J KAU: Earth Sci., **vol. 1**, pp. 149-163 (1408A.H./1988A.D.)

Petrology and Geochemistry of Ash Shafa Plutonic Rocks

F.M. MARZOUKI[1] and H.A. QURASHI[2]
Faculty of Earth Sciences, King Abdulaziz University[1],
and
Directorate General of Mineral Resources[2],
Jeddah, Saudi Arabia.

ABSTRACT. Ash Shafa area is underlain by metamorphic rocks consisting of amphibolite schist, quartzo-feldspathic gneiss and marble. These metamorphic rocks were later invaded by different types of plutonic rocks including gabbro-diorite, tonalite-quartz diorite and gneissic granite-granite. Chemical data indicate that Ash Shafa plutonic rocks have a calc-alkaline affinity. The gabbro-diorite-quartz diorite-tonalite were formed in an ensimatic island-arc, whereas the granites were formed by continental collision-related magmatism.

Introduction

The purpose of this paper is to describe briefly the regional geology, petrography and geochemistry of the various plutonic rocks in the Ash Shafa area. The Ash Shafa area lies in the southern part of At-Taif quadrangle between latitudes 21°07′00″N and 21°11′23″N and longitudes 40°21′21″E and 40°25′23″ (Fig. 1). This paper utilizes 14 chemical analyses from the various plutonic rocks in Ash Shafa area. The plutonic rock petrographic terminology follows Streckeisen (1976) and Ramsay *et al.* (1986b).

Regional Geology

The tectonic setting model proposed by Stoeser and Camp (*cf.* Stoeser 1986) subdivided the Saudi Arabian part of the Arabian Shield into five terranes separated by four suture zones. The three terranes (Asir, Hijaz, Midyan) west of the Nabitah suture are of ensimatic character, whereas the eastern two terranes (Afif, Ar Rayn) are of continental-marginal to continental (Stoeser 1986). The Asir terrane, which includes the studied area, can be divided into a number of tectonostratigraphic belts that contain assemblages of primitive to moderately evolved arc-type volcanoclastic sedimentary rocks, basaltic and dacitic volcanic rocks, and dioritic to tonalitic plutonic rocks (Greenwood *et al.* 1982, Johnson and Vranas 1984).

The Ash Shafa area is underlain by rocks of the Baish, Samran, Hali and probably Jeddah Groups of the southern Shield (Andreason *et al.* 1977, and Smith and Irvine 1980). Andreason *et al.* (1977) correlated the metamorphosed layered rocks which

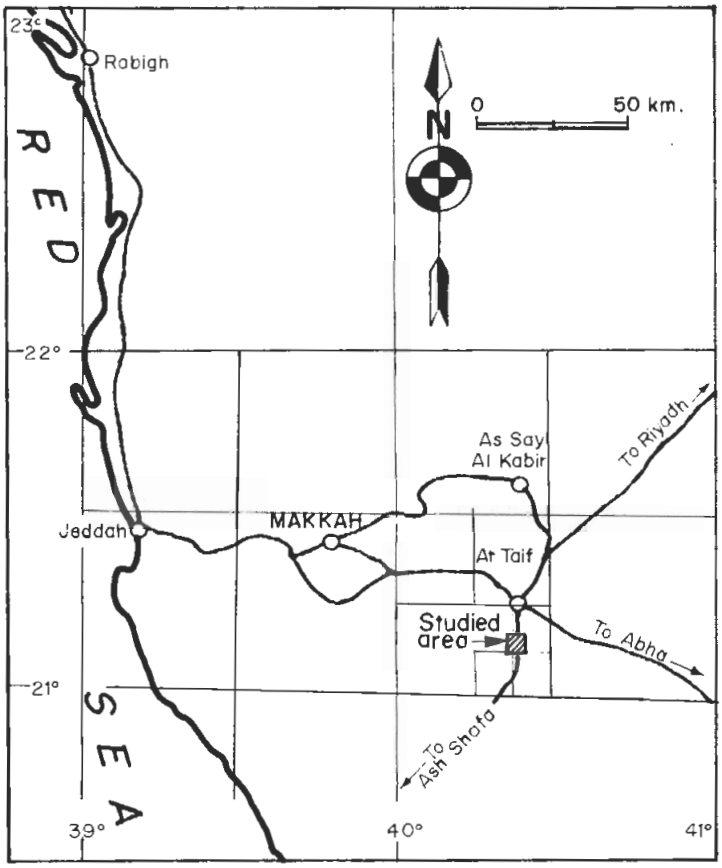

FIG. 1. Location of Ash Shafa area.

include amphibolite schist, quartz-mica schist, quartz-mica feldspar schist, marble and quartzite, with the "Hali Group", whereas Smith and Irvine (1980) referred to this succession as the "Wij Group". The Samran and Baish Groups are probably lower grade partial equivalents to "Wij Group" (Skiba, personal communication, in Smith and Irvine 1980) suggested that the amphibolites and gneisses were originally igneous rocks of calc-alkaline affinity. However, Smith and Irvine (1980), demonstrated that these metamorphic rocks were originally a sequence of acidic to basic volcanic rocks with some sedimentary phases, which were regionally metamorphosed to green-schist and amphibolite facies. Whereas Stoeser (1986) [(after Ramsay *et al.* (1981) and Fairer (in press)] stated that the western flanks of the Asir Terrane contain quartzo-feldspathic sedimentary rocks that appear to be continental in character and possibly derived from African craton to the west.

