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AN EXAMPLE FOR A PRE-EARLY ORDOVICIAN ARC MAGMATISM FROM NORTH TURKEY: GEOCHEMICAL STUDY OF THE ÇAŞURTEPE FORMATION (BOLU, W PONTIDES)

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ABSTRACT.- Three different units are exposed underneath the Palaeozoic sequence of W Pontides in the Bolu-Yedigöller area. These are, from the structural base to the top: i) high grade metamorphic rocks (the Sünnice group), ii) granitoids and, iii) a volcanic sequence (the Çaşurtepe formation) into which the granitoids intruded. The granitoidic intrusions are a part of an extensive group of intrusions, called the "Bolu Granitoid Complex" (BGC) and, together with the Çaşurtepe formation, they crop out structurally ontop of the Sunnice group along a NE-SW trending, NW-dipping tectonic contact. The granitoids are cut by a number of lamprophyre dykes. The Çaşurtepe formation, the main subject of this paper, comprises of andesitic lavas at the base, overlain by an ignimbrite serie in which rhyolitic volcaniclastics are dominant. Both the volcanic sequence and the granitoids were metamorphosed to greenschist facies and as a result, an albite+epidote+chlorite+actinolite mineral assemblage was developed, together with relict igneous minerals. An extensive pyrite mineralization is developed along sinous shear zones in locally developed intense hydrothermal alteration areas. Massive lavas of the volcanic sequence are calc-alkaline andesitic and locally rhyo-dasitic in composition with high SiO_2 content (> % 54). These have LIL-element enrichment relative to N-type MORB and show Nb depletion relative to LREE (La, Ce, Nd). The dykes within the granites have similar chemical characteristics. One sample analysed from the Çaşurtepe formation gave $^{87}Sr/^{86}Sr$ 550 Ma model age value of 0.706482, $^{143}Nd/^{144}Nd$ model value of 0.512450 and $^{\epsilon}Nd$ value of 10.2. Both major and trace elements of volcanic rocks indicate that the lavas are products of calc-alkaline active margin arc volcanism, developed above a subduction zone. $^{143}Nd/^{144}Nd$ - $^{87}Sr/^{86}Sr$ isotope ratios depart from typical MORB values and are compatiple with those of intra-oceanic arcs. The Sünnice group, the Çaşurtepe formation and the BGC are unconformably overlain by Lower Ordovician continental elastics of the Palaeozoic of Istanbul. Therefore, the data presented here points out to the existence of subduction-related magmatism during the pre- Early Ordovician period in W Pontides.

INTRODUCTION

The Pontides are a mosaic of amalgamated Palaeozoic-Early Mesozoic continental and oceanic assemblages that differ in their metamorphizm, magmatism and tectonic settings (Şengör et al., 1984; Robertson and Dixon, 1984). The study area is in the western part of the Pontide tectonic belt, within what is termed the Istanbul nappe (Şengör et al., 1984), the Istanbul zone (Okay, 1989) or the Istanbul fragment (Ustaömer and Robertson, 1993); geographically it is located in the north and northeast of the Bolu city, between Bolu and Yedigöller (Fig. 1). Although the post-Ordovician geological evolution of the West Pontides is well understood (Şengör and Yılmaz, 1981), there is limited data for the pre-Ordovician period. The Palaeozoic of Istanbul (Abdüsselamoğlu, 1977) and its basement units, composed of high-grade metamorphics (the Sunnice group), low-grade metamorphic plutonic (the Bolu Granitoid Complex-BGC) and volcano-sedimentary rocks (the Çaşurtepe formation), are exposed underneath an Upper Mesozoic-Tertiary volcano-sedimentary cover (Fig. 2). The Palaeozoic of Istanbul and the Upper Mesozoic-Tertiary cover units are outside the scope of this paper. We here describe the basement units but emphasis is given to the Çaşurtepe formation. Stratigraphy, petrography, major- trace- elements and isotope geochemistry of the Çaşurtepe formation will be described in detail and its implication for regional geology will be evaluated. This work brings a different approach to the age and source problem of magmatic rocks, based on field work as well as geochemical studies on massive lavas of the Çaşurtepe formation, and petrographically and mineralogically similar dykes that intrude the granitoids. In this paper, an active margin magmatism of pre- Early Ordovician period is described.

HISTORY OF RESEARCH

The Çaşurtepe formation was considered part of metamorphic basement rocks (the Sunnice group of

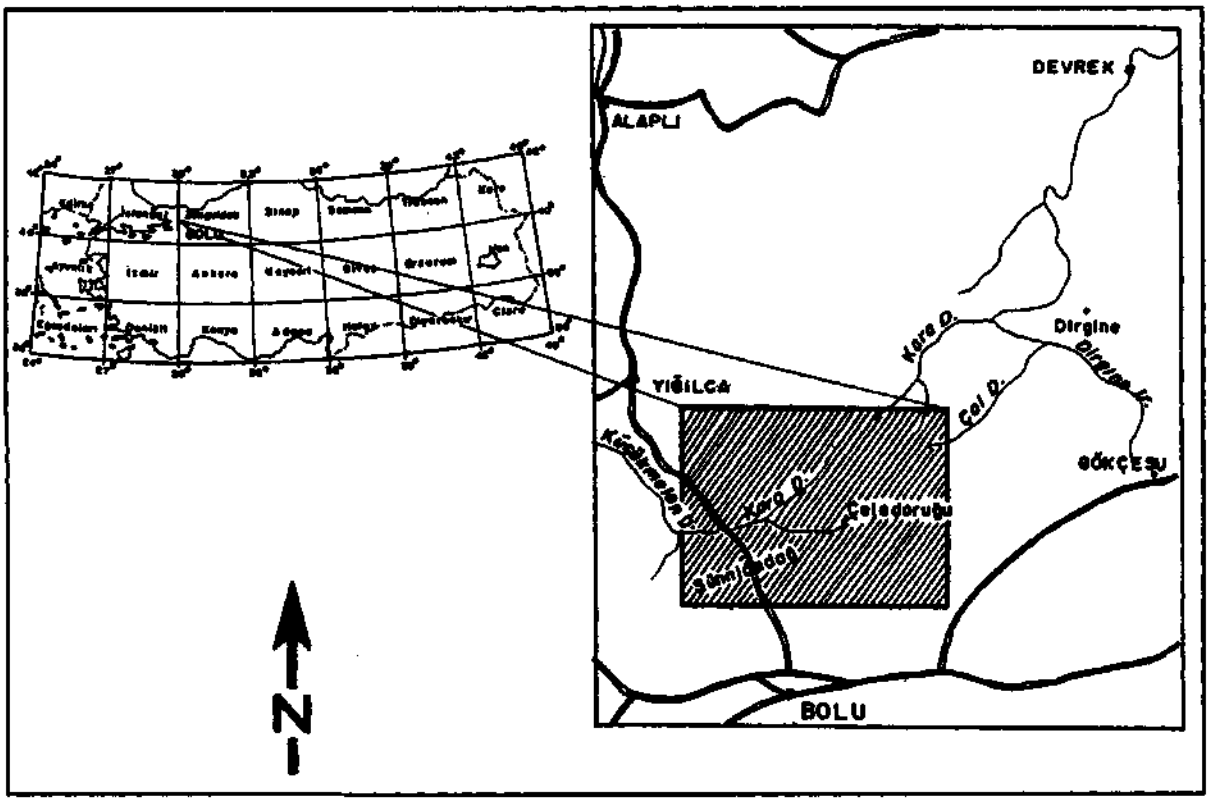

Fig. 1- Location map of the study area.

this study) and its metamorphosed basic volcanic and volcaniclastic member (Kaya, 1978; Canik, 1980; Serdar and Demir, 1983). Aydın et al., (1987) termed the unit the "Orhandağ metabasics", and Erendil et al., (1991) named it the "Yellice member" of the "Bolu massif. The volcanic rocks, however, during this study and a previous work (Cerit, 1990) are considered as a separate formation (Fig. 3).

