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IGNEOUS PETROLOGY OF THE BULFAT AREA (NORTH-EAST IRAQI ZAGROS THRUST ZONE)

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ABSTRACT

Two intrusions can be distinguished in the Bulfat-postcollision igneous complex, an older one with a nearly complete differentiation series; from ultrabasic rocks through to nepheline syenite and younger one composed of olivine gabbro, with olivine diorite at the chilled margin. Peridotite occurs at the lowest part of the older intrusion, probably tectonically emplaced. The original rock was harzburgite but most has been altered to serpentinite. The older intrusion is composed predominantly of gabbro and diorite, both containing many xenoliths. The chemical composition of these rocks differ from the normal calc-alkaline magmatic suite. Calcium enrichment is widespread due to magmatic assimilation of the calcareous rocks. At the latter stage of differentiation silica migrated into the host country rocks where a skarn zone developed, this caused silica deficiency in the magma and locally nepheline crystallized at the expense of alkali feldspars. This complex process of assimilation and silica migration resulted in the original calc-alkaline magma changing to an alkalic-calcic suite. Foliation and mylonitization are widespread due to intensive tectonism during the emplacement and cooling of the magma. The younger olivine gabbro and diorite intruded through the older igneous complex without calcareous rock assimilation. A slight alkali characteristics (e.g. kaersutite) is observed suggesting crustal contamination.

The igneous complex is considered to be a postcollision event with emplacement into the continental crust after the Arabian and Iranian plates collided during late Cretaceous or early Paleogene.

INTRODUCTION

The Bulfat metamorphic-magmatic complex is situated in the Iraqi Zagros thrust zone as a north-east member of igneous complexes at the boundaries between the Arabian and Iranian plates. The southern complexes (Mawat, Penjwin) are Cretaceous ophiolites without thermal contact aureoles represent mantle and oceanic crust (MASEK and ETABI 1973; BUDA and HASHIMI 1977). The Bulfat alkali-calcic igneous complex has a large thermal contact zone. It is believed to be a postcollision intrusion emplaced in the continental crust after the Arabian and Iranian plates collided during late Cretaceous or early Paleogene (BUDA, SAHAGIAN and SALEM 1978, JASSIM, WALDHAUSROVA and SUK 1982a, JASSIM, BUDA, NEUŽILOVA and SUK 1982 b). The present paper deals only with the petrology of the intrusive complex.

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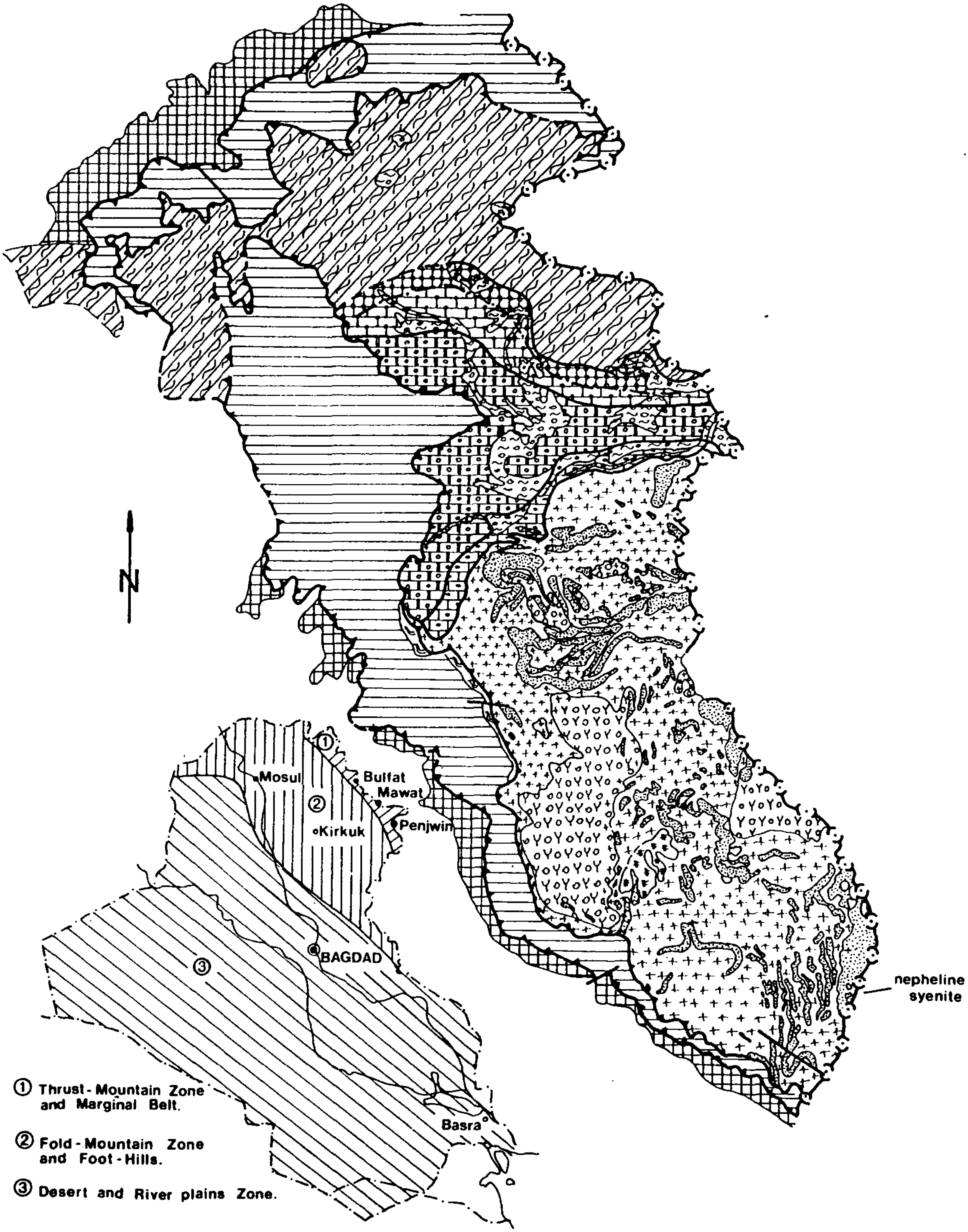
Fig. 1. Igneous and metamorphic rocks of Bulfat thrust block (Northeast Iraq).



IGNEOUS AND METAMORPHIC ROCKS OF BULFAT THRUST BLOCK (NORTHEAST IRAQ)

0 1 2 3 km

LEGEND

– Qandil regional metamorphic rocks	Green schist facies
– Ultrabasic rocks	Old intrusion
– Serpentinite (in the Thrust Zone)	
– Amphibole-pyroxene gabbro and diorit	
– Nepheline syenite	
– Olivine-amphibole-pyroxene gabbro	Young intrusion
– Olivine-amphibole-pyroxene diorite	
– Xenoliths in gabbro and diorite	Pyroxene hornfels facies
– Contact metamorphic calcareous rocks	
– Cont. metam. pelitic rock	
– Cont. metam. calcareous rocks	Hornblende hornfels facies
– Cont. metam. pelitic rocks	
– Cont. metam. calcareous rocks	Transitional facies
– Spotted schist	
– Cont. metam. calcareous rocks	Albit epidot facies
– Spotted slated	
– Walash volcano-sedimentary series	
– Red beds	

GEOLOGICAL SETTING OF INTRUSIVE COMPLEX

The exact shape and size of the intrusive complex unknown as it stretches into Iran and presently no data is available from this area. The mapped outcrop of the elongated plutonic complex is about 15—19 km in a NNW—SSE direction and up to 5—7 km in width. Contact metamorphosed calcareous rocks occur on the highest summits (about 2340 m) and most probably capped the intrusive body. The complex is tilted towards the east (88°/45°). The exposed thickness through the complex is about 1500 m. In summary the lower part of the complex consist of probable tectonical emplaced peridotite, in the middle gabbro-diorite and in the upper part nepheline syenite occurs just below the contact with the calcareous skarn rock (*Fig. 1*). The main pluton was intruded by a younger, smaller olivine gabbro-diorite.

