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Evolution of Alluvial Gold Mining Technologies †

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Abstract: This work provides historical information and examines changes in the methods and equipment used in gold recovery and processing operations. Alluvial gold recovery methods, mainly based on gravity separation combined with mercury (amalgamation), have been applied since the early days of mining. Historically, mining gold from the riverbeds was first implemented in Ancient Anatolia (also called "Asia Minor") and Ancient Greece. As a first attempt to recover gold, the traditional immersion of sheepskin in river water to trap alluvial gold was developed. This technique has been considered a milestone in the famous myth of the Golden Fleece. Since then, gold extraction and processing technologies have evolved. In this respect, Emperor Augustus developed hydraulic gold mining during the period of the Roman Empire. Subsequently, the innovative machines of Georgius Bauer (Agricola) were widely used during the Renaissance, while Spanish colonialists in America improved their techniques by observing the efficient methods of the natives. Finally, the "American Gold Rush" era was perhaps the most crucial period of the alluvial gold mining process. It took place along the rivers of America during the 19th and 20th centuries. Today, in the technologically advanced society, various gold mining machines, including spiral and jig concentrators, provide higher production rates and less environmental harm.

Keywords: "American gold rush"; alluvial gold mining; Golden Fleece; gold processing

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1. Introduction

The recovery of gold from alluvial deposits is considered one of the oldest methods practiced, referred to as "mining". Grains of the mineral, which is defined as "native gold", are found in gold ores or gold-bearing rocks, and are released when they are oxidized or weathered. Due to the gravity force, the grains are displaced to lower parts of the topography and may, together with other minerals, form sandy, gold-enriched deposits. So, they may create an "alluvial gold deposit", while the specific grains are defined as "gold nuggets".

Previously, several studies have been conducted on the evolution of alluvial gold mining processes, but only to some extent on a large chronological scale. The primary purpose of this report is to record the historical evolution of alluvial gold mining and processing methods, from its initial discovery in Ancient Anatolia and Egypt till today's industrially advanced era. Emphasis is given to the procedures implemented during the gold rush era, one of the most essential periods in extracting precious metals [1].

2. Historical Evolution of the Alluvial Gold Processing Methods

2.1. The Initial Discovery of Gold in Egypt, Ancient Anatolia, and Greece (5000–1000 BC)

Gold finds date back to around 5000 BC. in the Mediterranean area (a gold earring was found in Dimini during the late Neolithic era and a gold bead in the settlement of Sitagro in Drama between 4600–4200 BC). It is reported that the initial gold production in

Ancient Anatolia dates back to the Late Chalcolithic and Early Bronze Age (3000–2000 BC). An early example of gold used in Ancient Anatolia comes from the ancient city of Melid (or Arslantepe), where a gold disc was found around 3000 BC. After the advent of the Bronze Age (2000–1000 BC), more gold objects were found in Ancient Anatolia, as well as in the second level of the "Troy" excavation (2500 BC), which were mainly used as decorative objects. During this period, there was a strong interest in gold mining involving processing methods such as panning. Around 2450 BC the ancient Egyptians mined gold in Nubia. An Egyptian alchemist named Zosimus was the first to find pure gold. The discovery of gold is attributed to the ancient Egyptians, who made jewellery when other metals were rare and precious [2].

2.2. The Argonautic Expedition (1300 BC)

The Argonauts started from Iolkos and settled in Colchida, a part of today's Georgia, to claim the golden fleece. However, based on the bibliographical references, the route they followed on their return indicates their interest in exploiting the ores of the time (copper, iron, lead, and gold). They passed through the central Mediterranean, southern Europe, the Danube, the rivers of the Alps, Egypt, and the Aegean, zones that constituted the most important mining centers of the specific chronological period [3].

