A PRELIMINARY STUDY OF THE: TERTIARY VOLCANIC AND SEDIMENTARY ROCKS, GÜMELE, ESKİŞEHİR

Eskişehir, Gümele Çevresindeki Tersiyer Volkanik ve Sedimanter Kayaçlarda Bir Ön Çalışma

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ÖZ. — Seyitgazi-Eskişehir antiklinoriumu'nun çok fazla deforme olmuş ve metamorfizmaya uğramış kayaçlarının kuzey-kuzeybatısında bulunan sedimanter ve volkanik kayaçlar incelenmiştir. Karasal ve gölsel fasiyesde meydana gelen Tersiyer sedimanter kayaçlar Güney Eskişehir küvetinde olunmuşlardır. Karasal fasiyesi meydana getiren kayaç birimlerini kaba kumtaşları, kumtaşları, bitki kalıntıları ihtiva eden kil ve marnlar ve serpantinit blokları taşıyan bazal konglomerası teşkil etmektedir. Gölsel fasiyes ise genellikle killi ve tüflü kalkerler, kalkerler, marnlar, konglomeralar ve tüflerden meydana gelmiştir. Küvetteki en eski sedimanlar ve piroklastikler Alt Miosen'de oluşmuşlardır. Yataya yakın konumlanmış bazik-intermediyar lav akıntıları Pliosen yaşlı olup Altüst Neojen sedimantasyon kesikliğinde meydana gelmiştir. Üst Neojen sedimanter kayaçları intermediyar-basaltik volkaniklerin üzerinde ince bandlar şeklinde bulunurlar. Bu birim marn ve kalkerlerden meydana gelmiştir. Alt Miosen'de asid volkanik faaliyetler neticesinde meydana gelen sillar (unweldd tuffs) oligomikt konglomeralardan evvel teşekkül etmiştir. Bu volkanik aktitivite muhtemelen kesikli ve kısıtlı olarak devam etmiş ve tüflü kalkerleri meydana getirmiştir. Pliosen yaşlı bazik-intermediyar (benmoreit) volkanik kayaçlar, gölsel fasiyesde meydana gelmiş sedimanter ve piroklastik kayaçların oluşmasını ve erozyonunu müteakiben teşekkül etmişlerdir.

Sillar, benmoreit, tüflü kalker ile dolomitik ve kalsitik konglomeraların matriks ve çimentoları üzerinde petrokimyasal yönden ayrıntılı olarak çalışılmış ve bu kayaçların petrojenezi üzerinde bazı teklifler ortaya konmuştur.

ABSTRACT. — The sedimentary and volcanic rocks occuring north-northwest of highly deformed and metamorphosed rocks of Seyitgazi-Eskişehir anticlinorium are discussed in this paper. The Tertiary sedimentary rocks of terrestrial and lacustrine *fades were deposited in the Southern Eskişehir cuvette. Terrestrial fades consist of grits, sandstones, clays and marls with plant remains and a basal conglomerate with serpentinite boulders. Lacustrine fades on the other hand, are mainly made of argillaceous and tuffaceous limestones, limestones, marls, conglomerates and tuffs. These oldest sediments and pyroclastics of the cuvette were formed during the Lower Miocene. Pliocene volcanic rocks consist of flat-lying basic-intermediate lava flows and occur at the Lower-Upper Neogene sedimentation break. Upper Neogen sediments or found as thin bands over the intermediate basaltic volcanic rocks and consist of marls and limestones. The acid volcanic actvity of Lower Miocene age which produced the unwelded tuffs (sillar) occured prior to the deposition of the oligomict conglomerate formation and probably continued to a lessr extent gwing rise to the tuffaceous limestones. The basicintermediate (benmoreite) lava flows of Pliocene age followed, the formation and erosion of these sedimentary and pyroclastic rocks of the lacustrine fades.*

The sillar, benmoreite, tuffaceous limestone and the matrices and cements of dolomitte and calcarous conglomerates are studied, in detail, petrochemically and some suggestions are made to explain their petrogenesis.

INTRODUCTION

In the course of geological investigation of metamorphic and igneous rocks occuring within Subren - Karaalan - Yukarıçağlan triangle of Eskişehir Country, the author mapped a small area that consists of Young Tertiary volcanic and sedimentary rocks, which overlie the older igneous and metamorphic formations.

The area is situated about 13 km. SSW of Eskişehir. The average elevation is about 950 meters above sea-level, and the area slopes gently down towards the north.

The part of Eskişehir area discussed in this work forms part of the younger Tertiary rocks which lie unconformably over the older metamorphic and igneous rocks probably of Lower Paleozoic or Pre-Paleozoic age. These older rocks constitute a small part of the Central Anatolian Shield.

The general geology of the Eskişehir district (Figure 1 and 2) is considerably complex due to several phases of tectonic deformation and several stages of metamorphism. There are seven main stratigraphical units : (1) retrogressive low grade (epizonal) metamorphic rocks forming the basement, (2) igneous intrusives emplaced in metasediments and metavolcanics, (3) Permo-Carboniferous limestones and volcanics, (4) Jurassic-Creta-

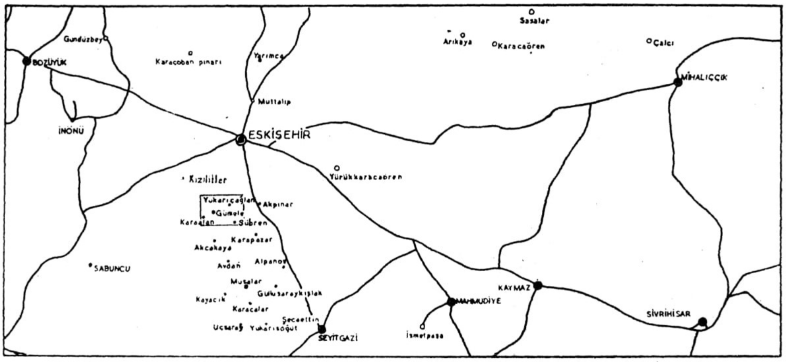


Fig. 1. LOCALITY MAP OF ESKİŞEHİR AREA

ceous limestones, (5) Ophiolitic series of doubtful age, consisting of slightly metamorphosed sedimentary and volcanic rocks, (6) Paleocene-Eocene limestones, and (7) Neogene-Quarternary formations.

