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DISTRIBUTION, SETTING AND METALLOGENESIS OF COPPER DEPOSITS, IN IRAN

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Abstract - Iran, as a bridge between Gondwana and Eurasia, is composed of composite subduction-collisional belts. Each of these resulted from the resorption and closure of Tethys components and related successive episodes of volcano-plutonism. Although many authors have explained the genesis of copper deposits in Iran by a simplified geodynamic model and consumption of Zagrosside Tethys, recent geological and metallogenic research studies suggest a new model of structural and tectono-magmatic evolution for the genesis of different types of copper deposits in various segments of the country. The successive stages of opening, closing and subduction of oceanic basins resulted in the formation of different types of copper deposits during Alpine structural evolution.

The major copper deposits of Iran can be classified into: a) porphyry, b) manto, c) pluton-related vein, d) pluton-related stockwork/breccia, e) Cyprus-style massive sulphide, f) skarn, and g) volcanogenic hydrothermal ore types.

The widespread copper mineralisation in Iran is represented by Cu-Mo, Cu, Cu-Ni-Co, Cu-Ni-Co-polymetallic and Cu-Pb-Zn associations. It has been found in recent years that many copper deposits and occurrences show a considerable admixture of silver and gold.

There are twelve major copper bearing districts within Iran (Fig. 2). In order of economic significance, the most important of these are the:

- Anarak-Sarcheshmeh-Kharestan Cu belt with many porphyry deposits. Of these, only Sarcheshmeh is currently mined, although there are several that could be exploited in the future such as Miduk, Kali Kafi, Dozardalu and Kharestan.
- Qarahdagh-Sabalan volcano-plutonic zone in NNW Iran, the second most important copper bearing district in Iran, which except for the Songun porphyry deposit, has not been explored in detail.
- Torud-Abbasabad region in north and north-eastern Iran where Cu mineralisation occurs as veins in andesitic volcanic rocks although Cu has also been found in the metamorphic bedrock.
- Ferdows-Qalehzari belt in NE Iran, within continental margin-type volcanics which were developed after consumption of Neo-Tethys oceanic crust beneath the Central Median Mass. Qaleh Zari is the only deposit being mined in this region, but there are other prospective zones yet to be explored.
- Mokran Ophiolite complex in south-eastern Iran, which hosts massive sulphide-type copper mineralisation, similar to those explored in the Sultanate of Oman.

The other districts are:

- Maku-Khoy ophiolite belt in north-western Iran,
- Takab-Mianeh volcanogenic zone,
- Tarom volcano-plutonic zone,
- Rudbar-Taleghan volcanogenic zone,
- Saveh-Ardestan volcano-plutonic zone in central Iran,
- Sebzevar-Kashmar ophiolite mélange in north-eastern Iran,
- Khash-Birjand ophiolite-flysch zone in east Iran.

Among the known deposits, a brief description of a representative selection will be presented in this paper. These are the Sarcheshmeh porphyry Cu(Mo), the Kale Kafi porphyry Cu-Mo (Au), the Songun porphyry Cu and the Qaleh Zari manto-type Cu-Au deposit.

INTRODUCTION

Copper mining in Iran is believed to have commenced by the 6th millennium BC and to have been well developed by 2000 BC. This country is considered to be one of the major copper provinces in Alpine-Himalayan or Tethyan metallogenic belt. Although more than 800 copper indications, occurrences and deposits are known, only a few deposits are currently being mined. Copper occurrences are widely dispersed in Iran, and are principally found in zones containing Mesozoic ophiolites and Tertiary volcano-plutonic rocks.

Basic work relating to copper occurrences has been carried out by the Geological Survey of Iran (GSI). About 214 copper deposits and occurrences were described in a GSI, 1969 report. In that report, the copper occurrences were treated scientifically in relation to their geological setting, and their features were set out comparatively in the tables given in appendices. Following the discovery of the Sarcheshmeh porphyry copper deposits in mid 1966, the Kerman region was intensively explored within a short period (1966 to 1972), especially for copper ore, by the Institute for Geological and Mining Exploration and Investigation of Nuclear and other Raw Materials, of Beograd, Yugoslavia (GSI 1973)

Although there are many copper occurrences distributed over a great part of Iran, only 60 500 km^2 of the Kerman region was investigated by systematic prospecting, detailed geologic mapping and evaluation of ore deposits. The Yugoslavia Institute studied about 60 deposits and occurrences, comprising 34 porphyry, 21 vein and 4 "impregnated" types, of which Sarcheshmeh was one.

In addition, systematic exploration was carried out over 42 000 km^2 of the Anarak region by Techno-export during 1975-1979. The Kali-Kafi Cu-Mo (Au) deposit is the major porphyry deposit in this latter region. Prospecting in east and south-east Iran was also conducted as part of regional 1:250 000 and l:1 000 000 scale geological mapping projects by Australian, Canadian and French companies between 1973 and 1978.

In recent years the Ministry of Mines and Metals has carried out reconnaissance programs covering the country, although detailed exploration has only been performed over a few deposits. In this paper twelve copper metallogenic zones, are defined as having high potential for Cu, Mo, Au, Ag and associated base metals.

Although around $3x10^9$ tonnes of copper ore have been outlined, there are still several prospective districts, which may be considered promising areas for systematic exploration and mining investment.

GEOLOGICAL ZONATION AND STRUCTURAL HISTORY

Regional Arrangement

Iran as a collisional belt between Gondwana and Eurasia (Figure 1) has:

- Four major ophiolitic and orogenic belts: a1). Minor Caucasus-Qarah Dagh-Talesh; a2). Binalud-Hezarmasjid-Aqdarband; a3). Central and East Iran; and a4). Sanandaj-Sirjan-Mokran.

- Three folded belts with miogeosynclinal characteristics: b1). Zagross; b2). Kopeh Dagh; and b3). Alborz.
- Seven volcano-plutonic belts, namely: c1). Qarahdagh-Sabalan; c2). Takab-Saveh-Ardestan; c3). Mianeh-Tarom-Taleghan; c4). Torud-Abbasabad; c5). Ferdows-Qalehzari-Lut; c6). Bandan-Ahangaran; and c7). Anarak-Sarcheshmeh-Kharestan.
- Intra-continental depressions surrounded by high mountains.
- Continental blocks or/ribbons exposed adjacent to the aforesaid zones.

Structural History

The structural history of Iran can be divided into the following stages:

I The formation of sub-mature continental crust (1300-1000 Ma) on the edge of the Gondwana super continent, potassium granite magmatism (850-800 Ma) and the consolidation of a platform overlain by sedimentary cover.

II Upper Precambrian rifting (780-550 Ma) in central Iran and Zagros accompanied by a rift related series and tectono-magmatic activation.

III Formation of epi-continental type sediments from Cambrian to Permian time, accompanied by early Palaeozoic epeirogenic movements, early Devonian to Permian extensional dynamics and late Permian emergence. The entire complex is generally 3000-4000 m thick with a maximum of 8000 m to the north of the Tabas area. The late Permian emergence affected great parts of Iran, which were eroded, subjected to sub-tropical weathering and formation of bauxites. This emergence was possibly related to a eustatic sea level change, and formation of an oceanic trench in northeast Iran.

IV The Triassic (early Cimmerian) was a time of orogenic events, which are represented in the metamorphic zones of the Zagros, the volcanogenic series of the Sanandaj-Sirjan zone, and at the upper Triassic to lower Jurassic boundary where two different litho-bio-facies known as Gondwana and Eurasia types are found. At this time the Palaeo-Tethys was in the process of subduction on its northern margin, with the Binalud-Hezarmasjid-Aqdarband ophiolite belt (a2 above), considered to be reflecting the Iranian sector of this collision. The magmatic series of Meso-Tethys consists of an island arc type tholeiitic-calc-alkaline series which were differentiated from a sub-alkaline basaltic melt (Emami 1998). This event is characterised by an extensional regime, detachment faulting, formation of continental blocks or ribbons, and associated metamorphism. It seems that this extensional event was coincident with the formation of real oceanic crust until Cretaceous time in North-west and South-east Iran. Ophiolites and ophiolite mélanges obducted in the Kermanshah, Neyriz and Mokran regions are considered as the remnants of this ocean development.

V During middle Jurassic time, former extensional structures (early Cimmerian), and northward subduction of Meso-Tethys combined together and caused the development of a back-arc spreading type basin in central Iran. It is assumed (Samani 1998) that this new oceanic development occurred in three branches, which formed a conjunction in the Central Kavir desert. This stage is accompanied by extensional metamorphism, granitoid magmatism, angular unconformities, separation of continental blocks and formation of different sedimentary basins. The event is known as the mid Cimmerian (or Lutian) orogeny (Seyed-Emami and Alavi 1990). This event has important taphrogenic

