

Petrochemical characteristics and genetic interpretation of the basaltic volcanism of Kula (Manisa, Turkey)

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Еркан, Т., Динсел, А., Туркекан, А., Гюнай, Е. — Петрохимическая характеристика и генетическая интерпретация базальтового вулканизма г. Кула (Маниза, Турция). Плио-четвертичные щелочные базальтовые породы преобладают в строении окрестностей г. Кула в Манизской провинции Восточной Анатолии (Турция). Древнейшие породы имеют возраст в 7,5 млн. лет. Выделены последовательные стадии вулканической активности. Самая последняя стадия произошла 15—20 000 лет тому назад, и следы человеческой деятельности были обнаружены в туфах. Согласно петрохимическим исследованиям было сделано заключение, что вулканические породы в области образовались в условиях растяжения путем поднятия конически оформленного первичного магменного тела из расплавленного мантийного центра.

Abstract. Alkaline basaltic rocks of Plio-Quaternary age are dominant in the vicinity of Kula town in the Manisa province in Western Anatolia (Turkey). The oldest rocks are of 7.5 m. y. There have been intermittent stages of volcanic activity. The last stage occurred 15-20 000 years ago and human footprints are observed in tuffs. According to petrochemical work carried out it was concluded that these volcanic rocks in a domain characterized by a tensional regime were formed via uplift of a plume shaped primitive magma generated from a hot spot of the mantle.

Introduction

The Kula volcanics crop out in an area which is 30-35 km in length and 10-15 km in width of the Manisa province in Turkey. These are Plio-Quaternary aged alkali basaltic lava flows and tephra. Kula is one of the areas which the young volcanic rocks are showed in Turkey. Investigators worked in Kula even in ancient times. For example, the famous Greek historian Strabon travelled to Kula and named it as "Katakekaumane" (burnt-land) 2000 years ago. After him many scientists have visited this region.

Geological outline

The volcanic area extends from Kula to the west of the Demirköprü Dam (Fig. 1) and is mostly on a plateau which is 600-700 m high. This plateau is bordered by Gediz River to the north and the Alaşehir-Salihli graben to the south. Volcanic cones in this area are in a NW-SE line, fitting the extension of the Alaşehir-Salihli graben (Gediz graben) (Fig. 2) and related to the graben system of Western Anatolia. "Aa" type lavas were formed by a typical "fissure" volcanism. There are "hornitosses" on the lavas and scorias. The lava tunnels are observed in places. All the volcanoes are in "Maar" type.

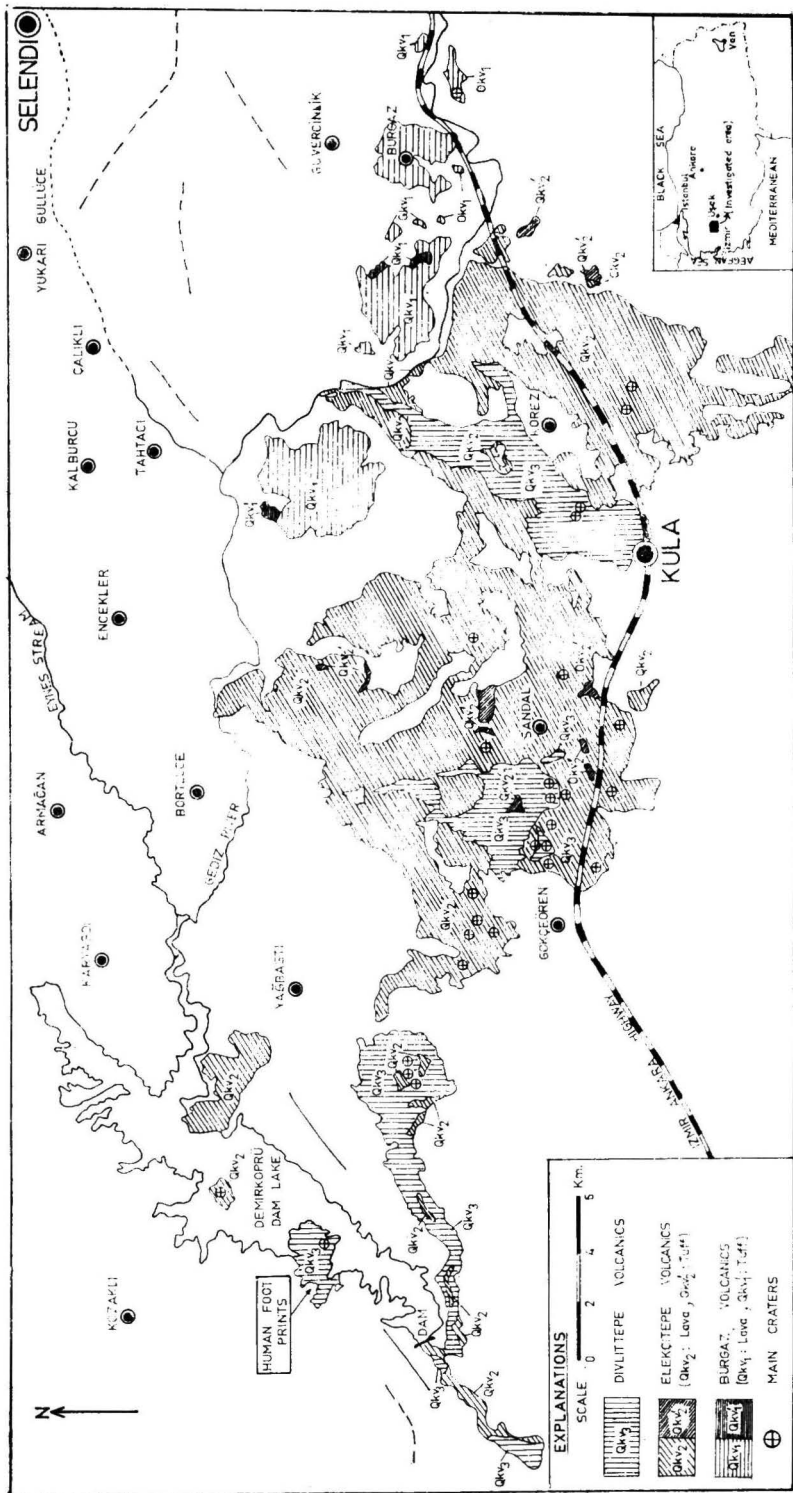


Fig. 1. Distribution of Quaternary aged Kula basalts in study area

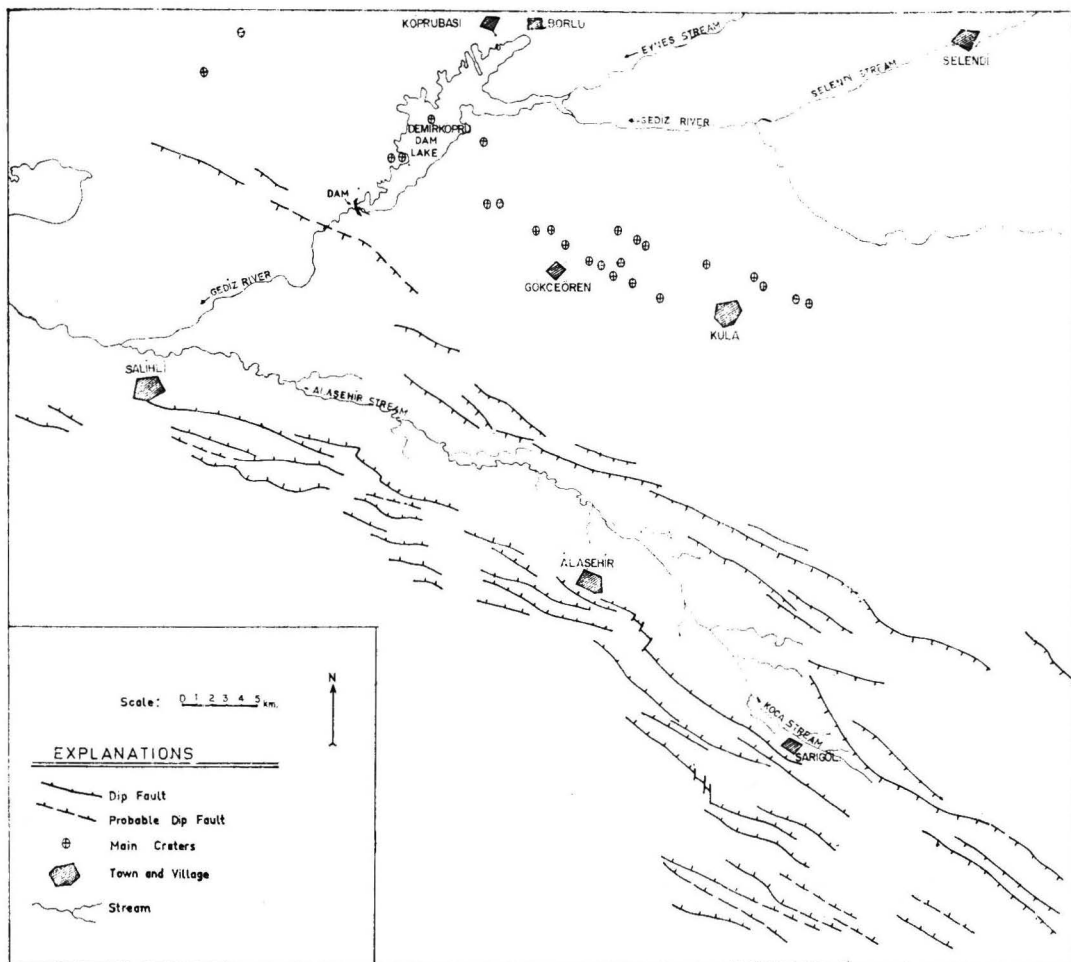


Fig. 2. Alaşehir-Salihli graben

Volcanic cones are in "sinder" or "spatter" type. They have some differences according to their ages and erosional grades. Craters of the old cones are bigger than the younger ones. The cones consist of lavas, lapillis, scorias and the pyroclastics such as volcanic bombs in various coarseness. Black basaltic lava flows are seen around these seventy cones. The youngest cones have views the same as actual ones. There are double craters at some volcanic cones. Kula volcanics have been active in three different stages in the investigated area. They are named as "Burgaz Volcanics" "Elekçitepe Volcanics" and "Divlittepe Volcanics" (Ercan, 1981). The flow directions of the lavas of Kula Volcanics are shown in Fig. 3.