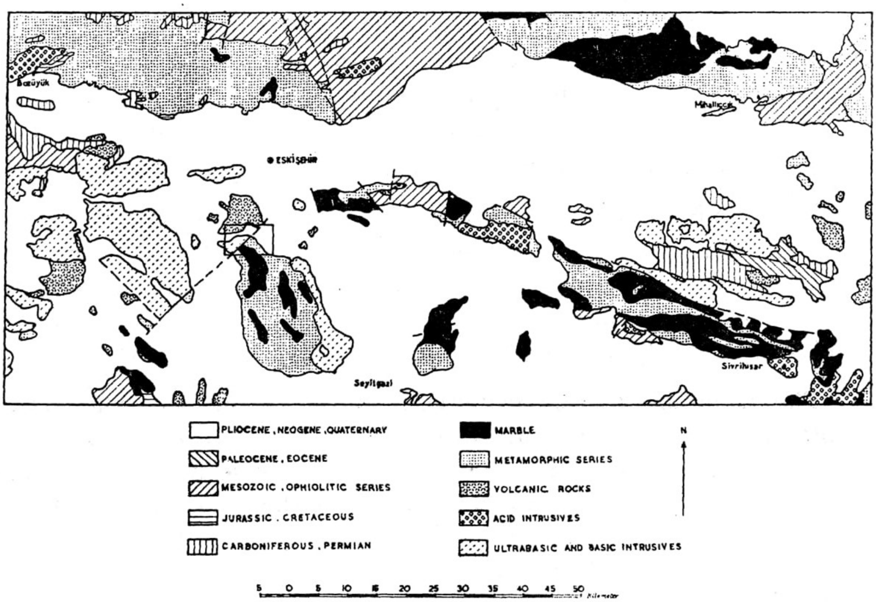


Fig. 2. GEOLOCICAL MAP OF ESKİŞEHİR AREA (Northwest of ANKARA Sheet).

In the area under consideration only units 1, 2, 5 and 7 were observed. Except for the Tertiary rocks all the older units have suffered complex deformation. All the phases of deformation appear to have affected the pre-Tertiary rocks whereas the Tertiary rocks are only affected by normal faulting.

TERTIARY SEDIMENTARY ROCKS

GİRİŞ

The Tertiary sedimentary rocks around Eskişehir are deposited in cuvettes bordered by highly deformed older series, consisting generally of metamorphic and igneous rocks. The formation of the cuvettes is thought to have been occurred during the close of the Mesozoic.

Signs of early Paleocene sedimentation are found in the northern cuvettes, while near the borders of the eastern cuvettes the deposits are of Eocene and Oligocene age. The earliest sediments of the southern Eskişehir cuvette were formed during Lower Miocene (Kupfahl, 1954).

There are two types of sedimentary facies found in the southern Eskişehir cuvette. The terrestrial facies occur on the northern side. The lacustrine facies, on the other hand, is developed further south and overlaps the terrestrial facies. The junction of the change of facies is obscured by thick piles of Pliocene lava flows, between Kızılitler and Yukarıçağlan (Figure 2).

The members of the terrestrial facies do not occur in the mapped area, but were observed along road cuttings a few kilometers south of Eskişehir. The rocks are red and yellow coloured grits, sandstones, clays and marls with plant remains. A basal conglomerate rests on and contains boulders of serpentinite.

The members of the lacustrine facies consist of limestones, argillaceous limestones, tuffaceous limestones, tuffs, marls and conglomerate horizons. The conglomerates occuring in the lacustrine facies are cemented with carbonates while those of the terrestrial facies are cemented with clays and hydrous iron oxides. Within the conglomerates of the lacustrine facies meerschaum bearing horizons occur, which may be of economic importance. The meerschaum was originally formed in magnesite-opal veins, in serpentinite by the action of hydrothermal solutions and later eroded and redeposited in certain horizons of the conglomerate formations.

Pre-Tertiary rocks are strongly deformed. There are nine phases of deformation of which the first four have isoclinal folds (Lunel, 1967). Tertiary rocks on the other hand, are only affected by one normal fault. The strike of the vertical fault plane is N50°E, with an estimated minimum southeast downthrow of about 20 meters (Figure 3).

Tertiary deposits are found as almost undisturbed flat-lying strata. Hence their deposition is indicated as being later than the major Alpine movements.

PETROGRAPHY

The conglomerate can be divided into two types according to their cementing materials: calcareous and dolomitic conglomerate. The calcarous conglomerate (TL 212) contains fragments of glaucophane schists, quartzite, Lawsonite-quartz schist, hornblende gabbro and serpentinite, with detrital quartz, plagioclase, lawsonite, glaucophane, epidote and chlorite. The cement consists of micro-crystalline calcite, sometimes concentrically deposited around pebbles, with a few patches of goethite. Recrystallization has occured along fractures and around some pebbles (Plate 1).

The dolomitic conglomerate (TL 162) contains pebbles of serpentinite, quartzite, spilite and meerschaum with detrital quartz, chlorite, feldspar, epidote, glaucophane and grains of opaque ore probably with high nickel content. The cement is microcrystalline dolomite.

Limestone proper has not been found in the mapped area but it was observed in the vicinity of Akpınar. The limestone northeast of Gümele is a tuffaceous limestone (TL 179) displaying a well developed graded bedding which is made of volcanic material. The rock is formed of collapsed pumice fragments, sub-angular glass fragments and broken quartz crystal with a cement of microcrystalline calcite. About 40 per cent of the rock consists of pyroclastics.

COMPOSITION

Chemical analyses of the calcareous (TL 212) and dolomitic (TL 162) conglomerate and the tuffaceous limestone (TL 179) with a composite analysis of 345 limestones (Clarke, 1924) are given in Table 1.