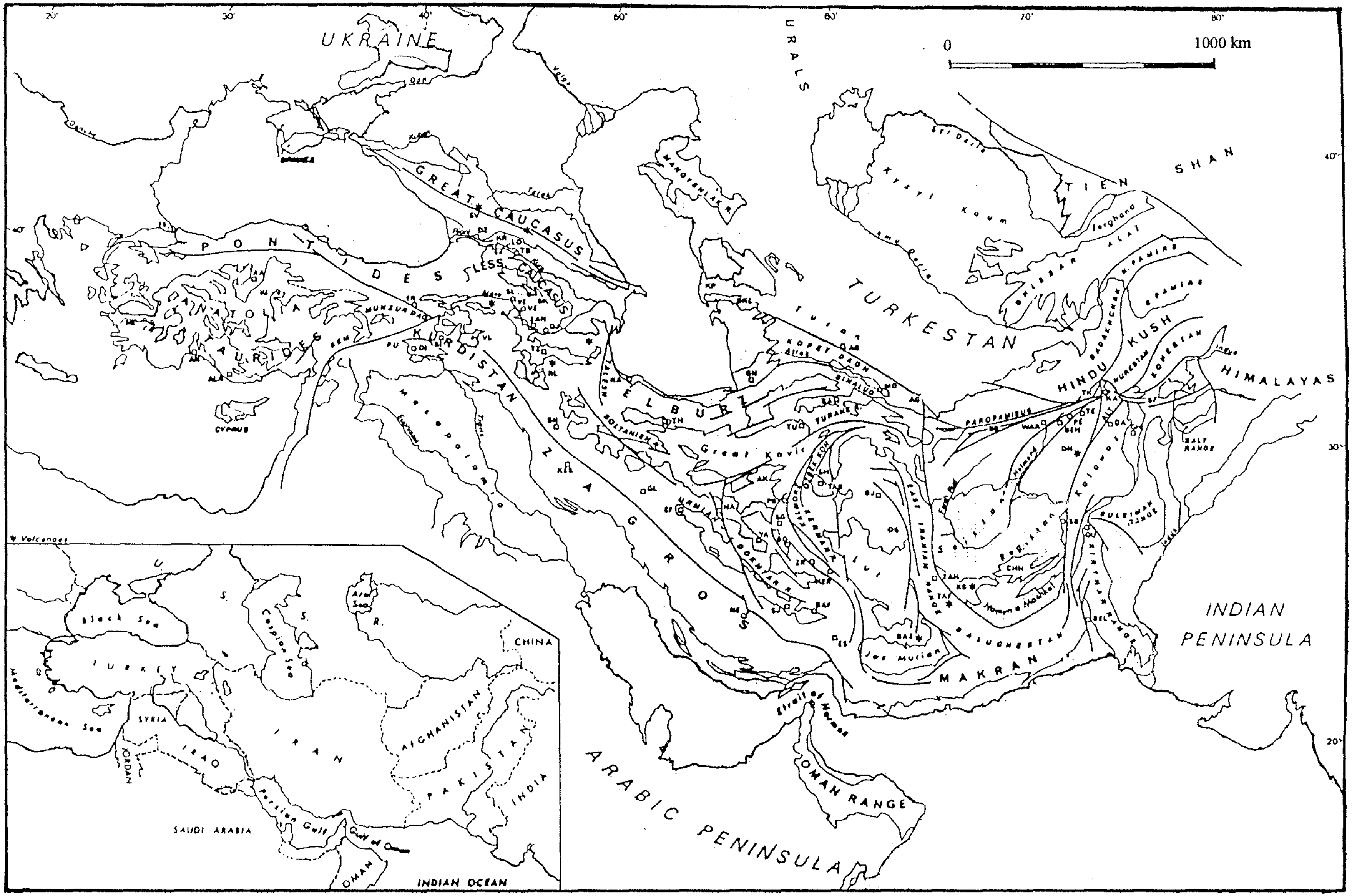


Fig 1: Map showing the major geographical and structural features, and localities of South Asia. AA=Ankara; AG=Aghdarband; AK=Anarek; ALT=Altimur; ALA=Alanya; AN=Antalya; AR=Arghandab; AS=Ashkhabad; BAF=Baft; BAZ=Bazman; BB=Band e Bayan; BEH=Behsud; BEL=Bela; BI=Bitlis; BJ=Birjan; BKL=Balkhan; BQ=Bafq; CHH=Chagai Hills; DI=Diyarbakir; DJ=Djulfa; DN=Dasht e Nawar; DS=Deh Salm; DZ=Dzirula; EF=Esfahan; ER=Erzincan; ES=Esfandageh; GA=Gardez; GH=Ghost; GL=Golpaygan; GN=Gorgan; IS=Istanbul; KA=Kabul; KEM=Keban-Malatya; KER=Kerman; KES=Kermanshah; KI=Kirchir; KP=Krasnovodsk Peninsula; KR=Krami; KS=Koh e Sultan; LO=Loki; MD=Mashad; ME=Menderes; NA=Nain; NE=Neyriz; PB=Posht e Badam; PE=Penjaw; PU=Pütürge; QU=Quetta; RA=Rasht; RL=Rezayeh Lake; SA=Sabzevar; SB=Spin Boldak; SF=Safed Koh; SG=Saghand; SH=Shotori Range; SJ=Sirjan; SK=Sevan-Akera; SL=Sevan Lake; SN=Sanandaj; SV=Svanetia; TAB=Tabas; TAF=Taftan; TB=Tbilisi; TE=Tezak; TH=Tehran; TK=Turkman Mountains; TU=Turane; TZ=Tabriz; VE=Vedi; VL=Lake Van; WA=Waras; YA=Yazd; YE=Yerevan; ZAH=Zahedan; ZAN=Zangezur; ZR=Zarand.

implications, where its evolution played the major role in the formation of the present geological configuration of Iran. This structural phase continued from middle Jurassic to Cretaceous and early Paleocene time. The Central Median Mass (or Central Micro-continent) was formed and surrounded by the oceanic crust (formation of Neo-Tethys) and its subsequent tectono-magmatic features are apparent in several volcano-plutonic belts throughout the country. Ophiolites and oceanic rock units exposed in the Tabriz-Anguran, Anarak, Naiin-Taft, Jandaq, Savzevar-Kashmar, Birjand-Khash and Mokran districts belong to this geological event.

VI During the late Cretaceous and early Palaeocene a consequence of the subduction and consumption of Neo-Tethys oceanic crust was the development of several volcano-plutonic belts in the Tertiary which are listed as c1 to c7 in the discussion of geological zonation above. Subduction, apparently during the late Tertiary, resulted in large volumes of intermediate to acidic extrusive and intrusive rocks being emplaced as a result of partial crustal melting in an extensional and compressional tectonic regime. These magmatic series range from tholeiitic calc-alkaline to shoshonitic in composition and are the main host rocks for the most of the copper deposits in Iran.

VII During the Neogene and Quaternary tectono-magmatic activity was restricted to the margins of structural blocks, back-arc and fore-arc basins, and deep seated lineaments in the forms of volcanism, formation of geothermal fields, and the development of different types of intra-continental basins.

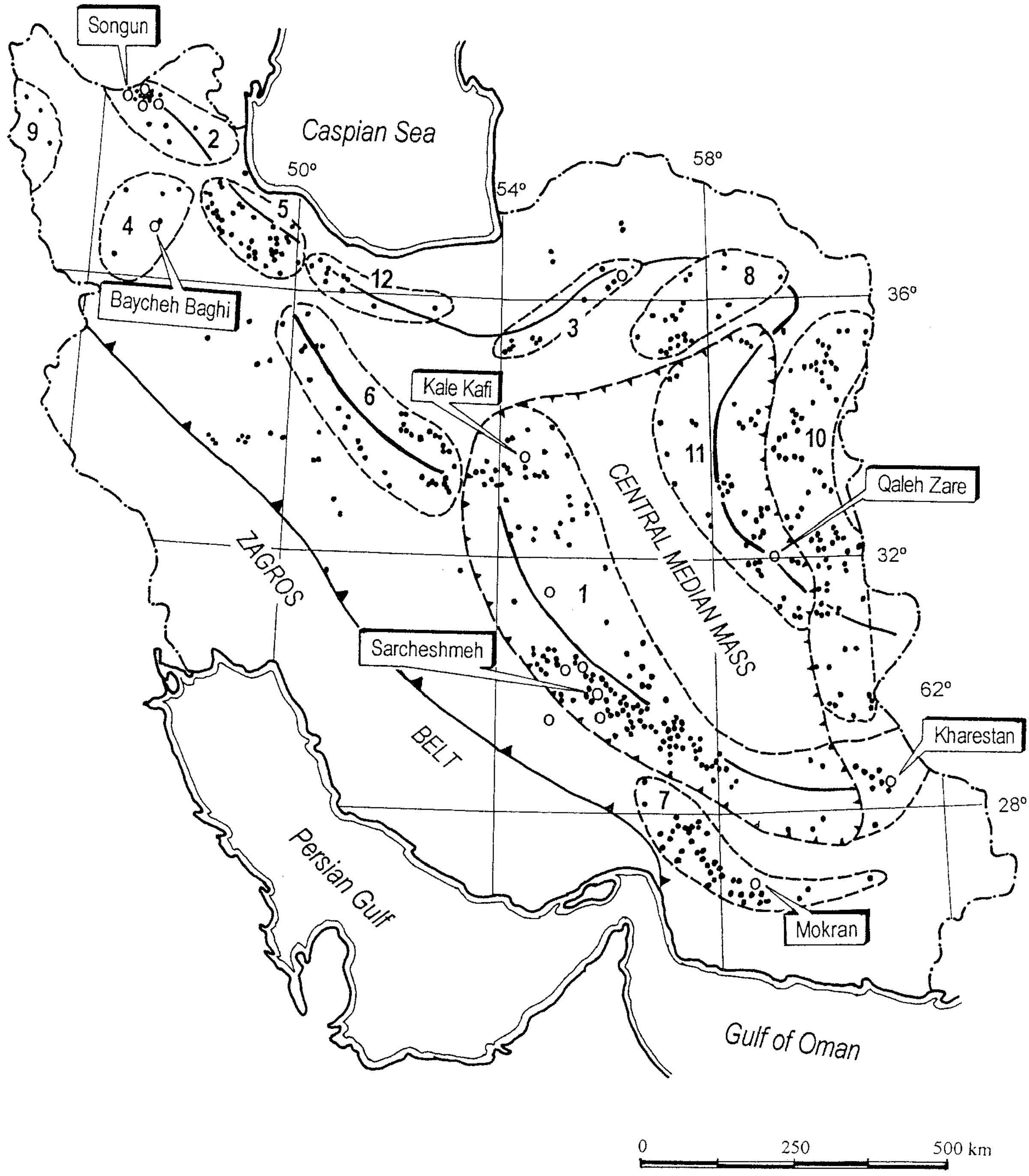
METALLOGENESIS AND ORE PROVINCES

The major metallogenic features of particular importance inside the main copper belts of Iran are the magmatic activity, particularly the distribution of ultrabasic and basic rocks, volcanic-sedimentary complexes and syn-orogenic intrusives. The ultrabasic rocks are an indication of deep lineaments, and occur in the so called "mélange zone" composed of a mixture of various sediments (such as limestones, cherts and sandstones) and various mainly basic intrusive rocks (gabbros, spilites, and diabase), with frequent transitions to diorites and granites. Their age is upper Jurassic to Cretaceous, and probably also partly Palaeocene in Iran. Several minor copper deposits are located within these complexes.

