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The current status of gold mining in Turkey: An overview

Türkiye'de altın madenciliğinin güncel durumu: Genel bir bakış

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Abstract

Gold has been treasured since ancient time for its beauty, purity, power, valuable asset and investment, accomplishment, and many more. However, gold also appeared in the last quarter of 20 th century as a basic metal due to its superior electrical conductivity, resistance to corrosion and required combinations of physical and chemical properties. Turkey has many gold deposits, which generally occurred in Late Mesozoic and Tertiary formations, and related to Mesozoic and Cenozoic volcano plutonic acts. However, the most economic porphyry, epithermal including both low and high sulphidation systems, volcanic associated massive sulphide gold deposits are abundantly found. Orogenic, placer and skarn host gold deposits are relatively less significant in terms of their abundance and reserve/resource sizes. Gold is embedded in Turkish life and plays a significant and innovative role in Turkey's economy. Gold production has increased almost every year since 2001, rising from 1.4 tons to 45 tons in 2021. However, gold consumption does not meet gold production. Because Turkey is the fifth largest gold consumer in the world. The gold consumption is about 6 % of global demand. The review currently outlines a focus on geological and mining characteristics of gold deposits and features of gold such as its use, import, export and price.

Keywords: Gold deposits, Gold mining, Gold uses, Gold import, Gold export

Öz

Altın ilk çağlardan beri onun güzelliği, saflığı, gücü, değerli servet olma, yatırım yapma ve daha birçok özelliği için biriktirilmiştir. Ancak, yirminci yüzyılın sonlarında süper elektriksel iletkenliği, korozyona karşı dayanıklılığı, istenen fiziksel ve kimyasal özellik birleşimleri nedeniyle ana metal olarak ortaya çıkmıştır. Türkiye, genellikle geç Mezozoik ve Tertiary formasyonlarda, Mezozoik ve Senozoik volkanik-plütonik aktivitelerle oluşmuş birçok altın yatağına sahiptir. Ancak, en ekonomik porfiri, düşük ve yüksek sülfür sistemlerini içeren epitermal, volkanik masif sülfür tipi birçok altın yatakları oldukça yaygın bulunmaktadır. Orojenik, plaser ve skarn türü altın yatakları rezerv/kaynak büyüklüğü ve sıklığı bakımından daha az önemlidir. Altın, Türk insanının yaşamına girmiş olup, Türkiye ekonomisinde önemli ve yenilikçi bir rol oynamaktadır. Altın üretimi 2001 yılından bu yana 1.4 tondan 2021 yılında 45 tona yükselişiyle hemen hemen her yıl artmıştır. Ancak, altın üretimi altın tüketimini karşılamamaktadır. Çünkü Türkiye, küresel altın tüketici talebinin %6'sını oluşturmakta olup, dünyanın en büyük dördüncü altın tüketicisidir. Bu derleme incelemesi, güncel olarak altın yataklarının jeolojik ve maden karakteristiklerine; altın kullanımı, ithalatı, ihracatı ve fiyatı gibi özelliklerine odaklanmayı özetlemektedir.

Anahtar kelimeler: Altın yatakları, Altın madenciliği, altın kullanımları, Altın ithalatı, Altın ihracatı

1 Introduction

Gold is the oldest metal in the world. It was used in 5000 B.C. Legend and historical records reveal that metal mining in Turkey dates back to 8000 years. The first gold coins were made in Lydia (western Turkey) in about 700 B.C. [1]. Although Turkey has a long history of mining, modern geological exploration and discoveries of ore deposits have not been fully applied in site investigation until 1985. The Turkish Geological Survey (MTA), established in 1935, has made ore inventors, [2, 3], metallogenic maps of Turkey [4]. Mining law and regulations have been considerably changed and renewed in 1985. The regulations provide that successful mineral exploration and discoveries have been carried out by many global companies using modern exploration methods. Many discoveries of gold deposits have been made in recent years.

The geological framework of the Alpine-Himalayan segment results from the complex of two main lithospheric plates (Eurasia and Gondwana). At present time, the boundary between the plates extends irregularly from the Gibraltar arc to the Burmese ranges, passing through the western and eastern Mediterranean basins, Turkey, Iran, Pakistan and the 2000 km long Himalayan range [5]. Most of economic gold deposits have been formed at these belts of Alpine Orogenic segment. Turkey is in Alpine orogenic belt between Eurasian, Arabian and African plates. Turkey's geology, is rather complex, has four main tectonic belts, includes Pontid, Anatolid, Taurid and Border Fold Belts. Most of metal deposits have been occurred in these tectonic belts. Turkey has a substantial number of gold deposits, which include porphyry, high and low sulphidation types of epithermal, volcanic associated massive sulphide, orogenic, placer and skarn hosted. Recent gold reserves/resources are estimated as 1500 tons in these deposits [6]. Recently,

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explorations and discoveries for gold deposits have mostly focused on porphyry and epithermal of geologic systems.

Turkey is the fifth largest gold consumer in the world after India, USA, Saudi Arabia and China. Gold production of the country, officially started in 2001 with 1.4 tons of gold, gradually increased every year, was 45 tons in 2021. However, the gold production does not meet the consumption of gold. Turkey has annually imported an average of 157 tons gold every year in the last 25 years, spend 3.13 billion dollars only in 2021 (importing 55 tons of gold). This payment significantly affects foreign trade deficit. On the other hand, it is estimated that Turkish householders have accumulated 3500-4000 tons of gold ‘‘under-the –pillow’’.

This overview fills a knowledge gap in the current status of gold mining in Turkey. There are many old dated review publications or available most of small and local reports that describe only single issue and provide few or no guidelines necessary focusing on practical applications of the gold mining research. This review addresses present time comprehension of Turkey’s gold deposits which include the available data, its geology and mining characteristics, and its use, import, export and price. The review may be used by a wide range of practitioners, geological and mining engineers, and others involved in gold mining.