Cerit (1990) called the unit the "Yellice formation or Yellice metavolcanics" and assumed it to be the oldest unit of the Palaeozoic sequence. He separated five different rock group within the formation; metavolcanics, metasandstones, contact metamorphic felsic rocks, quartzites and cataclastics. According to Cerit (1990) and Cerit and Batman (1992), the Dirgine granitoids (The BGC of this study) of Early Palaeozoic (Ordovician?) age and the Cambro-Ordovician aged metavolcanic rocks (the Yellice formation) are products of the same magmatic event and this magmatism took place during the early stages of the Caledonian orogeny. Thus the yianitoids (based on 23 major element analysis) and the metavolcanics emplaced onto southern margin of Eurasia as products of arc magmatism. Later Cerit changed his view and thought that the "Dirgine granitoids" are of S-type, products of partial melting of the Karadere metamorphics (the Sünnice group of this study) of sedimentary origin (Cerit, 1995).

Erendil et al., (1991) considered the granitoids and the volcanic rocks as "Magmatic core rocks" of the "Bolu massif (Blumenthal 1949). They gave a post-Devonian-Valangian emplacement age to the granitoids. They observed that the granitoids and the "Yellice membef cut each other, thus, they are the products of the same magmatic event.

Interpretation of the volcanic rocks by the previous workers is wholly based on field observation, contact relations and petrographic work. No geochemical data was provided.

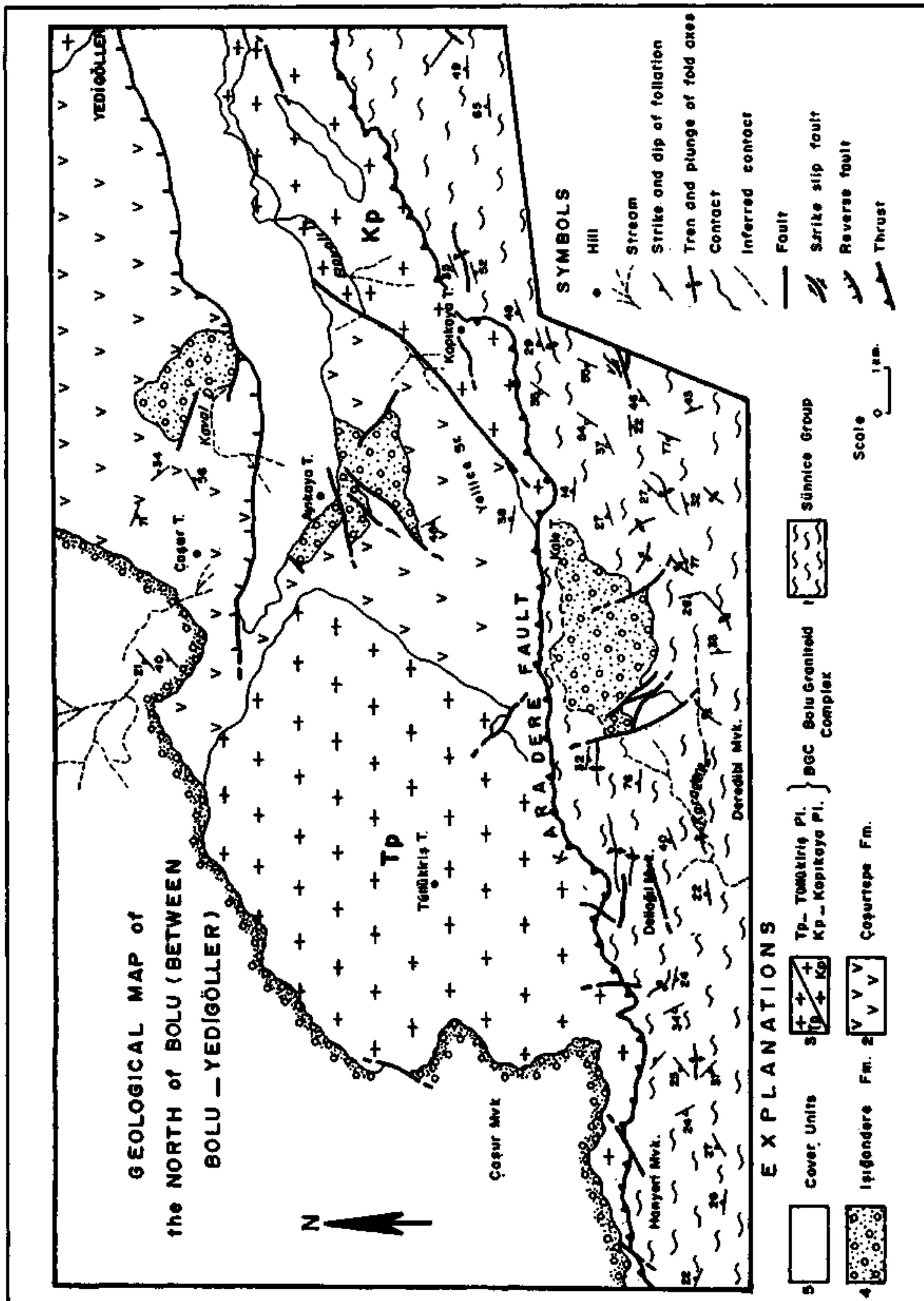

Fig. 2- Geological map of the study area. Simplified after Ustaömer (1996).

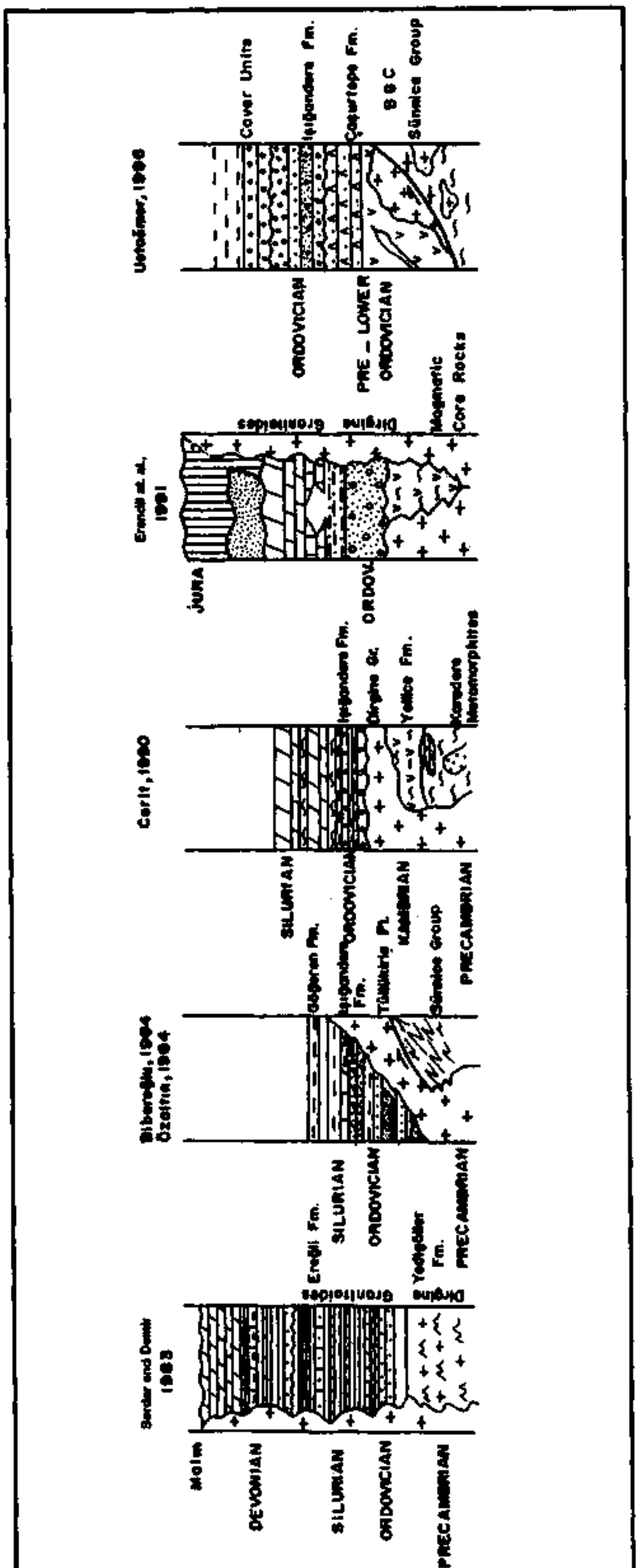

Fig. 3- Stratigraphic column sections of the study area proposed by previous workers and this study (not to scale).

