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Palaeozoic deformation and magmatism in the northern area of the Anatolide block (Konya), witness of the Palaeotethys active margin

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Keywords: Menderes-Tauride block, Konya region, Cimmerian, Palaeotethys, magmatic arc, active Eurasian margin

ABSTRACT

The study area, located north of Konya (Central Turkey), is composed of Silurian to Cretaceous metamorphosed rocks. The lower unit of the oldest formation (Silurian-Early Permian) is mostly made up of Silurian-Early Carboniferous metacarbonates. These rocks pass laterally and vertically to Devonian-Early Permian series having continental margin, shallow water and pelagic characteristics. They are intruded or juxtaposed to different kinds of metamagmatic rocks, which show MORB, continental arc and within plate characteristics. The Palaeozoic units are covered unconformably by Triassic-Cretaceous metasedimentary units. All these rocks are overthrusted by Mesozoic ophiolites. The Palaeozoic sequence can be seen as a northern Palaeotethys passive, then active margin. The northward subduction of the Palaeotethys ocean during the Carboniferous-Triassic times, induced the development of a magmatic arc and fore-arc sequence (Carboniferous-Permian). Before the Early Triassic (?Late Permian) time, the fore-arc sequence was uplifted above sea level and eroded. The Triassic sequences are regarded as marking the onset of back-arc opening and detachment of the Anatolian Konya block from the active Eurasian margin. Finally, a suture zone formed during the Carnian between the Konya region and the Menderes- Tauride Cimmerian block due to the closing of Palaeotethys. This geodynamic evolution can be correlated with the evolution of the Karaburun sequence in western Turkey.

RESUME

La région étudiée, située au nord de Konya (Turquie centrale), se compose de séries métamorphiques siluriennes à crétacées. L'unité inférieure de la formation la plus ancienne (Silurien-Permien inférieur) est dominée par des métacarbonates d'âge Silurien à Carbonifère inférieur. Ces roches passent verticalement et latéralement à une série de marge continentale présentant des caractéristiques d'eau peu profonde à pélagique, d'âge Dévonien à Permien inférieur. Ces roches sont juxtaposées ou intrudées par différents types de roches méta-magmatiques, présentant des caractères de MORB, d'arc volcanique ou intraplaques. Les unités paléozoïques sont recouvertes en discordance par une série méta-sédimentaire d'âge Trias à Crétacé. Tout cet ensemble est chevauché par des ophiolites mésozoïques. La séquence paléozoïque peut être regardée comme la marge nord passive puis active de la Paléotéthys. La subduction vers le nord de la Paléotéthys du Carbonifère au Trias, créa tout d'abord la formation d'un arc magmatique et d'un bassin d'avant-arc d'âge Carbonifère à Permien, puis, avant le Trias basal, l'ouverture d'un bassin d'arrière arc à l'intérieur de l'arc, provoquant le soulèvement et l'érosion de celuici. Les séries triasiques marquent le détachement du bloc anatolien de Konya de la marge active eurasiatique. Finalement, une zone de suture se développa pendant le Carnien entre ce bloc de Konya et le bloc cimmérien Taurique-Menderes, suite à la fermeture de la Paléotéthys. Cette évolution géodynamique se corrèle avec celle observée à Karaburun dans l'ouest de la Turquie.

Introduction

The study area (Fig. 1) is located approximately 20 km to the north of Konya, (Central Anatolia) on the northern margin of the Menderes-Tauride platform immediately southwest of the Kırşehir block (Central Turkey). It comprises a thick sequence of metamorphosed sedimentary and magmatic rocks, Early Palaeozoic to Cretaceous in age (Wiesner 1968; Göğer & Kıral 1969; Özcan et al. 1988; Eren 1993a, 1993b, 1996 a, 1996b; Kurt 1994, 1996; Göncüoğlu & Kozur 1998). The geology of Turkey was mainly shaped by the opening and closing of both Palaeo and Neo Tethys oceans and their derived marginal basins (Şengör & Yılmaz 1981; Şengör 1985; Okay 1986; Okay et al. 1996; Stampfli et al. 1991, 2001a; Stampfli 2000, Stampfli & Borel 2002, 2004).

The Palaeotethys opened as a back-arc basin due to the slab rollback of the Rheic and Asiatic oceans, resulting in the rifting of a several thousand km long ribbon like Hun superterrane off the Gondwana margin, during Ordovician-Silurian times (von Raumer et al. 2002; Stampfli et al. 2002). Onset of Palaeotethys sea-floor spreading is placed in the Early to Middle Devonian. The northward subduction of Palaeotethys, following the accretion of the Hunic terranes to Eurasia during

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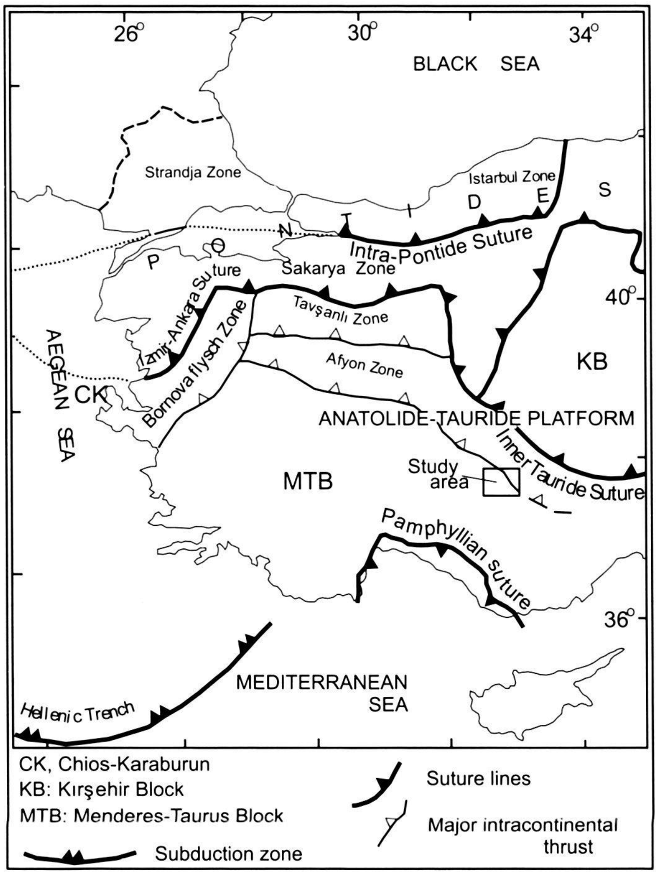

Fig. 1. Tectonic map of western Turkey (modified from Okay et al. 1996) with the location of the study area.

the Variscan cycle, resulted in the tectonic inversion of the Hunic southern passive margin, where flysch sedimentation replaced a carbonate ramp type sedimentation usually in Late Devonian to Early Carboniferous times, (e.g. Carnic Alps; Venturini 1990; Schönlaub & Histon, 1999). This was followed by Carboniferous-Early Permian calc-alkaline cordillera type magmatism found in the Variscan-Alpine Mediterranean domain (e.g. Stampfli, 1996; Vavassis et al. 2000). Gondwana collided with Laurasia in Late Carboniferous time to form the Alleghanian and Variscan mountain belt and the Pangea landmass, but final closure of the Palaeotethys in the Tethyan domain (e.g. in Turkey) took place during the Cimmerian (Triassic to Jurassic) orogenic cycle.

The Neotethys opened from the Late Carboniferous to the late Early Permian, starting east of Australia and progressing to the east Mediterranean area (Stampfli et al. 2001a). This opening was associated with the drifting of the Cimmerian superterrane (Şengör 1979, 1985). At the same time, slab roll-back of the Palaeotethys opened numerous back-arc oceans (Küre, Meliata, Maliac, Pindos, Fariman) and corresponding fore-arc basins (Eastern Crete, Karaburun, Karakaya, Agh-Darband) along the Eurasian margin. Some of these Permo-Triassic marginal basins closed during the Cimmerian collisional events, whereas others remained open, and their delayed subduction induced the opening of younger back-arc basins such as the Vardar, Izmir-Ankara, in the Jurassic and the Lycian and Black-sea domains in the Cretaceous (Stampfli et al. 1991, 2001b; Stampfli 1996, 2000; Ziegler & Stampfli 2001; Stampfli & Borel 2002; 2004).