At-Taif (8 km north of Ash Shafa) province of the Asir terrane appears to be distinct from the rest of the terrane in that it contains significantly more granitic plutonic rocks, and Johnson and Vranas (1984) have proposed that a suture separates the At Taif and Abha provinces. The magmatic arc rock assemblages of the Asir terrane were formed between approximately 900 and 680 Ma (Cooper *et al.* 1979, Marzouki *et al.* 1982, Stoeser *et al.* 1984). The plutonic rocks comprise 75% of the At-Taif region. These rocks include intermediate varieties (diorite-gabbros, diorites, quartz diorite) and granitic varieties (granodiorite, granites). They are foliated (pre- to syn-tectonic) to mostly unfoliated (post-tectonic) (Smith and Irvine 1980).

Intermediate plutonic rocks constitute about 30% of the plutonic rock assemblage in the shield. Radiometric ages for these rocks indicate that most of them were formed from about 900-630 Ma (Stoeser 1986). The oldest reported intermediate plutonic rocks are from the tonalitic Bidah pluton of the central Asir Terrane and have a Rb-Sr whole-rock isochron age of 90±37 Ma (Marzouki *et al.* 1982). Most other dioritic and tonalitic plutonic rocks of the central Asir have ages 900-790 Ma (Stoeser 1986). The early intermediate plutonic and volcanic rocks of the western part of the shield are chemically primitive and tend to have tholeiitic affinities typical of ensimatic island arcs (Marzouki *et al.* 1982, Jackson 1986). The younger intermediate plutonic and volcanic rocks are typically more mature in character and are of calc-alkaline affinity (Jackson *et al.* 1984).

Granitic plutonic rocks constitute about 63% of the plutonic rock assemblages of the shield. The emplacement of granite within the shield did not begin until about 680 Ma, after which it became the dominant plutonic rock type (Stoeser 1986). Granitic rocks in the At-Taif area predominate and can be divided into two main groups: Pre- to syn-tectonic granite distinguished by migmatitic margins, gneissose structures and alkaline affinities (?), and post-tectonic granites, which are more abundant and believed to be derived from calc-alkaline to alkaline magmas (Sindi 1976).

Rock Units

The Ash Shafa rock units are described in terms of two main classes: metamorphic and plutonic rocks.

Metamorphic rocks occur as roof pendants within younger plutonic rocks and underlie extensive areas in the northwest (Fig. 2). They include amphibolite schist with intercalations of feldspar-biotite-quartz gneiss, granitic gneiss, and a few marble bands, and are characterized by a well-developed schistosity striking northeast (N50E) and dipping southeast. The amphibolite schist is dark-green to dark-grey and is composed predominantly by hornblende (40%), plagioclase (Andesine to labradorite) (37%), with minor secondary tremolite-actinolite (5%), biotite (5%), quartz (3%) and accessory minerals (10%). The feldspar biotite-quartz gneiss is dark grey and is mainly composed of plagioclase (Albite) (37%), biotite (28%), quartz (18%), orthoclase (10%) and accessory minerals (7%). The granitic gneiss is greyish

white and is composed essentially of potash feldspar (41%), quartz (26%), biotite (18%), plagioclase (10%) and accessory minerals (5%).

Plutonic rocks include tonalite, quartz-diorite, gabbro-diorite and granite. Tectonically they can be divided into pre- to syn-tectonic intrusions (gneissic granite and tonalite-quartz diorite) and post-tectonic plutons (gabbro-diorite and granite).

The gneissic granite is pinkish, medium to coarse grained and is composed of potash feldspar (41%), quartz (27%), plagioclase (albite-oligoclase) (23%), biotite (4%) and accessory minerals (opaques, apatite, sphene and alteration products) (5%).

The tonalite-quartz diorite is light to dark grey, massive to slightly foliated and medium to locally coarse grained. The mineral constituents are plagioclase (andesine) (66%), hornblende (13%), quartz (10%), secondary tremolite-actinolite (6%), and accessory minerals (opaques, zircon and sphene) (5%).

The gabbro-diorite is generally medium to coarse grained, dark green to dark grey, consisting essentially of plagioclase (labradorite-andesine) (49%), hornblende

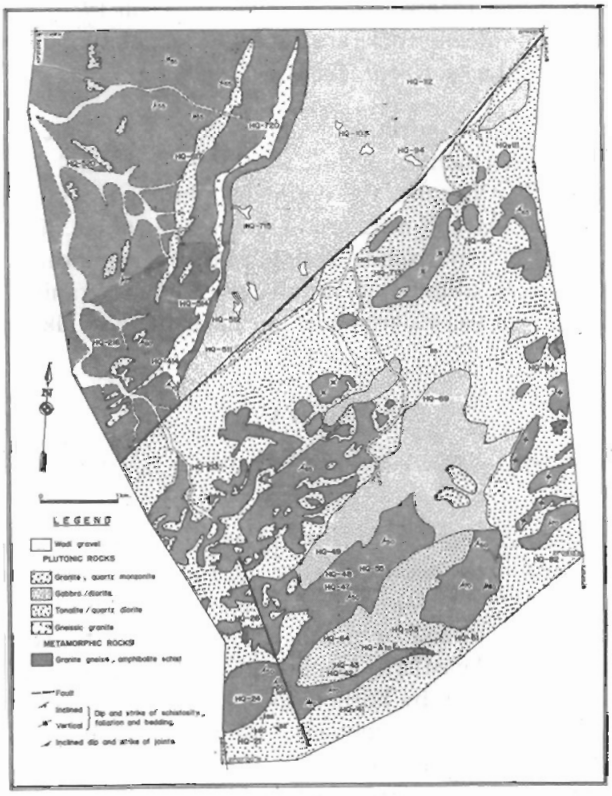

FIG. 2. Geologic map showing the major rock units of Ash Shafa area.

