



ELSEVIER

Available online at www.sciencedirect.com

SCIENCE @ DIRECT®

Ore Geology Reviews 28 (2006) 147–179

ORE GEOLOGY
REVIEWS

www.elsevier.com/locate/oregeorev

Gold in Turkey — a missing link in Tethyan metallogeny

Ozcan Yigit

Department of Geological Engineering, Canakkale Onsekiz Mart University, Canakkale 17020, Turkey

Received 25 February 2004; accepted 14 April 2005

Available online 1 July 2005

Abstract

The gold metallogeny of Turkey constitutes a sector of the Tethyan Eurasian Metallogenic Belt (TEMB) within the Alpine–Himalayan orogenic system that formed from Jurassic–Cretaceous to the present. This orogenic system produced many different types of deposits related to subduction, collision, post-collision and rifting processes. Gold deposits, as well as other mineral deposits of Turkey, are mainly concentrated in Late Mesozoic and Tertiary rocks. Evaluation of the gold metallogeny of Turkey is based on a GIS database compilation of known gold deposits and prospects. Currently available data show that Turkey has a gold endowment, including reserves and resources, of approximately 31.5 M oz [979 tonnes] in 51 deposits, 21 of which contain more than 0.2 M oz gold. The other 30 deposits contain a total of approximately 1 M oz [31 tonnes] gold resources. Two recent discoveries, Kisladag and Copler, currently contain total resources of 17.6 M oz Au [549 tonnes], more than 50% of the total Turkish gold endowment.

Turkey possesses a wide spectrum of gold deposits related to Mesozoic and Cenozoic volcanoplutonic arcs. However, porphyry gold (copper), epithermal gold (including both high- and low-sulfidation styles), and gold-rich volcanic-associated massive sulfide (including both Kuroko- and Cyprus-types) are the most economically important to date. Orogenic gold, including listwanite-hosted, placer gold and skarn-hosted gold are relatively less important or abundant deposit types. Other potential gold systems for exploration include Carlin-type gold, detachment-fault-related gold, iron oxide–copper–gold, and gold in carbonate-replacement and manganese deposits.

© 2005 Elsevier B.V. All rights reserved.

Keywords: Gold; Turkey; Tethyan metallogeny; Tethys; Pontides; Island arc; Magmatic arc; Mineral exploration

1. Introduction

The history of mining in Anatolia dates back to 7000 B.C., with the oldest artifacts found near Ergani–Diyarbakir, which were made from native copper and malachite (Cambel and Braidwood,

1970; Kaptan, 1990). Records and legends suggest that gold was mined before 1200 B.C. in Astyra (present day Madendag and Kartaldag, near Canakkale) for the Homeric city of Troy (Priam's treasure?). Archaeological records prove that gold was mined from the Pactolus River (present day Gediz) and the Sardis River (present day Sart) in western Turkey. This gold was refined by Croesus, last king of Lydia, who made the first gold coins in about 700

E-mail address: ozcanyigit@hotmail.com.

B.C. (Young, 1972). Midas, King of Phrygia, who was granted the power of turning everything that he touched into gold, lived in the city of Gordion near present day Eskisehir in central Anatolia.

Despite Anatolia's long history of mining, modern concepts of ore geology have not been fully applied to mineral exploration until the last couple of decades. The Turkish Geological Survey (MTA), founded in 1935, has produced mineral inventories (MTA, 1980, 1993a) and metallogenic maps (Gumus, 1970; Engin et al., 2000) of the country. However, the origin of the ore-forming systems has neither been fully explained nor placed in the framework of Tethyan Eurasian Metallogenetic Belt (TEMB) (Janković, 1997) (Fig. 1). Changes in the mining law in 1985 resulted in the resuscitation of mineral exploration by multinational companies using modern exploration techniques with successful results; at least 10 gold discoveries have been made in recent years.

While Turkey is known for its industrial minerals (Houssa, 1999; O'Driscoll, 2001), it is an emerging

country for precious- and base-metal mining on the doorstep of Europe. Turkey has the largest prospective land area in Europe, ca. 780,000 km², approximately 1.5 times larger than France or about 3 times the size of Nevada. Recent gold discoveries have brought the current total gold endowment of Turkey to 31.5 M oz (979 tonnes). These reserves/resources are contained in porphyry Au and Cu–Au, epithermal Au (both high- and low-sulfidation) and Au-rich VMS deposits.

Post-Jurassic gold metallogeny in Turkey is linked to the development of the TEMB within the Alpine–Himalayan orogenic system (Janković, 1977, 1997); a large part of the western TEMB is on Turkish territory (Fig. 1). The TEMB system formed as a result of convergence of the African, Arabian, Indian and Indonesian plates and their collision with Eurasia in the area of the former Tethyan oceans (Dixon and Pereira, 1974). The belt extends from the western Mediterranean via the Alps to southeastern Europe, through Turkey, the Lesser Caucasus, Iran and the Himalayas, to China and southwest Indonesia, reach-



Fig. 1. Gold deposits and prospects of Turkey (including >0.2 M oz Au as reserve and/or resource) along the Tethyan Eurasian Metallogenetic Belt (TEMB). Deposits shown include those with by-product gold. Mercator projection, scale accurate for the location's latitude.

ing to the West Pacific metallogenic belt. The TEMB contains many different types of mineral deposits related to subduction, collision, post-collision and rifting processes.

It should be borne in mind that TEMB consists of many different metallogenic zones also referred to as ‘belts’ in the literature, including the Banatitic Magmatic and Metallogenic Belt (BMMB; Berza et al., 1998) in SE Europe, and which can be extended to northernmost Turkey. The majority of gold deposits and prospects of Turkey formed during the Alpine orogeny related to the Neo-Tethys sensu lato. However, some gold mineralization discussed in this paper, i.e., orogenic gold, may have formed during the Variscan (=Hercynian) orogeny related to the Paleo-Tethys sensu lato since they were probably remobilized during the Alpine orogenic events.

This paper addresses present-day comprehension of Turkey’s gold metallogeny; a topic on which remarkably little has been published so far. The main purpose is to present available data in the context of current understanding of gold deposits and metallogeny, and compare Turkey’s gold metallogeny with

well-studied systems elsewhere in the world. The paper also classifies the gold deposits and prospects of Turkey and speculates about potential gold deposit types based on geologic, tectonic and metallogenic setting of Turkey and surrounding areas. The ultimate purpose of this paper is to evaluate gold exploration potential of the Turkish part of the TEMB.

2. Regional geology

Metamorphic massifs form the crystalline basement of Turkey sensu lato. These are widely distributed and include massifs such as Istranca and Kazdag Massifs in NW Turkey, Menderes Massif in western Turkey, Kirsehir Massif in central Turkey, and Bitlis Massif in SE Turkey (Brinkmann, 1976; Ketin, 1983) (Fig. 2). A minority of the metamorphic massifs are allochthonous, including the Poturge and Bitlis Massifs (Sengor and Yilmaz, 1981).

In western Turkey, seven belts of metamorphic rocks can be distinguished, based on age and grade of principal metamorphism. The age of metamor-

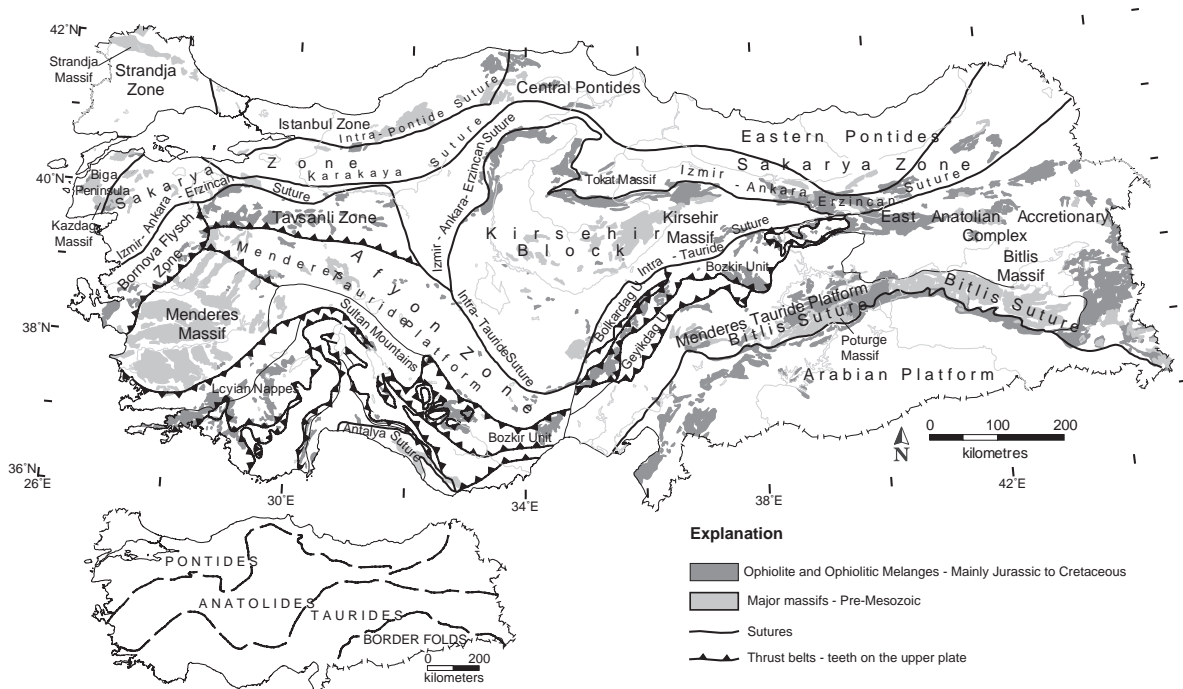


Fig. 2. Tectonic units of Turkey (modified from Gorur, 1998). Inset shows tectonic units (after Ketin, 1966) of Turkey. Lambert Conformal Conic Projection for Turkey, scale accurate for the location’s latitude.

phism ranges from Precambrian to Oligocene, and metamorphic facies range from greenschist- and amphibolite-facies to eclogite- and granulite-facies (Brinkmann, 1976; Ketin, 1983; Akkok, 1983; Satir and Friedrichsen, 1986; Hetzel and Reischmann, 1996; Oberhänsli et al., 1998; Bozkurt and Satir, 2000; Bozkurt and Oberhänsli, 2001; Candan et al., 2001; Lips et al., 2001; Rimmelé et al., 2003; Bozkurt, 2004). Some of the massifs, e.g., Menderes and Bitlis, consist of a high-grade metamorphic core (mainly gneiss, migmatite, and amphibolite), and low-grade metamorphic cover rocks (mainly schists and marbles). Even though the complex history of metamorphism in the Menderes Massif is still debated, five-phases of metamorphism are identified (Bozkurt, 2004). The first two are attributed to pre-Alpine orogenic events, the first probably associated with Pan-African collisional event (pre-550 Ma; Candan et al., 2001), and a second, pre-230 Ma, related to the closure of the Karakaya marginal basin of Paleozoic Tethyan ocean during the Late Triassic (Akkok, 1983). A major event affecting the whole massif—the main Menderes metamorphism—was associated with intense deformation and reached upper-amphibolite-facies conditions. The age of this event is Paleocene–Eocene, age data ranges from 36 ± 2 to 62 Ma (Satir and Friedrichsen, 1986; Hetzel and Reischmann, 1996; Bozkurt and Satir, 2000; Lips et al., 2001; Rimmelé et al., 2003; Bozkurt, 2004). This main metamorphic event is attributed to the closure of Neo-Tethys (Oberhänsli et al., 1998).

Paleozoic rocks of Turkey are dominated by non-metamorphosed sedimentary rocks and are distributed mainly in NE and SE Turkey, and some in the Taurus Mountains of southern Turkey. The distinctive Paleozoic rock succession of NE Turkey is called the Istanbul Zone (Fig. 2), hosting the country's largest hard-coal deposits in Zonguldak. In some places, Paleozoic rocks are represented by an uninterrupted and continuous section extending from the Cambrian to the end of the Permian. In contrast, the Paleozoic is represented in other places only by Permian rocks, as in NE Turkey. Infra-Cambrian rocks are exposed in SE Turkey (Ketin, 1983).

Mesozoic rocks of Turkey are exposed in extensive areas and consist mainly of platform limestones, volcanic rocks, flysch sequences and ophiolitic units. Although rocks of Triassic and Jurassic age have

limited exposures, Cretaceous rocks, especially Upper Cretaceous, cover large areas. Upper Cretaceous submarine volcanic rocks are mainly exposed in NE Turkey (Fig. 3). The Mesozoic rocks have a marked unconformity with the Paleozoic rocks and a gradual transition with Tertiary rocks in central and northern Turkey. The geological situation is opposite in Taurus Mountains in southern and SE Turkey (Ketin, 1983). In NE Turkey, the Mesozoic section starts with a Liassic transgression and continues with island-arc volcanic successions. Large areas of ophiolitic rocks are exposed with obduction ages ranging from Triassic to Paleocene, but mostly Upper Cretaceous (Sengor and Yilmaz, 1981) (Fig. 2). However, most of the ophiolitic assemblages are incomplete; the only complete ophiolitic sequence is Kizildag in Hatay (Dilek and Eddy, 1992).

Cenozoic rocks, generally unconformably overlying Mesozoic rocks, cover extensive areas and are dominated by shallow water sedimentary successions with thicknesses of several km, and Tertiary subaerial volcanic rocks (Fig. 3). In some places (e.g., central and western Turkey), sedimentary rocks have lagoonal and continental characters. The Cenozoic rocks mask the geology of Turkey due to their large aerial extension, although they host many economic mineral deposits including world-class borate deposits (Helvacı and Alonso, 2000; O'Driscoll, 2001).

2.1. Igneous rocks

The intrusive rocks of Turkey can be considered in two broad ranges based on their ages: pre-Middle Jurassic and Late Cretaceous to Late Miocene. These intrusive rocks outcrop extensively in NW, central and NE Turkey and are mainly granitic, granodioritic and syenitic in composition (Fig. 3). Gabbroic rocks are mainly related to ophiolitic assemblages. Metamorphosed granites are located within crystalline massifs.

Older granitoids of NW and northern Turkey are most probably Cambrian to Middle Jurassic in age, and have very scattered radiometric age dates ($^{40}\text{Ar}/^{39}\text{Ar}$), due to subsequent metamorphic events (Delaloye and Bingöl, 2000). Their geochemical composition ranges from granite to gabbro with a predominance of more acidic rocks. Pre-Middle Jurassic intrusions of NE Turkey are represented by the

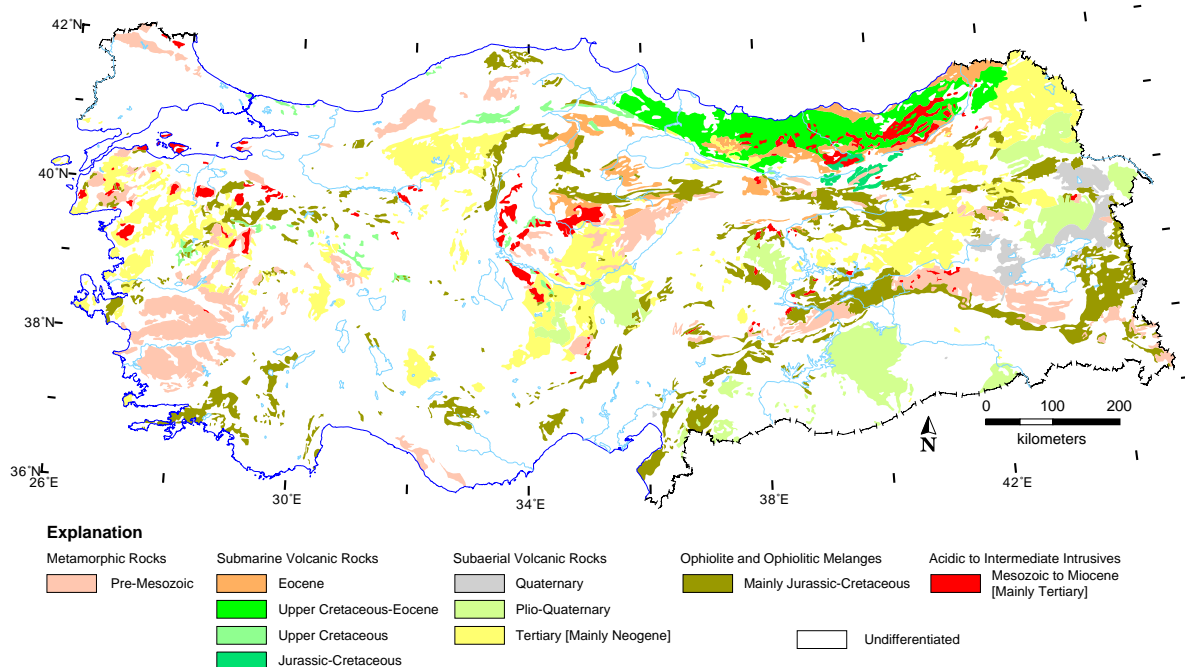


Fig. 3. Geology of Turkey with the emphasis on the host-rock lithologies of the known gold deposits and prospects. Geology modified from MTA (1989). Lambert Conformal Conic Projection for Turkey, scale accurate for the location's latitude.

Gumushane granite pluton of Carboniferous age, with ages ranging from 338 to 298 Ma (whole-rock Pb ages) (Cogulu, 1975).

Late Cretaceous to Late Miocene intrusive rocks of western Turkey have compositions ranging from calc-alkaline granites to granodiorites and monzogranites to syenogranites and have a subduction-related origin (Delaloye and Bingol, 2000). Plutonic rocks of central Anatolia, representing mainly syn-collisional and post-collisional events, are dominated by I-type, high-K calc-alkaline rocks of Late Cretaceous age, but S-type and A-type granitoids are also present. The S-type intrusive rocks are mostly Late Cretaceous in age, and A-type, high-K alkaline rocks are mainly Paleogene in age (Boztug, 2000).

Although intrusive rocks of NE Turkey have been evaluated in three categories *sensu lato* (Late Cretaceous, Paleocene and Eocene; Moore et al., 1980; Yalcinalp, 1995; Yilmaz and Boztug, 1996), recent studies suggest ages ranging from Early Cretaceous to Eocene (Boztug et al., 2004). The Cretaceous to Early Paleocene arc-related granitoids are metaluminous calc-alkaline granodiorite and granite in composition,

with I-type characteristics. These granitoids in the Eastern Pontides, as well as from Istranca (Western Pontides), show characteristic features of subduction-related magmatism, with low HFS/LIL ratios (Akyol and Tokel, 1991). The syn-collisional granitoids are peraluminous S-type leucogranites. The Eocene intrusive rocks are post-collisional, and are calc-alkaline and tholeiitic, with M-type characteristics, or alkaline in composition (Boztug et al., 2004).

Intrusive rocks of the Border Folds region form an arc-shaped trend (Fig. 3). Ages of granitoids in this belt are mainly Upper Cretaceous, (e.g., K/Ar ages of Baskil pluton 86 to 75 Ma; Dumanlilar et al., 1999). This trend is parallel to the Zagros suture zone, created as a result of closure of southern branch of Neo-Tethys from Late Cretaceous to Miocene time (Yilmaz, 1993).

Volcanic rocks of Turkey, covering large areas (Fig. 3), can be divided into three broad categories based on their origin: ophiolite, island- and continental arc-sequences. Ophiolite sequences are represented mainly by pillow lavas. Island arc-related submarine volcanic rocks are exposed in NE and SE Turkey.

Volcanic rocks in NE Turkey range mainly from Upper Cretaceous to Miocene in age, with minor volcanic rocks of Jurassic and Lower Cretaceous age (Fig. 3). The Upper Cretaceous rocks (Senonian) have calc-alkaline character and have wide aerial extension (Egin et al., 1979; Barbieri et al., 2000).

