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Geology and Geochemistry of the Pre-early Cambrian Rocks in the Sandikli Area: Implications for the Pan-African Evolution of NW Gondwanaland

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Abstract

The pre-Early Cambrian Sandikli Basement Complex in western Central Anatolia comprises a low-grade meta-sedimentary succession (Güvercinoluk Formation) and meta-rhyolites intruded by meta-quartz porphyry rocks (Kestel Cayi Porphyroid Suite). The Güvercinoluk Formation consists of alternation of meta-siltstones and meta-sandstones with olistostromal conglomerates, rare black chert and cherty meta-dolomite lenses. The Kestel Cayi Porphyroid Suite is a deformed, highly sheared dome-shaped rhyolitic body with quartz porphyry rocks. Quartz porphyry dykes intrude both the volcanic carapace and the meta-sedimentary rocks of the Güvercinoluk Formation. Both the meta-quartz porphyry rocks and meta-rhyolites are typically mylonitic with relict igneous textures. Geochemical data indicate that the felsic rocks of the Kestel Cayi Porphyroid Suite are subalkaline and display characteristic features of post-collisional, I-type granitoids. The basement complex is unconformably overlain by variegated conglomerates, mudstones and arkosic sandstones with andesitic lavas, followed by siliciclastic rocks and carbonates that yielded Early Middle Cambrian fossils.

Based on the geochemical characteristics of the felsic rocks of Kestel Cayi Porphyroid Suite and the depositional features of the associated sediments it is suggested that the Sandikli Basement Complex is related to a post-collisional extension event in NW Gondwanaland. Similar occurrences elsewhere have been related to a transition from continental plate convergence to continental plate divergence along the Pan-African Belt.

Key words: Late Pan-African, I-type granitoids, NW Gondwanaland, Turkey, Taurides.

Introduction

The Tauride Belt, located in southern Turkey (Fig. 1), is an Alpine unit, which has been considered as the northern part of Gondwanaland (e.g., Dean et al., 2000) or as one of the Perigondwanan terranes (e.g., Göncüoglu, 1997; Cocks, 2001). It has been mainly affected by the Pan-African, Variscan(?) and Alpine orogenies (for a brief review see Göncüoglu et al., 1997).

The Tauride Belt includes a low-grade metamorphic basement intruded by felsic igneous rocks, both in the eastern (Kozlu and Göncüoglu, 1997; Göncüoglu and Kozlu, 2000; Bozkaya et al., 2002, 2003) and western Taurides (Öngür, 1973; Gutnic et al., 1979; Kröner and Sengör, 1990; Özgül et al., 1991a, b; Dean and Özgül, 1994; Kozlu and Göncüoglu, 1995, 1997; Tolluoglu and Sümer, 1997; Ay et al., 1999; Gürsu and Göncüoglu, 2001; Gürsu, 2002). The basement rocks in the western Taurides, the main topic of this study, are named the "Sandikli Basement Complex" (SBC; Gürsu and Göncüoglu, 2001). Dean and Özgül (1994) have shown that the first fossil-bearing strata, 150 m above an assumed unconformity, are Early Middle Cambrian nodular limestones (Cal Tepe Formation). Similar rock-units were described since the early 1960s from SE Turkey by the pioneering work of Ketin (1966), and also in Iran (Stöcklin et al., 1964), Oman (Gorin et al., 1982) and the Arabian Peninsula (e.g., Husseini, 1989) and ascribed traditionally to the "Infracambrian" to include Eocambrian to Lower Cambrian rocks. Metamorphic equivalents of these Gondwanan basement rocks cover large areas in the Central Anatolian Crystalline Complex and the Bitlis Massif in central and SE Turkey (Göncüoglu et al., 1997). A brief account of the locations and stratigraphy of these "Infracambrian" rock units is given in Kozlu and Göncüoglu (1997).

Recent studies (Gürsu and Göncüoglu, 2001; Gürsu, 2002) in western Turkey, however, has shown that the main unconformity between the "basement" and the "cover" is located in a quite different stratigraphic position then previously suggested.

In this study, we will describe the rock units of the basement complex and their relationships with the palaeontologically-dated Lower Palaeozoic cover series in the Sandikli area. As the felsic igneous rocks, mainly meta-rhyolites and meta-quartz-porphyries within the basement have not yet been studied in detail, we will use the geochemistry of the felsic igneous rocks to decipher the tectonic setting of the magmatic event in the Taurides during pre-Early Cambrian time. Finally, we will correlate the igneous and sedimentary rocks along southern Turkey with those from northwest Gondwanaland for a better understanding of the geodynamic evolution of this critical region.

The Sandikli Basement Complex

The Sandikli Basement Complex (SBC) is mainly composed of the Güvercinoluk Formation and the Kestel Cayý Porphyroid Suite (KCPS; Gürsu and Göncüoglu, 2001). It outcrops along a roughly NNE-SSW trending antiform to the west of Sandikli. Along its southern contact, the unit overthrusts the Mesozoic cover rocks (Fig. 1).

The meta-sedimentary rocks of the SBC are known as the Güvercinoluk Formation (Özgül et al., 1991a; Gürsu and Göncüoglu, 2001). In the assumed lower part, the formation is made up of intensively folded dark phyllitic slates and/or phyllites with bands and lenses of black cherts (or phthanite in the sense of Bandres et al., 2002), cherty dolomites, dark grey turbiditic meta-sandstones and debris flow conglomerates (Fig. 2). The upper part mainly includes an alternation of meta-sandstones, recrystallized cherty limestones and greenish-grey slates. The observed thickness of the formation is a minimum of 800 m.

The fine-grained meta-sedimentary rocks preserve a remnant lamination and show a relatively well-developed foliation in which primary clastic texture is commonly obliterated. The metamorphic paragenesis is: quartz+albite+sericite+graphite±chlorite. The IC values of the white micas of this rock-unit correspond to high anchimetamorphic-low epimetamorphic conditions (Bozkaya et al., 2003). The meta-sandstones include elongated clasts of basic volcanic rocks and black chert. The cleavage is less penetrative and accentuated by the parallel alignment of fine-grained sericite flakes.

The meta-sedimentary rocks of the Güvercinoluk Formation are cut by dykes of meta-quartz porphyry and interfinger with deformed felsic pyroclastic rocks, interpreted as rhyolitic crystal- and lithic-tuffs.

The Kestel Cayi Porphyroid Suite includes meta-rhyolites and irregularly distributed dykes of meta-quartz-porphyry in a dome-shaped body around Büyükbakirli Hill. The contacts of the main rhyolitic body towards the Güvercinoluk Formation are generally sheared. However, meta-quartz porphyry dykes cutting both the meta-sediments and the rhyolitic carapace are frequently observed in the smaller streams to the west of the Kestel Cayi Valley (Fig. 1).

Both the meta-rhyolites and their coarser-grained equivalents are intensively mylonitized and variably foliated. Three sets of foliation planes (S_1, S_2 and S_3) are observed (Fig. 3). The finer-spaced penetrative one (S_1) parallels the main regional NNE-SSW foliation trend. S_2 is almost parallel to S_1 and to the foliation planes of the overlying Lower Palaeozoic rocks. S_3 is restricted (Fig. 3) to the alpine thrust-plane, along which the SBC overthrusts the Mesozoic cover units (Fig. 1).

