Abstract

The Spanish colonies used mercury to extract silver from ores, when the dominant approach in Europe involved smelting with lead. But economic factors of the late eighteenth century, including a shortage in Spain’s mercury supply, encouraged debate on the relative merits of both approaches. Ignaz von Born of Austria and metallurgists at the Freiberg Mining Academy, Saxony, developed an Enlightenment science of amalgamation. They translated alchemical conceptions of sympathy and digestion into a chemical language of oxidation and chloridation, and they pursued rhetorical strategies to promote their work: disavowing the experience of the azoguero (mercurist), touting the new amalgamation as rational public knowledge, and distinguishing Old World practice from more humanitarian technology. While these strategies appealed to European scholars and Spain’s Minister of the Indies, they also tied the new method to a civilizing mission would undermine its success in America.

In 1788, King Charles III of Spain authorized an expedition of leading Spanish and German metallurgists to bring the latest method of silver refining to the New World. Since the sixteenth century, Spanish metallurgists overseas had extracted silver from ores with mercury in large open patios (lavaderos). The method was simple and cost effective, but highly wasteful of precious and rare mercury, the production and distribution of which the Crown monopolized. Baron Ignaz von Born of Austria, and other high-profile men of the Enlightenment, especially chemical metallurgists at the new Freiberg Mining Academy, touted the new ‘Freiberg barrel’ method as a more rational and scientific approach. The King expected to save thousands of quintals of mercury with these rotating barrels, just when his supply was dwindling.¹ Leading European metallurgists headed the expedition, which included thirty-two German miners, divided into three missions: New Granada, New Spain, and Upper Peru viceroys. In the end, the experiment was a resounding failure. Friedrich Sonneschmid of the New Spain branch, himself a graduate of Freiberg, would argue that American amalgamation was superior to the German method, and he recommend its adoption in Europe.

There were important economic and environmental reasons for this failure, but cultural factors were as significant. Born and the Germans had not only devised a more

¹ Quintal=Centner= ~100lbs
scientific practice grounded on metallurgical chemistry, but also an Enlightenment agenda. They had formed a society to publicize the latest in metallurgical chemistry, especially amalgamation, and distinguish it from craft knowledge. Speaking to an international Republic of Letters, their language was highly rhetorical: the experts established dichotomies between Born’s approach and more secretive, craft-oriented methods such as smelting and patio amalgamation; the Freiberg method was grounded on principles of nature and demonstrated advanced mechanical power, whereas unlettered azogueros pursued a practice devoid of ‘principle’ and ‘law’, and used rude machines and muscle power; and the European technology was more humanitarian, the Europeans argued. In short, Freiberg barrels were not simply barrels: they embodied an Enlightenment agenda that Bourbon Spain would co-opt as part of its civilizing mission in the New World.²

We begin with the patio process, which had strong associations with European alchemy. It featured a master mercurist who mixed salt, mercury, and ‘magistral’ (copper or iron pyrites) into crushed ore. The best textual account of the azoguero and the alchemy of American amalgamation is Potosí metallurgist and priest Alvaro Alonso Barba’s Arte de los metales (1640), though later authors, such as Alexander von Humboldt, confirmed the long-standing importance of an alchemico-medical conception in American amalgamation. The paper then turns to Baron von Born, metallurgical chemistry, and the Freiberg method. Rhetorical language promoted the new technology as Enlightenment science, and the Spanish Minister of the Indies quickly adopted the innovation for the colonies. Freiberg barrels became part of the modernization program Bourbon Spain had for the New World. The barrels never performed to expectations, and

notwithstanding famous boosters like Humboldt, it would be many decades before European expertise reformed colonial silver refining, and then only after the experts dissociated technological innovation from the civilizing mission with which it was originally identified.

1. The Alchemy of Amalgamation

German miners had served the Spanish crown since the sixteenth century. Emperor Charles V and the Fugger network transported Saxon experts as early as the 1530s, initiating a dependence on German experience that continued into the eighteenth century, notwithstanding Spanish protectionism of the colonies. A veritable colony of German miners and smelters lived in Súltempec after 1536. One Bartolomé de Medina is credited with introducing mercury amalgamation into New Spain around 1555, having learned it from a “German in Spain.” Melero believes that Medina may have read about amalgamation in Vannocio Biringuccio’s text of 1540. But the Fugger ran Spain’s important Almaden mercury mine, and it stands to reason that they were also instrumental in the technology transfer to New Spain. Medina’s trial run at Pachuca was a failure, partly because Medina did not understand the difference between silver ore there and at Río Tinto in Spain. But once he added roasted copper sulfate (magistral) to his ground silver ore, the mercury finally bonded with the silver and could be processed. Medina’s technique, coupled with a German method for crushing the ore, became the

5 Joaquín Pérez Melero, Minerometalurgia de la Plata en México (1767-1849): Cambio Tecnológico y Organización Productiva (Valladolid, 2006), 81. Georg Agricola’s famous De re metallica had not yet been published.
6 Konrad Häbler, Die Geschichte der Fugger’schen Handlung in Spanien (Weimar, 1897).
most important alternative to smelting with lead in the New World, and the Spanish crown quickly monopolized the mercury trade.⁷

The developed patio process (beneficio de patio) involved grounding silver ore in an arrastra and spreading it over an open-air patio [fig.1]. The azoguero and his assistant, the beneficiador, then introduced magistral and salt, before sprinkling mercury over the mix. Constant stirring and natural heat over weeks gradually precipitated a heavy amalgam of mercury and silver that settled to the patio floor, which additional workers then parted. To the Jesuit, José de Acosta, these developments were a sign of God’s plan for the New World, and the special role of Spain: the patio process involved seven steps, he said, much as the soul was purified by seven sacraments.⁸ Alvaro Barba saw God’s Providence in the discovery of Huancavelica mercury mine, not far from Potosí, as if intended to supply the silver mines.⁹

