A hindered-settling model applied to the flat-washing platforms at Laurium, Greece

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ABSTRACT: The flat-washing platforms, prominent in the processing of silver-lead ores at Laurium, Greece in the 4th century BC, were probably not designed to work with sluices as proposed by Conophagos (1980). Rather, the stand tank at the rear of the platform was a primary settling basin and the ancillary system of channels and settling basins served as a staged operation to collect concentrate throughout a closed circuit. A hindered-settling model is proposed for the effective separation of lead minerals from the gangue. Ceramic bowls were used in a vanning process to evaluate the degree of liberation and separation of lead minerals at the ore-processing workshops.

Introduction

There are excellent descriptions of the excavated ore-processing workshops in the Laurium area (Fig 1), principally by Conophagos (1980), Jones (1984), Photos-Jones and Jones (1994) and Fragiskos (2000). Based on structures and materials found at these sites, four major operations were conducted. The release of galena and cerussite from gangue at the mines continued by hammering ore fragments on large marble blocks located at the ore-processing workshops (Conophagos 1980, 227, Fig 10-3 and 10-4). Based on the dimension of the feed slot in the upper grinding block of the hopper quern (Ardaillon, 1897, 69, Fig 22), crushed ore was reduced to fragments of no more than 25mm. This crushed material was in turn ground in hopper querns (Jones 1984, 69) to further liberate the lead minerals and to produce grains of a more uniform nature (sand size) for the succeeding separation and concentration process by washing. A review of the 19th century AD studies of the orebodies at Laurium by French engineers (Kepper, in preparation) strongly suggests that several types of ore were mined during the Classical period (5th-4th century BC). These consisted of galena, mixed sulphides (primarily galena, pyrite and sphalerite), galena hosted in carbonate, fluorite or quartz gangue, and galena and/or cerussite in an iron oxide gangue ('limonite' or goethite). Carbonate host minerals include calcite, dolomite, and various iron-rich carbonates such as siderite and ankerite. Except for pure galena, which went directly to the smelter, the other ore types were treated at the ore-processing workshops.

The flat-washing platforms (Fig 2) are one of the most distinctive ore-processing features of mining operations at Laurium during the 5th and 4th century BC. Figures 3 and 4 illustrate one such structure excavated at Souresa. That their purpose was for the preparation of concentrate prior to smelting and for the re-cycling of water is not in dispute. Water is and was a scarce commodity in the south-eastern part of the Attic Peninsula and the ancient Greeks developed systems of channels, dams and cisterns for collecting rainwater to feed the washing platforms (Conophagos 1980, 253–254). They devised a waterproofing compound (composed of lime and ground slag) to coat the cisterns and the platforms to reduce loss of water by infiltration. Tile or wooden roofs are believed to have covered the cisterns and the stand tank to reduce losses by evaporation. Conophagos (1980, 234) recognised two types of flat-washing

