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Ancient Gold Extraction at Bir Umm Fawakhir

CAROL MEYER, BRYAN EARL, MOHAMED OMAR,
AND ROBERT K. SMITHER

In 1997 the Bir Umm Fawakhir Project of the Oriental Institute of the University of Chicago undertook a special investigation of the ancient mines and ore reduction techniques attested at and around the site. The first four seasons of work in 1992, 1993, 1996, and 1997 focused on mapping the main settlement at Bir Umm Fawakhir in detail, surveying more generally the vicinity of the site, and addressing some specific questions about the site.¹ One of these questions—how did the ancient miners win gold from the rocks of Bir Umm Fawakhir—is the subject of this paper.

Bir Umm Fawakhir lies in the central Eastern Desert of Egypt at 26° 00' N and 33° 22' to 23' E, or about 5 km northeast of the Wadi Hammamat, on one of the most important routes between the Nile at Quft (ancient Coptos) and the Red Sea at Quseir (see fig. 1). Long called a Roman caravan station, the site looks nothing like the orthogonal, walled *hydreumata*, or watering stations, along the ancient route, and the pottery is not Roman, like that well attested at Quseir al-Qadim.² The 1992 project, then, was designed to map the site and to determine its date and function. Our plan to survey the entire site in two weeks proved hopelessly optimistic; only 55 buildings or roughly one-quarter of the main settlement could be plotted. The project did, however, determine that the date of the primary occupation was 5th–6th century A.D. Coptic/Byzantine, and it established the site's main function as a gold mine. We considered and rejected the possibility that it was a caravan station. The site is far too large and sprawling, many times larger than the modest number of people needed to man a watering station. Nor was it primarily a military installation. It has no walls or defensive structures at all, only a couple of rough guard posts on overlooking hilltops, though its situation in a long, narrow, steep-sided wadi could offer some protection. The possibility that it was a granite quarry could not be so easily dismissed. Quarrying does require a large labor force, and there is evidence of quarrying in several places.³ This is now considered to have been an earlier, Roman period activity at Bir Umm Fawakhir, perhaps only exploratory. There is a handful of Roman pottery around the quarries, and the quarry marks are virtually identical to those at the 1st–2nd century A.D. quarry at Mons Claudianus.

¹ The Bir Umm Fawakhir 1992 and 1993 seasons are reported in Meyer, "Gold, Granite, and Water: The Bir Umm Fawakhir Survey Project 1992," *The Annual of the American Schools of Oriental Research* 52 (1995), 37–92; and Carol Meyer, Lisa A. Heidorn, Walter Kaegi, and Terry Wilfong, *Bir Umm Fawakhir Survey Project 1993: A Byzantine Gold Mining Town in Egypt*, Oriental Institute Communication 28 (Chicago, 2000). Preliminary reports on the 1996, 1997, 1999, and 2001 seasons appear in Meyer, "The Bir Umm Fawakhir Survey Project," *The Oriental Institute 1995–1996 Annual Report* (Chicago, 1996), 31–39; idem, "Bir Umm Fawakhir," *The Oriental Institute Annual Report 1997–1998* (Chicago, 1998), 28–39; idem, "Bir Umm Fawakhir," *Oriental Institute 1998–1999 Annual Report* (Chicago, 1999), 25–37; and idem, "Bir Umm Fawakhir," *Oriental Institute 2000–2001 Annual Report* (Chicago, 2001), 17–25.

² W. Raymond Johnson, "Roman Pottery," in Donald S. Whitcomb and Janet H. Johnson, eds., *Quseir al-Qadim 1978: Preliminary Report* (Cairo, 1979), 67–103; Donald S. Whitcomb, "Roman Ceramics," in Whitcomb and Johnson, *Quseir al-Qadim 1980* (Malibu, California, 1982), 51–115.

³ Rosemarie Klemm and Dietrich Klemm, *Steine und Steinbrüche im Alten Ägypten* (Berlin, 1993), 355–58.

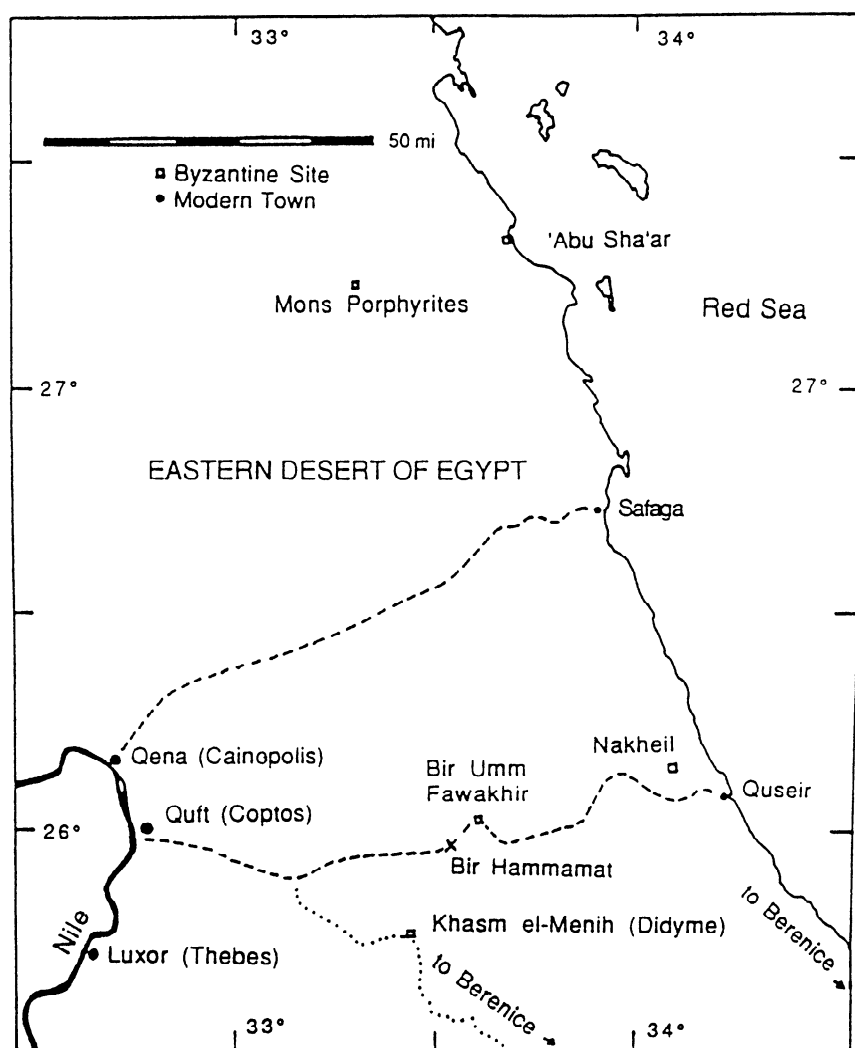


Fig. 1. Map of Eastern Desert

However, the Bir Umm Fawakhir quarries are far smaller and less extensive than those at Mons Claudianus or Mons Porphyrites, and there are no shelters for the draft animals needed to drag stone along the route back to the Nile. There are no remnants of any Roman buildings at all, much less any construction on the order of the forts, temples, and workers' villages at Mons Claudianus or Mons Porphyrites. One of the houses in the main settlement in fact is built *over* a quarry block.

On the other hand, the evidence for mining is everywhere.⁴ The surrounding hills are riddled and trenched with mines and hard rock mining does require a large labor force. Crushing and grinding stones are scattered all over the site. In fact, they are the second most common artifact after potsherds. Finally, gold-mining occurred at Bir Umm Fawakhir intermittently during the 20th century and especially in the 1950s in the Wadi el-Sid, about 4 km to the southeast. This mine is a large commercial plant, closed since the revolution and now maintained by the Egyptian Geological Survey and

⁴ Contra Dietrich D. Klemm, Rosemarie Klemm, and Andreas Murr, "Ancient Gold Mining in the Eastern Desert of Egypt and the Nubian Desert of Sudan," in Renée Friedman, ed., *Egypt and Nubia: Gifts of the Desert* (London, 2002), 219.

Mining Authority, and it has been called the richest gold mine in Egypt.

In 1993, 1996, and 1997 the Bir Umm Fawakhir Project continued mapping the main settlement and located fourteen outlying clusters of ruins of the same date (see fig. 2). One special question addressed was how many people lived at the ancient site: the current working estimate is a little over a thousand in the main settlement alone, assuming no one at all lived in any of the fourteen outliers. In 1996 we discovered New Kingdom remains near the modern Wadi el-Sid mines, and in 1997, we completed the map of all 237 buildings in the main settlement (fig. 2) and carried out the investigation of the ancient mines and ore reduction techniques reported here.

One of the first findings was that simply calling it a “gold mine” does not fully explain the site. Far from it. Virtually all discussions of ancient Egyptian gold sources refer to alluvial gold, primarily from Nubia or the south of Egypt. Alluvial or “placer” gold occurs as flakes in the beds of water courses; it is loose and can be panned or washed out. A small, temporary, unskilled labor force can do it, e.g., a forty-niner and his mule during the California gold rush. At Bir Umm Fawakhir, however, the gold occurs in quartz veins in granite—hard rock mining. This requires a large labor force, skilled engineers to determine where to mine, an efficient organization to assemble and support the miners, especially in so remote a region, and a significant investment of capital. Subsequent smelting required yet another skilled operation. The work force at Bir Umm Fawakhir seems to have consisted of career miners, well-supplied and probably reasonably well paid. They may have made a decent living but unlike a forty-niner or freelance gold panner, they could never have struck it rich.⁵ Profits if any would have flowed out to the organization providing the capital support, in this case almost certainly the Byzantine government, which

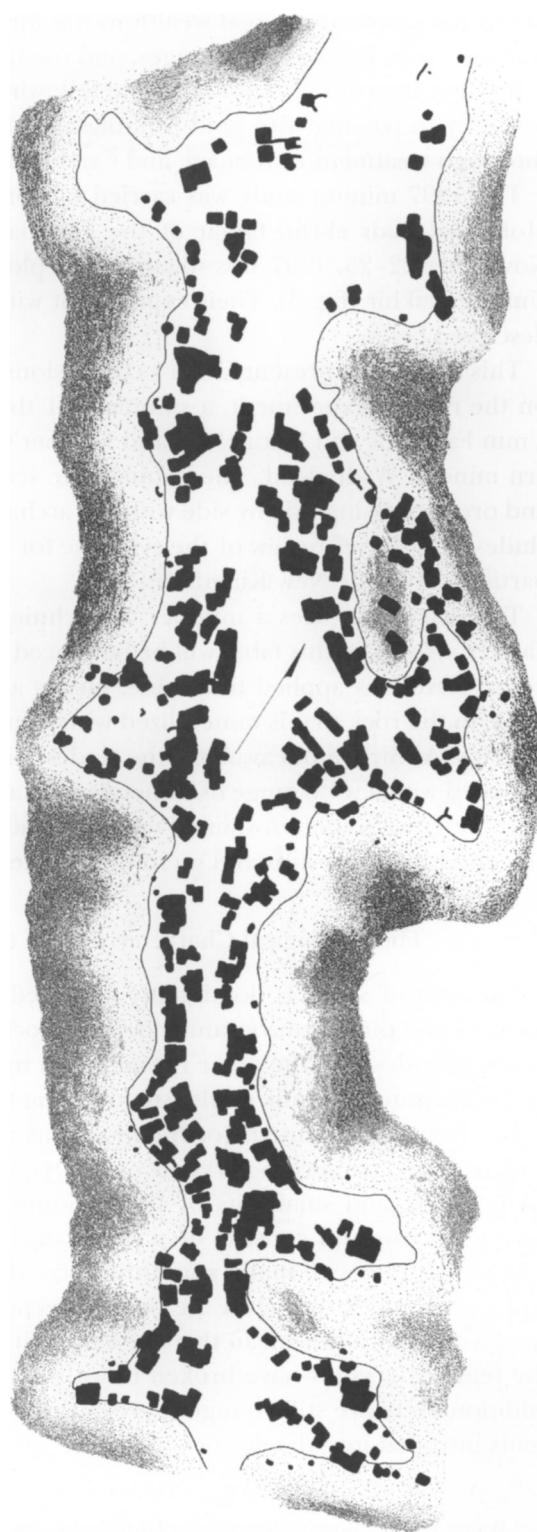


Fig. 2. Schematic map of Bir Umm Fawakhir main settlement

⁵ Carol Meyer “Gold-miners and Mining at Bir Umm Fawakhir,” in A. Bernard Knapp, Vincent C. Piggott, and Eugenia Herbert, eds., *Social Approaches to an Industrial Past* (New York, 1988), 258–75.

would have been using real wealth in the form of grain to obtain gold for special purposes such as coinage, wars, ransoming hostages, and the like.⁶

It is also important to note that the following study deals with mining, ore reduction, and smelting, and only in passing with gold refining and not at all with metal working. For gold refining see the thorough treatment in Ramage and Craddock's study of the industry at Sardis.⁷

The 1997 mining study was carried out primarily by Bryan Earl, a retired mining engineer, and Mohamed Badr el-Din Omar of the Egyptian Geological Survey. Omar and Earl spent four days, November 22–25, 1997, investigating and plotting the opencast and underground mines around Bir Umm Fawakhir (fig. 3). Their experiment with crushing and grinding the ore and then washing it is described below.

This article will present Omar's conclusions about the geology of Bir Umm Fawakhir, Earl's report on the mining experiment, a summary of the earlier 20th century evaluations of gold yields at Bir Umm Fawakhir and Wadi el-Sid and Smither's APS analysis of ore concentrate from the nearby modern mine at Wadi el-Sid. The penultimate section reviews the ancient texts concerning gold mining and ore processing side by side with the archaeological data from Bir Umm Fawakhir. The paper concludes with a brief review of the evidence for this kind of mining before the Coptic/Byzantine period, particularly in the New Kingdom.

The discussion uses a number of technical geological and mining terms, which are defined in Table 1. Words in this table will be boldfaced throughout, but two commonly used terms are defined here. "Level," as applied to a mine, means a tunnel. A "lode" is some form of fissure or weakness plane in the rock that is mineralized with valuable material, or a mineral deposit consisting of a zone of veins. At Bir Umm Fawakhir, the "lodes" are white quartz veins injected into granite. The quartz is enriched with a wide range of minerals such as pyrite (fool's gold), and the edge of the vein in contact with the granite is often stained with hematite. Those who wish may accept the geological, engineering, and physical results and go to the archaeological sections.

The Geological Characteristics of the Bir Umm Fawakhir Area (*Mohamed Omar*)

The area of study is dominantly occupied by low to moderately rugged mountainous terrain. It consists of a pink monzogranitic body of rock, the Precambrian Fawakhir Granite (roughly 590 Ma), which intrudes into the older Precambrian **mafic-ultramafic** country rock. (Country rock is the rock that constitutes the bulk of the surrounding terrain.)

The Fawakhir granite is for the most part a coarse to very coarse crystalline rock, mottled gray to pink in color, comprising crystals of quartz, feldspar (plagioclase), variably distributed pink feldspar (orthoclase), and small bits of black biotite and stained-opaque hematite. The granite is variably heterogeneous and consists of a wide range of composition from gray granodiorite to pink alkali feldspar granite with **mafic xenoliths** derived from the pre-existing rocks. The rock is jointed (fig. 4) and exfoliated, resulting in the normal rectangular pattern and in spheroidal masses of granite respectively. The joints mean that the Fawakhir granite is easily cut or split into blocks. In some places the feldspar crystals have broken down to kaolin, so the weathered granite may be very friable. In addition there are still younger dykes of pink felsite, **pegmatite**, and numerous quartz stringers and veins intruded into the granite.

⁶ Walter Kaegi, "Observations on the Historical Context of Bir Umm Fawakhir," in Carol Meyer, Lisa A. Heidorn, Walter E. Kaegi, and Terry Wilfong, *Bir Umm Fawakhir Survey Project 1993: A Byzantine Gold Mining Town in Egypt*, Oriental Institute Communications 28 (Chicago, 2000), 3–4.

⁷ Andrew Ramage and Paul T. Craddock, *King Croesus' Gold*, Archaeological Exploration of Sardis Monograph 11 (Cambridge, Massachusetts, 2000).