TABLE: 1 — CHEMICAL ANALYSES OF THE SEDIMENTARY AND PYROCLASTIC ROCKS

Analyses	**TL.179**	A	**TL.162**	**TL212**	**B**
SiO_2	44.49	71.10	18.13	16.76	5.19
$A1_2O_3$	8.57	13.70	3.45	2.56	0.81
TiO_2	0.05	0.08	0.15	0.14	0.06
Fe_2O_3	0.61	0.98	1.79	1.49	0.54
FeO	0.00	0.00	0.13	0.02	
MgO	0.39	0.62	16.01	1.96	7.90
CaO	23.19	2.85	23.35	40.76	42.61
Na_2O	1.08	1.73	0.13	0.06	0.05
K_2O	2.62	4.19	0.49	0.62	0.33
MnO	0.04	0.06	0.04	0.09	0.05
P_2O_5	0.10	0.16	*	0.56	0.04
H_2O	2.90	4.53	3.30	3.96	0.56
CO_2	16.78		33.55	30.69	41.58
Total	100.82	100.00	100.52	99.67	99.72
S	162		298	729	1100
Cl	871		178	125	200
Se	*		*	*	5
V	74		31	140	15
Cr	182		258	374	10
Co	*		5	16	4
Ni	18		444	206	12
Rb	**171**		38	22	5
Sr	146	*	802	390	500
Zr	55		55	19	20
Sn	35		34	45	4
Cs	2		1	1	
Ba	351		153	136	100
La	8		10	4	6
Ce	54		46	51	10

Niggli Values

si	132.1	413.6	34.3	33.7	8.9
al	15.0	47.0	3.9	3.0	0.8
fm	3.2	10.0	48.0	8.3	20.9
c	73.7	17.7	47.3	87.8	77.9
alk	8.1	25.3	0.8	0.9	0.4
ti	0.11	0.35	0.21	0.21	0.08
p	0.13	0.39	0.00	0.48	0.03
k	0.61	0.61	0.71	0.87	0.81
mg	0.54	0.54	0.94	0.71	0.96

C.I.P.W. Norm

q	24.0	38.4	12.4	9.2	3.0
or	15.5	24.8	2.9	3.7	2.0
ab	9.1	14.6	1.1	0.5	0.4
an	8.3	13.1		4.5	
c	0.9	1.5	2.7	0.1	0.4
opx	1.0	1.5	5.3	4.9	1.0
ilm	0.1	0.1	0.3	0.2	0.1
mt			0.1		
hm	0.6	1.0	1.7	1.5	0.5
ap	0.2	0.4		1.3	0.1
cc	38.2		41.7	69.8	76.0
mag			29.2		15.7

Standard Katanorm

Q	27.0	36.7	13.6	13.0	4.2
Or	19.4	26.5	4.3	5.7	3.3
Ab	12.2	16.6	1.7	0.8	0.8
An	10.5	14.1		7.6	
Cord	3.3	4.8	11.9		1.9
En	0.1	0.1	4.0	8.5	1.2
Mt	0.1	0.2	0.6	0.4	0.2
Hm	0.5	0.6	1.4	1.4	0.5
Cp	0.3	0.3		1.7	0.1
Ru	0.1	0.1	0.2	0.2	0.1
Cc	26.6		34.0	60.7	70.6
Mag			28.3		17.3

TL 179. Tuffaceous limestone.
TL 162. Matrix of the dolomitic conglomerate.
TL 212. Matrix of the calcareous conglomerate.
A. Recalculated to 100% from TL 179 after combining CO_2 with CaO to give pure calcite.
B. Composite analysis of 345 limestones (Clarke, 1924).

The major oxides of the two conglomerate matrices show significant variations only in MgO and CaO which are due to the varying proportions of dolomite and calcite. A comparison of two matrices* with an average limestone show a large difference in SiO_2, Al_2O_3, Fe_2O_3+FeO, P_2O_5 and H_2O contents. The first three oxides are present in large quantities as silicates: epidote, chlorite, lawsonite and hydrated iron oxides. The high P_2O_5 content is due to detrital apatite derived from metamorphic rocks. The H2O is largely contained in clay and serpentine minerals.

The trace element distribution between two different matrices is significant in S, V, Cr, Co (high in TL 212) and Ni, Sr, Zr, La (high in TL 162). In the samples under discussion contributions from three major rock types control the trace element composition of the matrices, namely peridotite (high in Sr, Cr, Co, Ni); blue-schists (high in V, Cr, Co) and greenschists (high in Sr, Zr, La). Of these peridotite fragments are present in both matrices while the blueschist fragments are present only in TL 212 and the greenschist fragments are present only in TL 162.

A comparison of the two matrices with an average limestone shows large differences in V, Cr, Ni, Rb, Sn and Ce. These high values of the trace elements, as explained previously, are due to detrital minerals and rock fragments derived from metamorphic and ultramafic rocks. The carbonate composition of the normative cement in TL 162 is $Co_{54.6}Mag_{45.4}$, i.e., within the field of dolomite, while that of TL 212 is almost pure calcite. An interesting feature is the appearance of anorthite molecule in the norm of TL 212 which is probably due to the abundance of detrital lawsonite.

Recognition, under the microscope, of pyroclastic fragments in the tuffaceous limestone (TL 179) correlates well with chemical analysis which shows high silica, alumina and alkalis and high Cl, Rb, Zr and Ba. In TL 179, high V, Cr, Sn and Ce values are probably due to derived metamorphic and ultramafic rock materials in the same way as they are in the matrix of calcareous conglomerate (TL 212).

(*) Analyses of the conglomerates (TL 162 and TL 212) were conducted on the matrix and cement. The pebbles were extracted from the starting material. In the text matrix denotes detrital mineral grains, microscopic rock fragments, and cementing material.

DISCUSSION

The conglomerate horizon occuring in the lacustrine facies have an essentially carbonate cementing material. In the neighbourhood of the blueschists and marbles; namely northeast of Gümele, east of Sübren and around Yukarıçağlan; the composition of tue cementing material, in the rudaceous rocks is calcite. This is the predominant feature of the early sedimentation in this area and which subsequently resulted in the precipitation of pure limestone. However, in the neighbourhood of the ultramafic rocks, especially southwest of Gümele, the composition of the cementing material is dolomite. The weathering and leaching of the serpentinized ultramafic rocks are probably the cause of the presence of Mg++ ions in localized depositional areas. This probably led to the formation of dolomitic cement.

Study of the rocks pebbles of the rudaceous rocks indicates that their transportation did not correspond over long distances, and they were probably derived from nearby outcrops. These rocks can be classified as oligomict conglomerates.

