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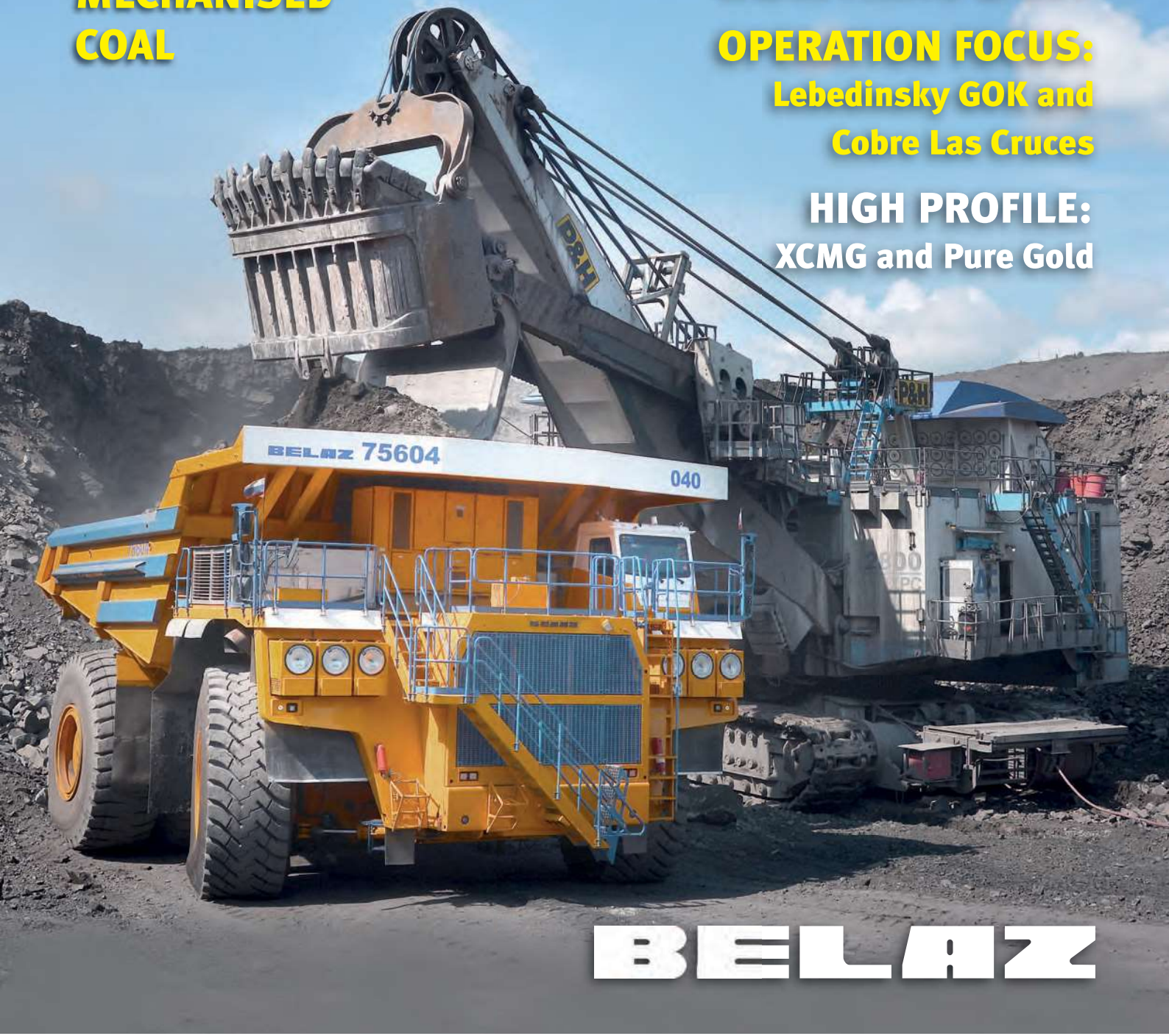

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Andalusia ore

Paul and I are in the very fortunate position of regularly being invited on trips by mining companies, equipment providers and local government ministries.

On these trips, the organisers look to highlight just how important these associations, products or regions are to the global/regional mining industries.

Whether it is being chauffeured around conferences to exchange ideas and business cards with executives, getting to sit in the cab of the latest ultra-class haul truck, or sipping sundowners in exotic locations while hearing about the impact mining has had on an economy, we normally come away from these events tired but with a much better understanding of the subject at hand.

I was fortunate enough to go on such a trip in June.

Travelling to Andalusia around this time of year is a tough ask, but someone had to do it!