2 Geology and types of gold deposits in Turkey

Geological frameworks (such as geologic environment, host rocks, mineralisation or metal associatıon, alteration, age, genetic origin, grade and reserve or size characteristics of ore body, structure or tectonic activities and metamorphic effects provide classification of gold deposits that are most significant for designing exploration strategies, evaluating prospect and performing reserve or resource assessments of selected sites. Robert et al. [7] have classified sixteen globally recognised types of lode gold deposits that are based on the geological settings, host rocks, nature of mineralisation and geochemical signature. The comprehensive inventories of Turkey’s gold and silver fields were studied using main geological frameworks, mining characteristics by Çolak [8].

Distinguishing significant ore deposits are described according to geological framework, wall rock type, mineral assemblage and depth ranges. Turkey has many discovered and prospecting stages of gold deposits which can be classified into six groups. They comprise low sulphidation epithermal and high sulphidation epithermal types, intrusion related to porphyry gold, volcanic hosted massive sulphide (VMS) deposits, orogenic gold including Listwanite-associated and placer deposits. Characteristics of the gold deposits in Turkey are summarised in Table 1. Gold prospects in investment and development phase in Turkey are presented in Table 2.

2.1 Epithermal gold deposits

Turkish literatures use Lindgren [9] ore deposit classification which depends on depth and temperature-pressure relationship in the Earth crust as epithermal, mesothermal and hypothermal. Majority of epithermal gold deposits occur in transported zones with the temperature range 180-280 °C, equivalent to depths about 100 m to 800-1500 m (Table 3) [10]. In high sulphidation epithermal deposits are closely associated with volcanic and magmatic centres and are hosted in extremely altered rocks. Low sulphidation epithermal deposits are associated with excessively altered mineralisation and especially more vein styles [11]. They are frequently more distal to volcanic centres. Open-space veins and stockwork ore are dominant, dissemination and replacement of ore are minor in low sulphidation system. However, dissemination and replacement of ore are common and stockwork ore is minor and veins subordinate, locally dominant in high sulphidation systems [12].

Epithermal gold deposits form at relatively low temperatures 150-300 °C and shallow depths near volcanic areas and in hydrothermal fields [13]. Mineralisation fluids in low sulphidation gold deposits are generally formed by deeply transporting aqueous solution containing absorbed acid magmatic gases. Most of Low sulphidation deposits occurring in low relief areas are generally distributed above a magmatic zone continuation to bedrock. High sulphidation gold deposits emerge by high sulphidation acidic and oxidised fluid near volcanoes.

The majority of the operated gold deposits, prospect, investment and development stage in the mineral deposit database of Turkey are epithermal about 50 % (Table 1 and 2). Epithermal operated gold deposits are distributed in two regions of Turkey, north-eastern (NE) Turkey and western (W) Turkey. There are both high and low sulphidation epithermal gold deposits in Turkey. However, low sulphidation gold deposits are more economic than high sulphidation system gold deposits in the regions. High sulphidation system is distributed mainly in the Çanakkale region, northwest (NW) Turkey. Ovacık, Efemçukuru, Çukuralan operated gold deposits (in İzmir region), Lapseki (Çanakkale) in W Turkey, Altıntepe (Ordu) and Mastra (Gümüşhane) gold produce deposits in northern (N) Turkey, Himmetdede (Kayseri) operated gold deposits are typical examples of low sulphidation system. High sulphidation epithermal operated or the production of gold deposits of Turkey are represented by Ağı Dağı-Kirazlı (Çanakkale) in W Turkey, Çorak-Taç (Artvin) in NE Turkey and Öksüt (Kayseri) in E Turkey (Table 1).

The Ovacık, Efemçukuru, Çukuralan and Ağı Dağı gold deposits are associated with submarial volcanic rocks in W and NW Turkey. The Ovacık gold deposit located along the northern boundary of the ENE-trending Bergama graben, are hosted in andesite porphyry of Early Miocene [14]. The Efemçukuru deposit is hosted by rhyolite domes of Neogene and flysch facies rocks Late Cretaceous rocks to Paleogene age. The orebody is associated with faults control vein, stockworks, breccias and replacement mineralisation and also serve as local for rhyolitic intrusions. Mastra (Gümüşhane) and Altıntepe (Ordu) gold deposits are associated with submarine to subaerial volcanic rocks, are hosted by andesite lava and tuffs of Miocene age, porphyry andesite and rhyolite domes of Upper Cretaceous age, respectively.

Table 1. Geological and mining characteristics of operated gold deposits in Turkey