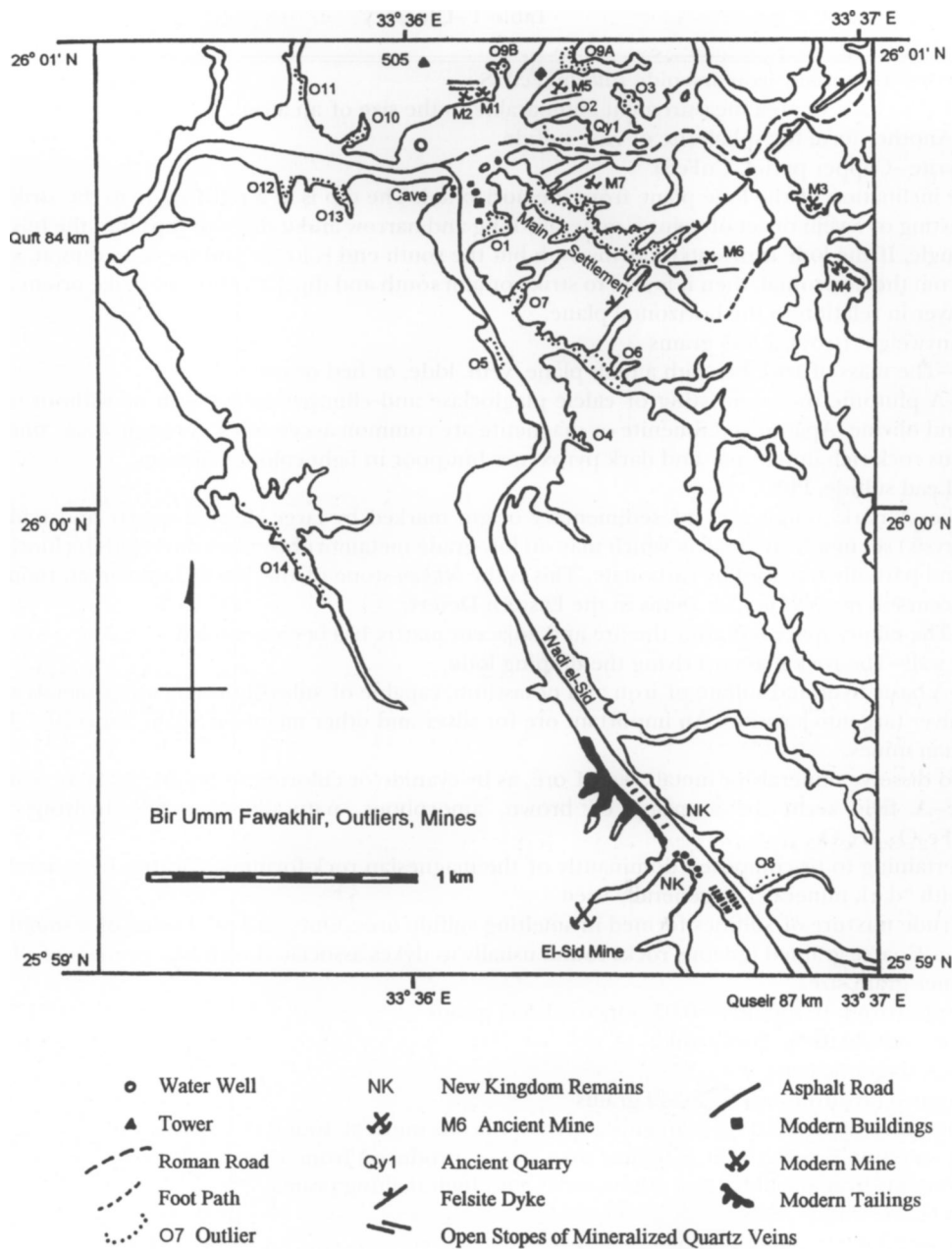


Fig. 3. Map of Bir Umm Fawakhir, Wadi el-Sid, and Vicinity (map by Carol Meyer and Mohamed Omar)

The occurrence of gold is restricted to quartz veins that are controlled by the structure of the rock into which they were injected. The veins are intensive fracture-fissure fillings. The trending of the veins is mostly east-west, associated with subordinate northeast-southwest and southeast-northwest directions, dipping southwards at moderate to steep degrees. The mineralized veins are made up of a number of lenticular bodies occurring in zones rarely continuous for more than 200 meters along **strike**. They are confined to zones of intensive fracturing of variable extent and thickness, and may

Table 1—Glossary

Arsenopyrite—Essentially iron arsenide sulfide, FeAsS
barns— 10^{-24} sq cm. An area measurement comparable to the size of an atom.
Blende—Another term for sphalerite or zinc sulfide
Chalcopyrite—Copper pyrite, CuFeS ₂
Dip—The inclination of the lode plane from the horizontal. The dip is at a right angle to the strike. A lode consisting of a vein or set of veins is generally long and narrow and it dives or dips into the host rock at some angle. If the lode is oriented north-south but the south end is lower and the lode dips at, say, 15°, down from the horizontal, then it is said to strike or aim south and dip 15°. Dip and strike orient any geological layer in relation to the horizontal plane.
dwt—Pennyweight (troy), 1.555 grams
Footwall—The mass of rock beneath a fault plane, vein, lode, or bed or ore.
Gabbro—A plutonic rock consisting of calcic plagioclase and clinopyroxene, with or without orthopyroxene and olivine. Apatite and ilmenite or magnetite are common accessories. A tough, dark, fine-grained igneous rock rich in feldspar and dark pyroxenes but poor in light-colored silicates.
Galena—Lead sulfide, PbS
Graywacke—A dark, tough rock of sedimentary origin marked by large detrital quartz and feldspars (phenocrysts) set in a “clay” matrix which may on low-grade metamorphism be converted to chlorite and sericite and partially replaced by carbonate. This is the <i>bekhen</i> -stone of the Wadi Hammamat, though graywacke occurs in many other locations in the Eastern Desert.
Gunnis—The empty space left after the ore and adjacent matrix has been removed
Hanging wall—The rock mass overlying the dipping lode
Jarosite—A basic hydrated sulfate of iron and potassium, capable of substitution by other metals such as lead or silver (argento-jarosite). An important ore for silver and other metals in Spain, especially the ancient Roman mines.
Leach—To dissolve minerals or metals out of ore, as by cyanide or chlorine solutions, acids, or water
Limonite—A field term for a group of brown, amorphous, naturally occurring hydrous ferric oxides, 2Fe ₂ O ₃ ·3H ₂ O
Mafic—Pertaining to or composed dominantly of the magnesian rock-forming silicates. In general, synonymous with “dark minerals” as generally used.
Matte—Crude mixture of sulfides formed in smelting sulfide ores. One kind of residue of a smelting operation.
Pegmatite—Coarse-grained igneous rocks found usually as dykes associated with a large mass of plutonic rock of finer grain size.
Pennyweight (troy) = 24 grains = 0.05 ounce = 1.555 grams
Pyrite—Iron sulfide, FeS ₂ . Fool’s gold.
Pyrrhotite—Magnetic pyrite Fe _{1-x} S
Regular ounce (avoirdupois) = 28.349 grams
Serpentine—Mg ₆ (Si ₄ O ₁₀)(OH) ₈ , a greenish, greasy, fibrous mineral; found in igneous and metamorphic rocks
Speiss—A smelting product that is lighter than matte, produced from an ore with antimony or arsenic. Speiss contains iron arsenides and antimonides with high melting points.
Sphalerite—Zinc sulfide, ZnS
Stibnite—Antimony trisulfide, Sb ₂ S ₃
Stope—An excavation from which the ore has been extracted, either above or below a level, in a series of steps.
Stopping—Mining out ore, the loosening and removal of ore in a mine either by working upward (overhead or overhand) or downward (underhand).
Strike—The plane direction or course of a lode. See “dip” above.
Troy ounce = 20 pennyweight = 480 grains = 31.103 grams, slightly heavier than the commonly used avoirdupois ounce of 28.349 grams
Xenolith—Allothogenic rock fragments that are foreign to the body of igneous rock in which they occur; an inclusion of rock from some other source in igneous rock.

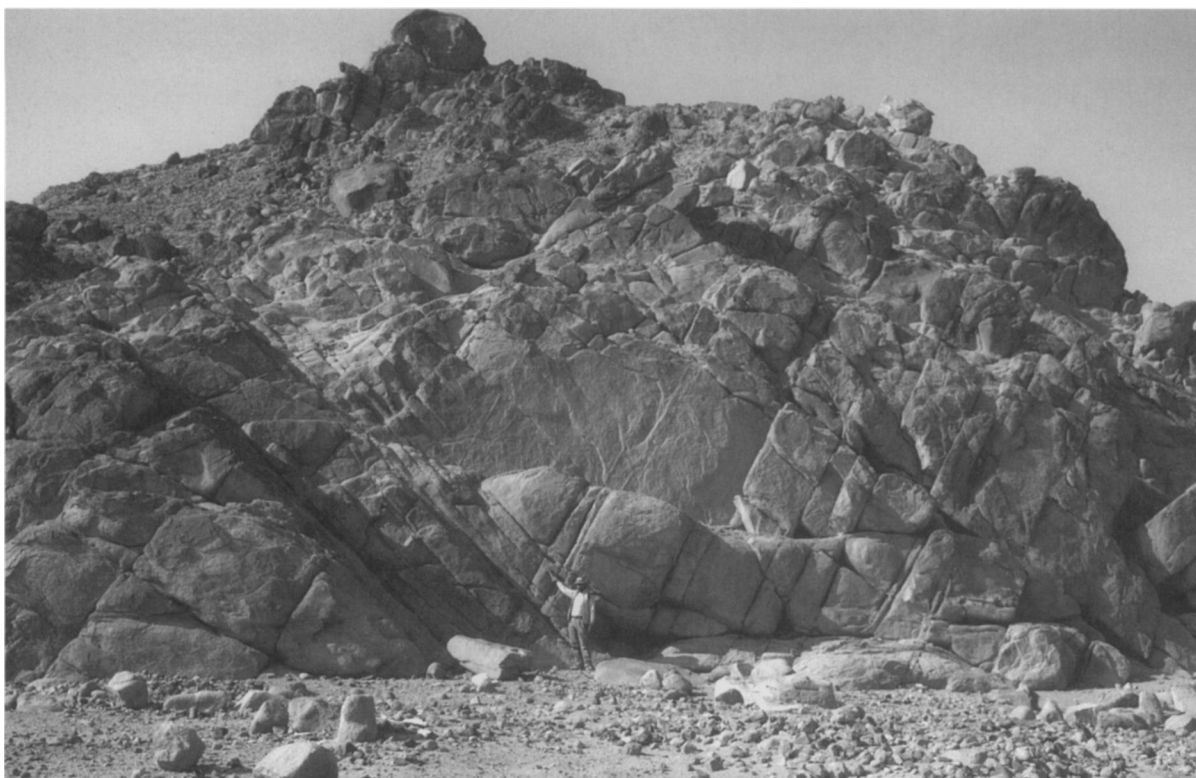


Fig. 4. Jointed granite (photo by Henry Cowherd)

reach up to 0.5 meter in width. The veins, however, are typically narrow, and are always associated with parallel veinlets and stringers (fig. 5).

Mineralogically, gold-bearing veins are composed of milky white, dense quartz. Barren, gold-free quartz commonly can be found in the vicinity of mines. Gold is unevenly disseminated in auriferous veins, and is intimately intergrown with other minerals, notably **pyrite**, **chalcopyrite** (CuFeS_2), **pyrrhotite**, **sphalerite**, and **galena**.

In the vicinity of the Bir Umm Fawakhir site, the quartz veins were intensively prospected for gold and exhausted by ancient workers wherever their mining techniques could win gold by hand milling and **leaching**. Discarded crushing and grinding stones and hand-held stone hammers are still to be found at most mines and mining sites. First, the ore substance dug out was crushed, washed, and collected as a soft powder. Roasting and smelting of the ore were the next processing stages, which presumably were performed on site or in a special refinery elsewhere.

There are at least seven mines for gold (fig. 3) in the area of Bir Umm Fawakhir, associated with abandoned workings such as small trenches and open **stopes** or casts. Three of them are provided with short adits, access tunnels cut at right angles to the quartz veins. There are some old tailings bisected by the asphalt road in the vicinity of the wells of Bir Umm Fawakhir. Reported tonnages and grades, according to Kochin are some 30,000 to 40,000 tons of ore, averaging 3.63 grams per ton.⁸

⁸ R. Kochin, Ms. report to EGSMA on Eastern Desert gold occurrences (1968).

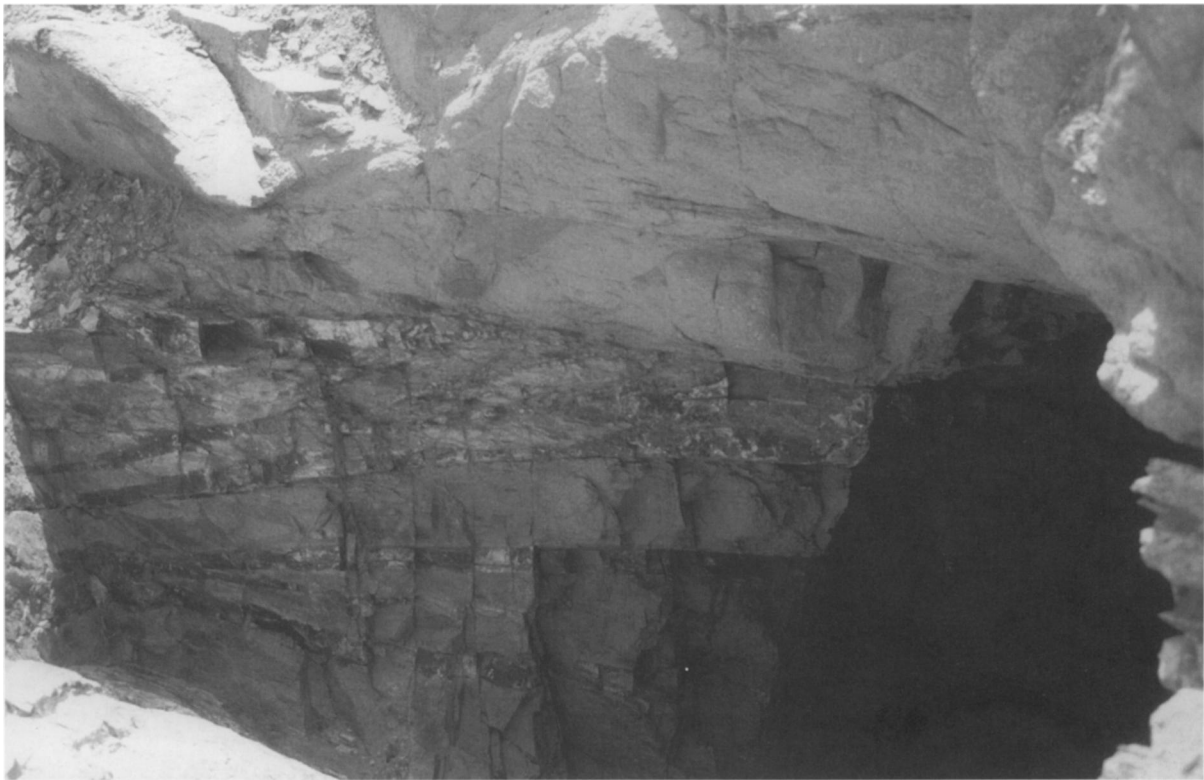


Fig. 5. Quartz veinlets (photo by Henry Cowherd)

The Mines of Bir Umm Fawakhir (*Bryan Earl*)

The Bir Umm Fawakhir area appears to have been mined for gold in three phases: very early, in the Roman/Byzantine period (by the appearance of the cuts and the associated sherds), and recently—ca. 1950 A.D. There is no doubt that the locality is a gold source.

Examination

The cuts into the mountainside, which have been labeled by the archaeologists as “mines,” are four levels (tunnels) driven in from the wadi floors, through country rock, to intersect lodes in the rock mass. These lodes are reported to be gold bearing, and frequently show evidence of ancient workings. The levels themselves appear to be recent; rock with narrow-gauge shotholes (drill holes) over half a meter long can be found in the waste rock piles of material coming from the work. They were probably exploratory **drives** (tunnels), designed to reach the lodes exposed in the surface of the hill above and enable valuations to be made of them. In some cases these levels had broken into the old **gunnises** of the ancient miners’ workings. This prospecting was probably undertaken early in the 20th century or in the 1950s by the company that was operating the el-Sid gold mine (GPS location 25° 59.47 N; 033° 36.80 E), some of whose workings were reported as being ancient.

Two levels, mines 1 and 2 (mean GPS 26° 00.80 N; 033° 36.29 E, fig. 3) were driven to intersect a lode in the rock mass, which can be seen in the hill surface above, over a **strike** length of at least 200 meters, probably worked down **dip** for at least 100 meters in places (cf. fig. 6, opencast mine). Some

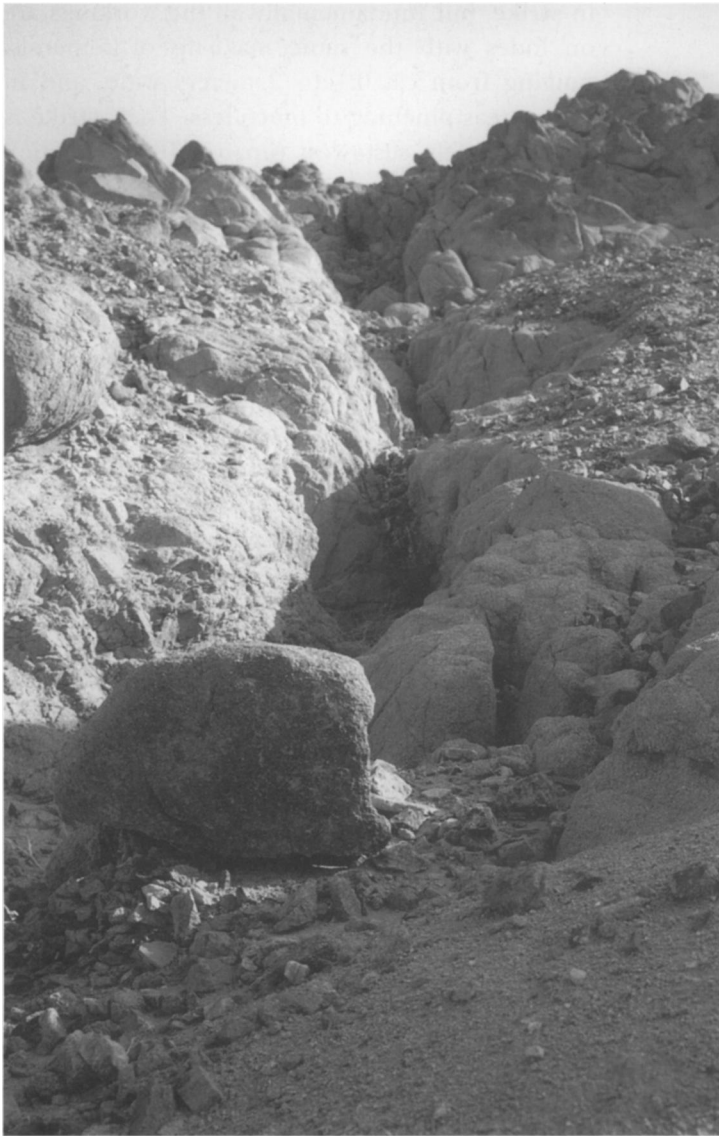


Fig. 6. Opencast mine (photo by Henry Cowherd)

modern **stopping** may have been done at depth, but there are signs that a wall, possibly of Roman/Byzantine date, had been constructed around one **gunnis** exposure, to prevent tailings and dump material from falling into the workings (fig. 7). This lode appears to be the same (on the same **strike**) as that worked into at the crest of the hill at the opposite side of the wadi; here it has also been opened up and worked to some extent by a shaft sunk into the wadi floor. By the nature of this work the shaft was recent work. The **stopping** in the crest of the hill has a considerable scatter of old sherds, mostly Roman or Byzantine. There are the remains of a human hilltop burial adjacent to the **gunnis**. The operation has been labeled “mine 5” (GPS 26° 00.81 N; 033° 36.45 E; fig. 3).

Traveling away from these workings, two further “mines” have been identified: mines 3 and 4 (fig. 3). Again, it appears that the modern miners had driven in from the wadi floor to intersect lodes that had been worked down into the hillside above. At “mine 3” (GPS 26° 00.61 N; 033° 36.99 E) the exposed **strike** was ca. 150 meters; at “mine 4” (GPS 26° 00.53 N; 033° 37.08 E) about 250 meters of the vein along **strike** had been cut into. Numerous early sherds and evidence of hand picking of

orestuff (raw ore, both the pure white quartz and that stained with minerals) at a crushing stone was notable, but the material around the stone looked fresh, so it may be the result of some fairly recent experimenting. There are almost certainly more mining operations in the area.

In all the examples seen, the **gunnises** have been more or less filled by rock debris, almost certainly from long weathering causing material either to fracture from the **hanging wall** or to fall in from the rocks above.