Continental-arc rocks cover ca. 10% of the whole land area of Turkey and are mostly post-Oligocene in age. In western Turkey volcanic activity started in Late Oligocene–Early Miocene with widespread andesitic and dacitic calc-alkaline volcanism, and continued with a gradual transition to basaltic alkaline volcanism during Late Pliocene. In contrast, in eastern Turkey, volcanic activity started in Late Miocene with basic and intermediate alkaline rocks and continued with widespread calc-alkaline volcanism during the Pliocene. During the Late Pliocene to Quaternary alkaline volcanism dominated in both areas of Turkey (Yilmaz, 1990).

3. Tectonic setting

Tectonic units of Turkey, the easternmost segment of the Alpine orogenic belt, are distinguished from each other by complex suture zones (Fig. 2) representing remnants of the Tethyan oceans, called Paleo- and Neo-Tethys. The geological evolution of Turkey was mainly governed by these two main phases of Tethyan evolution that partly overlap in time. Paleo-Tethyan evolution of Turkey took place mainly in Permian to Triassic times, while Neo-Tethyan evolution occurred mainly from Jurassic to Miocene times (Sengor and Yilmaz, 1981).

A fourfold E–W trending subdivision of tectonic units of Turkey was proposed by Ketin (1966). These subdivisions are, from N to S: Pontides, Anatolides, Taurides, and Border Folds (Fig. 2, inset). This simplest, and most widely accepted, tectonic division of Turkey (Fig. 2) has been modified by many later workers (Sengor et al., 1980, 1984; Sengor and Yilmaz, 1981; Sengor, 1984; Gorur, 1998; Okay and Tuysuz, 1999; Stampfli, 2000). Two main sutures divide Turkey into three parts; the Izmir–Ankara–Erzincan suture separates the Pontides in the north from the Anatolide–Tauride platform to the south, whereas the Bitlis suture marks the northern edge of the Arabian plate in southeastern Turkey (Fig. 2).

The Paleo-Tethyan evolution of Turkey is controlled by southward subduction of the Paleo-Tethyan Ocean beneath the northern margin of Gondwanaland during the Permo–Triassic. Terminal closure of the Paleo-Tethys occurred during the Middle Jurassic (Sengor and Yilmaz, 1981). Neo-Tethyan evolution began in the Late Triassic with the opening of southern branch of Neo-Tethyan Ocean in southern Turkey, while the multi-armed northern branch of Neo-Tethyan Ocean formed during the Early Jurassic with the Anatolide–Tauride platform between the two branches (Sengor and Yilmaz, 1981). During the Late Cretaceous, north-dipping subduction activity related to closure of the Neo-Tethyan Ocean was initiated all along the Pontides. The opening of the Black Sea north of the Rhodope–Pontide island arc took place while extensive ophiolite obduction occurred throughout the Anatolide–Tauride platform and the northern portion of the Arabian platform. Final closure of the northern branch of Neo-Tethyan (Vardar) Ocean by N-dipping subduction concluded when the Anatolide–Tauride platform collided with the Pontide arc along the Izmir–Ankara–Erzincan suture during the latest Paleocene–Early Eocene (Sengor and Yilmaz, 1981) (Fig. 2). During the Late Eocene–Early Miocene, general N–S tightening continued while closure of basins in SE Turkey marked the beginning of the Arabia–Eurasia collision along the Bitlis–Zagros suture zone (Fig. 2). This event created a compressional tectonic regime in eastern Turkey, which in turn caused the Aegean N–S extensional regime with related volcanism. This was the origin of the current tectonic regime in Turkey, creating the Anatolian plate bounded by the North and the East Anatolian transform fault systems (Sengor and Yilmaz, 1981) (Fig. 4).

In spite of the fact that Sengor and Yilmaz (1981) model has been widely used, a number of controversial views have been introduced in subsequent studies. These include the number of Tethyan oceans, the timing of all events (Dercourt et al., 1986; Robertson and Dixon, 1984; Robertson et al., 1996; Stampfli, 2000), the timing and geotectonic setting of ophiolite emplacement (Robertson, 2002) and the direction of subduction events (Aslaner, 1977; Adamia et al., 1981; Bektas, 1984, 1987, 1990; Tokel, 1995). Discussions of various tectonic models for the Late Paleozoic–Early Tertiary evolution of Turkey can be

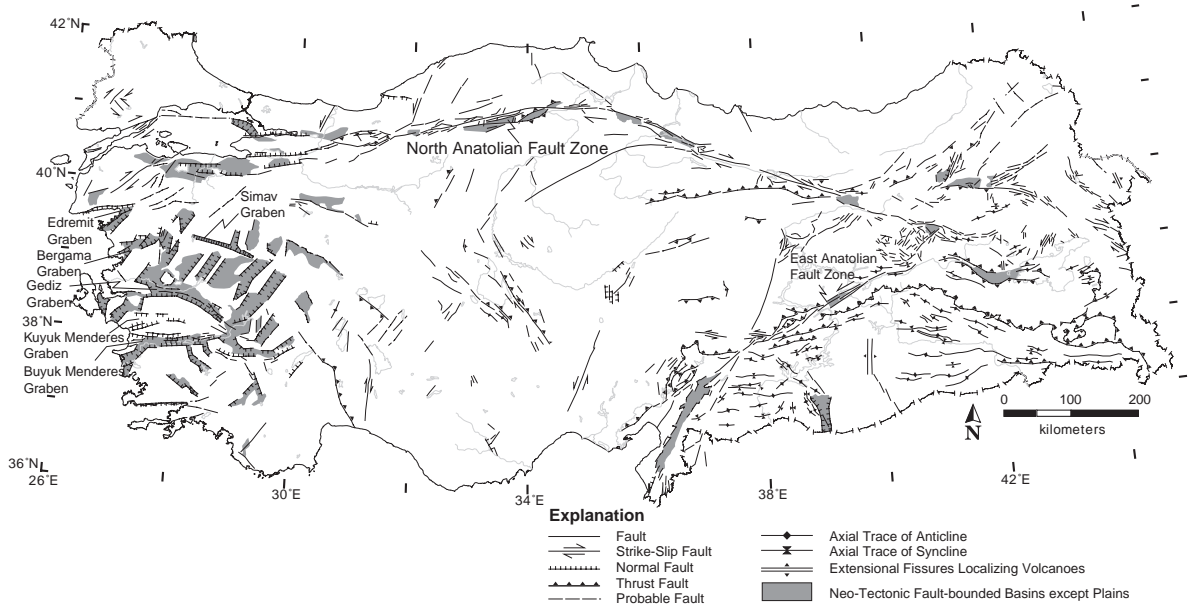


Fig. 4. Neotectonic map of Turkey with major extensional basins (modified from Gorur, 1998). Lambert Conformal Conic Projection for Turkey, scale accurate for the location's latitude.

found in Robertson and Dixon (1984) and Robertson et al. (1996). Tethyan sutures in Turkey have been reviewed by Stampfli (2000), who proposed that the Izmir–Ankara suture, a remnant of Izmir–Ankara Ocean, is not along the Neo-Tethyan suture (Fig. 2). Furthermore, timing of opening and rifting of Izmir–Ankara ocean could be earlier than Late Triassic (Tekin et al., 2002).

Ophiolitic rocks of Turkey are associated with closure of Paleo-Tethyan and Neo-Tethyan oceans and are mainly Jurassic and Late Cretaceous in age (Sengor and Yilmaz, 1981) (Fig. 2). Robertson (2002) argues that most of the Late Cretaceous ophiolites of Turkey and Cyprus are supra-subduction zone (SSZ) type, forming above subduction zones rather than at mid-ocean ridges (MORs). Furthermore, age and formation of the Kure Ophiolite are controversial; Sengor et al. (1980, 1984) and Sengor (1984) interpreted the Kure Ophiolite as a remnant of the Paleo-Tethyan Ocean and pre-Late-Jurassic in age. Later, Ustaomer and Robertson (1994) concluded that the Kure Complex is a subduction-accretion complex related to southward closure of the Kure marginal basin, which opened along the southern margin of Eurasia in Late Paleozoic as a

back-arc basin, resulting from northward closure of the Paleo-Tethys further south.

The origin and timing of the extension in western Turkey are other contentious issues; tectonic escape, back-arc spreading and orogenic collapse are the proposed models. In the tectonic escape model, collision of the Arabian and Eurasian plates across the Bitlis–Zagros suture zone in SW Turkey caused the Anatolian plate to move westward along the dextral North Anatolian fault system and sinistral East Anatolian fault system during the Middle Miocene (~15 Ma) (Fig. 4). This event gave rise to the N–S extensional regime in western Turkey, which led, in turn, to the formation of E–W trending grabens (Dewey and Sengor, 1979; Sengor, 1979, 1982, 1987; Sengor et al., 1985) (Fig. 4). In the back-arc spreading model, inception of subduction in the Hellenic arc is the critical factor. Migration of the Hellenic arc to the south and southwest gave rise to a back-arc extensional regime, combined with the roll-back of the subducting plate. However, the inception date for the subduction roll-back process is still controversial. Ages of this event range from 60 to 5 Ma: 13 Ma (Le Pichon and Angelier, 1979, 1981); 5 Ma (McKenzie, 1978; Jackson and McKenzie, 1988); from 60–15 to 10 Ma

(Kissel and Laj, 1988), and 26 Ma (Meulenkamp et al., 1988, 1994). The orogenic collapse model involves the spreading and thinning of over-thickened crust during the latest Oligocene–Early Miocene, after the latest Paleocene collision across Neo-Tethys. This process caused the extensional regime in western Turkey (Dewey, 1988; Seyitoglu and Scott, 1991, 1992, 1996).

A related area of debate is the origin of the Tertiary volcanic rocks of western Turkey. The changing tectonic regime from N–S compression to extension in Late Miocene (Sengor, 1979, 1982; Sengor and Yilmaz, 1981) caused a change from calc-alkaline to alkaline volcanism (Yilmaz, 1990; Savascin and Gulec, 1990; Gulec, 1991). However, other workers concluded that N–S extensional tectonics may have commenced as early as the Late Oligocene–Early Miocene, and therefore the change from calc-alkaline to alkaline volcanism in Middle Miocene reflects a decreasing amount of crustal contamination with time (Seyitoglu and Scott, 1992, 1996; Seyitoglu et al., 1997). Recent work in Biga peninsula, NW Turkey suggests voluminous calc-alkaline volcanic and plutonic rocks of Late Oligocene–Early Miocene age formed above the N-dipping Hellenic subduction zone, and the latest Oligocene regional extension was mainly associated with roll-back of the subduction zone rather than gravitational collapse (Okay and Satir, 2000).

4. GIS database

Evaluation of the gold metallogeny of Turkey is based on a GIS database compilation consisting of a total of 194 gold deposits and prospects. Data are mostly derived from MTA inventories (including but not limited to Ryan, 1957; Gumus, 1970; MTA, 1980, 1993a; Ersecen, 1989) and reports with published and unpublished data from numerous sources including company news releases. The database contains all available relevant descriptive information about deposits and prospects. Deposit types for some deposits and prospects in the database have been inferred from published descriptions because most of the MTA inventories do not contain genetic classifications. Therefore, considerations on some of the deposits in terms of their genetic type are based on author's own

reasoning. Finally, the database was imported into the GIS environment to perform geospatial analyses using geological, structural, geophysical, tectonic, and metallogenic maps.

Gold in Turkey occurs in a wide variety of deposit styles, ranging from Au-only systems to Au-rich (by-product gold) systems. Epithermal deposits account for 43% of the deposits and prospects in the database with 14% VMS, 12% porphyry, and 11% orogenic gold including listwanite-hosted gold. Other deposit types make up 20% of the database, 6% of which are assigned to 'unknown genetic origin'. Data indicate that economically important deposit types are porphyry, epithermal including both high- and low-sulfidation styles, and VMS including both Kuroko and Cyprus types.

5. Gold reserves and resources

Current available data show that Turkey has a current gold endowment, including reserves and resources, of ca. 31.5 M oz Au (979 tonnes) in 51 deposits; 21 of these contain more than 0.2 M oz Au (Table 1). The other 30 deposits contain total of ca. 1 M oz (31 tonnes) Au resources. Two recent discoveries (Kisladag and Cople), contain current total Au resources of 17.6 M oz (549 tonnes), constituting more than 50% of the total gold endowment of Turkey. Kisladag in particular has the potential to be a world-class porphyry Au deposit (5.1 M oz reserves, 8.4 M oz resources). Total gold reserves of Turkey are ca. 9 M oz (290 tonnes) in 8 deposits, including by-product gold in VMS deposits (Table 1). Six deposits, Kisladag, Cople, Sahinli, Efemcukuru, Ovacik and Cerattepe, each contain over 1 M oz Au as reserve and/or resources (Table 1).

The gold metallogeny database of Turkey indicates that all of the new gold deposits currently in a development stage (e.g., Kisladag, Cople, Efemcukuru, Cerattepe and Mastra; Table 1) have been discovered in the past two decades, after the change in the mining law. It has to be stated that some of these new discoveries resulted from reinvestigation of long-known prospects (although not previously explored for gold), which had already been documented by MTA, e.g., Cople and Mastra. Ovacik (Izmir) is presently the only active gold mine in Turkey with Au and Ag as

Table 1
Gold deposits of Turkey, which contain more than 0.2 M oz gold as a reserve and/or resource

Deposit name	State	Commodity	Mineral reserves and/or Resources	Total Au M oz	Total Au Tonnes	Status	Data sources
Kisladag	Usak	Au	Reserve: 135.02 Mt @ 1.16 g/t Au Resource: 214.80 Mt @ 1.04 g/t Au (measured and indicated), 45.5 Mt @ 0.75 g/t Au (inferred)	13.44	418.1	D	Eldorado Gold News Release, 09.15.2003
Copler (Cukurdere)	Erzincan	Au	Resource: main zone: 33 Mt @ 2.1 g/t Au, marble cover zone: 4 Mt @ 7.7 g/t Au; old mn mine zone: 7 Mt @ 4.1 g/t Au 4 Mt @ 3 to 4 g/t Au(inferred)	4.20	130.6	D	AMDL, 2003
Sahinli	Canakkale	Au, Ag	Resource: 7.5 Mt @ 8.5 g/t Au (unclassified)	2.05	63.7	P	Yildirim and Cengiz, 2004
Efemcukuru	Izmir	Au	Reserve: 1.81 Mt @ 13.31 g/t Au Resource: 1.83 Mt @ 14.44 g/t Au (measured and indicated), 0.59 Mt @ 12.63 g/t Au (inferred)	1.87	58.0	D	Eldorado Gold News Release, 05.02.2002
Ovacik	Izmir	Au, Ag	Reserve: 1.24 Mt @ 13.1 g/t Au Resource: 4.17 Mt @ 7.6 g/t Au	1.54	47.9	M	Newmont, 2002
Cerattepe	Artvin	Cu, Au, Ag	Reserve: Oxide: 3 Mt @ 4.2 g/t Au, 151 g/t Ag, Sulfide: 3.7 Mt @ 1.2 g/t Au, 25 g/t Ag, 5.2% Cu Resource: Oxide 5.2 Mt @ 3.8 g/t Au, 117 g/t Ag (indicated), Sulfide 0.2 Mt @ 1.8 g/t Au, 30 g/t Ag, 5.2% Cu (indicated)	1.20	37.2	D	Cominco, 2000
Asikoy ^a	Kastamonu	Cu, Au, Ag	Reserve: 11.23 Mt @ 2.48 g/t Au, 10 g/t Ag and 1.56% Cu	0.90	27.8	M	Cagatay, 1993; Erler, 1995
Corak	Artvin	Au	Resource: 1.8 Mt @ 10 g/t Au	0.58	18.0	P	Manhattan Minerals News Release, 09.21.2004
Agi Dagi	Canakkale	Au	Resource: 11.3 Mt @ 1.2 g/t Au+0.143 M oz Au (inferred)	0.58	18.0	P	Fronteer Development Group, 2003
Ergani ^a	Elazig	Cu, Au, Ag	Reserve: 14.94 Mt @ 1.2 g/t Au	0.58	17.9	M	Erler, 1993
Tac	Artvin	Au	Resource: 5 Mt @ 3 to 4 g/t Au	0.56	17.5	P	Manhattan Minerals News Release, 09.21.2004
Mastra	Gumushane	Au	Resource: 1.09 Mt @ 12.34 g/t Au	0.43	13.5	D	Newmont News Release, 10.01.2002
Madendag	Canakkale	Au	Resource: 8 Mt @ 1.25 g/t Au+past production	0.32	10.0	P	MTA, 1993a
Altintepe	Ordu	Au	Resource: 2G zone; 1.19 Mt @ 1.87 g/t Au (indicated), 3.16 Mt @ 1.52 g/t Au (inferred); Extension Ridge; 2.19 Mt @ 1.21 g/t Au (inferred)	0.31	9.7	P	Odyssey Resources Ltd. News Release, 03.10.2003
Madenkoy ^a (Cayeli)	Rize	Cu, Zn, Au, Ag	Reserve: 6.56 Mt @ 4% Cu, 5.7% Zn, 0.7 g/t Au, 43 g/t Ag (proven), 9.37 Mt @ 3.2% Cu, 5.4% Zn, 0.5 g/t Au, 45 g/t Ag (probable) Resource: 3.2 Mt @ 3.8% Cu, 5.9% Zn (inferred)	0.30	9.2	M	Inmet Mining, 2003

(continued on next page)

Table 1 (continued)

Deposit name	State	Commodity	Mineral reserves and/or Resources	Total Au M oz	Total Au Tonnes	Status	Data sources
Kucukdere	Balikesir	Au, Ag	Resource: 1.28 Mt @ 6.43 g/t Au (measured and indicated), 0.14 Mt @ 6.45 g/t Au (inferred)	0.29	9.1	P	Eldorado Gold News Release, 05.02.2002
Tavsan	Kutahya	Au	Resource: 7.89 Mt @ 1.15 g/t Au (unclassified)	0.29	9.1	P	Odyssey Resource Ltd. News Release, 05.14.2003
Gumushane	Artvin	Cu, Au, Mo	Resource: 30 Mt @ 0.3 g/t Au and 0.3% Cu or 80 Mt @ 0.5% Cu equivalent	0.29	9.0	P	Soylu, 1999
Murgul ^a	Artvin	Cu, Au	Reserve: 40 Mt @ 0.2 g/t Au, 25 g/t Ag, 1.25% Cu, 0.1% Zn and 0.005% Pb, (past production: 38 Mt @ 1.1% Cu)	0.26	8.0	M	Schneider et al., 1988; Cagatay, 1993
Kirazli	Canakkale	Au	Resource: 0.250 M oz @ 29 g/t Au	0.25	7.8	P	Fronteer Development Group News Release, 02.12.2004
Kaymaz	Eskisehir	Au	Resource: 1.09 Mt @ 6.25 g/t Au	0.22	6.8	D	Eldorado Gold News Release, 05.02.2002

Status: M: Mine, D: Development, P: Prospect, Reserves: proven or probable, Resources: measured, indicated or inferred.

^a By-product gold.

the primary commodities; several mines produce by-product Au from VMS deposits.

6. Types and distribution of gold deposits and prospects

Turkey possesses a wide spectrum of gold deposits including porphyry gold (Cu–Mo), gold in skarns, epithermal gold, volcanic-associated massive sulfide (VMS), orogenic gold including listwanite-hosted, and placer gold. There are some known occurrences of deposits which are potentially of Carlin-type, detachment-fault-related gold-type, iron-oxide copper-gold (IOCG), gold in carbonate replacement and Mn-deposits, which could become exploration targets (Fig. 5). Characteristics of the gold deposits of Turkey containing more than 0.2 M oz Au as reserve or resource, including by-product gold are summarized in Table 2. Most of porphyry and VMS gold deposits vary from gold-only systems to by-product gold systems.