My thoughts on the trip go beyond sampling Seville's excellent local tapas, to gaining an appreciation of the mining tradition that can be felt only a few miles from the city.

Within this issue of ***IM***, you'll find a detailed site visit report on First Quantum Minerals' Las Cruces copper operation, but we were also able to fit in a visit to MATSA's Magdalena mine (write up coming soon), a short excursion to Atlantic Copper's metallurgical complex in Huelva, a trip to AGQ Labs' facility just outside of Seville, a stop at the venue of October's *Mining and Minerals Hall* event (FIBES) and a chat with local politicians.

This isn't my first rodeo in Spain, having been treated to an Asturias trip all the way back in 2012 run by a Canada-based exploration company.

This previous trip – a no expenses spared visit involving a chartered aircraft and more wine and politicians than you could shake a stick at – ended very differently with the exploration company since folded and the project in purgatory.

There was no such (false) promises uttered on this trip to Andalusia.

What I found was a region aware of its history and looking to build a sustainable future.

There were acknowledgements of learning from past mistakes, with the Los Frailes tailings dam disaster in 1998 mentioned on several occasions, and of laying the groundwork for more mining companies to develop operations in the region.

All conversations were grounded in realism, with the miners seeing electrification and automation underground as inevitable, the politicians realising the mine approval process could only be sped up so much and the AMINER association acknowledging it needed to become more open to build on the region's existing legacy.

My Las Cruces site visit would imply its PMR project will play a major role in future developments on the Iberian Pyrite Belt, but equally important to companies looking to move into production is Atlantic Copper's smelter.

Owned by major copper producer Freeport-McMoRan, the Huelva facility takes concentrated copper ore from all over the globe and produces 99.99%-pure copper cathodes through a series of processes that sees the raw materials separated into their three main components: copper, sulphur and iron. This energy-efficient facility utilises Outokumpu's Flash Furnace technology and sold 283,000 t of cathodes and 13,000 t of anodes last year.

But, even before prospective copper concentrate producers get to the stage of selling their products, the facilities at AGQ Labs are worth considering in the mining lifecycle. The company's dedicated mining offering has been carrying out metallurgical test work, scaled acid generation prediction trials, groundwater tests and tailings analysis since 2010.

Such a facility is not set up without taking a long-term view on the health of the local mining sector; the same could be said for FQM, Freeport and MATSA and, arguably, the biennial *Mining and Minerals Hall* – an event that attracted 11,000 visitors back in 2017.

While companies cannot move mines, they are not willing to invest for the long term without evidence the foundations are solid.

It appears Andalusia's rocks are just that.

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CLC digs deep in innovation drive

Since starting up operations a decade ago, the Las Cruces copper mine has become a trailblazer in terms of applying new technology and innovation. Dan Gleeson visited in June and found out this tradition is set to continue into the future

Technology has proven decisive in the success of the Cobre Las Cruces (CLC) copper operation in Andalusia, Spain, over the last 10 years, and it will be equally significant in extending the operation's life for another 15 years beyond 2020.

Located in the municipalities of Gerena, Salteras and Guillena, in Seville province, the mine, owned 100% by First Quantum Minerals (FQM) through CLC, celebrated its 10th anniversary as a copper producer in June; at which point it had produced 585,000 t of copper cathode.

IM visited the operation that month as part of a trip highlighting the region's mining sector ahead of October's biennial *Mining and Minerals Hall* event in Seville.

Top of employees' minds, at this point, was recovering from a January 23 pit wall slide that had seen mining operations suspended.

While there were no injuries or impact on third-party facilities or land resulting from the slippage, FQM has previously said the suspension of operations was estimated to result in around 25,000 t of lost copper production in 2019, followed by another 25,000 t in 2020.

CLC personnel, in tandem with local authorities, had been quick to confront the issue, with reclamation work involving rebuilding and reinforcing the pit wall, as well as employing real-time surveillance tools. This included adding **IDS GeoRadar** and **Maptek** Sentry slope stability monitoring equipment, as well as employing a new **Datum** remote seismograph.

It was only a few weeks after ***IM***'s visit that the operation was given approval by the Andalusia Government to resume exploitation work at the mine, with the first blast since the pit slide taking place shortly after.

The next few months will be busy for the mine operations team as it looks to start mining at the final Phase 6 pit pushback. They will need to quickly provide the plant operators with the fresh – and high grade – ore they require to keep the overall metal recoveries consistent with the high levels they have worked so hard to achieve over the last five-to-six years.

