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ORIENTATION OF THE ANDESITIC DYKES IN THE İSTANBUL REGION: AN APPROACH TO THE CRETACEOUS STRESS DISTRIBUTION

Zahide ÖZGÖRÜŞ* and Aral I. OKAY*

ABSTRACT.- For dykes in the upper crust, the strike of the dyke is parallel to the σ_1-σ_2 plane, and the normal to the dyke is aligned with the least compressive stress σ_3. This relation enables the determination of the palaeo-stress distribution from the orientation of the dykes. In order to estimate the stress distribution in the Late Cretaceous in the Istanbul region, the orientation of the dykes in the Paleozoic sedimentary rocks have been measured. The dykes consist of andesite and basaltic andesite, and form massif, highly fractured pale yellow, beige and grey rocks. Their thickness ranges from 10-20 cm to 10-11 m and their length generally is measured in several tens of metres. Petrographically the dykes show a porphyritic texture with plagioclase, hornblende and augite phenocrystalls, 1.5-3.5 mm across, in a fine grained microlithic matrix. The measured strikes of the dykes show a wide scatter with a few prominent directions (N80°E, N40°E and N35°W). The wide scatter in the dyke direction suggests that the Istanbul dykes form a local dyke swarm above an unexposed pluton. Another possibility is that the Istanbul dykes were emplaced in a complex stress regime controlled by the opening of the oceanic West Black Sea basin and activity of the West Black Sea fault.

Key words: Black Sea, dykes, Istanbul, Cretaceous, andesite, stress.

INTRODUCTION

Presence of dykes, sills and small intrusions cutting the Palaeozoic sedimentary rocks in the Istanbul region is known since the 19th Century. These andesitic hypabyssal rocks, which are generally considered to be of Cretaceous age, are mentioned in many regional geological studies (Paeckelmann, 1925; Okay, 1947, 1948; Erguvanlı, 1949; Ketin, 1959) and their distribution is shown schematically in some geological maps of the Istanbul region (Paeckelmann, 1938; Sayar, 1949). However, there is no systematic information on the orientation of these andesitic dykes and sills. Such data will provide information on the stress field in the Istanbul region during the Cretaceous, as explained below. In this study we provide information on the orientation of dykes in the Istanbul region in attempt to estimate the orientation of the stress axis during the Cretaceous.

Theoretical and empirical studies have shown a close relation between the orientation of the principal stress axis in the crust and the orientation of a dyke (Anderson 1936, 1972; Pollard, 1987; Marinoni, 2000; Ramsay and Lisley, 2000). The strike of the dyke is parallel to the σ_1-σ_2 plane during the injection of the dyke, and the normal to the dyke represents the minimum compressive principal stress σ_3. Just prior to the emplacement of the dyke a tiny crack forms in the crust, perpendicular to the prevailing σ_3, and the dyke follows this crack upwards enlarging and thickening it (Anderson, 1936, 1972; Hills, 1963).

Dykes in the continental crust are generally found in swarms. The dyke swarms can be divided into regional and local swarms. The regional dyke swarms consist of hundreds to thousands of subparallel dykes, which can be followed for hundreds of kilometres. A typical

* Istanbul Technical University, Eurasian Institute of Earth Sciences, Maslak TR-80626, Istanbul.
e-mail: zahide307@yahoo.com, okay@itu.edu.tr)

example of a regional dyke swarm is that found in northwestern Britain, which forms a Tertiary swarm made up of thousands of dykes striking northwest-southeast (Richey, 1939; Hills, 1963; Johnstone, 1966). This Tertiary dyke swarm is related to the rifting and opening of the Northern Atlantic oceans. In contrast to the regional dyke swarms, local dyke swarms form around plutonic bodies and have lengths measured in tens of kilometers. In the local dyke swarms, the strike of the dykes generally shows a radial distribution, with individual dykes striking perpendicular to the margins of the pluton. The radial dyke swarms around the plutons in the interior of USA constitute typical examples for local dyke swarms (Parsons, 1939; Johnson, 1961; Hills, 1963).

