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Genetic Relations Between Skarn Mineralization and Petrogenesis of the Evciler Granitoid, Kazdağ, Çanakkale, Turkey and Comparison with World Skarn Granitoids

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Abstract: Most skarn deposits are directly related to magmatic activity, and there is a systematic correlation between the composition of causative plutons and the metal contents of the related skarns. This paper documents the composition of facies within the Evciler pluton and correlations between intrusion composition and the metal contents of associated skarns. There have been previous studies of mines (e.g., Cu mines) in the Evciler district, however, there have been no detailed geological investigations of such ore deposits or associated skarn mineralization. In the Evciler district both calcic exoskarn (garnet-pyroxene) and endoskarn (pyroxene-epidote) occur along the contacts between granitoid and marble. Calc-silicate mineral compositions in the Evciler skarns are similar to those in Au-Cu and Fe-Cu skarns.

Based on mineralogy and geochemistry, three main facies have been recognized in the Evciler pluton: (1) the Çavuşlu monzodiorite, (2) the Karaköy granodiorite and (3) the Evciler quartz diorite-granodiorite, the mesocratic unit of the Evciler pluton. At the Evciler district, monzogranitic rocks, termed leucocratic Evciler, have a limited distribution compared to the mesocratic Evciler rocks. Field evidence for the relative timing of intrusions and trace-element geochemistry of the individual facies suggest that the Evciler pluton formed in a magmatic arc or post-collisional setting from a hybrid source, having crustal and mantle components contaminated by interaction with the upper crust.

Whole rock $\delta^{18}O$ values of the Evciler granitoid decrease from 8.5 to 2.5‰ towards the intrusive contact, which is closest to the calcic skarn mineralization (Au-Cu), and the quartz $\delta^{18}O$ composition of the Evciler granitoid varies from 7.2 to 10.9‰. These values are normal for I-type, primary unaltered values for this intrusive rock, but are too large to be accounted for by simple magmatic differentiation. Therefore, the Evciler granitoid must have been subjected to post-emplacement open-system hydrothermal alteration with introduction of external fluids (probably meteoric water) which changed the original magmatic $\delta^{18}O$ values.

The present study shows that the geochemical characteristics of the Çavuşlu monzodiorite, Karaköy granodiorite and mesocratic Evciler rocks are similar to averages for Au-Cu and Fe-skarn granitoids, whereas the geochemical characteristics of the leucocratic Evciler rocks are similar to averages for Sn- and Mo-skarn granitoids. The Evciler granitoid is also characterized by relatively unevolved to moderately evolved and oxidized suites, as in most Au-Cu core metal associations globally.

Key Words: gold, copper, skarn, mineralization, Evciler granitoid, Kazdağ, NW Turkey

Skarn Mineralizasyonu ve Evciler Granitoyidinin (Kazdağ, Çanakkale, KB Türkiye) Petrojenezi Arasındaki Kökensel İlişki ve Dünyadaki Skarn Granitoidleri ile Karşılaştırılması

Özet: Birçok skarn yatağı doğrudan magmatik aktivite ile ilişkilidir ve skarn yataklarının metal içerikleri ve skarn oluşumuna neden olan plutonların bileşimleri arasında sistematik bir ilişki söz konusudur. Bu çalışma, Evciler plutonu içindeki fasiyeslerin bileşimleri ve intrüzyon bileşimi ve bir arada bulundukları skarnların metal içerikleri arasındaki korelasyonu ortaya koymaktadır. Evciler bölgesinde eski maden işletmeleri (örn., Cu madeni) bulunmaktadır, bununla birlikte skarn mineralizasyonu veya benzer maden yatakları açısından ayrıntılı bir jeolojik çalışma yapılmamıştır. Evciler bölgesinde, kalsik eksoskarn (granat-piroksen) ve endoskarn (piroksen-epidot) granitoid ve mermer arasındaki dokanak boyunca ortaya çıkmaktadır. Evciler skarnlarındaki kalk-silikat mineral bileşimleri, Au-Cu ve Fe-Cu skarnlarından alınan alterasyon minerallerinin bileşimlerine benzerdir.

Evciler plutonunda mineralojik ve jeokimyasal açıdan üç ana fasiyes ayırt edilmektedir; bunlar, (1) Çavuşlu monzodiyoriti, (2) Karaköy granodiyoriti ve (3) mezokratik-tip Evciler olarak adlandırılan Evciler kuvars diyorit-graondiyoritidir. Aynı zamanda, Evciler bölgesinde monzogranit bileşimli kayaçlar mezokratik-tip Evciler'e göre daha sınırlı yayılım sunmaktadır ve lökokratik-tip Evciler olarak adlandırılmaktadır. Sokulum zamanına ilişkin arazi verileri ve her bir fasiyesin iz element jeokimyası Evciler plutonunun, üst kabukla etkileşim ile kirlenmiş, kabuk ve manto bileşenlerine sahip melez bir kaynaktan, magmatik-yay veya çarpışma sonrası bir ortamda oluştuğunu önermektedir.

Evciler granitoyidinin tüm kayaç $\delta^{18}O$ değerleri kalsik skarn mineralizasyonuna (Au-Cu) oldukça yakın sokulum dokanağına doğru 8.5‰'den 2.5‰'e azalmaktadır ve Evciler granitoidine ait quartz $\delta^{18}O$ bileşimleri 7.2'den 10.9‰'e değişmektedir. Bu değerler I-tipi altere olmamış intrüzif kayaçlar için normaldir, fakat basit bir magmatik farklılaşma için oldukça geniş bir aralığa sahiptir. Bu nedenle, Evciler granitoyidi, bölgeye yerleşimi sonrasında açık-sistem hidrotermal alterasyona uğramış ve muhtemelen meteorik su girişi ile ilksel magmatik $\delta^{18}O$ bileşimi değişmiştir.

Bu çalışma, Evciler granodiyoritinin jeokimyasal özelliklerinin Au-Cu, Fe-skarn granitoyidlerinin ortalama değerleri ile benzerlik sunduğunu göstermektedir. Buna karşın, Evciler lökograniti ise Sn- ve Mo-skarn granitoyidlerine benzerlik göstermektedir. Evciler granitoyidi dünyadaki birçok Au-Cu çekirdek metal topluluklarına benzer şekilde ilksel-orta derecede evrim geçirmiş ve okside olmuş magmalarla benzer karakter sunmaktadır.

Anahtar Sözcükler: altın, bakır, skarn, mineralizasyon, Evciler granitoyidi, Kazdağ, KB Türkiye

Introduction

The Evciler granitic pluton is located in Kazdağ, northwestern Anatolia, and is a 170 km^2 elliptical metaluminous calc-alkaline body, with its long axis trending WSW–ENE, of Late Oligocene–Early Miocene age (25±3 Ma; Birkle 1992), which intrudes the Kazdağ Massif (Figure 1).

Although there are historical workings (mainly Cu mines) in the Evciler district, no modern exploration occurred until 1996 when a company conducted detailed stream-sediment geochemical surveys to identify anomalies caused by hydrothermal alteration. Numerous copper and gold anomalies were found to be associated with exoskarn. The exploration studies by this company focused on geology and ore-reserve estimation of mineralization within individual bodies, such as the pyrrhotite-rich Au skarn zone at the south end of the Evciler pluton. However, the relationship between skarns and associated plutons, and the potential for different types of mineralization associated with the Evciler granitoid, have not yet been studied.

Broad correlation between igneous compositions and the metal contents of associated skarns has been described by several workers (Zharikov 1970; Shimazaki 1975, 1980; Kwak & White 1982; Meinert 1983, 1995; Newberry & Swanson 1986; Newberry 1987; Keith *et al.* 1989; Newberry *et al.* 1990; Meinert *et al.* 1990; Paktunc 1990; Ishihara & Sasaki 1991; Blevin & Chappell 1992; Naldrett 1992; Ray *et al.* 1995; Srivastava & Sinha 1997; Nicolescu *et al.* 1999; Martin-Izard *et al.* 2000; Meza-Figueroa *et al.* 2003). These studies have documented the relationship between metal contents in mineral deposits and major- and trace-element compositions, degree of crystallization, and tectonic settings of the related plutons.

The present study is the first report of correlations between skarns and the related Evciler granitoid in the Kazdağ region, northwestern Anatolia, Turkey.

Geological Setting

Studies on the geology, tectonics, petrology and geochronology of the Kazdağ Massif have been carried out by several workers (e.g., Şengör & Yılmaz 1981; Yılmaz 1989, 1990, 1995, 1997; Okay *et al.* 1990, 1996; Öngen 1992; Şengör *et al.* 1993; Genç 1998; Okay & Satır 2000; Duru *et al.* 2004). The high-grade metamorphic rocks of the Kazdağ mountain range, named the Kazdağ group, crop out as a tectonic window under the Karakaya complex (e.g., Duru *et al.* 2004; Göncüoğlu *et al.* 2004; Okay & Göncüoğlu 2004; Okay & Altıner 2004; Pickett & Robertson 2004 and references therein) in northwestern Turkey. The Kazdağ group forms a doubly plunging, NE–SW-trending anticlinorium.

Duru *et al.* (2004) subdivided the metamorphic rocks into four formations. The lowermost unit is the Fındıklı formation, comprising amphibole-gneiss, marble and minor amphibolite, and crops out mainly in the southern part of the Kazdağ Massif. The overlying unit, comprising metadunite and orthoamphibolite, is the Tozlu formation, which in turn is overlain by the Sarıkız marble. The uppermost unit, which crops out in the northern parts of Kazdağ Massif, is the Sutuven formation; it comprises sillimanite-gneiss, migmatite, marble, amphibolite and granitic gneiss.

The Sutuven formation rests with a sharp contact on the Sarıkız marble and Fındıklı formation (Duru *et al.* 2004), and is intruded by the Oligo–Miocene Evciler granodiorite. The Sutuven formation comprises mainly grey, dark grey and brown, well-banded quartzo-

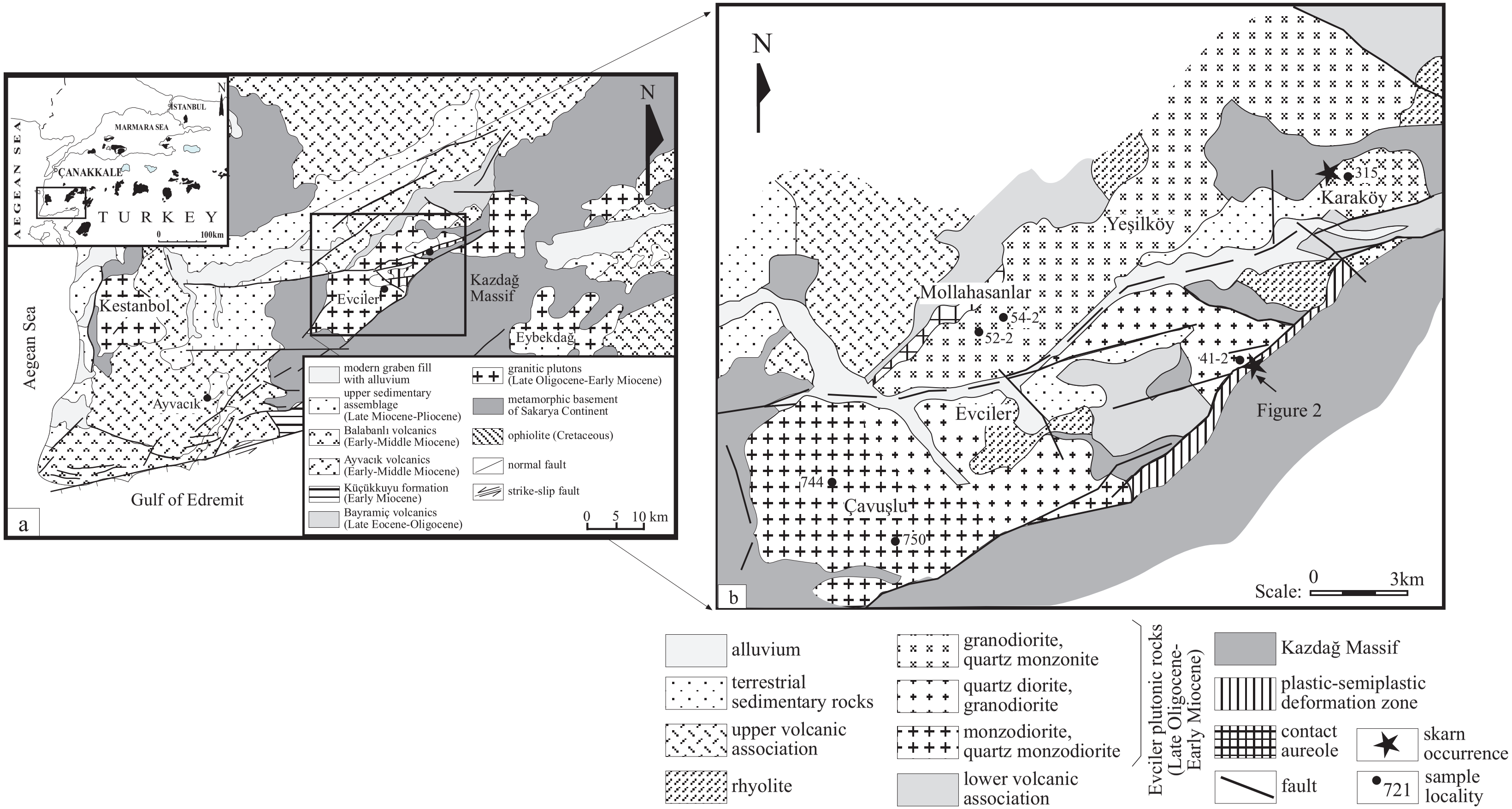

Figure 1. (a) Regional geologic map showing location of the Evciler district (simplified from Yılmaz & Karacık 2001); (b) geologic map of the Evciler district (simplified from Genç 1998).

feldspathic gneisses. These gneisses, which constitute the dominant lithology, comprise marble, amphibolite and granitic-gneiss horizons and lenses (Duru *et al.* 2004).