6.1. Gold in porphyry systems

Gold-enriched (accessory gold) and gold-rich (gold as primary commodity) porphyry deposits and pro-

spects are mainly associated with granitoids of Late Cretaceous to Late Miocene age (Fig. 3). The three distinct metallotectonic settings, trending roughly E–W, and representing both island-arc and continental-arc settings, are the Pontides, Anatolides and Border Folds regions (Fig. 5). Although the tectonic division of Turkey in Ketin (1966) (Fig. 2, inset) was used for these metallogenic belts in this text, the belts do not necessarily coincide with these divisions (Fig. 5).

6.1.1. Pontides

In spite of the fact that there are no economic Au-rich porphyry deposits in the Pontides, there are several porphyry Cu–Au prospects with significant mineralization (Fig. 5), e.g., Derekoy, Sukrupasa and Ikiztepelers (Kirkclareli, NW Turkey), and Yuksekoba and Gumushane (Artvin, NE Turkey). In Kirkclareli, porphyry mineralization is associated with Late Cretaceous age, magnetite series, I-type granitoids (Ohta et al., 1988). Although prospects have been classified as being porphyry Cu–Mo, and skarn prospects in the past, the gold potential of the district was only recently brought to attention as a result of exploration activity in the area. At Derekoy, mineralization is associated with tonalite and monzonite porphyry. The age of the mineralization is 76.7 ± 3.8 Ma using

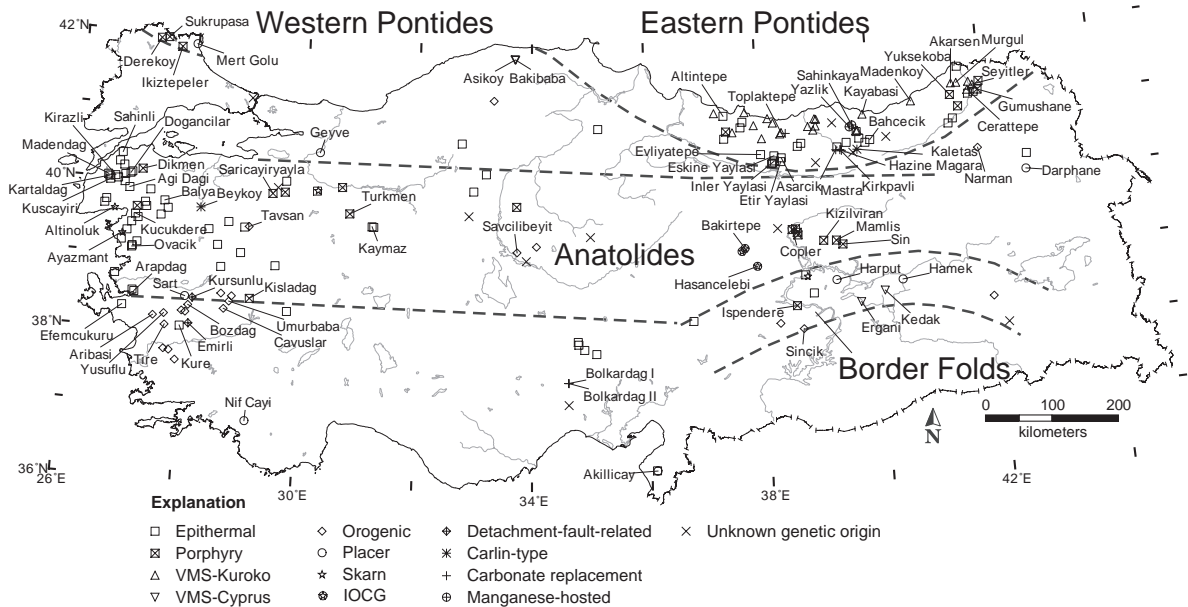


Fig. 5. Distribution and types of 194 gold deposits and prospects in Turkey. Lambert Conformal Conic Projection for Turkey, scale accurate for the location's latitude.

K–Ar on tonalite porphyry from the potassic alteration zone (the K–Ar age of fresh monzonite porphyry is 70.9 ± 3.5 Ma; Ohta et al., 1988). At the Sukrupasa prospect, the K–Ar age of the monzodiorite to granodiorite associated with porphyry mineralization is 81.7 ± 1.6 Ma (Moore et al., 1980). Derekoy has 270 Mt ore resources at 0.28% Cu (Mutschler et al., 1999). The contribution of the Au grade to the system has not been evaluated, but combined with Cu and Mo, could produce an economic orebody (Ohta et al., 1988). Potassic alteration at Derekoy is found within major intrusions of the tonalite porphyry; however, main mineralized zones are within the phyllic zone (Ohta et al., 1988). At Sukrupasa and Ikitzepeler porphyry prospects, W-mineralization is prominent, indicating a possible reaction of parent magma with the gneissic rocks of the basement (Ohta et al., 1988).

Porphyry prospects in the Eastern Pontides are associated with intrusives whose ages range mainly from Late Cretaceous to Eocene (79 to 26 Ma by K–Ar; Moore et al., 1980). The Gumushane porphyry Cu–Au prospect, Artvin, is related to granodiorite porphyry of Middle to Late Eocene age, and contains higher grade Au values, up to 13 ppm, with more extensive argillic alteration zones compared to other

porphyry Cu systems in the Eastern Pontides (Soylu, 1999). This prospect also includes base- and precious-metal mineralization as carbonate replacements at the contact between limestone and granodiorite.

6.1.2. Anatolides

This belt contains the two largest gold deposits in Turkey (Table 1): Kisladag in Usak and Copler (Cukurdere) in Erzincan. In addition, the belt contains many old and new porphyry prospects such as Dikmen, Saricayiryayla, Turkmen (Yilmaz, 2003), Kizilviran, Mamlis and Sin (Fig. 5).

Kisladag was effectively defined as a potential low-grade, bulk tonnage Au deposit in 1998 (Eldorado Gold, 2003). The deposit, hosted by multi-phase latite porphyry intrusions of Late Tertiary age, most probably Miocene (Eldorado Gold, 2003), is the first example of an economic porphyry Au deposit in Turkey and will commence production in 2005. Kisladag is an exceptionally Au-rich porphyry deposit with high Mo content (Sillitoe, 2002). Typically, Au-rich porphyry deposits are deficient in Mo, with the notable exceptions of Bingham, Ok Tedi and Skouries (Sillitoe, 2000). Gold is associated with at least three stages of partially overlapping stockwork veins

Table 2
Geologic characteristics of gold deposits of Turkey, which contain more than 0.2 M oz gold as a reserve and/or resource

Deposit name	State	Deposit type	Principal host rocks	Age of host rock	Orebody	Structure	Data sources
Kisladag	Usak	Porphyry Au	Multi-phase latite porphyry intrusions	Late Tertiary	Stockworks, breccia	Strong WNW and W trends	Eldorado Gold, 2003
Copler (Cukurdere)	Erzincan	Porphyry Au–Cu	Granodiorite, quartz monzonite (1), skarnified limestone (2)	Paleocene (1), Liassic–Campanian (2)	Stockworks	1 × 2 km depression	AMDL, 2003
Sahinli	Canakkale	Epithermal	Andesitic volcanic rocks (1), schist (2)	Eocene? (1), Paleozoic (2)	Veins	Mainly NE-trending veins with some E- and N-trends	Yildirim and Cengiz, 2004
Efemcukuru	Izmir	Epithermal LS	Flysch, hornfels (1), rhyolite intrusions pre-mineralization (2),	Late Cretaceous–Paleogene (1), Neogene (2)	Veins, stockworks, breccia, replacements	NW-trending faults and veins	Oyman et al., 2003
Ovacik	Izmir	Epithermal LS	Andesite porphyry	Early Miocene	Veins with breccia	E-trending M vein and NW-trending S vein	Yilmaz, 2002
Cerattepe	Artvin	VMS-Kuroko/Epithermal	Dacitic tuffs	Upper Cretaceous	Massive, veinlets, disseminations	NE-trending fault zone	O'Brien, 1997
Asikoy	Kastamonu	VMS-Cyprus	Basaltic pillow lavas (spilites), carbonaceous argillites, turbidites	Middle Jurassic	Massive lens, stringers	Thrust fault	Cagatay, 1993; Erler, 1995
Corak	Artvin	Epithermal	Andesitic flow and agglomerates	Upper Cretaceous	Veins and stockworks	NE-trending fault zone	Manhattan Minerals News Release, 09.21.2004
Agi Dagı	Canakkale	Epithermal HS	Flow dome complex	Oligocene?	Disseminations, breccias	NE-trending zone	Fronteer Development Group, 2003
Ergani	Elazig	VMS-Cyprus	Mafic submarine volcanic rocks, mudstone, red-black limestone	Eocene	Massive lens, stockworks, disseminations	Thrust fault	Erler, 1984; Gumus, 1998

Tac	Artvin	Epithermal	Andesitic flow and agglomerates	Upper Cretaceous	Veins and stockworks	NE-trending fault zone	Manhattan Minerals News Release, 09.21.2004
Mastra	Gumushane	Epithermal LS	Andesite porphyry, andesitic tuff	Eocene	Stockworks, local breccia	NW-trending shear zone	MTA, 1993b; Tuysuz et al., 1995
Madendag	Canakkale	Epithermal HS	Schists, andesite	Lower Miocene	Veins, breccia, stockworks	NW-trending veins, NE-trending mineralized fissures and fractures	MTA, 1993a
Altintepe	Ordu	Epithermal	Volcano-sedimentary rocks, feldspar porphyry andesite, rhyolite domes	Upper Cretaceous	Veins, stockwork, breccia, disseminations	E-trending fault zone at Extension Ridge	Odyssey Resource Ltd., 2002
Madenkoy (Cayeli)	Rize	VMS-Kuroko	Dacitic lava and tuffs	Upper Cretaceous	Massive, stockworks	NE-striking orebody with a dip of 60–80°	Cagatay, 1993
Kucukdere	Balikesir	Epithermal LS	Andesite porphyry	Miocene	Banded-quartz–carbonate veins	NE-trending veins	Colakoglu, 2000
Tavsan	Kutahya	Orogenic/ Listwanite-hosted	Serpentinites, metamorphosed graywackes, limestones	Jurassic–Upper Cretaceous	Disseminations, pods, stockworks	NE-trending zone with a series of low-angle thrust faults	Larson and Erler, 1993
Gumushane	Artvin	Porphyry Cu–Au	Granodiorite porphyry (1), limestone (2)	Middle to Upper Eocene (1), Paleocene (2)	Stockworks	NNW-trending fault	Soylu, 1999
Murgul	Artvin	VMS-Kuroko/ Epithermal	Dacitic lava and tuffs	Upper Cretaceous	Stringers with disseminations, minor massive ore	Funnel shape stockwork zone of mineralization with oval surface section having NNW trend	Schneider et al., 1988; Cagatay, 1993; Tuysuz, 2000
Kirazli	Canakkale	Epithermal HS	Andesite	Lower Miocene	Stockworks, breccia, disseminated and replacement	Sub-horizontal ore zones	Pirajno, 1995
Kaymaz	Eskisehir	Orogenic/ Listwanite-hosted	Marine sediments and associated ophiolites	Upper Cretaceous?	Disseminations in mostly breccia	Highly deformed rocks	Eldorado Gold, 2001

and brecciation forming a horseshoe wrapping around northern, eastern and southern sides of a late weakly-mineralized stock with dimensions of 800 m N–S and 500 m E–W. Another conspicuous feature of the system is the paucity of quartz veinlets. However, intense quartz–tourmaline stockwork veining is very prominent. A zone with vuggy barren silica featuring intense acid leaching could represent a lithocap. The oxidation zone varies from 20 m to over 100 m in depth and tends to be deeper around the flanks of the deposit, decreasing toward the stock intruding the center of the deposit (Eldorado Gold, 2003).

Copler, the second biggest gold deposit in Turkey, is hosted in granodiorite, quartz monzonite and limestone. The age of the intrusive is most probably Paleocene and the skarnified limestone is Liassic (Ozer, 1994). Mineralization and alteration in Copler porphyry Cu–Au deposit have characteristics of a typical porphyry system, albeit that a classic, concentric porphyry alteration is not evident in the system (AMDL, 2003). Mineralization is mainly associated with phyllic alteration, which is overprinted by argillic alteration. The Copler deposit is characterized by a prominent surface depression with 1×2 km diameter, which can be easily recognized from air or from satellite imagery (LANDSAT or ASTER data). This surface depression may suggest that the system is relatively quartz deficient, as with alkaline-hosted deposits which are unlikely to resist erosion and do not crop out prominently (Sillitoe, 2002). Outlying skarn and/or replacement gossans occur along the limestone and marble contact with the intrusive rocks. Structurally-controlled mineralization in jasperoid breccias is present mainly along the Copler Fault and along the metasediment and marble contact. A Cu–Au-bearing Mn-oxide-rich orebody, previously mined for Mn, is located approximately 1 km NE of the main porphyry zone (AMDL, 2003).

Gold bearing skarn deposits of Turkey are dwarfed by base-metal skarns; the only Au-bearing skarns are located in this belt. The Altinoluk base- and precious-metal deposit, Biga Peninsula, (Gumus, 1970) is hosted by schist, marble and amphibolite of Kazdag Massif and contains limited resources (average 5 g/t Au, 25 g/t Ag, 8.21% Pb, 6.72% Zn; MTA, 1993a) (Fig. 5). Additionally, several Au-bearing skarn mineralizations are associated with Yenice granitoid in Biga Peninsula, NW Turkey.

6.1.3. Border folds

The only known prospect in this belt is Ispendere (Fig. 5). Porphyry Cu–Au mineralization is associated with I-type calc-alkaline granitoids of Late Cretaceous age (86 to 75 Ma by K–Ar; Dumanlilar et al., 1999). No gold anomalies appear on surface while up to 2.62 g/t gold is found in drill cores. The E-trending altered and mineralized zone contains weak potassic, phyllic, argillic and propylitic alteration, though mineralization is usually associated with phyllic–propylitic and/or phyllic zones (Dumanlilar et al., 1999).

6.2. Gold in epithermal systems

Subaerial to submarine volcanic rocks of Upper Cretaceous to Quaternary age cover 20% of the total land area of Turkey, not including mafic volcanic rocks related to ophiolites (Fig. 3). Tertiary subaerial volcanic rocks of calc-alkaline composition associated with continental-arc volcanism are, of course, favorable host-rock for epithermal gold mineralization (Cooke and Simmons, 2000). Epithermal gold deposits and prospects are clustered in two distinct regions of Turkey, Eastern Pontides, northeastern Turkey, and western Turkey (Fig. 5). In the Eastern Pontides, most of the epithermal mineralization is spatially associated with Late Cretaceous to Eocene calc-alkaline volcanic rocks (MTA, 1993b). Some of the vein deposits with formation temperatures extending up to ~ 300 °C are included in epithermal type, though defined as mesothermal type in the Turkish literature using the classification of Lindgren (1933), e.g., some vein deposits in the Sebinkarahisar vein district of Giresun in Eastern Pontides.

The majority of the gold deposits and prospects in the mineral deposit database of Turkey are epithermal (Fig. 5). However, none of these is yet known to be large or high-grade by world standards. Two deposits in Izmir contain in excess of 1 M oz Au as combined reserves and resources: Ovacik (the only working gold mine in Turkey) and Efemcukuru. Sahinli also contains over 2 M oz Au; but these resources are unclassified. High- and low-sulfidation epithermal gold deposits (Hedenquist, 1987; Hedenquist et al., 2000; Cooke and Simmons, 2000; Sillitoe and Hedenquist, 2003) and prospects are both represented, although the latter is to date the most important economically in Turkey. High-sulfidation systems are clustered mainly

in the Biga Peninsula, NW Turkey, which nevertheless also contains some low-sulfidation systems. Ore and alteration mineralogy of the many prospects are not studied sufficiently to characterize the type of epithermal environment. Some exceptions are Kusçayiri (Yilmaz, 2002), Kirazli and Dogancilar (Pirajno, 1995) in NW Turkey and Bahcecik (Yigit et al., 2000) in the Eastern Pontides.

The Ovacik, Efemcukuru, Kucukdere, Agi Dagi and Sahinli deposits are associated with subaerial volcanic rocks in W and NW Turkey. The Ovacik Au–Ag deposit, located along the northern boundary of the ENE-trending Bergama Graben (Fig. 4), is a typical example of a low-sulfidation vein deposit hosted in andesite porphyry of Early Miocene age. East-trending and NW-trending banded-quartz veins, known as M and S, respectively, dipping steeply north are the only economical veins (Newmont, 2002) (Table 1). Higher Au grades with in excess of 100 g/t Au are associated with colloform to crustiform banded quartz–adularia veins and late stage breccias. Gold is mostly Au-rich (.750) electrum. Fluid inclusion studies from quartz samples associated with gold shows that mineralizing fluids had temperatures between 150 and 250 °C with salinities of 7 to 8 wt.% NaCl equiv. (Yilmaz, 2002).

The Efemcukuru, low-sulfidation epithermal Au deposit is hosted by rhyolite domes of Neogene and flysch facies rocks of Late Cretaceous to Paleogene age. This is a boron-rich epithermal system that consists of two major veins, Alanicidere and Kestanebeleni, and numerous late-stage small sulfide-rich veins. NW-trending faults control not only vein-style mineralization with associated stockworks, breccias and replacement mineralization, but also act as loci for rhyolitic intrusions. Gold mineralization is associated with at least two distinct hypogene events: an early metasomatism and a later hydrothermal alteration and mineralization event consisting of least three stages. However, Au grades are enhanced as a result of supergene alteration in an oxidized zone up to 100 m depth (Oyman et al., 2003). Fluid inclusions from quartz samples show a broad range of homogenization temperatures between 200 and 300 °C, and salinities of 0 to 8 wt.% NaCl equiv., indicating the existence of a complicated geothermal system (Oyman et al., 2003). Alternating quartz, rhodonite and axinite bands with lesser amounts of calcite, rhodochrosite

and adularia can be seen in some veins, which may reflect geochemistry of skarnified host rocks.

Kucukdere is another relatively small low-sulfidation vein deposit in western Turkey (Table 1), hosted by andesite of Miocene age. Gold mineralization is associated with NE-trending veins and the highest Au grades are associated with banded-quartz veins (Colakoglu, 2000). Agi Dagi, Madendag and Kartaldag are sub-economic high-sulfidation epithermal mineralization associated with Neogene volcanism in the Biga Peninsula, NW Turkey (Fig. 5). Some of the epithermal base metal deposits in the district may contain high precious-metal values, e.g., Balya Pb–Zn–Ag deposit with 3 t Au past production as by-product (Agdemir et al., 1994); lead bullions were said to contain on average 7 g/t Au and 1,938 g/t Ag (Kovenko, 1940). Arapdag in Izmir, W Turkey, hosted in dacitic lava and tuffs of Late Oligocene to Middle Miocene age, is a similar system. Some of the high-sulfidation epithermal prospects in the Biga Peninsula could be barren lithocaps situated at the upper parts of porphyry systems.