Tuffaceous limestone, northeast of Gümele, displays well developed graded bedding structure consisting of subangular pyroclastic detrital fragments, which also probably show that they have not been transported far. The source of these volcanic material is presumably the series of volcanic activities which gave rise in their early stages to the unwelded tuffs (sillar) and then continued on a smaller scale to produce tuffaceous limestones. The turbulent flows comprised of solid and viscous volcanic material and volcanic gases were probably responsible for the graded bedding in this area as they settled in the carbonate deposition basin. Hence, in order to establish this, the CO_2 in the analysis of tuffaceous limestone is combined with CaO to give pure calcite, as in the matrix of the calcareous conglomerate, the remaining material is presumably mostly pyroclastic material. Therefore, if the calculated calcite is subtracted from the rock analysis and the result is recalculated to 100 per cent some notion of the chemical composi-tion of the pyroclastic material can be obtained (Table 1.A). Such a calculation gives a chemical composition remarkably close to that of sillar (Table 2; TL 521). The comparison of the trace elements also points to similar conclusion, i.e., that the pyroclastic material incorporated in the tuffaceous limestone has probably originated from a later volcanic activity of similar composition to that which produced the earlier sillar horizon.

Field evidence also supports this view, as it was found that, in the lower part of the conglomerate layers northwest of Gümele, pieces of the sillar occur among the derived pebbles of the conglomerate; on which lies the tuffaceous limestone, northeast of Gümele. The pyroclastic material present in the tuffaceous limestone cannot have been derived from the sillar because the sillar (910 m) occurs at lower elevations than the tuffaceous limestones (980 m) and a thick layer of conglomerate separates the two formations.

The laboratory work together with field evidence collated in this study suggests that the main acid volcanic activity which produced sillar occurred prior to the deposition of the conglomerate formation and continued on a smaller scale to produce tuffaceous limestone.

TERTIARY VOLCANIC ROCKS

The west-northwest part of the mapped area consists mainly of flat-lying acid and intermediate-basic volcanic rocks which rest unconformably on a blueschist-ultramafic-greenschist complex.

They consist of two types of major flows; acid unwelded tuffs (sillar) and intermediate-basic lava flows, benmoreite. The benmoreite lies directly on top of the sillar in the western part of the area. The contact is generally covered with talus. The sillar shows silicification and becomes more compact near the contact. The benmoreite is vesicular and amygdaloidal at its lower contact.

The intermediate-basic lava flows are observed lying on top of the limestones of lacustrine facies, 3.5 kilometers southsoutheast of Kızılitler (Figure 2), and also over oligomict conglomerates, northwest of Gümele.

The age of the sillar is determined to be Lower Miocene, while that of the intermediate-basic lava flows is suggested to be Pliocene (Kupfahl, 1954).

These rocks are of local economic importance since they supply a large proportion of local construction needs. The intermediate-basic volcanic rocks are used for cobbles and road metal, while sillar is widely used for building stones which are supplied as large blocks from a quarry 1.5 kilometres northwest of Gümele.