At the present (Fig. 1), the Izmir-Ankara Suture Zone divides Turkey into two main tectonic units, the Pontides and the Anatolide-Tauride Platform (Şengör & Yılmaz 1981; Okay et al. 1996). The Pontides consist of the Sakarya, Istanbul and Strandja zones and belong to Laurasia. South of the suture, the Anatolide-Tauride platform, belonged for its southern part (Taurus s.str.) to Gondwana, at least until Permian times. According to Şengör & Yılmaz (1981) the Inner Tauride Suture Zone subdivides the platform into two continental fragments; the Menderes-Tauride and Kırşehir blocks. North of the Menderes-Tauride block, the Tavşanlı and Afyon zones of Okay (1984, 1986) correspond to the Anatolides of Ketin (1966). The Tavşanlı zone, represents the northward subducted continental margin of the Anatolide-Tauride platform and is thrusted over the Afyon zone. The latter is composed of Devonian to Paleocene metamorphosed sedimentary rocks in greenschist facies (Okay 1986; Okay et al. 1996).

According to Stampfli (2000) and Stampfli & Borel (2002; 2004) the Anatolide and Tauride blocks are not sealed by a platform until the Late Triassic, before that the two blocks show a drastically different evolution and origin. The Tauride one is a typical Cimmerian block (sensu Şengör 1979), it shows an evolution similar to the Cimmerian-Iranian blocks and the most external part of the Hellenides (Stampfli et al. 1991; Stampfli et al 2003). Together with the Pan African Menderes Massif (Şengör 1984; Hetzel & Reischman 1996; Dannat & Reischman 1998 and 1999) which is part of it, the Taurus block has no Variscan deformation, but it records the opening of the Neotethys south of it, during its separation in Permian time from Gondwana (Stampfli 2000; Stampfli et al 2001a). This rifting event is responsible for numerous unconformities found in the Taurus within the Permo Triassic sequence.

The Anatolides are of Eurasian origin and joined the Tauride block due to the Carnian closing of Palaeotethys (Stampfli et al. 2001a, b; 2003). The Kırşehir "block" could represent the root zone of the Anatolides nappes, then, the inner Taurides suture does not exist and the Kırşehir "block" is regarded as a core complex (Fayon et al., 2001). The pre-Late Triassic eo-Cimmerian phase of deformation is mainly recorded in the Taurus domain (Monod & Akay 1984) accompanied by major clastic input, unconformities and flysch like deposits (Gutnic et al. 1979), sealed by a Late Triassic widespread molassic event, followed by the development of the Late Triassic-Liassic carbonate platform, found on both domains. A similar evolution is also recorded in Greece and Iran (Krahl et al. 1983; Baud & Stampfli 1989; Stampfli et al. 2003; Bagheri et al. 2003). In these two regions, subduction of Palaeotethys is clearly towards the north, the Eurasian margin being the active margin

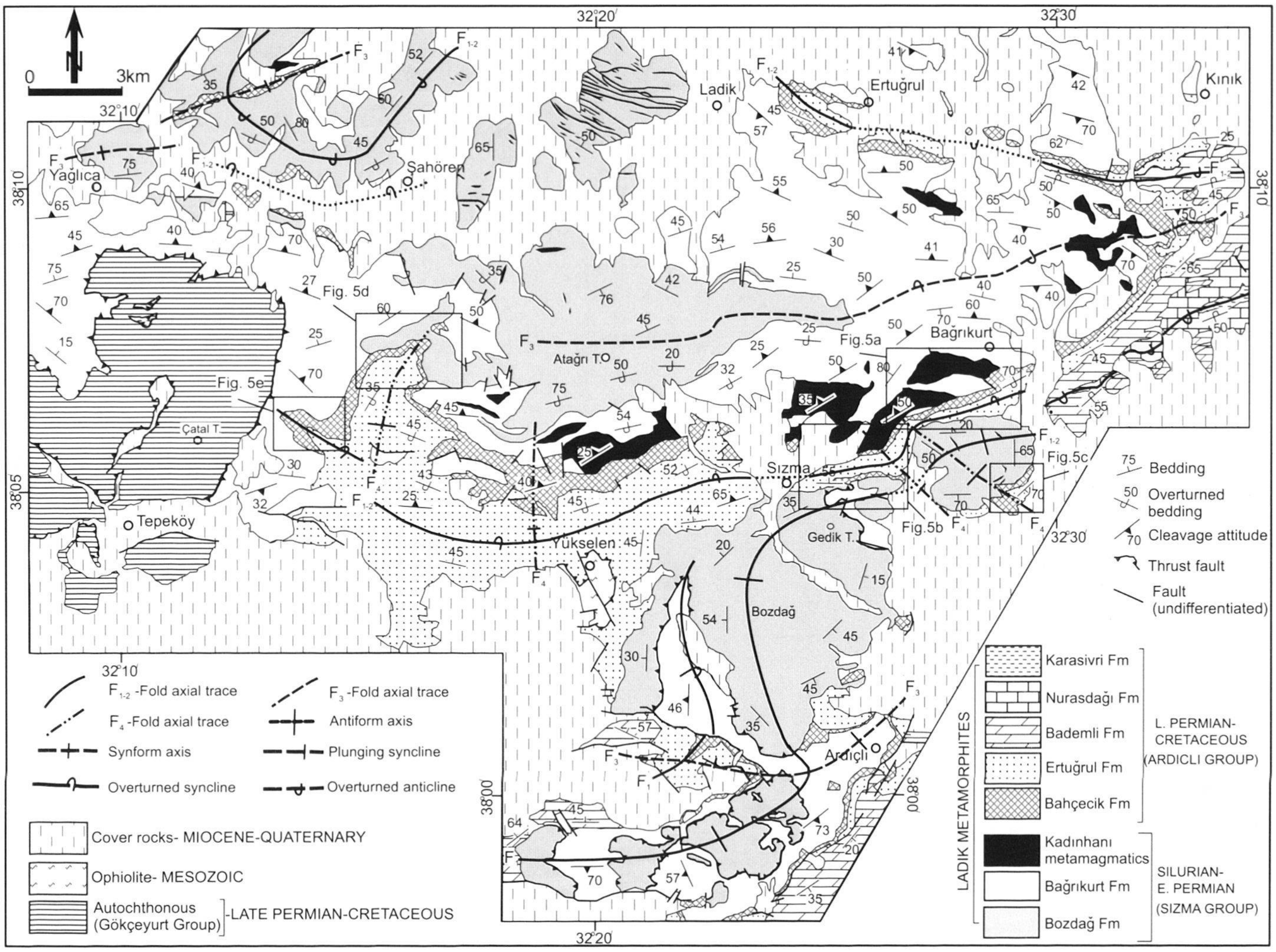

Fig. 2. Geological map of the studied area.

and the Cimmerian margins being passive. Although the eo-Cimmerian event has clearly been recognised in the Taurus, little is known on the location of the Palaeotethys suture, most likely largely subducted during the Alpine tectonic events, starting with a major Late Cretaceous ophiolitic obduction (Lycian type) covering most of the Anatolides region.

The rocks in the study area are considered to be a part of the Afyon and Tavşanlı Zones of Okay (1986) or the Kütahya-Bolkardağ Zone of Özcan et al. (1988), and belongs to the Anatolides block as defined above. The stratigraphic, magmatic and structural features of these rocks show that this part of the Anatolides was affected by Alpine as well as by the Palaeotethyan (Cimmerian) events. The purpose of this paper is to explain the stratigraphic, geochemical, and structural features of the study area, with an emphasis on the existence of the Late Palaeozoic deformation and magmatism in the region, and, to show that this area represents one of the few remnants of the Paleotethys suture zone.