Metamorphism in the Kazdağ group has been dated using zircon Pb-Pb and mica Rb-Sr and K-Ar methods on gneisses from the Fındıklı and Sutuven formations. Pb-Pb data from the gneisses yield Mid-Carboniferous ages (308±16 Ma: Okay *et al.* 1996), whereas the biotite and muscovite Rb-Sr and K-Ar ages are Oligo–Miocene (19–22 Ma: Bingöl 1968, 1969; Okay & Satır 2000). These isotopic data have been interpreted as indicating two periods of high-grade metamorphism; the initial one during the Mid-Carboniferous and a later one in the Oligo–Miocene. The P-T conditions of the high-grade metamorphism have been estimated as 640±50 °C and 5±1 kbar (Okay & Satır 2000).

Magmatism in Western Anatolia

Many studies have been published concerning granitoids in an effort to understand the geodynamic evolution of western and northwesten Anatolia (Bingöl 1977, 1978; Şengör & Yılmaz 1981; Bingöl *et al.* 1982; Altherr *et al.* 1988; Genç 1998; Gülen 1990; McKenzie & Yılmaz 1991; Bozkurt *et al.* 1993, 1995; Bozkurt & Park 1994; Harris *et al.* 1994; Okay *et al.* 1996; Karacık & Yılmaz 1998; Delaloye & Bingöl 2000; Işık & Tekeli 2001; Gessner *et al.* 2001, 2004; Koralay *et al.* 2001, 2004; Bozkurt 2004; Erdoğan & Güngör 2004; Işık *et al.* 2004). Delaloye & Bingöl (2000) subdivided the granitoids in western and northwestern Anatolia, based on their ages, into two major groups: (1) younger granitoids (Late Cretaceous to Late Miocene) caused high-temperature metamorphic aureoles, and are defined by six isochronous belts which become progressively younger from north to south; and (2) older granitoids (Cambrian to Middle Jurassic), present in the northwestern and northern parts of Anatolia.

During the Oligocene–Middle Miocene, widespread magmatic activity had developed in western Anatolia, following the collision of the Sakarya Continent with the Tauride-Anatolide platform (Şengör & Yılmaz 1981; Yılmaz 1989, 1990, 1995, 1997; Şengör *et al.* 1993). Bingöl *et al.* (1982, 1992) suggested that the young granites formed in a post-collisional environment as a result of crustal thickening. However, complementary data presented by Delaloye & Bingöl (2000) are more consistent with a subduction-related origin. The Aegean subduction zone is an especially good candidate to play this role for the Eocene–Miocene granitoid belts (Delaloye & Bingöl 2000). The chemical signature of the granites is that of volcanic-arc granites (VAG), and may be related to N-dipping subduction. The still-active subduction zone must have begun by Oligocene time, but Delaloye & Bingöl (2000)'s data suggest that it may have been initiated earlier. This widespread magmatic activity produced both intrusive and extrusive rocks (Genç 1998), which appear to be associated in space and time in this region. In the Bayramiç area, magmatic activity began with intrusion of the Evciler granite, coeval with the lower volcanic association. This intrusive event was followed by an upper volcanic association. These rock groups collectively form the Bayramiç Magmatic Complex (Genç 1998).

Local Geology

Two main rock units are exposed in the Evciler district: the Kazdağ metamorphic rocks and the Evciler granitoid. The metamorphic rocks comprise mainly grey, dark grey, and brown well-banded quartzo-feldspathic gneisses which include marble, amphibolite and granitic gneiss horizons and lenses. Gneisses are characterized petrographically by the presence of biotite, sillimanite, garnet and hornblende along with ubiquitous quartz and feldspar. The marble has a granoblastic texture and is fine-grained. The grain size increases towards igneous contacts. Diopside-bearing amphibolites occur as bands, up to several meters thick, within gneiss and marble (Okay & Satır 2000).

The Evciler pluton occurs as a WSW–ENE-trending elliptical body that intruded gneiss and marbles of the Kazdağ Massif in the south, and its volcanic equivalents in the north. The Evciler pluton consists mainly of granodiorite to quartz-diorite, medium-grained and granular at its centre, and porphyritic and fine-grained towards its margin (Genç 1998). The pluton contains numerous aplite dykes, veins and rounded to lensoidal mafic microgranular enclaves.

Mineralogy and Petrology of the Evciler Granitoid

The Evciler pluton comprises mainly granodiorite, quartz monzonite, monzodiorite and quartz diorite. Öngen

(1992) and Genç (1998) subdivided the pluton into three main facies (Figure 1b): (1) The Çavuşlu monzodiorite is the earliest facies of the pluton and has equigranular and coarse-grained texture. This unit mainly consists of intermediate microcline (15%, Or_{89-90}), automorphic plagioclase (48%, An_{45-35}), quartz (14%), biotite (10%), poikilitic magnesium hornblende (9%) and augite (4%). (2) The Karaköy granodiorite is the main facies of the pluton and occurs in the northeasthern part of the pluton. This unit has fine- to medium-grained, porphyritic texture, and consists essentially of plagioclase (39%, An_{40-27}), interstitial orthoclase (24%, Or_{80-85}), quartz (24%), actinolitic hornblende (8%) and coarse-grained biotite (5%). (3) The contact between these two plutonic members is graditional and represented by melanocrate granodiorite, containing coarse-grained magnesium hornblende, here termed mesocratic-type Evciler rocks. It is medium to dark grey due to a higher abundance of mafic components. Phenocryst mineralogy includes major K-feldspar, plagioclase and quartz; minor amphibole, and pyroxene; and accessory titanite, apatite and magnetite. The presence of primary titanite and magnetite, combined with the absence of ilmenite, indicates that these are relatively oxidized magmas. Secondary minerals, formed via alteration, are epidote, sericite and chlorite, with pyroxene altered to amphibole. In the southern part of the pluton, monzogranitic rocks have a limited distribution compared to the mesocratic-type Evciler rocks, and are here termed leucocratic-type Evciler rocks. This rock type is light grey, fine- to medium-grained, and equigranular to porphyritic in texture, and consists mainly of K-feldspar, plagioclase, quartz, and secondary epidote and amphibole crystals, plus accessory titanite, apatite, and pyroxene. The K-feldspar is medium- to coarse-grained and has perthitic and myrmekitic textures. The boundaries of the leucocratic and mesocratic rocks are poorly mapped in the Evciler district because their contacts are not clearly observed. Although they are geochemically classified as two different granitoids, the field relations are unclear because of their obscured contacts.

Skarn Occurences

Skarns in the Evciler district (1) are mostly calcic, (2) have an oxidized mineralogy dominated by garnet, clinopyroxene, epidote and amphibole, (3) have epidote endoskarn close to the contact between marble and granitoid, and (4) contain pyrrhotite, chalcopyrite, magnetite, garnet, pyroxene, epidote, actinolite and chlorite at Ayazma, SE of Evciler village (Figure 2).

Endoskarn

Endoskarn formation began with epidotization, and was coincident with sericitization during metasomatic reactions. The endoskarn consists mainly of epidote and pyroxene. Along the contact with the exoskarn, replacement of granodiorite by massive epidote and minor garnet-pyroxene endoskarns over widths of centimetres to 0.5 m may result in complete destruction of the original igneous texture. This zone consists of fine- to medium-grained epidote accompanied by interstitial quartz (Figure 3a & b). Endoskarn located at Evciler also contains garnet and pyroxene accompanying the aforementioned mineral association. Farther into the granite, endoskarns occur only as disseminated epidote skarns, and are enriched in garnet towards the marble. The garnet-rich skarn predominantly comprises exoskarn. However, garnet locally developed by dissolution and replacement of primary igneous minerals, particularly feldspar, in the granodiorite (Figure 3c & d). Most garnets in the granodiorite are isotropic, whereas some garnets display anisotropy and sector and oscillatory zoning (Figure 3e & f).

Exoskarn

The alteration of the host rock (marble and gneiss) in the Evciler district is marked by the formation of coarsely crystalline skarn lenses due to the introduction of Si-, Al-, Fe-, and Mg-rich fluids into the host rock. At the contact between the Evciler granitoid and Kazdağ Massif, the earliest changes observed in the protolith involve recrystallization to fine-grained, dark grey-green hornfels with an assemblage of clinopyroxene-feldspar-quartz. Metasomatism of carbonate lithologies at Evciler produced grossular-andradite/pyroxene exoskarn. The dominant minerals of the exoskarn are pyroxene and garnet as components of the prograde assemblage, and epidote, tremolite/actinolite, chlorite and/or calcite and quartz as components of the retrograde mineral assemblage.

In the Evciler skarn, the exoskarn shows slight zoning in the pyroxene-epidote assemblages with plagioclase,

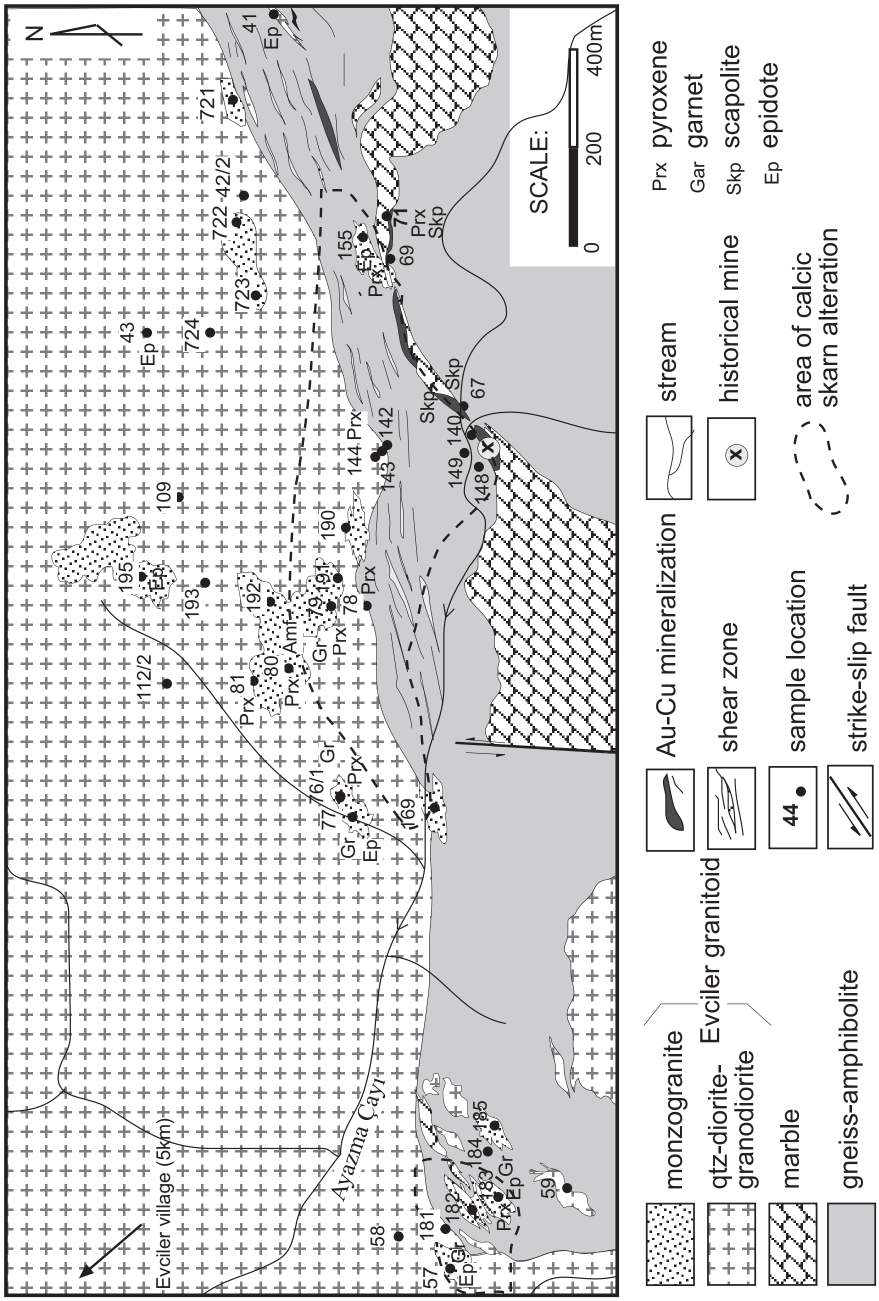

Figure 2. Geological map showing location of the skarn alteration and mineralization.