The lode exposed and examined in the recent (ca. 1950s) underground working from the main incline shaft of the mine at el-Sid, as well as all the ancient workings exposed in the hills of this site at the side of the wadi leading to the el-Sid shaft, look very similar in character and mineral suite to the lode exposures at “mines” 1, 2, 3, 4, and 5. There are differences in width and some small variations



Fig. 7. Entrance shaft to deep mine with retaining wall (photo by Henry Cowherd)

in **strike**, but fundamentally all the workings are on lodes with the same make-up of minerals, ranging from ca. 0.1 to 2 meters wide, and in some areas pinching to much less. Their **strike** is approximately east-west (up to 110° magnetic), dipping south at ca. 80° . The host rock is a brownish-pink granite, which has suffered decomposition to a greater or less degree, depending on location. The valuable mineralization in the granite appears to be controlled by the close unconformity to the **gabbro**, **serpentine**, and schist rocks around the granite.

The mining appears to have developed in three phases. The first was the discovery of gold in the orestuff that was mined by a series of pits following the quartz ore exposures, which seem to be most notable above mines 1 and 2. The system of mining with pits can just be seen by surface examination, but would be more visible in stereo pairs of aerial photographs of the exposure. This type of mining is characteristic of the most ancient workings, although there are examples of this mining technique still being used in England during the last century.⁹ The overall view, however, is that the original work being examined was very old; this kind of work could be earlier than

2000 B.C. The mining later evolved into more widespread excavation down into the orebody, leaving pillars of ore unworked if the ground was judged liable to collapse. Such working could be Roman or somewhat later, or both. The rock may have been excavated, in most sites, by breaking the rock with a hammer and levering it out, as the lodestuff is moderately friable. Bearing in mind the great skill developed in Egypt to quarry and work the hardest rocks, mining this lodestuff would not have been a great problem. There were traces of what could be pick or toolmarks in the mines, but the indications were not very clear. It is possible that the rocks were fractured by building a fire against them. The expansion of the rock near the fire caused by the heat develops stresses in the rock, so that it can be hammered or wedged out with greater ease. However, in the workings viewed there were no characteristic burning spots nor signs of charcoal, although it is possible these indications have been lost in the decomposition of the country rock. Such firesetting would have been restricted to particularly hard sections of ore as fuel does not appear to have been at all plentiful in the area.

The primary mineral found in all the lodes is quartz, with a range of silicate minerals. Distributed in a typical patchy fashion in this is a wide selection of metalliferous minerals. In hand specimens, **limonite** ($2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$), **pyrite** (FeS_2), **chalcopyrite** (CuFeS_2), **galena** (PbS), **sphalerite** (ZnS) and possibly **stibnite** (Sb_2S_3) could be seen. No obvious gold was detected in the hand specimens chipped from the lodes. Orestuff from mine 3 (fig. 8) was selected for the crushing and washing experiment because it was comparatively remote from human disturbance and appeared entirely typical of the

⁹ See the editorial on celestine mining in "Strontium," *Chemistry and Industry* no. 45 (November 7, 1953), 1185.

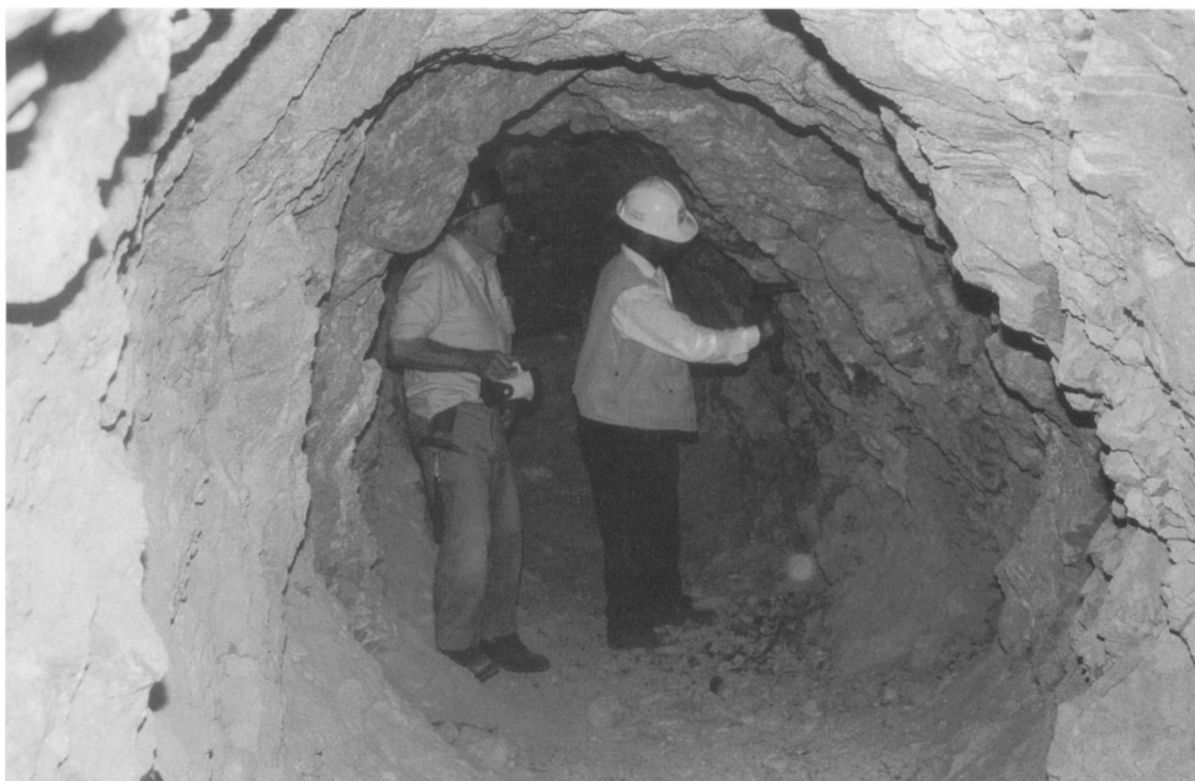


Fig. 8. Mine 3 (modern) (photo by Henry Cowherd)

whole set of orebodies, which seem to have been faulted and heaved several hundred meters in places. The hand specimens were crushed by stamping (fig. 9) and then powdered on a bucking plate at the mill of el-Sid (fig. 10). The finely powdered ore was then vanned (washed) on a Cornish vanning shovel¹⁰ (fig. 11), chosen to be the most satisfactory tool for examining this kind of ore. The heavy head (concentrate) was collected, after a re-grind to ensure that the maximum amount of occluded heavy mineral, such as gold, had been set free. Because of the large number of characteristic ore grinding stones found in the area and also the finely crushed tailings at the modern el-Sid mine, it was anticipated that any gold present would be in very fine particles and so would only be released for recovery if the orestuff was well powdered. By hand lens the vanning concentrate did not reveal any obvious gold; but this is often the case with ores holding fine gold.

It is interesting that many hand crushing dimple stones (figs. 19 and 22 below) seen during this visit were somewhat larger than similar stones found in other mining areas, such as in Cornwall or the Taurus Mountains of Turkey.¹¹ A full complement of rather flat bucking stones (fig. 20 below) for the hand stones to work on, along with top and bottom rotary quern stones (figs. 22 and 23 below) and saddle querns, was scattered around the main site and most if not all the outliers. A very fine example of the bottom stone of a rotary quern was found at the el-Sid camp.

¹⁰ Bryan Earl, "The Cornish Vanning Shovel," *Tool and Trade* 10 (1997), 68–73.

¹¹ J. A. Buckley and Bryan Earl, "Preliminary Report on the Tin and Iron Working Site at Crift Farm," *Journal of the Trevithick Society* 17 (1990), 66–77.

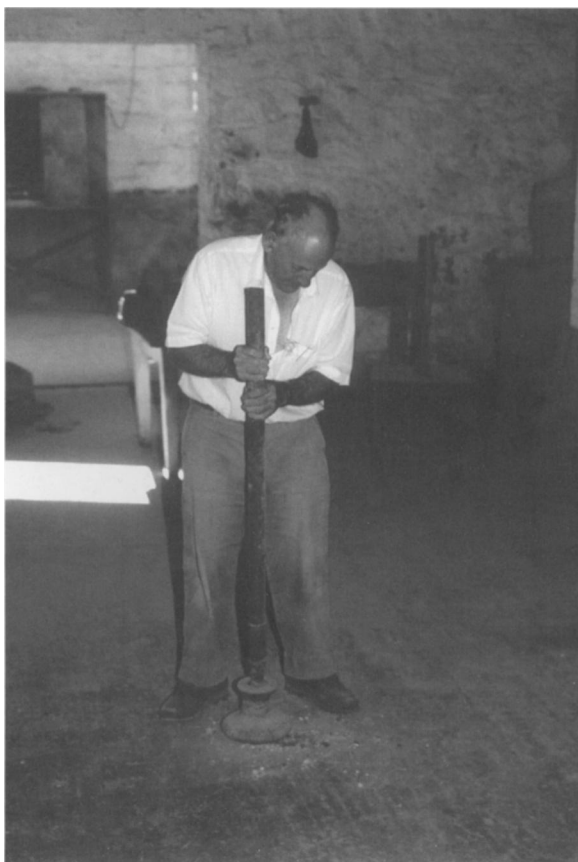


Fig. 9. Crushing chunks of ore (photo by Henry Cowherd)

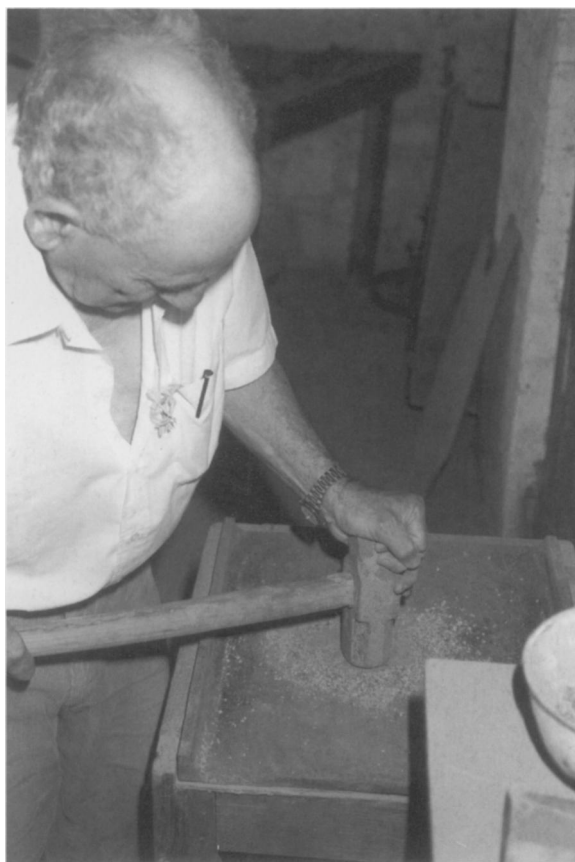


Fig. 10. Grinding ore on bucking plate (photo by Henry Cowherd)

Grains of the vanned head were then examined by A. S. Ball at Camborne School of Mines in Cornwall using SEM/EDS techniques (scanning electron microscope with energy dispersive spectrometer). The object was to determine the nature of the mineralization, and if gold was present, its form and association. Ball reported that the investigation was made difficult by the presence of much dense material, particularly **galena** or lead sulfide. However, two gold particles (actually electrum, the gold/silver alloy that is the most common form of lode gold) were studied. In both cases these were small, ranging from 1 μm to 1.5 μm in gauge. The associated gangue (waste material coming with the valuable ore) was a calcium-iron-silicate material. **Arsenopyrite** (FeAsS) was detected along with some other sulfide minerals in the hand specimen. While this is an isolated sample of orestuff, the small size of the gold found by SEM and the widespread distribution of crushing stones in the area point to the need for thorough crushing. This was confirmed by the fine dump material resulting from the cyanide process used at the modern el-Sid mine, which has been milled to ca. -100 mesh to expose the gold.

While it is possible that gold was visible on the surface to the ancients and led to their working the lodes, this would have been a rare occurrence at these mines. The evidence clearly indicates that fine crushing and heavy involvement of labor was needed. This also points to the great skills of miners in finding these deposits for their gold and developing the methods used to work them.

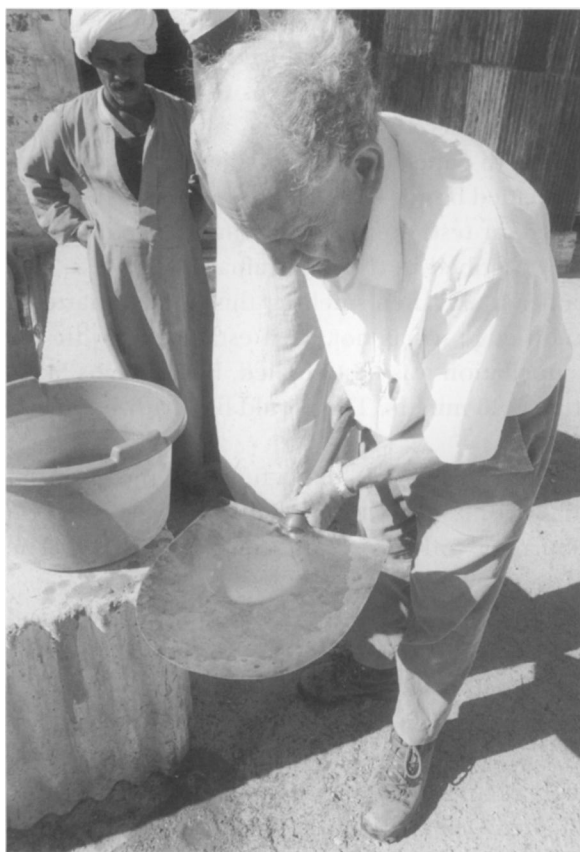


Fig. 11. Vanning powdered ore (photo by Henry Cowherd)

The method by which the gold was won from this orestuff in antiquity is a problem of considerable interest. The isolation of gold from this type of ore is far more difficult than when gold can be recovered by panning or some form of “washing.” Even after hand picking and throwing out what was thought to be low grade material, fine grinding, and washing by some method (water can be re-circulated, and so would not have been too great a limit at this hyper-arid site) such as the vanning undertaken during this study, the concentrate that can be made from this ore is still far from gold metal that can be melted and cast. In particular, the concentrate is much contaminated by pyritic orestuff and other sulfides.

To recover the gold from such ore, two methods might have been used. In the first, the ore is finely crushed and then concentrated by washing in some form of bowl. The concentrate is then ground with mercury, catching the gold and silver as a mercury amalgam. The excess mercury is removed by squeezing the concentrate through a semi-porous material such as thin leather, leaving the amalgam as a lump, which is heated to volatilize the mercury, leaving the crude electrum (gold/silver alloy). Finally, the silver could be “parted” from the gold; the most likely route to this in antiquity would be by hammering the metal into thin sheets and heating these with sand and salt for some time, thereby dissolving the silver and leaving the fine gold.¹² However, the complex sulfide material in this ore might have made amalgamation unsuitable. No date for the introduction of the amalgamation process is known to the author. A small ball mill and flask of mercury at the el-Sid mill indicated that amalgamation had been used for gold recovery from modern smelting slags but not for the main gold recovery from orestuff.

The second, more likely route to the gold would have followed the method described in clarity by Biringuccio in the 16th century.¹³ The minerals that occur with the gold in these lodes have the right associations to allow a smelting followed by a “gold separation from lead” technique to be used. The suite of sulfides and gangue (waste) demonstrates how “. . . benign nature often generates the said things in the company of these sour ores or other stones or earths disposed to such an effect, as if she had pleasure in fulfilling the need of our appetites. . . .”¹⁴ The concentrate would be amenable to a smelting operation that would yield two main products: an upper layer of a mixed **matte** (chiefly sulfides of iron and copper) and a lower layer of lead metal holding the gold and silver. The ore concentrate mix has in it all the materials needed to flux and collect the valuable metals in this manner.

¹² Paul T. Craddock, *Metal Mining and Production* (Washington, 1995), 116–19.

¹³ Vannoccio Biringuccio, *Pirotechnia*, Cyril Stanley Smith and Martha Teach Gnudi transl. (New York, 1943), 153–61.

¹⁴ Biringuccio, *Pirotechnia*, 143.

With the well-developed fire assay for gold and silver ores used today,¹⁵ mixtures very similar to that being considered are made so that the ore can be fluxed and lead metal produced to collect the gold and silver. This fire assay technique is the most suitable for gold and silver ores to this day and, indeed, may even have been developed by early miners who observed the “benign” mixture that could bring this effect about. The lead would be then subjected to cupellation, that is, melted to red heat on a porous bed—often ashes and sand, or powdered, calcined bones—with free access to air. The lead oxidizes to liquid litharge, which is absorbed into the bed, or test, eventually leaving the gold and silver as a bead or cake. This could be rendered fine as described in the amalgamation process. The route described—crushing the ore, concentrating to a head, and then smelting this to lead/**matte**—is described in detail by Biringuccio. To the writer’s knowledge it has not been established with any degree of certainty when such smelting followed by cupellation was first applied, but it seems likely that the art must have been known to the early Egyptian gold miners. This would link with very early and Byzantine Anatolian polymetallic ore smelting.¹⁶

If **stibnite** is present in significant proportion in the ore, it is possible that a fining of the electrum could take place during the smelting. Silver preferentially combines with the sulfur in the **stibnite** on heating, the antimony collecting with the lead and “burning” off during the cupellation stage. The silver sulfide collects in the **matte** and so is removed from the gold.¹⁷

It is possible that only the initial hand picking, crushing, and concentration to a mixed ore head was undertaken at the ancient site. This, along with the mining of the ore, is the most labor intensive process in the separation of the gold. The concentrate, which would not be viewed as of great value because of the difficulty of extracting the gold held in it, could then have been taken to some central site for final treatment, as suggested by Dunn.¹⁸

Waste rock from these mining operations can be seen as large rock piles in several places over the Bir Umm Fawakhir area. These have been sampled and assayed, as reported in a 1988 Minex document that covers a recent survey. Gold values ranging from virtually nil to 100 grams per ton (very rich) are quoted from the results of assays of samples from three different assay offices. However, the results quoted for a given sample differ by a factor of up to 10, depending on the office undertaking the assay. This may be caused by trying to assay orestuff of a difficult nature by unsuitable methods. It is noted that no fire assays—usually the most reliable if carefully made—were attempted. A figure of 27.8 grams of gold per ton for the recent el-Sid mining operations was given to the writer, but bearing in mind that this work was on both primary orestuff hoisted from the lode mine workings and on well-established “waste” dump material, it would be unwise to assume that this is the average gold content of the el-Sid orestuff. The el-Sid lode was probably the richest in the area, hence its recent mining. As a guide, a value of 2 grams/ton is now considered to be at the “limit of payability.” Of course, if labor was cheap, ore of a lower value might have been workable, but then problems of technical feasibility arise.

If the gold was separated at Bir Umm Fawakhir in antiquity, only a small working space would be needed for the operation. Archaeologically, the material to look for would be remains of metal in

¹⁵ W. C. Lenahan and R. de L. Murray-Smith, “Assay and Analytical Practice in the South African Mining Industry,” *South African Institute of Mining and Metals Monograph Series M6* (Johannesburg, 1996).