The İstanbul region is located on the southwestern corner of the Black Sea, which is considered a back-arc basin opened during the Cretaceous behind the Pontide magmatic arc (Letouzey et al., 1977; Tugolesov et al., 1985; Görür, 1988; Finetti et al., 1988; Okay et al., 1994). The Black Sea consists of two oceanic basins, called the West and East Black Sea basins, separated by the Mid Black Sea ridge (Figure 1). The West Black Sea basin comprises a Cretaceous to Recent sedimentary sequence, over 15 km thick, deposited on oceanic crust. The thick sedimentary cover in the West Black Sea basin disguises the magnetic anomalies that must be present in the underlying oceanic crust. Therefore, there is no information on the orientation of the oceanic ridge in the West Black Sea basin and hence on the distribution of the principal stresses during the opening of the Black Sea. The mid-ocean ridges strike parallel to the σ_1-σ_2 plane and are perpendicular to σ_3 direction. Therefore, it is hoped that a systematic determination of the orientation of the dykes in the Istanbul region would also provide information on the direction of opening of the West Black Sea basin.

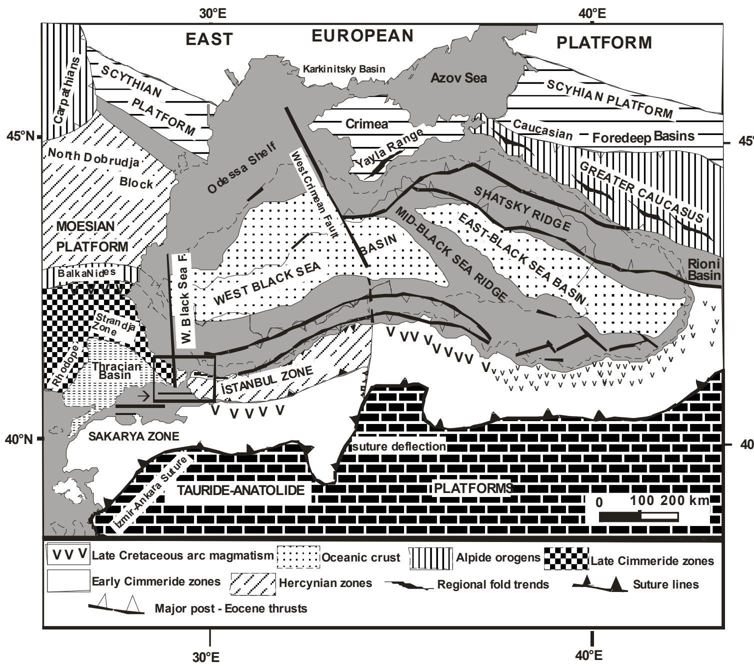

Figure 1- Tectonic map of the Black Sea region showing the setting of the Istanbul region (modified after Okay et al., 1994)

THE GEOLOGICAL SETTING OF THE CRETACEOUS HYPABYSSAL ROCKS IN THE İSTANBUL REGION

A transgressive sedimentary sequence of Ordovician to Carboniferous age crops out on both sides of the İstanbul strait (Paeckelmann, 1938; Kaya, 1973; Görür et al., 1997). This sequence, consisting of sandstone, quartzite, conglomerate, shale, limestone and chert is thrust northward over the Upper Cretaceous volcano-sedimentary rocks (Figure 2). In the east, Triassic conglomerate and sandstone lie unconformably over the Palaeozoic rocks. The Triassic sequence is in turn overlain unconformably by the Upper Cretaceous (Maastrichtian) limestones and cherts (Özer et al., 1990). All these units are overlain unconformably by the Eocene and younger sequences (Figure 2).

The Palaeozoic rocks in the İstanbul region are cut by numerous andesitic dykes and sills. Although there is no published isotopic data on the age of these rocks, all the studies including this one, regard the age of these hypabyssal rocks as Cretaceous. There are three indirect lines of evidence for the Cretaceous age of the andesitic hypabyssal rocks in the Istanbul region.

