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Volcanic Rocks of Turkey

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Abstract

Turkey is situated in the Alpine orogenic zone intercalated between African and Eurasian continents. Intense submarine volcanism occurred there repeatedly before the early Tertiary. Probably after the middle Tertiary, it has been a land with nearly the same area as is seen today. About twenty percent of the territory is covered by volcanic products ranging in age from the Oligocene to the Recent, and the post-volcanic action is still going on in some places even today.

Turkish volcanic rocks are mostly those of the calc-alkali rock series derived from alkali olivine basalt magma through fractional crystallization closely related to contamination, accompanied by those of the alkali rock series derived from the same magma through fractional crystallization.

The former is composed of the following rocks; olivine basalt, olivine-augite basalt, augite andesite, hypersthene-augite andesite and andesite whose mafic phenocrysts are some combinations of pyroxene, hornblende and biotite as a result of contamination, with a small quantity of dacite and rhyolite whose phenocrysts are hornblende and biotite.

The latter is composed of olivine trachybasalt, trachyandesite, trachyte, alkali-rhyolite, hawaiite, phonolite and nepheline- or leucite-bearing rocks. Their distribution is nearly all over Anatolia except its southeastern part and their geological ages range from the middle Tertiary to the Quaternary.

Besides spilite and a small quantity of keratophyre are found in the Cretaceous submarine sediments.

1. Introduction

OTA, one of the authors, worked for the Mineral Research and Exploration Institute of Turkey, MTA in Turkish abbreviation, for two years from August, 1971, on the basis of the Middle and Near East Asian and African Technical Co-operation Programme of the Overseas Technical Co-operation Agency of the Japanese Government. He had the opportunity to observe thin sections of various kinds of Turkish rocks, especially those of volcanic rocks, while on duty. Although the rocks collected by himself are all from the eastern Black Sea coast region and sulfur ore deposit areas dotted in West and East Anatolia, the thin sections used are mostly to be found in the repository of the MTA. Ali DINCEL, the other author, co-operated with him in observing thin sections. This paper states their views on Turkish volcanic rocks.

Some of Turkish proper nouns cannot always be put into English correctly, because some of Turkish letters are deficient in Roman letters. In such cases, however, it is customary to put the nouns in question into English, paying more attention to their spelling rather than their pronunciation for the readers' convenience. The name of the highest mountain, for instance, is

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spelt not Auru but Agri, though the former stands for its correct pronunciation.

2. Distribution of Volcanic Rocks and their Geological Ages

The greater part of the present Turkish territory is a part of the Tethys Sea, which is another name for the Paleo-Mediterranean Sea, where submergence, sedimentation, folding, upheaval and erosion have followed one after another repeatedly from ancient times to the present day. Turkey is composed of many kinds of sedimentary rocks deposited through all the periods of geological age, in which are intercalated the green rock series peculiar to the Alpine orogeny, volcanic and plutonic rocks of various geological ages, which erupted or intruded respectively in connection with the orogenic movements, and metamorphic rocks resulted from these movements.

The volcanic rocks are found even in the rocks of such times as Precambrian and Ordovician-Silurian, and are observable in the green rock series ranging in age from the late Cretaceous to the early Paleocene. This series is extensively distributed in the Pontic orogenic zone along the present-day Black Sea coast, where various kinds of volcanic rocks ranging from basic to acidic are intercalated in sedimentary rocks, while the series, extensively developed on the Anatolian Heights, abounds in ultrabasic rocks and is poor in other kinds of igneous rocks.

An upheaval took place in the period from the late Eocene tc the Oligocene and the present Turkish land gradually emerged by the end of the Tertiary. The Tertiary volcanic rocks ranging in age from the Oligocene to the Pliocene are mostly terrestrial, but their original volcanic topographyh as been nearly lost.

As the Quaternary volcanoes, Agri, Tendurek, Suphan, Nemrut, Erciyas, Hasan, Haravil,

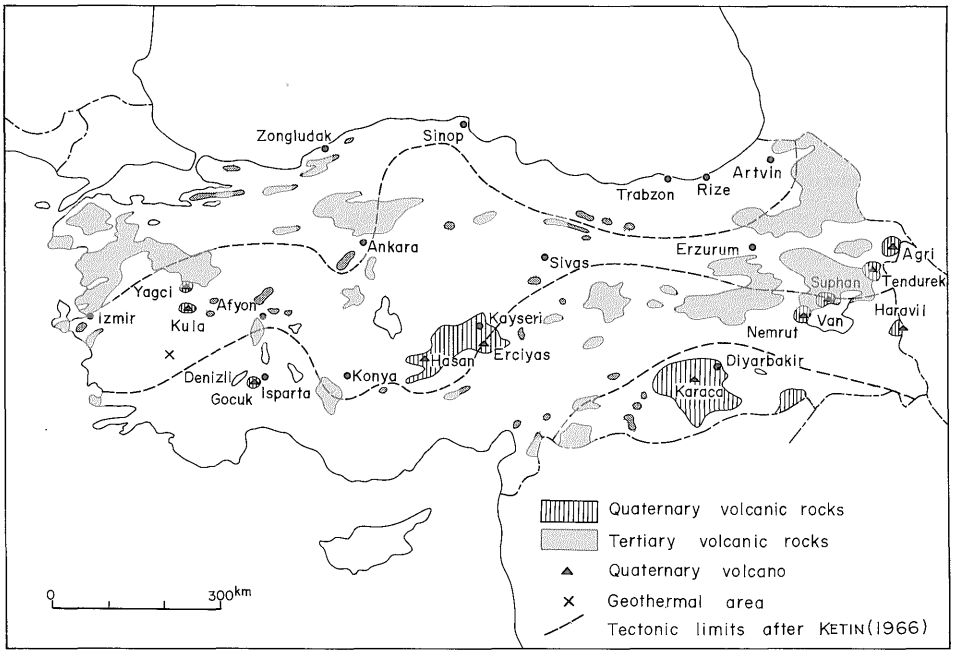

Fig. 1 Distribution of the Tertiary and the Quaternary volcanic rocks in Turkey.

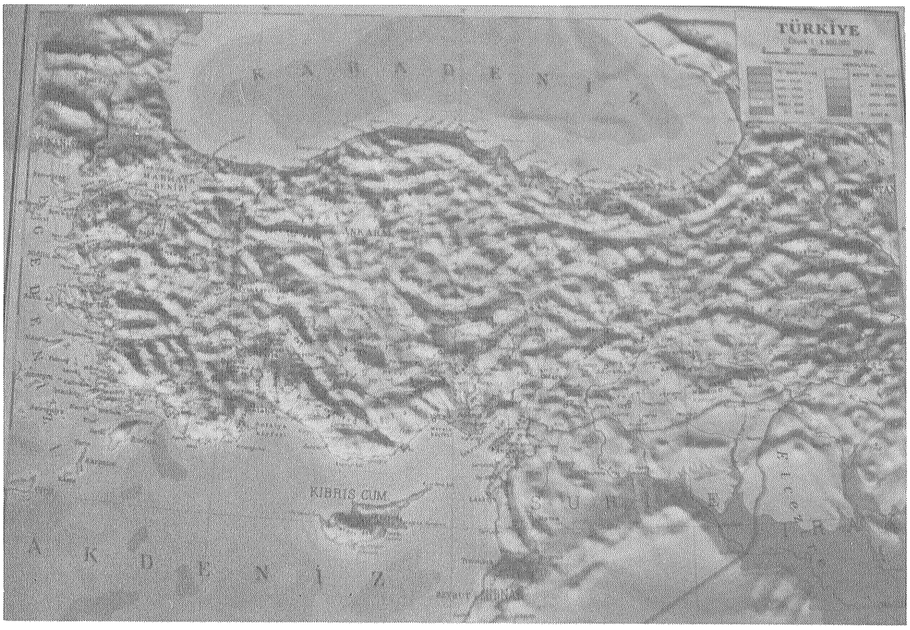

Fig. 2 Topographic model of Turkey, in which mountain ranges are conspicuous in the E-W trend.

Kula, Yagci, Gocuk and Karaca can be cited (Fig. 1). The activity of these volcanoes ranges in age from the late Neogene to the Recent, some of them being still active in post-volcanic action. Haravil on the boundary between Turkey and Iran, and Gocuk near Isparta can be included in the Quaternary volcanoes, because their post-volcanic action is still active, though they have never been regarded as of the mentioned geological age.

The mountain ranges in Turkey are mostly fold mountain ranges caused by the Alpine orogeny and show general trend of the E-W direction (Fig. 2). Referring to the relation between the Quaternary volcanoes and the geotectonics, the former are mostly situated on tectonic lines,

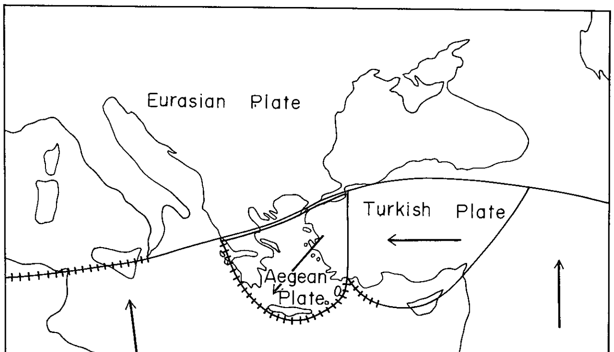

Fig. 3 Approximate positions of plate boundaries active at present. The directions of motion relative to the Eurasian plate are shown with arrows. Boundaries creating lithosphere are shown with a double line and boundaries consuming plates with short lines at right angle to them (after McKENZIE, 1970).