(17%), secondary tremolite-actinolite (after augite and hornblende) (16%), quartz (5%), biotite (3%) and accessory minerals (including opaques, zircon, chlorite, serpentine) (10%).

The granite is typically pink, and medium to coarse grained but in places porphyritic with phenocrysts of potash feldspar and plagioclase. The mineral constituents are potash feldspar (35%), quartz (33%), plagioclase (oligoclase) (24%), biotite (4%), and accessory minerals (including muscovite, opaques, sphene and zircon) (4%).

Geochemistry

Techniques

Major oxide and selected trace element analyses of 14 representative plutonic rocks of the Ash Shafa area are given in Tables 1,2 and 3. The analyses of major oxides were carried out at Faculty of Earth Sciences laboratory by means of X-ray flourescence spectrometry, (for SiO_2, Al_2O_3, TiO_2, MnO, Fe_2O_3, P_2O_5, CaO), atomic absorption spectrometry (for MgO, and CaO in some samples), flame photometry (for Na_2O and K_2O) and titration was used to determine FeO. Trace element analyses were made in Australia by ComLab Tty Ltd. The analyses were done by means of fully automated Philips PW 1220 or PW 1400 X-ray fluorescence with an accuracy of ±3%.

TABLE 1. Major oxides (wt.%) and CIPW Norms of Ash Shafa gabbro/diorite and tonalite/quartz diorite rocks (recalculated 100% anhydrous).

	Gabbro/diorite			Tonalite/Quartz-diorite			
	HQ 103	HQ 512	HQ 112	HQ C	HQ A	HQ B	HQ 43
SiO_2	47.94	48.14	56.45	60.24	64.23	64.78	64.95
TiO_2	0.89	0.94	0.79	1.02	0.92	0.80	0.79
Al_2O_3	18.54	17.94	20.68	16.21	16.50	15.84	16.99
Fe_2O_3	1.56	2.21	2.68	3.74	2.32	2.84	2.09
FeO	6.78	8.77	4.53	1.51	1.87	0.90	1.35
CaO	10.59	11.59	7.38	7.18	7.12	6.43	6.16
MgO	10.93	8.20	2.18	3.35	3.02	2.90	3.52
Na_2O	2.16	1.22	4.69	2.83	3.40	4.44	3.56
K_2O	0.29	0.61	0.34	3.51	0.27	0.79	0.30
MnO	0.13	0.18	0.10	0.16	0.12	0.09	0.09
P_2O_5	0.20	0.21	0.18	0.26	0.23	0.20	0.20
Total	100.01	100.01	100.00	100.01	100.00	100.01	100.00
D.I.	19.99	20.97	48.97	58.14	55.62	62.71	57.11
CIPW Norms							
Qz	0.00	5.83	7.28	13.46	25.26	20.47	25.21
Cor	0.00	0.00	0.00	0.00	0.00	0.00	0.08
Or	1.71	3.92	2.01	20.74	1.60	4.67	1.77
Ab	18.28	11.22	39.69	23.94	28.77	37.57	30.12
An	40.03	45.29	34.37	21.16	28.96	20.69	29.25

Table 1 (contd.).

	Gabbro/diorite			Tonalite/Quartz-diorite			
	HQ 103	HQ 512	HQ 112	HQ C	HQ A	HQ B	HQ 43
Wo	4.67	6.56	0.45	5.33	2.03	4.02	0.00
En	10.85	22.20	5.43	8.34	7.52	7.22	8.77
Fs	3.96	0.00	4.99	0.00	0.22	0.00	0.00
Fo	11.47	0.00	0.00	0.00	0.00	0.00	0.00
Fa	4.61	0.00	0.00	0.00	0.00	0.00	0.00
Mt	3.89	0.38	3.89	2.43	3.36	0.88	2.36
Hm	0.00	2.14	0.00	2.06	0.00	2.24	0.47
Il	1.50	1.94	1.50	1.94	1.75	1.52	1.50
Ap	0.43	0.54	0.43	0.62	0.55	0.47	0.47
Total	100.01	100.01	100.01	100.02	100.01	100.01	100.01

TABLE 2. Major oxides (wt.%) and CIPW Norms of Ash Shafa granitic rocks (recalculated 100% anhydrous).

