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Latest Cretaceous Magmatism in the Central Anatolian Crystalline Complex: Review of Field, Petrographic and Geochemical Features

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Abstract: Magmatic, metamorphic and ophiolitic rock assemblages in Central Anatolia are collectively named as the Central Anatolian Crystalline Complex (CACC). Magmatic rocks form significant portion of the CACC and display a range of fabrics, mineralogies and compositions. However, composite granitoid intrusions, such as the Yozgat, Ağaçören, Ekecikdağ and Cefalıkdağ, dominate the geology of the complex. Overall, there are two main types of Central Anatolian Granitoids (CAG): a) the C-type (crustal) leucogranites and b) the H-type (hybrid) hornblende ± K-feldspar megacrysts ± mafic microgranular enclave bearing granites. The emplacement of granitoid magmatism was followed by the syenitoid magmatism where the quartz syenitoids (e.g., the İdişdağı Intrusion) predate the feldspathoid bearing syenitoids (e.g., the Atdere Intrusion). The type of magmatism in the CACC varies from peraluminous, metaluminous to alkaline/peralkaline through time.

The C-type granitoids represent the early granitoid phase of the CACC and are considered to be products of the syn-collisional magmatism. The H-type granitoids and the syenitoid intrusions represent the advanced and final stages of the post-collisional magmatism, respectively. The C-type granitoids are likely derived from upper crustal sedimentary protolith by partial melting induced by crustal thickening with or without intrusion of mantle-derived mafic melts. Most of the field and petrographic features of the H-type granitoids require mantle-derived mafic magma contributions in the genesis of these rocks which can be explained in terms of mafic magma underplating of lower crust as a result of lithospheric delamination. Transition from silica-saturated to silica-undersaturated magmatism can be attributed to variation of availability of water in the melting zone. In general, the nature of magmatism in the CACC and related magmatic processes and the relative contributions of source material varied through time.

Orta Anadolu Kristalen Karmaşığında En Geç Kretase Magmatizması: Arazi, Petrografi ve Jeokimya Bulgularının Gözden Geçirilmesi

Özet: Orta Anadolu'daki magmatik, metamorfik ve ofiyolitik kayaç toplulukları hep birlikte Orta Anadolu Kristalen Karmaşığı (OAKK) olarak adlanırlar. Magmatik kayaçlar, OAKK'nın önemli bir bölümünü oluştururlar ve farklı dokular, mineralojik içerikler ve bileşimler sergilerler. Ancak, Yozgat, Ağaçören, Ekecikdağ ve Cefalıkdağ gibi kompozit granitoid intrüzyonları karmaşığın jeolosinde egemen durumdadır. Genel olarak Orta Anadolu Granitoidleri (OAG) iki ana gruba ayrılır: a) C-tipi (kabuksal) lökogranitler ve b) H-tipi (hibrid) hornblend±K-feldspat megakristleri±mafik mikrogranüler anklavlar içeren granitler. Granitoid magmatizmasının yerleşmesini izleyen siyenitoid magmatizma evresinde ilk fazı kuvars siyenitoidler (örneğin, İdişdağı intrüzyonu) ikinci fazı ise feldspatoidli siyenitoidler (örneğin, Atdere intrüzyonu) oluşturur. Zaman boyunca OAKK'ndaki magmatizma türleri peralüminalıdan metaalüminalıya ve giderek alkalin/peralkaline doğru değişir.

C-tipi granitoidler OAKK'ndaki erken granitoid evresini temsil ederler ve çarpışma-sırası magmatizmasının ürünleri olarak kabul edilirler. H-tipi granitoidler ve siyenitoid intrüzyonları çarpışması-sonrası magmatizmasının, sırasıyla, ilerlemiş ve son evrelerini temsil ederler. C-tipi granitoidler, olasılıkla üst kabuğa ait kayaçlarda kabuksal kalınlaşmanın yol açtığı kısmi ergimeyle oluşmuşlardır. Bu evrede manto-kökenli mafik ergiyiklerin katkısı belirgin değildir. H-tipi granitoidlerin arazi ve petrografik özelliklerinin çoğu bu kayaçların evriminde, litosferik sıyrılma sonucu olarak alt kabuğun mafik magma ile altlanması biçiminde açıklanabilen, manto-kökenli mafik magma katkıları gerektirir. Silikaca-doygun magmatizmadan silikaca-doymamış magmatizmaya geçişin nedeni ergime zonundaki su miktarındaki değişmeler olabilir. Genel olarak, OAKK'ndaki magmatizmanın türü, ilişkili magmatik süreçler ve kaynak malzemenin göreceli katkıları zaman boyunca değişmiştir.

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Introduction

Magmatic, metamorphic and ophiolitic rock assemblages in Central Anatolia are collectively named as the Central Anatolian Crystalline Complex (CACC; Göncüoğlu et al., 1991). The complex lies in a triangular area bounded by the Tuzgölü fault to the west, the Ecemiş fault to the east and the İzmir-Ankara-Erzincan suture to the north (Fig. 1). The CACC has been recently re-mapped by the METU-CACC Study Group (Göncüoğlu et al., 1994 and the references therein). Magmatic rocks dominate the geology of the complex and intrude the ophiolitic and metamorphic rocks of the complex. The complex is overlain by Uppermost Maastrichtian, Lower Paleocene and Eocene volcanic, clastic and carbonate rocks, Oligocene-Miocene evaporite and clastic rocks and Miocene-Pliocene continental clastic rocks (Göncüoğlu et al., 1991; 1992; 1993).