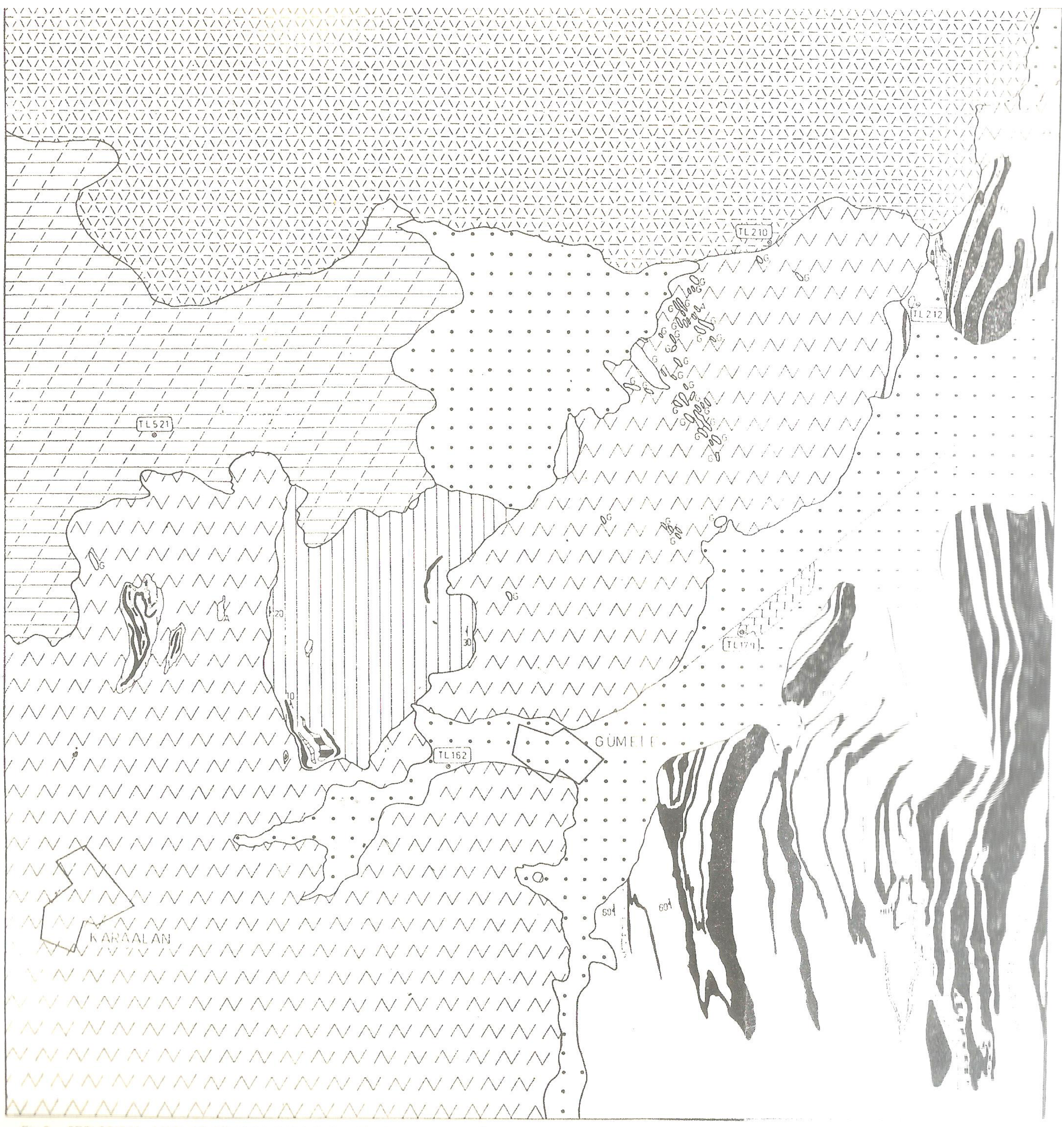


Fig 3 GEOLOGICAL MAP OF SUBREN-KARAALAN-GUMELE-YUKARIÇAĞLAN AREA, ESKİŞEHİR COUNTY, TURKEY

SILLAR

This is a pink, porous rock with a very low specific gravity. There are well rounded grit, chert and serpentinite fragments embedded in a soft, streaky, glassy matrix. Partly leached, very soft, white patches observed in the rock are collapsed pumice fragments.

Petrography

The sillar has a vitrophyric texture with 7.3 per cent phenocrysts and therefore can be classified as a vitric-tuff. A modal analysis of TL 521 shows 4.1% plagioclase, 2.0% biotite, 0.8% quartz, 0.4% opaque and 92.7% glass. Plagioclase, An_{32}, is euhedral, twinned and sometimes strongly zoned with sodic margins. Strongly pleochroic, euhedral biotite with inclusions of zircon; a little, magmaticly corroded quartz; slightly altered magnetite, and many collapsed and partially devitrified pumice fragments occur. The accessory minerals are apatite and zircon. Secondary calcite is present. The matrix consists of glass with broken shards (Plate 2.A), There is no evidence of welding.

Composition

Chemical analyses of the sillar, TL 521, and an average calc alkali rhyolite, A, are given in Table 2. The sillar is unusually rich in MgO and

TABLE: 2 — CHEMICAL ANALYSES OF THE VOLCANIC ROCKS

Analyses	TL 521	A	TL 210	B	C	D
SiO_2	70.57	73.66	56.59	51.33	57.50	57.97
Al_2O_3	13.76	13.45	18.24	18.04	17.33	18.56
TiO_2	0.18	0.22	1.23	1.10	0.79	1.06
Fe_2O_3	1.26	1.25	3.16	3.40	3.78	1.82
FeO	0.33	0.75	3.81	5.70	3.62	4.81
MgO	1.87	0.32	2.88	6.01	2.86	1.95
CaO	1.58	1.13	5.98	10.07	5.83	3.32
Na_2O	1.67	2.99	4.22	2.76	3.53	6.74
K_2O	4.45	5.35	2.95	0.82	2.36	2.79
MnO	0.11	0.03	0.12	0.16	0.22	0.24
P_2O_5	0.04	0.07	0.45	0.16	0.30	0.54
H_2O	4.26	0.78	0.80	0.45	1.88	0.18
CO_2	0.36		0.52			
Total	100.44	100.00	100.95	100.00	100.00	100.08

S	222		67	
Cl	1000		281	
Sc	5	5	8	38
V	41	20	134	250
Cr	*	4	85	200
Co	2	1	12	50
Ni	10	0.5	97	150
Rb	357	150	154	30
Sr	243	285	661	465
Zr	177	180	435	150
Sn	9	3	4	1
Cs	5	5	2	1
Ba	1247	600	1349	250
La	50	25	63	10.5
Ce	98	46	131	35

Niggli Values

si	384.3	420.5	171.0	125.1	181.3
al	44.2	45.3	32.5	25.9	32.2
fm	22.3	11.8	30.1	40.0	32.6
c	9.2	6.9	19.4	26.3	19.7
alk	24.3	36.0	18.0	7.8	15.5
ti	0.74	0.94	2.80	2.02	1.87
p	0.09	0.17	0.58	0.17	0.40
k	0.64	0.54	0.32	0.16	0.31
mg	0.68	0.23	0.43	0.55	0.41

C.I.P.W. Norm

q	38.8	33.1	5.5	2.4	11.4	
or	26.3	31.6	17.4	4.8	14.0	16.68
ab	14.1	25.3	35.7	23.4	29.9	56.59
an	5.3	5.2	22.1	34.4	24.3	11.95
c	4.3	0.9				
opx	4.7	0.8	9.2	15.5	8.8	
cpx			1.1	11.7	2.0	0.68
ilm	0.3	0.4	2.3	2.1	1.5	2.13
mt	0.9	1.8	4.6	4.9	5.5	2.55
hm	0.6					
ap	0.1	0.2	1.0	0.4	0.7	1.34
cc	0.8		1.2			

Standard Katanorm					
Q	34.4	30.4	4.1	1.4	10.2
Or	27.9	32.3	17.5	4.9	14.3
Ab	15.9	27.4	38.0	25.0	32.5
An	5.7	5.3	22.2	34.7	25.1
Cord	13.5	2.5			
Wo			0.7	5.9	1.1
En	0.6		8.0	16.7	8.1
Hy		0.3	3.9	6.8	3.4
Mt	1.1	1.3	3.3	3.6	4.1
Hm	0.2				
Cp	0.1	0.1	0.9	0.3	0.6
Ru	0.1	0.2	0.9	0.8	0.6
Cc	0.5		0.7		

TL 521. Sillar.
TL 210. Benmoreite.
A. Average calc-alkali rhyolite (Average of 22 analyses; Nockolds, 1954).
B. Average 'central' basalt (Nockolds, 1954, p. 1021).
C. Average augite andesite (Average of 33 analyses; Daly, 1953, p. 16).
D. Benmoreite, trachyte trending towards mugearite (Macdonald and Katsura, 1964).

H_2O. This is probably due to microscopic inclusions of serpentine minerals derived from the serpentinized peridotite intrusion and also to the presence of hydrous alteration products of the matrix and pumice fragments. The low alkali and high water content of the rock, when compared with a typical calc-alkali rhyolite, suggests that leaching of alkalies may have taken place. This is strongly supported by the large t'=al-(alk+c)=10.7, value which results from the removal of alkalies leaving excess alumina. This excess of alumina is not the result of contamination by sedimentary rocks as the constituents Fe and Ti do not show any appreciable increases.

