CHAPTER 5

MERCURY MINERALIZATION IN THE REGION OF ALMADÉN

View of Almadén mine, with San Joaquín shaft in the foreground, and the village of Almadén in the background.
With its almost 2000 years of extractive activity of such a scarce element in the Earth’s crust, Almadén, in the province of Ciudad Real, is a world classic and unique mining district which has produced more than 35% of the mercury used in human history. It is the biggest accumulation of mercury minerals in the world, spread along seven deposits: Almadén, El Entredicho, Las Cuevas, La Vieja Concepción, La Nueva Concepción, Guadalperal and El Nuevo Entredicho.

What is exceptional about this district, and specifically about the giant deposit in Almadén, is the peculiar geological evolution leading to such high concentration processes and great accumulation volumes, giving it the status of a model for ore body. The historical evolution of this area, always determined by mining, must be highlighted. Very important archaeological and industrial mining remains are preserved, which represent a unique heritage with great interest and cultural value.

Geologically, the Almadén mining district sits on the Southern sector of the Central Iberian Zone of the Iberian Massif (Figure 1), deformed during the successive stages of Variscan Orogeny. The result was the main structure of the zone, the Almadén Syncline, 25 km long and 10 km of maximum width, with the shape of a basin fold striking WNW-ESE, with a vertical south flank and low-angle dips to the north.

The rocks forming the syncline, mostly siliciclastic, belong to one of the more complete Lower Paleozoic stratigraphic series in the Central Iberian zone, with ages spanning from the Early Ordovician (500 Ma) to Late Devonian (345 Ma). They are mostly orthoquartzite, sandstone and slate originally deposited in a siliciclastic marine shelf environment.

Four different orthoquartzite beds stand out among the different lithostratigraphic units, which are used as a reference to establish the syncline geological structure (García Sansegundo et al., 1987) as well as the location of the mineralized packages (Figure 2). From base to top, these are: the Areginian (lower Ordovician) Armorican Quartzite, the Caradocian (upper Ordovician) Canteras (Quarries) Quartzite, the Hirnantian-Llandoverian (uppermost Ordovician-lower Silurian) Criadero Quartzite, where the mineralization is hosted (Figure 3), and the Gedinian-Siegenian (Lower Devonian) Basal Quartzite.

A very important feature is the existence of a basic volcanism with alkaline affinity. These igneous rocks crop out as intrusive bodies (dykes and sills), diatreme bodies (explosive tuffs) and well-bedded volcanosedimentary layers. In general, intrusive rocks prevail in the end-Ordovician and Silurian sequence, whereas volcano-sedimentary rocks prevail in the Devonian.

The explosive tuff bodies are presently limited by faults, so it is not possible to determine the timing and contact relations with the host rocks, although they seem to be deposited between the Silurian and Devonian. These tuffs are very peculiar within the Almadén syncline and are called “Roca Frailesca” (“Friars Rock”). Their composition is basaltic, with ultramafic rock fragments, clasts of black slate and quartzite, and a strong weathering with deposition of carbonate and argillaceous materials (sericite).
There are two main types of mineralization. The most important one, represented at Almadén Mine, consists of a cinnabar impregnation of the Criadero Quartzite. It is an early mineralization formed when the rock had not yet undergone any important lithification, and prior to the emplacement of the “Roca Frailesca”. The second type of mineralization consists of cinnabar filling veins and replacing the volcanic rocks, creating a vein network (stockwork) on any lithology, although it is more frequent on strongly carbonized volcanic rocks. The emplacement of these mineralization followed tectonic deformation, since the veins cut the Variscan foliation. They are therefore epigenetic mineralizations, or veins formed by the filling of pre-existent mineralizations, by water carried minerals, vapours or hot gasses which have circulated through them.