TECTONO-STRATIGRAPHY

In the study area (Fig. 1), three different units are exposed underneath the Palaeozoic of Istanbul sequence. Structurally lowest unit is the Sünnice group (Biberoğlu, 1984; Özaltın, 1984; Seyitoğlu, 1984), comprises of gneises and amphibolites cut by metagranitic) intrusions. Structurally above is the Çaşurtepe formation (P.A. Ustaömer, 1996). This unit is made up of andesitic lavas at the base, overlain by dacite-rhyodacites and meta-ignimbrites, consisting of rhyolitic volcaniclastic sediments. The third rock group is the intrusions of the "Bolu Granitoid Complex" (BGC) (Mugan-Ustaömer, 1992) that cut the volcanic rocks of the Çaşurtepe formation and are in tectonic contact with the Sünnice group along a NE-SW trending fault zone. All these three units are unconformably overlain by continental elastics (the Işığandere formation) that are lateral equivalent of the Kurtköy formation (Haas, 1968; Kaya, 1978) of the Istanbul and adjacent areas. The Işığandere formation is conformably overlain by quartzites and shales in the NW of the study area. These are equivalents of the Aydos and Gözdağ formations (Önalan, 1981) of the İstanbul area. Following Middle Ordovician fossils were found within the study area from the shales (Özaltın, 1984; Biberoğlu, 1984): *Orthambonites* sp., *Mcewanella* sp., *Mcewanella* sp. cf. *berwynansis* (Mac Gregor), *Glyptorthis* sp., *Dalmanella* aff. *parva* Williams, *Parastrophinella* sp., *Christiania* sp., *Oligorhynchia* aff.*subplana* Cooper, *Protozygasp., Bryozoer,* and *Crinoid.* By its stratigraphic position underneath the Middle Ordovician shales, the age of the Işığandere formation can be given as Lower Ordovician.

The Sünnice group

The Sünnice group, the highest grade metamorphics of the study area comprises of gneisses and amphibolites, retrograded into greenschist facies (P.A. UStaömer, 1996). The Sünnice group is exposed as a north dipping tectonic slice, sandwiched between the Mesozoic sediments in the south (outside the study area) and the Bolu Granitoid Complex and the Çaşurtepe formation in the north, and unconformably overlain by the Lower Ordovician continental (fluvial) elastics

The Sünnice group is a migmatitic assemblage and consists, at the base (in the south), of pale and dark green, cm to m thick amphibolites, alternated with white, cream coloured quartz- feldspatic bands. The contact between the two is sharp and irregular in places. Further up, the unit is composed of thick gneisses, alternating with thin bands of amphibolites: At the uppermost levels the unit is cut by tonalitic, granodioritic and granitic (sensu stricto) rocks that are a few meters to tens of metres thick and metamorphosed in greenschist facies conditions. The most interesting structural feature of the Sünnice group is existence of extensive extensional structures in the form of normal faults. These structures are observed in the structurally upper levels (close to the northern contact of the unit) and do not exist in the younger (Lower Ordovician and Upper Mesozoic) units (P.A. Ustaömer, 1996).

The age of the unit can be given pre-early Ordovician as it is unconformably overlain by the Lower Ordovician continental elastics (the Işığandere formation). Aydın et al., (1987) described a clastic sequence (Soğuksu formation; Kaya, 1982) of Cambrian age stratigraphically underneath the Işığandere formation (Gormus, 1980). There is no metamorphism within this unit. This unit is not exposed in the study area due to either erosion or non-deposition. Therefore, the age of the Sünnice group can be given as Precambrian. There is a general concensus on the age of the similar units of the area among the previous workers (P.A. Ustaömer, 1996). High grade metamorphosed gneisses and amphibolites crop out in the Central and West Pontide tectonic belt in the Devrekani massif, in the Araç-Karadere area and in Kaplandededağ. These metamorphics are thought to be Precambrian in age by all the researchers (Arpat et al., 1978; Yılmaz, 1980; Ustaömer and Robertson, 1993). Kaya (1982) gave a Precambrian age to the unit as the Ordovician aged elastics unconformably overlie the metamorphic rocks.

The Bolu Granitoid Complex

Structurally above the Sünnice group, two members of the "Bolu Granitoid Complex", the Tüllükiriş pluton (Biberoğlu, 1984) in the west and the Kapıkaya pluton (P.A. Ustaömer, 1996) in the east are exposed along a NE-SW trending thrust zone. Petrographically, the plutons are tonalite, granodiorite and in restricted areas (northern areas for the Tüllükiriş pluton, central and northern areas for the Kapıkaya pluton) granite (sensu stricto) in composition, and exhibit a typically granophyric texture, implying that the granitoids were emplaced in shallow crustal levels and are high-level intrusives (emplacement depth is between <5 km and >2 km). Major- trace- elements and isotope geochemistry of the granitoids indicate that they are products of melts of supra-subduction zone arc magmas, contaminated by a crust at a certain degree (P.A. Ustaömer, 1996).

The plutons are cut by a number of lamprophyre and aplite dykes. The dykes are a few cm to a few m thick with a general NE-SW strike, compatible with general trends of the intrusions and their margins. Field and petrographic characteristics of the lamprophyre dykes are similar to those of the lavas of the Çaşurtepe formation. Therefore, chemical characteristics of the dykes are studied along with the volcanic rocks of the Çaşurtepe formation.

There is a general debate on the emplacement age of the granitoids. Suggested ages range from Early Ordovician (Aktimur et al., 1983; Cerit, 1990), post-Devonian (Erendil et al., 1991), post-Silurian (Biberoğlu, 1984; Özaltın, 1984; Seyitoğlu, 1984), End-Carboniferous- Upper Jurassic (Aydın et al., 1987) to pre-Middle Jurassic (Yazman et al., 1984) (Fig. 3).

The age of the intrusions can be given as pre-Early Ordovician as they are unconformably overlain by the continental Işığandere formation. They are, however, younger than the Çaşurtepe formation as they intrude it.

The Çaşurtepe formation

The Çaşurtepe formation is a volcano-sedimentary rock assemblage metamorphosed into greenschist facies. The unit is made up of massive, locally foliated, neutral to acidic lavas and volcaniclastic sediments. Clastic and carbonate sediments join the assemblage in the east, outside the study area (Fig. 2). The unit is named the Çaşurtepe formation as its best exposures and stratigraphy could be seen in the Çaşurtepe and in the Kaval dere valley adjacent to Çaşurtepe (P.A. Ustaömer, 1996).

The Çaşurtepe formation crops out between the tectonic line that separates the Sünnice group to the south and the Işığandere formation to the north (Fig. 2).

As the area is heavily vegetated, the best exposures can be seen in the road cuts along valleys. White rhyolitic lavas could be seen along the Yedigöller National Park-Homrus village road section. Hydrothermal alteration zones and mineralizations are best exposed on Kapıkaya Tepe-Boyalı Dere road sections. The Bolu river valley that flows in NW-SE direction between Gökçesu and Dirgine (outside the study area in the east) is the section where phyllites and metacarbonates dominate at the expense of volcanics.

