.20	22.57	23.98	23.85	23.81	23.81
Di	19.75	19.49	20.96	21.84	20.15	21.44	21.13	21.59	19.11	19.23	19.88	19.89
Fs	—	—	9.98	—	9.88	—	—	—	—	—	—	—
En	—	—	7.46	—	7.62	—	—	—	—	—	—	—
Ol	10.22	10.36	—	10.24	—	9.64	9.82	10.06	9.56	9.53	9.47	9.39
Ne	8.01	7.28	—	16.33	—	12.17	12.18	15.13	5.58	5.98	7.65	7.78
Mt	2.55	2.47	3.01	3.64	2.83	3.65	3.57	3.64	3.49	3.49	3.57	3.57
Ap	0.66	0.61	0.46	1.21	0.46	1.06	1.06	1.20	1.21	1.21	1.21	1.21
Il	4.56	4.54	2.98	4.75	2.98	4.64	5.64	4.74	4.65	4.66	4.65	4.76
N. C. I.	37.08	36.86	44.39	40.47	43.46	39.37	40.16	40.03	36.81	36.91	37.57	37.61
An. Con.	67.66	64.30	55.13	90.14	56.17	72.53	71.76	85.99	55.32	55.67	59.15	59.45

	Dhamar- Rad'a (Northern Yemen)			Shuqra (Southern Yemen)				St. John's Island	
	13	14	15	16	17	18	19	20	21
Q	—	—	5,79	—	—	—	—	—	—
Or	2,89	2,95	1,47	6,62	9,02	6,78	6,22	1,62	1,67
Ab	25,01	21,21	18,67	31,23	21,25	10,13	12,24	29,89	23,52
An	24,49	25,04	29,63	24,57	25,65	26,29	24,84	28,49	26,14
Di Wo	9,12	7,31	6,83					7,91	12,04
Di Fs	3,65	2,73	2,47	13,75	13,77	21,98	18,33	3,14	6,62
Di En	5,09	4,23	4,01					6,99	17,67
Hy Fs	2,63	8,90	7,33	—	—	—	—		
Hy En	3,67	13,77	13,20	—	—	—	—		
Ol Fa	4,97	0,62	—	15,79	10,25	16,73	22,39	5,34	2,46
Ol Fo	6,27	0,87	—					10,30	5,71
Ne	—	—	—	1,41	7,20	9,83	7,50	—	—
Mt	4,71	7,14	5,24	1,61	6,82	2,83	3,22	2,46	1,70
Ap	0,85	1,21	0,85	1,23	1,57	0,95	1,26	1,88	0,82
Il	4,00	3,78	4,86	3,77	4,47	4,49	4,01	1,98	1,63
N. C. I	44,96	50,56	44,79	36,15	36,88	46,98	49,21	40,00	48,65
An. Con.	49,47	54,14	61,34	44,03	54,69	72,18	66,99	48,80	52,64

and Baragar, 1971] and later defined by Raschka and Muller [1974] for Hawaiian tholeiite.

A prominent chemical difference between more basic members of typical calc-alkaline and tholeiitic basalt is their alumina content. This difference is well illustrated by plotting Al_2O_3 *vs* normative plagioclase composition *(Fig. 11)* where a convenient