Geological setting

The general stratigraphy of the region was outlined first by Wiesner (1968) and Göğer & Kıral (1969). Kaaden (1966) stated that these rocks underwent blueschist metamorphism due to the Variscan orogeny and Bayiç (1968) described sodic amphibole bearing magmatic rocks. Özcan et al. (1988, 1990) revealed that the rocks north of Konya displayed different features from the surrounding tectonic units. They also pointed out that these Palaeozoic rocks, forming the Hercynian basement of the region, evolved in a Late Carboniferous back-arc setting. Eren (1993a, 1993b, 1996 a, 1996b, 1996c, 2001) made a detailed mapping and study of the stratigraphy and structural features of the region and found several tectono-stratigraphic units, and included them into the Bozdağlar massif supergroup. Kurt (1994, 1996, 1997a, 1997b; Kurt & Eren 1998; Kurt & Arslan 1999) also investigated in detail the geochemical and petrological features of the area. According to these studies

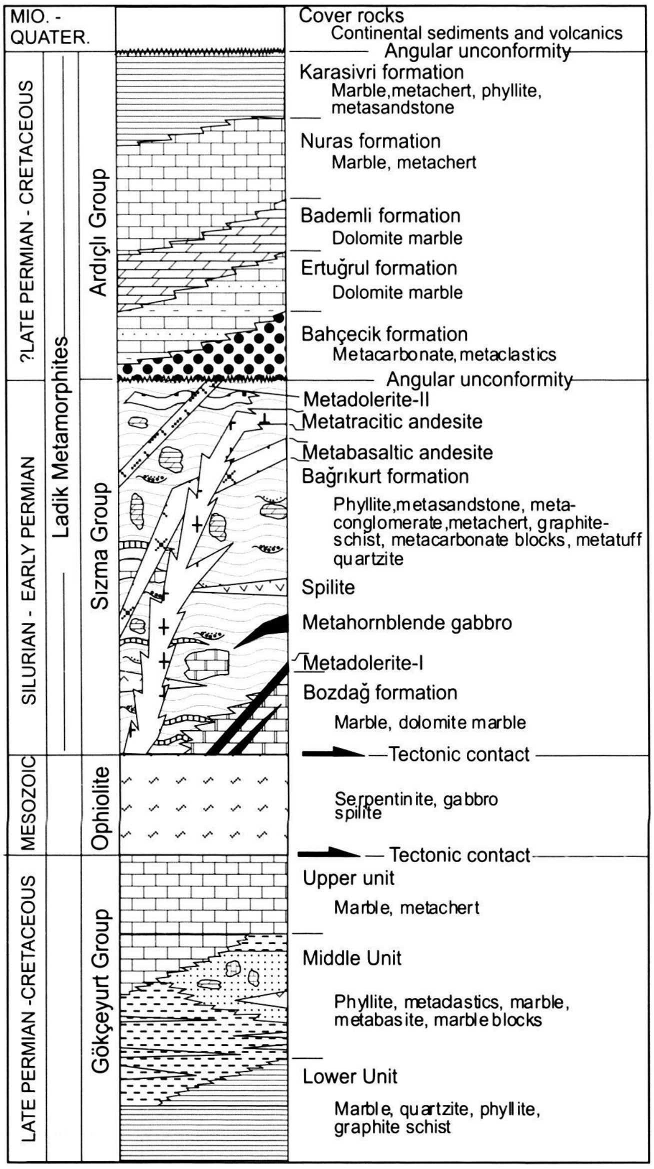

Fig. 3. Generalized tectono-stratigraphic section of the studied area.

the stratigraphy and geochemistry of the region can be given as follows.

In the study area, rocks forming the basement of the Bozdağlar massif can be structurally divided into three main units, from bottom to top: the autochthonous Late Permian-Cretaceous Gökçeyurt Group, the allochthonous Mesozoic ophiolite and the allochthonous Silurian-Cretaceous Ladik Metamorphites. The Late Miocene-Quaternary continental sediments and volcanics constitute the cover of these basement rocks (Figs. 2 and 3).

1: Gökçeyurt Group

The autochthonous or parautochthonous Gökçeyurt Group crops out in a tectonic half-window in the southwestern part of the area, and consists mainly of low-grade metamorphic rocks, representing an original shelf sequence. The Group is subdivided into three units.

The lower unit (dark gray-black recrystallized limestone, marble, graphite schist, phyllite and pink-white coloured quartzite) is very fossiliferous and contains fusulinids, algae, corals, crinoids and bivalvia indicative of a Late Permian (Murgabian) age (Eren 1993b).

These rocks pass gradually upwards into the varicoloured metacarbonate-metaclastic middle unit. It contains an olistostromal facies that include metacarbonate blocks mainly derived from the underlying unit. At this level, rare metabasite sills are present. Fusulinids in the metacarbonates of the lower part indicate a Late Permian age. Upwards the oolithic limestones of the unit contain foraminifera indicative of a Scythian to Anisian age (Eren 1993b).

The varicoloured middle unit is conformably overlain by the platform-type upper unit with thick limestones and dolomites, which have yielded Late Triassic to Cretaceous fossils (Göğer & Kıral, 1969; Özcan et al. 1990; Eren 1993b). West of Konya, the platform-type metacarbonates of the Gökçeyurt Group are conformably overlain by Late Cretaceous (Campanian) pelagic rocks (Göğer & Kıral, 1969).

2: Ladik Metamorphites

The Ladik Metamorphites of Silurian-Cretaceous age tectonically overlie both the Gökçeyurt Group and Mesozoic ophiolite. The Ladik Metamorphites include the Silurian-Early Permian Sızma Group, the Devonian-Early Permian Kadınhanı Metamagmatics and the ?Late Permian-Cretaceous Ardıçlı Group. The rocks of the Ladik Metamorphites were metamorphosed during the Alpine orogenic events (Eren 2001).

a- Sızma group

The oldest unit of the Sızma Group is the Bozdağ Formation which originally represented a shelf sequence with a reefal metacarbonate complex occurring as separated bodies or lenses with varying geometry. The Bozdağ Formation consists of light coloured marble and dark coloured (grayblack) laminated metadolomite and dolomitic limestone (Kurt & Eren 1998). The dolomite consists of wide spread Amphipora biostromes. Marble at the lower parts contains nautiloids, corals, brachiopods and conodonts of Late Silurian-Early Devonian ages (Wiesner 1968; Göncüoğlu et al. 2001); the middle part of the formation contains stromatoporoids, corals and crinoids indicative of a Middle-Late Devonian age and in its upper parts corals, fusulinids, algae and crinoids of Early Carboniferous age (Eren 1993a; Kurt 1994). These rocks pass laterally and vertically into the Bağrıkurt Formation, which is the most widespread unit in the region.

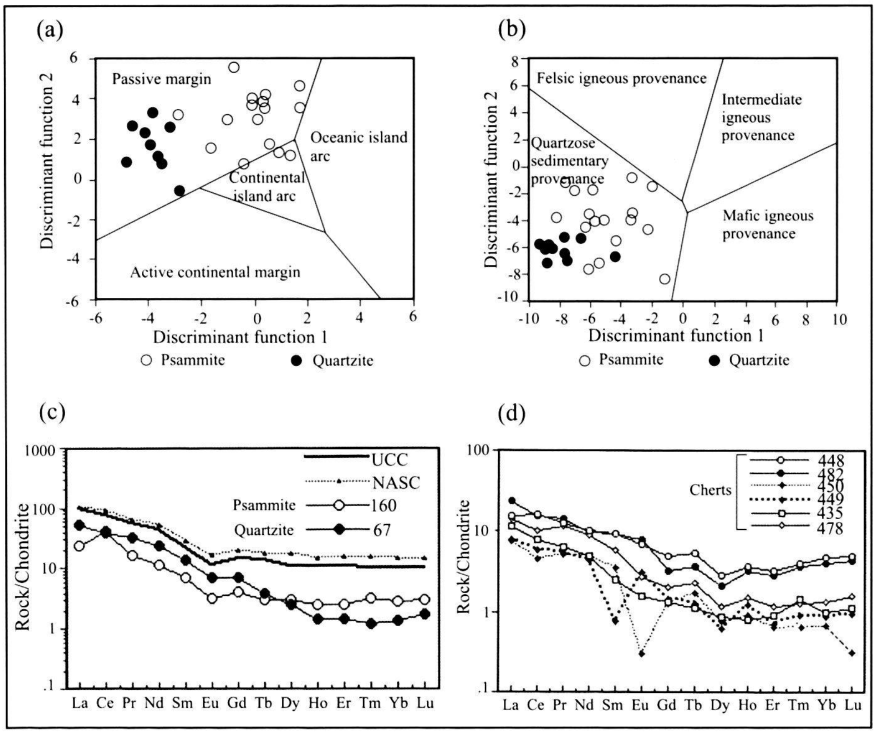

Fig. 4. **(a)** Plot of discriminant functions F1 and F2 (Bhatia, 1983) showing the position of psammites and quartzite from Devonian – Early Permian Bağrıkurt formation. **(b)** Plot of discriminant function F1 and F2 (Roser & Korsch 1988) showing the provenance of psammites and quartzite. **(c)** Chondrite normalised REE patterns for psammite (160) and quartzite (67) (UUC; upper continental crust, NASC; North American shale composition) (after Boynton 1984). **(d)** Chondrite-normalised rare earth element distribution patterns for metacherts from the Kadınhanı area. Chondrite normalising values from Boynton (1984).