	Granite					
	HQ82 A	HQ 213	HQ 84	HQ 111	HQ 21	HQ 92
SiO_2	72.65	74.49	74.84	75.63	75.85	76.20
TiO_2	0.27	0.13	0.17	0.13	0.13	0.04
Al_2O_3	15.51	14.27	14.37	14.06	13.21	13.92
Fe_2O_3	0.44	0.81	1.09	0.67	1.47	0.54
FeO	0.43	0.58	0.25	0.18	0.18	0.22
CaO 1.32	0.91	0.64	0.74	0.52	0.32	
MgO	0.42	0.22	0.24	0.18	0.26	0.11
Na_2O	4.07	3.56	3.36	3.51	3.53	3.88
K_2O	4.74	4.88	4.95	4.80	4.75	4.66
MnO	0.05	0.06	0.03	0.03	0.06	0.05
P_2O_5	0.10	0.10	0.07	0.07	0.06	0.05
Total	100.00	100.00	100.01	100.00	99.99	100.01
D.I.	90.08	91.93	92.49	93.25	93.76	95.44
CIPW Norms						
Qz	27.63	32.98	34.82	35.19	35.81	35.08
Cor	1.52	1.72	2.49	1.91	1.46	2.03
Or	28.01	28.83	29.25	28.37	28.07	27.53
Ab	34.43	30.12	28.43	25.70	29.78	32.82
An	5.90	3.86	2.72	3.21	2.19	1.26
Wo	0.00	0.00	0.00	0.00	0.00	0.00
En	1.05	0.55	0.60	0.45	0.65	0.27
Fs	0.07	0.29	0.00	0.00	0.00	0.00
Fo	0.00	0.00	0.00	0.00	0.00	0.00
Fa	0.00	0.00	0.00	0.00	0.00	0.00
Mt	0.64	1.17	0.41	0.30	0.30	0.78
Hm	0.00	0.00	0.81	0.46	1.26	0.00
Il	0.51	0.25	0.32	0.24	0.25	0.08
Ap	0.24	0.24	0.17	0.17	0.14	0.12
Total	100.01	100.01	100.00	100.00	100.00	100.00

TABLE 3. Trace elements concentrations (ppm) in Ash Shafa plutonic rocks.

Trace Elements	Gabbro/Diorite			Tonalite/Quartz-diorite			
	HQ 103	HQ 512	HQ 112	HQ C	HQ A	HQ B	HQ 43
Nb	2	5	8	10	12	10	10
Zr	30	22	700	125	200	190	210
Sr	350	530	1250	440	570	400	570
Rb	L(2)	10	4	95	4	22	L(2)
Ba	55	120	390	850	145	260	130
Y	10	12	6	26	22	24	26
Ni	185	25	L(5)	5	10	5	10
Co	50	40	15	10	15	10	20
K/Rb	622	249	311	153	311	151	623
Ba/Rb	27.5	12	97.50	8.95	36.25	11.82	65.0
Rb/Sr	0.005	0.01	0.001	0.22	0.007	0.06	0.001
Ba/Sr	0.16	0.23	0.31	1.93	0.25	0.65	0.23
K/Ba	0.40	0.03	0.01	0.03	0.01	0.02	0.02

Trace Elements	Granite					
	HQ 82A	HQ 213	HQ 84	HQ 111	HQ 21	HQ 92
Nb	14	18	16	20	16	22
Zr	145	125	125	135	105	65
Sr	310	95	130	75	95	20
Rb	110	145	160	140	195	150
Ba	650	175	380	155	240	25
Y	12	16	10	20	10	10
Ni	L(5)	L(5)	L(5)	L(5)	L(5)	L(5)
Co	15	15	20	20	40	15
K/Rb	177	140	106	142	102	130
Ba/Rb	5.91	1.21	2.38	1.11	1.23	0.17
Rb/Sr	0.35	1.53	1.23	1.87	2.05	7.50
Ba/Sr	2.10	1.84	2.92	2.10	2.53	1.25
K/Ba	0.07	0.30	0.15	0.30	0.20	2.10

Major Oxides

Silica content in the gabbro-diorite-tonalite group are generally low (47-65%). Al_2O_3 values range between 16-18%. Soda have intermediate values (1.2-4.7%), while K_2O value are low (0.3-0.8%). In the granite group, silica contents are high (72-76%). Al_2O_3 contents range between 13-15%. Soda values vary between 2-4% while K_2O have higher values (4.6-6.1%). The content of Al_2O_3 is greater than (Na_2O+K_2O). All the granite samples have varying amounts of corundum in their norms (1.5-2.2%).

Trace Elements

Trace elements contents are given in Table 3. Ba in the gabbro-diorite-tonalite group averages 183 ppm while it is higher in the granites (average 271 ppm). Nb is

very low in both groups (8-15 ppm). Sr is low in the granite (120 ppm) and higher in the diorite group (476 ppm).

Classification

The normative albite-orthoclase-anorthite diagram (Fig. 3), with fields defined by O'Connor (1965) and modified by Barker (1979) has proved to be useful for chemical classification. Accordingly, Ash Shafa plutonic rocks could be classified into two main groups: 1) Tonalites and 2) granites. Furthermore, an alternative approach to