The principal types of plutonic rocks observed are follows:

A. *Ultrabasic rocks* (subordinate); including harzburgite and serpentinite;

B. *Basic and intermediate rocks (older intrusion)*: including pyroxene gabbro, pyroxene diorite, pyroxene-amphibole diorite, amphibole diorite and contaminated rocks: pyroxene diorite, pyroxenite, nepheline syenite.

C. *Basic and intermediate rocks (younger intrusion)*; including olivine-amphibole-pyroxene gabbro and diorite.

The larger and earlier intrusive has a wide thermal contact aureole. In north it extends up to 2.5 km from the last outcrop of the intrusive body. It is considered probably that the igneous body dips gently beneath the metamorphic (Quandil Formation) rocks giving reason for the apparently anomalously wide contact-metamorphic aureole. The western and southern borders of the complex are structurally controlled. Along these tectonic zones the plutonic-metamorphic complex has been thrusted over the Walash volcano-sedimentary formation. The movement has been facilitated by the serpentinite acting as a lubricant for the thrust-slice. Consequently the current position of the igneous-metamorphic complex is allochthonous having been transported from the ENE to its present position.

PETROGRAPHY OF THE IGNEOUS COMPLEX

OLDER INTRUSION

A. Ultrabasic rocks

Harzburgite: The main constituent is olivine (Fo_{92}, Table 1). Kink-bands, wavy extension and granulation are always present, indicating a strong solid-state deformation, along cracks and cleavages, strongly serpentinized. Many clinopyroxenes have been altered to tremolite and many orthopyroxenes to talc and serpentine (bastite), but some small remnants of pyroxene can be recognized. The orthopyroxene was probably enstatite (Mg_{95} Fe_5, calculated from CIPW norms). The clinopyroxene composition is most probably diopside ($Ca_{53}Mg_{44}Fe_3$, calculated from CIPW norms). Tremolitic hornblende (Table 1) is common, occurring as acicular, slender-prismatic, colourless crystals; it is an alteration product of clinopyroxene. Serpentine is a ubiquitous constituent; sometimes the whole rock serpentinized. Chromite is an accessory mineral (0.5V%—2.5V%), it forms rounded, anhedral or rare subhedral crystals. Usually they are opaque, sometimes the middle of the crystal is reddish-brown and the rim is black (opaque). The rim is Fe-rich and the core is Cr-, Al-rich and Fe-poor chromite. These grains are surrounded by Cr-bearing Mg-chlorite and sometimes by magnetite. These are altered crystals formed simultaneously with serpentinization (BUDA 1988). During alteration, Al and a small amount of Cr were released and formed chlorite instead of serpentine, with Fe realtively enriched in the rim. Alteration of olivine released iron, which formed magnetite in the middle of serpentine veinlets. Calcite also may occur as a secondary mineral.

TABLE 1

Microprobe analyses of olivine, tremolite and accessory chromites from ultrabasic rocks

	OLIVINE			TREMOLITE		CHROMITE		
wt %	1	2	3		4		5	6
SiO_2	40.01	39.96	41.26		54.04	Cr_2O_3	46.92	48.39
TiO_2	-	0.03	0.07		0.05	Al_2O_3	6.58	10.61
Al_2O_3	-	0.02	-		4.33	FeO	36.25	30.27
FeO	8.21	8.27	7.90		2.56	MgO	5.60	7.37
MnO	0.18	0.15	0.08		0.09	MnO	0.35	0.26
MgO	51.23	51.29	50.51		22.97	ZnO	0.31	0.30
CaO	0.04	0.01	0.02		12.50	SiO_2	0.08	0.32
Na_2O	-	-	-		1.03	TiO_2	0.18	0.12
K_2O	-	-	-		0.06	Σ	96.27	97.64
Σ	99.67	99.73	99.84		97.63			
				Numbers of ions on the basis				
		of 4 (o)			23 (o)		of 4 (o)	
Si	0.979	0.978	1.002	Si	7.346	Cr	1.320	1.299
Al	-	0.001	-	Al^{IV}	0.654	Al	0.276	0.425
Ti	-	0.001	-	Al^{VI}	0.040	Fe^{3+}	0.393	0.248
Mg	1.869	1.870	1.829	Ti	0.005	Ti	0.005	0.005
Fe	0.168	0.169	0.180	Fe^{3+}	0.291	Si	0.003	0.017
Mn	0.004	0.003	0.002	Mg	4.654	Fe^{2+}	0.686	0.612
Ca	0.001	-	0.001	Mn	0.010	Mg	0.297	0.373
				Ca	1.821	Mn	0.011	0.008
Fo	91.8	91.7	92.0	Na	0.179	Zn	0.008	0.008
Fa	8.2	8.3	8.0	Na	0.092			
				K	0.010			

1. Olivine from amphibole peridotite; 2. Olivine from serpentinized peridotite; 3. Olivine from amphibole peridotite; 4. Tremolitic hornblende (γ/c=22°) from serpentinized peridotite; 5. Ferrianchromite from amphibole peridotite; 6. Ferrianchromite from serpentinized peridotite

The composition of the chromite (Table 1) is ferrianchromite according to THAYER's (1964) classification. Its chemical character differs from the chromite composition of ophiolitic complexes of Iraq (BUDA 1988).

The mineralogical composition of the unaltered rocks was harzburgite, was calculated from chemical analyses using CIPW norms (Table 2a).

Serpentinite occurs in the thrust zones, and acted as a lubricant that promoted tectonic movement. Two main thrust zones can be distinguished, the first one in the immediate vicinity of the igneous body and the second about 3—5 km from, and approximately parallel with, the first one.

The rocks are strongly foliated. They frequently form a "mesh" texture. The fibrous variety is chrysotile and the flaky one is most probably antigorite. Bastite is also very common, it may contain remnant of pyroxene. Mg-rich, chlorite is also common. Bastite, chlorite and talc indicate orthopyroxene in the original rock, therefore the rock was probably harzburgite. Few samples contain large amounts of tremolite (as tremolitic schist), which was originally clinopyroxenite, perhaps a dike. The accessory minerals are magnetite and chromite. The common strong foliation indicates dynamometamorphism caused by the thrust movement.

B. Basic and intermediate rocks

a. Pyroxene gabbro occurs in the north-eastern part of the plutonic body near the Iranian border. The rock is coarse-or medium-grained. The plagioclase is tabular, sometimes prismatic. Twin lamellae are deformed, showing wavy extinction. The average An content is An_{66} (An_{52}—An_{77}, measured by U-stage) or An_{69} (An_{67}—An_{72}, measured by microprobe, Table 3). The pyroxene is eu-or subhedral, the large tabular crystals show ophitic texture, with green or pink colour. Composition is salite (Table 3). Amphibole occurs in a very small amount. Two types can be distinguished. The first is green, pleochroic (γ'= green, α'= colourless or yellowish-green), mostly fibrous, and occurs around the green pyroxene as an uralitization product ($\gamma/c=17°$). The second is greenish-brown hornblende (γ' = brownish-green, α' = yellowish-green), also formed by uralitization of the Ti-rich pinkish pyroxene. Some samples contain a very small amount of Mg—Ti biotite (Table 3). Chlorite was formed by alteration of biotite and amphibole. Zoisite and calcite are not very common. Titanite and apatite occur in an accessory amount.