Granitoids and syenitoids form a significant portion of the complex. Although they have been subjected to numerous geological, petrographical and geochemical studies, their tectonic setting and nature of the relevant magmatism are still unresolved. This paper summarizes main field, petrographic and geochemical features of the selected granitoid and syenitoid intrusions of the CACC mainly based on the studies of the METU-CACC Study Group. The main goal of this compilation is to construct a common framework upon which a petrogenetic model for the diverse magmatism of the CACC can be based. In this study, the Yozgat, Ağaçören, Ekecikdağ and Cefalıkdağ intrusions are reviewed to characterize the granitoid magmatism of the CACC, whereas the İdişdağı and Atdere intrusions are discussed to represent the syenitoid magmatism of the complex. Note that this study is presented (Aydın et al., 1997) during the TÜBİTAK-BAYG/NATO-D program on Alkaline Magmatism in Central Anatolia in September 1997 in Sivas.

Geologic and Petrographic Framework

The granitoid rocks dominate the geology of the complex and reveal a wide range of fabrics, mineralogies and compositions. They crop out within three distinct belts (Fig. 1). These are: a) a large number of individual

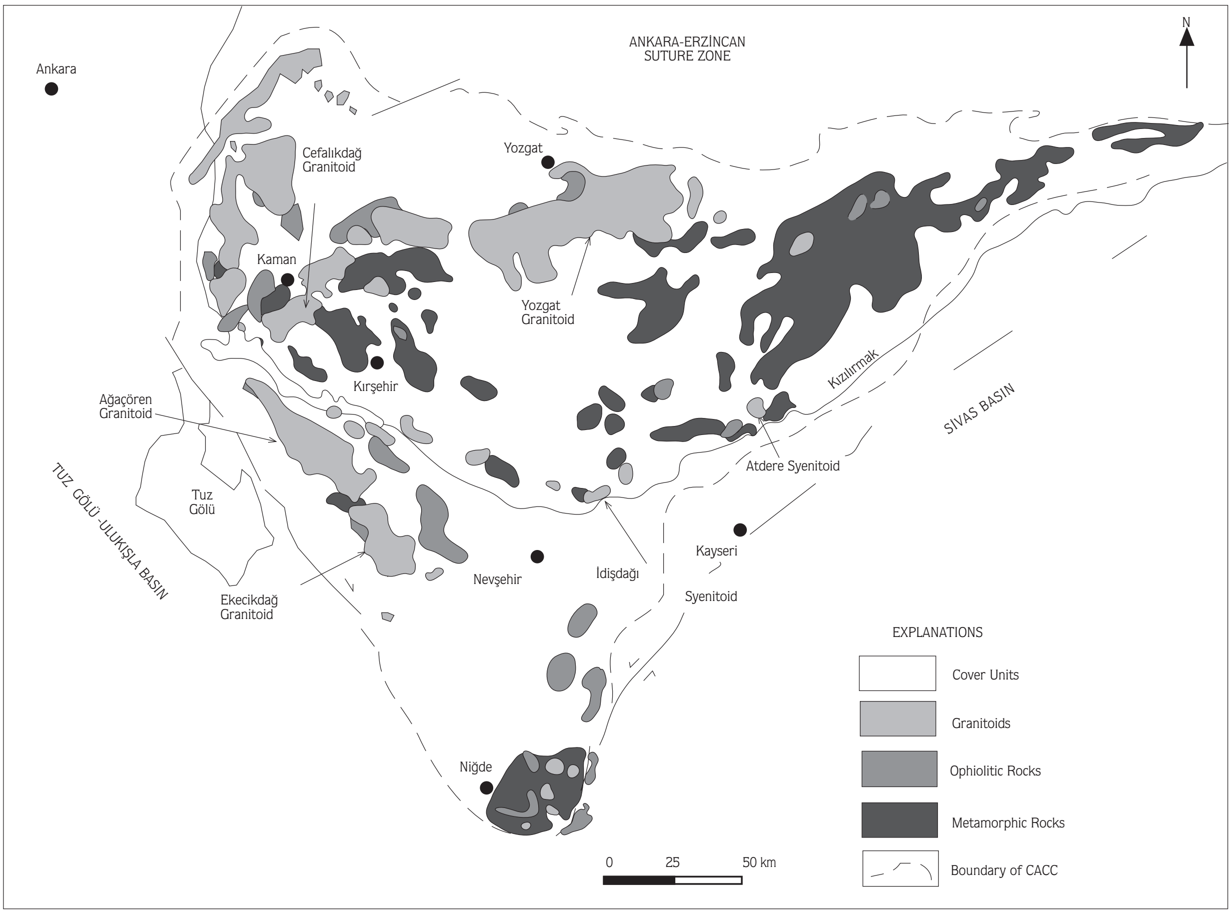

Figure 1. Location map and simplified geological setting of the Central Anatolian Crystalline Complex.

