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Volcanic Rocks from Foça-Karaburun and Ayvalık-Lesvos Grabens (Western Anatolia) and Their Petrogenic-Geodynamic Significance

Dedicated to Prof.Dr. FABRIZIO INNOCENTI

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Abstract: The Foça-Karaburun and Ayvalık-Lesvos grabens (western coast of Anatolia, Turkey) are two important NW–SE-trending extensional areas generated in response to the Early Miocene–Holocene extension of the Western Anatolian region, related to the opening of the 'unconventional' back-arc basin of the Aegean Sea. The abundance of geo-structural evidence and the occurrence of volcanic rocks representing all the stages of the Aegean-Western Anatolia volcanism render the Foça-Karaburun and Ayvalık-Lesvos Grabens key localities to exemplify the petrogenetic and geodynamic evolution of the area. In this context, the Foça-Karaburun and Ayvalık-Lesvos grabens, possibly formerly a single graben, formed along an original NE–SW-trending extension, later dissected by E–W-trending transtensional faults, are investigated to constrain the petrogenetic and geodynamic evolution of the whole Aegean region. Calc-alkaline and shoshonitic volcanic rocks with scattered ultrapotassic-shoshonitic or lamproitic lavas and dykes represent the orogenic phase of the magmatic activity, while the younger K- and Na-rich alkaline basaltic rocks are the result of later magmatism characterized by an intraplate geochemical signature reflecting progressively decreasing subduction rates.

While the tectonic lineaments and the structures of the study area allow the reconstruction of the tectonic evolution of Western Anatolia and Aegean Sea, the volcanic rocks from the different stages of Neogene volcanism within the two studied grabens and surrounding areas permit a precise record of the geochemical evolution of the magma sources.

Key Words: Turkish Aegean region, volcanic rocks, extension tectonics, Cenozoic, geochemistry, petrology

Foça-Karaburun ve Ayvalık-Midilli Grabenlerindeki (Batı Anadolu) Volkanik Kayalar ve Onların Petrojenetik-Jeodinamik Önemleri

Özet: Foça-Karaburun ve Ayvalık-Midilli grabenleri, Batı Anadolunun kıyı kesiminde kalan, KB–GD yönlü iki önemli genleşme alanlarıdır. Bu grabenler, Ege Denizinin yay arkası havzasının açılımı ile de ilişkili olan Erken Miyosen–Holosen genleşmesinin etkisinde kalmış geniş alanların petrojenik ve jeodinamik gelişimlerine örnek teşkil eden çok önemli lokasyonlardır. Bu bağlamda, Foça-Karaburun ve Ayvalık-Midilli grabenleri, D–B transtansiyonel faylar ile parçalara ayrılmış, KD–GB yönlü açılma sunan bölgedeki büyük graben sistemleridir. Batı Anadolu'da, kalk-alkali ve şoşonitik volkanikler ile UK, UK-şoşonitik veya lamproitik kayalar orojenik ortamları yansıtırlarken, daha genç olan K ve Na alkali bazaltik kayalar kıtasal koşullar altındaki kıta içi magmatizması ürünleri olan okyanus adası bazaltları (OIB) ile temsil edilirler.

Çalışma alanının tektonik hatları, Batı Anadolu ve Ege Denizi'nin tektonik evrimini yeniden yapılandırabilirken, çalışılan iki grabendeki ve çevresindeki Neojen volkanizmasının farklı seviyelerindeki kayaları, bu kayaları üreten magma kaynaklarının jeokimyasal gelişiminin kesin bir kaydını tutmaktadırlar.

Anahtar Sözcükler: Ege Bölgesi, volkanik kayalar, açılma tektoniği, Senozoyik, jeokimya, petroloji

Introduction

The Western Anatolian-Aegean area underwent a series of multiple continental collisions starting in the Mesozoic (Şengör & Yılmaz 1981) and since the Early Miocene it has been subjected to major extension. Additionally, it represents a key area to investigate the relationships between geodynamics and magmatism, due to the occurrence of widespread Neogene volcanism with an affinity ranging from orogenic to intraplate-alkaline.

Several models have been proposed to explain the extension in Western Anatolia (WA), the related volcanic activity and their mutual relationships. These models have been recently critically reviewed, and a new model based on the integration of geodetic, structural and petrologic-geochemical data has been proposed to explain the geodynamic evolution of the region (Agostini *et al.* 2010). In this model, reported for the first time in Doglioni *et al.* (2002) and Innocenti *et al.* (2005), the Early Miocene–Holocene extension in Western Anatolia is linked to the opening of the 'unconventional' back-arc basin of the Aegean Sea. According to these authors, the rifting affecting western Anatolia, the Aegean Sea, Greece, Macedonia and Bulgaria results from the differential convergence rates between the northeastward-directed subduction of Africa relative to the disrupted Eurasian lithosphere. Indeed, in an Africa-fixed reference frame, both the Greek and Anatolia microplates override Africa southwestwards, yet the Greek microplate is faster. As a result, a diffuse extensional margin is created in the Aegean-Western Anatolia region.

In this paper we present new data on the extensional region of western Anatolia, integrating geological and petrological information. In particular we focus on the Foça-Karaburun graben (FKG) and Ayvalık-Lesvos graben (ALG) systems.

The FKG and ALG systems are two important NW–SE-trending extensional areas (Figure 1) on the western coast of Anatolia that exhibit similar lithologies, with continental sedimentary units intercalated with diverse volcanic rock units of Miocene to Pliocene age. Based on tectonic evidence, and the occurrence of volcanic rocks representing all stages of the Aegean-Western Anatolia volcanism, the FKG and ALG represent key localities to exemplify the petrogenetic and geodynamic evolution of the area in the context of the new geodynamic model of Agostini *et al.* (2010).

General Remarks on the Geology of the Western Anatolia

Geological-Geotectonic Setting

The main rock assemblages from northwestern to southwestern Anatolia (Figure 2) can be grouped into the pre-Neogene tectonic units of: (i) the Western Pontides (Sakarya Continent; Şengör 1979), which contains the Kazdağ Metamorphics and Permo–Triassic olistostroms; (ii) the ophiolitic mélange of the İzmir Ankara Zone (Brinkmann 1971), formed during Middle Eocene times by the closure of the İzmir-Ankara branch of the Neo-Tethys, (iii) the metamorphic core complex of the Menderes Massif, characterized by multiple events, with ages spanning a wide interval from 1200 to 10 Ma, with the main tectonic phases between Late Cretaceous and Early Miocene (e.g., Lips *et al.* 2001; Erdoğan & Güngör 2004); (iv) the ophiolitic nappes (Lycian and Antalya nappes) of the Western Taurides, overthrust onto the Menderes Massif and the Beydağları autochthonous carbonate succession of Late Palaeozoic to Middle Eocene age (Hayward & Robertson 1982; Collins & Robertson 1998; Güngör & Erdoğan 2001; Rimmelé *et al.* 2003).

The exhumation of the gneissic core of the Menderes Massif is marked by post-metamorphic granitic intrusions (Dora *et al.* 1987), which were generated during the opening of extensional basins related to the Miocene detachment.

Magmatic Activity and Former Approaches to the Geodynamics and Petrogenesis of the Region

Subduction-related magmatic activity in the Aegean Region and in WA has long been the subject of extensive studies (see Innocenti *et al.* 2005 and references therein). This activity, characterized mainly by high-K calc-alkaline products, started in Paleocene–Eocene times and progressively shifted southwards. Remnants of strato-volcanoes with intercalations of continental sediments (Lower–

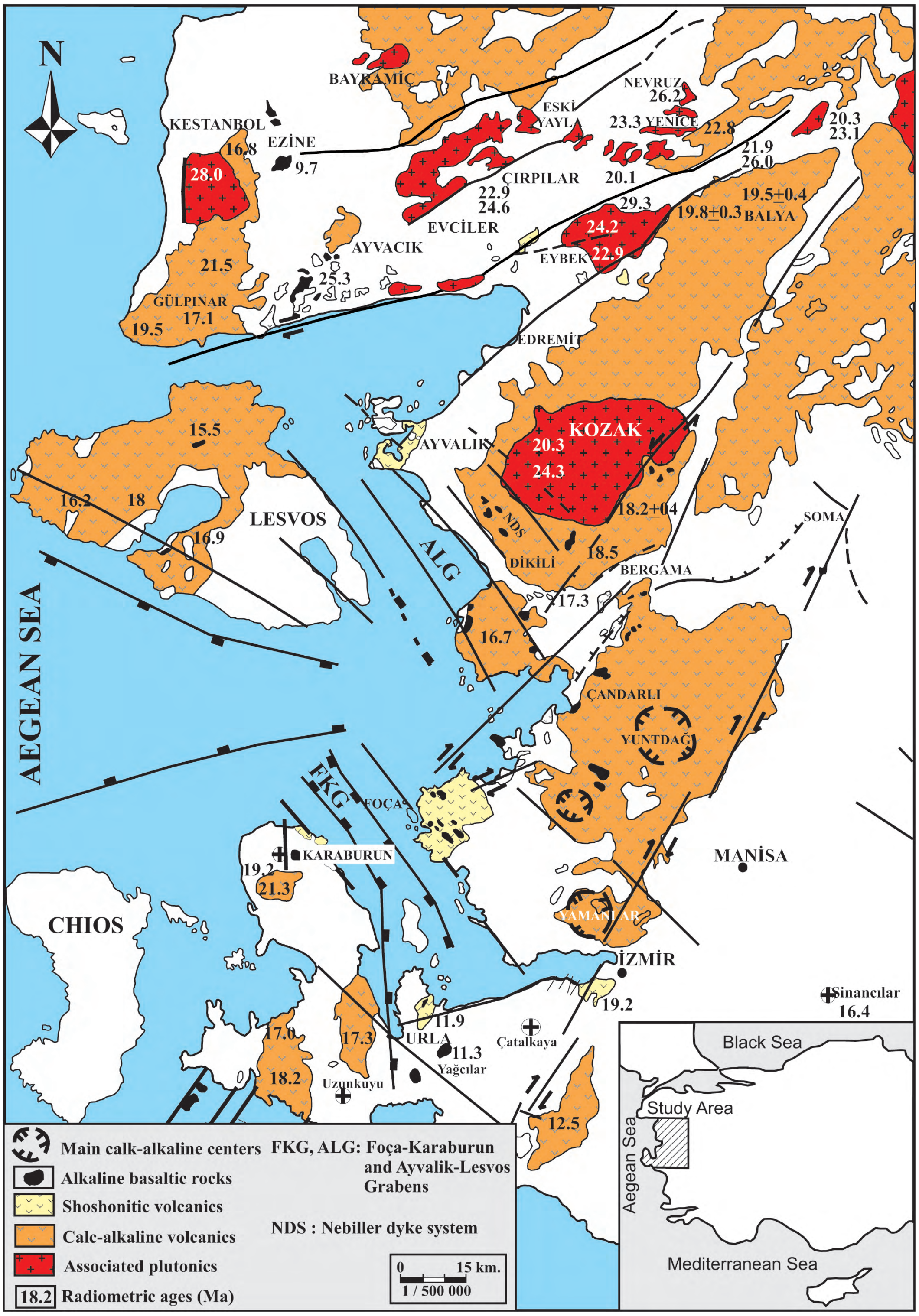

Figure 1. Tectonic-volcanological map of the study area (Foça-Karaburun and Ayvalık-Lesvos grabens) and surroundings (modified after Savaşçın 1976; Kaya 1979, 1982; Aksu *et al.* 1987; Savaşçın & Erler 1994; Yılmaz *et al.* 2000; Pfister *et al.* 2000; Altunkaynak & Yılmaz 2000; İnci *et al.* 2003; Sözbilir *et al.* 2003; Ocakoğlu *et al.* 2004, 2005, 2006; Emre & Sözbilir 2005).

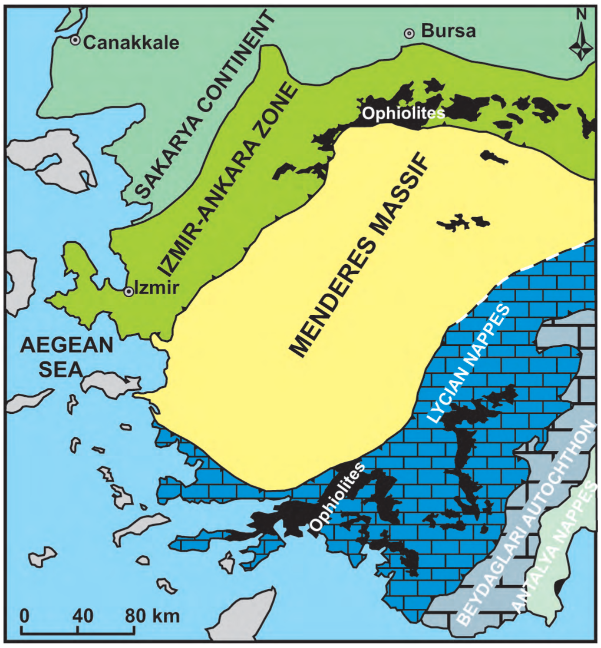

Figure 2. Palaeo-neo tectonic rock assemblage of Western Turkey.

Middle Miocene) are widely distributed in WA (Figure 1). These calc-alkaline products are gradually superceded by shoshonitic rocks in the final stages of the subduction related magmatism. Ultrapotassic (u-K) products also occur, some of which have lamproitic affinity (Innocenti *et al.* 2005). From Late Miocene to Holocene time, sparse K- and Na-alkaline basaltic activity took place and the related products are found in small outcrops mainly as lava flows and dykes. The most abundant and youngest alkali basaltic lavas are found in the Kula Volcanic field, which have been extensively studied by many authors (e.g., Alıcı *et al.* 2002; Tokçaer *et al.* 2005 and references therein). Based on the geochemical and isotopic data two groups of alkali basalts have been distinguished (Agostini *et al.* 2007): the first group (Urla, Selendi, Aliağa, Foça) has a geochemical affinity that shifts from the previous orogenic to an intraplate signature, while the second group (Biga, Thrace and Kula) retains a typical intraplate affinity, without any evidence of a subduction signature.