The Mastra, Evliyatepe (Dogan, 2001) and Altintepe deposits, all associated with submarine to subaerial volcanic rocks in the Eastern Pontides (Fig. 5), could be typical examples of epithermal systems. The Mastra deposit is an example of low-sulfidation style epithermal mineralization and is hosted by andesite lava and tuffs of Miocene age. A NW-trending shear zone, dipping 70° to NE, controls the trend of mineralization and associated alteration. Gold is mainly associated with stockworks of quartz–adularia and sulfide mineralization. Late stage supergene advanced argillic alteration with alunite and vuggy silica is barren. Fluid inclusion studies from two stages of quartz related to gold mineralization have homogenization temperatures ranging from 160 to 340 °C with salinities ranging from 4.1 to 10.9 wt.% NaCl equiv. (Tuysuz et al., 1995). High salinities with relatively higher homogenization temperatures may explain the high base-metal content of the system, base metals being generally transported as chloride complexes. Furthermore, the epithermal environment could be shallow submarine with easily available chloride in the system as indicated by sedimentary rocks of same age conformably overlying the andesitic rocks.

The Sebinkarahisar district contains numerous epithermal vein-type ores, such as Eskine Yaylasi,

Etir Yaylasi, Inler Yaylasi and Asarcik (Fig. 5), some of which show transition to a mesothermal environment. Polymetallic base- and precious-metal veins, hosted generally by Upper Cretaceous rhyolitic, dacitic and andesitic rocks, can contain up to 78.8 g/t Au as seen in Etir Yaylasi. The veins are associated with E- and NW-trending fault and fracture systems, and contain pyrrhotite, pyrite, arsenopyrite, chalcopyrite, Bi-minerals, tetrahedrite–tennantite, galena, and pitchblende; the latter is found only in the Asarcik vein. Gold and silver are ubiquitous in the veins in Eskine Yaylasi; gold is associated with fahlore–enargite–luzonite–quartz. Quartz, fluorite, carbonate, barite and tourmaline are common gangue minerals. The Asarcik polymetallic base- and precious metal veins are epi-mesothermal (>300 °C), however, the gold appears to be epithermal within the system. The veins, hosted in quartz syenite and quartz monzonite, consist of a major polymetallic vein with 2 to 4 m thickness, striking NW and approximately 2.25 km in length, and a secondary vein, approximately 2 m thick, striking E along a length of 800 m. Homogenization temperatures of fluid inclusions within quartz, fluorite and sphalerite range from 140 to 300 °C with salinities ranging 3 to 15 wt.% NaCl equiv., except for the Asarcik vein where the early base-metal phase has temperatures up to 360 °C (Ayan and Dora, 1995). In Asarcik, tourmalinization, up to 1 m thick, kaolinization, epidotization and pyritization can be followed successively from vein to host rock (Ayan and Dora, 1995). Vein type mineralization in Sebin-karahisar is limited to Upper Cretaceous units and is accompanied by intensive alunization (alunite+kaolinite+quartz+sericite+pyrite) in advanced argillic zone. Sulfur isotopes for alunite-sulfide pairs indicate a hypogene origin for the alunite (Ozgenç, 1993).

The Altintepe gold deposit, with approximately 0.3 M oz Au (Table 1), is hosted by volcano-sedimentary rocks, porphyry andesite and rhyolite domes. Alteration assemblages and accompanying sulfides suggest possible formation of low-alongside high-sulfidation mineralization or an overprinting of high-by low-sulfidation mineralization (Odyssey Resources Ltd., 2002). This pattern is also observed in the Bahcecik (Yigit, 1997; Yigit et al., 2000) and Kirazli prospects (Pirajno, 1995). At Bahcecik, an early quartz–sericite alteration was overprinted by later, spatially more extensive, advanced argillic alteration; Au mineraliza-

tion accompanies both stages of alteration (Yigit et al., 2000). The coexistence of this kind of high- and low-sulfidation epithermal environments has also been documented in Comstock district of Nevada, USA by Hudson (2003) and in Mount Skukum, Yukon Territory, Canada by Love et al. (1998).

6.3. Gold in volcanic-associated massive sulfide deposits

Gold is a common by-product in volcanic-associated massive sulfide deposits, and can be significant in some deposits (e.g., Horne, Quebec; Eskay Creek, British Columbia; Henty, Tasmania; Huston, 2000). VMS deposits of Turkey can be evaluated in two separate types, Kuroko-type and Cyprus-type. These deposits can contain either Au-enriched orebodies, in which gold is an accessory, or Au-rich orebodies, in which gold is the primary economic commodity.

6.3.1. Gold in Kuroko-type VMS deposits

Volcanic-associated massive sulfide deposits of Kuroko type in Turkey are limited to bimodal volcanic rocks of the Eastern Pontides (Aslaner, 1977; Pejatovic, 1979; Schneider et al., 1988; Akinci, 1984; Ozgur, 1993; Cagatay, 1993; Cagatay and Eastoe, 1995; Tuysuz, 2000). These are mainly submarine volcanic rocks of Late Cretaceous age (Fig. 3). The Cerattepe, Murgul and Madenkoy (also known as Cayeli) deposits are typical examples of gold hosted in VMS-type ores. A barite–Au–Ag association with minor base metals is present in the Toplaktepe prospect. The Akarsen, Seyitler and Kayabasi prospects, with unclassified resources, can be categorized in the same group (Fig. 5). In these systems, Au mineralization is either within massive sulfide lenses or in the stockwork zones, analogous to both modern sea floor deposits and ancient VMS districts (e.g., Hannington et al., 1999; Huston, 2000). Cerattepe and Toplaktepe have some characteristics of epithermal mineralization in submarine environments (e.g., Sillitoe, 1994; Sillitoe et al., 1996). Gold mineralization is either related to a Au–Cu association (Cerattepe, Murgul), or a Au–Zn–Pb–Ag association (Madenkoy).

Cerattepe, hosted in the Late Cretaceous Artvin Volcanic complex, is a unique VMS deposit in Turkey because of exceptionally high precious-metal grades (average 4.2 g/t Au and 151 g/t Ag; Table 1). The

deposit is characterized by a basal zone of very high-grade Cu-sulfide ore, and an overlying and flanking Au–Ag–Pb–barite-rich oxide zone. The Cerattepe deposit is associated with a resurgent type of felsic cauldron, called the Artvin Cauldron, and formed under transitional submarine to subaerial conditions. The deposit shows characteristics of Kuroko-type VMS deposits with features of high-sulfidation epithermal style deposits (O'Brien, 1997; Ciftelian and O'Brien, 1998).

The Murgul deposit, the largest VMS deposit in Turkey, consists of mainly disseminated and stockwork Cu-ore spatially associated with intense wall-rock alteration. A late stage of intense silicification followed early phyllic and argillic alteration (Schneider et al., 1988). Two orebodies (Anayatak and Cakmakaya) contain 40 Mt ore, not including significant past production (Table 1); Au grades can be very high in the late-stage siliceous veinlets with epithermal signatures. Homogenization temperatures of 140 to 170 °C were determined by fluid inclusion studies (Tuysuz, 2000). In the Akarsen deposit (Ozgur, 1991), higher Au values, up to 8.2 g/t, also with elevated Sb and As, have been concentrated in silicified zones.

The Madenkoy deposit, representing the Au–Zn–Pb–Ag association, consists of mainly massive ore with subordinate stringer ore in dacitic tuffs. The main orebody is lens-shaped and dips to NW at moderate to steep angles. It contains clay and carbonate alteration zones in both foot- and hanging-wall rocks. Madenkoy has approximately 16 Mt ore contained in both yellow and black ore. Gold and Ag grades are relatively higher in clastic ore in the hanging wall, containing clasts of sphalerite, pyrite, bornite and sulfosalts with minor chalcopyrite. A S-isotope study of disseminated, stringer, and massive sulfides from eight Kuroko-type VMS deposits of Eastern Pontides (Cagatay and Eastoe, 1995) indicated that massive ore at Madenkoy is isotopically different from the other deposits. Massive sulfides have $\delta^{34}\text{S}$ values of 4.3‰ to 6.1‰, compared to stringer sulfides with $\delta^{34}\text{S}$ values of 6.3‰ to 7.2‰, indicating increasing input of H_2S derived from marine sulfate through time.

Toplaktepe is a massive barite–quartz deposit that has already been mined for barite. Barite mineralization is hosted by Upper Cretaceous dacitic lava and

pyroclastic rocks and may form the cap of Kuroko-type VMS mineralization. No economic massive sulfide mineralization has yet been found in the prospect. All of the known mineralization in the area is limited by intensively altered dacitic rocks that form a NW-trending corridor, ca. 3.5 km long and up to 1 km wide (Yigit, 1993; Aslaner and Yigit, 1996). Most of the mineralization occurs at the contact between dacitic lava, pyroclastic rocks and porphyry andesite, and contains massive barite + quartz veins, stockworks and disseminations of pyrite, sphalerite, galena, cinnabar, pyrargyrite, bornite, fahlores and covellite. Silicification, baritization, sericitization and argillic alteration are ubiquitous. Toplaktepe has local high-grade Au zones with enrichment of an element suite (Au–Ag–Hg–As–Sb–Tl), typical of epithermal gold deposits (Romberger, 1990). Geochemical data indicates that Au is most probably associated with fine-grained As-bearing pyrite. In some places, Au is also associated with low temperature opaline silica and colloidal pyrite (Yigit, 1993). Mineralization of similar type has also been documented from some of the other Kuroko-type massive sulfide deposits of Eastern Pontides, e.g., Murgul.

6.3.2. Gold in Cyprus-type VMS deposits

The term “Cyprus-type” is used in this paper for any ophiolite-hosted VMS deposits, without genetic connotation to tectonic setting or the geochemistry of the host mafic volcanic rocks (i.e., Galley and Koski, 1999). Although large areas of ophiolitic rocks are exposed in Turkey (Fig. 3), known VMS deposits are restricted to the Kure district, N Turkey and the Ergani district, SE Turkey (Fig. 5).

The Kure district includes two VMS deposits, Asikoy in the west and Bakibaba in the east, as well as a number of small occurrences. The orebodies are hosted in the basaltic sequence of the Kure ophiolite, which includes massive lava flows, pillow lavas, brecciated pillows and tuffs. The Asikoy and Bakibaba deposits are hosted by spilitized tholeiitic pillow lavas overlain by carbonaceous argillites and turbidites of probably Early Jurassic age. North- and NE-trending folds, N- and E-trending faults and the Kure thrust fault, exposed in the eastern wall of Asikoy open pit mine, are the dominant structural elements in the district. Orebodies are underlain by alteration pipes that consist of chlorite, quartz, and sulfides

with lesser epidote, calcite, siderite and specular hematite; illite–mica alteration occurs at the top of the pipes. The chlorite is Fe-rich and the Fe-content increases towards the massive ore (Cagatay, 1993). Asikoy is the largest known single deposit in the district (Table 1), and has high Co values (0.09% to 0.68%, mean 0.30% Co; Cagatay et al., 1980). It is a single, lens shaped, massive orebody consisting essentially of pyrite and chalcopyrite and underlain by disseminated and stockwork pyrite and occasional chalcopyrite. Trace element studies (Erler, 1995) indicated that Asikoy orebody was formed at a relatively low temperature, because it is poor in V, Ni and Ti, and rich in Zn, Cd, Co, Pb and Sb. Geochemical studies of the host rock indicated that volcanic rocks are island-arc tholeiites and formed during early stages of island-arc volcanism in a fore-arc environment (Koc et al., 1995).

The SE Anatolian ophiolite belt (Fig. 3), known for numerous Cyprus-type VMS deposits (Erler, 1984, 1989), is regarded as the eastern extension of suture zone of the Troodos Massif, Cyprus. Ophiolitic rocks, flysch and submarine volcanic rocks of the SE Anatolian orogenic belt formed during Late Cretaceous to Middle Miocene times and are poorly understood due to structural complexities of imbricated thrust sheets. Cupriferous pyrite dominant VMS deposits of the SE Anatolian thrust belt are directly associated with mafic volcanic rocks, which are mainly basaltic and/or spilitic pillow lavas or massive lava flows intruded by diabase dikes. The most studied rocks hosting VMS deposits outcrop in the Ergani mine area, which is called Maden Complex. Age, stratigraphic and structural position, and origin of Maden Complex are, however, ill defined, though recent attempts have been made to redefine the complex (Yigitbas and Yilmaz, 1996). Erler (1984) proposed that the tectonic settings of massive sulfide deposits of SE Anatolian thrust belt differ from a typical Cyprus-type setting (MORB), and were instead formed along a back-arc spreading zone. The main association in the massive sulfides consists of pyrite, pyrrhotite, chalcopyrite, magnetite, hematite and minor sphalerite.

Gold and silver content of most of the deposits are not known. An exception is Ergani, a Cu–Au deposit in Elazig consisting of two orebodies (Anayatak and Mihrapdag). The deposit contains relatively high-grade Au (mean 1.2 g/t Au; Table 1). The orebodies

are hosted by mafic submarine volcanic rocks, mudstone and red-black limestone of Eocene age. The ore assemblage consists of mainly pyrite, chalcopyrite, pyrrhotite and magnetite; silicification and chloritization are dominant alteration types. At the Anayatak deposit, there is a distinct magnetite-rich zone below the massive lens (Erler, 1984). In the same district, the Kedak prospect contains up to 45 g/t Au, 43 g/t Ag and 2% Cu (results obtained from samples in old workings; Aslaner, 1977).

6.4. Orogenic gold deposits

Orogenic gold deposits of Turkey include mesothermal gold and listwanite (=listwaenite)-hosted Au deposits. Most European orogenic gold deposits are related to Late Paleozoic Variscan orogeny resulting from closure of the Paleo-Tethys and are hosted in crystalline rocks of Late Proterozoic to Early Paleozoic age, e.g., Iberian Massif, Massif Central and Bohemian Massif (Groves et al., 1998; Goldfarb et al., 2001). Small orogenic gold deposits of Oligocene age related to Alpine orogeny, can be found, however, e.g., Burusson (Italy) and in the Hohe Tauern, Austria (Heinrich and Neubauer, 2002).

6.4.1. Mesothermal gold deposits

Pre-Mesozoic crystalline metamorphic rocks of Turkey, including the Menderes, Kirsehir, Bitlis and Istranca Massifs, contain orogenic gold deposits and prospects (Fig. 2). Gold–quartz veins have been reported from Kaman area in Kirsehir Massif, such as Savcilibeyit (Genc and Turkmen, 2002) and Sincik–Adiyaman area in Bitlis Massif (Gultekin et al., 2003) (Fig. 5).

Crystalline metamorphic rocks including mainly mica schist, gneiss and marble are the host-rocks for gold mineralization in the Menderes Massif. Quartz–arsenopyrite–gold mineralization with elevated As and Bi contents (Erler and Larson, 1992) is present at Tire, Bozdog, Aribasi, Yusufllu, Umurbaba, Kure and Cavuslar (Gumus, 1970) (Fig. 5). Most of these prospects contain small-scale, discontinuous veins and veinlets of mineralization and are sub-economic. However, due to the coarser grain size of gold, they could represent a critical source for placer mineralization. The origin of the arsenopyrite-rich gold–quartz veins in the Menderes Massif is nonetheless debated

since they are thought to be remobilized and overprinted by later orogenic events, e.g., Kure prospect.

6.4.2. Listwanite-hosted gold deposits

Listwanite-hosted gold mineralization occurs along the sheared contacts of ophiolitic ultramafic rocks, mainly serpentinites. Thrust faults, normal faults and shear zones are favorable loci for high-fluid flow and related gold mineralization accompanied by quartz–carbonate (listwanite) alteration. Calcite, dolomite, ankerite and magnesite are ubiquitous carbonate minerals in this type of mineralization. Quartz–carbonate alteration and the associated Au mineralization, mainly as quartz veinlets, postdate serpentinization of ultramafic complexes (Ucurum and Larson, 1999). The Tethyan ophiolitic melanges, mostly of Cretaceous age along the Izmir–Ankara–Erzincan Zone (Robertson, 2002), are the host-rock for this type of gold mineralization, and control their distribution in Turkey (Fig. 2). Tavsan (Orencik), Kaymaz in western Turkey and Narman in eastern Turkey are examples of this style of mineralization (Fig. 5).

The Tavsan prospect, located near the southern border of Izmir–Ankara melange belt, is hosted within serpentinites, graywackes and limestones of the ophiolitic melange assemblage (Larson and Erler, 1993). Pervasive silicification could be as a result of quartz–carbonate alteration of serpentinites, or the result of limestone replacement (jasperoid formation), as in Carlin-type systems (Yigit, 2001). The Tavsan prospect contains unclassified resources of 0.28 M oz Au (Table 1) and contains 5 mineralized zones along a NE-trending corridor containing low-angle thrust faults.

The Kaymaz prospect, hosted in marine sediments and associated ophiolite, contains 0.22 M oz Au as a resource (Table 1). Fine-grained gold mineralization is associated with multiple phases of silicification and brecciation. Quartz, serpentine, ankerite, and dolomite are the main gangue minerals (Eldorado Gold, 2001). Because of multiple phases of brecciation and silicification, no primary textures are preserved in most places. Tiny disseminated chromites may help to identify its ultramafic origin in some mineralized areas.

6.5. Placer Au

Stream or alluvial, eluvial and beach placers are the most common types of placer deposits in Turkey. Sart

and Mert Lake in W Turkey, and Darphane (Kazıkaya) in E Turkey are examples; other prospects include Akillicay, Nif Cayi, Geyve, Hamek and Harput (Fig. 5). None of the placer deposits of Turkey are currently economic, despite a long history of placer mining in Anatolia. Pilot studies are currently being carried out on the Sart river placers by a domestic company.

In Sart, placer native gold is in both alluvium and conglomerate of Miocene to Quaternary age; most resources are in conglomerates (20 M m³ of average 96.5 mg/m³). Additional resources are in stream terraces of Neogene age, containing average 65 mg/m³. Other than gold, rutile, zircon and magnetite are common minerals in the area (MTA, 1993a). Crystalline rocks, mainly schists, of Bozdag are the source rock for the placer gold. A heterogeneous distribution of Au content negatively affects the economics of hydraulic mining. Similar placer gold deposits are known in terraces and alluvium of Ortakale–Kars, E Turkey, such as the Darphane placer (Tuysuz, 1991).

Examples of beach placers of Holocene age are located in NW Turkey in Mert Lake, Igneada–Kirkarelili (Fig. 5). The source rock for heavy minerals is most probably the Late Cretaceous Demirkoy granodiorite. Additionally, placers contain magnetite and zircon with trace amounts of cinnabar, rutile, ilmenite, scheelite and specular hematite. Although average Au grade is 0.5 g/t, reserves are too small to allow economic exploitation (MTA, 1993a).

7. Potential gold systems

Gold deposit types with insignificant or no economic occurrences in Turkey, but with the potential to be exploration targets, will be discussed in this section. These deposit types have not fully been explored for, even though favorable geologic and tectonic settings are present. Carlin-type, detachment-fault-related gold, Fe-oxide Cu–Au (IOCG) and gold in carbonate replacement and manganese deposits are some of the potential deposit types (Fig. 5).

7.1. Carlin-type deposits

The only known prospects with Carlin-type affinities in Turkey are reported from Kaletas in Gumush-

ane, south of the Eastern Pontides (Tuysuz et al., 1994), Beykoy in Balıkesir (Yildirim, 2002) and Sb-districts in Kutahya, western Turkey (Janković, 1982; Oygur and Erler, 1999) (Fig. 5), but the true nature of mineralization is unknown. In the known prospects, observations do not discriminate Carlin-type systems from other systems hosted in sedimentary rocks, such as distal-disseminated, low-sulfidation and/or sedex-types (Yigit, 2001; Hofstra and Cline, 2000). Most of the conclusions are based on relatively poor field observations, although one or more characteristics of Carlin-type deposits are present in each case, such as μm -size gold in sedimentary host rock, and alteration consisting of jasperoid.

