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The 2010 Chilean Mining Rescue (A)

On August 5, 2010, 700,000 tons of some of the hardest rock in the world collapsed in Chile's century-old San José mine. The collapse buried 33 miners at a depth almost twice the height of the Empire State Building—over 600 meters (2,000 feet) below ground. Never had a recovery been attempted at such depths, let alone in the face of challenges like those posed by the San José mine: unstable terrain, rock so hard it defied ordinary drill bits, severely limited time, and the potentially incapacitating fear that plagued the buried miners. Could the trapped miners and rescue workers mobilize before air and resources were depleted? The ensuing efforts would draw the attention and resources of countless people in Chile and around the world—and theirs would become a story of human survival, ingenuity, and hope facing the most desperate of circumstances.

The Mining Industry of Chile

With volcanoes, glaciers, deserts, and an immense continental mountain range, the geographically varied country of Chile extends along more than half of the Pacific coast of South America. Often referred to as the mining capital of the world, Chile was the world's largest producer of copper, accounting in 2009 for about 35% of the world's copper production. Copper was also a pillar of Chile's economy, contributing 14.4% of the country's GDP in 2010.¹

Much of Chilean copper production lay in the hands of international investors until the 1950s, when the Chilean government, under President Carlos Ibáñez del Campo, initiated a nationalization process that succeeding governments continued. Through negotiations with foreign investors, the government gradually acquired control of Chile's largest copper mines. Even after General Augusto Pinochet's junta seized control of the government in 1973 and began to implement reforms that favored the free market, the mines remained in government possession.²

Codelco

The National Copper Corporation of Chile (known by its Spanish acronym, Codelco) was established in 1976. With control of Chile's largest mines, Codelco became the largest copper-producing company in the world and in 2010 accounted for 12.5% of total global copper production.³ With annual revenues of over US\$12 billion in 2009 alone, Codelco also constituted a major source of income for the Chilean government, which played a key role in the company's foremost decisions. The president of Chile appointed Codelco's board of directors, and Codelco's president was Chile's

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Minister of Mining.⁴ Shortly after the San José mining accident in August 2010, Chilean President Sebastian Piñera placed Codelco in charge of the response.

Despite the dominant size of Codelco, many of the world's private mining companies (including Canada's Barrick Gold Corporation, the United Kingdom's Antofagasta plc, BHP Billiton of Australia and the United Kingdom, and Phelps Dodge Corporation of the United States) remained major investors in Chile's mining sector. In 2010, the Escondida mine, with a 57% controlling ownership interest by BHP Billiton,⁵ produced about 7% of global copper production, making it the world's largest single-mine producer of copper.⁶ Many of these private companies would self-mobilize their resources in the wake of the 2010 mining accident.

Safety Practices

With an industry average of 34 deaths per year since 2000⁷ and countless day-to-day injuries, work in Chilean mines was risky. It demanded employees to drive truckloads of mining explosives across an earthquake-prone region.⁸ Job-site safety practices, however, remained highly variable across mining companies in Chile, and a number of mines, such as the San José mine, were known for emphasizing production over safety.⁹

The San José Mine

In 2010, Compañía Minera San Esteban Primera owned the San José mine. Located in the mineral-rich Atacama Region of Chile (see **Exhibit 1**), the San José mine had been operational since 1889.¹⁰ The inside of the mine included long, sloping tunnels that spiraled over 16 kilometers, reaching a depth of over 700 meters (see **Exhibit 2**). The mine produced roughly 2,700 kilograms of copper daily (US\$22,000) and boasted gold reserves worth almost a billion dollars (at 2010 prices).¹¹

In the last decade alone, accidents at the mine had repeatedly brought the operations under scrutiny. In 2007, the death of a geologist during a mine accident led to a total shutdown. Many safety procedures, however, remained negligent even after the mine was reopened in 2008.¹² Outdated maps, missing escape ladders in ventilation shafts, and the absence of backup exits¹³ made the mine an extremely dangerous work site. One of the miners lost a leg in an accident in July 2010.¹⁴