At the observable base, there are massive lavas, dark green at altered surface, pale green to gray at fresh surfaces. At these levels, the lavas are represented by aphyric, locally quartz and plagioclase-phyric lavas. Chlorites are seen widely along foliation planes. Upward, the unit is cut by white, acidic lavas. These acidic lavas are 40-50 cm thick, fine grained and altered. These are best exposed to the south of Hümrüs village.

At upper part of the unit, pale green volcaniclastic sediments are seen. These are medium (15-20 cm thick) bedded, silicified and contains sedimentary structures such as grading and lamination. Base of individual beds are tabular, sharp and not erosional. At individual beds where grading is seen, base of the beds are represented by coarse sands, followed by fine sands and then silts. Dark green muds are found at the uppermost part of the beds. In such sandstone dominated sections, the sandstones alternate with 10-20 cm thick, dark green, finely laminated mudstones. The unit appears as a volcanic turbidite sequence in such areas. Volcanic conglomerates, on the other hand, were not encountered in the unit.

The volcanic rocks exhibit intense hydrothermal alteration at lower levels where massive lavas dominate and in places in the north where volcaniclastic sediments are exposed. Such alteration zones can easily be recognised with their reddish brown and local sulphuric yellow colours. Another characteristics of such areas is existence of associated intense deformation (shear zones). Thus, there is a strong control on genesis of the mineralization. When closely examined, the shear zones separate lensoidal massive lava blocks. Along the shear planes of 2- 3 cm thick, there are pyrite-rich veins in which pyrite crystals are 5-6 mm long. Lava blocks contain disseminated pyrites and are silicified.

It is impossible to give a stratigraphic thickness to the unit as it is faulted at the base and erosional at the top and also as it is composed dominantly of massive lavas with only rare stratigraphic horizons (bedding, lava flows). A 5 km structural thickness is estimated for the exposures within the study area (Fig. 2).

The Çaşurtepe formation is in tectonic contact with the Sünnice group and the Kapıkaya pluton. Along the contact with the Sünnice group, the Çaşurtepe formation is thrust over it. The volcanic rocks are cleaved in the contact zone. The Çaşurtepe formation is thrust over the Palaeocene-Eocene aged volcanic rocks along the northern slopes of the Ayıkaya tepe (Fig. 2).

The Çaşurtepe formation is unconformably overlain by red continental conglomerates of the Işığandere formation in the Kapıkaya tepe, north of the Çaşurtepe and in the southeast of Hümrüs village, outside the study area in the north. The Işığandere formation here contains clasts of volcanics of the Çaşurtepe formation. Another important observation is that the Işığandere formation do not show any trace of hydrothermal alteration where it inconformably overlies zones of intense hydrothermal alteration and mineralization. The Çaşurtepe formation is unconformably overlain by the Upper Cretaceous limestones (Ayıkayası formation; P.A. Ustaömer, 1996) near south of Ayıkaya tepe peak (Fig. 2).,

Along the intrusive contact with the Tüllükiriş pluton, apophysis (2-3 m thick) of the pluton intrudes the volcanic rocks and large volcanic blocks are seen within the plutonic rocks. A few tens of metres thick contact aerole is developed along this contact.

There is no radiometric age data on the Çaşurtepe formation. Therefore, the age of the unit can be constrained by taking into account of its contact relation with other units. As stated above, the Çaşurtepe formation is unconformably overlain by the Lower Ordovician Işığandere formation. This indicates that the Çaşurtepe formation was uplifted and become a source area for the Işığandere formation elastics before Early Ordovician. The hydrothermal mineralization and deformation that control it must be pre-Early Ordovician in age as such zones are also unconformably overlain by the Işığandere formation. It is obvious that metamorphic grade of the Çaşurtepe formation is lower than that of the Sünnice group. This implies that metamorphism of the Çaşurtepe formation took place at shallower crustal levels in comparison to the Sünnice group. The unit can be said to be older than the granites as it is cut by them.

PETROGRAPHY

When examined under the microscope, the neutral-acidic volcanics and volcaniclastics comprises of plagioclase, quartz, chlorite, actinolite and epidote minerals set in a dark green chloritized. Calcite and pyrite join the assemblage where the rock is heavily deformed, evidenced by development of secondary shear zones.

Plagioclases are found as both large crystals and as microlites within the matrix. They show mainly carlsbad and albite-carlsbad twinning, and appear brownish in colour due to carbonate alterations. Among the plagioclase crystals, there are quartz (5-10 %), chlorite with bluish extinction colour in places, and tabular actinolites. Epidote minerals of various sizes are widely seen in sections rich in plagioclase. Thus, mainly andesitic neutral rocks typically show porphyric textures. In some sections with cryptocrystalline matrix, fine grained quartz minerals are seen to be dispersed throughout. But, matrix / quartz ratio changes place to place at the expense of each other. In such sections, there are also dispersed fine grained plagioclase, chlorite and actinolite in trace amounts.

Extinction angles of he plagioclase minerals were measured by using universal table and change between 12 to 26°. Thus, anorthite content of the plagioclases varies in a wide interval between An_{28-46}.

The rhyolitic volcaniclastic sediments of the Çaşurtepe formation are made up of large quartz grains as well as plagioclases.

In summary, petrographic examination of the lavas of the Çaşurtepe formation showed that an albite + epidote + actinolite + chlorite ± quartz greenschist fades mineral assemblage was developed on a primary igneous mineral assemblage of neutral plagioclase, quartz and glassy matrix.

GEOCHEMISTRY

6 samples of lavas of the Çaşurtepe formation and 8 samples of dykes that cut the granitoids were collected to analyse for major- and trace- elements. The result is given in Table 1. Major- and trace- elements analysis were carried out by using XRF (X-Ray Fluoresans) technique at Edinburgh University. Sample preparation method is given in Fitton and Dunlop (1985).

Major- and trace- elements geochemistry

LOI (Loss on ignition) values of the lavas and the dykes are up to 5 %. This indicates that these rocks are variably altered. Most of the major oxides, except Ti and P, and Large Ion Lithophile (LIL) elements (Rb, Sr, Ba) are known to be mobile under greenschist facies metamorphism conditions (Pearce and Cann, 1973). It is possible to determine mobility of an element by plotting it against an immobile element. Here, all the elements are plotted against Zr and it is found out that concentrations of K_2O, Na_2O, CaO, MgO, MnO, Sr, Rb, Ba were affected by hydrothermal alterations. When the dykes are taken into consideration, in addition to above oxides and elements, the SiO_2 concentrations were also affected (P.A. Ustaömer, 1996). Therefore, the discussion below is based op immobile elements.

SiO_2 values of the volcanics is less than 54 %. MgO values are generally < 6 %, varying between 2-3%. Thus, the volcanic rocks appears to be products of fractionated and evolved melts (P.A. Ustaömer, 1996). In Zr-Ti diagram (Pearce 1980; 1982), the lavas plot in evolved IAT (Island Arc Tholeites) field (Fig. 4a). Therefore, it is not correct to plot these lavas in basalt discrimination diagrams. In the same diagram, two dykes that cut the Tüllükiriş pluton plot in the basic field, five dykes of the Kapıkaya pluton plot in the evolved IAT field and one sample plot in the basic WPB (Within Plate Basalt) field.

In Nb/Y-Zr/Ti nomenclature diagram (Winchester and Flyod, 1977), the lavas of the Çaşurtepe formation plot in the andesite field,of which two samples plot close to the rhyodacite field (Fig. 4b). Four dyke samples of the Kapıkaya pluton plot in the rhyodacite and the two plot in the andesite fields. But one of these two samples plot in the andesite-rhyodacite boundary and the other is on the basaltic andesite-andesite boundary. The two dykes of the Tüllükiriş pluton plot in the basaltic andesite field on the same diagram (Fig. 4b).