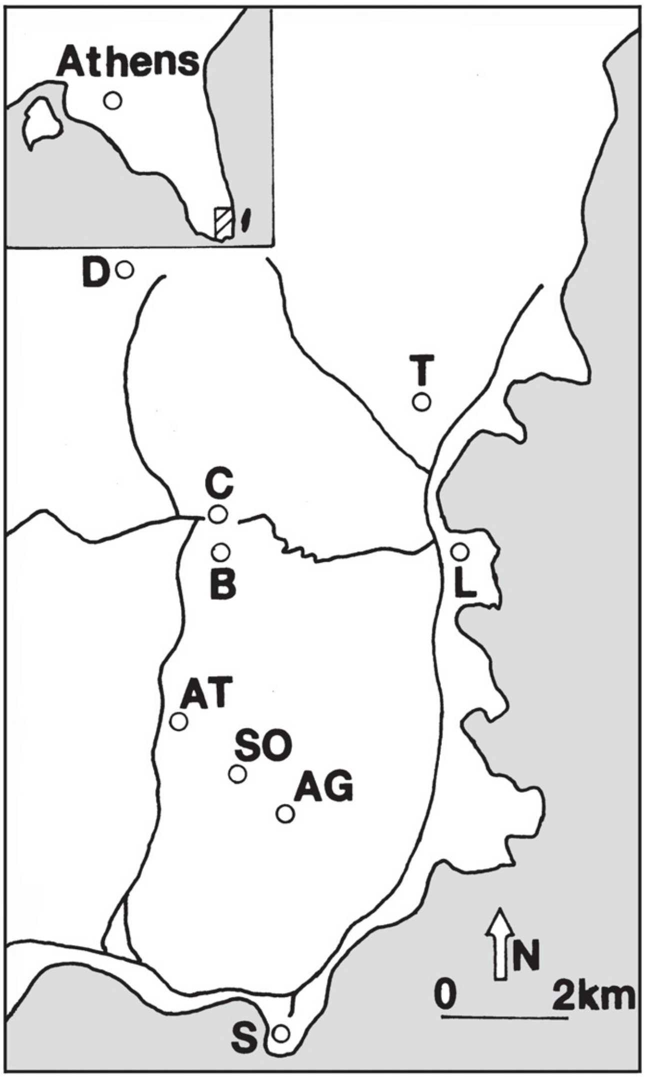

Figure 1: Laurium is about 60km SE of Athens (see the hatched area on the inset map). Laurium or modern Lavrio (L), Cape Sounion (S), and Camaresa (C) – the major mining centre – are plotted on the local map. Excellent examples of the flat-washing platforms can be found at Thorikos (T), Demoliaki (D), Bertseco (B), Agia Triada (AT), Souresa (SO) and Agrileza (AG). Demoliaki and Bertseco are better known for their well-preserved helicoidal washers. AT, AG and SO are in the Valley of Souresa, which has the highest concentration of ore-processing workshops.

platforms, one with a broad drying floor (Type I), which is by far the more common, and a variation without a drying floor (Type II).

The various interpretations for the operation of the flat-washing platforms are addressed in the following questions:

- Did the stand tank in the rear of the platform serve only to supply water to the rest of the circuit or was the tank utilised directly in the concentration process?
- Was the system of channels and settling basins used just to clean and recycle water or was this a staged operation by which lower-grade concentrate was periodically recovered from each of the elements of the system?
- Why are the outlets in the front of the stand tank always located mid-level and why are the outlets cone-shaped with the smaller diameter toward the working platform?
- Why is there no drain or clean-out outlet at the base of the tank?
- What function(s) were performed on the working floor in front of the stand tank?
- What was the purpose of the shallow ceramic dishes found in abundance near the workshops?

There are two distinctly different opinions on the role of the stand tank and the recirculation system in the operation of the flat-washing platform. It is clear that the stand tank was the immediate source of water for the washing operation and that it was periodically refilled with recycled water from the last settling basin. Ardaillon (1897, 68) and Negris (cited in Ardaillon, 1897, 63) believed that water discharged from the outlets in the front of the stand tank swept across the working floor, separating the denser ore minerals from the lighter material. Tailings and finer ore were subsequently further concentrated in the channels and settling-basins leading to the recycling of water for more processing. Ardaillon's evidence for the recovery of concentrate in the channels consists of baffles or low barriers constructed across the channels to trap denser particles (Ardaillon 1897, 72; see also Photos-Jones and Jones 1994, 317). He noted that the elevation of the intake for each channel is slightly higher than the outflow level of the immediately up-gradient channel. Water had to be

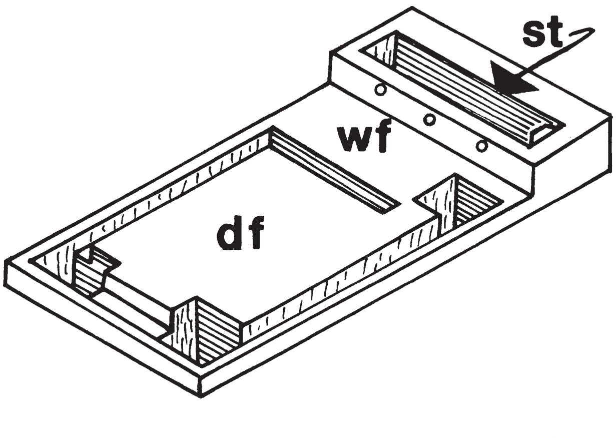

Figure 2: Schematic of a flat-washing platform, based on Conophagos (1980, 234, Fig 10–16), illustrating the stand tank (st) with three outlets, working floor (wf), and drying floor (df). Water flow through the recycling system of channels and settling basins is anti-clockwise. Dimensions of these platforms are typically 8–9m wide and 10–12m long.