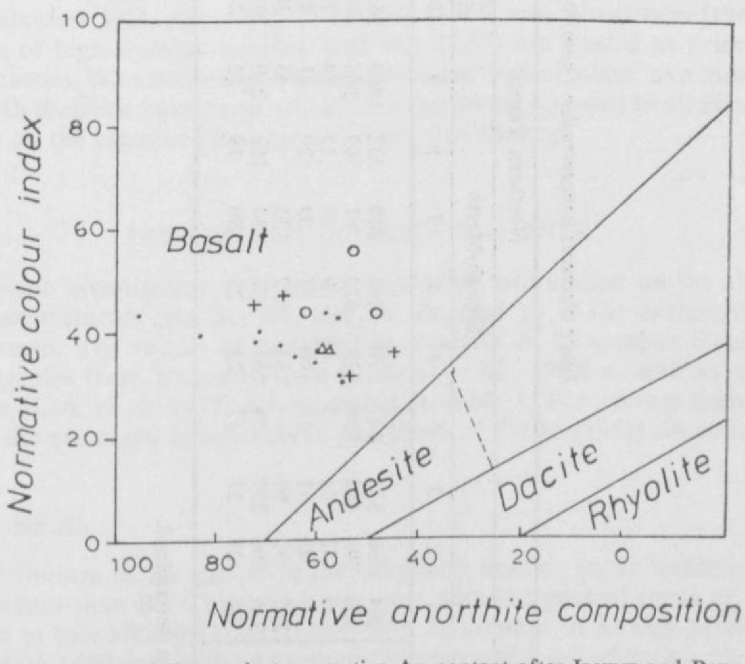

Fig. 10. Normative colour index against normative An content after Irvine and Baragar [1971]. Symbols as in *Fig. 2.*

TABLE 3

Trace elements concentration (ppm) of Northern and Southern Yemen basaltic rocks

	Northern Yemen															Southern Yemen				Average of Prinz, (1967)
	Sirwah-Marib												Dhamar-Rad'a			Shuqra				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
Ba	204	406	535	947	270	264	440	332	1400	265	243	448	100	140	80	n. d.*	n. d.*	n. d.*	n. d.*	244
Sr	450	598	603	630	618	610	761	569	568	670	613	657	460	390	430	649	665	597	596	450
Rb	5	32	44	5	8	9	29	15	24	24	8	27	35	30	23	67	37	28	26	39
Co	77	49	31	13	40	41	39	20	41	42	43	41	40	50	40	n. d.*	n. d.*	n. d.*	n. d.*	39
Ni	243	92	69	—	181	159	135	—	45	138	143	182	65	60	50	99	99	159	256	85
Zr	235	300	257	109	263	267	234	159	280	207	219	233	96	80	125	230	218	171	160	108
Y	25	29	27	17	25	28	30	18	22	24	23	27	n. d*	n. d*	n. d*	26	27	25	25	32

* Not determined.

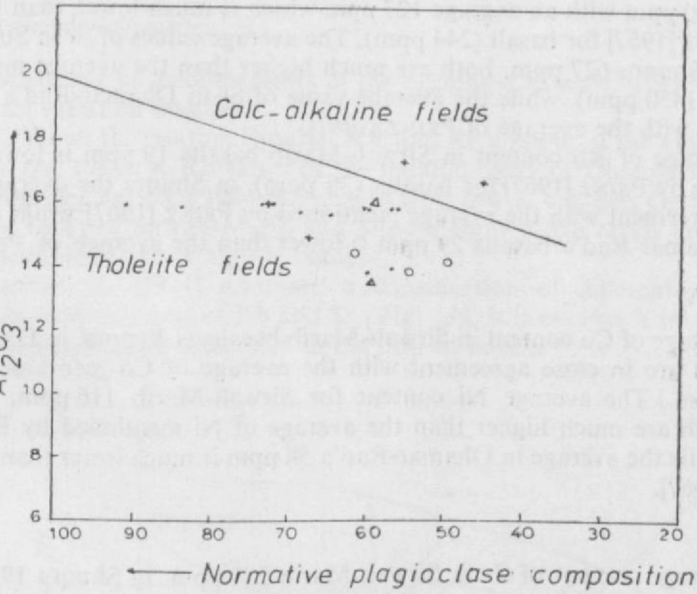

Fig. 11. Al_2O_3 wt per cent *vs* normative plagioclase composition for the basalts examined after IRVINE and BARAGAR [1971]. Symbols as in *Fig. 2*.

dividing line is drawn from very calcic-plagioclase down to about An_{35}. According to the diagram the majority of the examined basaltic rocks are classified as tholeiitic types, with the exception of two samples from Shuqra (Nos. 16 and 17, Table 1) falling in the calc-alkaline field. According to CHAYES [1966] and WILKINSON [1968], these two samples of high-alumina basalt (16.80 and 17.57) are treated as principally of calc-alkaline series. WILKINSON (op. cit.) used the term "sub-alkaline" as a more general name for both tholeiitic basalt and calc-alkaline series (as opposed to alkaline basalt). Accordingly all the examined basaltic rocks are sub-alkaline.

