COPPER II. COPPER RESOURCES IN IRAN
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Introduction. The archeological evidence discovered at Sialk (Kashan district, Isfahan province) and other mining localities such as Tālmesi and Anārak (Anārak district, Isfahan province), and Tall-e Eblis (in Kerman), indicates that several of the earliest sites of copper extraction were located in Iran. The sites that have yielded the most ancient evidence in Iran on copper smelting are the first and second levels of excavation at Sialk, which is undoubtedly older than Tall-e Eblis. It has been suggested that the oldest copper mine in Iran was Tālmesi, which probably supplied the raw material needed for the furnaces at Sialk (Zāvoš, p. 272). Another view (Momenzadeh) holds that the copper required for the smelters was supplied from the Vešnava copper mine near Qom. Various artifacts made of copper and bronze, discovered during archeological excavations in different regions of Iran, point to the fact that copper was well-known and used in ancient Iran. (See also ELAM ii, sec. “The Setting.”)

The trend in the use of different copper minerals in Iran points to native copper as having first attracted attention (Qorbāni). The Mejdar (< Mes Darra “Copper Valley”) native copper deposit (near Ardabil) was among the oldest known copper deposits in the country. Native copper deposits such as Tālmesi, Mejdar, and Vešnava comprise the earliest mines, exploited from at least the late 4th century BCE (the time of Šahdād in Kerman or Šahr-e Suḵ-ta [Shahr-i Sokhta] in Sistan). Subsequently, copper oxide and copper sulfide minerals were extracted in quick succession. In many ancient copper mines, only the oxide fraction of the copper deposit was extracted, with the sulfide fraction left intact. Copper oxide deposits exploited in ancient Iran include Āhangarān (Qāʾen), Čehel Kura (Baluchistan), Čāh-e Musā (Torud), ʿAbbāsābād (Sabzavār), and those of the Kerman area.

During the 5th and 4th millennia BCE in Iran, craftsmen were able to create enough heat to reach temperatures required for the melting of most of the then known raw materials, and thus extract metals. Cuprite and malachite were melted using coal extracted from mines in the Anārak area, where remains of smelters that consumed these types of raw materials can be found. According to Mikhail D'yakonov (Pers. tr., p. 127), copper-smelting techniques became well known in various parts of Iran in this period. With the advancement of the knowledge of metallurgy in the Achaemenid era, finely crafted copper and bronze objects were created, continuing on through ancient times.

The medieval Arab traveler Abu Dolaf wrote about the Nišāpur copper mine, but the extent of the deposits in Iran became known only from accounts of European travelers from the Safavid period onwards. Sir John Chardin (1643-1713), for instance, wrote that "copper is found in Sāri, Khorasan, and Qazvin. However, Iranian copper is not malleable. It has to be mixed with copper from Sweden and Japan to make it soft" (Chardin, tr., 1956-57, II, p. 117). The physician and traveler Engelbert Kaempfer, who resided in Persia in the 1680s during the reign of the Safavid Shah Solaymān (r. 1666-94), wrote: "Kerman possesses enormous resources of copper. Copper is found in Khorasan also" (Pers. tr., p. 117). Also during the 17th century, Giovanni Francesco Gemelli Careri (see ITALY iii) stated: "three miles from Tabriz, there exists a gold mine which is not operational because the extracted gold is not sufficient to cover the running cost of the mine. A copper mine is situated four miles from there whose produce is enormous and has huge revenues for the Royal Treasury" (Pers. tr., p. 36). During the Qajar period, the French ambassador Comte Julien de Rochechouart (in his *Souvenirs d'un voyage en Perse*, Paris, 1867) wrote: "Copper consumption is very high in Iran with no equivalents around the world. Every domestic device is made of copper. Most of the copper utensils are produced at Kashan" (Zāvoš, p. 286).

Copper alloys. Copper alloys historically found in Iran include brass (Pers. *berenj*), which is made up of copper and zinc; it was used in the making of tools and utensils. Due to the difference in the proportion of copper and zinc, the density of brass was estimated by Biruni (d. 1048 as 8.67 (based on gold) and 8.58 (based on mercury (Nasr, p. 140), and as 8.6 by the astronomer and physician Abu'l-Fatḥ ʿAbd-al-Raḥmān Ḵāzeni (d. 1121; Zāvoš, p. 280).

