THE DELHUYAR BROTHERS, TUNGSTEN, AND SPANISH SILVER

Lyman R. Caswell and Rebecca W. Stone Daley, Texas Woman's University

The brothers Juan José and Fausto Delhuyar y Lubice were leaders in the transfer of European chemical and metallurgical technology to colonial Spanish America in the late eighteenth century. Juan José Delhuyar was the first person to isolate tungsten metal, and is recognized as its co-discoverer. Fausto Delhuyar organized the Royal College of Mines (Real Seminario de Minería) in Mexico City, the first technical college in the New World, and served as its first director(1).

The lives of the brothers form a study of contrasts. The elder brother, Juan José, was a brilliant chemist and metallurgist; but, shy and reserved in personality, and without political skills, he was unsuited for the administrative position assigned to him. His efforts to improve the silver mining industry of New Granada ended in failure. On the other hand, Fausto, the socially adept younger brother, possessed great self-confidence and leadership ability. He succeeded as an administrator and educator in colonial Mexico, and, after Mexican independence, as a public servant in Spain.

Juan José Delhuyar y Lubice

Juan José was born on June 15, 1754, and Fausto on October 11, 1755, in Logroño, Spain. A sister, María Lorenza, was born on August 8, 1757. The parents were Juan Delhuyar Surrut (2), a surgeon, and Ursula Lubice Sarrasti (3), who were of French Basque ancestry. Other than brief attendance at a Jesuit academy, nothing is known of the brothers' early education. With the intent of becoming physicians, in 1772 the brothers went to Paris, where they studied medicine, surgery, chemistry, mathematics, physics and natural history. Juan José returned to Spain in 1777. He was accompanied by Angel Díaz Castellanos, who had been a fellow student in Paris and who married Juan José's sister, María Lorenza. Upon his return, Juan José joined the Royal Basque Society of Friends of the Country (Real Sociedad Bascongada de los Amigos del País), which had been chartered by King Charles III in 1765 for the purpose of promoting the applied sciences in the service of Spain (4). This society had been founded by a group of Basque intellectuals under the leadership of the Count of Peñaflorida.

Among the goals of the Basque Society was the modernization of the Spanish iron industry, most of which was located in the Basque provinces of northern Spain. At the same time the Navy Minister González de Castejón sought advice for improvement of the quality of Spanish cannon, which were of poorer quality than those made elsewhere in Europe. At the suggestion of a Basque naval officer, José de Mazarredo, Castejón consulted the Basque Society in

this matter. The two goals were combined. The Basque Society was to select two technically trained persons, one to visit the British cannon works at Carron in Scotland, the other to study mining engineering and metallurgy at the Freiberg Mining Academy (Bergakademie Freiberg) in Saxony and visit the cannon factories in Germany and Austria. The Basque Society selected Juan José for the latter mission. He left Spain in April 1778 to study at Freiberg on a fellowship provided by the Society. He also had secret instructions from the Navy to visit the cannon factories of northern Europe to learn as much as possible about the technologies of cannon manufacture in use there. The Navy would reimburse the Basque Society for his expenses. It was understood that he would be supervisor of the Spanish cannon works upon his return to Spain.

Fausto Delhuyar y Lubice

As part of the drive to improve Spanish technology, the Basque Society founded the Patriotic Seminary (Seminario Patriótico) in Vergara in 1777. This was the first technical college in Spain, and the first to have chairs of chemistry and mineralogy. These two professorships were to be financed by the Navy, while the Basque Society financed the chair of physics.

Two members of the Basque Society who were in Paris, Javier María Eguía and Antonio María de Munibe y Areyzaga, the son of the Count of Peñaflorida, were asked to recruit faculty for the Patriotic Seminary. They nominated their friend and fellow student, Fausto Delhuyar, for the chair of mineralogy. Hilaire-Marin Rouelle, with whom Fausto had studied chemistry, supported his appointment. Louis-Joseph Proust, who later established the Law of Definite Proportions, received the chair of chemistry. Fausto accepted his appointment in December, 1777, with the condition that he first take advanced studies in geology and mineralogy in Germany and Austria. The Basque Society sent him from Paris to join his brother in Freiberg to study with Abraham Gottlob Werner, who at that time was Europe's leading geologist. In addition to their studies at Freiberg, the brothers visited mineralogists and mines in Germany and Austria. Among the persons whose acquaintance they made was Baron Ignaz von Born, Court Counselor in the Austrian Department of the Mint and Mining (Hofrat bei der Hofkammer in Münz und Bergwesen). At a musical evening at Born's home in Vienna, Fausto met his future wife, Juana Raab de Moncelos, daughter of an Imperial Councilor (Consejero Áulico de Imperador). Following the conclusion of their studies at Freiberg, the brothers toured the mining districts of Hungary, including a visit to the Imperial Royal Mining Academy (Kayserliche Königliche Bergwesens-Akademie) at Schemnitz (now Banská Stiavnica in Slovakia). Fausto returned to Spain in October 1781, and initiated his course in mineralogy at Vergara the following year.