small plutons exposed along the western margin extending from NE-SW to NW-SE ; b) a relatively narrow and smaller set of disconnected plutons exposed along the eastern margin; and c) a large intrusion exposed along the northern margin (Erler et al., 1991). The granitoid rocks can be grouped as a) two-mica leucogranites; b) biotite/hornblende granites; c) K-feldspar megacryst-bearing granites; d) granodiorites; e) tonalites; and f) aplitic K-feldspar granites (Erler and Göncüoğlu, 1996). Most of the granitoid intrusion of the CACC, e.g. the Yozgat, Ağaçören, Ekecikdağ and Cefalıkdağ intrusions, comprises several subunits (Erler et al., 1991; Erler and Bayhan, 1995; Erler and Göncüoğlu, 1996; Kadıoğlu, 1996; Kadıoğlu and Güleç, 1996; Tatar and Boztuğ, 1997; Aydın, 1997; Aydın et al., 1997; 1998). However, overall they contain two main granitoid types: a) locally garnet bearing leucogranites and b) hornblende ± biotite ± clinopyroxene bearing granites.

Leucogranites forming only a minor part of the complex represent the early magmatic phase of the complex (Akıman et al., 1993; Erler and Göncüoğlu 1996; Boztuğ, 1997). Their size and form vary significantly from meter scale patches to several km scale geographically distinct subunits within Ağaçören, Ekecikdağ and Yozgat intrusions. Main minerals are K-feldspar, quartz and plagioclase, the accessory minerals are apatite, zircon, garnet, muscovite and opaque phases. Presence of garnet ± muscovite ± tourmaline, clearly suggest their peraluminous nature. The leucogranites are typically free of K-feldspar megacrysts and mafic microgranular enclaves, and have been classified as crustal-type (C-type) (Aydın, 1997; Aydın et al., 1997; 1998) according to the classification system proposed by Barbarin (1990).

Hornblende ± biotite ± clinopyroxene bearing granites display compositional variation from quartz monzonites to monzogranites. Main minerals are perthitic K-feldspar, plagioclase, quartz and hornblende, the accessory minerals are apatite, zircon, sphene and opaque minerals. In general, lack of riebeckite, garnet, muscovite, sillimanite or cordierite imply that these granitoid bodies are neither peralkaline nor peraluminous. They typically contain variable size K-feldspar megacrysts (2-15 cm in length) and mafic microgranular enclaves. The examined K-feldspar megacrysts from the granitoids of the CACC are euhedral and ubiquitously display simple twinning and poikilitic texture suggesting their magmatic nature. Mafic microgranular enclaves of the CACC (on the basis of the data particularly from the Ağaçören and Yozgat intrusions) are characterized by the following physical features. The presence of a) primary igneous features, i.e. lack of deformation and recrystallization; b) acicular apatite grains; and c) blade-shape biotite ± quartz ocelli rimmed by mafic minerals (Kadıoğlu and Güleç, 1996; Tatar and Boztuğ, 1997). These features clearly suggest that commingling of contrasting magmas play a significant role in the formation of the hornblende ± biotite ± clinopyroxene bearing rocks of the CACC (Kadıoğlu and Güleç, 1996; Tatar and Boztuğ, 1997; Aydın et al., 1997). Thus, this type granitoid rocks of the CACC have been classified as hybrid-type (H-type) to emphasize their nature (Aydın, 1997; Aydın et al., 1997; 1998) according to the classification system proposed by Barbarin (1990).

Following the granitoid intrusions, an extensive syenitoid magmatism was developed. The syenitoid magmatism has been subjected to many studies (e.g., Özkan, 1987; Erler et al., 1991; Özkan and Erkan, 1994; Bayhan and Tolluoğlu, 1987; Boztuğ, 1997; Otlu and Boztuğ, 1997; Göncüoğlu et al., 1997). The syenitoid magmatism includes both silica-oversaturated /saturated syenitoids and monzonites and silica-undersaturated syenitic rocks. İdişdağı Intrusion represents the silica-saturated/oversaturated syenitoids, whereas the Atdere Intrusion characterize the silica-undersaturated syenitoids.

The following features of the İdişdağı Intrusion are summarized from Göncüoğlu et al. (1997). The intrusion is composed of quartz and K-feldspar bearing syenites. They are medium- to fine- grained and locally display porphyritic texture and composed of K-feldspar, quartz, plagioclase and amphibole with minor amounts of biotite, muscovite and clinopyroxene. Sphene and opaque minerals are ubiquitous accessory phases.