A schematic stratigraphic section of the volcanic rocks of Western Anatolia and Thrace is given in Figure 3. It is evident that there is no time gap

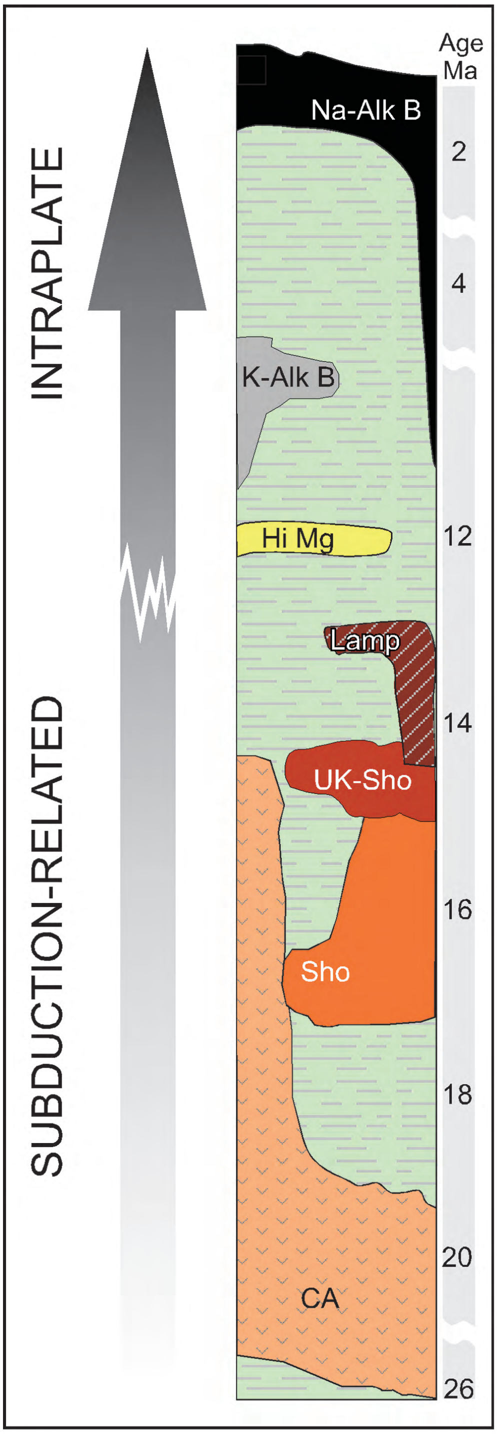

Figure 3. Schematic generalized stratigraphic column of WA and Thrace volcanics (CA– calc-alkaline rocks; Sho– shoshonitic rocks; Lamp– lamproitic rocks; UK-Sho– ultra-potassic shoshonitic rocks, Hi-Mg– high-mg andesites; K-Alk B– potassic alkaline rocks, Na Alk B– sodic-alkaline basaltic rocks).

between the calc-alkaline, shoshonitic and u-K rocks, all of which can be ascribed to the same orogenic volcanic cycle. Following a very short time interval (from Middle to Late Miocene) alkali basaltic volcanism was initiated.

Foça-Karaburun and Ayvalık-Lesvos Grabens

Geology

Geological maps and a stratigraphic column of the studied area are given in Figures 4–8. Some detailed volcano-geological descriptions of these areas are given below.

Urla-Karaburun Region– This region has the appearance of a typical block fault mountain. Platform carbonate successions of Mesozoic age in the Karaburun area constitute the pre-Neogene basement (Erdoğan 1990). The Neogene units are composed of calc-alkaline volcanics, Neogene sediments, intrusive rocks and alkaline volcanics (Figure 4).

Calc-alkaline and shoshonitic volcanic rocks, occurring as deeply eroded strato-volcano structures (Alaçatı, Gülbahçe, Küçükbahçe), are observed over a wide area (Figure 4). These centres lie either directly on the pre-Neogene basement or overlie a thin volcano-sedimentary sequence, which starts with coarse-grained clastic deposits such as conglomerates or agglomerates. Radiometric ages of lavas of 17.0–18.2 Ma (Alaçatı), 16.6–17.3 Ma (Gülbahçe) and 19.2–21.3 (Küçükbahçe) were reported by Borsi *et al.* (1972). The tuffs and related volcano-clastic rocks of Mordoğan (Figure 4) are the lateral extensions of the Foça Tuff Formation, which is typically exposed in the Foça (Figure 1 & 7) region (Kaya 1979, 1981). Shoshonitic rocks (mainly alkali trachytes), are found around Urla; these products overlie the calc-alkaline volcanics and are attributed an Early–Middle Miocene age (Figures 4–6). Karaburun andesites are typical examples of volcanics that form step-like exposures in response to generally NW-trending faults (Figures 4 & 6), indicating that: (i) the graben formation dates back at least to early Miocene, (ii) the calc-alkaline rocks were emplaced after the onset of extensional tectonics.

Along with the pre-Neogene basement and the calc-alkaline to shoshonitic volcanics, rocks outcropping in Urla-Karaburun peninsula include: (i) intrusive rocks, (ii) Neogene sediments as well as (iii) alkaline basalts, which are here briefly described.

Intrusive Rocks– some intrusive or sub-volcanic tonalites and monzonites, associated with orogenic volcanics, crop out in this area mostly in the form of stock-type apophyses. These rocks are found west of Karaburun, in Uzunkuyu, in Çatalkaya (SW of İzmir) and Yamanlar (NW of İzmir) (Figure 1).

Neogene Sediments– the distribution of the Neogene sediments follows the subsiding basins. Fluvial conglomerates and mudstone-dominated shale-marl alternations, observed at the base of the sequence, grade upward into lacustrine clayey limestone-marl alternations with thin tuff intercalations: bedded limestones constitute the uppermost layers. These sediments are often intercalated with Foça tuff and volcanoclastic products and the whole volcano-sedimentary sequence is characterized by frequent lateral changes, due to active tectonics during its emplacement.

Alkali Basalts– K-alkaline basalts crop out in Urla İskelesi, Yağcılar and Ovacık around Urla (Figure 4), as small lava flows or subvolcanic products cutting through the sedimentary sequence and the calc-alkaline and shoshonitic rocks. Borsi *et al.* (1972) reported K/Ar ages of 11.3 Ma for the Na-hawaiites of Ovacık-Urla and 11.9 Ma for the alkaline basalts of Urla İskelesi, in accordance with stratigraphic evidence. These products are related to N and NW-trending normal faults (Figures 4–6), accounting for the continuing active extensional dynamics.

Foça Region– The Foça Peninsula (Figure 1) is located within the FKG (Savaşçın 1976) and consists entirely of pyroclastics, volcano-sedimentary series, lava flows and domes of calc-alkaline, shoshonitic and, rarely, u-K affinity (Figure 7). These rocks are overlain and crosscut by younger lavas and NW-trending dykes, which have mostly K-trachybasaltic, and rarely Na-hawaiitic, affinity.

On the basis of morphological evidence, the Foça Peninsula is considered to be a caldera complex whose characteristic structures were strongly modified by later erosion and extensional tectonics.

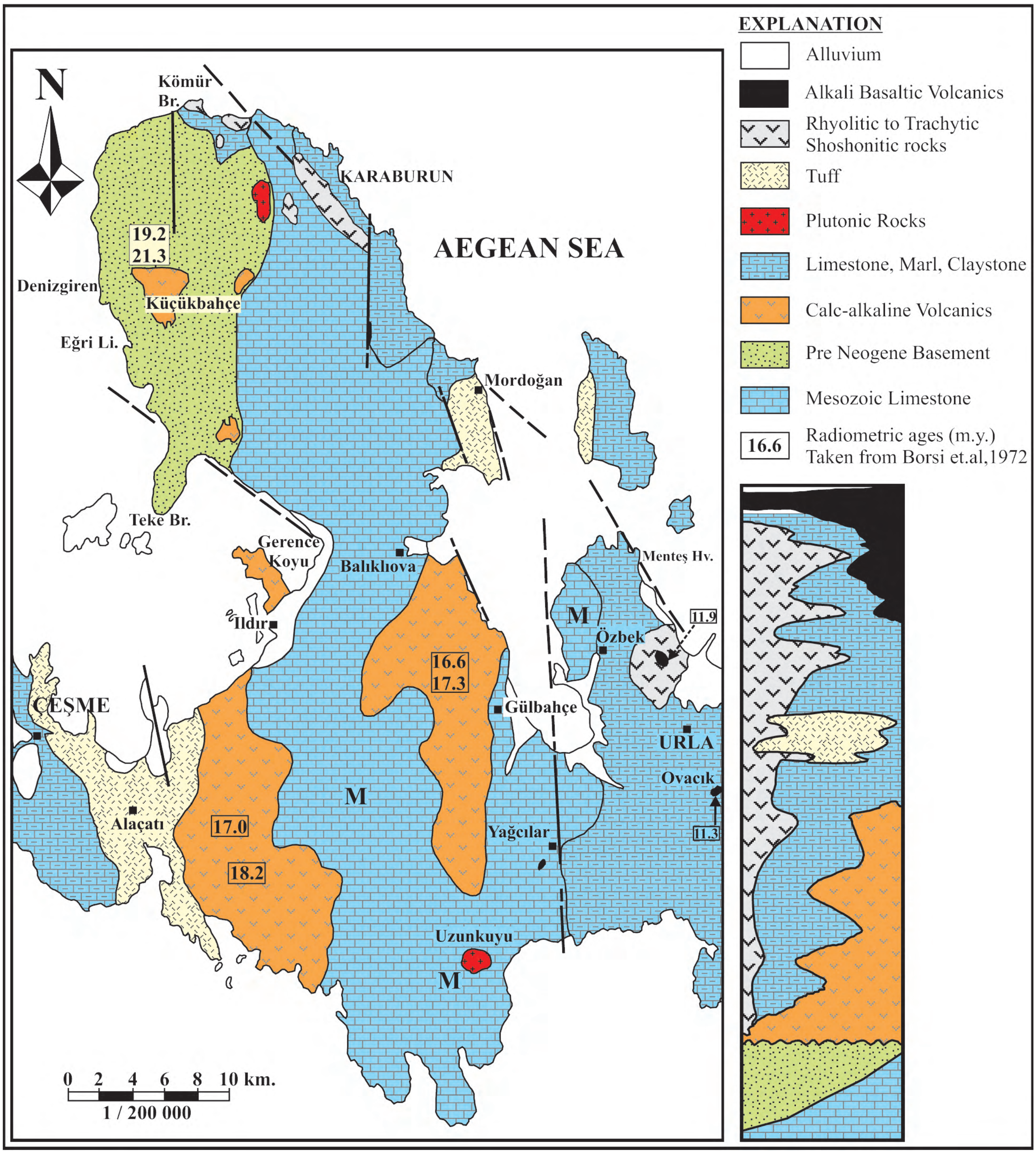

Figure 4. Geological map of the Karaburun Peninsula (modified after Savaşçın & Erler 1994).

According to Kaya (1981), the sedimentary and volcano-sedimentary filling of the Foça depression reaches 2000 m in thickness. The Foça Tuff Unit, one of the units that fill the Foça depression of Kaya (1981), is up to 400 m thick with the best exposures around Yeni Foça.

The stratigraphic setting of the Foça volcanics rules out a significant time gap between the calc-

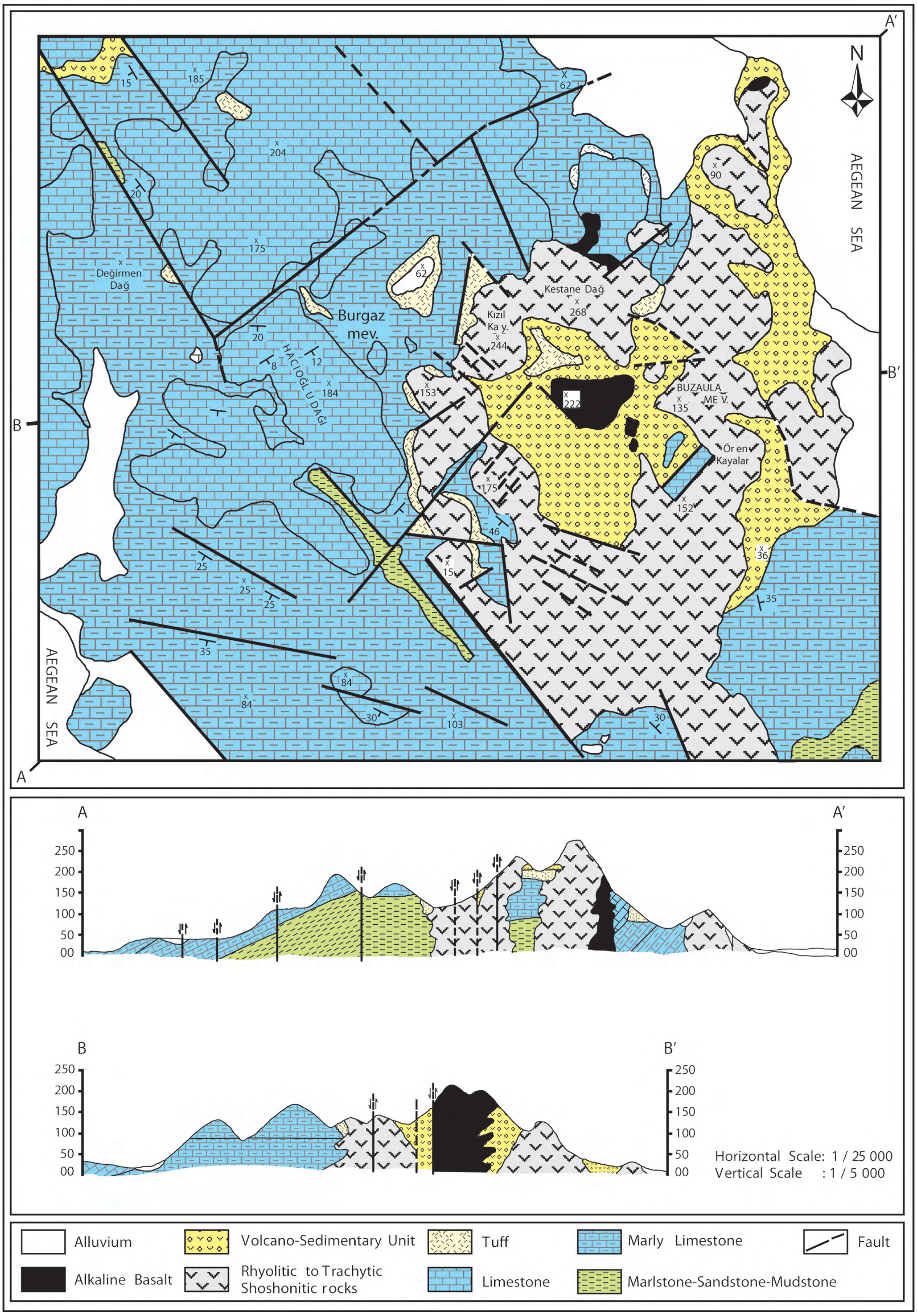

Figure 5. Geological map of the Urla Iskelesi area (modified after Savaşçın & Erler 1994).