Burgaz Volcanics

They are the products of the first stage and overlie the older rock units as plateau basalts on the hills. These are on higher altitude than the volcanics of the second and the third stages. The volcanic cones have been spoiled and their shapes have been rounded in time. Lavas form high plateaus which have slopes up to 30-40 m high. Pliocene sediments have been abundantly eroded between the first and the second explosion stages. Thus the lavas of the second stage have been occurred on the lower levels. The K/Ar

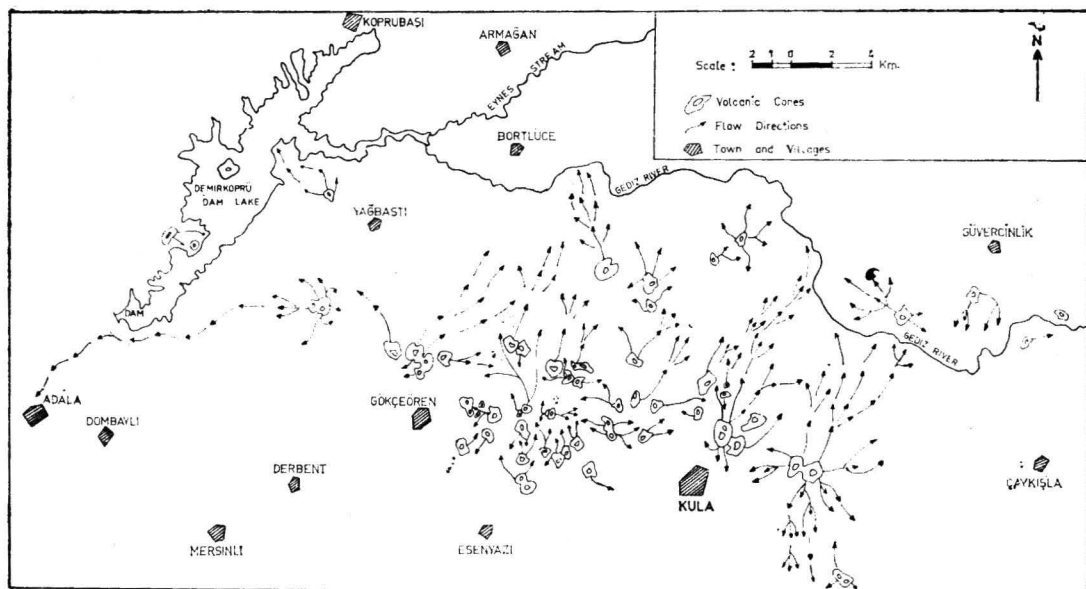


Fig. 3. Flow directions of Kula lavas

method of the radiometric dating on Burgaz Volcanics have been carried out by Erca n et al. (1985). The age has been found to be 7.55 ± 0.11 m. y. Miocene sediments which are underlain by Burgaz Volcanics have been cooked by the heat of the lavas. So 2-3 m thick a contact zone has been occurred. Hexagonal cooling faces are seen in basalts.

Elekcitepe Volcanics

The volcanic cones and craters of the second stage of Kula volcanics have been eroded less than the ones of the first stage and they have maintained their shapes more than the older ones. Some volcanic products such as base surge deposits which are absent in the first and the third stages of the volcanism are seen in this second stage. Volcanic products crop out a wide area in this region. More than 45 volcanic cones were observed. Some of them had been eroded. Frequent lava eruptions had been occurred. Some chimneys were closed and most of the cones was subsided and was broken. E r i n ç (1970) who made detailed geomorphologic investigations in the area surrounding Kula suggested that the second stage of the volcanism was more intensive than the first one and the volcanic products of this stage are 2.6 km^3 in volume. B o r s i et al. (1972) found a 1.1 million year age of Elekcitepe volcanics by K/Ar method.

Divlittepe Volcanics

Volcanic cones, craters and lava flows related to Divlittepe Volcanics which have been formed in the third and the last stage of Kula volcanics are completely seen as recent volcanism. They flowed in valleys and went on alluvial sediments in kilometers. The lavas are fresh as if they have just occurred. There is not any covering of plant on them. It is difficult to walk on the lavas and scorias. Lavas and scorias cover a 60 km^2 area. Lavas are distinguishable among the ones belonging to the other stages, and consist of very fluent basalts. They had gone long distance, and lava falls had been created (Fig. 3). The gases which had been accumulated in lava flows occasionally had formed

hornitos on surface, and the lava tunnels had been made under some lavas when they had lost their gases and had become solid. Primitive human beings used the craters as natural castles and lived in them thousands years ago. The remnants of the ancient primitive buildings and tools were found in some craters. Furthermore, primitive human footprints that are shown on the basaltic tuffs of the third stage volcanism have been maintained near the Lake of Demirköprü Dam, and the samples of the footprints are exhibited in some museums of the world. Those footprints are fourth finding in the world, according to Tekkaya (1976) they are 12.000 years old. Erinc (1970) suggested that the last stage volcanism had started 10.000 years ago. Erçan et al. (1985) have found the ages of $30,000 \pm 5,000$ m.y. and $25,000 \pm 6,00$ m. y. of the youngest basaltic lavas by K/Ar method. According to these results the volcanics of the last stage might have been formed approximately 10,000-30,000 years ago.

Petrography

It was proved that there is not any petrographic distinction between the different aged lavas of the three stages of Kula basalts after the investigation of hundreds of samples collected in the studied area.

Kula basalts are well known in petrographic literature. They were registered for the first time by Washington (1884 and 1900). This author named them as "Kulaite" and pointed out that they were hornblend basalt, nepheline basalt, plagioclase basalt and olivine basalt.

Later, Borsini et al. (1972) proposed that these rocks are "Nepheline trachyandesite" according to Coombs and Wilkinson (1969) classification. Petrographic and petrochemical nomenclatures of the lavas have some difficulties. There is not any international confirmation on classification of these volcanic rocks yet. The same lavas were differently named.

The lavas are black, dark-grey, grey, red, and porous. Generally show porphyritic or hyalopilitic texture in a groundmass chiefly consisting of glass, plagioclase microclites, abundant small crystals of augite, olivine, hornblende and smaller crystals of hypersthene, nepheline, leucite, analcime, apatite, magnetite, orthoclase and mafic minerals. The principal phenocrysts are of abundant augite, titanaugite, olivine and hornblende. The phenocrysts of ilmenite, plagioclase, nepheline, epidote, leucite occur in less abundance. Hornblende phenocrysts are of basaltic hornblende and syntagmatite (kersutite), and have been altered. Plagioclase phenocrysts are generally labradorite, anortite and less andesine, oligoclase and bitovnite. Quartz xenocrysts are observed in some thin sections. The olivine phenocrysts are partly converted into iddingsite and serpentine. The augite phenocrysts are also partly uralitized. All the lavas are named as "alkali olivine basalt" in general. According to results of petrographic investigation the lavas named as hornblende-pyroxene basalt, ilmenite-olivine basalt, hornblendeolivine basalt, ilmenite-pyroxene basalt, nepheline basalt, hornblende-augite basalt, olivine bearing hornblende-pyroxene basalt, hypersthene-pyroxene basalt, olivine pyroxene basalt.

Petrochemistry

Eleven samples of the first stage, eight samples of the second stage and sixteen samples of the third stage were selected for whole-rock chemical analysis of major elements (Tables 1 and 2). Results of the chemical analysis was programmed for computer and various parameters of the volcanics were calculated. Later, those parameters were casted on various graphs and the characters of the volcanics were investigated by chemical method. Sample points in the study area are shown in Fig. 1.

Table 1

Results of major element chemical analysis, C.I.P.W. norms and Rittman parameters of volcanics

Sample No	KU 51 Kula İncirlik	KU 52 Kula İncirlik	KU 53 Kula Boztepe	KU 54 Kula Burgaz köyü	KU 55 Kula İnkale T.	KU 56 Kula Kavtepe	KU 57 Kula Sarnic köyü	KU 58 Kula Kargılık
1	2	3	4	5	6	7	8	9
SiO ₂	47.65	47.85	46.65	48.60	47.80	50.15	49.55	48.35
Al ₂ O ₃	16.51	14.71	14.83	16.85	14.99	17.99	15.09	16.58
Fe ₂ O ₃	3.07	3.04	3.79	4.04	2.39	5.50	2.64	3.85
FeO	5.17	5.73	4.62	5.29	6.49	3.41	5.63	4.55
MgO	5.70	8.00	8.00	3.70	5.30	1.90	6.60	5.50
CaO	9.30	10.07	10.20	8.68	10.11	8.00	10.54	10.27
Na ₂ O	4.80	4.20	4.20	5.22	3.55	5.45	4.20	4.00
K ₂ O	1.60	1.15	1.20	1.65	2.30	1.40	1.10	0.85
H ₂ O	1.63	1.84	2.16	1.96	2.02	3.31	1.29	1.81
TiO ₂	2.04	2.04	2.06	2.26	2.02	2.02	2.10	2.09
P ₂ O ₅	0.78	0.73	0.64	0.87	0.69	0.92	0.83	0.85
MnO	0.16	0.15	0.15	0.16	0.15	0.15	0.14	0.15
CO ₂	0.58	0.42	0.50	0.35	0.42	0.35	0.38	0.58
TOPLAM (Total)	98.99	99.93	99.00	99.63	98.23	100.55	100.09	99.43
Q	—	—	—	—	—	—	—	—
Or	9.55	6.80	7.16	9.78	13.83	8.22	6.49	5.05
Ab	28.55	27.32	25.30	33.81	23.78	44.28	32.02	34.04
An	18.97	17.90	18.25	17.74	18.50	20.37	19.05	24.91
Hy {Fs	—	—	—	—	—	—	—	0.48
En	—	—	—	—	—	—	—	3.27
Mt	4.49	4.41	5.55	5.88	3.53	5.59	3.82	5.61
Hm	—	—	—	—	—	1.61	—	—
Cc	1.33	0.95	1.15	0.80	0.97	0.79	0.86	1.32
Ap	1.86	1.73	1.53	2.07	1.66	2.16	1.96	2.02
Ne	6.76	4.46	5.74	5.70	3.68	0.86	1.89	—
OI {Fo	6.11	8.72	8.17	2.91	4.84	0.53	6.29	3.48
Fa	1.84	2.37	1.00	1.02	2.78	—	2.08	0.56
Wo	7.84	10.29	10.62	7.33	10.55	4.56	10.59	7.12
Di {En	5.61	7.49	8.46	5.09	6.52	3.94	7.45	5.54
Fs	1.53	1.85	0.94	1.63	3.40	—	2.24	0.81
Il	3.91	3.87	3.95	4.31	3.90	3.81	3.98	3.99
Al	15.01	13.24	13.48	15.21	13.73	16.10	13.57	15.01
Alk	8.89	7.45	7.57	9.52	7.75	9.52	7.40	6.88
FM	20.53	24.94	25.29	17.49	20.66	13.14	22.15	20.13
k	0.18	0.15	0.16	0.17	0.30	0.14	0.15	0.12
an	0.25	0.28	0.28	0.23	0.28	0.25	0.29	0.37
P	45	46	46	45	48	47	49	52

