# From old mining to new mining: the introduction of differential flotation in Spanish mines and its environmental impact*

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## Introduction

Mining is a peculiar economic activity that is conditioned by factors that are different to those of most other types of production. First, it exploits a non-renewable natural resource that, in time, will run out and cannot be replaced. Hence, mining in a particular area is a finite operation and therefore has a transient nature, with mining companies constantly on the lookout for new deposits in order to maintain their production levels. Second, mining is also conditioned by technological development and the demand for certain metals and minerals. The introduction of new innovations has made it possible to mine at greater depths, to profit from lower grade minerals, to reach less accessible minerals or to separate out the useful parts of complex minerals. This has meant that deposits in Europe which the Romans began to mine were exploited again in the industrial revolution and that, even today, the development of markets and new technologies can lead to the reopening of abandoned mines that had apparently been exhausted decades ago.

An important task in exploiting mining metal deposits is selecting, cleaning and concentrating the ore to improve the grade and so obtain profitable concentrations or ores that will give maximum yield during smelting. General-

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ly, these operations were carried out on site by the companies themselves, although there were businesses that specialised in these activities in some mining areas that tendered their services to small and medium-sized mining companies. As time passed and mining companies slowly grew in size and in concentration, this became a key part of the production process organisation.

However, the advance of modern mining has been accompanied by an increase in poorer quality minerals as higher-grade deposits have been exhausted. This has been the case in Spain since the end of the First World War, unlike Africa, Australia and North America where new fields are emerging. Along with the slowly declining richness of the mineral lodes, a need emerged for the mining of more complex deposits that required new preparation methods. This led to the search for improved mineral concentration techniques. Moreover, new technological developments in the area meant that old slag heaps and dumps could be re-worked, since they still retained a recoverable percentage of metal that had been discarded in the past because of inefficient mineral processing technology. This was the backdrop for the emergence of the modern differential or froth flotation system, which today is a fundamental method for obtaining concentrates of metallic ores in mines all over the world. The process provides an efficient and profitable means to treat both low grade and complex ores, i.e. those with a highly variable mineral composition.[1]

In Spain, flotation plants have been in use since the onset of modern mining. The flotation process makes use of the chemical and adhesive properties of a specific mineral, so that the mineral will become attached to an ascending air bubble. Before this can be achieved, the mineral is pulverised into a fine powder to produce slurry, an innovation developed to complement the flotation process. The modern differential flotation process can extract practically all the metals found in polymetallic ores by varying the amounts and type of chemical reagents in the slurry. For example, potassium xanthates are commonly used to recover galena, whilst copper sulphate is used to activate the adhesive properties of zinc blende. Flotation replaced a method in use since the mid-nineteenth century, which was very different, and sometimes very inefficient, that relied mainly on the sizing and density of the ore. Hence, ore processing plants of this period were called gravity separation mills.

As we will discuss later, this technology took some time to be introduced into the Spanish mining industry, even though Spain was still the leading mineral producer in Europe during the first three decades or so of that century.[2] There was no lack of initiative on the part of the local or foreign-owned min-

1. Hovis and Mouat (1996) analyse the relationship between changes in extraction and transport techniques and the development of new concentration systems. One of the first cited books on the flotation process was Rickard (1916).

2. In 1910 Spain was the leading European producer of lead and second in the world, behind the USA. It was world leader in pyrites, first in Europe for copper (although a large part of the pro-

ing firms, but rather a lack of capacity to innovate by adapting technologies that had been used elsewhere for decades. So it was both a problem of innovation and of dissemination of specific technology.

On the one hand, this paper offers an in-depth view of the factors that led to the incorporation of this important technological change in Spanish metal mining and its tardiness, in relative terms, compared to other countries; on the other hand, it will also analyse the direct economic consequences of incorporating this new technology in certain mining areas and companies since the 1950s, as well as the limits and drawbacks of implementing it. While triggering the resurgence of an activity that was, quite frankly, in dire straits, this technology produced one of the severest cases of environmental harm in the recent history of Europe, which can only be explained by the internal dynamics of the companies involved and the institutional problems besetting the Spanish economy at the time. The issue is related to the difficulties in renewing the sector in certain mining areas of southern Spain, especially in zinc and lead mining. Was it a problem of technological knowledge, production costs, price or the size of the mines? Or was it, rather, a classic case of a lack of entrepreneurship? Once the technological change had been introduced, what were the reasons enabling its rapid and unlimited development? What were the reasons that allowed mining activity to continue over time, despite its low profitability and the immense environmental impact that it generated, while preventing the emergence of other economic activities in the area?

The literature on technological change has addressed factors that have encouraged the emergence of new technology and the problems inherent in applying innovation and incorporating it into production processes. According to neoclassical theory, technological dissemination can be explained by the evolution of the cost of the factors of production. Businesses will substitute work with capital or obsolete capital with new capital, depending on the profitability of each factor (the difference between its productivity and costs). Yet, while not denying the importance of the costs of technological innovation, Mokyr and Rosenberg[3] consider these insufficient in themselves, since history itself shows that dissemination requires other explanatory elements. Rosenberg talks of the "absorption capacity of these new technologies", i.e. a certain level of development, specific human capital, entrepreneurs and a suitable institutional framework, all of which tie in well with our case.[4]

duction was smelted abroad), world leader in mercury production and the fifth zinc producer in Europe.

3. Mokyr (1990 and 2002) and Rosenberg (1971 and 1982).

4. The seminal Nelson and Winter (1982) examined the same elements in depth, as have other authors like Fernández and Rose (2010) and Jacob (2014). For a general view of innovation see Farbergerg, Mowery and Nelson (2005).

The question is whether the Spanish mining sector had the capacity to absorb this new froth flotation technology in the first third of the twentieth century, and what caused the delay.[5] The answer is complicated because many issues came into play, some of which were endogenous and others circumstantial. Furthermore, the effects were often different for larger companies (national and international) than for smaller local ones.

The literature on the environmental effects of the technological change in mining in Spain has focused on copper and sulphur mining. It was a major cause of the conflicts in the mining basins where the mining giants Rio Tinto and Tharsis operated.[6] With respect to lead mining, there are hardly any specific studies that focus on the negative externalities of mining and galena transformation. This is largely because this type of mining is historically more dispersed among small and medium-sized firms. However, there are a few studies on the specific case in hand, from other perspectives more related to geology.[7] However, there is a lack of studies that examine the origins of the most important environmental pollution phenomenon in the history of the Mediterranean, which is still far from being resolved.

## The origins of flotation

The concept of froth flotation was conceived of around 1860 when W. Haynes discovered that oil has an adhesive attraction for certain minerals. His findings were followed by others in Germany (A. Bessel in 1877) and in the United States, (C. Everson in 1885).[8] However, it was not until the end of the century that the idea was used in the preparation of mining products. Various experiments in Great Britain (Elmore, 1898) and Australia (Potter, 1901) paved the way for the new technology. The interest in research in new technologies to make better use of complex and low grade minerals was especially important in the mines at Broken Hill (Australia), where this concentration system was perfected and from where it spread to other countries during the early twentieth century.

In 1902, G. D. Delprat, director of BHP, the company that developed Broken Hill, was given the credit for inventing a procedure based on Potter's analysis, which would later be refined. By 1905, Sulman, Picard, Cattermole and

5. General studies on the incorporation of new industrial technologies in Spain have focused on patents (See Saiz, 2014; Cayón, 2017). There are few specifically dedicated to mining, although noteworthy are Sánchez Picón (1995), Escudero (2008) and Salkied (1987).

6. Pérez Cebada, 2008 and 2014.

7. Robles-Arenas *et al* (2006). See also problems of water contamination caused by mining activities in the Iberian Peninsula in Pérez Cebada and Guimarães (2017).

8. Lynch, Harbort and Nelson (2010), pp. 4-6.

Ballot had been patented in Australia, and were among the first to perfect the froth flotation method. Later, these were followed by the inventions of C. Howard, J. Hyde and H.C Hoover, the latter two of which were taken up by Minerals Separation Ltd., and introduced mechanical stirring or agitation into the mix of reagents and ore. This company was one of the most active in the world in terms of introducing new systems of ore concentration,[9] and participated in the beginnings of flotation in Spain, as described below.