- There are no volcanic intercalations in the İstanbul Palaeozoic sequence. Similarly, volcanic rocks are absent in the overlying Triassic sequence, with the exception of some basaltic lava flows in the basal part of the Triassic series. As discussed in the next section, andesitic volcanic rocks are present in the Cretaceous sequence in the northern parts of Istanbul. However, magmatic rocks are again lacking in the Eocene and younger series around Istanbul, which are unconformably over all the older rocks. These stratigraphic observations bracket the age of the Istanbul andesitic dykes, which cut the Palaeozoic rocks, between Triassic and Eocene.

- A volcano-sedimentary sequence of Cretaceous age has been mapped between Şile and Kilyos on both sides of the İstanbul strait north of Istanbul (Baykal, 1943; Yeniyol and Ercan, 1990). This series, which constitutes part of the Pontide magmatic arc, consist of agglomerate, tuff, sandstone and siltstone, which are intercalated with andesitic lavas. A genetic connection is expected between these andesitic lavas north of Bosphorus, and the andesitic dykes cutting the Palaeozoic sedimentary rocks.

- A granitoidic pluton, with a diameter of 4.5 km, crops out on the Anatolian side of the Bosphorus east of Beykoz (Figure 2). This pluton, known as the Çavuşbaşı granitoid, cuts the Ordovician arkosic sandstones (Ketin, 1941; Okay, 1947), and its age is determined by Rb/Sr biotite method as 65 ± 10 Ma (Öztunalı and Satır, 1975). The andesitic dykes in the İstanbul region can be plausibly linked tothe same magmatic cycle, that generated the Çavuşbaşı pluton.

The three indirect lines of evidence, cited above, strongly suggest that the andesitic dykes in the Istanbul region, which cut the Palaeozoic rocks, are Late Cretaceous in age. These hypabyssal rocks, together with the Upper Cretaceous volcano-sedimentary sequence north of Istanbul, form part of the Pontide magmatic arc, which formed above the northward subducting Neo-Tethyan ocean (Şengör and Yılmaz, 1981; Okay and Tüysüz, 1999).