Many miners at San José wondered why the mine had not already collapsed, given a century's worth of disorganized dynamiting, drilling, and extractions that had diminished the mine's support structure. Inside San José (as in most deep mines), hot, humid conditions were common, with temperatures usually over 32° Celsius (90° Fahrenheit). To avoid dehydration, miners drank an average of three liters of water daily. In addition, they had to dodge falling rocks and regularly flee from debris slides. Because of the dangerous work conditions, miners at San José were paid up to 30% more than the competitive wage.¹⁵

Buried Alive: The San José Cave-In

Around 2 p.m. on August 5, 2010, a part of the San José mine collapsed, blocking the passage to the tunnels deep within the mine. The miners close to the entrance, although shaken by the deafening thump, emerged unscathed from the mine shortly thereafter. But a group of 33 miners working deeper within the mine were now buried some 700 meters underground with a 700,000-ton rock corked between them and the mine entrance. Trapped deeper than the height of many modern-day

landmarks—the Statue of Liberty (93 meters), the Eiffel Tower (324 meters), and the Empire State Building (381 meters)—the miners were blinded by a thick cloud of dust. In spite of falling debris and a slippery tunnel floor (the cave-in had unleashed trapped water between rocks), the 33 miners managed to make their way to a 50-square-meter (540-square-foot) predesignated “refuge” within the mine. No one was critically injured or had broken any bones. The loud cracking sounds inside the mine, however, indicated that the ground was far from stable.¹⁶

The First 24 Hours

Luis Urzúa, the 54-year-old shift foreman, immediately checked provisions in the refuge. He found two oxygen tanks, some expired medicine, and food—1 can of peaches, 1 can of salmon, 2 cans of peas, 4 cans of beans, 20 cans of tuna fish, 96 packets of crackers, 10 liters of water, 16 liters of milk, and 18 liters of juice—which could feed 10 miners for two days.¹⁷

Even-keeled and soft-spoken, Urzúa held formal leadership; in the Chilean mining culture the authority of the shift foreman was considered absolute. But Urzúa had worked at San José for less than three months and did not know the miners well. Soon arguments caused by fear, frustration, and anger erupted. Many miners had long predicted a cave-in and felt bitter and betrayed. Those with years of experience working at the mine felt frustrated by how little the company had done to safeguard them. One miner in particular, the energetic and charismatic 39-year-old Mario Sepúlveda, was galvanized. He felt that the miners must take action.¹⁸

Along with 63-year-old Mario Gómez, Sepúlveda rallied the miners to explore escape routes and send signals to the rescue workers. Sepúlveda’s appeals resonated with the miners, but most did not follow, staying in subgroups based on kinship and past friendships. Despite the mine’s instability, many ventured out of the refuge, either individually or in small groups. One miner, 27-year-old Richard Villarroel, drove a pickup truck upward through the tunnels until he came across a blockage. He stuffed the edges of the fallen rock with tires and oil filters and ignited them in hopes that the smoke would alert rescue workers. Others ignited dynamite at regular intervals to signal there was life underground. Urzúa, a topographer by training, stayed back to sketch a map of their surroundings and the mine.¹⁹

By the end of their first 24 hours, the miners were exhausted by failed attempts to communicate with the outside world and disoriented by lack of natural light. Most felt accountable to no one. They urinated and defecated wherever they found it convenient. Eventually, subdued by hunger and fatigue, each found spots in the tunnel or trucks and attempted to sleep.²⁰

Search Attempts: The First 24 Hours

Soon after the collapse, rescue personnel from the Chilean Carabineros Special Operations Group (GOPE)—an elite and extremely well-trained police unit—were called. They attempted to reach the miners through ventilation shafts, but continued ground movement rendered these shafts unusable. Meanwhile, as news of the mine cave-in spread through media broadcasts, the San José site quickly became crowded with family members, emergency response teams, rescue workers, and reporters.²¹

