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Contribution to the petrography, geochemistry, and tectonic setting of the basalt flows of the Umm-Qais plateau, north Jordan.

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Abstract

The Umm-Qais plateau is situated in north Jordan, south of the Yarmouk River. It consists of eleven basalt flows (about 190 m. thickness). The basalt flows belong to the Arabian Harrat volcanism. Petrographical, mineralogical and geochemical analysis of 11 rock samples indicated that the rocks are products of a continental intra-plate magmatism, mostly as coarse-grained silica-undersaturated olivine-rich alkali basalt (AOB). Nepheline and Fo-olivine are among the normative minerals.

The age of the basalt flows can be correlated with the basalt of the northern extension of the Umm-Qais plateau north the Yarmouk River (Zamlat Bkhila plateau basalt) in the Golan Heights which was found to be 3.7±0.36-3.11±0.16 Ma. Flow eruptions are contemporaneous with the second spreading stage of the Red Sea during the Cainozoic over the past 5 Ma.

Analysis of fractures showed mainly four dominant directions, namely ENE/WSW, NW/SE, NNE/SSW and NE/SW. They coincide with the trends of the Red Sea, Dead Sea transform fault, and some other distinct tectonic features.

INTRODUCTION

An extensive continental intra-plate basalt province of alkaline nature extends for about 3000 km over a north-south direction from Syria through Jordan, Saudi Arabia to Yemen (Fig. 1 and Fig. 2). It comprises one of the world's largest alkaline volcanic provinces named the Arabian Harrat province, and covers an area of 180.000 km2 (Coleman et al, 1983). The basalt originated during several phases of eruptions, which were closely associated in space and time with: 1. the Cainozoic evolution of the Red Sea through two-stages of spreading; the first was before 30-15 Ma and the second was initiated over the past 5 Ma-recent, 2. collision of the Arabian

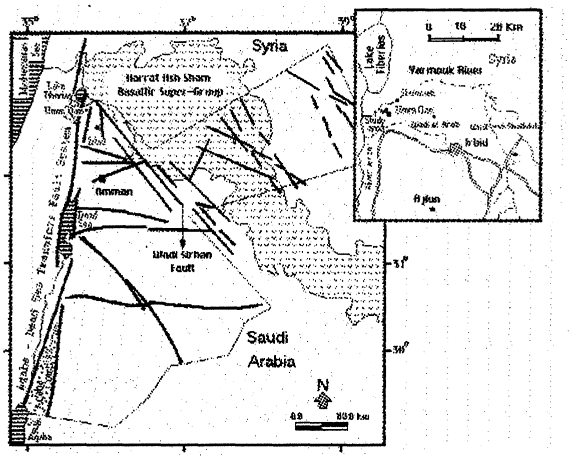

Figure 1. Location of the study area and simplified tectonic map of Jordan showing the distribution of the Neogene to Quaternary volcanism (Harrat Ash Shaam Basaltic Super-Group). [(Map modified after Ibrahim, 1996)].

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^arrat is an Arabic word and means "stony area, volcanic province, lava field"; Wher, 1976.

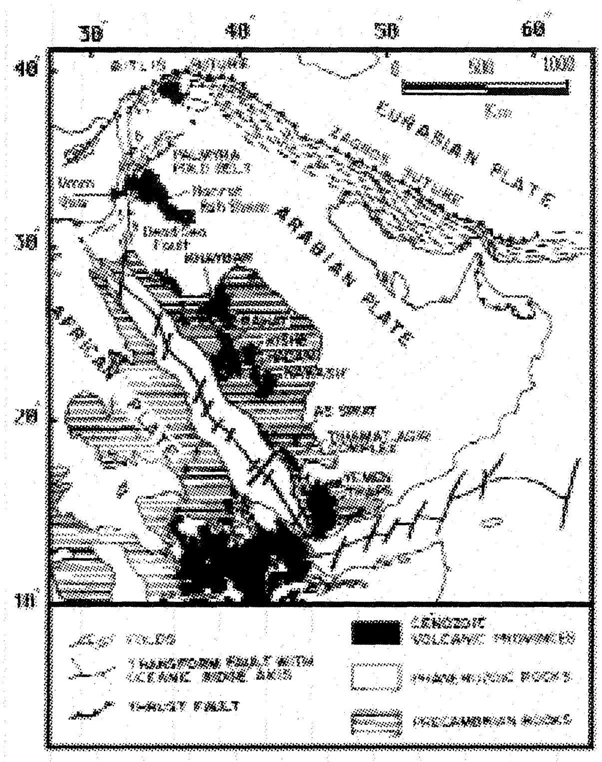

Fig 2: Regional map of the basalt flows in the Arabian Plate.

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and Eurasian plates and 3. the uplift of the Afro-Arabian dome (Camp and Roobol, (1989). In Jordan basalt flows cover about 11 000 km2.

The basalts are mainly distributed over the northeast (NE-basalt plateau), north, and the middle parts to the east of the Dead Sea. In general, the extent of the volcanic province is parallel with the NW-SE trending Wadi Sirhan fault zone (Fig. 1) which propably caused by tensional forces parallel to the Red Sea. The above mentioned basalt flows were considered by Ibrahim (1993) as the lHarrat Ash Shaam Basaltic Super-Group, and this term was applied in Jordan to all of the Neogene-Quaternary basalts exposed in the North Arabian Volcanic Province.