Ku 59 Kula Çakırca	KU 61 Kula Kıran sr.	KU 62 Kula İbrahim Aga Köyü	KU 29 Kula Gediz Vadisi	KU 33 Kula Kırpini T.	KU 36 Kula Palan-kaya Mah	KU 37 Kula Palan-kaya mah	KU 43 Kula Divlit T.	KU 50 Kula Kepez	KU 96 Kula Sandal Köyü	KU 97 Kula Erikli T.
10	11	12	13	14	15	16	17	18	19	20
47.40	49.00	50.75	45.88	46.40	46.25	45.65	46.55	46.15	43.20	44.05
14.75	17.73	16.19	16.53	17.26	16.66	18.40	17.91	15.72	18.25	18.52
2.42	3.49	2.78	2.87	6.47	4.46	5.18	4.08	3.40	5.17	6.39
5.94	4.60	5.21	5.47	3.70	6.47	5.73	4.99	5.56	4.93	2.96
6.90	4.20	5.50	6.90	7.30	5.20	4.40	7.20	6.20	6.83	7.06
11.15	7.56	7.29	9.73	9.33	9.28	8.95	8.17	9.18	10.11	9.51
3.20	6.00	5.35	5.97	3.95	4.00	5.25	4.20	4.85	4.18	5.10
1.65	1.35	3.30	1.68	2.30	2.10	1.35	2.63	1.20	2.63	2.70
2.61	2.26	—	1.47	0.26	0.30	0.85	0.47	2.49	0.46	0.45
2.03	1.87	1.72	2.17	2.02	2.11	2.17	1.98	1.94	2.34	2.11
0.73	0.84	0.81	1.13	1.04	1.34	1.64	0.99	1.15	0.68	0.76
0.16	0.18	0.17	0.16	0.16	0.19	0.18	0.16	0.18	0.99	0.41
0.42	0.42	0.50	—	0.61	0.44	0.67	0.39	0.27	—	—
99.36	99.50	99.57	99.96	100.80	98.80	100.42	99.72	98.59	99.77	100.02
—	—	—	—	—	—	—	—	—	—	—
9.81	8.02	19.58	9.93	13.48	12.56	7.94	15.58	7.19	15.57	15.95
23.33	37.35	27.32	15.38	22.76	26.40	31.19	21.21	29.07	4.35	6.04
21.14	17.54	10.46	13.35	22.39	21.56	22.56	22.31	17.83	23.32	19.66
—	—	—	—	—	—	—	—	—	—	—
3.53	5.08	4.05	4.16	6.54	6.54	7.48	5.93	5.00	7.51	4.76
—	—	—	—	1.90	—	—	—	—	—	3.10
0.96	0.96	1.14	—	1.37	1.01	1.51	0.89	0.62	—	—
1.74	2.00	1.92	2.67	2.44	3.21	3.87	2.35	2.76	1.61	1.80
2.12	7.40	9.83	19.04	5.62	4.26	7.06	7.81	6.80	16.84	20.10
6.68	4.85	6.16	6.21	9.36	6.58	6.23	10.48	7.04	6.88	6.62
2.51	1.43	2.35	1.74	—	2.83	1.87	1.81	2.28	1.23	—
11.29	4.99	7.25	11.50	5.41	5.58	2.82	3.91	7.94	9.39	9.41
7.75	3.58	4.96	8.32	4.67	3.71	2.02	3.02	5.61	7.22	8.13
2.64	0.96	1.72	2.12	—	1.45	0.55	0.47	1.64	1.17	—
3.88	3.57	3.28	4.12	3.80	4.05	4.10	3.77	3.73	4.45	4.00
—	—	—	—	—	—	—	—	—	—	—
13.36	16.03	14.63	14.88	15.40	15.17	16.49	16.16	14.34	16.46	16.66
6.49	10.40	11.36	10.63	8.16	8.20	9.18	8.95	8.60	8.92	10.35
23.07	17.23	19.77	22.86	25.11	22.44	20.40	24.20	22.43	25.40	24.21
0.25	0.13	0.29	0.16	0.28	0.26	0.14	0.29	0.14	0.29	0.26
0.34	0.21	0.12	0.16	0.30	0.30	0.28	0.28	0.25	0.29	0.23
49	45	42	39	46	47	44	46	45	43	41

Table 1 (continued)

Rittmann's name	Andesine Basalt	Andesine Basalt	Andesine Basalt	Nepheline Tephrite	Olivine Andesine Trachybasalt	Andesine Basalt	Andesine Basalt	Andesine Basalt
Irvine & Baragar's name	Hawaiite (Sodic)	Hawaiite (Sodic)	Hawaiite (Sodic)	Hawaiite (Sodic)	Alkaline Basalt (Potassic)	Hawaiite (Sodic)	Hawaiite (Sodic)	Hawaiite (Sodic)
1	2	3	4	5	6	7	8	9
N. P. C.	32.27	33.99	34.36	29.05	38.21	30.83	35.14	42.26
N. C. I.	24.22	29.68	29.31	21.45	25.61	16.12	26.78	24.52
D. I.	44.86	38.59	38.21	49.30	41.30	53.37	40.40	39.09
S. I.	28.02	36.17	36.68	18.59	26.46	10.76	32.72	29.33
σ	8.14	5.87	7.22	8.23	6.26	6.75	4.31	4.23
r	5.74	5.15	5.16	5.14	5.65	6.20	5.18	6.02
Log σ	0.91	0.77	0.86	0.91	0.79	0.83	0.63	0.62
Log r	0.76	0.71	0.71	0.71	0.75	0.79	0.71	0.78
(FeO+Fe ₂ O ₃)/SiO ₂	0.17	0.18	0.18	0.19	0.18	0.17	0.16	0.17
Al ₂ O ₃ /SiO ₂	0.34	0.30	0.31	0.34	0.31	0.36	0.30	0.34
(Na ₂ O+K ₂ O)/(Na ₂ O+K ₂ O+CaO)	0.40	0.34	0.34	0.44	0.36	0.46	0.33	0.32
An.100/(Ab+An)	39.92	39.58	41.90	34.41	43.75	31.50	37.30	42.25
K ₂ O/Na ₂ O	0.33	0.27	0.28	0.31	0.64	0.25	0.26	0.21
Rock groups							Kula (Burgaz) Qkv ₁	
Symbols								+

Table 2

Results of major element chemical analysis, C.I.P.W. norms and Rittman parameters of volcanics

Sample No	KU 30 Kula Divlit T.	KU 31 Kula Karadivili T.	KU 32 Kula Karakuz dere	KU 34 Kula Köfekelli T.	KU 35 Kula Divlit T.	KU 38 Kula Küçük Divlit T.
1	2	3	4	5	6	7
SiO ₂	47.07	47.32	48.15	48.50	47.55	46.50
Al ₂ O ₃	17.80	17.78	17.87	18.14	18.50	17.23
Fe ₂ O ₃	2.98	2.41	3.56	3.81	4.32	3.92
FeO	4.85	5.08	5.36	4.99	5.07	5.57
MgO	5.57	5.79	6.60	5.90	5.80	6.30
CaO	8.62	8.63	8.29	8.04	8.21	8.71
Na ₂ O	6.05	5.73	4.19	4.35	4.08	4.08
K ₂ O	3.28	3.31	2.55	2.68	2.68	2.68
H ₂ O	0.58	0.65	0.46	0.07	0.51	0.34
TiO ₂	2.11	1.99	1.75	1.80	2.00	1.89
P ₂ O ₅	0.97	0.83	0.90	0.72	1.02	0.88
MnO	0.16	0.13	0.16	0.15	0.17	0.25
CO ₂	—	—	0.28	0.44	0.44	0.44
TOPLAM (Total)	100.04	99.67	100.12	99.59	100.35	98.79