The Greek-born Roman historian Appianos Alexandrinos (90–170 BC) and other historians expressed that actual mining practices inspired the Golden Fleece. The description of the Golden Fleece refers to using sheepskin to extract gold from riverbeds. Their thick fur trapped the gold the water carried away as nuggets or dust, taking on a golden glow. The above description is one of the first historical records regarding exploiting alluvial gold deposits from riverbeds [4].

2.3. The Processing of Alluvial Gold Deposits during the Roman Period (27 BC–476 AD)

The Romans used various techniques to extract metals from their ores. In particular, gold was refined either by exposure to heating for a long time in the presence of other metallic (or nonmetallic) substances (refining by cementation processes), or by amalgamation with mercury, one of the oldest methods of gold extraction. The Roman miners also used the particular method of "ground sluicing", which is considered the most suitable for deposits with a thickness of 4 to 6 m. For dry soils, mining involved digging 6 to 8 convergent trenches with a 5% inclination to the horizontal plane. A single trench could supply the entire amount of water for the operation. Thus, the miners were pushing the alluvial deposits against the walls of the trenches, driving them towards the lower part of the slope with the contribution of the running water. The pebbles were washed and removed (outside the trenches), while the sand and clay were carried by water flow to the outlet [5].

2.4. The Contribution of Agricola's Methods (1494–1556)

Georgius Bauer Agricola was a humanist, scholar, and scientist who spent most of his time in the mines and wrote ''De Re Metallica", one of the most essential engineering books of the 16th century. The water pumps that Agricola sketched were used in a series of new machines to explain his proposed methods of extracting the metals from their ores. Agricola described in pictorial detail the methodologies and equipment used. Notably, forty-nine exquisite illustrations depicted various apparatuses such as troughs, sluices, launders, weirs, and ditches, meticulously designed to direct and combine ore with water. These depictions vividly demonstrated the process of separating refined grains from lumps, providing a visual guide to the equipment employed in ore washing [6].

2.5. Colonialism and Gold Mining in America (1492–1511)

In 1492, Christopher Columbus discovered America, miscalculating the earth's circumference by 25%. Then, Spanish colonization began on the American continent. Colonial miners processed the alluvial deposits through gold concentration pans and sluice boxes

in their basic form. In addition, they developed and applied the efficient gold mining methods of the natives. Specifically, they used magnets to separate iron oxide from gold, mercury to platinum from gold, and fruit juice to separate iron and gold oxides within gold-concentration ''bateas" pans [7].

2.6. The Gold Rush Era on the Rivers of the American West (19th–Early 20th Century)

The methods used to mine alluvial gold deposits in Western America during the gold rush have been known for centuries. These included using the well-known gold pan (batea), the rocker box (or cradle box), the Long Tom, and the sluice box. Each device was a refinement of the previous one. For example, a rocker box handles finer material better than the gold concentration pan (although the pan was applied in the final separation stage). Subsequently, the Long Tom device was more effective than the rocker box, while the sluice box performed better than the Long Tom.

Dredging represents the last development of the mining methods for the alluvial deposits of the period, while the most successful types of dredging operated during the 20th century. The dredging fields were located at low altitudes, usually where rivers or large tributary streams emerged from the mountains [8].

3. The Fundamental Alluvial Gold Processing Systems

3.1. The Gold Concentration Pans

The gold concentration pans were one of the earliest methods of mineral separation based on the differences in mineral density and particle size. The circular or back-and-forth agitation of the ore and water directs the heavier minerals to the lower part of the pan, while the lighter material overflows to the top. The low operation cost and the simplicity of the method allowed many operators, who lacked the proper equipment, to participate in America's "gold rush" era. However, the process is extremely limited, as only the heavier gold particles are recovered, while the finer particles are carried away with the water flow along with the pebbles [9].

3.2. The Rocker or Cradle Boxes

The Rocker boxes were effective in locations with little water supply and were also used extensively during the early years of the "gold rush" era in Western America. The material was fed into the hopper of the box, and the box was vigorously shaken back and forth while water flowed over the material.