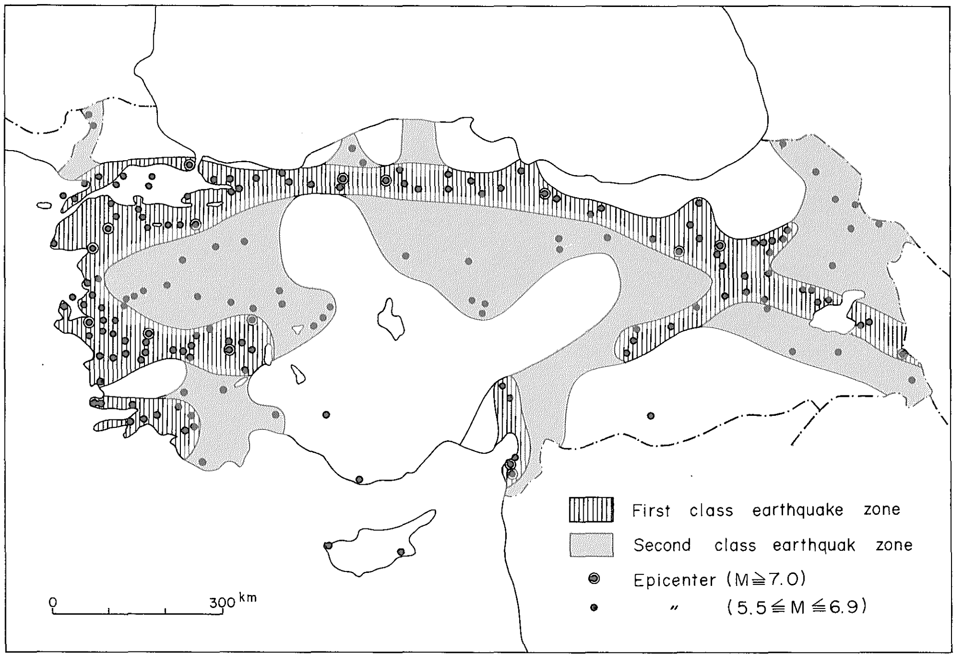

Fig. 4 Earthquake zones with epicenters in Turkey, arranged from OMOTE's report (1968).

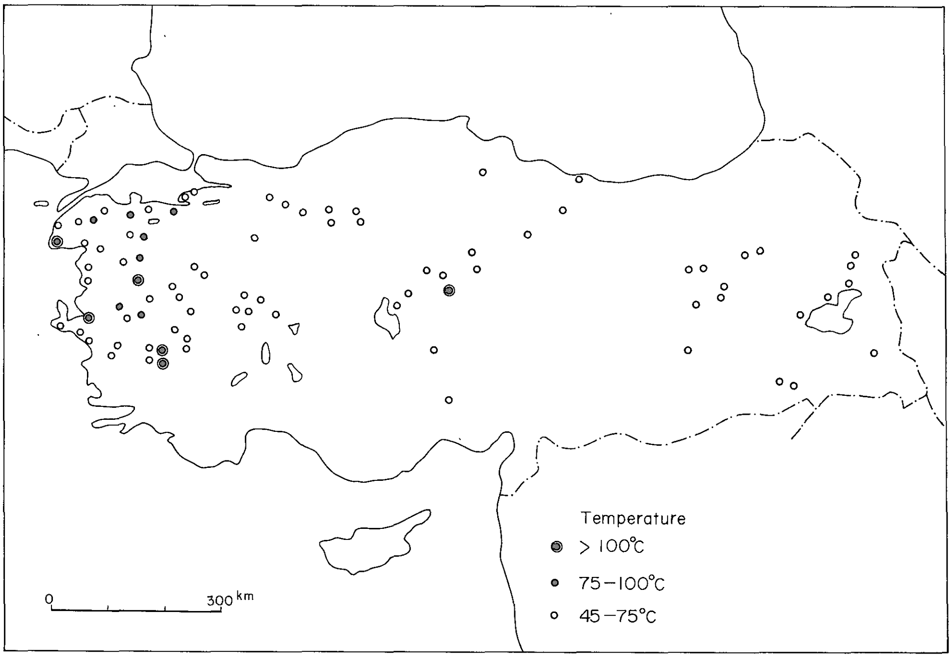

Fig. 5 Distribution of hot springs in Turkey, arranged from a MTA pamphlet.

namely, Erciyas and Hasan are on tectonic lines nearly in the E-W direction as is shown by KETIN(1966), and Agri, Tendurek, Suphan and Haravil on the mentioned lines nearly in the same direction as is shown by ALTINLI(1966) respectively, though all of the tectonic lines are not shown in Figure 1. Nemrut may also be on a tectonic line, because contamination phenomena seen in the rock is as remarkable as those in the rocks of the mentioned volcanoes. Though Agri, Tendurek, Nemrut and Suphan appear to be situated on a tectonic line which is oblique to the direction of the Alpine orogeny, the fact is that every one of them is on minor tectonic lines nearly parallel to the mentioned direction respectively.

According to McKENZIE(1970), there exist two small rapidly moving plates, or Turkish and Aegean plates, in the eastern Mediterranean region, intercalated between African and Eurasian plates (Fig. 3). Yagci and Kula volcanoes and a geothermal area near Denizli appear to be situated on the boundary between Turkish and Aegean plates. Plateau basalt lavas headed by Karaca Volcano, needless to note, represent a continental form of volcanism contrasting with the differentiated assemblages in Anatolia. It is well-known in Japan that distribution of not only volcanoes and epicenters but also hot springs is closely related to geotectonics. The distribution of epicenters and hot springs, over 45°C, in Turkey is shown in Fig. 4 and Fig. 5 respectively. Even though mutual relationship among volcanoes, hot springs, epicenters and geotectonics has never been discussed from the genetical point of view in Turkey, it seems that they are closely related with each other from the collective consideration of the mentioned four figures. Incidentally Bouguer anomaly map of Turkey has not been made public yet.

3. Pre-Tertiary Volcanic Rocks

The oldest volcanic rocks in Turkey are rhyolite and andesite dikes found in the Precambrian formation in the southeastern part of Anatolia near the boundary between Turkey and Syria. There is tuff in the Ordovician-Silurian formation in the southeastern corner of Anatolia, quartz-bearing andesite, partly silicified tuff and hornblende-biotite andesite in the Permo-Carboniferous formation in the east of the Black Sea coast region, and quartz-bearing andesite in the early Jurassic formation in the east and the middle of the same region.

The green rock series is extensively distributed nearly all over Turkey, ranging in age from the late Cretaceous to the early Paleocene. Especially in the Pontic folding zone along the Black Sea coast, sedimentary rocks of the flysch stage, in which various kinds of volcanic rocks are predominant, are widely distributed. According to KAWADA's unpublished report in the MTA, the volcanic stratigraphy near Cayeli, Rize, for instance, is as follows.

Quaternary	Alluvium
	Terrace deposit
	Volcanic conglomerate
Paleocene	Andesite dikes
	Andesite tuff breccia
	Andesite lava
	Dacite lava & welded tuff

Late Cretaceous:
- (Intrusion of granitic rocks)
- Upper basic series
- Lower dacitic series
- Lower basic series

The lower basic series is composed mainly of spilite, spilitic basalt and keratophyre with a comparatively small quantity of pyroclastics. The lower dacitic series, or the host rock of copper ore deposits in this area, is composed mainly of altered lavas and pyroclastics of dacite and rhyodacite. The upper basic series is composed of altered lavas and pyroclastics of olivine basalt, augite-olivine basalt and augite andesite. The above-mentioned rocks have undergone remarkable alteration.

The dacite lavas of Paleocene age have more or less undergone alteration, but the mafic phenocrysts of comparatively fresh ones are hornblende. The andesite lavas of the same age, more or less altered, are augite andesite. The above-mentioned andesite dikes are composed of augite andesite, pyroxene-hornblende andesite and hornblende andesite, all of them being free from alteration. Spilite and keratophyre found in the Pontic folding zone are described as follows.

Spilite found in Surmene, Rize

Under the microscope, it is porphyritic in texture. The phenocrysts are composed of albitized plagioclase, 0.2–0.3 mm in length, and chlorite pseudomorph after olivine or pyroxene. Magnetite appears as a microphenocryst. The groundmass is subophitic or ophitic in texture with albitized plagioclase, chlorite, occasionally accompanied by epidote, magnetite, ilmenite and other accessory minerals, and it is remarkably traversed by chlorite veinlets and rarely by quartz ones. Often it has cavities filled with zeolite or calcite.