Olivine Andesine Trachybasalt	Nepheline Tephrite	Phonolitic Nepheline Tephrite	Phonolitic Nepheline Tephrite	Olivine Andesine Trachybasalt	Olivine Andesine Trachybasalt	Hepheline Tephrite	Nepheline Basanit	Andesine Basalt	Nepheline Basanite	Nepheline Basanite
Alkalite Basalt (Potassic)	Mugearite (Sodic)	Trachybasalt (Potassic)	Hawaiite (Sodic)	Alkaline Basalt (Potassic)	Trachybasalt (Potassic)	Hawaiite (Sodic)	Trachybasalt (Potassic)	Hawaiite (Sodic)	Alkaline Basalt (Potassic)	Trachybasalt (Potassic)
10	11	12	13	14	15	16	17	18	19	20
44.04	26.09	19.31	22.08	41.06	39.16	34.42	39.45	30.62	41.83	33.21
27.90	19.94	23.10	27.75	27.03	25.60	22.52	25.92	26.00	29.48	27.90
35.27	52.78	56.73	44.36	41.88	43.22	46.21	44.61	43.07	36.78	42.09
34.31	21.38	24.84	30.14	30.78	23.39	20.08	31.17	29.23	28.77	29.16
5.06	8.74	9.47	20.21	12.68	10.00	17.57	12.75	9.15	155.52	58.41
5.70	6.27	6.29	4.87	6.60	5.98	6.06	6.90	5.59	6.00	6.36
0.70	0.94	0.97	1.30	1.10	1.00	1.24	1.10	0.96	2.19	1.76
0.75	0.79	0.80	0.68	0.82	0.77	0.78	0.84	0.74	0.78	0.80
0.17	0.16	0.15	0.18	0.22	0.23	0.24	0.19	0.19	0.23	0.21
0.31	0.36	0.32	0.36	0.37	0.36	0.40	0.38	0.34	0.42	0.42
0.30	0.49	0.54	0.44	0.40	0.39	0.42	0.45	0.42	0.40	0.45
47.53	31.95	27.68	46.46	49.59	44.95	41.97	51.26	38.01	84.27	76.49
0.51	0.22	0.61	0.28	0.58	0.52	0.25	0.62	0.24	0.63	0.53

volcanics
Qkv₁

Kula (elekcitepe) volcanics
Qkv₂

+

▼

KU 40 Ku'a Divlit T.	KU 41 Kula Divlit T.	KU 48 Kula Divlit T.	KU 49 Kula Ilçe	KU 60 Kula Karatas	KU 63 Kula Koncak T.	KU 95 Kula Baghada T.	KU 98 Kula Adala köyü	KU 99 Kula Saraclar köyü	KU 100 Kula Gökceören köyü
8	9	10	11	12	13	14	15	16	17
47.80	46.80	47.25	47.90	50.40	49.30	46.27	45.56	45.24	42.77
17.59	17.36	17.08	18.32	18.05	18.25	19.51	20.50	20.42	18.75
5.01	8.70	4.24	2.21	2.55	1.96	2.76	2.39	2.39	3.63
3.97	1.60	4.69	5.71	4.86	6.34	5.61	5.70	5.70	6.13
5.50	5.30	5.70	5.80	4.00	4.00	4.89	5.19	6.03	5.96
8.66	7.94	8.25	8.15	7.59	7.85	8.21	7.84	8.27	11.14
4.20	4.35	5.00	5.22	5.75	5.30	5.41	5.25	4.85	3.35
2.78	2.78	3.35	3.45	3.60	3.30	3.50	4.10	3.95	2.38
0.20	0.79	0.25	—	0.02	0.08	0.10	—	—	1.86
1.90	1.86	1.85	1.89	1.76	1.85	1.80	2.10	2.00	2.63
0.96	0.94	0.98	0.88	0.84	0.99	0.51	0.65	0.63	0.90
0.16	0.18	0.18	0.16	0.15	0.16	0.99	0.61	0.56	0.43
0.28	0.39	0.50	0.27	0.38	0.42	—	—	—	—
99.01	98.99	99.32	99.96	99.95	99.80	99.56	99.89	100.04	99.93

Table 2 (continued)

	1	2	3	4	5	6	7
Q		—	—	—	—	—	—
Or		19.37	19.62	15.05	15.90	15.78	16.03
Ab		10.53	10.34	24.19	25.80	25.40	20.26
An		11.72	13.06	22.39	22.14	24.16	21.04
Hy {Fs		—	—	—	—	—	—
En		—	—	—	—	—	—
Mt		4.32	3.50	5.15	5.54	6.24	5.75
Hm		—	—	—	—	—	—
Cc		—	—	0.63	1.00	0.09	1.01
Ap		2.29	1.97	2.13	1.71	2.41	2.11
Ne		22.01	20.75	6.07	6.04	4.88	7.95
OL {Fo		4.42	5.10	9.17	8.10	8.54	8.19
Fa		1.14	1.69	2.65	2.02	1.79	2.49
Di {Wo		10.31	10.21	4.61	4.33	2.92	5.87
En		7.56	7.10	3.32	3.20	2.21	4.19
Fs		1.77	2.15	0.87	0.72	0.42	1.16
IL		4.00	3.79	3.32	3.43	3.78	3.63
Al		16.02	16.05	16.06	16.39	16.60	15.70
Alk		12.35	11.94	8.82	9.24	8.77	8.90
FM		19.63	19.81	22.80	21.34	21.60	23.21
k		0.26	0.27	0.29	0.29	0.30	0.30
an		0.12	0.14	0.29	0.28	0.30	0.27
P		38	40	48	48	47	46

Rittmann's name	Phonolitic Nepheline Tephrite	Phonolitic Nepheline Tephrite	Olivine Andesine Trachybasalt	Olivine Andesine Trachybasalt	Olivine Andesine Trachybasalt	Nepheline Tephrite
Irvine & Baragar's Name	Trachybasalt (Potassic)	Trachybasalt (Potassic)	Trachybasalt (Potassic)	Trachybasalt (Potassic)	Trachybasalt (Potassic)	Trachybasalt (Potassic)
N. P. C	19.88	22.52	39.48	38.17	41.89	38.56
N. C. I	24.20	24.30	24.91	23.43	23.29	25.94
D. I	51.92	50.72	45.32	47.75	46.06	44.25
S. I	24.51	25.94	29.65	27.15	26.42	27.94
σ	21.47	18.38	8.90	8.74	10.35	11.51
r	5.56	7.26	7.81	7.64	7.22	6.96
Log σ	1.33	1.26	0.95	0.94	1.01	1.06
Log r	0.74	0.86	0.89	0.88	0.86	0.84
(FeO+Fe ₂ O ₃)/SiO ₂	0.16	0.16	0.18	0.18	0.19	0.20
Al ₂ O ₃ /SiO ₂	0.38	0.37	0.37	0.37	0.39	0.37
(Na ₂ O+K ₂ O)/(Na ₂ O+K ₂ O+CcO)	0.52	0.51	0.45	0.46	0.45	0.43
An.100/(Ab+An)	52.67	55.81	48.56	46.18	48.74	50.94
K ₂ O/Na ₂ O	0.54	0.57	0.61	0.61	0.65	0.65

Rock groups

Kula (Divlit tepe) Volcanics

Qkv₃

Symbol



8	9	10	11	12	13	14	15	16	17
—	—	—	—	—	—	—	—	—	—
16.59	16.59	19.93	20.39	21.28	19.54	20.77	24.25	23.33	14.07
24.85	25.76	18.11	14.13	22.95	22.61	6.68	2.20	0.96	5.48
21.14	19.83	14.36	16.37	12.81	16.29	18.69	20.28	22.27	29.11
—	—	—	—	—	—	—	—	—	—
7.33	0.35	6.19	3.20	3.70	2.85	4.02	3.47	3.46	5.26
—	8.54	—	—	—	—	—	—	—	—
0.64	0.89	1.14	0.61	0.86	0.95	—	—	—	—
2.29	2.25	2.33	2.08	1.99	2.30	1.21	1.54	1.49	2.13
5.98	6.19	13.26	16.28	13.93	12.09	21.29	22.90	21.70	12.39
6.18	6.49	6.15	6.91	3.73	4.78	5.23	6.39	7.70	6.27
0.15	—	1.14	3.08	1.73	3.84	3.26	3.36	3.52	2.19
5.90	4.70	7.19	6.94	7.08	5.67	7.88	6.01	6.10	8.47
5.01	4.06	5.50	4.58	4.63	3.15	4.76	3.81	4.01	5.90
0.11	—	0.92	1.85	1.95	2.30	2.69	1.81	1.66	1.87
3.64	3.57	3.54	3.59	3.34	3.52	3.43	3.99	3.79	4.99
16.00	15.78	15.48	16.50	16.25	16.46	17.64	18.46	18.36	16.88
9.17	9.39	10.91	11.28	12.22	11.27	11.66	11.99	11.22	7.40
20.74	21.47	21.14	20.26	16.06	17.12	19.87	19.74	21.33	22.76
0.30	0.30	0.31	0.30	0.29	0.29	0.30	0.34	0.35	0.32
0.27	0.25	0.17	0.18	0.14	0.18	0.20	0.21	0.24	0.39
47	45	41	42	42	43	42	41	42	46

Olivine Andesine Trachybasalt	Nepheline Tephrite	Phonolitic Nepheline Tephrite	Phonolitic Nepheline Tephrite	Phonolitic Nepheline Tephrite	Phonolitic Nepheline Tephrite	Phonolitic Nepheline Tephrite	Phonolitic Nepheline Tephrite	Phonolitic Nepheline Tephrite	Nepheline Basanit
Trachybasalt (Potassic)	Trachybasalt (Potassic)	Trachybasalt (Potassic)	Trachybasalt (Potassic)	Trachybasalt (Potassic)	Trachybasalt (Potassic)	Trachybasalt (Potassic)	Trachybasalt (Potassic)	Trachybasalt (Potassic)	Alkaline Basalt (Potassic)
37.78	35.47	26.32	28.41	21.72	27.59	30.72	33.44	37.49	52.69
23.22	23.67	24.21	23.73	19.59	20.67	23.83	23.23	24.60	27.21
47.43	48.54	51.31	50.81	58.17	54.25	48.74	49.36	46.00	31.95
25.63	23.32	24.80	25.90	19.27	19.14	22.06	22.93	26.31	27.79
9.42	12.13	15.45	15.29	11.79	11.60	23.05	33.57	34.83	—164.33
7.04	6.99	6.54	6.93	6.99	7.01	7.82	7.26	7.78	5.85
0.97	1.08	1.19	1.18	1.07	1.06	1.36	1.52	1.54	—
0.84	0.84	0.81	0.84	0.84	0.84	0.89	0.86	0.89	0.76
0.18	0.22	0.19	0.16	0.14	0.17	0.18	0.17	0.18	0.23
0.36	0.37	0.36	0.38	0.36	0.37	0.42	0.44	0.45	0.43
0.44	0.47	0.50	0.51	0.55	0.52	0.52	0.54	0.51	0.34
45.96	43.49	44.22	53.67	35.82	41.87	73.66	90.21	95.86	84.15
0.66	0.64	0.67	0.66	0.62	0.62	0.64	0.72	0.81	0.71

Kula (Divli ttepe) Volcanics
Qkv₃

C. I. P. W. norms of the lavas show us the lacking of silica. Olivine (mostly as forsterite) and nepheline are seen on the C. I. P. W. norms calculations. They also point out the lacking of silica. There is not hypersthene externally, and diopside is presented generally in wallstonite. Magnetite is presented in all samples and hematite is presented in few ones on the norm calculations. Besides the results of the petrographic investigation both the results of the chemical analysis and the C. I. P. W. norms which were externally calculated demonstrate that Kula lavas are alkali.