The rocker boxes contain three parts, namely screen, riffles, and apron. The material is screened with water poured over it. The screen holds the larger particles, where the clay can be broken down until all the tiny gold particles are finally removed. The riffles, which are placed at the lower part of the box, are used to trap the gold particles, while the finer particles are washed with water on a collection "apron" of wood or cloth with a certain inclination. The apron is used to retain the largest possible quantity of gold and is made of canvas stretched over the frame of the apparatus [10].

3.3. The Sluice Boxes

The sluice boxes (Figure 1) are inclined devices similar in shape to a "trough" and have a suitable mechanism for trapping gold (or other heavy mineral particles) in their flat lower part. Sluices work on the principle that heavy particles tend to sink to the bottom of a stream of flowing water while lighter particles tend to be carried downstream and discharged off the end of the sluice. In sluices where turbulent flow does not develop, the difference in settling rate between the light and heavier particles leads to the separation of the slurry into stratified zones. As a result, the slurry stream flows along the sluice box with the higher density and larger-sized particles accumulating in a zone near its lower part, where they can be trapped within the apron and removed from the stream. Conversely, lighter particles tend to remain near the top of the stream and are removed at the discharge

end of the sluice. The Long Tom is a small sluice that uses less water than a regular sluice but requires more manual labour [10].

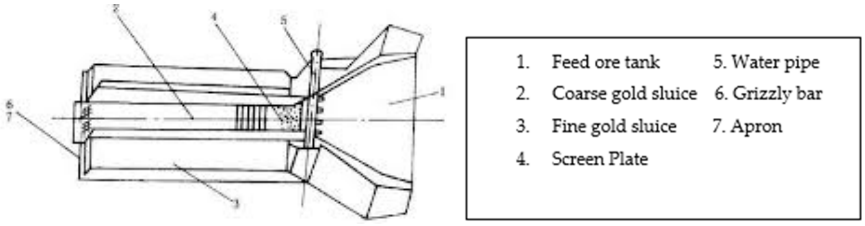


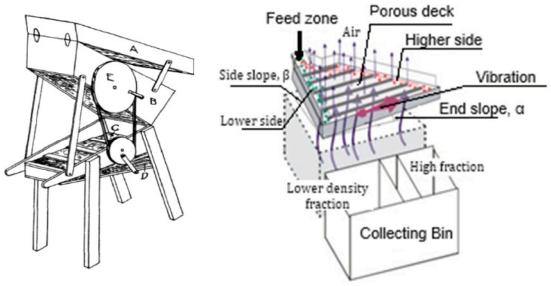
Figure 1. The functional parts of a sluice box [11].

3.4. The Gold Dredges

A gold dredge is a type of mining machine that uses water and mechanical techniques to extract gold accumulated in a placer deposit. A typical gold dredge consists of a floating surface on which the structure is deployed, a digging arm, a chain of digging buckets, a screening device, and gold recovery equipment. The initial use of the dredging method in mining alluvial deposits began in New Zealand in 1882, and its first successful application in the United States took place in the Bannack of Montana in 1894. Dredging ensured that the river pebbles were dredged along the entire river in search for gold, while at the same time, the tailings were deposited in piles behind the dredging unit. The dredging excavators operated either from land with floating washing devices (portable or not) or on floating platforms [12].

3.5. The Dry Washers and the Air Tables

In dry washers [9] (Figure 2a), the separation of gold from sand is determined by the pulsating motion of air passing through a porous medium. This technique provides a combined action of agitation and sorting of the material. The sand is fed to the top of the device, where a screen separates the large from the fine particles of gold. The largest particles are removed, and the fine particles pass through the screen and are directed, through the inclined box, to the riffles in the lower part of the apparatus, where they can be trapped in the apron. The ore must be completely dry and moisture free for recovering gold [13].



