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The geology of Mount Taftan stratovolcano, southeast of Iran

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Summary. — Mount Taftan is a double-peaked stratovolcano, located in southeast of Iran. This volcano constructed a number of calderas among which one of the most important is Anjerk. The magmas erupted from this multi-caldera complex range from andesi-basalt to dacite, but are dominated by andesite and dacite. Two terminal cones, Narkuh and Matherkuh, culminate at 4100 m and 3950 m, respectively. There are three evolutionary stages in the history of the volcanic complex (stage 1: Palaevolcanism, 6.95 ± 0.72 Ma, stage 2: Mesovolcanism, 6.01 ± 0.15 Ma and stage 3: Neovolcanism, 0.71 ± 0.03 Ma). The eruptive products consist of lava flows, ignimbrites and pyroclastic rocks. The later include tuffs, nuees ardents, breccias and sometimes reworked as lahars. Textural and mineralogical data suggest that both magma mixing and fractional crystallization were involved in the generation of the andesites and dacites. The magmas erupted from this volcano show a calc-alkaline trend. The corresponding lavas are calk-alkaline with a potasic tendency.

PACS 91.40.-k – Volcanology.

1. – Introduction

Only a few works on geology of the Taftan volcano are available in the literature [2-4]. This volcano is located in Makran zone and is formed by subduction of Oman-oceanic lithosphere below Iran's Eurasia plate. Extensive structural studies are reported in [5, 6]. Their studies focused on topography, ophiolitic nappe and accretion prism on Makran's trench and showed subduction activity at this zone, which had been formed in Cretaceous. Quaternary volcanoes are shown in fig. 1. Only few volcanoes such as Taftan and Bazman have still fumarolic activity.

Taftan volcano consists of two principal mountains, Narkuh and Matherkuh, which culminate at 4100 m and 3950 m, respectively and attached together with thin saddle

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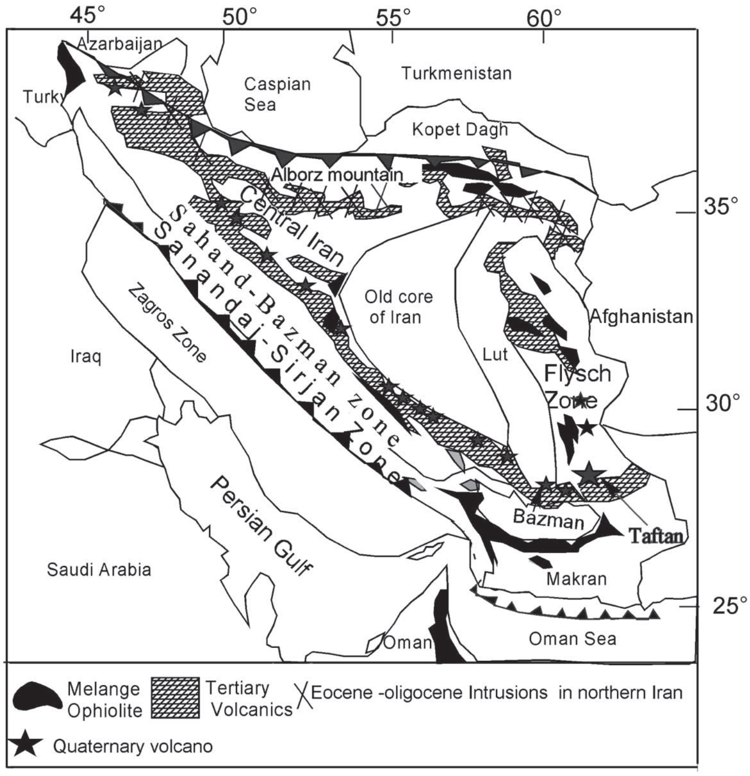

Fig. 1. – Main structural zone of Iran with widespread Quaternary volcanoes in central Iran ([1], with change).

horse-like part. Mathekuh is covered with thick and young andesite lava flows, and shows fumarolic activity (fig. 2).

In this paper, we present a structural and petrological investigation of spatio-temporal evolution of the Taftan stratovolcano (fig. 3).

2. – Volcano-structural evolution of Mount Taftan

The main activity of Taftan occurred during Quaternary although it appears to have started before Quaternary time. Three activity stages have been identified within the volcanic stratigraphy of Mt. Taftan volcano. They have been classified as Paleo, Meso and Neovolcanism according to radiometric and stratigraphic dating.

2˙1. *Palaeovolcanism.* – The volcano was built on the colored mélange and sedimentary basement that belong to Cretaceous and Eocene age, respectively. Remnants products of this stage of activity outcrop on the southeastern flank of Mt. Taftan, near Tamandan village (2100 m). They include lava flows (sub-aphanitic basaltic andesite with emulsified texture), lahars, and ignimbrites overlying the sedimentary and colored melange basement. Basaltic andesite lava flows of this stage have K/Ar ages of 6.95 ± 0.72 Ma.

The lahars are 50 m thick with well-rounded large blocks. The sub-rounded to angular fine grains suggest a proximal facies. These units overlie the flysch facies and colored

Fig. 2. – The landscape mounts of Taftan volcano.

melange complex. Flow directions and slope values indicate that the sources of this stage of activity were located South of the Tamandan village.

The ignimbrite consists of ash and pumice fragments. The pumice grain size varies between 15 cm at the base to 5 cm at the top. Lithics are andesitic and dacitic in composition and are scattered in a matrix consisting of coarse ash.

2·2. *Mesovolcanism*. – The principal products are lava flows, pyroclastics, tuffs and ignimbrites. Pattern of the lava flows and caldera forms indicate that these products are younger than Paleovolcanic products and older than Neovolcanic products. Mesovolcanism activities produced mainly andesite and dacite lavas flows containing plagioclase, biotite, amphibole and quartz with scarce pyroxene. These rocks have porphyritic heterogeneities banding and emulsified textures suggesting mechanical mixing of two chemically and mineralogically distinct magmas.

2·2.1. Anjerk caldera. Anjerk caldera is one of the main Mt. Taftan calderas formed during the Mesovolcanism stage. It is on a large (7 × 10 km), important composite stratovolcano, which is about 2500 m of elevation above sea level, rising on the NE slope of Taftan volcano. The NW of the Anjerk caldera is cut by a SE-NW directional lineament corresponding to a buried regional fault seen on a SPOT image. The lava flows and tuffs overlying this lineament show signs of hydrothermal alteration. Anjerk caldera has completely kept its form. It is composed of lavas and pyroclostic rocks (fig. 4). The products emitted from the caldera are pyroclastic rocks, ignimbrites, pumices, lahars and lava flows.