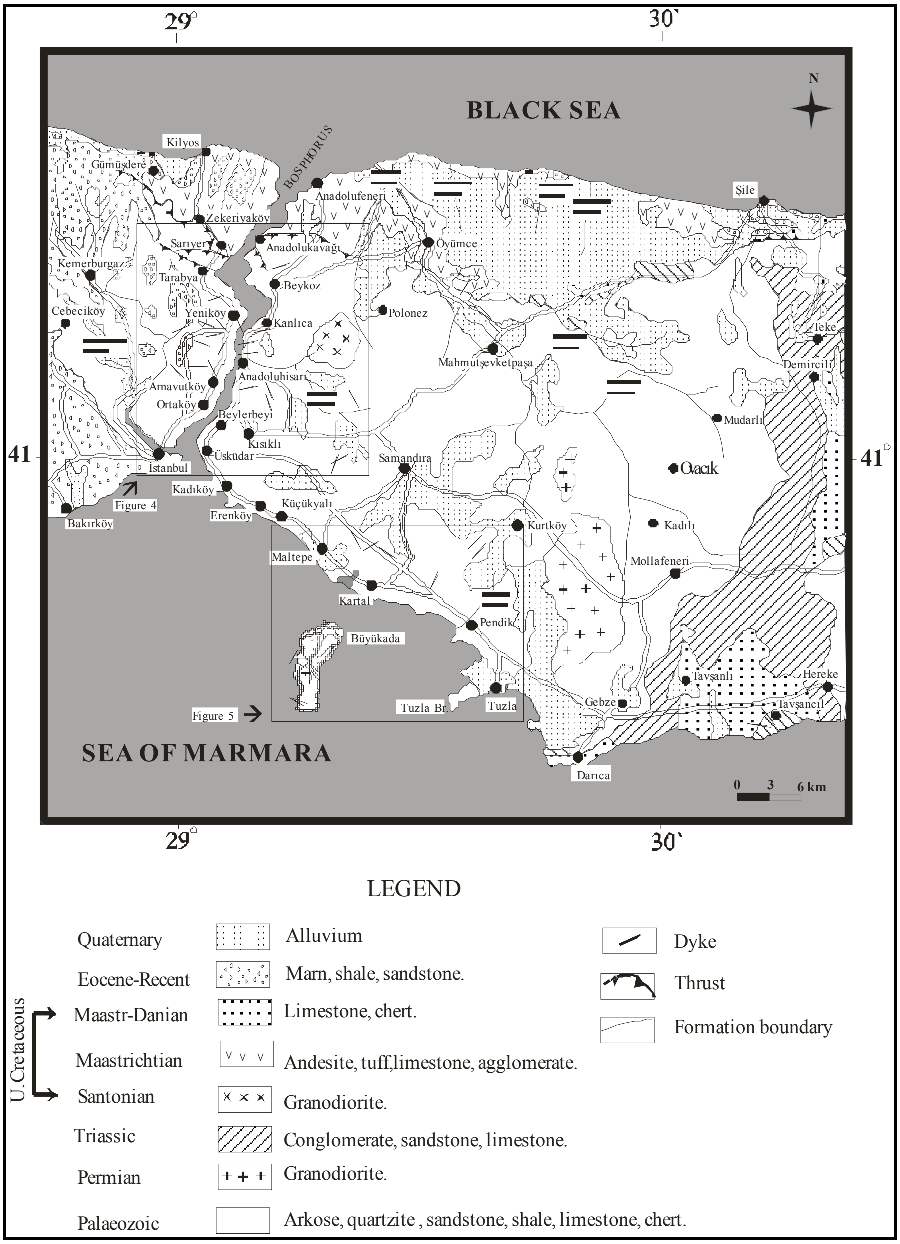

Figure 2- The geological map of the İstanbul region with the dyke locations (modified from Türkecan and Yurtsever, 2002)

CRETACEOUS DYKES IN THE İSTANBUL REGION

A large area on both sides of the İstanbul strait has been systematically searched for the presence of dykes. Outcrops are very rare in this region, which is densely urbanized and build-up. Furthermore, many of the andesites in this region form minor intrusions of irregular shape. The geometry of such intrusions is not useful in obtaining the paleo-stress distribution. The best structures for obtaining the paleo-stress distribution are subvertical dykes, as shown in figure 3, in which both margins are readly observed.In the İstanbul region thirty two of such dykes are found and described. The geographic coordinates of these dykes, as measured by GPS, their strikes and dips, and geographic locations are given in table 1 and their distribution is shown in figure 3 and figure 4.

Table 1- The location and geometric features of the studied dykes in the Istanbul region.