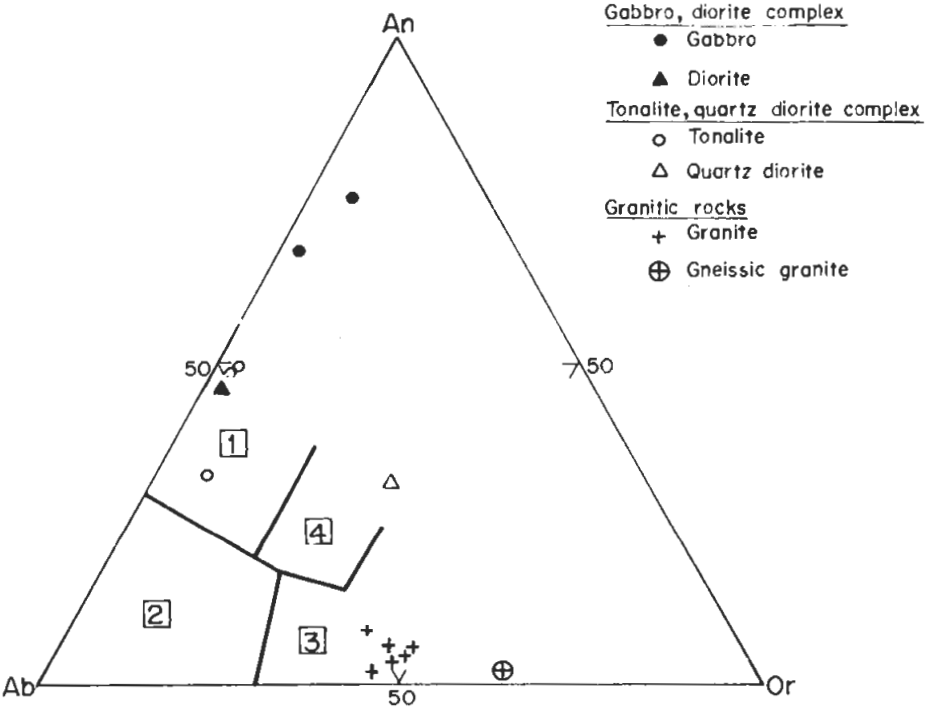

FIG. 3. Classification of Ash Shafa plutonic rocks according to their relative contents of normative albite, anorthite and orthoclase (after O'Connor 1965, Barker 1979). 1 – Tonalite, 2 – Trondhjemite, 3 – Granite, 4 – Granodiorite.

the discrimination of various granitoid series is to use cationic/molecular values found in French classification schemes which express whole-rock chemistry as cationic parameters in terms of mineralogical component (Batchelor and Bowden 1985). R_1-R_2 multicationic scheme (de la Roche *et al.* 1980) is used to show the petrographic divisions (Fig. 4). This diagram shows that Ash Shafa plutonic rocks fall

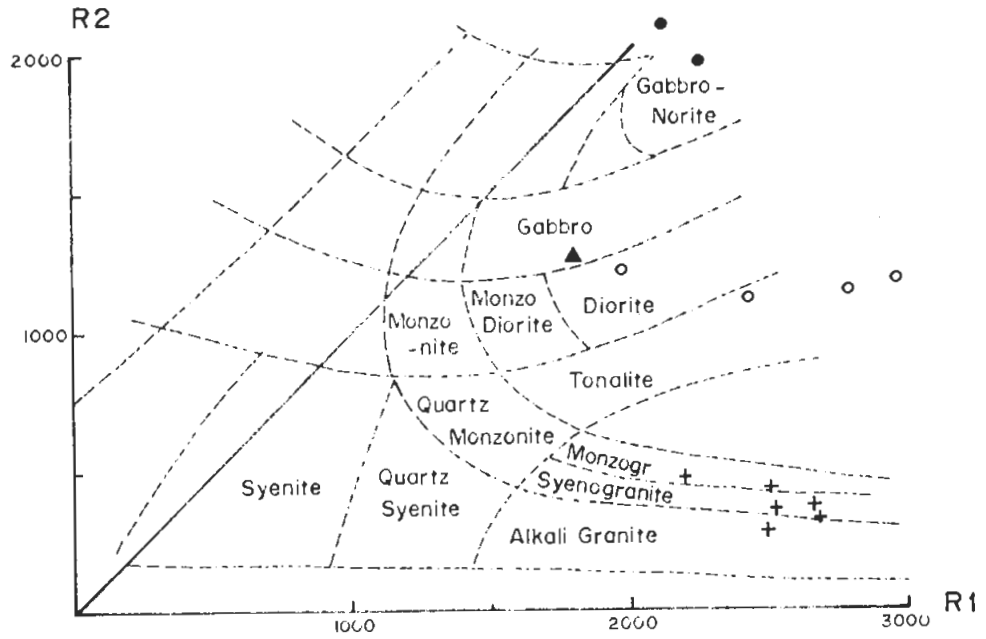

FIG. 4. Classification of Ash Shafa plutonic rocks based on de la Roche R_1-R_2 diagram showing petrographic divisions (after de la Roche *et al.* 1980). Key samples as in Fig. 3.
$R_1 = 4Si - 11(Na + K) - 2(Fe + Ti)$
$R_2 = 2Ca + 2Mg + Al$

within the gabbro, diorite, tonalite, monzogranite and syeno-granite fields. AFM (Fig. 5A), FeO(t)-CaO+MgO-Al_2O_3 (Fig. 5B), and K_2O-Na_2O-CaO (Fig. 5C), diagrams of Ash Shafa plutonic rocks show that these rocks follow a calc-alkaline differentiation trend. The variation diagram (Fig. 6) of some major oxides and some trace elements with the Differentiation Index (DI) shows that Ash Shafa plutonic rocks could be separated into three groups ranging from early differentiates represented by the gabbro-diorite to highly differentiated rocks represented by the granites. The granitic rocks form one cluster characterized by high differentiation indices (higher than 90), which reflects highly evolved stage of magmatic differentiation. These rocks also have very low solidification indices (SI). The gabbro-diorite is characterized by very low differentiation indices (less than 30) and reflects an early differentiation stage. The third cluster is formed by the tonalites occupying an intermediate position between the previous two clusters and is characterized by intermediate values of differentiation and solidification indices.