The volcanic-sedimentary formations mark the most important mineralised sequences in Iran and contain the most important copper deposits within the Alpine-Himalayan (Tethyan) orogenic belt. They are composed of different pyroclastic rocks, ranging from rhyolitic to andesitic in composition, related lava flows, limestones, marls and sandstones. These formations are of Eocene age in Iran. The synorogenic and other intrusives of post Eocene age have been the direct carriers of copper and other mineralisation.

Metallogeny

The general characteristics of Iranian copper deposits have been presented by Bazin and Hubner (1969), Geological Survey of Iran (1973, 1984). There is a general consensus that the Tertiary volcano-plutonic series played a key role in the formation of copper deposits, and the Kerman region is considered the major Cu metallotect in Iran. Most authors postulate an Orumieh-Dokhtar volcanic belt (Berberian & Berberian 1981, Takin 1972, Sengor et. al. 1988 & 1979, Boulin 1991) as a single arc-type volcano-plutonic belt formed after consumption of the Zagrosside Tethys parallel to the Zagros mountain range. Many geologists have long



The Copper Provinces of Iran

1 Anarak - Sarcheshmeh - Kharestan
2 Qarahdagh - Sabalan
3 Torud - Abbasabad
4 Takab - Mianeh
5 Tarom
6 Saveh - Ardestan
7 Mokran
8 Sabzevar - Kashmar
9 Maku - Khoy
10 Khash - Birjand
11 Ferdows - Qalehzari
12 Rudbar - Taleghan

---- Outline of Copper Province

—— Axis of volcano-plutonic belt

o Large to medium copper deposit

• Small copper showing or occurrence

Fig. 2 The Copper Deposits of Iran

debated the link between the structural evolution of Zagros and the formation of volcano-plutonic belts in Iran.

The existence of bifurcated volcanic chains with differences in nature, irregular distribution and types of copper deposits, magmatic associations and a wide range of geological settings can not be explained by a single subduction model as proposed by many authors of the plate tectonic school. Recent analysis of geological, geophysical and geochemical data revealed another model of tectono-magmatic evolution and formation of copper deposits in Iran (Samani 1998).

As mentioned earlier, the Neo-Tethys ocean was formed in central Iran beyond the Zagros and Sanandaj-Sirjan belts during upper Jurassic to Cretaceous time. Tertiary magmatism developed on the margins of this oceanic basin. The formation of copper deposits and occurrences are linked to Neo-Tethys oceanic complexes and marginal volcano-plutonic arcs. It seems that the subduction environment in the Central Median Mass (CMM) is of Mariana-type in the Torud-Abbasabad region in North-eastern Iran and as such different from the Chilean-type. The Chilean-type is believed to have been relatively shallow and gave rise to a series of linear longitudinal volcano-plutonic arcs of calc-alkaline composition (Sillitoe 1991) where major porphyry-type copper deposits were formed. The volcano-plutonic arcs of the Anarak-Sarcheshmeh-Kharestan belt of the CMM, Qarahdagh-Sabalan, Tarom-Taleghan and Saveh-Ardestan belong to this type.

The Neo-Tethys is inferred to have been characterised by steep Mariana-type subduction and as a consequence by extensional conditions in the upper crust of the over-riding plate (Sillitoe 1992) as in the Torud-Abbasabad region. Ensialic volcano sedimentary extensional basins existed behind the volcano-plutonic arc. Huge volumes of volcanic rocks accumulated in shallow marine, lacustrine and sub-aerial environments, with tholeiitic calc-alkaline and shoshonitic compositions.

The more than 800 known copper deposits and occurrences in Iran can be classified into the following types:

- **Manto-type** which are hosted both by steep structures and in permeable stratigraphic horizons, especially vesicular lava flow tops. They exhibit high Cu and Au grades, and were formed during Cretaceous and Eocene time.
- **Porphyry-type** which are formed under compressive tectonism and calc-alkaline magmatism during late Eocene-Oligocene-Miocene time. These deposits possess several common geological features and ore mineralogies. The major introduction of copper took place at all deposits during K-silicate metasomatism events with consequent alteration. Most of these deposits are Cu-Mo-(Pb, Zn, Au, Ag) types.
- **Pluton related deposits** comprising contact metasomatic, and intra-plutonic sub-types which were formed during intrusive magmatism and associated hydrothermal activity. These deposits are a polymetallic type, mainly consisting of Cu-Mo, Mo-(W, Pb, Zn, Au, U), Cu-Fe-(Pb, Zn, TR) mineralisation.
- **High sulphide-type** occurrences which display evidence of extreme telescoping, alteration and mineralisation. Alunite rich high sulphide-type alteration is developed in many sectors of the volcano-plutonic zones which could be regarded as prospective provinces for Cu, Au, and Ag mineralisation.

Table 1 Magmatic Evolution & Metallic Fund of the Neo-Tethys-Alpine Copper Belts in Iran

Geodynamic Setting & Magmatic Characteristics	Age & Genetic Types Of Sulphides	Metallic Fund Trace Metals	Metallic Fund Ore Metals
4. Post-Orogenic Faults And Shear Zones - between trench & southern flank; basalt, rhyodacite, rhyolite.	**Pliocene** telethermal type	Cr, Zn, Pb	As, Au, Ag Hg, Sb, Au
3. Main Orogeny - maximum uplift, granodiorite magmatism; gabbro, diorite, syenite, monzonite, granodiorite, granite, granite porphyry, dyke & stock.	**Oligocene-Miocene** porphyry, skarn, vein and epi-thermal high sulphidisation types	As, Au, Ag	Cu, Cu-Mo, Mo, Pb-Zn, (As,Au,Mo,Ag,Cu) alunite, Th, Zr
2. Collision of Arcs - back-arc spreading marginal basin; basic - calc-alkaline-shoshonite; alkali basalt - basalt, andesite, latite, trachyte, dacite.	**Middle Eocene** vein-type, skarn-type	As, Au, Mo	Cu Pb, Zn
1. Outer Arcs Generation - mélange forming, subduction related arc forming basin, basic-intermediate-acidic magmatism.	**Upper Jurassic to Cretaceous** massive sulphides	Te, Sb, Au, As, Hg	Cu-Py (Pb,Zn,Ag,Cd,Ba)

The major known copper deposits and occurrences of Iran are shown in Figure 2. The magmatic evolution, 'metallic fund' and ore types are listed in Table 1. According to the evolutionary stages, erosion level and telescoping feature of each volcano-plutonic system, certain type(s) of ore deposits can be defined. The following criteria can be used to define the formation of copper ore fields and districts in Iran:

- Metallogenic structures, otherwise known as mineralising conduits, are the most important geological feature that may be considered as they are the channels directing the ingress of ore melts and solutions from deep sources into an ore field or metallogenic district. Major faults or geological sutures between a continental slope and deep oceanic basins are often portrayed as the conduits where ore fields are emplaced.
- Development of volcano-plutonic systems after a period of magmatic up-welling, crustal melting, and tectono-magmatic reactivation during the Tertiary are considered to be the major geological feature influencing copper metallogeny.
- Proximity of individual intrusions, extrusives and hydrothermal alteration systems belonging to different epochs of mineralisation which are controlled during their emplacement by long lived and developing geological features responsible both as conduits of the rising magma and for the ascent of hydrothermal solutions.
- There are direct or parental genetic links, between most of the copper deposits and defined massifs of igneous rocks, although paragenetic, indirect or fraternal evidence exists where post-magmatic deposits and intrusions are derivatives of a common, deep-seated magma chamber of Palaeogene plutonism.
- Shallow erosion to the mineralised zone related to a cupriferous intrusion creates a situation in which uniform outcrops of the intrusion occur over a broad area within a metallogenic

district. This type of environment is the most favourable for the maximum development of post-magmatic deposits emplaced both within the wall rocks and the intrusion itself.

- The principal and most common wall-rock alteration styles that are linked with copper deposits are propylitisation, argillisation (or kaolinisation), silicification, beresitisation and K silicate metasomatism.
- Most of the copper deposits and occurrences of Iran were formed during the Cimmerian and Alpine epochs. Cyprus-type massive sulphide deposits are found in Tethys oceanic series rocks, while manto-type deposits are restricted to the Cretaceous and Eocene volcanogenic units. Skarn, porphyry and pluton-related deposits associated with Oligocene-Miocene plutonism are the major Cu resources of Iran.

Copper Provinces

Copper deposits and occurrences are known in most parts of the country (Fig. 2) except in the Zagros Kopeh Dagh and intra-continental basins. On the basis of known metallogenic relationships the principal areas with copper potential in Iran are located in the following regions and are listed according to their economic importance.

- **Anarak-Sarcheshmeh-Kharestan province** - This province is located on the margin of the central micro-continent or Central Median Mass (Fig. 2) and is characterised by calc-alkaline volcano-plutonism and associated mineralisation. Copper deposits and occurrences are present in composite granodiorite to quartz diorite and monzonite porphyry stocks and andesitic volcanic host rocks.

  This metallogenic zone coincides with the central parts of the Eocene volcanic sedimentary complex and is characterised by the presence of important endogene mineralisation formed in several epochs.