The rock contains about equal amounts of pyroxene and plagioclase and less than 3V% of amphibole (Table 2b). According to STRECKEISEN'S (1967) classification, the rock is mesotype pyroxene gabbro *(Fig. 2)*.

The bulk chemical composition shows slightly udersaturated characters (Ne norms, Table 2a), Ca-content is rather high and Mg- and Fe- contents are low. This Ca enrichment, which is characteristic in the whole igneous intrusion, is most probably due to limestone assimilation.

b. Pyroxene diorite: is coarse- or medium-grained. It occurs in two belts. One is in the eastern part of igneous body, forming a north-south belt, usually far from the calcareous xenoliths. The other is an east-west belt at a lower elevation (average: 1600 m).

The main constituent is plagioclase, which forms large tabular or lath-shaped crystals. The most frequent twins are albite, manebach and albite/ala. Some crystals are zoned. In the sheared belt (central part) the plagioclase is granulated and shows wavy extinction and bent twin lamellae (An_{28}—An_{47}). Pyroxene is common, mostly forming large prismatic, slightly greenish or colourless crystals. It contains more Fe than the pyroxenes in the gabbroic rocks, indicating a later stage of crystallization (Table 4). Some pyroxenes are deformed, showing wavy extinction. The rims of the crystals are uralitized (green hornblende, $\gamma/c = 29°$) or surrounded by kaersutite (Table 4). Kaersutite can form large euhedral crystals, some of which contain small rounded grains of pyroxene. Biotite is very rare, mostly occurring around the opaque grains (Ti-magnetite or ilmenite). The biotites are strongly pleochroic, indicating Ti enrichment (γ'= reddish-brown,

TABLE 2a

Average chemical composition, CIPW norms of plutonic rock of BULFAT

wt %	1	2	3	4	5	6	7	8	9	10
SiO_2	40.39	48.57	53.41	52.23	51.39	42.31	56.55	61.13	49.78	51.30
TiO_2	0.06	1.11	0.88	1.49	1.61	3.40	0.52	0.04	0.46	1.16
Al_2O_3	0.74	15.84	16.69	16.08	19.51	9.00	20.34	18.45	21.08	16.98
Cr_2O_3	0.25	0.03	0.03	0.01	0.01	0.01	0.02	0.04	0.01	0.03
Fe_2O_3	4.29	2.46	1.90	1.87	1.92	4.68	2.53	0.34	1.48	1.96
FeO	3.89	3.59	3.48	6.01	3.79	7.70	2.99	0.48	4.66	5.90
MnO	0.10	0.11	0.10	0.15	0.10	0.19	0.11	0.03	0.11	0.14
MgO	40.54	6.19	4.53	5.51	2.20	6.64	0.60	0.30	6.87	6.30
CaO	1.11	17.27	12.17	7.93	12.15	22.29	2.32	3.64	9.93	9.46
ZnO	0.04	0.14	0.13	0.05	0.10	0.06	0.09	-	0.13	0.46
Na_2O	0.11	2.23	4.03	5.00	4.69	0.96	8.09	7.70	3.54	4.42
K_2O	0.04	0.36	0.57	1.05	0.52	0.20	3.39	4.48	0.13	0.31
P_2O_5	0.08	0.25	0.09	0.29	0.36	0.70	0.13	0.02	0.10	0.22
CO_2	0.14	0.20	0.07	0.10	0.07	0.13	0.08	-	0.06	0.18
H_2O^+	7.31	1.22	1.25	1.89	1.45	1.08	1.52	1.32	0.99	0.91
H_2O^-	0.45	0.14	0.22	0.27	0.20	0.21	0.26	0.30	0.13	0.14
F	-	0.01	0.01	0.04	0.03	0.04	0.03	-	0.02	0.04
Cl	-	0.01	0.01	0.01	0.01	0.01	·0.01	-	0.01	0.01
S	-	0.06	0.03	0.04	0.05	0.05	0.04	-	0.07	0.12
Σ	99.5	99.79	99.60	100.02	100.16	99.66	99.63	98.23	99.56	100.04
					CIPW norms					
Q	-	-	1.05	-	-	-	-	-	-	-
Or	0.24	2.13	3.37	6.20	3.07	1.18	20.03	26.47	0.77	1.83
Ab	0.93	16.30	34.08	41.02	36.31	1.01	49.16	52.27	29.94	37.38
An	1.41	32.15	25.77	18.34	30.65	19.66	9.19	2.46	41.25	25.58
Ne	-	1.39	-	0.69	1.82	3.85	10.44	6.96	-	-
Wo	1.15	20.41	14.04	7.79	8.89	23.54	0.44	1.38	2.94	7.89
En	0.96	15.41	9.79	4.79	5.48	16.53	0.16	0.75	1.95	4.99
Fs	0.04	2.93	3.08	2.55	2.90	5.01	0.29	0.59	0.77	2.41
Wt	-	0.79	-	-	2.40	12.36	-	5.08	-	-
Et	22.99	-	1.49	-	-	-	-	-	5.02	2.05
Ft	0.84	-	0.47	-	-	-	-	-	1.99	0.99
Fo	53.95	-	-	6.26	-	-	0.94	-	7.11	6.06
Fa	2.17	-	-	3.67	-	-	1.90	-	3.10	3.22
Mt	6.22	3.57	2.76	2.71	2.78	6.79	3.67	0.49	2.15	2.84
Il	0.11	2.11	1.67	2.83	3.06	6.46	1.00	0.08	0.87	2.20
Ap	0.19	0.59	0.21	0.69	0.85	1.66	0.31	0.05	0.24	0.52
Ca	0.32	0.46	0.16	0.23	0.16	0.30	0.18	-	0.14	0.41

TABLE 2b

Average modal composition of plutonic rocks of Bulfat

	1	2	3	4	5	6	7	8	9	10
Plag.	-	45.35	73.1	54.0	66.4	7.6	88.0	+	74.0	67.2
Oliv.	65.51	-	-	-	-	-	Kf.ne.plag	+	10.3	5.5
Pyrox.	6.10	46.20	24.1	4.2	26.0	84.1	-		9.6	18.2
Amph.	7.73	2.60	2.6	39.3	2.3	0.7	10.8		4.5	7.3
Biot.	-	0.40	-	-	-	-	2.2		+	0.1
Serp.	18.73	-	-	-	-	-	-	-	-	-
Chlor.	0.40	1.95	0.2	1.0	-	-	-		Bow 0.2	-
Talc	0.30	-	-	-	-	-	-	-	-	-
Zoiz.	-	+	-	+	-	-	-	-	-	-
Calc.	+	0.75	-	-	-	1.2	-	-	-	-
Tit.	-	1.15	+	-	1.9	4.2	1.0	-	-	-
Ap.	-	0.70	+	1.0	1.7	1.6	+	+	0.3	0.3
Chrom.	1.13	-	-	-	-	-	-		-	-
Mag.	0.10	0.90	-	0.5	1.7	woll 0.6		+	1.4	1.4

1. Amphibole peridotite (Average of four samples); 2. Pyroxene gabbro (Average of three samples); 3. Pyroxene diorite (Average of two samples); 4. Pyroxene-amphibole diorite (Average of three samples); 5. Contaminated pyroxene diorite (Average of three samples); 6. Contaminated pyroxenite (Average of two samples); 7. Nepheline syenite (Average of four samples); 8. Pegmatite; 9. Olivine gabbro (Average of three samples); 10. Olivine diorite (Average of three samples).