The Bağrıkurt Formation is made up of an original shallow marine, continental margin and basinal facies. At the base, it begins with alternating units of calcschists, phyllites, metasandstones, metaconglomerates and metacherts. In some places metacherts occur at the boundary between the Bozdağ and Bağrıkurt formations alternating with the lithologies of both. At this transition zone, metacarbonates containing widespread crinoid fragments occur as lenses. The middle part of the Bağrıkurt Formation contains the metaclastic, radiolarian metachert and metavolcanic alternations with metacarbonate and metamagmatic blocks. The metacarbonate blocks or olistoliths vary in origin; some of them were derived from the Bozdağ Formation, while others have an unknown origin. They are mainly shallow-marine metacarbonates and contain corals, crinoids, nautiloids and brachiopods. Some of the blocks have pelagic characteristics. The metacarbonates in the middle part of the formation contain fusulinids and crinoids indicative of the Carboniferous. Fusulinids from metacarbonate blocks give a "middle" Carboniferous age. The metacarbonate intercalations at the upper part of the formation contain fusulinids, corals, trilobites, bryozoa and crinoids indicative of the Permian (Eren 1996b). The metaclastics show turbiditic features and their coarse clastic parts consist mainly of metachert and phyllite clasts derived from the formation itself. The upper part of the formation consists mainly of phyllites, metasandstones, metaconglomerates and quartzites. Locally, the upper part of the formation contains an alternation of metacarbonate, phyllite, graphite schist and metasandstone. The radiolarian metachert horizons are 1 mm to 20 cm thick, and are generally black. They are separated by thinner layers of phyllite or graphite schist. Because the metaclastics of the formation interfinger with the Devonian reefal rocks of the Bozdağ formation, Devonian to Early Permian age were assigned to the Bağrıkurt formation. The psammites and quartzites in the Bağrıkurt Formation have a passive continental margin origin and a quartzose sedimentary provenance is deduced (Figs. 4a, 4b; Table 1; Kurt 1996, 1997a). The psammites consist of quartz, calcite, muscovite and groundmass, which includes calcite, sericite, chlorite, quartz and accessory zircon, ilmenite, hematite and Fe-oxides. The quartzites consist of quartz, sericite, chlorite, albite, K-feldspar, tourmaline, zircon, magnetite, hematite with Fe-oxides in a granoblastic texture. The REE patterns from these rocks are quite similar to NASC (North American Shale Composition) and upper continental crust REE patterns rocks (Fig. 4c; Table 2), similar to cratonic sedimentary rocks. The general similarity of the REE patterns in the psammites and quartzites, variable LREE enrichment, Eu depletion and flat HREE reflect this sedimentary province. Some of the cherts in the Bağrıkurt Formation have been deposited in an environment similar to recent continental shelf slope environment (Fig. 4d; Table 2).

b- Kadınhanı Metamagmatics

The Kadınhanı Metamagmatic rocks comprise Devonian-Early Permian lavas, dikes, sills and blocks and include former

Table 1. The average of major oxides and trace elements for each rock types: Major oxides are in wt %, and trace elements are in ppm, bdl is below the detection limit.
1 – metatrachyandesite, 2 – metabasaltic andesite, 3 – metahornblende gabbro, 4 – metadolerite-II, 5 – metabasites, 6 – high-K metatrachyandesite, 7 – quartzites, 8 – psammites, 9 – metacherts, 10 – metapelites.

Sa.No	1	2	3	4	5	6	7	8	9	10
SiO_2	57.4	53.9	52	52.1	55.3	56.19	93.31	82.00	93.08	65.2
TiO_2	0.1	0.7	1.3	1.4	0.51	0.71	0.20	0.38	0.07	0.81
Al_2O_3	15.0	15.4	14.6	15.6	13.5	14.55	1.91	6.60	1.38	16.8
FeO	3.3	4.8	7.0	7.1	3.6	2.04	0.72	0.84	0.26	3.4
Fe_2O_3	3.6	5.4	5.1	2.5	5.4	3.16	0.96	2.82	2.00	4.0
MnO	0.1	0.2	0.2	0.1	0.16	0.09	0.05	0.07	0.02	0.79
MgO	4.3	4.0	5.5	6.5	4.1	1.86	0.20	0.63	0.37	1.59
CaO	4.4	5.2	6.7	5.1	6.6	4.23	0.70	1.10	0.30	0.22
Na_2O	2.6	3.2	3.1	2.9	1.9	0.37	0.60	1.00	0.28	1.05
K_2O	5.1	2.5	1.1	2.4	1.3	9.01	0.70	1.42	0.29	3.04
P_2O_5	0.6	0.3	0.2	0.2	0.2	0.55	0.02	0.05	0.04	0.11
CO_2	0.2	0.4	0.4	0.4	0.5	0.00	0.00	0.60	0.07	0.55
H_2O	2.6	2.8	2.4	2.7	3	6.04	1.49	2.06	0.3	2
TOTAL	99.7	99.0	98.7	98.8	98.3	98.61	98.95	98.90	98.48	98.1
Cr	200	88	103	337	230	165	81	145	100	146
Co	20	22	31	42	29	14	5	9	4	21
Ni	36	13	18	85	69	22	6	18	8	72
Cu	40	94	22	40	117	76	3	14	5	31
Zn	74	120	92	90	67	30	16	39	6	85
Ga	19	16	15	18	14	17	2	8	1	20
Rb	185	51	14	30	26	259	9	76	16	05
Sr	600	193	219	198	308	256	14	52	29	76
Y	19	20	36	21	26	22	12	15	8	30
Zr	256	121	105	111	107	243	155	169	31	189
Ba	2156	973	147	234	162	2659	64	289	285	423
La	27	12	5	5	14	75	14	18	3	30
Ce	1	1	bdl	1	32	158	21	31	13	55
Pb	31	14	4	4	6	16	9	12	13	8
U	53	59	3.7	15	0	9	0	2	2	0
Nb	15	9	7	12						
Th	125	122	9.8	33	5	55	6	7	1	12

meta-hornblend-gabbros and related metabasites, spilites, meta-dolerites, meta-basaltic-andesites, meta-trachyandesites and meta-tuffs. The meta-hornblend-gabbro was observed as blocks (Eren & Kurt 1998) in the metaclastics of the Bağrıkurt formation. The metabasites (Metadolerites-I) occur as dike swarms that cut Silurian-Devonian marbles of the Sızma Group west of Ladik and east of Sızma villages (Fig. 2 and 3). The lengths of the dikes range from 50 m to 3 km and their thickness varies between 1 to 75 m. Metaspilites with pillow structures crop out north of the Bağrıkurt village. A few meta-dolerite dykes (Metadolerite -II) vary in width from 1 – 3 m, and cross the Bozdağ formation. The meta-trachy-andesite and high-K meta-trachy-andesite are seen in the northwest part of the study area as lava flows between the metaclastic rocks. It is more common near the Kadınhanı town (Kurt 1996; Kurt & Arslan 1999). The metatuff interlayers occur commonly in the middle part of the Sızma Group in various thicknesses. They are seen as mappable units between the Bağrıkurt and Meydan villages. As described above, the Kadınhanı metamagmatics can be observed as lava flows, sills, pyroclastics in the metasedimentary rocks of the Silurian – Early Permian Sızma Group. Also the dikes of the Kadınhanı magmatics cut the Silurian-Early Carboniferous metacarbonates. These magmatic bodies and dikes were truncated and covered by ?Late Permian-Early Triassic coarse clastics of the Ardıçlı Group (Figs. 2, 5a, 5b, 5c). Also, these coarse clastics contain pebbles and clasts of the magmatic rocks. For these reasons, a Devonian to Early Permian age was assigned to the Kadınhanı metamagmatics.