  The main factors in localising the primary mineralisation were magmatic and structural. In forming the secondary supergene enrichments other factors such as climate hydrogeology, geomorphology and geochemistry played the most important roles.

  The major mineral deposits and occurrences are related to hypabyssal and sub-volcanic Eocene-Miocene intrusive bodies. Most of the deposits are either located within these intrusive bodies or in their immediate vicinity. Both the intrusives and mineralisation are contemporaneous phenomena, formed in roughly the same time span. The geochemical characteristics of the intrusives frequently feature elevated copper background concentrations. Even the mineral occurrences located at appreciable distances from the intrusives have mineral paragenesis, geochemical features, and alteration processes identical with those located in or near the intrusives, indicating their common origin in the same structural and magmatic cycle.

  Structural features play an important role both in the spatial distribution of intrusive bodies and in the formation and distribution of the mineralisation and mineral deposits. In places where longitudinal fault systems intersect the general northwest-southeast trend of geological formations, the intrusives are frequently hydrothermally altered over extensive areas and mineralised with sulphides. The huge Sarcheshmeh copper deposit is located at such an intersection (GSI, 1973).

  The copper occurrences and deposits were formed by mineralising processes in a hydrothermal phase, at temperatures ranging from catathermal to telethermal. Mineralisation of porphyry, stockwork, impregnation and vein-type have been identified. The porphyry, stockwork and impregnation-type mineral deposits and occurrences are located in the apical sections of intrusives and their volcanic envelopes. The primary

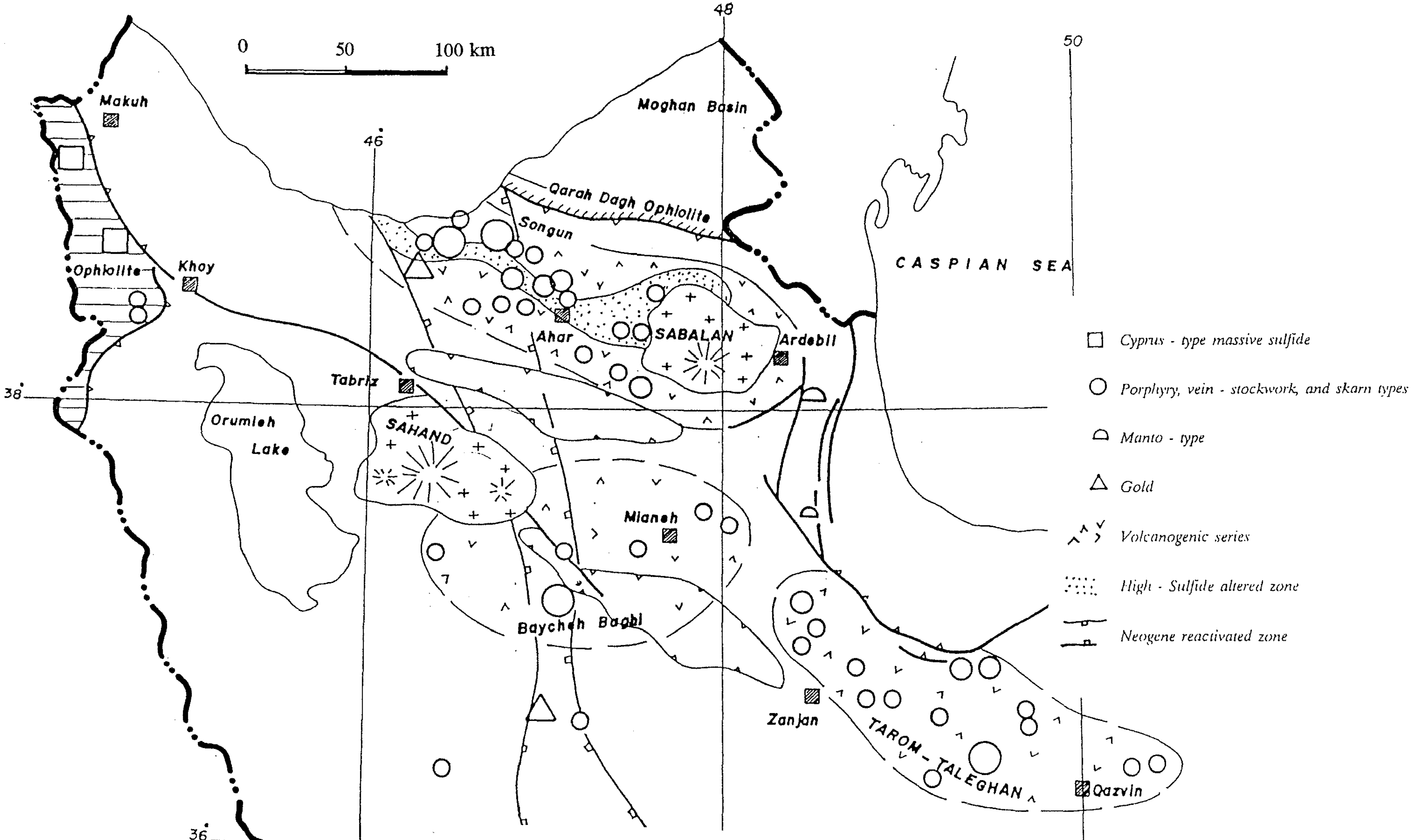


Fig. 3 Location of the main copper districts of North-west Iran

copper mineralisation is usually low grade, although concentrations of high grade may be located within the supergene enrichment zones.

The most important porphyry type deposits currently identified are Kali Kafi, Sarcheshmeh, Miduk, Daralu, Deh Siahan and Kharestom (Fig. 2). In addition there are more than 80 other porphyry, vein and impregnation types prospects. Vein-type deposits and occurrences are abundant. They are less common within the intrusives, but are plentiful in the surrounding volcanic rocks and are related to shear and fracture fault zones. Talmessi, Messkani, Chahmessi, Sargoad, Damaneh, Qanat Marvan, Chahar Gonbad, Bondar Baghu, etc., all represent this type of mineralisation.

- **Qarahdagh-Sabalan Cu Province -** This province is located in the northwest of Iran, adjacent to the Azerbaijan and Armenian Republics. It is subdivided into two zones (Fig. 3). The rocks and structures in the Qaradahg mountains are a continuation of the Lesser Caucasus. The Palaeogene-Neogene volcano-plutonic series are an extension of the structural border zone between epi-continental platform to the south and the deep trough of the Lesser Caucasus towards the north with submarine volcanogenic complexes of Jurassic Cretaceous age.

  Extensive intermediate to acidic volcanism, mainly of Eocene age, is developed with calc- alkaline-shoshonitic characteristics and intruded by subsequent granitoids (granitic, dioritic, syenitic and monzonitic) of upper Eocene-Oligocene age. It should be noted that many of intrusions are small in size and their contact with adjacent rocks are irregular and generally complicated by apophyses, dykes and extensive high sulphide type alteration zones. Tectono-magmatic reactivation during the Miocene-Pliocene has resulted in effusive, explosive and subvolcanic formations of trachytic and rhyodacitic to dacitic composition. Quaternary volcanic activity is indicated by basaltic and rhyolitic fissure controlled effusives. Recent volcanic activity is manifested by the Sabalan and Sahand volcanoes and the formation of several geothermal fields.

  The main known copper occurrences are listed in Table 2. The Songun porphyry type deposit is the only occurrence where detailed exploration has been carried out for ore reserve evaluation and mine planning.

  The distribution of ore formations shows a regional zonation around the intrusions. The batholithic masses predominantly contain vein type Mo mineralisation. The peripheral parts are dominated by copper minerals, pyrite, magnetite and traces of tungsten and molybdenum. In the vicinity of the intrusions Zn, Pb and traces of U and Th can also be found. High-sulphide type alteration with alunite, As, Cu, Ag, Th, kaolinite, sulphates and native sulphur are widespread above the hidden intrusives, and at the contacts of the intrusives with Eocene volcanogenic rocks.

  Five types of copper mineralisation can be distinguished in this zone, namely:

  Skarn-type mineralisation occurs at or near the contact of granitoid intrusions. The ore minerals generally occur in crystallised limestone and skarn, mainly comprising magnetite, pyrite, chalcopyrite and in some cases also molybdenite and scheelite (GSI 1969).

  Vein-type deposits are found in the vicinity of intrusions where the Cretaceous and Eocene country rocks are slightly metamorphosed/altered. Pyritisation has affected the metamorphosed country rocks and is generally associated with Pb-Zn, magnetite, and Cu occurrences.