α' = yellowish-brown). Titanite is not very common. It forms large anhedral crystals with polysynthetic twins. The SiO_2 content of the rocks is between 51—55 wt% (Table 2a). The rock is leucocratic pyroxene diorite (*Fig.* 2, Table 2b).

TABLE 3

Microprobe analyses of pyroxene, plagioclase and biotite from pyroxene gabbro

	PYROXENE				PLAGIOCLASE			BIOTITE
wt %	1	2	3		4	5		6
SiO_2	48.10	51.23	47.44		52.66	53.80		36.19
TiO_2	1.69	1.29	1.97		-	-		4.43
Al_2O_3	6.32	3.87	5.70		30.44	29.74		5.73
FeO	10.52	6.00	9.50		0.27	0.10		15.02
MnO	0.25	0.20	0.22		0.05	0.03		0.20
MgO	10.22	13.78	10.26		0.19	0.01		14.63
CaO	22.36	23.01	24.03		13.72	13.10		0.03
Na_2O	0.72	0.67	0.76		2.91	3.44		0.20
K_2O	-	0.02	0.01		0.16	0.13		9.27
Σ	100.18	100.07	99.44		100.40	100.35		95.70
				Numbers of ions on the basis of				
		6 (o)				32 (o)		22 (o)
Si	1.817	1.894	1.808	Si	9.503	9.684	Si	5.397
Al^{IV}	0.183	0.106	0.192	Al	6.476	6.311	AlIV	2.603
Al^{VI}	0.099	0.063	0.064	Ti	-	-	AlVI	0.162
Ti	0.048	0.036	0.056	Mg	0.051	0.002	Ti	0.497
Mg	0.575	0.759	0.583	Fe	0.041	0.015	Fe	1.873
Fe	0.332	0.186	0.288	Mn	0.008	0.004	Mn	0.025
Mn	0.008	0.006	0.007	Na	1.017	1.201	Mg	3.251
Ca	0.905	0.912	0.981	Ca	2.653	2.653	Ca	0.004
Na	0.053	0.048	0.056	K	0.037	0.030	Na	0.057
K	-	0.001	0.000				K	1.764
Mg	28.5	37.8	28.6	Ab	27.4	32.0		
Fe	24.1	14.4	20.6	An	71.6	67.2		
Ca	47.4	47.8	50.8	Or	1.0	0.8		

1. Salite (green, γ/c = 48 °, No. 285); 2. Salite (zoned, slightly green γ/c = 42 °, No. 27); 3. Salite (pinkish, γ/c = 39 °, No. 306); 4. Bytownite (No. 285); 5. Labradorite (No. 27); 6. Biotite (γ'= reddish brown, α' = yellowish brown, No. 27).

c. Pyroxene-amphibole gabbro and diorite. This group of rock is variable in many respects. The grain size is medium-to coarse. The majority are strongly sheared, foliated, mylonitized and some are folded. Well-developed ophitic texture and layering (white feldspar-rich layers alternate with dark pyroxene-, amphibole-rich ones) can be observed. They occur in the middle and northern part of the

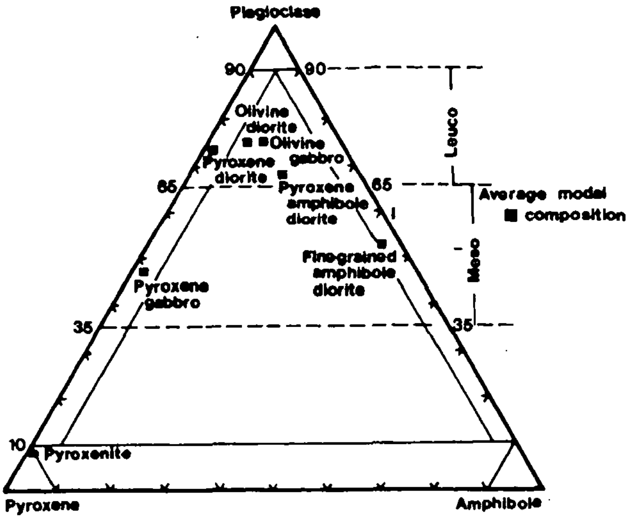


Fig. 2. Modal composition of the basic plutonic rocks of Bulfat.

intrusion. Plagioclase is the prevailing constituent, with average composition about An_{42}, but with a range between An_{28-76}. Sometimes two generations of plagioclase can be distinguished. The large grains with a higher An content are usually altered (saussuritisation). They formed earlier than the small, rounded, fresh grains around them. Granulation can also be observed. The large, strongly deformed, crystals are surrounded by finer grains of angular plagioclase of the same composition. Faint zonation is also common. Pyroxene occurs in nearly every sample, but in variable amounts depending on the degree of uralitization. Usually a very small relict of pyroxene can be observed in the middle of amphibole. The pyroxene is usually colourless or slightly greenish, with fine ilmenite lamellae (Average: $\gamma/c = 43°$).

In the northern part of the intrusion, few samples contain hypersthene in ophitic texture with lath-shaped plagioclase. They most probably formed by contamination of pelitic rocks.

The amount of amphibole is variable (3—29 V%). Three varieties can be distinguished: /1/ uralitization product of pyroxene. It is fibrous actinolite ($\gamma/c = 18°$); /2/ green hornblende ($\gamma/c = 24°—27°$) that is pleochroic (γ' = dark-green, bluish-green α' = pale-yellowish-green); /3/ prismatic or tabular brown hornblende. It commonly has ophitic texture, and is strongly pleochroic (γ'= dark or reddish-brown, α' = yellowish-brown, $\gamma/c = 32°$). Biotite was determined in few samples as an accessory mineral. They are small prismatic crystals with strong pleochroism (γ' = dark-reddish-brown, α' = yellowish-brown). Apatite and titanite occur as accessory minerals. The latter was observed around the opaque minerals as an alteration product indicating Ti enrichment in the opaque (Ti-magnetite and ilmenite).

Chlorite is a common alteration product of amphibole and biotite. It sometimes forms aggregates or secondary vein fillings. Zoisite and calcite are alteration products of plagioclase. Prehnite occurs as a vein filling.

d. Fine-grained pyroxene-amphibole diorite and amphibole diorite. The fine-grained, amphibole-rich variety is foliated, some are folded and laminated.