A homogenous mixture of copper and lead, called *petrōy* in Persian, was used in the manufacture of pestles and mortars (Zāvoš, p. 278). This alloy is called *tāl* in the 13th century *Tansuq-nāma-ye ilḵ-āni* by Naṣir-al-din Ṭusi, and the early 14th century *ʿArāyesal-jawāher wa nafāyes al-aṭāyeb* by Abu'l-Qāsem Kāšāni(Zāvoš, p. 278).Biruni, in his *al-Jamāher fi maʿrefat al-jawāher* discusses alloys, including brass (*al-šabah*; see also Biruni's *Ketāb al-Ṣaydana*, *shin*, no. 17) and *esfidruy* (pp. 431-33), the medieval term for bronze, an alloy of copper and tin. Biruni and Ḵāzeni both mention *esfidruy*, estimating its density as 9 and 8.9, respectively (Zāvoš, p. 280).

In modern Persian the word *mefraḡ* (Ar. *mofraḡ*) has replaced *esfidruy* as the term for "bronze." M. Zāvoš (1968-76) believed that in the early Islamic period (8th century), *mofraḡ* indicated the alloy of copper and lead; the present authors agree, since both these metals occur together in the ancient mines exploited in Iran. It is now established that there are no tin reserves in Iran (Qorbāni, 2002-03); the areas previously thought to have contained tin mines, such as Lorestān and Sistan, have in fact lead and copper mines.

Copper metallogeny in Iran. More than 2,000 km of the global copper belt passes through Iran (extending diagonally from Azarbaijan in the northwest, to Sistan and Baluchistan in the southeast, and from Semnān to Sabzevār in Khorasan), resulting in the existence of about 100 copper deposits that have been explored and surveyed (FIGURE 1). Many of the prominent economic geologists who have worked on the country's copper deposits believe that there is a strong likelihood of discovering new porphyry copper deposits in the country. However, no detailed investigation has been carried out on the mineralogy and metallogeny of copper in Iran. The results of chemical analyses of magmatic or metamorphosed igneous rocks there reveal the existence of nominal copper concentration in the pre-Tertiary (> 65 million years ago), intrusive igneous rocks. Only a few such bodies contain higher than average copper content, comparable to the Tertiary deposits in quality and quantity, e.g., Taknār Formation.

