International Geology Review, Vol. 43, 2001, p. 695–710.

A Review of the Nature of Magmatism in Central Anatolia during the Mesozoic Post-Collisional Period

N. S. DÜZGÖREN-AYDIN, J. MALPAS,

Department of Earth Sciences, The University of Hong Kong, Hong Kong

M. C. GÖNCÜOGLU, AND A. ERLER

Department of Geological Engineering, Middle East Technical University, TR-06590 Ankara, Turkey

Abstract

Magmatism in central Anatolia is characterized by petrographically and chemically distinct granitic and syenitic rocks. The granitic magmatism comprises C-type (crustal-derived) and H-type (hybrid) monzogranites and monzonites. Garnet-bearing C-type leucogranites represent the oldest magmatic phase, but younger hornblende ± biotite ± K-feldspar H-type plutons dominate the geology of the Central Anatolian Crystalline Complex (CACC). These typically include mafic microgranular enclaves. The granitic magmatism predates syenitic intrusions, among which quartz-bearing syenites were emplaced prior to feldspathoid-bearing ones.

The nature of magmatism in central Anatolia varies through time from peraluminous to metaluminous to alkaline. These different magma types reflect distinct stages of post-collisional magmatism, in which interaction between crust and mantle varied considerably. The C-type granites of the early stages of post-collisional magmatism were likely derived by partial melting of the lower continental crust induced by mafic magma underplating as a result of lithospheric delamination. The H-type granites and syenites of the mature and advanced stages of post-collisional magmatism indicate a significant contribution from mantle-derived magma within a continuous or episodic extensional tectonic regime.

Introduction

GRANITIC ROCKS dominate the geology of the continental crust and provide significant information on its origin and evolution. The origin of granites has been the subject of ongoing debate since the birth of modern geological science, but we now realize that their geochemical and isotopic signatures may carry signs of source characteristics that are closely linked to their tectonic setting. Based on their intrusive setting, granites have been classified as ocean ridge (ORG), syn-collisional (Syn-ColG), volcanic-arc (VAG), within-plate (WPG), and post-collisional (Post-ColG) types (Pearce et al., 1984).

Although it is widely accepted that post-collisional magmatism commences after the climax of plate collision and wanes when the anorogenic episode begins, there are no clearly defined limits (Liegeois, 1998). This stems from the fact that post-collisional magmatism displays highly variable geological, mineralogical, and geochemical features, some of which are comparable with those of the syn-collisional, anorogenic, and subduction-related magmatism.

In central Anatolia, physically and chemically distinct magmatic rocks display close spatial and temporal associations with each other and form a significant portion of the Central Anatolian Crystalline Complex (CACC; Göncüoglu et al., 1991). These rocks have been the focus of several studies, but their origin, evolution, and tectonic setting are still equivocal. The present paper compiles geological, mineralogical, and geochemical features of the magmatic rocks and proposes a common petrogenetic model for diverse magmatism in the CACC. In this paper, five major intrusions have been selected, simply because of the availability of data (Yozgat, Cefalikdag, Ekeçikdag, Idisdag, and Atdere). The first three are essentially granitic intrusions, and the latter two are syenitic.

General Geological Setting

The CACC, which contains metamorphic, ophiolitic, granitic, and syenitic rocks, is also known as the Central Anatolian Massif (Erkan, 1981), the Kirsehir Massif (Seymen, 1982), or the Kirsehir Complex (Lünel, 1985). It lies in a triangular area

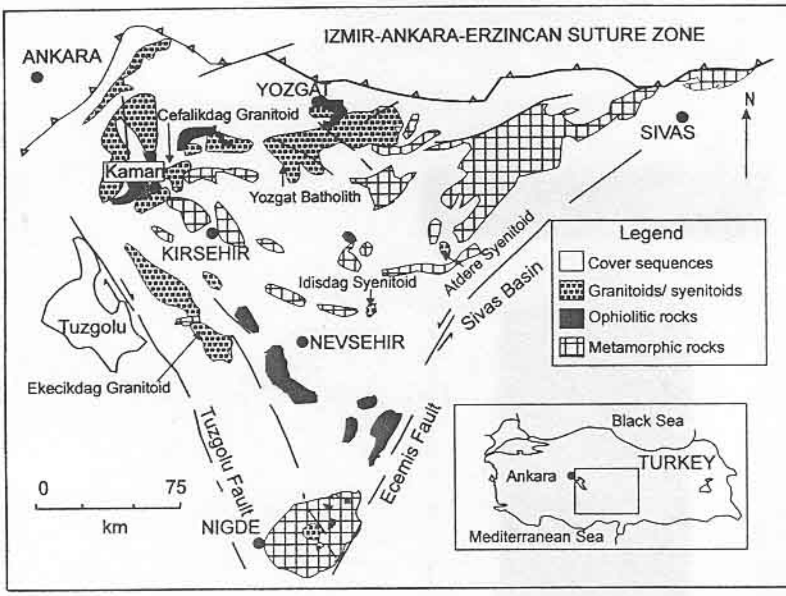

FIG. 1. Location map and simplified geological setting of the Central Anatolian Crystalline Complex (after Erler and Göncüoglu , 1996).

TABLE 1. Radiometric Data and Ages of the Central Anatolian Granites

Location	Method	Reference	Age (Ma)
Nigde-Ückapili	Rb/Sr whole-rock	Göncüoglu, 1986	95 ± 11
Nigde-Ückapili	K/Ar biotite and muscovite[1]	Göncüoglu, 1986	78 – 75
Cefalikdag	Rb/Sr whole-rock[1]	Ataman, 1972	71 ± 1
Agaçören	Rb/Sr whole-rock	Güleç, 1994	110 ± 14
Terlemez	K/Ar mineral	Yaliniz et al., 1997	81 – 67

[1]Cooling age.

bounded by the Tuzgölü fault to the west, the Ecemis fault to the east, and the Izmir-Ankara-Erzincan suture to the north (Fig. 1).

Gneisses, schists, calc-schists, phyllites, and marbles are considered the oldest lithologies of the CACC. These high-temperature/low-pressure (HT/LP) metamorphic rocks (Seymen, 1984) are tectonically overlain by Mesozoic ophiolitic rocks, remnants of Neo-Tethys (Özgül, 1976; Görür et al., 1984). The metamorphic and ophiolitic rocks are intruded by granites and syenites and overlain by Maastrichtian and/or Eocene volcanic, clastic, and carbonate rocks, Oligocene–Miocene evaporites and clastic rocks, and Miocene–Pliocene continental clastic rocks (Göncüoglu et al., 1991).