A detailed geological map of Anjerk caldera, based mainly on fieldwork and aerial photographs. It is reported in figs. 5 and 6. The final Mesovolcanism activity was the emplacement of ignimbrites and associated air-fall deposits in two major eruptive sequences.

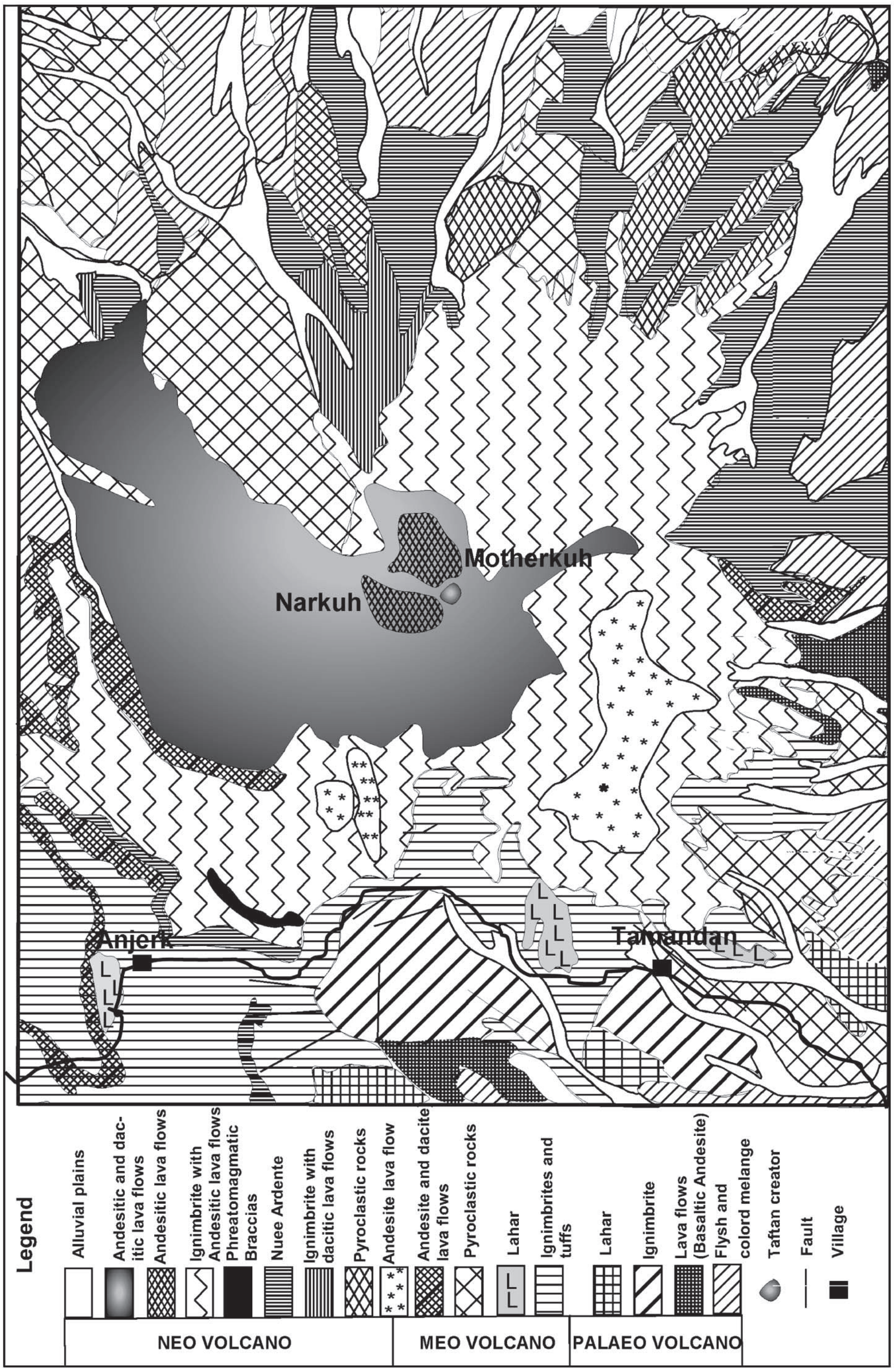

Fig. 3. – Geological map of the Mount Taftan and the surrounding area (scale: 1/100000).

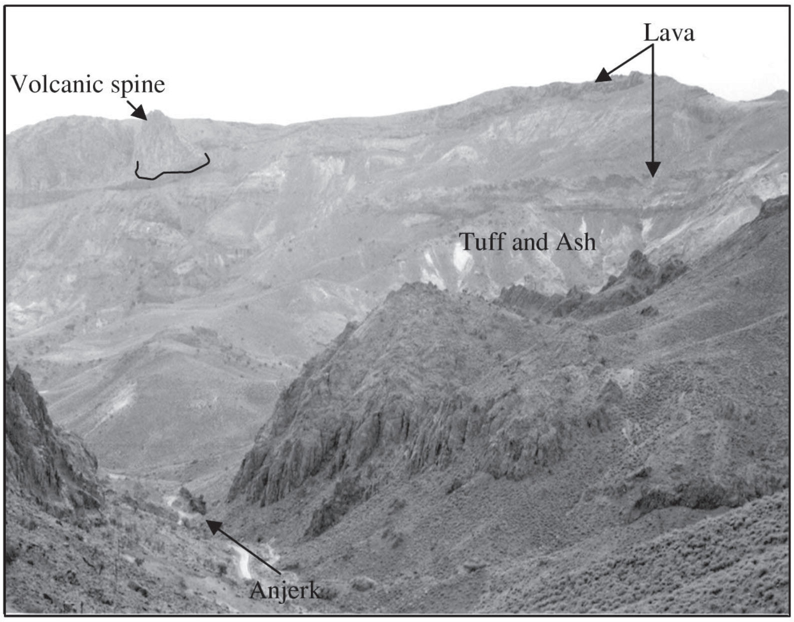

Fig. 4. – The landscape of Anjerk caldera.

2.3. *Neovolcanism.* – Its products include nuees ardents (term used descriptively), breccias, ignimbrites, andesite and dacite lava domes and flows.

2.3.1. Nuees ardentes. The extrusive andesitic and dacitic lava domes and flows were the source of the nuees ardents generations. These deposits were produced in two sequences during the early phase of the Neovolcanism growth, following the collapse of the Mesovolcanism calderas.