Previous studies on the North Arabian volcanic province suggested the derivation of this basalt from deep mantle source material and are also characterized by a low degree of partial melting of upper mantle peridotites with minor secondary differentiation (Barberi et al., 1979; Brenner, 1979; Saffarini et al., 1985; Ibrahim, and Saffarini, 1990; Khalil, 1991). The depth of the basalt source material is between 37-60 km (Green and Ringwood, 1967; Ibrahim, 1987; Nassir and Al Fugha, 1988a).

The present study deals with the petrography, geochemistry, origin, and tectonic setting of the Cover Basalt and deformations affecting the Umm-Qais and adjacent areas to the east of the Jordan Rift.

LOCATION, TOPOGRAPHY AND STRATIGRAPHY

The Umm-Qais plateau is located in north Jordan and delimited by the latitudes 320 30' 9" - 320 30^{f} 11" N and longitudes 350 40' 64"- 350 40' 11" E. It occurs at about 30 km northwest of Irbid and 3 km south of the Yarmouk River (Fig. 1).

The height of the plateau is about 340 m; the upper 190 m consist of eleven basalt flow units.

The basalt flows (Cover Basalt) constitute the southern part of the Zamlat Bkhila plateau of Syria (Ponikarov et al., l^{or}>7) which is also called as Mevo Hama plateau (Mor and Steinitz, 1985). The original plateau was deeply dissected and led to the formation of the Yarmouk River Ravine between the two subplateaus (Wiesemann & Abdullatif, 1963) (Fig. 3). Stratigraphically, the basalt flows in the study area are disconformably overlying the older carbonate rock sequences (Coniacian-Eocene) (see Fig. 4).

GEOLOGIC SETTING AND TECTONIC EVOLUTION OF THE COVER BASALT

The study area is greatly affected by the uplift and vertical movements of the Jordanian block as a part of the regional uplift of the Afro-Arabian dome started with the second-stage of the Red Sea spreading over the past 5 Ma during late Neogene and Pleistocene times. Huge amounts of basalt lavas were erupted from vertical fissures and

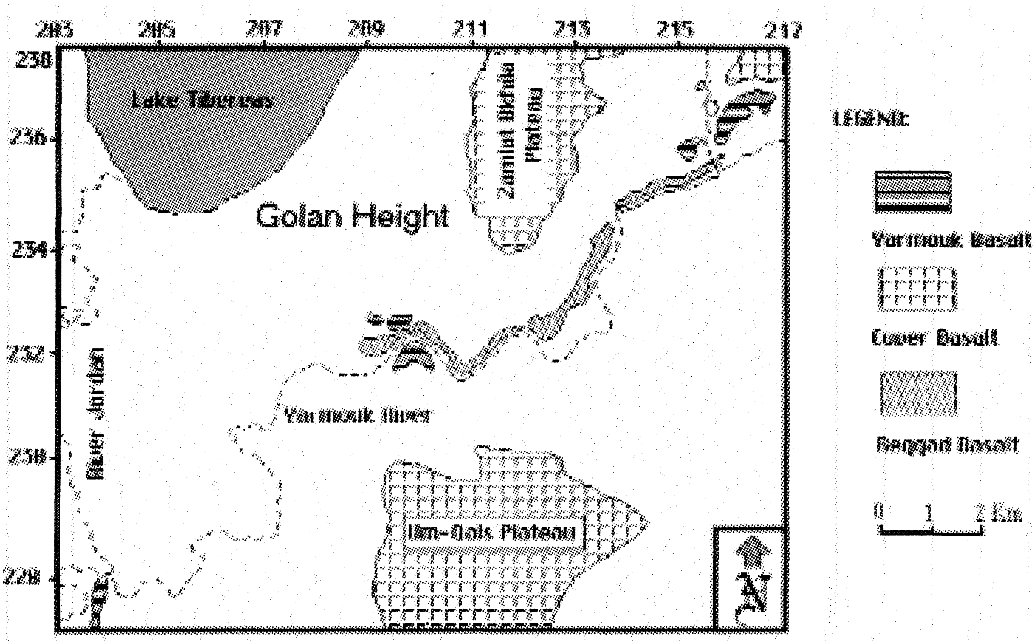

Figure 3. Simplified, modified map after Mor and Steinitz (1985) showing the sites of the Cover and other basalts north and south of the Yarmouk River ravine.