OBSERVATION MUMBER	LOCATION	GPS VALUE	STRIKE AND DIP DIRECTION	THICKNESS AND LENGTH
1	Tarabya	N:41° 08,07' E:29° 02,97	70 / 90 ☻☻☻	T: 4,0 m. L: 13,0 m. (min.)
2	Ayazağa	N:41° 07,37' E:28° 59,80'	80 / 90 ☻☻☻	T: 1.5 m. L: 5,0 m. (min.)
3	İstinye	N:41° 07,56' E:29° 02,23'	115 / 90 ☻☻☻	T: 2.7 m. L: 6,0 m. (min.)
4	Emirgan	N:41° 06,69' E:29° 03,37'	155 / 90 ☻☻	T: 1.5 m. L: 7,0 m. (min.)
5	Poligon	N:41° 06,69' E:29° 02,43'	140 / 90 ☻☻	T: 1.5 m. L: 50 cm. (min.)
6	I.T.U Cam.	N:41° 06,06' E:29° 01,31'	80 / 90 ☻☻☻	T: 70 cm. L: 5,0 m. (min.)
7	I.T.U Cam.	N:41° 05,90' E:29° 01,63'	80 / 90 ☻☻☻	T: 2,0 m. L: 20,0 m. (min.)
8	I.T.U Cam.	N:41° 05,94' E:29° 01,00'	110 / 90 ☻☻☻	T: 3,0 m. L: 8,0 m. (min.)
9	Baltalimanı	N:41° 05,91' E:29° 02,96'	90 / 75 N ☻☻☻	T: 2,0 m. (min.) L: 4,0 m. (min.)
10	Baltalimanı	N:41° 05,59' E:29° 03,29'	30 / 82 NW ☻☻☻	T: 1.5 m L: 15,0 m. (min.)
11	B.Bebek	N:41° 04,39' E:29° 02,67'	35 / 88 SE ☻☻	T: 1,0 m. L: 4,0 m. (min.)
12	B.Bebek	N:41° 04,39' E:29° 02,67'	35 / 90 ☻☻	T: 60 cm. L: 4,0 m. (min.)
13	Çamlıbahçe	N:41° 04,19' E:29° 02,71'	150 / 60 ☻☻☻	T: 1,5 m. (min.) L: 2,0 m. (min.)
14	Çamlıbahçe	N:41° 04,19' E:29° 02,71'	60 / 90 ☻☻☻	T: 60 cm. L: 10,0 m. (min.)
15	Arnavutköy	N:41° 04,18' E:29° 02,68'	92 / 80 N ☻☻☻	T: 1,0 m. L: 2.5 m. (min.)
16	Ulus	N:41° 03,91' E:29° 01,64'	140 / 90 ☻☻☻	T: 1,0 m. L: 3,0 m. (min.)
17	Yalıköy	N:41° 08,87' E:29° 05,95'	75 / 82 SE ☻☻	T:1,0 m. L:2,0 m. (min.)

Table 1- Continue

OBSERVATION MUMBER	LOCATION	GPS VALUE	STRIKE AND DIP DIRECTION	THICKNESS AND LENGTH
18	Zerzevatçı	N:41° 06,86' E:29° 09,47'	40 / 90 ☻☻	T:1,0 m. L:3,0 m. (min.)
19	Kanlıca	N:41° 05,84' E:29° 03,85'	80 / 90 ☻☻	T:1,8 m. L:8,0 m. (min.)
20	Kanlıca	N:41° 05,84' E:29° 03,89'	90 / 90 ☻☻☻	T:40 cm. L:3,0 m. (min.)
21	Kanlıca	N:41° 05,84' E:29° 03,89'	80 / 90 ☻☻☻	T:1,0 m. L:10,0 m. (min.)
22	Anadoluhisarı	N:41° 05,44' E:29° 04,02'	85 / 90 ☻☻	T:1,0 m. L:3,0 m. (min.)
23	Vaniköy	N:41° 03,74' E:29° 03,24'	75 / 65 NW ☻☻	T:4,0 m. L:10,0 m. (min.)
24	Üsküdar	N:41° 03,35' E:29° 04,71'	160 / 90 ☻☻	T:10,0 m. (min.) L:2,5 m. (min.)
25	Üsküdar	N:41° 03,33' E:29° 04,05'	165 / 90 ☻☻☻	T:1,5 m. L:3,0 m. (min.)
26	Çekmeköy	N:41° 02,22' E:29° 10,40'	150 / 90 ☻☻☻	T:2,0 m. L:4,0 m. (min.)
27	Dudullu	N:41° 00,57' E:29° 09,38'	20 / 90 ☻☻☻	T:1,5 m. L:4,0 m. (min.)
28	Dudullu	N:41° 00,57' E:29° 09,38'	65 / 90 ☻☻☻	T:60 cm. L:4,0 m. (min.)
29	Maltepe	N:40° 56,33' E:29° 08,14'	150 / 90 ☻☻☻	T:2,0 m. L:3,0 m. (min.)
30	Maltepe	N:40° 56,33' E:29° 08,14'	60 / 65 NW ☻☻☻	T:3,0 m. L:6,0 m. (min.)
31	Maltepe	N:40° 55,87' E:29° 08,67'	120 / 65 NE ☻☻☻	T:5,0 m. (min.) L:12,0 m. (min.)
32	Kurtköy	N:40° 55,35' E:29° 17,86'	43 / 90 ☻☻☻	T:6,0 m. L:2,5 m. (min.)
33	Kurtköy	N:40° 55,35' E:29° 17,86'	45 / 90 ☻☻☻	T:3,5 m. L:2,5 m. (min.)
34	Pendik	N:40° 52,86' E:29° 15,01'	25 / 80 SE ☻☻☻	T:5,0 m. L:1,0 m. (min.)
35	Tavşancıl	N:40° 46,22' E:29° 34,16'	100 / 80 NE ☻☻	T:1,5 m. L:5,0 m. (min.)
36	Tavşancıl	N:40° 46,22' E:29° 34,16'	140 / 90 ☻☻	T:8,0 m. L:10,0 m. (min.)
37	Cape of Dil Büyükada	N:40° 51,67' E:29° 06,80'	32/ 75 NW ☻☻	T: 2,5 m. L: 20,0 m. (min.)
38	Cape of Ayine Büyükada	N:40° 49,20' E:29° 06,60'	120 / 76 NE ☻☻☻	T: 1.5 m. L: 15,0 m. (min.)
39	Cape of Ayine Büyükada	N:40° 49,20' E:29° 06,60'	105 / 90 NE ☻☻☻	T: 2.0 m. L: 10,0 m. (min.)