TABLE 4

Microprobe analyses of pyroxene and amphibole from pyroxene diorite and fine-grained pyroxene amphibole diorite

	PYROXENE	AMPHIBOLE	AMPHIBOLE		PYROXENE
wt %	1	2	3	4	5
SiO_2	50.62	41.46	41.36	42.98	54.26
TiO_2	0.62	4.90	4.25	3.67	0.29
Al_2O_3	1.86	11.21	11.04	10.38	1.58
FeO	12.78	13.40	17.10	14.90	9.50
MnO	0.38	0.25	0.44	0.35	0.40
MgO	9.83	11.74	10.30	11.03	12.67
CaO	23.45	11.74	11.32	10.38	20.41
Na_2O	0.43	2.43	3.05	2.88	0.78
K_2O	0.01	0.89	0.92	0.89	0.03
Σ	99.98	98.02	99.78	97.46	99.98
		Numbers of ions on the basis of			
	6 (o)	23 (o)	23 (o)		6 (o)
Si	1.939	6.171	6.138	6.410	2.014
Al^{IV}	0.061	1.829	1.862	1.590	—
Al^{VI}	0.023	0.137	0.069	0.234	0.069
Ti	0.018	0.548	0.474	0.412	0.008
Mg	0.561	2.605	2.278	2.452	0.701
Fe^{3+}			0.191	0.213	
Fe^{2+}	0.409	1.668	1.932	1.645	0.295
Mn	0.012	0.032	0.055	0.044	0.012
Ca	0.962	1.872	1.800	1.659	0.814
Na	0.032	0.128	0.200	0.341	0.056
Na		0.573	0.678	0.492	—
K	—	0.169	0.174	0.169	0.001
Mg	27.7				Mg 35.8
Fe	23.1				Fe 19.8
Ca	49.2				Ca 44.4

1. Salite from pyroxene diorite, (green, $\gamma/c=47°$, No. 56); 2. Kaersutite from pyroxene diorite (γ'=reddish brown, α'= yellowish brown $\gamma/c=17°$, No. 251); 3. Magnesian-hastingsite (γ'=greenish-brown, α'=yellowish green, $\gamma/c=28°$) from fine grained pyroxene-amphibole diorite (No. 43); 4. Ferroan pargasitic hornblende (γ'=greenish brown, α'=yellowish green) from the same rock (No. 52); 5. Ca-augite (greenish, $\gamma/c=39°$) from the same rock (No. 52).

Two main types were distinguished: thin layers of fine-grained diorite alternating with the coarse-grained gabbro and the chilled margin of the intrusion near the xenoliths or at the outer contact.

The main constituent is plagioclase. Some are strongly deformed, with wavy extinction and bent twin lamellae. (An_{35-20}). A faint zonation is rather common, which is characteristic at the margin of the intrusion, together with lower anorthite content. Pyroxene occurs in a minor amount as anhedral grains or as irregular patches in the amphibole. Pyroxene was sometimes found without any trace of uralitization. The composition is Ca-rich augite (Table 4).

Amphibole is very common. Two varieties can be distinguished: green-hornblende, ($\gamma/c = 26°$) formed by uralitization and magnesian-hastingsite or ferroan pargasitic-hornblende with strong pleochroism (Table 4). Nepheline is very rare; it occurs as a tabular, usually altered, grain. Calcite was sometimes observed as an interstitial constituent, indicating contamination from the Ca-rich xenoliths. Biotite was found in a very small amount, sometimes in the amphibole as an alteration product. Apatite and titanite occur as accessory minerals. Opaque minerals are Ti-magnetite and ilmenite.

The rocks is mesotype pyroxene-amphibole diorite, according to the average modal composition (*Fig.* 2, Table 2b). Contamination can be observed in these rocks, for example at the calcareous contact. They are undersaturated, containing nepheline norms (Table 2a), which sometimes also appear in the modal.

e. Contaminated rocks: Two types of contaminated rock can be distinguished: pyroxene diorite and pyroxenite. Both rocks occur at the contact with calcareous rock.

Pyroxene diorite is coarse- or sometimes medium-grained, with tabular plagioclase, large black prismatic pyroxene and yellowish-brown titanite. It occurs in the southern and northern part of the intrusion, always next to the contact marble. The plagioclase composition is An_{43} but some much lower values (An_{28}) were also determined. Pyroxene is always present, but in variable amount (4—43 V%). It appears in large prismatic or anhedral form, some of which show typical ophitic texture. The pleochroism is γ' = purplish or pinkish, α' = greenish, yellowish-pink. Colour zonation is common. Two types can be observed. In the first, the crystal core is slightly pinkish, which goes gradually into pinkish or pinkish-brown pleochroic rim. The composition of the core is salite and the rim is titanoferrosalite (Table 5). In the second the core is pinkish and contains higher Ti. This colour gradually goes into green, due to decreasing Ti and increasing Fe content. The composition of the core is titanoferrosalite and the rim is ferrosalite. The extinction angle of the Ti-rich salite is $\gamma/c = 38°$ and the Fe-rich is $\gamma/c = 43°$. The brown hornblende is an uralitization product of pyroxene. They are strongly pleochroic (γ' = dark-reddish-brown, α' = yellowish-brown) which is caused by the high Ti-content ($\gamma/c = 21°$). This rock usually contains large, slightly yellowish, sub- or euhedral titanite. Nepheline is rare. Apatite is common, mostly as large prismatic crystals. Calcite also occurs, but it is not an alteration product of plagioclase because it forms a well-separated crystal. Most probably it derived from the adjacent calcareous rock. Secondary minerals are chlorite, zoisite and prehnite. Opaque minerals are rather common, most probably titanomagnetite or ilmenite. Titanite rims are common around them. These rocks are slightly undersaturated, containing nepheline norms (Table 2a). Silica most probably escaped and formed Ca-silicate minerals at the immediate contact with limestone and caused silica deficiencies in the magma. According to the modal composition, two types were distinguished, leuco-pyroxene diorite and meso-pyroxene-amphibole diorite.

Pyroxenite contains coarse, medium-grained, black, slightly pinkish pyroxene and white interstitial plagioclase. It occurs at the immediate contact with the coarse-grained forsterite-, diopside- wollastonite- and melilite marble or diopside hornfels or less commonly, in the coarse-grained marble.

TABLE 5

Microprobe analyses of clinopyroxene and nepheline from contaminated pyroxene diorite

	PYROXENE						NEPH.
wt %	1	2	3	4	5	6	7
SiO_2	52.83	48.31	47.54	47.86	48.17	47.43	45.62
TiO_2	1.62	3.22	2.70	2.63	2.23	1.19	-
Al_2O_3	2.82	6.00	4.92	3.83	4.13	3.94	33.84
FeO	9.13	12.14	14.74	15.02	16.26	20.78	0.16
MnO	0.26	0.32	0.35	0.35	0.37	0.40	-
MgO	11.25	7.78	7.48	7.66	6.75	4.02	-
CaO	20.66	20.66	21.70	21.38	21.18	20.58	1.61
Na_2O	0.75	0.89	0.83	0.98	0.89	1.01	12.53
K_2O	0.02	-	-	-	-	-	5.22
Σ	99.34	99.32	100.26	99.71	99.98	99.35	98.98
	Numbers of ions on the basis of 6 oxygen						32 (o)
Si	1.974	1.845	1.836	1.859	1.870	1.893	8.668
Al^{IV}	0.026	0.155	0.164	0.141	0.130	0.107	7.580
Al^{VI}	0.098	0.115	0.060	0.034	0.059	0.078	-
Ti	0.046	0.092	0.078	0.076	0.065	0.036	-
Mg	0.626	0.443	0.430	0.444	0.391	0.239	-
Fe	0.285	0.388	0.476	0.488	0.528	0.693	0.025
Mn	0.008	0.010	0.011	0.011	0.012	0.013	-
Ca	0.827	0.845	0.898	0.890	0.881	0.880	0.328
Na	0.054	0.066	0.062	0.074	0.067	0.078	4.615
K	0.001	-	-	-	-	-	1.265
	Atomic ratios						
Mg	32.1	22.6	21.4	22.1	19.6	11.8	-
Fe	22.7	30.9	30.8	30.2	33.0	40.8	-
Ca	45.2	46.5	47.8	47.7	47.4	47.4	-

1. Salite, core of a large crystal (pinkish, No. 22); 2. Titanoferrosalite, rim of the same crystal (brownish, No. 22); 3. Titanoferrosalite core of a large crystal (pinkish, No. 55); 4. Titanoferrosalite intermediate zone of the same crystal (pinkish, No. 55); 5. Titanoferrosalite, outer zone of the same crystal (greenish, No. 55); 6. Ferrosalite, rim of the same crystal (green, No. 55); 7. Nepheline (No. 55).