Over the following years there were more advances, such as the processes developed by Wood in 1912 and Callow in 1914. Several companies were researching in this field in the quest to develop new flotation techniques or adapt existing ones to the types of ore in their areas, with most work being done in Australia and the USA. As one text in 1919 states,[10] many of these experiments were kept secret until they were proved to be feasible, because of the competition between firms and the attempts being made to exploit the huge possibilities that new flotation techniques could offer. In 1922 Sheridan and Griswold used cyanide as a depressing agent for the blend, and in 1924 Pallanch achieved the same result with sulphites.[11] The description of these continuous advances is complicated since we are not dealing with a single process. The reagents are different depending on the characteristics and complexity of each mineral. What is important is that gradually more and more of the metal was being recovered, with concentrations of close to 100 per cent.

The technology was disseminated quite fast internationally. In Australia, it spread widely in the years prior to WWI, but flotation was not widely used in the main lead, zinc and copper areas until 1920.[12] Differential flotation expanded rapidly. It was Minerals Separation itself that developed an active search for companies that could use its system (1910 – USA, Southern Rhodesia, Russia; 1912 – Chile, “El Teniente”…).[13] Its implementation had to overcome legal problems and technical difficulties.[14] It can be said that in the 1920s it was implemented internationally, relegating the old systems of concentration by gravity.

In Spain, where differential flotation processes enjoyed more success in lead and zinc mining, the new system widely replaced the old gravity separation method from the 1940s onwards. Basically, the mechanics are the same for any mineral. Take, for example, a galena/zinc blende rich ore. After the in-

9. On the role of Minerals Separation in the development of the flotation processes, see Lynch, Harbort and Nelson (2010), p. 43.

10. Fronkart (1919), p. 559.

11. Fuerstenau, Graeme and Yoon (2007), p. 448; Blazy (1977), p. 264.

12. On the expansion of the flotation system in these years in Australia, USA, Chile and Japan, see Lynch, Harbort and Nelson (2010), pp. 46-59 (lead and zinc) and 82-84 (copper).

13. A description of the company activity of Minerals Separation and the international diffusion of the flotation process in Lynch, Harbort and Nelson (2010) pp. 47-53.

14. See Hovis and Mouat (1996), p. 450.

itial, or primary, crushing, the mineral is introduced into one or more "ball mills", where it is ground down (pulverised) into a fine powder.[15] The powdered ore is then conditioned with chemicals to form a slurry that is passed through a battery of "flotation cells". The flotation cells are usually lined up back-to-back in parallel batteries. In medium-sized flotation plants the slurry is in constant circulation, so they are always full to the same level. At this stage of the flotation process, air is injected into the base of the cell to create a stream of air bubbles. The galena particles adhere to the air bubbles and are buoyed up to the surface to form a mineral-rich froth. This froth, that contains the galena particles in suspension, is then swept by rotating blades into an overflow trough, where the heavier metal or "concentrate", is deposited in a tank. When the tank is full of concentrate, it is opened to allow the most recent and, therefore, more liquid deposits to drain off onto a platform area, while the more solid part, 75 per cent, remains inside. This part which is known as the "head", will be ready the next day to be loaded onto lorries and taken to a lead smelter. The rest, known as the "tails", is left to dry for a few days and is also taken to the smelter. The residues from the cells still contain zinc blende, so the cycle is repeated in a second series of flotation cells using copper sulphate as a reagent. In this part of the process, the zinc blende adheres to the surface of the rising air bubbles.

The residues in the cells, now depleted of minerals, are run off at the other end of the battery, through a system of constant level gates into a waste tank, or a large collection pond (tailing dam). There, the water evaporates and deposits the remaining sediments. Obviously, the lower the grade of the ore, the greater the amount of tailings, in proportion, are produced.

## The development of differential flotation in Spain

The early twentieth century was a challenging time for Spanish metal mining. The intense activity of the second half of the nineteenth century had depleted the richest deposits of the traditional mines and work was hindered by growing problems associated with increased depth, mine drainage and more complex and lower grade minerals. The world market was also hit by increased competition (new mining areas, modern mining systems, concentration, transport, etc.). Mining technology underwent a profound change: the emergence of new energy sources (especially electricity), the mechanisation

15. It should be noted that the flotation process requires extra fine grinding, usually between 100 and 200 micras (thousandths of a millimetre) in order to free the sulphur grains. The weight of the particles has to be lower than the surface tension forces that hold the particle against an air-bubble.

of mining systems (mechanical drills, diggers, etc.), changes in the selection of ores (increasing use of vibro-classifiers over other methods)[16] and, especially, the development of innovative ore concentration methods, in particular differential flotation, which opened up possibilities for mining new deposits by allowing a wider range of resources to be exploited, rather than just a single metal.

Information about new systems of leaching minerals arrived early in Spain. In 1902 the Ellmore procedure was reported in the *Revista Minera*[17] (the leading journal in this field in Spain), and in 1904 this was followed by the use of differential flotation in Broken Hill.[18] The international interest that the emergence of the new mineral concentration systems had aroused was shared in the scientific media and among mining companies. A different issue was the possibilities for its implementation in Spanish mines.

In order to use differential flotation, the mining companies either had to pay a patent to the companies that had registered the process or develop their own systems, which hindered its diffusion.[19] The first documented case is that of the Société Miniére et Metallurgique Peñarroya (hereinafter Peñarroya), which was using the technology in 1918, after reaching an agreement with the Australian company Minerals Separation to sell its patent in France, Spain, Portugal and North Africa (as well as in their colonies), which, in the case of Spain was done through the Sociedad Española de Tratamientos de Minerales por Flotación. In principle, the French multinational sought to use the technique to treat the low quality minerals from their mines in San Quintín (Ciudad Real), but they also wanted to make a profit from the sale of the monopolised technology to other mining businesses in Spain.[20] However, in 1922, the French company waived exclusivity rights in Spain on the patents of Minerals Separation, due to the scarce mining activity in Spain at the time

16. Romero (1928, p. 503) mentions the disappearance during this period of the so-called “monda en el interior”: the prior selection made in the galleries. The better possibilities afforded by modern methods of transporting the minerals to the outside enabling all the treatment to be done at the surface.

17. “Empleo del aceite en la preparación mecánica”, *Revista Minera, LII*, 1902: 299.

18. “Fabricación de ácido sulfúrico en Broken Hill”, *Revista Minera, LIV*, 1904: 475. In 1906 we find a brief note of the new concentration system and a description of the systems used in the Australian mines: “Separación de minerales por flotación”, *Revista Minera, LVI*, 1906: 130; “Aprovechamiento del zinc en los minerales mixtos”, *Revista Minera, LVI*, 1906: 343-344.

We also find news in other scientific journals: *Industria e invenciones* (6 Feb. 1907, 63) published an article by José Cabanach entitled: “Tratamiento de los sulfuros de plomo y cinc por el procedimiento de flotación”, which reported the good results obtained with the system in Australian mines. One of the first books on flotation in Spain, Díaz (1920).

19. “The predilection of the Minerals Separation company for patent litigation hindered the widespread implementation of flotation, but by the mid-1920s the legal barriers had largely disappeared” (Hovis and Mouat, 1996, p. 450).

20. Agreement Peñarroya-Mineral Separation, 23 April 1918. Archive Metaleurop, PYA Juridique, no. 247. The patent affected the treatment of minerals containing gold, silver, copper, lead, zinc, graphite, molybdenum and antimony.

and the few prospects of any improvement.[21] Later, the Sociedad Española de Tratamientos de Minerales por Flotación was set up to deal with the use of patents belonging to Minerals Separation, which was then joined by a subsidiary company called Aprovechamiento de Residuos Minerales. The modus operandi was twofold: it could either assign a transfer of the patent (providing technical support) on payment of a levy or use the patent directly for a given period (usually 15 years) in exchange for a percentage of the value of the concentrates obtained.[22]

En 1929, Peñarroya had two flotation plants in operation in the province of Ciudad Real. The Santa Isabel, for the minerals of the Grupo de Nava de Riofrío, which processed 60 tonnes/day, and the Grupo de San Quintín, with a capacity of some 24 tonnes/day.[23] Both processed low-grade complex minerals. In the case of the former, these contained lead, zinc, iron and some copper and antimony. In the latter, the lead minerals were accompanied by iron and zinc sulphide.