State-Deposit Name	Company	Measured Resources Mt	Au Average Grade g/t	Contained Au ozx1000	Deposit Type	Main Host Rock	Age of Host Rock	Ore Body	Operation Processing	Production Start Year	References
Kışladağ-Uşak	Tüprag	345	0.70	4352	porphyry	Multi-latite porphyry intrusions	Late Tertiary	stockworks, breccia	Open pit, heap leaching	2006	[17,18, 19,20]
Çöpler-Erzincan	Anagold	72	1.30	6000	porphyry	Granodiorite, quartz monzonite, skarn limestone	Palaeocene Campanian	stockworks	Open pit, POX heap leaching	2010	[20,21, 22,23]
Ovacık -İzmir	Koza	150	4.82	-	Epithermal LS	Andesite porphyry	Early Miocene	Veins with breccia	Underground, tank leaching	2001	[20, 22, 24, 25]
Efemçukuru-İzmir	Tüprag	255	6.90	651	Epithermal LS	Flysch, hornfels rhyolite intrusions	Late Cretaceous Paleogene	Veins, stockworks, breccia, replacements	Underground, flotation	2011	[20, 22, 26, 27]
Himmetdede-Kayseri	Koza	30	0.70	1060	Epithermal LS	Gneiss marble, ignimbrite	Palaeozoic, Late Pliocene	Disseminations, veinlets	Open pit, heap leaching	2013	[20, 22, 28, 29]
Kaymaz-Eskişehir	Koza	6	5.01	215	Orogenic Listwanite	Marine sediments, ophiolites	Upper Cretaceous	Disseminate, breccia	Open pit, tank leaching	2011	[20, 22, 28, 30]
Mastra-Gümüşhane	Koza	-	2.55	-	Epithermal LS	Andesite porphyry, andesitic tuff	Eocene	Vein-stockworks, local breccia	Open pit, underground, tank leaching	2009	[20, 22, 31, 32]
Çukuralan-İzmir	Koza	26	4.90	2000	Epithermal LS	Porphyrydyke, granodiorite, metamorphic complex	Permian	Stockworks, veins, replacement	Open pit, underground, tank leaching	2009	[20, 22, 33]
Bakırtepe-Sivas	Demir-export	3	1,30	150	Epithermal HS	Quartzite, schist	Upper Cretaceous-Palaeocene	Veins, disseminations	Open-pit, heap leaching	2015	[20, 22, 34, 35]
Öksüt-Kayseri	Öksüt	25.8	1.35	1200	Epithermal HS	Andesitic volcanic complex	Miocene-Pliocene	Breccia, Veins	Open pit, heap leaching	2020	[20, 22, 36, 37]
Lapseki-Çanakkale	Tümad	7.15	1.85	-	Epithermal LS	Andesite, schist	Lower Miocene	Veins, breccia, stockworks	Open pit, tank leaching	2018	[20, 22, 38]
İvrindi-Balıkesir	Tümad	45	0.67	-	Epithermal	Andesite porphyry	Miocene	Veins, stockworks	Open pit, heap leaching	2019	[20, 22, 39]
Sart-Manisa	Pomza	20 Mm^3	97mg/m^3	355	Placer	Conglomerates, crystalline rocks, schist	Miocene - Quaternary	Placer native gold	Open pit, gravity separation	2002	[20, 22, 40]
Bolkardağ-Niğde	Gümüştaş	0.5	8	-	Karstic	Marble, porphyry, volcanic	Permien-Trias, Palaeocene-Eocene	Placer (secondary), Replacement, veins	Underground, open pit, tank leaching	2012	[20, 22, 41, 42]
Altıntepe-Ordu (Fatsa)	Stratex	10	1.22	345	Epithermal	Volcano-sedimentary porphyry andesite rhyolite domes	Upper Cretaceous	Veins, stockworks, breccia, disseminations	Open pit, heap leaching	2015	[20, 22, 43]
Midi-Gümüşhane	Yıldızlar	-	7	-	Epithermal-Mesothermal	Volcano-sedimentary rocks, limestone	Liyas	Veins, Filling, replacement	Open pit, flotation	2012	[20, 44]
Kaş-Kayseri	Demir Export	1	1.25	-	Epithermal	Limestone		Veins, filling	Open pit, heap leaching	2016	[20, 22, 35]
İnlice-Konya	Esan	12	2.94	-	Epithermal HS	Volcanic, basaltic andesite	Upper Miocene-Pliocene	Disseminations, fillings	Open pit, heap leaching	2015	[45, 46, 47]
Kızıltepe-Balıkesir	Zenit	1	2	-	Epithermal LH	Volcanic rocks, dasitic ignimbrite	Early Miocene	Vein	Open pit, tank leaching	2017	[48, 49]

Table 2. Gold projects in investment and development phase in Turkey

State-Deposit Name	Company	Measured Resources Mt	Au Average Grade g/t	Contained Au ozx1000	Deposit Type	Main Host Rock	Age of Host Rock	Ore Body	Operation Processing	Current status	Refer-ences
Çorak-Artvin	Akdeniz	23.80	1.30	1.58	Epithermal HS	Volcano-Clastic, flows	Upper Cretaceous-Eocene	Veins, stockworks, breccias	Open pit, gravity, flotation	Permit process	[50]
Aği Dağı-Çanakkale	Biga-Alamos	12	0.76	8	Epithermal HS	Flow dome complex	Oligocene, Miocene	Disseminations, breccia	Open pit, heap leaching	Permit process	[51, 52]
Tac-Artvin	Akdeniz	25.70	0.80	-	Epithermal HS	Volcanic, volcano-sedimentary	Upper Cretaceous-Eocene	Veins, stockwork, brecciass	Open pit, gravity, flotation	Permit process	[50]
Kirazlı-Çanakkale	Alamos Gold	-	0.80	515	Epithermal HS	Andesite	Lower Miocene	Disseminations, breccia	Open pit	Permit process	[52]
Yeni Pazar-Yozgat	Aldridge Mineral	30	1.10	100	Poly metal VMS	Meta-sedimentary	Trias-Cretaceous	Disseminated, breccia	Open pit, tank leaching	Permit process	[53]
Hod-Artvin	Lidya	9.1	8.9	350	VMS	Dasitic volcanic rocks	Cretaceous	Breccia, veinlets	Tank leaching, testing	Permit process	[54, 55, 56]
Tavşanlı-Kütahya	Zenit	4.50	1.76	253	Orogenic Listwanite	Serpentines, metamorphic greywackes	Jurassic-Upper Cretaceous	Disseminations, pods, stockworks	Testing	Permit process	[57]

Table 3. Hydrothermal ore deposits associated with magmatic process HS: High sulphide, LS: Low sulphide [10].