At the time of the collapse, Chilean President Piñera and the Minister of Mining, Laurence Golborne, were traveling abroad. Piñera knew that the government needed to get involved. Against the recommendations of his advisers, he asked Golborne and his top aides to go to San José. Legally, San José was a private mine, not under government jurisdiction. Historically, no mining minister had

visited the site of a crisis.²² Piñera recalled his reaction: “There was no possibility for them [the San Esteban company] to respond. The option was thus very simple. The government would assume responsibility for the rescue or nobody would.”²³

The Survival Challenge below Ground: Days 2–5

When the miners awoke the next day, 54-year-old José Henríquez, who had experience preaching, urged everyone to begin their day with a collective prayer. Most heeded the call. After their failed attempts the prior day, many miners wanted to conserve their energy and be patient, but Sepúlveda disagreed. He urged for engagement as on the previous day. With nothing else to do, the miners started making noise by honking horns, hitting metal on metal, and exploding dynamite. Sepúlveda and Raul Bustos explored the option of escaping through the ventilation ducts, but many ducts were missing ladders. This option turned out to be nearly fatal when falling rocks barely missed Sepúlveda as he was rock climbing through one of the ventilation ducts.²⁴

The next day, the miners gathered around Henríquez to begin the day with a collective prayer. Many started drinking the grimy water from the 15,000-liter water tanks stored for use in mining machinery. It was now day 3, and almost all were aware that they urgently needed to make decisions about the food supply. A democratic process, one vote per each man, was instituted. Having detected no sound of a rescue operation, the miners agreed that no more than a sliver of food every 12 hours should be eaten. Urzúa and Sepúlveda would guard the food supplies. This co-guardianship was democratically approved. By the end of the day, permanent sleeping sites were emerging.²⁵

On day 4, the men gathered together for collective prayer. Afterwards, Sepúlveda urged the group to respect Urzúa and suggested that if Urzúa were willing to lead, the miners should accept him as their leader. If Urzúa were unwilling to lead, Sepúlveda would be willing to take charge. The miners spent the day performing constructive tasks like building canals to drain accumulated water in their sleeping areas and creating lighting via rigged vehicle batteries. Bathroom rules were established; it was decided that everyone would use empty oil drums for human waste. When full, the waste would be covered with dirt and gravel, poured downstream, and covered with more dirt and gravel. Meanwhile Gómez, a former merchant marine, shared with others the story of his own 11-day journey aboard a Brazilian cargo ship, where he survived mostly on rainwater.²⁶

The miners soon began to react in distinctive ways. Victor Zamora began to write a diary. Nineteen-year old Jimmy Sánchez began to hallucinate. Some began to oversleep and others began to walk through the sloping tunnels, either staring in silence at the boulders around them or cursing them in rage. Many also craved tobacco and alcohol, making it difficult to avoid mood swings.²⁷

On day 5, the miners again began their day with a collective prayer. Sepúlveda decided to make soup out of a can of tuna and all the miners ate together. Later they spent time searching for escape routes they might have missed in earlier attempts. At 1 p.m., which they decided would become their daily meeting time, each miner’s daily intake was reduced to 100 calories. It was clear that conserving food supply might be critical for survival. Most of the miners were overweight and understood that they could afford to be on a meager intake for a while, despite severe hunger pangs.²⁸

Throughout the day, the miners gave more authority and respect to both Urzúa and Sepúlveda; Gómez was also widely respected for his experience and wisdom. Sepúlveda had started to assign specific tasks to people based on their skills, experience, and mental stability. The miners also began to use the lighting system to simulate day and night, each lasting 12 hours. When the skin of the miners began to develop mold patches and canker sores due to the heat and humidity, Yonni Barrios

volunteered as the group's medical advisor. Although not a doctor, he had a passion for medicine and was well-read on various illnesses, especially those that his family members had endured.²⁹

Challenges above Ground: Days 2–5

Mining Minister Golborne arrived at San José on August 7, 2010. He found the owners of the mine in shock, overwhelmed by the scale of the accident. "I arrived around 2–3 a.m. at the mine and then I saw the human drama that we had. At that moment, all the families were there . . . there was no trust, there was no information, [and] nobody knew what was going on."³⁰ He added:

The main problem was with the families. They were really upset, sad, and mainly they didn't have trust that anybody could help them and they were fearing that the company, [and] the government were lying to them. I had to start trying to establish with them a relationship based on trust and initially trying to avoid the responsibility of the whole operation because according to our legislation, we have no right to interfere in that process. The responsibility is on the shoulders of the company.³¹

On August 7, Piñera decided to go to San José. Golborne recalled, "Politically speaking, this was not something advisable to do. My personal opinion I remember when he was traveling to Chile was don't come here, I mean go directly to Santiago. I will go there [to San José] and keep you informed about what is going on here, but don't come here because you will get personally involved in this."³²

Nevertheless, Piñera traveled to San José and met with a small group of family members because "to face 300 or 400 people that were in the middle of such suffering was too complicated,"³³ explained Golborne. Piñera committed the government to putting all its efforts toward the rescue, and Golborne later recalled, "In that moment I felt empowered to take control really."³⁴ Golborne, who had previously been CEO of Cencosud, Chile's largest retail chain, explained, "I [was] not knowledgeable in mining . . . what I [did] know [was] how to manage challenging projects, lead people, build teams and provide the necessary resources."³⁵ Meanwhile, Piñera turned to the highest executives at the state-run Codelco to provide a technical leader for the search-and-rescue operation.³⁶

Self-Dispatched Responders at San José

As news of the cave-in spread, the Chilean mining community began to mobilize, sending personnel and equipment to San José. Among them was Walter Véliz, general manager of geology and in charge of drilling and probing at BHP Escondida. On August 8, Véliz had received a call from BHP Escondida's VP of Safety, Jorge Pino, to report to San José to see what the company could do to help. Véliz took Marcos Bermúdez and Nicolás Cruz with him for an initial diagnosis. Bermúdez, a mining engineer and superintendent of drilling and operations at BHP Escondida, had excellent planning skills and a thorough knowledge of drilling. Trained in what he called "adaptive leadership," Bermúdez believed in matching technical soundness with clear goal-setting and a strong team. Cruz, a geology expert at Escondida, had over 25 years of experience. He was also trained in negotiations and team management in tough situations such as workers' strikes.³⁷

Véliz, Bermúdez, and Cruz decided to go to San José with a support staff, drilling machinery, and equipment. They requested three drilling machines, four trucks, a bus, and about 45 support and operating staff members. Upon arrival, they found a disorganized crowd of hundreds of people, but no one seemed to be in charge. They worked through the crowd to talk to the mine's leadership and found them overwhelmed and without a response strategy.³⁸

As Véliz, Cruz, and Bermúdez looked for familiar faces, they saw José Toro, a geologist from Codelco. Toro was speaking with the mine's geologists. Véliz, Cruz, and Bermúdez joined these conversations and learned that a massive rock, twice as hard as granite, had blocked the mine entrance, just as a cork would seal a bottle. They thought that if the miners followed the emergency protocol they would be at the refuge, 700 meters underground. By drilling a small borehole, 15 centimeters in diameter, they could transport oxygen and food to the miners. Because oxygen- and food-supply holes might eventually be needed to sustain the miners till they were rescued, the men decided to begin drilling. They obtained outdated tunnel maps and a rough drilling plan from the mine leadership. Six drilling spots were identified, and the site soon filled with drilling equipment. With inaccurate maps of the circuitous tunnels swirling underground, drilling would be an inexact science.³⁹

Breaking New Ground: Technical Challenges

The depth of the refuge was discouraging. Available drills had a precision of about 5%, which meant that at a depth of 700 meters, the drill could hit anywhere in a base area of 3,850 square meters. As the refuge was only 50 square meters, the chance that any given drill hole would hit the refuge was just over 1 in 80—and that assumed accurate targeting at the center of the refuge when drilling began at the surface (see **Exhibit 3**). The poorly mapped, snake-like tunnels inside the mine complicated matters further. Additionally, drillers had to set their equipment off to the side and drill at an angle to avoid pressure on the mine head.⁴⁰