The Rittmann parameters of the lavas which are needed in Rittmann nomenclature (1952 and 1962) were used on Rittmann diagrams and the samples were classified. Kula lavas are classified as phonolitic nepheline tephrite, nepheline tephrite, nepheline basanite, andesine basalt, olivine-andesine trachybasalt according to Rittmann.

The results of the chemical analysis of the lavas and various parameters which were calculated by computer were casted on various graphs and those results were obtained as follows:

- 1 — Volcanics are alkali according to SiO_2/Alk ($\text{Na}_2\text{O} + \text{K}_2\text{O}$) diagram (Fig. 4).
- 2 — Basalts are alkali. This result was deduced from Rittmann (1953) diagram. If P value of the basalts is less than 55 the lavas are alkali. P values of the Kula lavas are between 39 and 52, all of them fall into the alkali area of the diagram (Fig. 5).
- 3 — $\sigma: (\text{Na}_2\text{O} + \text{K}_2\text{O})^2/(\text{SiO}_2 - 43)$ Rittmann index was calculated and the Rittmann (1960) diagram was plotted (Fig. 6). If the Rittmann index is less than 4 the lavas are calc-alkaline. The Rittmann indices of Kula lavas changes between 4,21 and 155,52. Their mean value is around 10 and it is deduced that the Kula basalts are strongly alkaline. σ values of the first stage lavas are the lowest and the alkaline ratios of the lavas become higher to the third stage. Furthermore, the lavas vary to more potassic from the oldest stage to the youngest one.
- 4 — Alkaline character of the volcanics were confirmed by Ol'-Né-Q' triangle diagram (Fig. 7). All the lavas fall into the alkaline area of the diagram offered by Irvine and Baragar (1971).
- 5 — Keller et al. (1978) classified the volcanics of the Mediterranean region according to their $(\text{K}_2\text{O} + \text{Na}_2\text{O})/(\text{K}_2\text{O} + \text{Na}_2\text{O} + \text{CaO})$ contents. Kula volcanics fell into the basalt and trachybasalt areas of that offered diagram.
- 6 — It was pointed out that Kula lavas are alkali basalts according to Kuno (1960) diagram which was arranged considering their Al_2O_3 ; $(\text{Na}_2\text{O} + \text{K}_2\text{O})$ and SiO_2 contents (Fig. 8).
- 7 — Saggerson (1970) diagram of the volcanics which was offered regarding their alkali-iron contents $(\text{Na}_2\text{O} + \text{K}_2\text{O})$ and $(\text{FeO} + \text{Fe}_2\text{O}_3)/(\text{FeO} + \text{Fe}_2\text{O}_3 + \text{MgO})$ shows us that Kula volcanics fit the Hawaii alkaline trend and they are strongly alkaline (Fig. 9).
- 8 — r values which were developed by Gottini (1968 and 1969) were calculated in order to investigate the origin of the magma which was formed Kula lavas. 4.87-7.81 values have been obtained from $r = (\text{Al}_2\text{O}_3 - \text{Na}_2\text{O})/\text{TiO}_2$ formula. r values versus SiO_2 diagram were plotted and it was found out that the r values are nearly constant when SiO_2 increases. However the low r values of the first stage slightly increase on the third stage. $r > 10$ for the volcanics of the sialic origin and $r < 9$ for the volcanics of the simatic origin. Therefore, Kula volcanics have simatic origin.

Gottini also established a concern between the Gottini index (r) and the Rittmann index (σ). He calculated the logarithmic values of those indices and offered a sialic origin-simatic origin diagram. Logarithmic values of the both indices of the Kula volcanics were calculated and the lavas fell into the simatic origin area of the log. r-log. σ diagram (Fig. 10).

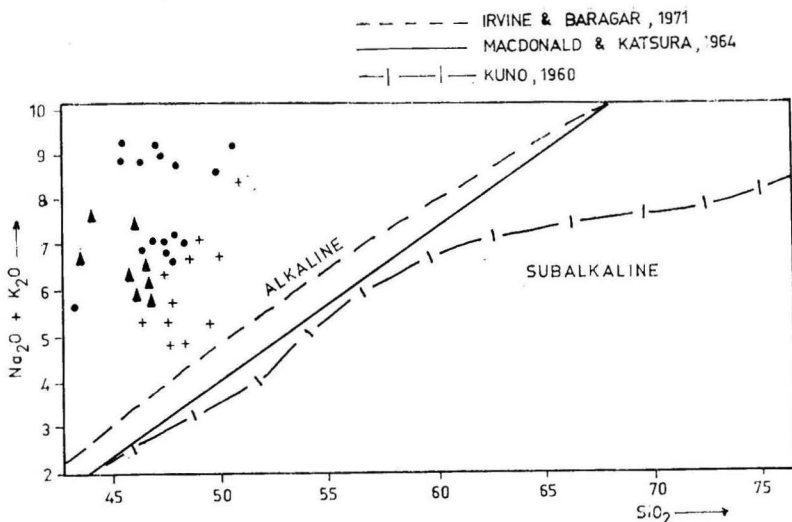


Fig. 4. Classification of the volcanics according to alkali-silica content

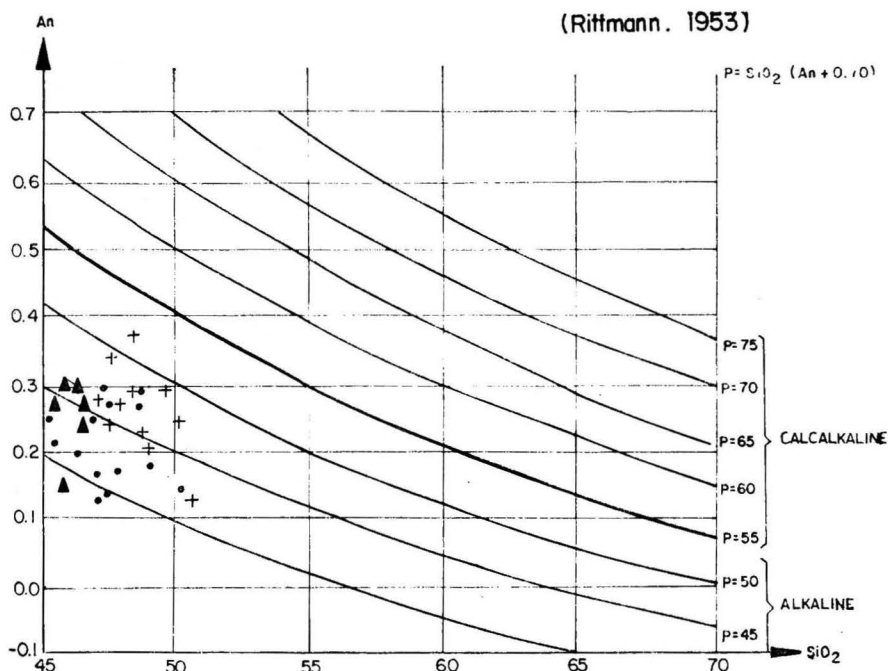


Fig. 5. Rittmann diagram of Kula volcanics

9 — Differentiation indices of the Kula lavas were also calculated. The formula of that index is $D.I. = q + or + ab + lc + ne + ks$ according to Thornton and Tuttle (1960). The D.I. indices of Kula volcanics vary from 31.95 to