Ore deposit type	Relation to magma	Temperature (°C) / depth (km)	Fluid	Associated metals	Active analogue
Porphyry	Adjacent or hosted intrusions	>600-300/2-5	Hypersaline and immiscible vapour	Cu±Mo±Au, Mo, W or Sn	Shallow magma bodies beneath stratovolcano
Skarn	Adjacent to intrusion in carbonate rock	400-600 / 1-5	Saline to moderate	Fe, Cu, Sn, W, Mo, Au, Ag, Pb-Zn	Shallow magma bodies beneath stratovolcano
Pluton-related veins	Fractures in and near intrusion	300-450 / Variable	Moderate to low salinity	Sn, W, Mo±Pb-Zn, Cu, Au	Shallow magma bodies beneath stratovolcano
Epithermal HS	Above parent intrusion	<300 / Near surface to >1.5	Moderate to low salinity	Au-Cu, Ag-Pb	High-temperature fumaroles and acidic springs near volcanic vent
Epithermal LS	Magmatic heat source	150-300 / Near surface to 1-2	Very low salinity, gas-rich	Au (Ag,Pb-Zn)	Geothermal systems with hot springs
Massive Sulphide	Near extrusive domes	<300 / on or near sea floor	Near seawater salinity, gas-rich	Zn-Pb-Ag (Cu or Au)	Back-arc seafloor vents, black smokers

Fluid is used to non-silicate, aqueous liquid and/or vapour. The salinities (Na, K chloride) of fluids in these deposits vary from hypersaline (>50 wt.%) to moderate (10-20 wt.%), low (<5 wt. %), very low (0.2-0.5 wt. %) salinity. HS: high sulphidation, LS: low sulphidation.

2.2 *Porphyry gold deposits*

Porphyry gold deposits are formed in volcanic-magmatic belts in both island and continental crust belts. The deposits are associated with pervasive hydrothermal alteration, porphyritic stocks and volcanic rocks consisting of calc alkaline to alkaline [15]. High fines gold is found in veins, stockworks and disseminations, generally in zones of hydrothermally altered silicate rocks [16].

Porphyry deposits are basically associated with granitoids of Late Cretaceous to Late Miocene age. The two district metallogenic settings are known as the Pontides and Anatolides in Turkey. There are many porphyry Cu-Au deposits and discoveries with significant mineralisation e.g. Gümüşhane and Artvin (NE Turkey). These are hosted by granodiorite porphyry of Middle to Late Eocene age, contains higher grade Au values (up to 15 ppm), with more widespread argillic alteration zone.

Anatolides comprise the two largest gold deposits, Kışladağ (Uşak) and Çöpler (Erzincan) in Turkey. Kışladağ was effectively described as a large tonnage of low-grade, Au deposit which is associated with multi-phase latite porphyry intrusions of late Tertiary age (most probably Miocene). The deposit is the first significant economic porphyry gold deposit in Turkey [17]. Kışladağ gold mineralisation has high Mo content [58].

Çöpler is the second largest gold deposit in Turkey. The deposit is generated in granodiorite, quartz monzonite and limestone. Mineralisation and alteration in Çöpler porphyry Cu-Au deposit present features of a typical porphyry system [21, 23]. Mineralisation is generally associated with overprinted argillic alteration.

2.3 Volcanic hosted massive sulphide (VHMS) gold deposits

Volcanic-hosted massive sulphide (VHMS) deposits or volcanogenic massive sulphide (VMS) depsits are associated with sulphide mineralisation, disseminated, replacement and stockwork ores and sulphide bearing veins that occurred below the sea floor above a mid-sea floor magma. The host rocks of VMS are submarine volcanic rocks. VMS mineralisation have polymetals which include many combinations of sulphides of Cu, Zn, Pb, Au and Ag. The permeability of rocks strongly affects gold occurence. The hydrothermal solution transport to permeable crust, large VMS generate by excessive alteration and replacement of volcanic units. The typical settings of VMS deposits include ophiolitic sequences of mafic ocean crust, deformed and metamorphosed rock of Archaean and early Proterozoic greenstone belts, submarine volcanic successions and intrusions, marine sedimentary rocks with interbedded volcanic rocks. The host rocks of VMS gold deposits are exposed to strong deformational metamorphism.

VMS deposits in Turkey may be classified into two types, Kuroko type and Cyprus type. Gold is an accessory (Au-enriched orebodies) or gold is economic (Au-riched orebodies). The Hod, Cerattepe, Murgul (Artvin) and Çayeli (Rize) are typical examples of gold hosted in Kuroko-type VMS deposits which are mostly sub-marine volcanic rocks of late Cretaceous age.

Economic operated and prospect in Cyprus type deposits in Turkey are not known except for Ergani (Diyarbakır) Cu-Au deposit consisting of two orebodies. The deposit contains relatively high grade Au (mean 1.2g/t) [14]. The mineralisation is associated with mafic submarine volcanic rocks, mudstone and red-black limestone of Eocene age.

2.4 Orogenic gold deposits

Orogenic gold deposits of Turkey consist of mesothermal gold and Listwanite (quartz-carbonate alteration) hosted gold. Orogenic gold deposits are also known as mesothermal gold deposits. Vein and replacement gold mineralisation are a dominant type of orebody. The deposits occurred in orogenic belts and during the periods of regional metamorphism. They are associated with metamorphic and intrusive igneous host rocks. Mesothermal gold deposits are affected by variable structural settings. Vein and replacement ore bodies are formed along fault zones.

The Menderes, Kırşehir, Bitlis and Istranca massifs contain Pre-Mesozoic crystalline metamorphic rocks and orogenic gold deposits and prospects in Turkey. Crystalline metamorphic rocks include mica schist, gneiss and marble, which are the host rocks for gold mineralisation in the Menderes massif. However, there is no economic mesothermal gold deposit in Turkey due to small scale, discontinuous veins and veinlets of mineralisation.

Tavşan (Kütahya) and Kaymaz (Eskişehir) gold deposits in western Turkey are the typical examples of Listwanite mineralisation. Listwanite gold ores form faults or sheared zones of ophiolitic ultramafic rocks, mostly serpentines (thrust and normal) and shear contacts control local high-fluid flow and associated with quartz-carbonate alteration. Kaymaz gold deposits are associated with marine sediments and ophiolite rocks. Fine grained gold ores have occurred with multiple phases of silification and brecciation, and the most gangue minerals are quartz, serpentine, ankerite and dolomite [30].