Keratophyre found in Mulgul, Artvin

According to the authors' presumption, occurrence of keratophyre has never been officially reported in this country. Under the microscope, it is porphyritic in texture. The phenocrysts are composed of plagioclase, potassium felspar, quartz and epidote-chlorite pseudomorph. The plagioclase, andesine, is 0.3–0.8 mm in length, being columnar or fragmental. It is turbid, occasionally abounding in minute grains of chlorite. The potassium felspar is nearly the same as the plagioclase in size, being turbid as well. The quartz, 0.3–1.2 mm in diameter, is mostly fragmental in shape and transparent. Original name of the epidote-chlorite pseudomorph cannot be presumed from its outer crystal form. The groundmass is composed of two parts, nearly equal in quantity; one is trachytic in texture with felspar microlites, 0.02–0.1 mm in length, and interstitial chlorite, and the other is holocrystalline with comparatively coarse-grained quartz, about 0.05 mm in diameter, accompanied by a small quantity of plagioclase, epidote, chlorite and dotted ilmenite. The former is irregularly or reticulately penetrated by the latter. The mentioned felspar microlites are considerably albitized. This rock is impregnated with minute grains of iron sulfide, 0.02 mm in diameter.

4. Tertiary Volcanic Rocks

Distribution of the Tertiary volcanic rocks is shown in Fig. 1. The following seven districts, in which the Tertiary volcanic rocks are widely distributed, are described. The distribution of volcanic rocks on the geological sheet maps, 1:500,000 in scale, is printed with one kind of color with several signs which indicate the several kinds of rocks, e.g., basalt, andesite, rhyolite and so on, regardless of their geological ages, origins of eruption and other details. Accordingly there might be a little confusion as to the mentioned points in the following descriptions.

4.1 The District to the North of Lake Van

According to Altinli(1966) and the geological sheet map "Van", this district is composed of thick piles of basalt, andesite, rhyolite, trachyte and other rocks, the first two being of a large quantity. The basalt is of Oligocene and Miocene ages and the andesite is mostly of Miocene age.

Thin sections, 24 pieces in all, of the volcanic rocks in the district, stored in the MTA, can be classified as follows under the microscope. Those safely supposed to be of the Quaternary are omitted here.

Olivine basalt	7
Augite-olivine basalt	4
Olivine-augite basalt	1
Olivine-augite andesite	1
Augite andesite	1
Hypersthene-augite andesite	6
Biotite-hypersthene-augite andesite	1
Dacite	1
Rhyolite	1

Every section of olivine basalt contains phenocrystic plagioclase, its groundmass being intergranular or subophitic with plagioclase, monoclinic and rhombic pyroxenes and other accessory minerals. The phenocrysts of the andesite are composed of plagioclase, augite and hypersthene, or plagioclase and hypersthene, often containing sodic plagioclase or biotite xenocrysts. Their groundmass is composed of plagioclase, monoclinic and rhombic pyroxenes, iron ore and other accessory minerals.

4.2 Erzurum District

According to the geological sheet map "Erzurum", volcanic rocks, composed mainly of basalt and andesite with a small quantity of trachyte, are extensively distributed. The basalt is of post-Miocene age and composed not only of plateau lava but also of the lava which accompanies pyroclastic rocks. The andesite, generally speaking, is composed mainly of lavas, which are found in or on the Miocene formation. As to the geological age of the trachyte, it is unknown in this district, but the rock is intercalated in flysch of the Eocene in the Trabzon sheet map area.

Thin sections, 35 pieces in all, of the volcanic rocks in this district, stored in the MTA, can be classified as follows under the microscope.

Olivne basalt	3
Augite-olivine basalt	4
Hypersthene-olivine basalt	1
Aphyric basalt	1
Augite andesite	1
Olivine-augite andesite	1

Augite andesite	5
Hypersthene-augite andesite	2
Hornblende-bearing hypersthene-augite andesite	2
Biotite-hornblende andesite	2
Hornblende andesite	2
Aphyric andesite	1
Hornblende dacite	1
Pyroxene-hornblende-biotite dacite	1
Dacite	1
Hornblende-biotite rhyolite	3
Rhyolite	1
Olivine trachybasalt	1
Augite trachyandesite	1
Trachyte	1

The alkali rocks are to be described in another chapter. The geological ages of the mentioned rocks are unknown, but they surely do not come from active volcanoes. They are supposed to be mostly of Tertiary and partly of Quaternary ages. The aggregates of pyroxene grains, which are supposed to have grown from opacite by the reaction with the magma, are found in the olivine basalt. The opacite is generally believed to be an altered product mainly due to reheating from hornblende or biotite which was originally contained in acidic rocks. Accordingly the basalt seems to have been contaminated by granite or granitic rocks. The hypersthene phenocryst in the hypersthene basalt is probably a xenocryst captured into aphyric basalt, because it has a reaction rim composed of monoclinic pyroxene grains along its margin. The unusual combination of phenocrystic mafic minerals in some of the andesites and the dacites, and the occasional existence of xenocrysts such as sodic plagioclase and opacite in these rocks suggest that contamination by acidic rocks took place on a remarkable scale.

4.3 Sivas District

According to the geological sheet map "Sivas", basalts, mostly olivine basalt accompanied by a small quantity of hyalo-basalt and enstatite basalt, are mainly of Neogene age. Andesites, mostly augite andesite often accompanied by biotite or quartz as additional phenocrysts, and a nepheline-bearing rock are found intercalated in sedimentary rocks of Eocene and often of Neogene ages.

Thin sections, 25 pieces in all, of the volcanic rocks in this district are classified as follows.

Olivine basalt(without phenocrystic plagioclase)	1
Olivine basalt(with phenocrystic plagioclase)	1
Augite-olivine basalt	7
Augite andesite	1
Hypersthene-augite andesite	2
Opacite-bearing pyroxene andesite	2
Pyroxene-hornblende andesite	2
Hornblende-biotite andesite	1
Hornblende andesite	1

Biotite andesite	1
Hornblende dacite	1
Biotite-hornblende dacite	1
Biotite dacite	1
Rhyolite	2
Hornblende trachyte	1

Referring to kinds of their groundmass mafic silicate minerals, the basalts have olivine and monoclinic pyroxene, the andesites without phenocrystic hornblende have monoclinic and rhombic pyroxenes, and the andesites with phenocrystic hornblende and the dacites have only rhombic pyroxene, occasionally accompanied by hornblende and biotite. But the last mentioned two mafic minerals were produced not on the surface, but under the ground. They remain as they were without undergoing opacitization because of the comparatively low temperature and rapid cooling of the magma at the time of flowing out on the surface, as glassy texture of the groundmass suggests.

The mentioned rocks, generally speaking, show contamination phenomena. Some of the augite-olivine basalt contain xenocrysts of quartz or potassium felspar, both surrounded by a reaction rim of pyroxene grains, or aggregates of pyroxene grains which seem to have grown from opacite. In the opacite-bearing pyroxene andesite, a parallel intergrowth of hypersthene and augite, in which the former is surrounded by the latter, is found. The mentioned parallel intergrowth is commonly observable in contaminated rocks. Referring to the chemical composition of phenocrystic plagioclase, it is bytownite close to labradorite in the olivine basalt, labradorite in the andesite and labradorite close to andesine in the dacite.

The alkali rock is to be described in another chapter.

4.4 Konya District

According to the geological sheet map "Konya", volcanic rocks, extensively distributed about 30 km west of Konya, are composed mainly of andesite, but details are unknown because it has no explanatory text. Thin sections, 13 pieces in all, of the volcanic rocks in this district, stored in the MTA, can be classified as follows.

Quartz-bearing hypersthene-augite andesite	1
Pyroxene-bearing hornblende andesite	1
Pyroxene-bearing hornblende-biotite dacite	3
Hypersthene-augite-biotite dacite	2
Hornblende-biotite dacite	2
Biotite dacite	4

The above-mentioned rocks often contain remarkably corroded sodic plagioclase and extraordinarily abound in cristobalite in the groundmass and cavities. Considering the combination of the mafic phenocrysts in addition to the mentioned facts, the various kinds of rocks mentioned were derived from pyroxene andesite magma which had been contaminated by granite or granitic rocks.

4.5 Ankara District

Volcanic rocks are widely distributed to the north of Ankara. Thin sections of the volcanic rocks in this district, 31 pieces in all, which are stored in the MTA, can be classified as follows.

Olivine basalt	2
Aphyric andesite	3
Augite andesite	2
Opacite-augite andesite	2
Hypersthene-augite andesite	2
Hornblende-hypersthene-augite andesite	2
Opacite-hypersthene-augite andesite	5
Biotite-hornblende-hypersthene-augite andesite	1
Quartz- and biotite-bearing hypersthene-augite andesite	2
Biotite-hypersthene-augite andesite	2
Hypersthene-hornblende andesite	1
Hornblende andesite	2
Biotite-hornblende andesite	3
Biotite dacite	2

One of the two pieces of olivine basalt does not accompany phenocrystic plagioclase, but the other accompanies a small quantity of it. Their groundmass mafic minerals are olivine and monoclinic pyroxene. The pyroxene andesite and the aphyric andesite rarely contain plagioclase xenocrysts, corroded and turbid. The hornblende- and biotite-bearing pyroxene andesites and the andesites, the main phenocryst of which is hornblende, abound in xenocrystic plagioclase. They also contain phenocrystic plagioclase with abundant dust inclusions, cristobalite which is extraordinarily rich in the groundmass and cavities, glomeroporphyritic aggregates or small spherical patches filled by quartz. From the above-mentioned facts and the combination of mafic phenocrysts, the mentioned andesites seem to have been contaminated by granite or granitic rocks to produce the above-mentioned various kinds of rocks.