The main constituent is pinkish, pleochroic and zoned large prismatic or anhedral titanosalite, titanoferrosalite and Ti-augite (85—90 V%). The colour zonation is similar to the first type of zoned pyroxene in diorite, but in this case the core has a higher Ti content (Table 6). Some pyroxene is altered to strongly pleochroic, Ti-rich amphibole (γ'=dark-green, greenish-brown, α'=yellowish-brown). Plagioclase is subordinate, anhedral and fills the intersticies among the pyroxene. The composition is andesine (An_{42}) or labradorite (An_{52-58}). Titanite is common as large subhedral or euhedral crystals. They are slightly pleochroic (brownish or pinkish) with polysynthetic twins. Apatite is also common in some samples. It forms large eu- or subhedral prismatic grains and occurs in pyroxene as an inclusion. Calcite fills intersticies between pyroxene grains as plagioclase does. Wollastonite and biotite are very rare. Prehnite is an alteration product of plagioclase. The rock has very high Ca and Ti content (Table 2a) due to the prevailing Ti-augite and titanite. The wollastonite and nepheline norms suggest Si migration towards the calcareous rock (Table 2a).

f. Nepheline syenite is mostly medium-grained. The amphiboles are oriented and occur in a feldspar- and nepheline- bearing groundmass. Some biotite can also be recognized. The nepheline syenite has a very restricted occurrence at the south-eastern part of the igneous complex at a very high elevation *(Fig. 1)*. It is usually surrounded by calcareous metamorphic rocks. The prevailing mineral is oligoclase (An_{28}) but orthoclase is also common with string perthites. Very rarely, cross-hatched anorthoclase can be observed. Nepheline occurs in every sample as an anhedral, prismatic or tabular crystal. Commonly altered to colourless mica. Hastingsitic hornblende (Table 7) is prismatic, oriented, and strongly pleochroic. Biotite is Fe-rich (siderophyllite, Table 7). It occurs together with amphibole or around the opaque minerals. Titanite is usually small, rounded, and mostly yellowish in colour. Opaque minerals are sometimes surrounded by anhedral titanite, indicating that they have formed from it by alteration. SiO_2 content of the rock indicates an intermediate composition but with a high content of alkalis (Table 2a). According to nepheline, orthoclase micropertite, and hastingsitic hornblende, the rock is an undersaturated sodium-type syenite.

Two kinds of genesis can be proposed: /1/ Alkaline rock formation by differentiation and assimilation from calc-alkaline or alkali-calcic magma. /2/ Alkaline rock crystallization from alkali magma.

The very common occurrence of carbonate-rich xenoliths in the intrusion could produce a relative alkali enrichment at the contact, caused by silica migration to country rocks. Silica deficiency would consequently occur in the melt (instead of plagioclase, nepheline would crystallize). Silica-poor magma could even intrude into metasediments. This way of forming of alkali magma is restricted only to a small area like in Bulfat.

According to the agpaitic coefficient, mineralogical composition the Bulfat alkaline rocks belong to the miaskitic nepheline-syenite group. In this type of rocks, zircon, pyrochlore, and in the potassium-rich variety, uranium enrichment can occur. Further detailed studies are recommended in order to prove whether carbonatite occurs in the area, which could be suspected from the miaskitic character, from melilite occurrences etc.

The close association with calcareous metasediments and very restricted occurrences suggests "limestone assimilation" genesis, but if chemical and mineralogical composition are taken into consideration, the second type of genesis also possible.

TABLE 6

Microprobe analyses of pyroxene from contaminated pyroxenite

	PYROXENE				
wt %	1	2	3	4	5
SiO_2	46.34	45.25	44.18	43.99	43.83
TiO_2	2.29	2.75	3.10	3.31	3.35
Al_2O_3	6.55	7.90	8.53	9.66	9.74
FeO	14.65	9.68	15.21	15.46	15.59
MnO	0.26	0.18	0.24	0.21	0.25
MgO	7.10	9.43	5.85	5.54	5.15
CaO	21.36	23.73	21.13	21.21	21.25
Na_2O	0.50	0.69	0.48	0.55	0.65
K_2O	—	0.02	—	—	0.05
Σ	99.05	99.63	98.72	99.93	99.86
	Numbers of ions on the basis of 6 (o)				
Si	1.804	1.729	1.734	1.706	1.705
Al^{IV}	0.196	0.271	0.266	0.294	0.295
Al^{VI}	0.105	0.085	0.129	0.148	0.152
Ti	0.067	0.079	0.092	0.097	0.098
Mg	0.412	0.537	0.342	0.320	0.298
Fe	0.477	0.309	0.499	0.502	0.507
Mn	0.009	0.006	0.008	0.008	0.008
Ca	0.891	0.972	0.889	0.881	0.886
Na	0.038	0.051	0.036	0.041	0.049
K	—	0.001	—	—	0.003
	Atomic ratios				
Mg	20.6	26.3	17.1	16.0	14.9
Fe	32.9	23.6	36.6	37.9	38.3
Ca	46.5	50.1	46.3	46.1	46.8

Titanoferrosalite, core of a crystal (pinkish, No. 71A); 2. Titansalite, rim of the same crystal; 3. Titanoferrosalite, core of a crystal (pinkish, No. 2C); 4. Titanoferrosalite, intermediate zone of the same crystal (No. 2C); 5. Titanoferrosalite, rim of the same crystal (No. 2C).

TABLE 7

Microprobe analyses of amphibole, biotite and orthoclase from nepheline syenite

	AMPHIBOLE	BIOTITE		ORTHOCLASE
wt %	1	2		3
SiO_2	40.05	34.60		67.19
TiO_2	1.70	2.21		-
Al_2O_3	9.40	13.24		17.59
FeO	29.94	34.08		0.05
MnO	0.77	0.90		0.07
MgO	2.13	2.92		0.03
CaO	9.15	0.04		0.34
Na_2O	2.83	0.16		3.28
K_2O	1.89	9.29		11.22
Σ	97.83	97.44		99.76
	Numbers of ions on the basis of			
	23 (O)	22 (O)		32 (O)
Si	6.406	5.611	Si	12.194
Al^{IV}	1.594	2.389	Al^{IV}	3.762
Al^{VI}	0.178	0.142	Al	-
Ti	0.204	0.269	Ti	-
Fe^{3+}	0.599	-	Mg	0.008
Mg	0.508	0.705	Fe	0.009
Fe^{2+}	3.406	4.622	Mn	0.011
Mn	0.104	0.124	Na	1.154
Ca	1.568	0.007	Ca	0.067
Na	0.432	0.050	K	2.598
Na	0.446			
K	0.386	1.923		
			Ab	30.2
			An	1.8
			Or	68.0

1. Hastingsitic hornblende (γ'=dark green, α'=yellowish green, γ/c=30°, No. 55C); 2. Fe-biotite (γ'=black, α'= yellowish brown, No. 55C); 3. Orthoclase (No. 55C).