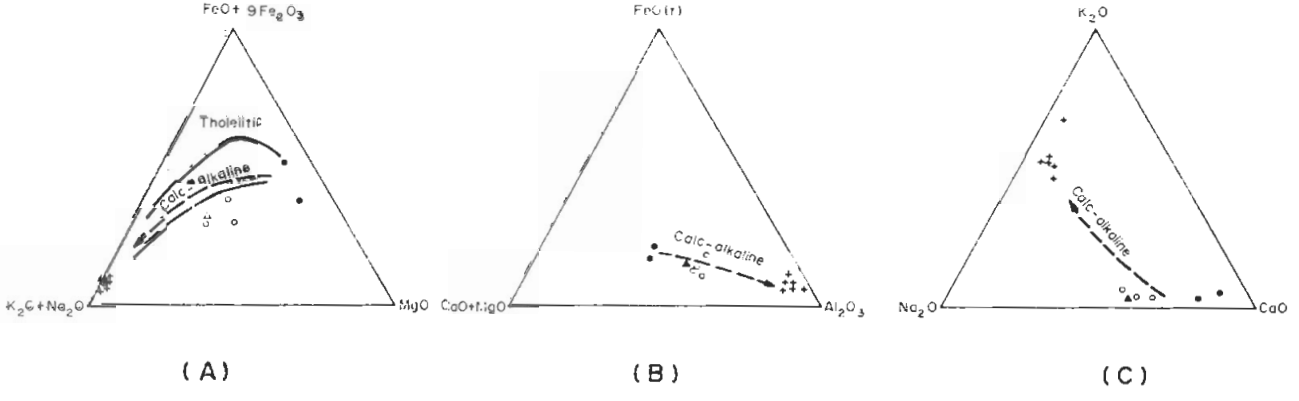

FIG. 5. Chemical compositional fields for Ash Shafa plutonic rock (A) AFM diagram (weight percentage), (B) FeO(t) – (CaO + MgO) – Al_2O_3 diagram (weight percentage), (C) K_2O-Na_2O-CaO diagram (weight percentage). Key samples as in Fig. 3.

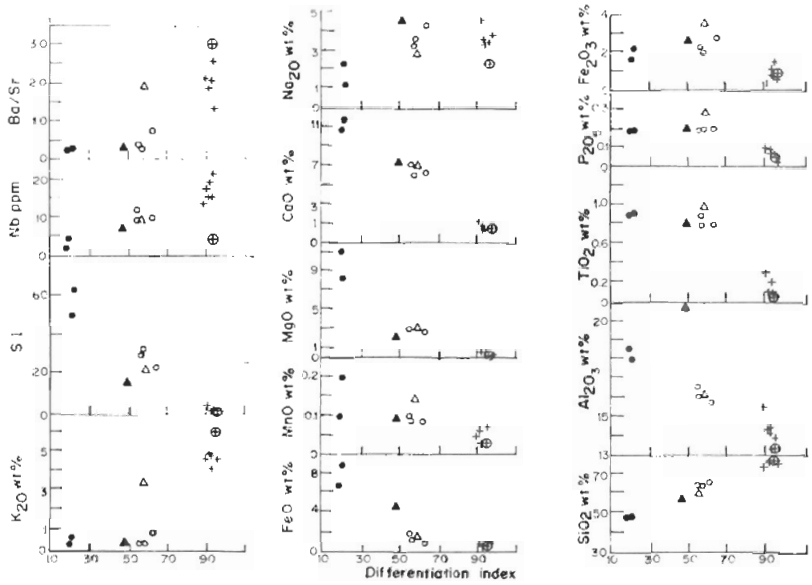

FIG. 6. Differentiation index vs Solidification index and major oxides (weight percentage). Key samples as in Fig. 3.

Petrogenesis

Numerous geologic and petrologic studies have demonstrated that Arabian Shield volcanic rocks are compositionally similar to lavas erupted in contemporary island arcs (Jackson 1986). The coeval intrusions, at least in the Hijaz and Asir regions, are lithologically and chemically similar to plutonic rocks found in Mesozoic and Cenozoic island arcs or accreted terranes containing island-arc assemblages (Jackson *et al.* 1984, Jackson 1986). Further support for an island arc origin for plutonic and volcanic magmas is provided by Sr isotopic data. Initial $^{87}Sr/^{86}Sr$ ratios for intermediate plutonic rocks of the western Asir terrane range between 0.7025 and 0.7030 (Jackson 1986). The gabbro-diorite-tonalite of Ash Shafa show close compositional similarities with plutonic rocks emplaced in island arcs such as New Britain, Solomon Islands and Fiji (Fig. 7), the monzo and syenogranite are similar to those in Sierra Nevada. Similar interpretations have been arrived at for At-Taif and Al-Hadah plutonic rocks (Naseef 1971, Sindi 1976, Naseef and Gass 1977 and Marzouki and Fyfe 1977). Jackson (1986) interpreted that the initial fusion products of Arabian Shield calc-alkaline island arc and continental crust protoliths are likely to be granitic in composition with moderate to high K content. Thus Ash Shafa granites which are characterized by high K_2O (4.7%) are most probably produced by initial melting of calc-alkaline island arc and continental crust. Concerning the tectonic environment of the granitoids plutonic rocks, a Pitcher (1979, 1982) diagram was used (Fig. 8)

from which it is obvious that the gabbro and diorite samples are mantle fractionates, the tonalites were formed in the pre-plate collision state and the granites belong to the syntectonic to late tectonic stage.