On the basis of the trace elements the sillar is similar to a typical granitic rock as regards Sc, Cr, Co, Sr, Zr and Cs; but V, Ni, Rb, Sn, Ba, La and Ce values are high. High nickel is probably due to finely divided serpentinite contamination. High content of the rest of the trace elements are probably characteristics of the sillar. The K/Rb ratio (104) shows that TL 521 falls into the zone of Rb enrichment of Taylor (1965, p. 144, Fig. 1).

Discussion

The acid vitric tuff, TL 521, according to its essential chemical characteristics falls into the quartz-latite division of Rittmann (1952).

An attemp has been made to determine the composition of the glass, by subtracting 4.1% plagioclase (An_{32}), 2.0% biotite and 0.8% quartz from the standard katanorm, using the following formulae

8 Bi + 3 Q = 5 Or + 6 En

33 Cord + 1 Q = 10 Ant + 24 Kaol

6 En = 5 Ant + 1Q

The composition of the unaltered part of the glassy matrix is probably, thus $Q_{43.5}Or_{34.4}Ab_{16.8}An_{5.3}$ Biotite-Antigorite-Kaolinite variant of the katanorm has 2.0% biotite, 3.3% antigorite and 9.8% kaolinite. Therefore, it can be inferred that about 11 per cent of the glassy material is altered.

Recalculation of the quartz, albite and orthoclase in C.P.I.W. norm to 100 per cent and plotting it in the anhydrous SiO_2-$NaAlSiO_4$ ($NaAlSi_3O_8$)-$KAlSiO_4$($KAlSi_3O_8$) system, at atmospheric pressures (Schairer, 1950), gave a maximum value of 1200 °C for the liquidus temperature; while in the quarternary system of SiO_2-$NaAlSiO_4$-$KAlSiO_4$-H_2O, at 5000 bars of water pressures (Ltuh, Jahns and Tuttle, 1964), gave a value of 770°C for the temperature of the liquidus. Since no independent estimate of pressure is available no definite estimate of liquidus temperature for the calculated composition can be made.

The petrographie study indicated that the matrix is made of glass with broken shards with no evidence of welding. According to Boyd (1961, p. 387) "the minimum temperature at which rhyolite glass will weld, determined experimentally is approximately 600°C". Therefore, it can be suggested that the sillar was formed from clouds of volcanic ash whose temperature was below 600 °C.

BENMOREITE

This is a dark porphyritic rock ith elongated vesicles, occuring at the base of the intermediate-basic lava flow. Amygdules consist mainly of zeolites and calcite. The middle part of the lava flow is more massive and has olivine phenocrysts. The elongated tubular vesicles lie in a northeast-southwesterly direction and are not vertical, but plunge 70° to thenorthwest. This suggests that the flows came from northwest.

There are well developed, closely spaced joint systems probably originated during the cooling of the lava flows.

Petrography

The texture is intergranular-porphyritic with euhedral iron rich olivine phenocrysts which invariably have an altered iron-richer rim. Alteration products of the rims consist of a hematite-limonite mixture. Plagioclase and clinopyroxene phenocrysts are very rare, and are generally confined to the groundmass. Clinopyroxene phenocrysts have no iron-rich rims and are free from alteration (Plate 2JB).

The groundmass consists of interlocked andesine-labradorite (An_{54}) microliths, prismatic clinopyroxene, a little olivine with minute magnetites, interstitial sanidine and very little quartz. The accessory mineral is apatite. Secondary calcite is present. A modal analysis of TL 210 shows 70.8% feldspar (including microliths and interstitial alkali feldspar), 5.7% olivine, 13.5% clinopyroxene, 1.3% calcite, 1.1% apatite and 7.6% opaques (including the altered iron-rich rims of the olivine phenocrysts).

Composition

Chemical analysis of the intermediate-basic rock, TL 210, an average "central" basalt, B (Nockolds, 1954), an average augite andesite, C (Daly, 1933), and benmoreite 'trachyte trending towards mugearite', D (Macdonald and Katsura, 1964) are given in Table 2.

The chemical analysis of the TL 210 closely resembles the average augite-andesite and benmoreite, rather than the average "central" basalt. Compared with augite-andesite, TL 210 shows a remarkable resemblance in the major oxides ; Al_2O_3, TiO_2 and Na_2O slightly higher in TL 210 whereas SiO_2 and H_2O is slightly higher in augite-andesite. The differences, in the major oxides, between benmoreite and TL 210 lies in Fe_2O_3, FeO, MgO, CaO and Na_2O. Higher MgO, CaO and lower Na_2O is most probably due to more basic character of TL 210. The sum of the iron oxides content (Fe_2O_3+FeO) in the two rocks is very similar, however, due to the oxidation of the rims of the olivines in TL 210, the proportions of FeO: Fe_2O_3 show large variations between the TL 210 and benmoreite.

The trace elements show the analysed benmoreite from Eskişehir area is poorer in Sc, V, Cr, Co and Ni than an average basalt, while Rb, Sr, Zr, Ba, La and Ce are higher than average basalt, and is supported by plots of Ni: Co, Fe: Co, and Mg: Co (Taylor, 1965, pp. 172-3, figures 8&9) in which TL 210 falls into the late differentiation region of basaltic rocks.

Discussion

The classification of TL 210 based on the feldspar microliths (An_{54}) and interstitial alkali feldspars places the rock in the olivine bearing trachy-basalt division, however, according to Rittman's classification based upon the chemistry of the rock, TL 210 falls into the trachy-andesite group. Na_2O+K_2O versus SiO_2 plot shows that both benmoreite and TL 210 fall into the late differentiates region of the alkali basalt series, where TL 210 is somewhat closer to tholeiite-alkali basalt division (Tilley et. al. 1964, p. 78, Figure 6).