¹⁶ H. Özbal, Bryan Earl, A. Adriaens, and B. Gedik, “Metal Sources of İkiztepe: Surveys at Merzifon–Durağan Region,” paper delivered at the 21st International Symposium of Excavations, Surveys, and Archaeometry, May 24–28, 1999, Ankara, Turkey.

¹⁷ Lazarus Ercker, *Treatise on Ores and Assaying*, Annaliese Grünhaldt Sisco and Cyril Stanley Smith, transl. (Chicago, 1951), 195–96; J. Percy, *Metallurgy—Silver and Gold*, pt. 1, London, 1880), 367–68.

¹⁸ Dunn in J. Vercoutter, “The Gold of Kush,” *Kush* 7 (1959), 140–42.

process: possibly pots holding ore concentrate or small crucibles with signs of vitrification. There might only be traces of slag. The smelting would most likely have been in small crucibles using charcoal as a fuel and blown to the temperature required for the smelting (about 1200° C) by mouth blowpipe—a tube, maybe a reed, tipped with a clay nozzle, or tuyere, to withstand the heat of the fire when held close to the burning charcoal. Such nozzles can be found in a variety of shapes. Illustrations of those found in Peru indicate what might be expected.¹⁹ Blowpipe melting or smelting is recorded as having been practiced in Egypt at a distant time.²⁰ Cupellation would probably leave fragments of the “tests” that have been used to soak up the litharge. These can be in the form of rather porous fragments that are heavy due to the lead content. Their color can range from yellowish brown to gray-blue.

Future Research

Four lines to develop the archaeological examination of the gold operations might be followed in the overall study of Bir Umm Fawakhir. The first could be to examine the remains of what appears to be a settlement much like the main one but smaller and more ruinous. This is located on the east side of the mine car track leading from the el-Sid main incline shaft to the gyratory crusher station above the present treatment mill. These ruins may be on mine tailings from earlier workings and a trial trench into them might reveal interesting dateable sherds. The second would be to investigate the early mine workings. From this initial examination it appears that old workings could be entered from the modern mining operations at el-Sid. Plans made by the modern mining company of the workings may be available from the Egyptian Geological Survey, and such plans usually give an indication of the location of earlier mining. Another possibility may be to enter old operations at mines 1 and 2, where the level driven into the hill from the wadi floor has broken into old **gunnises**. In undertaking such explorations great care has to be taken. From the material found during this visit it seems likely that interesting remains are present that could fix a more precise dating sequence. For example, carbonaceous residues such as wood props or firesetting debris can yield useful C¹⁴ dating samples—particularly as accelerator techniques only require small samples, as low as 3 mg—in the old mine workings in the Bir Umm Fawakhir area. The third would be to attempt small scale smelting trials of typical Bir Umm Fawakhir concentrates to investigate the conditions for isolating the gold. This would require the backup of SEM/EDS analysis. The fourth would be to “characterize” the Bir Umm Fawakhir gold by the isotopic components of the gold and associated trace elements. This might be related to gold objects recovered from, for example, the ancient tombs.

It is virtually impossible to work out the overall values held by the lodes, as the material has been mined out. However, from the samples examined it does not seem that, overall, the material was “rich.” This highlights the skills deployed by the ancient miners. Waste rock picking was obviously an important part of the mining techniques used, and there are some large dumps of such “waste” in the area. From an examination of the plant layout, it seems that the recent el-Sid operation was treating both material **stoped** underground and brought out by skip from the main incline shaft situated some distance from the mill and also waste dump material tipped into an ore bin at wadi floor level, then elevated by skip up to the gyratory crusher feeding the mill. This makes it difficult to assign a

¹⁹ Izumi Shimada, Stephen S. Epstein, and Alan K. Craig, “The Metallurgical Process in Ancient North Peru,” *Archaeology* (Sept.–Oct. 1983), 38–45.

²⁰ U. Zwicker, H. Greiner, K.-H. Hofmann, and M. Reithinger, “Smelting, Refining and Alloying of Copper and Copper Alloys in Crucible Furnaces during Prehistoric up to Roman Times,” in Paul T. Craddock and M. J. Hughes, eds., *Furnaces and Smelting Technology in Antiquity*, British Museum Occasional Papers 48 (London, 1985), 110.

value to the orestuff in place as lode, and no breakdown of the tonnages milled and from which source is known at present.

Summary

Although ore minerals such as those of copper and lead are present in the Bir Umm Fawakhir lodes, they are in low concentration and would not constitute a reasonable source of such metals. The overall view is that the area was engaged in gold mining of low-grade ore, from ancient times, on a considerable scale.

Geological Reports on Gold Yields, Mines, and Antiquities (*Carol Meyer*)

It is difficult to determine the gold production of the Bir Umm Fawakhir and el-Sid mines in the 20th century, much less in antiquity. Evaluating mines is a specialty unto itself, but in this case even how much gold the modern mines actually produced is not easily reckoned. For one thing, reports from a producing gold mine are generally intended for company use, not scholarly publication, and they may not be easily accessible. The main problem in this case, however, is that the reports seldom say how the assays were made. Tests made from opposite ends of the same hand sample, for instance, could yield different estimates of gold content. The ancients with their simple tools followed the veins as closely as possible, whereas modern miners excavate passages large enough for entire mining machines, or even scoop out whole mountainsides; estimates of yield per ton will obviously be grossly different in the three cases. A summary of old geological and mining reports is collected on Table 2 for the sake of what can be gleaned from them. Reports that have notes on the actual mines or on archaeological remains now lost are summarized below.

As early as October 1906, Home wrote of the Bir Umm Fawakhir mines that “nothing [has been] done with the workings since last winter,” at which point apparently as many as 150 men had been employed.²¹ Almost all the work was in the granite hills north of the road, in those days a camel track, and he describes three excavated mines. The first mine is described as 200' long with cross-cuts at 100' and 154' from the entrance, running 40' and 60' respectively. The first cross-cut had a rise to the surface. The second mine lay east of the first, had a drive of 76' and a cross-cut 26' from the entrance. The latter had foot- and **hanging walls** and quartz veins about 10" thick. The last mine lay “some hundreds” of yards to the north. It had a 46' drive, then 61' to the west in the direction of the **strike**. The quartz vein was a 3' **footwall**, which is quite thick for Bir Umm Fawakhir.²²

Simpson says nothing about Fawakhir but does describe what may be evidence of ancient mining, apparently at Wadi Atalla,²³ which is about 3 hours by foot from Bir Umm Fawakhir. He mentions evidence of firesetting, such as **hanging walls** and **footwalls** blackened from smoke and brushwood fires, and much charcoal. He notes mine supports consisting of two upright stone slabs with a “cap” or “headtree” and two well-preserved iron picks and numerous stone hammers. Unfortunately it cannot be determined from this description whether the old workings were Medieval, Roman, or earlier.

Couyat mentions some ten thousand cubic meters of crushed quartz at Fawakhir, and his seems to be the sole publication of two battered, Classical style statues and a papyrus, now lost, found in the “quarries.”²⁴

²¹ Douglas R. Home, Ms. report to Inspector-General of Mines, October 28, 1906 (1906).

²² Home, Ms. report to Inspector-General.

²³ Ernest H. S. Simpson, “Gold Mining in Upper Egypt,” *Mining Journal*, Bulletin of the Institute of Mining and Metallurgy, #76445A (April 21, 1906).

²⁴ M. Jules Couyat, “Ports gréco-romaines de la Mer Rouge et grandes routes du désert arabe,” *Comptes Rendus des Séances de l'Année 1910* (Paris, 1910), 533.

Hume says little about Bir Umm Fawakhir, but he has more to say about Wadi Atalla. The mines there were reopened in 1914–1918 and are “. . . probably the only instance where a profit has been made in working an Egyptian gold mine during the last twenty years.”²⁵ It is, or was, a small but rich vein, the quartz varying in color and including “. . . amongst other minerals **galena**, **pyrites**, and **blende** . . . The percentage of *silver* remains fairly constant, notwithstanding the fact that the *gold* (emphasis added) value varies from a few **dwt** up to as much as 14 or 15 oz to the ton (2240 lbs).” The gold has a high proportion of silver, ca. 1:3.2 to 1:3.8; it is actually electrum. Cyanide treatment yields an even higher percentage of silver, about one-third. The old working ran at least 150' deep. Hume cites Simpson's description of the old workings and adds the comment that they appear to have been hastily abandoned. This he derives from the piles of rich quartz and the mine faces left untouched after firesetting. In addition he mentions a stone tool like a hand axe, acacia wood roof props, stone [retaining?] walls, and a “vertical shaft that cut the vein on the **hanging-wall** below the ‘run.’”²⁶ Again, there is no suggestion as to the date of the “ancient” workings.

Guéraud says that the Egyptian Mining and Prospecting Company worked at Bir Umm Fawakhir in 1940 and 1941 with little profit. The Company did, however, recover antiquities such as lamps, bead, a few coins, and about sixty 1st–2nd century A.D. ostraca, apparently from the crushed ore dumps near the wells.²⁷

Lethbridge gives a very interesting account of his visit to Bir Umm Fawakhir in 1944.²⁸ He mentions the modern workings around the well, tin-roofed sheds, a water tower, a small **leaching** plant, and the miner's bungalow some “hundreds of yards up valley to left.” He adds that “for some hundreds of yards around [the well] were mounds of sand and gravel and it was from here that the gold-bearing samples had been taken.” The original size of the dump was hard to estimate even in 1944 as it lay in the path of the road and flash floods. Still, some 70,000 tons of material passed through the “primitive” **leaching** plant nearby, presumably the ruined tanks still existing at the entrance to Bir Umm Fawakhir. The gravels were low-grade, ca. 3 **dwt**/ton (4.665 grams/ton) but only half that was recovered, and the **leaching** was completed before the war, ca. 1939. Work at the dumps turned up many artifacts, including an inscribed column, though he does not say what language or script, “alabaster feeding bowls made perhaps 40 centuries ago,” votive statuettes of which one was “highly improper” (Min perhaps?), a dice box and dice that could be Roman, and a small sarcophagus which at that time was set in cement for a camel trough. Prospecting around the Bir Umm Fawakhir wells “brought to light one of the most extensive complexes of ancient workings in the whole Eastern Desert district.”²⁹ He may be referring at least in part to the Wadi Atalla mines because he says that the material from the reopened veins was carried to a simple plant at the well. These ores yielded a rich 10 **dwt**/ton (15.55 grams/ton) but only from amalgamation. The rubble in the old mines was cleared to a depth of 300', which is very deep for an ancient mine, and the vein is said to have been strong below the old workings, down to about 450'. The old workings were followed 600'–800' along **strike** in one mine, 300'–400' in the second. They strictly followed the veins and so varied from fairly wide to very narrow **stopes**. Lethbridge reported marks of gads (heavy chisels for mining), firesetting, and scraps of baskets but no washing basins or crucibles, though he did look for them.

In short, then, if it is not known whether the modern Wadi el-Sid mine yielded 3110 or 2650 kg of gold (see Kochin and Hall on Table 2), it is virtually impossible to determine how much was extracted in antiquity. The ancient miners surely concentrated on the richest and most easily accessible ores;

²⁵ Hume, *Geology of Egypt*, 2/3, 730.

²⁶ Hume, *Geology of Egypt*, 2/3, 730–32.

²⁷ O. Guéraud, “Ostraca Grecs et Latins de l'Wâdi Fawâkhir,” *BIFAO* 41 (1942), 143.

²⁸ R. R. St.G. Lethbridge, “Some Ancient Gold Workings in Egypt, *The Mining Magazine* 75, no. 4 (1946), 222–25.

²⁹ Lethbridge, “Some Ancient Gold Workings,” 223.

Table 2—Estimates of Gold Content of Bir Umm Fawakhir and Wadi el-Sid Ores

Date	Site	Gold Yield	Comments	Reference
1897–98	Fawakhir	17 assays cited, avg. 6.22 grams/ton	“many stone huts,” temple, quarrying noted	T. Barron and William F. Hume, <i>Topography and Geology of the Eastern Desert of Egypt</i> (Cairo, 1902), 261
1901	Fawakhir	few pennyweight to 10 ounces per ton	Citing Alford 1901; quartz discards in ancient tailings [311 grams/ton is suspect]	Herbert A. Sommerlatte, “Das Gold der Ägypter—Wahrheit und Legende? Betrachtungen eines Bergingenieurs zu einem alten Thema,” <i>Nubica</i> (1994), 137
1929	Fawakhir	28 grams/ton	Citing Greaves	Sommerlatte, “Das Gold der Ägypter,” 138
1937	Fawakhir	None cited	Stone huts, temple, good water supply	William F. Hume, <i>Geology of Egypt</i> , vol. 2, pt. 3 (Cairo, 1937), 712–13
	Atalla	14–15 grams/ton	See text for description of modern workings	
1940–41	Fawakhir	“little profit”	See text for description of antiquities recovered	O. Guéraud, “Ostraca Grecs et Latins de l’Wâdi Fawâkhir,” <i>BIFAO</i> 41 (1942), 143
1944	Fawakhir	4.665 grams/ton but only half recovered	See text for description of modern workings and antiquities	R. R. St.G. Lethbridge, “Some Ancient Gold Workings in Egypt,” <i>The Mining Magazine</i> 75, no. 4 (1946), 222–25
	Atalla	15.55 grams/ton	only from amalgamation	
1962	6 ancient mines	None cited	gold varies from 76% to 86% (18.2 to 20.6 carats) assuming silver only impurity	A. Lucas and J. R. Harris, <i>Ancient Egyptian Materials and Industries</i> (London, 1962), 228–29
1968	Fawakhir, old tailings	3.63 grams/ton	No indication how values obtained	Kochin, Ms. report to EGSMA on Eastern Desert gold occurrences (1968)
	1944–48 tailings	9.1 grams/ton		
	el-Sid, all	3110 kg total	total amount gold produced	
	el-Sid main vein	avg. 27.9 to 13 grams/ton	“the UAR’s largest and richest gold deposit,” notes ancient workings	
	second vein	“high gold content”	No indication of how tests made	
	S and SE of main vein	18 grams/ton	ancient workings noted	

Table 2—*continued*

Date	Site	Gold Yield	Comments	Reference
1988	Fawakhir		120 samples, no indication	David J. Hall, Ms. Report on Regional Exploration of the El Sid Concession Carried Out by Minex Minerals—Egypt, February 1987 to June 1988 (1988)
	“dump 1”	1.97 grams/ton	how test made	
	“dump 2”	2.05 grams/ton		
	“dump 3”	1.73 grams/ton		
	el-Sid, all	2653.6 kg total	total amount gold produced	
	el-Sid south (Shemamiya?)		ancient workings noted, see text for description; 153 samples but no indication of how tests made	
	north dump	17.8 and 40 grams/ton		
	central	4+ grams/ton		
1994	All ancient mines	15–20 grams/ton	“a miner can work about 25 kg of lode ore per day by hand”	Sommerlatte, “Das Gold der Ägypter,” 138

what they left was what they did not want or could not reach. Almost all the modern estimates of gold yields from the ancient mines and tailings are so high—by modern standards—that if two grams/ton is considered viable, it is surprising that all the gold companies are not currently operating in the Eastern Desert. The problem is that there is no indication of how the assays were made—on hand samples, beneficiated ore, crushed and concentrated samples, fire assays, SEM, or some other method—so it is hard to know what they actually represent. What is apparent is that the actual gold yields from the Wadi el-Sid mines, versus assays, are consistently much higher than the yields at Bir Umm Fawakhir. The Wadi el-Sid yields range from 4+ to 27.9 grams per ton, versus 1.73 to 9.1 grams per ton at Bir Umm Fawakhir. Thus it is not surprising that the latter mines were not worked until relatively late, the Coptic/Byzantine period, when the older el-Sid mines had presumably been exhausted by ancient techniques. At this time also, imperial Byzantine demand for gold was so urgent that the low-yield Fawakhir mines became worthwhile.

Mass Sensitivity Experiment—El-Sid Gold Samples (*Robert K. Smither*)

Partly to verify the existence of traces of gold in the exhausted mines and partly to obtain one assay with a known input and technology, several chunks of ore were collected from the modern mine 3 and from tailings at the modern el-Sid mine. A five-gram capsule of the powdered, concentrated ore from the tailings at the modern el-Sid mine was submitted the Advanced Photon Source at Argonne National Laboratory in August 1998 to try to determine whether any gold was present, and if so, make an estimate of how much per ton (of concentrate).³⁰

The very high intensity of the x-ray beams available at the Advanced Photon Source, a large synchrotron facility at Argonne National Laboratory, combined with a special experimental beamline facility,³¹ allows one to measure trace amounts of elements in a sample at the sub-microgram level, in small samples. Measurements at the 10⁻⁷ to 10⁻⁹ gram level are common.

³⁰ With assistance from Dean Haeffner, Sarvjit Shastri, and Anton Stamp.

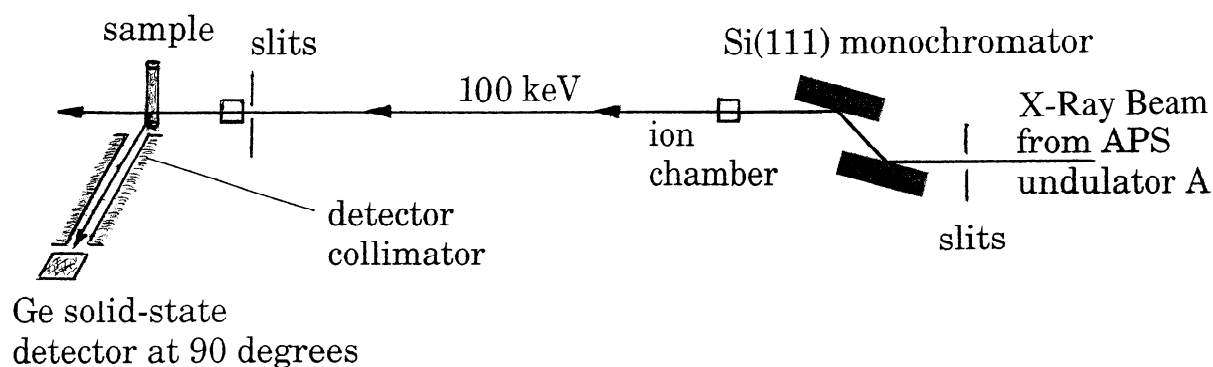


Fig. 12. APS beam setup

A schematic diagram of the experimental setup is shown in fig. 12. The very intense x-ray beam is generated in the undulator source shown on the right. The double crystal monochromator selects a narrow band of x-ray energies centered around 100 keV. This beam passes through an aperture that limits size to $1 \text{ mm} \times 1 \text{ mm}$ in area. The very intense x-ray beam (3×10^{10} photons per sq. mm) then passes through the sample being investigated, the powdered ore in this case. Some of the 100 keV photons are absorbed in the sample. This generates characteristic x-rays for the elements in the sample. A detector mounted at right angles to the beam detects some of the characteristic x-rays. The strength of this generated beam of characteristic x-rays is used to calculate how many atoms of each element are present in the volume swept out by the x-ray beam. This information is then combined with the density of the sample, the cross section for the production of the x-rays by the incident 100 keV x-rays, the time taken to perform the experiment, and the intensity of the x-ray beam to calculate the concentration of an element in the sample—gold on the ore concentrate in this case.