7.2. Detachment-fault-related gold deposits

In the Menderes Massif, some of the gold mineralization (e.g., Kursunlu and Emirli prospects; Fig. 5) has very close spatial and temporal relationship to detachment faults associated with core complex development. Quartz–stibnite–pyrite associated gold mineralization with very high As, Sb and Hg is present in these prospects. In Kursunlu, mineralization occurs along hanging- and foot-walls of a detachment fault near intersection with a high-angle fault in the southern margin of WNW-trending Gediz graben (Fig. 4). High Au values with elevated values of toxic metals are associated with arsenopyrite, stibnite, pyrite and marcasite, although it also has an epithermal lithogeochemical signature with elevated Au, Ag, Sb and Hg (Erler and Larson, 1992; Larson and Erler, 1993). In Emirli, gold mineralization occurs as veins and disseminations with quartz–stibnite–pyrite association and is related to listric faulting. Most likely it is similar to Kursunlu in tectonic setting.

7.3. Iron oxide Cu–Au (IOCG) deposits

Despite the fact that Turkey contains 900 known iron occurrences, 500 of which have economic potential as iron ore, there is very little research about their base- and precious-metal contents or their REE potential. These deposits are poorly understood due to lack of detailed geologic and geochemical studies. The only available data is an inventory of Fe-deposits of Turkey by MTA (Cihnioglu et al., 1994). Even though this is a drawback in terms of com-

parison with other well-studied systems, from an exploration point of view it can be an advantage as these iron deposits have not been explored for their gold potential.

Based on available data the potential for IOCG deposits in Turkey can be evaluated within two broad categories, IOCG ('Olympic Dam'-type) and magnetite–apatite ('Kiruna'-type) systems, which are end members of the spectrum of IOCG deposits (Hitzman et al., 1992; Hitzman, 2000). The largest Fe-district, Divrigi, in central Anatolia, and the Avnik (Bingol) district, SE Turkey, could be examples of these two broad categories, respectively. Other potential areas could be Pınarbaşı in southeastern Turkey and Ayazmant in Balıkesir, northeastern Turkey.

Iron deposits of the Divrigi district occur in extensively hydrothermally altered serpentinites bordering the contacts to mainly alkaline intrusive rocks. The Divrigi Fe-mine, the largest deposit in the district, consists of two main ore bodies (A- and B-Kafa), and a placer deposit formed from the main ore bodies (C-Placer). The deposit contains 133.8 Mt of ore with 56% Fe and 0.5% Cu. Iron mineralization, relatively poor in Fe-sulfides, occurs at the triple junctions of shoshonitic to monzonitic alkaline intrusive rocks, recrystallized limestone and serpentinitized ultramafic rocks (Zeck and Unlu, 1991). In A-Kafa, a brecciated zone is present at the contact between recrystallized limestone and ore, and syenite clasts in breccia have been observed in the ore. The B-Kafa orebody is funnel-shaped. Although classically interpreted as pyrometamorphic and magnesian skarn deposits (Unlu et al., 1995; Ciftci et al., 1996; Gumus, 1998), alteration minerals including scapolite, diopside, tremolite, actinolite and andradite (Gumus, 1998) may form sodic–calcic alteration assemblages, very common in IOCG deposits (Hitzman et al., 1992; Pollard, 2001). Furthermore, the spatial and temporal association with felsic alkaline intrusive rocks, late stage sulfide mineralization and silicification, funnel-shaped orebody, presence of breccia, and relative lack of iron sulfides are reminiscent of IOCG deposits.

The Divrigi district contains a newly discovered hydrothermal Fe-oxide–Au mineralization (Bakir Tepe; Fig. 5), containing visible gold and up to 90 ppm Au in some samples (Kaptan, 2000). Mineralization is most probably associated with alkaline intrusive rocks. To the south, the Hasancelebi Fe-district

in Malatya (Fig. 5) contains 685 Mt iron ore grading 19% Fe (Cihnioglu et al., 1994). Iron mineralization covers 0.3 km wide and 6 km long area, and is spatially associated with extensive scapolitization and alkaline volcanism (Gumus, 1998). Recent studies have found copper and hematite veins with some similarities to IOCG systems, which contain up to 2 g/t Au and 0.8% Cu in the district (Ay et al., 2004).

The Avnik district, containing 104 Mt ore with 14 to 58% Fe, comprises apatite-rich iron deposits occurring within Paleozoic metamorphic rocks of the Bitlis Massif, SE Turkey. The massif consists of mainly calc-alkaline metavolcanic rocks of intermediate to felsic composition (Helvacı, 1984). The Fe-oxide deposits are similar to the Paleozoic Bafq metallogenic province in Iran containing 'Kiruna'-type apatite-Fe-oxide ores, REE, Th-U, Pb-Zn, and Cu-Au mineralization (Forster and Jafarzadeh, 1994; Daliran, 2002).

7.4. Gold in carbonate-replacement deposits

Although economic gold is not commonplace in carbonate-replacement deposits, a few Turkish deposits, such as Hazine Magara and Kirkpavli-Gumushane area in the Eastern Pontides and Bolkardag-Nigde in the Taurides contain minor Au resources (Fig. 5). The Gumushane district is known for its Ag-bearing base metal mineralization hosted by Upper Cretaceous limestones. Polymetallic mineralization contains mostly galena in massive pyrite, with sphalerite, chalcopyrite, fahlore and Bi-minerals, and contains up to 48.7 g/t Au (Cagatay and Copuroglu, 1990). Mineralization is most probably associated with granitoids of Tertiary age. At Bolkardag, Au-Ag-bearing Pb-Zn mineralization is hosted by Permian to Triassic age limestones. Mineralization is spatially and temporally associated with post-Upper Cretaceous-pre-Lower Eocene granitoids. Primary sulfide mineralization has residual enrichment zones in karstic caves, containing higher grade Au and Ag (up to 20 and 500 g/t, respectively) (Ayhan, 1984). In addition alluvial placers formed in the district, enriched in Au and Ag (MTA, 1993a).

7.5. Gold hosted in manganese deposits

Turkey contains a large number of manganese and ferromanganese deposits in a variety of tectonic and

geologic settings, from hydrothermal to black-shale-hosted and diagenetic replacement deposits (Ozturk, 1997). Manganese deposits of Turkey are closely associated with evolution of both Paleo- and Neo-Tethys, and form generally E-trending metallogenic belts. These deposits are very important, not only as a host to gold mineralization, but also as an indicator of (otherwise hidden) gold mineralization. Manganese commonly scavenges gold in mineralized systems, causing the gold to become concentrated. For example, an old Mn-mine hosts one of the orebodies with 0.9 Moz Au in Copley porphyry copper-gold deposit (Table 1). Hydrothermal Mn deposits of the Eastern Pontides are hosted in Upper Cretaceous volcano-sedimentary rocks, mostly dacitic tuff and maroon color biomicritic limestone, and are higher in the stratigraphic section than the Kuroko-type VMS deposits. Some of the hydrothermal Mn deposits contain anomalous gold, e.g., the Yazlık and Sahinkaya deposits in the Macka-Trabzon area (up to 18 ppm Au; Yalcinalp and Tashan, 1999). Another potential area could be the Zonguldak district, NW Turkey, with many known Mn deposits (MTA, 1980). A detailed evaluation of known Mn deposits in Turkey could be critical for gold exploration.

8. Metallogenic correlations

Gold deposits of Turkey, as well as other mineral deposits, are mainly associated with Late Mesozoic and Tertiary rocks (Fig. 6). The current understanding of the tectonic units of Turkey and eastern Mediterranean (Stampfli, 2000; Stampfli et al., 2004) is inconsistent with what is known about the metallogenic evolution of the area. Furthermore, the defined tectonic units (Fig. 2) do not coincide exactly with the metallogenic terrains (Fig. 5). Despite this, however, certain metalotectonic terrains of Turkey can be correlated with metallogenic units of SE Europe. For example, the Late Cretaceous Banatitic Magmatic and Metallogenic Belt (BMMB) (Berza et al., 1998; Ciobanu et al., 2002), and also referred to as the 'Carpatho-Balkan metallogenic province' (Janković, 1997), or the Apusenı-Banat-Timok-Srednegorie belt (Popov et al., 2000), which can be traced through the Eastern Pontides into the southern Transcaucasus belt (Pejatovic, 1979; Janković, 1997). It is also believed

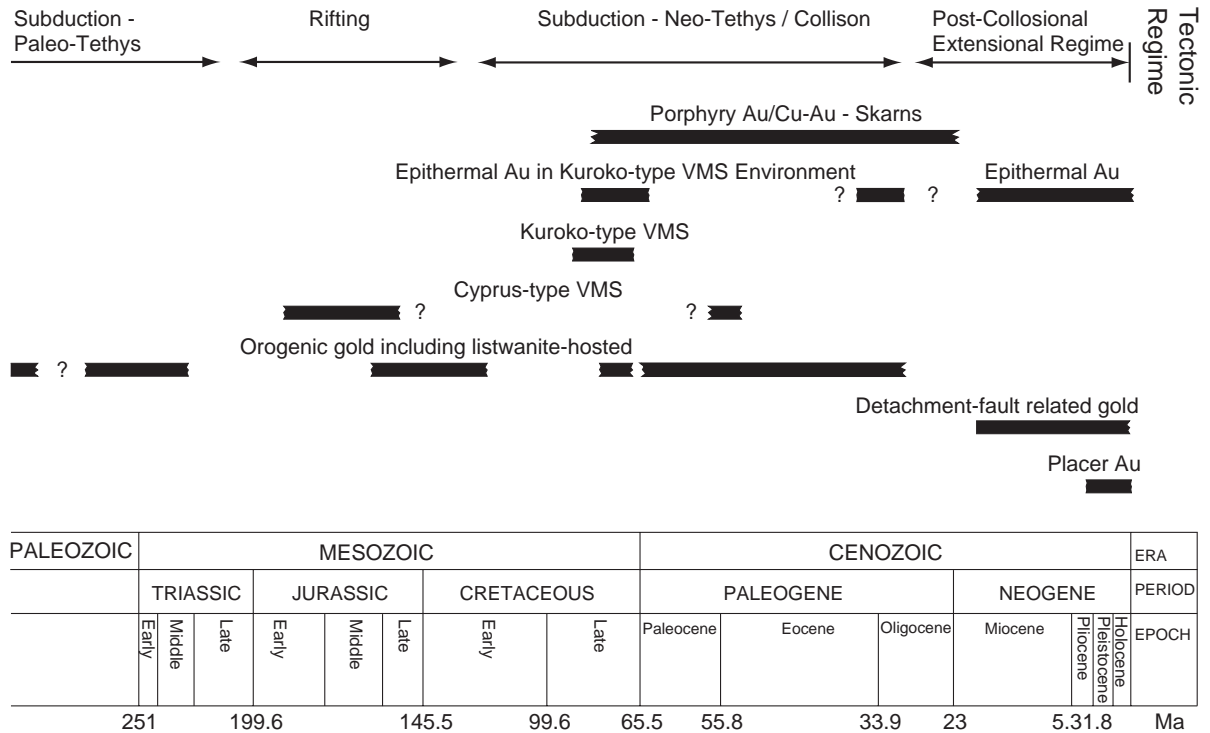


Fig. 6. Timing of emplacement of major gold deposit types in Turkey with respect to the tectonic regime sensu lato. Continuous ore deposition of any particular deposit type is not implied. Time scale modified from Gradstein et al. (2004).

that Oligocene–Miocene Serbomacedonian–Rhodope belt (Heinrich and Neubauer, 2002) continues south-east through Sakarya zone in NE Turkey (Janković, 1997) (Fig. 2). Ophiolite and ophiolitic melanges of SE Europe, mainly of Jurassic–Cretaceous age, extend to S and SE Turkey (Janković, 1997) where they host Au-rich VMS deposits. Furthermore, the Au deposits of the Eastern Pontides can be readily correlated with those in the Georgian sector of the TEMB (Moon et al., 2001).

The porphyry deposits of the Pontide belt form a sector within a major magmatic belt extending from Romania, Serbia and Bulgaria, through NW Turkey, continuing through NE Turkey (Eastern Pontides), Georgia (Southern Transcaucasus), Armenia and Iran (Figs. 1, 2 and 5). In SE Europe, this belt (BMMB) hosts world-class porphyry deposits such as Majdanpek, Bor in Serbia (Ciobanu et al., 2002) and Medet and Elatsite in the Srednegorie area of Bulgaria (Strashimirov and Petrunov, 2000). The eastward extension of the Srednegorie–Istranca granitoid chain can be

traced to the Eastern Pontides and existed as an island-arc of Late Cretaceous age formed on Hercynian basement. The porphyry and VMS gold systems of Turkey, especially in the Eastern Pontides, may show transition to epithermal environments similar to those at Bor (Serbia) and Chelopech (Bulgaria) within the BMMB of SE Europe (Ciobanu et al., 2002), and also in the Madneuli deposit (Bolnisi district of Georgia; Migineishvili, 2001). Although epithermal deposits in the Bor and Panagyurishte districts are closely associated with porphyry Cu deposits, they also share some characteristics with seafloor massive sulfide deposits (Karamata et al., 1997; Bonev et al., 2002). Porphyry deposits of the Eastern Pontides appear to overprint earlier Upper Cretaceous VMS mineralization during mainly Eocene–Oligocene epochs, forming an E-trending zone in the north of a porphyry belt (e.g., Gumushane porphyry Cu–Au in Artvin). Unlike the Eastern Pontides, magmatism related to mineralization in the BMMB is Upper Cretaceous (mainly occurring between 90 and 65 Ma, K–Ar ages; Cio-

banu et al., 2002). Some of the VMS deposits of the Eastern Pontides can be considered as hybrid VMS-epithermal deposits, formed proximal to or in Kuroko-type VMS deposits of island-arc setting, such as Cerattepe and Toplaktepe. This is similar to deposits from the Bolnisi district, Georgia (i.e., Madneuli; Moon et al., 2001). The southern zone of the Eastern Pontides also contains numerous epithermal deposits and prospects, such as the Sebinkarahisar district and the Gumushane area (Fig. 5).

A belt of porphyry deposits, here called the Anatolides, starts from the Biga Peninsula in the west and goes through central Anatolia and eastern Turkey, where relatively shallower parts of intrusive systems are exposed. Porphyry deposits of the Anatolides are associated with intrusives with a conspicuous WNW-trend which overprints the tectonic grain of Turkey, including the Sakarya Zone, the Izmir–Ankara–Erzincan Suture, and the Kirsehir Block (Figs. 2 and 5). Although reported ages for intrusions in this belt range from Late Cretaceous to Tertiary (Boztug, 2000), they crosscut the tectonic units indicating they intruded mainly in the Tertiary. Volcanic rocks in this belt are also Tertiary in age, younger than those in the Eastern Pontides (mainly Upper Cretaceous to Eocene). Moreover, epithermal deposits associated with porphyries in this belt, such as in the Biga Peninsula, are mainly Tertiary in age. The distributions of fluorite mineralization, trending E–W (MTA, 1980; Ersecen, 1989; Engin et al., 2000), also follows this newly proposed trend. Fluorine has a positive correlation with alkaline magmatism and related porphyry and epithermal mineralization (Westra and Keith, 1981; Jensen and Barton, 2000; Sillitoe, 2002). Most importantly in a metallogenic context, the Anatolide porphyry trend could be an eastern extension of the Serbomacedonian–Rhodope metallogenic unit. Porphyry Cu–Au deposits of which contain relatively high PGE contents, such as the Skouries shoshonite-hosted porphyry Cu–Au–(Pd) deposit in Greece (e.g., Kroll et al., 2002). Even though there is no published data concerning PGE contents of Turkish porphyry deposits, this would appear to be a logical target of investigation.

Even though the Border Folds belt in SE Turkey lacks Au-rich porphyry deposits, with only one known prospect (Ispendere), it should not be forgotten that little exploration was carried out in the area due to

social conflicts until late 1990's. This belt also contains several base-metal skarn deposits, some of them containing elevated Au values, as well as epithermal mineralization, e.g., in the Keban district, Elazig. The southern portion of the Border Folds belt also contains Cyprus-type VMS deposits and prospects, parallel to the porphyry belt (Fig. 5). The eastward continuation of the Border Folds belt hosts world-class porphyry deposits such as Sar Cheshmeh in Iran (Waterman and Hamilton, 1975).

9. Exploration potential and concluding remarks

Priority targets for grassroots exploration include the favorable geologic and tectonic settings of western Turkey and the Eastern Pontides together with the newly proposed porphyry Cu–Au belt of the Anatolides. The extensional tectonic regime of western Turkey with active seismicity, high geothermal gradients, hot springs, sinters and epithermal mineralization is remarkably similar to the Basin and Range province of the western USA, known for world-class Au deposits (Yildiz and Bailey, 1978; Janković, 1982; Sengor, 1987; Larson, 1989; Seedorff, 1991). Although the detailed geology is not well known, unambiguous graben structures (such as the Simav, Edremit and Bergama grabens; Fig. 4) could be critical to locate epithermal gold trends in western Turkey. For example, the veins in the Ovacik epithermal deposit are obviously associated with E-trending graben structures (Yilmaz, 2002), related to N–S extension.

Detailed geophysical and geochemical studies could be useful to define the structure of the continental crust (microplates), and implicitly of metallogenic trends in Turkey. In the Carlin Trend of Nevada, crustal structures controlling the mineralized trends are commonly inferred from geophysical and isotopic studies (e.g., Kistler, 1991; Tosdal, 1998; Grauch et al., 2003). For example, location of the 0.706 isopleth of initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios reflects western edge of rifted Precambrian continent in western US (Kistler, 1991). In Turkey available $^{87}\text{Sr}/^{86}\text{Sr}$ data are, at present, insufficient to perform isotopic mapping of the country to investigate the relationship between Au deposits and crustal structures.

The Anatolides porphyry belt, containing the largest Au deposits in Turkey, is open through eastern

Turkey and promises future discoveries. To the east, most of the porphyry intrusives are not exposed due to young volcanic and sedimentary cover and therefore, regional scale maps do not contain them. Detailed mapping, coupled with supplementary satellite imagery and geophysical data could be highly instructive in future exploration of these terranes.

Mineralized systems hosted by alkaline rocks are generally quartz-deficient and will tend to underlie recessive topography and be concealed beneath surficial cover (Sillitoe, 2002). Therefore, they could form an easily recognizable depression in topography, as in the Copley deposit. Satellite imaging and reconnaissance flight over prospective geologic settings could be successful to locate favorable areas for further exploration.

Porphyry deposits of Turkey, such as Kisladag, have hydrothermal tourmaline similar to porphyry deposits in the American Cordillera, in contrast to porphyry deposits of the western Pacific Rim (Sillitoe, 1985, 1991; Skewes et al., 2003). The nature of the downgoing slab is an important factor in the generation of boron necessary to form tourmaline. Higher content of subducted pelagic sediments and altered oceanic crust with higher thermal signature causing continuous slab dehydration is conducive to transport of boron into the mantle wedge (Ryan and Langmuir, 1993; Wunder et al., in press). Furthermore, the depth of subducting slab may contribute to the boron enrichment in arc magmas, the shallower magma generation creating boron rich fluids. One or more of these favorable tectonic settings must exist in western Turkey to explain the presence of boron-rich epithermal system in Efemcukuru (Oyman et al., 2003), and world-class Neogene borate deposits, which are from west to east Bigadic, Sultancayir, Kestelek, Emet, and Kirka districts (Floyd et al., 1998; Helvacı and Alonso, 2000).