Despite the presence of 5.7 per cent modal iron rich olivine there is no normative olivine but quartz is however present in the calculated norms. Alteration of the iron-rich rims of the olivine and appearance of a little quartz in the interstitial material and secondary calcite is probably the cause of this abnormality; but if all Fe_2O_3 is assumed as FeO, the normative quartz content falls down to 0.1% (Tilley, Yoder and Scharier, 1965 (65), p. 80). Now there is 2.1% wollastonite, 8.0% enstatite and 10.5% hypersthene in the calculated norm. Therefore, total pyroxene becomes 20.6 sum of the observed modal olivine and clinopyroxene (19.2%) per cent which has approximately the same numerical value as the Considering the fact that both phenocrysts of Fe-rich olivine and interstitial quartz occur together in the rock, the standard katanorm is recalculated to its iron rich olivine-quartz variant. Hence, after subtracting 5.7% Fo_{43}* from the norm, the variant has 2.1% wollastonite, 4.8% enstatite and 6.2% hypersthene; i.e., pigeonite as pyroxene; 2.4% fosterite, and 3.3% fayalite; i.e., hortonolite as olivine; and 1.9% free quartz. The composition of the leucocratic material, including the plagioclase microliths, calculated to 100 per cent, thus, is $Q_{2.4}Or_{22.0}Ab_{47.7}An_{27.9}$.

(*) Fo_{43} is calculated from the basis.

Recalculation of the orthoclase-albite-anorthite in the C.I.P.W. norm to 100 per cent and plotting it in the anhydrous $NaAlSi_3O_8$ - $KAlSi_3O_8$-$CaAl_2Si_2O_8$ system at atmospheric pressures (Franco and Scharier, 1951) gave a maximum value of 1365°C for the liquidus temperature, while in the quarternary system of $NaAlSi_3O_8$-$KAlSi_3O_8$- $CaAl_2Si_2O_8$-H_20 at 5000 bars of water pressure (Yoder, et. al., 1957) gave a value of 1010°C for the liquidus temperature.

Investigations into the melting relations in volcanic rocks carried out by Tilley, Yoder and Scharier (1964) led to the conclusions that there are correlations between liquidus temperatures of the volcanic rocks and their total alkali content (Na_2O+K_2O) and iron enrichment; represented as FeO+Fe_2O_3/MgO+FeO+Fe_2O_3 ratio. An attempt in the determination of the liquidus temperature from these relations was carried out by plotting TL 210 in previously mentioned composition-temperature diagrams (Tilley et. al. op. cit. pp. 72-9, Figures 1, 2 & 7). Referring to TL 210's late differentiate alkali basalt character, total alkali content of TL 210 gives 1135°c on 'Hebridean trend' and 1150°C on 'Hawaian trend', while that of iron enrichment value gives 1170 °C on 'Hebridean trend' and 1185 °C on 'Hawaian trend'.

However, comparison of the liquidus temperatures estimated from anhydrous and hydrous orthoclase-albite-anorthite systems with that of the liquidus temperatures obtained from iron enrichment and total alkali contents indicate that the benmoreite from Eskişehir was probably formed from a melt whose liquidus temperature was approximately between 1100-1150°C under water pressures less than 5000 bars.

The prominence of olivine (hortonolite) as phenoncrysts and the plotting of TL 210 on the "plagioclase on liquidus" limb of the trend probably suggests that olivine crystals are inherited crystals. This would also explain the abnormality found in the standard norm calculations.

SUMMARY AND CONCLUSIONS

The Tertiary sedimentary rocks of terretrial and lacustrin facies are deposited in the Southern Eskişehir Cuvette border d by highly deformed older series, consisting generally of metamorfic rocks of green and blueschist fades, and mafic and ultramafic rocks of probably Lower Paleozoic or pre-Paleozoic age.

The members of the terrestrial facies are red and yellow coloured grits, sandstones, clays and marls with plant remains. A basal conglomerate rests on and contains boulders of serpentinite. The members of the lacustrine facies, consist of limestones, argillaceous limestones, tuffaceous limestones, tuffs, marls and conglomerate horizons. The matrices and cementing materials of two oligomict conglomerates, a tuffaceous limestone, as well as two different extrusive volcanic rocks (a sillar and a benmoreite) are petrochemically studied.

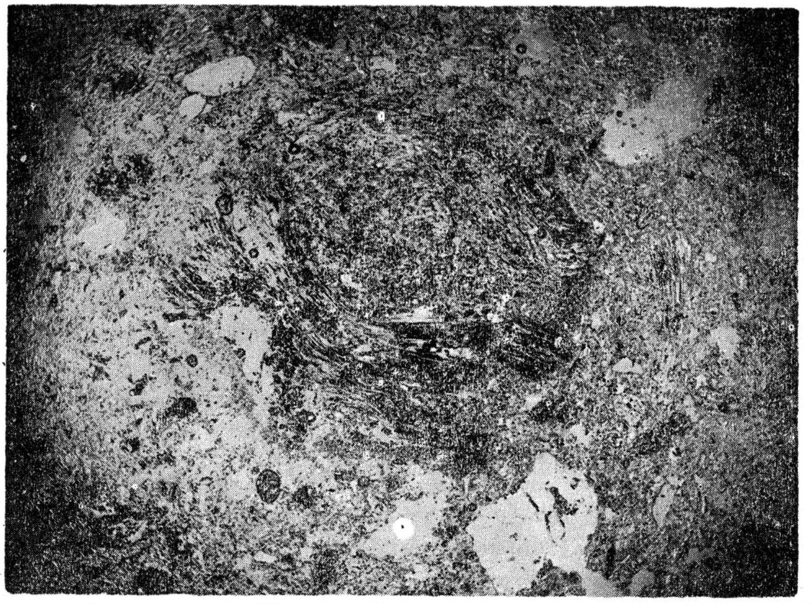
The oligomict conglomerates are dolomitic or calcareous, according to their cementing material. Calcareous conglomerates are dominant; with decreasing amount of detrital material they pass into pure limestones. However, in the neighbourhood of the ultramafic rocks, possibly due to the presence of Mg++ ions in localized depositional areas, dolomite becomes the cementing material. The chemical composition, especially the trace element distribution of the matrices, are controlled by contributions from the source rocks represented by the three major rock units; peridotite, blueschists and greenschists.

The tuffaceous limestone displays a well developed graded bedding structure, with subangular pyroclastic detrital fragments. The turbulent flows comprised of solid and viscous volcanic material and volcanic gasses were probably responsible for the graded bedding in these rocks. The estimated chemical composition of the pryroclastic material is remarkably close to that of a sillar, which strongly suggests that they are a product of a later volcanic activity of similar composition to that of the earlier sillar producing one.