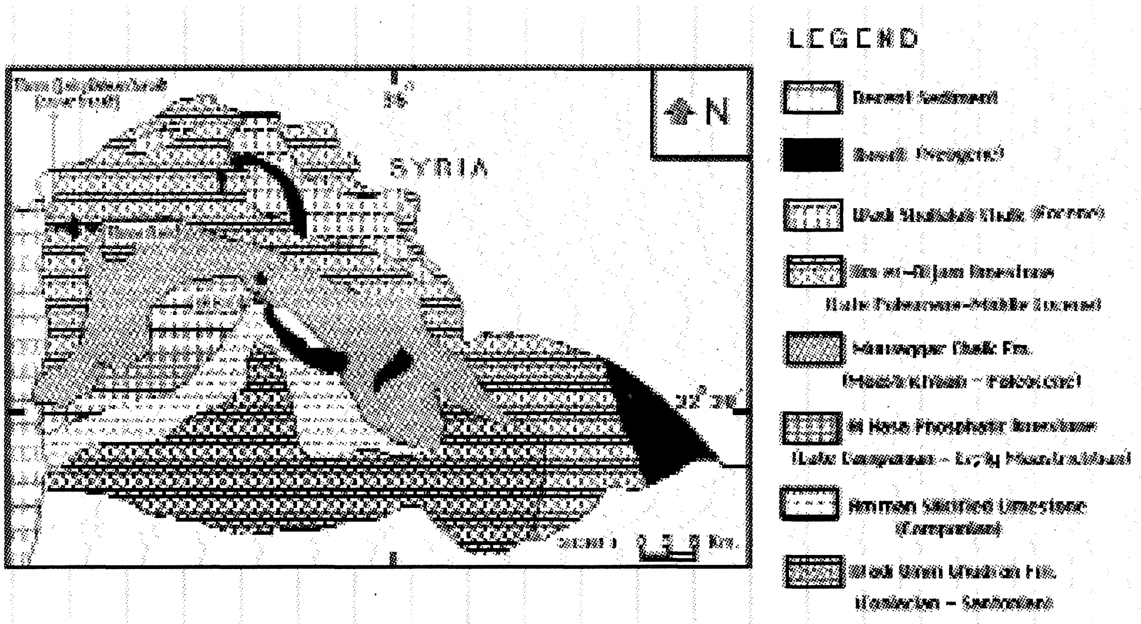

Fig. 4: Simplified geological map of areas in north Jordan surrounding Irbid City.

local vents along regional extensional fault lines (Ghent et al., 1980; Gregory et al., 1982; Coleman et al., 1983; Voggenreitter et al., 1988; Camp and Roobol, 1989). Mor and Steinitz (1982) dated the Cover Basalt of the Mevo Hama plateau in the Golan Heights (Zamlat Bkhila plateau basalt) as 3.7±0.36 Ma at its base to 3.11±0.16 Ma at its top using K-Ar dating, method.

The tectonic framework of the Cover Basalt and all the Neogene-Quaternary volcanism (the Harrat Ash Shaam Basaltic Super-Group HSB) can be explained by the tectonics and evolution of the regional Trans-continental rift system which formed the East-African-Red Sea-Dead Sea fault zone during Cainozoic time. The role of the NE-SW regional extensional forces can be supported by the NW-SE alignment of the Arabian Cainozoic basalts (Arabian Harrats) over a distance of 3000 km, from Yemen through Saudi Arabia, Jordan, and Syria (Fig. 2). These extensional stresses reactivated Proterozoic basement faults in the direction NW, NNW, NE, NNE, and E-W during the Cainozoic evolution of the Red Sea (Garson and Krs, 1976; Camp, 1984; Ramsay, 1986; El-Akhal et al., 1999).

RESULTS AND DISCUSSION

STRUCTURE

To understand the structure of the study area, brittle deformational features including joints and faults were measured at different intervals within the basaltic flow units and represented by rose diagrams (Fig. 5 A,B).

The results showed four dominant directions, namely ENE-WSW, NW-SE, NNE-SSW and NE-SW. They are coincident with the pattern of the most distinct regional structures in the region such as the Red Sea, Dead Sea transform fault, Wadi Sirhan fault system, and some other features. The N to NNE trending fracture and fault systems (Fig. 5B) are parallel-subparallel with the present Aqaba-Levant zone (e.g. the Dead Sea transform or the Wadi Araba-Jordan Valley structure). The almost E-W-directed fractures lie perpendicular to the Dead Sea transform, point to an extension in the region between Dead Sea transform and Wadi Sirhan fault.

It can also be suggested that the NE-SW-trending fractures were formed by extensional stresses normal to their direction. Such a suggestion is consistent with the late Pan-African stress pattern (Stern, 1985; Eyal and Eyal, 1987; Blasband et al., 2000; El-Akhal et al., 1999).

The major NW to NNW trending fracture system (Fig. 5 A) consists of a number of distinctive regional fault sets such as the Wadi Sirhan fault zone (Fig. 1), which extends about 325 km in the same direction, starting from Saudi Arabia to the north of Jordan. The fault system is truncated at its northern edge by the Gulf of Aqaba-Dead Sea transform fault, the Anti-Lebanon and the Palmyrides (Fig. 2). According to Ramşay (1986) and Camp (1986) these fault sets caused by transtentional forces initiated during the time of the Red Sea evolution and were commonly erupted by Cainozoic basalt flows.

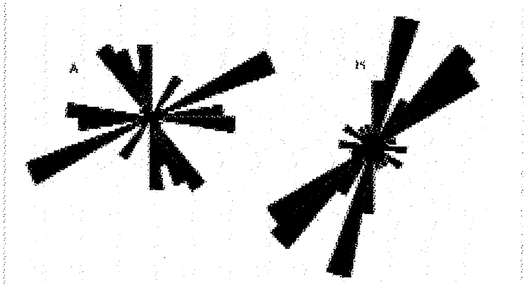

Figure 5 A, B. Illustration of the pattern of brittle deformations that had affected the area.