(**a**) (**b**)

Figure 2. (**a**) A typical dry washer and (**b**) the air table's operating principle. ↑ with small purple arrows in (**b**) displaying the air flow direction and with thick arrow the longitudinal direction of vibration.

The air table operates similarly to the wet shaking tables based on the principles of shallow bed fluidization and stratification, with small purple arrows in Figure 2b displaying the air flow direction and with thick arrow the longitudinal direction of vibration [14]. This technique exploits the differences in specific gravity to separate particles. As air enters from underneath the deck screen, it generates an upward force to provide varying degrees of support to particles, depending on their size and density. As a result, the particles are

stratified vertically. The heavier particles are forced sideways and towards the upper end of the deck's surface due to the moment of inertia combined with the adhesion it provides. The lighter particles are directed to the bottom of the surface and are collected [13].

3.6. Spiral and Jig Concentrators

Spiral concentrators (Figure 3a) [10] are one of the most essential systems for the gravity concentration of gold particles. They first appeared as a production unit in 1943 as "Humphrey's" spirals for separating chromite-bearing sand in Oregon. It consists of a helical conductor of 4–5 spirals, with a modified circular cross-section. Furthermore, it has a water channel for flushing the particles and a series of exit points to collect the concentrated product. A complex system of centrifugal forces, differential settling, and displacement of heavy particles cause particle classification. Thus, the heavier particles progress to the inner profile of the spiral, while the lighter particles are forced towards the outer profile. Finally, three products (concentrate, middlings, and tailings) are collected [15].

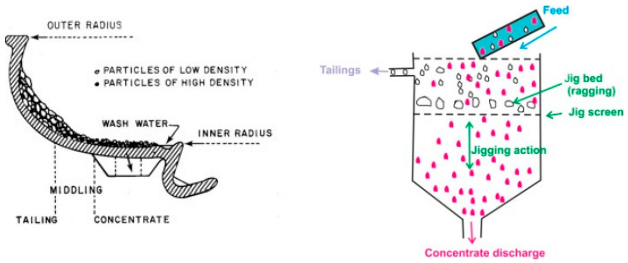


Figure 3. (**a**) The operating principle of the spiral and (**b**) Jig concentrators.

Jigs are open and water-filled tanks [16] (Figure 3b), with a horizontal screen in their upper part and a concentrate collection nozzle at the bottom. The mechanical pistons cause the water's pulsating movement, thus separating particles with different specific gravities. In order to separate particles of different specific gravity there must be a difference in the settling rates of the solid particles being processed. More specifically, the heavier particles have a higher settling velocity than the lighters, so they remain in the lower part of the bed during the stratification. As a result, a portion of the heavy particles that pass through the screen holes is collected and placed back on its surface (ragging bed), allowing only the very high specific gravity particles to reach it and be further separated in the next feed.

4. Conclusions and Discussions

Gold is a precious metal that has been used since ancient times and continues to be used in modern times because of its important properties. Tracing the various techniques used over the centuries, from the myth of the Golden Fleece to modern separators, in addition to the historical value of mining technology, will help to create more efficient and environmentally friendly techniques by identifying the limitations and weaknesses of the previous techniques used over the years. The factors on which the development and optimization of mining technologies were based in the last centuries are the following:

- The minimization of manual labour
- Increasing production through automated processes
- The processing of a wider range of gold grades

It is highlighted that today, from the environmental protection viewpoint, it is considered necessary to develop efficient devices for recoverinand processing gold, that consume less energy, thus reducing CO_2 emissions, and following the principles of zero waste and circular economy. For large-scale mining, in particular, it is necessary to use alternative technologies and modern practices, including replacing diesel with so-called green energy and sustainable water management practices. Another important problem in countries with intense activity in small-scale alluvial gold mining is the contamination of water bodies

from the use of mercury (Hg). Given that mercury is a highly toxic metal, sustainable environmental protection and proper management are essential throughout the life of mining.

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