Figure 3: Flat-washing platform at a workshop site located in the upper part of the Valley of Souresa, a few hundred metres SE of Agia Triada church, on the main road south from Camaresa. A rock-lined channel for carrying water to the cisterns is in the foreground. The edge of the main cistern is on the right. The adjacent smaller cistern was used to remove sediment from the water before it was added to the stand tank. The washing platform, with a portion of the marble slab at the front of the stand tank preserved, is in the background.

Figure 4: Detail of the flat-washing platform shown in Figure 3. Marble slab representing the front portion of a stand tank (one outlet visible on the left portion) is located behind the working floor. A narrow channel separates the working floor from the larger drying floor. The wooden grate in the foreground covers the first settling basin.

baled from the settling basin and poured into the next channel. Indeed, examination of washing platforms at the Souresa and Agrileza workshops in the valley of Souresa by the author confirms these earlier observations. The purpose for this system of channels and settling basins was firstly to recover concentrate that bypassed the working platform and secondly to remove as much of the tailings as possible, so that the return water was suitable for the next cycle of processing.

Conophagos (1980, 241) hypothesised that wooden sluices (supported by blocks), sloping towards the channel in front of the working floor, were aligned with the outlets in the outer wall of the stand tank to effect the separation of concentrate. Cup-like depressions cut into the surface of the sluice trapped the denser minerals while the tailings settled out in the settling basins, clarifying the water. He stressed that the purpose of the recirculation system was for the recycling of the water, not for recovery of concentrate. Depending on the mix of ore and gangue, the slope of the sluice was changed by varying the height of the supporting blocks. Papadimitriou (cited in Fragiskos 2000, 50) proposed that the sluices were suspended by ropes from roof beams and a jigging action was used. Trikkalinos (cited in Photos-Jones and Jones 1994, 329) thought that the sluices were too short (about 2m in length) to allow for an efficient separation. However, experimental work by Tsaimou (2000, 122) demonstrated that sluices of this length result in adequate separation.

Kakavoyiannis (1992 cited in Photos-Jones and Jones 1994, 330 and Fragiskos 2000, 52) suggested that the finding of a large number of fragments of shallow ceramic bowls (see Conophagos 1980, 229, Figure 10-23) at the washing workshops indicated that panning may have been the choice for separation of the concentrate. Panning took place over the tank and after a period of time, when the tank water was murky with sediment, water released through the outlets (normally plugged with clay) circulated through the rest of the system. A recent photograph by National Geographic (1988, 281) shows two Malaysian women panning tin ore from sediments using similar ceramic bowls. Domergue (1998), based on archaeological studies at a site in Spain, thought that crushed ore was mixed in the stand tank and allowed to settle for a period of time before water was released through the outlets. In his model the stand tank is a true settling basin in which the concentrate collects, and sluices are not necessary.

Purpose of the ceramic bowls

Based on my experience in heavy mineral exploration, the shallow ceramic bowls (those around 40 cm in diameter or less), were probably used to sample the product from the hopper quern and along the washing circuit, rather than for panning. A handful of sediment mixed with some water is thrown into the bowl, tilted slightly and struck repeatedly on the bottom with the hand to cause separation. The heavier minerals form a crescent pattern of concentrate on the up-slope side of the sample (called vanning, see Thrush 1968, 1197). With practice, a reasonable estimate of the percentage of heavy mineral (or concentrate) is made. In the 4th century BC, such information might have been used by the washing platform operator to make a number of processing decisions. He could judge the mineralogy and grain-size distribution of ore and gangue, the percentage of solids to put into the stand tank, when to break the clay plugs to release the water or ore slurry and also evaluate how successful the concentration was at any point in the circuit.