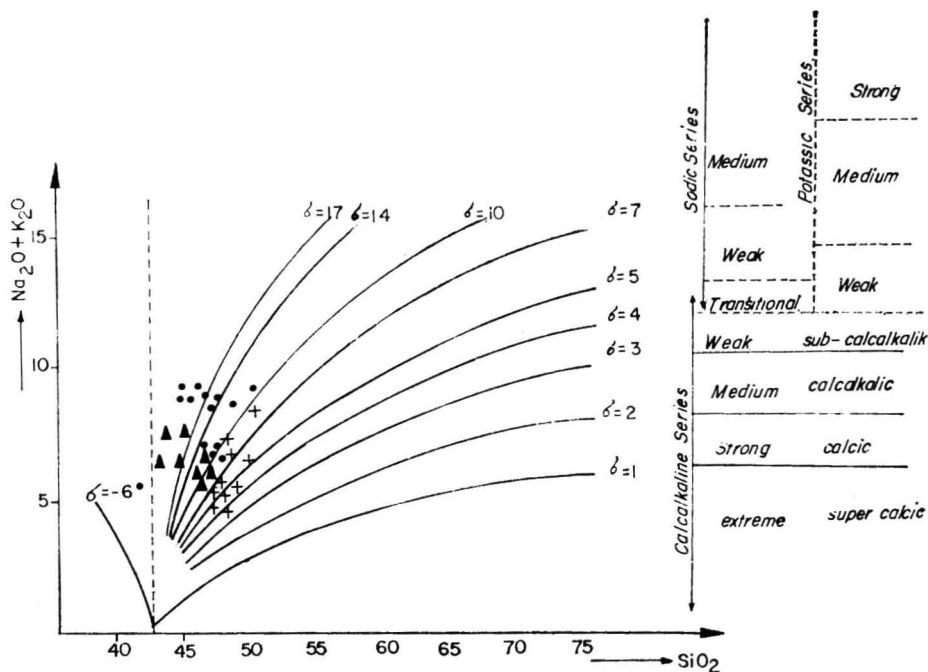


Fig. 6. Rittmann (1960) diagram of Kula volcanics

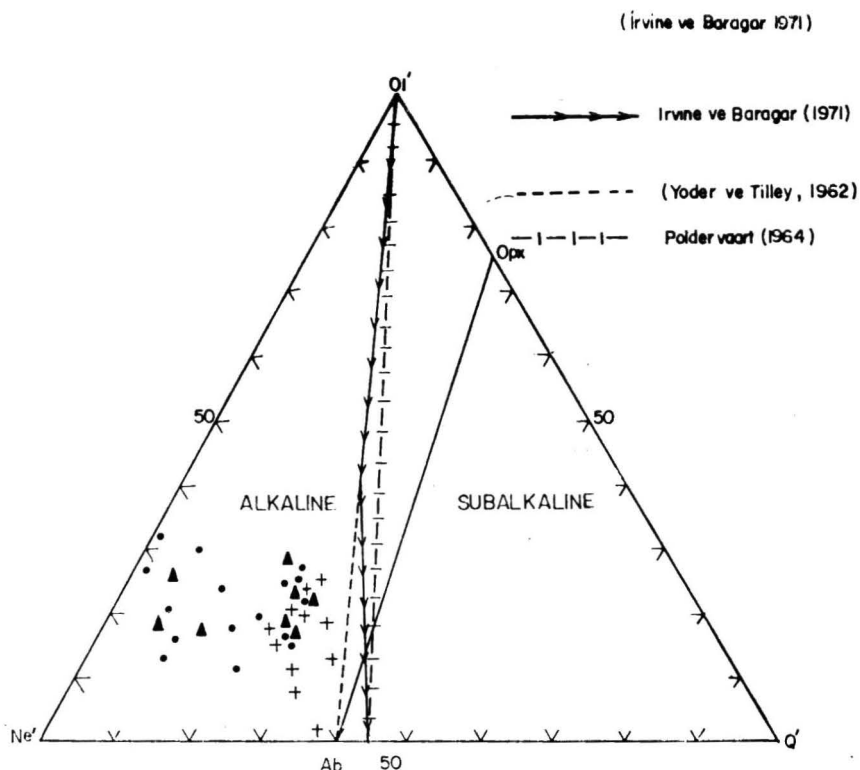


Fig. 7. Classification of Kula volcanics according to Ol'-Ne'-Q' triangle diagram

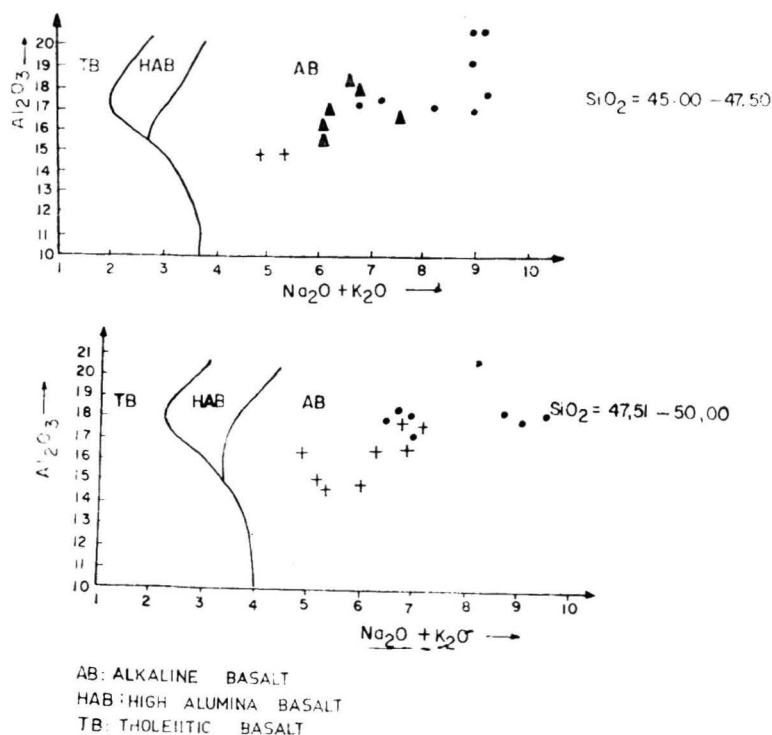


Fig. 8. Kuno diagram of Kula basalts

58.17. They are lower in the first stage lavas and higher in the third stage. The mean index value is 46. The mean differentiation indices of the basalt family lavas in the world according to statistical researches are as follows (Le Maitre, 1976):

Rock Name	Mean D. I. value
Mugearite	54.5
Trachybasalt	46.5
Hawaiite	42.5
Basalt	31.5
Basanite	33.5
Nepheline-Leucite Basalt	28.5
Tephrite	47.5

Therefore it is realized that Kula Basalts are tephrite, trachybasalt and hawaiite in nature.

Additionally the diagram of variation of major elements versus D.I. values were plotted (Fig. 11). It shows us the increase of D.I. values is dependent on the increase of SiO_2 , K_2O , Na_2O , Al_2O_3 contents and the decrease of CaO , MgO , TiO_2 and total Fe oxide contents. These peculiarities conform the variations which Thornton and Tuttle (1960) offered. Thus, it was proved that basaltic magma has a normal crystallization stage.

(Saggerson, 1970)

SA = STRONGLY ALKALINE SERIES
 MA = MILDLY ALKALINE SERIES
 HE = HEBRIDEAN ALKALINE SERIES
 H = HAWAIIAN ALKALINE SERIES
 K = KILAUEA ALKALINE SERIES

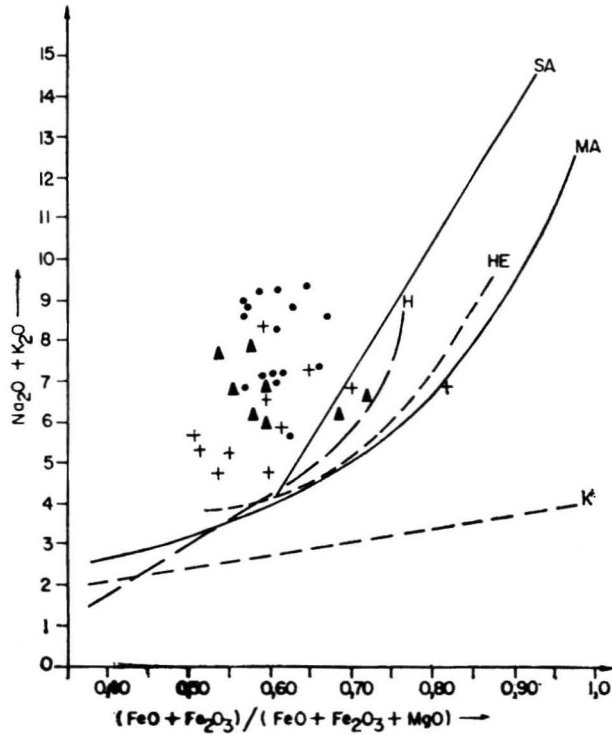


Fig. 9, Saggerson diagram of the volcanics

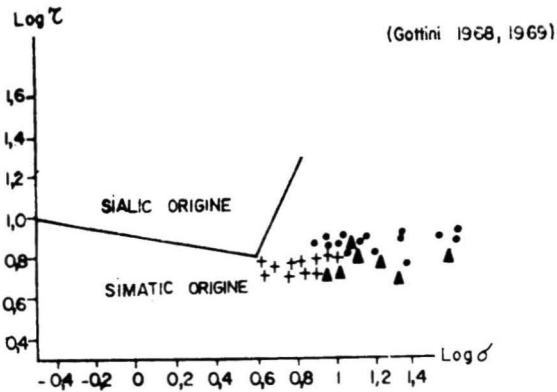


Fig. 10. Gottini diagram of Kula basalts

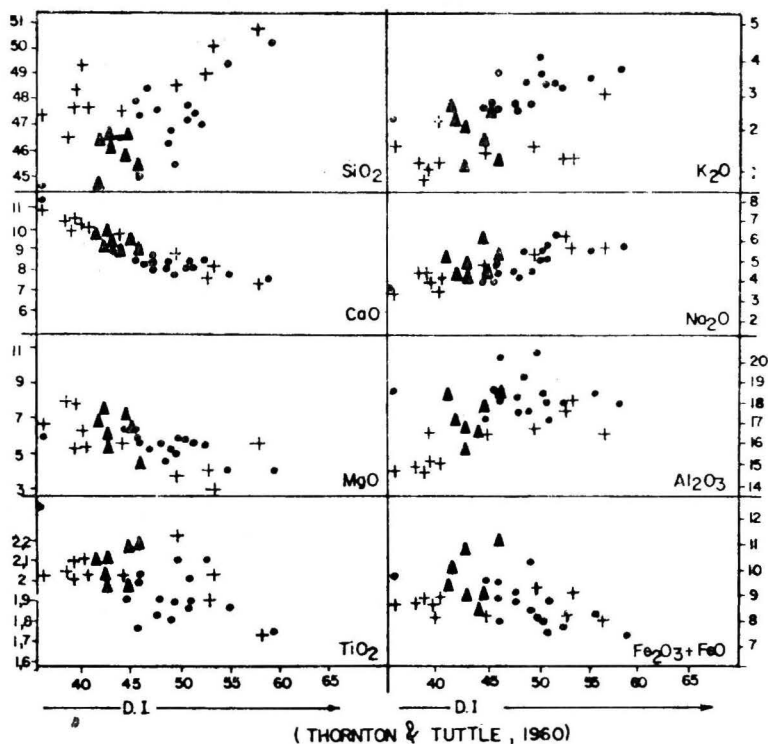


Fig. 11. Variation of major elements of basalts versus D. I. values

10 — Kula basalts were also named according to Coombs and Wilkinson (1969) classification (Fig. 12). For this purpose, D. I. values and $(An. 100)/(Ab + An)$ contents of the lavas were calculated and they were used in the diagram. It was confirmed that the lavas are partly sodic and partly potassic. Calculated values fell into the areas of trachybasalt, alkali olivine basalt, hawaiite and nepheline hawaiite, trachyandesite and feldspathoidal trachyandesite of the diagram.