PETROGRAPHY

Each basalt flow unit begins at the bottom with a massive part, characterized by fine to microvesicular texture, and evolves upwards into obviously vesicular one. They are dark to medium gray in colour with a porphyritic appearance. A fresh sample has been taken from the massive part of each flow unit.

Microscopically, the rock samples are variably vesicular, amygdaloidal, almost doleritic, coarse-, subordinately medium-, and rarely fine-grained. They are sometimes characterized by the presence of variable amounts of glass in the groundmass; however, most are holocrystalline, with intergranular to intersertal textures.

The phenocrysts consist predominantly of olivine and subordinate amount of plagioclase, while the pyroxene is not found. The olivine phenocrysts, form about 10-15 vol. % of the rock and occur as subhedral and sometimes as euhedral crystals without zoning. Therefore they indicated presence of enough time to equilibrate with the melt at mantle depth. Olivine phenocrysts occur sometimes as clots displaying glomeroporphyritic texture.

Plagioclase phenocrysts were found in some samples as elongated crystals making 2-5 vol. % of the phenocrysts.

The matrix consists almost of coarse-to medium-grained plagioclase laths, olivine, augite, little apatite and opaques. Plagioclase laths are the most abundant representing 45-50 vol.% of the matrix in most studied samples. They are both pilotaxitically and randomly arranged, and sometimes they exhibit trachytic arrangement around the olivine phenocrysts. Nepheline, pale brown clinopyroxene, needle-shaped apatite, ore minerals, brown glass and cryptocrystals fill the interstices between plagioclase laths. A few samples showed vesicles filled with secondary calcite, prehnite, and zeolites

GEOCHEMISTRY

For geochemical studies representative fresh samples were selected from the massive parts of the flows. They were chipped, handpicked to yield the freshest material, and finally crushed. They were analyzed for major elements and some trace elements: Rb, Ba, K, Nb, Sr, P, Zr, Ti, Y, Sc, V, Cu, Ni, and Zn. The concentrations of these elements were determined by the mean of x-ray fluorescence spectrometry in the Physics Department at the Yarmouk University. CIPW-norms were calculated for each sample. The results (Table 1) showed that all the studied samples have normative nepheline ând forsteritic olivine. The presence of these minerals supports silica-undeisatumtion of the flows.

For classification, nomenclature* and tectonic setting interpretation, proper discrimination diagrams were applied. The alkali-silica diagram (Cox et al., 1979) (Fig. 6) reveals that the basalt samples of the Umm-Qais plateau fall within a trend of alkali differentiation, and all the samples fall in the alkali olivine basalt (AOB) field. The two-component diagram of Zr/Y-Zr (Fig. 7) represents the behaviour of the ratio Zr/Y relative to the index of fractionation Zr. It illustrates the distribution of non-cumulate basalts from three tectonic settings after Pearce et al. (1979). The diagram also demonstrates that the basalts of the study area occupy the within-plate field with higher Zr/Y ratios than the MORB and Island Arc basalts. This character reveales that the samples are alkalic in composition and is valid for most basalts erupted in within-plate settings (Pearce and Cann, 1973, Floyd and Winchester, 1975). The discrimination diagram TiO2 versus Y/Nb (Floyd and Winchester, 1975) (Fig. 8) distinguishes oceanic alkali basalt (OAB), continental alkali basalt (CAB), oceanic tholeiites (OTB) and continental tholeiites (CTB). The samples occupy the (CAB) field indicating an origin of a continental within plate tectonic setting. The within plate character of the studied basalt flows (AOB) confirmed by means of a spider diagram (Fig. 9). The calculated trace elements are plotted in order of decreasing incompatibility with mantle rocks from left to right. They are normalized to the primitive mantle values of Sun and McDondugh (1989). The characteristic Nb-peak conform with the Tertiary to Recent continental alkali basalt provinces (Nony and Fitton , 1983). On the contrary, the more incompatible large-ion lithophile elements of the analyzed samples show a trough at K- and a depletion in the Rb.

SUMMARY AND CONCLUSIONS

1. Umm-Qais plateau basalt consists of eleven flow units with an aggregate thickness of about 190 m. The massive parts of each flow unit are characterized by fine to micro-vesicular texture and change upward into coarse vesicular one.

2. Petrographical study shows that the rocks are mainly coarse-grained, variably vesicular, and amygdaloidal. Phenocrysts consist predominantly of olivine; plagioclase is less common and pyroxene is absent. In the matrix, plagioclase laths are the most abundant and subordinate amounts of olivine, augite, apatite, opaques and nepheline are detected.

3. Geochemical results showed that the basalt is an intra-continental alkali olivine type. Nepheline and

Table 1: Chemical analysis and CIPW-Norms of eleven selected basalt samples from the flows of Umm-Qais plateau (oxides in %, trace elements in ppm)