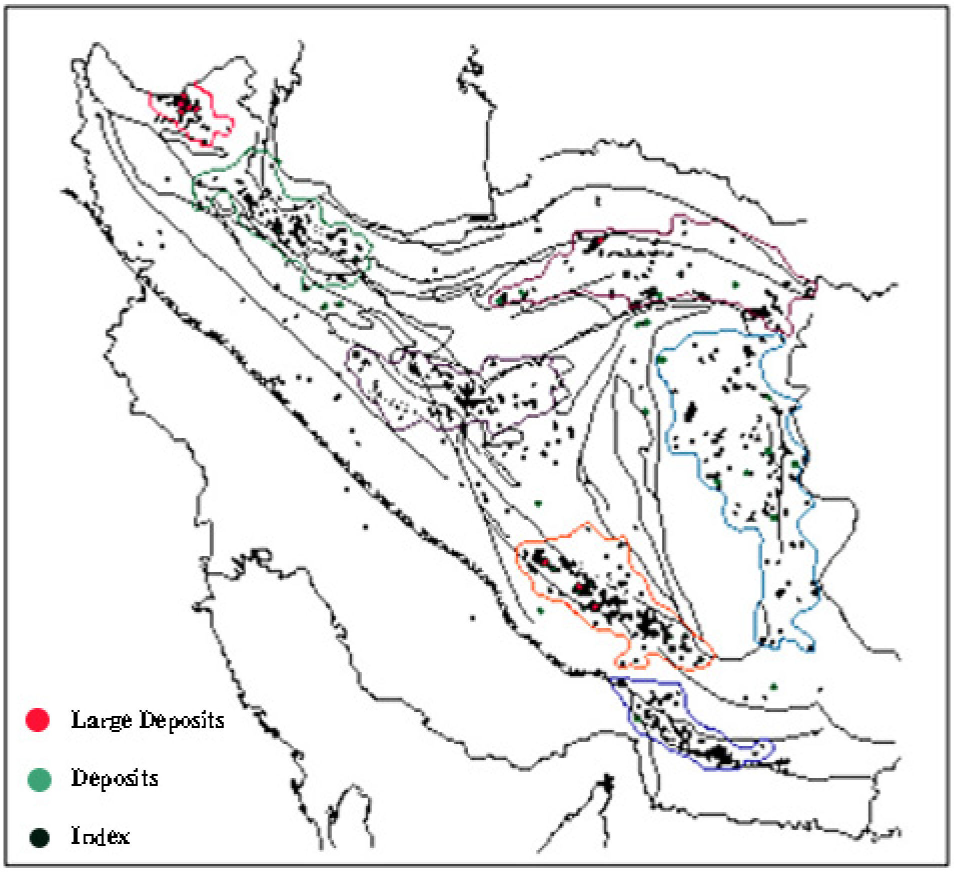

Figure 1. Distribution of copper deposits and indications in Iran (Qorbāni, 2002/03).

Most of the porphyry copper deposits of Iran are associated with Tertiary (to 1.8 million years ago) intrusive and extrusive igneous rocks. Wherever Tertiary copper is found, a definite relation exists with Eocene (55.8 to 33.7 million years ago) extrusive and shallow intrusive rocks. Most of the volcanics, andesites, andesitic basalts, trachyandesites, and basalts of the Middle Eocene have significant copper. At some of metallogenic zones where Eocene extrusive activity is voluminous, such as in Kerman, T'ārom, and Ahar, high anomalies of copper have been recorded. It can be deduced that the volcanics acted as the host rock, having been invaded by the copper-rich magmas of the Late Eocene-Pliocene. Leaching and recycling of copper from pre-existing rocks, and the chemically active solutions thus produced, have resulted in formation and enrichment of copper deposits.

Phases of copper mineralization. While there are indications of copper mineralization in Iran from the Late Proterozoic Era (> 543 million years ago) to the Pliocene Epoch (5.3 to 1.8 million years ago), most of the copper deposits of the country belong to the Tertiary Period (especially the Oligocene and Miocene epochs, 33.7 to 5.3 million years ago). The overall phases of mineralization of copper can be categorized into the following:

Late Precambrian-Cambrian (> 490 million years ago). No major copper deposits are known to have been formed in this period. However, a number of indications (detected in Yāsuj and Šahr-e Kord) occur within the rocks of these periods, which are not of significant economic interest (Kar-e Maʿdan indication at the foothills of Dena). Though the volcanic, sedimentary volcanic as well as metamorphosed igneous types of rocks (such as those exposed in Takāb, Anārak, Bāfq, etc.) have low copper contents, their lead-zinc content is abnormally high.

Late Paleozoic (> 248 million years ago). Traces of copper have been reported in association with some of the metamorphic rocks of the Late Paleozoic that are of igneous or pyroclastic origin, e.g., the massive Taknār sulfide deposit associated with the Taknār Series). The lead, zinc, and copper ore body of Čāh-e Gāz also belongs to this period. There is a high probability of discovering new deposits if the equivalents of these rocks (such as the Gorgān Schists and the Šandorman Metamorphics) are further investigated, particularly in localities where a follow-up magmatic activity took place.

Cretaceous-Paleocene (> 55 million years ago). There are indications of massive sulfide reserves of copper associated with Cretaceous and Paleocene ophiolite suites, for instance, copper indications at Ḥājjiābād (Bandar ʿAbbās), Ḵoʾi, and Jāzmuriān.

Tertiary. Most of Iran's copper reserves were formed during the Tertiary phase of mineralization. These deposits are closely related to the Tertiary magmatism that can be further divided into the following phases:

Eocene. Predominantly volcanic in nature, the rocks of this phase have a high background copper content. A number of deposits and indications are recognized.