Magmatism in Central Anatolia

The magmatic rocks of the CACC have recently been the focus of several studies (e.g., Erler and Bayhan, 1995; Erdogan et al., 1996; Kadioglu, 1996; Boztug, 1998; Aydin and Önen, 1999). However, there is no general consensus on their age and

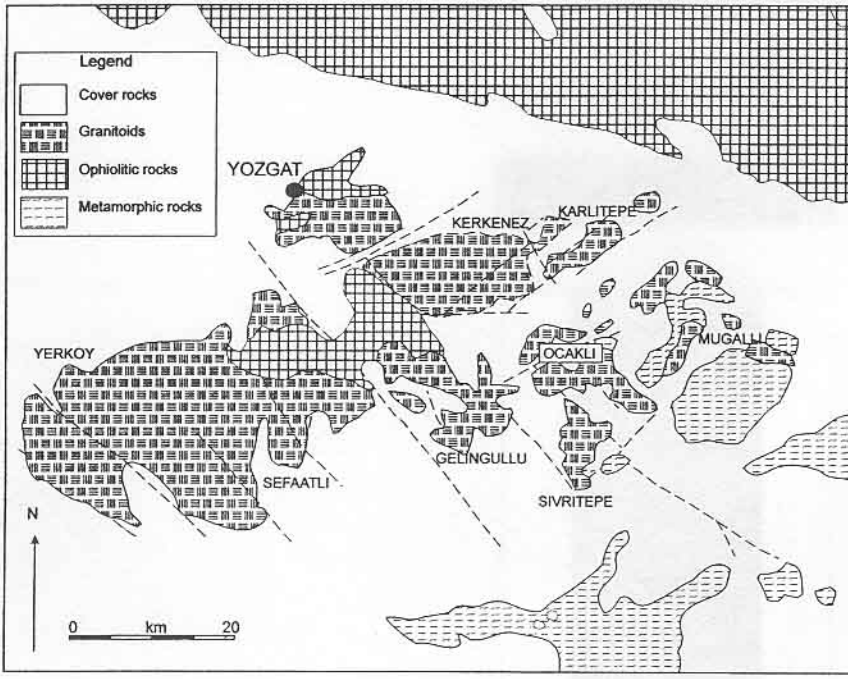

FIG. 2. Geological map of the Yozgat batholith (after Erler and Göncüoglu, 1996).

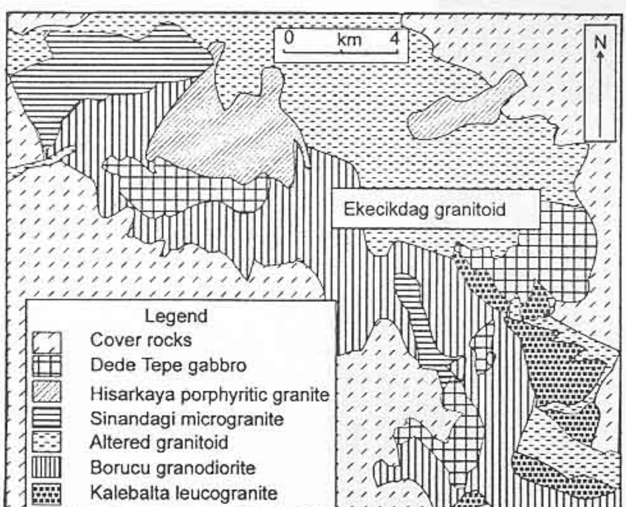

FIG. 3. Geological map of the Ekecikdag intrusion (after Türeli et al., 1993).

tectonic setting. The granitic rocks dominate the geology of the complex and were postdated by the emplacement of syenites. Both granitic and syenitic rocks are intruded by aplitic dikes, which represent the youngest igneous activity in the area. As shown in Table 1, radiometric ages of the granites of the CACC are somewhat limited and vary significantly. Recently, Yaliniz et al. (1997) reported that granitic

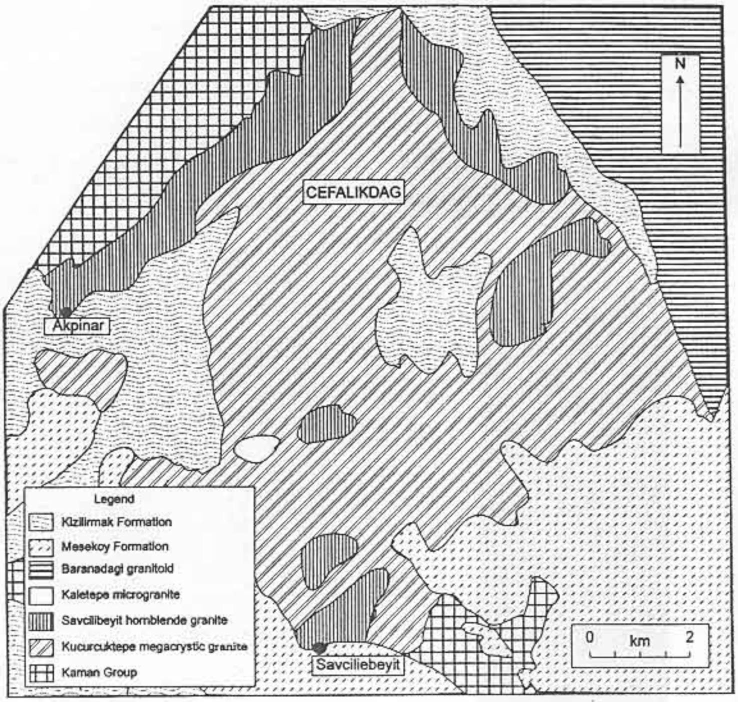

FIG. 4. Geological map of the Cefalikdag intrusion (after Geven, 1992).

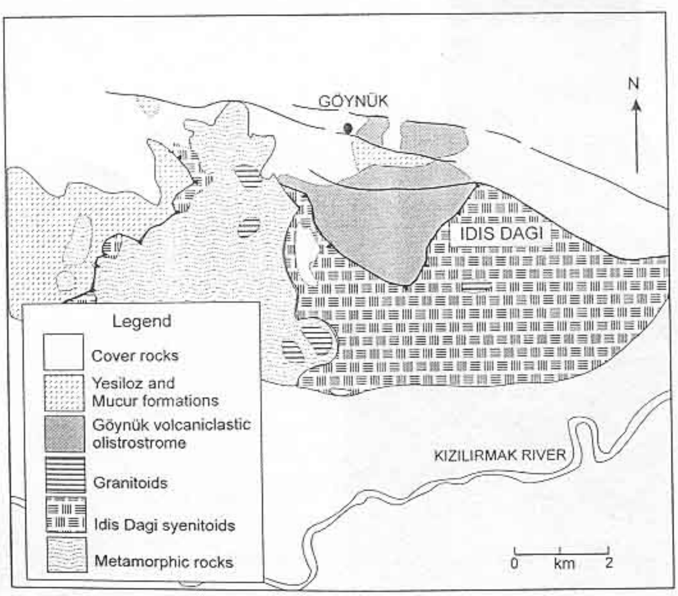

FIG. 5. Geological map of the Idisdagi intrusion (after Köksal and Göncüoglu, 1997).