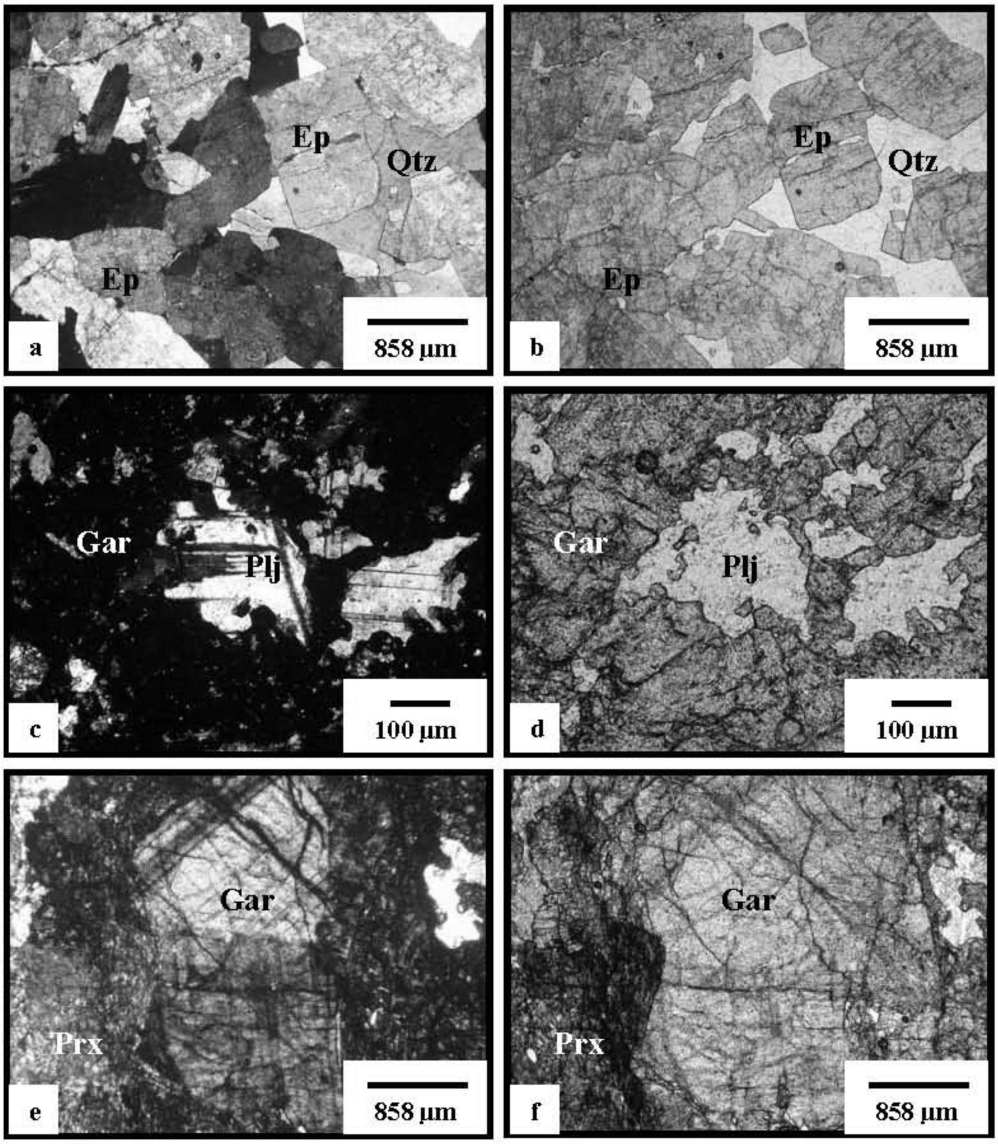

Figure 3. Typical endoskarn textures in the Evciler district. (a, b) massive epidote with interstitial quartz, (PPL and cross-nicols); (c, d) replacement of primary igneous minerals (plagioclase) by garnet (PPL and cross-nicols); (e, f) garnet showing oscillatory and sector zoning within the granodiorite (PPL and cross-nicols). Ep– Epidote, Qtz– Quartz, Gar– Garnet, Plj – Plagioclase, Prx– Pyroxene.

scapolite and titanite, close to marble front (distal skarn), and as garnet-pyroxene assemblages with chlorite and epidote close to the endoskarn zone (proximal skarn). The width of the individual zones ranges from cm-scale to 2–3 m (even locally 15–25 m). Epidote, tremolite/actinolite, chlorite and/or quartz and calcite typically represent the retrograde mineral phases formed by alteration of pyroxene and garnet in the advanced stages of skarn formation.

The prograde skarn mineral assemblage comprises garnet, clinopyroxene and scapolite (Figure 4a & b). Garnet and pyroxene are intimately intergrown, suggesting synchronous growth of these minerals. The garnet consists of anisotropic and isotropic zoned andradite to grossular ($Ad_{70-50}Gr_{30-50}$). Two types of garnets are observed in the exoskarns – smaller, isotropic garnets and largely anisotropic garnets with oscillatory zoning (Figure 4c & d). Their compositions are close to

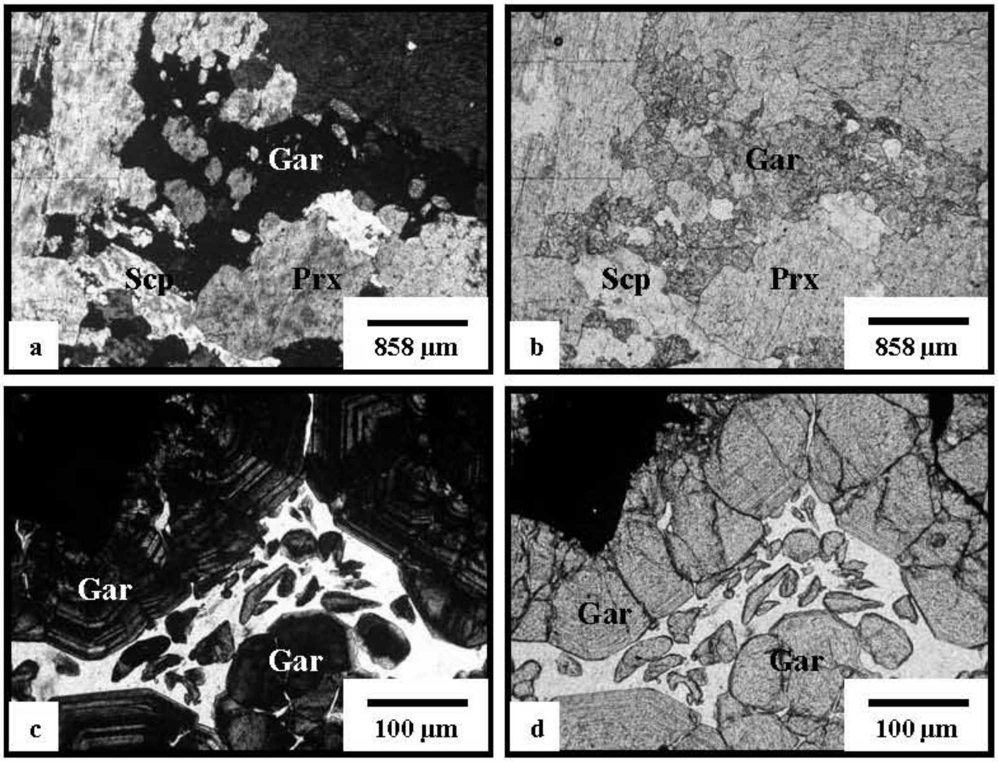

Figure 4. Typical exoskarn textures in the Evciler district. (a, b) Prograde skarn mineral assemblage comprising garnet, clinopyroxene and scapolite (PPL and cross-nicols); (c, d) garnet exoskarn consisting of anisotropic and isotropic zoned andradite to grossular (PPL and cross-nicols).

those of garnets from Au-Cu and Fe-Cu skarns (Einaudi *et al.* 1981; Meinert 1992). The pyroxenes are generally anhedral to subhedral, and hedenbergitic to diopsidic in composition ($Hd_{50-75}Di_{50-25}$), and are similar to those of pyroxenes from Au-Cu and Fe-Cu skarns (Einaudi *et al.* 1981; Meinert 1992). The pyroxenes were converted into tremolite/actinolite during retrogression. Calcic scapolite (meionite) typically formed during prograde alteration; its presence in the Evciler exoskarn suggests either a low-temperature scapolite variety or a former skarn assemblage. In so far as the Ca-scapolite grains are intergrown with clinopyroxene and garnets, the latter hypothesis is favoured (Figure 4c & d).

The main pyrrothite-rich mineralization is observed within exoskarn and resulted from the retrograde alteration of prograde calc-silicate assemblages, to chlorite and/or calcite. A magnetite-pyrrhotite-chalcopyrite assemblage is widespread, and magnetite is replaced by both pyrrhotite and chalcopyrite. Pyrrhotite is the main sulfide phase replaced by chalcopyrite. The sulfide mineralization typically developed within the pyroxene exoskarns and occurs intermittently along ~ 600 m of the contact between gneiss and marble belonging to the Sutuven formation (Kazdağ Massif).

Geochemistry and Petrogenesis

Thirty samples were collected from the several localities within the Evciler pluton for geochemical analysis and were analysed for both major- and trace-element contents. The results of the geochemical analysis are presented in Table 1.

In terms of major elements, most plutons associated with skarn deposits are fairly normal calc-alkaline rocks. All values from the Evciler granitoid plot as calc-alkaline (Figure 5a) and subalkaline (Figure 5b) rocks in the Irvine & Baragar (1971) classification scheme. The mesocratic- (quartz diorite-granodiorite) and leucocratic- (monzogranite) types, distinguished by field observations and petrographically, also appear as two distinct groups on these diagrams, suggesting that these are the products of two different magmas or that the leucocratic rocks are

Table 1. Major- and trace-element compositions of the Evciler pluton.