2.3.2. Ignimbrites and breccias. Ignimbrites are indurate or poorly welded. They include pumices (max: 15 cm in diameter) and fine grained lithics (1-2 cm in diameter). Ignimbrite layers reach a thickness of 20 m (?) close to Jamchin, where they outcrop in a valley. The lithics are generally ellipsoid in shape and andesitic to dacitic in composition.

Breccias were formed by reinjection of magma within the caldera filling deposit along the northwestern calderas boundary fault. They display peperitic textures including sometimes jigsaw-fit fracturated juvenile lithics with glassy surface. The glassy surfaces of braccia clasts are red due to hydrothermal alteration.

2.3.3. Andesitic and dacitic lava dome and lava flows. After the nuees ardentes and breccias emplacement, eruptive activity continued with the emission of andesite and dacite lava flows from two terminal cones: Motherkuh and Narkuh. K/Ar dating of an andesitic lava flow from the summit of Matherkuh gives an age of about 700000 years. Weak explosive phases sometimes preceded lava emission from the flanks of the volcano and in the summit area. The summit of Mothekuh is occupied by five ringed craters. Morphology of Narkuh is very fresh, and the andesitic lavas contain numerous cognate inclusions.

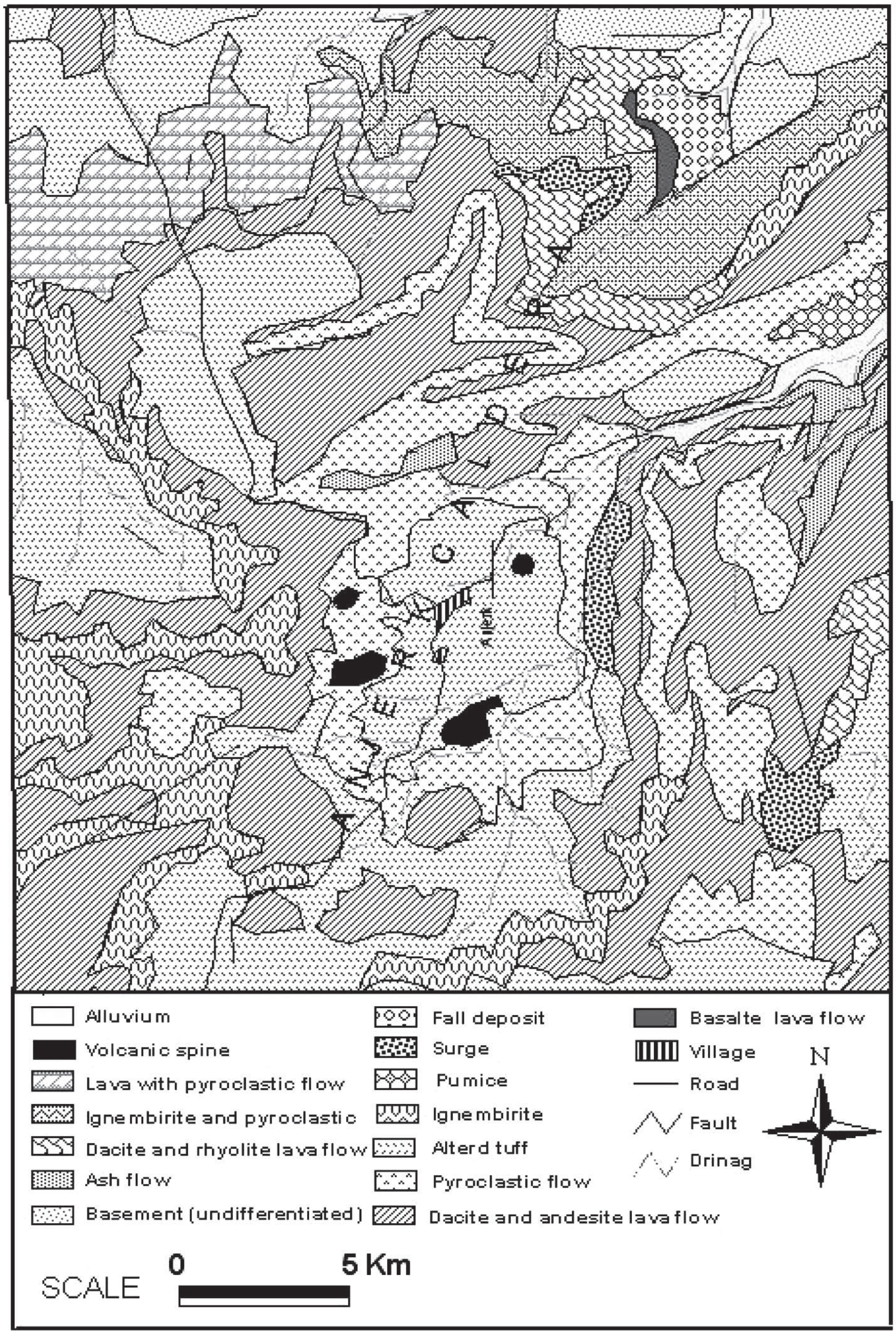

Fig. 5. – Geological map of the Anjerk caldera.