2.5 Placer gold deposits

Placer and paleoplacers in coarse grained sand and pebble sediment, unconsolidated alluvial gravels and conglomerates are the most common sources of gold. These are exploited due to easy mining excavation of loose, close surface sediments, gold extraction or processing with minimum investment. Gold of fluvial placers and paleoplacers are obtained from erosion of hard rocks. Very thin high garde veins are gold ore in the majority of fluvial placers. Gold placer fields have relatively high relief in most cases.

Alluvial, eluvial and beach placers are the most common types of placer deposits in Turkey. Sart (Manisa) is a typical example of economic and operated placer gold deposit in western Turkey. In the deposit, placer native gold occurs in both alluvium gravels and conglomerate of Miocene to Quaternary age. Gravity ore processing method is applied to produce gold by domestic company [40]. A heterogeneous distribution of gold content negatively affects performances and economics of hydraulic mining operation.

3 Gold processing

Gold processing competing techniques and their advantages and economics have become a major issue in the gold mining industry. The four main mineral processing methods are employed in the gold processing. Pressure oxidation method is rarely applied to increase recovering of gold treatment. Flotation, heap and tank leaching techniques are most frequently used for gold extraction process. The methods applied in modern leaching technologies in optimised operation and atmospheric conditions to develop production.

3.1 Flotation

In the gold-mining industry, flotation constitutes one of the most common methods due to its wide range of applicability. Following the introduction of collector types for selective separation of sulfide minerals in the 1930s, the applicability of the recovery of gold from these sulfide or refractory ores made the flotation process to be evaluated on a wide scale [59]. As its well-known, flotation is a physico-chemical process that utilizes the wettability differences of minerals and separates the hydrophobic ones, either by their natural form or with the addition of suitable reagents (collectors, frothers, etc.) by floating them. Despite gold flotation has been widely used for a long time, the flotation characteristics of gold or gold minerals in sulphide ores have not been defined in detail in the literature. There are lack of fundamental literature studies on gold flotation. However, a great deal of many researches are related to on site specific gold ores. Overall finding of many literature studies indicates that the liberated gold ore under 150 µm in size can be floated in the presence of anionic collector types as xanthates and dithiophosphates [59, 60]. The studies showed that while almost 80 % flotation recovery can be obtained for liberated gold in the presence of potassium amyl xanthate, it can be only up to 50 % for the flotation of refractory gold ore samples. This result revealed that in addition to the chemical type and dosage, the presence and properties of other gangue ores should also be evaluated. Accordingly, in a more recent study, [61] it was found that while the flotation recovery of gold can be 60 % in the presence of clay, it can increase up to 80 % following the removal of clay. There are many parameters or factors such as particle size and shape, collector or reagent composition and type, combinations of collectors, frother type, pulp pH, surface characteristics of gold, gold mineralogy, Eh, flotation gases and impact oxidation, flotation kinetics, electrical double layer, natural metal and organic coatings on gold significantly affect recovering and developing of gold extraction process. Considering that knowledge in mind, it can be clearly suggested that, the flotation of gold is a very complex process that still needs further investigation. It is very important to create new conditions in order to increase the recovery in gold flotation due to the gradually decreasing liberalization sizes. The details of gold flotation method may be found in the literature[59, 62].

3.2 *Pressure oxidation*

Pressure oxidation, commonly abbreviated as POX, has been used broadly for the pre-treatment of refractory gold ores over the past thirty years such as pyrite and marcasite at elevated temperature and pressure, being the first facility operated in 1985 [63, 64, 65].

This technology has been used successfully within the gold industry to treat whole ore and sulphide concentrates using both alkaline and acidic processes, while an alkaline route is typically used exclusively for whole ore only. The process is carried out in a pressure vessel, i.e., an autoclave [64, 65]. Whole-ore treatment is used when flotation gives poor gold recovery. There is important debate on which is better flotation, whether whole-ore or concentrate treatment. To put it more simply that the optimum process is site and ore specific conditions.

During pressure oxidation, sulphide minerals that hinder fine gold are oxidised which effectively liberates the encapsulated gold particles. This process is typically carried out at elevated temperatures (180 to 240°C) with oxygen partial pressure (350 to 700 kPa) [66, 67].

Although the objective of the alkaline and acidic pressure oxidation is indistinguishable, the chemistry inside the autoclave is very different which leads to different gold recovery and residence time. Alkaline pressure oxidation commonly gives a lower gold recovery (up to 10%) due to the gold entrapment in the hematite, which is formed at the oxidising surface of the sulphide mineral. Additionally, residence time in alkaline POX is generally longer due to the difference in the chemistry inside the two processes. To the lower capital and operating costs. Despite of these disadvantages, alkaline POX is often preferred for its lower capital and operating cost due to a more conventional material of construction [65].

The pre-treatment method is significantly affected by thermodynamic and kinetic properties. The thermodynamic properties of chemical system determine the overall reaction driving force in the process. The kinetic properties base on a combination of physical, chemical, mass transport factors and appropriate plant design.

The pressure oxidation method is used to develop gold recovery in Çöpler (Erzincan) gold mine in Turkey. The details of the pressure oxidation pre-treatment technique can be found in the literature e.g. [64, 65].

3.3 *Heap leaching*

Heap leaching is low cost, traditional and adopted low grade ore used in industrial mining process to extract gold. The leaching method is used in 20-25 % world gold production. Advantages, disadvantages and factors affecting gold extracting efficiency of the technique is given in Table 4. The details on the topic can be found in the current published literature e.g. [68-71]. Here, the heap leaching method is simply summarised step by step.

Table 4. Heap leaching characteristics: advantages, disadvantages and factors affecting the process

Advantages	Disadvantages	Factors affecting the process
Widely used	Time consumption	Local conditions
Flexible	Water loss	Efficiency of crushing
Economic	Slow kinetics	Ore properties
Low grade on large scale	Acid mine drainage	Ore particle sizes
Simple and competitive	Accidental leakage of leach solution	Spray intensity of the cyanide solution
Less equipment		Cyanide solution concentration
Less environmental problems		Pile height
No use of a tailing disposal		Clay and muddy content
Strong adoptability		Leaching time
Low cost, yield quick return		Oxygen concentration
		Temperature

The mined ore is crushed into small particles generally between 30-50 mm using jaw or cone crusher. The crushed ore is separated as a stuck over an impermeable plastic or clay lined leach pad. The large piles are sprayed cyanide leaching solvent often using drip irrigation minimising evaporation, providing uniform distribution of the solution and undamaging the exposed ore. The precious metals will dissolve into the ''pregnant'' solution. Then, gold recovery is obtained through the dissolved precipitation using electro-wining and carbon adsorption processes. A simplified flow chart of a gold heap leach process is presented in Figure 1.