11 — H. de la Roche (1978) chemical parameters of the volcanics were calculated as well. By using the values of $K/(Na+Ca)$; $Si/3(K+Na+2Ca/3)$; $6Ca+2Mg+Al$; $4Si-11Na+K-2(Fe+Ti)$ on the graphs it is once more confirmed that Kula lavas are hawaiite, tephrite and basanite according to chemical characteristics (Fig. 13).

12 — Kula lavas were also named as latite basalt (trachybasalt), phonolitic tephrite, tephritic phonolite, alkali basalt by using Streckeisen (1967) pair triangle diagram (Fig. 14).

13 — The Irvine and Baragar (1971) classification which is the most developed classification on basalts was also applied to Kula lavas (Fig. 15). The An-Ab'-Or triangle diagrams were plotted in order to distinguish the sodic lavas and potassic ones. N. P. C. and N. C. I. parameters which were calculated were used on diagrams. N. P. C. is normative plagioclase composition and was calculated by using the formula of $100 An/(An+Ab+\frac{5}{3}Ne)$. N. C. I. is normative color index and was calculated by using the formula of $OL+Opx+Cpx+Il+Hm+Mt$. It was confirmed that alkali sodic Kula lavas can be named as hawaiite (one of them is mugearite), and alkali potassic Kula lavas can be named as alkali basalt and trachybasalt.

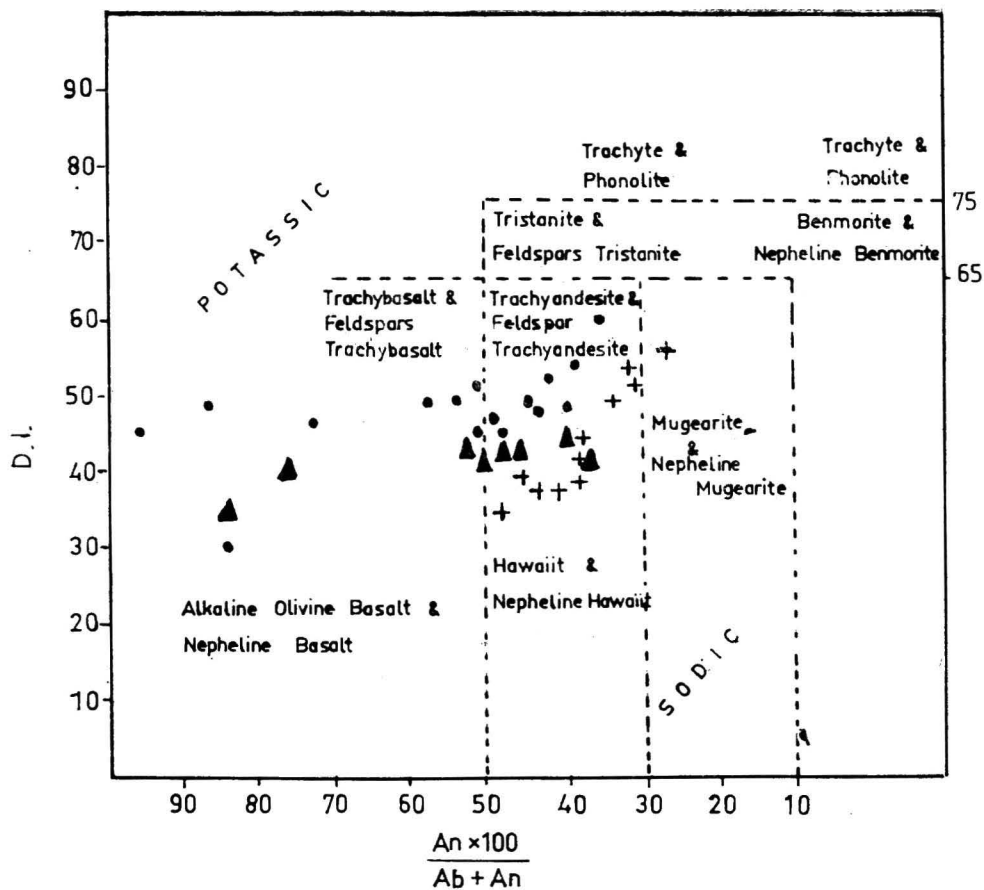


Fig. 12. Coombs and Wilkinson (1969) classification of Kula basalts

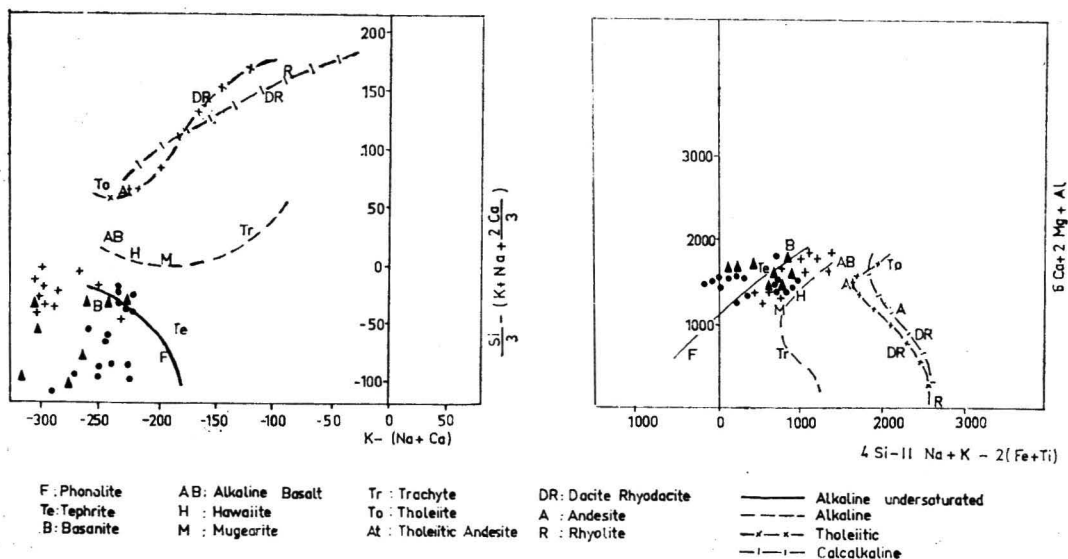


Fig. 13. H. de la Roche (1978) diagrams of Kula basalts

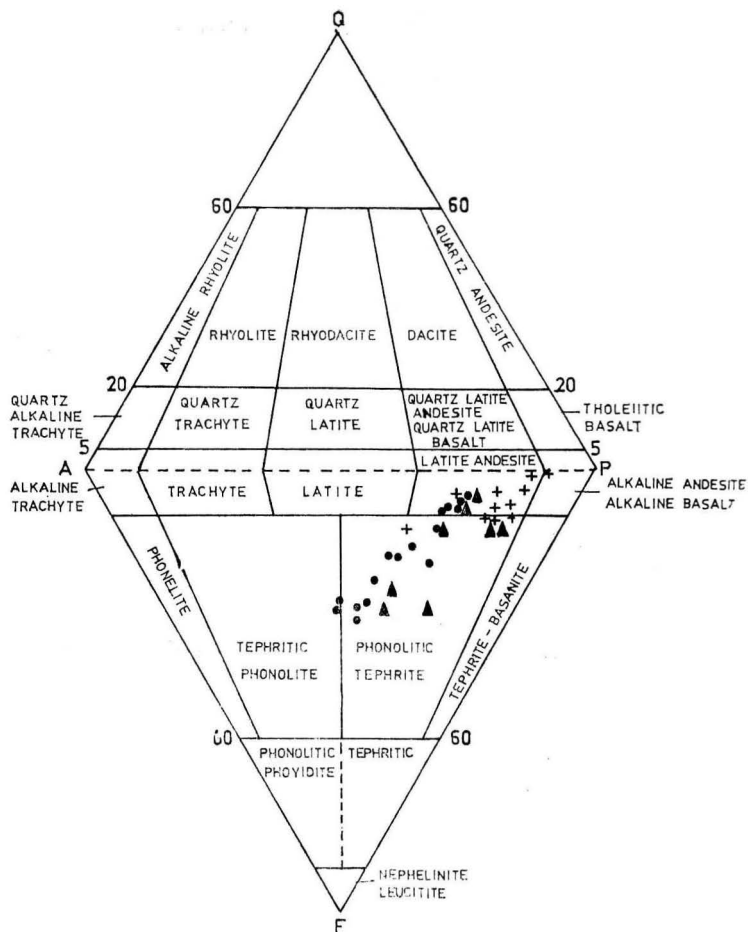


Fig. 14. Nomenclature of Kula basalts according to Streckeisen (1967) triangle diagram

The results which were obtained by scattering the consequences of the chemical analysis of the Kula lavas on the graphs can be summarized as follows;

a) There is no chemical difference between the lavas of all three stages and all the lavas are merely alkaline. They derived from an alkali olivine basaltic magma and have a direct mantle origin. They had been formed by partial melting of the peridotitic mantle.

b) The lavas are partly sodic and partly potassic. Their potassium content increase from first to third stage. The younger lavas are more potassic than the old ones.

c) Lavas are named various names according to methods which were offered by various investigators. Regarding all nomenclatures Kula lavas which had been named as "Kulaite" by Washington (1894-1900) long time ago, generally can be named as hawaiiite and trachybasalt and secondly can be named as tephrite and mugearite. Sodic lavas are hawaiiite, potassic lavas are trachybasalt in nature. Potassium content increase from the oldest lavas to the younger ones.