sample no	720-2	721	722-1	723-3	42-1	223/3	41-2	744	750	52-2	54-2	315
	Evciler leucogranite					Evciler granodiorite		Çavuşlu monzodiorite		Karaköy granodiorite		
SiO_2 (%)	73.71	72.64	73.81	74.41	73.34	68.66	56.46	62.14	58.22	61.7	64.79	66.55
TiO_2	0.08	0.12	0.10	0.05	0.09	0.23	0.72	0.57	0.65	0.55	0.47	0.37
Al_2O_3	13.91	14.14	13.32	13.25	14.04	15.15	16.81	15.81	16.25	16.41	15.73	15.18
$Fe_2O_3^T$	1.23	1.58	1.17	0.78	0.89	0.96	5.97	5.82	6.91	5.10	4.55	3.59
MnO	0.02	0.03	0.02	0.01	0.01	0.02	0.10	0.10	0.13	0.11	0.10	0.06
MgO	0.16	0.24	0.25	0.11	0.33	0.86	3.28	2.10	2.91	2.10	1.97	1.51
CaO	1.27	1.51	1.56	0.95	1.39	3.14	8.11	4.52	6.19	5.11	4.65	3.77
Na_2O	3.06	3.22	2.82	2.41	2.92	2.83	3.58	3.08	3.22	3.45	3.14	3.28
K_2O	5.40	4.83	5.41	6.40	5.87	6.51	2.36	4.17	3.20	2.97	3.43	3.73
P_2O_5	0.01	0.01	0.01	0.03	0.07	0.15	0.22	0.18	0.19	0.14	0.11	0.10
Ba (ppm)	699	817	1046	634	925	2611	1097	944	722	697	840	826
Sc	2	2	2	1	2	3	14	10	12	10	9	6
Co	1	2	3	1	2	3	15	15	20	12	11	7
Cs	2	1	1	3	1	1	1	3	6	2	10	6
Ga	20	20	17	16	17	20	19	18	20	18	17	17
Hf	3	4	3	2	2	6	5	6	6	5	4	4
Nb	10	5	6	6	3	14	9	10	12	9	8	9
Rb	196	152	142	231	151	188	61	139	129	93	112	133
Sn	1	2	1	< 1	< 1	< 1	3	1	2	1	< 1	< 1
Sr	196	381	260	205	188	1005	677	525	616	462	448	427
Ta	1	0	1	2	1	1	1	1	1	1	1	1
Th	25	17	26	19	7	32	6	21	21	35	14	21
U	7	5	6	12	8	7	2	6	6	7	4	7
V	13	23	15	13	10	25	178	132	155	103	98	73
W	2	3	1	1	2	2	2	2	2	2	5	2
Zr	66	111	63	47	43	197	160	198	176	144	116	124
Y	19	9	11	12	11	18	27	23	28	23	21	17
Mo	9	8	7	0	0	3	1	7	1	1	1	2
Cu	7	7	40	1	1	2	2	49	45	7	5	12
Pb	5	7	4	6	4	4	23	6	22	3	148	5
Zn	10	17	11	7	11	5	34	39	39	45	115	15
Ni	8	8	7	2	4	5	3	9	4	5	5	4
As	1	< .5	< .5	< .5	< .5	< .5	< .5	1	1	< .5	1	1
Au	< .5	< .5	< .5	1	9	< .5	1	1	1	1	< .5	< .5
La	18	28	21	12	16	63	32	32	38	26	32	41
Ce	30	44	33	22	45	95	54	56	62	41	46	56
Pr	3	6	4	3	3	11	7	7	8	5	5	6
Nd	13	21	14	10	12	41	30	26	32	22	20	21
Sm	3	4	3	3	2	6	6	6	6	4	4	3
Eu	1	1	1	1	1	1	1	1	1	1	1	1
Gd	2	2	2	2	2	4	5	4	5	4	3	3
Tb	0	0	0	0	0	1	1	1	1	1	1	1
Dy	2	2	2	2	2	3	5	4	4	3	3	2
Ho	1	0	0	0	0	1	1	1	1	1	1	1
Er	2	1	1	1	2	1	3	2	3	2	2	2
Yb	2	1	1	2	1	2	3	2	3	3	2	2

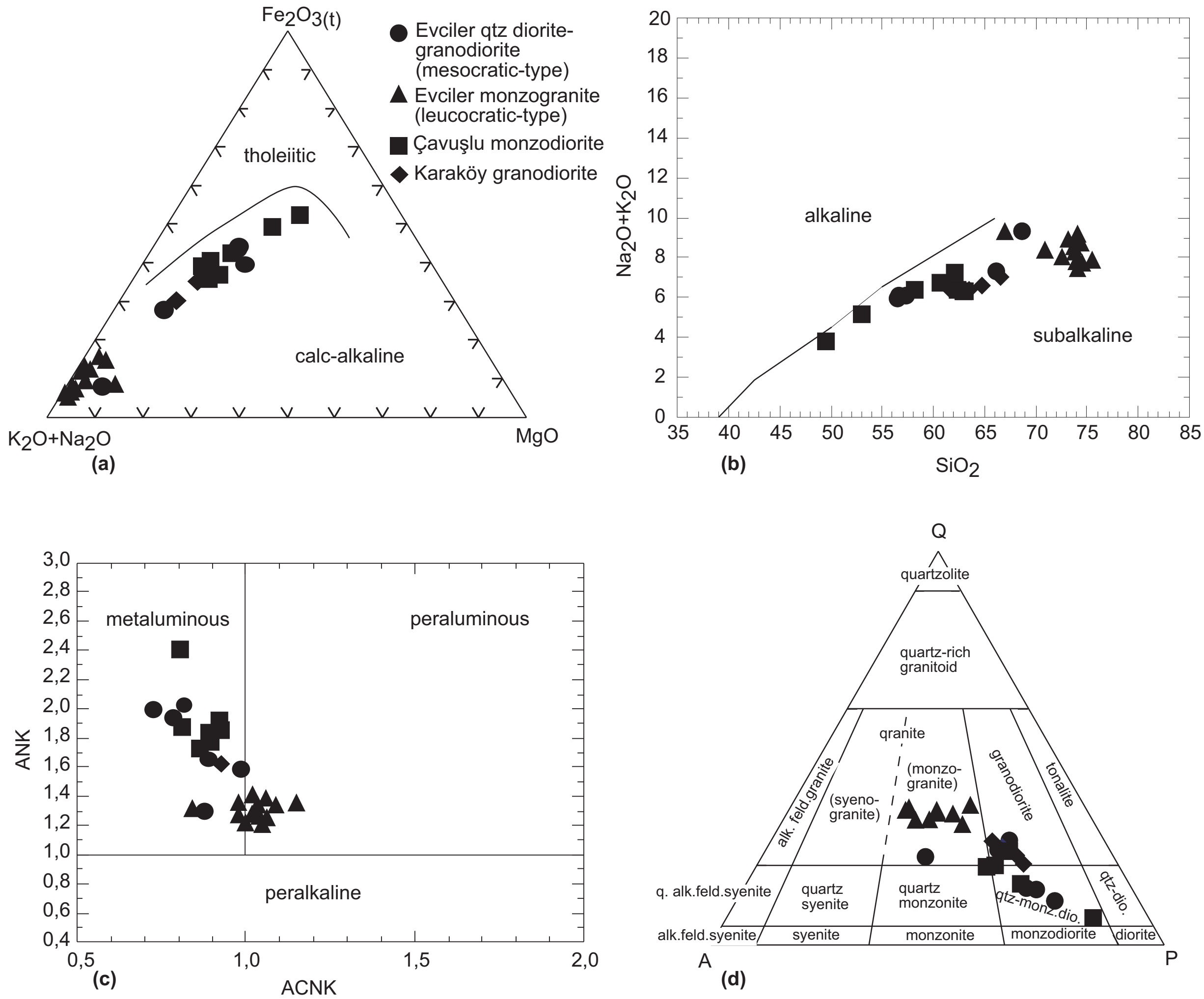

Figure 5. Classification of **(a)** calcalkaline, **(b)** subalkaline, **(c)** Al-saturation index (according to Peacock 1931) and **(d)** nomenclature (according to Streckeisen 1976) diagrams of the Evciler granitoid associated with skarn occurrence.

the late-stage products of the same magma. The mesocratic Evciler rocks plots in the high MgO (Figure 5a) and low SiO_2 fields (Figure 5b). However, all values from the Evciler pluton plot in the metaluminous to mildly peraluminous fields. The mesocratic Evciler rocks are characterized by a higher total-alkali content (Figure 5c). In the classification diagram of Debon & Le Fort (1983) (Figure 5d), rocks of the Evciler granitoid form a continuous spectrum from quartz diorite to granite. The mesocratic Evciler rocks are granodioritic to quartz monzodioritic in composition, whereas the leucocratic Evciler rocks are monzogranitic in composition.

In the K_2O versus SiO_2 diagram (Figure 6a), the Evciler granitoid shows high-K characteristics. The K_2O contents correlate positively with silica. In contrast, the MgO, Fe_2O_3, TiO_2, Al_2O_3, P_2O_3 and CaO contents display a clear negative trend against silica increase (Figure 6b-g) suggesting that the Evciler pluton was derived from highly evolved melts (Genç 1998). In these diagrams, MgO, Fe_2O_3, TiO_2 and P_2O_3 values appear more depleted for the Evciler leucogranite, with the exception of K_2O which appears more enriched, than for the Evciler granodiorite (Figure 6).

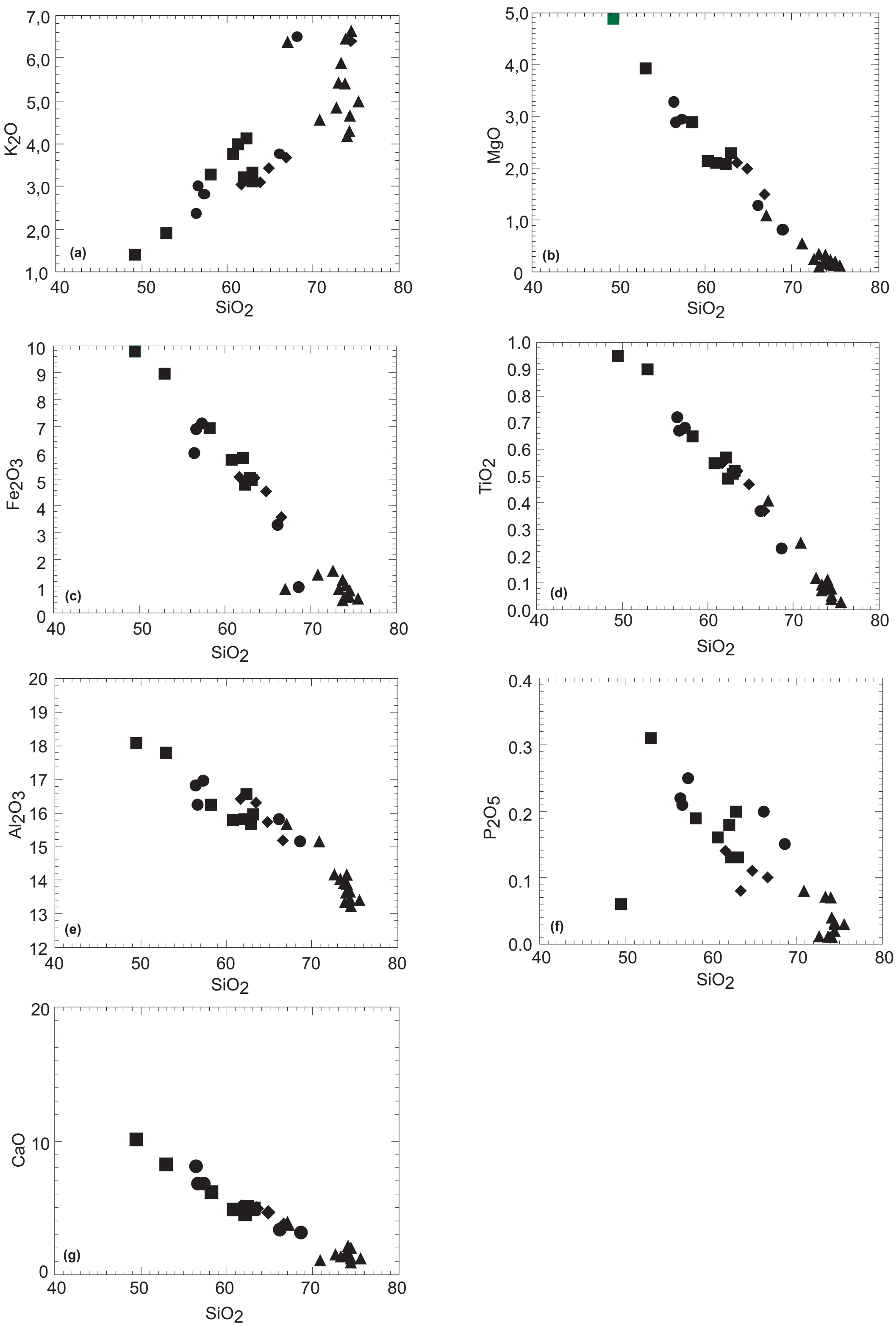

Figure 6. Harker variation diagrams for major elements of the Evciler granitoid (see Figure 5 for symbols).

The SiO_2 and Na_2O contents, molecular A/CNK ratios, K_2O/Na_2O ratios, key CIPW minerals and key modal minerals (such as amphibole and titanite) all suggest that the Evciler granitoid has I-type characteristics on the basis of the schemes of Chappell & White (1974) and Raymond (1995).

The trace-element data are used in the discrimination of tectonic or geologic provinces associated with particular magma types (e.g., Pearce *et al.* 1984). In the Rb versus Y+Nb (Figure 7a) and Nb versus Y (Figure 7b) diagrams, values from the Evciler pluton plot in the VAG and VAG + Syn-COLG fields, respectively. However, the Rb/Zr versus SiO_2 diagram indicates crustal contamination (Figure 7c).

Rare-earth element (REE) data are also presented in Table 1. The mesocratic-type Evciler, Çavuşlu monzodiorite and Karaköy granodiorite are enriched in REE. They have smaller negative Eu anomalies and a horizontal normalized pattern for the HREE (Figure 8). However, normalized patterns for leucocratic-type Evciler are characterized by LREE enrichment, strong negative Eu anomalies and well-defined, positively sloping HREE. A characteristic feature of the leucocratic-type Evciler is that it is extremely depleted in HREE compared to other associations (Figure 8). These rocks indicate little or no residual plagioclase in the source magma. These data are consistent with numerous examples from continental or continental-margin settings (Delaloye & Bingöl 2000).