4.6 The District around Afyon

According to KELLER & VILLARI(1971), the geology around Afyon is as follows: To the south of Afyon, trachyandesitic to trachytic lavas and breccias, associated with leucite-bearing lavas and tuff breccias, are distributed. They are of the upper Miocene to lowermost Pliocene. The ignimbrite sheets to the north of Afyon cover an area of about 2,000 km^2 with the maximum thickness of 300m. They are rhyolitic and are of the Pliocene. In their opinion, the sheets are of an anatectic origin of rhyolitic melt, and are not related to the above-mentioned and the following lavas from the genetical point of view. The basic lavas which overlie the ignimbrite sheets are of the upper Pliocene to lowermost Pleistocene, some of which carrying leucite in the groundmass.

4.7 The District to the North of Izmir

BORSI *et al.* (1972) and INNOCENTI & MAZZUOLI (1972) made geochronological and petrological studies on the volcanic rocks extensively distributed around and to the north of Izmir. According to them, the volcanic rocks are of the early and middle Miocene. They are mostly trachyandesite, andesite, dacite and rhyodacite with a small quantity of alkali basalt, hawaiite, alkali trachyte and alkali rhyolite. Ignimbrite widely distributed 120 km NW of Izmir is rhyodacitic.

OTA was able to collect rock samples at seven sulfur prospects when he made an investigation trip there. The rocks are classified as follows.

Augite andesite	1
Hornblende-, biotite- and quartz-bearing augite andesite	1
Biotite-bearing augite andesite	4
Biotite- and augite-bearing hornblende andesite	1

All of the mentioned rocks always contain xenocrysts of sodic plagioclase and biotite, rarely hornblende and quartz. Some of them abound in glomeroporphyritic aggregates. Their groundmass is pilotaxitic with plagioclase, monoclinic and rhyombic pyroxenes (rarely the latter only), often tridymite being produced in cavities.

5. Quaternary Volcanoes and their Rocks

Distribution of the Quaternary volcanic rocks is shown in Fig. 1. Every Quaternary volcano is described as follows.

5.1 Agri Volcano (5,185m)

It rises near the boundary on the USSR and Iran in the easternmost area of Turkey. Its other name is Ararat, which is well-known for the Biblical story stating that it is the place where Noah's ark drifted ashore (Fig. 6). According to ALTINLI (1966) and the geological sheet map "Van", it is a composite volcano, composed of Great Agri and Little Agri (3,925m). The former is a strato-volcano with an explosion caldera at the top. Out of many craters at the top and mountain-side, lavas and pyroclastic rocks were erupted. The lavas are more than the pyroclastic rocks in quantity. The latter is 12 km southeast of the former. It is a strato-volcano with an explosion caldera at the top. The lavas of the two volcanoes are mostly hypersthene-augite andesite, accompanied by a little more basic or acidic lavas. But the Great Agri has olivine-andesine basalt at the top. The last volcanic activity occurred in the Quaternary period. This volcano is older than Tendurek Volcano, because no post-volcanic action is reported there.

Microscopic observation of five thin sections of this volcano which are stored in the MTA is as follows. They are hypersthene-augite andesite. The phenocrysts are composed of plagioclase, hypersthene and augite. The plagioclase has an intermediate chemical composition between

Fig. 6 Agri Volcano, the highest mountain in Turkey.

Fig. 7 Tendurek Volcano, covered by block lava flowed out of a crater at the top.

bytownite and labradorite. It is euhedral with a turbid interior, wholly or zonally, surrounded by a clear zone at the periphery. The groundmass is commonly pilotaxitic with plagioclase, monoclinic and rhombic pyroxenes, iron ore and other accessory minerals.

5.2 **Tendurek Volcano**(3,542m)

It rises between Agri Volcano and Lake Van. According to ALTINLI(1966) and the geological sheet map "Van", it is a strato-volcano with an explosion caldera at the top and is composed mostly of andesite. Finally it erupted basalt pyroclastics, followed by basalt block lava during the Recent(Fig. 7).

OTA, one of the authors, visited sulfur ore deposits at the southern foot of this volcano. Post-volcanic action, e.g., steaming out of fumaroles, impregnation of sulfur and gushing-out of hot springs, is still active there. He had an opportunity to look over the block lava which widely covered the volcano. The activity is safely supposed to be of the Recent, from fresh appearance of the block lava and the post-volcanic action which is still active.

The block lava in question, compact and black, looks like basalt. Under the microscope, however, it is olivine-augite trachyandesite, in which opacite pseudomorph after biotite and remarkably corroded plagioclase xenocrysts are contained. In addition, biotite granite is exposed about 20 km west of the top of this volcano. OTA did not ascertain whether there is andesite under the block lava or not. But, judging from the above-mentioned facts, it seems that the block lava is an evolved one from fairly mafic magma contaminated by biotite granite.

5.3 **Suphan Volcano**(4,434m)

It rises on the north shore of Lake Van. According to ALTINLI(1966) and the geological sheet map "Van", it is a strato-volcano composed mainly of hornblende andesite with a scoria mound in a caldera at the top. It erupted ash, followed by obsidian, during the Recent.

Two thin sections of this volcano which are stored in the MTA are hypersthene-augite-hornblende andesite, often accompanied by sodic plagioclase xenocrysts.

5.4 **Nemrut Volcano**(2,408m)

It rises on the west shore of Lake Van. According to ALTINLI(1966) and the geological sheet map "Van", it is a comparatively flat and low strato-volcano, composed mainly of hornblende andesite lavas and pyroclastic rocks, with an explosion caldera at the top, in which mofettes exist. The latest explosion happened at the mountain-side to erupt pumice, ash and obsidian.

Two thin sections of this volcano which are stored in the MTA are pyroxene-hornblende andesite and augite-hornblende andesite respectively, both being rich in sodic plagioclase xenocrysts.

5.5 Erciyas Volcano(3,918m)

It rises to the south of Kayseri in central Anatolia. According to BEEKMAN(1966) and the geological sheet map "Kayseri", it is a composite volcano composed of many volcanic bodies headed by Erciyas with ten and several craters. It is composed mostly of andesite lavas and pyroclastic rocks with a small quantity of basalt lava. The pyroclastic rocks are extensively distributed around the volcano. It is said that the activity of this volcano began in the late Miocene and continued through the Quaternary with the latest activity in the historic times.

The microscopic observation of the lavas is to be mentioned together with those of Hasan Volcano.

5.6 Hasan Volcano(3,253m)

It rises about 120 km to the southwest of Kayseri in central Anatolia. According to BEEKMAN (1966) and the geological sheet map "Kayseri", it is a composite volcano including Hasan, the highest mountian, and next Melendiz(2,935m) and others, and it has several craters in the volcanic area. The volcano is composed of basalt lavas and pyroclastic rocks with a small quantity of andesite. The pyroclastics are extensively distributed around the volcano. It is said that the volcanic activity began in the late Miocene and continued through the Quaternary. A wall-painting of about 6,000 years ago in a shrine in ruins at Catal Huyuk (near present Konya) shows a scene of volcanic eruption, probably of Hasan (MELLARRT, J., 1965).

Thin sections, 30 pieces altogether, from the Erciyas-Hasan district which are stored in the MTA can be classified as follows.

Olivine basalt (without phenocrystic plagioclase)	2
Olivine basalt (with phenocrystic plagioclase)	1
Augite-olivine basalt	4
Hypersthene-augite andesite	4
Hornblende-bearing augite andesite	3
Hornblende-hypersthene-augite andesite	2
Biotite-hypersthene-augite andesite	3
Biotite-hornblende-hypersthene-augite andesite	3
Hypersthene-augite-biotite-hornblende andesite	5
Biotite-hornblende andesite	1
Biotite andesite	1
Biotite dacite	1

In the basalts, there is little trace of contamination. The chemical composition of plagioclase which coexists with olivine is bytownite(An around 80). The groundmass mafic silicate minerals are olivine and monoclinic pyroxene, but rarely the latter only. In the pyroxene andesites, the evidences of contamination are not so remarkable, but plagioclase with a turbid interior surrounded by a clear margin is often observable. The pyroxene andesites which accompany hornblende and biotite always have evidences of contamination which are to be given in chapter 8, e.g., corroded and turbid plagioclase, glomeroporphyritic aggregates and others. The hornblende and the biotite always underwent opacitization; some of them are wholly opacitized and the others have remarkably pleochroic interiors surrounded by an opacite margin due to oxidation.

Karaca Volcano, which rises 40 km to the SSW of Hasan Volcano, belongs to the Erciyas-Hasan volcanic area, too. Thin sections of the volcano, which are stored in the MTA, are classified as follows.