Gold-rich porphyry and epithermal deposits and prospects of Turkey formed in both continental-arc and island-arc settings. Although there is no clear relationship between Au-rich porphyry deposits, epithermal Au deposits and the nature of the underlying crust (Sillitoe, 1997, 2000), the currently economic porphyry deposits of Turkey are most probably underlain by continental crust. Differing erosional rates within each of the volcanoplutonic arc settings could be the biggest factor influencing the distribution

of porphyry deposits. Relatively deeper levels of the porphyry systems are exposed in Eastern Pontides compared to the porphyries of Anatolides, reflecting higher erosional rates in an island-arc setting. Therefore, in the Anatolides shallow level features of porphyry deposits with epithermal mineralization are relatively better preserved, i.e., in the Kuscaiyiri prospect, W Turkey.

Mineral assemblages and alteration of the polymetallic base- and precious-metal veins of the Sebinkarahisar district, Eastern Pontides are reminiscent of Cordilleran-type veins, e.g., at Butte, Montana (Miller, 1973), which may show transition to the porphyry environment. In main stage alteration assemblages of veins in Butte, advanced argillic assemblage is present within pervasive sericitic alteration (as in the Leonard shaft and Berkeley pit area; Meyer et al., 1968). However, alunite formation in the advanced argillic assemblage is not as conspicuous as in the Sebinkarahisar vein district.

Recent studies of volcanic-associated massive sulfide environments (Huston, 2000) have indicated that gold can be present outside of massive sulfide lenses. Therefore, historical VMS districts, such as Eastern Pontides (Fig. 5), could represent 'new' exploration targets. Several other known Kuroko-type VMS districts in the Eastern Pontides have a great potential for hybrid epithermal-VMS deposits, for example, in the Tirebolu and Lahanos districts, Giresun (Pejatovic, 1979; Leitch, 1981). The Lahanos district contains hypogene advanced argillic alteration related to massive sulfide mineralization (Leitch, 1981). Interpretation of the depositional environments of volcanic rocks could be very useful to locate regional or district scale targets to find hybrid Au-rich VMS deposits. Current studies suggest epithermal precious-metal deposition can take place in submarine VMS environments (Sillitoe et al., 1996), such as Lerokis and Kali Kuning (Indonesia; Sewell and Wheatley, 1994), and Eskay Creek (British Columbia; Roth et al., 1999; Sherlock et al., 1999). For example, the Au–Ag–barite association in Toplakepe with high Au values and multiple ounces of silver and elevated epithermal suite elements is remarkably similar to that seen at Lerokis and Kali Kuning.

The porphyry, epithermal and VMS deposits in the Srednegorie zone of BMMB contain relatively high Te, Se and PGE contents (Tarkian and Stribny, 1999;

Tarkian et al., 2003). The potential for these elements in deposits of the Eastern Pontides is not studied, even though sulfide minerals from Murgul VMS deposit are known to contain high concentrations of Bi, Se and Te (Willgallis et al., 1990).

Some of the Au deposits and prospects in the Menderes Massif have unequivocal relationships with active and extinct geothermal systems related to the extensional tectonic regime of western Turkey, since the Early Miocene (Ozgun, 2003). For example, the Kursunlu prospect displays a close temporal and spatial relationship with detachment faulting (Erler and Larson, 1992; Larson and Erler, 1993). Similarly, the detachment-fault controlled Ada Tepe Au deposit, Rhodopes, SE Bulgaria, is related to metamorphic core complex development rather than nearest magmatism (Marchev et al., 2003). The lack of a similar type of mineralization in other Pre-Mesozoic metamorphic rocks of Turkey also suggest that gold mineralizing systems in the Menderes Massif may be linked to extensional tectonics of western Turkey (Figs. 2 and 4). Some of the orogenic gold deposits in Menderes Massif may have been remobilized during the Alpine orogeny, i.e., the Paleocene to Eocene major metamorphic event. Therefore, origin of these deposits may be obscured leading to controversy over their classification. For example, arsenopyrite–gold–quartz veins and veinlets in Kure prospect have some epithermal characteristics with formation temperatures ranging from 210 to 300 °C in the first ore phase (Ozgun, 2003), though petrographic evidence suggests that, at least the arsenopyrite, predates the latest metamorphic event (Erler and Larson, 1992).

Listwanite-hosted gold deposits of Turkey are similar to mineralization in Neoproterozoic Arabian shield, where many examples of this type of mineralization occur in suture zones, indicating that they may be formed from the same fluids and processes as orogenic gold veins (Jeff Doebrich, written comm., 2003). In these systems, therefore, although only little gold is introduced, it may be freed and perhaps mobilized by carbonatization of the ultramafic rocks.

Carlin-type sedimentary-rock hosted disseminated gold deposits occur typically in continental setting in Basin and Range province of the USA, as well as in China (Rui-Zhong et al., 2002). However, these deposits may also occur in other tectonic settings, such as Jeronimo, Chile (Maximino E. Simian, pers.

comm., 1999), Mesel in North Sulawesi, Indonesia (Turner et al., 1994) and in Zarshuran, Iran (Mehrabi et al., 1999). Carlin-type deposits are typically characterized by silicification (jasperoid formation), decalcification, argillic alteration, sulfidation, auriferous pyrite (marcasite or arsenopyrite), low base-metals and high Au/Ag ratio (Arehart, 1996; Hofstra and Cline, 2000; Yigit, 2001; Yigit and Hofstra, 2003; Yigit et al., 2003). They also display strong structural controls, ranging from regional, district to deposit scale (Yigit and Nelson, 2000; Yigit et al., 2003) and lithologic controls (Yigit and Hofstra, 2003), such as favorable host rocks (Teal and Jackson, 1997). Known Carlin-type prospects in Turkey are not well characterized, but suggest potential for this type of system. It is expected, however, that deposits formed in tectonic settings distinct from classic Carlin-type deposits will produce different geologic and geochemical signatures. Jeronimo in Chile, for example, has a strong positive correlation with manganese unlike other Carlin-type systems. In addition, spatial association with porphyry environment and high-sulfidation epithermal systems indicates distal disseminated deposit signature, rather than Carlin-type system *sensu stricto*.

Some well-studied porphyry Cu systems with sodic, calcic–sodic, and potassic alteration suites are hybrid magmatic-hydrothermal systems involving the influx of non-magmatic brines (Dilles and Einaudi, 1992). Thus, according to Hitzman (2000) there is probably a spectrum of deposits stretching from classic porphyry Cu deposits to the magnetite–apatite and IOCG systems. The critical factor for creation of an IOCG system is the influx of non-magmatic, oxidized, saline, and relatively Cu-rich solutions. Therefore, the close spatial relationship between alkaline magmatism and Fe-deposits in Divrigi district demands further investigation, i.e., the Bakir Tepe prospect.

To summarize: the known major economic gold deposit types include porphyry gold, epithermal and VMS. Turkey also has a great potential for the discovery of orogenic gold, Carlin-type and IOCG deposits. Other potential deposit types of relatively minor importance include detachment-fault-related gold deposits, gold skarns, carbonate-replacement and manganese deposits. To date, exploration efforts in Turkey have been mainly focused on large and easy targets, mostly using geochemical exploration techniques. Detailed

geology has not been considered in the early stages of exploration, especially during prospect evaluation and testing. Past experience by multinational companies has proven that simple testing of geochemical anomalies was unsuccessful in the majority of cases. Future exploration efforts need to consider the geologic framework of ore-forming systems from the regional to prospect scale, combining available descriptive data with genetic models in order to gain a better understanding of the mineralizing system.

Acknowledgements

Thanks are due to Catherine Yigit for helping with the compilation of GIS data and discussions during the writing of this paper. Exceptionally thorough and beneficial reviews by Cristiana L. Ciobanu and Nigel J. Cook improved the manuscript greatly. The review by Huseyin Yilmaz was greatly appreciated. For their critical review and helpful comments on an earlier version of the manuscript, Jeff Doebrich (USGS) and Jeff Hedenquist are thanked. Finally, thanks are given to Erdinc Yigitbas for sharing his knowledge of the complicated geology of Turkey.

References

- Adamia, S.H.A., Chkhotua, T., Kekelia, M., Lordkipanidze, M., Shavishvili, I., Zkariadze, G., 1981. Tectonics of the Caucasus and adjoining regions: implications for the evolution of the Tethys Ocean. *Journal of Structural Geology* 3, 437–447.
- Agdemir, N., Kirikoglu, M.S., Lehmann, B., Tietze, J., 1994. Petrology and alteration geochemistry of the epithermal Balya Pb–Zn–Ag deposit NW Turkey. *Mineralium Deposita* 29, 366–371.
- Akinci, O.T., 1984. The Eastern Pontide volcano-sedimentary belt and associated massive sulfide deposits. In: Dixon, J.E., Robertson, A.H.F. (Eds.), *The Geological Evolution of the Eastern Mediterranean*, Special Publication, Geological Society of London, vol. 17, pp. 415–427.
- Akkok, R., 1983. Structural and metamorphic evolution of the northern part of the Menderes Massif: new data from the Derbent area and their implication for the tectonics of the massif. *Journal of Geology* 91, 342–350.
- Akyol, A., Tokel, S., 1991. The geochemistry and tectonic setting of the Demirkoy pluton of the Srednogie–Istranca granitoid chain NW Turkey. *Mineralogical Magazine* 55, 249–256.
- AMD, 2003. Update of the geology and mineral resources of the Copley prospect, Turkey. Unpublished report, May 1st 2003. 96 pp.
- Arehart, G.B., 1996. Characteristics and origin of sediment-hosted disseminated gold deposits: a review. *Ore Geology Reviews* 11, 383–403.
- Aslaner, M., 1977. Geological and regional classification of copper–lead–zinc deposits of Turkey and their plate tectonic settings. Black Sea Technical University Publication, vol. 85. 70 pp. (in Turkish).
- Aslaner, M., Yigit, O., 1996. Geologic and petrographic investigation of the Dereli barite deposit, Giresun, Turkey. In: Korkmaz, S., Akcay, M. (Eds.), *30th Annual Symposium of the Department of Geology and Geological Engineering*, Black Sea Technical University, vol. 1, pp. 140–154 (in Turkish with English abstract).
- Ay, Y., Yildirim, S., Dumanlilar, O., Turgut, O., Tablaci, A., Yildiz, H., Dumanlilar, H., 2004. An example of Olympic Dam-type Fe oxide–Cu–Au–(Ag–Ba–F–U–Th–REE) deposits from Turkey: Hasancelebi Fe deposit. *57th Geological Congress of Turkey*, Extended Abstracts Book, 8–12 March, 2004. MTA, Ankara, pp. 107–108.
- Ayan Z., Dora, O.O., 1995. Mineralogic study of the vein-type lead and zinc deposits at the northwest of Sebinkarahisar (Giresun). In: Erler, A., Ercan, T., Bingol, E., Orcen, S. (Eds.), *Proceedings of the International Symposium on the Geology of the Black Sea Region*. September 1992, General Directorate of Mineral Research and Exploration and Chamber of Geological Engineers, Ankara, pp. 219–225.
- Ayhan, A., 1984. Genetic comparison of lead–zinc deposits of central Taurus. In: Tekeli, O., Goncuoglu, M.C. (Eds.), *Geology of the Taurus belt*. Proceedings of International Symposium 26–29 September, 1983, Ankara, Turkey, pp. 335–341.
- Barbieri, M., Conforto, L., Garbarino, C., Masi, U., Nicoletti, M., Akinci, O., 2000. Geochemistry of hydrothermally altered volcanic rocks of the Upper Volcanic Cycle from the Eastern Pontides (Northeastern Turkey). *Chemie der Erde* 60, 81–95.
- Bektas, O., 1984. Upper Cretaceous shoshonitic volcanism and its geotectonic setting in the Eastern Pontids (northern Turkey). *Black Sea Technical University, Bulletin. Geology* 3 (1–2), 53–62.
- Bektas, O., 1987. Volcanic belts as markers of the Mesozoic–Cenozoic active margin of Eurasia—discussion. *Tectonophysics* 141, 345–347.
- Bektas, O., 1990. Porphyry copper systems as markers of the Mesozoic–Cenozoic active margin of Eurasia—Comment. *Tectonophysics* 172, 191–194.
- Berza, T., Constantinescu, E., Vlad, S.N., 1998. Upper Cretaceous magmatic series and associated mineralization in the Carpathian–Balkan orogen. *Resource Geology* 48, 291–306.
- Bonev, I.K., Kerestedian, T., Atanassova, R., Andrew, C.J., 2002. Morphogenesis and composition of native gold in the Chelopech volcanic-hosted Au–Cu epithermal deposit, Srednogie zone, Bulgaria. *Mineralium Deposita* 37, 614–629.
- Bozkurt, E., 2004. Granitoid rocks of the southern Menderes Massif (southwestern Turkey): field evidence for Tertiary magmatism in an extensional shear zone. *International Journal of Earth Sciences* 93, 52–71.

- Bozkurt, E., Oberhänsli, R., 2001. Menderes Massif (Western Turkey): structural, metamorphic and magmatic evolution—a synthesis. *International Journal of Earth Sciences* 89, 679–708.
- Bozkurt, E., Satir, M., 2000. New Rb–Sr geochronology from the southern Menderes Massif (southwestern Turkey) and its tectonic significance. *Geological Journal* 35, 285–296.
- Boztug, D., 2000. S–I–A-type intrusive associations: geodynamic significance of synchronism between metamorphism and magmatism in central Anatolia, Turkey. In: Bozkurt, E., Winchester, J.A., Piper, J.D.A. (Eds.), *Tectonics and Magmatism in Turkey and Surrounding Area*, Geological Society of London, Special Publication, vol. 173, pp. 441–458.
- Boztug, D., Jonckheere, R., Wagner, G.A., Yegingil, Z., 2004. Slow Senonian and fast Palaeocene–Early Eocene uplift of the granitoids in the central Eastern Pontides, Turkey: apatite fission-track results. *Tectonophysics* 382, 213–228.
- Brinkmann, R., 1976. *Geology of Turkey*. Elsevier, New York. 158 pp.
- Cagatay, M.N., 1993. Hydrothermal alteration associated with volcanogenic massive sulfide deposits: examples from Turkey. *Economic Geology* 88, 606–621.
- Cagatay, A., Copuroglu, I., 1990. Mineralogy of the lead–zinc deposits of Gumushane. *MTA Dergisi*, vol. 111, pp. 61–71 (in Turkish).
- Cagatay, M.N., Eastoe, C.J., 1995. A sulfur isotope study of volcanogenic massive sulfide deposits of the Eastern Black Sea province, Turkey. *Mineralium Deposita* 30, 55–66.
- Cagatay, A., Pehlivanoglu, H., Altun, Y., 1980. Cobalt–gold minerals in Kure pyritic copper deposits (Kastamonu Province, N. Turkey) and their economic values. *MTA Bulletin* 93–94, 110–117.
- Cambel, H., Braidwood, R.J., 1970. An early farming village in Turkey. *Scientific American* 222 (3), 51–56.
- Candan, O., Dora, O., Obershanli, R., Cetinkaplan, M., Partzsch, J., Warkus, F., Durr, S., 2001. Pan-African high-pressure metamorphism in the Precambrian basement of the Menderes Massif, western Anatolia, Turkey. *International Journal of Earth Sciences* 89, 793–811.
- Ciftci, D., Unlu, T., Sayili, I.S., 1996. Discussion on the origin of Otluklilise iron deposit Gurun–Sivas. *Mineral Research Exploration Bulletin* 118, 25–50.
- Ciftehan, H., O'Brien, N.P., 1998. The Cerattepe Cu–Au–Ag deposit. *Third International Turkish Geology Symposium*. METU, Ankara, Turkey, p. 153.
- Cihnioglu, M., Isbasarir, O., Ceyhan, U., Adiguzel, O., 1994. *Iron Inventory of Turkey*. MTA publication, Ankara. 408 pp. (in Turkish).
- Ciobanu, C.L., Cook, N.J., Stein, H., 2002. Regional setting and geochronology of the Late Cretaceous Banatitic Magmatic and Metallogenic Belt. *Mineralium Deposita* 37, 541–567.
- Cogulu, E., 1975. *Petrologic and Geochronologic studies of Gumushane and Rize region*, vol. 1034. Istanbul Technical University publication, Istanbul. 112 pp. (in Turkish).
- Colakoglu, A.R., 2000. The characteristics of Kucukdere epithermal (Havran–Balikesir) gold vein. *Geological Bulletin of Turkey* 43 (2), 99–110.
- Cominco, 2000. *Annual Report for 2000*. 58 pp.
- Cooke, D.R., Simmons, S.F., 2000. Characteristics and genesis of epithermal gold deposits. In: Hagemann, S.G., Brown, P.E. (Eds.), *Gold in 2000, Reviews in Economic Geology*, vol. 13, pp. 221–244.
- Daliran, F., 2002. Kiruna-type iron oxide–apatite ores and apatites of the Bafq District, Iran, with an emphasis on the REE geochemistry of their apatites. In: Porter, T.M. (Ed.), *Hydrothermal iron oxide copper–gold and related deposits: a global perspective*, vol. 2. PGC Publishing, Adelaide, pp. 303–320.
- Delaloye, M., Bingol, E., 2000. Granitoids from Western and Northwestern Anatolia: geochemistry and modeling of geodynamic evolution. *International Geology Review* 42, 241–268.
- Dercourt, J., Zonenshain, L.P., Ricou, L.E., Kazmin, V.G., Le Pichon, X., Knipper, A.L., Grandjacquet, C., Sbotshikov, I.M., Geysant, J., Lepvrier, C., Pechersky, D.H., Boulain, J., Sibuet, J.C., Savostin, L.A., Sorokhtin, O., Westphal, M., Bazhenov, M.L., Lauer, J.P., Biju-Duval, B., 1986. Geological evolution of the Tethys belt from the Atlantic to the Pamirs since the Lias. *Tectonophysics* 123, 241–315.
- Dewey, J.F., 1988. Extensional collapse of orogens. *Tectonics* 7, 1123–1139.
- Dewey, J.F., Sengor, A.M.C., 1979. Aegean and surrounding regions: complex multiplate and continuum tectonics in a convergent zone. *Geological Society of America Bulletin* 90, 84–92.
- Dilek, Y., Eddy, C.A., 1992. The Troodos (Cyprus) and Kizildag (S. Turkey) ophiolites as structural models for slow-spreading ridge segments. *Journal of Geology* 100, 305–322.
- Dilles, J.H., Einaudi, M.T., 1992. Wall-rock alteration and hydrothermal flow paths about the Ann–Mason porphyry copper deposit, Nevada—a 6 km vertical reconstruction. *Economic Geology* 87, 1963–2001.
- Dixon, C.J., Pereira, J., 1974. Plate tectonics and mineralization in the Tethyan region. *Mineralium Deposita* 9, 185–198.
- Dogan, R., 2001. Ore deposits related to acidic magmatism; general concepts and examples from Turkey. In: Boztug, D., Otlu, N. (Eds.), *Magmatik Petrojenez, Tubitak Lisans Ustu Yaz Okulu*, 7–12, pp. 474–494 Haziran 2001, Akcakoca, Duzce, Turkiye (in Turkish).
- Dumanlilar, H., Aydal, D., Dumanlilar, O., 1999. Geology, mineralogy and geochemistry of sulfide mineralization in the Ispendere region (Malatya). *MTA Dergisi* 121, 225–250 (in Turkish).
- Egin, D., Hirst, D.M., Phillips, R., 1979. The petrology and geochemistry of volcanic rocks from the northern Harsit River area, Pontid volcanic province, northeast Turkey. *Journal of Volcanology and Geothermal Research* 6, 105–123.
- Eldorado Gold, 2001. *Annual information leaflet*, September 12th 2001. 42 pp.
- Eldorado Gold, 2003. *Technical report, Kisladağ project feasibility study*. March 2003. 70 pp.
- Engin, T., Ozkan, Y.Z., Sener, F., Toprak, B., 2000. *Metallogenic map of Turkey*. MTA publication, Ankara.
- Erler, A., 1984. Tectonic setting of the massive sulfide deposits of the southeast Anatolian trust belt. In: Tekeli, O., Goncuoglu, M.C. (Eds.), *Geology of the Taurus Belt Proceedings of Inter-*