In March, 1781 Juan José wrote to the Count of Peñaflorida that he had learned that tests made at the Hamburg proving grounds showed that Swedish-made cannon were superior to the British cannon from Carron. In December, Juan José used this information to justify a trip to Sweden, where he took an advanced chemistry course with Torbern Olaf Bergman at the University of Uppsala (5). In July, 1782, accompanied by Charles André Hector de Virly, president of the Chambre de Comptes of Dijon, France, Juan José visited the laboratories of Carl Wilhelm Scheele at Köping. At this time Scheele and Bergman were investigating the composition of a mineral called in Swedish *tung sten* ("heavy stone"), whose modern name is scheelite. Chemically it is calcium tungstate. Scheele had prepared tungstic acid, from which Bergman had obtained tungsten(VI) oxide. Both Scheele and Bergman suspected the presence of a new element in these materials, but neither of them had been able to isolate it. Among Juan José's assignments in Bergman's laboratory at Uppsala had been the task of repeating this work.

Juan José returned to Spain in October, 1782. He recommended to the Navy that the Spanish method of hollow casting of cannon be abandoned. Instead the cannon should be cast solid and the barrel bored out, following the method used in Germany and Sweden. Upon receiving this report, the Navy Minister, Marqués González de Castejón, fired Juan José. Castejón placed the management of the munitions factories under a naval officer, Antonio Valdés, with orders to continue hollow casting. The Navy refused to reimburse Juan José for the expenses of his trip to Sweden (6). Temporarily

out of a job, Juan José joined Fausto at Vergara in the analysis of a mineral from the Zinnwald, near the border between Saxony and Bohemia. This mineral, which had the German name *wolf rahm*, or "wolf foam," is known today as wolframite, and is a mixed tungstate of iron(II) and manganese(II). From this mineral the brothers prepared substances which Juan José recognized as identical with the tungstic acid and tungsten(VI) oxide he had prepared in Uppsala. The training in smelting techniques, learned at Freiberg, enabled the brothers to reduce the oxide and obtain tungsten metal, which neither Bergman nor Scheele had been able to do. Their method, reduction by powdered carbon in an air-tight crucible, produced pellets of tungsten. The Delhuyars proposed the name *wolframium* for the new metal. The international symbol W for tungsten derives from their name. The brothers' report of the new element, entitled "Chemical Analysis of Wolfram, and Examination of a New Metal, Which Enters into its Composition," was published in the *Extractos* of the Basque Society in 1783 (7). A French translation was published in 1784 in the *Mémoires* of the Academy of Toulouse, of which Fausto was a corresponding member. Translations of this report were published in Swedish in the same year, in English in 1785, and in German in 1786 (8). Although the brothers shared equally the credit for the discovery of tungsten, Juan José deserves the greater share, perhaps the principal share. He had already become familiar with the compounds of tungsten in Bergman's laboratory; and it was he who had studied smelting technology at Freiberg. Unlike his brother, he had no classes to teach and he could spend as much time as he wished in the laboratory. It was Fausto, however, who communicated the news of the isolation and properties of the new metal to Bergman, in a letter of January 15, 1784 (9). By this time Juan José had departed for Cádiz to prepare for embarkation to America.

Juan José received his new appointment late in 1783. Antonio Valdés, who had succeeded Castejón as Navy Minister in March, reviewed Juan José's qualifications and recommended him to José de Gálvez, the Minister of the Indies (colonial minister). Gálvez offered him an appointment as Director of Mines of New Granada (modern Colombia). Juan José's assignment was to increase the *quinto*, the fraction of the mining production reserved for the government. This required finding ways to increase production of the mines, while at the same time holding down costs. Since the founding of the Spanish colonies in the Americas, a significant portion of the Spanish government's revenue derived from the *quinto*. During the seventeenth and eighteenth centuries, the value of the *quinto* declined as the result of inflationary trends in the home country. This, combined with the exhaustion of the richer ores, had resulted in increased production costs in the colonies. A large part of the production costs lay in the cost of the mercury needed for the *patio amalgamation method* used to separate silver and gold from their ores (10). In this method the pulverized ore was spread on an open, paved court, acidified, and mixed with mercury. The process was labor-intensive and required five weeks to five months to complete, depending on the weather and the nature of the ore. When the managers deemed the amalgamation to be complete, the earthy residue was washed away, the amalgam was formed into cones and the mercury was distilled out, leaving "pinecones" (*piñas*) of silver sponge. Production of mercury from American mines was inadequate to meet the need. Most of the mercury had to be shipped from Europe. In times of war adequate supplies of mercury could not be obtained. A solution to the problem was suggested by the naturalist José Celestino Mutis, the Director of the Royal Botanic Expedition in New Granada (Real Expedición Botánica del Nuevo Reino de Granada). He recommended to the Viceroy of New Granada, Antonio Caballero y Góngora, that amalgamation be replaced by smelting, which could be done with charcoal manufactured from the local forests, as was done in the mining regions of Germany. Caballero forwarded the recommendation to Gálvez. The latter, noting Juan José's expertise, ordered him to smelt the ores of New Granada.