DISTRIBUTION OF TRACE ELEMENTS

The present investigation is intended to provide information on the abundance of seven trace elements (Ba, Sr, Rb, Co, Ni, Zr, and Y) in the examined basaltic rocks of Yemen. The results of quantitative analysis of 12 samples from Sirwah-Marib, 3 samples from Dhamar-Rad'a [KABESH *et al.*, 1980] as well as 4 samples from Shuqra [COX *et al.*, 1977] are presented in Table 3. The average trace element contents of the examined basaltic rocks and those of PRINZ [1967] are also given in Table 3.

Ba, Sr, and Rb

The distribution of Ba and Sr in the examined basaltic rocks indicates that Sr is more abundant than Ba. This is in agreement with the general trend of variation of Ba and Sr in calc-alkaline associations. The Ba content in Sirwah-Marib ranges from 204 ppm to 1400 ppm with an average 480 ppm which is higher than the average of PRINZ [1967] for basalt (244 ppm). In Dhamar-Rad'a the Ba content ranges from

80 ppm to 160 ppm with an average 127 ppm which is much lower than the average given by PRINZ [1967] for basalt (244 ppm). The average values of Sr in Sirwah-Marib 612 ppm, in Shuqra 627 ppm, both are much higher than the average mentioned by PRINZ [1967] (450 ppm), while the average value of Sr in Dhamar-Rad'a 427 ppm is in agreement with the average of PRINZ [1967].

The average of Rb content in Sirwah-Marib basalts 19 ppm is lower than the average given by PRINZ [1967] for basalts (39 ppm), in Shuqra the average of Rb 40 ppm is in agreement with the average mentioned by PRINZ [1967] while the average of Rb in Dhamar-Rad'a basalts 29 ppm is lower than the average of PRINZ [1967].

Co and Ni

The average of Co content in Sirwah-Marib basalts is 40 ppm, in Dhamar-Rad'a 43 ppm both are in close agreement with the average of Co mentioned by PRINZ [1967] 39 (ppm.) The average Ni content for Sirwah-Marib 116 ppm, for Shuqra 153 ppm both are much higher than the average of Ni mentioned by PRINZ [1967] (85 ppm), while the average in Dhamar-Rad'a 58 ppm is much lower than the average of PRINZ, [1967].

Zr

The average content of Zr in Sirwah-Marib 230 ppm, in Shuqra 195 ppm both are much higher than the average of PRINZ [1967] (1908 ppm), while the average in Dhamar-Rad'a 100 ppm is very close to the average of PRINZ [1967].

Y

The average content of Y in Sirwah-Marib (25 ppm), in Shuqra (26 ppm), both are close to the average mentioned by PRINZ [1967] (32 ppm).