Nine zircon grains from two different samples from the "Sandikli Granite", representing the quartz-porphyry rocks of KCPS, yielded single zircon $^{207}Pb/^{206}Pb$ ages that range between 543±7 and 2448±3 Ma (Kröner and Sengör, 1990). Five of the nine grains yielded identical ages of 543±7 Ma, strongly suggesting that this age reflect the time of granite intrusion. The authors suggest that the "granite" was derived at 543±7 Ma from melting of a chronologically heterogeneous crustal source, up to Early Proterozoic in age.

The Kestel Cayi Porphyroid Suite is traversed by meta-lamprophyre rocks, which mainly include alkali feldspar (orthoclase) and biotite (chloritized) as primary igneous minerals. The matrix is replaced by the paragenesis tremolite+chlorite+sericite, indicating a low-grade metamorphic overprint.

The Lower Palaeozoic and Mesozoic Cover

The SBC rocks are disconformably overlain by the Early Cambrian Gögebakan Formation. To the north of the study area around Orta Tepe (Fig. 1), where the primary contact relations are well-observed, the basal conglomerate (approximately 10 m) of the Gögebakan Formation include apron-type deposits with angular meta-rhyolite, meta-sandstone and meta-chert fragments (Fig. 4). The overlying succession is dominated by conglomerates with sub-rounded to rounded metamorphic pebbles of the underlying SBC and is interstratified with coarse-grained arkosic meta-sandstones. Along the eastern (to the west of Kalayik Hill) and northwestern contacts (eastern slope of Kestel Cayi Valley) towards the SBC, the Gögebakan Formation is overturned (Fig. 1). Variegated basal clastics of the formation around Gögebakan Hill (Fig. 1), the type locality of this formation, include discontinuous pockets

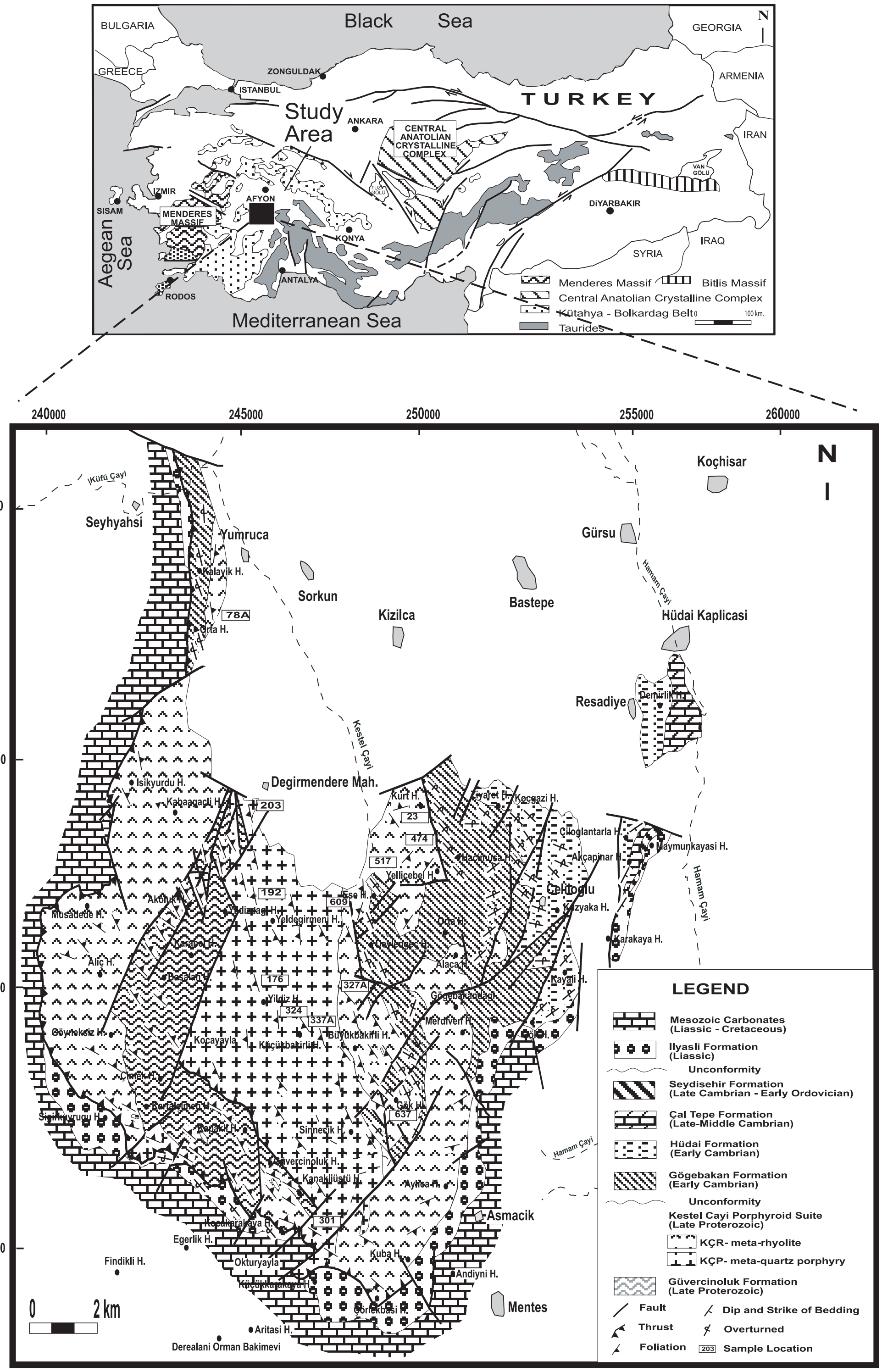

Fig. 1. Geological map of the Sandikli area (after Gürsu, 2002). The general map shows the location of the study area and the main tectonic units of the Tauride-Anatolide Belt (simplified after Göncüoglu et al., 1997).

of basal conglomerates. The well-rounded clasts are derived from the underlying SBC and include gravel-size meta-rhyolite, recrystallized limestone and black chert (Fig. 5). Foliation planes and low-grade metamorphism exhibited in these pebbles are markedly different than the matrix of the basal conglomerate of Gögebakan Formation.

Stratigraphically upwards, the formation includes an almost 150 m thick alternation of fluvial red and violet arkosic meta-sandstones and meta-siltstones with black and green meta-mudstones. Spilitic lava-flows and sills together with discontinuous lenses of dark green pyroclastic rocks are observed in this part of the succession. Meta-diabase dykes cutting the Gögebakan Formation are only observed in the lower part of the formation. No felsic dykes cutting this unit have been observed in the Sandikli area, or in the surrounding regions. Where not affected by the late Alpine deformation along the thrust-plane between the SBC and its Mesozoic cover (Fig. 1), the fine-grained clastic rocks of this formation are characterized by a weakly-developed slaty cleavage (S_2), along which fine-grained sericite is formed. The lower b_0 value (9.026 Å) of these white micas in the Gögebakan Formation with respect to those in Güvercinoluk Formation (mean 9.043 Å) and Kestel Cayi Porhyroid Suite (mean 9.042 Å) indicates high anchi-metamorphic to low epi-metamorphic conditions (Bozkaya et al., 2003). Towards the top, the Gögebakan Formation grades into siliciclastic rocks of the Celiloglu Member.

Fig. 3. Deformation and development of S_1, S_2 and S_3 planes in the meta-rhyolite of the KCPS. Ser–Sericite, Q–Quartz.