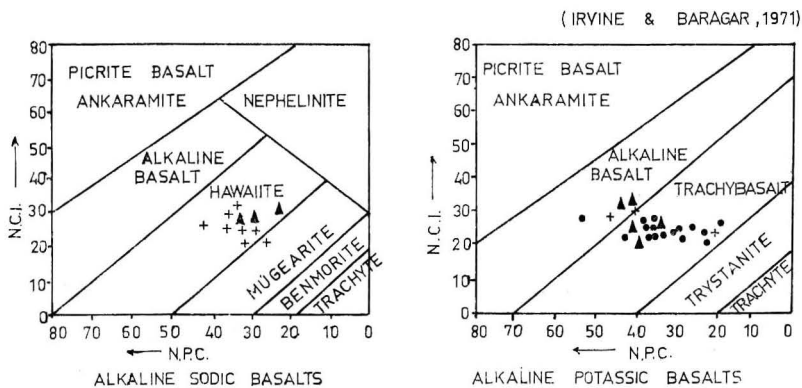
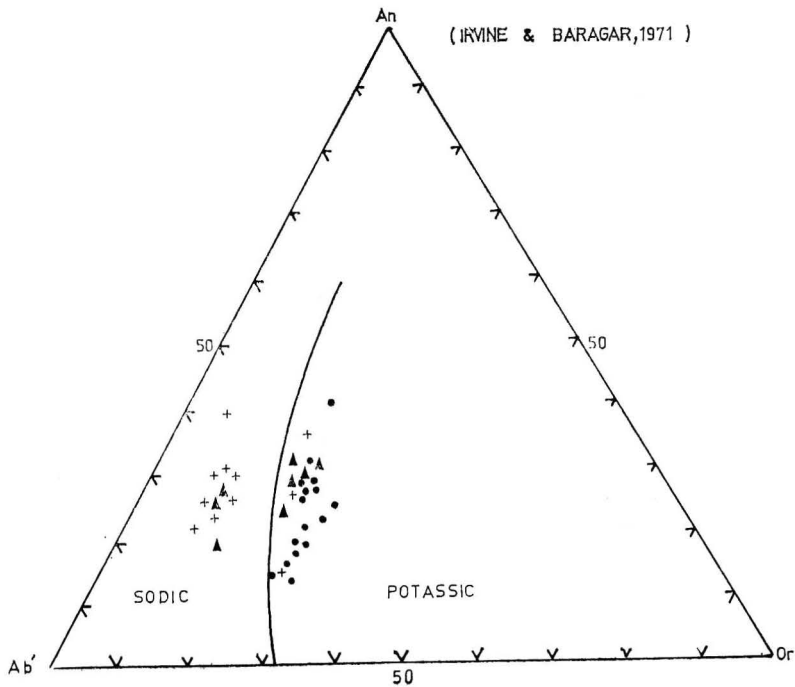
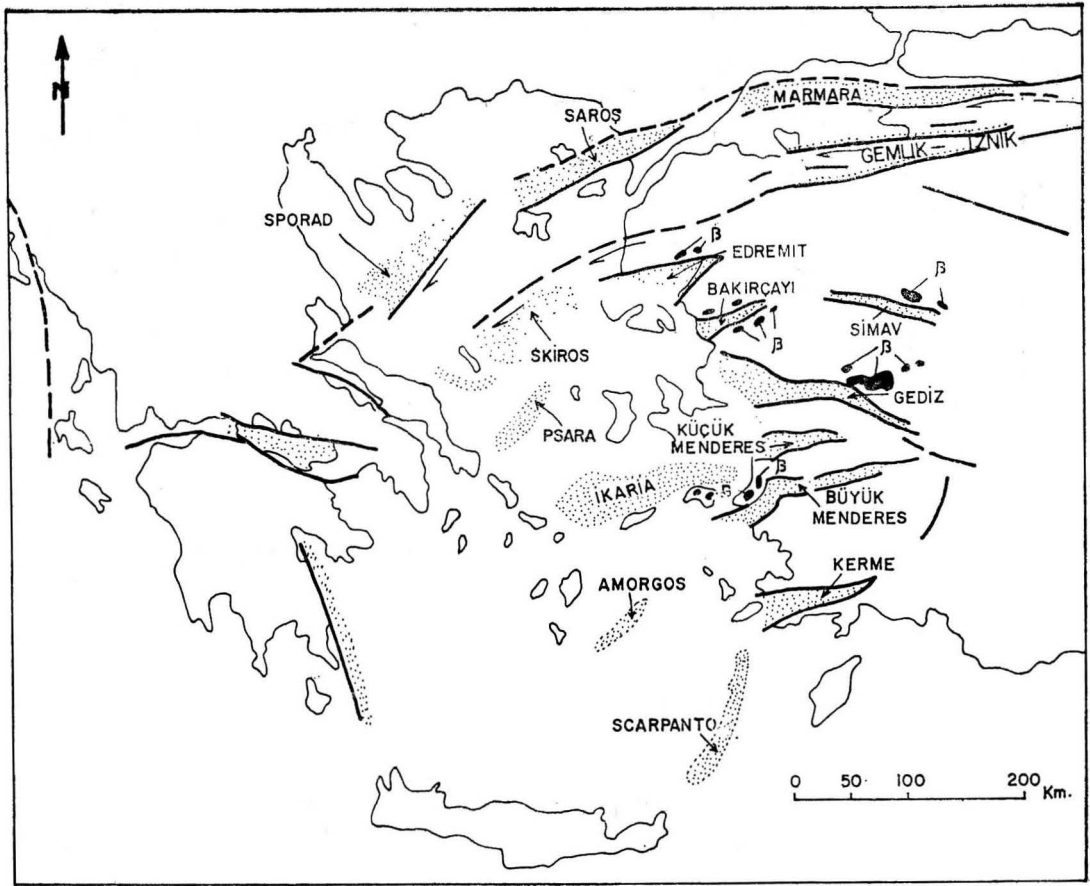


Fig. 15. Irvine and Baragar classification of Kula basalts

Discussion

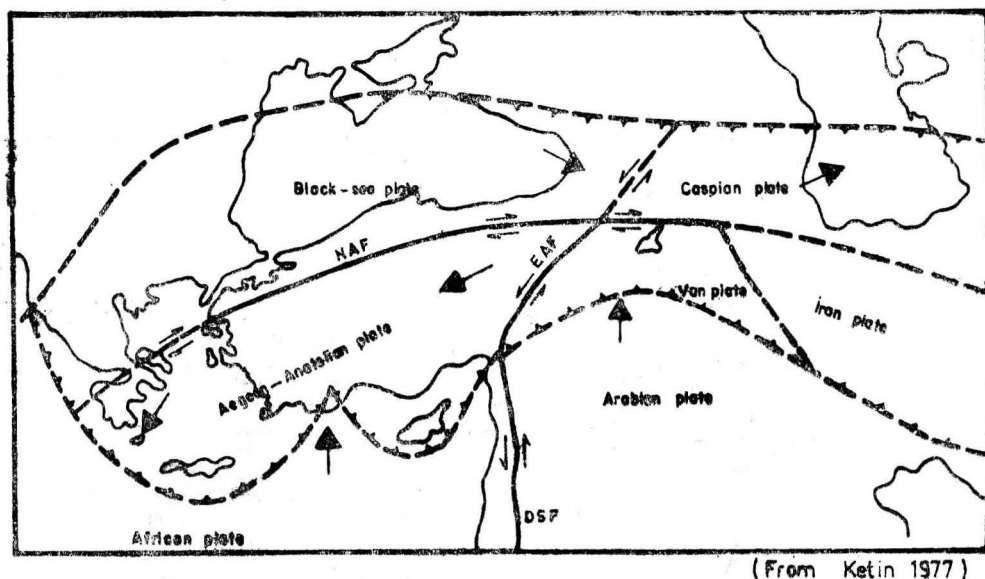
Studied area is in the north of Alaşehir-Salihli (Gediz) graben and it is clear that volcanism is related to that graben system (Fig. 2). If all grabens in Western Anatolia are considered it will be realized that they have been active since Middle Miocene (Fig. 16). Some investigators — Dewey and Şengör (1979), Şengör (1980), Gök-



(Revised from Dewey & Şengör 1979)

Fig. 16. Graben system in Western Anatolia

z ü b o l and G ü r p i n a r (1980) suggested that in Eastern Anatolia, Aegean plate and Anatolian plate started to collide in Middle Miocene and as a result of that collision a compression tectonic dominated in the region. After that collision and continental crust thickening East Anatolian transform fault was developed in the progressive stages of the compression according to plate tectonics model of Turkey was taken from Ketin (Fig. 17). The Aegean-Anatolian plate had started to be pushed along the East Anatolian and the North Anatolian transform faults. Eastward moving Aegean-Anatolian plate met the African plate in the west of Greece. For African plate hindered the move of Aegean-Anatolian plate (Şengör, 1980) an E-W compression occurred in all Aegean Sea and Western Anatolia. Additional N-S tension against compressional power caused to originate Aegean graben system (Fig. 16). Thus, it was concluded that Kula alkali basaltic lavas which were formed from a plume shaped primitive magma generated from a hot spot of the mantle reached to the surface via the fracture system of Alaşehir-Salihli (Gediz) graben which was originated together with the other grabens of West Anatolia. Actually, Borsi et al. (1972) found 0,7020; Ercan et al. (1985) also found 0,70342-0,70299-0,70315 values of $^{87}\text{Sr}/^{86}\text{Sr}$ isotope measurements on Kula basaltic lavas. These results proved that volcanism has a mantle origin. The rift system



NAF North Anatolian Fault
 EAF East Anatolian Fault
 DSF Dead Sea Fault

Fig. 17. Plate tectonic model for Turkey

in Western Anatolia is recently active and according to the theory of plate tectonics it will continue for a while. Therefore, it is possible that Kula volcanism will be re-active and new alkali basaltic lavas will be formed in future.

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