The stand tank as a settling basin

Conophagos's colleagues at National Technical University at Athens (NTUA), Papadimitriou (2000) and Fragiskos (2000), have continued to champion the sluice as the primary means of separation. However, Fragiskos (2000, 50) pointed out that if the head is to be maintained at the level of the outlets, the stand tank would have to be filled at a rate of about 45 litres per minute per outlet. For a four-outlet tank this would be 180 litres/minute, an impossible task for one or two workers to accomplish. His solution was that the ancient workers mixed crushed ore (to form a slurry of 10% solids) in the rear tank, stirred vigorously, then broke the clay plugs in the outlets so that the slurry could run down the sluices. As in the case of Conophagos, denser grains settled out of this slurry in the depressions, and the lighter grains carried into the channel and settling-basin system where further recovery occurred.

Domergue (1998, 39-40) compared the operation of an ancient washing facility near the Coto Fortuna silver-lead mine, Mazarron (Murcia), Spain with the flat-washing platforms at Laurium. At Coto Fortuna crushed ore was deposited in a small basin, stirred and allowed to settle. Wooden planks in the front of the basin were removed to allow the lighter fraction in the upper part of the water column to be separated. This operation was repeated in a sequence of basins. Domergue (1998, 40) interpreted the stand tank at Laurium as the primary settling basin, with the plugged outlets in the front of the basin functioning in the same way as the wooden planks in the Spanish structure. Further recovery of concentrate occurred on the working platform and in the channel and settling-basin system.

The free settling of particles in water with less than 15% solids is governed by grain size and density. Grains finer than coarse silt settle according to Stokes' Law and those coarser than fine pebbles settle by Newton's Law. Neither law fits sand-size grains, reported to be the dominant size range for the crushed ore (Conophagos 1980, 214). The settling velocity ratios (Wills 1985, 262–4) or the Law of 'Equal-Falling' Particles (Simon 1924, 17) are useful in evaluating gravity concentration in water. These ratios (see below) represent the difference in particle size between two minerals of different density which will settle at the same rate. In the free-settling column of Table 1, the ratio for the galena and calcite pair is 2.58. This means that a calcite grain of 2.58mm in diameter settles at the same rate as a galena grain of 1mm. The free-settling column represents grains settling in water with less than 15% solids. Hindered settling occurs in water with more than 15% solids (but not enough solids to suspend the densest grain). If the solid fraction increases beyond 15%, under hindered settling conditions, the effect of the density differential increases. At higher solids content, larger grains meet more resistance and their settling rate is less. A calcite grain five times larger than a galena grain will settle at the same rate (see Table 1).

Table 1: Settling velocity ratios for mineral pairs and for admixed grains (mixtures of ore minerals)

Mineral pair	Free-settling velocity ratio	Hindered-settling velocity ratio
galena/calcite	2.58	5.08
galena/smithsonite	1.54	2.10
galena/siderite	1.80	2.59
galena/goethite	1.41	1.74
galena/fluorite	2.16	3.59
galena/quartz	2.63	5.30
galena/pyrite	1.42	1.74
galena/sphalerite	1.74	2.44
cerrusite/fluorite	2.41	2.94
cerrusite/goethite	1.24	1.43
admixed: 50% galena, 50% goethite	-	1.37
admixed: 80% galena, 20% goethite	-	1.59
admixed: 50% galena, 50% quartz	-	3.16
admixed: 80% galena, 20% siderite	-	2.28
admixed: 80% galena, 20% fluorite	-	2.55
admixed: 90% cerrusite, 10% goethite	-	1.38

The following formulae (Wills 1985, 263–4) were used to prepare Table 1. For the free-settling velocity ratio:

$$da/db = [(Db\text{-}Df)/(Da\text{-}Df)]^n$$

where da = diameter lighter grain, db = diameter denser grain, Db = density of denser grain, Da = density of lighter grain, Df = density of fluid = 1.0 for the free-settling ratio. For Stokes' Law, n = 0.5 (small particles) and n = 1 for coarser particles following Newton's Law. Intermediate values apply to sand-size grains whereby n = 0.7

For the hindered-settling velocity ratio:

$$da/db = [(Db\text{-}Df)/(Da\text{-}Df)]$$

where Df = 1.5 (from Wills 1985, 264)

Simon's method (1924, 17) for calculating the density of water containing different percentages of solids suggests, given the minerals involved, that Df was likely higher than 1.5. The effect of a higher Df is to enhance the density separation, so using 1.5 here is conservative. Crushing and grinding of mine-run material normally results in grains which are mixtures of ore and gangue rather than pure ore. Settling velocity ratios for admixed ores addresses this issue. For admixed grains (see the lower portion of Table 1) composed of a mixture of ore and gangue (*eg* 80% galena and 20% siderite) density is calculated such that Db = density of galena + siderite grain and Da = density of the lighter mineral, siderite. Note that the 'limonite' or iron oxide mineral used for the density calculations is goethite.