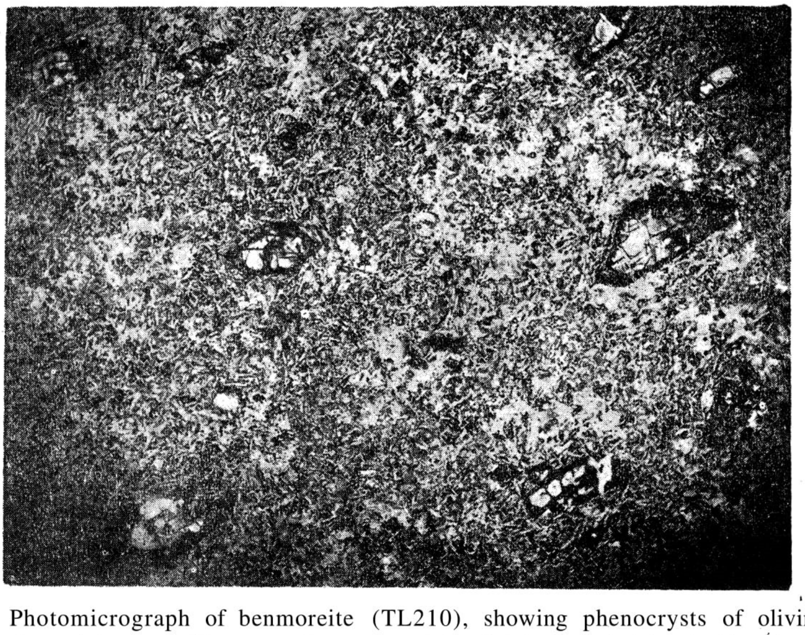
The sillar has a vitrophyric texture with plagioclase, bıotıte and quartz phenocrysts. The glassy material is made of collapsed pumice fragments and broken shards. There is no evidence of welding which suggests that the sillar was formed by settling from clouds of volcanic ash, whose temperature was below 600°C.

The benmoreite is a porphyritic rock with elongated vesicles. The phenocrysts consist of iron rich olivine and very rarely plagioclase and clinopyroxene. The essential chemical characteristics of the benmoreite show that it falls into the late differentiate region of the alkali-basalt series. Benmoreite from Eskişehir was probably formed from a melt whose liquidus temperature was between 1100-1150° C, under water pressures less than 5000 bars.

Plate: 1 — Hand specimen of the calcareous basal conglomerate (TL 212), showing concentrically arranged microcrystalline calcite around the pebbles.



A. Photomicrograph of sillar (TIL 521), showing collapsed and partially devitrified pumice fragments. The matrix consists of glass with broken shards. Magnification 13X.



iS. Photomicrograph of benmoreite (TL210), showing phenocrysts of olivine with iron rich rims. The groundmass consists of interlocked labradorite microliths, prismatic clinopyroxene, a little olivine and minute Mack magnetites. Magnification 13X.

Plate: 2 — Photomicrographs of the volcanic rocks, TL 210 and 521.

The sequence of deposition observed in the Sübren - Karaalan -Yukarıçağlan Triangle, which constitutes a small part of the Souther Eskişehir Cuvette, started with a major acid volcanic activity. The formation of oligomict conglomerates and tuffaceous limestones followed this outburst. The source of these volcanic materials in both sillar and tuffaceous limestone was presumably a series of similarly composed acid volcanic activities which gave rise in their early stages to the unwelded tuffs (sillar). This volcanic activity ceased for a time, as no pyrpclastic material was observed in the matrix or the cementing material of the oligomict conglomerates, and then continued on a smaller scale to produce tuffaceous limestones in a carbonate deposition basin.

Following the formation and erosion of sedimentary and pyroclastic rocks of the lacustrine facies of Lower Miocene age, basic intermediate lava flows of Pliocene age were probably extruded from fissures west-northwest of Yukarıçağlan and spread over both these lacustrine facies and terrestrial facies occuring further north.

Thin bands of Upper Neogene sedimentary rocks consisting of marls and limestones were laid down after the close of the volcanic episode.

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REFERENCES

Boyd, F. R., 1961. Welded tuffs and flows in the Rhyolite Plateau of Yellowstone Park, Wyoming. Geol. Soc. Amer. Bull. 72, 387.

Clarke, F. W., 1924. The data of geochemistry. U.S. Geol. Surv. Bull. 770.

Daly, R. A., 1933. Igneous rocks and the depths of the earth. McGraw-Hill, New York.

Franco, R. R. & Schairer, J. F., 1951. Liquidus temperatures in mixtures of the feldspars of soda, potash and lime. J. Geol. 59, 259.

Kupfahl, H. G., 1954. 55/4 ve 56/3 paftalarının löveleri hakkında yapılan jeolojik inceleme hakkında rapor. M.T.A. Report, No. 2247 (unpublished).

Luth, W. C, Jahns, R. H. & Tuttle, O. F., 1964. The granite system at pressures of 4 to 10 k. bars. J. Geophys. Research. 69, 759.

Lünel, T., 1967. Geology of Sübren - Karaalan - Yukarıçağlan Area, Eskişehir Country, Turkey. Unpublished Ph. D. Thesis.

MacDonald, G. A. & Katsura, T., 1964. Chemical composition of Hawaiian lavas. J. Petrology 5, 82.

Nockolds, S. R., 1954. Average chemical composition of some igneous rocks. Geol. Soc. Amer. Bull. 65, 1007.

Rittmann, A., 1952. Nomenclature of volcanic rocks. Bull. Volcanology, Ser. II, 12, 75.

Schairer, J. F., 1950. The alkali feldspar join in the system $NaAlSiO_4$-$KAlSiO_4$-SiO_2. J. Geol. 58, 512.

Taylor, S. R., 1965. The application of trace element data to problems in petrology, physics and chemistry of the earth. 6, 133.

Tilley, C. E., Yoder Jr., H. S. & Schairer, J. F., 1964-5. Melting relations of volcanic tholeiite and alkali rock series. Yb. Carnegie Instn. Wash. 65, 69.

Yoder Jr., H. S,, Stewart, D. B. & Smith, J. R., 1957. Ternary feldspars. 56, 206.