The San Quintín plant was built at the same time as another of the French company's plants at the Soldado mine, in Villanueva del Duque (Cordoba), which began operating in 1922. Here, an old gravity separation mill was replaced with 15 flotation cells which used pine oil as well as silicate or sodium carbonate. The output was very low, at between one and six per cent of the materials processed, and lead concentrations of 35 per cent were obtained, and 25 per cent for zinc. However, these were offset by the silver recovered (600 to 800 grams per tonne), so the investment was deemed to be worthwhile.[24]

The first example of the flotation method being used in Spain was at the Real Compañía Asturiana de Minas in 1916, which started experimenting with flotation systems to treat its zinc deposits in Reocín (Cantabria). The chief mining engineer, Leopoldo Bárcena, ran the preliminary tests and in 1922 a flotation plant was opened which could process 60 tonnes of mineral per day. According to the 1927 report by *Estadística Minera* about Santander, the value of the system in processing the Reocín blende was soon appar-

21. Peñarroya had rights on 10% of the company's commissions, but had to bear half the expenses. The company terminated the agreement since costs exceeded the small commissions. PYA-Juridique, no. 258. Procès-Verbaux des Séances du Conseil d'Administration, book 7, session of 27/07/1922.

22. All expenses in this case were borne by the subsidiary of Minerals Separation, which built the installations and undertook to treat all the production and fix the concentration level of the ores. These installations were to be turned over for use by the mining company once the agreement expired (Romero, 1928, pp. 540-541).

23. Santa Isabel could process five tonnes per hour and the San Froilán two tonnes per hour. With regard to the first, *Estadística Minera y Metalúrgica de España* in 1929 wrote that the reagents in use at the time varied greatly since the plant was still in a trial phase. Tests were also being run on the machinery.

24. Contreras and Dueñas (2010), p. 305.

ent, on account of its "performance, concentration and costs". In 1922, a new flotation plant with a 200-tonne-per-day capacity was opened.[25] This was followed by a third in 1927 which could handle 500 tonnes per day. All three were under the control of Leopoldo Bárcena and were run solely by the company's own employees.[26]

At Rio Tinto, the largest mining deposits in the country, differential flotation was also introduced relatively early, albeit at a very subsidiary level, to process copper pyrites. In the first three decades of the twentieth century, almost all of the mine's production, when not exported directly, was processed through natural cementation, or by directly smelting the richer ores. In 1926, a series of experiments were undertaken to measure the possibilities of using flotation for the processing of the poorer ores from the Filón Norte (north lode), which could not be done by other processes. The experiments led to the opening of a small plant in July 1930, which was designed to process 150 tonnes per day, although it never reached even 100 tonnes. The results were poor and the installation was closed down in 1932 on account of falling copper prices and low outputs. Moreover, the real costs far exceeded the forecasts and the plant was finally dismantled in 1937.[27] It would not be until the late 1970s that sequential differential flotation was incorporated into the Iberian Pyrite Belt by Minas de Almagrera S.A., and other companies working the Aznalcollar deposits.[28]

## Consolidation of the flotation system: the case of the Sierra de Cartagena-La Unión (Murcia)

### *Conditioning features of the mining area*

The Sierra de Cartagena-La Unión was where flotation of sulphide minerals was most prevalent in Spain. The technology was perfect for this particular mining field, with its abundance of lead, zinc and iron (as well as other elements), although they were complex and low-grade. Despite continued attempts, and the clear economic advantages flotation offered over the traditional methods, there were huge delays in introducing it into the area. It was finally installed more than half a century after its widespread applica-

25. A description of the installations in Bárcena (1922). It explains how the system chosen mixed gravimetric concentration with differential flotation.

26. *Revista Minera* (1928), p. 547

27. Salkied (1987), pp. 74-75 and *Revista Minera* (1932), pp. 110-113 and pp. 184-186.

28. In 1998, a huge environmental catastrophe occurred at the mine, which was similar to that outlined below. It was caused when the tailing dam failed. At the time, the mine was under the control of the Swedish company, Boliden.

tion in the afore-mentioned Australian mines. What was the cause for such a delay? According to Lynch, Harbor and Nelson,[29] the three groups of agents involved in developing flotation at Broken Hill were the engineers, the managers and the financers. We will therefore analyse how each group acted in the area of the study and ascertain to what extent they were responsible, along with other factors, for the delay and for the later success enjoyed by the technology.

In the case of the engineers, the difficulties of incorporating the new methods in Sierra de Cartagena-La Unión do not seem to have been due to the lack of a qualified workforce,[30] nor to a lack of knowledge of the possibilities or technical problems of adapting it to the characteristics of the minerals. A number of tests were run in the 1920s and 1930s, as we shall see, by both private companies and the state. These show that there was a lot of interest, in general, in learning about flotation methods and applying them to the ores in this mining area, and that there was both internal and external qualified collaboration available.[31] The activity in this field is reflected in the wealth of publications about the new technology and complex minerals.[32] So, there was both human capital and sufficient experience in the processing of minerals for a rapid response to the challenges of the new systems, which is what happened later.

On the management side, the big companies in the area (especially Peñarroya and the Mancomunidad Zapata-Portmán) sponsored pioneer experiments in new concentration methods and were, as previously mentioned, directly in contact with various foreign companies which worked at the cutting edge of flotation technology. The business records of these companies that have been consulted clearly prove the interest at the time to test and adapt these systems to the minerals being mined in the area. However, this interest was not confined to private initiatives; we cannot overlook the state's involve-

29. Lynch, Harbort and Nelson (2010), chapter V.

30. Spain can boast a long history of mining engineers. The School of Mining Engineers was established in 1777 and was one of the leading schools of its kind in the world. While not constituting a large number, there were engineers in the Murcia mining areas from the moment the mining boom started in 1840. As of 1883, Cartagena also had a School of Mining Foremen, where sufficient training was given to install flotation plants from as early as 1931.

31. On the degree of development of flotation technology in the 1920s, see Romero ("Los minerales complejos de plomo y cinc en España", 1928, p. 541), which highlights that there were only small differences in the workshops for separation and concentration of complex minerals between Spain and other countries. The only real difference was one of volume, with Spain processing on a smaller scale than some of the international giants.

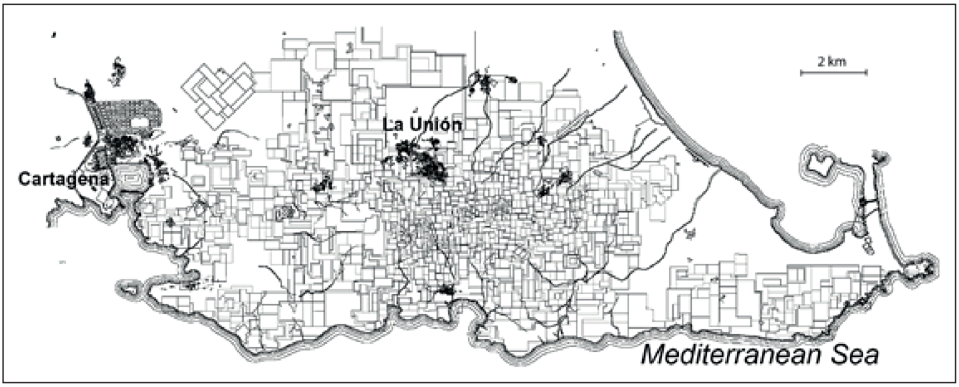
32. Arrojo and Templado (1927); Rolandi and Templado (1928); Romero (1928); Arrojo (1927); Rubio de la Torre (1929). Noteworthy is the role of the *Boletín Oficial de Minas y Metalurgia*, which was of an institutional character, was the publication of greatest interest in the dissemination of research work.

ment,[33] which is apparent in its participation in promoting advances in concentration techniques in a variety of ways.

As regards financing, this is not something that the literature of the time cites as a problem for advancements in this field. The leading mining companies in the area were economically solvent. Furthermore, the results of the experiments indicated that there were enormous cost advantages to be had from using the new techniques. Neither would the investment have been excessively high. The businessmen in the sector would have had few problems assuming this cost (just as in the 1940s, when the economic situation in Spain was evidently much worse).

Yet there was another factor that hindered the development of the technology in the Sierra de Cartagena-La Unión: the structure of mining ownership. Most of the mining concessions in the area had been granted before 1859, the year in which the legislation removed the caps on mining exploitation.[34] This led to the mining district being taken up by small concessions. It also gave rise to a very complicated mining organisation, characterised by a

**FIGURE 1 ▪** *Mining concessions in the Sierra de Cartagena-La Unión in 1907. Each rectangle shows a mining boundary (total 1,151 concessions)*




*Source:* map by Lanzarote from 1907 (digitalisation by the authors; available in downloadable pdf, with different layers, at https://www.um.es/hisminas/wp-content/uploads/2016/10/Mapa-de-Lanzarote-para-PDF.pdf).