Wills (1985, 302) states that gravity concentration is most effective if the settling velocity ratio is greater than 2.5 and ineffective if less than 1.25. Most of the above ratios are above 1.25, suggesting that under either set of settling conditions, separation should occur. However, it is very clear that separation markedly improves under hindered-settling conditions. Galena hosted in any of the primary gangue minerals, calcite, quartz, fluorite, or siderite, particularly under hindered-settling conditions, easily separates from them. Among the sulphides, galena separates from sphalerite and to a lesser degree from pyrite, again under hindered-settling conditions. The one gangue mineral that offers the most difficulty for the separation of both galena and cerussite is goethite.

Although the ratios are in the intermediate range under hindered-settling conditions, the low value for cerussite suggests, at first look, some difficulty in separation. Considering that goethite at Laurium is often powdery and porous, its effective density may be lower than the 5.0 used for goethite calculations and the ratios higher than those in Table 1. Since grinding does not necessarily result in a complete liberation of the lead minerals from the gangue, hindered-settling ratios are calculated for a few admixed grains. If the density difference is sufficiently large between the lead mineral and the associated gangue mineral (*e.g.* quartz, calcite, fluorite, siderite gangue), then the settling ratio is favourable. Admixed goethite with either lead mineral reduces the ratio.

Using the stand tank as a settling basin emphasises the importance of pre-washing liberation to effect as clean a release of lead minerals from the gangue as possible. Grinding to sand size at the hopper querns greatly enhances the chance of liberating one of the lead minerals from the enclosing gangue. Goethite may not have been as much of a problem to separation as it appears because, as noted before, it is typically a powdery or porous cellular material that could be easily removed during grinding. Galena is the limiting factor in the grinding operation because it is a very soft, easily cleavable mineral compared to the other associated minerals. Too much crushing and grinding quickly reduces it to a black powder, lost on the surface of marble slabs or the quern (*ie* the over-liberation case of Wills 1985, 17). Quern operators had to stop grinding before the galena powdered (although some powdered galena may have been recovered by brushing the crushing and grinding surfaces). This is likely to have resulted in a higher frequency of coarser galena or admixed galena grains available for the subsequent washing stage. However, concentrating under hindered-settling conditions allows for admixed and coarser grains to be effectively separated.

Both Fragiskos (2000) and Domergue (1998) suggest that the crushed ore was mixed in the stand tank, but from this point on, their interpretation of the processing sharply diverges. For Fragiskos, the stand tank is not so much a settling basin as a mixing tank that feeds crushed ore to the sluices. In his explanation of the process (Fragiskos 2000, 50), a fixed amount of crushed ore is placed in the stand tank, stirred and then released through the outlets to the sluices where the primary concentrate is collected. Presumably, the finely ground ore, after vigorous stirring, rises to a level above the outlets. One possible difficulty with using the tank as a mixing basin, depending on the particular mix of ore and gangue and the uniformity of grain size in the feed, is that a certain amount of this crushed ore might quickly sink below the level of the outlets and accumulate on the bottom of the tank rather than be supplied to the sluices. Fragiskos is a strong advocate of the 'sluice theory', and his approach does solve the problem with the earlier Conophagos model of maintaining head in the tank. Domergue (2000, 41), by contrast, treated the stand tank as a true settling basin and eliminated the sluices. Both Fragiskos and Domergue recognised that the channel and basin system led to recovery of concentrate that bypassed the working platform. In Fragiskos' criticism (Fragiskos 2000, 52) of Domergue's model he appears to misinterpret the role of the working platform. He argues that if recovery were to occur on the working platform, then the outlets should be closer to the base of the tank creating a thin, uniform flow of water for separation. Domergue's illustration of the flat-washing platform showed workers apparently using a 'rake' to separate material from the slurry moving across the working platform, but he quite clearly believed that the stand tank was the primary basin in which concentrate was collected.