The details of the sample and the x-ray beam are shown in fig. 13. The powdered ore sample is mounted in a quartz tube with a 1.5 mm inside diameter. The average density of the sample in this case is $(2.41 \pm 0.16) \text{ grams per cm}^3$. The $1 \text{ mm} \times 1 \text{ mm}$ x-ray beam passes through the ore sample as shown. The characteristic x-rays of the elements in the sample are detected in a Ge-solid-state, with the x-ray detector mounted 19.0 cm from the sample. A collimator placed in front of the detector limits the solid angle seen to by the detector to 2.20×10^{-6} . This results in a very small acceptance angle for the x-rays striking the detector, which is located precisely at 90 degrees to the x-ray beam. These two features are very important to the experiment in that they reduce the background from the Compton scattered x-rays to almost zero. Without these special experimental arrangements the sensitivity of the experiment would be much poorer.

Samples at two positions in the quartz tube were measured to check the uniformity of the concentration of gold in the ore. The gold signals in both positions were quite strong so the experiment needed only about half an hour to obtain good results. The other very strong signal that came through in the data was from lead, so the lead concentration was measured as well.

The data from the sample at the first position is shown in fig. 14, and the data from the sample at the second position appears in fig. 15. The figures are a plot of the counts in each channel as a function of energy. The two strong gold lines, Au K-L_{II} and Au K-L_{III}, at energies of 67 and 69 keV, and

³¹ G. Brian Stephenson, Bruce Stephenson, and Dean R. Haeflner, "Investigations of Astrolabe Metallurgy Using Synchrotron Radiation," *MRS Bulletin* (January 2001), 19–23.

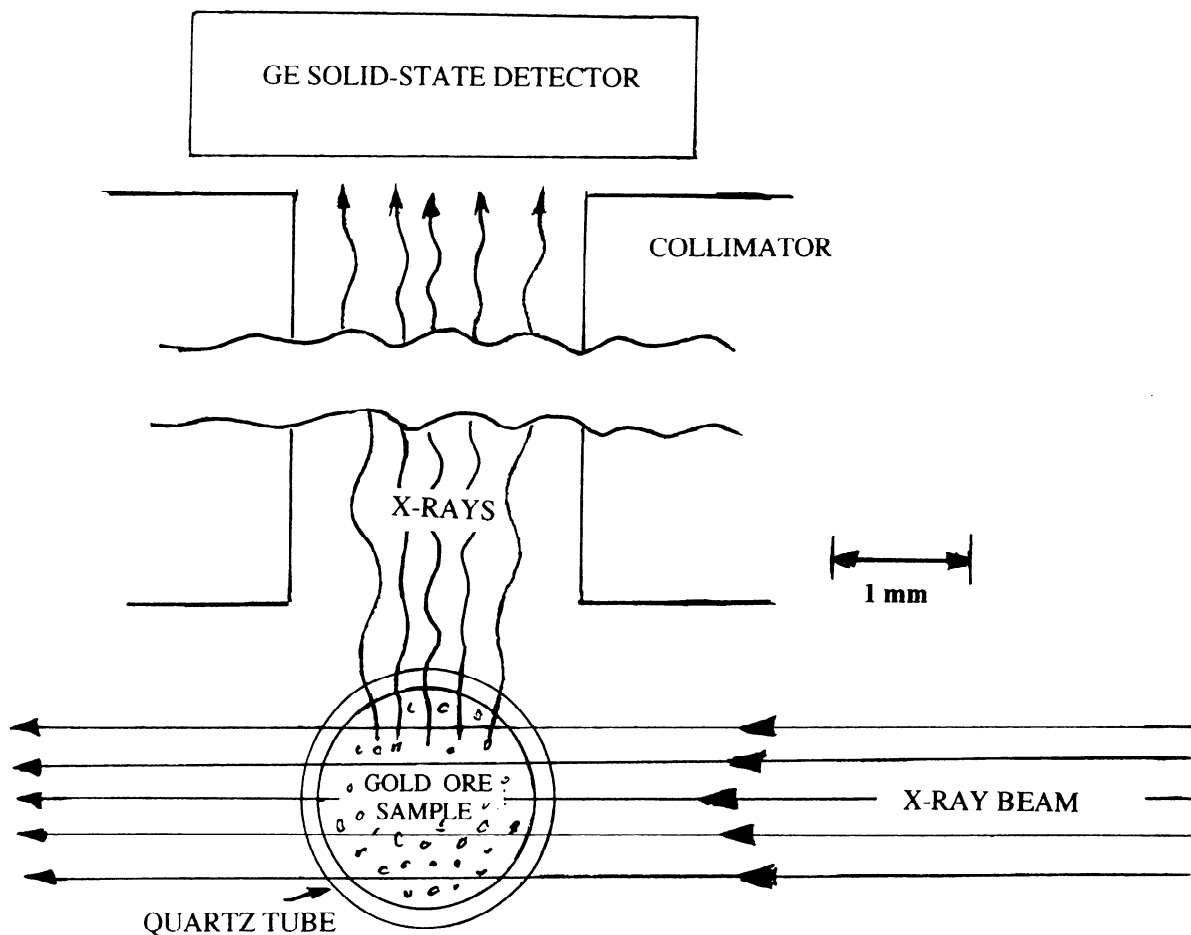


Fig. 13. Detector setup

the two lead lines, Pb K-L_{II} and Pb K-L_{III} at 73 keV and 75 keV are of similar intensities at the first position. At the second position the lead lines are about 40 percent stronger. This unevenness is expected for these small samples containing a few mg of material. The large peak on the right results from Compton scattering in the sample, and its tails are the main source of background. If the data were not taken at 90 degrees, this peak would be much larger and would dominate the region, making the measurement of the gold and lead very much more difficult.

The summary of the data and calculations for the first position are given in Table 3. The summary of the data and calculations for the second position are given in Table 4.

The concentration of gold varied by a factor of 5 in the two samples, but the ratio of gold to lead remained very similar. This is to be expected. The concentration of gold in the samples is quite high for hard rock mining, but as the experiment was run on partly processed, concentrated ore, the raw ore would show a smaller gold content.

Since Argonne ran the experiment on the ore concentrate, the value of the gold in the concentrate would be *about* 100 times its ore valuation. The vaning assay as carried out on site gave about 1% concentrate from the crushed sample. This would make the mine ore *about* 2 grams per ton, which is

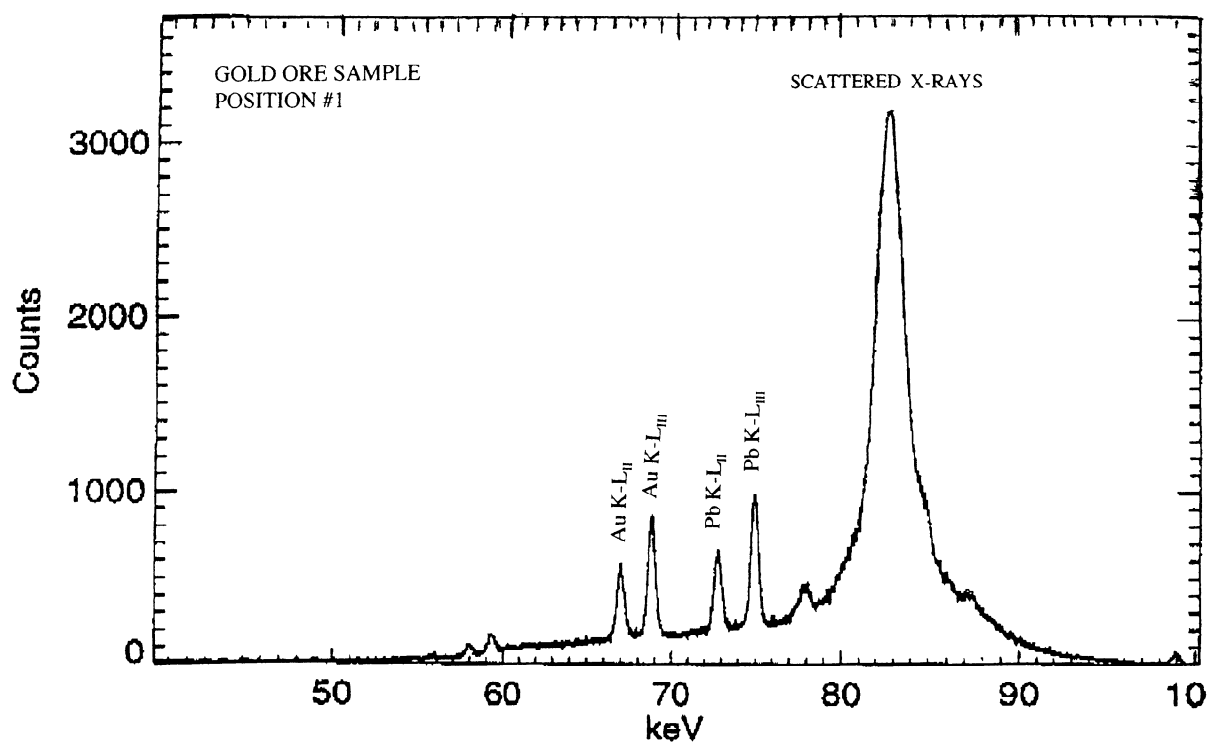


Fig. 14. Position 1, graph of scattered x-rays

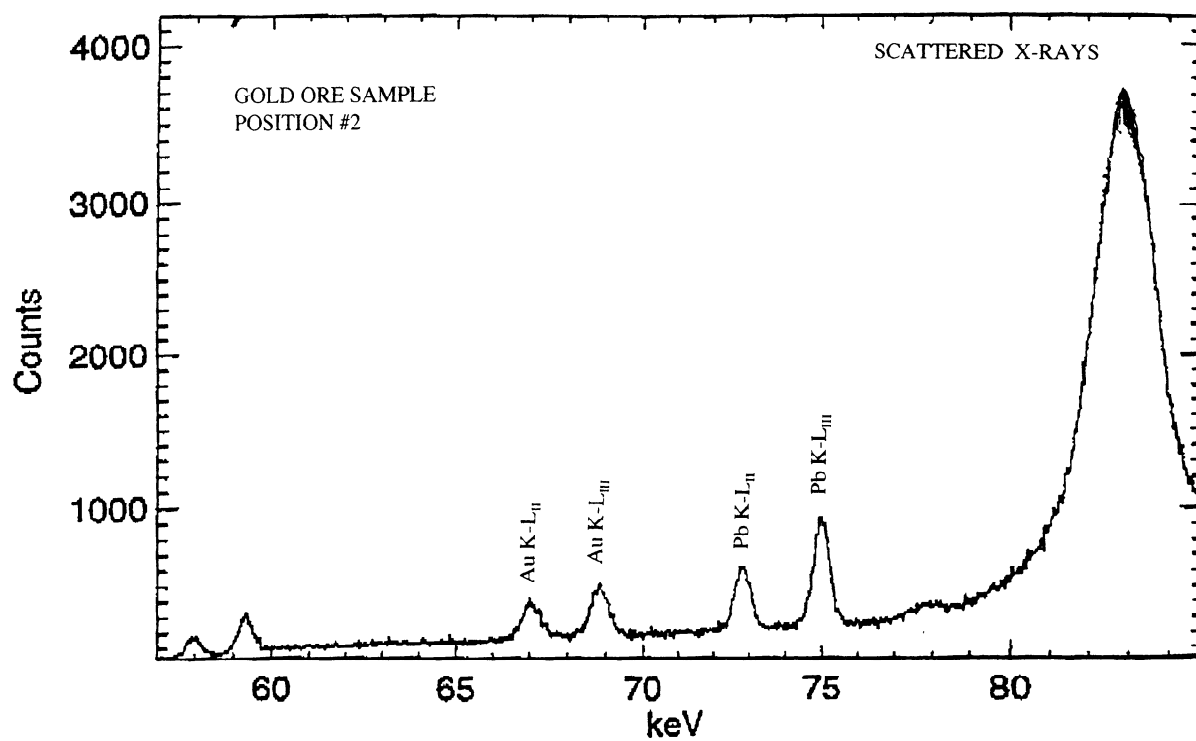


Fig. 15. Position 2, graph of scattered x-rays

Table 3. El-Sid Sample, Position 1

A. Data
X-Ray Beam: 100 keV – 3×10^{10} x-rays per sec per 1 mm $\times$ 1 mm area
Beam size = 1 mm $\times$ 1 mm = 1 mm ²
Photons per sec per cm ² = 3×10^{12}
Length of run = 1983 sec
Detector solid angle = 1 mm $\times$ 1 mm at 19.0 cm = 2.20×10^{-6}
Detector efficiency assumed to be 100%
Density of powder sample = (2.41 ± 0.16) gm per cm ³
Volume of sample irradiated in capillary = 1.261 mm ³
Weight of sample irradiated = $(3.04 \pm 0.16) \times 10^{-3}$ gm
The photo absorption cross section for the K shell hole:
In gold = 1114 barns = 1.114×10^{-21} cm ²
In lead = 1332 barns = 1.332×10^{-21} cm ²
Ratio of total x-ray emission to x-ray emission in the K-L _{III} line
Au Total / K-L _{III} = 2.00
Pb Total / K-L _{III} = 2.01
Measured counts in K-L _{III} line
Au K-L _{III} = (13129 ± 115) counts
Pb K-L _{III} = (15150 ± 123) counts
B. Calculations
Total x-rays emitted = Measured counts $\times$ (Total K-L ratio) / solid angle
Au $13129 \times 2.00 / (2.20 \times 10^{-6}) = 1.19 \times 10^{10}$
Pb $15150 \times 2.01 / (2.20 \times 10^{-6}) = 1.38 \times 10^{10}$
Total x-rays emitted per sec = Total X-Rays emitted / Run time in sec
Au $1.19 \times 10^{10} / 1983 = 6.00 \times 10^6$
Pb $1.38 \times 10^{10} / 1983 = 6.76 \times 10^6$
Number of atoms = Total x-rays / (100 keV photons per sec) $\times$ (cross section)
Au = $(6.00 \times 10^6) / (3 \times 10^{12}) \times (1.114 \times 10^{-21}) = 1.80 \times 10^{15}$
Pb = $(6.96 \times 10^6) / (3 \times 10^{12}) \times (1.332 \times 10^{-21}) = 1.74 \times 10^{15}$
Weight of Au or Pb = number of atoms $\times$ weight of atom
Au = $1.80 \times 10^{15} \times 197 \times 1.67 \times 10^{-24} = 5.92 \times 10^{-7}$
Pb = $1.74 \times 10^{15} \times 207 \times 1.67 \times 10^{-24} = 6.02 \times 10^{-7}$
Ratio of weight of Au or Pb to weight of sample = Wt (Au or Pb) / Wt of sample
Au = 5.92×10^{-7} gm / 3.04×10^{-3} gm = $(1.95 \pm 0.14) \times 10^{-4}$
Pb = 6.02×10^{-7} gm / 3.04×10^{-3} gm = $(1.98 \pm 0.14) \times 10^{-4}$

very close to the estimate in Earl's report (see above). The lead content is actually quite good for processing the ore. If the original ore was lead-poor, then lead or lead ore had to be added to help collect the gold and silver.

Reconstructing the Ancient Gold Processing at Bir Umm Fawakhir (*Carol Meyer*)

Winning gold from quartz veins in granite is a laborious, multi-stage process. The ore has to be detected somehow, hacked out of the rock, crushed and ground, washed, and smelted. As mentioned earlier, this paper is not concerned with the subsequent steps of refining or metalworking. The techniques used in prospecting for metals and valuable stones in antiquity are a potentially fascinating study and a topic about which virtually nothing is known.³² Unfortunately, the Bir Umm Fawakhir

³² But see Rosemarie Klemm and Dietrich D. Klemm, "Chronologischer Abriss der antiken Goldgewinnung in der Ostwüste Ägyptens," *Mitteilungen des Deutschen Archäologischen Instituts Kairo* 50 (1994); Dietrich D. Klemm, Rosemarie Klemm, and Andreas Murr, "Ancient Gold Mining in the Eastern Desert of Egypt and the Nubian Desert of Sudan," in Renée Friedman, ed., *Egypt and Nubia: Gifts of the Desert* (London, 2002).

Table 4. El-Sid Sample, Position 2

A. Data

X-Ray Beam: 100 keV – 3×10^{10} x-rays per sec per 1 mm × 1 mm area

Beam size = 1 mm × 1 mm = 1 mm²

Photons per sec per cm² = 3×10^{12}

Length of run = 2270 sec

Detector solid angle = 2.20×10^{-6}

Detector efficiency assumed to be 100%

Density of powder sample = 2.41 gm per cm³ (± 0.16)

Volume of sample irradiated in capillary. = 1.26 mm³

Weight of sample irradiated = 3.04×10^{-3} gm

The photo absorption cross section for the K shell hole:

In gold = 1114 barns = 1.114×10^{-21} cm²

In lead = 1332 barns = 1.332×10^{-21} cm²

Ratio of total x-ray emission to x-ray emission in the K-L_{III} line

Au Total / K-L_{III} = 2.00

Pb Total / K-L_{III} = 2.01

Measured counts in K-L_{III} line

Au K-L_{III} = 7384 (± 86) counts

Pb K-L_{III} = 13679 (± 117) counts

B. Calculations

Total x-rays emitted = Measured counts × (Total K-L ratio) / solid angle

Au $7384 \times 2.00 / (2.20 \times 10^{-6}) = 6.71 \times 10^{10}$

Pb $13679 \times 2.01 / (2.20 \times 10^{-6}) = 12.50 \times 10^{10}$

Total x-rays emitted per sec = Total X-Rays emitted / Run time in sec

Au $6.71 \times 10^{10} / 2270 = 2.96 \times 10^7$

Pb $12.50 \times 10^{10} / 2270 = 5.51 \times 10^7$

Number of atoms = Total x-rays / (100 keV photons per sec) × (cross section)

Au = $(2.96 \times 10^7) / (3 \times 10^{12}) \times (1.114 \times 10^{-21}) = 8.86 \times 10^{15}$

Pb = $(5.51 \times 10^7) / (3 \times 10^{12}) \times (1.332 \times 10^{-21}) = 13.79 \times 10^{15}$

Weight of Au or Pb = number of atoms × weight of atom

Au = $8.86 \times 10^{15} \times 197 \times 1.67 \times 10^{-24} = 2.91 \times 10^{-6}$

Pb = $13.8 \times 10^{15} \times 207 \times 1.67 \times 10^{-24} = 4.79 \times 10^{-6}$

Ratio of weight of Au or Pb to weight of sample = Wt (Au or Pb) / Wt of sample

Au = $2.91 \times 10^{-6} \text{ gm} / 3.04 \times 10^{-3} \text{ gm} = (9.57 \pm 0.67) \times 10^{-4}$

Pb = $3.60 \times 10^{-6} \text{ gm} / 2.41 \times 10^{-3} \text{ gm} = (15.69 \pm 1.10) \times 10^{-4}$

data contribute nothing to the question. We therefore start at the point at which the gold ores had already been detected by one means or another and note only that ancient Egyptian exploitation of the Eastern Desert resources, and especially those of the Wadi Hammamat, reached far back into prehistory. Despite the expressed dichotomy between the desert and the sown land, Red Land and Black, the deserts were in fact traversed and exploited for millennia.