- national Symposium, 26–29 September, 1983, Ankara, Turkey, pp. 309–316.
- Erler, A., 1989. Geochemical character of the hydrothermal alteration zones around the Madenkoy–Siirt massive sulfide deposit and implications of geochemical exploration. *Journal of Geochemical Exploration* 32, 405–407.
- Erler, A., 1993. Gold and Turkey. *Metalurji Dergisi* 87, 27–32 (in Turkish).
- Erler, A., 1995. Wall rock alteration and trace element content at Asikoy–Kure massive sulfide deposit, Kastamonu, Turkey. In: Erler, A., Ercan, T., Bingol, E., Orcen, S., (Eds.), *Proceedings of the International symposium on the geology of the Black Sea Region*. September 1992, General Directorate of Mineral Research and Exploration and Chamber of Geological Engineers, Ankara, p. 214–218.
- Erler, A., Larson, L.T., 1992. Genetic classification of gold occurrences of the Aegean region of Turkey. In: Savascin, M.Y., Eronat, A.H. (Eds.), *Proceedings, IESC in Aegean Regions*, Izmir, Turkey, pp. 12–23.
- Ersecen, N., 1989. Known ore and mineral resources of Turkey. MTA publication, vol. 185. 108 pp.
- Floyd, P.A., Helvacı, C., Mittweck, S.K., 1998. Geochemical discrimination of volcanic rocks associated with borate deposits: an exploration tool? *Journal of Geochemical Exploration* 60, 185–205.
- Forster, H., Jafarzadeh, A., 1994. The Bafq mining district in central Iran—a highly mineralized Infracambrian volcanic field. *Economic Geology* 89, 1697–1721.
- Frontier Development Group, 2003. Annual report for 2003. 36 pp.
- Galley, A.G., Koski, R.A., 1999. Setting and characteristics of ophiolite-hosted volcanogenic massive sulfide deposits. In: Barrie, C.T., Hannington, M.D. (Eds.), *Volcanic-associated Massive Sulfide Deposits: Process and Examples in Modern and Ancient Settings*, *Reviews in Economic Geology*, vol. 8, pp. 221–246.
- Genc, Y., Turkmen, H., 2002. Gold–quartz veins in Kirsehir metamorphic massif. 55th Geological Congress of Turkey, Abstracts Book. 11–15 March, 2002. MTA, Ankara, pp. 102–103.
- Goldfarb, R.J., Groves, D.I., Gardoll, S., 2001. Orogenic gold and geologic time: a global synthesis. *Ore Geology Reviews* 18, 1–75.
- Gorur, N. (Ed.), 1998. *Triassic to Miocene Paleogeographic Atlas of Turkey*. MTA–ITU–TUBITAK.
- Gradstein, F.M., Ogg, J.G., Smith, A.G., Bleeker, W., Lourens, L.J., 2004. A new geologic time scale, with special reference to Precambrian and Neogene. *Episodes* 27 (2), 83–100.
- Grauch, V.J.S., Rodriguez, B.D., Wooden, J.L., 2003. Geophysical and isotopic constraints on crustal structure related to mineral trends in North-Central Nevada and implications for tectonic history. *Economic Geology* 98, 269–286.
- Groves, D.I., Goldfarb, R.J., Gebre-Mariam, M., Hagemann, S.G., Robert, F., 1998. Orogenic gold deposits: a proposed classification in the context of the crustal distribution and relationship to other gold deposit types. *Ore Geology Reviews* 13, 7–27.
- Gulec, N., 1991. Crust–mantle interaction in western Turkey: implications from Sm and Nd isotope geochemistry of Tertiary and Quaternary volcanics. *Geological Magazine* 128, 417–435.
- Gultekin, B., Genc, Y., Dumanlilar, O., 2003. Sincik–Adiyaman gold-bearing quartz veins. 56th Geological Congress of Turkey, Extended Abstracts Book, 14–20 April, 2003. MTA, Ankara, pp. 122–123.
- Gumus, A., 1970. Metallogeny of Turkey; Explanation of 1:2 500 000 scale metallogenic map of Turkey. MTA publication, no. 144 Ankara (in Turkish).
- Gumus, A., 1998. *Endogenic Ore Deposits*. Bilim Ofset, Izmir. 481 pp.
- Hannington, M.D., Poulsen, K.H., Thompson, J.F.H., Sillitoe, R.H., 1999. Volcanogenic gold in the massive sulfide environment. In: Barrie, C.T., Hannington, M.D. (Eds.), *Volcanic-associated Massive Sulfide Deposits: Process and Examples in Modern and Ancient Settings*, *Reviews in Economic Geology*, vol. 8, pp. 325–356.
- Hedenquist, J.W., 1987. Mineralization associated with volcanic-related hydrothermal systems in the Circum-Pacific Basin. *Transactions, 4th Circum Pacific Energy and Mineral Resources Conference*, Singapore, 1986. pp. 513–524.
- Hedenquist, J.W., Arribas, A.R., Gonzalez-Urien, E., 2000. Exploration for epithermal gold deposits. In: Hagemann, S.G., Brown, P.E. (Eds.), *Gold in 2000*, *Reviews in Economic Geology*, vol. 13, pp. 245–277.
- Heinrich, C.A., Neubauer, F., 2002. Cu–Au–Pb–Zn–Ag metallogeny of the Alpine–Balkan–Carpathian–Dinaride geodynamic province. *Mineralium Deposita* 37, 533–540.
- Helvacı, C., 1984. Apatite-rich iron deposits of the Avnik (Bingol) region, southeastern Turkey. *Economic Geology* 79, 354–371.
- Helvacı, C., Alonso, R.N., 2000. Borate deposits of Turkey and Argentina: a summary and geological comparison. *Turkish Journal of Earth Sciences* 24, 1–27.
- Hetzel, R., Reischmann, T., 1996. Intrusion age of Pan-African augen gneisses in the southern Menderes Massif and the age of cooling after Alpine ductile extensional deformation. *Geological Magazine* 133, 565–572.
- Hitzman, M.W., 2000. Iron oxide–Cu–Au deposits: what, where, when and why. In: Porter, T.M. (Ed.), *Hydrothermal Iron Oxide Copper–Gold and Related Deposits: A Global Perspective*. Australian Mineral Foundation, Adelaide, pp. 9–25.
- Hitzman, M.W., Oreskes, N., Einaudi, M.T., 1992. Geological characteristics and tectonic setting of Proterozoic iron oxide (Cu–U–Au–REE) deposits. *Precambrian Research* 58, 241–287.
- Hofstra, A.H., Cline, J.S., 2000. Characteristics and models for Carlin-type gold deposits. In: Hagemann, S.G., Brown, P.E. (Eds.), *Gold in 2000*, *Reviews in Economic Geology*, vol. 13, pp. 163–220.
- Houssa, C-E., 1999. Talking Turkey—an update on the Turkish minerals industry. *Industrial Minerals* 379, 21–47.
- Hudson, D.M., 2003. Epithermal alteration and mineralization in the Comstock district, Nevada. *Economic Geology* 98, 367–395.
- Huston, D.L., 2000. Gold in volcanic-hosted massive sulfide deposits: distribution, genesis, and exploration. In: Hagemann, S.G., Brown, P.E. (Eds.), *Gold in 2000*, *Reviews in Economic Geology*, vol. 13, pp. 401–426.
- Immet Mining, 2003. Annual Report for 2003. 94 pp.

- Jackson, J.A., McKenzie, D., 1988. The relationship between plate motions and seismic moment tensors and rates of active deformation in the Mediterranean and Middle East. *Geophysical Journal* 93, 45–73.
- Janković, S., 1977. The copper deposits and geotectonic setting of the Tethyan Eurasian metallogenic belt. *Mineralium Deposita* 12, 37–47.
- Janković, S., 1982. Sb–As–Tl–Ba mineral assemblage of hydrothermal–sedimentary origin, Gumuskoy Deposit, Kutahya (Turkey). In: Amstutz, G.C., El Goresy, A., Frenzel, G., Kluth, C., Moh, G., Wauschkuhn, A., Zimmermann, R.A. (Eds.), *Ore Genesis, The State of the Art*, vol. 2. SGA Special Publication, pp. 143–149.
- Janković, S., 1997. The Carpatho–Balkanides and adjacent area: a sector of the Tethyan Eurasian metallogenic belt. *Mineralium Deposita* 32, 426–433.
- Jensen, E.P., Barton, M.D., 2000. Gold deposits related to alkaline magmatism. In: Hagemann, S.G., Brown, P.E. (Eds.), *Gold in 2000, Reviews in Economic Geology*, vol. 13, pp. 279–314.
- Kaptan, E., 1990. Findings related to the history of mining in Turkey. *Mineral Research Exploration Bulletin* 111, 75–84.
- Kaptan, E., 2000. On the mining history of Turkey; ancient gold mining in Bakir Tepe, Sivas. MTA Report, vol. 10375 (in Turkish).
- Karamata, S., Knežević, V., Pécskay, Z., Djordjević, M., 1997. Magmatism and metallogeny of the Ridanj–Krepoljin belt (eastern Serbia) and their correlation with northern and eastern analogues. *Mineralium Deposita* 32, 452–458.
- Ketin, I., 1966. Tectonic units of Anatolia (Asia Minor). *MTA Bulletin* 66, 23–34.
- Ketin, I., 1983. Overview of Geology of Turkey (in Turkish). Istanbul Technical University, Istanbul, Turkey. 595 pp.
- Kissel, C., Laj, C., 1988. The Tertiary geodynamical evolution of the Aegean arc: a paleomagnetic reconstruction. *Tectonophysics* 146, 183–201.
- Kistler, R.W., 1991. Chemical and isotopic characteristics of plutons in the Great Basin. In: Raines, G.L., Lisle, R.E., Schafer, R.W., Wilkinson, W.H. (Eds.), *Geology and Ore Deposits of the Great Basin*. Geological Society of Nevada, Reno, pp. 107–109. Symposium Proceedings.
- Koc, S., Unsal, A., Kadioglu, Y.K., 1995. Geology, geochemistry and geotectonic setting of volcanics comprising Kure (Kastamonu) ore mineralization. *MTA Dergisi* 117, 41–54 (in Turkish).
- Kovenko, V., 1940. Balya lead mines. *MTA Dergisi* 4 21, 580–593 (in Turkish).
- Kroll, T., Muller, D., Seifert, T., Herzig, P.M., Schneider, A., 2002. Petrology and geochemistry of the shoshonite-hosted Skouries porphyry Cu–Au deposit Chalkidiki, Greece. *Mineralium Deposita* 37, 137–144.
- Larson, L.T., 1989, Nov. Geology and gold mineralization in western Turkey. *Mining Engineering*, 1099–1102.
- Larson, L.T., Erler, Y.A., 1993. The epithermal lithochemical signature—a persistent characterization of precious metal mineralization at Kursunlu and Orencik, two prospects of very different geology in western Turkey. *Journal of Geochemical Exploration* 47, 321–331.
- Leitch, C.H.B., 1981. Mineralogy and textures of the Lahanos and Kizilkaya massive sulphide deposits, northeastern Turkey, and their similarity to Kuroko ores. *Mineralium Deposita* 16, 241–257.
- Le Pichon, X., Angelier, J., 1979. The Hellenic arc and trench system: a key to the neotectonic evolution of the eastern Mediterranean area. *Tectonophysics* 60, 1–42.
- Le Pichon, X., Angelier, J., 1981. The Aegean sea. *Philosophical Transactions of the Royal Society, London* A300, 357–372.
- Lindgren, W., 1933. *Mineral Deposits*, 4th ed. McGraw-Hill, New York. 930 pp.
- Lips, A.L.W., Cassard, D., Sozibilir, H., Yilmaz, H., 2001. Multi-stage exhumation of the Menderes Massif, western Anatolia Turkey. *International Journal of Earth Sciences* 89, 781–792.
- Love, D.A., Clark, A.H., Hodgson, C.J., Mortensen, J.K., Archibald, D.A., Farrar, E., 1998. The timing of adularia–sericite-type mineralization and alunite–kaolinite-type alteration, Mount Skukum epithermal gold deposit, Yukon Territory, Canada: $^{40}\text{Ar}/^{39}\text{Ar}$ and U–Pb geochronology. *Economic Geology* 93, 437–462.
- Marchev, P., Singer, B., Andrew, C., Hasson, S., Moritz, R., Bonev, N., 2003. Characteristics and preliminary $^{40}\text{Ar}/^{39}\text{Ar}$ and $^{87}\text{Sr}/^{86}\text{Sr}$ data of the Upper Eocene sedimentary-hosted low-sulfidation gold deposits Ada Tepe and Rosino, SE Bulgaria: possible relation with core complex formation. In: Eliopoulos, D.G., et al. (Eds.), *Mineral Exploration and Sustainable Development*. Millpress, Rotterdam, pp. 1193–1196.
- McKenzie, D., 1978. Active tectonics of the Alpine–Himalayan belt: the Aegean sea and surrounding regions. *Geophysical Journal of Royal Astronomical Society* 55, 217–254.
- Mehrabi, B., Yardley, B.W.D., Cann, J.R., 1999. Sediment-hosted disseminated gold mineralization at Zarshuran, NW Iran. *Mineralium Deposita* 34, 673–696.
- Meulenkamp, J.E., Wortel, W.J.R., Van Wamel, W.A., Spakman, W., Hoogerduyn Strating, E., 1988. On the Hellenic subduction zone and the geodynamic evolution of Crete since the late Middle Miocene. *Tectonophysics* 146, 203–215.
- Meulenkamp, J.E., van der Zwaan, G.J., van Wamel, W.A., 1994. On Late Miocene to Recent vertical motions in the Cretan segment of the Hellenic Arc. *Tectonophysics* 234, 53–72.
- Meyer, C., Shea, E.P., Goddard, C.C., Zeihen, L.G., Guilbert, J.M., Miller, R.N., McAleer, J.F., Brox, G.B., Ingersoll, R.G., Burns, G.J., Wigal, T., 1968. Ore deposits at Butte, Montana. In: Ridge, J.D. (Ed.), *Ore Deposits of the United States, 1933–1967, The Graton–Sales Volume*: New York, American Institute of Mining and Metallurgical Engineers, vol. 2, pp. 1373–1416.
- Migineishvili, R., 2001. Contemporaneous factors controlling formation of the Madneuli Cu–Au deposit. In: Piestrzynski, A., et al. (Eds.), *Mineral Deposits at the Beginning of the 21st Century*. Balkema, Lisse, pp. 301–304.
- Miller, R.N. (Ed.), 1973. *Guidebook for the Butte field meetings of the Society of Economic Geologists, Butte, Montana*. Society of Economic Geologists, United States Geological Survey and The Anaconda Company. Section A–P.
- Moon, C.J., Gotsiridze, G., Gugushvili, V., Kekelia, M., Kekelia, S., Migineishvili, R., Otkhmezuri, Z., Ozgur, N., 2001. Comparison of mineral deposits between Georgian and Turkish sectors of the

- Tethyan metallogenic belt. In: Piestrzynski, A., et al. (Eds.), *Mineral Deposits at the Beginning of the 21st Century*. Balkema, Lisse, pp. 309–312.
- Moore, W.J., McKee, E.H., Akinci, O.T., 1980. Chemistry and chronology of plutonic rocks in the Pontid mountains, northern Turkey. In: Jankovic, S., Sillitoe, R.H. (Eds.), *European Copper Deposits*, Belgrade, pp. 209–216.
- MTA., 1980. *Ore Deposit Inventory of Turkey* (in Turkish). MTA Publication, vol. 179. 571 pp. (in Turkish).
- MTA, 1989. *Geologic map of Turkey*. Scale 1:2000000, MTA, Ankara.
- MTA, 1993a. *Gold and Silver Inventory of Turkey*. MTA publication no. 198. 46 pp. (in Turkish).
- MTA, 1993b. *Study of Gumushane–Mescitli (Mastra) Gold Prospect*. 4 volumes Report no. 9592, MTA, Ankara (in Turkish).
- Mutschler, F.E., Ludington, S., Bookstrom, A.A. 1999. Giant porphyry-related metal camps of the world—a database. *United States Geological Survey Open File Report 99-556* (Digital Format).
- Newmont, 2002. *Ovacik epithermal gold deposit*, Unpublished internal report. 7 pp.
- O'Brien, B.P.M., 1997. The geology and genesis of the Cerattepe volcanogenic Cu–Au–Ag deposit and its place in the geological development of the Artvin volcanic complex, Artvin, northeastern Turkey. PhD thesis, Queen's University, Ontario, Canada. 559 pp.
- Oberhänsli, R., Monie, P., Candan, O., Warkus, F.C., Partzsch, J.H., Dora, O.O., 1998. The age of blueschist metamorphism in the Mesozoic cover series of the Menderes Massif. *Schweizerische Mineralogische und Petrographische Mitteilungen* 78, 309–316.
- O'Driscoll, M., 2001. Borates—the Turk of the town. *Industrial Minerals* 402, 30–45.
- Odyssey Resources Ltd., 2002. *Altintepe Gold Property* (Eastern Pontides Belt, Turkey). Curtis and Associates Inc. 47 pp.
- Ohta, E., Dogan, R., Batic, H., Abe, M., 1988. Geology and mineralization of Derekoy porphyry copper deposit, northern Thrace, Turkey. *Bulletin of the Geological Survey of Japan* 39 (2), 115–134.
- Okay, A.I., Tuysuz, O., 1999. Tethyan sutures of northern Turkey. In: Durand, B., Jolivet, L., Horvath, L., Serranne, M. (Eds.), *The Mediterranean Basins: Tertiary Extension Within the Alpine Orogen*, Geological Society of London Special Publication, vol. 156, pp. 475–515.
- Okay, A.I., Satir, M., 2000. Coeval plutonism and metamorphism in a latest Oligocene metamorphic core complex in northwest Turkey. *Geological Magazine* 137, 495–516.
- Oygur, V., Erler, A., 1999. An example to the jasperoidal-type epithermal mineralization from the western Anatolia: Degirmenciler antimony mineralization (Simav–Kutahya). *MTA Dergisi* 121, 97–113 (in Turkish).
- Oyman, T., Minareci, F., Piskin, O., 2003. Efemcukuru B-rich epithermal gold deposit (Izmir Turkey). *Ore Geology Reviews* 23, 35–53.
- Ozer, E., 1994. Stratigraphy of the Munzur Mountains (Kemah–Ilic–Erzincan). *Geological Bulletin of Turkey* 37 (2), 53–64 (in Turkish with English Abstract).
- Ozgenç, I., 1993. The geology of Saplica (Sebinkarahisar–Giresun) alunite deposit and an approach to the genesis of alunite by using sulfur isotope data. *Geological Bulletin of Turkey* 36, 25–36 (in Turkish).
- Ozgun, N., 1991. Gold contents of the Akarsen copper deposit, E. Pontides, Turkey. In: Ladeira, E.A. (Ed.), *Proceedings of 5th International Conference; Brazil Gold '91, Belo Horizonte, Minas Gerais Brazil, 13–17 March, 1991*, A.A. Balkema, Rotterdam, pp. 477–480.
- Ozgun, N., 1993. Volcanogenic massive sulfide deposits in the East Pontic Metallotect, NE Turkey. *Resource Geology* 17, 180–185 (Special Issue).
- Ozgun, N., 2003. Active and fossil geothermal systems in the continental rift zones of the Menderes Massif, Western Anatolia, Turkey. In: Eliopoulos, D.G., et al. (Eds.), *Mineral Exploration and Sustainable Development*. Millpress Science Publishers, pp. 515–518.
- Ozturk, H., 1997. Manganese deposits in Turkey: distribution, types and tectonic setting. *Ore Geology Reviews* 12, 187–203.
- Pejatovic, S., 1979. Metallogeny of the Pontid-type massive sulfide deposits. *Mineral Research and Exploration Institute of Turkey (MTA), Bulletin*, vol. 177. 98 pp.
- Pirajno, F., 1995. Volcanic-hosted epithermal systems in northwest Turkey. *South African Journal of Geology* 98, 13–24.
- Pollard, P.J., 2001. Sodic (calcic) alteration in Fe oxide–Cu–Au districts: an origin via unmixing of magmatic H₂O–CO₂–NaCl ± CaCl₂–KCl fluids. *Mineralium Deposita* 36, 93–100.
- Popov, P., Berza, T., Grubic, A., 2000. Upper Cretaceous Apusani–Banat–Timok–Srednogorie (ABTS) magmatic and metallogenic belt in the Carpathian–Balkan Orogen. Abstract volume, ABCD-GEODE 2000 workshop, Borovets, Bulgaria, May 2000, 69.
- Rimmelé, G., Oberhänsli, R., Goffé, B., Jolivet, L., Candan, O., Cetinkaplan, M., 2003. First evidence of high-pressure metamorphism in the “Cover Series” of the southern Menderes Massif. Tectonic and metamorphic implications for the evolution of SW Turkey. *Lithos* 71, 19–46.
- Robertson, A.H.F., 2002. Overview of the genesis and emplacement of Mesozoic ophiolites in the Eastern Mediterranean Tethyan region. *Lithos* 65, 1–67.
- Robertson, A.H.F., Dixon, J.E., 1984. Aspects of the geological evolution of the Eastern Mediterranean. In: Dixon, J.E., Robertson, A.H.F. (Eds.), *The Geological Evolution of the Eastern Mediterranean*, Special Publication, Geological Society London, vol. 17, pp. 1–74.
- Robertson, A.H.F., Dixon, J.E., Brown, S., Collins, A., Morris, A., Pickett, E., Sharp, I., Ustaomer, T., 1996. Alternative tectonic models for the Late Paleozoic–Early Tertiary development of Tethys in the Eastern Mediterranean region. In: Morris, A., Tarling, D.H. (Eds.), *Paleomagnetism and Tectonics of the Mediterranean region*, Geological Society of London Special Publication, vol. 105, pp. 239–263.
- Romberger, S.B., 1990. Geochemistry of epithermal precious metal deposits. In: Hausen, D.M., Halbe, D.N., Petersen, E.U., Tafuri, W.J. (Eds.), *Proceedings of Gold '90 Symposium*. Society for Mining, Metallurgy and Exploration, Littleton, Colorado, pp. 181–188.