These rocks are different from the pyroxene-amphibole gabbro and diorite in many respects. Their fresh colours are grey or brownish-grey and on weathered surfaces they are always brown. The grain sizes are variable but usually coarse- or medium-grained. Oriented, foliated varieties are not as common as in the pyroxene-amphibole gabbro or diorite. They occur in the western part of the plutonic complex. According to the plagioclase composition and SiO_2 content, two varieties were distinguished:

— olivine-amphibole pyroxene gabbro and olivine-amphibole-pyroxene diorite

Olivine-amphibole-pyroxene gabbro: The main constituent is plagioclase (74V%, average: An_{55}). The coarse-grained variety contains large tabular and finer-grained one has lath-shaped plagioclase, some of which are zoned. Strongly deformed (bent twin lamellae, wavy extiction), granulated plagioclases were observed only in the sheared zone. The crystals show ordered structure, indicating a typical plutonic origin. The most frequent twin law is albite, but albite/ala, albite/pericline, acline/pericline laws were also observed. Olivine occurs in every sample (Fo_{60-70}, Table 8). They are subhedral, or less commonly euhedral, transected by cracks and cleavages where very fine-grained "dust-like" magnetite occurs. They are usually surrounded by pyroxene or brown hornblende. Bowlingite (saponite) is the most common alteration product, although serpentinization was also observed. Bowlingite occurs along the rims and cracks (cleavages), or sometimes the whole olivine crystal has been altered to bowlingite. Every sample contains pyroxene in a variable amount (0.32—27V%). They form large tabular or prismatic crystals. The tabular ones commonly show ophitic texture. They are colourless or slightly pinkish and greenish. (100) parting is common, containing ilmenite, which is characteristic of diallage. The composition is salite-augite (Table 8). The rims of the crystals are usually altered to amphibole. Some form aggregates with olivine and brown hornblende. In this case, a sharp boundary occurs between the brown hornblende and pyroxene indicating the later stage of crystallization of amphibole. The amphibole is rather common. Two varieties can be distinguished: magnesio-hastingsite (Table 8) formed from pyroxene (uralitization) and strongly pleochroic or tabular (sometimes with ophitic texture) kaersutite (Table 8). They occur separately and around the pyroxene or ilmenite. This type of amphibole indicates an alkaline enrichment during the later stage of crystallization. Biotite is very rare and mostly occurs around the kaersutitic hornblende. It forms very small, prismatic, strongly pleochroic crystals (γ'= dark-reddish-brown, α'= yellowish-brown).

Two kinds of opaque minerals were distinguished: magnetite, which occurs along the cleavages and cracks of olivine; ilmenite which is anhedral and mostly surrounded by kaersutite and biotite. Apatite occurs in an accessory amount. Average SiO_2 content is less than 50 wt% (Table 2a).

Olivine-amphibole-pyroxene diorite: mineralogical composition of this rock is the same as the olivine amphibole pyroxene gabbro, although some differences can be observed in detail.

The following features are characteristic of this rock: /1/ An content of plagioclase less than 50 mol% (Average: An_{43}); /2/ zoned plagioclases are common; /3/ biotite is more common; /4/ SiO_2 is more than 50 wt% and Al_2O_3 content (Table 2a) is lower than in gabbro. This rock is the marginal facies of the olivine-gabbro intrusion and represents a slightly lower crystallization temperature.

Microprobe analyses of olivine, clinopyroxene, amphibole and plagioclase from olivine gabbro and diorite

	OLIVINE			PLAGIOCLASE			PYROXENE				AMPHIBOLE			
wt %	1	2	3	4	5		6	7	8		9	10	11	12
SiO_2	35.52	36.72	36.11	56.52	57.96		51.59	49.93	51.90		42.34	41.30	42.98	43.32
TiO_2	0.03	-	0.02	0.02	0.07		0.56	1.50	0.73		4.34	5.52	3.36	4.76
Al_2O_3	0.02	0.02	0.03	27.57	26.48		2.49	4.03	1.61		12.07	12.48	10.59	10.15
FeO	34.59	26.85	35.78	0.16	0.12		8.64	6.48	9.20		13.27	10.04	14.83	12.36
MnO	0.75	0.60	0.69	-	0.02		0.41	0.23	0.33		0.25	0.18	0.29	0.23
MgO	29.01	35.58	26.22	0.02	-		14.32	14.02	14.31		12.62	13.16	11.30	12.69
CaO	-	-	0.04	11.38	10.27		21.05	22.70	21.41		11.04	11.84	10.38	11.22
Na_2O	-	-	0.01	4.21	4.84		0.37	0.67	0.33		2.49	2.73	2.85	2.27
K_2O	-	-	0.02	0.17	0.16		-	0.03	0.03		0.58	0.49	0.95	0.96
Σ	99.92	99.77	98.92	100.05	99.92		99.43	99.59	99.85		99.00	97.74	97.53	97.96
						Numbers of ions on the basis of								
		4 (o)		32 (o)				6 (o)				23 (o)		
Si	0.987	0.983	1.018	10.140	10.375	Si	1.931	1.864	1.942	Si	6.119	6.059	6.387	6.377
Al	0.001	0.001	0.001	5.831	5.588	Al^{IV}	0.069	0.136	0.058	Al^{IV}	1.881	1.941	1.613	1.623
Ti	0.001	-	-	0.003	0.010	Al^{VI}	0.041	0.041	0.013	Al^{VI}	0.175	0.217	0.242	0.138
Mg	1.202	1.419	1.101	0.005	-	Ti	0.016	0.042	0.021	Ti	0.472	0.609	0.375	0.527
Fe	0.804	0.601	0.843	0.024	0.018	Mg	0.799	0.780	0.798	Fe^{3+}	0.532	-	0.311	0.063
Mn	0.018	0.014	0.016	-	0.003	Fe	0.271	0.202	0.288	Mg	2.719	2.878	2.503	2.784
Ca	-	-	0.001	2.187	1.969	Mn	0.013	0.007	0.011	Fe^{2+}	1.072	1.232	1.532	1.459
Na				1.464	1.680	Ca	0.844	0.908	0.859	Mn	0.030	0.022	0.037	0.029
K				0.039	0.037	Na	0.027	0.048	0.024	Mn	0.001	-	-	-
						K	-	0.001	0.001	Ca	1.710	1.861	1.653	1.770
										Na	0.289	0.139	0.347	0.230
										Na	0.409	0.638	0.474	0.418
										K	0.107	0.092	0.180	0.180
							Atomic ratios							
Mg	59.9	70.2	56.6	Ab 39.7	45.6	Mg	39.8	38.4	39.6					
Fe	40.1	29.8	43.4	An 59.3	53.4	Fe	16.9	14.5	16.6					
				Or 1.0	1.0	Ca	43.3	47.1	43.8					

1. Olivine from gabbro (No. 221); 2. Olivine from gabbro (No. 304); 3. Olivine from diorite (No. 50); 4. Labradorite from gabbro (No. 221); 5. Labradorite from gabbro (No. 304); 6. Augite from gabbro (No. 221); 7. Salite from gabbro (No. 304); 8. Augite from diorite (No. 50); 9. Magnesio-hastingsite from gabbro (No. 221); 10. Kaersutite from gabbro (No. 304); 11. Kaersutite from diorite (No. 50); 12. Magnesian hastingsitic-hornblende from diorite (No. 52).