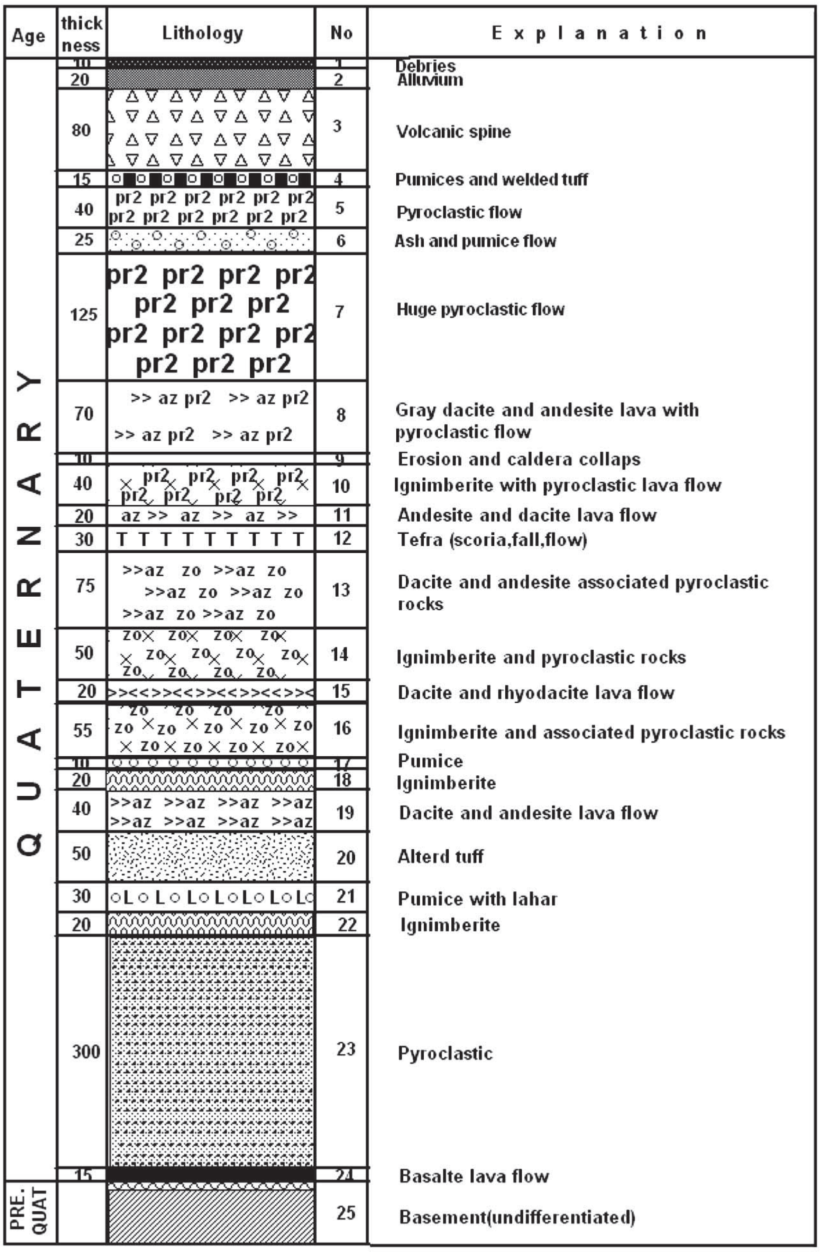

Fig. 6. – Generalized stratigraphic section of the Anjerk caldera deposit. 1-Slope waste and debris. 2-Alluvium, 3-Volcanic spines, 4-Pumice and welded tuffs, 5-Pyroclastic flows, 6-ash and pumice flows, 7-Huge pyroclastic flows, 8-Gray dacite and andesite lavas with pyroclastic flows, 9-Erosion and caldera collaps, 10-Ignimbirite with pyroclastic flows, 11-Andesite and dacite lava flows, 12-Tephras (scoria, fall, flow), 13-Dacite and andesite associated pyroclastic rocks, 14-Ignimbirite and pyroclastic rocks, 15-Dacite and rhyodacite lava flows, 16-Ignimbirite and associated pyroplastic rocks, 17-Pumice, 18-Ignimbirite, 19-dacite and andesite lava flows, 20-Alterd tuffs, 21-Pumices and lahars, 22-Ignimbirite, 23-Pyroplastics, 24-Basalte lava flows, 25-Basement (undifferentiated).

3. – Petrology and geochemistry of Mount Taftan

Petrological investigation has been carried out on different products of each stage. Different petrographical types, all typical of a calc-alkaline volcano (basaltic andesites, andesites, dacites, etc.), were identified. In addition, cognate inclusions and cumulates were investigated.

3˙1. *Petrography and mineral chemistry*

3˙1.1. Basalts and basaltic andesites. Basaltic lava flows mainly are found around of Taftan volcano. No age determination is available, so that their relationship to the Palaeovolcanic stage of activity is uncertain.

Basaltic andesite lava flows are found in Taftan volcanoes and they belong to the Palaeovolcanic activity stage. They contain clinopyroxene, orthopyroxene, plagioclase and oxides. The plagioclase composition covers a wide range, from oligoclase to labrador, even within a same rock sample, displaying slightly reverse zoning. Other distinctive features of basaltic andesite are the coexistence of different clinopyroxene and the presence of xenoquartz. These maybe show happen that magma mixing has occurred.

3˙1.2. Andesites. Most of the lavas from Neo and Mesovolcanism are andesite and dacite in composition. The mineral assemblages of Mesovolcanism andesites include different combinations of clinopyroxene, plagioclase biotite and amphibole. Reversely zoned plagioclase and clinopyroxene are observed. Textural heterogeneities such as cognate inclusions, banding and emulsified facies in the lavas are related to mechanical mixing processes.

Reversely zoned plagioclase and clinopyroxene, destabilized pyroxene and corroded and/or resorbed quartz are very common in the andesites of both stages. The cognate inclusions found in these lavas are also andesitic in composition, but more mafic than the host rocks. Beside the textural heterogeneities, the mineralogical disequilibria also suggest that magma mixing has occurred. Microcumulates, consisting of amphibole, pyroxene and plagioclase, are also present in andesites, and can be ascribed to fractional crystallization.

3˙1.3. Dacites. They are found as ignimbrites, lava flows and domes. Mesovolcanism dacites are represented by ignimbrites of Anjerk caldera and lava flows. The plagioclase of the dacite ignimbrites shows reverse and/or oscillatory zoning.

The dacites of the Neovolcanism occur as a lava flow and as non-welded ignimbrites. They contain plagioclase, biotite and quartz. Plagioclases show occasional oscillatory zoning and, rarely reverse zoning.

3˙2. *Major and trace elements determination and K/Ar dating*

3˙2.1. Analytical methods. About 500 samples of the different rocks were collected from Mt. Taftan. In order to correctly characterize their chemical compositions, 40 least-altered samples were chosen for major, trace and rare-earth-elements (REE) analysis. Samples for whole rock analysis were crushed and powdered in agate ball-mills. Major elements were analyzed with ME-ICPO6 instrument in Ltd Canadian institute. Representative chemical analysis for major is presented in table I.