Variations on the patio process dominated in the Americas until cyanide amalgamation after 1900. Of course, none of the early Spanish and German metallurgists involved understood the metallurgical chemistry of amalgamation, how silver sulfides converted into chlorides that bonded with mercury. Had they an interpretive framework within which to explain the reactions, it conformed rather to Acosta’s theology and alchemy. Since the translation of medieval Arabic alchemical treatises, Spanish scholars had understood the generation and properties of minerals in alchemical terms. Spanish explorers and chroniclers of the New World described mines and minerals in these terms, and German miners of the sixteenth century may have transferred additional alchemical notions to New Spain. Because mercury in particular was so central to alchemy it was inevitable that mercury amalgamation, whether in the Old or New World, became

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⁷ Bakewell, Mines of Silver and Gold, 110-115. We cannot address here Medina’s difficulties and the gradual spread of patio amalgamation through New Spain and into Peru. He may not have been the first to use magistral, which Bakewell believes resulted from trial-and-error among many miners. Peter Bakewell, Silver Mining and Society in Colonial Mexico. Zacatecas, 1546-1700 (Cambridge: Cambridge University Press, 1971), 144.


⁹ Barba, 83.
something akin to alchemy per se—the extraction of silver from ores with mercury resembled the transmutation of noble metal from baser ones. Indeed, the effort to artificially produce gold was grounded in real metallurgical processes, many of which were known since antiquity, including amalgamation, cementation, alloying, and gilding.\(^\text{10}\)

Textual evidence for an alchemical understanding of New World amalgamation begins with Alvaro Barba’s 1640 *Arte de los metales*. He attributed his understanding to Dioscorides, Pliny, Geber, Raymond Lull, Albertus, Georg Agricola, and other classical, Arabic, and humanist scholars.\(^\text{11}\) Spanish authors after Barba added little to his foundation, some confirming the alchemy of the art, and others turning to the principle chemistry that dominated European inquiries by the turn of the eighteenth century.\(^\text{12}\) An early treatise of decidedly alchemical stamp was Hernando Becerra’s *Tratado de la cualidad manifesta y virtud del azogue* (1649), and a work steeped in the newer principle chemistry was Lorenzo Felipe de la Torre Barrio y Lima’s *Arte ó Castilla del Nuevo Beneficio de la Plata* (1738). An excellent observer of silver amalgamation in New Spain during the late eighteenth century was Friedrich Sonneschmid. This Freiberg graduate participated in the expedition to export German technology to America to which we return, but unlike contemporary German metallurgists, Sonneschmid grew convinced of the futility of applying German methods in New Spain. That made him a more faithful observer of patio amalgamation, which he confirmed remained steeped in alchemical notions.


All the major ingredients of the process—salt, magistral, and mercury—had deep associations with alchemy. According to Arabic and Christian sources, mercury and sulfur were the female and male components, respectively, in a union that, after combination with the elusive Philosopher’s Stone, could produce gold in a furnace. Modern chemistry identifies cinnabar, the most common mercury-bearing ore, as mercury sulfide (HgS). But to Barba cinnabar was “one part sulphur and two of mercury,” and it was no surprise that at least one pharmacist tried to produce cinnabar by combining sulfur and mercury.\(^\text{13}\) After the sixteenth-century German mystic and physician, Paracelsus, the three central ingredients in European alchemy—fundamental properties of nature—were mercury, sulfur, and salt.

Magistral went by a variety of names, including green vitriol, iron vitriol, and copperas. Barba claimed that some believed magistral to be the Philosopher’s Stone.\(^\text{14}\) It did promote the release of silver from its ore, which might be construed as a transmutation of sorts. According to Sonneschmid, magistral was the “master” of the work, the very preparation of which demanded great experience.\(^\text{15}\) The mercurist chose only a certain quality of copper pyrite earth, pulverized it, added water, and roasted in a reverberatory furnace to burn off sulfur. He then stirred occasionally, but not too violently, so as to prevent sulfuric acid from releasing into the atmosphere. He tested the product by holding a sample with water in his hands—since sulfuric acid reacts with water, good magistral ought to feel warm. Compared to magistral, the production of salt or mercury was not such a delicate art, as these substances generally appeared in singular form. There was more than one ‘magistral,’ and much depended on the quality of particular ores, and the needs of particular mercurists. So identified was the *azoguero* 

\(^\text{13}\) Barba, 23, 84. 
\(^\text{14}\) Barba, 13. Magistral differed in composition from region to region. Roasted copper pyrite would have yielded iron and copper sulphate, and together with salt converted silver sulphurets in the ore into silver chlorides, which bonded easily with mercury. Barba explained that there were many ‘magistrales,’ the active ingredient in all being copper sulphate. Barba, 131. 
\(^\text{15}\) Sonneschmid, 87.
with magistral, he wore a special pouch on his body from which he grabbed this reagent and sprinkled it on the mix.

Barba described the action of mercury and magistral on crushed ores in decidedly alchemical and iatrochemical language. When the mercury became too pasty, “sickened,” as it were, the introduction of magistral ‘heated’ the mercury, rendering it active once again. But when the mercury failed to combine with the material, an opposing ‘coolness’ was necessary, generally in the form of lime or chalk. Sonneschmid confirmed that the reagents introduced before and during ‘incorporation’ — the process by which mercury was *consumed* by the substances — had heating and cooling properties, although he wished to substitute a theory of oxidation to replace the “old manner” of speaking. Otherwise, he confirmed that the *azoguero* determined the quality of the amalgam based on its consistency, color, wetness, and other external qualities, especially by pressing samples between his thumb and fingers, and even by observing the relative speed of the horses or mules that rotated the mixers. Many believed that the great loss of mercury in the patio, the bane of the Spanish silver industry, was due to mercury’s complete digestion by contrary metals, though Barba argued that mercury could be recovered after processing. He would develop an important alternative to cold amalgamation in the patio: Barba’s experiment with boiling the mercury mix in copper cauldrons to expedite the amalgamation process (Cazo process) found few adherents before Baron Ignaz von Born of Austria.