The mesocratic-type Evciler, Çavuşlu monzodiorite and Karaköy granodiorite are exceptionally rich in Ce, Pr, Nd, and Sm in comparison to the leucocratic-type Evciler. Occurrences of accessory minerals, such as apatite, are responsible for this enrichment (Delaloye & Bingöl 2000).

Ocean-ridge granite (ORG) – normalized patterns for the Evciler granitoid are characterized by K_2O, Rb, Ba and Th enrichment. However, it is depleted in Zr and Y (Figure 9a), indicating crustal interaction.

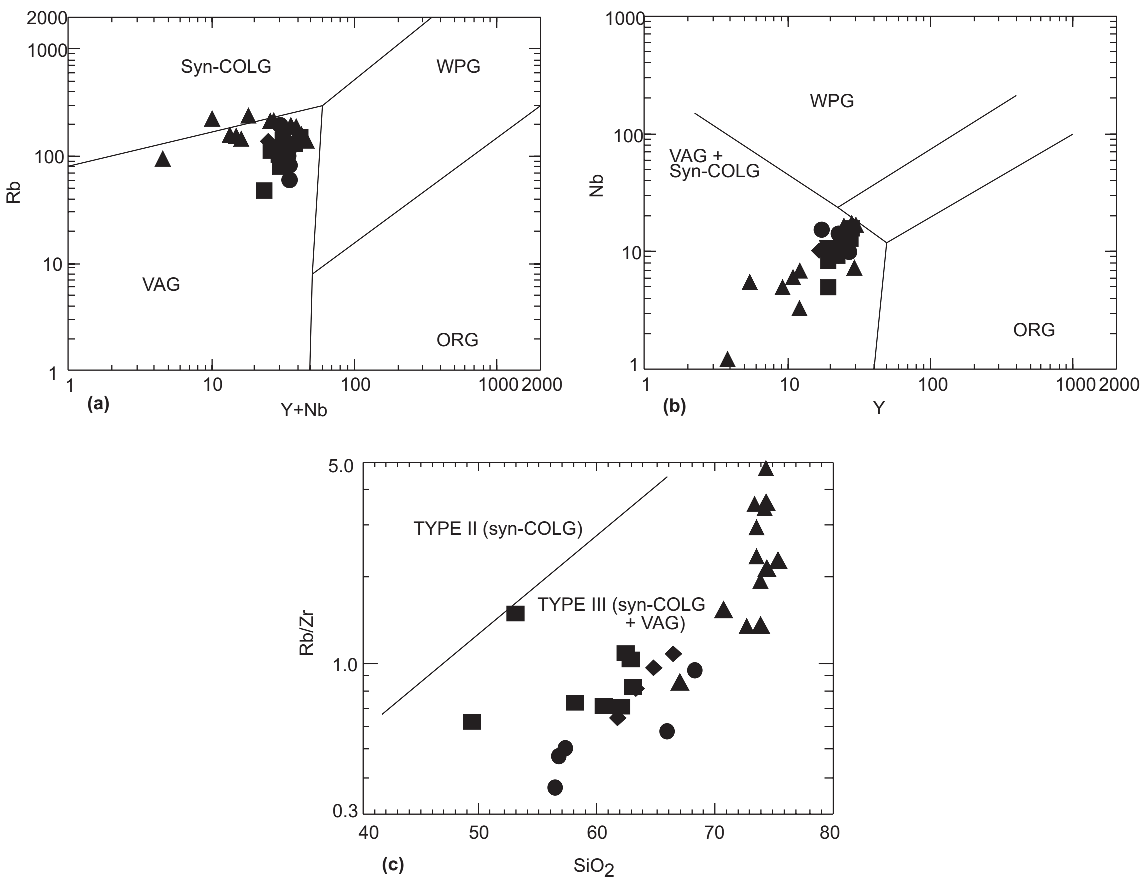

Figure 7. (a) Rb vs (Y+Nb), (b) Nb vs Y and (c) (Rb/Zr) vs SiO_2 granitoid discrimination diagram to discriminate the magma characteristics of the Evciler granitoid (field boundaries and nomenclature after Pearce *et al.* 1984). See Figure 5 for symbols.

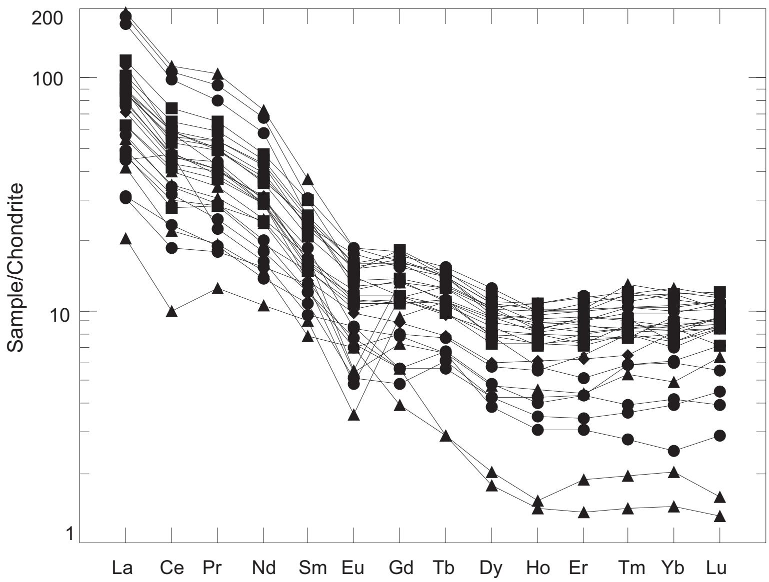

Figure 8. Chondrite-normalized REE patterns for Evciler granitoid. See Figure 5 for symbols.

Comparison of the trace-element contents of the Evciler granitoid with those of the lower and upper crust (Wilson 1989) shows that the Evciler granitoid is fairly similar to the upper crust (Figure 9a & b), in so far as the LIL elements are enriched with respect to HFS elements. Enrichment in Th and Nb indicates that the source rocks are also enriched in these elements. According to Genç (1998), the Evciler pluton yields a cafemic trend on the A-B diagram of Debon & Le Fort (1983). The cafemic associations are known to have been derived mostly from a hybrid source, having crustal and mantle components (Debon & Le Fort 1983). This conclusion is supported by the ORG-normalized trace-element systematics of the Evciler granitoid as discussed above. These features indicate a source region in the mantle, enriched by subduction processes (e.g., Pearce *et al.* 1984; Rogers *et al.* 1985; Harris *et al.* 1986). Therefore, the trace-element and REE patterns of the Evciler granitoid compare favourably with magmas formed in a magmatic arc or in a post-collisional setting (Genç 1998).

Oxygen-Isotope Chemistry

Because of its proximity to the skarn mineralization and its possible role in the genesis of ore-forming fluids, we analyzed for oxygen isotopes whole-rock samples and mineral separates from the Evciler granitoid collected from near pyrrhotite-bearing mineralization of the Evciler district. Oxygen-isotope analyses of the granite reported here (Table 2) were performed on mineral separates (quartz and amphibole) in preference to whole-rock powders because oxygen-isotope ratios of the whole rock are vulnerable to the effects of post-crystallization and sub-solidus alteration.

Quartz and amphibole were separated and purified by magnetic seperation and hand picking. The purity of all mineral separates was checked by X-ray diffraction, and is greater than 95%. The oxygen-isotope compositions

Table 2. $\delta^{18}O$ values of samples from Evciler granitoid.

sample no.	$\delta^{18}O$ (‰)			$\delta^{18}O_{magma}$ (‰)
	quartz	amphibole	whole rock	
195	10.2			
193	10.4			
112/2	10.4	6.6	7.2	8.0
191	8.9		8.1	
79	10.9		8.3	
192/2	1.3		6.1	
109	7.2		6.0	
58	10.2		8.7	
76/1	7.2		5.7	
42/2	10.2	5.9	2.5	7.2
148/2	9.0	5.2	6.5	6.5
184	3.7	-0.6		7.2
140/S5	4.5		7.1	
222/1	8.5	5.2	4.8	6.6

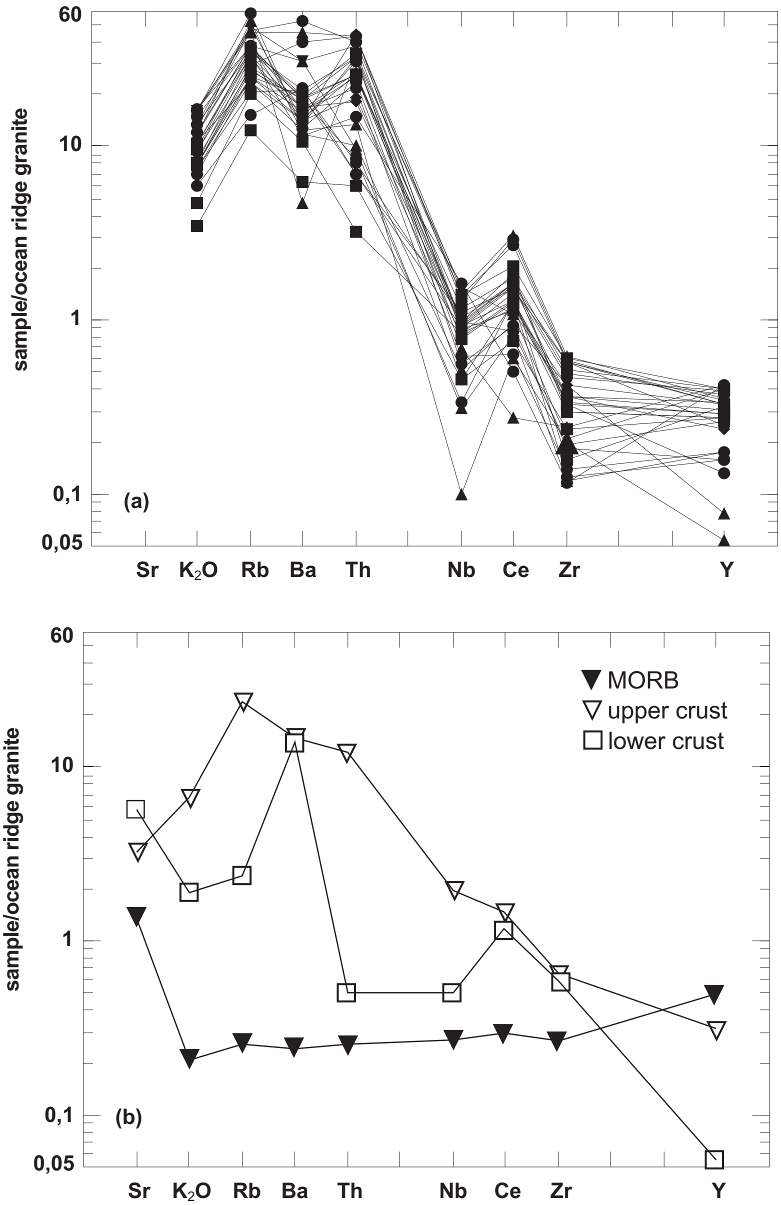

Figure 9. Ocean ridge granite (ORG)-normalized spider diagrams for **(a)** the Evciler granitoid; **(b)** MORB, upper crust and lower crust, for comparison. Normalizing values are from Pearce *et al.* (1984). See Figure 5 for symbols.

(^{18}O, ^{16}O) of the samples were measured, using a method similar to that described by Sharp (1990) and Rumble & Hoering (1994). Between 0.5 to 2 mg of each sample was loaded into a small Pt-sample holder and pumped out to a vacuum of about 10^{-6} mbar. After overnight preflourination of the sample chamber, the samples were heated with a CO_2-laser in 50 mbars of pure F_2. Excess F_2 was separated from the O_2 produced by conversion to Cl_2 using KCl held at 150 °C. The extracted O_2 was collected on a molecular sieve (13X) and subsequently expanded and analyzed using a Finnigan MAT 252 isotope ratio mass spectrometer at Tübingen University, Germany. The results are reported herein as conventional permil $\delta^{18}O$ values relative to SMOW. The reproducibility is better than ±0.1‰. The mean value for the NBS-28 standard obtained during the present study was +9.64 ‰.

The whole rock $\delta^{18}O$ values of the Evciler granitoid decrease toward the intrusive contact, which happens to be the region closest to the pyrrhotite-bearing mineralization of the Evciler district (Figure 10). The whole-rock $\delta^{18}O$ values of samples, collected only a few metres from the skarn mineralization, are 2.5, 5.7 and 6.0 ‰, lower than the normal range for fresh granites (Taylor 1968), suggesting that granite at this locality has been altered.