Analyses of K and Ar for radiometric dating were carried out on groundmass-rich whole rock samples (ca.100 mg) powdered using an agate mortar and decomposed by solution of HF and HNO3 in Teflon beakers for about 12 hours. In addition, they were

TABLE I. – *Selected whole-rock major oxide analyses (ICPMS method) and corresponding CIPW norms of Taftan volcano (three stages).*

		Paleovolcanism Stage											Mesovolcanism Stage									
%	86	71	69	145	128	127	102	176	181	182	183	185	92	93	106	111	112	115	116	118	126	129
SiO2	49.80	58.70	58.70	57.70	50.1	51.7	57.00	62.7	53.4	62.1	61.1	57.5	58.50	58.40	61.30	59.90	62.00	61.10	57.70	63.40	61.20	62.80
Al2O3	17.30	18.20	18.40	16.45	17.75	17.70	16.55	16.12	17.45	15.64	16.65	16.85	17.70	17.45	16.30	17.15	17.15	17.50	17.40	16.30	17.20	16.50
Fe2O3	7.93	6.34	6.52	6.20	7.15	6.83	5.97	4.75	7.21	4.44	4.91	6.55	5.42	5.62	4.85	4.99	5.28	4.03	5.98	4.57	4.23	4.10
CaO	9.62	6.97	6.66	7.40	9.60	7.35	7.02	5.13	7.97	8.82	5.59	7.84	5.93	6.61	4.94	6.35	5.78	5.77	6.91	5.08	5.43	4.85
MgO	5.96	3.44	3.43	4.72	4.72	3.88	2.97	2.28	4.32	1.97	2.61	3.47	2.48	3.05	1.80	1.09	2.60	2.49	3.66	2.45	1.98	2.10
Na2O	3.14	3.75	3.39	3.35	3.42	3.45	2.96	2.5	2.59	2.74	2.95	3.10	3.24	3.17	2.97	3.88	3.77	3.29	3.43	3.76	3.63	3.72
K2O	1.21	1.46	1.46	1.65	1.26	1.21	2.50	2.92	1.72	2.98	2.82	1.99	2.43	1.86	2.90	2.48	2.37	2.15	1.99	2.31	2.13	2.34
Cr2O3	0.03	00.1	0.01	00.2	00.2	0.02	0.01	0.01	0.01	0.02	0.01	0.02	3.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
TiO2	0.98	0.79	0.81	0.77	0.93	0.87	0.78	0.67	0.99	0.63	0.75	0.97	0.68	0.70	0.67	0.86	0.75	0.65	1.01	0.61	0.61	0.59
MnO	0.13	0.10	0.10	0.10	0.13	0.10	0.15	0.07	0.10	0.07	0.08	0.11	0.07	0.10	0.10	0.09	0.08	0.07	0.09	0.08	0.06	0.06
P2O5	0.36	0.18	0.21	0.21	0.32	0.27	0.22	0.19	0.23	0.18	0.22	0.24	0.20	0.24	0.26	0.36	0.27	0.21	0.37	0.13	0.22	0.20
SrO	0.83	0.07	0.08	00.9	00.9	0.07	0.11	0.06	0.09	0.06	0.07	0.06	0.08	0.11	0.08	0.10	0.08	0.06	0.14	0.06	0.06	0.07
BaO	0.18	0.04	0.04	00.3	00.4	0.04	0.07	0.08	0.04	0.06	0.07	0.05	0.06	0.06	0.07	0.07	0.06	0.05	0.05	0.05	0.05	0.05
LOI	0.90	0.027	0.20	0.61	40.2	4.73	2.28	2.15	3.35	3.13	1.80	1.06	1.37	1.03	2.98	2.90	1.33	2.69	0.87	1.24	2.78	1.15
Total	100	100	100	99.3	99.6	98.2	98.6	100	99.5	88.9	99.6	99.8	98.2	98.4	99.2	100	99.7	100	99.6	100	99.6	98.5
CIPW																						
Qz	0	11.98	13.08	10.28	0.05	5.78	12.11	20.55	8.7	22.35	17.9	11.44	14.12	14.39	2035	15.17	13.89	18.04	10.98	18.77	17.98	19.37
Or	7.44	8.66	8.66	9.9	7.81	7.67	15.38	17.67	10.6	18.44	17.08	11.94	14.87	11.32	17.85	15.11	14.27	13.13	11.95	13.84	13.03	14.23
Ab	27.6	30.26	28.74	28.73	30.3	3123	26.03	25.5	22.81	24.23	25.52	26.57	28.33	27.56	26.12	33.17	32.43	28.59	29.42	32.2	31.73	32.33
An	30.67	29.35	30.73	25.3	30.74	31.27	25.43	22.52	32.15	22.55	24.38	26.5	27.45	28.65	23.45	23	23.24	27.3	26.55	21.01	25.13	21.97
C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Di-Wo	7.01	1.78	0.5	4.47	7.2	2.55	3.96	1	3.2	0.56	1.13	4.81	0.75	1.53	0.2	3.05	1.82	0.37	2.53	1.57	0.59	0.66
Di-En	4.7	1.16	0.32	3.12	4.8	1.64	2.5	0.68	2.1	0.38	0.79	3.15	0.49	0.99	0.13	1.8	1.27	0.26	1.77	1.12	0.4	0.46
Di-Fs	1.77	0.5	0.15	0.98	0.86	0.74	1.21	0.23	0.87	0.15	0.25	1.32	0.21	0.43	0.06	1.09	3.39	0.07	0.54	0.31	0.14	0.13
En	9.42	7.47	8.28	8.85	7.58	8.75	5.23	5.15	9.16	4.77	5.89	5.65	5.93	6.86	4.55	1.01	5.35	6.14	7.51	5.09	4.72	4.93
Fs	3.54	3.26	3.73	2.77	2.94	3.93	2.52	1.73	3.8	1.85	1.84	2.28	2.5	3.02	1.93	0.61	1.64	1.72	2.29	1.41	1.73	1.43
Fo	0.47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fa	0.19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mt	4.43	3.69	3.8	3.65	4.14	4.04	3.61	3.25	4.14	3.03	3.28	3.85	3.57	3.36	3.44	3.51	3.66	2.64	3.69	3.22	2.85	2.88
Il	1.94	1.5	1.54	1.48	1.85	1.77	1.54	1.3	1.96	1.25	1.46	1.87	1.34	1.37	1.32	1.68	1.45	1.27	1.95	1.17	1.2	1.15
Ap	0.82	0.39	0.46	0.47	0.73	0.63	3.5	0.42	0.52	0.41	0.49	0.53	0.45	0.54	0.59	0.81	0.6	0.47	0.82	0.29	0.5	0.45