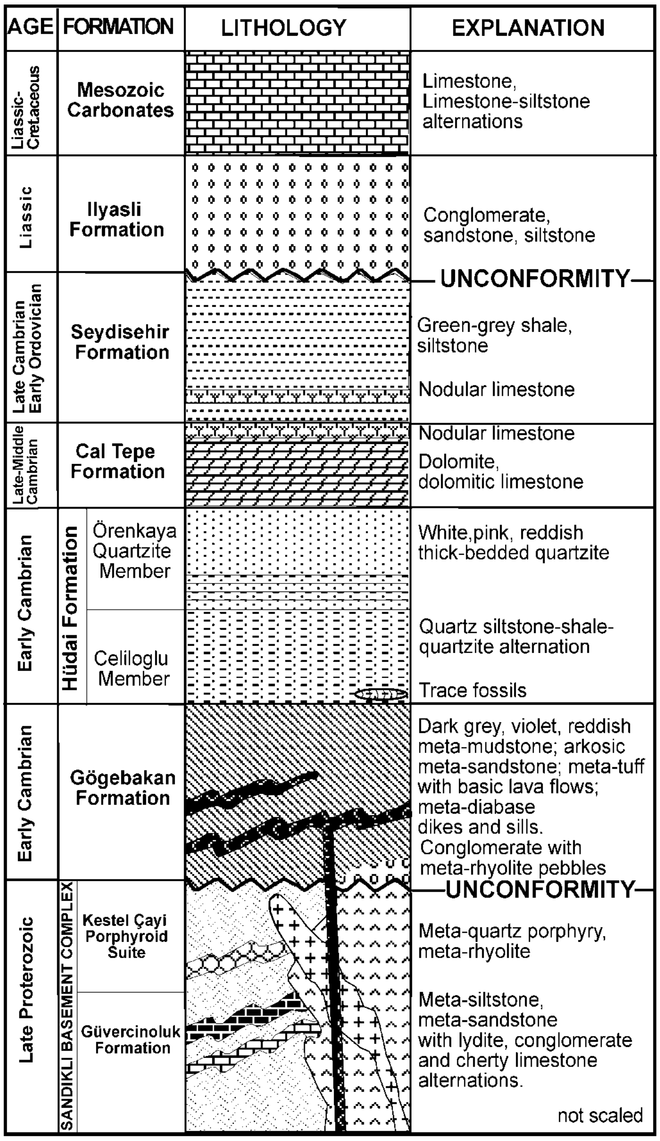

Fig. 2. Generalized columnar section of the Sandikli Basement Complex and its lower Palaeozoic and Mesozoic cover (after Gürsu and Göncüoglu, 2001).

The Celiloglu Member is made up of an alternation of pink, white and yellow siliceous mudstones, quartz-siltstones and quartzites (Fig. 2). The thickness of the member is about 100 m. In the siliceous mudstones at the transition between the Celiloglu Member and the Gögebakan Formation, Erdogan et al. (2000) and Uchman et al. (2000) found trace fossils, indicating a Tommotian (Earliest Cambrian) deposition age for this unit.

The Celiloglu Member is conformably overlain by the Örenkaya Quartzite member of Hüdai Formation (Fig. 2), which is mainly made up of white, pink and reddish, thick-bedded quartzites and followed by the Cal Tepe Formation. Both units are the typical representatives of the Middle Cambrian rocks along the Tauride Belt (Dean et al., 1991; Göncüoglu and Kozlu, 2000). The Nodular Limestone Member in the upper part of the Cal Tepe Formation has yielded Middle Cambrian fossils (Gedik, 1989; Dean and Özgül, 1994) in the study area (to the North of Örenkaya Village in Fig. 1). The Gray Limestone Member in the lowermost part of the formation at its type locality in Seydisehir area has yielded small shelly fossils that mark the Lower-Middle Cambrian transition (Sarmiento et al., 1997).

The Mesozoic cover of the SBC and its Palaeozoic cover is unconformably overlain by the conglomerates and sandstones and siltstones of the Liassic Ilyasli Formation, followed by the Late Dogger-Early Malm carbonates (Özgül et al., 1991a, b) (Fig. 1). The overthrusting of the basement units on their Mesozoic cover (Fig. 1) is related to the late Alpine (late Eocene) compressional period in the Taurides (Özgül et al., 1991b).

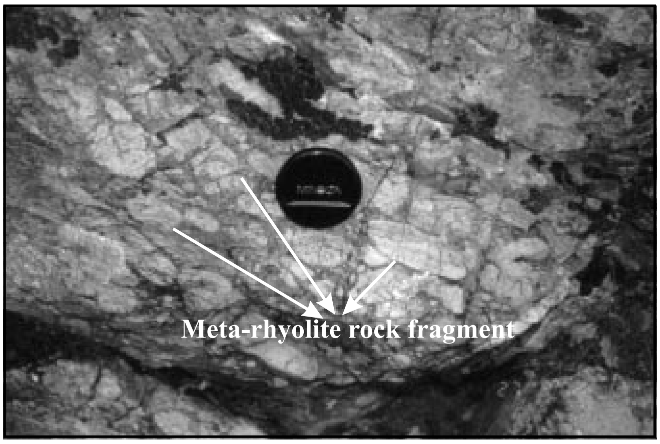

Fig. 4. Field occurrence of the basal conglomerates with angular fragments of meta-rhyolites in the lowermost part of the Gögebakan Formation in the northwest of Orta Tepe.

Geochemistry of the Kestel Cayi Porphyroid Suite

To study the geochemistry of the felsic igneous rocks of the SBC and compare them with similar lithologies of assumed Pan-African age in Turkey (Sengör et al., 1984), North Africa/Arabia and East Europe we have examined more than 200 thin-sections of meta-rhyolites and meta-quartz porphyry rocks. Thirteen representative samples (7 from meta-rhyolites, 6 from quartz porphyry rocks) were selected and analysed for major, trace and REE elements by XRF and ICP-MS in the ACME-Laboratories in British Colombia, Canada (Table 1). The sample locations are shown on figure 1.

Petrographically, both the meta-rhyolites and meta-quartz porphyry rocks are mylonitic schists (Higgins, 1971). They are characterized by the presence of "augen structures", the augens being partly recrystallized porphyroclasts made up of either single felsic minerals (K-feldspars, strongly retrogressed and derived from twinned sanidine in meta-rhyolites, perthitic orthoclase and quartz in meta-quartz porphyry) or highly deformed rock-fragments, preserving the textural evidence of the protolith (Fig. 6a, b). The porphyroclasts are larger than about 0.3 mm and make up more than about 25% of the rock. The meta-rhyolites can be distinguished from the meta-quartz porphyry rocks by detailed petrographic examination of these porphyroclasts. Even in the extremely sheared samples, the volcanic rocks include skeletal quartz phenocrysts reflecting strong undercooling effects and euhedral-subhedral retrogressed K-feldspar (probably sanidine) phenocrysts surrounded by a very fine-grained groundmass with recrystallized quartz and sericite minerals (Fig. 6a). Granitic texture is commonly preserved within the meta-quartz porphyry rocks. The quartz grains are euhedral/subhedral and associated with microperthitic feldspars (Fig. 6b). The mylonitic schists of lithic tuff origin are more readily identified than the crystal tuffs. The groundmass surrounding the porphyroclasts in all rock-types has been recrystallized and neomineralized, sericite and rarely chlorite being the main metamorphic phases (Fig. 6a, b).

Although the felsic igneous rocks of the SBC have retained a broadly granitic composition, as revealed by their bulk chemical compositions (Table 1), Gürsu (2002) has shown that mylonitic deformation and the low-grade metamorphism may have caused chemical changes in the composition of the protoliths. To avoid the effects of mobility, geochemical diagrams used for discriminations were mainly based on less-mobile/immobile elements (e.g., Zr, Ti, Nb, etc.).