Note that the range of $\delta^{18}O$ values for quartz from the granite samples collected farthest from the skarn mineralization is restricted, ranging from +7.2 to +10.9 ‰, possibly near close to the primary unaltered value for this intrusive rock. This range is normal for I-type granitic rocks (e.g., Taylor & Sheppard 1986; +8 ‰ – +10 ‰).

In this paper, the $\delta^{18}O$ value for the original magma (δ_{magma}) has been estimated from the $\delta^{18}O$ values of quartz. In theory, the $\delta^{18}O$ value of the fresh rock (and hence δ_{magma}) can be calculated from the mineral $\delta^{18}O$ values and modal proportions, provided that oxygen-isotope data are available for all of the constituent minerals (Harris *et al.* 1997). The $\delta^{18}O$ values calculated for the granite magmas from quartz $\delta^{18}O$ values of the Evciler granitoid range from 6.0 to 8.0 ‰.

In slowly cooled, coarse-grained rocks (e.g., the Cape granites, Harris *et al.* 1997), the difference between the $\delta^{18}O$ value of quartz and δ_{magma} is not only dependent on $\Delta_{qtz\text{-}melt}$, but is also dependent on grain size, the rate of cooling, and the mineral's temperature of closure to oxygen diffusion (e.g., Giletti 1986; Jenkin *et al.* 1991). Larger grain size generally results from slower cooling, which in turn means that oxygen diffusion and re-equilibrium continues for a greater period of time.

The difference between the $\delta^{18}O$ value of quartz and the other constituent minerals in a slowly cooled rock will be larger than for a more rapidly cooled rock. To correct for these 'closure' effects, $\Delta_{quartz\text{-}magma}$ was assumed to be +1‰ in the quartz porphyries (e.g., Taylor & Sheppard 1986) and +2 ‰ in the remaining granites, which relatively coarse-grained (see Giletti 1986). Calculated $\Delta_{quartz\text{-}magma}$ for the Evciler granitoid range from +1.8 to +3.0 ‰. Under equilibrium conditions, the O-isotope fractionation between quartz and constituent minerals (e.g., $\Delta_{qtz\text{-}feld}$) should fall in the range of 0.5–2.0 ‰ at magmatic temperatures (Chiba *et al.* 1989). For the granitoid of the Evciler district, the only readily applicable fractionation for equilibrium conditions was quartz-amphibole. Quartz-feldspar, the fractionation most often chosen for felsic igneous rocks, is not applicable at Evciler due to the lack of measured $\delta^{18}O$ values for feldspar. The average $\Delta_{qtz\text{-}amph}$ observed in the Evciler granitoid ranges from 3.0 to 4.2 ‰, indicating that the O isotopes did not reach equilibrium in these samples. Therefore, the present isotopic characteristics demonstrate that the Evciler granitoid has experienced post-emplacement, open-system hydrothermal alteration. Meteoric water was the most probable fluid involved in the water-rock interactions of the granitic intrusion.

Discussion

Comparison of the Compositional Variation of the Evciler Granitoid with World Skarn Granitoids

Broad correlation between igneous composition and skarn type with respect to their metal contents has been described by several workers (Zharikov 1970; Shimazaki 1975, 1980; Kwak & White 1982; Meinert 1983, 1990, 1993, 1995, 1997; Newberry & Swanson 1986; Newberry 1987; Keith *et al.* 1989; Newberry *et al.* 1990; Meinert *et al.* 1990; Paktunç 1990; Ishihara & Sasaki 1991; Naldrett 1992; Blevin & Chappell 1992; Ray *et al.* 1995; Srivastava & Sinha 1997; Nicolescu *et al.* 1999). Parameters that are most important in determining the overall metallogenic 'flavour' of intrusive igneous suites include granite type, compositional evolution, degree of fractionation and oxidation state (Blevin 2004).

In terms of major elements, the Evciler granitoid was compared with averages of world granitoids associated with Au-Cu and Fe skarns (Meinert 1995) and with skarn granitoids of Ertsberg, Indonesia (Meinert *et al.* 1997); Bocşa and Ocna de Fier, Romania (Nicolescu *et al.* 1999); McKenzie, Canada (Moore & Lentz 1996); Millstream, Canada (Lentz *et al.* 1995); British Columbia, Canada (Meinert 1984) and the Rio Narcea gold belt (RNGB), Spain (Martin-Izard *et al.* 2000) by using Harker diagrams similar to those used by Meinert (1993, 1995).

As is illustrated in the Harker-type diagrams, Au- and Fe-skarn averages are characterized by higher MgO and lower K_2O and SiO_2 contents compared to Cu-skarn and other types (W-, Mo-, Sn-, Zn-, and Pb-skarns). The MgO contents of the Evciler monzogranite (leucocratic) and

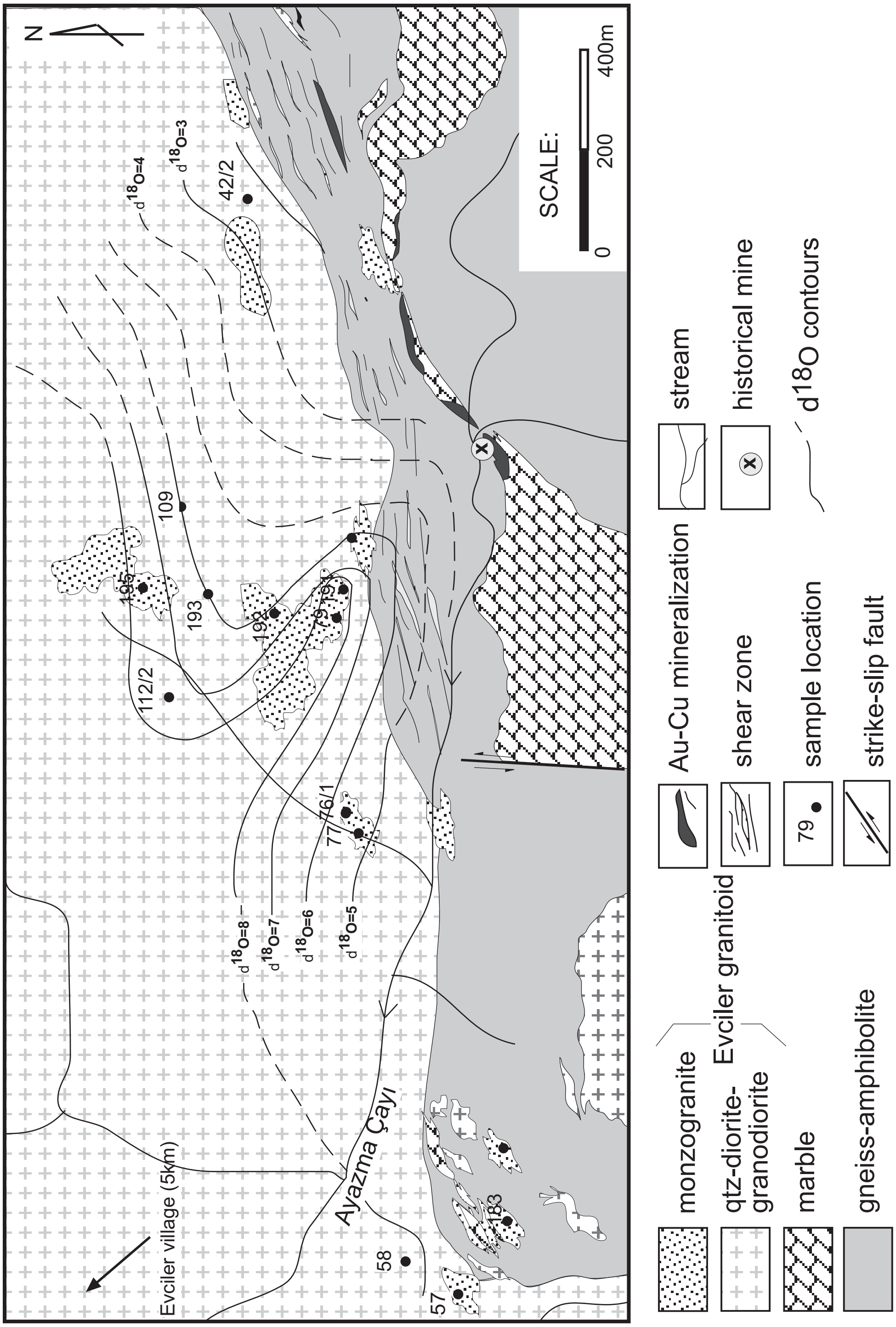

Figure 10. Geological map showing $\delta^{18}O$ values of the Evciler qtz diorite-granodiorite.

Evciler quartzdiorite-granodiorite (mesocratic) are 0.28% and 2.30%, respectively. However, this value is 3% for Fe-skarn granitoids, 3.2% for Au-skarn granitoids, and 1.8% for Cu-skarn granitoids (Meinert 1995). The MgO contents of the mesocratic Evciler rocks is close to Fe- and Au-skarn granitoids, and the Çavuşlu monzodiorite and Karaköy granodiorite are close to Cu-skarn granitoid (Figure 11a). In contrast, the MgO contents of the leucocratic Evciler rocks are fairly similar to values of Mo- and Sn-skarn granitoids and plots close to Mo-Sn granitoid averages (Figure 11a). Therefore it is suggested that the Evciler quartzdiorite-granodiorite could be associated with Cu-Au and Fe skarns and the Evciler monzogranite could be associated with Mo and Sn skarns. Similarly, in terms of the K_2O contents of these rocks, the Evciler values appear to trending towards Au-, Cu- and Fe-bearing granitoids (Figure 11b).

The total-alkali contents of the Evciler quartzdiorite-granodiorite (mesocratic), Çavuşlu monzodiorite and Karaköy granodiorite are fairly similar to values of Au-Cu and Fe-skarn granitoids and the values of these rocks plot close to Au-Cu and Fe-granitoid averages (Figure 11c). The Evciler granitoid, in general, has a single trend in terms of iron content and other major oxides (Figure 11d).

Consequently, in terms of major-element contents, the overall geochemistry of the Evciler granitoid, except the leucocratic Evciler, is comparable to Au-Cu and Fe-skarn granitoids. Although it is not clear in the field, the geochemistry of the leucocratic rocks is comparable to Mo- and Sn-skarn granitoids (Figures 11a–d). Pyrrhotite-bearing Au-Cu mineralization in the Ayazma (Evciler) district should be related to the mesocratic Evciler quartz diorite-granodiorite.

According to Meinert (1995), most compositions of skarn-related plutons cluster close to the division between metaluminous and peraluminous, and almost none would be classified as peralkaline, in terms of Al-saturation. The mesocratic Evciler quartz diorite-granodiorite, Çavuşlu monzodiorite and Karaköy granodiorite are characterized by higher ANK and lower ACNK values than the leucocratic Evciler rocks (Figure 11e). In this diagram, the Evciler granitoid shows lower ANK and higher ACNK values than typical Fe-skarn granitoids. In terms of Al-saturation index, Fe-skarn granitoids are interpreted as skarns derived from mantle granitoids with little or no crustal interaction (Meinert 1984). The Al-saturation index of the Evciler granitoid is lower than that of Fe-skarn granitoids – unlike average Fe-skarn granitoids – suggesting more crustal interaction. The Evciler granitoid, except for the leucocratic phase, appears to be trending towards Cu- and Zn-skarn granitoids. However, in this regard, the leucocratic type is fairly similar to Mo- and Sn-skarn granitoids.

The degree and type of fractionation is important in determining both the potential for mineralization and the type of mineralization with which a granite suite might be associated. Fractional crystallization can be measured in many ways: use of compatible/incompatible element ratios (e.g., Rb/Sr ratio), and the behaviour of selected trace elements that indicate the entrance and exit of crystallizing phases (Blevin 2004). For example, Rb should increase and Sc should decrease as crystallization and differentiation proceed for magmatic rocks. Figure 12a illustrates this relationship for the Evciler granitoid. The Evciler monzogranite (leucocratic type) is characterized by higher Rb and lower Sc contents than the Evciler quartz diorite-granodiorite, the Karaköy granodiorite and the Çavuşlu monzodiorite. However, the Evciler (mesocratic type), Çavuşlu and Karaköy plots are very close to those of Cu- and Au-skarn granitoids, but are higher than Fe-skarn granitoids. The Evciler monzogranite plots are also higher than those of Fe-skarn granitoids but lower than those of Mo- and Sn-skarn granitoids (Figure 12a). The variation of 'mobile' large-ion lithophile trace elements, such as Rb and Sr, relative to 'immobile' high-field-strength elements, such as Zr, Nb, and P, is also important to understand the petrogenesis of plutons associated with skarn deposits. For example, Newberry & Swanson (1986) have noted that W, Sn, and Mo deposits have high Rb/Sr ratios, and this suggests that the process of differentiation, rather than a particular magma composition, is critical in the formation of these deposits. In contrast, Zn-, Cu-, Au-, and Fe-skarn systems have low Rb/Sr ratios, and show little evidence for differentiation. In Figure 12b, the Evciler granitoid is characterized by lower Rb/Sr ratios than Mo-, W-, and Sn-skarn granitoids but the leucocratic Evciler rocks have slightly higher Rb/Sr ratios than the other associations. However, the mesocratic Evciler quartz diorite-granodiorite is fairly close to Au-, Cu-, and Fe-skarn granitoids, suggesting potential for Au and Cu in the area.