Table 2. Rare Earth Element data for each rock types: metatrachyandesite (227a, 323), metabasaltic andesite (277, 408), metahornblende gabbro (337, 344), metadolerite-II (417, 414), quartzites (67), psammites (160) and metacherts (448, 482, 449, 450, 435, 478). REE are in ppb.

sam. No	448	482	449	450	435	478	160	67	227a	323	277	408	337	344	417	414
La	15.4	23.7	7.8	7.5	11.6	14.3	7.4	16.8	53.1	52.0	80.6	36.1	2.9	4.5	18.2	11.9
Ce	16.3	15.4	5.8	4.5	7.7	10.0	33.0	31.8	116.3	134.5	159.6	85.0	7.8	11.8	39.6	27.2
Pr	12.8	14.0	5.4	5.2	6.4	11.5	2.0	4.1	13.9	15.7	17.3	9.4	1.3	1.8	4.8	13.3
Nd	9.9	9.8	4.3	5.0	4.8	8.8	6.9	14.3	52.5	57.0	63.0	37.2	6.3	9.0	19.1	13.7
Sm	9.5	9.2	0.8	3.6	2.5	5.9	1.4	2.8	9.4	9.8	11.9	7.8	2.0	3.3	4.1	3.3
Eu	6.9	7.7	3.1	0.3	1.6	2.7	0.2	0.5	2.0	2.8	3.0	2.5	0.8	3.2	1.5	1.3
Gd	1.0	1.6	0.4	0.4	1.5	0.5	1.2	2.1	7.1	7.6	9.4	6.8	2.6	3.9	4.0	3.7
Tb	5.4	3.6	1.3	1.9	1.1	2.3	0.2	0.2	0.8	0.9	1.1	0.9	0.5	0.6	0.6	0.6
Dy	2.8	2.1	0.6	0.8	0.9	1.2	1.0	0.8	4.4	4.4	5.7	4.4	3.0	4.3	3.3	3.3
Ho	3.7	3.2	3.6	0.9	0.8	1.5	0.2	0.1	0.7	0.7	0.9	0.7	0.6	0.8	0.6	0.6
Er	3.2	2.9	0.7	0.7	0.9	1.2	0.6	0.3	1.9	1.9	2.5	2.0	1.8	2.5	1.4	1.6
Tm	4.0	3.7	0.9	0.6	1.4	1.3	0.1	0.5	0.3	0.2	0.3	0.3	0.3	0.3	0.2	0.2
Yb	4.6	4.1	0.9	0.7	1.0	1.4	0.6	0.3	1.6	1.6	2.1	1.7	1.7	2.2	1.1	1.4
Lu	5.0	4.3	0.9	0.3	1.1	1.6	0.1	0.1	0.2	0.2	0.3	0.2	0.3	0.3	0.1	0.2

c- Ardıçlı Group

The Sızma Group and Kadınhanı Metamagmatics are overlain by the ?Late Permian-Cretaceous Ardıçlı Group. The Ardıçlı group, at its base, covers the different units of the Sızma Group and the dikes, sills and stocks of the Kadınhanı magmatics end at this boundary (Figs. 2 and 5a-e). These demonstrate the existence of an angular unconformity between the Ardıçlı Group and the underlying older units. This group consists of a transgressive sequence that from bottom to top, contains five different formations which all interfinger. The continental Bahçecik Formation is present at the base of Ardıçlı Group, and is composed of violet to red phyllites, metasandstone and metaconglomerates. The metaconglomerates mainly contain rock fragments derived from the Sızma Group and the Kadınhanı metamagmatics. Some of the clasts with unknown origin are more metamorphosed than other clasts and matrix of the metaconglomerates. This feature shows the existence of a metamorphosed source before the deposition of the rocks of the Bahçecik formation. No fossils have been found in this unit.

The Ertuğrul Formation formed by alternating units of phyllites, metasandstones, calcschists and yellow-gray and black metacarbonates interfingering with the Bahçecik Formation. Özcan et al. (1988), have found Early Triassic foraminifera and conodonts in the metacarbonate at the lower part of the Ertuğrul formation. Besides this, the Bahçecik and Ertuğrul formations are equivalent in age and in lithology to the middle part of the autochthonous Gökçeyurt Group. For these reasons ?Late Permian to Triassic ages were assigned to both the Bahçecik and Ertuğrul formations.

These rocks pass gradually into gray and black metadolomites of the Bademli Formation. According to the foraminifera and algae from similar rocks in the west of Konya (Göğer & Kıral 1969), the age of the formation is Triassic-Early Jurassic. This unit also grades laterally and vertically into the Late Triassic-Cretaceous Nuras Formation (Karaman, 1986), which is made up of a thick sequence of light coloured marbles. The youngest formation of the Ardıçlı Group is the Late Cretaceous Karasivri Formation that consists of pelagic, thin-bedded metacherts, metacarbonates, phyllites and metasandstones. The upper parts of the Ardıçlı Group are equivalent in age and in lithology to the upper parts of the autochthonous sequence (Gökçeyurt Group).

Petrography and geochemistry of magmatic rocks

In the metatrachyandesite, former primary minerals like plagioclase, diopsite, sanidine, actinolite, quartz and accessory magnetite, sphene and apatite are preserved as relics, whereas actinolite, ferro-winchite, winchite, magnesio-riebeckite, crossite, calcic ferro glaucophane, albite, epidote, sericite, paragonite, margarite, chlorite, pumpellyite, quartz and calcite represent the products of metamorphic overprint (Fig. 6; Kurt 1996). The metabasaltic-andesite crops out north of the Sızma village with east-west trends. At some localities, it is parallel to the lithological layering of the metaclastic rocks. The metabasaltic-andesite includes primarily minerals like plagioclase, augite, biotite, actinolite, accessory sphene, apatite, magnetite and quartz. The metamorphic minerals in these rocks are epidote, chlorite, stilpnomelane, actinolite, ferro-glaucophane, calcite and sericite. All the primary plagioclase is albite containing epidote and sericite. The augite microphenocrysts and phenocrysts are generally replaced by green metamorphic actinolite or ferro glaucophane and also include calcite, chlorite, epidote and amphibole (Fig. 6). In the metahornblende-gabbro, primary minerals are plagioclase, magnesio- and ferro-hornblendes, actinolite, mica, augite, quartz, orthoclase, and

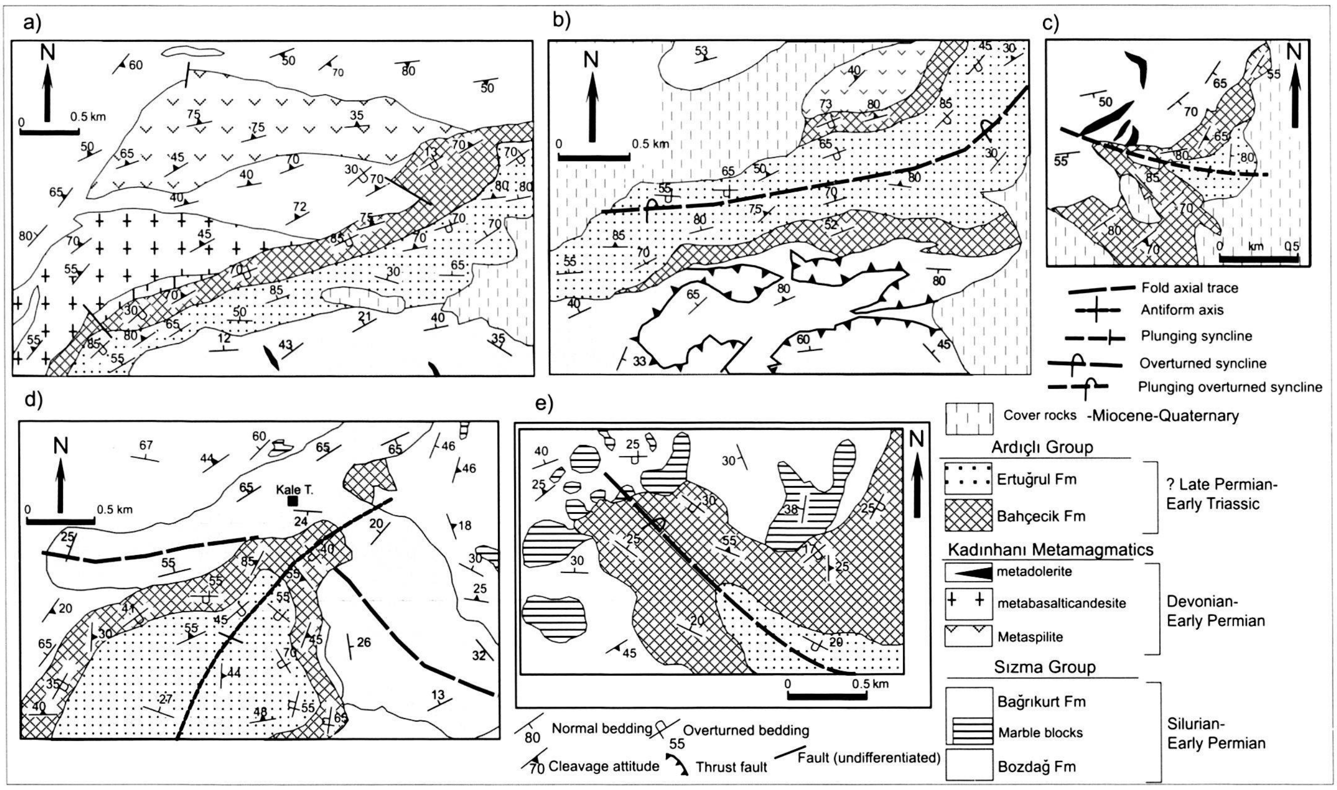

Fig. 5. Detailed geological maps of selected areas discussed in the text (for location see Figure 2)

accessory magnetite, sphene and apatite, whereas actinolite, winchite, ferro-winchite, crossite, chlorite (diabanite, phenochlorite and ripidolite), epidote, calcite and muscovite (paragonite and margarite) represent the products of metamorphic overprint. Plagioclase is saussuritized, epidotized and sericitied. Magnesio- and ferro-hornblendes were replaced by actinolite, winchite, ferro-winchite, crossite, chlorite and epidote (Fig. 6). The metadolerite primarily consists of plagioclase, augite, accessory minerals like ilmenite, magnetite, sphene and apatite. The metamorphic minerals are sericite, chlorite, calcite and epidote.