The Zr/TiO_2 versus Nb/Y diagram trace-element classification diagram based on relatively less mobile elements (Winchester and Floyd, 1977) indicates that both the intrusive and extrusive felsic rocks of the KCPS are subalkaline and plot in the rhyolite/dacite field (Fig. 7).

The Harker variation diagrams, Al_2O_3, Fe_2O_3, K_2O and TiO_2 decrease with increasing SiO_2 and display negative trends (Fig. 8) compatible with magmatic differentiation. The scattered data points for Na_2O and CaO from meta-quartz porphyry rocks indicate element mobility during the low-grade metamorphism. On the other hand, Na_2O and K_2O of the meta-rhyolites display more linear trends than meta-quartz porphyry rocks with increasing SiO_2 (Fig. 8). MgO-SiO_2 variation diagrams indicate a lack of linear relationship because of element mobility during the mylonitic deformations and low-grade metamorphism

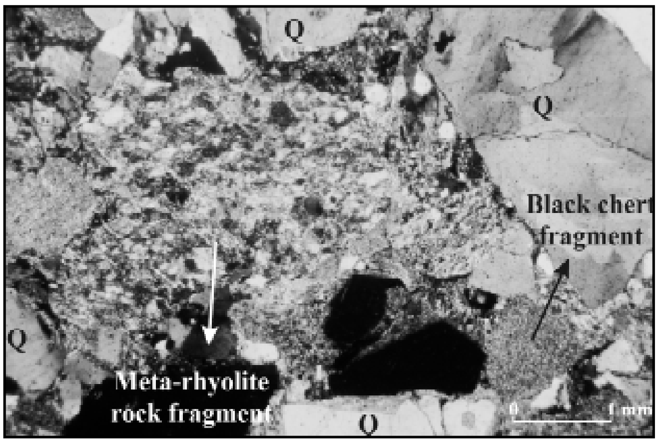

Fig. 5. Microphotograph of the coarse-grained sandstones in the lower part of the Gögebakan Formation at Kalayik Tepe. The clasts are mainly made up of angular to sub-rounded quartz (Q), black chert and meta-rhyolites. The clayey matrix includes sericite minerals. The clasts are derived from the underlying Güvercinoluk Formation and KCPS and their metamorphic textures are distinctly different then that of the matrix, indicating that they were metamorphosed prior to their incorporation into the sandstones of the Gögebakan Formation.

Table 1. Major, trace and REE data from the SBC felsic igneous rocks.

Sample No	Meta-rhyolite 23	Meta-rhyolite 78A	Meta-rhyolite 327A	Meta-rhyolite 474	Meta-rhyolite 517	Meta-rhyolite 609	Meta-rhyolite 637	Meta-quartz porphyry 176	Meta-quartz porphyry 192	Meta-quartz porphyry 203	Meta-quartz porphyry 301	Meta-quartz porphyry 324	Meta-quartz porphyry 337A
SiO_2	77.03	75.40	74.91	76.48	76.78	76.19	75.83	74.58	76.42	79.45	77.09	73.36	74.38
Al_2O_3	11.5	12.03	11.44	12.11	11.27	12.44	12.46	13.04	12.03	11.36	12.32	13.34	12.58
Fe_2O_3	1.55	1.91	2.19	1.25	1.38	1.24	1.41	1.77	1.5	1.21	1.55	2.76	2.94
MgO	0.31	0.5	0.21	0.39	0.09	0.32	0.25	0.68	0.77	0.32	0.5	0.67	0.27
CaO	0.02	0.04	0.02	0.02	0.01	0.01	0.02	0.16	0.12	0.23	0.19	0.09	0.17
Na_2O	0.07	0.11	0.13	0.1	0.13	0.12	0.16	2.52	2.22	1.64	0.9	2.1	1.87
K_2O	7.89	8.42	10.06	8.43	9.43	9.22	8.21	5.25	4.73	4.22	5.61	7.94	6.09
TiO_2	0.12	0.19	0.19	0.11	0.11	0.12	0.13	0.3	0.16	0.21	0.29	0.35	0.4
P_2O_5	0.01	0.02	0.03	<0.01	0.02	<0.01	<0.01	0.06	0.02	0.11	0.13	0.07	0.08
MnO	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01
Cr_2O_3	0.02	0.026	0.018	0.008	0.05	0.01	0.002	0.002	<0.001	<0.001	0.002	0.015	<0.001
LOI	1	1.9	2.5	1.6	1	1	1.4	2.1	1.5	1.1	1.3	1	1.1
Total	99.64	100.66	101.84	100.62	100.46	100.78	100	100.59	99.55	99.92	100.02	101.86	100.07
Ba	813	876	1144	757	1436	768	1017	1110	496	530	1099	1346	1542
Sc	5	15	6	6	4	5	6	7	3	11	13	7	9
Ga	12.5	21.2	13.2	20.6	8.6	20.3	21.5	21.2	15.8	17.4	19.9	23.4	16.9
Sr	18.5	35.5	24.8	10.2	21.7	8.3	10.8	57	24.9	30.1	31.1	33.1	41
Hf	4.9	7.6	6.8	5.5	5.2	4.5	5.3	7.5	4	4.6	5.5	10.2	7.9
Nb	10.1	22.8	12.2	13.5	12.2	14.3	12.8	15.7	9.4	15.4	17.9	18.5	14.3
Rb	240	251.5	289.7	262.7	257.9	302.8	299.5	156.3	162.6	168.1	182.3	269	231.1
Ta	1.1	1.6	1.2	1.2	1.2	1.8	1.7	1.2	1.3	1.4	1.6	1.3	1.1
Th	24.3	26.2	21.2	29	25.5	34.3	29.8	27.9	17.5	14.6	23.8	32.1	25.3
Zr	119	212.3	177.8	133.9	127.1	119.1	130.7	248.3	116.9	135.5	170	324.7	292.9
Y	40	87.7	51.1	38.1	44	62.9	49.1	51.9	46.9	69.5	62.6	40.6	38.8
V	5	5	9	5	5	11	8	18	5	14	10	16	16
La	41	63.2	94.9	81.2	86.7	41.3	15.9	59.3	30.1	44.2	53.6	69.3	58.5
Ce	90	135.2	196.9	172.7	162.3	94.1	27.1	109	57.6	101	107.9	140.4	115.9
Pr	9.91	15.22	21.45	19.38	17.37	10.23	3.91	13.06	7.66	11.38	12.96	15.42	12.99
Nd	35.1	58.5	75.7	68.2	60.8	37.8	15.6	46.4	29.1	45.1	51.7	54.8	51
Sm	6.5	12.8	15.7	13	12.8	7.3	3.4	9	6.5	11	10.8	10.3	9
Eu	0.12	1.14	0.99	0.3	0.54	0.1	<0.05	0.65	0.33	0.71	0.87	0.83	0.71
Gd	4.87	13.16	11.79	8.27	9.5	7.67	4.06	8.21	6.43	11.46	10.43	8.11	8.02
Tb	0.92	2.44	1.68	1.2	1.38	1.44	1.02	1.46	1.2	2.06	1.7	1.24	1.23
Dy	6.72	15.24	8.83	7.18	7.52	10.78	8.66	9.19	8.03	13.89	11.73	7.35	7.38
Ho	1.42	3.14	1.64	1.45	1.46	2.44	2.01	1.73	1.78	2.93	2.5	1.4	1.57
Er	4.69	9.36	4.91	4.4	4.5	7.09	6.01	5.24	5.09	7.77	7.32	4.34	4.12
Tm	0.66	1.23	0.66	0.63	0.63	1	0.85	0.71	0.71	1.05	1.01	0.58	0.59
Yb	4.41	8.49	4.67	4.37	4.1	7.14	6.06	4.46	4.78	6.81	6.89	4.18	4.1
Lu	0.67	1.19	0.72	0.66	0.62	1	0.85	0.68	0.68	0.87	0.95	0.68	0.56
(La/Yb)N	6.28	5.03	13.73	12.56	14.29	3.91	1.77	8.98	4.26	4.39	5.26	11.2	9.64
(Gd/Lu)N	0.91	1.38	2.04	1.56	1.91	0.95	0.59	1.5	1.18	1.64	1.37	1.48	1.78
Eu/Eu*	0.065	0.268	0.222	0.088	0.149	0.04	-	0.231	0.155	0.193	0.250	0.277	0.255