When plotted on an AFM diagram (Fig. 5), the Çaşurtepe volcanics show calc-alkaline trends, while the dyke samples plot in the tholeiitic field (care should be taken, however, when using this diagram as the oxides used in constructing this diagram are known to be mobile).

The samples are plotted on spidergrams by using Sun and McDonough (1980) normalizing values (Fig. 6). In MORB-normalized spidergrams, the dykes (Fig. 6 a,b) show light rare earth element (La, Ce, Nd) enrichment relative to Nb. The Kapıkaya pluton dykes show LIL element (Sr, K, Rb, Ba) enrichment and Ti depletion relative to Zr. These are characteristics of the calc-alkaline volcanics. The Tüllükiriş dykes, on the other hand, show relative flat patterns that are similar to those of island arc tholeiites. The Çaşurtepe volcanics

Table 1- Major- and trace-element analysis of the Çaşurtepe formation and the dykes.

Örnek*	93-54	93-11	93-48	93-3	91-42	91-45		93-41	93-64		91-13	91-15	91-17	91-24	91-25	91-26
SiO_2	63.09	66.08	70.76	62.64	54.92	70.23		50.29	57.06		58.21	62.39	60.07	47.1	53.61	53.8
Al_2O_3	13.32	14.53	13.22	13.21	16.94	13.41		14.66	13.39		17.06	15.88	16.74	15.3	19.48	19.6
Fe_2O_3	9.51	5.94	4.32	8.92	9.11	4.74		17.77	11.59		7.28	6.02	7.46	14.26	7.27	6.65
MgO	4.91	1.95	0.86	6.5	3.59	1.99		3.88	6.28		1.3	1.24	1.75	5.92	4.53	3.31
CaO	0.24	5.06	4.44	0.21	6.14	2.88		3.28	2.54		5.3	2.82	2.29	7.48	7.85	6.57
Na_2O	3.93	3.18	3.54	0.07	3.6	3.8		4.38	3.12		4	7.16	5.53	3.79	3.03	4.48
K_2O	0.047	0.416	0.497	1.174	0.888	0.719		0.232	0.014		1.727	0.539	2.167	0.949	0.721	1.005
TiO_2	0.832	0.464	0.465	0.721	0.996	0.496		1.639	0.999		0.796	0.594	0.935	2.825	0.675	0.646
MnO	0.297	0.11	0.104	0.522	0.127	0.121		0.209	0.295		0.131	0.097	0.126	0.237	0.123	0.125
P_2O_5	0.103	0.15	0.082	0.114	0.192	0.098		0.233	0.112		0.328	0.224	0.242	0.387	0.154	0.169
LOI	3.3	2.01	1	4.76	3.59	1.6		3.09	4		3.59	3.36	2.44	1.58	2.65	3.7
Toplam	99.57	99.89	99.28	98.7	100.1	100.09		99.66	99.39		99.74	100.33	99.75	99.83	100.1	100.05
Sc	32.9	16.8	21.7	32.3	45.8	17.1		59.5	34.2		9.4	14.1	19.8	33.1	18.4	13.4
Ba	40.6	202.2	111.4	2355.3	4.3	461.5		76.9	5		368.9	182.2	506.3	223.9	119.2	174.7
V	240,1	84.9	48.6	72.4	466.9	71.9		430.2	331.6		56.7	20.4	59.9	351.5	143.7	118.6
La	4.6	21.1	9.3	6.7	0.8	6.6		2.8	2.6		20.2	21.9	16	8.9	9	15.5
Ce	24.8	41.4	19.3	23.3	6.5	8.6		20.1	13		36.3	38.9	28.7	29.4	19.7	19.9
Nd	15.5	17.5	9.9	16.6	4.6	5.2		13	7.4		17.8	18.3	11.7	16.7	3.3	10.5
Cr					84.2	8.2					4	0.5	0.9	80.3	36.3	9.5
Ni					20.3	7					4.2	4.1	3.1	38.9	20.7	8.9
Cu	139.5	40.8	38.8	24.5	20.4	8.1		86.7	10		11.8	13.2	15.3	36	29.1	23.5
Zn	322.1	76	50.2	634.5	295.2	82.7		114.2	163.8		74.7	64.1	63.2	120.4	52.2	65.5
Pb	3.7	3.2	8.5	3.2	57.2	17.6		6.5	1.9		3.2	7.9	3.5	5.8	3.7	5.5
Th	0.8	0.6	3.4	0.9	0.2	1.6		5.2	1		3.7	3.3	4.2	0.3	1	2.7
Rb	0.9	14.8	14.5	21	0.2	11.2		7.4	1.2		35.2	9.9	49.4	23.4	18.8	23.1
Sr	22.9	309	160.5	10.1	480.5	131.6		268.4	44.3		208.1	210.9	306.4	445.1	247.6	245.6
Y	32.7	20.8	25.3	38.7	38.7	23.9		29.7	26.9		36.3	43.6	39.5	38.1	17.4	19.4
Nb	2.7	5.3	2.4	2.8	2.7	6.5		1.8	1.1		13.8	10.7	9.6	16.3	6.4	7.8
Zr	87.9	75.1	60.2	81.8	103.8	71.6		50.1	67.5		209.4	204	171.7	214.2	94.1	103.6
Zr/Y	2.688	3.611	2.379	2.114	2.682	2.996		1.687	2.509		5.769	4.679	4.347	5.622	5.408	5.34
Nb/Y	0.083	0.255	0.095	0.072	0.07	0.272		0.061	0.041		0.38	0.245	0.243	0.428	0.368	0.402
Fe/Mg	1.937	3.046	5.023	1.372	2.538	2.382		4.58	1.846		5.6	4.855	4.263	2.409	1.605	2.009
Ce/Y	0.758	1.99	0.763	0.602	0.168	0.36		0.677	0.483		1	0.892	0.727	0.772	1.132	1.026
Y/Nb	12.111	3.925	10.542	13.821	14.333	3.677		16.5	24.455		2.63	4.075	4.115	2.337	2.719	2.487
Ce/Nb	9.185	7.811	8.042	8.321	2.407	1.323		11.167	11.818		2.63	3.636	2.99	1.804	3.078	2.551
Zr/Nb	32.556	14.17	25.083	29.214	38.444	11.015		27.833	61.364		15.174	19.065	17.885	13.141	14.703	13.282