Patio amalgamation was a complex craft the proud *azoguero* mastered. Humboldt summarized this alchemico-medical practice, exposing some of the prejudice that had contributed to its relative neglect among Europeans since Medina:

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16 Barba, 131.
17 Sonneschmid, 164.
18 Sonneschmid, 129, 152, 160, 165
19 Barba, 138.
“The azogueros speak of a mass of minerals as of an organized body, of which they augment or diminish the natural heat. Like physicians who in ages of barbarism divided all ailments and all remedies into two classes, hot and cold, the azogueros see nothing in minerals but substances which must be heated by sulphates if they are too cold, or cooled by alcalies if too warm.”\(^\text{20}\)

2. Amalgamation returns to Europe

The relative neglect of American amalgamation among German scholars ended in the late eighteenth century. Austrian silver production slowed, which encouraged innovation in silver refining; but even more notably, Spain confronted a bottleneck in mercury supply just when its colonies’ need for mercury was increasing. Production at Huancavelica mercury mine declined markedly as miners across Lower and Upper Peru increasingly hit lower-grade (deeper) silver ore that required amalgamation.\(^\text{21}\) This put renewed pressure on Almaden, Spain, and compelled Charles III to contract with Austria for cheap access to its Idria mercury, though neither site could adequately replace Huancavelica. The cost of production and overseas transport, compounded by war with England, made shipping mercury difficult. The Minister of the Indies, José de Galvez, sponsored a prospecting expedition to New Spain to explore new sources of mercury, but nothing feasible was found.\(^\text{22}\) A debate on the relative merits of smelting and amalgamation accordingly arose among scholars and metallurgists in the Old and New Worlds, but Galvez was prepared to reintroduce smelting to colonial mining (largely

\(^\text{20}\) Alexander von Humbolt, *Travels to New Spain*, 268

\(^\text{21}\) Amalgamation was necessary for lower-grade (deeper) ores in which silver was found as complex sulfides. The Spanish distinguished between surface-level paco, for which traditional smelting generally sufficed, and deeper negrillo ores. See entries in Peter Bakewell, ed., *Mines of Silver and Gold in the Americas*...

\(^\text{22}\) Whitaker, “The Elhuyar Mining Missions…” 575-76. Spanish and Mexican miners would continue searching for a new mercury source until New Almaden (California) was finally discovered around 1845 by a Mexican soldier.
abandoned since the sixteenth century). Fuel, furnaces, and lead for smelting operations were costly prospects, but independence from mercury had become attractive.\(^{23}\)

This was the context in which Ignaz von Born, then royal head of minting and mines at Prague, announced a revised version of Barba’s boiling technique. That Bourbon Spain would experiment with his method was no surprise, considering Spain’s continued dependence on German-speaking experts, including at Almaden, where the chief director since 1783 was one Johann Martin Hoppensack.\(^{24}\) An early edition of Born’s book was dedicated to Charles III. Galvez sent Spain’s leading metallurgists, Fausto and Juan José Delhuyar, to Saxony, Sweden, and Austria to learn the latest in mining sciences, especially Born’s technique. The brothers were present at the gathering at Schemnitz (see below), where Born demonstrated his work, and they visited Freiberg when Gellert and Charpentier were improving upon the technology.

Born’s primary scientific accomplishment was to update and mechanize the boiling method, introduce independent roasting with salt prior to amalgamation, and suggest an interpretation in light of phlogiston chemistry. Born did not utilize Lavoisier’s theory of combustion nor the latest chemical theory of minerals, as Freiberg chemists eventually would. Certain of Born’s explanations in fact recalled the alchemy he claimed to discard (for example, his use of an ‘elective affinities’ concept). But otherwise Born’s study of the salt roast would launch a comprehensive chemical analysis of how oxidation and chloridation—oxides from the atmosphere during heating, and chloride from the salt (NaCl) thrown in—rendered the silver-bearing ores more amenable to mercury. He may not have understood the chemistry of how silver sulfide converted into silver chloride in his fire, which mercury could easily attack, but Born’s experiments had demonstrated

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\(^{23}\) A major proponent for smelting in New Spain was one Joseph Coquette de Gallardo from Pachuca, who addressed the viceroy in 1783 on the comparative benefits of amalgamation and smelting. Howe, *The Mining Guild*, 304.

\(^{24}\) Tascón lists a series of experts, many of them from the Harz Mountains, who headed Almaden mining after the 1750s. Hoppensack... He dedicated his *Ueber den Bergbau in Spanien* of 1796 to the Prussian minister and former head of Saxon mining, and co-founder of the Freiberg Mining Academy, Freiherr Anton von Heynitz. Antonio Matilla Tascón, *Historia de las Minas de Almaden* vol. II (Madrid: Instituto de Estudios Fiscales, 1987), 270-282.
how to ‘free up’ the silver. Fausto Delhuyar, shortly after studying with Born, was the first to recognize the production of silver chloride (horn silver) in the process, and bring amalgamation in closer line with Lavoisier’s chemistry—though neither did Delhuyar understand oxygen.25

Born issued a substantial challenge to defenders of both the patio process and smelting, notwithstanding his adherence to pre-oxidation chemistry. He understood that because the open-air patio introduced mercury to raw (sulfuric) ores, much of it failed to bind with silver and was lost; and that the patio relied solely on sunlight and natural heat to catalyze processes, which took many weeks to complete. His salt roast prior to amalgamation burned off impurities and freed silver from the sulfides, thereby allowing less mercury to bind with more silver; the entire process now took days, not months. While Born still preferred an adaptation of Barba’s boiling method for the mercury stage, he did imagine (and depict) rotating barrels and cold (unheated) amalgamation of the kind his Freiberg colleagues would perfect. Born convinced a skeptical audience that mercury could bind to the complex sulfide ores he was using. The common assumption among European metallurgists was that mercury only bonded with native silver in ores, and could not penetrate ‘disguised’ or ‘mineralized’ silver particles.26 It was assumed that American silver appeared mostly in native form, and therefore the patio process worked; but that most European ores were complex, and therefore smelting was preferred there.