(Fig. 8). As mentioned before, meta-quartz porphyry rocks of KCPS are more enriched in Na_2O and K_2O than meta-rhyolites. Al_2O_3, Fe_2O_3, TiO_2, Na_2O, CaO, K_2O and P_2O_5 negative trends are broadly consistent with fractionation of an assemblage consisting of plagioclase, alkali feldspar and iron oxides. The behavior of Rb, Ba, V, Zr and Nb versus increasing SiO_2 is indicative for differentiation and reflects the influence of minerals such as feldspar, zircon, rutile, ±magnetite and ±biotite. On the other hand, Y roughly increases with increasing SiO_2. The Harker variation diagrams (Fig. 8) are interpreted in terms of fractional crystallization. Major and trace element variations both in meta-rhyolites and meta-quartz porphyry rocks of KCPS are largely similar.

Chondrite-normalized trace element patterns (normalized after Sun and McDonough, 1989) of the felsic rocks of KCPS are shown in figure 9a. Both groups (meta-rhyolites and meta-quartz porphyry rocks) generally show enrichment in LIL (large ion lithophile) elements relative to high-field strength (HFS) elements. Meta-rhyolites and meta-quartz porphyry rocks of KCPS display negative anomalies in Nb, Sr, P, Ti and enrichment in Th, La, Ce and Zr. The patterns are very similar to each other and correlate well with upper continental crust datum rather than lower continental

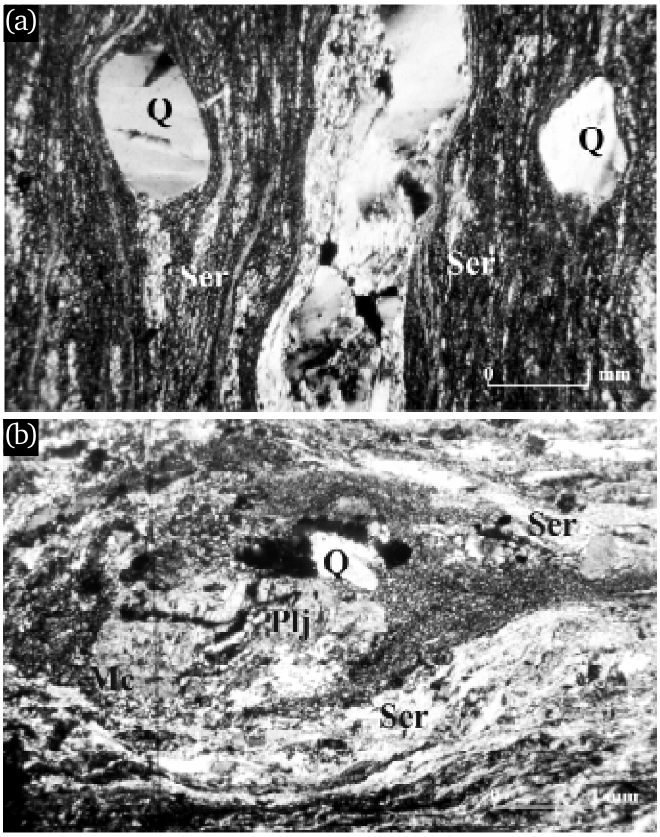

Fig. 6. Microphotographs of the meta-felsic rocks of the KCPS (a) embayed lentils and porphyroclasts in the meta-rhyolite. The quartz porphyroclasts display undulatory extinction and are surrounded by very fine-grained recrystallized quartz and neoformations of sericite parallel to the mylonitic foliation; (b) mylonitic deformation and metamorphism in meta-quartz porphyry. Porphyroclasts of quartz (Q), microcline (Mc) and plagioclase (Plj) phyric original rock are surrounded by very fine-grained recrystallized quartz and metamorphic sericite (Ser).

crust datum (data taken from Taylor and McLennan, 1995). A comparison of the patterns with their distinct enrichment and depletion with the upper continental-crust datum (Taylor and McLennan, 1995) suggests a crustal origin. Moreover, the wide scatter of igneous zircon $^{207}Pb/^{206}Pb$ ages (543–2488 Ma; Kröner and Sengör, 1990), indicative for assimilation of xenocrystic zircons from different sources also indicates a crustal source for the protolith. The studied samples plot in I-type granitoid field in Nb-SiO_2 and Y-SiO_2 diagrams (Fig. 8) and indicate that both the meta-rhyolites and meta-quartz porphyry rocks of KCPS were formed from an igneous source.

The chondrite-normalized rare earth element (REE) diagram of the studied rocks reveals that both rock groups display similar REE patterns (Fig. 9b). Other than differences in Eu anomalies, REE patterns are sub-parallel for all samples. They typically show light rare earth element (LREE) enrichments relative to heavy rare earth element (HREE) and display clear negative Eu anomaly. $(La/Yb)_N$, $(Gd/Lu)_N$ and Eu/Eu* ratios display a wide scatter of data in meta-rhyolites (1.77–14.29; 0.59–2.04; 0.065–0.268) and in meta-quartz porphyry rocks (4.26–11.20; 1.18–1.78; 0.155–0.277) respectively. The latter feature is typical of fractionation of meta-rhyolites relative to intrusive equivalents and is in accordance with the fractionation trend observed in figure 8.

Tectono-magmatic discrimination diagrams (Maniar and Piccoli, 1989 and Pearce et al., 1984) were used to identify the tectonic setting of the felsic igneous rocks of KCPS (Fig. 10a, b). On these diagrams, the studied rocks were correlated with the Late Proterozoic Pan-African granitic rocks of the Eastern Egypt (Younger Granite), Brno and Bohemia massifs in Central Europe and Menderes Massif-Turkey (Saleh, 2001; El-Nisr et al., 2001; Finger et al., 2000; Dostal et al., 2001; Bozkurt et al., 1995). All Late-Pan African granitic rocks display a post-orogenic setting in Al_2O_3 versus SiO_2 tectonic discrimination diagram of Maniar and Piccoli (1989) (Fig. 10a). In the Rb/Y+Nb tectonic discrimination diagram of Pearce et al. (1984), all the KCPS samples and Late Pan-African granitic rocks plot near the triple-junction of WPG (within plate granite)-synCOLG (syn collisional)-VAG (volcanic arc granite) fields (Fig. 10b). Pearce et al. (1984) and Pearce (1996) have shown that most of the post-collisional granites (PostCOLG) from areas with better-known tectonic history plot in the same area.