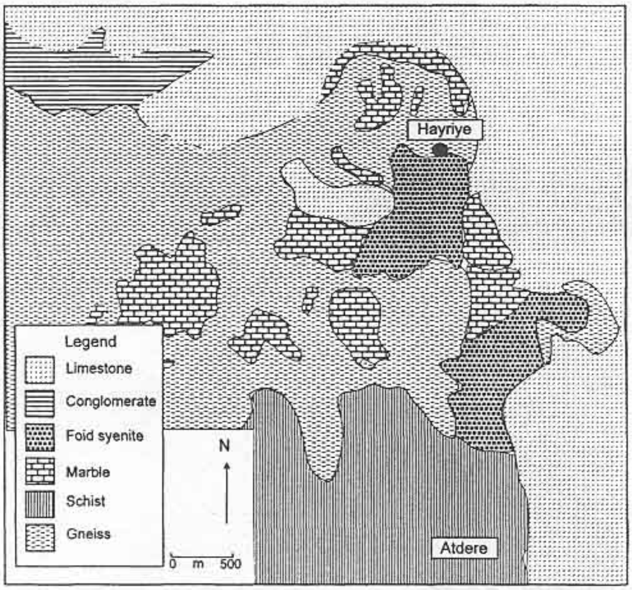

FIG. 6. Geological map of the Atdere intrusion (after Özkan and Erkan, 1994).

rocks, in particular the Terlemez pluton, intrude fossil-bearing epi-ophiolitic sediments of early Middle Turonian to Late Coniacian age. This geological constraint is in overall agreement with the data presented in Table 1.

Field and petrographic features of the granitic rocks

The granites display a range of fabrics, mineralogies, and compositions and crop out in three distinct geographical associations in the CACC (Fig. 1): as a large number of individual small plutons exposed along its western margin extending from NE-SW to NW-SE; as a relatively narrow and smaller set of disconnected plutons exposed along its eastern margin; and as a large intrusion exposed along its northern margin (Akiman et al., 1993). These granites are petrographically identified as: (a) two-mica leucogranites; (b) biotite/hornblende granites; (c) K-feldspar megacryst granites; (d) granodiorites; (e) tonalites; and (f) aplitic K-feldspar granites (Erler and Göncüoglu, 1996). In this paper, emphasis is placed on the Yozgat, Cefalikdag, and Ekecikdag intrusions (Fig. 1) and their main geological features are briefly summarized as follows.

The Yozgat batholith is the largest granitic intrusion (approximately 500 km^2) exposed along the northern margin of the CACC (Fig. 1) and consists mainly of monzogranites and quartz monzonite. The batholith includes eight main subdivisions, namely the Yerköy-Sefaatli, Kerkenez, Karlitepe, Geligüllü, Sivritepe, Ocakli, Mugalli, and Yozgat units (Fig. 2; Erler and Göncüoglu, 1996). It consists of both C-type and H-type granites (Aydin, 1997; Düzgören-Aydin, 2000) with the C-type confined to the Yozgat unit and the H-type comprising the remaining units. The C-type granite consists of garnet-bearing leucogranites, whereas the H-type contains hornblende ± biotite ± clinopyroxene-bearing monzogranites and quartz monzonites. The H type typically includes K-feldspar megacrysts (2–6 cm in length) and mafic microgranular enclaves.

The Ekecikdag intrusion, studied by Türeli (1991), covers approximately 250 km^2 and is exposed along the western margin of the CACC (Figs. 1 and 3). It ranges in composition from monzogranite to granodiorite and is divided into five units: the Borucu granodiorite-monzogranite; the Sinandag microgranite; the Hisarkaya porphyry granite; the Kalebalta leucogranite; and the aplitic granites (Türeli, 1991). The Borucu unit is characterized by the presence of K-feldspar megacrysts (4–15 cm in length), an abundance of hornblende and biotite, and microgranular mafic enclaves. The Kalebalta leucogranites represent the early phase of the intrusion (Göncüoglu and Türeli, 1994) and

TABLE 2. Representative Whole-Rock Major and Trace-Element Analyses of Granitic Rocks of the CACC

Location: Sample no.:	Yozgat Yk72	Yozgat Yk73	Yozgat Yk74	Yozgat Yk75	Yozgat Yz76	Yozgat Gl79	Yozgat Gl83	Yozgat Kr84	Yozgat Kr86	Yozgat Oc92	Ekecikdag KTBr12	Ekecikdag KTBr129	Ekecikdag KTBr154	Ekecikdag KTBr180
							wt%							
SiO_2	55.24	48.73	64.91	63.62	76.11	64.86	68.62	68.91	69.86	64.90	67.80	68.74	71.45	64.40
TiO_2	0.80	1.47	0.68	0.49	0.06	0.45	0.47	0.29	0.25	0.55	0.43	0.29	0.34	0.58
Al_2O_3	17.24	20.08	15.51	15.18	14.12	15.97	15.53	16.44	16.03	16.16	14.16	14.17	12.71	15.28
Fe_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.39	4.25	4.52	6.12
FeO	7.27	9.19	4.63	4.80	0.77	3.97	2.67	2.04	1.71	3.78	0.00	0.00	0.00	0.00
MnO	0.14	0.15	0.09	0.10	0.04	0.06	0.05	0.04	0.02	0.08	0.12	0.10	0.09	0.12
MgO	4.27	4.89	2.38	2.71	0.24	2.07	1.82	0.81	0.53	1.47	1.44	1.07	0.96	2.09
CaO	9.03	10.53	5.01	4.33	0.43	4.48	3.29	3.23	3.04	4.77	3.29	3.61	2.59	4.00
Na_2O	3.15	3.40	2.42	2.24	3.62	3.08	2.62	3.13	3.06	2.86	2.48	2.96	2.23	2.78
K_2O	2.40	1.00	4.20	6.34	4.61	4.89	4.79	5.00	5.42	5.17	4.10	3.56	4.25	3.36
P_2O_5	0.46	0.56	0.19	0.19	0.01	0.17	0.13	0.10	0.08	0.26	0.00	0.07	0.08	0.13
							ppm							
Zn	84	117	42	33	74	16	19	8	–	47	80	47	49	85
Rb	85	45	166	234	475	184	213	212	239	203	168	128	169	151
Ba	1124	519	915	2197	29	1459	677	1386	1122	1113	532	446	437	442
Sr	1169	1562	735	742	12	677	577	786	722	1165	127	147	114	169
Ga	27	33	21	16	15	20	22	22	20	21	0	0	0	0
Nb	12	15	25	22	42	25	24	19	15	34	11	8	9	14
Zr	266	131	242	181	71	210	242	279	312	347	187	111	129	195
Y	22	21	22	17	61	20	14	13	12	30	38	27	23	30
Th	7	3	31	32	29	30	28	39	56	34	26	12	17	17
La	51	53	56	64	28	50	44	60	92	88				
Ce	101	113	106	119	36	89	86	102	127	182				
Pr	11	13	11	12	7	10	9	10	11	21				
Nd	42	50	38	39	28	34	33	34	34	74				
Sm	8	8	6	6	10	6	6	6	5	13				
Eu	2	2	1	1	0	1	1	1	1	2				
Gd	6	6	5	5	13	5	4	4	3	9				
Tb	1	1	1	1	2	1	0	0	0	1				
Dy	4	4	4	4	14	4	3	3	2	6				
Ho	1	1	1	1	2	1	1	0	0	1				
Er	2	2	2	2	7	2	2	1	1	3				
Tm	0	0	0	0	1	0	0	0	0	0				
Yb	2	2	3	2	6	2	2	1	1	3				
Lu	0	0	0	0	1	0	0	0	0	0				