Table 2 Copper Occurrences in the Qarahdagh-Sabalan Cu Province

No.	Name	Associated Elements	Ore Mineralisation	Form Of Deposit	Type Of Country Rock	Type Of Alteration
1.	Qarachilar	Cu, Mo (Pb, Au, W)	py, cp, mo, ga, li, cu-car	vein filled fractures	granite	silicification
2.	Qarahdarreh	Cu, Mo	mo, py, cp, ma	veinlets, imprg.	granite	silicification
3.	Astamal	Py (Cu)	py, cp, li, ma	alteration zone	meta-volcanics	silicification, pyritisation
4.	Cheshmehkhan	Py (Cu)	py, li, cu sulph, cu carb.	alteration zone	meta-volcanics	silicification, pyritisation
5.	Chemtal	Cu	py, cp, mgt	lens	marble, granite	pyritisation
6.	Mardanal	Cu	cp, py, ma	veins	limestone	silicification
7.	Aghamirra	Cu	py, cp, ma, cc	veins	metamorphics	silicification
8.	Balunje	Cu	Dec. cu-minerals	veins	granite, porphyries	silicification
9.	Songun	Cu (Au)	py, cp, mgt, (au-cp), cr, az, ma	porphyry skarn	granite, hornfels	porphyry-type
10.	Barmulk	Cu, Pb	cp, ga, ma	lenses	skarn & granite	contact metamorphism
11.	Anjerd	Cu (Mo)	cp, py, fo, mo, ma, az	lenses	skarn	contact metamorphism
12.	Saleh Darreh	Cu	py, cp	veinlets	altered tuff	pyritisation
13.	Zandabad	Cu (Mo)	cp, py, mgt, mo, ma, az	lens, dissem.	skarn & granite	silicification
14.	Mazraeh	Cu (Au)	mgt, cp, py, bo, te	lens, dissem.	skarn & granite	contact metamorphism
15.	Gowdal	Cu	spc, cp, py, ma	veins & dissem.	skarn & granite	contact metamorphism
16.	Gummusholan	Cu, (Au, Pb)	Au-cp, py, ga Au: 8-9 ppm, Ag: 100 ppm	veins	granite	hyd. alteration
17.	Mahmudabad	Cu	mgt, spc, cp	lenses	skarn	contact metamorphism
18.	Messgar	Cu	cu carb		limestone	hyd. alteration
19.	Dagherdagh	Cu, Fe	sec-cu, mgt	lens	skarn	contact metamorphism
20.	Barghzar	Cu	cp, ma, mgt	fissure filling impregnation	skarn, diorite	contact metamorphism
21.	Aynelu	Cu	cp, mgt, ma	na	na	na
22.	Abbasabad (Aynelu)	Cu	cp, mgt, ma	lens, stock	limestone, diorite	contact metamorphism
23.	Andab-e-Jadid	Cu (Mo)	cp, ma	veinlet	granite	silicification
24.	Noghduz	Cu	cp, ma, az	vein, impreg.	granite	silicification
25.	Ahle-Iman	Mo (Cu)	mo, cp, ma	vein	granite	silicification
26.	Dustbeiglu	Cu (As, Mo, Ag, Au)	cp, ma, az, cu-sulph, aspy, alunite	vein, dissem. impreg.	granite, altered rock	high sulphide type alteration, porphyry-type alt
27.	Anzan	Cu (As)	cp, ma, li	veinlet	granite	silicification
28.	Dechan	Cu (U)	cc, ma, az	disseminated	syenite	low silicification
29.	Suma	Cu	cp, ma, az	impregnation	monzonite	hyd. alteration
30.	Sheran	Cu (U)	ma, az, native Cu	veinlet	pyroclastics	silicification & argillisation

High sulphide-type occurrences with extensive hydrothermal alteration are known above concealed intrusives as well as at the contact zones of exposed batholiths. Although this style of mineralisation is not represented by any important ore concentrations, it could be considered as indicating a favourable exploration target for epithermal-porphyry type Au-Ag-Cu-Mo exploration. This style of mineralisation is associated with alunite ore deposits and thorium occurrences.

Intra-plutonic type mineralisation is represented by a system of siliceous veins, stockwork ore bodies and disseminated mineralisation in granitoid intrusives, sometimes bordered by a small alteration zone. Molybdenite, chalcopyrite, secondary copper minerals and pyrite appear in veins and as impregnations in the granitic, syenitic, and monzonitic host rocks. Porphyry-type deposits are also considered as intra-plutonic.

Volcanogenic-type mineralisation was formed locally in Palaeogene and Neogene volcano-clastic sequences. Chalcopyrite, galena, and copper-carbonates occur as fissure fillings together with quartz, pyrite, barite and hydrothermally altered minerals.

From an economic point of view the *Intra-plutonic* type is considered to be the most promising based on the presence of favourable regional criteria and local ore controlling factors. The Songun porphyry deposit is typical of this class. Systematic regional prospecting is necessary to localise promising zones with Cu, Au, Ag, Mo mineralisation in high sulphide type altered areas and in association with hidden porphyry systems.

- **Torud-Abbasabad Cu Province -** The volcano-plutonic arc of Torud-Abbasabad has an east-west trend and is located on the northern margin of central Kavir desert (Fig. 2). This zone is characterised by steep Mariana-type subduction as indicated by extensional conditions and low angle detachment faulting. Volcanic rocks were accumulated in shallow marine, lacustrine, and subaerial environments and included rocks of tholeiitic, and low and high potassic calc-alkaline composition.

  The extrusive rocks, mainly lava sheets, are andesitic and show local transitions to dacite and melaphyre (GSI, 1969). The plagioclase phenocrysts, and rare pyroxene are commonly altered. Typical alteration minerals are calcite, chlorite, and epidote. Magnetite is a primary accessory. These volcanics are more or less concordant with the Tertiary sedimentary rocks. The andesitic lavas are normally fine grained and contain phenocrysts (up to 2 cm) of andesine-labradorite and diopside. The fine-grained groundmass comprises microlites of plagioclase, pyroxene, serpentine, and Fe-oxides and hydroxides. Calcite, zeolite, opal, and sulphides occur in joints, vugs and steep structures. Agglomeratic flows and breccias are also present. The volcanic complex is gently folded along a south-westerly trend. These structures are cut by a swarm of basic dykes and fault-controlled silicified zones. Stocks and dykes of granodiorite and quartz monzodiorite are intruded into these series.

  Extensive volcanism developed in the middle Eocene as the first phase, and then was repeated during late Eocene or early Oligocene time but in limited volume.

  The copper deposits of this zone, are epigenetic manto-type occurrences. They are hosted by steep structures, as well as vesicular flow tops. Localisation of copper deposits is attributable to structural and/or lithologic permeability combined with contrasts in the redox state of the host rocks. Deposits are typically found in reduced horizons, commonly juxtaposed upon red oxidised rock units.

  This is a polymetallic metallogenic zone with Cu, Au, Pb, Zn, Fe, Mn, bentonite, kaolin, feldspar, barite, zeolite, quartz and turquoise as ore minerals.

- **Takab-Mianeh Cu Province** - Most of the volcanic activity has occurred during the Eocene-Oligocene and Miocene-Pliocene over a wide zone in this region (Fig. 3).
  The volcano-sedimentary succession can be subdivided into:
  1). Volcanogenic series consisting of dacites, rhyodacites, andesites, and andesitic basalts of Eocene age.
  2). Volcano-clastic series including tuffs, tuffites and volcanic breccia of Palaeogene age.
  3). Rhyolite, dacite, trachyte and basalts of Mio-Pliocene age.

  There are two stages of volcanism and associated alteration-mineralisation. The first stage has calc-alkaline characteristics similar to subduction related continental margin-type volcanics and is associated with base metal mineralisation. The most important deposit of this zone is Baycheh-Baghi, a polymetallic-type with Cu, Bi, Ni, Pb, Zn, Th, U, Au mineralisation.

  The second stage of volcanism was developed in a tensional regime after the Oligocene compressional tectonic cycle. Bimodal volcanism, formation of inter-montaine basins, and copper mineralisation associated with Sb, As, Au, B, Pb, Zn were developed. Well known deposits include Angouran (Pb-Zn), Zarehshuran (Au-As), Moghanlu (Sb) and Qarahgol (Boron) which resulted from the tectono-magmatic reactivation of this region in Neogene time.

- **Tarom Copper Zone** - The zone is a volcano-plutonic belt characterised by intermediate submarine lavas and pyroclastics, sandstones and shales formed during the Palaeogene. Linear, elongate granitoid bodies have been intruded into these units. The calc-alkaline intrusives resulted in the formation of manto-type copper deposits with associated Pb-Zn vein-type mineralisation. The major ore deposits and occurrences are shown on Figure 3. This zone has not been explored in detail, although Ag and Au mineralisation have been known in some of the deposits and occurrences.

- **Saveh-Ardestan Copper Zone** - This zone comprises a volcanic and volcano-clastic sequence formed in middle Eocene to lower Oligocene time. The principal rock types are tholeiitic, calc-alkaline, and alkaline in composition, intruded by granite, granodiorite and porphyries. These magmatic complexes are bimodal in nature, resulting from mantle, and crustal sourced magmatism. Exhalative-type Mn (Fe), porphyry-type Cu (Mo), skarn-type Cu (Co, Fe), vein-type Pb-Zn (Ag), and quartz vein hosted Au deposits were formed in this zone.

- **Mokran Copper Zone** - The Mokran mountains in south-eastern Iran, are an ophiolitic terrane, composed of ultrabasic intrusions, tholeiitic volcanics, and associated deep ocean sediments. The major copper occurrences are hosted in the upper part of an ophiolitic suite composed of basaltic to intermediate lavas. These occurrences have rich copper ore with associated Ag, and at times Au. This type of ore formation could be classified as Cyprus-type massive sulphide and manto-type copper deposits. The major ore occurrences are indicated on Figure 2.

- **Sabzevar-Kashmar Copper Zone** - This zone is a geological unit between the southern border fault of the Binalud, the eastern prolongation of the Alborz in the north, and the Rivash fault in the south which merges with the Doruneh fault.

  Several units are restricted to the Sabzevar-Kashmar zone, namely: a) The volcano-pelagic series; b) The ophiolitic mélanges along the southern and northern boundaries of the zone; c) The non-ophiolitic mélanges in the centre of the area; d) The sheeted diabase complex.

According to the GSI report (1969) there are several indications of mineralisation with the principal sulphides being pyrite chalcopyrite, chalcocite and bornite. This zone has not yet been explored in detail, although there are favourable regional and local criteria for either manto or Cyprus-type massive sulphide copper and gold mineralisation.

- **Maku-Khoy Copper Zone** - This zone is located on the border of Iran and Turkey (Fig. 3). It is an ophiolitic zone consisting mainly of ultrabasic complexes, volcano-pelagic series and ophiolitic mélanges of Neo-Tethys oceanic crust. These units were obducted by an early Eocene compressional regime and were followed by flysch-type sedimentation. The zone has been reactivated by Neogene volcanism, associated alteration and related ore formation. There are Cyprus-type massive sulphides, stockwork of chalcopyrite, and veinlets of graphite. Neogene volcanism and related hydrothermal alteration resulted in Hg, As, Cu and Au mineralisation.