33. The state did this directly or through entities that it created to tackle national mining and metallurgical issues: trade unions, metal consortiums and others. In the Sierra de Cartagena-La Unión the government's aims were threefold: grouping the mines, constructing large flotation plants, and improving trade with big organisations (Exposición del Ministerio de Fomento 26-VII-1928, *Gaceta de Madrid, 213*, 31-VII-1928). In the last case, the Sindicato Minero was set up, with the aim of purchasing the largest possible amount of minerals from the mountain range and then trying to sell it at profitable prices.

34. Sánchez Picón (2018). The mining act of 6 June 1859, Article 16 states, "Individuals and companies may obtain the number of holdings they esteem convenient […] They may also, if they so wish, agglomerate large groups of mines […]". This spelled the end of the restrictions that had limited the extension of mining concessions in Spain.

high percentage of indirect exploitation: owner companies, lessee companies and other types of subcontracting that only served to further complicate the overall mining picture.[35]

As Figure 1 shows, the concession map of this area is a complex mesh of mining activity: well over 1000 concessions are marked out in this relatively small area of land.[36] In addition, the most productive part (the central area) was the first to be registered, when legislation was still more restrictive, which meant that the average size was limited, in other words the concessions were very small. Therefore, micro-mining became standard practice in the area, which suffocated any large scale attempts to take economic advantage of the deposits. The institutional framework was quite simply unsuitable for developing modern mining techniques (open-pit) and making good use of the minerals (and mining the minerals efficiently). Texts from the time reflect this difficulty and call for state action to facilitate the concentration of the smallholdings.[37] As we shall see, this process was undertaken at the end of the 1940s by Minera Celdrán and, in particular, SMM Peñarroya.

One last consideration is the huge amounts of water necessary for the flotation processes. Water reserves are scarce in the area. The old gravity separation plants utilised the water drained from the mine workings, but this was insufficient for large scale flotation.[38] The solution adopted later would be to use sea water.[39] The proximity of the coast also meant that the waste tailings from the process could be discarded into the sea, as we shall see below.

### *First trials*

The first attempts to introduce differential flotation in Murcia were made just after the First World War by the most emblematic company in the district, Mancomunidad Zapata e Hijos, (the successors of Miguel Zapata, the most important mining entrepreneur), whose engineers had given forewarning of the approaching drop in the mineral grade, which was subsequently confirmed (see Graphic 1). So, over the medium-term, mining and mineral concentrating

35. On this, see: López-Morell and Pérez de Perceval (2010), pp. 69 and thereafter.

36. 1,151, as specified in Figure 1.

37. Romero (1928), p. 564. For example, Rubio (1929), p. 1,221, states, "The current state of mining in Cartagena is in need of government measures. The trend is towards agglomerations, which owners are obliged to facilitate, since it is not viable to exploit such small mines as exist…". Domínguez (1943, p. 19) continues to draw attention to the problem in the 1940s: "[…] the huge number of owners and the subsequent diversified capital make modern installations impossible".

38. The shortage of water meant that it had to be reused for several processes. In the flotation plant of El Gorgel, Domínguez (1943), p. 37, states: "[…] it is an area of scarce water […] which there is reused, after washing the minerals, in the conditioner with all the brackish products and poisonous matter for the flotation of the zinc".

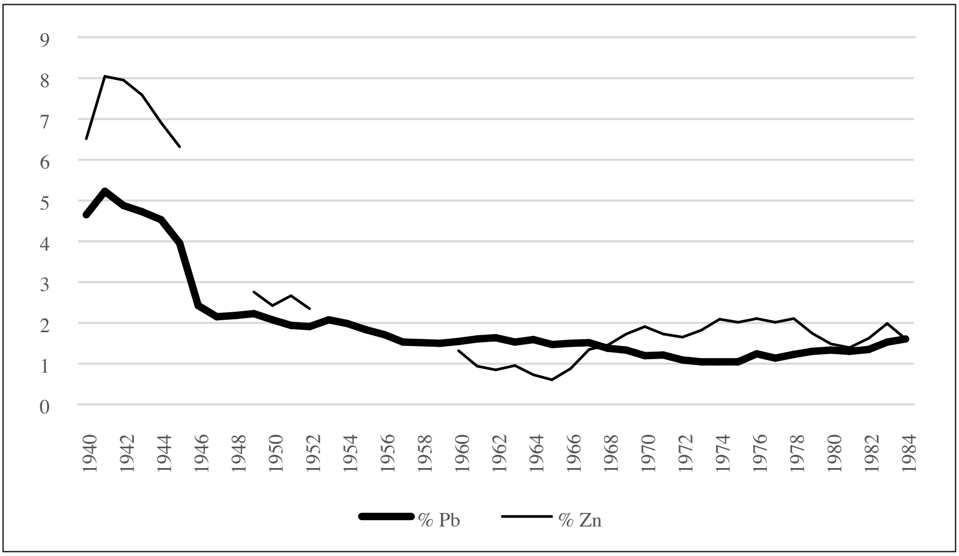
39. A description of its virtues and problems in the treatment of minerals from the Sierra de Cartagena-La Unión can be found in SMM Peñarroya (1970), pp. 50-53.

switched to exploiting these ores with the new system. The Mancomunidad company signed a private contract with The British Metal Corporation Limited, in 1926, by which the British firm undertook the construction of an experimental flotation installation.[40] In 1928, the two firms signed a further contract to exploit the mixed minerals of El Beal (in the same mining field). The contract clearly stated that, given the results of the experimental flotation installation, the future of the area resided in using the galena and blending minerals interspersed among the waste pyrites (which would become widely referred to in the area as "silicatos").

However, relations between the two companies did not prosper and Peñarroya put an end to them in 1930 when it signed an agreement with Mancomunidad Zapata e Hijos to form a new company, the Sociedad Minero Metalúrgica Zapata-Portmán in the same year, with a capital of 26 million pesetas and a 50 per cent share for each company, although initially there was no a large-scale investment plan.[41]

An interest in the new ore processing technique was also shared by the federation of employers, Sindicato Minero de Cartagena y Mazarrón and the state-

**GRAPHIC 1 ▪** *Evolution of the grade of the minerals mined by Peñarroya in the Sierra de Cartagena-La Unión, 1940-1985*




*Source:* SMM Peñarroya España (1970, 1984a and 1984b).

40. This information and what follows is taken from copies of the contracts and reports held in the SMM Peñarroya Archives of the IGME, bundle A0641, folder 5.

41. In fact, the agreement clearly related to the specific problems of the Maestre-Zapata family and the need to buoy up its declining business.

owned Consorcio del Plomo.[42] In April 1929, they made a call for tenders to be submitted for the "industrial application of the flotation procedure for processing the complex lead and zinc ores of the Sierra de Cartagena".[43] The winning proposal by Juan Rubio de la Torre,[44] who happened to be chief engineer at Sociedad Minero y Metalúrgica Zapata-Portmán, emphasised the advantages of the system in maximising benefits from the enormous quantities of low-grade complex minerals in the mountains, and identified the main problem in implanting the technology as the mine ownership system.[45] The profits, calculated in broad terms, of the traditional and modern systems are shown in Table 1, where the economic advantages of flotation for all types of minerals are clearly visible.

Juan Rubio de la Torre performed numerous experiments with different trituration (the process of reducing ore to a fine powder) combinations, and

**TABLE 1** ▪ *Calculated costs of processing different minerals in the Sierra de Cartagena-La Unión using mechanical gravimetric methods and flotation methods (weights in tonnes and value in current pesetas)*

| | Tonnes galena 65% | Value of the galena | Tonnes blende at 30% | Tonnes blende at 50% | Value of blende | Cost of treatment | Profit |
|---|---|---|---|---|---|---|---|
| Simple minerals with 8% lead content | | | | | | | |
| Mechanical plants (70%) | 8.61 | 2,826.5 | | | | 600 | 2,226 |
| Flotation (85%) | 10.5 | 3,433.8 | | | | 1,200 | 2,234 |
| Simple minerals with 12% zinc content | | | | | | | |
| Mechanical plants (70%) | | | 28 | | 551.6 | 600 | -48 |
| Flotation (85%) | | | | 20.4 | 3,599.58 | 1,200 | 2,400 |
| Complex minerals with 6% of lead and 15% of zinc | | | | | | | |
| Mechanical plants (70%) | 6.46 | 2,120.68 | | | 689.5 | 600 | (*) 2,210 |
| Flotation (85%) | 7.85 | 2,573.71 | | | 4,499.47 | 1,200 | 5,873 |

(*) A discount has to be applied to the value of the galena as in the Cartagena plants the first 5% was exempt, leaving a profit of just 595.05 pesetas.