TABLE 2. (*continued*)

Location:	Ekecikdag	Ekecikdag	Ekecikdag	Cefalikdag	Cefalikdag	Cefalikdag	Cefalikdag	Cefalikdag	Cefalikdag	Cefalikdag	Cefalikdag	Cefalikdag	Cefalikdag	Cefalikdag
Sample no.:	KRBr267	KTKb298	KTAG256	AGC1	AGC5	AGC33	AGC40	AGC43	AGC61	AGC71	AGC81	AGC49	AGC52	AGC72
							wt%							
SiO_2	69.21	71.63	76.33	63.93	64.33	66.02	60.43	64.77	62.96	65.58	65.22	58.49	58.95	64.41
TiO_2	0.39	0.19	0.05	0.54	0.63	0.52	0.60	0.46	0.65	0.48	0.40	0.65	0.85	0.35
Al_2O_3	13.82	13.96	12.62	15.98	15.11	15.66	15.75	16.30	15.64	15.72	15.80	17.12	15.72	16.69
Fe_2O_3	4.91	3.07	1.69	2.35	1.09	1.69	2.09	1.31	2.06	1.57	1.30	6.68	3.00	0.71
FeO	0.00	0.00	0.00	2.12	3.89	2.47	2.89	2.25	2.80	2.01	1.89	0.00	3.49	2.26
MnO	0.11	0.08	0.07	0.08	0.09	0.08	0.07	0.06	0.08	0.06	0.05	0.13	0.09	0.06
MgO	1.30	0.42	0.00	1.99	2.33	1.91	4.02	1.77	2.50	1.78	1.86	3.92	3.63	1.18
CaO	3.12	1.80	1.03	3.85	4.28	3.89	5.33	3.67	4.50	3.52	3.27	5.58	6.21	3.21
Na_2O	2.05	2.96	3.76	3.39	3.00	3.59	3.22	3.58	3.20	3.55	3.79	2.49	3.04	4.33
K_2O	3.97	4.43	3.70	4.74	4.13	2.95	4.54	4.98	4.38	4.74	5.06	3.75	3.94	5.41
P_2O_5	0.11	0.02	0.01	0.20	0.13	0.13	0.18	0.09	0.06	0.14	0.41	0.29	0.10	0.66
							ppm							
Zn	51	31	24	–	–	–	–	–	–	–	–	–	–	–
Rb	161	198	253	197	189	189	225	226	178	242	257	106	141	281
Ba	347	623	74	–	–	–	–	–	–	–	–	–	–	–
Sr	124	152	19	427	354	438	–	–	433	526	462	520	441	488
Ga	0	0	0	–	–	–	–	–	–	–	–	–	–	–
Nb	10	13	26	14	14	14	13	14	14	14	15	–	12	15
Zr	142	125	70	184	191	213	213	241	195	231	213	102	193	240
Y	29	25	33	13	14	14	15	14	14	15	14	23	12	17
Th	14	16	27	25	25	31	26	19	21	23	34	78	15	38

TABLE 3. Representative Whole-Rock Major and Trace-Element Analyses of Syenitoid Rocks of the CACC

Location	Idis	Idis	Idis	Idis	Idis	Idis	Atdere	Atdere	Atdere	Atdere	Atdere	Atdere	Atdere	Atdere	Atdere	Atdere	Atdere
Sample no.:	Sk-2	Sk-3	Sk-4	Sk-5	Sk-6	Sk-7	MOYE31	MOYE38	MOYE92	MOYE97	MOYE114	MOYE121	MOYE116	MOYE118	MOYE35	MOYE39	MOYE44
									wt%								
SiO_2	65.35	65.25	67.38	66.34	62.34	64.91	52.52	54.48	53.02	52.14	53.54	55.39	52.19	54.81	51.57	53.34	54.60
TiO_2	0.39	0.49	0.25	0.43	0.44	0.44	0.29	0.26	0.22	0.16	0.23	0.21	0.20	0.25	0.29	0.26	0.25
Al_2O_3	17.61	16.40	17.31	16.53	17.12	15.79	24.20	22.93	22.74	25.15	23.62	23.15	23.32	22.97	23.21	23.80	20.43
Fe_2O_3	2.63	3.72	1.70	2.93	3.53	3.48	–	–	–	–	–	–	–	–	–	–	–
FeO	1.18	1.67	0.76	1.32	1.59	0.57	2.13	2.61	2.89	2.18	1.62	1.86	1.60	2.31	3.07	2.22	2.65
MnO	0.05	0.07	0.02	0.03	0.05	0.07	0.10	0.12	0.57	0.11	0.14	0.08	0.06	0.12	0.13	0.09	0.35
MgO	0.95	0.75	0.04	0.75	0.08	0.80	0.50	0.39	0.57	0.56	0.16	0.10	0.17	0.18	0.36	0.48	0.35
CaO	2.87	4.29	1.14	3.48	1.72	2.37	1.54	1.70	1.70	1.01	1.29	1.96	1.09	1.97	2.47	1.26	1.42
Na_2O	4.78	4.13	5.32	3.77	3.04	3.82	6.72	7.19	7.06	6.31	4.18	4.77	6.87	5.97	7.65	5.96	6.13
K_2O	4.40	4.68	6.00	4.82	8.87	5.31	9.26	8.54	9.06	9.56	11.28	10.83	8.74	9.38	8.52	8.82	10.79
P_2O_5	0.09	0.09	0.09	0.14	0.13	0.09	0.11	0.12	0.10	0.11	0.11	0.08	0.07	0.09	0.13	0.11	0.11
									ppm								
Zn	44	46	37	28	49	57	–	–	–	–	–	–	–	–	–	–	–
Rb	146	179	262	159	259	198	349	106	199	139	429	343	–	–	–	–	–
Ba	1370	1180	991	1424	2933	1130	238	228	227	240	244	250	–	–	–	–	–
Sr	1249	997	592	826	847	650	3385	4657	1648	2126	2268	2852	–	–	–	–	–
Ga	19	20	23	19	21	18	17	17	31	25	27	17	–	–	–	–	–
Nb	11	20	20	14	36	19	38	57	107	88	20	32	–	–	–	–	–
Zr	240	284	343	235	331	281	266	394	101	575	164	245	–	–	–	–	–
Y	17	31	13	17	25	27	–	–	–	–	–	–	–	–	–	–	–
Th	14	30	62	30	61	40	–	–	–	–	–	–	–	–	–	–	–