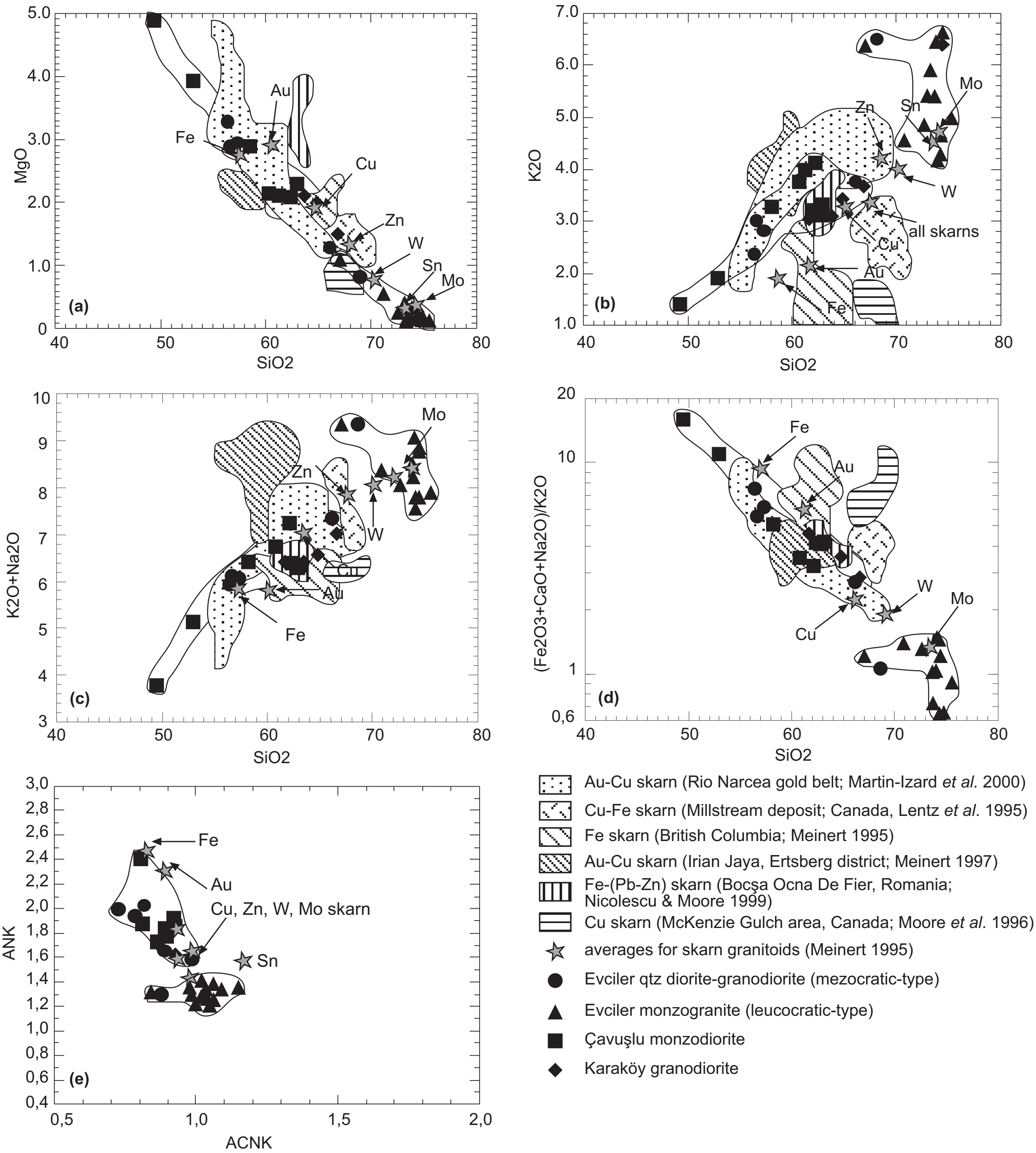

Figure 11. Harker-type **(a)** MgO vs SiO_2, **(b)** K_2O vs SiO_2, **(c)** total alkalies vs SiO_2 **(d)** Fe_2O_3+CaO+Na_2O/K_2O ratio vs SiO_2 and **(e)** ANK vs ACNK diagrams for the Evciler granitoid and comparison with world skarn granitoids (the averages for skarn granitoids are taken from Meinert 1995).

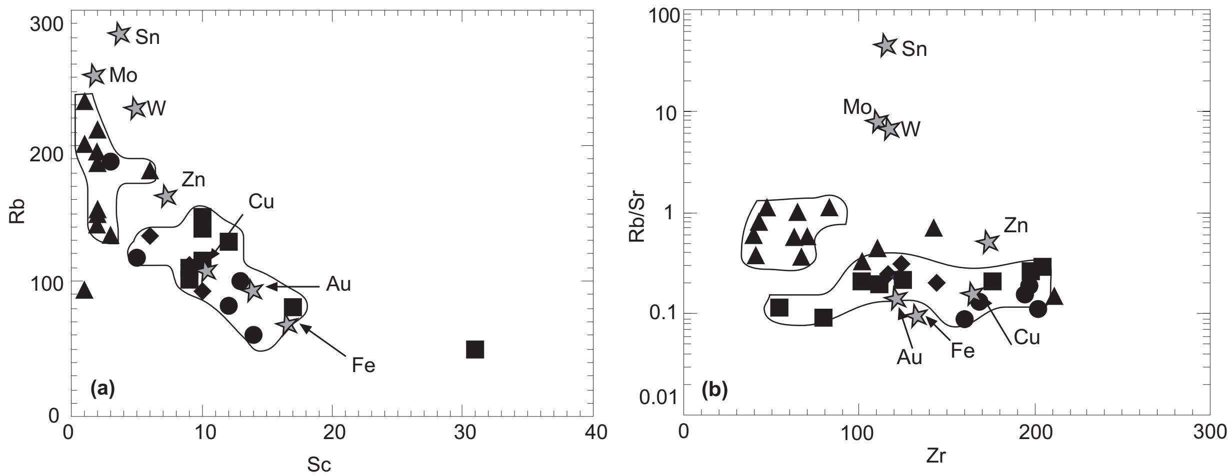

Figure 12. Trace-element contents of the Evciler granitoid and skarn granitoid averages taken from Meinert (1995). **(a)** Rb vs Sc and **(b)** Rb/Sr vs Zr.

In so far as metallogenic associations depend on the compositional character of granites, K/Rb ratios are particularly useful in the evaluation of highly fractionated melts. According to Blevin (2004), suites that show classic petrographic and compositional behaviour consistent with the processes of fractional crystallization are most commonly associated with significant mineralization. In the K/Rb versus SiO_2 diagram, there is a progressive decrease in K/Rb values with granite evolution (Figure 13a & b). This diagram shows that the Evciler pluton is similar to I-type granites from continental margins (Figures 13c) and was derived from moderately evolved melts (Figure 13d).

Relative metal abundances in magmas and different types of intrusion-related deposits are a function of compositional evolution, fractionation and oxidation state. It is the 'core element association' that most closely relates to magma composition. For example, Cu-Au deposits are associated with oxidized, relatively unevolved suites (Blevin 2004). In Fe_2O_3/FeO versus Rb/Sr plot (Figure 14a), The Evciler granitoid is characterized by relatively unevolved to moderately evolved and oxidized suites and are fairly close to Au-Cu deposits in many respects.

The combination of the parameters used above can be used on a district to regional scale to interpret relationships between igneous rocks and ore deposits. Deposit zoning and mineral occurrence data can also be used as key input in recognising magmatic-hydrothermal 'districts'. The most intrusion-proximal, high temperature metal association within these districts is defined as the 'core metal association' (Figure 14b). In this diagram, there are five core metal associations recognized, and the Evciler granitoid plots fairly near the Au-Cu association and is similar to rocks of the Cadia district, Australia (Blevin 2004). Such an approach has a predictive capacity in being able to recognize potential for particular metallic elemental associations in the poorly explored Evciler pluton and in other young granitoids of northwestern Anatolia.

Oxygen-Isotopic Constraints on Petrogenesis of the Evciler Granitoid

For some granites, little or no interaction with external fluids seems to have taken place (e.g., the Berridale batholith in eastern Australia: O'Neil & Chappell 1977; the Manaslu granite, Himalayas: France-Lanord *et al.* 1988) and the whole-rock oxygen isotope ratios probably reflect quite closely the original magma values. Other granites have undergone extensive exchange with external fluids, thus the original magmatic $\delta^{18}O$ values have been changed. Some Hercynian granites of the Pyrenees (Wickham & Taylor 1987), the Idaho batholith and many other Tertiary batholiths of the western USA (Criss *et al.* 1991) and some Caledonian granites of Britain (Harmon 1984) can be classified in this category.

Whole-rock samples from Evciler granitoid, collected only a few metres from the skarn mineralization, have

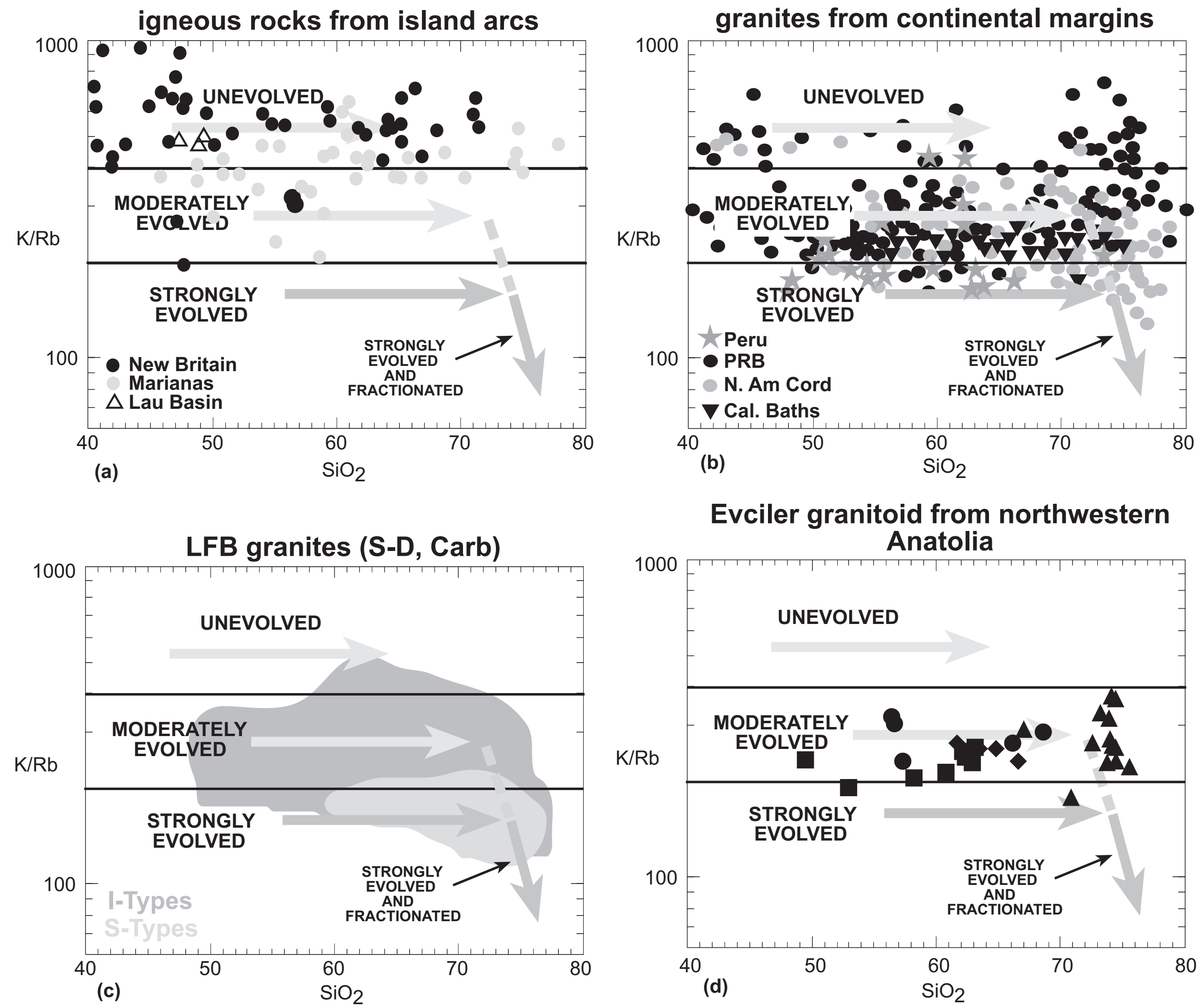

Figure 13. K/Rb classification scheme showing classification fields/typical trends for (a) igneous rocks from island arcs, (b) granites from continental margins, (c) I- and S-type granites (all data from Blevin 2004) and (d) the Evciler granitoid.