*Source:* Rubio (1929), pp. 1216-1220.

42. Set up in 1927 and 1928, respectively, to counter the production and price problems besetting Spanish mining at the time.
43. *Gaceta de Madrid*, 7 April 1929.
44. Rubio de la Torre (1929), pp. 1220-1221.
45. Rubio de la Torre was a lecturer at the Escuela de Minas in Cartagena from 1931 and its head in 1945.

varying mixtures of minerals and reagents, which included pine oil, copper sulphate, sulphuric acid, xanthate, etc. These experiments were 'cloned' by Peñarroya in 1930, when it ordered reports on the actions to be taken prior to its agreement with Zapata-Portmán, and the results were encouraging (see Table 2). Yet it was not until 1935 that the company was able to assemble its first differential flotation plant in the Regente-Concilio mines, with a capacity of just 150 tonnes per day of mixed galena and blende minerals. To make things worse, the Spanish Civil War put a stop to the project, and the plant was not opened again until May 1940. Although a success, the plant was not enlarged until 1949, when it was processing 200 tonnes a day, concentrating products from La Ocasión mine.[46]

After the Civil War and two decades of widespread crisis, the rebirth of the lead mining areas, and in particular La Unión and Cartagena, was undoubtedly due to the development of froth flotation, which processed ores from the old mines that operated from the 1840s to the 1970s. The process generated appreciable production results, even if output levels never reached those achieved at the end of the nineteenth century (see Graphic 2).

As well as the Zapata-Portmán plant, two other small froth flotation plants, which were copies of it, were opened almost immediately in the Cartagena-La Unión area (owned by Enrique Carrión and the Coto Azul). However, the biggest investor in the new technology was a practically unknown miner called Francisco Celdrán, who between 1947 and 1952 built no fewer

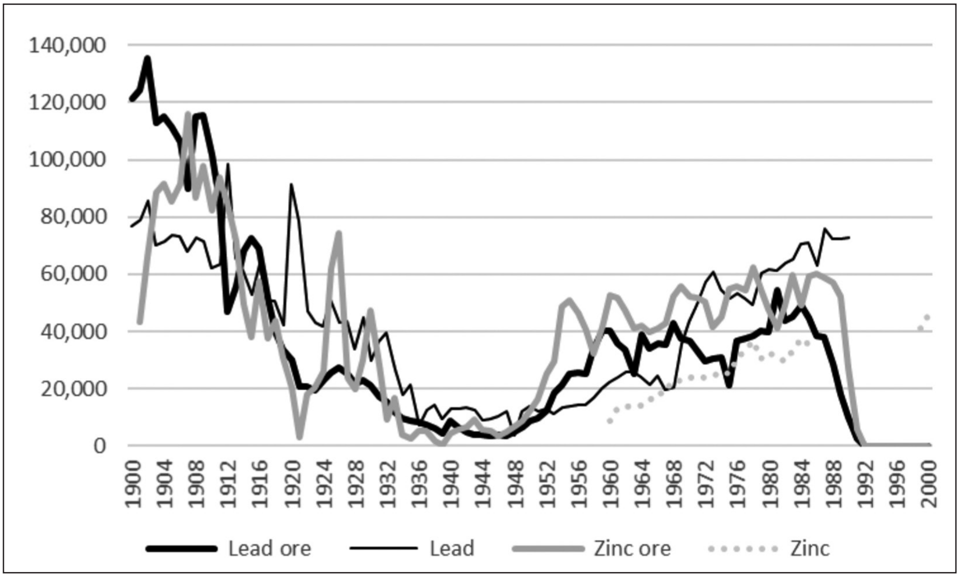
**TABLE 2 ▪** *Flotation assays made in 1930 of minerals from various mines in the Sierra de Cartagena-La Unión by SMM Peñarroya*

| Mine | Concentrate grades | | Output | |
|---|---|---|---|---|
| | galena | blende | lead | zinc |
| Concilio | 70 | 46 | 95 | 85 |
| Sancho Panza y Mentor | 65 | 44 | 80 | 80 |
| La Colosal | 70 | – | 90 | – |
| Emilia | 75 | – | 97 | – |
| La Cierva a) | – | 45 | – | 95 |
| La Cierva b) | 70 | 50 | 90 | 95 |
| Lo Veremos | 68 | – | 98 | -- |
| Consuelo | 75 | 48 | 92 | 80 |

*Source:* Archivo Peñarroya, IGME, leg. A0641/5 (Affaire Maestre – Essais de flottation, 1-02-1930).

46. López-Morell and Pérez de Perceval (2010), p. 54. A description of this froth flotation plant can be found in Domínguez (1943), pp.19-25.

**GRAPHIC 2 ▪** *Production in tonnes of lead and zinc minerals and smelted lead and zinc in Murcia, 1900-2000*




*Source: Estadística Minera y Metalúrgica* for the respective years.

than five froth flotation plants in different parts of the mining field. His method was to agglomerate the small mines into the first of the large holdings. He took advantage of the many abandoned mines and the fall in prices of the concessions and started to buy up mines en masse.[47] As a result, from the early 1950s, he was the biggest producer in the area, out-producing Peñarroya and its partners Zapata-Portmán. In 1951, Celdrán produced 3,469 tonnes of 60 per cent lead concentrate, out of a total production in Murcia of 9,498 tonnes, comfortably ahead of the 2,762 tonnes produced by Zapata-Portmán. The froth flotation plant he owned, named Brunita, accounted for 3,570 of the 16,432 tonnes of zinc concentrates produced in the region.[48] However, he did not stop there. In 1954, he started building the modern electrolytic smelter, La Española de Zinc, in Cartagena with finance from the Banco Central. The aim was to collect and smelt the growing zinc production in the whole area.

In the early 1950s, following the success of the Celdrán family, other companies began to follow suit. One of these was La Mancomunidad de Herederos de Dorda, which established its own froth flotation plant at Cabezo Rajao, as did other companies in the Consuelo, La Esperanza, Montaña and Lolita, Adra and San Eloy mines and the MINECASA and Ángel Celdrán groups

47. López-Morell and Pérez de Perceval (2010), pp. 94-101.
48. *Estadística Minera y Metalúrgica de España 1951*, p. 344.

(see Table 3). Many more would copy the system over the next 20 years, enabling them to end their dependency on underground mining as this technique could take advantage of the huge amounts of slag and old froth flotation tailing lagoons that abounded in the area.

**TABLE 3 ▪** *First froth flotation plants in the Sierra de Cartagena-La Unión (prior to 1957)*

| Name | Start of activity | Company | Capacity (tonnes/ day) | Activity in 1957 | | |
|---|---|---|---|---|---|---|
| | | | | Water used ** | Minerals recovered | Reagents used (1957) |
| Concilio y Regente | 1940 | SMM Zapata Portmán | 150 (1949=200 t) | M, m, R | Pb, Zn, S | Sodium cyanide and lime cyanide |
| Enrique Carrión | 1941 | Enrique Carrión | 70 | ? | ? | ? |
| Coto Azul | 1946 | SMM Zapata Portmán/Bibiano Fernández | 200 | m, R | Pb, Zn, Fe | Lime cyanide, ethyl xanthate and copper sulphate |
| Segunda Paz | 1948 | Francisco Celdrán | 150 (1949= 200 t) (1951=350 t) | m, R | Pb, Zn, Fe | Calcium oxide, lime cyanide, ethyl xanthate, pine oil and copper sulphate |
| Mendigorría | 1949 | ? | 40 | ? | ? | ? |
| Santa Teresa (Brunita) | 1950 | Francisco Celdrán | 150 (1951=300 t) | m, R | Pb, Zn, S | Calcium oxide, sodium cyanide, lime cyanide, ethyl xanthate and copper sulphate |
| Montaña y Lolita | 1951 | ? | 150 | ? | ? | ? |
| Adra y San Eloy | 1951 | ? | 150 | ? | ? | ? |
| Pablo y Virginia | ? | Francisco Celdrán | 100 | ? | ? | ? |
| Cabezo Rajao | 1952 | Mancomunidad de Herederos de Dorda | 150 | ? | ? | ? |
| Coto Ponce (experimental washing) | 1952 | Minas de Cartes S.A. | 25 | ? | ? | ? |
| El Bosque | 1952 | Francisco y Juan Barrionuevo | 72 | ? | ? | ? |
| Artesiana | 1952 | Domingo Jiménez | 60 | ? | ? | ? |
| En el tranvía | 1952 | Bernal & Castejón | 160 | ? | ? | ? |
| Esperanza | 1952 | ? | 70 | ? | ? | ? |