While early drilling attempts failed to locate the miners, they revealed some features of the mine and the fallen rock that were not obvious. The fallen rock trapped water and sediments, increasing drill deviations and further hampering drill precision. Moreover, in routine drilling operations, precision was measured after a hole was completely drilled. Here, measurements would have to be made every few hours to promptly discard holes that deviated too much.⁴¹

Managing the Search Effort: Strategic Challenges

When Piñera contacted Codelco, executives selected André Sougarret to lead the rescue. Known for his calm temper and composure, 46-year-old Sougarret was an engineer with over 20 years of experience in mining, an underground mine specialist, and a manager at Codelco's El Teniente mine. With over 2,400 kilometers of tunnels and a 15,000-person workforce, El-Teniente was the world's largest underground mine. "André has remarkable technical competence and is a man with a strategic view. He has a lot of patience, assertiveness, an exceptional ability to listen and reach conclusions after listening to all sides, and a tendency to speak frankly with everyone whether they are above or below his authority," explained Ricardo Alvarez, a senior Codelco executive who recommended Sougarret to lead in the crisis.⁴²

Alvarez, who had worked for over a decade to develop a teamwork culture among Codelco employees, put together a support team for Sougarret. "We wanted to send André with as much support in the beginning, which, if not needed, we could pull back. But we didn't want him to get there and waste time calling us for more support," noted Alvarez. Sougarret was supported by 32 people from Codelco, including staff for food and camp provisions, two highly experienced mine superintendents, a communications expert to guide interactions with the media, and René Aguilar, a psychologist known for his stellar communication skills, who had over 10 years of experience in risk and human resource management in the mining industry.⁴³

On the morning of August 9, Sougarret was asked to come to La Moneda, the presidential palace in Santiago. After a 90-minute car drive from his home to La Moneda, Sougarret was escorted to the airport, where he boarded the presidential jet to San José. During the flight, Piñera asked Sougarret to develop a plan to rescue the miners and gave him his full support. At San José, Piñera introduced Sougarret to the families and press as the leader of the operation.⁴⁴

Sougarret first met with his support team from Codelco. Sougarret, Aguilar, and the Codelco mine superintendents knew each other well and had undergone leadership and team-building training together over the course of many years. They decided that Aguilar would oversee the nontechnical aspects of the operation while Sougarret would focus on the technical aspects. To learn more about the situation, Sougarret and Aguilar conversed with mine owners and workers, experts, and heads of the drilling companies on-site and concluded that, given the resources at the refuge, the miners could survive up to a month. They also observed that the simultaneous drilling efforts lacked a coordinated strategy. To clear the drilling site, they established a drilling perimeter within which only people with technical expertise were allowed.⁴⁵

Organizing Search Efforts

Sougarret had intended to work through the mine tunnels, but the mine's instability rendered this option unviable. Even though it was not his expertise, he concluded that drilling would have to be the key approach and decided to focus on coordinating the drilling efforts; he thought some efforts could be faster but less accurate, while others could be relatively slower, with more room for course correction, yielding an overall balanced portfolio of search efforts.⁴⁶

Noticing Véliz's credibility on-site, Sougarret appointed him in charge of all drilling efforts. Véliz now had direct access to Sougarret and full authority over the drilling operations. Véliz put Cruz in charge of drilling operations and data analysis. He put Bermúdez in charge of ground operations, logistics, and maintaining collaboration among the workers. In turn, Bermúdez engaged in what he described as "consultative leadership," in which he explained the rationale of every decision to his workers to promote buy-in and input during execution. Bermúdez was given direct access to Piñera's aides, who could expedite delivery of needed resources. "The support we received regarding the tools we needed [spare parts, drill bits] would normally take a few days to arrive, but here the response time was very short—same day in some cases or even just hours," Bermúdez recalled.⁴⁷

Bermúdez, Cruz, and Véliz planned a daily routine: to meet for half an hour every morning and call for a quick meeting whenever necessary. They developed a protocol for transitioning between day and night drill shifts and for routine maintenance of machinery. "The team generated a working structure, which was presented and shared with the larger group and was finally the way we were organized. We worked as a team, that is, we consulted and shared the strategy and, based on this, we defined and made all important decisions," said Bermúdez.⁴⁸