☻☻☻ Dyke contact zone with host rock best defined.
☻☻ Dyke contact zone with host rock moderately defined

Most of the 39 dykes, where the strikes and dips are measured unambiguosly, are located on both sides of the İstanbul strait (Figure 3). The concentration of the andesitic hybyssal rocks on both sides of the İstanbul strait and their relative scarcity farther inland can also be seen in the geological map of Sayar (1949). Apart from the vicinity of İstanbul strait, dykes have been located on the E5 highway between Küçükyalı and Pendik cutting the Palaeozoic rocks (Figure 4), and in the Gebze-Tavşancıl region cutting the Triassic sediments.

The dykes in the İstanbul region form highly fractured, massive yellow, beige and green rocks (Figure 5). Locally cataclasis is observed along the contacts of the dykes with the surrounding sedimentary rocks. The thickness of the dykes ranges from 10-20 cm to 10-11 m (Figure 6). The dykes cannot be followed long distances along thje strike; generally they are lost after a few tens of metres either because of lack of outcrops or because of deformation.

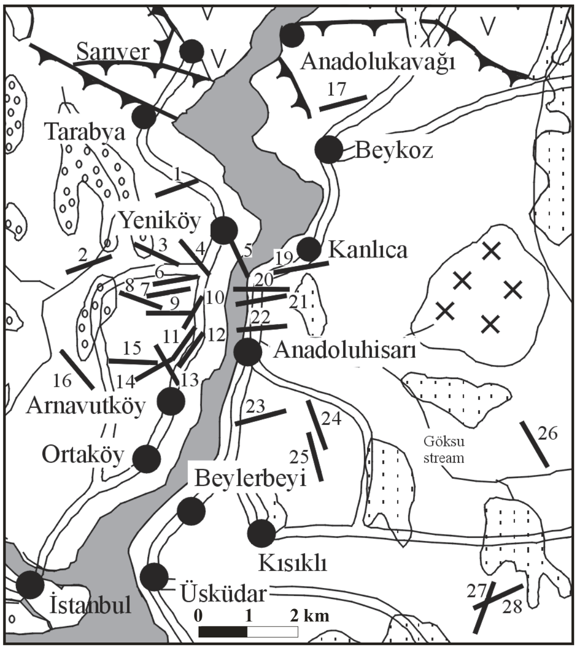

Figure 4- Dyke locations on both sides of the İstanbul strait (The dyke numbers are linked to those in table 1 and legend is same as figure 2)