The origin and metallogenic (ore forming) process capable of generating such a high concentration of a scarce material are still controversial. Two hypotheses have been proposed. The first one assumes a pre-concentration in the Paleozoic marine environment, setting the mercury in the abundant black slates (Saupé, 1973, 1990). The second one assumes an anomaly in the Earth’s mantle, and the elevation of mercury and volcanism due to important crustal fractures (Ortega and Hernández, 1992). The frequent association of mercury mineralizations to deep mafic rocks, together with the local evidence, lead to consider the second one as the most probable.

Every known deposit includes both of the previously mentioned typologies: bedded deposits and stockwork deposits. The first ones are the biggest, and the most representative mines are Almadén, El Entredicho and Vieja Concepción. The second ones are smaller, although they generally present higher concentrations, and the most remarkable examples are the mines of Nueva Concepción, Las Cuevas and the yet-to-be-developed deposit of Nuevo Entredicho.

Almadén Mine was the biggest mercury deposit in the district and, without any doubt, also was the biggest concentration of the liquid metal in the Earth’s crust. It is a model for giant stratabound ore deposits, and a unique case in the known geological frameworks. It suffices to say that it has been exploited for more than 2000 years, with very few interruptions, being the only active mine within the district. Its production has exceeded 7 million mercury flasks (1 flask = 34.37 kg).

Even if the access to certain old mining areas is not easy nowadays, there are well preserved sites from the XVIII and XIX centuries where the masonry and brick support methods specific to Almadén can be seen. Buildings and mining works from the XVIII century with an easy access are preserved where interesting geological and archaeological mining observations can be made. Part of the town is built directly over the former deposit, and some exposures of the Criadero Quartzite host rock crop out between houses and buildings.

The origin and metallogenic (ore forming) process capable of generating such a high concentration of a scarce material are still controversial. Two hypotheses have been proposed. The first one assumes a pre-concentration in the Paleozoic marine environment, setting the mercury in the abundant black slates (Saupé, 1973, 1990). The second one assumes an anomaly in the Earth’s mantle, and the elevation of mercury and volcanism due to important crustal fractures (Ortega and Hernández, 1992). The frequent association of mercury mineralizations to deep mafic rocks, together with the local evidence, lead to consider the second one as the most probable.

Every known deposit includes both of the previously mentioned typologies: bedded deposits and stockwork deposits. The first ones are the biggest, and the most representative mines are Almadén, El Entredicho and Vieja Concepción. The second ones are smaller, although they generally present higher concentrations, and the most remarkable examples are the mines of Nueva Concepción, Las Cuevas and the yet-to-be-developed deposit of Nuevo Entredicho.

Almadén Mine was the biggest mercury deposit in the district and, without any doubt, also was the biggest concentration of the liquid metal in the Earth’s crust. It is a model for giant stratabound ore deposits, and a unique case in the known geological frameworks. It suffices to say that it has been exploited for more than 2000 years, with very few interruptions, being the only active mine within the district. Its production has exceeded 7 million mercury flasks (1 flask = 34.37 kg).

Even if the access to certain old mining areas is not easy nowadays, there are well preserved sites from the XVIII and XIX centuries where the masonry and brick support methods specific to Almadén can be seen. Buildings and mining works from the XVIII century with an easy access are preserved where interesting geological and archaeological mining observations can be made. Part of the town is built directly over the former deposit, and some exposures of the Criadero Quartzite host rock crop out between houses and buildings.

The economic mineralization has been subjected to workings at a maximum strike length of 500 m, and has reached a maximum depth of 600 m. For it to be exploited through time a vast infrastructure was built consisting of two main shafts, San Teodoro (522 m) and San Joaquín (700 m), and three auxiliary ventilation shafts, San Miguel (509 m), San Aquilino (378 m) and Robbins (360 m). For a long time, the main mine shaft was San Teodoro, reaching the 19th floor, having as auxiliaries San Miguel and San Aquilino. At the beginning of the 1970s, San Joaquín shaft was built to the west, reaching the 27th floor, but it was only worked until the 23rd. This one became the main shaft in the mine, being San Teodoro and San Joaquín the auxiliaries, and abandoning San Aquilino. In the 1980s, Robbins shaft was built to facilitate the ventilation in the western part of the mine.