The Atdere Intrusion (Kayseri) was investigated by Özkan (1987) and Özkan and Erkan (1994). These authors divided the Atdere Intrusion into four different subunits on the basis of their modal mineralogy. These are nepheline syenite, cancrinite-nepheline syenite, sodalite-nepheline syenite, and melanite-nepheline syenite. Although there is no direct dating on feldspathoid bearing syenitoid rocks, it is generally accepted that these rocks are younger than the granitoids and quartz bearing syenitoids (Ayan, 1963; Seymen, 1982; Bayhan and Tolluoğlu, 1987; Erler et al, 1991; Boztuğ, 1997; Otlu and Boztuğ, 1997). The Atdere Syenitoids display holocrystalline-hypidiomorphic granular texture. Alkali-feldspar and feldspathoid minerals including nepheline, sodalite, cancrinite and melanite are the main minerals. Main accessory minerals are biotite, aegirine-augite, zircon and sphene.

Radiometric data on the age of the Central Anatolian Granitoids is very limited. In general, Rb/Sr whole-rock isochron data from Niğde-Üçkapılı (95 ± 11 Ma, Göncüoğlu, 1986) and Ağaçören granitoids (110 ± 14 Ma, Güleç, 1994) indicate a late early Cretaceous to early late Cretaceous intrusion age. Syenitic rocks from the Bayındır area, that intrude the granitoids yield Rb/Sr whole rock isochron ages of 85.1 ± 3.6 Ma (Kuruç, 1990). Rb/Sr whole rock-mineral isochron ages from granitoids (Cefalık Dağ: 71 Ma, Ataman, 1972; Üçkapılı: 78 Ma, Göncüoğlu, 1986) as well as K/Ar biotite and muscovite ages (Üçkapılı, 78 to 75 Ma, Göncüoğlu, 1986) on the other hand are interpreted as cooling ages. According to this data, the radiometric ages for the granitoid intrusions range between 110 to 85 Ma. This data is in limited accordance with the recent findings, at least with those from the central (Terlemez) and northern (Çiçekdağ) parts of the CACC, where fossil-bearing epi-ophiolitic sediments of early Middle Turonian to latest Coniacian are intruded by monzonitic rocks. K/Ar mineral data from the Terlemez quartz-monzonite (81 to 67 Ma, Yalınız et al., 1997) as well as the regional transgression of latest Maastrichtian-earliest Paleocene marine-lacustrine sediments on the CACC (Göncüoğlu, 1986; Göncüoğlu et al, 1991) puts further restraints on the age of the granitic intrusions.

Geochemical Framework

Geochemical data presented in this paper are compiled from published as well as unpublished data sets. Data for the Yozgat, Ağaçören, Ekecikdağ, Cefalıkdağ, İdişdağı and Atdere intrusions are from Aydın et al. (1998), Kadıoğlu (1996), Türeli (1991), Geven (1992), Türeli et al. (1993), Göncüoğlu et al., (1997) and Özkan and Erkan (1994), respectively.

The main whole rock geochemical features of the granitoids of the CACC are as follows. The granitoids are subalkaline (Fig. 2) and exhibit well-developed calc-alkaline trend on the AFM diagram of Irvine and Baragar (1971) (Fig. 3). The H-type granitoids of the CACC are metaluminous, whereas C-type granitoids are slightly to strongly peraluminous (Fig. 4). Ocean ridge granite (ORG) normalized spider diagram is utilized to present the trace element chemistry of the granitoids of the CACC (Fig. 5). In general, samples from the complex reveal large ion lithophile elements (LILE- e.g., K_2O, Rb) enrichment relative to the high field strength elements (HFSE- e.g., Zr, Y). However, the C-type granitoids and aplitic dykes show strong negative Ba-anomalies together with moderate Zr anomalies, wheras the H-type granitoids display slightly to moderately developed negative Ba- and Zr anomalies.

The İdişdağı syenitoids are mostly subalkaline to slightly alkaline, whereas the feldspathoid bearing syenitoids (the Atdere Intrusion) are strongly alkaline (Fig. 2). Both of the syenitoid intrusions are typically rich in alkaline content and concentrated on the alkaline corner of the AFM diagram (Fig. 3) of the Irvine and Baragar (1971). The İdişdağı syenitoids are metaluminous, whereas the Atdere syenitoids are slightly peralkaline (Fig. 4). On the ORG normalized spider diagram, the İdişdağı Intrusion display weakly developed negative Ba- and Nb-anomalies (Fig. 5). Note that there is no enough data from the Atdere Intrusion to compare the trace-element geochemistry of the intrusion with those of the İdişdağı Intrusion.

Trace element classification diagrams of Pearce et al. (1984) are utilized to present the tectonic settings of the granitoids and syenitoids of the CACC (Fig. 6). Most of the investigated samples plot close to triple junction of WPG (Within Plate Granite), Syn-COLG (Syn-Collisional Granite) and VAG (Volcanic Arc Granite). In detail, the C-type granitoid rocks plot on WPG and Syn-COLG fields, whereas the H-type granitoids fall into WPG and Syn-COLG fields. Samples from the İdişdağı Intrusion plot mainly on the VAG, whereas samples from the Atdere Intrusion fall within the Syn-COLG and WPG fields.