$\delta^{18}O$ values between 4.8 and 6.0 ‰, with the most altered samples having the lowest $\delta^{18}O$ values, like other world skarn granitoids (e.g., Edough granitoid, Annaba, northeast Algeria: Laouar *et al.* 2002). In order to create granites with low $\delta^{18}O$ values observed in the Evciler samples, it is necessary to invoke hydrothermal alteration. Compared to normal granites, meteoric waters have relatively low $\delta^{18}O$ values (Figure 15). During water-rock interaction in the Evciler district, each isotopic value of the granitoid and meteoric water normalize the value of the other as $\delta^{18}O$ is exchanged. Thus, the Evciler granitoid $\delta^{18}O$ values would decrease to lower values during hydrothermal alteration and skarnization in the district.

$\delta^{18}O$ values of the original magma of the Evciler granitoid (δ_{magma}), calculated from quartz $\delta^{18}O$ values, range from 6.0 to 8.0 ‰, suggesting similarity to slowly cooled coarse-grained I-type granites (e.g., Cape granites: Harris *et al.* 1997) (Figure 15). Although the range of $\delta^{18}O$ values for quartz (7.2–10.9 ‰) from the fresh granitoid samples is normal for I-type granitic rocks, this range is too large to be explained by simple magmatic differentiation (Sheppard 1986).

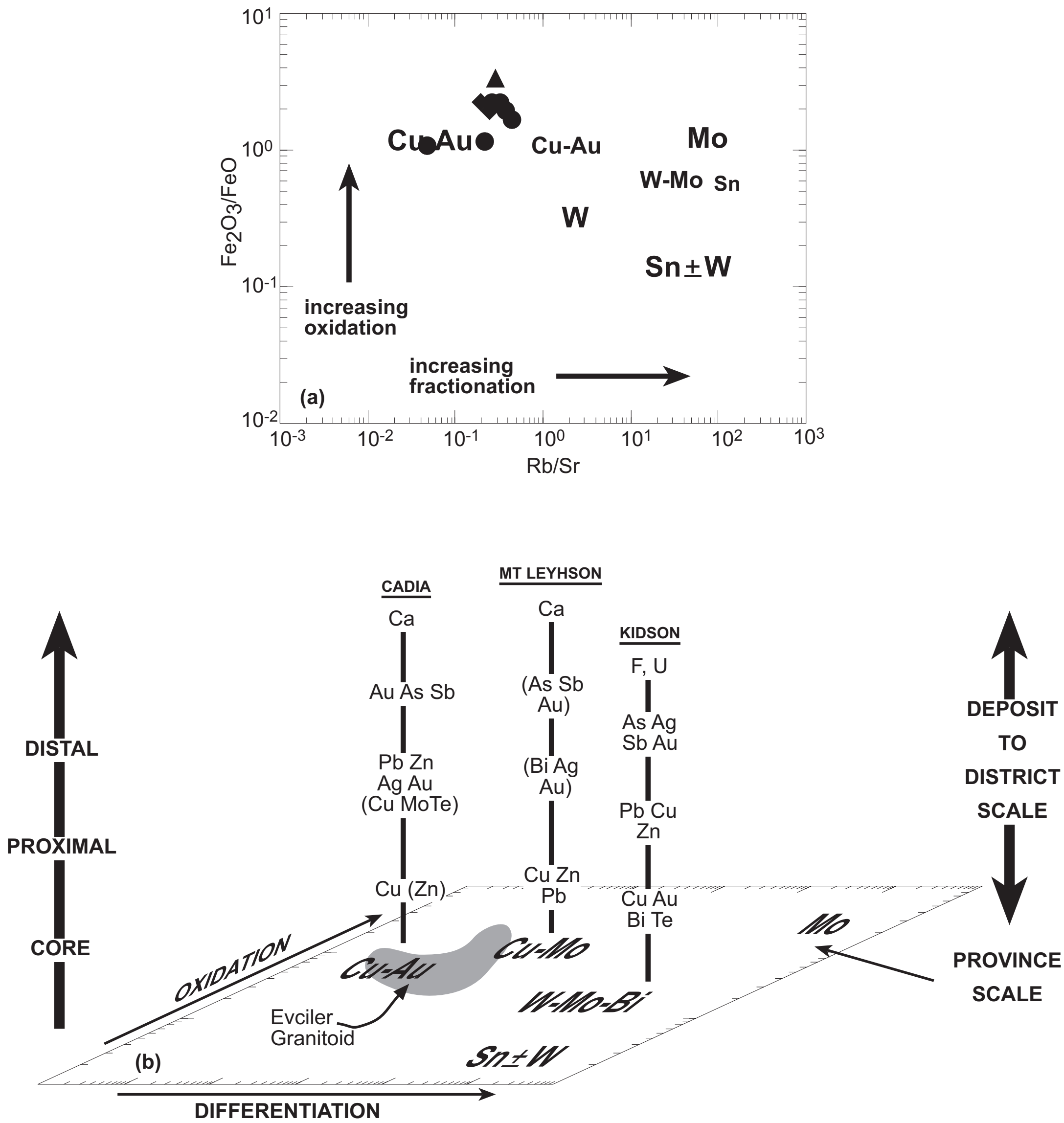

Figure 14. (a) Fe_2O_3/FeO vs Rb/Sr diagram for the Evciler granitoid and (b) conceptual diagram illustrating relationships between metal zonation at the deposit or district scale, and how it relates back to higher-temperature proximal igneous-centred systems (Cu-Au, Cu-Mo, W-Mo, Sn-W, Mo) (Blevin 2004).

Conclusions

Major-element chemistry indicates that the Evciler granitoid has a metaluminous to mildly peraluminous, calc-alkaline character. In terms of trace-element data, the Evciler granitoid is classified as VAG (volcanic arc granites) and syn-collisional granites. In the study area, two different rock types are observed: the mesocratic Evciler rocks are quartz dioritic to granodioritic in composition, whereas the leucocratic Evciler rocks are monzogranitic in composition; both show I-type characteristics. Pyrrhotite-bearing calcic skarn mineralization occurs at the contact between the Evciler quartz diorite-granodiorite and marble lenses belonging to the Kazdağ Massif to the south of the Evciler granitoid.

Oxygen-isotope analyses of quartz and calculated δ_{magma} from the Evciler granitoid support an I-type designation as suggested by previous geochemical studies. Whole-rock $\delta^{18}O$ values for the Evciler granitoid

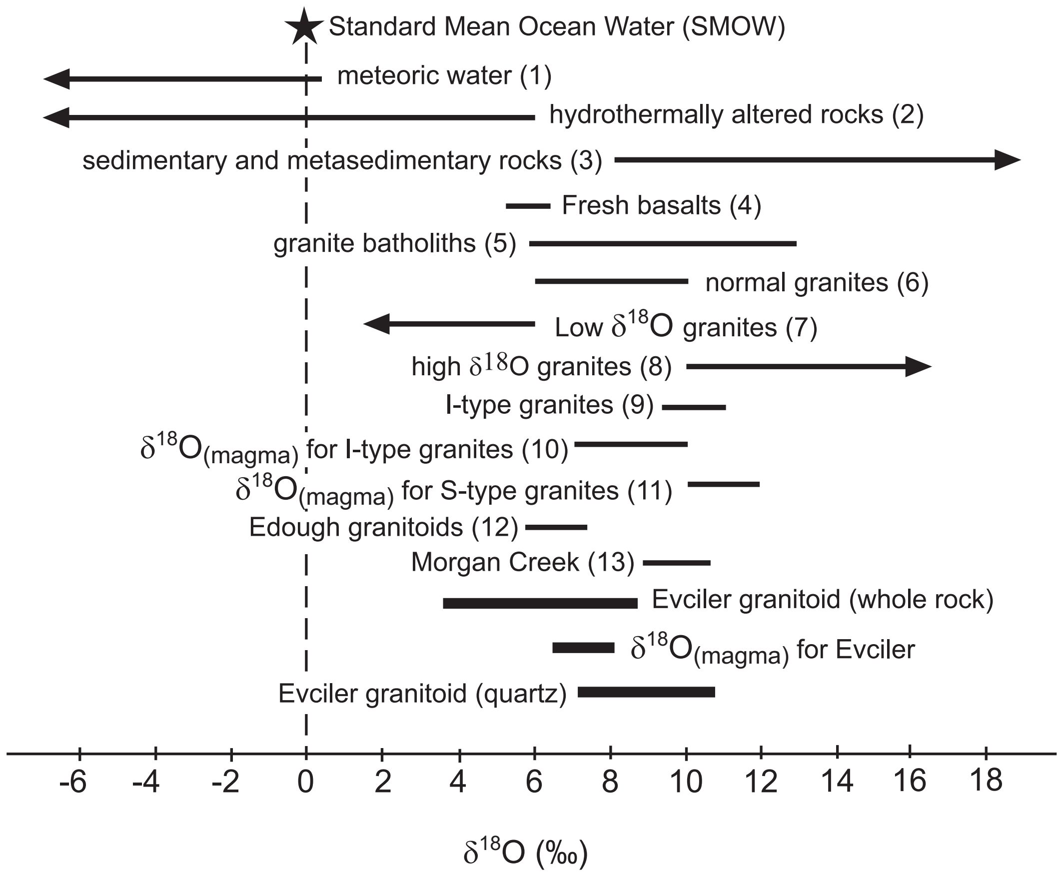

Figure 15. Oxygen-isotopic composition of the Evciler granitoid compared to those of typical terrestrial materials and other world skarn granitoids. (1) Craig (1961); (2) Ohmoto (1986); (3), (4) and (5) Taylor & Sheppard (1986); (6), (7) and (8) Taylor (1978); (9), (10) and (11) Harris *et al.* (1997); (12) Laouar *et al.* (2002); and (13) Brown *et al.* (1985).

decrease toward the intrusive contact, which happens also to be the area closest to the pyrrhotite-bearing mineralization in the Evciler district. There is significant evidence for the possibility of meteoric-water hydrothermal alteration, which generated low $\delta^{18}O$ values, as low as 5.7 ‰.

Relative metal abundances in magmas and different types of intrusion-related deposits are a function of compositional evolution, fractionation and oxidation state. It is the core element association that most closely relates to magma composition. Cu-Au deposits are associated with oxidized, relatively unevolved to moderately evolved suites. The Evciler quartz diorite-granodiorite is characterized by relatively unevolved to moderately evolved and oxidized suites, fairly similar to Au-Cu deposits. The geochemical characteristics of the Evciler quartz diorite-granodiorite, Çavuşlu monzodiorite and Karaköy granodiorite are also similar to some of the Cu-, Fe-, Cu-Au-, and Fe-Cu skarn granitoids of Canada, Indonesia, Spain and British Columbia. However, the geochemical characteristics of the Evciler monzogranite are similar to averages of Sn- and Mo- skarn granitoids.

The results of this study suggest that the composition and petrologic evolution of the Evciler pluton are the primary controls on skarn alteration, mineralization, and metal content (e.g., copper, gold, iron). The combination of all these parameters can be used on a district to regional scale to interpret relationships between the Evciler pluton and related ore deposits. However, the Evciler pluton and other young granitoids of western Anatolia are analogous to the Au-Cu core metal association, for example, the Cadia district, Australia.

Thus, field relations and igneous petrology have a predictive capacity in being able to recognize potential for particular metallic element associations in the poorly explored Evciler pluton and other young granitoids of northwestern Anatolia.

Acknowledgements

Oxygen isotopes were analyzed at the Institute of Geochemistry, Tübingen University (Germany), and we thank Heinrich Taubald, Gabriele Stoschek, Bernd Steinhilber and Gisela Bartholomä for the analyses. We also acknowledge Yücel Yılmaz and Erdin Bozkurt for their helpful suggestions. This paper constitutes part of the PhD study of Yeşim Yücel Öztürk. This study was also supported by two research project grants, (Project Number 101Y018) from the Scientific & Technological Research Council of Turkey (TÜBİTAK) and (Project Number 0922.01.01.17) from Dokuz Eylül University Scientific Research Projects (BAP). We thank the reviewers, Larry Meinert and Nurdane İlbeyli, and the editor for their encouraging suggestions that have improved significantly the content and clarity of the paper.

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Received 16 February 2005; revised typescript accepted 27 September 2005