Augite-olivine basalt	2
Augite andesite	1
Quartz- and opacite-bearing olivine-augite andesite	2
Augite-hornblende andesite	1
Augite-hornblende-biotite dacite	3
Augite (rarely hypersthene)-bearing hornblende-biotite dacite	10
Hornblende-biotite dacite	3

All the rocks, except the first two, show remarkable phenomena of contamination, i.e., xenocrysts of corroded sodic plagioclase and quartz surrounded by pyroxene grains, aggregates of pyroxene grains which seem to have grown from opacites and plagioclase phenocrysts which have remarkably turbid interiors with clear marginal zones are present.

5.7 Haravil Volcano (about 3,500m)

It rises on the boundary between Turkey and Iran, 150 km southeast of Lake Van. It is composed of andesite lavas and pyroclastic rocks with a small quantity of rhyolite pumice flow. It has never been looked upon as one of the Quaternary volcanoes, but it is presumably of Quaternary age, because its post-volcanic action is still active, i.e., steaming out of fumaroles, impregnation of sulfur and gushing-out of hot springs are arranged on three parallel tectonic lines in the basement rocks to the south of the volcano.

At the northwestern foot of this volcano, trachybasalt forms lava plateaus (Fig. 8), which seem to be a little older than the volcano.

The six rock samples of this volcano collected by Ota can be classified as follows.

Olivine-augite andesite

Olivine-hypersthene-augite andesite

Olivine-bearing biotite-hypersthene-augite andesite

Fig. 8 A trachybasalt lava plateau to the northwest of Haravil Volcano.

Olivine-bearing hornblende-biotite-hypersthene-augite andesite

Opacite-augite andesite

Biotite-hornblende-hypersthene-augite andesite

The hornblende and the biotite are partly or wholly opacitized. These rocks are supposed to have been formed as a result of contamination by granite or granitic rocks into pyroxene andesitic magma, judging from the combination of the mentioned mafic phenocrysts and the fact that every thin section always contains corroded and turbid plagioclase xenocrysts and aggregates of pyroxene grains which are presumed to have grown from opacites.

At the south of this volcano, biotite rhyolite pumice flow (partly welded) is found, supposedly having come from this volcano (Fig. 9). The trachybasalt at the northwestern foot is augite-olivine trachybasalt, which contains olivine and augite phenocrysts and rarely corroded plagioclase xenocrysts.

5.8 Kula Volcano(about 1,500m)

Kula Volcano, situated 130 km east of Izmir, is well-known for the name of "Kulaite", which was primarily described by WASHINGTON (1894). According to him, it is a kind of amphibole-nepheline tephrite, being light grey, fine-grained and slightly vesicular. Under the microscope, it shows a porphyritic texture with phenocrysts of pale green diopside, olivine and altered hornblende in a holocrystalline groundmass composed of bytownite laths, diopside, magnetite and an ill-defined mesostasis of nepheline and orthoclase. "Kulaites" can be classified as nepheline trachyandesite according to COOMBS and WILKINSON(1969).

Recently BORSI *et al.*(1972) made a geochronological and petrological study on the volcanic rocks in the eastern Agean Sea region. According to them, the volcanic history of Kula Volcano is as follows: The first volcanic activity, 1.1 million years ago determined by K-Ar method, is

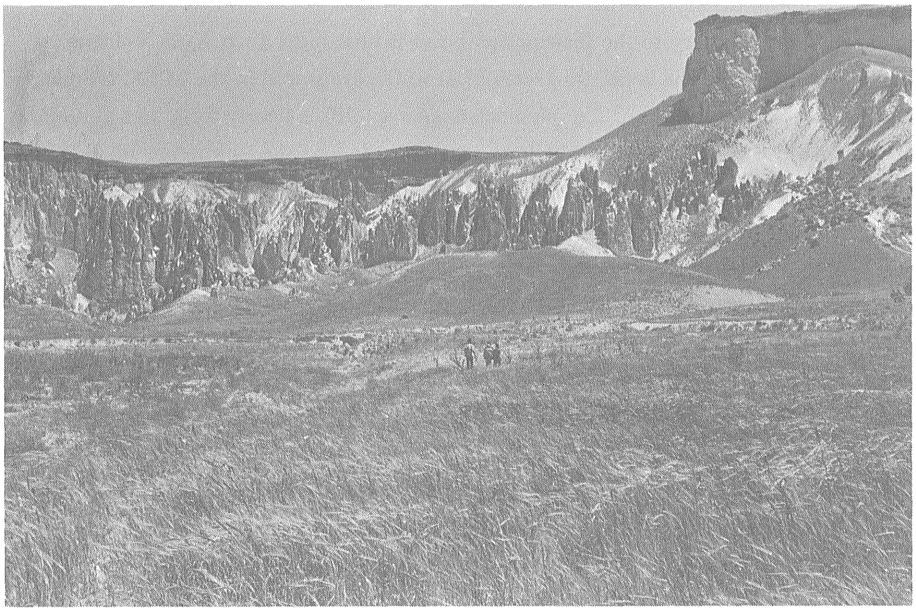

Fig. 9 A cliff made of pumice flow to the south of Haravil Volcano.

represented by plateau-forming lava flows with superimposed strato-volcanoes. The activity continued up to almost the historic times forming cinder and spatter cones and huge amounts of lava. All these products consist of undersaturated moderately potassic rocks. The recent lavas generally contain phenocrysts of olivine, clinopyroxene and amphibole with plagioclase (calcic andesine to sodic labradorite) usually confined to the groundmass in frequent association with nepheline. In the ancient lavas, however, amphibole is rarely present.

Thin sections of this volcano which are stored in the MTA can be classified as follows, although their exact localities are unknown.

Opacite (hornblende)-bearing olivine-augite trachyandesite	4
Olivine-bearing hornblende-augite trachyandesite	4
Olivine-hornblende-augite trachyandesite	3
Hornblende-augite trachyandesite	2

These rocks are usually compact, but occasionally porous. They are porphyritic in texture, their phenocrysts being composed of two or three of olivine, hornblende and augite. Phenocrystic plagioclase (labradorite) rarely appears, being small in size. The olivine is prismatic and partly iddingsitized. The augite often shows zonal struture. The hornblende includes augite and is often wholly or partly opacitized. The groundmass is hyalopilitic or glassy with plagioclase (andesine), olivine, monoclinic pyroxene and other minor minerals accompanied by numerous minute grains of iron ore and black glass. It is a noteworthy fact that aggregates of large-sized potassium felspar, xenocrystic sodic plagioclase, aggregates of minute pyroxene grains which seem to have grown from opacites and rarely aegirine-augite are observable.

5.9 Yagci Volcano(1,511m)

It is about 40 km northeast of Kula Volcano. According to the geological sheet map "Izmir", it has nine distinct craters. According to CROWFORD(1964), it is composed of biotite dacite and hornblende-biotite dacite lavas accompanied by pyroclastic rocks, and its geological age ranges from the younger Tertiary to the Pleistocene, being a little older than Kula Volcano.

The phenocrysts of the lavas, thin sections of which are stored in the MTA, are plagioclase, quartz, hornblende and biotite. The plagioclase (An 45–48) is nearly fresh and abundant. The quartz is corroded and abundant. While the hornblende and the biotite are of small size and small quantity. They are marginally opacitized with remarkably oxidized interiors showing strong pleochroism.

5,10 Cocuk Volcauo(abont 1.500 m)

It rises to the west of Isparta. It is a comparatively low volcano with a depression caldera of about 2 km in diameter, in which a central cone exists. At the northern outside of the somma, post-volcanic action, e.g., steaming out of fumaroles, impregnation of sulfur, gushing-out of hot springs and other phenomena, is still active. The somma is composed of an alternation of lavas and pyroclastic rocks. The somma lava is augite andesite, which contains biotite considered to be xenocrysts. Its groundmass is pilotaxitic with plagioclase, monoclinic and rhombic pyroxenes accompanied by plenty of apatite. The central cone lava resembles the above-mentioned lava with the exceptions that the biotite is larger in size and the apatite is greater in quantity. Though this volcano has never been regarded as one of the Quaternary volcanoes, it ought to be one of them.

5.11 Karaca Volcano(1,919m)

The rock of this volcano is extensively distributed to the southwest of Diyarbakir. According to the explanatory text of the geological sheet map "Diyarbakir", it is a Pleistocene plateau basalt flowed out of numerous craters. Rocks of the same kind are found not only in the neighbourhood of Cizre, 150 km east from here, but also at several places in Syria. Of three thin sections of this volcano which are stored in the MTA, one is olivine basalt and the rest are augite-olivine basalt. The former does not accompany phenocrystic plagioclase and its groundmass mafic silicate minerals are olivine and monoclinic pyroxene. The latter accompanies phenocrystic plagioclase (An 68–72) and contains glomeroporphyritic aggregates composed of augite, plagioclase and magnetite. Its groundmass mafic silicate minerals are olivine and monoclinic pyroxene or monoclinic pyroxene only. The latter can be regarded as an evolved type of the former.