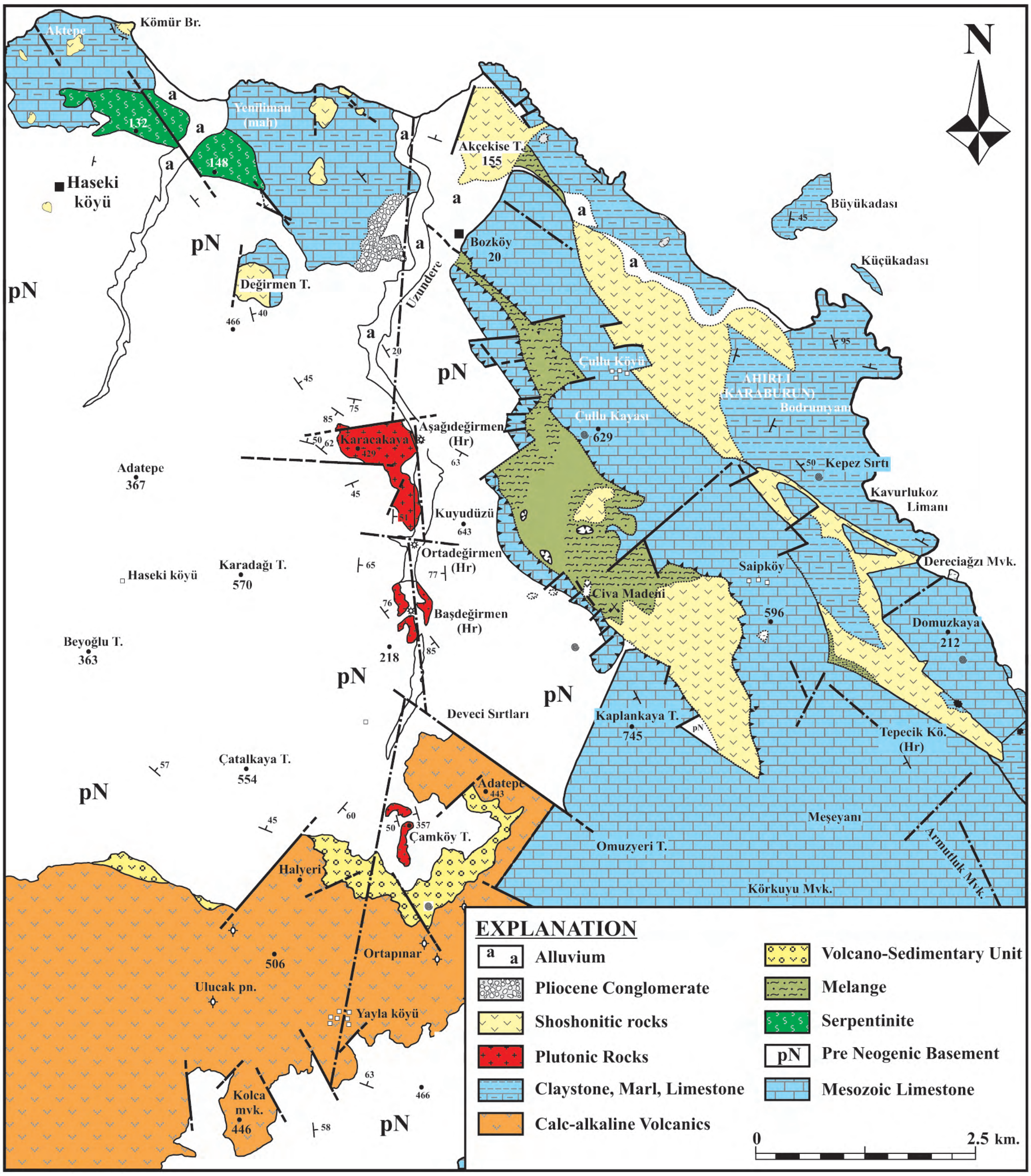

Figure 6. Geological map of the northern Karaburun Peninsula (modified after Savaşçın & Erler 1994).

alkaline and shoshonitic volcanism (with K-Ar ages of 16.5 Ma, Savaşçın 1978; 15.5–14.5 Ma, Altunkaynak & Yılmaz 2000), whereas the radiometric ages of 12.7 Ma for the Foça alkali basalts and 14.5 Ma for Aliağa alkali basalts are reported by Fytikas *et al.* (1976) and Ercan *et al.* (1996). Hence, both radiometric ages and stratigraphy show that the alkali basalts are younger than the calc-alkaline and shoshonitic rocks.

Ayvalık Region– Alibey and Maden Island, near Ayvalık, are located at the northern end of the ALG, and are characterized by a volcano-sedimentary

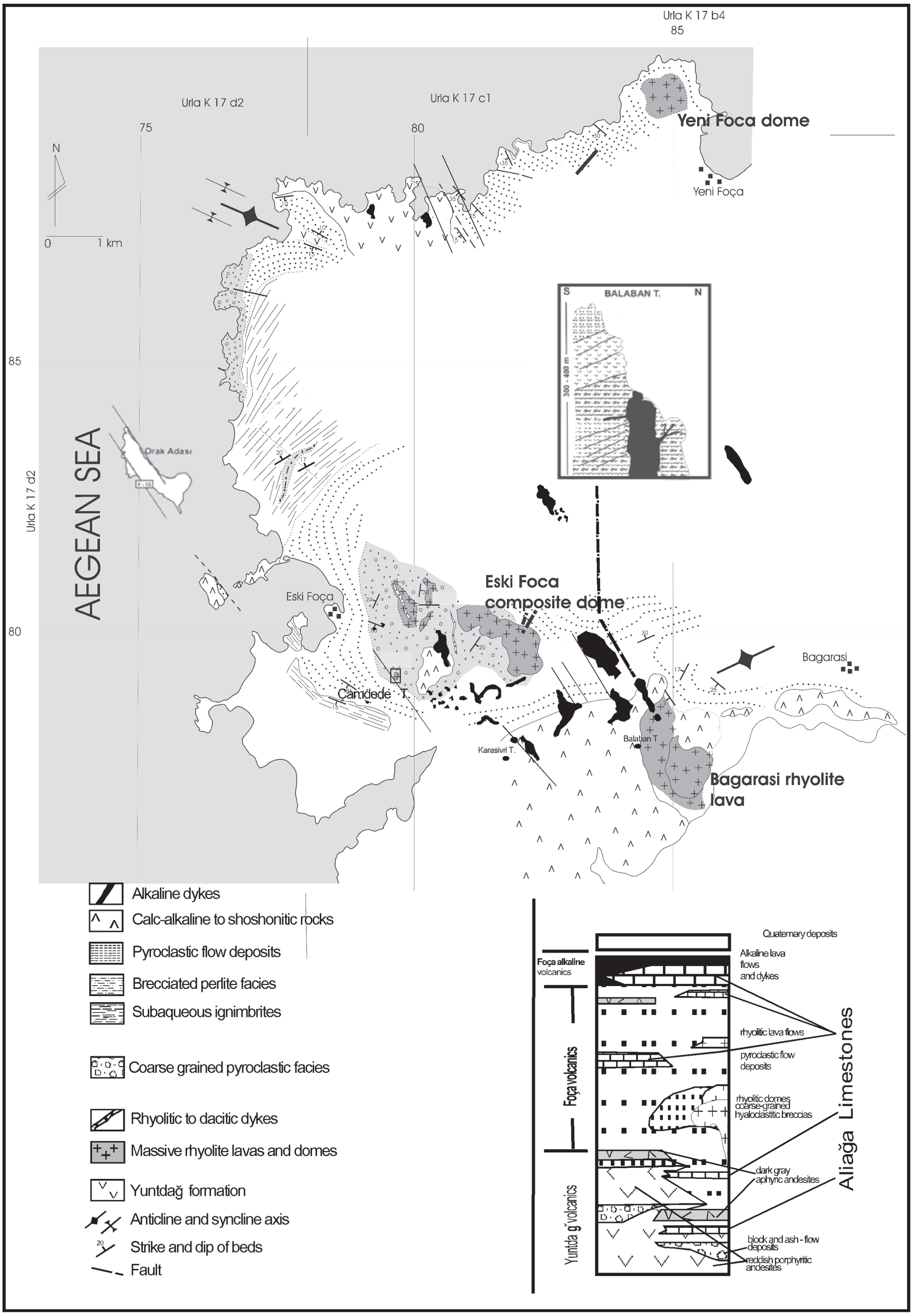

Figure 7. Generalized columnar section and volcanological map of the Foça region and surroundings (modified after Akay 2000 and Savaşçın 1978).

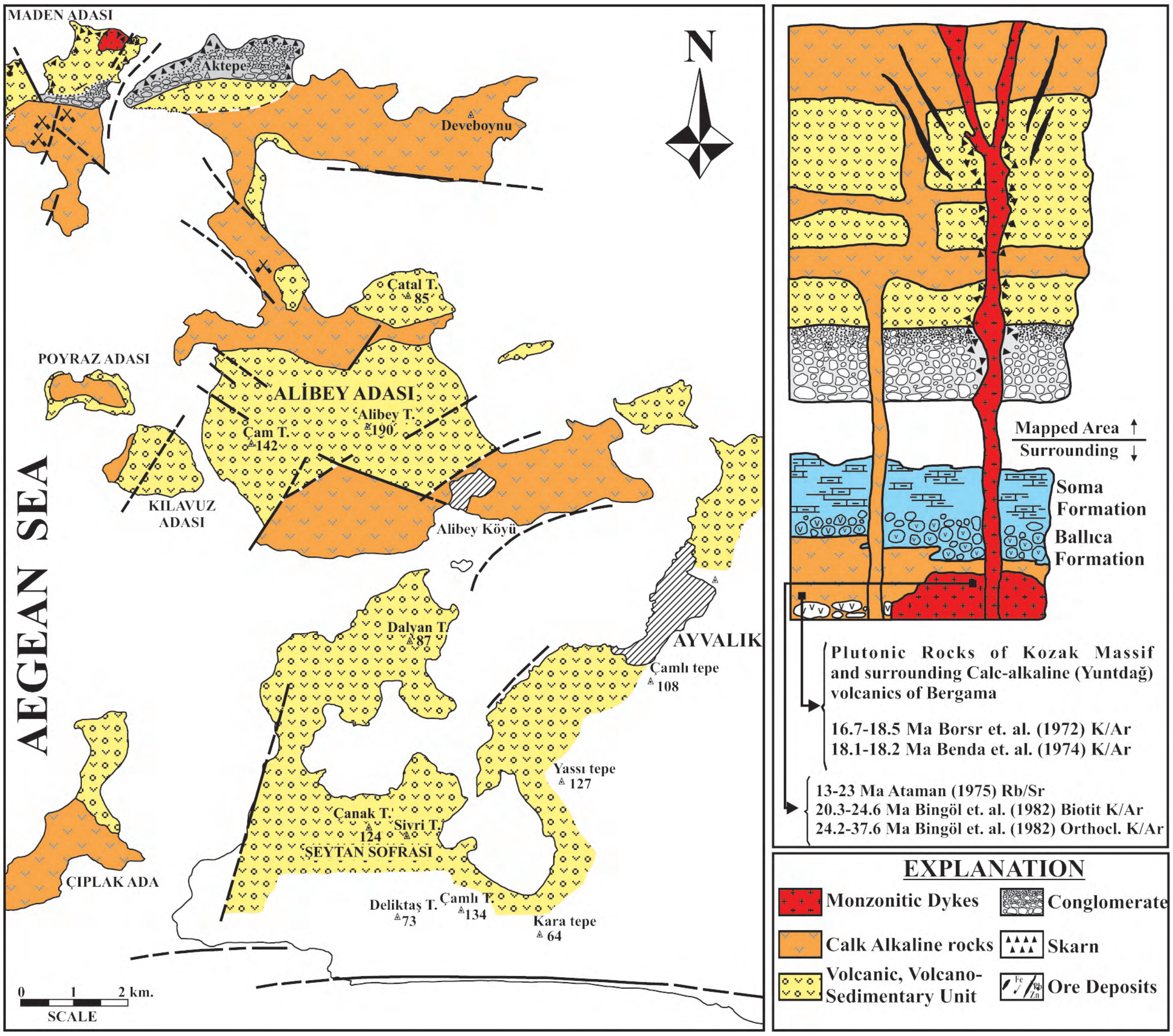

Figure 8. Geological map and generalized columnar section of the Ayvalık region and surroundings (modified after Savaşçın & Erler 1994).

sequence, which closely resembles that of the Foça Peninsula. Repetitions are common in the sequence (Dora & Savaşçın 1982). No alkali basaltic products have been found in this zone, and the whole volcano-sedimentary sequence can be dated to the Early to Middle Miocene, by comparison with available data for the neighbouring region.

Lithologic Sequence– The geological map of the Ayvalık region and nearby islands is given in Figure 8, along with a schematic stratigraphic section. Calc-alkaline igneous rocks and sedimentary formations of the surrounding areas (e.g., Kozak Granitoid and the surrounding calc-alkaline volcanics, the Ballıca and Soma formations) lie at the base of the stratigraphic section. The sequence observed in the mapped area consists entirely of the products of the extensional phase and includes a volcanic-volcanosedimentary unit, a volcanic unit and monzonitic-granodioritic dykes (Dora & Savaşçın 1982).

Ballıca Formation– The conglomeratic unit at the base of the sequence corresponds to the Ballıca formation of Akyürek & Soysal (1983), which is exposed over a large area around Bergama, Dikili and Edremit. This unit has a thickness locally exceeding 100 m and consists of alternations of the conglomerate, sandstone and shale-marl subunits.

Volcanic-Volcanosedimentary Member– The conglomeratic formation is made up from bottom to top of pyroclastics, silicified shales-marls and marl-bearing arkosic sandstones. Southwest of Maden Island, it is conformably overlain by volcano-sedimentary strata. This member is not widely exposed, and it is interpreted as the product of local volcanic-tectonic processes. Lateral gradations into lacustrine sediments were observed.

Volcanic Member (Calc-alkaline Lavas)– The volcanics on Çıplak Island, Şeytan Sofrası, Alibey and Kılavuz islands are observed as intercalations within the volcanic-volcano-sedimentary member, as previously described for the Foça Peninsula. Although, according to Dora & Savaşçın (1982) this volcanic unit was made up by trachybasaltic lavas, on the basis of geochemical data (see below) the composition of these rocks fall just below the line dividing the high-K calc-alkaline from the shoshonitic rocks on the K_2O-SiO_2 diagram. Indeed, this member encompasses andesitic-trachyandesitic lava flows and rhyolitic ignimbrites in Şeytan Sofrası and andesitic-trachyandesitic levels on Çıplak and Güneş Islands.

Dykes– A dyke swarm cutting the volcano-sedimentary and volcanic units was observed north and west of Maden Island. On Maden Island, extensive skarn zones (see below) suggest the occurrence of a large plutonic body at depth. Consequently, these dykes are considered as apophyses of this hidden pluton, which can be genetically linked to the Kozak granodiorite (aged 24–20 Ma; Altunkaynak & Yılmaz 1999). Nevertheless, due to limited outcrop and intense alteration, further petrological investigation of these rocks was not carried out.

Skarns– Skarn formation and mineralization represent the final phases of the geological processes on Maden and Alibey Islands. Depending on the original composition of the host rock, different skarn minerals developed, notably: garnet, epidote, amphibole, axinite, sillimanite, calcite and wollastonite (Agostini *et al.* in preparation).