Oxides	**FU 1**	**FU2**	**FU3**	**FU4**	**FU5**	**FU6**	**FU7**	**FU8**	**FU9**	**FU10**	**FU11**
SiO_2	43.22	45.92	46.14	43.83	43.75	47.5	45.25	47.02	46.49	48.85	44.23
TiO_2	3.25	3.39	3.07	3.36	3.25	3.11	3.14	3.14	3.2	3.06	2.98
Al_2O_3	14.22	13.87	14.3	13.54	13.63	13.28	13.62	13.48	13.54	14.57	13.4
Fe_2O_3	2.16	2.3	2.46	2.3	2.08	2.3	1.89	2.49	2.27	1.54	2.48
FeO	10.52	8.2	9.32	9.59	10.02	9.22	8.61	10.38	9.44	8.2	10.32
MnO	0.13	0.187	0.16	0.174	0.154	0.13	0.16	0.174	0.174	0.155	0.176
MgO	9.52	8.55	8.26	8.87	9.63	8.1	9.05	7.79	7.49	6.75	9.77
CaO	10.42	8.99	9.6	10.55	9.75	9.22	9.46	9.02	9.8	9.15	9.75
Na_2O	3.69	4.01	3.55	3.09	3.10	3.52	4.19	4.17	3.69	4.2	4.25
K_2O	0.57	0.69	0.60	0.62	0.62	.50	0.55	.53	0.5	0.64	0.52
P_2O_5	1.14	0.81	0.86	0.8	0.92	0.72	0.81	0.77	0.69	0.57	0.72
L.O.I	1.79	2.75	2.01	2.7	2.7	2.02	2.52	2.036	3.06	1.59	2.02
Total (%)	100.63	99.65	100.33	99.42	99.6	100.62	99.25	101.00	100.34	99.27	100.60
Ni	117	83	65	87	114	100	91	102	97	99	128
Ba	282	227	284	244	309	286	212	260	251	215	263
Rb	11	14	14	9	12	12	10	26	25	14	7
K	4044.9	4896.5	4257.8	4399.7	4399.7	3548.15	3903	3761	3548.2	4541.6	3960
Sr	663	500	709	707	609	632	750	625	532	800	760
P	4977.3	3536.5	3754.8	3492.8	4016.72	3143.5	3536.5	3361.8	3012.5	2488.6	3143.5
Zr	117	121	130	120	133	134	124	140	139	132	95
Ti	19483.8	20323	18404.7	20143	19483.8	18644.5	18824	18824	19184	18344.7	17865
Y	25	23	24	29	29	19	20	16	26	25	18
Nb	27	25	25	28	38	32	12	24	26	29	31
Cu	55	48	41	45	53	56	38	27	37	31	28
Zn	120	143	122	131	124	119	130	116	135	121	135
Sc	32	32	31	37	40	45	34	33	41	37	36
V	203	202	192	223	199	192	205	212	229	189	261
Or	3.42	4.21	3.61	3.79	3.78	3.00	3.36	3.17	3.04	3.88	3.12
Ab	16.08	28.12	27.42	19.69	20.93	29.79	23.36	29.81	29.08	34.62	17.44
An	20.82	18.35	21.65	21.93	22.10	14.65	17.24	16.65	19.41	19.44	16.15
Ne	8.43	3.71	1.68	3.96	3.31	4.85	7.15	3.14	1.61	0.93	10.29
Di	20.1	18.29	17.53	22.08	17.98	22.22	21.9	19.56	21.45	19.15	23.16
Fo	12.36	10.95	10.74	10.97	13.28	9.17	11.13	9.66	8.8	7.85	12.12
Fa	6.82	4.46	5.91	5.72	7.05	5.35	5.06	6.64	5.43	4.62	6.73
Mt	3.18	3.44	3.63	3.45	3.11	3.38	2.83	3.65	3.38	2.29	3.65
Il	6.25	6.65	5.93	6.60	6.37	5.99	6.16	6.03	6.25	5.95	5.75
Ap	2.52	1.82	1.91	1.81	2.07	1.59	1.82	1.70	1.55	1.27	1.59
Total (%)	100	100	100	100	100	100	100	100	100	100	100