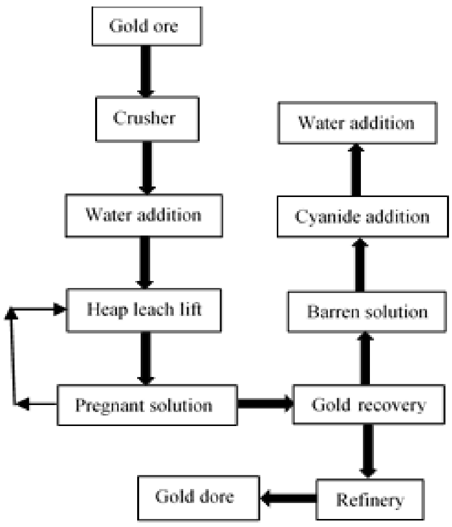

Figure 1. Schematic chart of heap leaching process

3.4 Tank leaching

Tank leaching methods have been largely used in precious metal mining to extract gold. In current times, the method is used by at least 60 % of world gold production. The mined ore is crushed and milled or grinded into fine particles. The methods are chemically operated in open tanks under the atmospheric conditions to recovery metal salts from the concentrated ore at an accelerated rate. This method is also known as ''semi-closed'' technique. Table 5 shows advantages, disadvantages and factors affecting the tank leaching process.

Table 5. Tank leaching characteristics: advantages, disadvantages and factors affecting the process

Advantages	Disadvantages	Factors affecting the process
Widely used	Not applicable low grade	Retention time of leaching system
High grade of ore	Complex process	Ore size
Less water used comparing with heap leaching	High cost	Appropriate amount of reagents
High extraction/efficiency	Cyanide risk for environment	Slurry density
High kinetics		Dissolved gas Number of tanks

Tank leaching processes (activated carbon adsorption of cyanides gold) can be divided into two types: carbon in pulp and carbon in leach. Carbon in column is often used in gold extracting from heap leach solutions. Leaching reagents are added to the tanks to obtain leaching reaction. In continuous tank system, the sullry overflows or pumps from tank to tank. Pregnant solution is then separated from the sullry. Ultimate solution goes on to the next phase of gold recovery. Finally, electro-wining method is applied to the gold bearing solution to recover the gold from the leaching chemicals. The gold solution passes into a container cell. There are two terminals, positive and negative, in the cell. The negative terminal collects gold. Smelting involves melting the negative terminals in a furnace at 1150 °C. A chemical mixture known as ''flux'' is added to molten material, the gold separates from the metal. The liquid gold is transformed to moulds to achieve solid bars known as ''Dore Bars''. These bars are sent to refineries for further gold processing.

4 Description and features of gold

Gold (Au), is a chemical transition metal, atomic number 79 and occurs naturally. In pure form, gold is a bright, slightly reddish lustrous yellow, dense, soft (2-3 Mohs Hardness), malleable, ductile, good conductor of heat and electricity, beautiful object, chemically stable (resistant to most acids), rare element and precious metal. It does no tarnish and corrode. Gold is universally accepted as standard and in exchange for goods and services because of its unique the cost of labour, currency and national economy. Gold has been applied as the standard in most countries of the world since the first coinage used in Lydia between 643-630 BC. From 1870's the World's currencies have accepted the gold standard. Gold's financial official role in the international monetary system ended in1970's. However, gold is continued as a high and significant valuable asset. For universal and international assets, the central banks of many developed/developing countries hold approximately 45 % of the whole world's gold. Gold name comes from the old English word ''geolo'', from the Latin name ''aurum'' (glowing down). Table 6 presents the basic characteristics of metal gold.

Table 6. The basic physical characteristics of gold

Physical property	Description
Chemical symbol	Au
Atomic number	79
Atomic Weight	197
Crystal system	Cubic
Colour	Yellow, silver white, minor orange red
Melting point	1064.43 °C (1948 °F)
Thermal expansion	14.2 x 10^{-6}/°C
Diaphaneity	Opaque
Seawater abundance	4 to 8 x 10^{-6} ppm
Hardness	2.5 to 3
Density	19.3 (when pure)
Magnetic sensitivity	Low
Resistivity	2.2 x 19^{-8}
Ductility	High
Lustre	Metallic
Tensile strength	138 MPa
Earth presence	0.005 ppm
Volatility	Starts below melting point

5 Gold uses

Gold is completely recyclable. The unequalled combination of chemical and physical characteristics of gold provides its uses in many commercial areas such as industrial, medical, electrical applications and many more. Gold applications are summarised in Table 7.

The purity of gold is measured by fineness. A standard trade known as 'carat'' was developed to designate fineness of gold. It is commercially available with a purity of 99.999 %. Gold of fineness 1000 is pure gold which is equivalent to 24 carat used by jewellers. Gold containing alloys of other metals or substances have lower value than pure gold. A 50 % gold alloy is equivalent to 12 carat. An alloy containing 75 % gold by weight is 18 carat. Generally, high carat jewellery is softer, resistant to tarnish and chemicals, whereas low carat jewellery is stronger and less resistant to tarnish especially when contact with perspiration.

Fineness is significant in geochemistry and sometimes evidence of a deposit type. Rather, fineness gold is typically extracted in larger grains at depth, high temperature and high pressure mesothermal deposit than epithermal deposit. However, high fineness gold may form in many rock types ranging from ultramafic through mafic and dioritic and gabbroic types, granites related to porphyries and volcanic rocks and high sulphidation epithermal deposits. Sillitoe [72] pointed out that porphyry gold deposits contain mainly fine grained gold which is less than 60 µm in size, it is frequently found as high fineness native metal.