The Criadero Quartzite in Almadén Mine is divided in four intervals which, from base to top, are the following:

- Lower Quartzite, with 8 to 15 m of massive white quartzites. The mineralization forming the so-called San Diego or San Pedro Bed is within this interval. It has a thickness of 3 to 8 m. The mineralization is either in most of the interval or in its upper part.
- Middle Slate, with 10 to 15 m of carbon-rich fine-grained sandstones, and frequent pillow structures. They are barren.
- Upper Quartzite, with 10 to 20 m of dark carbon-rich quartzites in thick packages with fine-grained
sandstone interbeds. This interval includes other mineralized beds called San Francisco and San Nicolás, with thicknesses from 2.5 to 5 m. Between them, there is usually a thin alternation of fine-grained carbonaceous sandstones. The separation between both beds varies from 0 to 0.5 m, probably due to tectonic lamination.

Stratigraphically beneath Criadero Quartzite there is a unit of black slates with sedimentary lamination and fine layers of sandstone called Lower Slates. On top of the quartzites there is another slate unit known as Upper Slates, mainly made up of fossiliferous, graphite-rich black slates. They are partially or completely replaced by diabase intrusive bodies known as Upper Lavas. There are also volcanic dykes and sills, compositionally equivalent to these Upper Lavas, cutting or interbedded among the sedimentary rocks. These dykes originated thermal contact metamorphism in the quartzites and mineralized banks.

The Almadén deposit structure is mainly controlled by fractures which can be grouped in the following two episodes:

1. Longitudinal and sub-vertical shear faults striking WNW-ESE to E-W and affecting the Criadero Quartzite parallel to bedding. Their movement creates hectometer-sized displacements, which complicates the general structure of the Criadero Quartzite in the mine zone. These faults were generated by the E-W shortening in the 2nd Variscan phase.

2. Transverse dextral shear faults striking NW-SE which caused decimeter to hectometer displacements to the Criadero Quartzite and are the consequence of late-Variscan shortening.

The intersection of these longitudinal and transverse shear faults within the Criadero Quartzite in a subvertical position has built a deposit structure which can be defined as a large, dismembered, subvertical-axis fold, and allows to differentiate three zones in the deposit, called from east to west: “Rama Mina” (mine branch) zone, “de los Masivos” (massive) zone, and “Rama Sur” (southern branch) zone (Figure 5).

Although there is no general rule, in San Pedro bed the impregnation mineral prevails, whereas in San Francisco and San Nicolás beds (Figure 6) the most common mineralization is filling of veins. The impregnation mineralization means the filling with cinnabar of the rock’s primary porosity, basically inter-granular spaces. Fissure fillings represent the sealing of the porosity generated after diagenesis of the quartzite and breaking of the competent rock.

With regard to the spatial distribution of the mineralization, outcrops of the Criadero Quartzite should appear in the “Southern Branch” area. This area was worked in ancient times up to the 5th floor, which means 165 m in depth. Everything points to the working of isolated bodies of the San Francisco and San Nicolás beds. The depth reached, the complete development of the ore body, and the discovery of “Rama Mina” led to the abandonment of this zone. The mineralization in “Rama Mina” was found at the 1st floor level, approximately 45 m deep, the shallower mineral belonging to San Francisco bed. In depth, the mineralization of the San Pedro and San Francisco beds reached the 23rd floor (600 m), whereas San Nicolás bed hardly went below the 17th floor (425 m).
The richest mineral banks of San Pedro bank were in “Rama Mina”, following a supposed axis going from San Aquilino shaft in higher levels, to San Miguel shaft in deeper levels. In the case of the minerals from San Francisco and San Nicolás, the richest were found in “de los Masivos” and “Southern Branch”.