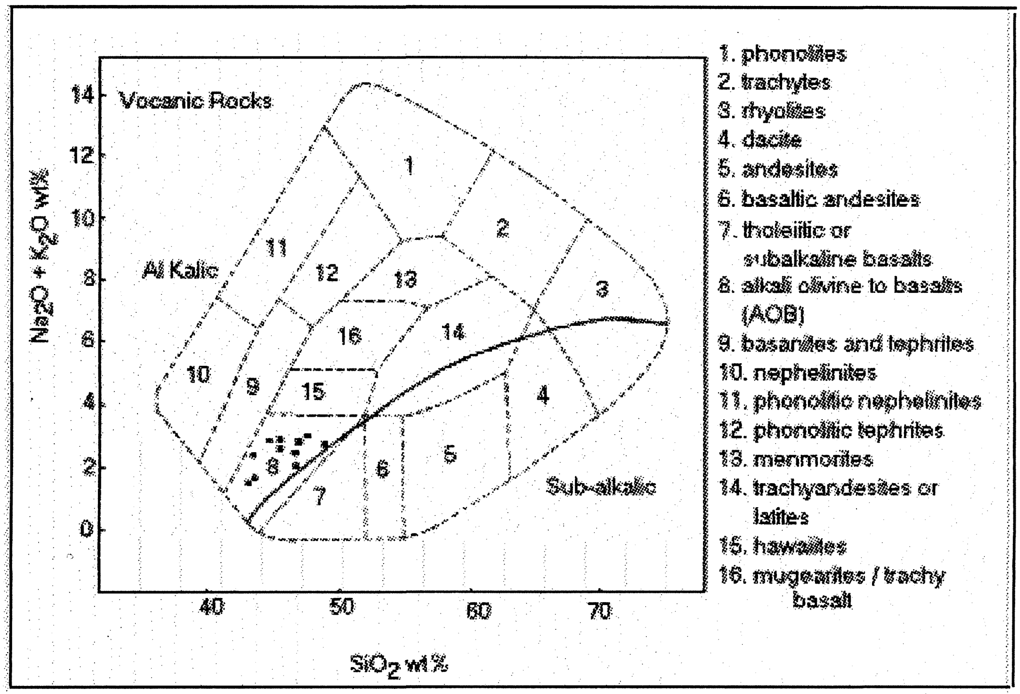

Fig. 6: Nomenclature of the common volcanic rocks based on their total alkalis and silica contents, after Cox et al. (1979). The dividing curve between alkalic and sub-alkalic magma series is from Miyashiro (1978).

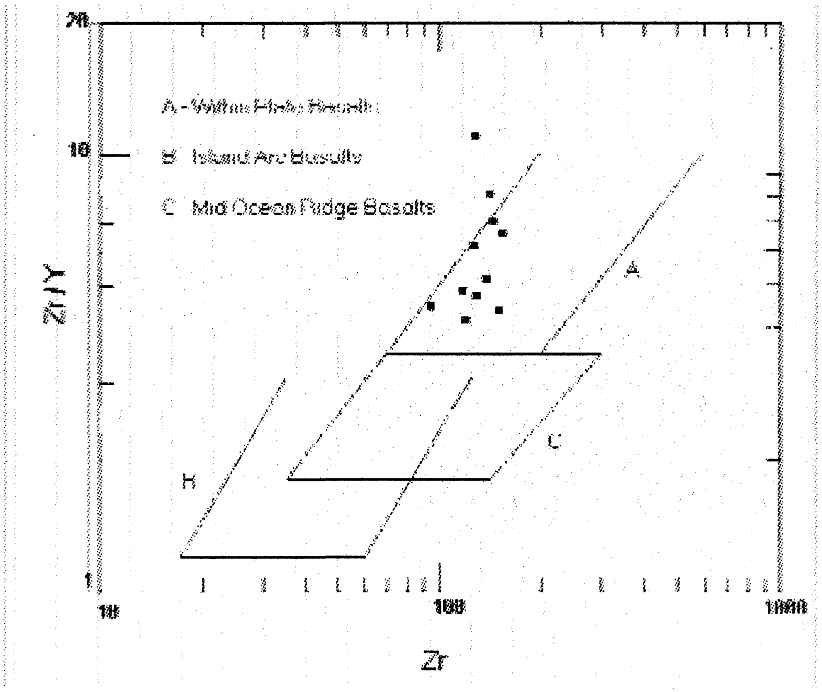

Fig. 7: Zr/Y vs. Zr diagram for the distinction between fields of Within-plate, MORB, and Island arc basalts, after Pearce and Norry (1979).

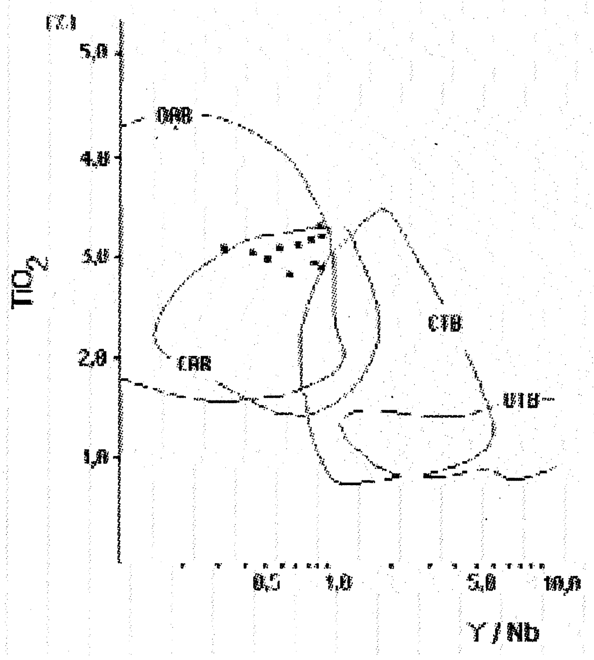

Figure 8. Diagram after Floyd and Winchester (1975) for the distinction between oceanic and continental alkaline basalts, (OAB) and (CAB), oceanic and continental tholeiitic basalts, (OTB) and (CTB).