Juan José accepted the appointment without full awareness of its nature. He saw the job as a technologist's position, in which he would work directly in prospecting, assaying, mining engineering, and metal production. The colonial authorities saw it as a management job. The two viewpoints did not overlap. Juan José, moreover, went into the job without first gaining assurances of an competent support staff and an adequate budget. After a six-month wait in Cádiz for a ship to New Granada, Juan José sailed on July 26, 1784. His brother-in-law, Angel Díaz, accompanied him. During the delay, Díaz had expended their resources on entertainments and fine clothes, and they were impoverished when they sailed. Juan José's salary did not begin until his arrival in New Granada. Juan José started work at a partially abandoned *real* (mining property) at the village of Santa Ana in New Granada on March 2, 1785. His inspection of the mines and assays of ore samples resulted in an optimistic preliminary report to the Viceroy, dated April 10, 1785, in which he recommended reopening the mines (11).

A few days after Juan José sent his first report to the Viceroy, word reached Spain that a new and highly efficient amalgamation method for extraction of silver had been invented by Baron Ignaz von Born. In response to this report, Fausto wrote to Born to request more information. Born replied through diplomatic correspondence that if the King would send Fausto to him, "it would make me an infinite pleasure to instruct him in the whole of this process, and to show him everything(12)." Discouraged by poor student interest in his classes, Fausto submitted his resignation from his professorship at the Patriotic Seminary on September 20, 1785, to be effective at the end of the year. On February 6, 1786, the Indies Minister, Gálvez, summoned Fausto to Madrid to discuss the various ore treatment processes which were of concern to Juan José in New Granada. Fausto advised his brother of the Born process in a letter of February 16. He left Madrid for Vienna soon thereafter with instructions to learn the details of the new process. He was also to recruit mining and smelting technologists from central and northern Europe to bring their expertise to the American mines.

Born invited not only Fausto Delhuyar, but also mining engineers and metallurgists from all over Europe to attend a conference held in the summer of 1786 near Schemnitz, at the village of Glashütte in Hungary (now Skleno in Slovakia), where he had set up a full-scale operation of his method (13). This meeting has been called the world's first international scientific congress (14). The conference was held with the approval of the Emperor Joseph II, who expected that adoption of Born's method would enhance the market for mercury from his mine at Idria (now Idrija in Slovenia). Born's book describing his process, *On the Amalgamation of Ores*, was also published in 1786 (15). In the *Born amalgamation process*, the ore was mixed with salt, roasted, pulverized, and slurried with mercury and water in heated copper kettles, with stirring by windmill-driven paddles. Completion of the amalgamation required only 24 hours. Workup was done in the same way as in the patio process. Fausto went to Austria to learn the details of what was actually a Spanish invention. Born himself admitted that his procedure was first described in a book published in Spain almost 150 years earlier by Alvaro Alonso Barba (16), who had been director of mines at Potosí in Upper Peru (modern Bolivia). In a letter to Gálvez on October 21, 1786, Fausto expressed the opinion that the abandonment of the Barba method in America may have been due to local conditions that made it less effective than in Austria and Germany (17).

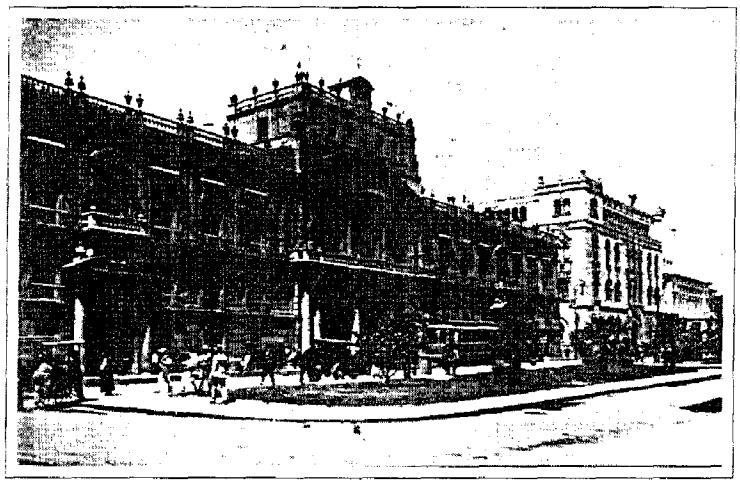
On July 3, 1786 Juan José reported to the Viceroy that he had completed preparations for smelting. Before he could begin smelting, however, he received the letter from Fausto advising him of the newly reported Born amalgamation method. Upon being advised of the Born method, the Viceroy ordered suspension of the plans for smelting. Juan José proposed a test of the Born method at the mines at Mariquita. This plan was approved by the Viceroy and subsequently by Gálvez. Juan José did not receive the full details of the Born method until nearly two years later, on June 17, 1788, when he received a copy of Born's book from his brother. In the interim a part of Juan José's attention found a very different direction. On December 1, 1788 he married María Josefa Bárbara Gaona y Lee, the daughter of a lawyer of Santa Fe (modern Bogotá). He returned with his wife to Santa Ana to make his home near the mines.