The Volcanic Products of the Study Area: Geochemistry and Petrology

Seven different Miocene to Recent volcanic associations can be recognized in Western Anatolia: according to their geochemical affinity these are (Figure 3): calc-alkaline, shoshonitic, u-K with Roman Magmatic Province affinity (hereafter called u-K shoshonitic, according to Innocenti *et al.* 2005), u-K with Lamproitic affinity, Hi-Mg andesites, K-alkaline basalts, and Na-alkaline basaltic rocks. The complex geochemical evolution of the eruptives mirrors the evolution of the mantle sources, in response to the extensional dynamics developed in a subduction-related context (e.g., Aldanmaz *et al.* 2000; Innocenti *et al.* 2005; Agostini *et al.* 2008).

Analytical Methods

Among the 50 samples analysed in this study for major elements, 17 were also selected for trace element analysis. These data are presented here along with additional data for 20 samples from the literature, including 16 Sr and Nd isotope ratios (Innocenti *et al.* 2005; Agostini *et al.* 2007). Rock powders were prepared, after crushing, by grinding in an agate mill. Major elements were determined by XRF (Philips PW1480) on fused disks and FeO by titration. Estimated precision is ≈1% RSD for SiO_2, and ≈2% RSD for the other major elements, except those with low concentrations (<0.50 wt%), for which the absolute standard deviation is about ±0.01%. Loss-on-ignition was measured by gravimetry at 1000 °C after pre-heating at 110 °C. Trace elements were determined by ICP-MS (Fisons PQ2 Plus®) at the Dipartimento di Scienze della Terra, Università di Pisa. Analytical precision, evaluated by repeated analyses of the in-house standard HE-1 (Mt. Etna hawaiite) is generally between 2 and 5 % RSD, except for Gd (6%), Tm (7%), Pb and Sc (8%).

Rock Classifications and Their Main Geochemical Characters

Data are listed in Table 1, and classification diagrams are reported in Figures 9 & 10. Notably, the study area includes the whole geochemical range of products described in the literature for WA, with the exception of lamproitic rocks. Most of the collected

Table 1. Major elements, CIPW norm, trace elements and Sr-Nd isotope ratios of volcanic rocks from the study areas.

Label	IZ 14	IZ 133	IZ 135	IZ 145	IZ 143	IZ 142	IZ 146	IZ 13	IZ 196	IZ 144	IZ 134
Zone	Ayv-Ber-BP	Ayv-Ber-BP	Ayv-Ber-BP	Ayv-Ber-BP	Ayv-Ber-BP	Ayv-Ber-BP	Ayv-Ber-BP	Ayv-Ber-BP	Ayv-Ber-BP	Ayv-Ber-BP	Ayv-Ber-BP
Place	Alibey	Ayvalık (Alibey)	Ayvalık (Alibey)	Çaltıdere	Çandarlı	Dikili	Dikili	Çaltıdere	Kınık	Kırıklar	Maden Is. (Alibey)
Major Elements (wt%)											
SiO_2	59.18	57.74	60.90	61.33	56.59	61.96	65.76	60.18	62.42	63.46	61.21
TiO_2	0.75	0.72	0.76	0.71	0.95	0.68	0.60	0.68	0.58	0.58	0.69
Al_2O_3	17.23	17.35	16.64	16.66	17.66	17.19	16.63	16.25	16.29	16.57	15.92
Fe_2O_3	2.68	5.81	3.98	2.13	4.75	5.09	4.28	1.36	2.28	3.84	3.55
FeO	3.86	1.60	2.65	3.62	2.20	0.24	0.14	4.02	2.99	1.14	2.81
MnO	0.14	0.34	0.11	0.11	0.11	0.07	0.02	0.09	0.08	0.07	0.14
MgO	2.92	1.61	3.27	2.75	3.06	2.55	0.89	4.30	3.57	2.74	3.60
CaO	6.57	8.08	6.08	7.02	8.04	5.23	4.19	7.38	6.27	4.45	6.95
Na_2O	3.07	3.14	2.75	2.90	3.22	3.47	3.63	2.90	3.71	3.34	2.36
K_2O	3.35	3.40	2.69	2.60	3.13	3.30	3.62	2.62	1.72	3.62	2.63
P_2O_5	0.25	0.22	0.16	0.18	0.30	0.21	0.22	0.21	0.09	0.19	0.14
CIPW Norm											
D.I.	55.5	54.2	54.3	55.2	50.9	62.3	71.9	51.8	56.7	65.1	52.1
Q	9.7	7.5	15.2	15.3	5.2	13.4	19.7	11.8	15.1	15.4	16.6
C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
or	19.8	20.1	15.9	15.4	18.5	19.5	21.4	15.5	10.1	21.4	15.5
ab	26.0	26.6	23.3	24.5	27.2	29.4	30.8	24.6	31.4	28.3	19.9
an	23.4	23.2	25.1	24.7	24.5	21.6	18.4	23.6	22.7	19.5	25.1
ne	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
di	6.3	13.0	3.3	7.3	11.0	2.5	0.8	9.5	6.3	1.0	6.9
wo	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
hy	10.1	4.4	12.8	8.8	8.0	9.5	5.3	11.4	10.9	10.6	11.8
ol	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
mt	2.7	2.9	2.4	2.1	2.8	2.1	1.7	2.0	1.9	2.0	2.3
il	1.4	1.4	1.4	1.3	1.8	1.3	1.1	1.3	1.1	1.1	1.3
ap	0.6	0.5	0.4	0.4	0.7	0.5	0.5	0.5	0.2	0.4	0.3
Mg#	53.0	36.3	55.2	53.8	53.4	56.2	35.2	65.8	62.4	59.1	58.4
ANOR	54.1	53.6	61.2	61.7	57.0	52.5	46.2	60.3	69.1	47.8	61.7
Q'-F'	12.3	9.7	19.1	19.1	6.9	16.0	21.8	15.6	19.1	18.2	21.5
Group	Calc-Alk	Calc-Alk	Calc-Alk	Calc-Alk	Calc-Alk	Calc-Alk	Calc-Alk	Calc-Alk	Calc-Alk	Calc-Alk	Calc-Alk
rock name	Lat	Lat	hK C-A And	hK C-A And	Lat	Lat	Dac	hK C-A And	C-A And	Dac	hK C-A And
Trace Elements (ppm)											
Li											
Be	2.0							1.9			
Sc	12							17			
V	140						66	120			
Cr	14						44	99			
Co	17						15	19			
Ni	10						20	44			
Cu											
Ga											
Rb	119						140	78			
Sr	600						660	642			
Y	28.0						16.6	21.0			
Zr	171						237	124			
Nb	12.76						19.66	8.02			
Mo	2.78							1.63			
Cs	7.47							3.20			
Ba	825						1153	1488			
La	38.7						47.6	29.1			
Ce	75.5						81.1	54.5			
Pr	8.92							6.27			
Nd	33.5							23.3			
Sm	6.26							4.34			
Eu	1.18							0.46			
Gd	5.38							4.27			
Tb	0.81							0.62			
Dy	4.78							3.60			
Ho	0.97							0.73			
Er	2.65							2.02			
Tm	0.43							0.34			
Yb	2.68							1.92			
Lu	0.39							0.28			
Hf	4.63							3.41			
Ta	0.90							0.57			
Tl	0.78							0.46			
Pb	25.9							30.7			
Th	19.4						29.7	11.0			
U	5.7						5.9	2.6			
Isotope Ratios											
$^{87}Sr/^{86}Sr$											
$^{143}Nd/^{144}Nd$											

*from Innocenti *et al.* 2005; **from Agostini *et al.* 2007.

Ayv– Ayvalık; Ber– Bergama; BP– Biga Peninsula; Fo– Foça; İz– İzmir; Ur– Urla; Ka– Karaburun.

Table 1. Continued.

Label	IZ 137	IZ 138	IZ 136*	IZ 139*	IZ 140*	IZ 141*	IZ 231	IZ 232**	IZ 233**	T 76**	IZ 16
Zone	Ayv-Ber-BP	Ayv-Ber-BP	Ayv-Ber-BP	Ayv-Ber-BP	Ayv-Ber-BP	Ayv-Ber-BP	Ayv-Ber-BP	Ayv-Ber-BP	Ayv-Ber-BP	Ayv-Ber-BP	Fo-Iz
Place	Nebiler	Nebiler	Nebiler	Nebiler	Nebiler	Nebiler	Ahmetçe	Akköy	Taştepe	Ezine	Beydere
Major Elements (wt%)											
SiO_2	53.65	56.15	53.90	56.06	68.44	64.98	57.32	43.62	48.37	47.72	60.78
TiO_2	0.88	0.79	0.87	0.95	0.43	0.56	0.86	3.18	2.64	2.79	0.91
Al_2O_3	16.80	17.26	16.80	17.97	15.72	15.88	17.97	13.34	13.51	13.26	16.15
Fe_2O_3	3.05	2.85	2.22	4.07	1.92	4.62	6.57	13.96	11.52	5.00	1.60
FeO	3.86	3.55	4.57	2.81	1.03	0.15	0.00	0.00	0.00	6.84	3.80
MnO	0.10	0.09	0.09	0.09	0.06	0.06	0.10	0.20	0.14	0.20	0.10
MgO	5.59	4.30	5.49	4.02	1.46	1.02	3.91	7.53	9.00	8.52	3.80
CaO	10.25	8.72	9.94	7.68	2.92	5.42	6.88	10.81	9.70	10.41	5.89
Na_2O	2.83	2.69	2.91	3.07	2.58	2.64	3.47	4.63	3.02	2.94	3.03
K_2O	2.71	3.37	2.93	2.95	5.27	4.48	2.60	1.70	1.51	1.63	3.63
P_2O_5	0.27	0.24	0.28	0.32	0.17	0.20	0.32	1.04	0.59	0.69	0.30
CIPW Norm											
D.I.	40.0	46.7	41.9	48.0	77.3	68.5	51.2	35.0	34.0	32.6	58.5
Q	0.0	4.0	0.0	4.5	24.3	19.7	6.4	0.0	0.0	0.0	11.4
C	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0
or	16.0	19.9	17.3	17.4	31.2	26.5	15.4	10.0	8.9	9.6	21.5
ab	24.0	22.8	24.6	26.0	21.8	22.3	29.4	8.2	24.5	20.8	25.6
an	25.1	25.0	24.1	26.5	13.4	18.3	25.8	10.6	18.8	18.2	19.7
ne	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	0.6	2.2	0.0
di	19.4	13.5	18.9	7.7	0.0	6.2	5.1	29.4	20.6	23.5	6.1
wo	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
hy	9.1	10.2	8.0	12.5	5.7	3.4	12.6	0.0	0.0	0.0	11.0
ol	1.4	0.0	2.2	0.0	0.0	0.0	0.0	11.1	16.7	15.7	0.0
mt	2.5	2.4	2.5	2.5	1.4	1.8	2.5	4.3	2.5	2.8	2.2
il	1.7	1.5	1.6	1.8	0.8	1.1	1.6	6.0	5.0	5.3	1.7
ap	0.6	0.6	0.6	0.7	0.4	0.5	0.7	2.4	1.4	1.6	0.7
Mg#	66.5	62.2	66.2	59.3	57.7	36.5	61.6	57.6	64.6	61.2	63.7
ANOR	61.1	55.7	58.2	60.3	30.1	40.9	62.6	51.5	67.9	65.4	47.9
Q'-F'	0.0	5.6	0.0	6.1	26.8	22.7	8.4	- 36.7	-1.1	-4.4	14.6
Group	Calc-Alk	Calc-Alk	Calc-Alk	Calc-Alk	Calc-Alk	Calc-Alk	Calc-Alk	Alk Bas	Alk Bas	Alk Bas	Calc-Alk
rock name	Sho	Sho	Sho	Sho	Dac	Dac	Lat	Basanite	Alk Bas	Alk Bas	Lat
Trace Elements (ppm)											
Li			8.7	10.2	15.4	12.9					
Be			2.4	2.8	5.6	3.2	3.0	3.0	1.8	2.3	3.3
Sc			17	16	8	11	17	17	19	18	16
V	173	176	144	148	50	94	157	208	197	208	146
Cr	172	86	138	29	40	39	41	109	249	201	98
Co	27	26	24	21	7	10	19	44	45	45	20
Ni	43	23	63	20	19	17	25	83	178	140	44
Cu							68	52	46	56	
Ga			16	17	15	16	20	24	20	22	
Rb	69	108	84	92	217	122	97	42	19	19	170
Sr	714	624	703	641	232	555	989	946	624	766	582
Y	23.5	19.7	24.3	24.9	18.7	29.5	21.6	32.7	23.5	27.6	24.2
Zr	158	182	152	181	103	79	217	328	207	258	266
Nb	12.30	14.76	11.45	15.60	23.65	10.10	10.89	95.71	49.95	64.06	15.36
Mo											3.24
Cs			1.24	2.25	6.06	3.66	9.11	0.78	6.19	0.46	9.30
Ba	1110	1138	1300	1236	717	1229	1509	494	314	368	1427
La	47.1	45.1	43.7	43.2	43.7	45.9	62.0	57.8	28.2	37.4	54.6
Ce	56.2	59.5	83.1	81.2	78.3	81.3	118.4	113.5	57.5	75.1	104.7
Pr			9.42	9.29	8.36	8.99	13.34	13.71	7.14	9.15	11.78
Nd			34.7	34.1	28.2	32.0	48.4	54.4	30.2	38.3	41.6
Sm			6.01	6.11	4.83	5.66	7.96	10.89	6.83	8.25	6.75
Eu			1.12	1.12	0.84	0.84	1.39	3.72	2.39	2.65	0.69
Gd			5.09	5.10	3.61	4.76	5.62	9.09	5.93	7.10	4.85
Tb			0.75	0.72	0.52	0.69	0.73	1.30	0.90	1.07	0.75
Dy			4.20	4.34	3.02	4.00	3.91	6.74	4.72	5.55	4.16
Ho			0.83	0.88	0.60	0.81	0.76	1.19	0.85	0.99	0.84
Er			2.27	2.39	1.63	2.20	1.96	2.80	2.02	2.32	2.28
Tm			0.34	0.36	0.27	0.34	0.27	0.37	0.27	0.31	0.37
Yb			2.19	2.22	1.85	2.05	1.77	2.12	1.58	1.87	2.20
Lu			0.29	0.33	0.26	0.29	0.26	0.28	0.21	0.24	0.32
Hf			3.86	4.69	3.48	2.68	5.68	7.13	4.71	5.81	6.88
Ta			0.81	1.02	1.77	0.92	0.66	6.05	3.12	4.02	1.05
Tl			0.29	0.44	1.61	0.84	0.39	0.04	0.10	0.05	0.97
Pb			21.9	25.7	37.6	37.4	35.8	3.3	2.6	2.6	32.2
Th	18.3	21.5	17.1	17.0	37.6	20.7	22.7	7.6	3.9	4.9	30.4
U	11.7	4.6	3.9	4.0	10.5	5.2	4.2	2.4	1.2	1.3	7.1
Isotope Ratios											
$^{87}Sr/^{86}Sr$			0.707830	0.707586	0.708646	0.708220		0.703049	0.703332	0.703087	
$^{143}Nd/^{144}Nd$			0.512383	0.512433	0.512364	0.512341		0.512935	0.512976	0.512952	

*from Innocenti *et al.* 2005; **from Agostini *et al.* 2007.