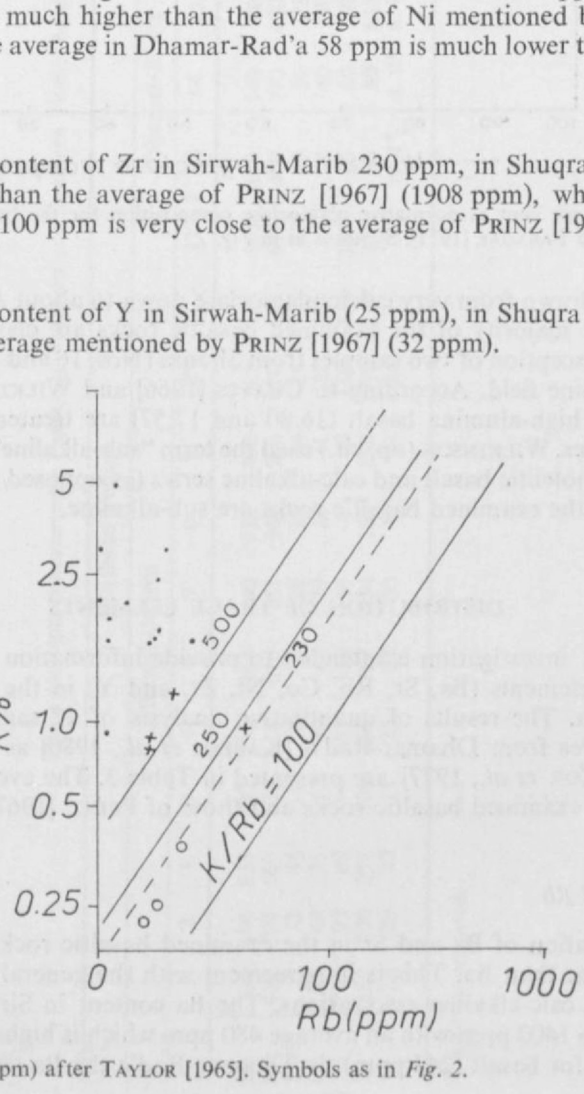

Fig. 12. K% *vs* Rb (ppm) after TAYLOR [1965]. Symbols as in *Fig. 2*.

Trace element chemistry

The behaviour of trace elements in the examined basaltic rocks is discussed by using several variation diagrams.

Fig. 12 shows the relation between K% and Rb content of the examined basaltic rocks [TAYLOR, 1965]. K/Rb ratios of the basaltic rocks of Dhamar-Rad'a are relatively low ranging between 100—300 due to their low K content. On the other hand, the basaltic rocks of Sirwah-Marib and Shuqra show K/Rb ratios greater than 500 which is attributed to their high K content.

KISTLER *et al.,* [1971] advanced a classification of different volcanic rocks according ot their contents of Rb and Sr *(Fig. 13)*. It is evident from the figure that all the examined basaltic rocks plot in the field of basalt.

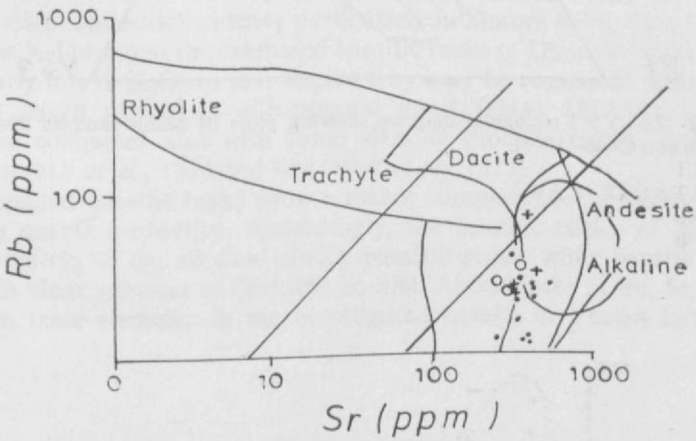

Fig. 13. Rb (ppm) — Sr (ppm) variation diagram after KISTLER *et al.*, [1971]. Symbols as in *Fig. 2*.

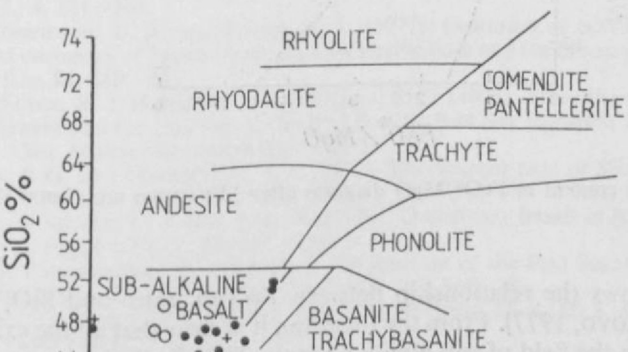

Fig. 14. SiO_2% *vs* Zr/TiO_2 diagram after WINCHESTER and FLOYD [1977]. Symbols as in *Fig. 2.*