Christoph Andreas Schlüter, a mining official in the Harz Mountains, confirmed that contemporary metallurgists did not entertain amalgamation for this very reason.27 The mineralization doctrine was a deep-seated prejudice that Born explicitly and successfully challenged, a necessary precondition behind acceptance of the new amalgamation.

26 Born, 4.
27 Christoph Andreas Schlüter, Gründlicher Unterricht von Hüttenwerken...nebst einem vollständigen Probier-Buch (Braunschweig, 1738), 211-12.
3. Metallurgical Chemistry at Freiberg

Scholars and officials affiliated with the Freiberg Mining Academy largely forged the scientific amalgamation to develop after Born. Freiberg was the heart of mining operations in Saxony, and a center of study and experimentation. Alexander von Humboldt, Goethe, Novalis, and other luminaries of the German Enlightenment and Romantic Movement all studied at Freiberg, and Humboldt would become a major promoter of Freiberg barrels for New Spain. But even before the founding of the Academy (1765), Johann Friedrich Henckel (1679-1744) offered informal instruction to an international audience. His extended the principle chemistry of his mentor, Georg Ernst Stahl of Halle, to Freiberg. Henckel’s textbook of 1747, *Unterricht von der Mineralogie*, described the mineral ‘kingdom’ as a great network of veins that resembled the human circulatory system. Water from the center of the earth moved upward and assumed hardened form as rocks, gems, or minerals according to the distinctive properties of the earth through which it passed. Jean Baptiste von Helmont, Johann Joachim Becher, and other alchemical thinkers said much the same about mineral generation.

Had these men treated the issue of silver amalgamation they may have arrived at conclusions similar to Born’s, and rediscovered Barba. But amalgamation was a neglected subject in Germany before Born, and the action of mercury on silver or gold was a subject handled by early chemists independent of the question of amalgamation. The leading chemical mineralogist at Freiberg after Henckel was his student, Christlieb Ehegott Gellert. His early work still drew on Henckel and the Stahlian-Becher school, providing an advanced principle chemistry still uninformed by Lavoisier or higher-powered microscopes. Gellert’s textbook, *Metallurgische Chemie* (1751), otherwise highly progressive, still listed chemical recipes in the manner of older alchemical manual, and presented a phlogiston theory of combustion. A representative recipe read: “To
dissolve a calx of lead with vinegar, and to make thereof sugar of lead.” The author showed little interest in mercury beyond its scientific value, adding that it was exceedingly rare and had “little use in human life.”

Amalgamation appeared as one among hundreds of metallurgical processes of marginal economic significance. Gellert acknowledged that some have used mercury to extract silver from crushed ores, but he, drawing on Schlüter, denied that the process worked for ‘mineralized’ silver.

But Gellert’s practice had clearly developed before his colleagues at Freiberg, Toussaint de Charpentier, Friedrich Wilhelm Heinrich von Trebra, and two refining masters (Hüttenmeister) visited Born in Schemnitz in 1786. Charpentier sketched the copper kettles and compared the performance of kettles to wooden barrels, and he traveled to Joachimstal in Bohemia to study the amalgamation works there, founded on the Born method. Back at Freiberg, Gellert began small-scale experimentation at the Academy laboratory. His team would test wooden barrels and cold amalgamation in particular, which suggested a number of advantages: barrels were cheaper than copper kettles, did not react with chemicals as copper did, required fewer workers, and contained mercury better. While the Freiberg method, following Born, called for an independent roast of crushed ore, cold amalgamation eliminated the need for additional fuel, whereas Born had used fuel both in roasting and then again when boiling during amalgamation.

After much trial-and-error, Gellert included iron and copper pieces in the barrels (following a suggestion by Delhuyar), as they contributed to the reduction of silver chlorides (which mercury completed). His first models involved churning the ore-salt-mercury mixture inside stationary barrels, much like butter, and other experimental forms involved copper lining on the inside like Born’s kettles; but rotating wooden barrels

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28 Gellert, Seiferth, trans, pg. 58.
29 Gellert, 374.
proved most effective, and this was the form Charpentier chose for Halsbrücke mill, plans for which began in 1787.30

The completed ‘Freiberg method’ as featured at Halsbrücke after 1790 was the product of laboratory science and progressive engineering [figs 2 and 3]. It required the oversight of a chemical metallurgist to carefully calibrate each step, and it required mechanical power that could be applied and detached precisely. It involved the following major steps: mechanically crushing silver-bearing ore into a fine powder, roasting the powder with salt in a reverberatory furnace, dumping the chloridized ore in rotating barrels with water (some 10 Centner, or 1000lbs per barrel), introducing mercury and metallic pieces, and parting the silver/mercury amalgam that collected at the barrel bottoms. This was the technique Fausto Delhuyar witnessed (and helped develop) at Freiberg, and it was a similar barrel method he spearheaded in New Spain, New Granada, and Upper Peru after 1788, where variations of the patio process still dominated. Minister Galvez and the Spanish crown expected that, notwithstanding the initial costs of independent roasting and of constructing and maintaining barrels, the advantages of the Freiberg method would outweigh the disadvantages of turning from amalgamation altogether. But before looking at the fate of Freiberg barrels in the Americas, we must recall the Enlightenment context behind their very conception. Barrels were not simply barrels, and their appeal to Spain extended beyond economic considerations.