- Roth, T., Thompson, J.F.H., Barret, T.J., 1999. The precious metal-rich Eskay Creek deposit, northwestern British Columbia. In: Barrie, C.T., Hannington, M.D. (Eds.), *Volcanic-associated Massive Sulfide Deposits: Process and Examples in Modern and Ancient Settings*, Reviews in Economic Geology, vol. 8, pp. 367–384.
- Rui-Zhong, H., Wen-Chao, S., Xian-Wu, B., Guang-Zhi, T., Hofstra, A.H., 2002. Geology and geochemistry of Carlin-type gold deposits in China. *Mineralium Deposita* 37, 378–392.
- Ryan, C.W., 1957. A guide to the known minerals of Turkey. United States Operations Mission to Turkey, Ankara. 199 pp.
- Ryan, J.G., Langmuir, C.H., 1993. The systematics of boron abundances in young volcanic rocks. *Geochimica et Cosmochimica Acta* 57, 1489–1498.
- Satir, M., Friedrichsen, H., 1986. The origin and evolution of the Menderes Massif, W Turkey: a rubidium/strontium and oxygen isotope study. *Geologische Rundschau* 75, 703–714.
- Savascin, M.Y., Gulec, N., 1990. Relationship between magmatic and tectonic activities in western Turkey—geological and geochemical features with examples from the coastal section. In: Savascin, M.Y., Eronat, A.H. (Eds.), *Proceedings, IESC in Aegean Regions*, Izmir, Turkey, vol. 2, pp. 300–313.
- Schneider, H.J., Ozgur, N., Palacios, C.M., 1988. Relationship between alteration, rare earth element distribution and mineralization of the Murgul copper deposit, northeastern Turkey. *Economic Geology* 83, 1238–1246.
- Seedorff, E., 1991. Magmatism, extension and ore deposits of Eocene to Holocene age in the Great Basin—mutual effects and preliminary proposed genetic relationships. *GSN Geology and Ore Deposits of the Great Basin Symposium, Proceedings*, vol. 1. Geological Society of Nevada, Reno, Nevada, pp. 133–178.
- Sengor, A.M.C., 1979. The North Anatolian transform fault: its age, offset and tectonic significance. *Journal of the Geological Society of London* 136, 269–282.
- Sengor, A.M.C., 1982. Factors controlling the neotectonic evolution of Aegean. In: Erol, O., Oygur, V. (Eds.), *Panel on Neotectonics and Young Volcanism of Western Anatolia*. Geological Society of Turkey, Ankara, pp. 59–71.
- Sengor, A.M.C., 1984. The Cimmeride orogenic system and the tectonics of Eurasia. *Geological Society of America Special Paper*, vol. 195. 82 pp.
- Sengor, A.M.C., 1987. Cross-faults and differential stretching of hanging walls in regions of low-angle normal faults: examples from western Turkey. In: Coward, M.P., Dewey, J.F., Hancock, P.L. (Eds.), *Continental Extensional Tectonics*, Geological Society of London Special Publication, vol. 28, pp. 575–689.
- Sengor, A.M.C., Yilmaz, Y., 1981. Tethyan evolution of Turkey: a plate tectonic approach. *Tectonophysics* 75, 181–241.
- Sengor, A.M.C., Yilmaz, Y., Ketin, I., 1980. Remnants of a pre-Late Jurassic ocean in northern Turkey: fragments of Permian–Triassic Paleo-Tethys? *Geological Society of America Bulletin* 91, 599–609.
- Sengor, A.M.C., Yilmaz, Y., Sungurlu, O., 1984. Tectonics of the Mediterranean Cimmerides: nature and evolution of the western termination of Paleo-Tethys. In: Dixon, J.E., Robertson, A.H.F. (Eds.), *The Geological Evolution of the Eastern Mediterranean*, Geological Society of London Special Publication, vol. 17, pp. 77–112.
- Sengor, A.M.C., Gorur, N., Saroglu, F., 1985. Strike-slip deformation basin formation and sedimentation: strike-slip faulting and related basin formation in zones of tectonic escape: Turkey as a case study. *Society of Economic Paleontologists and Mineralogists Special Publication* 37, 227–264.
- Seyitoglu, G., Scott, B.C., 1991. Late Cenozoic crustal extension and basin formation in west Turkey. *Geological Magazine* 128, 155–166.
- Seyitoglu, G., Scott, B.C., 1992. Late Cenozoic volcanic evolution of the northeastern Aegean region. *Journal of Volcanology and Geothermal Research* 54, 157–176.
- Seyitoglu, G., Scott, B.C., 1996. The cause of N–S extensional tectonics in western Turkey: tectonic escape vs back-arc spreading vs orogenic collapse. *Journal of Geodynamics* 22, 145–153.
- Seyitoglu, G., Anderson, D., Nowell, G., Scott, B., 1997. The evolution from Miocene potassic to Quaternary sodic magmatism in western Turkey: implications for enrichment processes in the lithospheric mantle. *Journal of Volcanology and Geothermal Research* 76, 127–147.
- Sewell, D.M., Wheatley, C.J.V., 1994. The Lerokis and Kali Kuning submarine exhalative gold–silver–barite deposits, Wetar Island, Maluku, Indonesia. *Journal of Geochemical Exploration* 50, 351–370.
- Sherlock, R.L., Roth, T., Spooner, E.T.C., Bray, C.J., 1999. Origin of the Eskay Creek precious metal-rich volcanogenic massive sulfide deposit: fluid inclusion and stable isotope evidence. *Economic Geology* 94, 803–824.
- Sillitoe, R.H., 1985. Ore-related breccias in volcanoplutonic arcs. *Economic Geology* 80, 1467–1514.
- Sillitoe, R.H., 1991. Gold metallogeny of Chile—an introduction. *Economic Geology* 86, 1187–1205.
- Sillitoe, R.H., 1994. Indonesian mineral deposits—introductory comments, comparisons and speculations. *Journal of Geochemical Exploration* 50, 1–11.
- Sillitoe, R.H., 1997. Characteristics and controls of the largest porphyry copper–gold and epithermal gold deposits in the circum-Pacific. *Australian Journal of Earth Sciences* 44, 373–388.
- Sillitoe, R.H., 2000. Gold-rich porphyry deposits: descriptive and genetic models and their role in exploration and discovery. In: Hagemann, S.G., Brown, P.E. (Eds.), *Gold in 2000, Reviews in Economic Geology*, vol. 13, pp. 315–345.
- Sillitoe, R.H., 2002. Some metallogenic features of gold and copper deposits related to alkaline rocks and consequences for exploration. *Mineralium Deposita* 37, 4–13.
- Sillitoe, R.H., Hedenquist, J.W., 2003. Linkages between volcanotectonic settings, ore–fluid compositions, and epithermal precious-metal deposits. In: Simmons, S.F., Graham, I.J. (Eds.), *Volcanic, Geothermal and Ore-forming Fluids: rulers and Witnesses of Processes within the Earth*, Society of Economic Geologists, Special Publication, vol. 10, pp. 315–343.
- Sillitoe, R.H., Hannington, M.D., Thompson, J.F.H., 1996. High sulfidation deposits in the volcanogenic massive sulfide environment. *Economic Geology* 91, 204–212.
- Skewes, M.A., Holmgren, C., Stern, C.R., 2003. The Donoso copper-rich, tourmaline-bearing breccia pipe in central Chile:

- petrologic, fluid inclusion and stable isotope evidence for and origin from magmatic fluids. *Mineralium Deposita* 38, 2–21.
- Soylu, M., 1999. Modeling of porphyry copper mineralization of the Eastern Pontides. PhD. thesis, Middle East Technical University, Ankara, Turkey. 127 pp.
- Stampfli, G.M., 2000. Tethyan oceans. In: Bozkurt, E., Winchester, J.A., Piper, J.D.A. (Eds.), *Tectonics and Magmatism in Turkey and Surrounding Area*, Geological Society of London Special Publication, vol. 173, pp. 1–23.
- Stampfli, G.M., Rosselet, F., Bagheri, S., 2004. Tethyan oceans and sutures. In: Chatzipetros, A.A., Pavlides, S.B. (Eds.), *Proceedings, 5th International Symposium on Eastern Mediterranean Geology*, Thessaloniki, 14–20 April, 2004, pp. 193–196.
- Strashimirov, S., Petrunov, R., 2000. Porphyry-copper mineralization in the central Srednegorie zone, Bulgaria. *Mineralium Deposita* 37, 587–598.
- Tarkian, M., Stribrny, B., 1999. Platinum-group elements in porphyry copper deposits: a reconnaissance study. *Mineralogy and Petrology* 65, 161–183.
- Tarkian, M., Hunken, U., Tokmakchieva, M., Bogdanov, K., 2003. Precious-metal distribution and fluid-inclusion petrography of the Elatsite porphyry copper deposit, Bulgaria. *Mineralium Deposita* 38, 261–281.
- Teal, L., Jackson, M., 1997. Geologic overview of the Carlin trend gold deposits and descriptions of recent deep discoveries. *Society of Economic Geologist Guidebook Series* 28, 3–37.
- Tekin, U.K., Goncuoglu, M.C., Turhan, N., 2002. First evidence of Late Carnian radiolarians from the Izmir–Ankara suture complex, central Sakarya, Turkey: implications for the opening age of the Izmir–Ankara branch of Neo-Tethys. *Geobios* 35, 127–135.
- Tokel, S., 1995. Magmatic and geochemical evolution of the Pontide segment of the northern Tethys subduction system. In: Erler, A., Ercan, T., Bingol, E., Orcen, S., (Eds.), *Proceedings of the International symposium on the geology of the Black Sea Region*. September 1992, General Directorate of Mineral Research and Exploration and Chamber of Geological Engineers, Ankara, p. 163–170.
- Tosdal, R.M. (Ed.), 1998. Contributions to the gold metallogeny of northern Nevada: United States Geological Survey Open File Report 98-338. 290 pp.
- Turner, S.J., Flindell, P.A., Hendri, D., Hardjana, I., Lauricella, P.F., Lindsay, R.P., Marpaung, B., White, G.P., 1994. Sediment-hosted gold mineralization in the Ratatotok district, North Sulawesi, Indonesia. *Journal of Geochemical Exploration* 50, 317–336.
- Tuysuz, N., 1991. Distribution and origin of detrital gold in Kazıkaya (Kagızman–Kars) placers. *MTA Dergisi* 113, 105–112 (in Turkish).
- Tuysuz, N., 2000. Geology, litho-geochemistry and genesis of the Murgul massive sulfide deposit, NE Turkey. *Chemie der Erde* 60, 231–250.
- Tuysuz, N., Ozdogan, K., Er, M., Yilmaz, Z., Agan, A., 1994. A Carlin-type gold occurrence in the Pontide island arc: the Kalesas fold occurrence (Gumushane, NE Turkey). *Geological Bulletin of Turkey* 37 (1), 41–46.
- Tuysuz, N., Sadiklar, B., Er, M., Yilmaz, Z., 1995. An epithermal gold–silver deposit in the Pontide island arc, Mastra, Gumushane, northeast Turkey. *Economic Geology* 90, 1301–1309.
- Ucurum, A., Larson, L.T., 1999. Geology, base-precious metal concentration and genesis of the silica–carbonate alteration (listwaenites) from Late Cretaceous ophiolitic melanges at central east Turkey. *Chemie der Erde* 59, 77–104.
- Unlu, T., Stendal, H., Makovicky, E., Sayili, I.S., 1995. Genesis of the Divrigi iron ore deposit, Sivas, Central Anatolia, Turkey—an ore microscopy study. *Mineral Research Exploration Bulletin* 117, 17–28.
- Ustaomer, T., Robertson, A.H.F., 1994. Late Paleozoic marginal basin and subduction-accretion: the Paleo-Tethyan Kure Complex, Central Pontides, northern Turkey. *Journal of the Geological Society of London* 151, 291–305.
- Waterman, G.C., Hamilton, R.L., 1975. Sar Cheshmeh porphyry copper deposit. *Economic Geology* 3, 568–576.
- Westra, G., Keith, S.B., 1981. Classification and genesis of stockwork molybdenum deposits. *Economic Geology* 76, 844–873.
- Willgallis, A., Ozgur, N., Siegmann, E., 1990. Se- and Te-bearing sulfides in copper ore deposits of Murgul, NE Turkey. *European Journal of Mineralogy* 2, 145–148.
- Wunder, B., Meixner, A., Romer, R.L., Wirth, R., Heinrich, W., in press. The geochemical cycle of boron: constraints from boron isotope partitioning experiments between mica and fluid. *Lithos*. doi:10.1016/j.lithos.2005.02.003.
- Yalcinalp, B., 1995. The geochemical characteristics of the granitoids bearing porphyry Cu–Mo mineralizations in Eastern Pontides. *Geological Bulletin of Turkey* 38, 25–32.
- Yalcinalp, B., Tashan, E., 1999. Geological setting, mineralogical and geochemical characteristics of the Degirmendere Valley (Macka–Trabzon) manganese mineralizations. *Proceedings, 52nd Geological Congress of Turkey 10–12 May, 1999, Ankara*, pp. 215–222.
- Yigit, O., 1993. Petrographic and mineralogical investigation of the Toplakepe–Kizilcaenek area, Dereli, Giresun, NE Turkey. B.Sc. thesis, Black Sea Technical University, Trabzon, Turkey. 63 pp. (in Turkish)
- Yigit, O., 1997. Structural control, geology, mineralogy and alteration of the Bahcecik epithermal gold occurrence, Trabzon, northeastern Turkey. MSc. thesis, Colorado School of Mines, Golden, CO. 126 pp.
- Yigit, O., 2001. Structural controls and geochemistry of Carlin-type gold mineralization in the Gold Bar district, Eureka County, Nevada. PhD thesis, Colorado School of Mines, Golden, CO. 194 pp+CD-ROM.
- Yigit, O., Nelson, E.P., 2000. Paleozoic structural controls on Tertiary gold mineralization in the Gold Canyon deposit, Eureka County, Nevada. In: Cluer, J.K., Price, J.G., Struhsacker, E.M., Hardyman, R.F., Morris, C.L. (Eds.), *Geology and Ore Deposits 2000: the Great Basin and Beyond*. Symposium proceedings, May 15–18, 2000. Geological Society of Nevada, Reno, NV, pp. 563–566.
- Yigit, O., Hofstra, A.H., 2003. Litho-geochemistry of Carlin-type gold mineralization in the Gold Bar district, Battle Mountain–Eureka Trend, Nevada. *Ore Geology Reviews* 22, 201–224.

- Yigit, O., Nelson, E.P., Hitzman, M.W., 2000. Early Tertiary epithermal gold mineralization, Bahcecik Prospect, northeastern Turkey. *Mineralium Deposita* 35, 689–696.
- Yigit, O., Nelson, E.P., Hitzman, M.W., Hofstra, A.H., 2003. Structural controls on Carlin-type gold mineralization in the Gold Bar district, Eureka County, Nevada. *Economic Geology* 98, 1173–1188.
- Yigitbas, E., Yilmaz, Y., 1996. New evidence and solution to the Maden complex controversy of the southeast Anatolian orogenic belt (Turkey). *Geologische Rundschau* 85, 250–263.
- Yildirim, S., 2002. Alteration and geochemical features of Beykoy gold mineralization, Kepsut–Balikesir. 55th Geological Congress of Turkey, Abstracts Book, 11–15 March, 2002. MTA, Ankara, pp. 311–312.
- Yildirim, S., Cengiz, I., 2004. Geological and geochemical characteristics of Sahinli (Lapseki–Canakkale) Au–Ag mineralization. 57th Geological Congress of Turkey, Extended Abstracts Book, 8–12 March, 2004. MTA, Ankara, pp. 87–88.
- Yildiz, M., Bailey, E.H., 1978. Mercury deposits in Turkey. *United States Geological Survey Bulletin* 1456 (80 pp.).
- Yilmaz, H., 2002. Ovacik gold deposit: an example of quartz–adularia-type gold mineralization in Turkey. *Economic Geology* 97, 1829–1839.
- Yilmaz, H., 2003. Geochemical exploration for gold in western Turkey: success and failure. *Journal of Geochemical Exploration* 80, 117–135.
- Yilmaz, S., Boztug, D., 1996. Space and time relations of the three plutonic phases in the Eastern Pontides, Turkey. *International Geology Review* 38, 935–956.
- Yilmaz, Y., 1990. Comparison of young volcanic associations of western and eastern Anatolia formed under a compressional regime: a review. *Journal of Volcanology and Geothermal Research* 44, 69–87.
- Yilmaz, Y., 1993. New evidence and model on the evolution of the southeast Anatolian orogen. *Geological Society of America Bulletin* 105, 251–271.
- Young, W.J., 1972. The fabulous gold of the Pactolus valley. *Boston Museum Bulletin* 70 (359), 5–15.
- Zeck, H.P., Unlu, T., 1991. Shoshonitic, monzonitic pluton near Murmano, Eastern Central Turkey; a preliminary note. *MTA Dergisi* 112, 103–115 (in Turkish).