- **Ferdows-Qalehzari Copper Zone** - The larger part of this area is covered by Recent and Quaternary sediments. The most prominent features are alluvial fans consisting of coarse debris sand dunes and muddy or clayey salt flats. Most of the surface is made up of a terrain of sub horizontal lava sheets and flows, subvolcanic rocks and intrusion of late Cretaceous to Tertiary age. Magmatic activity began in the late Cretaceous, before 77 Ma, and lasted for nearly 60 Ma (Yung et. al., 1983). It developed over a Paleozoic and older continental crust which is about 40 km thick. The rocks exposed are basaltic, andesitic dacitic, and rhyolitic, mostly lavas and ignimbrites with minor development of subvolcanic and pluton forms. The overall geochemical character of this rock association is calc-alkaline with all of the features of continental margin-convergent plate boundary volcanism.

  According to Tarkian et. al. (1983) there are about 15 prospects and deposits of copper and lead-zinc known. Among the reported deposits, Gazu, and Sorkh Kuh are porphyry type, while the old Qaleh Zari mine worked manto-type mineralisation. The mineralised Gazu intrusive contains up to 0.4 to 2.0% Cu, 5-12 ppm Mo and up to 2.4 ppm Au.

  The copper mine of Qaleh Zari is hosted by basaltic-andesite to high K-andesites with transitions to a shoshonitic association. The mineralisation occurs in ore veins of up to 10 m in width which can be followed to a depth of 250 m. Along the faults the mineralised zones often bifurcate into several separated ore bodies of massive chalcopyrite. The primary ore minerals are, in decreasing order of frequency: chalcopyrite, hematite, pyrite, bismuthinite, bornite and occasionally native gold.

- **Zahedan-Birjand Copper Zone** - This zone is a deformed accretionary prism and a flanking fore-arc basin extending from Birjand southeast to Zahedan. This structural zone was named "The Sistan suture zone of eastern Iran" by Jirrul et. al . (1983). It can be subdivided into:
  1). *The Rud-e-Shahvali block* belonging to the western edge of the Farah Fault Block which extends far to the east into Afghanistan;
  2). *The Eastern Ranges Domain* which is located immediately to the west of the Rud-e-Shahvali Block, separated by a concealed major fault. It is composed of flysch-like sediments of Cretaceous age;
  3). *The western assemblage* (called the Ophiolitic Domain), separated from the eastern domain by a major NNW-trending system of tectonic discontinuities. This domain is composed of an assemblage of fragmental sediments and upper Oligocene to mid-Miocene volcanics mainly of intermediate to basic composition. This sequence unconformably overlies the older units. The volcanics were deposited in a subaerial environment, and are missing in the Eastern Range Domain. In contrast, in this latter

domain, there is a belt of subvolcanic intrusives, mostly of quartz dioritic composition also Oligocene-Miocene in age, comagmatic with the volcanics.

Four main groups of copper occurrences can be distinguished in this zone: a) Occurrences related to the ophiolitic rocks; b) Occurrences located at the contacts of the Oligocene-Miocene intrusions; c) Subvolcanic pluton related, disseminated, stockwork, and vein copper associated with other base-metals and gold mineralisation; d) Structural and or stratigraphic controlled copper mineralisation without clear relation to the magmatic complexes.

This zone can be considered as an interesting belt for Cu, Pb, Zn, Sb, Au, and Ag mineralisation. Among the known prospects, Kuh-e-Lar, Siasetorgi, Assagi, Khanif and Chehel Kureh are considered as promising for further exploration.

PRINCIPAL COPPER DEPOSITS

From an economic standpoint and exploration level, five major deposits will be discussed below as representatives of copper deposits of Iran.

Sarcheshmeh Porphyry Cu (Mo) Deposit

The Sarcheshmeh porphyry Cu (Mo) deposit was developed within a continental margin type calc-alkaline volcano-plutonic series of Tertiary age, emplaced on the margin of the Central Median Mass (CMM) of Iran, (Fig. 2). The CMM was surrounded by an oceanic basin, the remnants of which are recognised as ophiolites and ophiolitic mélanges in Tabriz, Takab, Naiin-Baft, Sabzevar, and Gonabad-Birjand areas.

Subduction and consumption of this oceanic crust beneath the CMM caused the development of continental margin-type Eocene-Miocene volcano-plutonic complexes hosting Cu-(Mo, Au), and Pb-Zn deposits. The most important Porphyry Cu-deposits in Iran are located on the Kale Kafi-Sarcheshmeh-Kharestan metallogenic zone, extending from the Naiin area to Baluchestan province in south-eastern Iran.

The Sarcheshmeh porphyry Cu-deposit is hosted within Eocene biotitised andesite and the younger intruded granodioritic stock (Waterman & Hamilton 1975. Shahabpour 1982). The metallogenic evolution, magmatic activities and ore-forming stages of the ore deposit are outlined in Table 3, while the different types of ore bearing veinlets, and their characteristics are summarised in Table 4.

Sarcheshmeh is related to a granodioritic stock intruded into Eocene andesitic host rocks. About 50 percent of the ore reserve is in the andesitic host rocks which have been hydrothermally altered to the biotitic (brown), phyllic (light green) and propylitic (dark green) series. Intense biotite alteration is visible close to the contact zone of granodiorite and andesite and decreases with distance from the periphery.

The following magmatic units are reported from the Sarcheshmeh porphyry system (Shahabpour 1982, Waterman & Hamilton 1975, Shahabpour & Kramers 1987):

1. Major granodiorite stock	SCP	4. Late hornblende porphyry	LHP
2. Late feldspar porphyry	LFP	5. Feldspar porphyry dykes	FP
3. Early hornblende porphyry	EHP	6. Biotite porphyry dykes	BP

The major ore hosting unit is andesite with a zonality of alteration progressing from the centre towards the periphery from strong biotite, to weak biotite, to strong phyllic and then an outer zone of pyrophyllite alteration.

Table 3: Metallogenic Evolution of Sarcheshmeh Porphyry System

Stages	Magmatism, Alteration & Ore Formation			Ore Forming Stages Veins	Type Of System
V	Younger feldspar-biotite Porphyry dykes	sericite & calcite alteration		Post Mineralisation (V_4)	opened system
IV	Late Hornblende Porphyry	phyllic alteration (qtz, sericite, chlorite, py, cpy & clays) chlorite		Late Mineralisation (V_3)	opened to semi-closed systems
III	Early Hornblende Porphyry	qtz, mo, py, cpy		Transitional Mineralisation (V_2)	fracturing semi-closed system
II	Sarcheshmeh Porphyry (10-12 Ma)	Propylitic Alteration albite, chlorite, epidote, clays, pyrite and rare chalcopyrite	K-alteration biotite, cpy & py in andesite orthoclase, biot, cpy & mo in cpy & SCP.	Early Mineralisation (V_1)	closed system
I	EOCENE Tectono-Magmatism (Continental Arc-type Volcanism)				opened system

The first three units (SCP, LFP and EHP) are mineralised with copper although the major ores are hosted in biotitic andesite and the granodiorite stock (SCP), especially on the contact zone of the SCP. The grade of Cu decreases with depth in the hypogene zone, while the Mo content increases. The evolutionary stages of the Sarcheshmeh porphyry system are shown in Tables 3 and 4.

Shahubpur (1987, 1982) has reported eleven generations of biotite from a study of the geochemisty of the minerals and concluded that a genetic relation exists between magmatic crystallisation, formation of hydrothermal fluids, and their physico-chemical characteristics. The copper content of the "primary (magmatic) biotite" of the mineralised rocks is much higher than in "relatively mineralised" (early hornblende porphyry), and "non-mineralised" (late hornblende porphyry) types. This peculiarity indicates a magmatic source for copper while its lower content in secondary biotite of potassic rocks is related to redistribution of Cu by hydrothermal processes.

The major ore minerals are chalcopyrite, and rarely bornite. The chalcopyrite minerals can be divided into magmatic, potassic and phyllic types on the basis of metallic impurities such as Co, Ni, Zn and Au.

Saffari (1998) has studied gold, and silver distribution in the Sarcheshmeh deposit (Tables 5 & 6) and concluded that chalcopyrite is the major gold carrier mineral, regardless of its generation.