In the hindered-settling model, lead minerals form a concentrate in the bottom of the stand tank. The gangue minerals, along with any lower grade concentrate, are released through the outlets into the channel and settling basin system. Lower grade concentrate and tailings are recovered and water is recycled. Part of the problem for the workshop operators was knowing how much solid to mix in order to effect a separation. Vanning the material delivered from the hopper quern would give them an estimate of the size distribution and the percentage of ore and of gangue minerals. There was certainly some trial and error before a particular volume of ground material was introduced into the tanks. Crushed ore mixed and stirred in the tank, probably with wooden paddles, was allowed to settle for a period of time. The coarser sand-sized grains of galena and cerussite mixed with some gangue settled below the level of the outlets and accumulated on the bottom of the tank. At some point the clay plugs were removed and water plus finer ore grains and coarser gangue flowed out on to the working floor.

Design and function of the flat-washing platforms

The mid-level location for the outlets reflects the fact that the workers recognised the need for the maximum strength for the outflow. A jet of water from an outlet follows a curved path before striking the sluice or the working floor. An estimate of the horizontal trajectory of the water jet is based on the following formula from Webber (1968, 39):

$$x = (4hy)^{0.5}$$

where x = horizontal trajectory of the jet, h = vertical distance from the outlet to the water surface (head), and y = vertical distance from the outlet to the working floor. The formula can be used to calculate decreasing x as the head (h) falls. Thus, the maximum horizontal extent of the outflow from an outlet with a 400mm mid-level position would be 800mm and the minimum (at h = 10mm) 126mm. Using $y = -x^2/4h$ the trajectory for any given head can be plotted. At maximum head the jet intercepts the sluice (sloping line in Fig 5) about 400mm from the front wall of the tank. As the head falls, the point of interception moves up toward the top of the sluice.

Note that Webber's formula does not factor in the effect of viscosity, which would shorten the calculated trajectories, or the cone shape of the outlet which would lengthen them. Conophagos's photograph (1980, 238, Fig 10-21) of an outlet (called a tuyère in the illustration) shows a cone-shaped structure with the smaller diameter end toward the outer wall of the stand tank. He states (1980, 241) that the outlet was designed to 'improve hydrodynamic flow and reduce friction'. The equation of continuity requires equal masses of water to pass through the larger and smaller cross-sections of the outlet in a unit of time. This can only occur if velocity increases which, in turn, increases the distance the stream of water travels.

Why design an outlet to increase the horizontal component of the jet if the water was to intercept the sluice near its top? The likely answer lies in the need for a quick release of the slurry above the outlet level, sending lower-grade ore and tailings across the working floor, after a period of settling to collect concentrate in the stand tank. The mid-level position and cone shaped structure of the outlets results in a trajectory for the jet of water that does not favour the use of sluices. In the hindered-settling model, lead minerals form a concentrate in the bottom of the stand tank. The gangue minerals, along with any lower grade concentrate, are released through the outlets into the channel and settling basin system. Lower grade concentrate and tailings are recovered and water is recycled.

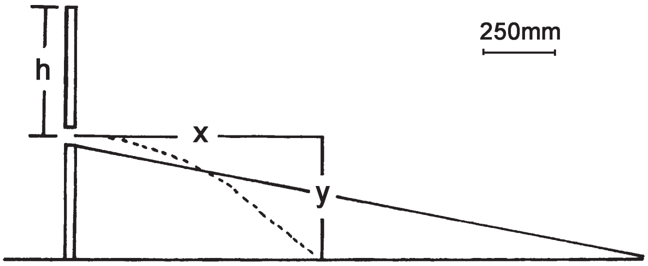

Figure 5: Calculated path for a jet of water issuing from an outlet located at mid-level in the front wall of a stand tank. The head is h, *the horizontal component of the jet is* x *and the vertical component is* y. *The jet of water intersects the sluice (sloping line) about 400mm from the front wall of the stand tank.*