On July 18, 1786, Gálvez wrote to Fausto in Vienna to advise him of his appointment to the post of Director-General of the Royal Mining Guild of Mexico (Director General del Real Cuerpo de Minería de México). Gálvez died on June 17, 1787. His successor as Minister of the Indies was the same Antonio Valdés who had called Gálvez's attention to Juan José. Valdés allowed Fausto to delay his departure for Mexico in order to marry Juana Raab de Moncelos, whom he had met at Born's home during his earlier trip to Austria. The wedding took place on October 16, 1787, the Spanish Ambassador serving as Fausto's best man. Fausto and his wife arrived in Vera Cruz late in the summer of 1788 and proceeded at once to Mexico City (18). They were accompanied by eleven German mining technicians who had been recruited in Saxony, headed by mineralogist Friedrich Sonneschmidt (19). The Germans went to the *real* of Sobrerete, in the present-day State of Zacatecas.

Fausto found the situation in Mexico very different from that found by his brother in New Granada. Mexico City had a scientific establishment, some of whose members had already directed their attention to the practical matter of improving mining technology and productivity in the colony. In 1774 two of these men, Joaquín Velázquez Cárdenas de León and Juan Lucas de Lassaga, had submitted to King Charles III a *Representación* which described problems in the mining industry of Mexico and recommended reforms. Included in the *Representación* was a recommendation for the establishment of a College of Mines. After a nine-year traverse of the *Representación* through the Spanish bureaucracy, the King issued the Royal Mining Ordinances (Reales Ordenanzas de Minería), which were published in Mexico City on January 14, 1784. Velázquez de León

was appointed president of the Royal Tribunal General of Mining (Real Tribunal General de la Minería), the body organized to govern the Mining Guild (Cuerpo de Minería). A fund was created for the endowment of a "Metallic College" (Colegio Metálico).

Ramón Ruíz de Liceaga became acting president of the Tribunal after the death of Velázquez de León in 1786. An ugly confrontation occurred upon the presentation of Fausto Delhuyar to the Tribunal, on September 13, 1788. Fausto demanded that Ruíz de Liceaga surrender the chair to him, on the ground that his royal appointment as Director-General gave him authority over the Mining Tribunal. Ruíz de Liceaga refused. Angry words and insults were exchanged, and the hall had to be cleared of spectators. Ruíz de Liceaga, believing his position to be secure, appealed to the Crown. The response was prompt. On December 30, 1788, the Viceroy of New Spain dismissed Liceaga, and on January 2, 1789, Fausto sat in the chair of authority, by order of the King.



School of Mines in Mexico City. From M. E. Weeks and H. M. Leicester, *Discovery of the Elements*, 7th ed., Journal of Chemical Education, Easton, PA, 1968; p. 256.

On January 12, 1789, Fausto asked the Tribunal General for all documents in their archives relative to the formation of the School of Mines. Three days later, in what can be construed as an act of bad faith on the part of the *diputados* of the Mining Tribunal, he was informed that no such documents existed. Fausto took this response as permission to proceed according to his own ideas. He prepared his "Plan for the School of Mines," which he presented to the Tribunal exactly one year later (20). The plan called for a six-year program. The first year of the curriculum was devoted to mathematics, beginning with arithmetic and ending with conic sections. The second year consisted of subterranean geometry, dynamics and hydrostatics. Courses in chemistry, mineralogy and metallurgy occupied the third year. The fourth year was devoted to "subterranean physics, or the theory of mountains." The students were also to study French and drawing. The final two years were devoted to internship in the mines. At the conclusion of the six years, each student was required to stand for examination before the Tribunal General and the faculty of the College. Provision was made for scholarships for twenty-five students, "none younger than fifteen years of age nor older than twenty," who were to be chosen from the various mining districts. The plan included the design of a uniform; a detailed list of the articles of clothing and bedding for each student; a schedule of the students' activities for each hour of the day, which included daily attendance at mass and two periods reserved for recreation; a schedule for daily meals, including a break for chocolate at 2:00 p. m.; and a schedule of salaries for the faculty and staff, from the rector to the scullery boy (21).