Summary and Conclusions

Granitoid and syenitoid rocks dominate the geology of the CACC and a wide range of composition. However, there are two main granitoid types in the complex: a) the C-type leucogranites and b) the H-type, hornblende ± K-feldspar megacrysts ± mafic microgranular enclave bearing granites. The emplacement of granitoid magmatism was followed by the syenitoid magmatism where the quartz syenitoids (e.g., the İdişdağı Intrusion) predate the feldspathoid bearing syenitoids (e.g., the Atdere Intrusion). The type of magmatism varies from peraluminous, metaluminous to alkaline/ peralkaline through time.

Petrographic, field and geochemical features of the leucogranites of the CACC including: a) their peraluminous nature; b) the presence of garnet; c) the lack of ferromagnesian minerals, K-feldspar megacrsyts and mafic microgranular enclaves, are typical of crustal derived granitoids (Barbarin , 1990). Although the C-type granitoids of the complex plot within both Syn-COLG and WPG, they typically have low Zr, Ce, Sm, and Ba contents

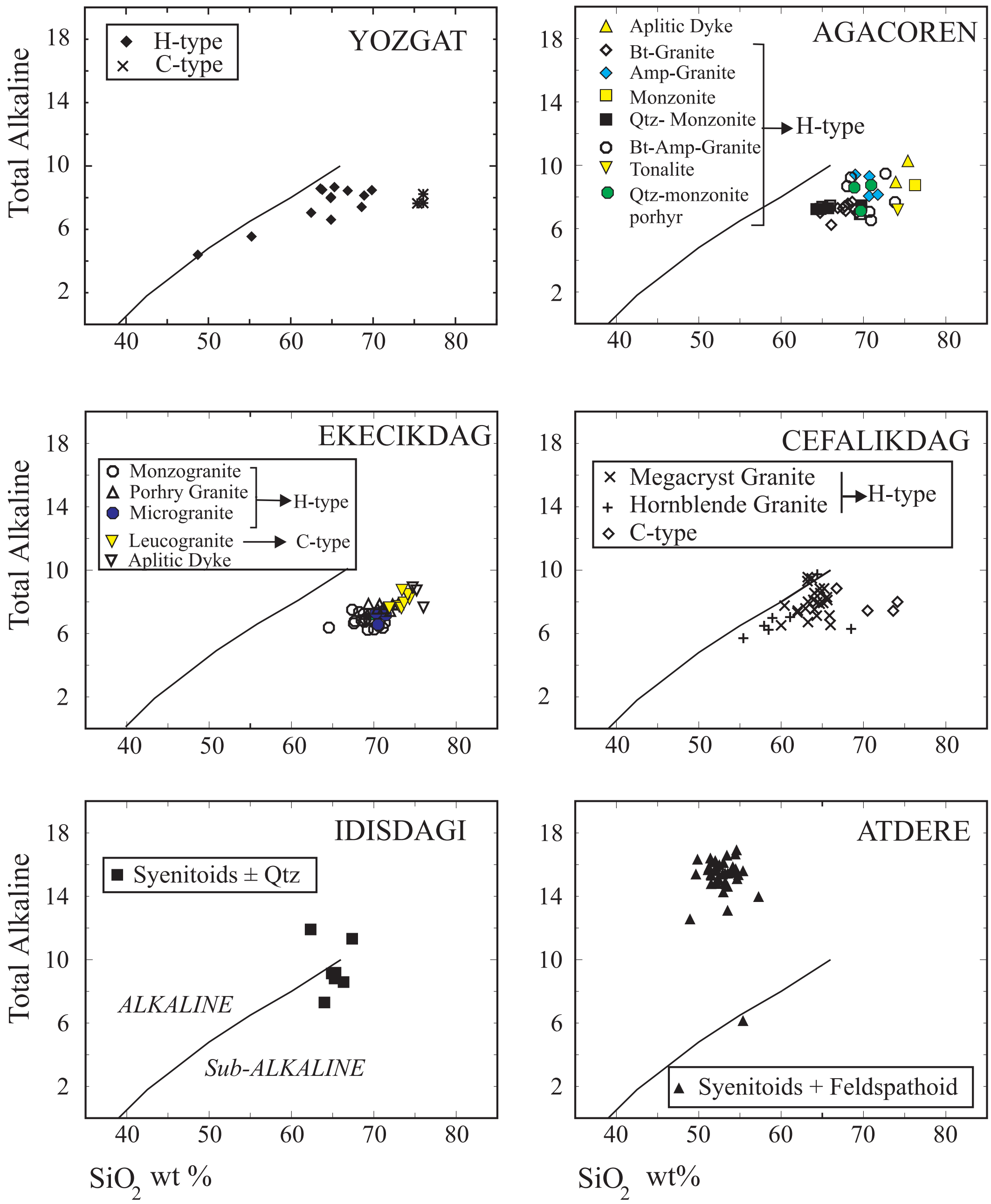

Figure 2. Plots of the total alkali *versus* SiO_2 diagram where alkaline and subalkaline fields are from Irvine and Baragar (1971).

which is inconsistent with WPG. Thus, the C-type granitoids can be considered to be products of syn-collisional magmatism which can be attributed to crustal thickening with or without any direct contribution from the mantle-derived mafic magma. They may have been derived from upper crustal sedimentary rocks.