In this present study, based on the trace and REE patterns and the tectonic discrimination diagrams, we conclude that the meta-felsic rocks of KCPS were generated during a post-collisional extension. The tectono-magmatic discrimination diagrams show that the meta-rhyolites and

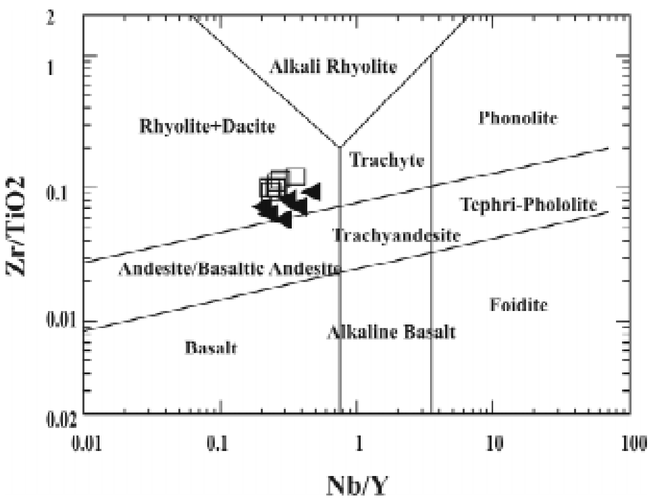

Fig. 7. Classification of the SBC felsic igneous rocks (after Winchester and Floyd, 1977). Open squares: meta-rhyolites, filled triangles: meta-quartz porphyry rocks.

meta-quartz porphyries of the KCPS are post orogenic I-type granitoids as it is the case in many igneous complexes of North Gondwana-derived terranes (El-Sayed, 1998; Finger et al., 2000; Saleh, 2001; El-Nisr et al., 2001; Dostal et al., 2001). This is also confirmed by the similarity of the REE patterns of the SBC felsic rocks and those obtained from the late- to post-tectonic I-type granitic rocks throughout the Arabian shield and eastern Egypt (e.g., Bentor, 1985; Saleh, 2001; El-Nisr et al, 2001).

Summary and Discussion

In most earlier studies, both in the eastern and western Taurides, the stratigraphy of the pre-Early Middle Cambrian clastic rocks was generally oversimplified, and attributed to a the "Infracambrian Emirgazi Formation" representing fluvial to shallow-marine deposition (e.g., Kozlu and Göncüoglu, 1997). Some others misinterpreted the stratigraphic succession (e.g., Erdogan et al., 1998b, 2000),

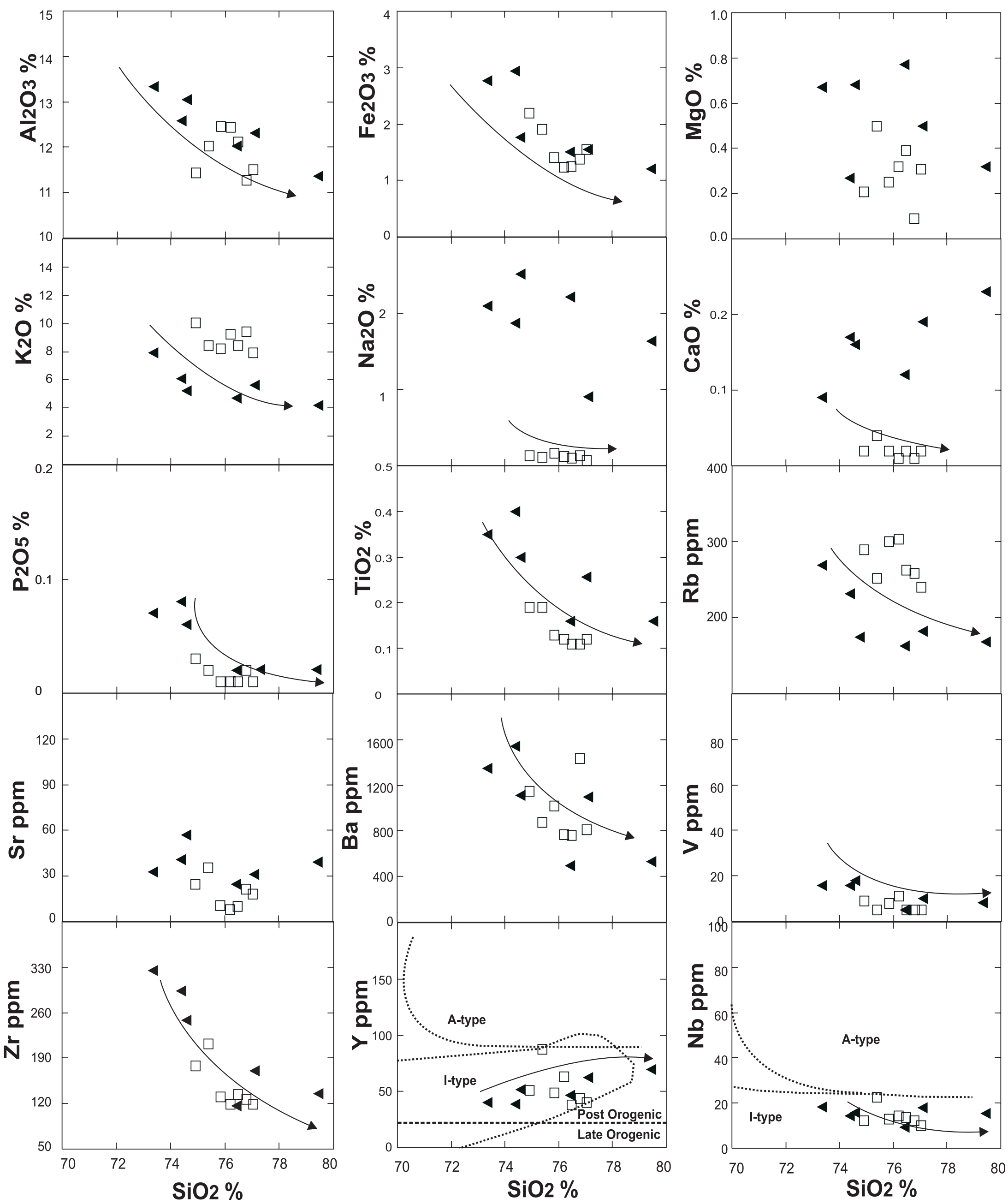

Fig. 8. Harker diagrams illustrating correlation of Al_2O_3, Fe_2O_3, MgO, K_2O, Na_2O, CaO, P_2O_5, TiO_2, and Rb, Sr, Ba, V, Zr, Y, Nb versus increasing SiO_2. Field boundaries for I and A-type granites taken from Collins et al. (1982). Symbols are same as figure 7.