As for hacking quartz out of granite, no sophisticated techniques were involved. The ancient Egyptians had long possessed the methods and skills for much more precise stone quarrying and masonry. We therefore concentrate on the questions of reducing the ore and extracting metal from it. The historical discussion begins with the usual suspects, Agatharcides and Pliny the Elder, and then moves on to the archaeological evidence from Bir Umm Fawakhir and other sites.

The one ancient textual source that is cited almost without fail as the one definitive description of ancient Egyptian gold mining from earliest pharaonic times through the Roman period—at least 3000

years in which ancient technologies are presumed to have changed not at all—is Diodorus Siculus. He wrote his account in the middle of the 1st century B.C. and based it on the work of Agatharcides of the preceding century. It is by no means clear that either author ever saw an operating gold mine, and in fact Diodorus' account of Egyptian mining is closely paralleled in his account of Spanish mining. Agatharcides' work survives only in scattered quoted fragments, primarily in Diodorus and in Photius of the 9th century A.D., which have been assembled for the first time by Burstein.³³ Burstein observes that Agatharcides did not rely on personal travel, experiences, or observations but on collecting documents available to him in Alexandria.

Agatharcides, and hence Diodorus Siculus, and Photius, all dwell on the extreme misery of the miners, whereas at Bir Umm Fawakhir there is virtually no archaeological evidence for deprivation or physical constraint. There are no town walls to keep people in or out, and only a couple of guard posts high on hills overlooking the site. If anyone wanted to walk out, it is about a two and a half day journey to the Nile and wells occur at least half a day's march apart. There is as yet no sign of a fort or military establishment, and within the main settlement, there is no apparent differentiation in layout, size, or special features between houses or sections of town. Indeed, the straggling layout of the main settlement (fig. 2) and all the outliers have nothing planned or regimented about them, but seem rather to have been laid out to take advantage of the wadi scarps, party walls, or shared open spaces. The numerous wine amphorae probably held wine only once, but it seems to have been in reasonably good supply.³⁴ Meat certainly was, judging from the results of the 1999 excavations and Ikram's analysis of the bones.³⁵ One of the two excavated houses yielded half a copper-gold bracelet, a cut oval carnelian gemstone, several small coins and raw emeralds.³⁶ This picture agrees with the results from the somewhat earlier 1st–2nd century A.D. quarry at Mons Claudianus. There, most workmen received a monthly salary of 47 drachmae plus wheat and sometimes wine. Since there was and is very little to purchase in the desert, the workmen routinely sent money and/or instructions to family members or representatives in the Nile valley to buy special foods or other goods, pay debts, or take care of other business.³⁷ Note that none of the ancient writers calls the miners slaves, whom they would readily have identified. In short, the Bir Umm Fawakhir workers were probably career miners making a decent living, if in a harsh locale, rather than prisoners of war or criminals.

Therefore we pass over the ancient descriptions of the miners' lives and present the technical information. Agatharchides' work survives in three sets of excerpts, Strabo, Diodorus, and Photius. The most extensive—and less well known—fragments are included in Photius' work:

At this point, near the aforementioned [Erythrean or Red] Sea, there are found some of the so-called 'noble' rocks, which contain abundant mineral deposits. In colour they are jet black but they contain such great outcrops of quartz that everything else pales by comparison to them for brilliance. . . . They [the miners] pursue their tasks in the mountains where the gold is found. They light wood fires on the stone outcrops, which are jagged and extremely hard, and crumble them with the heat. They break the fractured rock into little pieces with iron sledges. A technician, who sorts the ore, is in charge of the other workers. Whenever he points out veins to the miners, the whole task is then carried out by the miners. . . , in accordance with the following division of labour. Those who are strongest and young smash the quartzbearing rock with iron hammers, striking their blows not with skill but brute force. They also cut many galleries

³³ Stanley M. Burstein, transl., *Agatharcides of Cnidus* (London, 1989).

³⁴ See also Meyer "Gold-miners and Mining at Bir Umm Fawakhir," 269.

³⁵ Salima Ikram in Meyer, "Bir Umm Fawakhir," in *The Oriental Institute 2000–2001 Annual Report* (Chicago, 2001), 20–23.

³⁶ Meyer, "Bir Umm Fawakhir," *The Oriental Institute 1998–1999 Annual Report* (Chicago, 1999), 27.

³⁷ Hélène Cuvigny, "The Amount of Wages Paid to the Quarry-workers at Mons Claudianus," *The Journal of Roman Studies* 86 (1996), 139–40; and idem, "Deux ostraca du Mons Claudianus: O. Baharia 20 et 21," *Chronique d'Égypte* 72 (1997), 112.



Fig. 16. Iron wedge from Building 93 (photo by Henry Cowherd)

through the rock, not on a straight line, but in some places rising above the gold-bearing ore and sometimes falling below, and again, turning to the left and sometimes twisting back and intersecting like the roots of trees. They excavate wearing lamps fastened to their foreheads, following a sort of white vein. They often force their bodies to conform (to the shape of the gallery) as they throw on the ground the pieces of rock, not according to their own decision and ability but under the supervision of an overseer. . . .³⁸

Diodorus Siculus' account, minus the agonies of the miners, is a little more abbreviated.³⁹

Several aspects of this description remain puzzling, such as why the native rock is described as jet black and why the quartz would gleam any more brightly than normal quartz. No other ancient writer mentions lamps bound to the miners' heads, and it is difficult to see how this could have been achieved if they were also contorting themselves to fit narrow excavations.

As noted, the mines at Bir Umm Fawakhir are of two kinds, opencast workings following a vein down from the surface to no great depth (fig. 6), and deeper, irregular cuttings into the mountain-side (fig. 7). Few if any of these seem to have been excavated deeper than the twilight zone where at least a little daylight could be perceived. The mines at Wadi Atalla about 15 km away may have been deeper; the suggestions of firesetting are also interesting, but since there is no real dating of the old workings they could be Medieval as easily as Roman. At Bir Umm Fawakhir there are no signs of firesetting, but the account preserved in Photius' work seems to indicate that it was used for surface mines. If that were the case, the ashes would have long since blown away. Further, the granite at Bir Umm Fawakhir is generally rotten and crumbly at the surface and deeply jointed throughout, so firesetting would have been both costly in terms of fuel and unnecessary. The ancient accounts mention iron "sledges" and pestles, but metal tools are rare at ancient mining and quarrying sites. The major quarries at Mons Claudianus, investigated in six seasons of work, yielded impressive remains of smithies but only two possible working tools, both old surface finds, and a couple of iron plates.⁴⁰ The iron wedge excavated from Bir Umm Fawakhir Building 93 in 1999 is an all-purpose item, but it could have been used for wedging out pieces of rock (fig. 16). The actual process of hacking out quartz ore may well have been as unsophisticated as Agatharcides said it was.

Of the next step, crushing and grinding the ore, Photius' account says this:

Young boys, who go down into the galleries excavated by these men and gather up laboriously the piles of rock thrown down on the floor, carry it outside the entrance. From them the older men and many of the sick take the rock. These men bring it to men called 'pounders'. They are men less than thirty years old and more vigorous in appearance. After receiving the fragments of rock, they pound them vigorously with iron pestles; and having worked the stone until it is no larger than a vetch seed, they distribute them immediately to other workers. The next task, however, is that of women. . . . For several mills stand one after the other in a line and into these they cast the crushed rock. Three women, standing opposite one another at

³⁸ Burstein, transl., *Agatharcides of Cnidus*, 59–62.

³⁹ Burstein, transl., *Agatharcides of Cnidus*, 58–62.

⁴⁰ D. P. S. Peacock and V. A. Maxfield, *Survey and Excavation at Mons Claudianus*, Vol. I, *Topography and Quarries*, FIFAO 37 (Cairo, 1997), 190.



Fig. 17. *Open-cast trench up mountainside (Mine 4) (photo by Steven Cole)*

each handle . . . do the grinding; and they grind until the portion of rock given them has been reduced to the consistency of flour. . . .⁴¹

Diodorus is again briefer, though he gives the task of pounding the ore to men over thirty years.⁴²

The step that appears to have been ignored here is an initial hand-picking of ore at the mine entrance. This seems to be well documented at Mine 4. Here the ancient workings are visible as a gash up the hillside (fig. 17); the light colored material around the gash is chunks of white quartz pitched downslope. Right at the edge of the mine, we found a crushing stone mostly surrounded by chunks of discarded quartz (fig. 18) except for a clear space where presumably the workman squatted. Hand-picking ore mined in dimness or darkness right at the mine entrance makes sense as it would allow the workers to select only the most promising chunks for the very labor-intensive grinding stages.

The ancient description of ore reduction taking place in two steps, crushing and fine grinding, is supported both by our experiments and by archaeological evidence from Bir Umm Fawakhir. While many different kinds of crushing and grinding stones occur at and around the site, two kinds are by far the most common: dimple stones and rotary querns (figs. 19, 22, and 23).

The dimple stones are blocks roughly 20 cm across and 20 cm high. They generally have one smooth face with a pecked dimple in the center. They are used by inverting them over chunks of

⁴¹ Burstein, transl., *Agatharcides of Cnidus*, 62–63.

⁴² Burstein, transl., *Agatharcides of Cnidus*, 62–63.



Fig. 18. Hand-picking site with crushing stone at Mine 4 (photo by Steven Cole)



Fig. 19. Dimple stone with two working faces (photo by Henry Cowherd)

mined quartz placed on a broad flat surface such as the stone shown in figure 20 and pounding down and grinding around repeatedly until the quartz ore is reduced to small pieces. A demonstration with one of the dimple stones on a balustrade at camp nearly destroyed the cement. (The translation of both ancient texts refers to “mortars” and iron pestles, but the only mortar found at Bir Umm Fawakhir was a tapering cylindrical vessel 48 cm high with a hole pounded through the bottom. This



Fig. 20. Lower crushing stones (photo by Henry Cowherd)

mortar is made of nummulitic limestone, which is far too soft for crushing quartz.) When the dimple becomes too deep the stone can no longer crush ore to the desired fineness, so it is discarded or, if it has more than one flat face, rotated and the new face used (fig. 19). Used dimple stones occur by the hundreds at the main settlement, generally in secondary contexts. Sometimes people built them into walls, and in one case a dozen or so seem to have been assembled into steps to a room on a higher level (fig. 21).

The second stage of ore reduction used the rotary querns. The lower stones (fig. 22) are generally about 70 cm across and the upper, flatter ones about 35–40 cm in diameter (fig. 23). They were turned with a stick projecting from a hole near the edge. The ancient description of older men (over thirty according to Diodorus) pounding the stone and the women grinding it does seem plausible. Certainly our recent experiments demonstrated that the ore has to be ground to face powder to detect any metal at all. This also agrees with Craddock's observation that all gold ores have to be ground very fine, as do some tin ores.⁴³

Both Photius and Diodorus Siculus incorporate Agatharcides' description of gold washing; Photius says:

From those women men called *Selangei* receive the crushed ore. These men are technicians capable of completing the king's business. Their work is as follows. They throw the crushed quartz onto a flat board which has been polished smooth but is not level, having instead a slight incline. Then, while pouring on water, they rub the ore with their hands, at first gently, then more vigorously, whence, I think, the earthy part is dissolved and flows away in accordance with the slope of the table, but the heavy and solid part remains unmoved on the wood. After having repeatedly washed the rock with water, the *Selangeus* picks it up with light and very porous sponges. Applying these lightly to the quartz and working it briefly, the light and loose pieces become entangled in the interstices of the sponge. He takes these up and throws them away; but he

⁴³ Craddock, *Metal Mining and Production*, 161.



Fig. 21. Building 117 with dimple stones reused as steps (photo by Steven Cole)

leaves behind on the board the heavy, glittering pieces he has separated out, since, because of the heaviness of their nature, they are difficult to move.⁴⁴

Diodorus Siculus' excerpt is again shorter; he, too concludes with "the pure particles of gold" from washing, i.e., visible gold.⁴⁵

Gold washing presumably occurred at Bir Umm Fawakhir, and the obvious place for that would have been near the wells, an area now thoroughly disturbed by flash floods, modern mining, and settlement. The ancient description of repeated washing on an inclined wooden board is not unreasonable, providing there was some roughness or depression to catch the gold flecks. The most valuable study of gold washing remains Vercoutter's 1959 article, which is concerned mainly with Nubian gold. He included all seven known washing tables⁴⁶ and dates them to the Napatan (ca. 751–538 B.C.) or Meroitic (538 B.C.—A.D. 350) periods largely on historical grounds.⁴⁷ He observes that all Nubian washing tables are sited by the river, mostly in rocky places,⁴⁸ and he considers that washing and smelting mostly likely took place away from the mines. Whereas most mines have crushing stones, washing would have taken place where water was abundant.⁴⁹ The southern Egyptian and

⁴⁴ Burstein, transl., *Agatharcides of Cnidus*, 64–65.

⁴⁵ Burstein, transl., *Agatharcides of Cnidus*, 64.

⁴⁶ Vercoutter, "The Gold of Kush," 125–26.

⁴⁷ Vercoutter, "The Gold of Kush," 151–52.

⁴⁸ Vercoutter, "The Gold of Kush," 125.

⁴⁹ Vercoutter, "The Gold of Kush," 139.

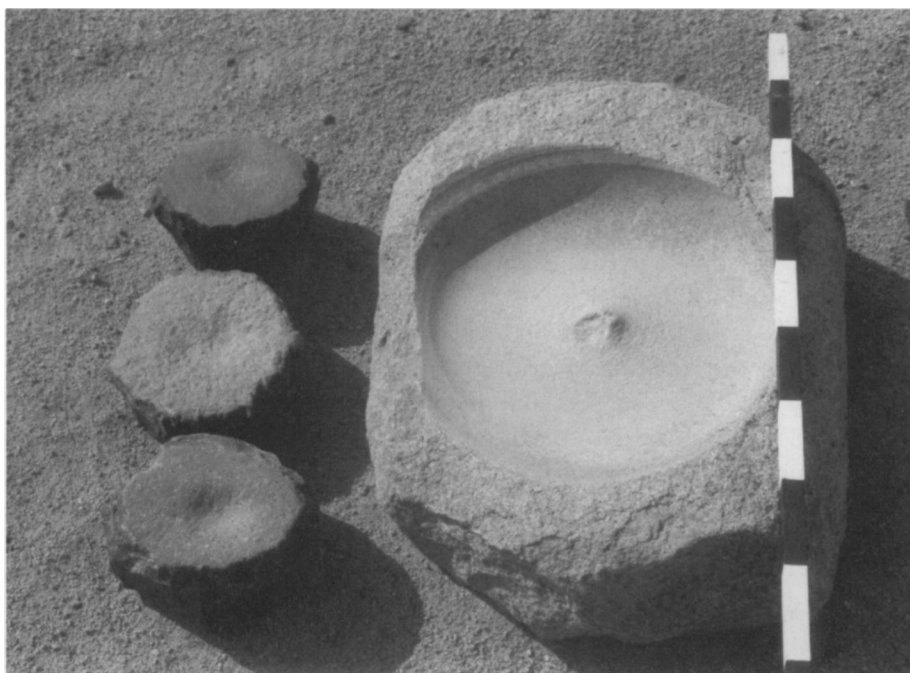


Fig. 22. Bottom of rotary grinding stone (quern) and three dimple stones (photo by Henry Cowherd)



Fig. 23. Top of rotary grinding stone (photo by Henry Cowherd)

Nubian gold fields apparently yielded visible gold after washing, whereas the low-yield ores of Bir Umm Fawakhir probably needed much more processing.

As the evidence now stands, we think that the ore from Bir Umm Fawakhir was washed to a heavy, dark concentrate, or “head,” which was then sent to the valley for smelting. That such a division of labor does occur in traditional gold mining gains a little support from modern panners in India. There, women working at the edges of the Kolar gold field dig small holes in “promising silt.” If there are any larger lumps in the silt, they are crushed on a handy stone. The women pan the silt and crushed rock to win a residue with **pyrite**, magnetite, and gold. They sell the concentrate to a middleman, who sells in turn to a local jeweler, who retrieves the gold with *aqua regia*,⁵⁰ a mixture of nitric and hydrochloric acids that dissolves the gold or platinum contained in the concentrate.

Due to the difficulty of the smelting operation and hence the need for skilled operators, plus the need for large amounts of fuel, we suspect that the washed, dark, sparkly concentrate was shipped to the Nile valley for smelting, and if desired, for refining. Also, sending only the concentrate or “head” would reduce the chances of theft both at the mining town and en route across the desert. Certainly there is as yet no evidence of smelting at Bir Umm Fawakhir or Wadi el-Sid; there is no litharge, slag, lead-impregnated vessels, or the like, though the project sought such items. Smelting operations, however, would not have required much space, and so poisonous an activity should not have been undertaken in the town itself.

While the data from Bir Umm Fawakhir do support some of Agatharcides’ descriptions, his account of smelting, as preserved in Photius is less than clear:

After, thus, completely separating out the gold nuggets, the *Selangeus* turns them over to the smelters. These take up the ore by set amount and weight and place it in a pottery vessel. Then, after adding in accordance with a fixed proportion a lump of lead, grains of salt and a little tin and barley bran, they put on a close fitting lid, seal it all around and smelt it continuously in a kiln for five days and an equal number of nights. On the next day, after cooling the smelted ore slightly, they pour it out into a vessel and find that of what was put in with the gold nothing remains, but of the gold there is a solid mass, albeit slightly reduced in size because of the dust.⁵¹

Diodorus Siculus’ account is nearly the same, though he says only that “gold” and not “gold nuggets” was turned over to the technicians.⁵²

Interpretations of Agatharcides’ description of gold smelting are nearly as numerous as interpreters, and most of them conclude that his account is garbled at least on some points.⁵³ In general, however, the process described seems to be cupellation with lead. To win visible, metallic gold or silver from a polymetallic ore such as that from Bir Umm Fawakhir takes several steps. Lead is the critical ingredient, so it is interesting that the Wadi el-Sid ores contain so much lead (figs. 14 and 15). Whether or not the ore is roasted first, the first critical step is melting it with lead or with an ore containing lead, such as **galena**. This results in a cake of lead on the bottom and a slag or **matte** on the top containing iron, silica, and other unwanted material. The lead is then placed on a bed or bowl called a “cupel” made of a porous material such as bone ash, brick dust, or even sand. The cupel and

⁵⁰ Paul T. Craddock, “Old Ways in the Kolar Gold Field,” *Gold Bulletin and Gold Patent Digest* 24, no. 4 (1990), 129–30.