Geochemical data indicate that the meta-igneous rocks are of a sub-alkaline (tholeitic and calcalkaline) type (Fig. 7a; Table 1). Immobile element discriminant diagrams show that the metatrachyandesites and the metadolerites have within-plate characteristics, and the metabasalticandesites have arc characteristics, but the metahornblende gabbro and related metabasites have MORB-like features (Fig. 7b; Table 1; Kurt 1996; Eren & Kurt 1998). The geochemical characteristics of the metahornblende gabbros are illustrated on N-MORB normalized patterns (Fig. 7c; Table 1) which demonstrate that the gabbros are similar to tholeitic N-MORB but relatively enriched in K,Th, Rb, Ba, Nb and depleted in Ce and Ti.

The metadolerites are enriched in Rb, K, Ba, Th, Ce, P and Nb and depleted in Ti and Y relative to MORB, being calc-alkaline as indicated by enrichment in K, Rb, Ba, Nb, Ce, P, Zr, and Ti compared with the tholeitic metahornblende gabbros with MORB -normalized patterns (Fig. 7c). The metatrachyandesite and metabasaltic-andesite have similar REE patterns and N-MORB normalized profiles, strongly suggesting a similar origin (Figs. 7c, 7d and Table 2) but the two rocks are not related via crystal fractionation as this conflicts with the REE pattern of the metabasaltic andesite. The metahornblende gabbros have flat REE patterns and compositional data suggesting derivation from a source similar to a mid ocean ridge type parent (Fig. 7d; Table 2).

The metavolcanics show similarities in chemical composition and tectonic setting, and are probably subduction related. They were derived from very similar enriched continental source regions and their incompatible element contents do not imply significant differences in melting as both types show marked enrichment in most incompatible elements (LILE, LREE) compared to N-MORB (Fig. 7c). Thus, they form a genetically related comagmatic suite. The geochemistry as a whole indicates that the metavolcanics may have been derived from a subcontinental lithospheric source enriched in LIL and HFS elements. However, the metadolerites and metahornblende gabbros show that they have probably been derived from different magmatic sources. The metadolerite has a higher Ni (56–119 ppm), Cr (150–516 ppm) and Mg number

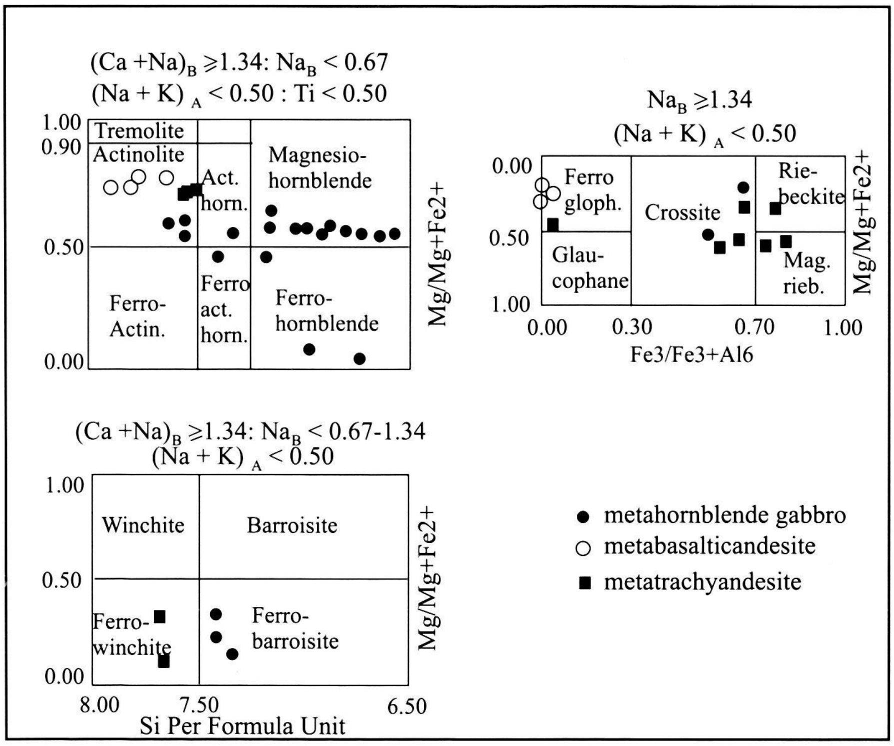

Fig. 6. Classification of amphiboles (after Leake 1978).

(25.6–31.4) compared to the metahornblende gabbros, which have low Ni (5- 53 ppm), Cr (0–294 ppm) and mg number (33.3–61.3). The combination of lower Ni+Cr with higher Mg is only compatible with two different and unrelated magmas. The low contents of Nb and other elements with high ionic potential in the metahornblende gabbro may be the result of their retention in residual phases stable in a hydrated mantle source region (Kay 1977; Pearce 1982). The metadolerite parental magma had a source similar to subduction related lavas in a continental margin environment, involving a mix of subcontinental lithosphere and subduction components.

The normalized incompatible element patterns (Fig. 7c; Table 1) of the calc-alkaline continental metadolerites are enriched in K, Rb, Ba, Nb, Ce, P, Zr and Ti, compared with the tholeitic oceanic metahornblende gabbros. These characteristics may be due to the involvement of subcontinental lithosphere in the magma genesis (Pearce, 1983). Furthermore, both upper mantle (subcontinental lithosphere) and subduction components can be identified in the incompatible element patterns of the metadolerite from continental margin environments (Watters & Pearce 1987).

Deformation and metamorphism

The autochthonous and allochthonous metamorphic rocks in the study area have been subjected to at least four phases of deformation and ductile folding (F1, F2, F3, F4) during the Alpine crustal shortening (Eren 1996a; Eren 2001). These intense and polyphased Alpine deformations overprinted and obliterated Cimmerian structures of the Sızma group. But some structures show the existence of Late Palaeozoic deformations in the region. One of these structures occurs in the south of the study area. There, metasedimentary rocks of the Sızma Group were sliced internally, the metacarbonates of the Sızma Group being thrusted over the metaclastic parts (Figs. 2 and 5b). At these boundaries, brecciated zones up to 1 m thick including rock fragments from both the underlying and overlying rocks, can be observed. These thrusts do not extend into the Ardıçlı Group, but are covered by coarse clastics of the Ardıçlı Group (Figs. 2 and 5b), indicating that tectonic slicing of the Sızma Group developed before the Early Triassic times (? before or during the Late Permian). The other eo- Cimmerian structure is the folding of the Sızma Group. In the middle part of the study area (about 5 km west of the Atağri T.; Figs. 2 and 5d), the marbles and metaclastics of the Sızma Group were folded isoclinally. The east-west trending axial trace of this fold is also covered unconformably by the basal clastics of the Ardıçlı Group showing the existence of the folding event prior to the depositions of the Ardıçlı Group. But polyphased and severe Alpine deformations made impossible the accurate mesoscopic analysis of these structures. In the study area, the Alpine Orogeny generated the map scale folds. Both Late Palaeozoic and Mesozoic rocks were deformed by these Alpine folding events. The main map-scale fold structures that