Ayv– Ayvalık; Ber– Bergama; BP– Biga Peninsula; Fo– Foça; İz– İzmir; Ur– Urla; Ka– Karaburun.

Table 1. Continued.

Label	IZ 192	IZ 11	IZ 12	IZ 188	IZ 189	IZ 191	IZ 8*	IZ 15*	IZ 202	IZ 10*	IZ 148
Zone	Fo-Iz	Fo-Iz	Fo-Iz	Fo-Iz	Fo-Iz	Fo-Iz	Fo-Iz	Fo-Iz	Fo-Iz	Fo-Iz	Fo-Iz
Place	Braza Ada (Aliağa)	Foça	Foça	Foça	Foça	Tavşan Ada (Aliağa)	Menemen	Beydere (Foça Tuff)	Karaçam (İzmir)	Foça	Foça
Major Elements (wt%)											
SiO_2	64.64	75.95	60.71	59.92	60.04	64.94	58.66	73.60	59.83	60.14	53.10
TiO_2	0.68	0.11	0.71	1.35	1.04	0.70	1.10	0.25	0.84	0.79	1.28
Al_2O_3	17.30	13.48	17.19	16.06	16.62	17.26	18.21	14.91	16.36	19.61	13.26
Fe_2O_3	5.13	1.04	4.36	5.54	5.17	3.46	2.73	0.93	6.86	4.04	4.08
FeO	0.04	0.00	1.37	1.06	1.12	0.29	2.73	0.18	0.00	0.64	3.30
MnO	0.02	0.07	0.10	0.06	0.07	0.05	0.08	0.05	0.10	0.08	0.13
MgO	0.61	0.17	2.49	2.48	2.42	1.17	2.93	0.26	3.11	0.82	9.19
CaO	3.76	0.82	6.84	5.94	6.52	4.46	6.36	1.36	6.07	2.60	7.83
Na_2O	3.71	3.38	3.22	3.67	3.43	3.66	3.60	3.65	2.70	4.80	1.56
K_2O	3.87	4.94	2.88	3.59	3.29	3.76	3.26	4.69	3.75	6.16	5.52
P_2O_5	0.23	0.05	0.14	0.32	0.28	0.24	0.35	0.10	0.38	0.30	0.74
CIPW Norm											
D.I.	72.6	92.9	56.8	61.8	59.2	71.0	57.3	89.7	57.0	78.3	45.8
Q	18.3	35.1	12.6	9.5	10.7	17.8	7.6	31.1	12.0	1.3	0.0
C	0.7	1.2	0.0	0.0	0.0	0.0	0.0	1.6	0.0	1.0	0.0
or	22.9	29.2	17.0	21.2	19.4	22.2	19.3	27.7	22.2	36.4	32.6
ab	31.4	28.6	27.2	31.1	29.0	31.0	30.4	30.9	22.8	40.6	13.2
an	17.1	3.7	23.9	16.7	20.2	19.5	23.9	6.1	21.5	11.0	12.9
ne	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
di	0.0	0.0	7.5	8.7	8.5	0.8	4.4	0.0	5.1	0.0	16.9
wo	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
hy	5.0	1.3	7.8	6.5	6.7	4.8	9.2	1.3	10.9	5.1	7.8
ol	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.6
mt	2.3	0.5	2.0	2.6	2.5	1.7	2.2	0.5	2.6	2.1	2.7
il	1.3	0.2	1.3	2.6	2.0	1.3	2.1	0.5	1.6	1.5	2.4
ap	0.5	0.1	0.3	0.7	0.6	0.6	0.8	0.2	0.9	0.7	1.7
Mg#	25.2	31.5	52.5	49.9	50.4	47.0	57.8	40.2	55.0	33.3	75.5
ANOR	42.8	11.3	58.4	44.1	51.0	46.8	55.4	18.0	49.2	23.2	28.3
Q'-F'	20.4	36.4	15.5	12.1	13.5	19.6	9.3	32.4	15.3	1.4	0.0
Group	Calc-Alk	Calc-Alk	Calc-Alk	Calc-Alk	Calc-Alk	Calc-Alk	Calc-Alk	Calc-Alk	Calc-Alk	Sho	U-K
rock name	Trach	Rhyol	hK c And	Lat	Lat	Trach	Lat	Rhyol	Lat	Trach	Sho
Trace Elements (ppm)											
Li											33.3
Be		4.4					3.1	3.6		2.8	7.5
Sc		1					16	3		5	28
V		2					159	4		40	179
Cr		2					22	3		1	485
Co		0					21	1		5	33
Ni		0					20	< d.l.		1	196
Cu											
Ga											17
Rb		231					135	157		195	123
Sr		67					531	228		502	706
Y		15.2					27.5	21.6		29.3	30.4
Zr		80					275	177		333	697
Nb		18.50					16.75	13.11		33.31	68.09
Mo		3.97					2.64	2.58		1.22	
Cs		14.58					4.56	5.59		6.23	1.68
Ba		355					1059	1490		757	1825
La		28.5					48.9	62.2		84.5	115.4
Ce		48.0					94.5	111.1		158.0	235.0
Pr		4.65					10.76	11.38		15.26	27.22
Nd		14.3					39.3	36.4		55.0	102.1
Sm		2.53					7.04	5.42		9.37	16.09
Eu		0.17					1.13	0.23		2.22	3.03
Gd		1.69					5.65	3.14		6.31	10.73
Tb		0.36					0.83	0.60		0.95	1.33
Dy		2.20					4.77	3.37		5.14	6.21
Ho		0.46					0.96	0.71		1.02	1.04
Er		1.40					2.54	1.94		2.67	2.56
Tm		0.25					0.42	0.34		0.45	0.35
Yb		1.60					2.39	2.05		2.74	2.14
Lu		0.25					0.35	0.32		0.41	0.29
Hf		3.14					6.80	4.92		6.88	18.21
Ta		1.95					1.09	1.22		2.31	3.71
Tl		1.99					0.79	1.18		1.39	0.68
Pb		47.0					23.4	45.9		35.1	24.7
Th		34.6					22.5	22.8		34.9	31.1
U		10.6					5.5	6.6		9.6	7.4
Isotope Ratios											
$^{87}Sr/^{86}Sr$							0.707914				
$^{143}Nd/^{144}Nd$							0.512402				

*from Innocenti *et al.* 2005; **from Agostini *et al.* 2007.

Ayv– Ayvalık; Ber– Bergama; BP– Biga Peninsula; Fo– Foça; İz– İzmir; Ur– Urla; Ka– Karaburun.

Table 1. Continued.

Label Zone Place	IZ 7* Fo-Iz Beşyol	IZ 170* Fo-Iz Beşyol	IZ 201 Fo-Iz Beşyol	IZ 9 Fo-Iz Foça	IZ 149* Fo-Iz Foça	IZ 147** Fo-Iz Aliağa	IZ 25* Ur-Ka Karaburun	IZ 132 Ur-Ka Çeşme	IZ 128 Ur-Ka Gülbahçe	IZ 22 Ur-Ka Karaburun	IZ 23 Ur-Ka Karaburun
Major Elements (wt%)											
SiO_2	54.16	54.96	54.38	48.37	48.31	50.93	58.40	61.25	65.03	61.13	58.30
TiO_2	1.43	1.46	1.45	1.23	1.40	1.11	0.69	0.60	0.58	0.69	0.66
Al_2O_3	13.96	13.30	13.27	15.61	16.84	14.99	17.05	16.61	16.67	16.97	16.52
Fe_2O_3	2.59	3.65	6.39	2.40	3.65	2.31	1.42	2.54	1.77	2.67	2.16
FeO	1.97	2.54	0.00	5.85	4.98	5.38	3.97	2.68	2.24	1.88	3.46
MnO	0.22	0.09	0.11	0.15	0.15	0.13	0.10	0.09	0.07	0.11	0.11
MgO	4.09	8.39	9.76	8.64	6.87	10.19	4.87	3.60	2.11	2.45	5.01
CaO	11.98	6.70	6.39	12.07	12.17	8.90	7.10	6.28	4.63	8.19	8.30
Na_2O	2.34	1.87	1.59	3.04	3.81	3.02	3.45	3.09	3.38	3.18	2.94
K_2O	6.56	6.36	5.99	2.30	1.36	2.70	2.65	3.05	3.37	2.61	2.44
P_2O_5	0.70	0.69	0.68	0.36	0.46	0.34	0.30	0.20	0.14	0.12	0.11
CIPW Norm											
D.I.	53.0	53.4	48.9	31.8	32.9	39.5	51.2	56.9	67.1	55.6	47.1
Q	0.0	0.0	0.0	0.0	0.0	0.0	6.4	12.7	18.6	13.3	7.9
C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
or	38.7	37.6	35.4	13.6	8.0	15.9	15.6	18.0	19.9	15.4	14.4
ab	7.7	15.8	13.5	9.5	16.2	21.2	29.2	26.2	28.6	26.9	24.8
an	8.2	9.1	11.4	22.2	24.8	19.4	23.2	22.4	20.3	24.3	24.7
ne	6.6	0.0	0.0	8.8	8.7	2.3	0.0	0.0	0.0	0.0	0.0
di	27.3	15.6	12.6	28.4	26.4	18.0	8.1	6.0	1.4	12.7	12.7
wo	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
hy	0.0	7.9	13.3	0.0	0.0	0.0	13.5	11.0	8.0	4.0	11.8
ol	0.0	7.0	6.9	11.6	9.1	17.6	0.0	0.0	0.0	0.0	0.0
mt	1.8	2.5	2.2	2.7	2.8	2.6	2.0	1.9	1.6	1.7	2.1
il	2.7	2.8	2.7	2.3	2.7	2.1	1.3	1.1	1.1	1.3	1.2
ap	1.6	1.6	1.6	0.8	1.1	0.8	0.7	0.5	0.3	0.3	0.3
Mg#	69.7	77.7	79.9	71.0	65.3	75.6	68.5	62.9	57.2	57.3	68.5
ANOR	17.5	19.5	24.3	62.1	75.5	54.9	59.8	55.4	50.5	61.2	63.2
Q'-F'	- 10.7	0.0	0.0	- 16.2	- 15.0	-4.0	8.6	16.0	21.2	16.6	10.9
Group	U-K	U-K	U-K	Alk Bas	Alk Bas	Alk Bas	Calc-Alk	Calc-Alk	Calc-Alk	Calc-Alk	Calc-Alk
rock name	Lat	Lat	U-K Sho	K-TrBas	Haw	K-TrBas	hK C-A And	hK C-A And	Dac	hK C-A And	hK C-A And
Trace Elements (ppm)											
Li		52.8			18.9	11.7					
Be	8.5	8.1		2.5	1.9	2.0	2.9				
Sc	20	21		27	16	20	13				
V	137	139		196	153	160	95				
Cr	420	472		388	149	490	243				
Co	21	30		37	29	32	21				
Ni	102	261		133	81	177	111				
Cu											
Ga		18			15	14					
Rb	227	233		92	59	111	99				
Sr	867	620		614	692	549	647				
Y	24.3	23.9		24.8	25.5	21.4	19.7				
Zr	688	679		157	165	167	192				
Nb	28.37	27.57		13.80	18.99	13.72	12.71				
Mo	1.32			1.60			1.75				
Cs	476.07	38.09		4.56	3.48	13.83	5.42				
Ba	753	716		549	743	669	1146				
La	82.5	83.9		43.0	53.2	33.1	37.9				
Ce	165.4	165.1		87.7	102.8	68.5	68.6				
Pr	17.79	19.08		10.57	11.53	8.16	7.69				
Nd	68.1	68.7		40.6	42.7	31.2	27.6				
Sm	11.03	10.68		8.19	7.60	5.66	4.66				
Eu	2.44	2.51		2.02	1.74	1.20	0.64				
Gd	7.01	7.33		6.74	5.85	4.59	3.97				
Tb	0.93	0.96		0.92	0.86	0.68	0.58				
Dy	4.57	4.66		4.79	4.62	3.80	3.31				
Ho	0.84	0.82		0.87	0.92	0.77	0.67				
Er	1.97	2.02		2.18	2.43	2.07	1.80				
Tm	0.31	0.28		0.33	0.34	0.30	0.30				
Yb	1.81	1.73		1.93	2.09	1.84	1.76				
Lu	0.26	0.25		0.29	0.30	0.24	0.27				
Hf	18.00	17.66		3.63	3.92	4.66	4.73				
Ta	1.74	1.70		0.83	1.25	0.94	0.95				
Tl	0.75	0.83		0.52	1.57	0.61	0.68				
Pb	25.2	25.2		16.3	21.3	17.3	24.2				
Th	23.4	22.9		11.6	15.3	12.0	13.6				
U	5.2	5.1		2.6	3.6	2.9	3.3				
Isotope Ratios											
$^{87}Sr/^{86}Sr$		0.707329			0.706498	0.707876					
$^{143}Nd/^{144}Nd$		0.512423			0.512531	0.512431					

*from Innocenti *et al.* 2005; **from Agostini *et al.* 2007.

Ayv– Ayvalık; Ber– Bergama; BP– Biga Peninsula; Fo– Foça; İz– İzmir; Ur– Urla; Ka– Karaburun.

Table 1. Continued.