6. Alkali Volcanic Rocks

The Cenozoic alkali volcanic rocks in the Mediterranean region constitute the Mediterranean petrographic province, which is characterized by high K_2O content. Olivine trachybasalt, trachyandesite, trachyte and alkalirhyolite accompanied by leucite, phonolite and

Table 1 Alkali rocks in Turkey.

Alkali rocks / Sheet map area	Description of alkali rocks in the explanatory texts of the sheet maps and other theses	Alkali rocks which the authors have found in the course of their microscopic observation
Van		trachybasalt trachyandesite
Trabzon	trachyte leucite-bearing rock*	trachyte
Erzurm	trachyte	trachybasalt trachyandesite trachyte
Diyarbakir		trachyandesite
Sivas	"nepheline-bearing andesite"	trachyte
Sinop	trachyandesite	
Kayseri	trachyte phonolite**	trachyte
Zongludak	trachyte	trachyte
Ankara (around Afyon)	alkali trachyte*** trachyandesite*** mela-trachyte*** leucite-bearing rock***	
Izmir	alkali basalt**** hawaiite**** alkali trachyte**** alkali rhyolite****	

* LACROIX(1891)
** KRAEéé & PASQUARE(1966)
*** KELLER & VILLARI(1972)
**** BORSI et al.(1972) and INNOCENTI et al.(1972)
As for the rocks not marked, see the explanatory texts of the sheet maps.

leucitite of Vesuvius Volcano are distributed in the province, including Italian Mainland, Sicily Island and many tiny islands in the Aegean Sea.

Turkey is a part of the mentioned province. According to the geological sheet maps of the whole of Turkey, 1:500,000 in scale, and other theses, alkali volcanic rocks are reported in the following ten areas (Table 1), except Kula Volcano of the Quaternary.

Referring to their geological ages, the explanatory texts state that the trachyte in Trabzon sheet map area is of the late Eocene to the Oligocene and the trachyandesite in Sinop sheet map area is mostly of the Miocene. According to KELLER & VALLARI(1972), alkali rocks around Afyon are of the late Miocene to the early Pliocene. According to BORSI *et al.*(1972), alkali rocks in Izmir sheet map area are of the Miocene. To sum up, it is highly probable that the alkali rocks, except Kula Volcano of the Quaternary, are mostly of the middle to late Tertiary. They are distributed all over Anatolia except its southeastern part. While in Japan, they are distributed not so much all over the country as along its continental side. It is an interesting problem how the difference between the two was caused from the standpoint of geotectonics.

Some alkali rocks are described as follows;

(1) Olivine trachybasalt in the Erzurum sheet map area

The phenocrysts are potassium felspar and olivine, the groundmass being trachytic with plagioclase, potassium felspar, aegirine, hornblende, biotite, iron ore and other accessory minerals.

(2) Augite trachyandesite in the same area

The phenocrysts are plagioclase, potassium felspar and augite, occasionally accompanied by biotite, the groundmass being trachyti cwith plagioclase, potassium felspar, aegirine, hornblende, monoclinic and rhombic pyroxenes and other accessory minerals.

(3) Hornblende trachyte in the Sivas sheet map area

The phenocrysts are composed of potassium felspar and hornblende with a small quantity of plagioclase, the groundmass being trachytic with plagioclase, potassium felspar, alkali pyroxene, hornblende and magnetite.

(4) Trachyte in the Erzurum district sheet map area

The phenocrysts are potassium felspar and biotite, the groundmass being cryptocrystalline with potassium felspar and secondary limonite.

(5) Nepheline phonolite near Kayseri

According to KRAEFF & PASQUARE(1966), it is found in the form of dike in nepheline syenite at Cukurkoy, 55 km NE of Kayseri. The phenocrysts are composed of sanidine and diopside, surrounded by a narrow aegirine-augite rim, with a small quantity of sericite pseudomorph and garnet, embedded in a holocrystalline groundmass composed of numerous subhedral aegirine-augite, biotite, interstitial anhedral nepheline and accessory magnetite grains.

A thin section of a nepheline-bearing rock, which is stored in the MTA, is as follows, but it is uncertain if this is the one which was used for the above-mentioned observation; under the microscope, it is porphyritic in texture. The phenocrysts are composed of potassium felspar and aegirine-augite. The potassium felspar is sanidine, 0.5–1.5 mm in length, which is euhedral and occasionally contains oligoclase-andesine in the center. The aegirine-augite is euhedral, 0.5–2.0 mm in length, and pleochroic: X = grass green Y = yellowish green Z = yellow. It includes minute crystals of garnet and is often partly replaced by aegirine at the margin. The groundmass is holocrystalline with reticulated laths of sanidine, 0.2–0.5 mm in length, aegirine-augite, aegirine, iron ore and interstitial nepheline, which is partly replaced by sericite, accompanied by small quantities of hornblende, biotite and garnet.

(6) Leucite phonolite near Trabzon

LACROIX(1891) described a leucite-bearing rock found in Trabzon, but the authors have never had an opportunity of reading his original. A thin section of a rock containing leucite found in Trabzon, which is stored in the MTA, is as follows.

Under the microscope, it is porphyritic in texture, the phenocrysts being leucite and augite. The leucite is euhedral, 0.3–0.8 mm in diameter, colorless and clear with no inclusion. Occasionally it shows weak double refraction. The leucite is rare, while the augite is frequent. The augite is euhedral, 0.4–1.5 mm in length, and occasionally includes minute crystals of leucite. It is weakly pleochroic: X = grass green Y = green Z = yellowish green. The angle between c and Z is below 55°. It often shows zonal structure. The groundmass is holocrystalline with augite, potassium felspar, plagioclase, leucite, biotite, iron ore and other accessory minerals.

7. Chemical Properties

Only a few chemical data of Turkish volcanic rocks had been published before 1972, when BORSI et al.(1972), INNOCENTI & MAZZUOLI(1972) and KELLER & VILLARI(1972) reported chemical analyses of ninety volcanic rocks of various kinds, including alkali and calc-alkali and from basic to acidic ones, from western Turkey. Average chemical compositions of the calc-alkali rocks among them are given in Table 2 and Figure 10.

Table 2 Average chemical compositions of the calc-alkali volcanic rocks from Western Turkey. (BORSI et al., 1972 & INNOCENTI & MAZZUOLI, 1972)

Number of analyses	4	4	7	23	9	6
Range of SiO_2	52.5—55.0	55.0—57.5	57.5—60.0	60.0—62.5	62.5—65.0	65.0—67.5
SiO_2	53.77	56.25	58.64	61.28	63.43	66.13
TiO_2	0.85	0.86	0.85	0.69	0.63	0.46
Al_2O_3	15.11	17.17	16.08	16.24	16.23	15.75
Fe_2O_3	3.29	3.31	4.14	2.99	2.99	1.97
FeO	3.34	2.95	1.66	1.82	1.37	0.82
MnO	0.13	0.12	0.10	0.09	0.07	0.05
MgO	8.03	4.23	3.27	2.72	1.70	1.03
CaO	7.56	7.30	6.37	5.60	4.59	3.35
Na_2O	2.75	3.36	3.28	3.41	3.58	3.26
K_2O	2.80	2.28	3.42	3.25	3.73	3.93
P_2O	0.49	0.33	0.35	0.25	0.27	0.17
H_2O / Ig. L.	1.90	1.97	1.65	1.70	1.15	2.60
total	100.02	100.13	99.81	100.04	99.74	99.52
Q	2.20	8.24	11.15	15.11	17.55	23.89
C	—	—	—	—	—	0.45
or	16.55	13.47	20.21	19.21	22.04	23.22

ab		23.27	28.43	27.75	28.85	30.29	27.59
an		20.62	25.03	19.05	19.41	17.20	15.51
di	wo	5.72	3.77	4.29	2.81	1.59	—
	en	4.55	2.94	3.70	2.43	1.37	—
	fs	0.51	0.41	—	—	—	—
hyp	en	15.45	7.59	4.44	4.34	2.86	2.57
	fs	1.74	1.07	—	—	—	—
mt		4.77	4.80	3.21	4.16	2.82	1.47
hm		—	—	1.92	0.12	1.05	0.95
il		1.61	1.63	1.61	1.31	1.20	0.87
ap		1.14	0.76	0.81	0.58	0.63	0.39

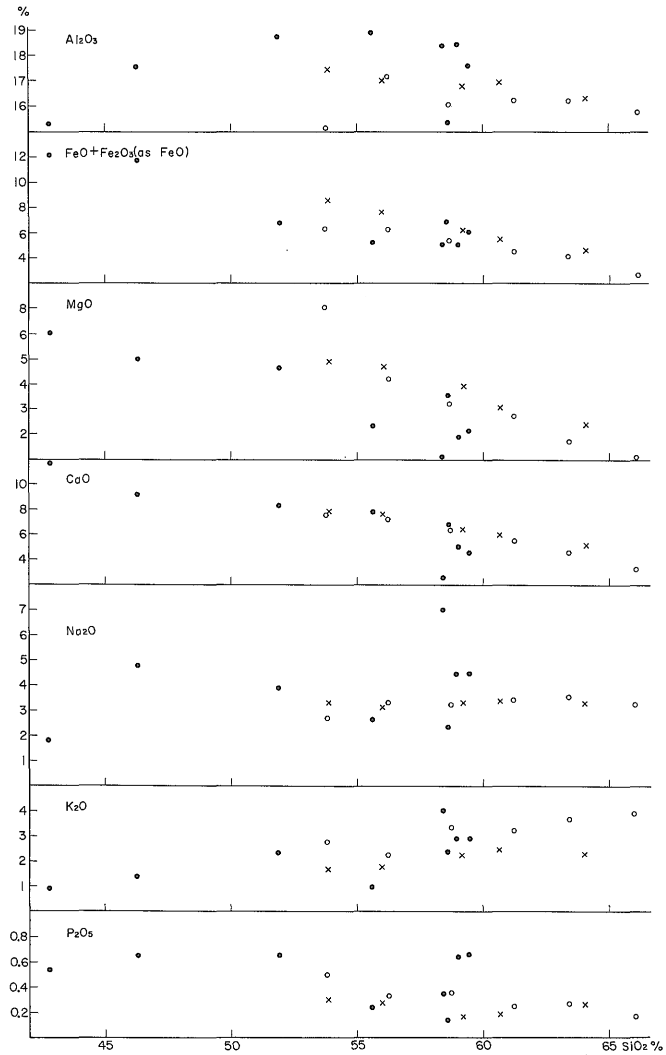

Fig. 10 Oxides-SiO_2 Diagram.