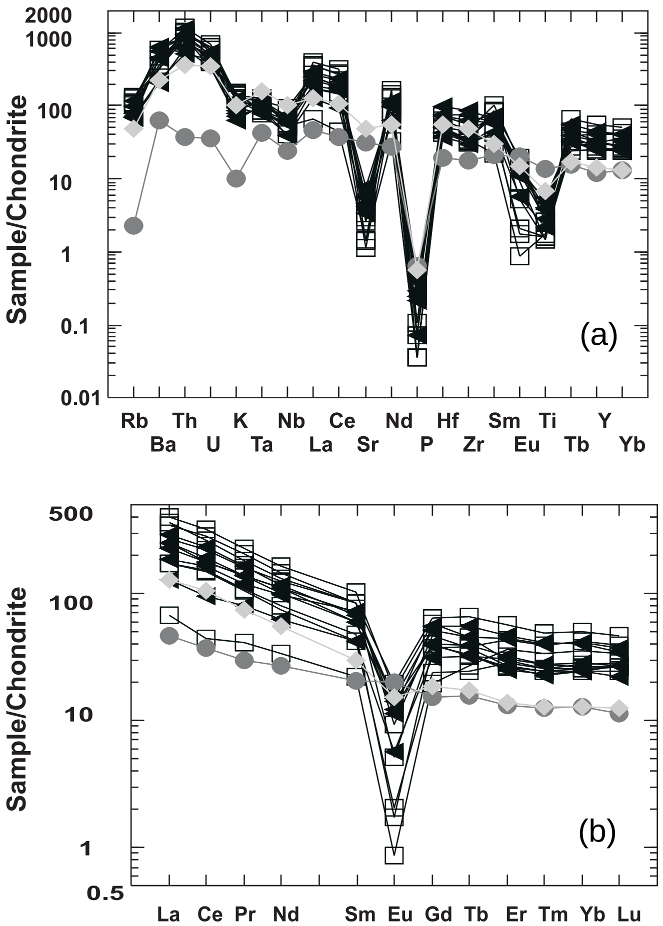

Fig. 9. (a) Chondrite normalized multi-variation diagram (normalizing values are from Sun and McDonough, 1989) (b) Chondrite-normalized REE diagram (normalizing values from Sun and McDonough, 1989). Filled circle: lower continental crust, filled diamond: upper continental crust. Other symbols are same as figure 7.

or assigned an Early Palaeozoic depositional age and attributed the metamorphism of these units to Caledonian events (e.g., Tolluoglu and Sümer, 1997; Ay et al., 1999).

Our detailed work in the Sandikli area, western Taurides, has revealed that the Late Proterozoic SBC was actually separated from Lower Palaeozoic cover by an unconformity. The low-grade dynamo-metamorphic sedimentary rocks of the lower unit (Güvercinoluk Formation) are interpreted as a shallowing-upward sequence formed near a tectonically active basin margin.

Another crucial feature of the SBC is the presence of felsic igneous rocks (KCPS) within this unit. The main felsic igneous body is dome-shaped and includes dominantly meta-rhyolites. Relict textures within these highly sheared rocks indicate that SBC comprises both intrusive (stocks) and extrusive (lavas and pyroclastic rocks) lithologies, the latter interfingering with the clastic rocks of the Güvercinoluk Formation. In these features the Güvercinoluk Formation differs from the unconformably overlying Gögebakan Formation, which mainly consists of variegated meta-conglomerates, meta-sandstones and meta-mudstones. The depositional environment of this succession in its lower part is typically fluvial. Where it directly overlies the felsic igneous rocks, the basal conglomerates of the Gögebakan Formation contain pebbles of deformed and metamorphosed felsic igneous rocks. This is a conclusive evidence for the relative age of the basement-cover relations in the Sandikli area. In the previous studies (e.g., Kozlu and Göncüoglu, 1995, 1997), the main (basement-cover) unconformity was assumed to be located at the base of the Hüdai Formation (Fig. 2). The new finding in the present study suggests that both the deposition of the Güvercinoluk sediments, the intrusion of the Kestel Cayi Porphyroid Suite and their dynamic metamorphism all predate deposition of the Gögebakan Formation.

The sedimentological features of the Güvercinoluk Formation suggest deposition in a marginal basin with local tectonic activity. The subsequent shallowing-upwards succession in the upper part of the formation and the accommodation of the felsic volcanic/volcanoclastic material indicate that the basin was rapidly filled, deformed and uplifted, as evidenced by the angular unconformity overlain by the fluvial deposits of the overlying Gögebakan Formation.

The geochemical characteristics of the associated felsic igneous rocks within the SBC support the above scenario. The tectonic discrimination diagrams suggest that the felsic igneous rocks were formed by the partial melting of crustal rocks in a post-collisional/post-orogenic extensional setting, similar to the I-type granites of North Africa and the Arabian Peninsula (Fig. 10).

The felsic magmatism around the Proterozoic-Palaeozoic boundary, around the northern edge of the Gondwana palaeocontinent, was ascribed to late Pan-African tectono-thermal events (Gass, 1981; Genna et al., 2002). These events have been described throughout North Africa and Arabia and also within some Perigondwanan terranes such as Avalonia-Cadomia and Cimmeria (e.g., Unrug, 1997). Even though the exact location of Turkey within the tectonic framework of this very complex area is disputed, there is a general consensus that the Taurides in southern Turkey also forms part of this Pan-African Gondwanan/Perigondwanan orogenic collage (e.g., Göncüoglu, 1997; Murphy et al., 2002) as shown on figure 11. However, it is still not clear whether the Taurides were attached to NE Africa-Arabian Peninsula, or to the Cadomian or the Cimmerian terranes. Kröner and Sengör (1990) suggested that the source region of the detrital and xenocryst zircons (with single zircon

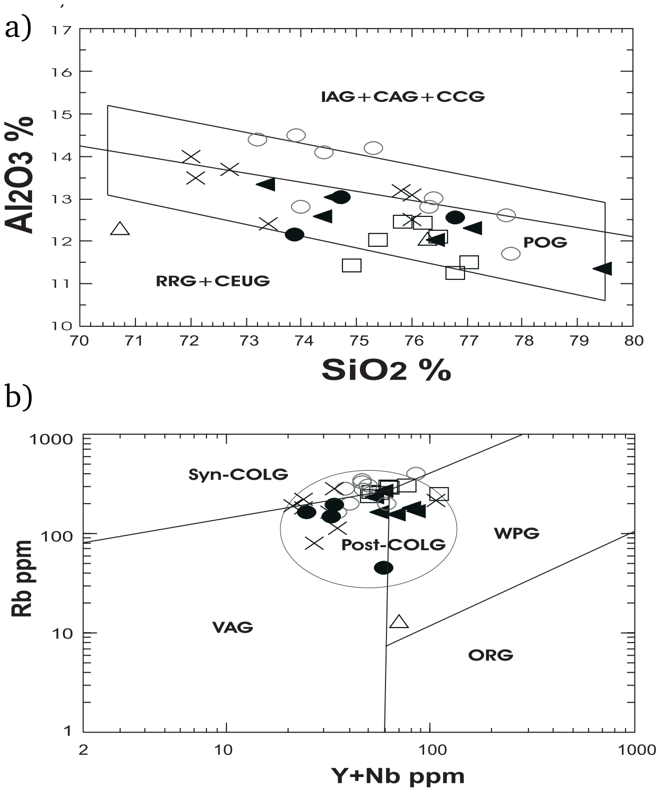

Fig. 10. Tectonic discrimination diagrams of the SBC felsic igneous rocks and their correlation with the southern Menderes Massif, Eastern Africa, Bruno and Bohemian Massifs. (a) after Maniar and Piccoli (1989), (b) after Pearce (1996) The augen gneisses of southern Menderes Massif (open circles; data from Bozkurt et al., 1995), late Proterozoic felsic igneous rocks from northeast Africa (X, data from Rogers et al., 1978 and El-Nisr et al., 2001), Bohemia (filled circle, data from Dostal et al., 2001) and Bruno Massif (open triangle, data from Finger et al., 2000). Other symbols are same as figure 7. IAG–island arc granitoids, CAG–continental arc granitoids, CCG–continental collisional granitoids, RRG–rift-related granitoids, CEUG–continental epiorogenic uplift granitoids, POG–post-orogenic granitoids, Syn-COLG–syn-collision granitoids, VAG–volcanic arc granitoids, WPG–within-plate granitoids, ORG–ocean ridge granitoids.