The College of Mines was inaugurated on January 1, 1792. The building initially occupied by the college was a former convent adjacent to the Hospice of Saint Nicholas (Hospicio de San Nicolás) at what is today 88, 90, and 92 Guatemala Street in Mexico City. In 1811-13, the College moved to a new building, the Palacio de Minería, on Tacuba Street. The first professor of chemistry at the college was Luis Lindner, a German mineralogist who had been a member of Sonneschmidt's team. Fausto Delhuyar taught chemistry in his place during Lindner's illness in 1795. The first course in mineralogy was initiated April 27, 1795 by Andrés Manuel del Río (22), who had also been a student of Werner at Freiberg, and who would later discover the element vanadium. The first publication of a Spanish translation of Lavoisier's *Traité Élémentaire de Chimie* was made in Mexico City in 1797, specifically for the use of the College of Mines. The identity of the translator is not known (23). In 1798 the second year of the curriculum was modified to include a full course in physics, to which instruction in calculus was added in 1802. A course in Latin was added in 1799, and courses in logic and geography were added in 1802.

Fausto's plan for the college included laboratory instruction in mechanics, electricity, optics, mineralogy, chemistry, and metallurgy. An invoice, from an agent in London, dated July 30, 1796, for the equipment for

these laboratories has been preserved (24). Items of chemical interest on the list included a variety of balances, thermometers, eudiometers, barometers, electric batteries, and "chemico-pneumatic apparatus," as well as an "electric pistol for inflammable air," and a "flask of Priestley to convert air into acid." The most expensive entry was "alembics, crucibles, mortars, evaporating dishes, flasks, jars, bottles &c. &c. &c. which cannot be specified individually in this list." Additional equipment was constructed locally. On November 29, 1803 the College purchased the instruments that had been carried by the naturalist Alexander von Humboldt in his explorations of Spanish America and commissioned Humboldt to purchase additional equipment on his return to Europe (25). During the period 1798-1811, the College of Mines admitted 92 students, and 34 of these completed the six-year course. The Mexican rebellion against Spain caused operations of the college to be suspended in 1811. Several of the graduates of the college joined the revolt, were captured by the Spanish authorities, and executed (26).

Spain recognized the independence of Mexico in 1821. Fausto Delhuyar resigned on October 17 of that year and returned to Spain with his wife and daughter. In Spain he served as Director General of Public Credit, Director General of Mines and director of the mining school at Almadén. He died in Madrid on January 6, 1833, from a blow to the head resulting from a fall on the stairs at his office.

Friedrich Sonneschmidt and his German colleagues had less success at the mines than Fausto Delhuyar in Mexico City. They found that the Born amalgamation was no more efficient than the patio method at extracting silver, and the cost of the fuel to run it in fuel-poor Mexico made it more expensive. They turned their attention to improving the patio method, at which they had greater success (27). While Fausto Delhuyar was establishing his authority in Mexico City, his brother Juan José in New Granada continued to experience frustration. A delegation of seven German miners, sent from Saxony under contract to the Spanish government, arrived at Santa Ana in December, 1788, shortly after the return of Juan José and his bride. They were not what Juan José needed. On January 2, 1789 he wrote to the Viceroy that "these fellows know nothing about the refining of ores(28)." Three of them were illiterate.

A new Viceroy, Francisco Gil y Lemos, took office on January 8, 1789. Three days later he ordered suspension of mining and extraction of metals. In order to make sure that his order was followed, the Viceroy cut off funding for the mines. Juan José was forced to issue scrip so that the miners could buy food, and to use personal funds to pay the costs of construction of the facilities for ore processing. The Germans were left with nothing to do. Some of them became ill, and the head of their delegation died. In April the new Viceroy inspected the operations at Santa Ana. He confirmed his predecessor's order to use the Born amalgamation process and promised to reimburse Juan José for his expenses. Before this could be done, however, Gil y Lemos was reassigned in July to the Viceroyalty of Peru. His replacement as Viceroy, José de Ezpeleta, finally reimbursed Juan José at the end of November. Ezpeleta summoned Juan José to appear before the viceregal court in Santa Fe to explain his operations. Following this audience, on December 15, the Viceroy authorized Juan José to continue his work and confirmed the order to process the ores by the Born method.

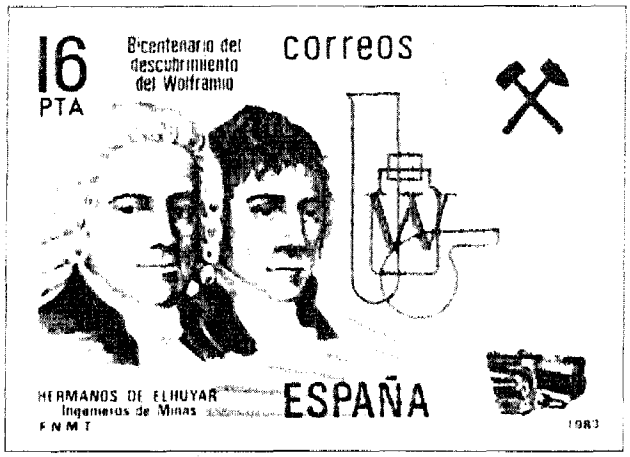
Upon their return to Santa Ana, in January 1790, Juan José and his wife were joined by his sister, María Lorenza, who had separated from her husband, Angel Díaz. Responsibility for her support fell to Juan José. Díaz, to whom Juan Josè had given responsibility for routine management of the mines of Santa Ana, had proven to be unreliable in this assignment as well.