TABLE I. – *Continued.*

	Neovolcanism Stage														Cognate inclusion		
	130	132	135	137	142	12	28	51	56	70	73	6	7	11	27	153	82	13
SiO2	59.40	61.70	61.70	61.70	61.60	63.40	59.40	61.40	61.40	62.00	61.90	62.50	63.10	63.50	59.20	58.00	60.30	56.90
Al2O3	17.55	16.30	17.15	17.00	16.45	16.70	17.05	18.05	17.60	17.50	16.55	16.30	16.40	16.30	16.55	16.90	17.60	17.35
Fe2O3	5.47	4.62	4.40	4.68	4.77	4.64	5.61	5.28	5.26	5.15	4.73	4.51	4.49	4.49	5.85	5.67	5.34	6.18
CaO	6.19	5.12	5.68	5.61	5.30	5.24	6.72	5.14	5.64	5.89	5.56	5.24	5.23	5.16	7.13	6.17	6.29	7.05
MgO	2.87	2.54	2.64	2.64	2.50	2.39	3.30	0.96	2.53	2.42	2.36	2.32	2.26	2.26	3.96	3.41	3.03	3.49
Na2O	3.80	3.64	3.71	3.77	3.71	3.78	3.70	3.57	3.68	3.63	3.73	3.78	3.79	3.81	3.55	3.80	3.73	3.64
K2O	1.82	2.32	2.18	2.05	2.44	2.38	2.28	1.96	1.98	1.85	2.36	2.33	2.36	2.39	1.76	2.09	1.85	1.73
Cr2O3	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
TiO2	0.53	0.59	0.64	0.62	0.08	0.62	0.93	0.69	0.78	0.66	0.60	0.55	0.54	0.55	0.69	0.90	0.79	0.75
MnO	0.10	0.9	0.08	0.08	0.08	0.08	0.09	0.04	0.09	0.09	0.09	0.08	0.08	0.08	0.09	0.09	0.06	0.9
P2O5	0.27	0.20	0.21	0.20	0.24	0.22	0.35	0.23	0.22	0.19	0.22	0.20	0.21	0.22	0.22	0.38	0.24	0.23
SrO	0.07	0.07	0.07	0.06	0.07	0.06	0.12	0.07	0.07	0.08	0.07	0.07	0.07	0.07	0.10	0.09	0.11	0.11
BaO	0.04	0.05	0.05	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.36	0.04	0.04
LOI	0.76	1.24	1.12	0.94	1.36	0.36	0.41	2.26	0.51	0.08	1.40	0.60	0.68	0.60	0.87	0.98	0.56	0.73
Total	99.01	98.5	100	99.4	99.3	99.9	100	99.7	100	99.6	99.7	98.5	99.3	99.5	81	98.6	100	98.3
CIPW																		
Qz	13.34	17.65	16.2	16.57	16.6	18.08	11.55	2081	15.62	11.64	16.71	17.87	18.28	18.64	12.04	10.92	0	9.63
Or	10.96	14.13	13.05	12.33	14.76	14.16	13.56	11.91	11.79	11.01	14.23	14.09	14.18	14.31	10.52	12.69	7.44	10.5
Ab	32.7	31.68	31.74	32.4	32.07	32.12	31.45	31	32.85	30.87	32.13	32.66	32.53	32.6	30.32	32.97	27.6	31.58
An	25.88	21.87	23.95	23.76	21.46	21.65	23.27	24.83	24.97	26.11	21.81	21.65	21.05	20.53	24.24	23.45	30.67	26.54
C	0	0	0	0	0	0	0	1.22	0	0	0	0	0	0	0	0	0	0
Di-Wo	1.59	1.29	1.4	1.4	1.67	1.34	3.43	0	0.08	0.1	2.15	1.81	1.7	1.71	3.43	2.38	7.01	3.34
Di-En	1.07	0.9	0.98	0.99	1.18	0.95	2.46	0	0.55	0.62	1.47	1.25	1.17	1.19	2.46	1.68	4.7	2.18
Di-Fs	0.39	0.28	0.3	0.3	0.34	0.27	0.65	0	0.19	0.23	0.51	0.41	0.39	0.37	0.65	0.49	1.77	0.92
En	6.23	5.64	5.7	5.73	5.21	5.06	5.84	2.47	5.82	5.47	4.55	4.68	4.57	4.53	5.84	7.07	9.42	6.78
Fs	2.26	1.78	1.74	1.73	1.52	1.47	1.55	2.35	1.98	2	1.58	1.53	1.52	1.4	1.55	2.04	3.54	2.87
Fo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.47	0
Fa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.19	0
Mt	3.56	3.18	3.24	3.17	3.32	3.24	3.69	3.55	3.53	3.47	3.22	3.13	3.11	3.17	3.55	3.71	4.43	3.68
Il	1.41	1.15	1.23	1.2	1.32	1.18	1.78	1.35	1.42	1.26	1.16	1.07	1.04	1.06	1.35	1.76	1.94	1.46
Ap	0.6	0.45	0.46	0.44	0.54	0.48	0.77	0.52	0.48	0.42	0.49	0.45	0.47	0.49	0.52	0.85	0.82	0.52

TABLE II. – *Result of potassium and K-Ar age from Taftan volcanic rocks.*

Sample name	K content (Wt%)	Average (Wt%)		Error (%)
TSM-92	2.4300	2.433		0.28
	2.4368			
TSM-128	0.9849	0.990		1.08
	0.9956			
TSM-153	2.0786	2.083		0.46
	2.0881			
Sample name	K (Wt%)	Rad.^{40}Ar (10^{-8} cc STP/g)	K-Ar age (Ma)	Non.rad.^{40}Ar (%)
TSM-92	2.433 ± 0.049	56.83 ± 0.79	6.01 ± 0.15	28.3
TSM-128	0.9990 ± 0.020	26.7 ± 2.7	6.95 ± 0.72	85.7
TSM-153	2.083 ± 0.042	5.75 ± 0.19	0.71 ± 0.03	55.9

evaporated and dried on hot plate, and then hydrochloric acid solution of them was created. Quantitative analysis of K was carried out by Flam photometry using a 2000-ppm Cs buffer. The analysis was performed twice or more to confirm the reproducibility of each sample. An average value of multiple runs was used for a calculation of age. The analytical error of this method is within 2% on basis of the multiple runs of two chemical standards (JG-1 granodiorite and JB-basalt). Ar isotopic analyses were carried out on about 1 g samples wrapped in thin aluminum foil and put into a sample holder consisting of a Pyrex-glass tube with 11 branches. They were then heated at 180–200 °C by ribbon and mantle heater for about 72 hours to emit adsorption gas in a vacuum. After cooling them, the samples were dropped to the Mo crucible that were heated for 30 minutes at about 1500 °C by Ta heater. Mixing with calibrated argon 38 spike occurred in ultra-high vacuum line. Activated gases such as oxygen, sulfur, hydrogen and carbon were removed by the titanium-zirconium getter that were heated about 800 °C by an electric oven. Purified argon gas was analyzed on a 15 cm radius sector-type mass spectrometer with a single collector by an isotopic dilution method using an argon 38 spike [7]. Ar isotopic analyses were done at the Nigata University in Japan. The results of K and Ar analyses are shown in table II.