Label	IZ 25 B	IZ 26	IZ 198	IZ 199	IZ 200	IZ 21 G	IZ 21P	IZ 118	IZ 204	IZ 129	IZ 116
Zone	Ur-Ka	Ur-Ka	Ur-Ka	Ur-Ka	Ur-Ka	Ur-Ka	Ur-Ka	Ur-Ka	Ur-Ka	Ur-Ka	Ur-Ka
Place	Karaburun	Karaburun	Menderes	Menderes	Menderes	Mordoğan (Foça Tuff)	Mordoğan (Foça Tuff)	Yağcılar (Urla)	Urla Iskelesi	Karaburun	Urla Iskelesi
Major Elements (wt%)											
SiO_2	59.08	57.75	76.66	76.33	76.76	75.94	75.30	64.80	63.41	51.47	63.37
TiO_2	0.68	0.64	0.02	0.06	0.08	0.08	0.14	0.69	0.67	1.11	0.71
Al_2O_3	16.74	16.38	13.02	13.52	12.90	12.87	14.00	17.75	16.81	15.49	16.62
Fe_2O_3	2.09	3.27	1.02	1.06	1.13	0.57	0.87	1.64	4.57	4.17	2.42
FeO	3.60	4.11	0.11	0.18	0.30	0.33	0.25	1.88	0.00	4.06	1.92
MnO	0.11	0.11	0.08	0.05	0.04	0.06	0.04	0.05	0.13	0.14	0.12
MgO	4.58	4.67	0.04	0.46	0.11	0.25	0.36	1.71	1.67	9.20	1.98
CaO	7.32	7.03	0.40	0.83	0.85	1.70	1.17	4.83	3.89	8.08	3.48
Na_2O	3.10	3.13	3.19	1.58	1.81	2.98	2.65	2.99	4.05	2.23	4.44
K_2O	2.46	2.70	5.44	5.93	5.99	5.20	5.16	3.50	4.60	3.43	4.76
P_2O_5	0.23	0.22	0.01	0.01	0.01	0.02	0.06	0.16	0.20	0.63	0.18
CIPW Norm											
D.I.	50.3	49.2	95.0	89.9	91.5	90.7	89.8	66.4	72.8	39.1	74.8
Q	9.4	6.8	35.9	41.5	40.7	34.8	36.9	20.3	11.4	0.0	9.0
C	0.0	0.0	1.2	3.0	1.9	0.0	2.1	0.7	0.0	0.0	0.0
or	14.6	15.9	32.1	35.0	35.4	30.7	30.5	20.7	27.2	20.2	28.1
ab	26.3	26.5	27.0	13.3	15.3	25.2	22.4	25.3	34.3	18.8	37.6
an	24.5	22.7	1.9	4.0	4.2	6.4	5.4	22.9	14.1	22.2	11.4
ne	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
di	8.4	8.8	0.0	0.0	0.0	1.6	0.0	0.0	3.2	11.1	3.8
wo	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
hy	12.9	14.8	1.2	2.3	1.5	0.6	1.7	6.9	5.8	9.9	6.1
ol	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.1	0.0
mt	2.1	2.7	0.5	0.6	0.7	0.4	0.5	1.4	2.1	3.0	2.1
il	1.3	1.2	0.0	0.1	0.2	0.2	0.3	1.3	1.3	2.1	1.3
ap	0.5	0.5	0.0	0.0	0.0	0.0	0.1	0.4	0.5	1.5	0.4
Mg#	66.2	60.8	9.2	51.2	18.2	43.2	47.4	55.2	51.2	73.4	55.4
ANOR	62.7	58.7	5.7	10.4	10.5	17.2	15.1	52.5	34.2	52.3	28.8
Q'-F'	12.6	9.4	37.0	44.2	42.6	35.8	38.8	22.8	13.1	0.0	10.5
Group	Calc-Alk	Calc-Alk	Calc-Alk	Calc-Alk	Calc-Alk	Calc-Alk	Calc-Alk	Calc-Alk	Calc-Alk	Sho	Sho
rock name	hK C-A And	hK C-A And	Rhyol	Rhyol	Rhyol	Rhyol	Rhyol	Dac	Trach	Sho	Trach
Trace Elements (ppm)											
Li											
Be							4.01			4.59	
Sc							1.91			26.36	
V							8	79		190	44
Cr							4	26		421	32
Co							2	14		31	14
Ni							3	11		140	10
Cu										48.65	
Ga										16.27	
Rb							204	113		131	151
Sr							122	414		676	306
Y							15.3	20.0		21.7	31.0
Zr							83	181		224	349
Nb							18.60	13.27		13.57	30.93
Mo							2.65				
Cs							13.83			4.01	
Ba							621	1082		994	517
La							26.1	42.9		38.7	66.7
Ce							44.2	49.5		79.9	106.5
Pr							4.41			10.06	
Nd							14.2			39.4	
Sm							2.57			6.87	
Eu							0.05			1.48	
Gd							1.88			5.27	
Tb							0.36			0.72	
Dy							2.17			3.98	
Ho							0.45			0.75	
Er							1.38			2.10	
Tm							0.26			0.31	
Yb							1.56			1.87	
Lu							0.24			0.28	
Hf							3.09			6.26	
Ta							1.85			0.76	
Tl							2.15			1.10	
Pb							43.2			15.1	
Th							33.2	6.8		17.9	28.1
U							10.9	2.9		3.6	1.5
Isotope Ratios											
$^{87}Sr/^{86}Sr$											
$^{143}Nd/^{144}Nd$											

*from Innocenti *et al.* 2005; **from Agostini *et al.* 2007.
Ayv– Ayvalık; Ber– Bergama; BP– Biga Peninsula; Fo– Foça; İz– İzmir; Ur– Urla; Ka– Karaburun.

Table 1. Continued.

Label	IZ 121	IZ 122	IZ 123	IZ 125	IZ 126	IZ 127	IZ 130*	IZ 117*	IZ 115*	IZ 114	IZ 119	IZ 120	IZ 203	T 92*	K 165*
Zone	Ur-Ka	Ur-Ka	Ur-Ka	Ur-Ka	Ur-Ka	Ur-Ka	Ur-Ka	Ur-Ka	Ur-Ka	Ur-Ka	Ur-Ka	Ur-Ka	Ur-Ka	Ur-Ka	Ur-Ka
Place	Urla İskelesi	Urla İskelesi	Urla İskelesi	Urla İskelesi	Urla İskelesi	Urla İskelesi	Küçükbahçe (Karaburun)	Yağcılar (Urla)	Ovacık (Urla)	Ovacık (Urla)	Urla İskelesi	Urla Iskelesi	Ovacık (Urla)	Urla	Ovacık (Urla)
Major Elements (wt%)															
SiO_2	63.58	69.87	64.71	64.70	68.65	69.97	56.25	50.08	49.92	50.25	48.59	49.68	49.83	50.06	50.81
TiO_2	0.72	0.42	0.61	0.72	0.22	0.16	0.82	1.48	1.55	1.66	1.45	1.47	1.62	1.78	1.69
Al_2O_3	16.74	16.99	16.76	17.63	16.53	16.05	17.02	18.55	17.27	16.89	15.25	15.59	17.01	17.32	17.04
Fe_2O_3	1.69	1.11	3.17	3.58	2.77	2.27	2.40	3.80	3.31	3.82	3.47	2.92	10.76	2.94	3.62
FeO	2.34	0.00	1.39	0.25	0.00	0.00	4.07	4.72	6.71	6.32	6.02	6.19	0.00	7.11	6.59
MnO	0.11	0.04	0.15	0.05	0.02	0.01	0.11	0.13	0.17	0.17	0.16	0.15	0.17	0.20	0.18
MgO	1.69	0.25	0.70	0.59	0.00	0.00	6.19	5.77	5.87	5.10	9.68	8.79	5.31	5.32	5.60
CaO	3.91	1.04	2.41	2.67	0.20	0.16	7.70	9.81	10.34	10.33	10.90	10.20	10.03	10.11	9.03
Na_2O	4.47	4.79	4.93	4.65	5.97	5.76	3.42	3.24	2.86	3.43	2.58	2.88	3.16	3.38	3.53
K_2O	4.56	5.41	4.99	4.97	5.60	5.58	1.82	2.09	1.71	1.71	1.61	1.79	1.79	1.45	1.62
P_2O_5	0.18	0.08	0.17	0.19	0.03	0.03	0.19	0.33	0.30	0.32	0.29	0.33	0.32	0.35	0.31
CIPW Norm															
D.I.	74.5	91.3	81.3	80.2	94.8	95.8	43.3	38.6	34.3	38.2	29.4	33.8	37.0	37.0	39.5
Q	9.8	18.7	10.0	11.5	11.2	14.0	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C	0.0	1.5	0.0	0.2	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
or	27.0	31.9	29.5	29.4	33.1	33.0	10.7	12.3	10.1	10.1	9.5	10.6	10.6	8.5	9.6
ab	37.8	40.6	41.7	39.3	50.5	48.8	28.9	24.8	24.2	27.0	17.7	21.8	26.2	28.2	29.9
an	12.2	4.7	8.8	12.0	0.8	0.6	25.7	29.9	29.3	25.6	25.3	24.3	27.0	27.8	25.8
ne	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	1.1	2.2	1.4	0.3	0.2	0.0
di	5.0	0.0	1.7	0.0	0.0	0.0	9.1	13.5	16.5	19.3	21.7	19.6	17.0	16.5	13.8
wo	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
hy	4.6	1.0	4.3	3.8	2.1	1.8	17.7	0.0	2.4	0.0	0.0	0.0	0.0	0.0	3.8
ol	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.5	11.4	9.5	17.7	16.5	11.9	12.0	9.7
mt	1.9	0.5	2.1	1.7	1.2	1.0	2.1	2.8	2.4	3.3	2.2	2.2	2.4	2.4	3.4
il	1.4	0.8	1.2	1.4	0.4	0.3	1.6	2.8	2.9	3.2	2.8	2.8	3.1	3.4	3.2
ap	0.4	0.2	0.4	0.4	0.1	0.1	0.4	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7
Mg#	53.1	39.5	29.9	30.4	-1.1	0.0	69.2	61.6	56.0	54.2	69.0	67.7	53.5	53.4	56.3
ANOR	31.1	12.7	23.0	29.0	2.4	1.8	70.6	70.8	74.3	71.8	72.6	69.7	71.9	76.5	73.0
Q'-F'	11.3	19.5	11.1	12.5	11.7	14.6	5.2	-2.0	0.0	-1.8	-4.1	- 2.4	- 0.5	- 0.3	0.0
Group	Sho	Sho	Sho	Sho	Sho	Sho	Hi-Mg And	Alk Bas	Alk Bas	Alk Bas	Alk Bas	Alk Bas	Alk Bas	Alk Bas	Alk Bas
rock name	Trach	Rhyol	Trach	Trach	Trach	Rhyol	C-A bas And	K-TrBas	thol Bas	K-TrBas	Alk Bas	Alk Bas	Alk Bas	Alk Bas	K-TrBas
Trace Elements (ppm)															
Li								6.46	11.55			45.52			
Be							2.31	1.77	1.59			1.97		1.81	1.83
Sc							22.06	17.30	23.45			28		27	25
V							146	161	227	240	202	221		253	249
Cr							233	13	45	62	325	303		48	56
Co							26	26	32	33	41	41		33	33
Ni							105	18	18	19	108	136		18	18
Cu							32.48							31.65	22.08
Ga							18.11	15.52	16.80			16.54		18.20	18.91
Rb							71	53	44	40	41	55		47	67
Sr							639	691	605	595	644	549		601	562
Y							22.1	25.7	27.7	29.3	22.3	25.4		28.4	29.1
Zr							152	176	143	152	131	153		145	146
Nb							9.61	13.21	11.93	12.03	11.49	13.24		11.25	11.83
Mo															
Cs							3.42	5.29	2.21			54.9		2.05	5.53
Ba							965	541	472	492	381	405		475	490
La							29.3	32.3	31.7	44.5	40.2	32.1		30.0	31.2
Ce							58.0	69.1	65.0	53.9	47.4	67.4		61.8	64.7
Pr							6.82	8.42	7.97			7.81		7.48	7.79
Nd							25.8	33.2	31.7			31.0		30.4	31.4
Sm							5.12	6.45	6.62			6.29		6.39	6.44
Eu							1.07	1.49	1.76			1.58		1.95	2.08
Gd							4.38	5.52	5.77			5.36		5.66	5.87
Tb							0.68	0.82	0.87			0.82		0.87	0.90
Dy							3.77	4.66	4.99			4.47		4.91	5.08
Ho							0.78	0.97	1.00			0.87		1.00	1.04
Er							2.18	2.53	2.66			2.40		2.63	2.73
Tm							0.32	0.36	0.37			0.34		0.39	0.39
Yb							2.01	2.26	2.26			2.06		2.48	2.51
Lu							0.29	0.30	0.33			0.28		0.34	0.35
Hf							4.09	4.50	3.57			3.54		3.48	3.54
Ta							0.69	1.03	0.79			0.88		0.72	0.76
Tl							0.53	0.14	0.06			0.31		0.15	0.23
Pb							28.5	21.6	19.7			13.4		16.5	19.0
Th							10.1	9.4	8.6	13.2	0.1	7.9		7.9	8.4
U							2.6	2.5	2.1	4.3	3.3	2.0		1.9	2.0
Isotope Ratios															
$^{87}Sr/^{86}Sr$							0.708544	0.707540	0.706277					0.706232	0.706262
$^{143}Nd/^{144}Nd$							0.512343	0.512492	0.512571					0.512564	0.512573

*from Innocenti *et al.* 2005; **from Agostini *et al.* 2007.

Ayv– Ayvalık; Ber– Bergama; BP– Biga Peninsula; Fo– Foça; İz– İzmir; Ur– Urla; Ka– Karaburun.

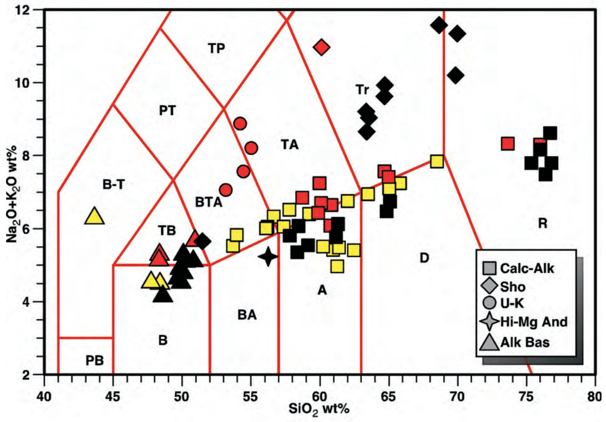

Figure 9. Total alkali vs silica (TAS) diagram for volcanic rocks from the study area, showing the different petrogenetic affinities of various volcanic suites. Calc-alk– calc-alkaline; Sho– shoshonitic; U-K– ultra potassic; Hi-Mg And– high-Mg andesitic and Alk Bas– alkaline basaltic. Yellow symbols refer to samples from Ayvalık, Bergama and the Biga Peninsula; Red symbols, samples from Foça-İzmir area; Black symbols, rocks sampled on the Urla-Karaburun peninsula. Fields according Le Maitre (2002).

samples (41 out of 70) belong to a high-K calc-alkaline association, reflecting the clear volumetric predominance of these products. Some straddle the line dividing the high-K C-A rocks from shoshonitic rocks on the K_2O-SiO_2 diagram, and are andesitic to rhyolitic in composition, with the lack of primitive terms (Figure 10). Shoshonitic rocks are present mainly around Urla as evolved trachytic domes, with the IZ 129 shoshonite sample from Karaburun the only exception. U-K rocks can be found as dykes (Foça) and lava flows (Beşyol). Sample IZ 130 from Küçükbahçe belongs to the Hi-Mg andesitic suite (Agostini *et al.* 2005), whereas alkali basalts are present as dykes (Foça) or more frequently as small lava flows, in Urla İskelesi, Yağcılar and Ovacık around Urla, in Foça, in Aliağa, and in the Biga Peninsula (Akköy, Ezine and Taştepe). Most of the alkali basalts are mildly alkaline and slightly SiO_2-undersaturated, and fall in the compositional fields of basalt and trachybasalt on the TAS diagram (Figure 9), although sample IZ 232, from Biga Peninsula, has very low SiO_2 and plots as a basanite.