Late Eocene-Early Oligocene. Most of the intrusive igneous rocks of this time, including granites, granodiorites, tonalites, and diorites are associated with vein-type copper deposits, e.g., Mazraʿa and Qalʿa Zari.

Late Oligocene-Early Miocene. During this phase, which is the second largest phase of Tertiary volcanism and magmatism, a number of porphyry- and vein-type copper deposits are formed in association with the igneous rocks.

Late Miocene-Pliocene. This phase mostly includes small, shallow, intrusive bodies that are believed to contain most of the porphyry coppers of Iran. The igneous activity subsides in this interval, but there are a number of deposits and indications that are formed during or just after this time; however, no information is available on them.

Distribution of copper deposits in Iran. Comparing the distribution of copper deposits of Iran with the maps showing the dispersion of magmatic rocks on the scales of 1:2,500,000 (Aghanabati. 1991), and 1:1,000,000 (Emāmi et al., 1993), the following zones of copper mineralization can be recognized:

Orumiya-Doḵ-tar Zone. This is further divided into three regions: Southern (Kerman), Central (Anārak-Kāšān), and Northern. The rocks of the Orumiya-Doḵ-tar Zone characteristically consist of Eocene to Miocene diorites, granodiorites, and granites. There is no agreement on the mode of origin of these rocks; some researchers consider them as products of a magmatic arc; some believe that they are results of rifting; and still another group associates them with an island arc. The southern (Kerman) region is rich in copper minerals. It hosts 600 kilometers of the copper belt with a varying width of 40 to 70 km. Geographically, this zone trends northwest-southeast, extending from Šahr-e Bābak to Bazmān. More than 300 copper deposits and indications exist within this belt, twenty of which are thought to be of porphyry type. The northern and central regions are comparatively poor in copper, which is replaced by other metals such as iron, lead, and zinc in the northerly direction. In the central region only a few porphyry copper deposits are known, e.g., Ḵonj-Tall-e Siāh and Kālakāfi (near Anārak), and Darra Zerešk (Taft); none exists in the northern region.

T'āleqān-T'ārom-Haštjin Belt (Western Alborz). There are extensive deposits of copper in the T'ārom region, all of which are associated with Eocene extrusive (mostly andesites) and intrusive (mostly tonalites and granites) rock bodies. They show high copper anomalies. The intrusive granite bodies of T'ārom are of I-Type (Cordilleran) accompanied by extensive iron and copper mineralization. In the T'āleqān area, a number of copper deposit and indications occur in association with monzonites and alkaline volcanic rocks (especially trachytes); the copper minerals of these rocks are of carbonate type.

Sabalān Zone (Ahar area, west of Ardabil). Only the Ahar area has the structural and mineralogical prerequisites to be termed Sabalān copper-rich zone. The area is very important for copper mineralization and hosts a number of deposits; its northward extension comprises the copper-molybdenum deposits of Armenia. The copper is of magmatic origin. Based on the habit and type of mineralization, the copper deposits can be divided into (1) porphyry copper deposits that are molybdenum-rich, e.g., the Songun and Kiqāl deposits; (2) vein and skarn copper deposits that sometimes contain gold, e.g., Mazraʿa, Bārmalek.

Kavir-Sabzevār Zone (Binālud and Taknār). This zone is situated on the north of the Daruna fault, to the south of the Miāmai fault and the Binālud Mountains. A number of copper ore deposits and indications are associated with Tertiary volcanics of this zone. Most of the ore bodies are in the form of veins formed in conjunction with andesitic and basaltic volcanic rocks.

Lut Zone. Numerous deposits and indications of copper occur along with the Tertiary volcanics, mostly in association with andesites, e.g., the Qalʿa Zari copper deposit.

Makrān Zone. A belt of copper mineralization occurs to the north of Makrān and south and southwest of Jāzmuriān. This zone trends northwest-southeast in the Fariāb area, but upon reaching Mok̲-tārābād changes its trend to east-west. Most of the fifty copper indications of this zone have been mineralized in association with flysch and volcanic-andesitic complexes. No detailed investigation has been carried out in the area, but the geological evidence is in support of massive sulfide origin of all the ore bodies.