Table 7. Gold applications

Application	The reason of use
Jewellery	The most malleable and ductile, very valuable asset, beautiful, rare and precious, tarnish resistance, unique density, tradition, cultural, natural trading medium, elite, power, scarcity
Financial: coinage, bullion banking	Long term high value, durable, portable, private, permanent, divisible, investments
Electronics	Electrical connector and conductor, chemically stable, and resistant, none-toxicity
Computers	Efficient, reliable conductor and connector
Medicine	Radioactive isotope, nonreactive in the medical instruments, highly reliable life support devices
Dentistry	Superior performance, aesthetic appeal, nonallergic, chemically inert, easy working
Aerospace	Dependable conductor and connector, lubricant, infrared radiation stabilise temperature, low shear strength
Awards and status symbols	Highest esteem and status, purity for religious objects, honouring
Glassmaking	Rich ruby colour, climate controlled buildings, cool in the summer, warm in the winter, protecting from solar radiation
Cuisine	Food additive, decorative ingredients

6 Production, import, export and price of gold

Gold production in Turkey firstly started officially in Ovacık (İzmir-Bergama) in 2001 with 1.4 tons. Turkey's gold production has been presented for 21 years in Figure 2. With new mine operations the production of gold significantly increased to 45 tons in 2021. 427 tons gold has been produced between 2001-2021. However, the gold production does not meet the consumption of gold. Turkey is the fifth largest gold consumer in the world (US, India, Saudi Arabia, China and Turkey). The sectoral uses of gold in Turkey is given in Figure 3. The Figure indicates that most of the sectoral use of gold is related to the manufacture of jewellery at the present time. An increase in jewellery demand, an investment in gold decreases relatively. Because it has been treasured since ancient to current times for its beauty, power, esteem, and performance.

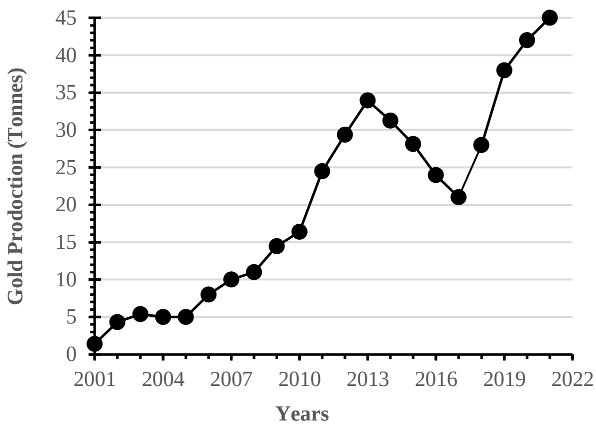

Figure 2. Turkey's gold production [61]

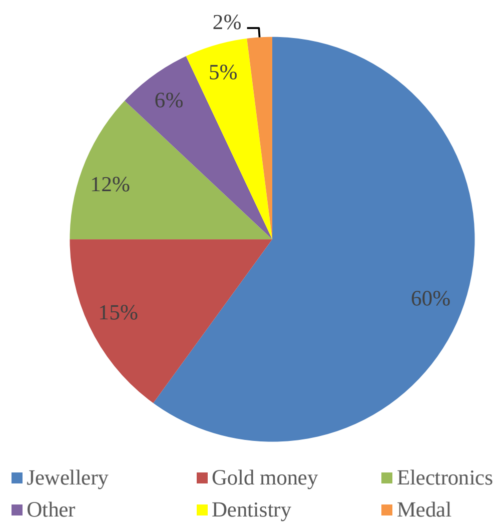

Figure 3. Sectoral use areas of gold in Turkey [62]

Gold mining operations/productions have been carried out by 52 % foreign international company capital and 48 % domestic company one. More than 6 billion dollars investments and providing 12000 person employment, tax paying equivalent 78 tons gold have been made from 2001 to 2021. Gold mining pays, 8 types of tax, 13.75 % state right due to increasing gold price, whereas other industries pay 4 types of tax. Turkey's purpose is that if sustainability in gold mining is ensured, its gold demand will be met by the country's own resources. Because necessary and required developments in gold sector chains is mostly completed. These are given as follows:

- ✓ High gold demand approximately 170 tons /year
- ✓ High gold potentials/resources about 6500 tons
- ✓ 45 tons gold production in 2021, estimated 50 tons/year for future use
- ✓ Four international accredited gold refiners
- ✓ A gold stock market
- ✓ Developed and strong Jewellery industry

Turkey is one of the world's most important gold importers. In the last 26 years, an average of 167 tons /year, a total of 4352 tons gold has been imported. Turkey's gold import between 1995-2021 years is shown in Figure 4. When the current price of gold is taken into account, 9.7 billion dollars are paid each year for gold import. The payments significantly affects foreign trade deficit. The demand from the country may continue to accelerate its production. The metal has a long and significant history in the nation and investors have tuned to gold to act as a hedge against inflation and declining paper currency values. Exploration incentives for gold mining should be regulated and bureaucratic processes could be reduced in state institutions. This will ensure to increase gold production.