Table 4: Types of Veinlets in Sarcheshmeh Porphry Deposit (after Shahabpour 1982)

Stages of Development	Magmatic group		Type	Alteration	Ore Mineralogy	Gangue Mineralogy
Post Mineralisation	**V4**	(EHP), Andesite S.C. Porphyry	gyp., ca qtz, ca	- -	±py py	gyp., ca qtz, ca
Late Mineralisation	**V3**	Andesite (EHP), (LHP) S.C. Porphyry	argillic qtz, ser, ca qtz, ser qtz, ser, py qtz, ser, chl, py	qtz, ser, clay qtz, ser qtz, ser qtz, ser qtz, ser	py py py py, cpy, Au py, cpy, mo, Au	qtz, ser, clay qtz, ser qtz, ser qtz, ser qtz, ser,mo, chl
Transitional Mineralisation	**V2**	(EHP), Andesite S.C. Porphyry	qtz, mo	-	mo, cpy, py, Au	qtz
Early Mineralisation	**V1**	Andesite Andesite S.C. Porphyry	qtz, sulphide chl, epid chl, epid, py biotite, qtz, cpy orth, qtz, cpy	- - chl, epid biotite orth	py±cpy py py, cpy cpy, py, Au cpy, py, ±mo	qtz ca, chl, qtz, epid chl, epid, qtz biotite, qtz orthoclase, qtz
Late Magmatic		S.C. Porphyry	Orthoclase	-	±cpy, ±Au	othoclase, qtz

ca=calcite, chl=chlorite, cpy=chalcopyrite, mo=molybdenite, py=pyrite, qtz=quartz, ser=sericite, SC=Sarcheshmeh, EHP=Early Hornblende Porphyry, LHP=Late Hornblende Porphyry

Table 5: Assay Results of Samples from Drilled Boreholes of Sarcheshmeh Cu Porphyry

Samp No.	Lithology	Mo	Cu	Au	Ag	As	Pb	Zn	K	Al	Mg	Fe
92	Sarcheshmeh porphyry	180	11596	115	1.5	<0.5	<5	253	3.95	9.44	0.35	3.73
85	Andesite, biotite 594.5 m	30	7204	162	0.7	6.5	19	91	5.56	7.77	0.15	1.59
76	Andesite, biotite 22.5-37.5 m	406	32564	330	2.2	21	<5	102	3.26	8.35	0.18	3.18
74	Andesite, q-biotite 5.5-18 m	435	1121	208	2.5	3.2	6	78	5.42	1016	0.17	2.89
73	Andesite, biotite 30-46.5	1399	10545	148	1.7	1.9	10	212	3.26	8.98	0.40	3.73
69	Andesite, biotite qtz (239-292)	3.4	8949	129	1.0	<0.5	<5	39	2.18	9.76	0.37	2.86
66	Biot, Ser Andesite (540 m)	12	14127	108	1.5	2.5	<5	115	1.60	7.78	0.42	6.24
68	AndesiteH'gene Qtz (90-102m)	8	806	6	<0.4	<0.5	<5	27	2.05	8.45	0.12	11.4
58	Andesite, Clay+Ser (34m)	90	55064	153	0.5	7.0	<5	151	3.60	11.71	0.16	1.87
25	S. porph, phyllic alt (261.5m)	136	13649	33	1.0	2.3	<5	132	3.39	7.99	0.11	2.37
19	S. porphyry. Andesite (743m)	5	675	5	0.4	3.6	5	51	0.75	7.73	0.36	3.77
14	Andesite	2	68	4	<0.4	4.2	6	135	0.78	9.89	0.67	8.76

Table 6 Assay Results of Samples from Mining benches of Sarcheshmeh Cu Porphyry

Samp No.	Lithology	Mo	Cu	Au	Ag	As	Pb	Zn	K	Mg	Fe
Z2	Sarcheshmeh. porphyry, malachite	93	35950	56	2.5	18	14	144	3.56	0.39	1.66
Z3	Coal (Elev. 2525m)	52	7418	31	1.1	62	200	1972	0.79	0.80	5.52
Z5	pyritic andesite (2537.5m)	14	21713	80	2.0	7.5	<5	184	2.82	3.36	10.5
Z6	pyritic clay (2526m)	65	6091	94	3.2	1100	397	1112	1.59	0.16	20.9
Z7	Sarcheshmeh porphyry (oxidized)	78	18513	142	2.4	17	6	52	4.20	0.40	1.15
Z8	cuprite vein	291	35773	173	3.4	750	3272	1692	0.93	0.05	5.15
Z10	phyllic Sarchesh porphyry (2500m)	5	4767	35	0.4	30	13	38	3.27	0.34	2.61
Z11	S. porphyry, silicic sup. (2500m)	31	1647	134	0.6	18	7	51	2.91	0.19	1.58
Z13	S. porphyry, dyke (2500m)	16	699	112	2.8	61	871	1479	2.12	0.37	5.45
Z16	S. porphyry, dyke phyllic alteration	85	29311	115	1.0	56	30	95	3.44	0.39	1.26
Z22	Andesite, hypogene. alt.	608	46689	83	2.7	190	92	165	3.31	0.88	2.21
Z24	Andesite,supergene (2475m)	217	24118	96	0.7	13	5	100	3.83	2.18	2.27
Z25	S. porph. suppgene phyllic (2512.5m)	128	11420	111	1.0	3.5	14	92	3.04	0.28	2.34
Z26	S. porphyry, phyllic (2512.5m)	162	9378	88	0.8	17	<5	212	3.80	0.51	3.07
Z28	Andesite hypogene. (2525m)	7	4985	33	0.4	3.5	<5	201	1.84	3.5	6.76
Z29	Andesite supergene. (2525m)	85	29767	111	0.9	58	32	97	3.46	0.39	1.26

Shahabpur (1987) reported a $^{87}Sr/^{86}Sr$ value of 0.7047 ±0.004, and a 12.20 ± Ma. age for the Sarcheshmeh porphyry. Rare Earth Elements analysis shows a Eu depletion which indicates crustal contamination of a sub crustal-sourced magmatic melt.

The total "proved" plus "probable" sulphide ore reserve from the surface to the 2350 bench elevation, at a 0.40% total Cu cutoff is as follows, (Waterman & Hamilton 1975):

Supergene Ore: 92 348 000 Mt. @ 1.996% Cu total
Hypogene Ore: 335 175 000 Mt. @ 0.895% Cu total
Total Ore: 449 532 000 Mt.

Kale Kafi Porphyry Cu-Mo (Au) Deposits

At Kale Kafi, copper and molybdenum mineralisation is developed on the southern contact of a stock of biotite granite, granodiorite and granite porphyry, piercing a granitic mass of the early phase biotite-hornblende granite, granosyenite and monzonite (Fig. 4). The host rocks of the Kale Kafi intrusive mass are upper Proterozoic schists and marble. Vein series are represented by dykes of granite-aplite and granodiorite porphyry.

The mineralisation is concentrated in an oval shaped stockwork, elongated sub-latitudinally, and covering an area of some 1400x700 m. In the central part of the stockwork K feldspar and weak biotite alteration, as well as silicification are developed mainly along the fissures.

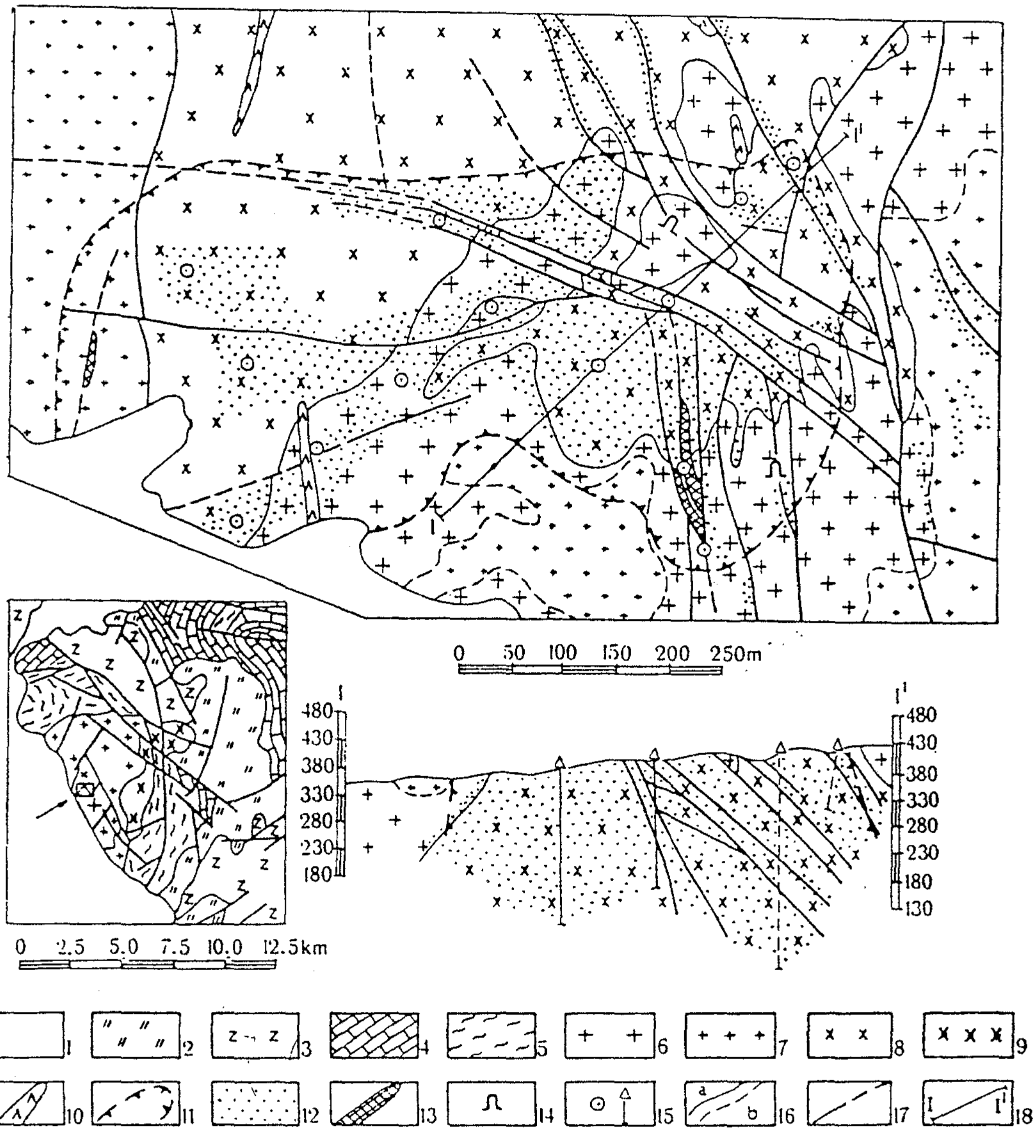


Fig. 4 Geological sketch map. Kal-e Kafi deposit

1 — Quaternary sediments; 2—3 — Lower Eocene: 2 — tuff-breccia, tuff-conglomerate, 3 — trachyandesite; 4 — Upper Cretaceous limestone marl, sandstone; 5 — Upper Proterozoic schists, marble; 6—9 — Late Eocene intrusives: 6 — biotite, hornblende granite, 7 — granosyenite, monzonite, 8 — biotite granite, granite porphyry, granodiorite, 9 — diorite; 10 — Diorite porphyrite dyke; 11 — Stockwork outlines; 12 — Hydrothermal alterations (silicification, argillization, feldspathization); 13 — Gold-polymetallic vein; 14 — Adit; 15 — Borehole; 16 — Geological boundaries: certain (a), facies (b); 17 — Faults; 18 — Geological section line;

Two ore mineral association types are distinguished within the deposit, namely:

- An early Cu-Mo, which is developed within the stockwork and impregnation of chalcopyrite, molybdenite and other ore minerals,
- A later polymetallic mineral association that tends to be restricted to steeply dipping north-south striking faults, and is spread outside the Cu-Mo stockwork. It is represented by an approximately 7 m thick quartz-carbonate-sulphide vein system, extending for up to 15m.