The H-type granitoids of the CACC are metaluminous, locally includes mafic microgranular enclaves and/or K-feldspar megacrysts and contain hornblende ± clinopyroxene ± biotite as the dominant ferromagnesian minerals. These features require a mantle derived mafic magma contribution in the genesis of these rocks which can be explained in terms of mafic magma underplating

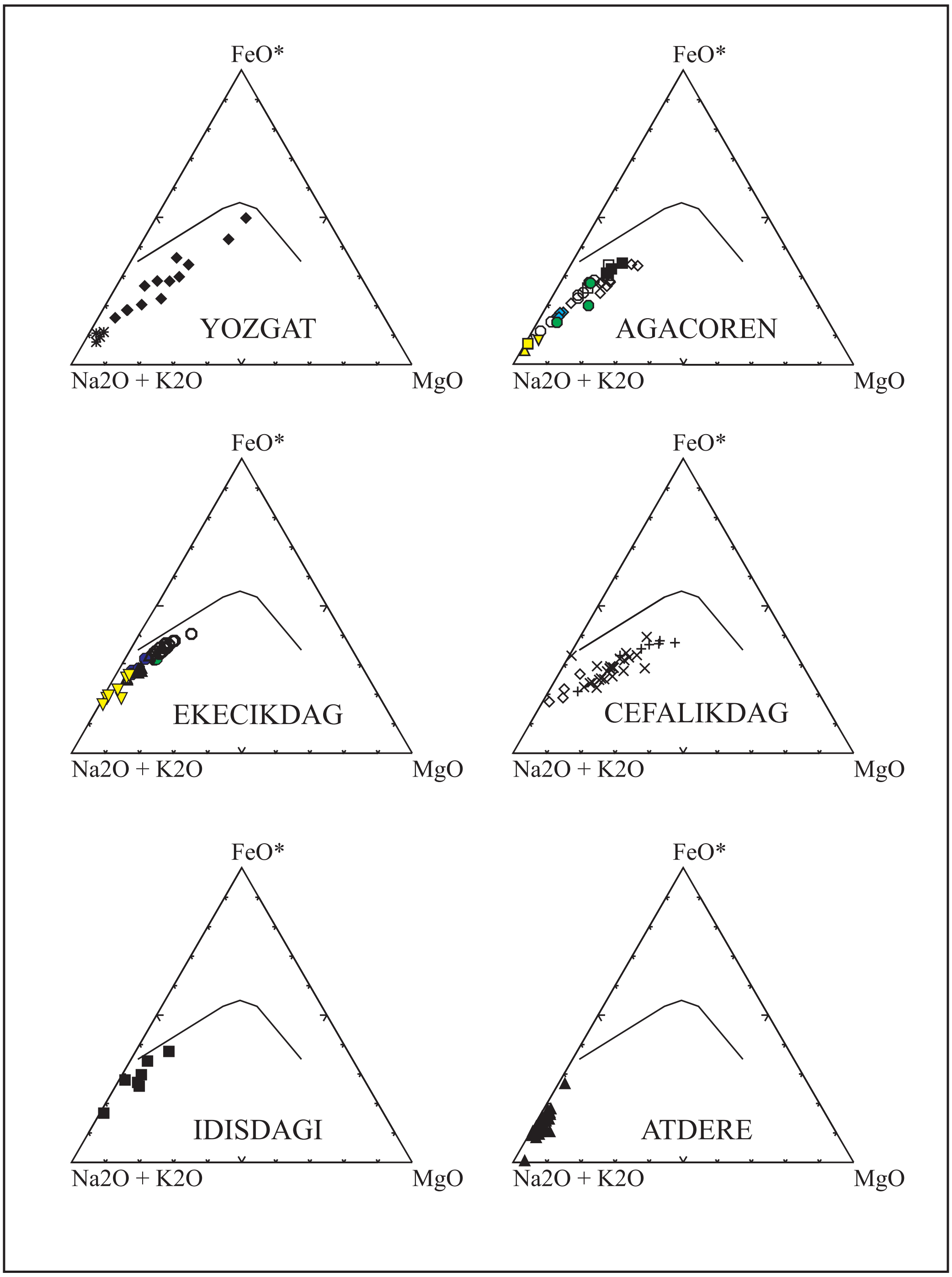

Figure 3. Plots of AFM diagram where tholeiitic and calc–alkaline fields are from Irvine and Baragar (1971). Symbols an in Fig. 2.

of lower crust as a result of lithospheric delamination following the crustal thickening. With this in mind, the H-type granitoids can be considered products of post-collisional magmatism of the CACC.