Having learned of the Mining Guild in Mexico from his brother Fausto, Juan José had proposed to Viceroy Caballero that a similar organization be formed to oversee the mining industry of New Granada. Since no action was taken by either Caballero or his temporary successor Gil y Lemos, Juan Josè sent a renewed proposal to the new Viceroy, Ezpeleta. Not only did Ezpeleta deny the request, he also ordered Juan José to use African slaves as laborers in the mines in place of paid workers, in order to reduce expenses, a usage which was illegal under the Royal Mining Ordinances. According to the Viceroy's interpretation, these laws applied only in Mexico, not in New Granada. Once approval had been given to proceed with all operations, the delaying tactics of the Viceroy were replaced by impatience that results were not immediately produced. Juan José had difficulty obtaining supplies of the chemicals and materials sufficient to carry out the Born process on an industrial scale. Salt, like silver, was a monopoly of the Crown, and he had to depend on the Viceroy to provide it. The artisans hired to construct the Born apparatus were barely competent, and lost work time in jail as the result of fighting.

Full-scale operation of the Born process was finally initiated on July 4, 1791. The first shipment of silver "pinecones" was sent to the mint in Santa Fe on November 30, 1791, six years and nine months after Juan José started his work in New Granada. The shipment

was accompanied by instructions to the mint to assay the metal and reduce it to ingots. These instructions displeased the Viceroy. Juan Josè replied that he lacked the resources to carry out these activities at the mines. With operations at Santa Ana finally up and running, Juan José was able to turn his attention to other mining districts. In November 1791, on order of the Viceroy, he sent two of the surviving Germans to supervise the gold mines at Quiebralomo in Popayán, as requested by the owner of these mines.

In 1793, Juan José financed and led an expedition to investigate the resources of the Páramo del Ruiz, an uninhabited plateau. He found there both wild cattle and significant mineral deposits, and filed claims to these resources. He contracted one Juan Isidro Jaramillo to supervise these claims. Jaramillo proved to be both incompetent and dishonest, and was unable to account for some of the supplies and pack animals that had been entrusted to him. To cover his own shortcomings, he spread slanders about Juan José. A confrontation occurred between Juan José and Jaramillo in the office of the mine at El Sapo in February, 1794. Angry words were exchanged. Juan José struck Jaramillo with his cane. Jaramillo stabbed Juan José, inflicting wounds to his left arm and left hand, which Juan José had raised to ward off the blow. Jaramillo fled, but was arrested a few days later at Mariquita. He was tried before the Audiencia in Santa Fe, found guilty of assault, and sentenced to four years in jail. Through his lawyer, Jaramillo sent a letter to the Viceroy, in which he accused Don Juan José of "frauds, extractions, and inlapidation" in the silver mines of Santa Ana and Lajas. The Viceroy withdrew Juan José from the direction of mines and placed him under house arrest at the town of Guaduas. Supervision of the mines of Santa Ana was assigned to Angel Díaz, the errant brother-in-law. Juan José departed from Santa Ana on August 7, 1795, leaving unfinished his research into methods for separating gold and platinum. The Viceroy's actual motivation in accepting the word of a convicted criminal and firing Don Juan José may have had a political basis. Spain was at war with revolutionary France. A Spanish translation of *The Rights of Man* and other revolutionary tracts had been clandestinely circulated in New Granada. Juan José was known to be of French ancestry, and relatives of his mother still lived in France. Juan José appealed to the Crown to review his case, on the ground that his contract as Director of Mines had been made with the King, not the Viceroy. His position was vindicated by a royal decree of January 19, 1796, in which the Viceroy was ordered to restore Juan José's rights.



Fausto (in wig) and Juan José Delhuyar on a Spanish stamp issued in 1983 to commemorate the two-hundredth anniversary of their discovery of tungsten.

Meanwhile, Angel Díaz proved to be no more competent at managing a mine than he had been at maintaining his marriage. When word of these problems reached Spain, the Minister of the Indies, Diego de Gardoqui, authorized the Viceroy to sell the mines. On November 19, 1796, the Viceroy recommended that the mines be freely ceded, with their slaves, to anyone who would obligate himself to continue their work.

Juan José's health declined from the middle of 1796. He suffered from an intermittent fever. On November 20, the day after the Viceroy's decision to abandon the mines, he had a seizure and died (29). He was survived by his wife, a son, and two daughters.