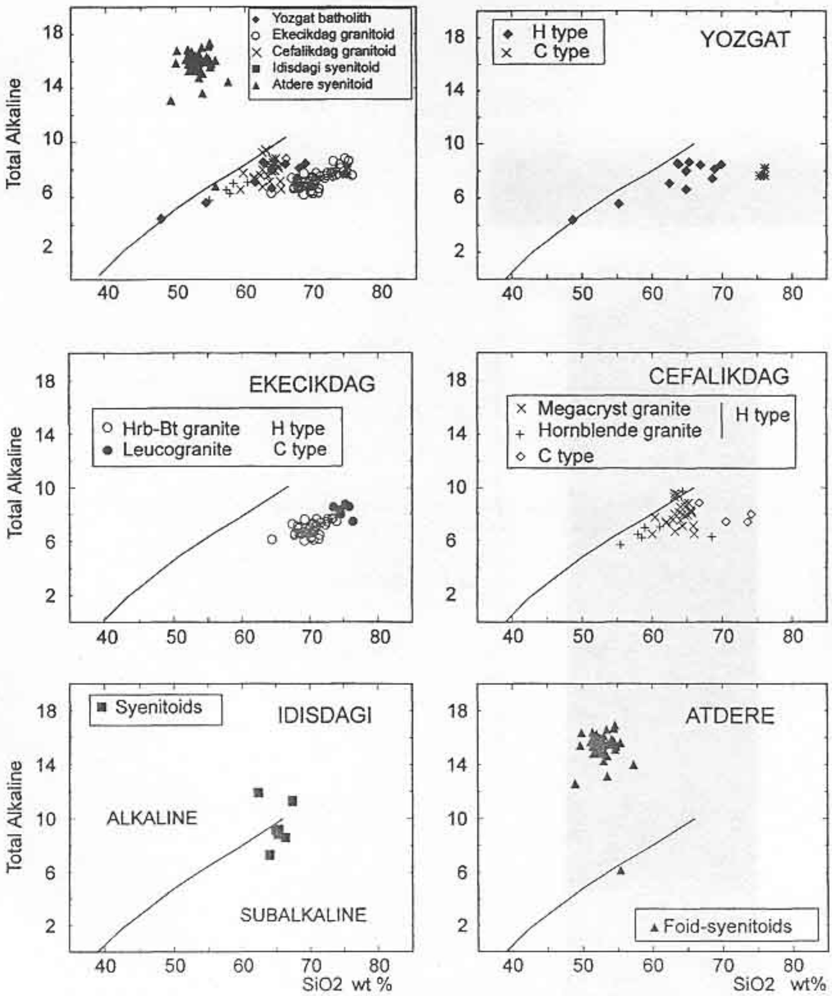

FIG. 7. Plot of total alkalis versus SiO_2, where alkaline and subalkaline fields are from Irvine and Baragar (1971).

typically are free of K-feldspar megacrysts and mafic enclaves.

The Cefalikdag intrusion has been investigated by Seymen (1982), Erler et al. (1991), and Geven (1992). It covers an area of 76 km^2 and comprises three units (Figs. 1 and 4): the Küçüktepe megacrystic quartz monzonite; the Savcilibeyit hornblende granite and quartz monzodiorite; and the Kaletepe micrograntite (aplite). The Küçüktepe and Savcilibeyit units dominate the intrusion (Geven, 1992).

All three intrusions are composite and essentially display two major granitic types—leucogranites and hornblende ± K-feldspar megacrystic granites with microgranular enclaves. In general, the leucogranites represent the earliest granitic phase and form only a minor part of the CACC. Their size and form vary significantly from meter-scale patches to geographically distinct intrusions of several square kilometers. They are composed of K-feldspar, quartz, and plagioclase with apatite, zircon, and opaques as accessory minerals. Additionally, the presence of garnet ± muscovite ± tourmaline clearly reflects their peraluminous nature. The leucogranites are classified as of the C type (see Aydin, 1997) and are likely to have been derived from crustal protoliths (Aydin et al., 1998).

Granitic magmatism in central Anatolia is dominated by hornblende ± biotite–bearing quartz-

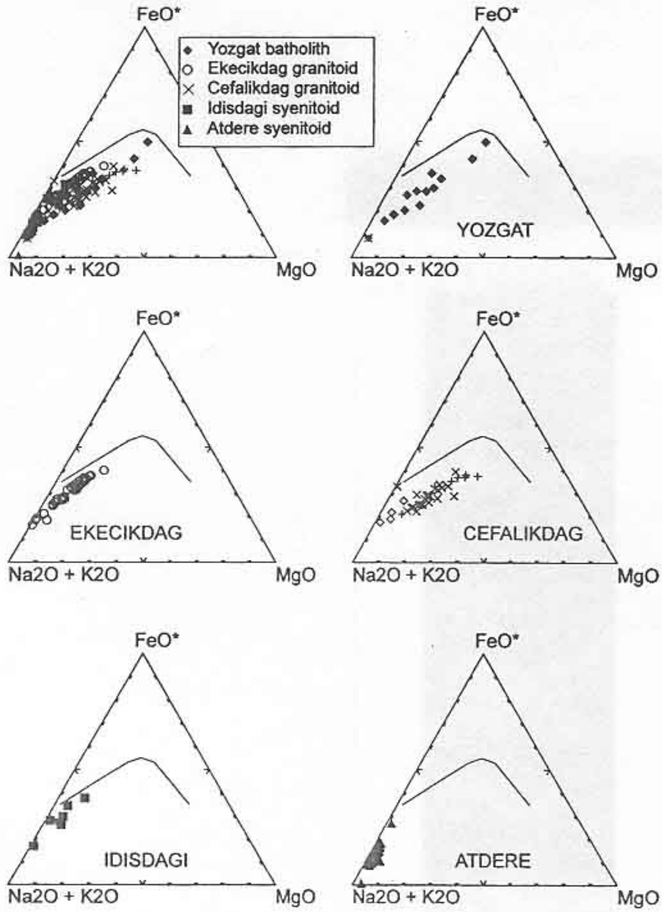

FIG. 8. AFM diagram, where tholeiitic and calc-alkaline fields are from Irvine and Baragar (1971).