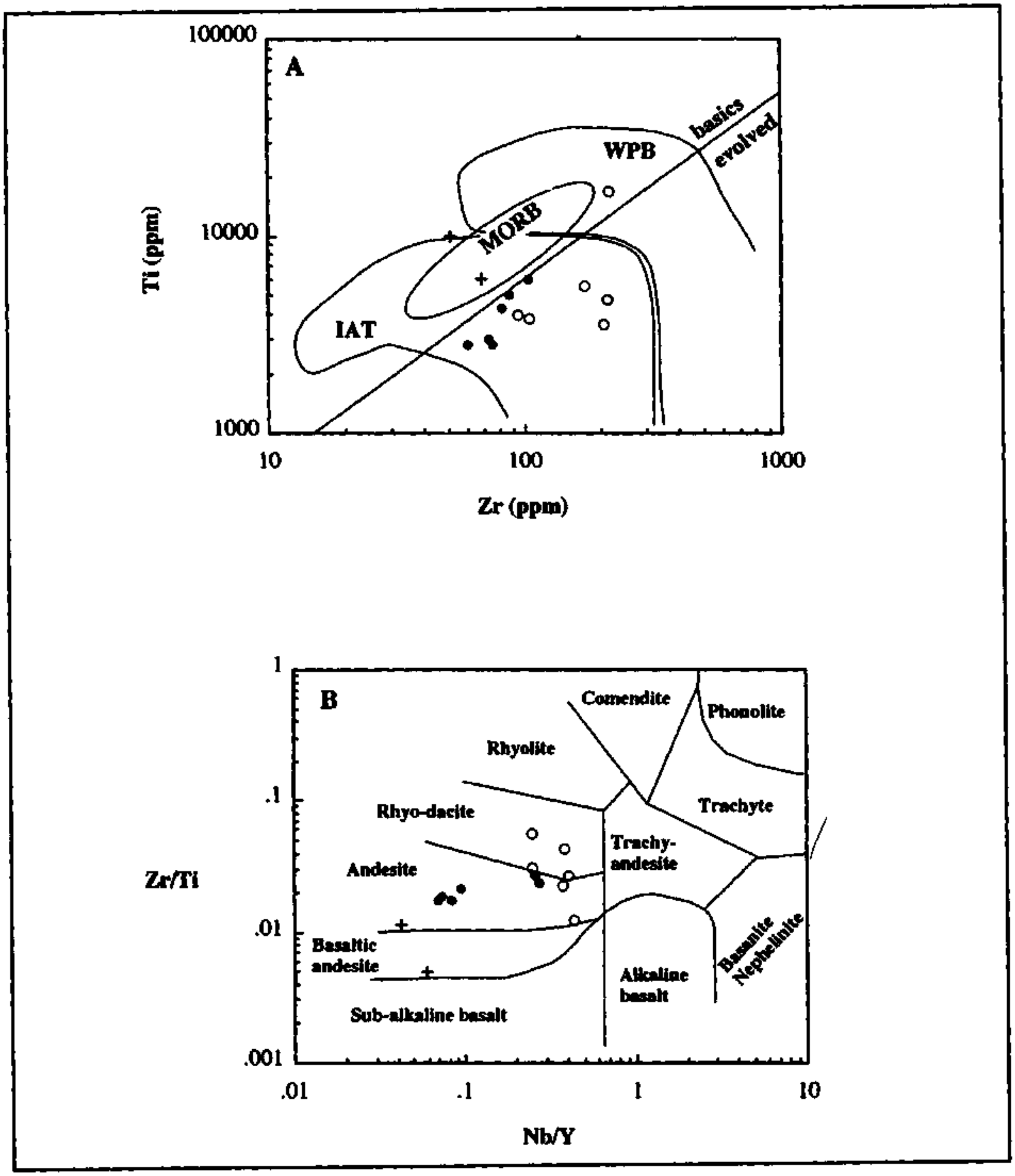

Fig. 4- A. Zr versus Ti diagram (Pearce, 1982) of the Çaşurtepe formation and the dykes (IAT-Island Arc tholeiites; MORB-Mid Ocean Ridge Basalt; WPB-Within Plate Basalt).
B. Nb/Y versus Zr/Ti nomenclature diagram (Winchester and Floyd, 1977) of the Çaşurtepe formation lavas and the dykes. See text for explanation (filled circles: the Çaşurtepe formation; empty circles: Kapıkaya dykes; +: Tüllükiriş dykes).

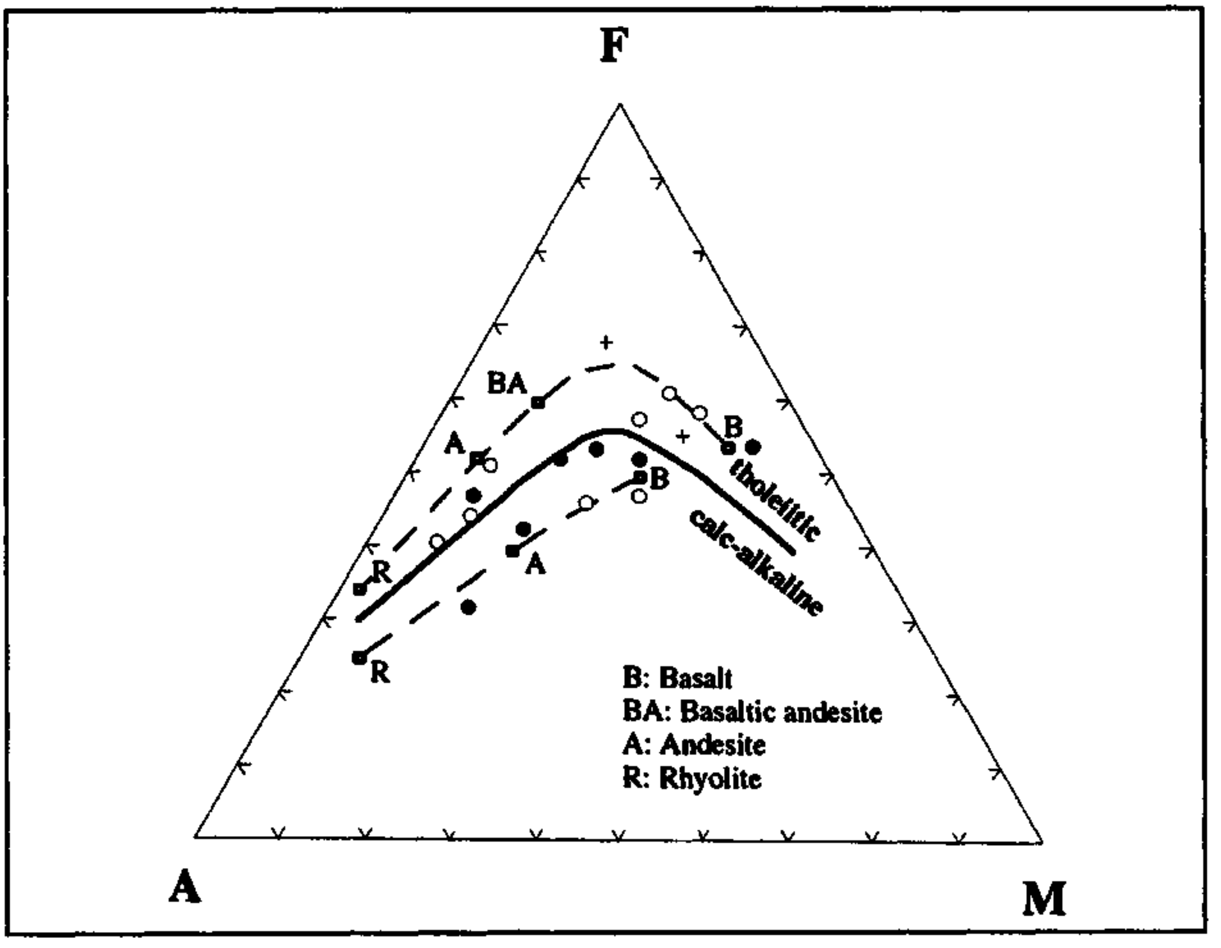

Fig. 5- AFM ternary diagram of the volcanic rocks and the dykes (Boundary line is taken from Irvine and Baragar, 1971). Filled circles: the Çaşurtepe formation; empty circles: the Kapıkaya dykes; + : the Tüllükiriş dykes.

are enriched in LIL elements, there is a marked Nb depletion relative to LREE and Ti depletion relative to Zr (Fig. 6c). The two dykes samples from the Kapıkaya pluton near Dorukhan (outside the study area) show LIL element enrichment, Nb depletion relative to La (Fig. 6d). But the elements between Nb and Y are distinct than the other dykes with these characteristics.

Sr-Nd isotope chemistry

During this study, one sample of the Sünnice group metagrantte, one sample of lava from the Çaşurtepe formation and four samples of the granitoids were analysed for Rb, Sr, Sm, Nd isotopes ar SURRC (Scottish Universities Research and Reactor Centre). Here Sr, Nd isotope data of one lava sample of the Çaşurtepe formation will be discussed.

$^{87}Sr/^{86}Sr$ 550 Ma model values of the sample is 0.706482, $^{143}Nd/^{144}Nd$ model value is 0.512450, 550 Ma €Nd value is 10.2.