⁵¹ Burstein, transl., *Agatharcides of Cnidus*, 65–66.

⁵² Burstein, transl., *Agatharcides of Cnidus*, 65–66.

⁵³ See, for example, J. H. F. Notton, “Ancient Egyptian Gold Refining,” *Gold Bulletin* 7, no. 2 (1974), 50–56; Burstein, transl., *Agatharcides of Cnidus*; Ramage and Craddock, *King Croesus’ Gold*, 34–35, 235.

lead are roasted in the presence of air until all the lead oxidizes to liquid litharge that soaks into the porous material and leaves drops of silver, gold, or a mixture of the two.

If further purification of the metal is wanted, a refining technique such as the cementation or parting described in Ramage and Craddock could have been employed.⁵⁴ Notton actually experimented with Diodorus' technique, though he used it to purify gold, not to smelt it.⁵⁵ He placed impure gold, specifically sheets consisting of 37.5% gold and the rest silver and copper, in a sillimanite⁵⁶ pot with salt, sealed it and heated it to 800° until fuming stopped, which was five days. It may be a coincidence that this is the time Diodorus specified, but the result was 93% pure gold. All the other materials were deposited in the walls of the vessel or the furnace itself. Adding salt alone worked well, but including charcoal (in the place of Diodorus' bran) got only 80% pure gold, and adding tin or lead reduced the percentage of gold even further. Both Notton's experiment and Ramage and Craddock's⁵⁷ discussion of it assume that the ancient workers started with washed, visible metal and that the main impurity was silver, and both agree that Diodorus' description may be a conflation of two steps, smelting the ore with lead (cupellation) and then refining the metal with salt (cementation).

Some further information about ancient gold production may be gleaned from the 1st century A.D. account of Spanish mines written by Pliny the Elder, which is a little closer to Bir Umm Fawakhir in time, if more remote in geography and hence geology. Pliny describes three methods of gold mining: the "detritus of rivers" or washing out alluvial gold, sinking shafts, and collapsing mountains. The last-named technique involved tunneling and hydraulic mining or "hushing" on a huge scale, major engineering, rivers of water, and certainly could not have been employed in a hyperarid desert. Pliny's account of purifying silver and gold is fairly detailed as well:

The substance [ore] dug out is crushed, washed, fired, and ground to soft powder. The powder from the mortar is called "scudes" and the silver that comes out from the furnace the "sweat"; the dirt thrown out of the smelting-furnace in the case of every metal is called "scoria," slag. In the case of gold the scoria is pounded and fired a second time; the crucibles for this are made of tasconium, which is a white earth resembling clay. No other earth can stand the blast of air, the fire, or the intensely hot material.⁵⁸

His comments on processing *silver* ores are also useful:

It [silver] cannot be smelted except when combined with lead or with the vein of lead, called galena . . . , which is usually found running near veins of silver ore. Also when submitted to the same process of firing, part of the ore precipitates as lead while the silver floats on the surface, like oil on water.⁵⁹

His only other specific reference to gold says that it is purified with lead and that the fuel must be chaff as charcoal will not work.⁶⁰ (Since silver is heavier than lead, Craddock assumes that there was something to absorb the lead and that the litharge was attacking the container or the furnace walls or both.⁶¹)

⁵⁴ Pliny mentions mercury for refining gold, but there is no evidence for this in Egypt (Pliny, *Natural History*, XXXIII.99); Ramage and Craddock, *King Croesus' Gold*.

⁵⁵ Notton, "Ancient Egyptian Gold Refining," 50–56.

⁵⁶ Sillimanite (Al_2SiO_5) is a fibrous mineral that is infusible and insoluble in acids and thus suitable for containers in furnaces.

⁵⁷ Ramage and Craddock, *King Croesus' Gold*, 178.

⁵⁸ Pliny, *Natural History*, vol. 9, H. Rackham, transl. (Cambridge, Massachusetts, 1952), XXXIII.69.

⁵⁹ Pliny, *Natural History*, vol. 9, XXXIII.95.

⁶⁰ Pliny, *Natural History*, vol. 9, XXXIII.60.

⁶¹ Craddock, *Metal Mining and Production*, 223.

Unlike the situation in Egypt, there are numerous studies of ancient European mines and mining, including many discussions of Pliny's description. One of the most useful is Bachmann's attempt to interpret the process in modern terminology.⁶² Figure 24 is based on his study.

Not all of these stages need be incorporated in smelting, and refining is optional unless coins or other standard purity are required. Indeed, Craddock argues that in antiquity refining gold was generally not desirable because it reduced the weight of the metal, and not until standard gold coins were issued did the purity of gold become critical.⁶³ If stage 3, a preliminary roasting, were included, it would have served to drive off or convert sulfides, chlorides, and carbonates to oxides, which would reduce the amount of fuel and heating needed for the actual smelting, and the sulfur itself is combustible.⁶⁴ Depending on the heating (below 600° or up to 850°) and the nature of the raw ores, a variety of chemical reactions could occur and range of roasted ores, slags, **mattes**, or **speiss** could result.⁶⁵ Stage 4, recrushing the roasted ore, is not critical either, but it would have exposed more surface of the ore material and hence made heating more efficient.⁶⁶ The temperature required for cupellation comes from Tylecote⁶⁷ and that for cementation, from Notton's experiments.⁶⁸ He heated his impure, experimental gold for five days; thus a considerable amount of fuel is involved. Evidence from Sardis indicates a somewhat lower cementation temperature of roughly 650° to 800° at maximum; salt melts at 804°.⁶⁹ Early smelting furnaces are generally small, about 15–40 cm interior diameter, which is the largest area that a manually operated bellows can reach. Either manual or more sophisticated mechanical bellows would have been needed to raise furnace temperatures to 1100° to 1200° C, the minimum temperature for smelting gold, and the maximum manual bellows can achieve.⁷⁰ Stages 8 and 9 do not concern gold smelting; they are optional steps to recover the silver if desired. Note also that the litharge produced in steps 6 and 9 could be recycled in steps 5 or 8.

Pre-Coptic Gold Mining in the Bir Umm Fawakhir Vicinity (*Carol Meyer*)

While the majority of the efforts of the Bir Umm Fawakhir project concentrated on the 5th–6th century main settlement and its outliers, it also located late New Kingdom and other pre-Coptic remains in the vicinity of the Wadi el-Sid mines. The tailings around the modern plant yielded a handful of sherds that are Roman, Late Period, and perhaps Ptolemaic.

Roman activity is further attested by an old description of coins, beads, lamps, and even two battered, Classical style statues.⁷¹ As noted above, several of the early geologists described ancient remains at Bir Umm Fawakhir or its vicinity. The sixty or so 1st–2nd century ostraca published by

⁶² Hans-Gert Bachmann, "Zur Metallurgie der römischen Goldgewinnung in Trêz Minas und Campo de Jales in Nortportugal," in Heiko Steuer and Ulrich Zimmerman, eds., *Montanarchäologie in Europa* (Sigmaringen, 1993), 153–60; Hans-Gert Bachman, "Sophisticated Roman Recovery Techniques for Gold," *Institute for Archaeo-Metallurgical Studies* 19 (1995), 8.

⁶³ Ramage and Craddock, *King Croesus' Gold*, 31.

⁶⁴ J. R. Marechal, "Methods of Ore Roasting and the Furnaces Used," in P. T. Craddock and M. J. Hughes, eds., *Furnaces and Smelting Technology in Antiquity*, British Museum Occasional Paper 48, (London, 1985), 30.

⁶⁵ J. R. Marechal, "Methods of Ore Roasting and the Furnaces Used," 30–31.

⁶⁶ Craddock, *Metal Mining and Production*, 167–68.

⁶⁷ R. F. Tylecote, *A History of Metallurgy*, 2nd ed. (London, 1992), 45.

⁶⁸ Notton, "Ancient Egyptian Gold Refining," 50–56.

⁶⁹ Ramage and Craddock, *King Croesus' Gold*, 205. Hall's cementation experiments were on silver. He attempted to determine the active agent in the cementation process, salt (HCl) or chlorine. He took sheets with 30% silver, added equal parts of salt, brick dust, and kaolin and heated the mixture at 850°. The result was 99% pure silver after six days. Since HCl reacts slowly with silver, the experiments point to the chlorine itself. This suggests further that water of crystallization or from wood fires was necessary to release the chlorine (Ramage and Craddock, *King Croesus' Gold*, 179–80).

⁷⁰ Craddock, *Metal Mining and Production*, 170–71.

⁷¹ Couyat, "Ports gréco-romaines de la Mer Rouge," 533–36.

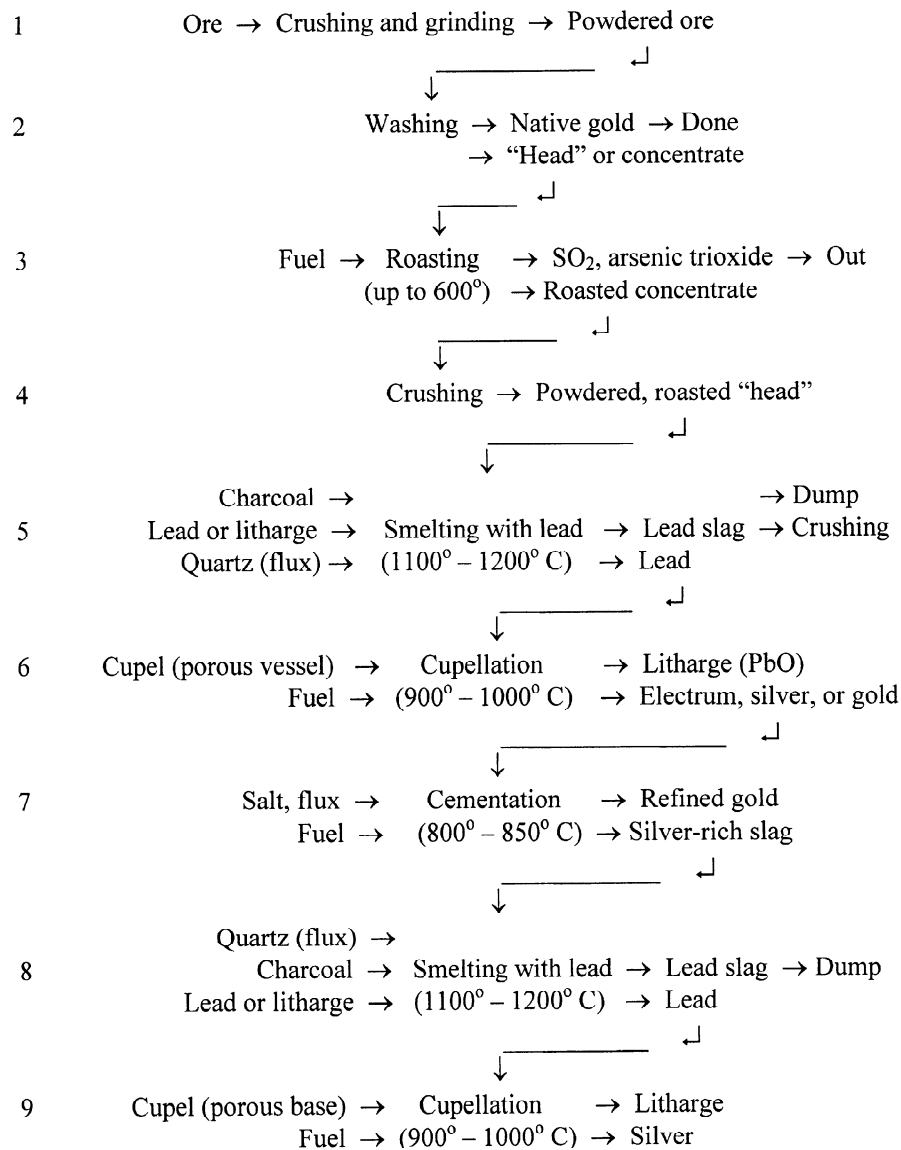


Fig. 24. Smelting steps

Guéraud mostly pertain to military activity in the Eastern Desert.⁷² There is a Roman (or perhaps earlier) tower on the mountain overlooking the wells; it is one of the chain of intervisible towers along the Roman road from the Red Sea to the Nile at Coptos. On the one hand, Fawakhir lacks anything like the fortified watering stations so well preserved elsewhere on the route, but on the other, it is hard to believe the ancient caravans ignored a good water source such as that at Fawakhir. Whatever may have existed in antiquity, the area around the wells has since been thoroughly re-worked by flash floods and modern mining activity. A cave behind the modern tea house preserves painted and cut graffiti dating to the 1st–3rd century A.D., and there are other fragments such as

⁷² Guéraud, “Ostraca Grecs et Latins.”

amphora toes, bits of faience, and at least one sherd of red Roman period glass. As mentioned, the scattered, small-scale granite quarries appear to be Roman, perhaps exploratory. As for gold mining, it is possible that some was attempted at Bir Umm Fawakhir, though there is no evidence for large-scale works such as those of the Coptic/Byzantine period. Rather, such evidence as there is suggests that the richer el-Sid mines were the ones worked in the Roman period.

Ptolemaic remains at Bir Umm Fawakhir are even skimpier. They consist of a segment of a column from the Ptolemy III temple to Min, and a few grinding stones. One deeply dished "ski slope" lower grinding stone was noted in Outlier 2 and photographed separately because it is so different from the scores of later rotary grinding stones. At least one of the two-handled upper millstones considered Ptolemaic⁷³ is built into the modern well house.

Most surprisingly, however, it is the late New Kingdom remains that are the best-preserved. Klemm and Klemm noted pharaonic remains in the heavily mined Shemamiyeh locale behind (to the west of) the modern mill.⁷⁴ In 1996 we located a couple of rough constructions that look like guard posts commanding a fine view of the narrow Wadi el-Sid and the modern mines across the road, about a half a dozen shallow graves, possibly New Kingdom, and a large sherd dump with characteristic blue-painted and burnished pottery. Later we located the ancient mines themselves, surviving just past the topmost hilltop overlooking the modern plant (fig. 3). The mines are no longer very obvious as they are simply opencast trenches now nearly filled with millennia of silt (fig. 25), but they are marked as ancient by remnants of huts, by crushing stones next to most of them, and by a few pot smashes of burnished vessels. All the information to date comes from surface collections,⁷⁵ but they are reasonably consistent and they are bolstered to an extent by textual evidence.

First and foremost of these is the Turin goldmining Papyrus, which can reasonably be read as a map of the route to the *bekhen*-stone quarries in the Wadi Hammamat.⁷⁶ What is less frequently noted, however, is that the road continues beyond the Wadi Hammamat to a place with three roads leading to the sea, a stele of Amenhotep I, "the houses of the village of gold workers,"⁷⁷ a well, a temple, and a mountain of gold and silver. This fits with the Fawakhir/el-Sid area. The Turin Papyrus is dated to the time of Ramses IV and seems to have originated from the royal workmen's village at Deir el-Medina, the home of the workmen who excavated and adorned the tombs in the Valley of the Kings. The "mountain of gold and silver" suggests electrum, which indeed is more common than silver or gold ores alone, and which is attested in the SEM analysis reported above.

Shaw's study of ancient Egyptian miners focused mainly on the Old and Middle Kingdom periods, but it makes the valuable point that mining does not seem to have been a full-time profession.⁷⁸ Rather, it was carried out seasonally, usually under trading or military officials, often with soldiers. In

⁷³ Rosemarie Klemm and Dietrich D. Klemm, "Chronologischer Abriss der antiken Goldgewinnung in der Ostwüste Ägyptens," *Mitteilungen des Deutschen Archäologischen Instituts Kairo* 50 (1994), 208; Klemm, Klemm, and Murr, "Ancient Gold Mining in the Eastern Desert of Egypt and the Nubian Desert of Sudan," 218.

⁷⁴ Klemm and Klemm, "Pharaonischer Goldbergbau im Wadi Sid und der Turiner Minenpapyrus," *Akten des 4 International Ägyptologen-Kongresses München 1985*, vol. 2, (Hamburg, 1988), Abb. 3. They also note Old and Middle Kingdom remains in the greenstone area southwest of the el-Sid mine. Klemm and Klemm, "Chronologischer Abriss der antiken Goldgewinnung in der Ostwüste Ägyptens," 215.

⁷⁵ It was planned to make some test excavations in the New Kingdom loci during the 1999 season, but a shortage of staff prevented the undertaking.

⁷⁶ James A. Harrell and V. Max Brown, "The World's Oldest Surviving Geological Map: The 1150 B.C. Turin Papyrus from Egypt," *Journal of Geology* 100 (1992), 3-18.

⁷⁷ Vercoutter, "The Gold of Kush," 143.

⁷⁸ Ian Shaw, "Exploiting the Desert Frontier: The Logistics and Politics of Ancient Egyptian Mining Expeditions," in A. Bernard Knapp, Vincent C. Piggott, and Eugenia Herbert, eds. *Social Approaches to an Industrial Past*, (New York, 1998), 246.

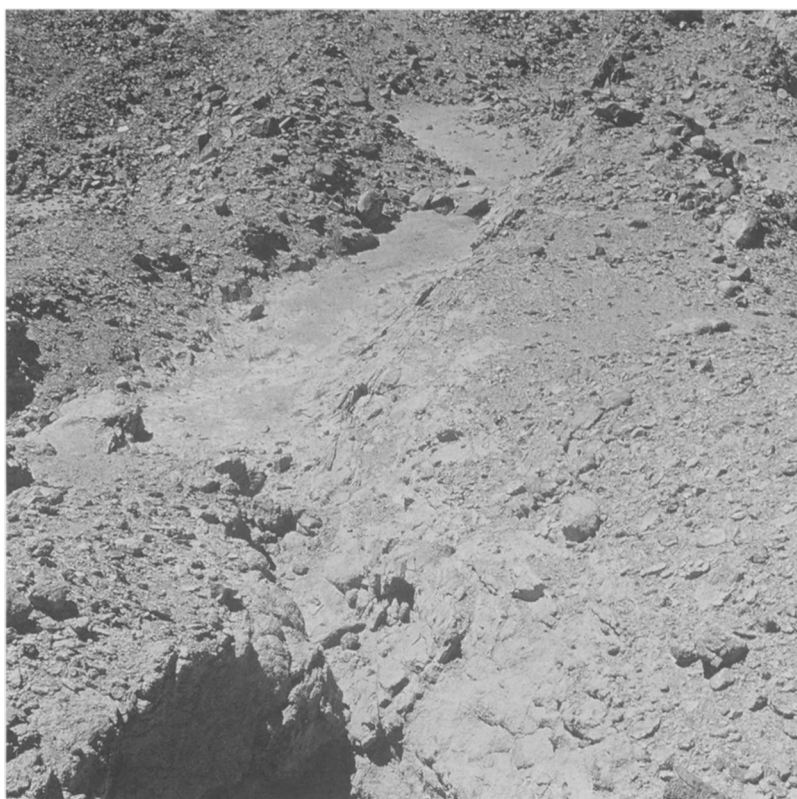


Fig. 25. New Kingdom opencast mine

the Middle Kingdom a thousand or more people might participate in a mining or quarrying expedition, but only for as long as it took to acquire the stones or metals desired.⁷⁹

The Wadi Hammamat was above all the *bekhen*-stone quarry whose fine-grained black stone (a graywacke) was valued in pharaonic times, but there are also a few references to gold-working in graffiti, as noted in Vercoutter,⁸⁰ and published in Couyat and Montet in hieroglyphic typeface but without translations.⁸¹ Inscriptions #35 and #114, the latter dated to the 8th year of Mentuhotep III of the 11th Dynasty, refer to an “overseer of gold” amongst many other titles,⁸² but this does not necessarily have anything to do with gold mining. The “gold workers” mentioned in inscriptions #123 and #87, dating to years 16 and 38 of Senusert I, likewise have no necessary connection to gold mining.