monzonites, monzonites, and monzogranites. They consist of perthitic K-feldspar megacrysts, plagioclase, quartz, and hornblende with the accessory minerals apatite, zircon, sphene, and opaques. K-feldspar megacrysts are euhedral and ubiquitously display simple twinning and poikilitic texture, suggesting their magmatic origin (Düzgören-Aydin, 2000). The mafic enclaves are characterized by the presence of primary igneous features—i.e., lack of deformation and recrystallization, acicular apatite grains, and blade-shaped biotite ± quartz ocelli rimmed by mafic minerals. The presence of K-feldspar megacrysts and/or mafic microgranular enclaves provides information on the origin and evolution of their host rocks (Hibbard, 1981; Vernon, 1984; Didier and Barbarin, 1991). It has been suggested that the mingling of contrasting magmas plays a significant role in the formation of the monzogranitic rocks of the CACC (Kadioglu and Güleç, 1996; Aydin, 1997; Düzgören-Aydin, 2000). These rocks, which represent the late phase of granitic magmatism in central Anatolia, are classified as belonging to the H type, emphasizing their hybrid nature, which requires a significant mantle-derived magmatic contribution to their genesis (Aydin et al., 1998).

Field and petrographic features of the syenitic rocks

After the intrusion of the granites, extensive syenitic magmatism developed in central Anatolia (Özkan, 1987; Özkan and Erkan, 1994; Bayhan and Tolluoglu, 1987; Boztug, 1998; Köksal and Göncüoglu, 1997). There is, however, no commonly accepted petrogenetic model to explain the origin and evolution of these syenites. They consist of sil-

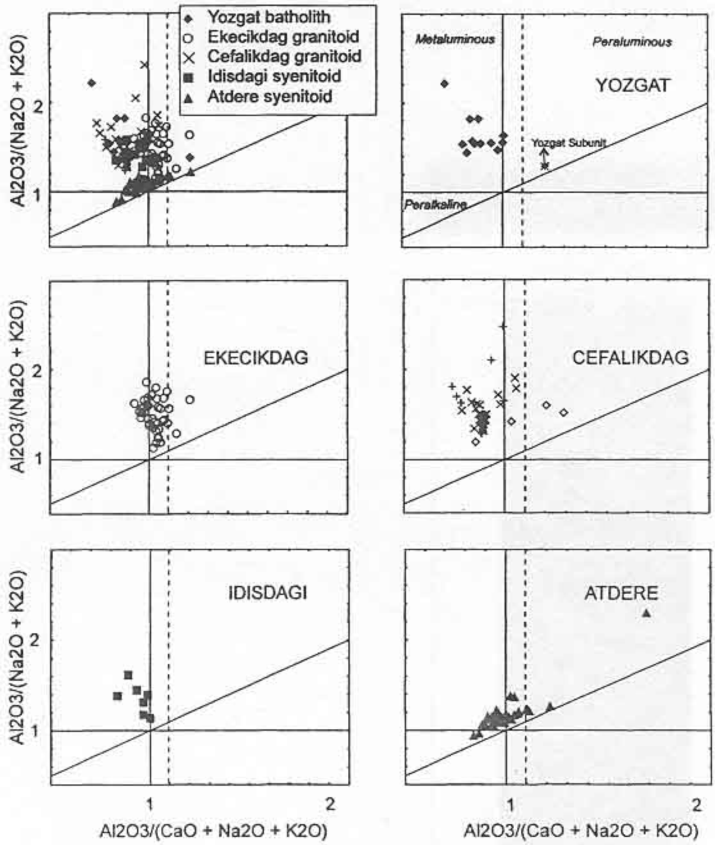

FIG. 9. Shand's diagram, after Maniar and Piccoli (1989).

ica-oversaturated/saturated syenites and monzonites, and undersaturated syenites. Here, the Idisdagi and Atdere intrusions (Fig. 1) are described as representatives of silica-oversaturated/saturated and undersaturated syenites, respectively.

Göncüoglu et al. (1997) indicated that the Idisdagi syenite intrudes both the Paleozoic–Mesozoic metamorphic basement and the Late Cretaceous granites (Fig. 5). It is overlain by uppermost Cretaceous(?)–Lower Paleocene volcaniclastic rocks and cut by feldspathoid dikes, and is therefore thought to be of Early Maastrichtian age. The intrusion consists of dominant quartz syenite and lesser amounts of K-feldspar–rich syenites. These rocks are medium to fine grained and locally display a porphyritic texture. They are composed of K-feldspar, quartz, plagioclase, and amphibole with minor amounts of biotite, muscovite, and clinopyroxene. Sphene and opaque minerals are ubiquitous accessory minerals.

The Atdere intrusion (Figs. 1 and 6) has been investigated by Özkan (1987) and Özkan and Erkan (1994), who divided this intrusion into four petrographic types on the basis of modal mineralogy: nepheline syenite, cancrinite-nepheline syenite, sodalite-nepheline syenite, and melanite-nepheline syenite. The Atdere intrusion displays holocrystalline-hypidiomorphic granular texture with alkalifeldspar and feldspathoids including nepheline, sodalite, cancrinite, and melanite as the main minerals. Accessory minerals include biotite, aegerine-augite, zircon, and sphene.