*(Continued on next page)*

| Name | Start of activity | Company | Capacity (tonnes/ day) | Activity in 1957 | | |
|---|---|---|---|---|---|---|
| | | | | Water used * | Minerals recovered | Reagents used (1957) |
| Tomasa y San Marcelino | 1953 | ? | 150 | ? | ? | ? |
| Balsa | 1953 | Peñarroya | 80 | ? | ? | ? |
| Angel Celdrán | 1953 | Ángel Celdrán | 500 | m, R | Pb, Zn | Sodium cyanide, lime cyanide, ethyl xanthate, pine oil and copper sulphate |
| Roberto | 1953-57 | Peñarroya | 300* | M | Pb, Zn, Fe | Calcium oxide, sodium cyanide, lime cyanide, ethyl xanthate and copper sulphate |
| MINECASA | 1954-55 | MINECASA | 300 | ? | ? | ? |
| Consuelo | 1954-55 | ? | 40 | ? | ? | ? |
| La Boltada | 1954-55 | Andrés Moreno | 100 | M, m, R | Pb, Zn, Fe | Sodium cyanide, lime cyanide, ethyl xanthate, pine oil, copper sulphate and sodium sulphide |
| Pinada | 1954-55 | Andrés Mercader | 120 | M, m, R | Pb, Zn | Sodium cyanide, ethyl xanthate, pine oil and copper sulphate |
| La Loba | 1954-55 | Francisco Celdrán | 90 | M, m, R | Pb, Zn | Sodium cyanide, ethyl xanthate and copper sulphate |
| Hércules | 1954-55 | ? | 130 | m, R | Pb, Zn, Fe | Sodium cyanide, lime cyanide, ethyl xanthate and copper sulphate |
| San Antonio (Mazarrón) | 1954-55 | Minas de Cartes | 200 | m, R | Pb, Zn | Calcium oxide, sodium cyanide, ethyl xanthate, pine oil and copper sulphate |
| Santa Florentina (Enrique Carrión?) | 1954-55 | ? | 70 | M, R | Pb, Zn | Calcium oxide, sodium cyanide, lime cyanide, ethyl xanthate and copper sulphate |
| Navidad | 1954-55 | ? | 80 | m, R | Pb, Zn | Lime cyanide, ethyl xanthate, amil xantato, pine oil, copper sulphate and sodium sulphide |
| Sol Vella | 1954-55 | Minas de Cartes | 140 | M, m, R | Pb, Zn | Calcium oxide, sodium cyanide, lime cyanide, ethyl xanthate, amyl xanthate, pine oil and copper sulphate |
| Torralba | 1954-55 | ? | 150 | m, R | Pb, Zn | Calcium oxide, sodium cyanide, lime cyanide, ethyl xanthate, amyl xantato and copper sulphate |

*(Continued on next page)*

| Name | Start of activity | Company | Capacity (tonnes/ day) | Activity in 1957 | | |
|---|---|---|---|---|---|---|
| | | | | Water used * | Minerals recovered | Reagents used (1957) |
| Santa María | 1954-55 | ? | 150 | M, m, R | Pb, Zn, S | Calcium oxide, lime cyanide, ethyl xanthate, amyl xanthate and copper sulphate |
| Virgen del Carmen | 1954-55 | ? | 140 | m, R | Pb, Zn, S | Calcium oxide, lime cyanide, ethyl xanthate, pine oil, copper sulphate and sulphuric acid |
| Ocasión | 1954-55 | Enrique Carrión | 120 | m, R | Pb, Zn | Sodium cyanide, lime cyanide, ethyl xanthate and copper sulphate |
| Rosalerta | 1954-55 | ? | 90 | m, R | Pb, Zn | Sodium cyanide, lime cyanide, ethyl xanthate and copper sulphate |
| Secretaria | 1954-55 | ? | 90 | m, R | Pb, Zn, S | Lime cyanide, ethyl xanthate, pine oil and copper sulphate |
| Minofer | 1954-55 | Minofer | 360 | m, R | Pb, Zn | Calcium oxide, sodium cyanide, lime cyanide, ethyl xanthate, pine oil and copper sulphate |

*Source:* López-Morell and Pérez de Perceval (2010), p. 53 and thereafter; Vilar, Egea Bruno and Fernández Gutiérrez (1991), p. 115; *Estadística Minera y Metalúrgica de España*; *Revista Minera*; Rolandi (1954); Technical report 1958 by Alejandro Evlampiev for General Química.
*Capacity of the Roberto flotation plant: 1957 (2,100 tonnes/day); 1970 (6,000-7,000 tonnes/day); 1978 (8,000 tonnes/day).

**M = Seawater; m = water from the mine; R = water recovered from the flotation process.

Indeed, the rise in international lead and zinc prices as a consequence of World War II was crucial in encouraging investment and to make the mines in the area profitable again. In other areas, however, as recorded in the provincial reports of the *Estadística Minera y Metalúrgica* of the time, the price increase was viewed at first with caution. The fear was that it might be merely circumstantial.

The evolution of the froth flotation plants in other Spanish mining areas took a slower course. The depletion of the traditional mines such as Soldado in Cordoba, or San Quintín and Nava de Riofrío, in Ciudad Real, halted the spread of flotation methods in some areas which had been the first to use them. This and the generalised fall in prices at the end of the 1940s limited the use of the technique. In the mining fields of Linares-La Carolina the technology would not make a comeback until the 1950s. According to the report in the *Estadística Minera y Metalúrgica de España* of

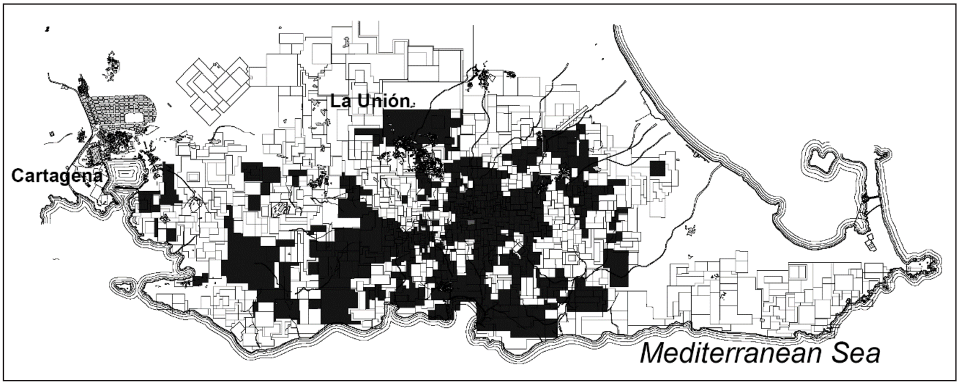
1949,[49] the old gravity separation mills in Jaen were not the most suitable for the ores but they employed a lot of very cheap workers who worked for themselves, and these businesses were often family concerns. In 1952, EMITER (Explotation de Minas y Terreros) installed a froth flotation plant at the Arrayanes mine to reprocess mine waste. It was the first company in the area with machinery for treating waste. It could be moved from one place to another and could be located close to the dumps.[50] Later, other plants followed, such as that of VIMORA, whose Santa Elvira plant treated the waste from the Coto La Luz from 1967. Other important plants in Andalusia, established after those in Murcia, included those at Minas del Centenillo (1950), Empresa Nacional Adaro (1954), and La Cruz (1959).

*The growth of the system: Peñarroya and the Roberto flotation plant*

Peñarroya, in the meantime, took it all in its stride; its focus was more on other mining projects in Africa and France than on boosting any projects in Murcia.[51] It is striking that despite the occurrences we have described, the company showed hardly any interest in incorporating new flotation plants in Murcia.

However, in 1947, when the Maestre family sold 50 per cent of the Sociedad Minero Metalúrgica Zapata-Portmán to Peñarroya, the company began to consider the possibility of investing in one or more plants, and especially

**FIGURE 2 ▪** *Mining concessions held by Peñarroya in the Sierra de Cartagena-La Unión in 1969 (in black)*




*Source:* map by Lanzarote from 1907 and Archivo IGME, Peñarroya, Cordoba (see Source Figure 1).