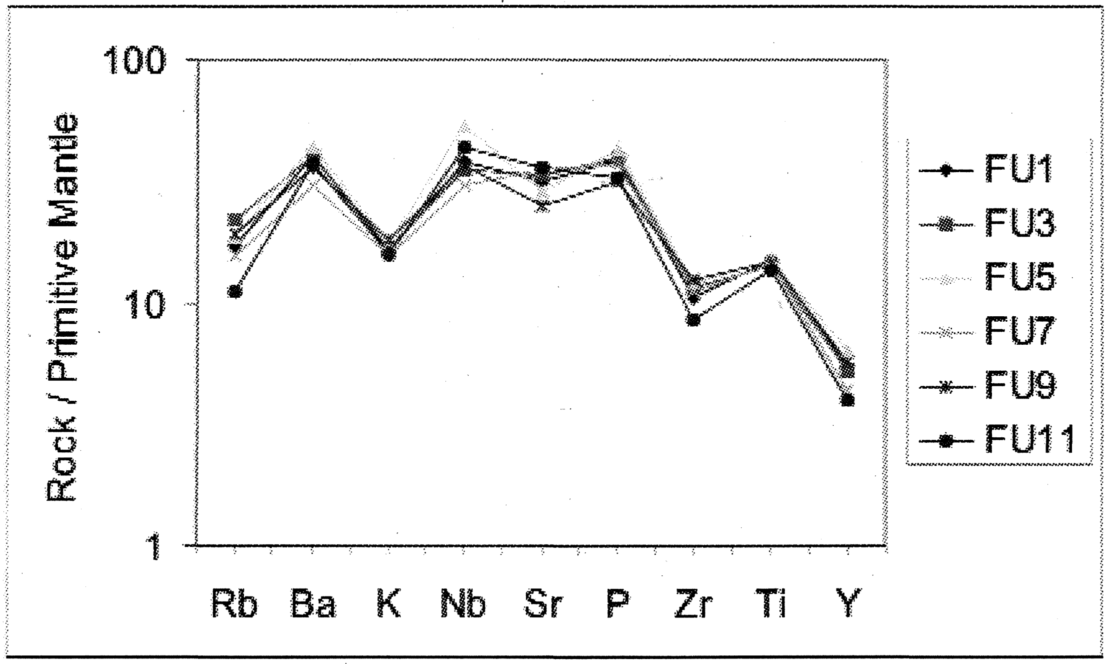

Fig. 9: Spider diagram of trace elements normalized to the primitive mantle of Sun and McDonough (1989). Trace elements are in order of increasing incompatibility with mantle rocks.

forsteritic olivine are found among the normative minerals indicating silica-undersaturated rocks.

4. Based on field observations, faults which are parallel and semi-parallel to the pattern of the Arabian Harrats and other distinct regional structures such as the Red Sea, the Dead Sea transform fault and Wadi Sirhan fault system are presumably created during the late Cainozoic tectonic evolution. They coincide with older fracture trends in the Precambrian basement and they have been probably reactivated by extensional stresses during the late Cainozoic evolution and second stage spreading of the Red Sea.

REFERENCES

Barberi, F., Capaldi, G., Gasperini, P., Marinelli, G., Santacroce, R., Scandone, R., Treuil, M., and Varet, J., 1979. Recent basaltic volcanism of Jordan and its implications on the geodynamic evolution of the Afro-Arabian rift system. Atti Conv Lincei, 47. 667-83.

Blasband, B., White, S., Brooijmans, P., Dirks, P., de Boorder, and Visser, W., 2000. Late Proterozoic extensional collapse in the Arabian Nubian Shield. Journal of the Geological Society, 157, 615-628.

Brenner, I. B., 1979. The geochemical relations and evolution of the Tertiary-Quaternary volcanic rocks in northern Israel. Ph.D. thesis, Hebrew UniTv. Jerusalem, 202 pp.

Camp, V. E., 1984. Island arcs and their role in the evolution of the western Arabian Shield. Geological Society of America Bulletin, v. 95, p. 913-921.

Camp, V. E., 1986. Geologic map of the Umm Birak quadrangle, sheet 23D, Kingdom of Saudi Arabia (with text). Saudi Arabian Deputy Ministry for Mineral resources Geoscience Map GM 87, scale 1:250000, 40 p.

Camp, V. E., Roobol, M. J., 1989. The Arabian continental basalt province. Part I. Evolution of Harrat Rahat. Kingdom of Saudi Arabia. Geological Society of America Bulletin, v. 101, p. 71-95.

Cox, K. G., Bell, J. D., and Pankhurst, R. J., 1979. The interpretation of igneous rocks. London; Allen and Unwin, 450 pp.

Colemann, R. G., Gregory, R. T., and Brown, G. R, 1983. Cainozoic volcanic rocks of Saudi Arabia. Saudi Arabian Deputy Ministry for Mineral Resources Open-File Report USGS-OF-03093, 82 p.

El-Akhal, H., Al-Tamimi, M., Greiling, 1999.Late Pan-African evolution and fracture pattern in the Sarmouj conglomerate, S W Jordan. Aspects of Pan-African Tectonics. V. 32, p. 173-181. Forschungszentrum Jiilich, Germany.

Eyal, Y., Eyal, M., 1987. Mafic dyke swarms in the Arabian-Nubian Shield. Isr. J. Earth Sci. Vol. 36, 1987 pp. 195-211.

Floyd, P.A., Winchester, J.A., 1975. Magma type and tectonic setting discrimination using immobile elements. Earth planet Sci. Lett. 27. 211-218.

Garson, M. S., and Krs, M., 1976. Geophysical and geological evidence of the relationship of the transverse tectonics to ancient features. Geological Society of America Bulletin. V. 87. P. 169-181.

Ghent, E. D., Coleman, R. G., and Hadley, D. G., 1980. Ultramafic inclusion and host alkali olivine basalts of southern coastal plain of the Red Sea. Saudi Arabia. Amer. J. Sci, 280-284, 499-527.

Green, D. H., Ringwood, A.E., 1967. The genesis of basaltic magmas. Contrib. Mineral. Petrl. 90. 18-28.