World copper reserves. The global copper reserve is estimated at 340 million tons (British Geological Survey, *World Mineral Statistics 1993-97*). Whereas the probable reserves are around 590 million tons, the total resources are believed to be approximately 2.3 billion tons. The countries with major resources of copper in the world are listed in TABLE 1.

World copper production. With an annual production of around 12,000,000 tons, copper is the third most-consumed metal in the world, after iron and aluminum. According to the British Geological Survey, 52 countries are actively exploiting their copper reserves. (Copper production by continent is presented in TABLE 2) The leading producers are: Chile (4,541,000 tons, 30 percent of world production), the United States (1,490,000 tons, 15 percent), and Indonesia (977,000 tons, 7 percent). In 2000 Iran ranked eighteenth among copper-producing countries, contributing only one percent to the total world output.

Iran's copper reserves. Over five hundred deposits and indications of copper are known to exist in Iran, but only a hundred have been subjected to scientific survey and investigation, ten of which are actively mined (TABLE 3). Preliminary and detailed investigations of a few copper deposits, including Songun (Azarbaijan), Darra Zār, Darra Ālu, and Nučun (all in Kerman) have been completed in recent years; and the mines are being equipped to start operations (TABLE 4). The total reserves of the country, based on the results of surveys carried out to date, are estimated at around 3 billion tons of ore containing 30 million tons of copper. This comprises about 9 percent of the world's known reserves, putting Iran in sixth place in terms of world copper reserves. Exploration work on all the known copper indications is not yet complete; and, since Iran hosts more than 2,000 km of the Mediterranean-Himalayan copper belt, there is a strong possibility of discovering more reserves.

Within the previously stated six copper zones of the country, only five regions are considered as potential exploration targets: (1) The Kerman region of the Orumiya-Doḵ-tar Zone, in which more than 150 copper deposits and indications have been discovered. About 10 percent of the ore bodies in the region show evidence of porphyry type of deposit. Some of the more important copper deposits of Kerman region are Sarčašma, Meyduk, Čahārgonbad, Darra Zār, and Nučun. (2) Azarbaijan, including parts of both western Alborz and Sabalān zones, hosting around 20 copper deposits and indications such as Songun and Mazraʿa. (3) South Khorasan-North Sistan, including Qalʿa Zari and Čehel Kura. (4) Semnān-Sabzevār, including Čāh Farsaḵ-. (5) T̄ārom with deposits, such as Ḵalifalu.

Iran's copper deposits have a relative advantage over the rest of the world in that the average grade of known porphyry copper deposits, with reserves exceeding 2.5 billion tons, is above 0.7 percent.

Gold, molybdenum, and occasionally silver, are associated with copper in all known porphyry copper deposits. These elements make Iran's copper reserves more valuable. For example, the Sarčašma copper deposit, with an estimated reserve of 1 billion tons of 0.70 percent grade ore, contains 270 ppb gold, 300 ppm molybdenum, and 3.09 ppm silver, and the Songun copper deposit has 1 billion tons of copper ore with an average 0.70 percent copper and 50 ppm molybdenum.

Though the reserves of vein-type copper deposits of Iran are not as great as in the rest of the world, the presence of a few veins in almost all the mineralized zones is sufficient to feed a large smelting plant.

The vein-type deposits are usually rich in gold content (around 10 ppm), e.g., Ḵalifalu (Ṭārom), and Mazraʿa and Anjard (both in the Ahar area).

From the standpoint of exploration, the copper deposits of the country have the following advantageous characteristics: except for a few, most of the deposits are either hosted by volcanic rocks (ranging in composition from dacite to andesite) or their intrusive equivalents of Miocene-Pliocene. The deposits are located in definite geological zones. Due to similar paragenesis of most of the deposits, copper-bearing zones with specific mineralization characteristics can be defined. Study of ore paragenesis and fluid inclusions reveal a forming temperature of 150° to 400°C. Most of copper-bearing zones show characteristic metasomatism similar to one another. This is even visible in aerial photographs and satellite imageries. Moreover, availability of technology and know-how for copper exploration, extraction, and processing, along with inexpensive electric supply compared to the other copper-rich countries, add to the above-mentioned facts in making Iran a promising venue for future investments.

See also: MINING IN IRAN.

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