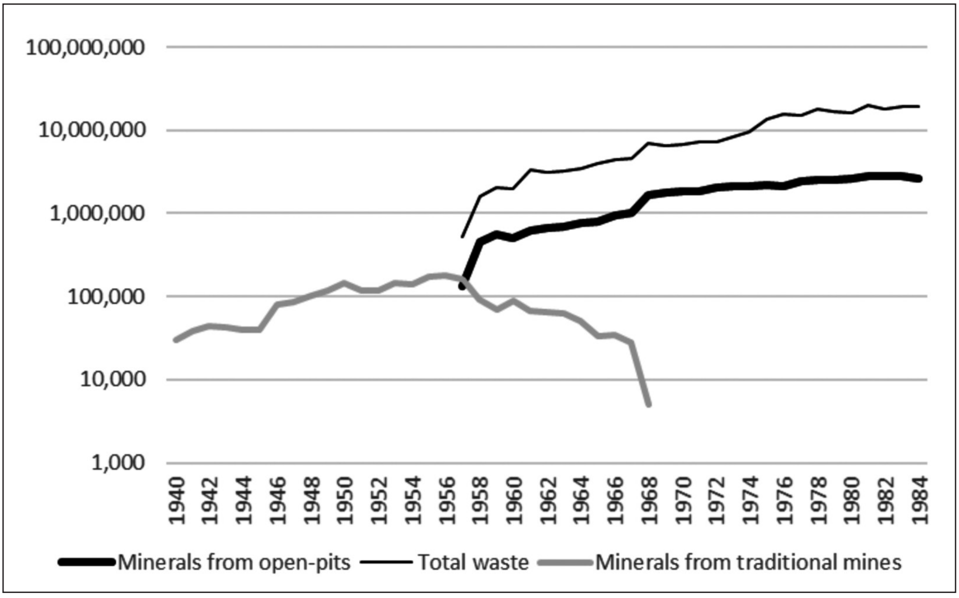
49. *Estadística Minera y Metalúrgica de España 1949*, p. 310. Other problems of the time are also mentioned, especially the electricity restrictions.
50. Cerón Cumbrero (2005), pp. 177 and thereafter.
51. López-Morell (2003).

in undertaking a vast programme to group its holdings in order to exploit the mining field on a truly large scale. Over the following years, the directors set about increasing the area they controlled by buying up the abandoned mines, including all those of the Celdrán family, until it held almost all the mining lands in the Cartagena-La Unión mountain range.

By the mid-1950s, Peñarroya had grown sufficiently to work large open-pits and was able to slowly move away from underground mining (see Graphic 3). The modern open-pit mines first appeared in 1953 with the Cantera Emilia, where large lorries and diggers of a size never seen before in the mountains of Murcia began to break up the land. This was followed by the Tomasa, San Valentín, Gloria, Los Blancos, San José, and La Brunita open-pits. The result was that the amount of land the company worked grew exponentially as it dismantled the old traditional system of shafts and galleries, all of which had gone by 1968, and the few that remained, that could not be converted, were rented out. In practice, the combination of flotation plants and open-pits meant that in the subsequent decades there was a huge growth in the quantity of minerals processed, as is clearly seen in Graphic 3.

The technological transformation was completed with the construction of a huge flotation mill in the bay of Portmán. The installation was baptised Roberto in honour of the French engineer who had designed the project. For

**GRAPHIC 3 ▪** *Evolution of open pit-mining by Peñarroya in the Sierra de Cartagena-La Unión, 1940-1984, in tonnes*




*Source:* SMM Peñarroya España (1970, 1984a and 1984b).

the next 30 years it processed all the low-grade minerals mined in the mountain range.[52] Once separated out, the metal concentrates were shipped to the Santa Lucía smelter in Cartagena, where the lead and silver were separated; or to the Española de Zinc, for zinc extraction.

The main feature of Roberto, which had been built on the site of a smelter, was its size. During trials in 1953, it began to process a modest 300 tonnes/day, but by 1956 this figure had risen to an impressive 2,100 tonnes/day. The plant was perfectly connected to all the open-pits, and was fed by the Emilia production by means of an underground electric railway that ran through a 1,900 metre tunnel called José Maestre directly to Roberto. Seawater was used in the installation, so the plant used the traditional flotation system described above, albeit on a much bigger scale, with the waste being dumped straight into the sea.

By 1970, Peñarroya was processing 6,000 tonnes of mineral per day at Roberto, a figure that would soon to rise to 7,000 tons. There were 517 employees, 337 in the open-pits and 180 at the plant.[53] This was not high compared to other periods, or in terms of the company's mining and treatment capacities, but it was perfectly in line with the massive mechanisation it had incorporated in all of its mines. Peñarroya had also just started an important modernisation of the Santa Lucía smelter which would double its capacity and would allow the company to close down its other metallurgical installations in Spain that processed these products. Henceforth, all the production of the mines in southern Spain would be processed in one place.

Peñarroya was able to handle half the lead production during the golden years of the area as well as attaining the highest ever levels of zinc for Murcia. Its share on a national level increased until 1987 when it accounted for 40 per cent of lead production and 10 per cent of zinc,[54] although by this stage the gross production did not translate so well into profits and operational facilities as in the past.

### *Environmental consequences of the process: the aggradation of Portmán bay*

This almost exponential growth in open-pit mining was matched by the capacity of the factory in Portmán to generate waste, which made it incompatible with other economic activities. In 1966, when Guy de Rothschild, Chairman of the Peñarroya Board, visited the mountains, he witnessed the

52. On the characteristics of the bay of Portmán: Pérez de Perceval, Martínez Soto and López-Morell, 2013.
53. SMM Peñarroya España (1970), p. 61.
54. *Estadística Minera 1987*.

first signs of tension with the local government, namely the mayor, Esteban Bernal, another mining businessman.

A large part of the problem was the result of a surprising mistake during the installation. It was not the fault of the engineers but of the State Coastal Office, which miscalculated the flow direction of the polluted waters from the outflow of the *Lavadero Roberto*, which had been situated at the *Punta Galera*, the southernmost part of the bay, with the idea that its waste would be taken by the current southwards down the coast. What the engineers did not know was that a few metres below the surface current, there was another more powerful one in the opposite direction, so the tailings in suspension drifted south for a short distance before being swept back to the bay and deposited at the bottom. Nobody picked up on this for some time and it was the local fishermen who began to notice that their catches were dropping alarmingly. The company made no effort, however, to modify its plans. A large proportion of some 60 million tonnes of waste were deposited in the bay in the ensuing years, and finally it was filled completely. Worse still, the pollution spread several kilometres along the coastal shelf. Evidently, not only tailings but also pollutants (lead, zinc, cadmium, among others) were also deposited. It is striking that at no time did Peñarroya even consider filtering its waste. Since the dawn of the twentieth century, when advances in mining began to reveal its enormous capacity to change the environment (especially in river courses), practical purification systems had been incorporated to treat mining waste.[55] Yet here, they were dumped straight into the sea without being treated until as late as 1990.

Peñarroya sailed easily enough in the waters of the Franco administration to obtain the necessary permits for its discharges both initially and for the subsequent enlargements made to the plant, first through Tomás Maestre Zapata, the then Chairman of the Sociedad Minera Zapata-Portmán and later, in 1959, through the engineer Tomás Martínez Bordiú, the brother of Franco's son-in-law. Jesús Romero Gorria, Labour Minister, and later Chairman of Peñarroya España, was one of the mainstays of the company when it came to obtaining extraordinary privileges from the state in the final decades of the *Lavadero Roberto*, and this meant the company did more or less as it pleased with its waste, and largely ignored the legislation in force.