When plotted on $^{143}Nd/^{144}Nd$ versus. $^{87}Sr/^{86}Sr$ diagram (Wilson, 1989), the sample departs from typical MORB field and plot in the intra-oceanic arc field (Fig. 7). Nd isotope values are not affected by crustal processes such as alteration, sedimentation and metamorphism (Wilkinson, 1982). Therefore, Nd isotopes give reliable results for petrogenetic processes.

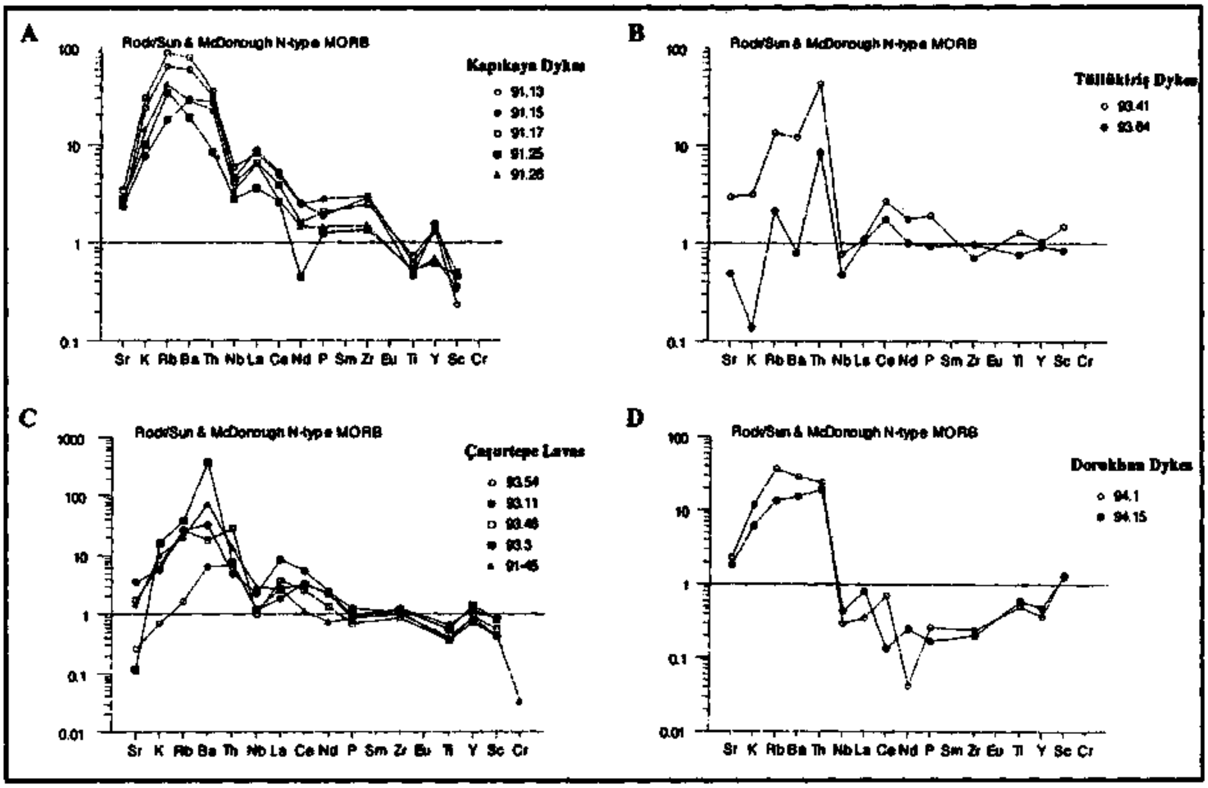

Fig. 6- MORB-normalised spidergrams of the Çaşurtepe formation and the dykes in granites. Normalising values are from Sun and McDonough (1989). See text for explanation.
A. Dykes of the Kapıkaya pluton
B. Dykes of the Tüllükiriş pluton
C. The Çaşurtepe formation lavas
D. The Dorukhan dykes (from the Kapıkaya pluton outside the study area in the east)

Interpretation of the geochemical data

The geochemical data show that the lavas of the Çaşurtepe formation are calc-alkaline, fractionated andesitic lavas. The patterns observed on the spidergrams are compatible with those of above subduction zone calc-alkaline volcanic rocks. LIL-elements enrichment and Nb depletion relative to LREE (Ce) are the characteristics of supra-subduction zone lavas. Similarly, the dykes of the plutons appear to be above subduction zone melts. The Kapıkaya dykes show typical calc-alkaline trends, while the Tüllükiriş dykes give patterns similar to island arc-tholeiites.

When the plutonic and the volcanic rocks are evaluated together the pre-Early Ordovician magmatic rocks of the Bolu-Yedigöller area represent half mature arc setting where subducton related tholeiitic and calc-alkaline intrusives and extrusives were accumulated (P.A. Ustaömer, 1996).

DISCUSSION

The Lower Ordovician continental clastic sediments (the Işığandere formation) unconformably overlies the older units. Pebbles of the Sunnice group, the granitoids and the Çaşurtepe formation are widely present within these clastic sediments. This implies that the basement rocks were uplifted a minimum of 5 km before deposition of the Işığandere formation and become a source area for them.

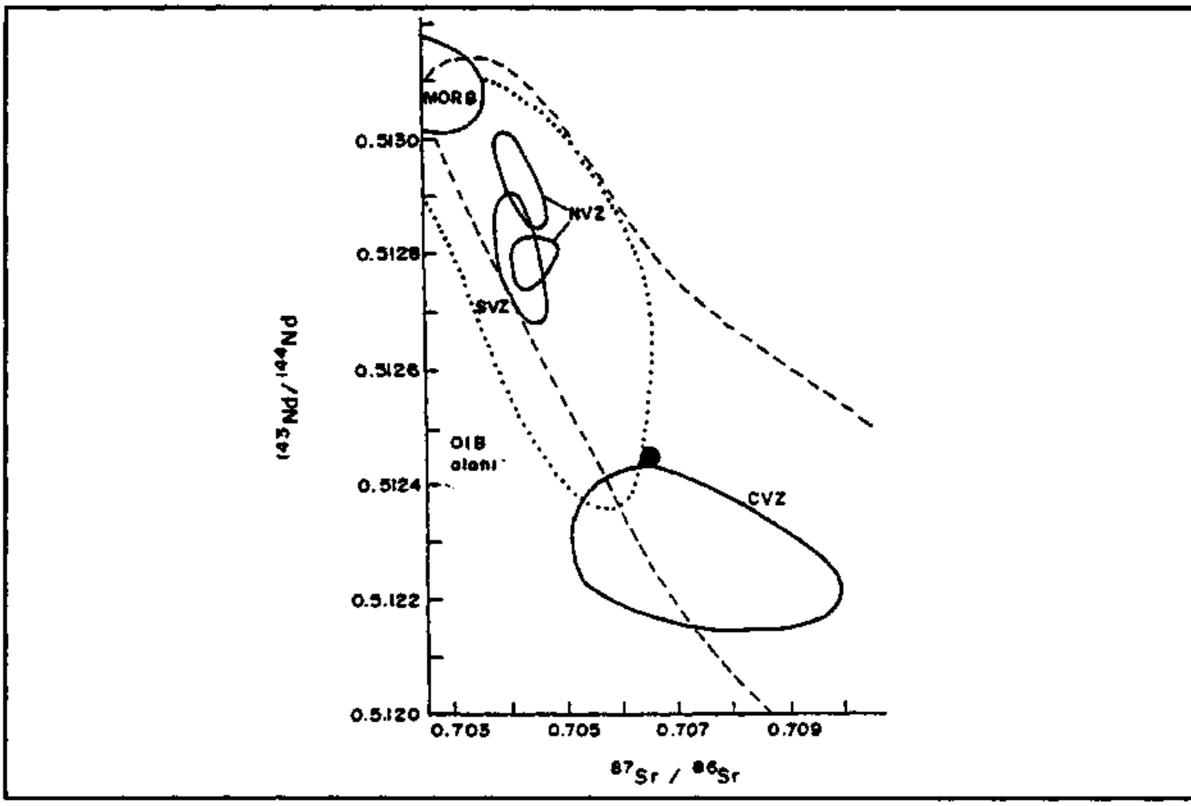

Fig. 7- $^{87}Sr/^{86}Sr$ versus $^{143}Nd/^{144}Nd$ diagram of one sample of the Çaşurtepe formation. The fields are taken from Wilson (1989). NVZ: North Volcanic Zone; CVZ: Central Volkanic Zone; SVZ: South Volcanic Zone (all from Andean active volcanos); MORB: Mid-Ocean Ridge Basalt; OIB: Oceanic Island Basalt.