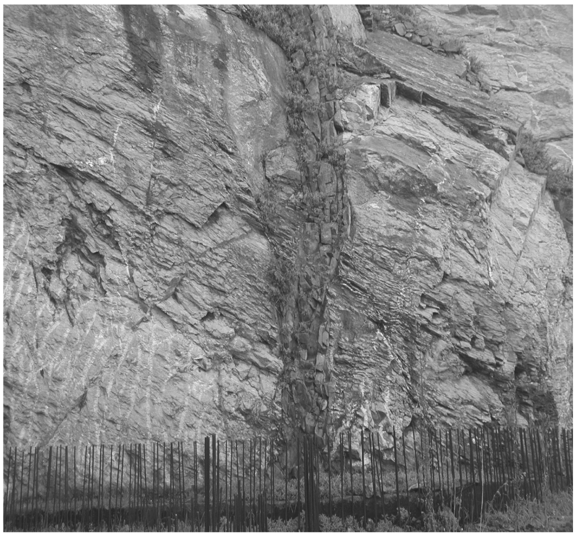

Figure 3- An example of a dyke from the European coast of İstanbul cutting the Devonian limestones. The thickness of the dyke is 60 cm (This dyke corresponds to the dyke no. 14 in table 1 and figure 4)

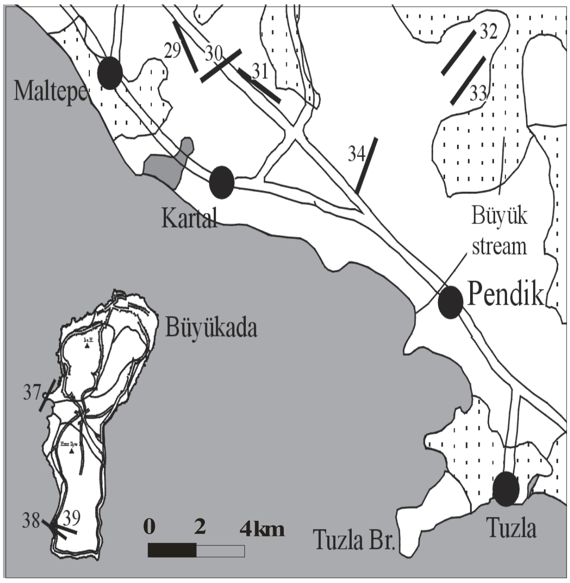

Figure 5- Dyke locations along the E-5 highway on the Küçükyalı-Pendik highway (The dyke numbers are linked to those in table 1 and legend is same as figure 2)

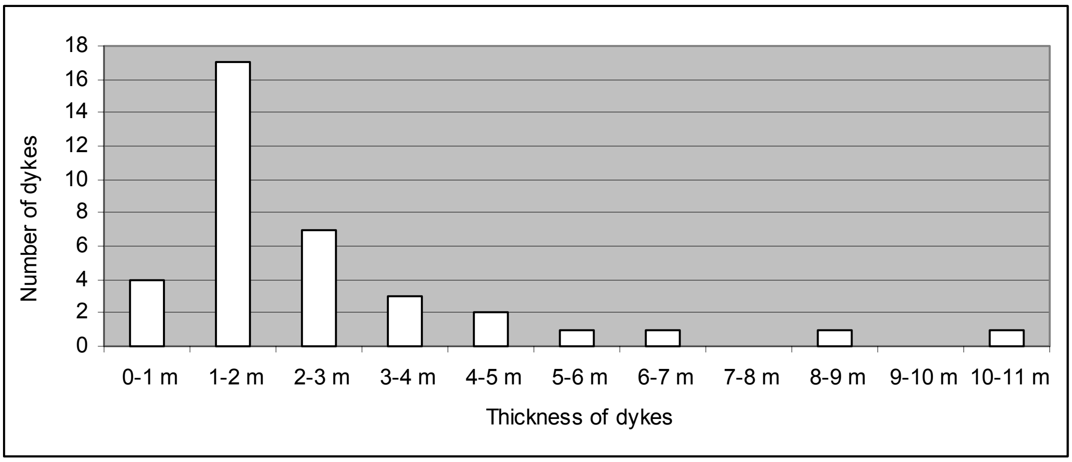

Figure 6- Thickness diagram for the 39 dykes in the İstanbul region.