By the end of 2020, the open-pit mine is expected to be finished, leaving the company with a void that, should all go according to plan, will be filled by an underground mine, a modified metallurgical processing operation and the potential to transform polymetallic mining on the Iberian Pyrite Belt.

The look of the Cobre Las Cruces open pit as of July 8: CLC personnel, in tandem with local authorities, were quick to confront the January 23 pit wall slide, with reclamation work involving rebuilding and reinforcing the pit wall, as well as employing real-time surveillance tools

Current copper

The CLC deposit occurs on the eastern end of the Iberian Pyrite Belt, a 300 km long and 80 km wide geologic belt that extends eastward from southern Portugal into southern Spain. The belt is host to more than 100 mineral deposits, some of which were exploited for metals as long ago as the Bronze Age.

Mineralisation at CLC consists of syngenetic massive sulphides containing polymetallic mineralisation, similar to several other Iberian Pyrite Belt deposits. The company, in this case, is extracting secondary sulphides during open-pit mining.

CLC is a blind deposit with no outcrop due to the 100-150 m of sedimentary marls overlying it. It is possibly for this reason that no other deposits have been found in the immediate area, with exploration difficult due to the thickness of cover.

It is this barren cover that accounts for the high strip ratio at the deposit, which, in 2014 for

example, came in at waste-to-ore ratio of 11.26:1. Iván Carrasco, Chief Mining Engineer for the Poly Metallurgical Refinery (PMR) project – the new development the company is working on to extend operations at CLC beyond 2020 – remarked that the company had to initially strip a quarter of the entire life of mine waste (around 25 million m^3) to access the first ore.

It is the deposit's high-grade nature that counters this. During the mine's initial stages, Stage 1, the pit shell had average ore grades of 9% Cu. The plant is, today, equipped to handle ore grading around 6% Cu with the remaining reserves coming in around the 5.2% Cu mark.

Open-pit mining is carried out through conventional means – drill and blast, followed by excavators loading haul trucks, before the ore is stockpiled and blended ahead of plant operations.

Carrasco says the company uses **Epiroc** ROC L8 blasthole rigs with down-the-hole hammers and 5 in (127 mm) holes for blasting ore in the pit. The company loads these holes with heavy ANFO from **MAXAM**, which has a plant some 10 km away, and uses remote detonators to carry out the blasts.

Following blasting, the company has eight 100-t **Liebherr** 984 shovels that load a fleet of 40 haul trucks. The haulage fleet is a rough 50:50 split between **Cat** 95-t 777s and **Komatsu** 90-t HD785-5s, Carrasco explains, adding that the contractor – Andaluza de Obras y Mineria SA, or AOMSA, a division of earthmoving company EPSA – carries out all mining in the pit. The support fleet, meanwhile, consists of graders (Cat G-14s), dozers (Cat D8 and Cat D10s), wheel loaders, service and lube trucks.

The secondary fleet (run of mine blending and re-handling and tailings placement) is comprised of two Cat 988 D wheel loaders and six 40-t capacity Cat 740 articulated dump trucks (ADTs) operated by a second contractor, San Martin Logistica Minera.

When back up and running, this equipment will help the open pit achieve its final dimensions of 1,600 m long by 900 m in diameter, which is expected to be reached next year.

Hydro heights

It is the processing side of the equation where CLC's innovation is on show. CLC is the only operator in Europe using a hydrometallurgical process plant with atmospheric leaching to produce a copper cathode.

The nearest analogue is in Laos at Sepon, which uses a similar process but under very different conditions, according to Carrasco. "The feed grade in Sepon is around 6% Cu, but the main difference is a geological one. Sepon has an outcrop and the oxidation of the massive sulphides is much more apparent than here, so they have carbonates – malachite, cassiterite, etc," he said.

"We don't have carbonates, we only have secondary sulphides."

The CLC haulage fleet is a rough 50:50 split between Cat 95-t 777s and Komatsu 90-t HD785-5s

The 144 electrowinning cells – containing 82 cathodes and 83 lead anodes – help produce LME grade copper cathodes weighing around 50 kg each

Joaquín Gotor, PMR Project Manager, added: "Also, the source of iron in Sepon...is from the autoclave. Our source of iron is the atmospheric leaching itself."

Considering the uniqueness of the flowsheet, it is no wonder the operation took two years to reach its nominal production and recovery target.

The crushing and grinding part of the processing flowsheet is innocuous enough; taking material measuring from millimetres to a metre, according to Rubén García, Senior Operations Supervisor at CLC, through three stages of crushing. The jaw and cone crushers, plus screens, are all provided by **Sandvik** in this case.