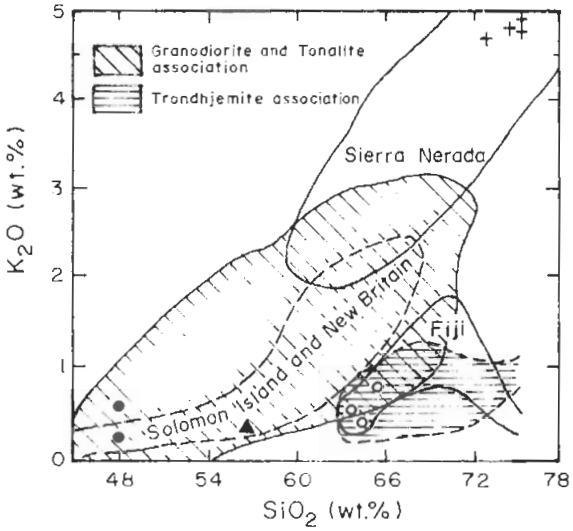

FIG. 7. K_2O-SiO_2 diagram for destructive plate-boundary plutonic suites and two composite fields for the Asir supersuite (after Jackson 1986). Data sources: Sierra Nevada (Bateman and Dodge 1970), Solomon Islands (Chivas 1978), New Britain (Hine and Mason 1978) and Fiji (Gill and Stork 1979). Key samples as in Fig. 3.

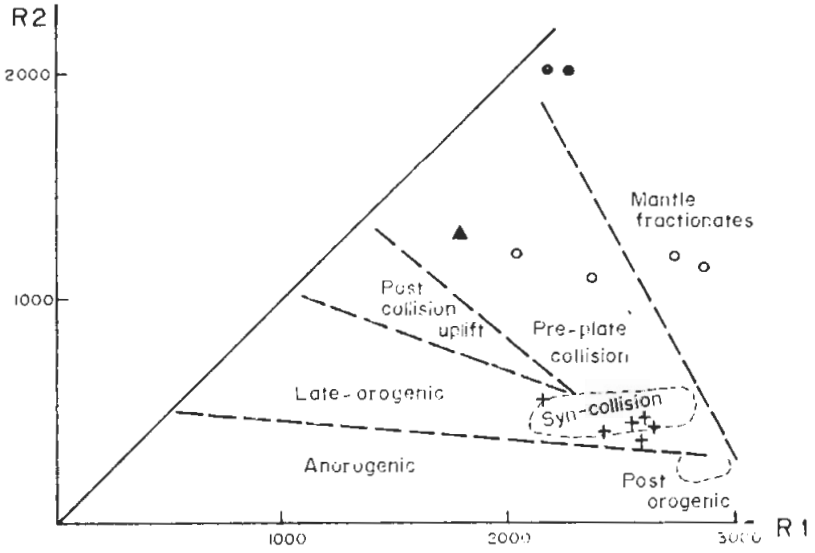

FIG. 8. Summary diagram of major granitoid associations (after Batchelor and Bowden 1985): group 1 – tholeiitic; group 2 – calc-alkaline and trondhjemitic; group 3 – high-potassic calc-alkaline; group 4 – sub-alkaline monzonitic; group 5 – alkaline and peralkaline; group 6 – anatectic Z-mica leuco-granites. Key samples as in Fig. 3.

$R_1 = 4Si - 11(Na + K) - 2(Fe + Ti)$

$R_2 = 6Ca + 2Mg + Al$

Conclusions

The Ash Shafa area is underlain by metamorphic host-rocks, including amphibolite schist and quartzo-feldspathic gneisses. These metamorphic rocks are intruded by a series of plutonic rocks. The earliest series (660-900 Ma) were composed of gabbro, diorite, quartz diorite and tonalite. These rocks are supposed to represent a mixture of mantle and crustal fusion products that have undergone varying degrees of magmatic differentiation and broadly analogous in composition to plutonic rocks emplaced in island arc settings. The youngest series (550-660 Ma) are represented by granites (monzo- and syenogranites) probably formed during the accertion stage from melting of a heterogeneous protolith and characterized by high K_2O content.

References

Andreason, P.G., Bashawri, M., Al-Hajeri, F., Jadaan, K., Al-Kolak, Z., Mawad, M., Al-Sagaby, I., Al-Sari, A. and **Zubair, M.** (1977) Geology of the central Taif region, Kingdom of Saudi Arabia. *Institute of Applied Geology, King Abdulaziz University, Bull.* No. 2, 38 p.

Barker, F. (1979) Trondhjemite-definition, environment and hypothesis of origin. *In:* **Baker, F. (ed.),** Trondhjemites, Dacites and Related Rocks, Elsevier, Amsterdam, pp. 1-72.

Batchelor, R.A. and **Bowden, P.** (1985) Petrogenetic interpretation of granitoid rock series using multicationic parameters, *Chem. Geol.* **48:** 43-55.

Bateman, P.C. and **Dodge, F.C.W.** (1970) Variations of major chemical constituents across the central Sierra Nevada batholith, *Bull. Geol. Soc. Am.* **81:** 409-420.

Chivas, A.R. (1978) Porphyry copper mineralization at the Koloula igneous complex, Guadalcanal, Solomon Islands, *Econ. Geol.* **73:** 645-677.

Cooper, J.A., Stacey, J.S., Stoeser, D.B. and **Fleck, R.J.** (1979) An evolution of the Zircon method of isotopic dating in the southern Arabian Craton, *Contr. Minera. Petrol.* **68:** 429-439.

De La Roche, H., Leterrier, J., Granclaude, P. and **Marchal, M.** (1980) A classification of volcanic and plutonic rocks using R_1-R_2 diagram and major element analyses – its relationship with current nomenclature, *Chem. Geol.* **29:** 183-210.