In summary, Fausto Delhuyar and his colleagues in Mexico were unable to apply the Born amalgamation method for the refining of silver ores but succeeded in reforming the Mexican mining industry and in establishing the School of Mines. His elder brother Juan José failed in his efforts to organize and improve the mining industry of New Granada, but succeeded in applying the Born method there. The availability of adequate fuel made this latter success possible; but if the authorities had allowed him a choice, Juan José would have used that fuel to smelt the ores instead. By the time of the initiation of the Born amalgamation process in New Granada, it had already been abandoned in Europe in favor of smelting (13).

ACKNOWLEDGMENT

The authors are grateful to a reviewer for calling their attention to some materials relating to the lives of the Delhuyar brothers which they had overlooked.

REFERENCES AND NOTES

1. Biographical information on the Delhuyar brothers in this paper has been drawn principally from eight sources: (a) A. Arnáiz y Freg, "D. Fausto de Elhuyar y de Zubice, descubridor del tungsteno," *Mem. Rev. Acad. Nacl Cienc. Antonio Alzate*, **1942**, *55*, 219-232; (b) B. J. Caycedo, *D'Elhuyar y el siglo XVIII neogranadino*, Ediciones de la Vista, Ximenes de Quesada, Bogotá, Colombia, 1971, a biography of Juan José Delhuyar written by a descendant of his daughter Fausta Facunda and Fernando Caycedo; (c) B. J. Caycedo, *Juan José D'Elhuyar, Discoverer of Tungsten*, Coronado Press, Lawrence KS, 1981, a translation of reference 1b by J. A. Schufle; (d) C. G. Motten, *Mexican Silver and the Enlightenment*, Octagon Books, New York NY, 1972; (e) J. Palacios Remondo, *Los Delhuyar*,Consejería de Cultura, Deportes y Juventud, Logroño, Spain, 1992; (f) P. Román, "El aislamiento del wolframio por los hermanos Elhuyar (1783-1983)", *Afinidad*, **1984**, *41*, 11-14; (g) M. E. Weeks, "The Scientific Contributions of the de Elhuyar Brothers", *J. Chem. Educ.*, **1934**, *11*, 413-419; and (h) A. P. Whitaker, "The Elhuyar Mining Missions and the Enlightenment", *Hispanic American Historical Review*, **1951**, *31*, 557-585.
2. The family name of the brothers has many variant spellings, of which Delhuyar, D'Elhuyar and de Elhuyar are the most common. The brothers themselves were inconsistent in their usage. At the International Symposium for the Bicentenary of the Foundation of the College of Mines of Mexico it was decided to accept exclusively the form "Delhuyar" (Ref. 1e, p. 61).
3. Ursula's family name is given as Zubice by some sources. Bernardo Caycedo, Juan José's descendent and biographer, cites contemporary documents in which the name is given as Lubice (Ref. 1b, pp. 20, 167, 185). In the marriage contract of the brothers' parents, the name is spelled Lubize (Ref.1e, pp. 58-59). The discrepancy may be due to misreading a script capital "L" with a long upper tail as a "Z".
4. Some sources refer to the "Royal Economic Society of Friends of the Country" (Real Sociedad Económica de Amigos del País). There were actually several societies with this name. They were regional societies organized on the model of the Basque Society, and with similar functions (Ref.1d, pp. 4-6).
5. Juan José's notes, in French, taken from Bergman's lectures, have been preserved and published: A. Fredga and S. Rydén, "Juan José de Elhuyars anteckningar after Torbern Bergmans förelsäsningar 1782", *Lychnos*, **1959**, 161-208. An English translation of these notes has been provided by J. A. Schufle in "Torbern Bergman, A Man Before His Time," Coronado Press, Lawrence KS, 1985, Appendix I, pp. 412-464.
6. Castejón had not authorized Juan José's trip to Sweden. He was displeased by Juan José's expense account (Ref. 1h) and by the long delay in Juan José's return to Spain.
7. J. J. and F. de Luyart, "Análisis químico del volfram, y examen de un nuevo metal, que entra en su composición", *Extractos de las Juntas Generales celebradas por la Real Sociedad Bascongada de los Amigos del País*, Sept. 1783, pp. 46-88 (Ref. 1f, footnote 1).
8. Ref. 1e, p. 211.
9. S. Rydén, *Don Juan José de Elhuyar en Suecia (1781-1782)*, Imp. S. Aguirre Torre, Madrid, Spain, 1954, Anexo I, pp. 41-48.
10. A detailed description of the patio amalgamation of silver ores is given by A. de Humboldt, *Political Essay on the Kingdom of New Spain*, J. Black, translator, Longman, Hurst, Rees, Orme, and Brown, London UK, 1811, Book IV, pp. 252-269.
11. There is a suspicion that some of the ore samples provided by local prospectors may have been carefully selected for a high silver content (Ref. 1b, p. 125).
12. "[J]e me ferai un plaisir infini de l'instruire de tout ce Proces, et de lui faire voir tout." (Ref.1h.)
13. É. Vámos and F. Szabadváry, "On Ignatius Born's Eighteenth-Century So-Called European Amalgamation Process", *Period. Polytech., Chem. Eng.*, **1981**, *25*, 211-221.
14. (a) F. Szabadváry, "Ignaz Born und die erste internationale wissenschaftliche Tagung und Gesellschaft der Welt", *Österr. Chem. Z.*, **1989**, *90*, 109-110. (b) M. Teich, "Born's Amalgamation Process and the International Metallurgic Gathering at Skleno in 1786," *Ann. Sci.*, **1975**, *32*, 305-340.
15. I. Edler von Born, *Ueber das Anquicken der gold-und silberhältigen Erze, Rohsteine, Schwarzkupfer und Hüttenspeise*, Christian Friederich Wappier, Vienna, Austria, 1786 (Ref. 13).
16. A. A. Barba, *Arte de los metales en que se enseña el verdadero beneficio de los de oro, y plata por açogue*, Imprenta del Reyno, Madrid, Spain, 1640. (F. Habashi, "Chemistry and metallurgy in New Spain and the Spanish American colonies," *Canadian Mining and Metallurgical Bulletin*, **1982** (June), 1-6.)
17. Ref. 1h, footnotes 64, 65 and 76.
18. In addition to Ref. 1d, the following sources have been used for the work of Fausto de Elhuyar and his colleagues in Mexico, and for the history of the Royal College of Mines: (a) W. Howe, *The Mining Guild of New Spain and its Tribunal General, 1770-1821*, Harvard University Press, Cambridge MA, 1949; (b) J. J. Izquierdo, *La primera casa de las ciencias en Mexico. El Real Seminario de Minería (1792-1811)*, Ediciones Ciencia, Mexico DF, 1958; and (c) S. Ramírez, *Datos para la historia del Colegio de Minería*, Imprenta del Gobierno Federal, Ex-Arzobispado, Mexico DF, 1890.
19. Ref. 18a, p. 307.
20. F. de Elhuyar, *Plan del Colegio de Minería presentado al Real Tribunal por el Director del ramo, D. Fausto de Elhuyar* (Ref. 18c, pp. 61-73), translated by Howe (Ref. 18a, Appendix D, pp. 490-500).