Crushing reduces the ore down to a P80 of <15 mm, with this sized material stored in a 3,500 t silo before it moves onto the wet processing stage. Here, an **Outotec** ball mill reduces the feed further to 150 microns in a one stage grinding process before being sent to a thickener.

It is what follows this in the flowsheet that represents the operation's uniqueness: in particular, the use of eight Outotec OKTOP agitated reactors to dissolve the copper under conditions of high temperature and high acidity, otherwise referred to as atmospheric ferric leaching.

This process generates the iron Gotor mentioned, which is one of three core elements dictating the process' effectiveness, according to colleague García. The other two are the levels of acid and oxygen and their interaction with the iron.

The eight 350 m³ OKTOP reactors operate in cascade for copper leaching, with the residency time, in recent years, increased to 10-12 hours, from eight hours.

This residency time change, part of several carried out in 2013-2014, were part of a debottlenecking process in the plant to accommodate lower-grade material from the later stages of pit development. It also included projects to enhance both throughput and recovery, with Gotor mentioning that CLC was able to reduce copper losses throughout the process by changing the filtration method and making reactor modifications. These efforts have paid off with copper recoveries rising to 92-94%, up to four percentage points higher than the original 90% guidance.

After leaching, liquid-bearing copper is produced. This solution is thickened, with the result being two separate streams (an aqueous and solids stream). The aqueous solution, after cleaning, becomes the pregnant leach solution (PLS) feed for the solvent extraction (SX) area, while the solids are taken to another filter where the moisture content is reduced to 10-11% for tailings storage (more on that later).

In the SX area, the copper is passed to an organic solution and then to the electrolyte that feeds the electrowinning cells. The 144 electrowinning cells – containing 82 cathodes and 83 lead anodes – help produce LME grade copper cathodes weighing around 50 kg each. An automated crane and stripping machine then harvest and package the cathodes for shipment.

The time taken from the mineral entering the plant until leaving it converted into LME grade copper cathodes is just eight days, according to CLC, with close to 90% of the process automated via an **Emerson** PLC system, according to García.

Ahead of its time

While many miners are only now adapting their processes to reduce and recycle water in line with resource scarcity and sustainability pressures, CLC had this in mind from the off.

The operation protects local groundwater and the Niebla-Posadas aquifer, in particular, through the use of a dewatering-reinjection system (DRS). This consists of a ring of pumping wells to intercept the flow of groundwater before it enters the open-pit mine. It then diverts the water via closed pipelines to the permanent water treatment plant, which uses reverse osmosis to purify the water before it is pumped to the different reinjection wells – located 1-2.5 km from the open pit.

CLC says: "Reinjection not only avoids the water resource from being lost, but also notably improves it in the area near the mine, since the water returned to the aquifer is of much better quality than the natural water."

The company also treats urban wastewater pumped from the San Jeronimo sewage plant, in Seville, and contact water collected from the base of the open pit, to make up the mine water balance required at the operation.

This isn't where CLC's innovation ends.

Instead of using a wet tailings dam, the company, since production started in 2009, has used dry stacked tailings to reduce its environmental footprint.

Filtering and disposal of the tailings as a paste was a permitting requirement for the project, which was a consequence of more stringent requirements for tailings disposal after the failure of the nearby Los Frailes tailings dam in 1998.

Two types of tailings streams are produced at CLC and require disposal: filtered leach residue and filtered solids from the neutralisation circuit.

The filtration process, in 2014, was adapted when the company replaced the existing belt filters with pressure filters – supplied by Outotec – to help reduce tailings disposal costs, according to a 2015 technical report.

The leach residue from the tailings represents around 92% of the total tailings and has acid and metal-bearing leachate potential. About 80% of this residue is made up of sulphide minerals, primarily as pyrite with minor amounts of chalcocite and chalcopyrite along with constituents like arsenic and mercury. The remaining 8% of the total tailings (neutralisation solids) are inert and contain mainly gypsum and magnetite with some metal hydroxides.

The tailings storage facility (TSF) is embedded within the North Dump with the tailings material being confined by a compacted marl embankment and both bottom and upper seals. The bottom seal has been constructed with 1.5 m of compacted marl covered by a 1.5 mm thick HDPE liner and a 0.5 m thick layer of sand and a geotextile material to allow moisture to pass into the sand layer.

A 1 t/h pilot plant worked continuously for eight months over 2016/2017, treating 5,000 t of ore, to prove the new polymetallurgical process for the PMR project

The tailings are delivered to the TSF by the Cat 740 ADTs, dumped, and then dozer-spread to an ultimate design density of 90% of standard Proctor maximum dry density and a thickness of circa-25 m.