4. The Enlightenment in Barrels

Freiberg barrels represented more than a savings in time, fuel, and mercury. When Born, the foremost leader of the Enlightenment in Austria, entertained some 27 metallurgists from across Europe in 1786 at Glashütte, near Schemnitz, Hungary (today, Skleno, Slovakia), the emerging science of amalgamation became an Enlightenment

30 Ortmann, 1788, 38. Still other models were tried at Glashütte mill in Hungary, and much depended on local ores and particular needs. As Spain would select ‘Freiberg barrels’ for the colonies, we continue focusing on those in particular.
agenda. When we consider how predisposed against amalgamation European
metallurgists were, and how tentative Born’s theoretical framework was—a phlogiston
theory, which he could only apply lightly, and which was fast being relegated to the past;
and an ‘elective affinities’ conception that had more in common with Barba and alchemy
than with Lavoisier—we begin to appreciate why Born sought the legitimization of the
Republic of Letters. Presenting the barrel process, not only as a more cost effective
approach, but also as a more ‘enlightened’ technology than smelting gave Born greater
exposure and fame. We can study the ideological agenda that surrounded and motivated
the new European amalgamation by distinguishing three rhetorical strategies through
which Born and his colleagues promoted their work. These strategies brought widespread
acclaim for Freiberg barrels in Europe, but contributed to their failure overseas, where
Enlightenment rhetoric often fell on deaf ears, and cultural constraints as well as
economic limitations determined the success of foreign technologies.

A. Openness and Universality

From the very outset, Born promoted the gathering at Schemnitz as a rejection of
trade secrecy and monopolization of knowledge. The Emperor Joseph II had issued a
decree forbidding state metallurgists to publish on mining in 1771, which Born had
quickly defied by producing a text on mining machinery. He was so disappointed in his
patron’s continued refusal to allow a free circulation of mining knowledge that Born
resigned his position. Now, some fifteen years later, a more enlightened Joseph allowed
Born to publish his new findings, and the international meeting he hosted shortly
thereafter furthered his cause. The object of Born’s frustration was no longer Austria, but
rather Spain. Had the Spanish monarchy not controlled all scientific expeditions to the
colonies—favoring natural historical investigations to enrich collections at home, but
neglecting scholarly interest in its mines—Europe would have known about American

31 Nikolaus Poda, Kurzgefasste Beschreibung der bey dem Bergbau zu Schemnitz in Nieder-Hungarn
errichteten Maschinen (Prague, 1771).
amalgamation sooner.\textsuperscript{32} Unlike Spanish monarchs before the present Charles III, Emperor Joseph II was an “Enlightened monarch” who advanced mining knowledge among the learned.\textsuperscript{33} Born’s comments were exaggerated, of course, considering the Emperor’s history with Born, and his own self-interest in promoting amalgamation: he was asking for a percentage of all income generated by his method (Joseph denied the request). Nevertheless, one participant from Britain, John Hawkins, claimed that monopoly and private interest had been “sacrificed for public benefit” at Schemnitz, and Born’s process would contribute to “general prosperity.”

Other statements issued shortly after the gathering conflated smelting with alchemy, distinguishing both from Born’s method. The presentation of amalgamation as an enlightened technology grounded on universal laws of nature required that smelting, otherwise favored in Europe, be seen as a quasi-magical practice associated with craft secrecy. Johann Jacob Ferber from Sweden, present at Schemnitz, wrote that the amalgamation master (\textit{Vorsteher einer Quickhütte}) demanded “more thorough grounding in chemistry” than the smelter.\textsuperscript{34} Olaus Henckel added that smelting involved a “multiplicity of operations” hiding behind a veil of “mystery and secrecy,” all of which merely obscured “blunders and ignorance.”\textsuperscript{35} Delhuyar similarly denounced “secrecy and mystery” in certain arts, which was a “disguise of imperfection.”\textsuperscript{36} Born, who promised to ignore Barba’s “philosophical and alchymical remarks,” questioned the use of dung and other “useless” reagents in the patio. Spanish miners had failed to “reduce their processes…upon principles,” he explained.\textsuperscript{37} By contrast, European metallurgy had been “reduced upon theoretical principles and raised from the mean rank of a plebian empirical trade to that of a science,” which Born equated to a process of ‘maturity.’\textsuperscript{38} Charpentier echoed the sentiment: Born’s discovery—and few attributed discovery status to Barba—

\begin{footnotesize}
\textsuperscript{32} Born, 10.
\textsuperscript{33} Born, 71, foot.
\textsuperscript{34} Ferber, Nachricht von dem Anquicken… xxv.
\textsuperscript{35} In Born, 212.
\textsuperscript{36} In Born, 199.
\textsuperscript{37} Born, 9
\textsuperscript{38} Born, 158
\end{footnotesize}
was “established upon accurate experiments and rational theory.”\textsuperscript{39} The roasting of ores prior to amalgamation proper proceeded, “by direction of a theory established upon chemical principles and experience,” to which Charpentier contrasted smelting. Who could object, he asked, to a method “established upon principles of chemistry and natural philosophy?”\textsuperscript{40}

Charpentier was referring, of course, to the phlogiston theory and principle chemistry Born invoked in his text, as few in the 1780s had come to absorb the oxidation theory and chemistry of Lavoisier. While it may be an exaggeration to argue that Born merely “adopted the ideas of the alchemist from Lepe [Barba] in a new linguistic form,”\textsuperscript{41} principle chemistry had a firm footing in alchemy. When Ferber referred casually to the “affinity between bodies” (Verwandtschaften der Körper) that an amalgamator must understand, he too meant the principle chemistry then available.\textsuperscript{42} Delhuyar, who also employed a phlogiston theory, praised the “natural philosophy and enlightened chemistry” of the Born process, which he even claimed “guided the hands of the workmen.”\textsuperscript{43} The rhetoric of universality did not require a complete scientific theory, it seems, only the promise that one would emerge.