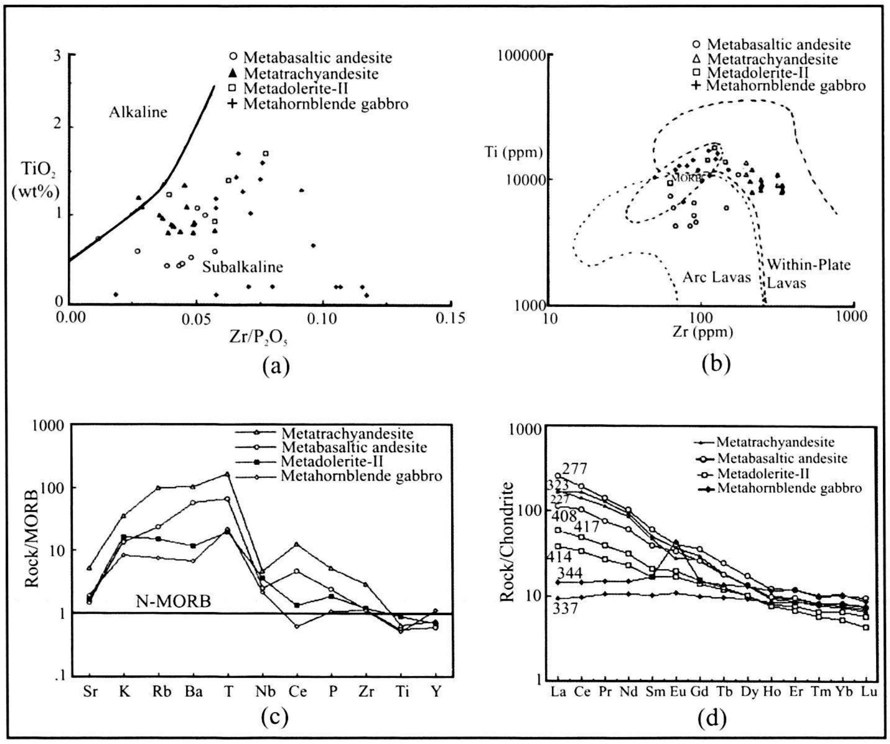

Fig. 7. (**a**) Zr/P2O5 versus TiO2 plot used to reveal the magma type. Field boundaries from Floyd & Winchester (1975) and Winchester & Floyd (1976). (**b**) Ti vs. Zr plot for the meta-igneous rocks of the Kadınhanı area. Field boundaries from Pearce (1982) and Pharaoh & Pearce (1984). (**c**) MORB-normalized incompatible element patterns for averages of the meta-igneous rocks. Normalizing values are as cited in Pearce (1982). (**d**) Chondrite-normalized rare earth element patterns for meta-igneous rocks. Chondrite normalizing values are from Boynton (1984). All analytical data are derived from Kurt 1996 and 1997.

dominate in the north of the study area are the Ertuğrul Syncline and Meydan Synform (Eren 2001). In the south, the doubly plunging Gediktepe Anticline is another major fold structure. The Ertuğrul Syncline is a F1- fold structure, and it can be traced over 45 km in the study area. Due to subsequent folding, the fold hinges and axial surfaces of this mega fold show a wide variation in orientation (Eren 2001). The Meydan Synform is a Type 2 refolded fold structure, which developed as a superposition of the F3- folding over the F1- folding. The metacarbonates, the oldest formation in the area, crop out in the core of the synform, and the other units of the Sızma Group and the Ardıçlı Group occur on its limbs. The F1- and F3- map scale folds were deformed by the F4- folds (Fig. 2). The Gediktepe anticline is a doubly plunging anticline, produced by the F1- folding event. The Sızma Group crops out in the core of this fold, whereas the rocks of the Ardıçlı Group occur on its limbs. The anticline has a mean NW-SE axial trace orientation, and plunges to the northeast in the east, and to the west in the west. The east- west trending F3- and north-south trending F4- map scale folds deformed the anticline. The Ardıçlı Group generally occurs in the cusp shaped synclines, whereas the Sızma Group crops out in the more wide and rounded dome-type structures in the region (Figs. 2 and 5c). This indicates that the rocks of the Sızma Group behaved more competently than those of the Ardıçlı Group during the Alpine deformation. The mesoscopic features of the above mentioned Alpine folding events could be outlined as follows. The first phase of folding (F1) produced isoclinal, recumbent folds and a penetrative cleavage (S1) under high-P/low-T metamorphic conditions caused by the Late Cretaceous ophiolite obduction. The S1- penetrative cleavage developed axial planar to these folds. The F2 folds are tight to close and contain an S2 axial planar crenulation cleavage. The F1 and F2-fold hinges are nearly parallel and superposition of these folds developed a Type 3 fold interference pattern (Ramsay 1967) on a mesoscopic scale. The third phase of deformation (F3) overprinted earlier structures and produced map scale Type-2 refolded folds. F3- phase structures developed a S3 crenulation cleavage and monoclinal and conjugate kink folds. The fourth deformation phase (F4) generated monoclinal (conjugate) kink folds on various scale and an S4- crenulation cleavage, similar to those of the F3- phase, but the F4- fold hinges are developed nearly orthogonally to F3- folds. The absence of any metamorphic mineral growth parallel to the S3- and S4- cleavage planes indicates that F3- and F4- phases were post metamorphic. The F1- and F3- deformational phases represent the major folding phases in the region. The above mentioned deformation history is the same both in the autochthonous Gökçeyurt Group and in the allochtohonous Sızma Group, but the intensity of deformation increases eastward in the region.

Data from hornblende-plagioclase geothermometers suggest that the temperature during metamorphism was about 521(±75)–482 (±75) °C, and a pressure about 3–6 Kbar for metahornblende gabbro, 431(±75)–400(±75) °C and a pressure about 5–7 Kbar for the metabasaltic andesite and 426 (±75)–395 (±75) °C and a pressure of about 5–7 Kbar for the metabasites (Kurt, 1994, 1996, 1997a). These estimates are based on Blundy & Holland's (1990) plagioclase-hornblende geothermometer. The common association with quartz + muscovite + chlorite + chloritoid in the study area is thought to have been produced by reactions similar to those proposed by Seidel et al. (1975). These mineral assemblages are indicative of metamorphic conditions in excess of 4–5 Kbar at 380–400o C. The albite (Ab99to95) component of the plagioclase is very high, which agrees with low temperatures. In the metatrachyandesite winchite + ferro-winchite + ferro-glaucophane + crossite + riebeckite + magnesioriebeckite + pumpellyite + chlorite + epidote + actinolite + quartz assemblage indicates metamorphic conditions near to 5–7 Kbar at 380–400 °C (Kurt 1994, 1996, 1997a).

Geological investigations by Okay (1986) in the north of the Menderes Massif and in the Afyon-Bolkardağ Belt suggest that the greenschist and the blueschist metamorphisms appear to have been completed before Late Cretaceous time, but the youngest rocks affected by metamorphism in the study area are Campanian in age. Therefore, the age of the metamorphism should be early Maastrichtian in the studied region, as Maastrichtian to Paleocene strata are usually trangressive on the obducted ophiolites and related mélanges in many areas of central Anatolia (e.g. Bolkar, Tuz Gölü basin, Demirtaşlı et al. 1984).

Tectonic evolution

Our observations show that part of the lithologies of the Sızma group (reef complex, quartzites, psammites and pelagic rocks) plead for a passive margin setting, whereas others (metabasaltic andesites, turbidites, olisthostromal rocks and pyroclastics) plead for an arc-forearc setting. We, consequently, interpret the Sızma group as characterising a fore-arc setting, recycling pelagic-oceanic material from an accretionary prism on one side (black lydites, MORB-type blocks) and from the arc-continent on the other side.

Lithological and palaeontological features of the Bozdağ Formation, the oldest formation in the region, show that it was deposited during Silurian-Early Carboniferous time as a carbonate shelf sequence and some part as a reef complex, including reefcore, backreef and forereef facies. Some reefal marbles in the Bozdağ formation have lenticular shapes interfingering with pelagic rocks of the Bağrıkurt formation and are cut by meta-dolerites with a MORB-like source. The relations between these marbles and pelagic, continental margin rocks of the Bağrıkurt Formation show that these carbonates were developed as carbonate buildups and/or patch reefs on a continental margin and also possibly on mid-oceanic highs and ridges. All these data and the geochemical characteristics of the metahornblende gabbro indicate an Atlantic-type continental margin in the area during the Devonian as found in most units of the Hun superterrane southern margin at that time.