Fairer, G.M. (in press). *Geology of the Wadi Baysh Quadrangle Sheet, 17F, Kingdom of Saudi Arabia.* Saudi Arabian Deputy Ministry for Mineral Resources Geosciences Map, Scale 1:250,000.

Gill, J.B. and **Stork, A.L.** (1979) Miocene low-K dacites and trondhjemites of Fiji. *In:* **Baker, F. (ed.),** Trondhjemites, Dacites and Related Rocks, Elsevier, Amsterdam, pp. 629-649.

Greenwood, W.R., Stoeser, D.B., Fleck, R.J. and **Stacey, J.S.** (1982) Late Proterozoic island-arc complexes and tectonic belts in the southern part of the Arabian Shield, Kingdom of Saudi Arabia, *Saudi Arabian Deputy Ministry for Mineral Resources Open-File Report* **USGS-OF-02-8.**

Hine, R. and **Mason, D.R.** (1978) Intrusive rocks associated with porphyry copper mineralization, New Britain, Papua New Guinea, *Econ. Geol.* **73:** 749-760.

Jackson, N.J., Walsh, J.N. and **Pegram, E.** (1984) Geology, geochemistry and petrogenesis of Late Precambrian granitoids in the central Hijaz region of the Arabian Shield, *Contr. Petrol.* **87:** 205-219.

Johnson, P.R. and **Vranas, G.J.** (1984) The origin and development of late Proterozoic rocks of the Arabian Shield: an analysis of terranes and mineral environments, *Saudi Arabian Deputy Ministry of Mineral Resources Open-File Report* **RF-OF-04-32.**

Marzouki, F.M.H. and **Fyfe, W.S.** (1977) Pan-African Plates – additional evidence from igneous events in Saudi Arabia, *Contr. Miner. Petrol.* **60:** 219-244.

Marzouki, F.M.H., Jackson, N.J., Ramsay, C.R. and **Darbyshire, D.P.** (1982) Composition, age and origin of two proterozoic diorite-tonalite complexes in the Arabian Shield, *Precamb. Res.* **19:** 31-50.

Naseef, A.O. (1971) *The geology of the northeastern At-Taif area, Saudi Arabia,* Ph.D. Thesis, Univ. Leeds, 229 p.

Naseef, A.O. and **Gass, I.G.** (1977) Granitic and metamorphic rocks of the At-Taif area, western Saudi Arabia, *Bull. Geol. Soc. Am.* **87**: 1721-1730.

O'Connor, J.T. (1965) A classification for quartz-rich igneous rocks based on feldspar ratios, *U.S. Geol. Surv. Prof. Pap.* **525-B:** 79-84.

Pitcher, W.S. (1979) Comments on the geological environments of granites. *In:* **Atherton, M.P.** and **Tarney, J. (eds.)**, *Origin of Granite Batholiths*, Geochemical Evidences Shiva, Orpington, pp. 1-8.

Pitcher, W.S. (1982) Granite type and tectonic environment. *In:* **Hsu, K.J. (ed.)**, *Mountain Building Processes*, Academic Press, London, pp. 19-40.

Ramsay, C.R., Basahel, A.N. and **Jackson, N.J.** (1981) Petrology, geochemistry and origin of the volcanosedimentary succession between Jabal Ibrahim and Al-Aqiq, Saudi Arabia, *Bull. Faculty Earth Sci., (King Abdulaziz University, Jeddah)*, **4:** 1-24.

Ramsay, C.R., Stoeser, D.B. and **Drysdall, A.R.** (1986b) Guidelines to classification and nomenclature of the Arabian Felsic Plutonic rocks, *J. African Earth Sciences*, **4:** 13-20.

Sindi, H.O. (1976) *The geology and geochemistry of the At-Taif quadrangle, sheet 21/40C, Kingdom of Saudi Arabia.* Geological map DGMR **GM-56.**

Stoeser, D.B. (1986) Distribution and tectonic setting of plutonic rocks of the Arabian Shield, *J. African Earth Sciences*, **4**: 21-46.

Stoeser, D.B., Stacey, J.S., Greenwood, W.R. and **Fischer, L.B.** (1984) U/Pb Zircon geochronology of the southern portion of the Saudi Arabian Shield, *Saudi Arabian Deputy Ministry for Mineral Resources Technical Record*, **USGS-TR-04-05.**

Streckeisen, A. (1976) To each plutonic its proper name, *Earth Sci. Rev.* **12:** 1-33.

بترولوجية وجيوكيميائية الصخور الجوفية لمنطقة الشفا

فؤاد محمد حامد مرزوقي وحاسن القرشي

كلية علوم الأرض – جامعة الملك عبد العزيز – وكالة الوزارة للثروة المعدنية – وزارة البترول والثروة المعدنية – جدة – المملكة العربية السعودية

تغطى منطقة الشفا بصخور متحولة تتكون من الشست الامفيبوليتي والنيس الكوارتزوفلسباتي والرخام والتي تداخلتها أنواع متعددة من الصخور السحيقية منها الجابرو – ديوريت والتونالیت والكوارتز ديوريت والجرانيت النيسي والجرانيت .

وتدل معطيات التحليل الكيميائي على أن صخور الشفا السحيقية ذات ميل كلس - قلى . وتكونت صخور الجابرو – ديوريت والكوارتز ديوريت والتونالیت في بيئة أقواس جزر داخل محيطية (إنسيماتية) بينما تكونت الجرانيتات كنتيجة للصهارة المنتسبة للتصادم القاري .