Syenitoid rocks are slightly to strongly alkaline. Although, they display similar trace element geochemical features with those of the WPG, they are considered post-collisional alkaline magmatism in the CACC on the

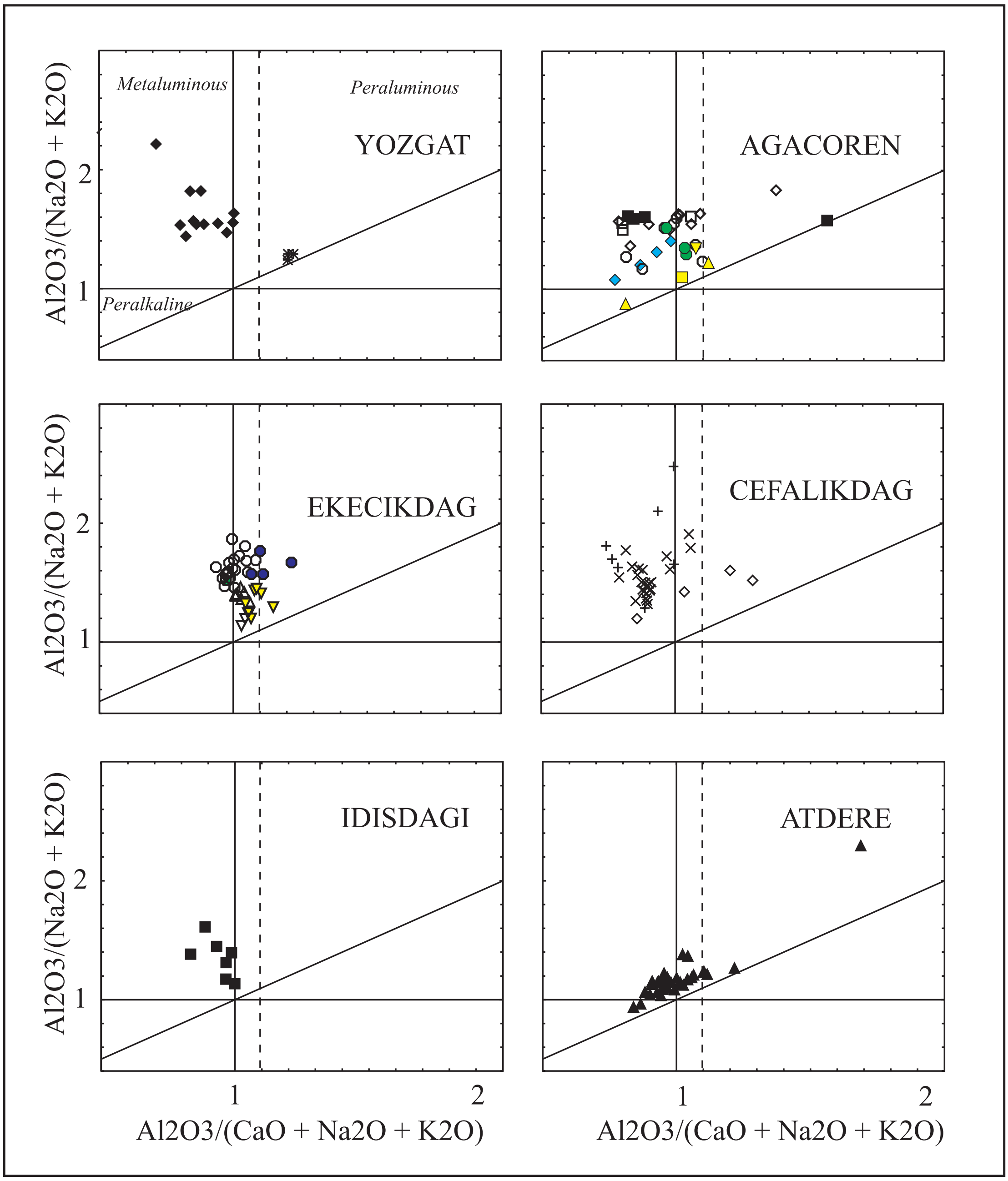

Figure 4. Shand Index diagram after Maniar and Piccoli (1989). Symbols as in Fig. 2.

basis of their mineralogical and geochemical features (Göncüoğlu et al., 1997; Boztuğ, 1997). Note that type of syenitoid magmatism vary from silica-(over)saturated to silica-undersaturated intrusions. This transition might reflect source characteristics or can simply be explained in terms of variation in availability of water in the melting zone (cf., Bonnin, 1988; Boztuğ, 1997).

The main implications of these observations are as follows. Through time, a) type of magmatism in the CACC varies from peraluminous, metaluminous to alkaline; b) the nature of the magmatic processes and relative contributions of source materials vary; c) relative contribution of mantle-derived mafic magma in the genesis of the magmatic rocks of the complex increases;