Hume noted mines at Um Esh, a waterhole that fills after rains, and an inscription of Ramses III over an Old Kingdom one.⁸³ He mentioned “many miners huts and pestles” as well as shallow pits, but no clear workings. While a pottery date would be useful, the “shallow pits” seem to fit with the earliest, simplest kind of opencast mining.

⁷⁹ Ian Shaw, “Exploiting the Desert Frontier,” 247.

⁸⁰ Vercoutter, “The Gold of Kush,” 146.

⁸¹ M. Jules Couyat, and Pierre Montet, *Les Inscriptions hiéroglyphiques et hiératiques du Ouâdi Hammâmât*, Mémoires de l’Institut Français d’Archéologie Orientale 34 (Cairo, 1912).

⁸² Couyat and Montet, *Les Inscriptions du Ouâdi Hammâmât*, 46, 81–82.

⁸³ Hume, *Geology of Egypt*, 2/3, 731–32. Gebel Umm Esh is roughly 40 km east of Bir Umm Fawakhir.

Vercoutter's important study of ancient Egyptian gold sources groups them from south to north as the "Gold of Kush," sources along the Nile between about Wadi Halfa and Kerma; the "Gold of Wawat," referring to sources along the Wadi Allaqi and Gabgaba; and the "Gold of the Desert of Coptos," reached by the Wadi Hammamat and Wadi Abad.⁸⁴ The Wadi el-Sid would have been connected with the "Gold of the Desert of Coptos." Vercoutter suggests further that a couple of Ramses II inscriptions in Luxor Temple might refer to Coptos gold. The first names "the Holy Mountain which brings gold by millions," and he considers this a reference to the Wadi Hammamat, as indicated by the (Ramses IV) Turin Papyrus and the rock inscriptions in the Wadi Hammamat.⁸⁵ The second inscription reads simply "the Mountain of Coptos" and what may be a broken hieroglyph for gold.⁸⁶ While these are interesting references, they are no strong proof of mining in the Wadi el-Sid. In general, New Kingdom Egypt seems to have acquired a lot of gold from Wawat and elsewhere in the 18th Dynasty; production declined in the 19th and 20th Dynasties, but revived in the time of Taharqa and in Meroitic times.⁸⁷

Recently several groups of rock inscriptions from the gold-mining regions of Barramiya and Dungash, south of the Edfu to Mersa Alam road, have been published. At Wadi Barramiya four out of seventeen New Kingdom inscriptions mention gold.⁸⁸ Klemm and Eichler's inscription #2 at Barramiya translates as "Scribe of the gold reckoning, Sa-Ibshek."⁸⁹ At Dungash, inscription D18 says only "gold" or *nb r*, but it was probably longer originally.⁹⁰ The group of inscriptions at D16 includes at least two scribes dealing with gold, "Chief(?) scribe of the goldworkers(?) Ahmose" and "The scribe of the controller of the goldworkers,"⁹¹ and D21 records the presence of "The prophet, the prince (overseer of?) the troop of gold-workers, Nebmose." All are probably New Kingdom; D21 certainly is.⁹² Another study of the Dungash inscriptions indicates that two groups are clearly New Kingdom, carved while the mines were being exploited. Three graffiti, numbers 6, 11, and 13, refer to gold or goldworkers, and another, inscription #16, may.⁹³

Lucas and Harris list textual references for Egyptian gold sources from the south: the 12th Dynasty has texts noting Coptos and Nubia; the 18th Dynasty, the "Highlands," Karoy, Coptos, Kush, and "South Countries"; the 19th Dynasty, Akita, "God's Land," Karoy, and Punt; and the 20th Dynasty, Edfu, Emu, Coptos, Kush, "Malachite Country" [copper], "Negro Lands," and Ombos.⁹⁴

Much of the archaeological evidence for early gold mining in the Eastern Desert comes from a broad survey of over 250 mining sites from the north of Egypt and into Sudan. Klemm and Klemm state that the earliest mines in the Eastern Desert in the Predynastic and Early Dynastic periods con-

⁸⁴ Vercoutter, "The Gold of Kush," 128.

⁸⁵ Vercoutter, "The Gold of Kush," 131–33; see also Georges Goyon, *Nouvelle inscriptions rupestre du Wadi Hammamat* (Paris, 1957), 4–5.

⁸⁶ Vercoutter, "The Gold of Kush," 131–33.

⁸⁷ Vercoutter, "The Gold of Kush," 135–38.

⁸⁸ Russell D. Rothe, George Rapp, Jr., and William K. Miller, "New Hieroglyphic Evidence for Pharaonic Activity in the Eastern Desert of Egypt," *Journal of the American Research Center in Egypt* 33 (1996), 103.

⁸⁹ Rosemarie Klemm, "Neue Expeditionsinschriften aus der Ostwüste Oberägyptens," *Mitteilungen des Deutschen Archäologischen Instituts Abteilung Kairo* 54 (1998), 252.

⁹⁰ Rothe, Rapp, and Miller, "New Hieroglyphic Evidence for Pharaonic Activity in the Eastern Desert of Egypt," 93.

⁹¹ Rothe, Rapp, and Miller, "New Hieroglyphic Evidence for Pharaonic Activity in the Eastern Desert of Egypt," 92–93.

⁹² Rothe, Rapp, and Miller, "New Hieroglyphic Evidence for Pharaonic Activity in the Eastern Desert of Egypt," 95.

⁹³ Klemm, "Neue Expeditionsinschriften aus der Ostwüste Oberägyptens," 243, 253–54.

⁹⁴ Lucas and Harris, *Ancient Egyptian Materials and Industries*, 227. The Archaic and Old Kingdom copper mines at Wadi Dara in the northern Eastern Desert were reworked for iron in Roman times and at least explored for gold in Byzantine and Arab times (Nicolas Grimal, "Travaux de l'IFAO en 1993–1994," *BIFAO* 94 (1994), 423), but this is later than the early sources in question here.

centrated on enriched quartz veins in granodioritic rock.⁹⁵ The very earliest mines are simply pounded out of the rock with heavy, 6 to 10 kg, two-handed pounding stones. On more splintery, schistose rock the miners might use smaller disk-shaped hammers. In any case, the ore seems to have been powdered in place and then presumably washed. All or most of these mines are associated with producing copper mines.⁹⁶ Somewhat later, Old and Middle Kingdom prospecting exploited the same sources, namely gold in copper-bearing zones, such as the distinctive green malachites.⁹⁷ Although mining does not seem to have been extensive in the Eastern Desert in this period, there were some significant changes in the tools employed. Smaller, one-handed pounding stones with a handle and stone axes or hammers with a medial groove come into use. Since the mines were still pounded out, the maximum depth of the open trenches seems to have been about 25 m. In the Middle Kingdom, stone mortars for crushing the ore were added to the tool kit.⁹⁸

In the New Kingdom and Late Period new areas were exploited in an “enlarged geological framework”⁹⁹ and with improved techniques and tools.¹⁰⁰ Klemm, Klemm, and Murr further state that within this period, almost all gold mining took place within the relatively short time span from Tutmosis III through Amenhotep IV.¹⁰¹ Significantly, new kinds of ores were sought, quartz in veins near dark mafic and ultramafic rocks, like the ores at Bir Umm Fawakhir, rather than the green-stained copper ores.¹⁰² In addition to opencast mines, the New Kingdom miners seem to have used the simple technique of “wadi working.” This basically means scraping up quartz chunks of quartz that have washed down into a wadi bed and crushing those.¹⁰³ Where workers did excavate mines, they could now use bronze chisels, with which they could follow the course of the ore more closely. Support pillars were left, but without ventilation the mines could not go more than about 30 m deep.¹⁰⁴ A new kind of ore crusher, a stone anvil with a pestle, and new kind of mill stone, a large oval stone with an upper hand stone, something like a simple mano and metate, also came into use. A few examples of washing tables are preserved as well. They are long, narrow tables slanting down to a collecting basin for the silt, plus a channel to lead the water back to the head of the table. The gold might have been collected on a sheepskin or rough board or grid,¹⁰⁵ though none of these have survived.

In New Kingdom times, then, the archaeological evidence and texts indicate that gold might have been obtained from the “Mountain of Coptos” and the Wadi Hammamat area. If the ancient workers were mining there, then it had to be hard rock mining. Hacking the quartz from an opencast mine

⁹⁵ Klemm and Klemm, “Evolution of Gold Mining and Processing Methods in Ancient Egypt.” Abstract in *International Conference on Ancient Egyptian Mining and Metallurgy and Conservation of Metallic Artifacts* (1995), 7; idem, “Antiker Goldbergbau in der ägyptisch-sudanesischen Ostwüste.” *Nürnberger Blätter zur Archäologie* 13 (1996/97), 149–66. Klemm, Klemm, and Murr, “Ancient Gold Mining in the Eastern Desert of Egypt and the Nubian Desert of Sudan,” 215–16.

⁹⁶ Klemm and Klemm, “Chronologischer Abriss der antiken Goldgewinnung in der Ostwüste Ägyptens,” 194; Klemm, Klemm, and Murr, “Ancient Gold Mining in the Eastern Desert of Egypt and the Nubian Desert of Sudan,” 216.

⁹⁷ Klemm and Klemm, “Antiker Goldbergbau,” 157.

⁹⁸ Klemm and Klemm, “Chronologischer Abriss der antiken Goldgewinnung in der Ostwüste Ägyptens,” 197; Klemm, Klemm, and Murr, “Ancient Gold Mining in the Eastern Desert of Egypt and the Nubian Desert of Sudan,” 216.

⁹⁹ Klemm and Klemm, “Evolution of Gold Mining and Processing Methods,” 7. For distribution maps of New Kingdom mines, see Klemm and Klemm, “Chronologischer Abriss der antiken Goldgewinnung in der Ostwüste Ägyptens,” 203; Klemm, Klemm, and Murr, “Ancient Gold Mining in the Eastern Desert of Egypt and the Nubian Desert of Sudan,” 224.

¹⁰⁰ Klemm and Klemm, “Antiker Goldbergbau,” 158.

¹⁰¹ Klemm, Klemm, and Murr, “Ancient Gold Mining in the Eastern Desert of Egypt and the Nubian Desert of Sudan,” 215.

¹⁰² Klemm and Klemm, “Chronologischer Abriss der antiken Goldgewinnung in der Ostwüste Ägyptens,” 200.

¹⁰³ Klemm, Klemm, and Murr, “Ancient Gold Mining in the Eastern Desert of Egypt and the Nubian Desert of Sudan,” 217–18.

¹⁰⁴ Klemm, Klemm, and Murr, “Ancient Gold Mining in the Eastern Desert of Egypt and the Nubian Desert of Sudan,” 217.

¹⁰⁵ Klemm, Klemm, and Murr, “Ancient Gold Mining in the Eastern Desert of Egypt and the Nubian Desert of Sudan,” 216–17.

would not have been a problem, and the innovation of metal tools would have helped. (Iron tools are not attested until the Ptolemaic period and could not have been used before the end of the New Kingdom, at the very earliest.) Nor would it have been technologically difficult to grind quartz ore to powder and wash it. In addition to the dimple stones and rotary querns at Bit Umm Fawakhir itself, there are other kinds of grinding and crushing stones scattered around the wells, built into the walls of the modern well house, and on the road to the modern plant at Wadi el-Sid. Some of the latter stones are the large (ca. 1 m. sq.), slightly scooped grinding stones believed to be pre-Roman.¹⁰⁶

It is possible that the original Wadi el-Sid ore was so high grade that the ancient workmen won visible gold simply by grinding and washing it. If so, the rich ore is long gone, and it will be difficult to prove one way or the other. If not, then the real problem facing the New Kingdom miners would have been smelting. Given a pyritic ore, this means a two-step operation to produce lead and then to burn it off by cupellation to leave only the precious metal.¹⁰⁷

How ancient is cupellation? Here we have to turn to silver production as there is virtually no literature on gold.

Silver seems to have been won by cupellation by at least 2000 B.C., judging from silver objects from Ur, Maikop, and other sites, or perhaps even earlier, as attested by silver and lead bars from Troy I and II, ca. 2500–2000 B.C.¹⁰⁸ There is no way of knowing what the original silver ore may have been in these cases.

The Cyclades, however, have yielded even older evidence of cupellation for silver, perhaps as early as the middle of the 4th millennium B.C. One of the ores in question seems to have been **galena** (PbS), which can be smelted at the relatively low temperature of 800° C; even an open hearth piled with wood, charcoal and **galena** would work.¹⁰⁹ A complex silver-lead-antimony on Siphnos in particular was worked for silver and lead at an early date. Thermoluminescence and C¹⁴ dates point to the first half of the 3rd millennium B.C., but metal production went back even further, to at least Early Cycladic times, as indicated by litharge from cupellation associated with obsidian tools and sherds.¹¹⁰

There is, then, at least some evidence for cupellation before New Kingdom times, if not in Egypt. The problem may be the kind of ore processed. In general, **galena** is more likely to yield silver with a little gold, and **pyrites**, especially **chalcopyrites**, can contain more gold than silver. The current consensus, however, seems to be that there is no evidence for extracting precious metals from **pyrites** until Classical Greek times at earliest,¹¹¹ though it certainly was done by Roman times.¹¹²

This conclusion is not entirely supported by the extensive archaeological work at the Spanish mines in the Huelva region. The most intensive activity occurred in the Roman period, Pliny's day; in one place the slags are eight meters thick.¹¹³ Gold, silver, copper, and iron were extracted over the millennia, exploiting various ore-stuffs and employing different technologies. At the huge Huelva mines in western Spain, however, silver was the main product in the Late Bronze Age, 12th to 9th

¹⁰⁶ Klemm, Klemm, and Murr, "Ancient Gold Mining in the Eastern Desert of Egypt and the Nubian Desert of Sudan," 216 and Pl. 118. The stone in the photograph is smaller, however, measuring about 55 × 35 cm square.

¹⁰⁷ Lead does not receive a great deal of attention in the study of ancient Egyptian metallurgy, but N. H. Gale and Z. A. Stos-Gale, "Ancient Egyptian Silver," *Journal of Egyptian Archaeology* 67 (1981), 115, do note a lead hawk model from Nagada as early as Nagada II times.

¹⁰⁸ Tylecote, *A History of Metallurgy*, 45.

¹⁰⁹ Gale and Stos-Gale, "Cycladic Lead and Silver Metallurgy," *The Annual of the British School at Athens* 76 (1981), 178.

¹¹⁰ Gale and Stos-Gale, "Cycladic Lead and Silver Metallurgy," 202.

¹¹¹ Gale and Stos-Gale, "Cycladic Lead and Silver Metallurgy," 176.

¹¹² Ramage and Craddock, *King Croesus' Gold*, 235.

¹¹³ Beno Rothenberg and Antonio Blanco-Freijeiro, *Studies in Ancient Mining and Metallurgy in South-West Spain* (London, 1981), 198–206.

centuries B.C., or the time of early Phoenician contact. Silver extraction implies a knowledge of smelting, including fluxing with silica, adding lead to collect the silver, and then cupellation.¹¹⁴ The primary ores in Spain are jarosites,¹¹⁵ and the Iberian Pyrite Belt of southern Portugal and southwestern Spain includes massive sulfide deposits.

Were the New Kingdom workers actually mining auriferous quartz ore and smelting it in a complex operation? The evidence from the Turin Papyrus and other texts, the silted-in mines, pre-Roman grinding stones, and the pottery are not extensive, but they are at least consistent. Certainly the open-cast trenches following quartz veins in granite point to hard rock mining. The ores at Wadi el-Sid are complex, polymetallic sulfides. It is possible that the first ores mined were so rich that only fine grinding and washing were needed to produce visible gold. Still, all the technological skills do seem to have existed—if documented so far only outside Egypt—for roasting, smelting with lead, and then cupelling to remove the lead and win the silver or gold. Certainly it is all too true that compared to places such as England, Germany, Spain, Greece, and Turkey, ancient precious metal production in Egypt is not at all well studied.

Conclusions

Ancient Egyptian textual sources are nearly mute on the subject of mining for precious ores, though gold and silver as gifts or tribute are well attested. Thus it has long been assumed that much or all of the gold in Egypt came from the south and was produced largely if not entirely by the simple process of panning. Hard rock mining is an entirely different enterprise, however, requiring a recruitment, organization, and administration of a large labor force, massive capitalization to support it, and a sophisticated technology to win gold or silver from igneous rock. Individual steps may be simple, e.g., hacking out an opencast trench, but some may be quite difficult, such as estimating the furnace temperatures, proportion of lead or lead ore and/or fluxes, and the duration of a smelt. At Bir Umm Fawakhir the most complete evidence for complicated, multi-stage gold mining, ore reduction, and smelting comes from the large 5th–6th century A.D. Coptic/Byzantine settlement and related mines, but there is some evidence for earlier workings at the near-by mines in the Wadi el Sid, perhaps in the Ptolemaic and Late Periods, probably in Roman times, and even as early as the late New Kingdom.

¹¹⁴ Rothenberg and Blanco-Freijeiro, *Studies in Ancient Mining and Metallurgy*, 171.

¹¹⁵ Paul T. Craddock, I. C. Freestone, N. H. Gale, N. D. Meeks, B. Rothenberg, and M. S. Tite, "The Investigation of a Small Heap of Silver Smelting Debris from Rio Tinto, Huelva, Spain," in P. T. Craddock and M. J. Hughes, eds., *Furnaces and Smelting Technology in Antiquity*, British Museum Occasional Paper 48 (London, 1985), 199.