The Bağrıkurt Formation contains turbiditic sediments, olistostromal facies and pyroclastic material, at the middle and upper levels. All these rocks are intruded by calc-alkaline and continental arc magmatic rocks (metabasaltic-andesites). These data suggest that the passive continental margin became an active continental margin. Beginning before Late Carboniferous times, oceanic lithosphere was subducted and the evolution of a magmatic arc was initiated. Therefore, the studied region represents a typical continuation of similar active margin domains found in the Hellenides-Dinarides or the Carnic Alps. During the subduction, the pelagic rocks and the metahornblende gabbros were accreted to the continental margin. Large amounts of metamorphic rock fragments, K-feldspar, plagioclase and volcanic quartz fragments in the metapsammitic rocks in the Bağrıkurt Formation (Eren 1993a; Kurt 1994), indicate that the magmatic arc grew above sea level during the Late Carboniferous (Eren 1996b; Kurt & Arslan 1999) and was subject to erosion providing a source for the psammitic rocks in the Bağrıkurt formation. While the subduction process continued, orogenic activity on the continental active margin was in progress and resulted in the deposition of olistostromal type series of the Bağrıkurt Formation, after which, shallow-marine conditions returned, with the deposition of limestones with bryozoans and trilobites remnants.

Late Permian(?)-Early Triassic basal clastics of the Ardıçlı Group rest with an angular unconformity on the above mentioned rocks and contain their clasts. This indicates that all the rocks in the Sızma Group were subsequently deformed, uplifted and eroded. Then, by ?Late Permian-Early Triassic times, continental coarse clastics of the Bahçecik Formation were deposited on the Sızma Group as alluvial to sub-marine fans. The Ardıçlı Group units laterally interfinger with each other (Özcan et al. 1990; Eren 1993b), and it suggests that marine conditions prevailed in the area and alluvial fan and fluvial sediments passed laterally into shallow sea and lagoonal sediments found in the upper part of the sequence. These relations indicate that the continental Bahçecik and shallow-marine Ertuğrul formations sealed the uplifted fore-arc rocks of the Bağrıkurt Formation.

The general evolution of the study area can be placed in a larger geodynamic scheme as exposed in the introduction and based on the proposals of Stampfli (1996, 2000), Stampfli et al. (1991, 2001a and b, 2003), Stampfli & Borel (2002; 2004) and von Raumer et al. (2002). In that model the Palaeozoic sequence as exposed in the Bozdağ formation represents the northern passive margin of Palaeotethys. As observed in many other areas, this passive margin became an active margin during the Late Devonian. Then an arc and fore-arc environment developed, represented by the Bağrıkurt formation, resting on the previous carbonate platform of the passive margin, and/or on its accreted fragments. The fore-arc sequence recycles elements from the former passive margin together with blocks of black lydites derived from the Palaeotethys accretionary prism.

The following event affecting the Palaeotethys active margin was the Permo-Triassic general collapse of the Variscan

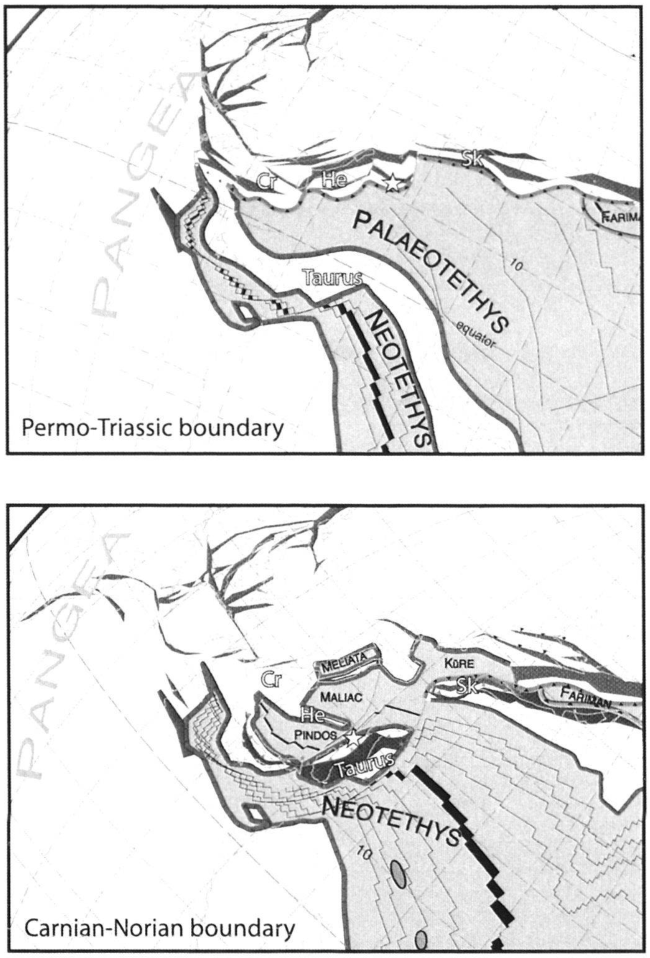

Fig. 8. Reconstructions of the western Tethyan realm in the Triassic, modified from Stampfli & Borel (2004). The star symbol represents the studied area; Cr, Carnic Alps, He, internal Hellenides (mainly Pelagonian), Sk, Sakarya. Dark stippled areas are rifts, white stippled areas are foreland basins. The main Pangea landmass is not changing its geometry during the Permo- Triassic period, but roll-back of the Paleotethys slab opened numerous back-arc basins within the Eurasian margin (Meliata, Küre, Maliac, Pindos), detaching elements of the Variscan cordillera from the mainland (e.g. the studied area). On the other hand, slab pull forces of the same Paleotethyan slab detached the Cimmerian terrane (e.g. Taurus and Iranian blocks) from Gondwana and induced the opening of Neotethys. The docking of the Cimmerian and Variscan elements took place in the Carnian, and the Cimmerian deformation are usually sealed by Norian or younger carbonate platforms.

cordillera in the Mediterranean domain (Ziegler & Stampfli 2001; Stampfli et al. 2002, 2003), characterized by the opening of Triassic back-arc oceans such as the Maliac-Meliata, Küre and Pindos basins. The Bahçecik and Ertuğrul formations can be seen as representing syn-rift deposits of such Triassic back-arc basins, as recognized in Greece and in Karaburun (Rosselet & Stampfli 2002; Stampfli et al. 2003), with which they have many common characteristics.

The middle part of the Gökçeyurt Group, which is the equivalent of the lower parts of the Ardıçlı Group, is partly composed of turbidites, metacarbonate blocks, rare metabasite intercalations and dolerite dykes. All these rocks indicating that the continental active margin started to be broken and foundered during Early-Middle Triassic time. The deposition of clastic sediments within this environment was reduced in time and platform type thick carbonates, belonging to Bademli and Nuras formations, were deposited, characterizing the Late Triassic passive margin stage of the back-arc basin. Pelagic and turbiditic rocks of the Karasivri Formation were gradually deposited on the continental shelf carbonates, due to continued thermal subsidence.

The geological evolution in the region during the Cretaceous and later time was explained in detail by Oktay (1982), Görür et al. (1984) and Özcan et al. (1988, 1990), the Late Cretaceous deepening corresponding to the flexure of the margin during the arrival of the ophiolitic nappes.

Conclusions

Data obtained in the investigated region indicate the existence of the Palaeotethys ocean at least from Devonian to Permian times. The oceanic domain was located between the Cimmerian Menderes-Taurus block and the Konya region belonging to the Eurasian active margin of this ocean. The subduction of the Palaeotethys beneath the Konya region (fig. 8), constructed an active continental margin and magmatic arc flanked by a fore-arc basin from the Late Devonian to the Early Permian. The fore-arc complex was uplifted before the Early Triassic (?Late Permian), then the Konya block and its attached accretionary units collided with the Menderes-Tauride block. This eo- Cimmerian docking event is well recorded by deformation and clastic deposits found in the middle to Late Triassic sequences of the Taurus domain. This was accompanied by the opening of a Triassic back-arc basin of Maliac-Küre type in the active Eurasian margin, due to accelerated Palaeotethyan slab roll-back (fig. 8). The typical lower to middle Triassic syn-rift deposits of the back-arc southern margin are characteristic of the Anatolide domain. Therefore, a Palaeotethys suture zone should be present between the Konya Anatolide region and the Tauride platform, a westward continuation of the Palaeotethys suture described in Karaburun and Greece (Stampfli et al., 2003), or eastward in Iran. This cryptic suture was buried under the major Late Cretaceous ophiolitic obduction on the Anatolian block, and only some of its elements were scrapped off and emplaced at the sole of the ophiolitic nappes, as found in the Konya region. Later Alpine shortening emplaced these units onto the Taurus platform, their root zone was then largely subducted under the Pontides.

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