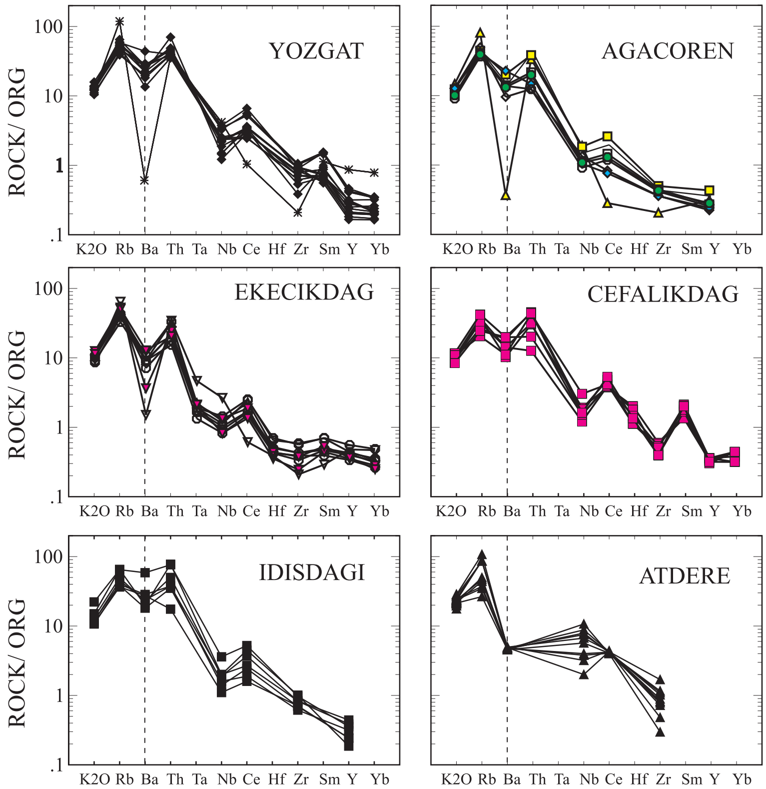

Figure 5. Occean ridge granite (ORG) normalized spider diagrams. Normalizing values are from Pearce et al. (1984). Symbolis as in Fig. 2. Note that samples from the Cefalıkdağ intrusion represent only the H–type granitoids (due to simply availability of samples).

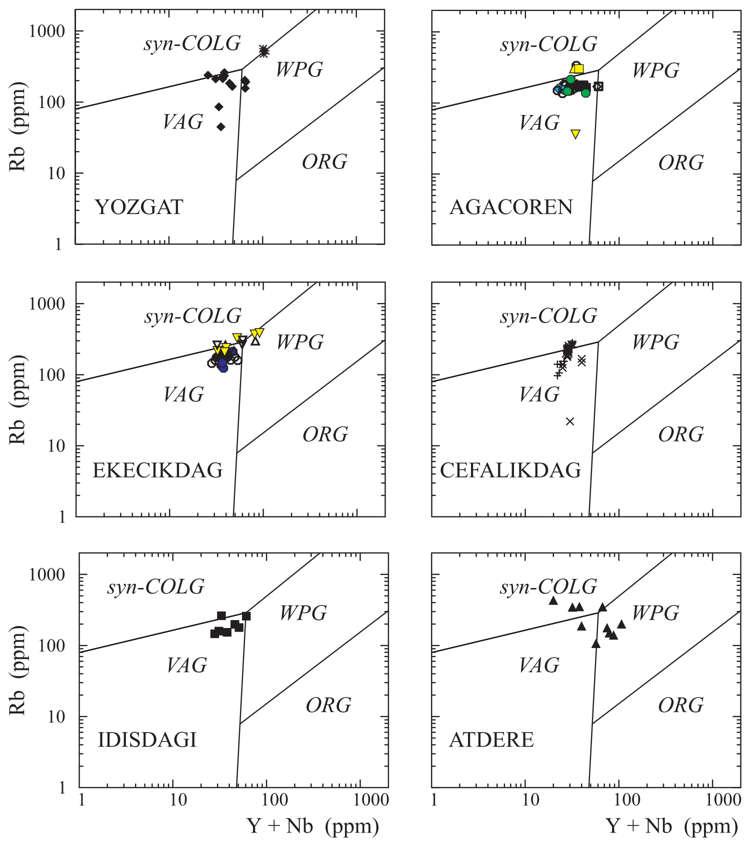

Figure 6. Tectonic discrimination diagrams of Rb *versus* Y+N and Nb *versus* Y (after Pearce et al., 1984). Symbols as in Fig. 2.

d) tectonic setting vary from syn-collisional to post-collisional; e) products of post-collisional magmatism vary from the H-type granitoids to the syenitoids ; f) syenitoid magmatism vary from silica-oversaturated/saturated to silica-undersaturated. However, the presented common framework for the magmatism in the CACC which is summarized in Table 1, need to be substantiated by relevant geochronologic and isotopic data.

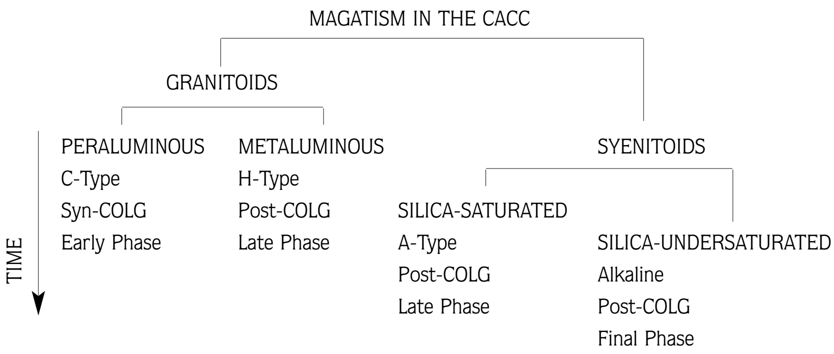

Table 1. Summary of diverse magmatism in the Central Anatolian Crystalline Complex (CACC).

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