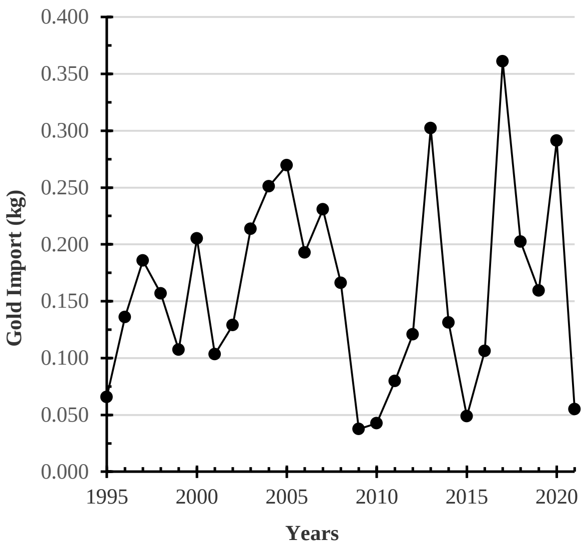

Figure 4. Turkey's gold import [75]

Turkey gold is exported as jewellery. Its export and import are presented as monetary in Table 8. The jewellery export has been made in the last two decades. The trade provides 5 billion dollars in 2019. This can be interpreted as significant performance. Domestic demand for gold jewellery has become narrow due to jewellery containing high labour cost and various investments in Turkish economy. These narrowing leads foreign markets to face jewellery industry.

Table 8. Gold jewellery export and import of Turkey[73, 74]

Year	Export ($x10^6$ US dollars)	Import ($x10^6$ US dollars)
2000	384.2	55.4
2001	431.1	51.0
2002	567.5	67.8
2003	707.8	93.3
2004	931.9	135.2
2005	1.128	174.1
2006	1.097	235.3
2007	1.490	370.5
2008	1.585	430.8
2009	1.087	211.6
2010	1.444	282.6
1011	1.847	349.6
2012	2.562	420.3
2013	3.307	664.5
2014	4.244	611.4
2015	3.660	367.9
2016	3.676	369.6
2017	4.035	513.7
2018	4.308	806.2
2019	5.000	1.572

Knowledge of historical gold price may potentially affect its buying and selling potential [76]. Throughout history, the price of gold has been substantially influenced by many different factors such as central bank buying, inflation, geopolitics, monetary policy equity markets, pandemic reasons (e.g. recent Covid 19), war, international politics, bank interest and many more. Changes in the gold price are significantly driven by currency values. Because gold is dominated in dollars which can have an important impact on the gold performance. A strong dollar makes gold more expensive for international buyers. However, a weaker dollar makes gold relatively less expensive for foreign buyers. Money currencies in the past several years have exhibited an inclination to downgrade its value. Gold price could generally continue to increase over and most probably the future as well. Thus, gold has long been regarded a reliable store and safe reserve of wealth and value, the reputation is likely to continue the future. Gold prices in US dollars per troy ounce for 22 years (between 2002-2022) have been annually given in Figure 5. The Figure indicates that gold prices gradually increase and makes the highest peak value at last quarter time of 2011, nearly $1900. Gold has ever since been moving lower and it has pulled back to $1100 at 2016. There were fluctuating changes in its prices between 2016-2019 years, then its price continues to rise average $2000 2020-2022 years most probably due to Covid 19 pandemic and recent Russian and Ukrainian war conditions.

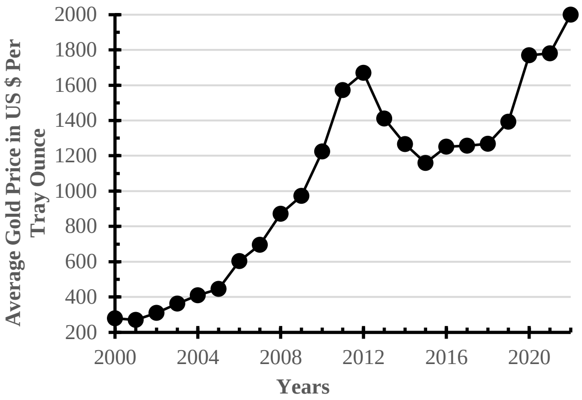

Figure 5. Annual average gold price from 2000-2022 [77]

7 Conclusions

Main conclusions from the study can be drawn as the follows:

Epithermal, porphyry gold, VMS, orogenic gold and placer gold are the most economic gold deposit types in Turkey. Generally geochemical exploration techniques have been applied to discover gold deposits of Turkey. However, past experiences have indicated that geochemical technique have not been successful in most cases. Thus, detailed geological considerations should focus on the first stages of exploration, typically prospect and testing evaluation. Ore forming system with genetic models, combining all the available data (e.g. geochemical, lithological, structural, alteration, mineralogical) need to be evaluated together in order to obtain a well understanding of geologic frame study. Although Turkey has a long history of metal mining and geology, the country started gold production in 2001. The gold production is generally made in west of Turkey. However, east and southeast Turkey has wilderness comparing to the west for gold prospecting and exploration. Turkey having active geological environment, high gold potential and resources, is attractive and favourable country for investment of gold mining.

Flotation, heap and tank leaching technologies have mostly been applied to extract or recover from gold ore. Heap leaching method is more economic than other methods, especially when applicable to low grade gold.

Gold has been used in many areas from ancient time such as investment asset, jewellery fabrication, purchasing of global central banks, technology, and industry.

Performance of gold price is driven by many factors such as real interest rates, economic uncertainty (e.g. market volatility linked to COVID), geopolitics (e.g. Russian invasion to Ukraine), global currency crises, bond bull market, commodity bull markets, trading tensions or a combination of few or all. Gold price likes especially elevated inflation, falling of real interest rates, market pullbacks, jewellery, and central bank demand. These variables increase the gold price.

Gold mining industry in Turkey is small compared to other gold producer countries in the world, however, the industry is growing rapidly. Turkey's gold production, started in 2001 with 1.4 tons, has gradually risen every year with 45 tons in 2021. On the other hand, Turkey's gold consumption is 3.5 times much as its gold production. Turkey has paid approximately 6.5 billion dollars (importing annually average 150-160 tons gold) every year in the last 25 years. The payment significantly affects foreign trade balance deficit.

Gold fabrication makes significant contributions to Turkish economy. Turkey exported the products of jewellery fabrication for at least 5 billion dollars value last year. The value chain also supports 6.000 gold fabricators, 40.000 retail outlets and employs approximately 260.000 people.

Conflicts of interest

The authors declare that there is no conflict of interest.

Similarity rate (iThenticate): 20%

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