21. The best salaries were those of the professor of chemistry and metallurgy, the professor of mining, and the professor of mechanics, each of whom was to receive 2000 pesos per annum (Ref. 20).
22. S. Ramírez, *Biografía del Sr. D. Andrés Manuel del Río*, Imp. del Sagrado Corazón de Jesús, Mexico DF, 1891, 18.
23. *Tratado Elemental de Chímica*, Mariano de Zúñiga y Ontiveros, Mexico City, 1797 (Ref. 18b, pp. 109-200). Izquierdo holds the opinion that either Luis Lindner or Fausto Delhuyar, or both, were involved in the translation, since they shared the chemistry instruction at this time.
24. The complete list is reproduced by Howe (Ref. 18a, Appendix E, pp. 501-508). See also Ref.18b, pp. 91-95 (laboratory instruction in physics), and pp. 115-119 (laboratory instruction in chemistry).
25. J. A. Ortega y Medina, *Cronología Humboldtiana. Datos de la Vida de Alejandro de Humboldt*, Anexo I to A. de Humboldt, Ensayo Poliítico Sobre el Reino de la Nueva España Editorial Porrua, S. A., Mexico DF, 1966, pp. lv-cxxi.
26. The College of Mines resumed operation after Mexican independence. In 1867 it became a part of the College of Engineering, which became the Faculty of Engineering of the Universidad Nacional Autónoma de México (UNAM) in 1910. The date of the founding of the College of Mines is today recognized as founding of engineering education in Mexico.
27. F. Sonneschmidt, *Tratado de la Amalgamación de Mexico*, Imprenta de d. Mariano de Zúñiga y Ontiversos, Mexico City, 1805 (Ref. 18b, p. 200). Humboldt's description of the patio amalgamation derives from the manuscript of this book (Ref. 10, p 252). Sonneschmidt found that the efficiency of the patio method was improved by treating different types of ores separately, rather than amalgamating different types indiscriminately mixed together.
28. "Esos sujetos no entienden nada del beneficio de los minerales." (Ref.1c, p. 172)
29. According to Ref.1f, death was due to a cerebral hemorrhage.

ABOUT THE AUTHORS

Lyman R. Caswell is Professor Emeritus at Texas Woman's University, Denton TX 76204, who now resides in Seattle, WA. e-mail address 72712.575@compuserve.com. His interests include the history of chemistry and chemical technology in Latin America. Rebecca Stone Daley is an osteopathic physician in Arlington, TX.