The mayor of La Unión, Esteban Bernal, took the French company to court over its continued non-observance of Spanish mining legislation. The case dragged on and went to the Supreme Court before a sentence was passed in 1972. Bernal was summarily dismissed as mayor by the Spanish government, and the law, just as the politicians had done, ruled in favour of the company on the grounds that the area's most solid economic base could not be

55. See Pérez Cebada (2014), pp. 178-182.

removed, and that while the permits awarded to it were extraordinary, they had been granted in time, and were in order. The state therefore expressed its support for the company and in 1978 even authorised an enlargement to the froth flotation plant so that it could process 8,000 tonnes per day. Over the next few years it was improved until it was able to process 10,000 tonnes per day.[56] However, in spite of the continual improvements, the plant's productivity was extraordinarily low, given that for each 1000 tonnes of gross minerals, the plant obtained only 15 kg of galena, 20 kg of blende (which had to be treated in the smelting plant) and 50 kg of pyrites. The remaining 915 kg was dumped directly into the sea, mixed with seawater with no treatment whatsoever.[57] The Spanish government did not penalise the company in any way for its polluting effects.[58]

In the meantime, the issue had now reached the new democratically elected parliament, and in 1977 the member for Murcia, Ricardo de La Cierva, levelled direct accusations against the Civil governors, Enrique Oltra (who had dismissed Bernal) and José Aparicio Calvo-Rubio, who had no qualms about passing the blame on to López Rodó, Manuel Fraga and the Minister for Industry, Silva Muñoz (all important figures in the Franco regime), for their connivance with Peñarroya when granting the permits.

It is noticeable, though, how these political manoeuvrings coincided with a growth in the internal problems that Peñarroya had been suffering from the early 1980s, one hundred years after its creation, that were sparked by the crisis in the lead sector, a slump in prices, the departure of the main shareholders, the Rothschilds, and accumulated losses.[59]

In short, during the 1980s the mines that the company had in the Sierra de Cartagena-La Unión were contributing very little to the balance sheet. For all its magnificence, this field was returning paltry profits compared to other mining areas exploited by the company in different parts of the world. Some specialist journals even classified the mine in La Unión as "the poorest in the world" in terms of activity, given the extremely low metal contents with which it worked, as its own graphs for mineral purity show (Graphic 2).

Until then the company had clearly been covering its costs since, for one thing, it was not liable for any environmental damage it caused. But by now the problem could no longer be ignored. In 1985, the issue was taken to an

56. López-Morell and Pérez de Perceval (2010), pp. 112-116 and 186. Companies controlled by the Rothschilds in Spain, such as Peñarroya, Rio Tinto and MZA, had a long tradition of interaction with the country's political elites and had generated administrative corruption for many decades. López-Morell and O'kean (2008).

57. Manteca (2013), p. 70

58. The Public Administration always hid behind the economic interests of mining activity to justify the exceptional dumping by the *Lavadero Roberto* into the Mediterranean. Soro, Alvarez and Peñas (2014).

59. López-Morell and Pérez de Perceval (2010), pp. 56-60

international level when Greenpeace launched a press campaign in favour of recovering the bay and to halt dumping into what was reported to be the most polluted area of the whole Mediterranean coast. The regional government, presided over by the socialist Carlos Collado, announced that a deadline for stopping the discharges had to be set and that in no case could it exceed the 1999 deadline established under the previous government authorisation. The outcome was an unofficial declaration that discharges would cease as of 31 March 1991, which meant that the company would have to invest some one billion pesetas in disposing of the waste on land.

In any case, from 1985, the Peñarroya mines in the Sierra de Cartagena-La Unión began to report significant losses (610 million pesetas), which rose the following year to 738 million and to 756 million in 1987.[60] Confronted by this deep crisis, at the end of January 1988 Peñarroya España informed its employees of its intention to sell the mine, or find a partner who could guarantee continued production.

The matter did not end there. In spring 1988, Peñarroya and the German company Preussac merged to form Metaleurop. The merger saved Peñarroya from bankruptcy, but the German group made it very clear that that the new company should move exclusively towards its lead and zinc smelters and move away from the increasingly problematic area of mining. A glance at the records of the new company over the last ten years suffices to show that in its short history it has shown no strategic interest in recovering any mining potential but rather in providing its industrial installations with the cheapest raw materials of the highest quality possible.

The company's position is to search for opportunities to sell off this increasingly cumbersome asset which, since 1985, has been consistently in the red. In 1988 it managed to transfer assets from the Sierra de Cartagena-La Unión to the recently established Portmán Golf, which, while sharing the name of the town, had interests that went far beyond mining. However, this company operated for two further years until the permits expired and the bay had been filled with 56.5 million tonnes of waste from the plant. After certain manoeuvrings, the mines were finally closed at the end of 1991, while the new company directed its efforts toward building a tourist resort area that has yet to materialise. It is a new era for Portmán, and one in which lessons from the mistakes of the past can be learned and new problems need to be solved, including the inherited pollution and the changes to the countryside.

60. López-Morell and Pérez de Perceval (2010), pp. 57-58.

## Conclusions

The emergence of differential flotation constituted a significant innovation for the mining industry. It meant that minerals with low metal content and greater complexity could be mined profitably. More sophisticated machinery was also required to mine and transport greater quantities of ore to keep the flotation plants operating efficiently. Compared to the traditional gravity separation method, which made use of the different densities of the metals, differential flotation works on the basis of reactants that provoke the selective flotation of certain metal particles. Although this technique does not rule out small mines, it does generally require large open-cast mining operations from which large volumes of minerals can be extracted. A lot more water is also required, along with various chemical compounds, so the method, particularly with low-grade ore, generates large amounts of waste and pollutants.

In the case of lead and zinc mining in Spain, differential flotation took some time to be incorporated on a large scale, but not because of any lack of technological know-how nor because of insufficient capital or entrepreneurship. Rather it was due to the ownership structure of the lead mining fields of southern Spain, where there was a prevalence of small-scale mining that prevented the development of a large-scale economy. It is still a drawback even today. In the golden age of Spanish mining (1860-1910) it was an obstacle to the introduction of new systems of mining and ore processing.

Differential flotation increased production levels in the second half of the twentieth century but it did not regain the importance that it had enjoyed during the golden age. It did serve, however, to prolong the life of this historical mining area for some 40 years and was clearly the best way of making use of the ores in the area. But the way it was introduced, and the sheer amount of materials that it mobilised, has led to terrible environmental costs.

Mining destroyed Portmán bay and with it many potential benefits from other activities, especially tourism. One cannot but wonder how this could have happened when other countries had been taking measures to limit the effects of the new systems for concentrating minerals for decades. Our interpretation is that it could only be due to the excessive permissiveness of the state authorities, who had little or no democratic tradition, and allowed the biggest mining company in Spain, Peñarroya, to systematically contravene environmental law for the best part of 40 years. During the process, the company showed few qualms about using all the administrative corruption mechanisms it had at hand in order to bear the costs of the mass pollution caused by its plant. In short, the aggradation of Portmán bay is one of the clearest examples in world history of environmental degradation caused by a production activity that had hardly any positive effects on the local economy and how an uncontrolled mining activity can jeopardise or render practically impossible other economic activities in the long term.

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## *From old mining to new mining: the introduction of differential flotation in Spanish mines and its environmental impact*

ABSTRACT

From the beginning of the twentieth century, the use of differential flotation gave rise to profound changes in mining as it enabled a wider range of minerals to be processed and low-grade and complex ores to be extracted profitably. This paper analyses how this technology spread throughout Spain, especially in the Sierra de Cartagena-La Unión, where it was heavily used. The question remains, however, regarding the long delay in the incorporation of such a profitable system in Spain. We will examine the reasons for this and highlight institutional elements as the main hurdle to adopting new concentration techniques. We will also study the huge impact that large-scale flotation had on this particular mining area, where it caused one of the greatest ecological disasters ever attributed to mining.

KEYWORDS: differential flotation, history of mining, technological change, Spain, twentieth century, environmental impact

JEL CODES: L72, N60, O33, Q51

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## *De la vieja a la nueva minería: la introducción de la flotación diferencial en las minas españolas y su impacto medioambiental*

RESUMEN

Desde principios del siglo XX, la utilización de la flotación diferencial produjo profundos cambios en la minería ya que permitió procesar una gama más amplia de productos y aprovechar de manera rentable los minerales complejos y de baja ley. Este artículo analiza cómo esta tecnología se extendió por toda España, especialmente en la sierra de Cartagena-La Unión, donde se utilizó de manera importante. La pregunta sigue siendo conocer las causas del largo retraso en la incorporación de un sistema tan rentable para la extracción en España. Examinaremos las razones de ello y resaltaremos los elementos institucionales como el principal obstáculo para adoptar nuevas técnicas de concentración. También estudiaremos el enorme impacto que tuvo la flotación a gran escala en esta área minera en particular, donde causó uno de los mayores desastres ecológicos que se hayan atribuido a la minería.

PALABRAS CLAVE: flotación diferencial; historia de la minería; cambio tecnológico; España; siglo XX

CÓDIGOS JEL: L72, N60, O33, Q51