It is generally accepted that the feldspathoid-bearing syenites are younger than the granites and quartz-bearing syenites (Ketin, 1955; Ayan, 1963; Seymen, 1982; Bayhan and Tolluoplu, 1987). However, the only available geochronological data for silica-undersaturated syenites of the CACC are published by Gündogdu et al. (1988). Their work is based on Rb/Sr whole-rock systematics of the Bay-

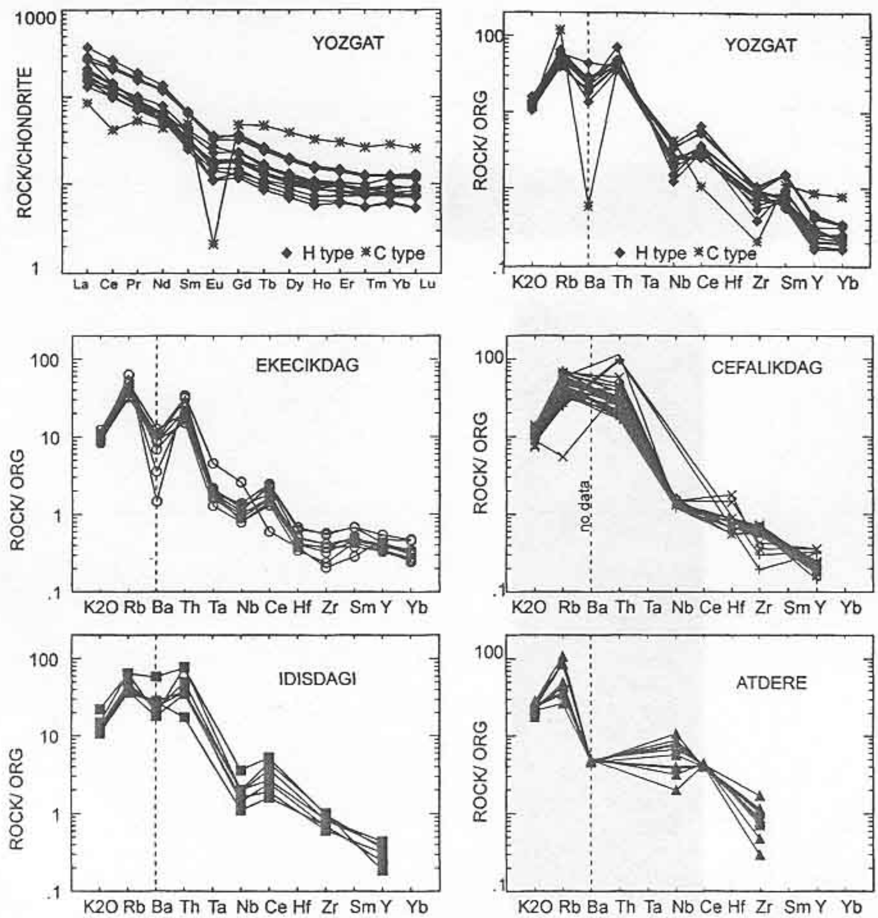

FIG. 10. Chondrite-normalized REE (for Yozgat Batholith) and ocean-ridge granite (ORG) normalized trace-element diagrams (normalizing values are from Sun, 1982 and Pearce et al., 1984, respectively).

indir feldspathoidal syenites, which provide an age of 70.1 ± 1.1 Ma.

Geochemical features of the granitic and syenitic rocks

The data presented in Tables 2 and 3 are complied from previously published as well as unpublished data sets. Those for the Yozgat, Ekecikdag, Cefalikdag, Idisdagi, and Atdere intrusions are from Düzgören-Aydin (2000), Türeli (1991), Geven (1992), Göncüoglu et al., (1997), and Özkan and Erkan (1994), respectively.

The granitic rocks of the CACC are subalkaline and reveal a well-developed calc-alkaline trend, whereas syenitic rocks are slightly to strongly alkaline and plot in the alkaline corner of the AFM diagram. (Figs. 7 and 8). The H-type granites fall into the metaluminous field of Shand's diagram, whereas the C types plot within the peraluminous field (Fig. 9). The Idisdagi intrusion, representing silica-saturated syenites, is metaluminous, whereas the Atdere intrusion representing the silica-undersaturated syenites displays rather scattered data, although most fall within the metaluminous field (Fig. 9).

The only reliable REE data for the granites is from the Yozgat intrusion (Fig. 10). The chondrite-normalized REE diagram reveals that each granite unit displays its own characteristic REE pattern. The H-type granites typically reveal LREE enrichment relative to HREE, moderate to weak MREE depletion, and weakly developed negative Eu-

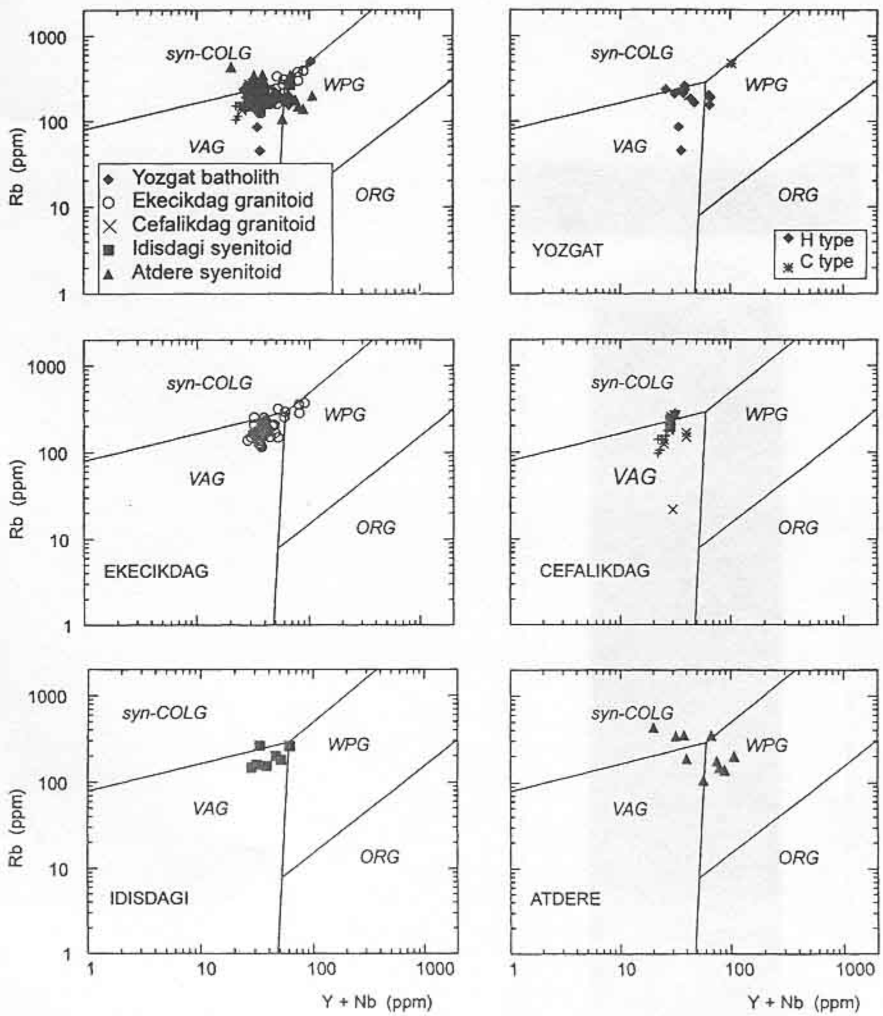

FIG. 11. Tectonic discrimination using Rb versus Y + Nb and Nb versus Y (after Pearce et al., 1984).

anomalies. The C-type granites exhibit flat REE patterns with well-developed negative Eu-anomalies. Unfortunately, no REE data are available for the syenites.