Open circles Average chemical compositions of the calc-alkali volcanic rocks from western Turkey, shown in Table 2.
Solid circles Chemical compositions of Turkish volcanic rocks collected by OTA, shown in Table 3.
Crosses Average chemical compositions of the volcanic rocks of the calc-alkali rock series derived from alkali olivine basalt magma from Southwest Japan, shown in Table 4.

OTA, one of the authors, brought eight rock fragments of his own collection to Japan in order to have them analysed. The results are given in Table 3 and Figure 10.

Table 3 Chemical compositions of Turkish volcanic rocks collected by OTA.

No.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
SiO_2	46.30	59.42	42.74	51.88	58.38	58.60	59.01	55.63
TiO_2	2.25	1.15	3.23	1.22	1.07	0.73	0.79	0.54
Al_2O_3	17.54	17.62	15.31	18.76	18.40	15.38	18.46	18.91
Fe_2O_3	2.16	2.97	8.12	3.99	2.62	4.25	3.72	4.03
FeO	9.85	3.37	4.80	3.22	2.69	3.11	1.66	1.58
MnO	0.22	0.11	0.40	0.16	0.20	0.20	0.09	0.13
MgO	5.02	2.14	6.05	4.66	1.09	3.56	1.90	2.36
CaO	9.26	4.66	11.64	8.29	2.58	6.85	5.10	7.93
Na_2O	4.81	4.50	1.77	3.91	7.06	2.47	4.53	2.66
K_2O	1.38	2.94	0.92	2.33	4.05	2.40	2.96	0.98
P_2O_5	0.66	0.66	0.54	0.66	0.35	0.15	0.65	0.24
$H_2O(+)$	0.09	0.01	3.18	0.47	0.89	1.47	0.66	3.16
$H_2O(-)$	0.16	0.16	0.96	0.26	0.31	0.27	0.30	1.66
total	99.70	99.71	99.66	99.81	99.69	99.44	99.83	99.81
Q	—	9.75	1.48	—	—	16.85	9.41	16.79
C	—	0.14	—	—	—	—	0.09	—
or	8.15	17.37	5.44	13.77	23.93	14.18	17.49	5.79
ab	19.88	38.08	14.98	33.09	52.27	20.90	38.33	22.51
an	22.19	18.81	31.11	26.76	6.55	23.79	21.05	36.76
ne	11.28	—	—	—	4.05	—	—	—
di wo	8.11	—	9.65	4.20	1.65	3.85	—	0.42
di en	3.92	—	8.34	3.43	1.03	2.98	—	0.36
di fs	4.07	—	—	0.27	0.52	0.46	—	—
hyp en	—	5.33	6.73	5.45	—	5.89	4.73	5.51
hyp fs	—	2.04	—	0.42	—	0.91	—	—
ol fo	6.02	—	—	1.96	1.18	—	—	—
ol fa	6.89	—	—	0.16	0.66	—	—	—
mt	3.13	4.31	7.41	5.79	3.80	6.16	3.35	3.95
hm	—	—	3.01	—	—	—	1.41	1.30
il	4.27	2.18	6.13	2.32	2.03	1.39	1.50	1.03
ap	1.53	1.53	1.25	1.53	0.81	0.35	1.51	0.56

Rock Names and Localities:

(1) Aphyric trachybasalt (a lava flow at the northwestern foot of Tendurek Volcano)
Phenocryst: none
Groundmass: plagioclase (60.8 vol. %), alkali felspar (0.3 vol. %), olivine (14.9 vol. %), titanaugite (20.3 vol. %) iron ore (3.4 vol. %) & aegirineaugite (0.3 vol. %).

(2) Aphyric andesite (a lava flow at the northern foot of Tendurek Volcano)
Phenocryst: none
Groundmass: plagioclase (59.4 vol. %), pyroxene (11.7 vol. %), iron ore (6.7 vol. %) & glass (22.2 vol. %).

(3) Augite-olivine basalt (plateau basalt, west of Diyarbakir)
Phenocrysts: plagioclase (4.4 vol. %), olivine (3.6 vol. %) & augite (3.5 vol. %).
Groundmass: plagioclase (44.4 vol. %), olivine (0.6 vol. %), augite (37.0 vol. %), chlorite

(1.1 vol. %) & iron ore (5.4 vol. %).
note: This rock has undergone weathering.
(4) Augite-olivine trachybasalt (a lava dome, 50 km northeast of Baskale, Van)
Phenocrysts: plagioclase (10.1 vol. %), olivine (3.4 vol. %) & augite (1.6 vol. %).
Groundmass: plagioclase (51.2 vol. %), alkali felspar (0.5 vol. %), olivine (8.6 vol. %), augite (18.7 vol. %) & iron ore (5.9 vol. %).
(5) Olivine-augite trachyandesite (the latest lava flow at the western foot of Tendurek Volcano)
Phenocrysts: plagioclase (3.1 vol. %), olivine (1.0 vol. %), augite (1.2 vol. %) & magnetite (1.1 vol. %).
Groundmass: 93.6 vol. %, including plagioclase, alkali felspar, pyroxene, iron ore & glass.
(6) Augite andesite (a lava of the Tertiary, at Bayramic near Canakkale)
Phenocrysts: plagioclase (20.6 vol. %), augite & chlorite (14.6 vol. %) & iron ore (0.7 vol. %).
Groundmass: plagioclase (43.2 vol. %), augite & chlorite (10.7 vol. %) & iron ore (10.2 vol. %).
(7) Hornblende andesite (a lava flow at the western foot of Haravil Volcano)
Phenocrysts: plagioclase (3.1 vol. %), hornblende (1.3 vol. %) and magnetite (0.2 vol. %).
Groundmass: 95.4 vol. %, including plagioclase, pyroxene & iron ore.
(8) Hornblende andesite (a dike of the Tertiary, at Cayeli, Rize)
Phenocrysts: plagioclase (23.3 vol. %), hornblende (7.6 vol. %) & magnetite (0.7 vol. %).
Groundmass: 64.4 vol. %, including plagioclase, pyroxene, hornblende, iron ore & glass.
Analysts: Na_2O, K_2O & H_2O: S. TERASHIMA (Geological Survey of Japan)
1, 2, 5 & 6 (except alkali & water): K. MAEDA (ditto)
3, 4, 7 & 8 (except alkali & water): Tokyo Coal & Mineral Laboratory

In Japan the volcanic rocks of the calc-alkali rock series derived from alkali olivine basalt magma have been thoroughly studied. Their average chemical compositions by AOKI & OJI (1966) are given in Table 4 and Figure 10.

Table 4 Average chemical compositions of the calc-alkali volcanic rocks from Southwestern Japan (AOKI & OJI, 1966).

Number of Analyses	16	17	6	5	3
Range of SiO_2	>55.0	55.0—57.5	57.5—60.0	60.0—62.5	>62.5
SiO_2	53.90	56.02	59.19	60.66	64.10
TiO_2	1.39	1.18	0.90	1.01	0.72
Al_2O_3	17.46	17.00	16.82	16.95	16.37
Fe_2O_3	3.18	2.57	2.61	2.55	2.64
FeO	5.67	5.28	3.90	3.29	2.27
MnO	0.14	0.13	0.16	0.12	0.09
MgO	4.93	4.78	4.04	3.08	2.45
CaO	7.89	7.64	6.51	6.15	5.36
Na_2O	3.41	3.26	3.39	3.47	3.35
K_2O	1.72	1.85	2.29	2.53	2.38
P_2O_5	0.31	0.28	0.18	0.19	0.26
total	100.00	99.99	99.99	100.00	99.99
Q	3.61	6.71	11.06	13.74	21.16
or	10.16	10.93	13.53	14.95	14.07

	ab	28.85	27.59	28.69	29.36	28.35
	an	27.25	26.29	23.91	23.20	22.60
di	wo	4.12	4.09	3.01	2.53	0.96
	en	2.62	2.57	2.02	1.76	0.74
	fs	1.23	1.27	0.77	0.57	0.12
hyp	en	9.66	9.34	8.05	5.92	5.96
	fs	4.52	4.60	3.05	1.92	0.85
	mt	4.61	3.73	3.78	3.70	3.83
	il	2.64	2.24	1.71	1.92	1.37
	ap	0.72	0.65	0.42	0.44	0.60

Generally speaking, Turkish volcanic rocks are rich in K_2O and P_2O_5, being poor in MgO and FeO + Fe_2O_3 (as FeO) as compared with Japanese volcanic rocks of the same kind. As to CaO, Na_2O and Al_2O_3, there is no remarkable difference between the two. The abundance of P_2O_5 is one of characteristics of Turkish volcanic rocks. The P_2O_5 content of over 0.50% is very rare in Japanese alkali rocks.