Rocks belonging to the calc-alkaline and shoshonitic association have the typical trace element pattern of supra-subduction rocks (Figure 11). These samples exhibit marked Ta-Nb, P and Ti negative anomalies and a positive K spike. Ultra-K rocks (e.g., IZ 7) have similar patterns, with more pronounced K positive anomalies as well as a Hf-Zr spike. However, alkali basalts exhibit a great variation in trace element patterns. Indeed, while some of them (e.g., IZ 9) have a pattern virtually indistinguishable from arc-related rocks, other samples, such as T 76, have the typical humped pattern of intraplate rocks, with Ta and Nb positive

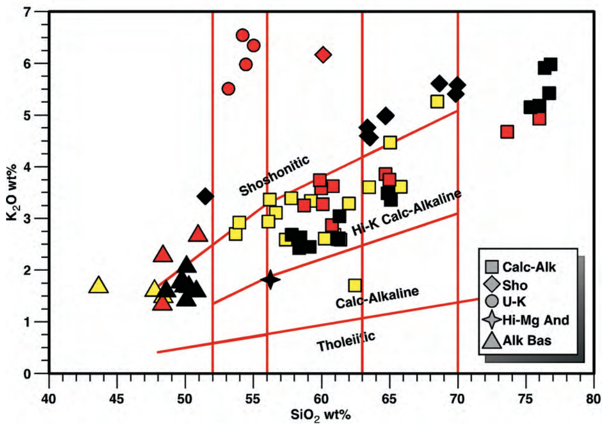

Figure 10. K_2O vs SiO_2 plots of volcanic rocks from the study area. Symbols and colours as in Figure 9.

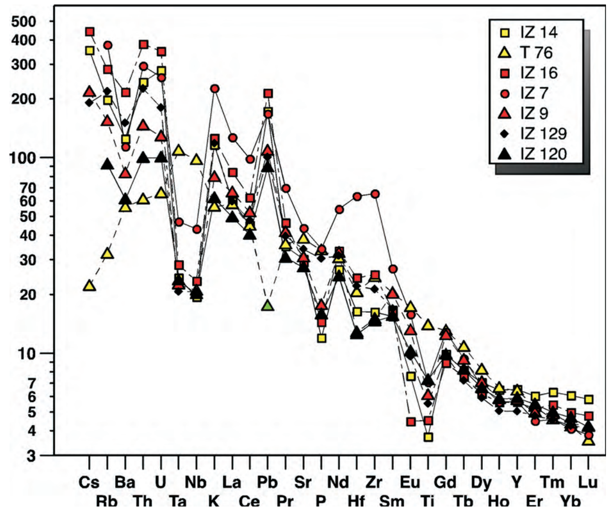

Figure 11. Incompatible trace element patterns for selected samples from the Ayvalık (yellow), Foça (red) and Urla-Karaburun (black) regions. Squares– calc-alkaline rocks; diamond– shoshonitic lava; circle– ultra-K rock; triangles– alkali basalts.

anomalies. From the Rare Earth Element (REE) distribution (Figure 12) it is evident that all the studied rocks are relatively Light REE-enriched and exhibit a fractionated pattern. In more detail C-A and u-K rocks have $(La/Yb)_N \approx 10–20$, with the steepest curves for the u-K rocks, whereas the alkali basalt profiles have more gradual slopes.

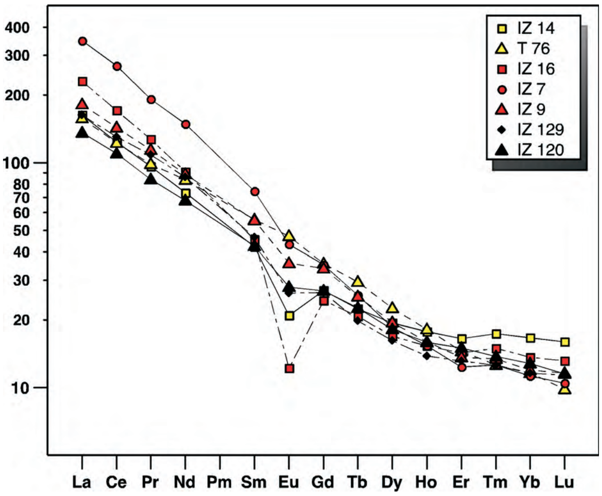

Figure 12. Rare earth element patterns for selected samples from the Ayvalık, Foça and Urla-Karaburun regions. Symbols as in Figure 11.

Discussion: A New Approach to Geodynamic and Petrogenesis

Geodynamics and Age of Magmatism

A number of authors stated that an extensional tectonic regime developed in Western Anatolia during the Cenozoic, resulting in widespread graben formation (e.g., Brinkmann 1966, 1968; McKenzie 1972; Angelier *et al.* 1977; Dewey & Şengör 1979; Kaya 1979, 1981; Koçyiğit 1984). Several interpretations were presented to account for the age of the inception of extensional tectonics and the relationships between the tectonic regime of Western Anatolia and its volcanic activity:

- N–S compression due to Africa-Eurasia convergence, southward migration of the subduction hinge and consequent back-arc extension in Western Anatolia (Fytikas *et al.* 1984; Pe-Piper & Piper 1989; Gülen 1990);
- N–S-directed extensional tectonic regime active since the Late Oligocene resulting from post-orogenic collapse (Seyitoğlu & Scott 1991, 1992; Seyitoğlu *et al.* 1997). According to this view, all the magmatic activity should have occurred under extensional tectonics;
- Oscillation between N–S compressional and extensional periods during the Middle–Late Miocene, with N–S extension associated with E–W compression induced by Eurasia-Arabian plate collision. Different episodes of magmatism occurred during the two tectonic regimes, with or without a time gap between them, i.e. 'orogenic' activity was linked to compressive tectonics versus 'intraplate' activity during extensional tectonics (Yılmaz 1989; Savaşçın & Güleç 1990).

Despite all these efforts, the geodynamic-petrogenetic relations were not satisfactorily explained, mainly because all these authors investigated the Western Anatolia extensional dynamics and related volcanism in the frame of the westward escape model of the Anatolian Plate (e.g., Dewey & Şengör 1979). This model dates Western Anatolia extension back to Late Miocene times, following the Arabia-Eurasia collision in the Bitlis-Zagros zone and the formation of the North Anatolian and East Anatolian faults. As a consequence, the Early to Middle Miocene subduction-related magmatic activity would have taken place under a compressional tectonic regime. Nevertheless, the ages of graben infill sediments and the exhumation of the Menderes Massif well constrain the initiation of extensional tectonics to Early Miocene times, or even earlier (e.g., Cohen *et al.* 1995; Işık *et al.* 2004). More complex models were then built in order to solve this contradiction, e.g. a multi-stage extension of the region (e.g., Koçyigit *et al.* 1999), in response to tectonic collapse in the first stage, and to the westward escape of Anatolia in the second stage.

It is worth recalling that in the literature there is no general consensus on the tectonic setting that characterized the emplacement of the Early–Middle Miocene subduction-related lavas, while there is general agreement that the younger alkaline volcanism took place under extensional tectonics, due to asthenospheric upwelling. However, irrespective of the preferred model on the cause of extensional tectonics, it is remarkable that all of the volcanic phases, even the older calc-alkaline products, were emplaced in an extensional context. This can be easily demonstrated considering the wealth of calc-alkaline, shoshonitic and u-K lava flows emplaced in alternation with graben infill sediments.

Doglioni *et al.* (2002) were the first to question the 'westward-escape of Anatolia' as the main cause of Aegean-Anatolian extension, claiming that this model had become a 'sort of dogma' and emphasized the contradiction between the Aegean Sea opening and the Anatolia Plate westward migration. These authors proposed a new geodynamic model capable of explaining the geodynamic evolution of the region along with its magmatic activity. Extension in Western Anatolia (and in the whole Aegean area) resulted from the differential convergence rates between the NE-directed subduction of Africa relative to the Greece and Anatolia microplates. This model originates from the observation of GPS-measured plate velocities and considers the Aegean Sea as an unconventional back-arc basin, whose spreading is driven not by slab roll-back (as in common west Pacific back-arc basins), but instead by the diffuse extensional margin formed by the differential hinge migration of the Crete and Cyprus trenches. This point of view closely matches the evidences of a shallow-dipping Aegean subducting slab (see Agostini *et al.* 2010 for a detailed review of these arguments).

In other words, in an Africa-fixed reference frame, Greece overrides Africa along the Hellenic Trench faster than Turkey does along the Cyprus trench (Figure 13a), implying that there is a positive velocity between Greece and Turkey in the hanging wall of the subduction zone, giving rise to a diffuse extensional margin. According to Doglioni *et al.* (2002), the horizontal NE–SW direction of σ_1 in the compressive stage became the trend of σ_3 from the Late Oligocene–Early Miocene onwards, so that NW–SE-trending normal faults or grabens formed, together with E–W-trending dextral transtensional faults and N–S-trending sinistral transtensional faults (Figure 13b).

The Stress Field

The study area is crosscut by a net of faults which fits this model well. Most Early Miocene to Middle Miocene volcanic rocks and dykes trend NW–SE or N–S (Figures 1, 4 & 8), showing that the magma emplacement during the orogenic phase followed the inception of the extensional tectonic regime. Furthermore, some younger (Late Miocene) alkali basaltic dykes present in this area also trend in the same directions. Also Jeckelmann (1996) reported formation of a NW-trending graben, as a consequence of NE–SW-directed extension in the Bergama-Nebiler area, with N–S sinistral transfer zones, and the emplacement of the Nebiler calc-alkaline dyke along NW-trending systems (NDS in Figure 1), as with the main graben faults.

This model, assuming (i) the lack of major changes in plate movements since Late Oligocene–Early Miocene to Recent times, and (ii) a NE–SW-directed extension, readily explains why most graben follow the observed NW–SE direction in WA and the Aegean Sea (Figure 1). In addition, several important tectonic lineaments reported in the literature, not fitting the westward escape of Anatolia model, do support well the model of Doglioni *et al.* (2002) (Figure 1). Indeed, the dextral fault components of WA grabens, the E–W-trending strike-slip fault of the Simav Graben with a dislocation of up to 5–6 km (Konak 1982), the Edremit Gulf fault (Westaway 1990) and other strike-slip faults, which have been considered 'not important' for more than twenty years play a relevant role in this new frame. The same is valid for E–W- and NE-trending transcurrent faults in the Foça and Dikili areas (Altunkaynak & Yılmaz 1999), the NE-trending strike-slip faults within the Gediz Graben (Bozkurt & Sözbilir 2004), the NW-trending grabens with NE- and N–S-directed strike-slip faults in Menderes Massif (Emre & Sözbilir 2005), and the strike-slip faults in the Bigadiç area which are dominantly NE-directed (Erkül *et al.* 2005). Moreover, some of the older NE–SW normal faults, such as the İzmir-Soma and Foça-Dikili-Kozak faults (Figure 1), were reactivated as strike-slip faults during Middle Miocene times (Kaya 1979, 1982). In this context, the FKG and ALG are interpreted as a former single graben, later dissected by trans-tensional faults.

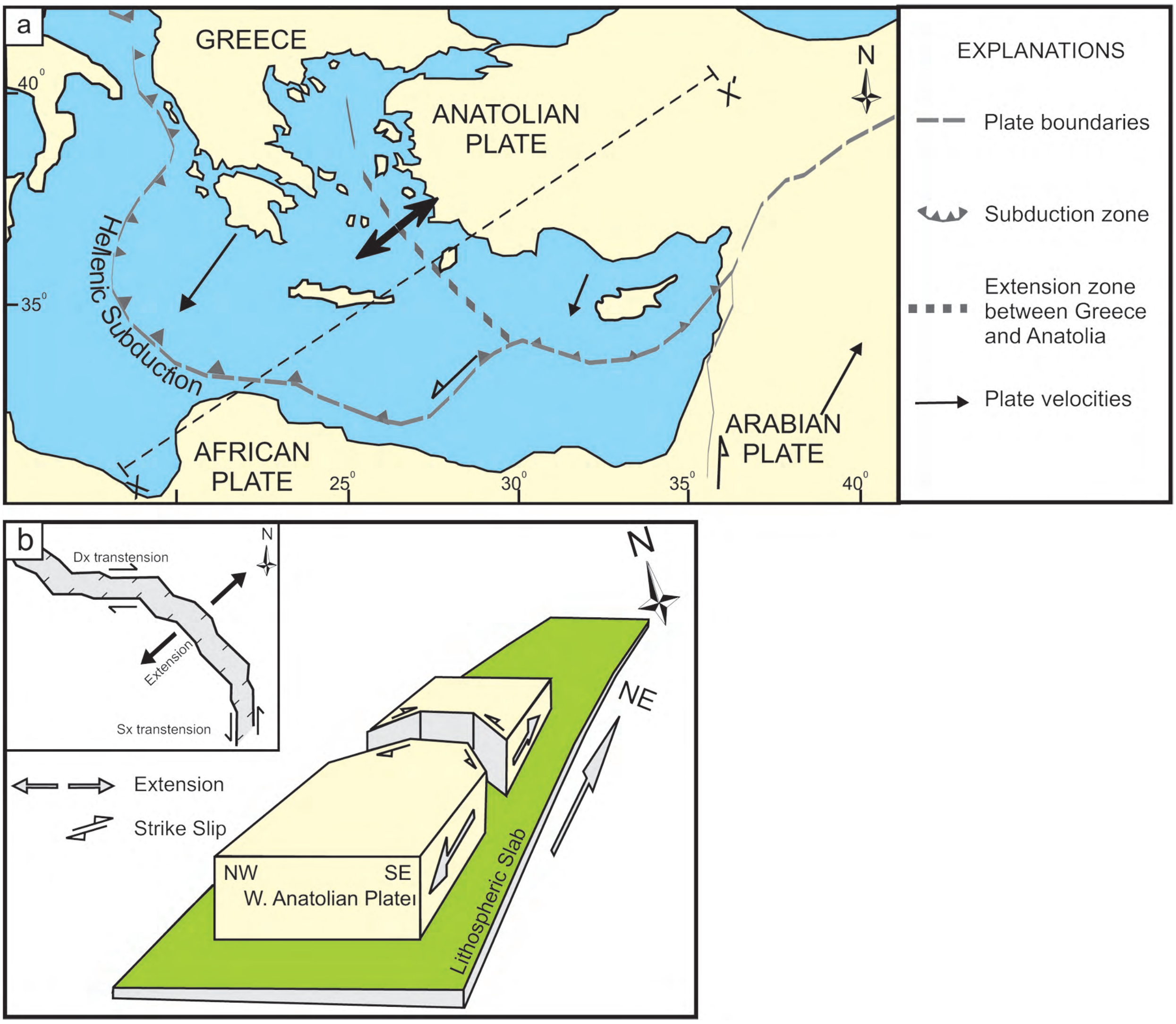

Figure 13. **(a)** Plate motions and extension in the Aegean-Anatolian system. Considering Africa as fixed, Greece is overriding Africa faster than Cyprus-Anatolia. This implies extension between Greece and Anatolia (thick double arrow). Thin arrows indicate present-day plate-motion vectors with respect to a fixed Africa, inferred from space geodesy after NASA data base (from http://sideshow.jpl.nasa.gov/mbh/series.html) (taken from Doglioni *et al.* 2002). **(b)** Block diagram evidencing tectonic setting of the Aegean-Western Anatolia region. Extension is NE–SW directed, giving rise to NW-trending grabens, E–W dextral and N–S sinistral transtensional transfer zones.