B. Republic of Letters

The opposition these men fabricated between trade secrecy and openness, obscurity and laws of nature, and smelting and amalgamation was propagated immediately within the Republic of Letters. To advance himself and the new technology Born and his chief colleague from Germany, Trebra, organized a Society of Mining Sciences (Societät der Bergbaukunde) that included major names in contemporary mining, chemistry, and the European Enlightenment more broadly, from some fifteen

\textsuperscript{39} Born, 185  
\textsuperscript{40} Born, 187-88  
\textsuperscript{41} Tristan Platt, “The Alchemy of Modernity…” 30.  
\textsuperscript{42} Ferber, xxv  
\textsuperscript{43} Born, 199
regions: these included Anton Lavoisier, Lorenz Crel, Johann Friedrich Gmelin, Martin Heinrich Klaproth, James Watt, and the Delhuyar brothers. Goethe was an honorary member. The society combined a commitment to freedom, rationality, and science that was the hallmark of the Enlightenment. The election of offices was highly democratic, and the express purpose was to mediate the free-flow of ideas in mining and metallurgy across Europe.

They inaugurated a journal to publicize the goals of the new society and publish members’ research, especially the latest in mercury mining and amalgamation. Bergbaukunde saw only two editions (1789 and 1790), but they were clear efforts to solidify amalgamation within the world of high culture. In their preface to the first edition, Born and Trebra promised to ‘extend Enlightenment to the underworld.’ This involved rejecting “secret-mongery [Geheimniskrämerei],” exposing trade secrets, and making public all useful knowledge. The editors praised the Spanish expedition that was to bring Freiberg barrels to the colonies, and which included specialists from the Freiberg Academy and some twenty Saxon miners (see below). Otherwise, the two editions of Bergbaukunde included a piece on Bohemian mercury mining, a history of amalgamation in Bohemia, Fausto Delhuyar’s theory of amalgamation, and Trebra’s “Contributions to Advances in Amalgamation.” Amalgamation had become the very epitome of Enlightenment science in Born and Trebra’s hands.

Meanwhile, Charpentier began plans for barrel amalgamation at Halsbrücke near Freiberg. The result was the largest amalgamation mill in all of Europe, if not the world. The access the Academy gave to its local amalgamation works embodied the spirit of Schemnitz, and Freiberg was already famous for its international student body. One gentleman from Spain thought it fit to publish his observations in French and German, so

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44 Teich, 335.
cosmopolitan were all things ‘Freiberg’ and ‘amalgamation’ at that time. At Halsbrücke all steps from crushing to retorting were housed within one large mill, which eventually included 20 large barrels for amalgamation, set in mechanical motion by a water wheel. The site became a tourist attraction.

C. Humanitarianism

Finally, Born and his followers claimed that the new amalgamation was actually safer than both the ‘barbaric’ American patio technique, and smelting in Europe. Born addressed this issue when comparing amalgamation and smelting, claiming that his method called for wet stamping of ores to eliminate dust, whereas common smelting allowed lead particles to disperse freely. More notably, Born had the royal physician at Schemnitz, one Hoffinger, give his expert opinion of the new amalgamation. Hoffinger praised the furnace Born used, which required far less heat than usual reverberatory furnaces, and did not require workers to come as near to the source of heat. During amalgamation, moreover, the Born technique brought the mix only to the point of boiling—far less heat, again, than in smelting—and mercury evaporation was therefore minimal. Hoffinger saw no residual amalgamation on jewelry or other gold pieces in the vicinity of the boilers, a sure sign of mercury evaporation. He conceded that workers came into contact with mercury after the amalgam was formed—they typically pressed excess mercury from the amalgam by hand—and especially during parting (retorting) of the silver from mercury, but he maintained that contact was short-lived and the mercurial fumes were mostly trapped in iron caps that sat above the furnaces. Having observed the workers for twelve months, the physician came to the point: “I have not seen or heard of any complaining of trembling limbs, palsy, salivation, soreness of the gums, or tooth-ach.” Those were sure signs of mercury poisoning. He then made the comparison with

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46 Siqueira, Beschreibung der Amalgamations…zu Freiberg, 1800.
47 Errinnerungen an Freibergs Bergbau: Ein Leitfaden für den Besuch der Gruben und Wäschen, sowie der Hütten, des Amalgamirwerks, und der Extractionsanstalt (Freiberg, 1850). Halsbrücke was also the site for the first gas lighting in the world, which Lampadius demonstrated in 1816.
American practice explicit: “The Spanish American process is certainly cruel and hurtful to the health of the workmen; but it absolutely differs from our operations. What we perform by engines is performed in America by hands; we triturate [amalgamate] in boilers with wooden stirrers; there trituration is performed by the feet of the workmen.”

Other participants at the Schemnitz gathering echoed Hoffinger’s expert opinion. Delhuyar found occasion to underscore the health value of amalgamation: “The quicksilver cannot affect them in any way of its operations; the heat they must undergo, and the work they have to do, are not in any way so troublesome and hard as before; and the smoke wherein they live and breathe, is not so poisonous and dangerous as that of the common furnaces.” Johann Daniel Weber from Freiberg, who would join Delhuyar to South America, condemned the poisonous smoke of the smelters’ furnaces, but praised the wet stamping, closed furnaces, and controlled heat that Born showcased.