Once the tailings are stacked to their ultimate height, over 5 m of compacted marl material will be placed on top and covered by geotextile material, 0.6 m of sand, more geotextile, 5 m of compacted marl, and 0.5 m of topsoil to grow vegetation.

The embankment or barrier berms have been built to a height of 30 m and constructed of upper marl material from the mine pit development. The marl that does not come into contact with tailings has been compacted to a minimum of 75% of standard Proctor density, while marl that will come into contact with tailings compacted to a minimum of 95% of standard Proctor density.

The way this material is stacked up means the TSF has low permeability, while allowing for progressive rehabilitation of the waste dumps as the operation has proceeded.

The future

As the company has been mining the open pit at Las Cruces for the last 10 years, it has also been thinking about the future of the operation.

Exploration drilling beneath the open pit has delineated more than 30 Mt of primary polymetallic sulphide resources containing copper, zinc, lead and silver. The problem, however, is that this tonnage will require an altogether different process route to the existing one in place.

This is where the PMR project comes in. This refers to the company's plan to produce several metals from these resources via a different – and, as the PMR name indicates – polymetallurgical route.

Not only will this project involve changes to the process plant; Gotor mentioned additions of flotation cells, zinc and lead plants and modifications of the milling and crushing circuits; it will also involve the development of an underground mine.

Initial underground mining for PMR took place last year, providing a portal to quickly access the orebody to complete further drilling of some areas and, at the time of ***IM***'s visit, the company was awaiting permits from the local administrators to proceed with the project. There is also the small matter of obtaining the over €400 million ($446 million) from CLC owner FQM to develop the project.

Gotor and Carrasco remained upbeat about the chances of receiving positive results on both fronts and the ability of the company to deliver the PMR project in a timely manner to coincide with the cessation of processing open-pit ore.

Details about the PMR project are thin on the ground, but it is billed as having the potential to prolong the operation by 10-15 years, at least; produce a variety of base and precious metals; and, Gotor says, "open the way to process polymetallurgical ore on the Iberian Pyrite Belt".

The metals will all be processed in a "single integrated refinery, unique in the world, that will operate with the company's own minerals and will be able to treat raw materials brought in from other sources", CLC says.

The project will involve the development of an underground mine, using mainly sub level open stoping with paste backfill, that is likely to operate at an average of 1.8 Mt/y.

Carrasco explained that the company will keep a pillar of 30 m between the open pit and underground workings, with part of this pillar recovered later by drift and fill mining.

Around 50% of the tailings from the mine will be used as stope backfilling material following treatment in a paste plant. The remaining tailings will be stored within the existing open-pit adapted as an in-pit facility.

It is the processing side of the equation that is the most intriguing and not just because CLC personnel on site were cautious about revealing too many details.

Long-term technology partner Outotec is helping the company go down this polymetallurgical route – that is public knowledge – and CLC, itself, has been granted certain patents for the process, with some more pending, according to Gotor.

The process to be used is also able to deal with the arsenic and antimony that accompanies ore in this part of the Iberian Pyrite Belt and has hindered integrated operations in the past. Smelters are able to get around using concentrates with such impurities by blending with material from other regions that have lower concentrations of these deleterious elements.

Gotor provided an explanation of the process – the closest ***IM*** got to the process specifics: "We are not searching for a final concentrate for a smelter. We are looking for a bulk concentrate to be treated in the refinery. With the standard sulphide processing route, you tend to get a 60% recovery in differential flotation for copper, 40% for lead and 50% for zinc. You then get a high recovery and efficiency from the smelter to make the process work.

"If you look at PMR, you have flotation and the hydrometallurgical plant, which is effectively the refinery. The refinery has high efficiency, which is the same as a smelter, but the flotation has high efficiency as well. The flotation is looking for a rougher, bulk concentrate in this case, so, instead of getting a 60% recovery as you do with differential flotation, you are getting 80%."

A 1 t/h pilot plant worked continuously for eight months over 2016/2017, treating 5,000 t of ore, to prove this process. It also verified the nature of the tailings that would be produced and used to manufacture the paste for backfilling.

This process will ultimately see the company produce copper cathodes, zinc ingots, and lead and silver cement products from the integrated refinery – something that has never been achieved on this part of the geological belt.

Carrasco said as much: "What we have achieved here is what the miners and metallurgists on the Iberian Pyrite Belt have been looking to achieve in the last 40 years."

It is for this reason that many companies in the region are intently watching the PMR project knowing that CLC could have come up with a profitable means of treating ore previously consigned to the uneconomic pile.