Finally, it is noteworthy that the occurrence of extensional NW grabens, together with the oblique E–W transtensional fault systems and the NE-trending strike-slip faults, allowed the uplift and exhumation of the Menderes Massif basement rocks and the ophiolitic belts of the İzmir-Ankara Zone.

Petrogenetic Constraints

One of the most important recent advances in the geochemical studies of subduction-related magmas is the detection of the subduction tracers, that is trace element and isotope ratios which are particularly sensitive to subduction processes.

Among the subduction tracers, a special role is assumed by the ratios between Fluid Mobile Elements (FME, such as B, Li, Cs, Rb, Ba, Pb, Th) and Fluid Immobile Elements (FIE: Ta, Nb, Ti and the Heavy REE). In the suite of subduction-related rocks in Western Anatolia good positive correlations are shown by FME/FIE ratios with respect to Sr, Nd, B and Li isotopes (see also Tonarini *et al.* 2005; Agostini *et al.* 2008). The same is observed for the rocks of the study area, which define good positive arrays e.g. for Ba/Nb vs Pb/Ce (Figure 14) and Th/Ta vs ^{87}Sr/^{86}Sr (Figure 15).

These results indicate that the calc-alkaline, shoshonitic and ultra-K rocks of the region were derived from a mantle wedge source variably enriched by subduction-related fluids. As for the age parameter (Figure 16), it is evident that the transition from calc-alkaline to shoshonitic to u-K magmas is marked by a progressive reduction of the subduction signal, i.e. the amount of slab-released fluids. This implies that the Western Anatolia mantle wedge was metasomatized by fluids released by a progressively dehydrating slab, as indicated by B and Li isotope fractionation (Tonarini *et al.* 2005; Agostini *et al.* 2008).

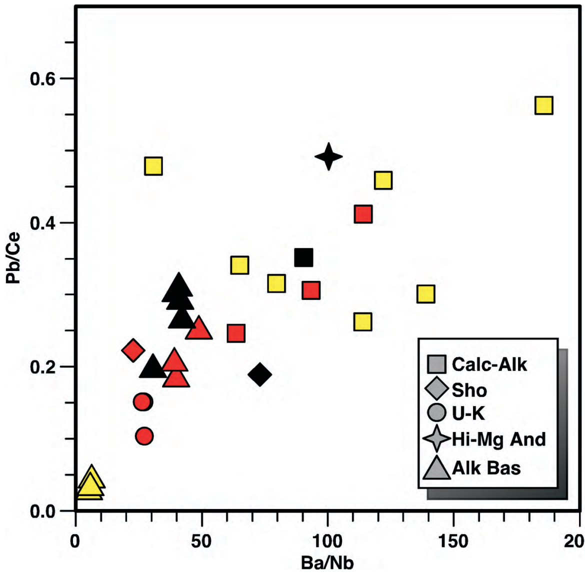

Figure 14. Ba/Nb vs Pb/Ce plot for selected samples from volcanic rocks from the study area. Symbols and colours as in Figure 9.

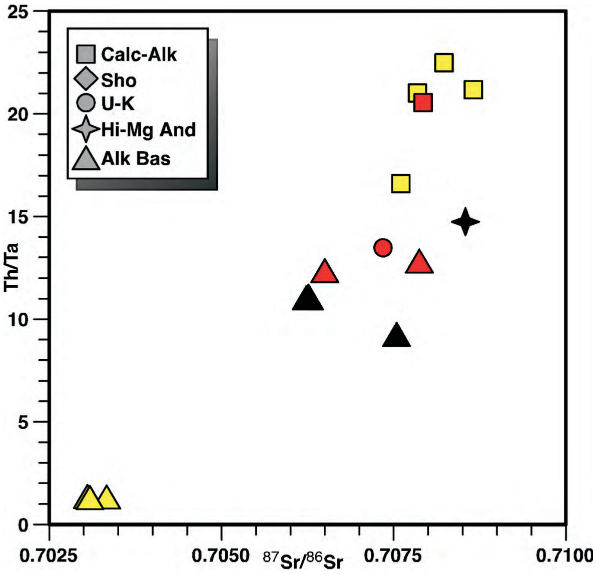

Figure 15. ^{87}Sr/^{86}Sr vs. Th/Ta plot for selected samples from volcanic rocks from the study area. Symbols and colours as in Figure 9.

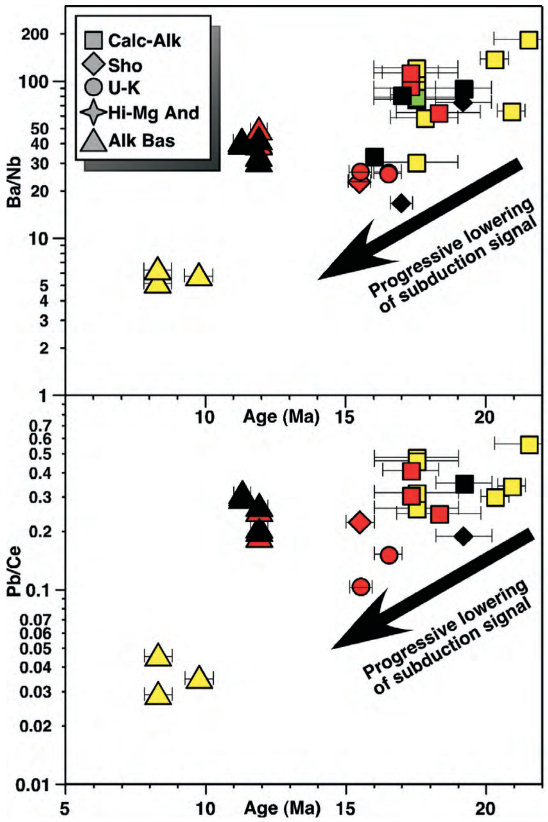

Figure 16. Age vs Ba/Nb, Pb/Ce plot for selected samples from volcanic rocks from the study area. Symbols and colours as in Figure 9.

The Western Anatolian alkali basalts can be subdivided into two groups: the first one comprises mildly alkaline, potassic rocks, which show higher FME/FIE and $^{87}Sr/^{86}Sr$ ratios, while the second one consists of markedly alkaline, sodic rocks, characterized by lower FME/FIE ratios (Figure 14) and $^{87}Sr/^{86}Sr$ (Figure 15). The intraplate-type geochemical character of the Na-alkaline basalts clearly displays that they were sourced in the sub-slab asthenosphere, with no subduction-related imprint. In contrast, the K-basalts, with geochemical features intermediate between the Na-alkaline basalts and the supra-subduction rocks, cannot be produced by mixing calc-alkaline (or shoshonitic) and intraplate-like melts, instead they derive from sub-slab magmas after interaction with residual slab fluids (Agostini *et al.* 2007).

In summary, two fundamental constraints on the geodynamic evolution of the region arise from magma petrogenesis:

(i) The geochemical-isotopic evolution of supra-subduction rocks implies that the source region of these rocks is a portion of mantle wedge subjected to successive episodes of fluid addition and partial melting. Moreover, fluids released by the slab and added to the mantle wedge are progressively less abundant and more fractionated in B and Li isotopes, indicating that these fluids come from the same, progressively dehydrated, portion of slab.

(ii) After the cessation of the mantle wedge-sourced magmatism, melts formed in the sub-slab asthenosphere and reached the surface after scarce or any interaction with residual slab fluids. The formation of these magmas strongly indicates asthenosphere upwelling, and their mode of ascent and emplacement suggests that both the subducted slab and the mantle wedge were stretched and torn.

Synthesis: Geodynamic and Petrogenesis

Geodynamic data indicate that the Aegean subduction system should be considered a ‘forced’ subduction, where the lower plate is forced to subduct by hinge migration, so the slab does not sink into the mantle, but is coupled with the overlying mantle wedge and lithosphere (Doglioni *et al.* 2007; Agostini *et al.* 2010). Then back-arc extension would affect the upper plate, the mantle wedge together with the subducting slab. However, magma petrogenesis requires the occurrence of: (i) a thin, stagnant mantle wedge over a stagnant slab, which underwent progressive stages of dehydration during the Early to Middle Miocene, and (ii) the later stretching and fracturing of this mantle domain from the Late Miocene onwards, matched by asthenosphere upwelling.

Conclusions

Extensional tectonics in Western Anatolia date back to Late Oligocene–Early Miocene time (e.g., Seyitoğlu & Scott 1996). Assuming that no major plate velocity variation occurred in the last 30 Ma, this geodynamic framework can be explained by a new model (Agostini *et al.* 2010), which considers extension as a direct result of the differential convergence rate between the Greek and Anatolian platelets overriding Africa. NE–SW extension led to the formation of NW-trending grabens, N–S sinistral and E–W dextral transtensional shear zones.

Continuing Aegean subduction was allowed by southwestwards hinge migration, whereby the lower plate was forced to subduct and the slab did not sink into the mantle but still and shallow-dipping. Thus, a thin portion of stagnant, non-convective mantle wedge was trapped between the lower and the upper plate. As a consequence these three layers, i.e. the lithosphere of the upper plate, the trapped mantle wedge and the subducted slab of the lower plate, were coupled, so back-arc extension and lithosphere upwelling affected them all (Figure 17).

Calc-alkaline, shoshonitic and ultra-K magmas were fed by consecutive episodes of mantle wedge partial melting, which in turn were triggered by influxes of slab-released fluids (Figure 17). The whole system was somewhat locked and the progressive dehydration of the slab, in this context, was not due to its downward progression, as in normal subduction contexts, but instead was caused by progressive heating of the slab induced by thermal re-equilibration and eventually reinforced by the upwelling of hot buoyant asthenosphere, related to the onset of extensional dynamics.

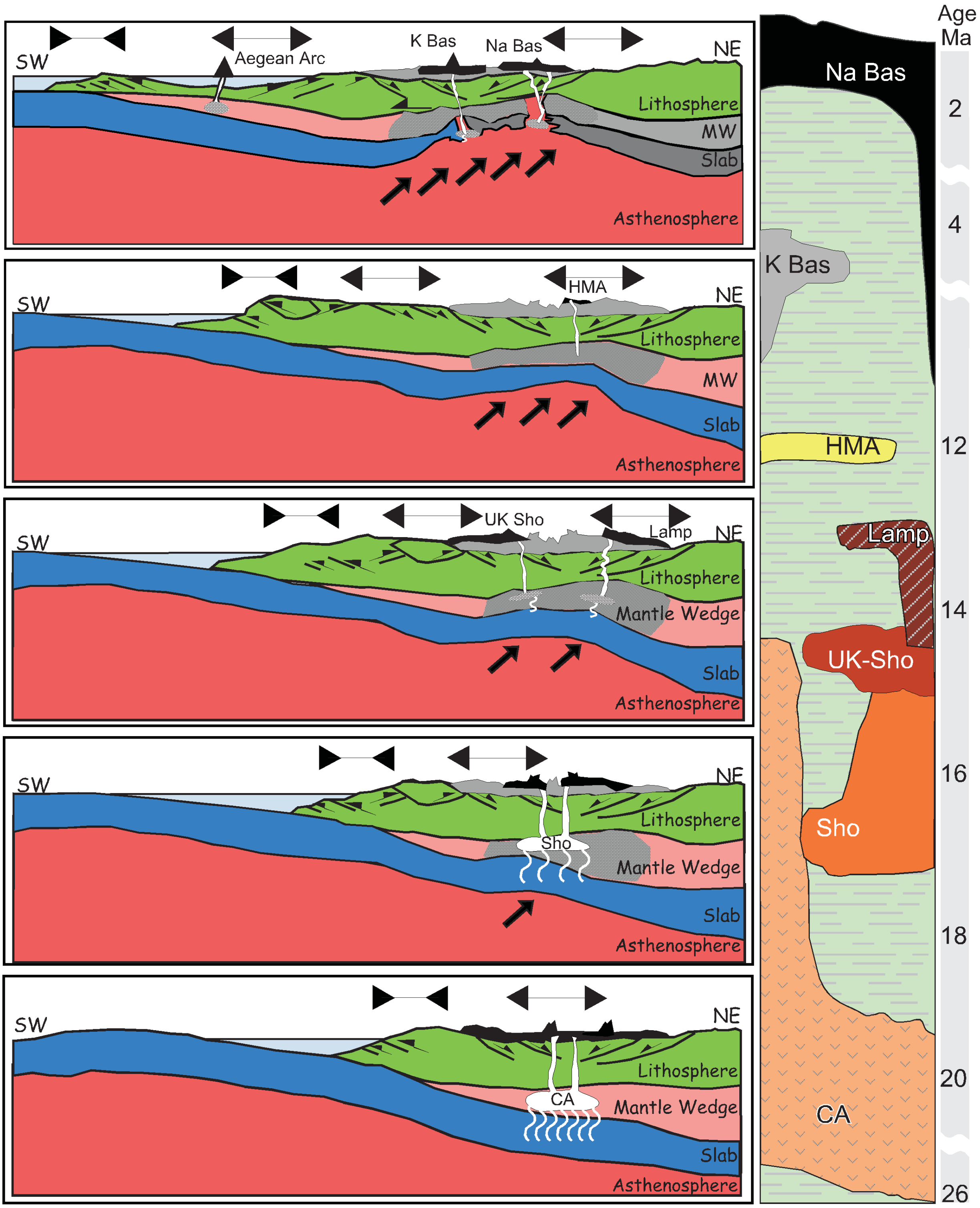

Figure 17. Schematic cartoon of the geodynamic evolution of the Western Anatolia region showing the mantle source of Western Anatolia volcanics from the Early Miocene onwards, along with the schematic stratigraphic column (CA– calc-alkaline rocks; Sho– shoshonitic rocks; Lamp– lamproitic rocks; UK-Sho– ultra-potassic shoshonitic rocks, HMA– High-Mg andesites; K Bas– potassic alkaline rocks, Na Bas– sodic-alkaline basaltic rocks).

Alkali basalts are sourced in the sub-slab asthenosphere and these 'intraplate' magmas reach the surface carrying little or no evidence of interactions with subduction-modified mantle domains. This is made possible by continuing extensional tectonics, which produces tears and breaks in the slab and mantle wedge, forming a vertical slab window (Figure 17). In this view, the superficial occurrence of the alkali basalts is a useful marker of ruptures in the slab, and the Na-hawaiitic rocks of Urla and Foça are the first sign of the occurrence of a magma reservoir unmodified by subduction processes (Agostini *et al.* 2007).

The study region, including the Foça-Karaburun and the Ayvalık-Lesvos graben systems, is the best area to test this model. Indeed, this area provides a wealth of significant geo-structural and geochemical-petrological data that can be integrated in a unique scenario:

(i) tectonic lineaments and tectonic structures, which allow the stress field of the region and its tectonic evolution to be well constrained;

(ii) outcrops of volcano-sedimentary sequences, which clearly indicate the onset of extensional dynamics;

(iii) volcanic rocks belonging to all the different stages of Neogene volcanism, which precisely record the geochemical evolution of the magma sources.

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