On extended normalized REE plots (extREE), the granites are clearly different from the syenites (Fig. 10). As predicted from previous diagrams, different granite types have distinct extREE patterns. The C-type granites display well-developed negative Ba anomalies compared to the H-type granites. The syenitic rocks have high Ba and Sr contents. Ba and Sr contents of samples from the Idisdagi intrusion vary from 903 to 2933 ppm and 650 to 1249 ppm, respectively, and from 227 to 238 ppm and 1648 to 3385 ppm, respectively, for the Atdere intrusion. In general, the rocks display moderately developed negative Nb anomalies.

Tectonic Setting: Discussion and Conclusion

The felsic rocks of the CACC appear to have been intruded immediately following the collision of the Tauride-Anatolide platform with the Pontides and/or Sakarya Continent (Akiman et al., 1993). It should be noted that, in our view, a post-collisional setting can include various geological events—

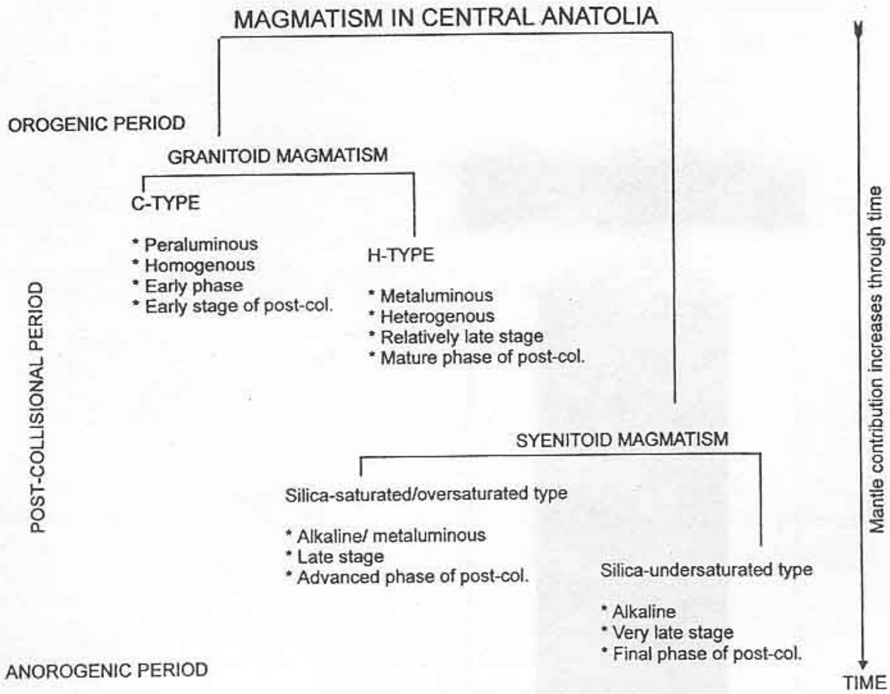

FIG. 12. Model for magmatism in central Anatolia during the Mesozoic post-collisional period.

including oblique collision and transtensional tectonics, lithospheric delamination, and rift generation—that characterize a continuous or episodic extensional regime (Liegeois, 1998). The trace element discrimination diagrams of Pearce et al. (1984) can be used to suggest the tectonic settings of the granitic and syenitic rocks of the CACC, although it is important to note that application of these diagrams does not unequivocally define tectonic setting. In general, most samples plot close to the triple junction of WPG, Syn-COLG, and VAG (Fig. 11). In detail, the C-type granites mainly plot as WPG and Syn-COLG, whereas the H-type granites fall into VAG and Syn-COLG fields. However, the C-type granites typically have low Zr, Ce, Sm, and Ba contents that are inconsistent with WPG. Similarly, many of the field and petrographic features of the H-type granites, particularly the presence and abundance of mafic micro-granular enclaves and K-feldspar megacrysts, and the presence of hornblende ± clinopyroxene ± biotite as the dominant ferromagnesian minerals, are inconsistent with both Syn-ColG and WPG.

Samples from the Idisdagi intrusion mainly plot as VAG, whereas samples from the Atdere intrusion fall within the Syn-COLG and WPG fields. Field, petrographic, and/or geochemical features of the syenitic rocks, such as their alkaline nature, are more consistent with WPG, although it is important to note that high Ba and Sr contents do not support such a classification. Because the high Ba and Sr contents suggest a significant crustal contribution to the genesis of these rocks, these syenites are best classified as orogenic alkaline rocks.

Any petrogenetic model of the diverse magmatism in central Anatolia must take into account the presence of: (1) composite (C- and H-type) granitic magmatism followed by syenitic magmatism in less than 50 m.y., the maximum time difference between granites and syenites, on the basis of available geochronological data; (2) leucocratic, peraluminous C-type granites, which represent the early magmatic phase and require mainly crustal sources; (3) metaluminous H-type granites, which dominate magmatism in central Anatolia and require a significant mantle-derived mafic magma contribution in their genesis; and (4) orogenic alkaline rocks (syenitic rocks) representing the advanced stage of magmatism, with physical and chemical features suggestive of mantle sources.

These observations suggest that, over time: (1) the type of magmatism varied from peraluminous, through metaluminous to alkaline; and (2) the relative direct contribution of mantle melts increased. With this in mind, the diverse magmatism of the CACC can be considered to have been produced in the same dynamic post-collisional setting. Figure 12 summarizes a model in which the early phase of the post-collisonal period gave rise to crustal-derived C-type granites, requiring significant thermal energy gained from mantle-derived mafic magma emplaced into the lower crust following lithospheric delamination. At this stage, no direct contribution from mantle-derived magma occurred. The following mature and advanced stages of magmatism occurred in a continuous or episodic extensional regime. In the mature stage, mingling/mixing processes between co-existing mantle-derived mafic and crustal-derived felsic magmas gave rise to H-type granitic rocks. In the advanced stages of the post-collisional period, alkaline orogenic rocks were formed. Thus, as the extensional regime developed either progressively or episodically, the relative contribution of the mantle in the genesis of the rocks of the CACC increased.

Acknowledgments

The authors would like to thank Drs. Quentin G. Crowley and Todd Housh for constructive criticism.

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