5. The Enlightenment Overseas

“Since the practice of amalgamation of silver minerals was introduced into Europe, and since the learned of every nation met at the metallurgic congress of Schemnitz, the confused theory of Barba and the Mexican azogueros has been succeeded by sounder ideas, better adapted to the present state of chemistry. It is supposed that the practice of Freiberg, where a mass of roasted minerals is amalgamated in a very few hours, will be gradually introduced into the Mexican amalgamation, where the minerals are generally not roasted.”

Humboldt, a graduate of the Freiberg Academy, drew a clear distinction between the ‘confused’ ideas of Barba and the azogueros, and the ‘sound’ notions of Born and European metallurgists. His work expressed all the rhetorical strategies that originated...

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48 Born, 255-6
49 Born, 203.
50 Born, 250.
51 Humboldt, Travels, 269.
with Schemnitz and the Society of Mining Sciences. So influential was Humboldt’s account of New Spain, British and German mining companies interested in Mexican mining continued to refer to it through the nineteenth century, notwithstanding the evident failure of most European methods in the Americas. But Freiberg barrels had attracted Spain’s attention before Humboldt. The Bourbon monarchy had for some time been improving colonial mining, which included establishing a mining guild and mining tribunal, and subsidizing the cost of mercury. When Born was still experimenting with independent roasting and the boiling method, the Minister of the Indies, José de Galvez, had sent Juan José Delhuyar to New Granada to report on the feasibility of replacing amalgamation with smelting. He and his brother, Fausto, had both been to Schemnitz, but only Fausto witnessed Gellert and Charpentier’s barrels at Freiberg. It was Fausto, as director of mines in New Spain, who the Minister charged with overseeing the introduction of barrels to the colonies in 1788, instructing local miners in European methods, and establishing a Royal School of Mines (f.1792), among other improvements in mining. Humboldt could marvel over the new mining school at Mexico City, which drew talent from Freiberg, but the promise of barrel amalgamation would never materialize.

The mission to export the Enlightenment in barrels was doomed to fail. Friedrich von Sonneschmid and Fausto Delhuyar headed the team to Sombrerete, Guanajuato, and other New Spain locations; Fausto’s brother oversaw a party to New Granada (he was already present inquiring into smelting); and Baron von Nordenflicht directed the expedition to Lima and Postosí in the newly established Upper Peru viceroy. Each team dispersed into smaller contingents to individual mining towns. Some of these men

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(Sonneschmid, Delhuyar, Nordenflicht) were recent Freiberg graduates, and the Baron was a privy counselor and manager of mines in Silesia. Beuchler, referring to Nordenflicht’s Protestantism, notes that he ensured the Spanish crown understood his “tastes and character” before joining the mission. \(^{54}\) That the Inquisition confiscated the Nordenflicht team’s prayer books at Cádiz before the men set sail was an ominous sign of trouble to come. The party’s sixteenth-century predecessors, miners transported by Charles V to New Spain, had sometimes been persecuted more formally as heretics. \(^{55}\)

All three missions failed, but we are best informed about events in Upper Peru. Nordenflicht’s group was headed by thirteen experts, only one of whom was Spanish speaking. Eleven were German, including Anton Zacharias Helms from Hamburg, Johann Daniel Weber from the Palatinate, and Gottlob Friedrich Mothes from Schneeberg, Saxony, and Nordenlicht was Swiss. Faced with major constraints in fuel and water supplies, and lack of proper expertise to build and operate the machines, among other economic challenges, the party maintained an optimistic faith in the superiority of its methods that inevitably undermined its credibility and own ability to overcome obstacles. Shortly after arrival, Nordenflicht promised the mining guild (\textit{Gremio de Azogueros}) at Potosí nothing short of a revolution in silver production: 200 percent output of silver, mercury consumption reduced by 7/8, salt consumption down by 1/2, time reduced to 24 hours, and the replacement of Indian labor in mixing mercury into the powder, and washing it out later, with machines. According to one miner, the Europeans had presented their plans “with their luggage,” by which he meant that their plans had never been accommodated to real conditions. \(^{56}\) Trial runs were indeed disappointing, and the great publicity that was the hallmark of the Enlightenment in Europe served now to spread “destructive” rumors about the incompetence of the foreign ‘professors.’ Barrels literally crashed to the floor, as the weight of ore proved too much

\(^{54}\) Rose Marie Beuchler, “Technical Aid to Upper Peru…” 39.

\(^{55}\) Wilhelm Pferdekamp, \textit{Deutsche in Frühen Mexiko} (Berlin: Deutsche Verlags-Anstalt, 1938).

\(^{56}\) Beuchler, “Technical Aid,” 71.
for the wooden frame, constructed by local carpenters. Nordenflicht rebuilt a sturdier frame and achieved more satisfactory results, but not before faith in the barrel method and its proponents waned, as results fell short of Nordenflicht’s promises. The mining guild began organizing formally against the foreigners, even publishing articles critical of the mission. 57

Anton von Helms kept a journal of his experiences (1798) in South America, which, while it covered economic problems such as lack of wood and water, also documented the mutual distrust that grew between the Europeans and Spanish workers, miners, and financiers, which sealed the fate of Freiberg barrels. His criticism of Spanish mining in America extended well beyond the issue of mining technology per se, but was a top-down attack on the entire colonial system. Even before arriving at Potosí, Helms, echoing German critics before him, and invoking the ‘noble savage’ trope then popular in Europe, condemned the treatment of natives by the Spanish. 58 Had the Indians not been harshly mishandled and subject to a faulty educational system, their inherent goodness, passivity, and industriousness would still be evident. But the lazy and self-interested Spanish, both missionary and miner, had warped the good nature of the Indian. 59