Subordinate minerals in the first association include magnetite, hematite, covellite, bornite, galena, sphalerite, scheelite, gold, arsenopyrite, marcasite, pyrrhotite, bismuth minerals, enargite, etc.. In the polymetallic association, galena is predominant, with sphalerite, chalcopyrite, chalcocite, covellite, native copper, pyrite, gold and stromeyerite also having been noted (GSI, 1984).

The main ore minerals of the stockwork are molybdenite, chalcopyrite and pyrite. Molybdenite forms impregnation veinlets (0.1-10 mm thick) of mono-minerallic composition, and nest-like aggregates in association with quartz, less frequently with pyrite and chalcopyrite, and locally comprises selvages of quartz veinlets. In quartz veinlets it occurs as flaky and platy coarse and medium grained segregations; in mono-minerallic veinlets its texture is fine grained, frequently with traces of deformation; the nest-like aggregates (1.5-2 mm) are composed of crystals up to 0.1 mm in size.

Chalcopyrite forms impregnations or thin veinlets, and is associated with quartz and other sulphides. Pyrite is observed as disseminations and in veinlets, frequently showing intergrowths with chalcopyrite and molybdenite. Subordinate minerals include magnetite, hematite, covellite, bornite, galena, sphalerite, grey ore, scheelite, gold, arsenopyrite, marcasite, pyrrhotite, bismuth minerals, enargite, etc..

In polymetallic associations galena is predominant; while sphalerite, chalcopyrite, chalcocite, covellite, native copper, pyrite, gold and stromeyerite are also noted. Galena forms large (1-2.5 mm) aggregates in quartz, and contains inclusions of sphalerite, chalcopyrite and their intergrowths. Stromeyerite in association with covellite forms rims around galena. Gold is observed as fine segregations in quartz or point-like accumulations in association with native copper

The formation of ore minerals occurred in several phases and was superimposed on the preceding K-feldspar alteration, secondary biotite formation and pre-ore silicification. After crushing and opening of fractures, impregnation and mono-minerallic veinlets of molybdenite were formed; then quartz with molybdenite, pyrite and chalcopyrite were segregated in a new system of fissures; subsequently, pyrite and quartz-molybdenite-pyrite-chalcopyrite veinlets were formed. The final polymetallic (with gold and rare molybdenite) association appeared after some break. It was replaced by crystallisation of post-ore calcite, and then of ferrous carbonate in association with gypsum

The oxidation zone at the deposit is 10 to 15 m thick, but locally (along fractures and faults) oxide minerals are observed at a depth-reaching 250 m. The zone is represented by a variable association of oxide minerals and new formations of chalcocite which fills in fissures and cavities. In the lower part of the zone of secondary sulphide enrichment, chalcocite is associated with primary sulphides. The copper content in this zone increases by 2 to 2.5 times, while the molybdenum grade decreases by 1.5 or more times.

Ore reserves at the deposit are estimated tentatively (in the drilled contour) at:

245 million tonnes @ 0.026% Mo and 0.26% Cu.

Molybdenum reserves are estimated at 60 to 65 000 tonnes, those of copper at 600 to 650 000 tonnes. The reserves are projected to increase to the north and west flanks of the stockwork and with depth, since the deepest borehole (400m) were still in the ore zone when terminated. Technological tests of primary ores based on a full-selective flotation flow sheet showed Cu and Mo recoveries of 75.5 and 72.5% respectively, with 23.8% Cu, 0.12% Mo, 4 g/t Ag in the copper concentrate, and 40% Mo, 2. 5% Cu, 18.5 ppm Re, 16 g/t Au and 28 g/t Ag in the molybdenum concentrate.

Songun Porphyry Cu Deposit

The Songun copper deposit is located in the Azerbaijan-Tarom volcano-plutonic belt, which is the extension of the lesser Caucasus into Iran from the northwest (Fig. 1 & 3). This copper belt was formed within continental margin type calc-alkaline, high K-Shoshonitic series rocks found on the boundary between the Mesozoic (mid Jurassic-Cretaceous) Caucasus eugeosyncline oceanic basin to the north, and the continental sialic crust (Iranian platform) to the south. Songun has been considered both as a skarn as well as a porphyry-type deposit (Etminan 1976; Khoi et. al. 1993; Mehrparto & Tarkian 1993).

The host rocks comprise granite, granodiorite, and monzonite, which are characterised by calc-alkaline I-type granitoids in a continental arc geotectonic setting. The emplacement of granitoids took place during the main orogeny with the compressional regime of the late Eocene-Oligocene which caused the development of regional uplifts. Advanced hydrothermal alteration produced K feldspar, phyllic, argillic and propylitic zones.

Ore mineralisation takes the form of disseminated, stockwork and vein-types which were formed in the hypogene zone. The main ore minerals within the feldspar altered zone is disseminated chalcopyrite which in the phyllic zone appears as veins. The argillic zone has low grade disseminated ores. Ore mineralisation has occurred in two stages. The first stage is an association of chalcopyrite, molybdenite, ilmenite, tetrahedrite, tennantite and pyrite accompanied by potassic and propylitic alteration which formed in the stockwork system. The ore forming and alteration temperature of this stage varied between 350 to 500 degrees C up to 500 degrees C in some parts. The second ore forming stage has a paragenesis of chalcopyrite, molybdenite, pyrite, bornite, chalcocite, rutile and Pb-Zn-Au mineralisation, associated with phyllic and argillic alteration which developed at temperatures of between 250-350 degrees C.

There are several skarn exposures of various sizes around the productive zone which have formed within the Cretaceous limestones. Skarn-type mineralisation has two types of paragenesis. The first type consists of pyrite, chalcopyrite, Pb-Zn minerals and magnetite. The second consists of a chalcopyrite, pyrite, Pb-Zn and magnetite association as veins and fracture fillings

This deposit is in the final stages of exploration. The reasonable assured ore reserves are estimated at about:

290 M tonnes @ 0.76% Cu and 0.015% Mo

This deposit is a representative example of the extended volcano-plutonic arc hosting several types of ore occurrences and deposits. The major ores are Cu, Cu-Mo, Mo and Pb-Zn associated with Au and Ag. Different types of ore mineralisation have been found in this metallogenic zone, namely porphyry-type, skarn-type, vein-type, and epithermal high sulphidation-type.

Qaleh Zari Cu Deposit

This deposit is located in the northern Dasht-e-Lut, within continental margin type calc-alkaline to high K shoshonites. The volcanogenic suite consists of a differentiated series of basalt-andesite-dacite-rhyolite rocks. According to Yulzg et. al. (1983), the volcanic rocks are mainly intra-continental calc-alkaline type and hyper-potassic andesites in composition. It is assumed that a continental margin-type volcanic arc developed during Palaeogene time from Torud-Abbasabad, and Kashmar towards the north of the Lut block. This arc magmatism developed after subduction and consumption of Cretaceous oceanic crust beneath the central Median Mass

Qaleh Zari is a manto-type deposit hosted in an andesitic series of rocks, in fracture filled veins associated with quartz mineralisation. The main ore minerals are pyrite, chalcopyrite, sphalerite and hematite. There are different secondary minerals of Cu such as bornite, chalcocite, covellite, malachite, cuprite and azurite. This deposit is a Cu (Au-Ag) type with about 1.2 million tonnes of ore reserves. The average grade of Cu is about 1.5 to 2%, with 0.5 g/t Au. The ore concentrate has 6 g/t Au and 400 g/t Ag.

CONCLUSIONS

The metallogenic analysis of copper occurrences in Iran has resulted in the following:

- It has been shown that the geodynamic evolution of the country during the upper Proterozoic orogeny resulted in the formation of continental crust which was subsequently destroyed by Tethys oceanic development.
- The structural evolution of the Meso- and Neo-Tethys oceans, from opening to closing, consumption of oceanic crust, and formation of marginal-type magmatic arcs, has resulted in the observed copper metallogeny of the Alpine epoch of Iran.
- There are twelve copper zones in Iran containing different types of deposits. These deposits can be classified into: Cyprus-type massive sulphide; porphyry-type Cu-Mo (Au); manto-type Cu-Au; hydrothermal vein-type Cu, Pb-Zn, As, Au, Ag; and intra-plutonic Cu-Mo-type.
- Among the known zones and deposits the Kali Kafi-Sarcheshmeh-Kharestan metallogenic belt is one of the most important copper provinces with several porphyry-type deposits. The Qarahdagh-Sabalan copper zone where the Songun porphyry deposit is located is also considered an important zone for further mining development.
- Despite the promising results obtained to date, the copper bearing provinces of Iran as a whole may be considered to have only been explored to a very low to moderate degree. The present level of exploration and available data may be considered as representing a good foundation for the planning of future investigation.
- Although a total 3.4×10^9 tonnes of proved and probable reserves of copper ore are currently estimated in Iran, this figure would certainly be increased by future exploration.

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