Pegmatites are white, coarse-grained, feldspar-rich dikes in the plutonic and sometimes in the metamorphic complexes. They have different composition depending on their occurrences. The feldspar of the pegmatite which occurs in pyroxene-amphibole gabbro and diorite is sodium rich (An_{32}). It contains orthoclase microperthite, cross-hatched microcline and biotite. The pegmatites near the nepheline syenite contain nepheline. Dikes, that transect the calcareous metamorphic rocks are very rich in alkalies due most probably to limestone assimilation. The pegmatitic dike rocks in olivine gabbro or diorite are calcium rich. The composition of plagioclase is labradorite (An_{56}), which commonly has been altered to zoisite and prehnite.

SUMMARY

a. Petrochemistry of plutonic rocks. The majority of the plutonic rocks belong to the alkali-calcic suite. The alkali-lime index of the pyroxene-amphibole gabbro-diorite series is 54 and the olivine gabbro-diorite is 55. Beside the two main gabbro-diorite series, a minor amount of alkaline rocks also occur. Nepheline syenite most probably formed by differentiation and assimilation (alkali-lime index: 44). The average bulk chemical composition of the Bulfat plutonic rock shows a different trend from the calc-alkaline suite *(Fig. 3)*.

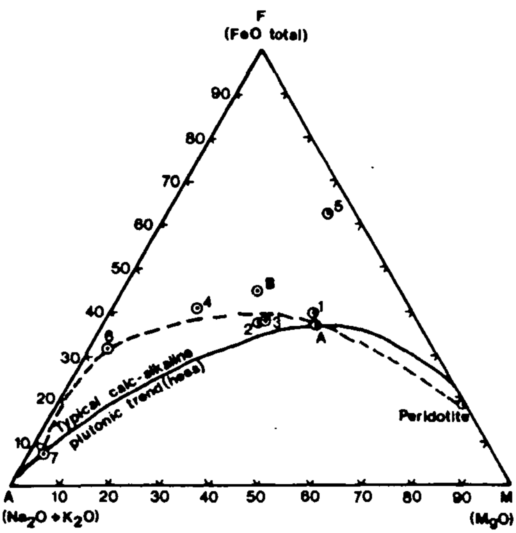


Fig. 3. AFM plot of Bulfat plutonic rocks. 1. Harzburgite; 2. Pyroxene gabbro; 3. Pyroxene diorite; 4. Pyroxene-amphibole diorite; 5. Contaminated pyroxene diorite; 6. Contaminated pyroxenite; 7. Nepheline syenite; 8. Pegmatite A. Olivine gabbro, B. Olivine diorite.

The Bulfat pyroxene gabbro has higher Ca and lower Mg or Fe contents than the average calc-alkaline gabbro. In the diorite, not only the Ca but also the Na content is high, the higher Fe content of pyroxene and larger amount of amphibole correspond with the normal trend of differentiation. Na-rich alkali-nepheline syenite crystallized during the later stage of differentiation.

The higher Ca content, together with alkali enrichment, suggests contamination and assimilation.

The olivine gabbro contains high Al and Na and low Fe, Mg and Ca. This olivine-bearing rock differs from the pyroxene-amphibole gabbro-diorite series with respect to chemical and mineralogical compositions and most probably represents a well-differentiated, feldspar-rich younger intrusion.

b. Composition of rock-forming minerals: The crystal differentiation can be followed by compositional changes of rock-forming minerals. The anorthite content of plagioclases decreases from the gabbro to nepheline syenite (Table 9, *Fig. 4*). Albite-rich plagioclase occurs together with potash feldspars and nepheline at the latter stage of magmatic differentiation.

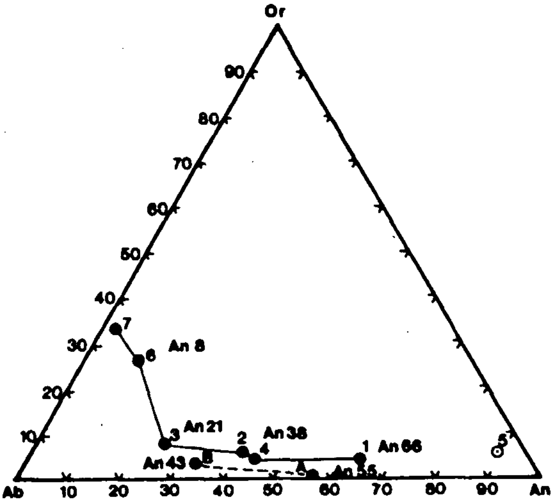


Fig. 4. Ab-An-Or CIPW plot of plutonic rocks of Bulfat. 1. Pyroxene gabbro; 2. Pyroxene diorite; 3. Pyroxene-amphibole diorite; 4. Contaminated pyroxenite; 6. Nepheline syenite; 7. Pegmatite. A. Olivine gabbro. B. Olivine diorite.
Remark: An content of plagioclases measured by optical or microprobe methods

Ca-rich clinopyroxene (salite) occurs in gabbro. Their Ca content decreased toward the latter stage of crystallization and augite crystallized in the pyroxene-amphibole diorite. The iron content of amphibole increases (100 Mg/Mg+Fe=61, 54, 13) towards the more acidic members of sequences.

Similar trends can be observed in the olivine gabbro and diorite; Fe enrichment is characteristic of the latter stage of crystallization (Table 9).

c. Contaminations: the Quandil metasediment (mostly calcareous) was partly assimilated by the basic intrusion. This assimilation contaminated the magma and shifted its (calc-alkaline) composition towards the alkalic-suite. The contamination is inferred from the following observations: /1/ The gabbro is rich in Ca and poor in Mg and Fe. /2/ Nepheline norms and mods are common, especially at the immediate contact with calcareous xenoliths and at the top of the whole magmatic sequence. The very small nepheline syenite occurrences are completely surrounded by calcareous rocks. /3/ Presence of Ti-augite (80 V%) between the igneous and calcareous rocks. Assimilation of calcareous rocks most probably caused Ca enrichment in the magma and dilution of all other elements (Mg, Fe, Si, Al, etc.)

Silica deficiences resulted from this dilution and nepheline appeared in addition to plagioclase. Silica deficiences could have resulted from reaction between the magmatic plagioclase, ilmenite and calcite, resulting in the crystallization of Ti-augite, nepheline and wollastonite.

calcite + plagioclase + ilmenite = Ti-augite + nepheline + wollastonite

The possibility of depletion of aluminium from the magma is not excluded because of the presence of Al-rich Ti-augite and gehlenite at the immediate contact.

TABLE 9

Composition of rock forming-minerals

Rock name	Plagioclase An %	Olivine Fo	Clinopyroxene Ca	Mg	Fe	Amphibole $Mg/Mg+Fe^{2+}$	Elevation (m)
Pyroxene gabbro	66	-	49	31	20	-	2050
Pyroxene diorite	38	-	49	28	23	0.61	1680
Pyroxene-amph. diorite	21	-	44	36	20	0.57	1420
Nepheline syenite	8 orthoclase+nepheline	-	-	-	-	0.13	2240
Contaminated rocks:							
Pyroxene diorite	36 (nepheline)	-	47	23	30	-	1860
Pyroxenite	-	-	46	18	36	-	2040
Olivine gabbro	55	65	45	39	16	0.71	
Olivine diorite	43	57	44	39	17	0.64	

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