The Sunnice group is a migmatitic assemblage metamorphosed in amphibolite facies and its formation corresponds to deeper crustal levels (P.A. Ustaömer, 1996). The granitoids are typical calc-alkaline and show I-type, and locally S-type characteristics due to crustal contamination. They are interpreted as products of mantle derived, crustal contaminated arc magmas that emplaced into shallow crustal levels. Compatibility of both strikes and composition of the dykes and the granitoids suggest that the dykes were the products of relict melts of the granitoids. Major- and trace-element composition of the dykes support this conclusion. In summary, the dykes observed in the granitoids represent a supra-subduction magmatism compatible with the geochemistry of the granitoids.

The Çaşurtepe formation is a 5 km thick (structural-thickness), subduction related, calc-alkaline volcanic assemblage in which andesitic lavas are dominant with lesser amount of dacite-rhyodacite and rhyolites. At the upper levels, volcaniclastic sediments join the sequence.

In the light of the data given here, it can be said that the granitoids and the volcanic sequence were formed in the same tectonic setting. While volcanic sequence was constructed as surface product of arc magmatism, the granitoids were emplaced into this volcanic pile in later stages of the arc evolution (Fig. 8). Similar evolution can be found in many modern and ancient magmatic arcs (Andean active margin and Cretaceous E Rontide arc; Pitcher, 1982; Tokel, 1995).

The data points out the existence of arc magmatism in pre-Early Ordovician time.

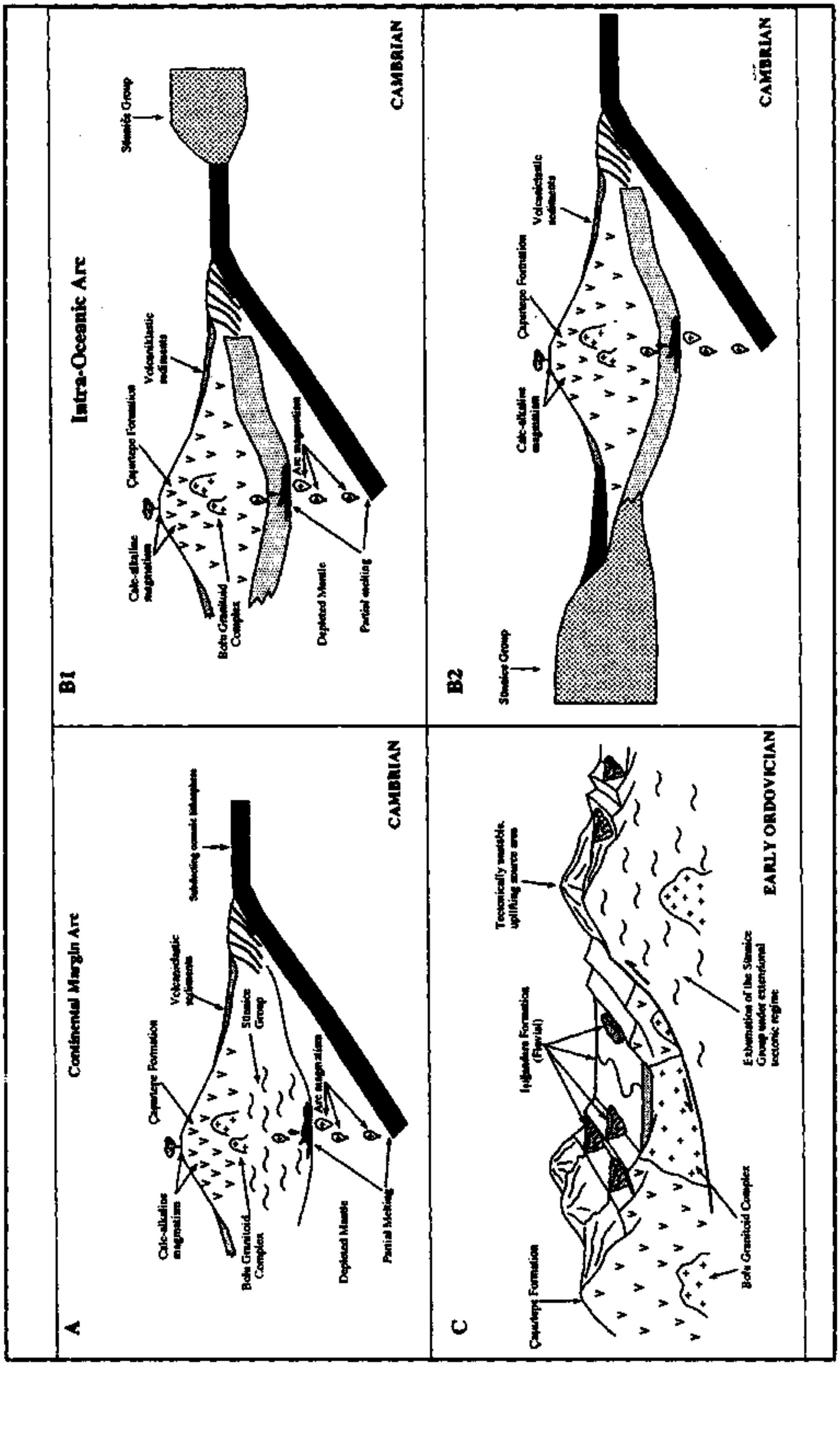

Fig. 8- Proposed alternative tectonic models of the study area. See text for explanation of the models.

Infra-Oceanic versus continental margin arc magmatism

As the stratigraphic basement of the Çaşurtepe formation is not exposed, it is not clear whether it was developed ontop of continental or oceanic crust.

Two different models can be proposed for development of the plutonic and volcanic assemblage. In the first model (Fig. 8a), the Çaşurtepe formation represents surface products of active continental margin arc magmatism into which the intrusions of the BGC were emplaced during later stages of arc evolution. In this model, the Sünnice group forms the continental basement of the active margin. This basement was detached and uplifted in pre- Early Ordovician time (Fig. 8c). In the second model, the calc-alkaline magmatism was developed in an intra-oceanic arc (Fig. 8b). In this model, the Sünnice group represents a separate continental silver. This continental block a) collided with the intra-oceanic arc, deeply buried, then detached and uplifted (Fig. 8b1) or b) the intra-oceanic arc was a near continental margin arc and it was thrust onto the continental margin (i.e. the Sünnice group) during pre-Early Ordovician period (Fig. 8b2). The second model requires that the present day outcrop pattern of the region is a result of post-Ordovician tectonism.

The Çaşurtepe formation, together with the granitoids, tectonically overlies the Sünnice group. There is no accretionary complex or an ophiolitic melange along the contact. Therefore, the contact with the Sünnice group is not a suture. The Sünnice group itself is not an accretionary complex either as the unit comprises of gneiss-amphibolite alternation into which granitic melts were emplaced. The unit does not contain ophiolite slices or blueschist blocks. Therefore, the first model is prefered here.

This paper presents first analytical data on existence of arc magmatism during pre-Early Palaeozoic period within West Pontide tectonic belt (P.A. Ustaömer, 1996; Ustaömer and Kipman, 1997). Similar tectonic events took place in Europe along Cadomian margins (Haydutov, 1995; Göncüoğlu, 1997).

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