Gregory, R. T., Coleman R.G., and Brown, G. F., 1982, Cenozoic volcanic rocks of Saudi Arabia. Evidence from continent for two stages of opening of the Red Sea. Geol. Sci. Am. Prog., 14 (7). 502 p.

Ibrahim, K. M., 1987. Geochemistry and petrology of some of the basaltic outcrops in central Jordan. MSc. Thesis , Univ. Jordan, Dep. Geol. Mineral. Amman, (Unpubl.). 164p.

Ibrahim, KM., 1993. Geological framework for the Harrat ash-Sham Basaltic Super-Group and its volcanotectonic evolution. Amman. Natural Resources Authority, Geol. Mapping Div., Geol. Dir., Bull. 25, Amman.

Ibrahim, K.M., 1996. The regional geology of Al Azraq area. Amman Natural Resources Aouthority. Geol. Mapping Div., Geol. Dir., Bull 28, Amman.

Ibrahim, K.M., Saffarini, G.A., 1990. Genesis of the nepheline basanites in Tafila District, Jordan. Proc 3d Geol. Conf., 315-343.

Khalil, I., 1991. Geochemishe and petrographische untersuchungen an Teriaren bis Quartareren kontinentalen intraplattenbasalten. Nordost-Jordanien. Ph. D. thesis, der technischen Universitaet Clausthal, Germany, 119p.

Lovelock, P.E.R., 1984. A review of the tectonics of the northern Middle East region. Geological Magazine, v. 121, no. 6, p. 577-587.

Miyashiro, A., 1978. Nature of alkalic volcanic rock series. Contrib. Mineral. Petrol. 66, 91-104.

Mohr, P., 1971. Outline tectonics of Africa: United Nations Educational Scientific and Cultural Organization UNESCO): Paris, France, Imprimie Atar, p. 477-584.

Mor, D., Steinitz, G., 1982. K-Ar age of the cover basalt surrounds the sea of Galilee. Interim Report. Isr. Geol. Surv. Rep. ME/6/82. 14 p.

Mor, D., Steinitz, G., 1985. The history of the Yarmouk River based on K-Ar dating and its implication on the development of the Jordan rift. Isr. Geol. Surv. Rep. GSI/40/85, 18 p., Jerusalem.

Nassir, S., Al Fugha, H., 1988a. Spinel-lherzolite xenoliths from the Aritain volcano. NE-Jordan. Mineral Petrl. 38..127-137.

Norry, M.J., Fitton, J.G., 1983. Compositional differences between oceanic and continental basic lavas and their significance, in Hawkesworth C.J, and Norry , M.J., eds., Continental basalts and mantle xenoliths: Chchire, England, Shiva Publishing, Ltd, P. 5-19.

Pearce, J. A., Cann, J. R., 1973. Tectonic setting of basic volcanic rocks determined using traceelement analysis. Earth Planet Sci. Lett, 19. 290-300.

Pearce, J. A., Norry, M.J., 1979. Petrogenesis implications of Ti, Zr, Y, and Nb variations in volcanic rocks. Contrib. Mineral. Petrol. 69. 33-47.

Ponicarov, V.P., Kazmin, V.G., Mikhailov, LA., Razvaliayev, A.V., Krasheninnikov, A.V., Kozlov, V.V., Souiidi-Kondratiyev, E.D., Mikhailov, K.YA.,Kulakov, V.V., Faradzhev, V.A., Mirzayev, K.M., 1967. The geology of Syria. Explanatory Notes of the geological map of Syria, Part 1. Dept. of Geological and Mineral Research. S.A.R.

Ramsay, C.R., 1986. Geologic map of the Rabigh quadrangle, sheet 22D. Kingdom of Saudi Arabia (with text). Saudi Arabian deputy Ministry for Mineral Resources Geoscience Map GM-84, scale 1:250,000. 49p.

Saffarini, G. A., Nassir, S., Abed, A. M., 1985. A Contribution to the petrology and geochemistry of the Quaternary-Neogene basalts of central Jordan. Dirasat, 12. 133-144.

Sengor, A.M.C., and Kidd, W.S.F., 1979. Post-collisional tectonics of the Turkish-Iranian plateau and a comparison with Tibet. Tectonophysics, v. 55, p. 361-376.

Stern, R. G., 1985. The Najd faults system, Saudi Arabia and Egypt. A late Precambrian rift system? Tectonics 4. 497-511.

Sun, S.S., MacDonough, W.F., 1989. Chemical and isotopic systematic of oceanic basalts: implications for mantle composition and processes. In Magmatism in the ocean basins. Geological Society, Special Publication, 42,313-345.

Voggenreitter, W., Hoetzl, H., and Mechie, J., 1988. Low-angle detachment origin for the Red Sea Rift System? Tectonophysics, v. 150, p. 51-76.

Wehr, H., 1976. Dictionary of modern written Arabic (3rd edition), Cowan, J. M, ed.: Ithaca, New York, Spoken Language Services, Inc., 1110 p.

Wiesemann, G., Abdullatif, A., 1963. Geology of the Yarmouk area, North Jordan. Unpubl. rept. with geol. maps, scale 1:10,000. Fed. Inst. of Geosc. and Nat. Res., Hannover; nat. res. auth., Amman.

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