4. – Whole-rock geochemistry

Taftan volcano exhibits nearly complete compositional series from andesite-basalt to dacite (fig. 7) with andesites and dacites being the most common (table I). These rocks have low alkali contents and are mostly calc-alkaline in character (fig. 8). All major element variation diagrams appear to exhibit fractional crystallization trends. Al_2O_3, MgO, CaO, MnO and TiO_2 all decrease with increasing SiO_2. Na_2O and K_2O increase in concentration with increasing SiO_2 (fig. 9). The behavior of the major elements against the increasing silica content suggests that magmas of Taftan volcano were generated by olivine and clinopyroxine fractionation.

Magma mixing appears to dominate the petrogenesis of intermediate compositions (andesites and dacites) especially the products of Neovolcanism. This was confirmed by

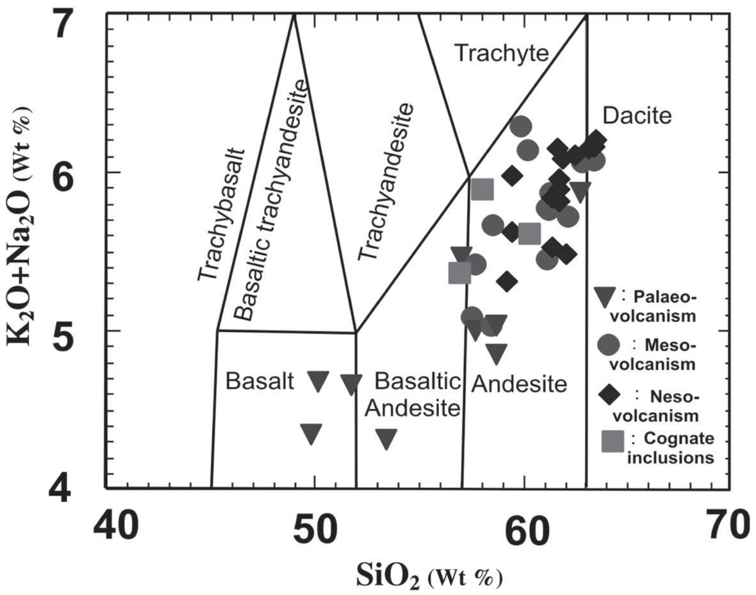

Fig. 7. – Position of the Mount Taftan volcanic rocks on total alkali *vs.* silica diagram of [15].

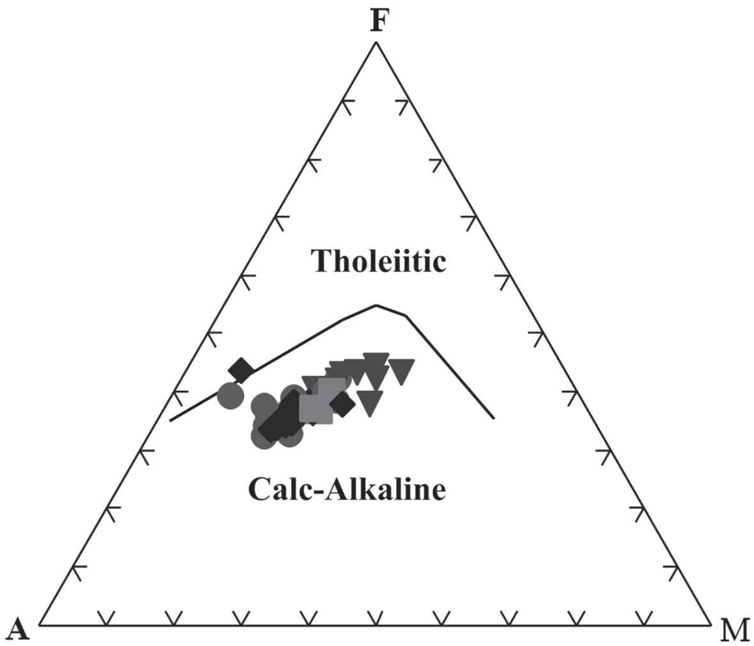

Fig. 8. – Calc-alkaline trend of Mount Taftan volcanic rocks. The symbols are same as in fig. 7.