The **El Entredicho mine** was the second mercury deposit in production of the Almadén district throughout its history. Currently, the extraction works are finished and the mineral reserves are almost empty. The mine began to be intensely exploited in 1979 and was closed in 1997. Since the beginning, it was conceived as an open pit mine and great infrastructure works were carried out. The final size of the pit when the works ended were 450 m maximum width across a NW-SE axis and 350 m perpendicular. The maximum depth was 70 m (Figures 7 and 8).

The mine, located in the SE end of the synclinal pericline closing (see Figure 2), shows a stratigraphic series similar to that of Almadén, characterized from base to top by the Lower Slates (crossed by several basic sub-volcanic rocks), the Criadero Quartzite, and the Roof Slates of Silurian age (graphite-rich, very fossiliferous black slates). The Criadero Quartzite shows the same features as in Almadén, with two mineralized banks, one at the base and one at the top (equivalent to the two upper banks in Almadén). The volcanic and sub-volcanic rocks are widely represented in the deposit; a very important tuff body the “Roca Frailesca” and two systems of basic dykes.

The deposit typology is also stratabound, although smaller in size than in Almadén mine. The mineralization in El Entredicho is found in beds equivalent to the Criadero Quartzite and also has very similar texture to those of Almadén. The mineral paragenesis is completely equivalent. The only peculiarity to be highlighted is a bigger amount of native mercury found at El Entredicho.

This open pit mine (Figure 7) allowed to identify the relative time relationships between mineralization and volcanism, which is of great relevance to understand metallogenesis and ore body evolution. In the deep levels of the pit, one of the sills with ultrabasic xenoliths was in contact with the Lower Bed, causing thermal metamorphism on the mineralized bed, which means that the emplacement of the mineralization is evidently prior to the sill. Since this sill is spatial and compositionally related to the “Roca Frailesca”, it can be inferred that the mineralization is older than the emplacement of the volcanic tuffs.

**Nueva Concepción mine** (Figure 9) is placed along strike of the Criadero Quartzite in the southern flank of the Almadén syncline. It was the third most important mine in the district. The first works seem to be from Roman times. Since the end of the XVIII century to the mid of the XIX century, it was intensively worked, going through different operational stages. The different research campaigns carried out since 1965 did not give any positive results. In this area, the quartzite is affected by frequent shear zones (Figure 10) acting
as tear faults and causing repetition of the quartzite bed, as well as sub-vertical axis folds. Volcanic and sub-volcanic rocks are frequent in the mine, cropping out essentially as sills and dykes.

Las Cuevas mine is the best studied example of the stockwork type deposit and is the only mineralization case in the northern flank of the Almadén syncline. Mining began in Roman times and was later abandoned until 1774, when exploration and extraction works were carried out, but the loss of mineralization in depth and the difficult working conditions led to its abandonment. Beginning in the 1960s, an important mercury seam was identified beneath the ancient works. The new mine development began in 1987 and lasted until 1999, when mineral extraction was discontinued.

This mineral deposit is irregular, hosted in volcanic and siliciclastic rocks of the Silurian-Devonian sedimentary sequence. These host rocks display a series of alternating black slates and thin sandstone layers, with quartzite and volcanic interbeds. Among this sequence there are massif bodies of sub-volcanic rocks and tuffs (“Roca Frailesca”).

All these mineral deposits, even the most important one at Almadén, have suffered the same ending: the final and definitive closing of the mining works. Extraction ended in 2001, and metallurgy stopped transforming...
cinnabar into mercury in 2003. After two millennia of continued development works, the reason has to be found in the drastic drop of demand, the high cost of works, and environmental issues. Nevertheless, the mines of Almadén will be remembered not only for the production of more than a third of the total world mercury consumption, but also for their significance as a lasting metallogenic model for ore body formation, as well as for representing a world example of historical mining heritage.

Figure 9, above. San Carlos shaft house of Nueva Concepción mine, where an animal-powered winch was used to extract the mineral obtained in the subterranean galleries. The conspicuous outcrops in the upper background are of the Canteras (Quarries) Quartzite.

Figure 10, left. Geological sketch of the 2nd level of Nueva Concepción mine.


REFERENCES