Petrographic studies of samples show that the dykes are of andesitic or basaltic in composition and show a porphyritic texture. Plagioclase, hornblend and rarely augite form phenocrysts, 1.5 to 3.5 mm across, and are set on a fine-grained granular microlitic matrix. The dykes are commonly altered. Plagioclase is commonly replaced by sericite, and hornblende by chlorite.

DISCUSSION AND CONCLUSIONS

The strikes of the 39 well-described dykes are shown in the rose diagram in figure 7. The distribution of the strikes is highly scattered with a few prominent directions. There are two possibilities. The first one is that the Istanbul dykes constitute a local dyke swarm related to a yet unexposed pluton at depth. The second possibility is that the Istanbul dykes form a regional dyke swarm. These alternatives are discussed below.

- Local dyke swarm: The local dyke hypothesis is supported by the scatter in the distribution of the strikes of their dykes and their preferred concentration on both sides of the Bosphorus. In this view there is a pluton, similar to the Çavuşbaşı underneath the İstanbul strait, and the Istanbul dykes constitute the local dyke swarm of this pluton. In this model the Late Cretaceous stress distribution in the Istanbul region is controlled by the plutons.

- Regional dyke swarm: The preference of certain directions, shown by the strikes of the dykes, and their common presence in the northern parts of the Strandja Massif (Okay et al., 2001) support the regional dyke swarm model. The most prominent direction shown by the strikes of the dykes is N80°E (Figure 7). This direction is parallel to the expected rifting direction in the West Black Sea basin. A second preferential direction in the strike of the dykes is N40°E. These dykes are oriented parallel to the extension direction expected from the West Black Sea fault, thought to have been active during the Cretaceous (Okay et al., 1994). In this view the Istanbul dykes were emplaced in a complex stress regime created by the opening of the oceanic West Black Sea basin and by the movement of the West Black Sea Fault.

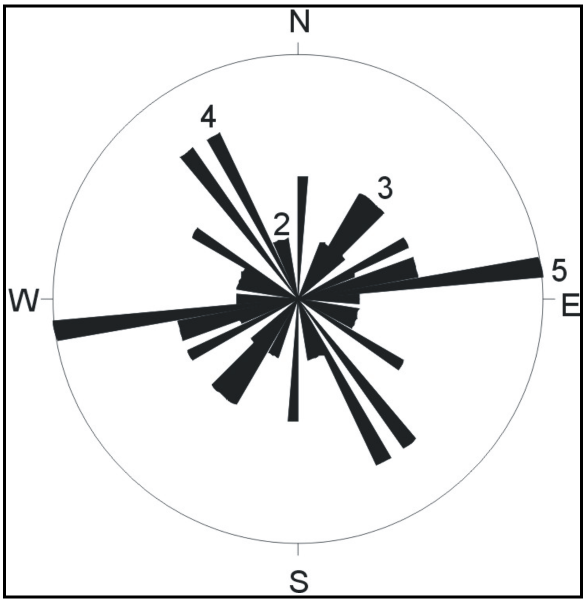

Figure 7- Strike diagram for the 39 dykes in the İstanbul region.

In this first study, devoted on the orientation of the Istanbul dykes, the number of dykes, whose strikes are measured confidently are limited. Therefore, it has not been possible conclusively to answer the question of whether the Istanbul dykes constitute a local or regional dyke swarm. However, the scatter in the direction of strikes of the dykes, and their spatial concentration on both sides of the İstanbul strait make the local dyke swarm model more probable. A conclusive answer to this problem can be found in future studies involving larger number of dykes.

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