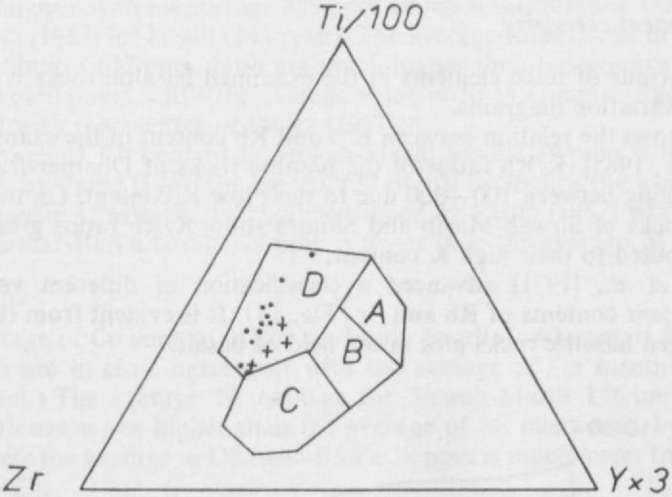

Fig. 15. Ti/100—Zr—Y×3 triangular diagram showing plots of basalt samples investigated after PEARCE and CANN [1973].
A: LKT
B: LKT+OFB+CAB
C: CAB
D: OFB

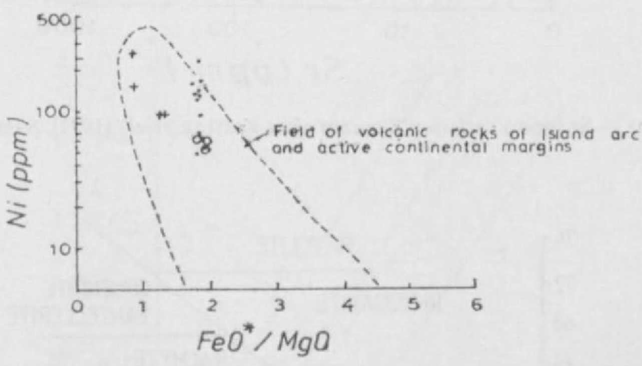

Fig. 16. Ni (ppm) content *vs* FeO*/MgO diagram after MIYASHIRO and SHIDO [1975]. Symbols as in *Fig. 2.*

Fig. 14 shows the relationship between Zr/TiO_2 ratio and SiO_2 content [WINCHESTER and FLOYD, 1977]. From the diagram, it is clear that all the examined basaltic rocks fall within the field of sub-alkaline basalt. Thus Zr/TiO_2 ratio can be used as an index of alkalinity of rocks (op. cit.),

Fig. 15 plot for the examined basalts using the Ti—Zr—Y discrimination diagram. It is clear from the diagram that the examined rocks fall within field D (within plate basalts). This diagram has been proposed by PEARCE and CANN [1973] as petrogenetic indicator for basaltic rocks.

Fig. 16 shows the relation between Ni ppm and FeO/MgO ratio of basaltic rocks. It is evident from the figure that all the examined basaltic rocks fall within the field of volcanic island arc and active continental margins. However, two samples from Sirwah-Marib plot very close to this field. This diagram has been proposed by MIYASHIRO and SHIDO [1975].

CONCLUSION

The basaltic rocks of Sirwah-Marib, Dhamar-Rad'a in Northern Yemen, Shuqra in Southern Yemen and of St. John's Island in Egypt, are petrochemically and geochemically evaluated. In terms of major oxides the examined basalts appear to have sub-alkaline characters with few alkaline affinities. According to the different systems of chemical classification, the examined basaltic rocks are classified as basalts with slight andesitic tendency particularly in Shuqra field, (Southern Yemen).

Based on K_2O content the examined basaltic rocks of Dhamar-Rad'a and Shuqra are particularly low in K_2O. In this respect they may be compared with the Red Sea axial trough basalt as well as with oceanic basalt, [GASS, 1977 and CHASE, 1977]. They may be compared also with some alkaline tholeiite basalt from St. John's Island [EL-SHAZLY *et al.*, 1974 and COLEMAN *et al.*, 1977].

The examined basaltic rocks show a rather complete compositional range from nepheline to quartz normative. Accordingly, the basaltic rocks of Sirwah-Marib and Shuqra belong to the alkaline olivine basaltic series, while basalts of Dhamar-Rad'a possess close affinities to tholeiitic basalts. Abundances of Ba, Sr, Rb, Co, Ni Zr and Y an trace elements in the investigated basalts in Yemen have also been discussed.

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Manuscript received, 10 September, 1983

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