$^{207}Pb/^{206}Pb$ ages ranging between 612–3140 Ma) in the clastic rocks in SBC was not the Pan-African belt but the Angora Craton of Siberia and suggest that the Pan-African evolution in the Middle East may have been terminated by the collision of Angora with Gondwana in the Early Cambrian. In contrast, Göncüoglu (1997) and Göncüoglu and Kozlu (2000) proposed that the Taurides together with some other Perigondwanan terranes (e.g., Balkan, Sardinia and E-Avalonia terranes) were located on the North African margin and that the pre-Middle Cambrian rocks (Emirgazi Formation) formed within an extensional/transtensional back-arc basin above the southward subducting (Pickering and Smith, 1995) Eastern Iapetus oceanic plate. Our data support extensional arc model for southern Turkey. The geochemistry of the Early Cambrian meta-basic rocks in the lower part of the Gögebakan Formation in Sandikli area clearly indicates a back-arc tectonic setting (Gürsu et al., 2003; Göncüoglu and Gürsu, 2003). We prefer, in contrast to Kröner and Sengör (1990), a North African paleogeographic position for the Taurides above the southward (present coordinates) subducting Eastern Iapetus oceanic plate during the Proterozoic time, as an almost identical succession of events (magmatic activity, basin formations, etc.) has been reported from this area (e.g., Hefferan et al., 2000; Chantraine et al., 2001).

In this model, the formation of the I-type granitoids within the SBC was related to an extensional event that followed the Pan-African deformation and thus may be considered as a late Pan-African feature. Barbarin (1999) indicates that similar granitic rocks represent the last magmatic events of the Pan-African orogenesis and indicate the transition from continental plate convergence to continental plate divergence in northern Africa.

Another critical issue is the relative timing of the succession of events in the study area and thus in the Taurides. The new data and its regional geological implications contrast with the suggestions of Uchman et al. (2000) and Erdogan et al. (2000) who suggest that the Celiloglu Formation is the lowermost unit in the study area. It is conformably overlain by the Gögebakan Formation that includes porphyroid and hyaloclastic rocks and changes upward into a quartzite-phyllite succession with channel-fill conglomerates in its basal part (Erdogan et al., 2000). Based on their trace fossil content within the transitional zone between their Gögebakan and Celiloglu Formations to the west of the Celiloglu Village (Fig. 1), these authors suggest that the depositional age of the Celiloglu unit is Tommotian (Early Cambrian). This would imply that the KCPS is post Early Cambrian in age. However the single zircon $^{207}Pb/^{206}Pb$ age data of Kröner and Sengör (1990), where the youngest zircons were dated as 543±7Ma, suggest a Late Proterozoic age. Our stratigraphic finding, that the Gögebakan Formation and Celiloglu Member actually unconformably overlie the felsic igneous rocks of SBC with an intervening basal conglomerate is consistent with this radiometric age data. We further suggest that the Tommotian age assigned to the deposition of the Celiloglu unit only indicates a possible lower age limit of deposition. Thus, the deposition of this unit may be of any age between the Tommotian and the Early Middle Cambrian, the latter being set by zone fossils within the overlying nodular limestones of the Cal Tepe Formation (Fig. 2) in the study area (Gedik, 1989; Dean and Özgül, 1994).

The discussion of the age of the felsic igneous rocks SBC may be expanded to the Menderes Massif (Fig. 1), the adjacent tectonic unit of "Tauride" origin and includes correlative rock-units, as proposed by Erdogan et al. (1998a). In the Menderes Massif, the augen gneisses of the "core" yielded $^{207}Pb/^{206}Pb$ single zircon ages between 572±7 Ma and 521±8 Ma indicating Late Neoprotorozoic-Early Cambrian age (Hetzel and Reischmann, 1996; Loos and Reischmann, 1999; Dora et al., 2001), whereas Bozkurt et al. (1993) assumed that the protoliths are of Tertiary age. The main disagreement here is based on the discrepancy between the radiometric age data and field evidence suggesting an intrusive contact between the granitic protoliths and the meta-sedimentary host rocks (for a brief discussion on this discrepancy see Bozkurt and Oberhänsli, 2001 and the references therein). The meta-sedimentary host rocks (mainly "schists and marbles") in the Menderes Massif were considered as a whole to be of Palaeozoic-Mesozoic age, in most cases without any reliable age data and based just on lithological correlation (e.g., Bozkurt et al., 1995; Okay, 2001). Our studies from the Sandikli area and other parts of the Taurides (Kozlu and Göncüoglu, 1997) show that such a correlation is inappropriate. We consider the protoliths of the "schists and marbles of the cover" intruded by the granitic protoliths of the augen gneisses to correspond to the Güvercinoluk Formation of the SBC and are also of Late Precambrian age. The geochemical characteristics of protoliths of the augen gneisses and their assumed tectonic setting (Bozkurt et al., 1995) on the other hand strongly resemble the felsic igneous rocks of the SBC (for comparisons see Fig. 10a and b). If this interpretation is correct, the "main supra - Pan-African unconformity" of Sengör et al. (1984) in the Menderes Massif may correspond to the unconformity between the SBC and the Early Cambrian sedimentary cover in the study area. Hence, we consider that the core of the Menderes Massif and the basement of the Taurides are parts of the Late Pan-African basement, the only difference being the intensive Alpine metamorphic event in the former.

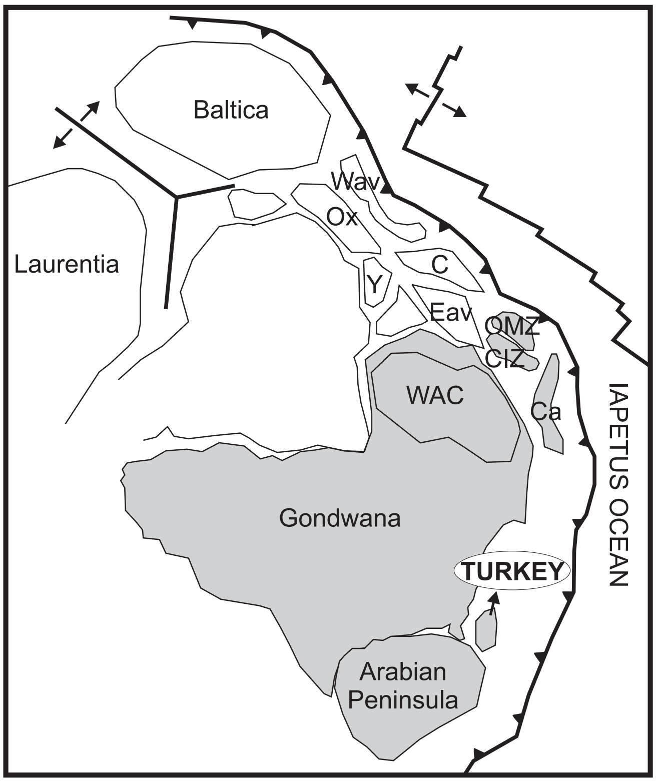

Fig. 11. Schematic reconstruction of Late Pan-African felsic rocks of KCPS (Turkey) during the Cadomian/Pan-African orogeny. C–Carolina, Ca–Cadomia, CIZ–Central Iberian zone (Iberia), Eav–East Avalonia, OMZ–Ossa-Morena zone (Iberia), WAC– West African craton, Wav–West Avalonia, (modified after Murphy et al., 2002).

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