Almost all the rocks given in Table 2 are of the Tertiary. No. 6 and No. 8 among the rocks given in Table 3 are of the Tertiary, the rest being of the Quaternary. It can safely be said that the Tertiary volcanic rocks are poor in Al_2O_3, Na_2O and P_2O_5, being rich in MgO in comparison with those of the Quaternary. No. 5 in Table 3 is rich in alkali, being poor in CaO and MgO, probably because of having been contaminated by granitic rocks. It is notable that No. 3, which is plateau basalt, is not tholeiitic but alkaline.

8. Comparison between Turkish and Japanese Volcanic Rocks

It is generally believed that there exist two types of parental basaltic magma at least; one is tholeiitic olivine basalt magma and the other is alkali olivine basalt magma. By fractional crystallization of the former, rocks of tholeiite series, namely, tholeiitic basalt, andesite, dacite and rhyolite, are formed. By that of the latter, rocks of alkali rock series, namely, trachybasalt, trachy-andesite, trachyte and alkali-rhyolite, are formed. Also by fractional crystallization closely related to contamination by granite or granitic rocks into the former or the latter, rocks of calc-alkali rock series, namely, basalt, andesite, dacite and rhyolite, are formed.

The rocks of three series are most typically distributed over the Japanese Islands. Turkey and Japan are situated in orogenic zones, but the former's orogenic zone is intercalated between two continents, while the latter's is situated between an ocean and a continent. It is one of the fundamental differences between the two. In the Japanese Islands, the rocks of the tholeiite series are distributed on the Pacific side and the ones of the alkali rock series on the continental side. The rocks of the calc-alkali rock series are distributed all over Japan, some of them being derived from the tholeiitic olivine basalt magma and the rest from the alkali olivine basalt magma. In this case, there are some differences between the two, e.g., the latter tends to be rich in alkali and poor in CaO as compared with the former, as far as their chemical compositions are concerned, though no remarkable difference is observed in their mineral assemblages.

Turkish volcanic rocks can be classified into two kinds of rocks; one is of the alkali rock series and the other of the calc-alkali rock series derived from alkali olivine basalt magma. But the latter is far more abundant than the former. Evolution of the mineral assemblage of the calc-alkali rock series is as follows.

(1) The phenocryst of the basalt in the most primitive stage of magmatic evolution is only olivine without plagioclase. The olivine is always euhedral, not surrounded by a reaction rim composed of pyroxene grains, which is common in the rocks of the tholeiite series or the calc-alkali rock ones derived from tholeiitic olivine basalt magma. It is partly or in some cases greatly iddingsitized, usually having no inclusion. The groundmass is intergranular or subophitic with plagioclase, olivine, monoclinic pyroxene, magnetite and other accessory minerals.

(2) At the next stage, the phenocrystic olivine coexists with phenocrystic plagioclase, which is sodic bytownite or labraorite, being more sodic than the phenocrystic plagioclase, usually bytownite, in the rocks of the calc-alkali rock series derived from tholeiitic olivine basalt magma. The groundmass is intergranular or intersertal with plagioclase, olivine, monoclinic pyroxene, magnetite, but often lacks olivine or contains rhombic pyroxene.

(3) Next augite crystallizes out as phenocryst. Three phenocrysts of plagioclase, olivine and augite coexist with each other, that is to say, olivine and augite keep parallel crystallization. The plagioclase in this stage is usually labradorite. The groundmass is intergranular or intersertal with plagioclase, monoclinic pyroxene, rarely accompanied by rhombic pyroxene. Glomeroporphyritic aggregates, an evidence of contamination, often appear.

(4) Next comes the stage of augite basalt and afterwards phenocrystic hypersthene appears. Olivine and hypersthene seldom coexist. Around this stage is a transitional period from basalt to andesite. The groundmass mafic silicate minerals are monoclinic and rhombic pyroxenes.

(5) As mentioned above, augite appears previous to hypersthene in all cases. In Japan, hypersthene-augite andesite is one of the commonest volcanic rocks. It is an interesting problem, determining which of hypersthene and augite appears first. In the case of Japanese Quaternary volcanic rocks, hypersthene appears first, next coexists with augite and becomes alone again with the disappearance of augite. It requires the contamination by granite or granitic rocks for the pyroxene andesite in order to accompany hornblende in it. Occurrence of augite andesite is limited to the Tertiary period in Japan. According to Tsuboi (1932), which of augite and hypersthene appears first depends on the ratio of pyroxene components of the magma at that time.

(6) Hypersthene-augite andesite is one of the commonest volcanic rocks in Turkey, too. It occasionally has evidences of contamination by granite and granitic rocks. But when the andesite comes to accompany hornblende and biotite, the evidences become remarkable. According to Ota (1958), the evidences in question are as follows:

a) Corroded and turbid sodic plagioclase or potassium felspar, occasionally with a clear zone along the margin.
b) Corroded quartz, usually without reaction rim, that is, pyroxene grains along the margin.
c) An aggregate of pyroxene grains which is supposed to have grown from opacite, which origin is hornblende or biotite.
d) Extraordinarily rich cristobalite or tridymite in the groundmass or cavities.
e) Glomeroporphyritic aggregates which are supposed to have derived from a xenolith.
f) A small spherical patch, in which quartz is the last mineral filling the spaces.

Appearance of a parallel intergrowth of hypersthene and augite, in which the former is usually inside surrounded by the latter, is often related to contamination.

The groundmass is pilotaxitic or hyalopilitic, rarely glassy, with monoclinic and rhombic pyroxenes, or the latter only. Hydrous minerals such as hornblende and biotite usually do not appear as groundmass minerals with the exception of the case that the groundmass is glassy. The glassy groundmass indicates that it abounds in alkali and silica. Anorthoclase, cristobalite, tridymite and apatite appear in the groundmass.

(7) The mafic phenocrysts of dacite are hornblende and biotite with the evidences of contamination. The groundmass is microcrystalline, cryptocrystalline or glassy, often abounding in spherulite. The groundmass mafic silicate mineral is usually rhombic pyroxene only when discernible. Cristobalite or tridymite appears in cavities.

(8) The occurrence of rhyolite is rare in Turkey. Its phenocrysts are composed of plagioclase, potassium felspar, quartz, biotite and rarely hornblende. The groundmass is microcrystalline with plagioclase, potassium felspar, quartz and a small quantity of mafic minerals and iron ore with tridymite in cavities.

Turkish alkali volcanic rocks are mostly composed of trachybasalt, trachyandesite and trachyte with a small quantity of phonolite and others. It seems that their distribution is nearly all over Anatolia except its southeastern part and that their geological ages are mostly the middle to late Tertiary with an exception of Kula Volcano of the Quaternary. In Japan, their distribution, generally speaking, is confined to the continental side of the Japanese Islands and their ages are the middle Miocene to the Pliocene.

9. Concluding Remarks

Turkey is situated in the Alpine orogenic zone with widely distributed volcanic rocks superimposed by the Quaternary volcanic rocks. It has many problems awaiting solutions from the standpoint of volcano-stratigraphy and petrogenesis. To the authors' great regret, the problems, especially those concerning petrology, have been hardly taken up, though there are a few descriptions of volcanic activity of some volcanoes and microscopic observations of some volcanic rocks. This paper is simple and short, but the authors would be delighted if it could be helpful to those who intend to make further researches on the problems.

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トルコの火山岩

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要旨

トルコは南北両側を大陸で挟まれた造山帯に位置し，太古から第三紀早期まで海中火山活動が盛んであった．第三紀始新世末ごろから隆起がおこり第三紀晩期にはほぼ現在のような地形を呈するようになった．国土の約20%は火山岩からなり，第四紀火山は10余を数える．これら火山岩の大部分はアルカリかんらん石玄武岩マグマから混成作用に密接に関係ある分別晶出作用によって分化したカルクアルカリ岩系に属し，一部に同マグマから分別晶出作用により分化したアルカリ岩系のものがある．前者は玄武岩・輝石安山岩およびこれに角閃石や黒雲母を伴ったもので，石英安山岩や流紋岩は少ない．後者は粗面玄武岩・粗面安山岩・粗面岩・アルカリ流紋岩・響岩その他である．なお白亜紀の海成層中にはスピライトやケラトファイアーがみられる．