In Conophagos's sluice model, the energy for the separation of the lead minerals from the tailings comes from the slope of the sluice, not the force of the jet. In this case the separation at maximum head begins not at the top of the sluice, but below a point some 30cm down the sluice. With falling head, water would eventually be fed to the top of the sluice. In order for any separation to occur, Conophagos required that workers stir the ground ore in the cups freeing the tailings from the lead minerals. However, having the head of the sluice at an outlet at the mid-point of the stand tank does not seem to be a very efficient method to effect separation. The better method would have the stand tank elevated above the top of the sluice with an outlet at the base such that water would fall on to the head of the sluice. It is interesting that Tsaimou (2000, 122, Fig 16), in her laboratory tests to determine the viability of the 2m sluices for ore concentration, placed them below the tank in order that the water would fall on the head of the sluice. This is a common position for the sluices (see drawings by Agricola 1556, 301–15, and Overman 1865, 708, Fig 368). The stand tank and its outlet system were not designed for sluices.

Using the stand tank for primary separation and the channels and settling-basin system for additional recovery obviates the need for sluices. Wills (1985, 323) indicates that a thin film of flowing water can effectively separate coarser lighter grains from denser finer grains and some separation may have happened on the working floor. However, it is more likely that the channel and settling-basin circuit (rather than the working platform) was the main means of recovery beyond the stand tank. The working floor gave the worker access to the stand tank for mixing in the ore from the hopper quern and for collecting the concentrate from the bottom of the tank. Periodically, containers of water were washed across the floor to flush any residue on it into a recirculation-recovery system.

As concentrate accumulated, the operator could van a sample of the material to decide whether to re-fill the tank and re-mix the slurry or to add a new mix of ground ore. With multiple outlets available, the tank operator could choose how many of them to open, depending on the particular ore mix and the discharge needed to effect separations. Once the concentrate reached some thickness, the layer of water between the top of the concentrate and the outlets could be baled and sent through the channels. Wet concentrate was then scooped out and placed on the drying floor. Operation of the washing workshops was seasonal, because water was largely collected during the winter months (Conophagos, 1980, 254). Any residual concentrate remaining in the bottom of the stand tank was easily recovered at the end of the working season.

Water, lower-grade concentrate and tailings would continue to circulate through the channels and the intervening settling basins for the purpose of recycling water and recovering some material for smelting. As indicated earlier, the ceramic bowls were used to check the grade of the material at various places starting at the stand tank and then continuing throughout the re-circulation system. Depending on the results of this testing, some material was probably re-processed. According to Conophagos (1980, 302) smelting-grade concentrate was placed on the drying floor and briquetted prior to being charged to the smelting furnaces. If the finely-ground concentrate was briquetted at the washing workshops, then some sort of binder, such as clay, would have been necessary. Recovery of clay as part of the tailings separation may have been an important aspect of the recirculation process.

There is a question regarding the absence of a drain or clean-out outlet near the base of the outer wall of the stand tanks. In the operational models proposed by Domergue (2000) and by the author, the primary concentrate is recovered from the bottom of the stand tank and there is no need for this material to circulate through the rest of the system. In addition, the absence of outlets in this position may be because the clay plugs occasionally failed. The operator would not have wanted to risk releasing concentrate from the stand tank through the circulation system due to failure of a drain outlet. Actually the only operational model with which clean-out outlets would be useful is that proposed by Fragiskos. Workshop operators would want to recover any concentrate that escaped to the bottom of the stand tank during the mixing process.

Ardaillon's observations (see above) of the baffles within channels and of the difference in the elevation of the inlets and outlets for the channels at the corner settling basins strongly support a staged operation in which workers recovered concentrate and tailings throughout the re-circulation system. Concentrate may have been collected in the channel along the edge of the working platform, in the next channel in sequence and from decantation at the first corner settling-basin. Tailings perhaps dominated the material in the remaining settling-basins prior to the re-use of the process water. As suggested above, some of the tailings could have been used as a binder for the briquetting of concentrate.

Conclusion

The stand tank, using hindered-settling conditions, was probably the primary point of separation for the galena and cerussite concentrate. Circulating water, carrying tailings and finer-grained ore released from the outlets, flowed across the working floor and into the channel and settling basin system for further recovery of concentrate and for recycling water. Vanning, in small, shallow ceramic bowls, allowed the ore-processing staff to evaluate the grain size and mineralogy of the product from the hopper quern and to determine the percentage of concentrate at various points along the flat-washing platform circuit.

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