Helms had the support of the Minister of the Indies and local governor in Potosí, but the mining community grew frustrated with the experts, given their inflated promises. The Spanish officials and metallurgists Helms instructed expected quick and obvious results. They levied charges, both real and fanciful, against the foreigners, calling them frauds, heretics, or Jews, and convincing the Indian workforce that machines would replace their labor. 60 Rather than implicate himself and his team, Helms could only resort to generalities and finger-pointing: the Spanish miners and metallurgists were everywhere “ignorant” for their neglect of proper tools, adits, tunnels, and metallurgy; the Creoles

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58 Helms, 17. German and Austrian Jesuits that Spain sent to the colonies since Kino Eusebius often commented on the harsh treatment of the Indian mine workers by the Spanish. Helms was chief assayer at Cracow, Poland, when Delhuyar recruited him for the Peru mission.
59 Helms, 10, 34.
60 Helms, 100.
simply hated “whatever is European,”61; and everybody was lazy and incompetent by comparison with the Germans.62 Spanish miners and merchants had a vested interest, it seemed to Helms, in maintaining the status quo. European amalgamation in America was a work of ‘civilization’ lost among the barbarous: the patio process was, “conducted in so slovenly, wasteful, and unscientific a manner, that to compare the excellent method of amalgamation invented by Baron Born, and practiced in Europe, with the barbarous process used by these Indians and Spaniards, would be an insult to the understanding of my readers.”63 Helms attempted to defend himself and barrel amalgamation, but he ultimately left Peru in disgust, having received permission to end his 10-year contract early in 1793.

To all accounts, events transpired similarly in New Granada and New Spain, even though neither was as geographical isolated as Potosí. The arrival of the Europeans in New Spain was broadcast throughout all the Reales de Minas, and the King’s desire that miners consult with them. Sonneschmid and Delhuyar were far more diplomatic than Helms was in Peru, and Delhuyar even advised his team to gain the confidence of locals before attempting to reform their practices.64 Still, one detects the sort of non-economic constraints we are discussing: Delhuyar’s feeling of cultural superiority, and audience’s resistance to foreign help. The Spaniard’s formal report on Guanajuato mine to the viceroy Valdés proves the author was a sharp observer of technical and economic challenges behind the incorporation of barrels, but also exposes certain frustrations with local miners. For example, Delhuyar was mystified that improvements in underground scaffolding, so “clear and simple” to anyone even without mining education, had not been undertaken. This could only be due to the “indolence or lack of curiosity” of the overseers, who refused advice simply out of “pride and self-esteem.” Again, “ignorance

61 Helms.
62 Helms, 23, 48, 58, 97.
63 Helms, 47.
64 Howe, The Mining Guild, 311.
and prejudice” were the chief obstacles Delhuyar faced, in addition to high costs.\textsuperscript{65} He doubted that a new method for raising water from mines would be adopted, not only because of the high capital output, but because “every novelty inspires a certain amount of fear.”\textsuperscript{66} On the subject of European-style amalgamation in particular, Delhuyar, conducting numerous small-scale assays, was at pains to prove to Guanajuato miners and investors that barrels would save on mercury and maximize silver production. He had only marginal success in disposing them to “examine with impartiality and without distrust.”\textsuperscript{67}

Delhuyar, having faced insurmountable economic, bureaucratic, and cultural challenges in the field, turned rather to establishing the School of Mines in Mexico City. A major owner of mines, Don José Mariano de Fagoaga, issued a telling summary of the mining mission to his viceroy: “the German miners that were sent to teach America, in spite of their scientific knowledge, could not improve one single thing, either in the method of working the mines, or in treating the metals.” He may have been exaggerating, but Fagoaga’s hostility to European ‘professors’ would seem authentic. Sonneschmid’s own disenchantment with barrel amalgamation at Sombrerete could only have fueled local resistance. He began a systematic re-evaluation of the patio method, which he ultimately recommended for Europe. “At least I have no embarrassment in declaring that with ten years of work…I have not been able to introduce either the refining process of M. de Born or any other process preferable to the patio.”\textsuperscript{68} Sonneschmid conceded that Europeans had been unjustly prejudiced against American amalgamation and the accumulated wisdom of the azoguero.\textsuperscript{69}

\textsuperscript{66} “Reflections,” in Howe, 479.
\textsuperscript{67} “Reflections,” in Howe, 486.
\textsuperscript{68} Sonneschmid, \textit{Tratato}, in Motten, Mexican Silver and the Enlightenment… 52. On the incorporation of American methods in European practice after Sonneschmid, see Dym, “Freiberg and the Frontier.”
\textsuperscript{69} Friedrich Traugott Sonneschmid, \textit{Beschreibung der spanischen amalgamation}, 9.
6. Conclusion

Barrel amalgamation was part of a civilizing mission to Spanish America that local mining communities mostly rejected. While it is tempting to explain the failure in purely economic terms, focusing on the cost and availability of fuel, labor, mercury, and other supplies, the fate of barrels was intimately tied to the Enlightenment agenda Ignaz von Born and his colleagues at the Freiberg Mining Academy in Germany had originally developed. They cast amalgamation as something more than a craft like smelting, and certainly distinct from alchemy, with which the patio process had a close association. The Freiberg method represented new laboratory science and the height of European progress, and its performance overseas became a trial run of the Enlightenment itself. Faced with the evident failure of the barrel method and comparative success of the patio, Helms could only judge the Spanish and Indian overseas as too un-enlightened to appreciate the gifts of civilization. Sonneschmid, by contrast, managed to shake the civilizing mission and begin a more objective analysis of the patio, one that was destined to transform both American and European amalgamation in decades to come.