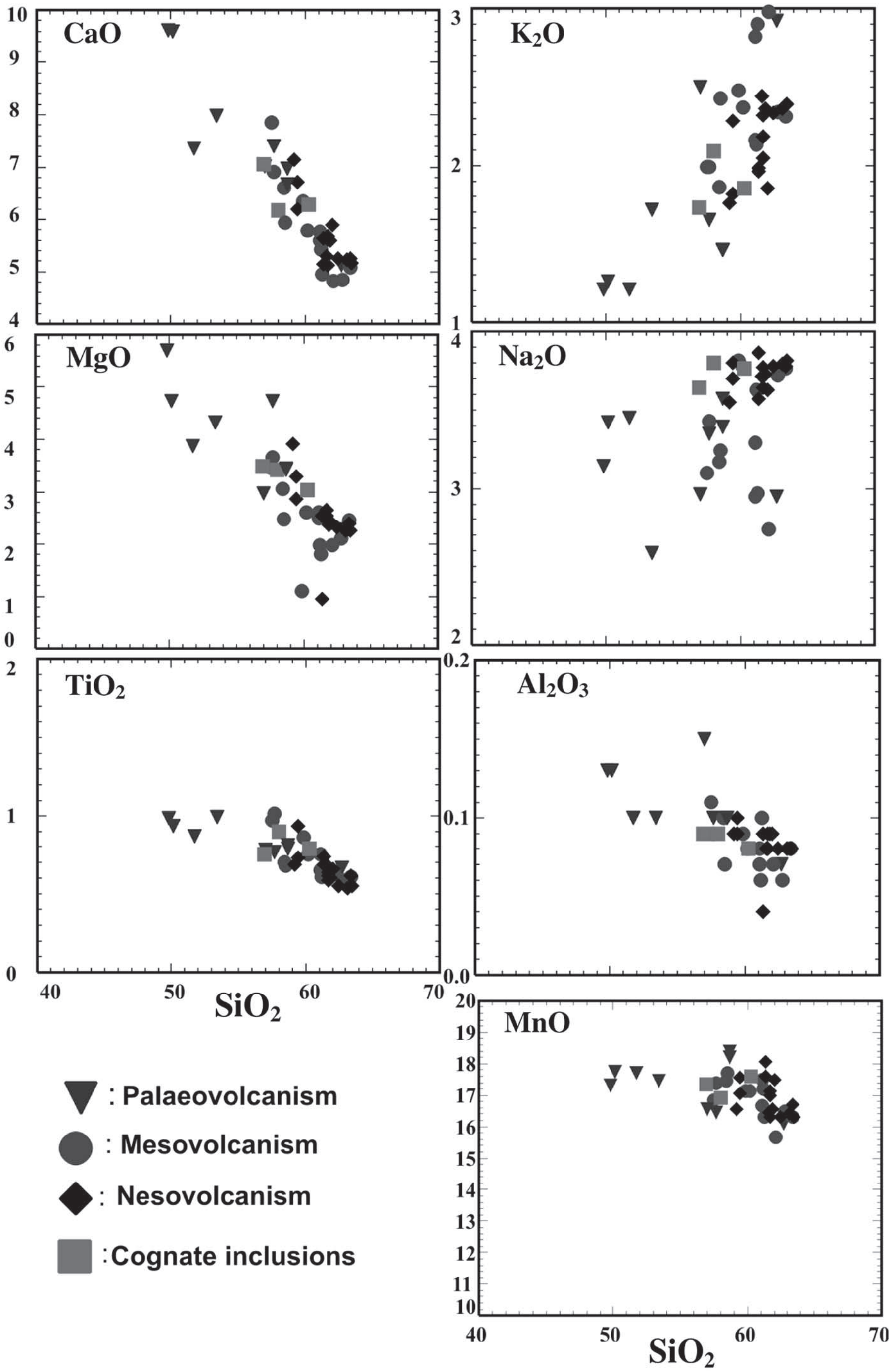

Fig. 9. – Oxide variation diagram of Mount Taftan volcano.

TABLE III. – *Mixing tests for andesites and dacites of Neovolcanism.*

Mixing test			
Mafic end-member:	90-50	Cognate inclusion from	
Felsic end-member:	90-47	Neovolcanism	
Tested hybrid:	90-49	Dacite from Neovolcanism	
		Dacite from Neovolcanism	
	Analysis	Estimated mixing	Deviation
SiO_2	63.40	63.10	−0.06
Al_2O_3	16.30	16.15	0.24
FeOt	4.57	4.58	−0.09
CaO	5.08	5.19	−0.14
MgO	2.45	2.50	−0.15
Na_2O	3.76	3.68	0.12
K_2O	2.31	2.07	0.14
TiO_2	0.61	0.61	0.00
MnO	0.08	0.10	−0.01
P_2O_5	0.13	0.15	0.01
Mixing test			
Mafic end-member:	90-7	Cognate inclusion from	
Felsic	90-30	Neovolcanism	
Tested hybrid:	90-5	Dacite from Neovolcanism	
		Andesite from Neovolcanism	
	Analysis	Estimated mixing	Deviation
SiO_2	60.30	60.16	0.13
Al_2O_3	17.60	16.35	−0.66
FeOt	5.34	5.51	−0.04
CaO	6.29	6.20	0.51
MgO	2.03	2.00	0.18
Na_2O	3.73	3.80	−0.35
K_2O	1.85	1.80	0.15
TiO_2	0.79	0.79	−0.04
MnO	0.06	0.06	−0.01
P_2O_5	0.24	0.25	0.01

% Mafic fraction: 8.37; %Felsic fraction: 89.83; Total: 98.21.
$\sum R^2 = 0.1484$; Variance = 0.0212.
% Mafic fraction: 58.14; %Felsic fraction: 40.46; Total: 98.61.
$\sum R^2 = 0.8931$; Variance = 0.1275.

the tests of mixing using least-square methods that have been performed on andesitic and dacitic lavas (table III).

5. – Discussion and conclusions

Although some publications on geochemical characteristics of the Quaternary volcanism of Iran are available in the scientific literature [8-10], Taftan volcano was poorly documented.

Detailed field research has allowed us to outline its volcano structural evolution. The volcanological history can be divided into three successive stages: Palaeo, Meso and

Neovolcanism. Chrono-stratigraphy and dating has allowed separate Palaeovolcanism from the recent volcanism, represented by Meso and Neovolcanismes.

During the Mesovolcanism stage forms, the Anjerk caldera, one of the major structures of the volcano, is formed. It produced many pyroclastic rocks, ignimbrites, pumices, lahars and lava flows. At the final stage of the Mesovolcanism, andesitic magmas were injected along the caldera boundary fault. This caused the formation of intrusive peperite-like breccias. We emphasize the phreatomagmatic character of these breccias. During the elevation phases, the extrusion of lava domes provoked the emplacement of nuee ardent deposits. The nuees ardents of mount Taftan are identified as Plinian type. Pyroclastic flows are defined as high concentration, semi-fluidized gas-particle mixtures that move in an essentially non-Newtonian, laminar manner [11]. On the other hand, pyroclastic surges are defined as turbulent, relatively low concentration currents [12]. These two current types have been discussed as the possible transport mechanism of pelean nuee ardente deposit by [13, 14]. There is consensus that gravity plays a major role controlling the mobility of nees ardents, as for other gravity mass flows (avalanches, debris flows, etc.).

The nuees ardentes deposits of Mount Taftan with their well-distinct internal stratighraphy were emplaced by a pelean style eruption. We agree with [13, 14] that flow is the major transport mechanism for nuees ardents. The style of current transport may be laminar flow or turbulent flow, depending on factors such as grain size distribution, initial velocity, topography, and channel shape.

The petrological study of Taftan volcano can be summarized as follows. The Palaeovolcanism is characterized by more basaltic andesite lava flows, while the Meso and Neovolcanism are mainly andesite to dacitic lava flows. This volcano exhibits a nearly complete compositional series from basalt to dacite. The main petrological process is mixing of contrasting magmas, which account for the andesites and dacites. Behavior all of the major element variation diagrams shows that fractional crystallization also occurred during magmatic evolution, as evidenced also by the presence of the microcumulates in the andesite lavas and dacitic members of series.

In summary, Quaternary volcanism in southeast of Iran at Taftan region has produced a wide range of magma products, especially pyroclastic and lava flows accompanying ignimbrite varying from intermediate to acidic composition.

The weak fumarolic activities at the summit and its activity in historical times make Taftan volcano a potentially hazardous volcano.

* * *

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