Managing External Communication

Golborne assigned Aguilar to communicate regularly with the families.⁴⁹ Aguilar also had to protect the search team from media exposure. "We wanted them [drillers, engineers, and geologists] to drill and work without any noise and distractions," noted Aguilar. To keep press and family aware of progress, Sougarret and Aguilar held two separate briefings every day to avoid mixing both parties' concerns. The first meeting was with families at 10 a.m., the second with the press at noon. Critical, in their view, was a consistent message. Aguilar knew families and press would communicate, and mixed messages could "very quickly damage people's trust in us."⁵⁰ Golborne

explained, “The decision of transparency was a conscious decision made early on. There were too many people, we could not hide anything . . . If we did, we would lose their confidence.”⁵¹

In initial meetings, Sougarret and Aguilar established the daily communication schedule and outlined their respective roles, expertise, intentions, and commitment to the operation. “We told them, we are workers in a mine too and dedicated 100% to bringing your families and loved ones home,” recalled Aguilar. But they were also realistic. He added, “The facts are what they are, and in a situation like this you really have to be patient and explain to people what is happening, what the problem is, what solutions we are thinking about, and why they are good. You cannot ignore people’s concerns and emotions, but you have to tell the truth in an understanding way to earn their trust.”⁵² But maintaining an honest tone met with continuous pressure. Golborne noted, “Every day I had to deal with people saying that we were doing the wrong thing . . . Now it is a little funny, but a mentalist was telling us about a guy with broken legs at the entrance of the mine asking to be rescued . . . [and] you have to manage all kinds of pressures.”⁵³

Managing Internal Communication

Sougarret briefed Golborne every day by email and once every three days in person. He also had a direct line to Piñera, who wanted regular updates and was ready to mobilize his network as needed. With search teams on-site, Sougarret and Aguilar developed an operating routine. Daily at 9 a.m. there was a coordination meeting with the heads of all drilling and geology teams; they reviewed commitments made the day before, discussed next steps, and identified resources needed by the drilling team. After the coordination meeting and daily briefing with the families and press, Sougarret and Aguilar spent time in the field, listening to concerns, asking questions, and answering queries.⁵⁴

Golborne and Sougarret worked together to create collaboration and openness on the search team. Sougarret recalled, “There was no super leader who had all the answers . . . I liked the honesty with which we were working . . . I could feel we were playing with our cards open on the table.”⁵⁵ Without micromanaging, Golborne asked numerous questions to probe the rationale behind technical actions: “I did what I normally do, let the experts talk.”⁵⁶ He also served as an arbiter on unresolved issues.⁵⁷

Sougarret and Aguilar communicated many times a day, including every morning before the coordination meeting and every evening. These conversations included frequent discussion of values. “Values are really important in a situation like this. For me, I was there to save the miners and be of help to others,” said Sougarret. Aguilar noted, “André [Sougarret] and I talked a lot about our values . . . All we wanted to do was save the miners and help in whatever way we can . . . That was our job, to help. If your values are clear, then it is easier to stay focused.” All involved in the drill efforts appeared impressed by the leadership of Golborne, Sougarret, and Aguilar. They liked, respected, and trusted them, and felt that they kept everyone highly focused on saving the miners.⁵⁸

Managing Stress, Anxiety, and Blame

Aguilar sought to inspire collaboration among drilling companies that were usually competitors. As he recalled, “It was important from day one to keep reminding everyone that we are here for one purpose only—rescue [the] trapped miners as soon as possible. We don’t have time for fighting, competing, and blaming because you are risking lives by doing that.” Aguilar regularly checked “how people were emotionally coping with the situation,” as he later put it. He emphasized that “this was a pressure environment, and when someone looked low and frustrated we would try to ask each

other, hey, are you okay? Is your family okay? Why don't you take some rest? These are small things, but they help create a sense that we are there for each other."⁵⁹

Sougarret and Aguilar welcomed input from San José mine employees. "They knew the site well, offered their support by moving trucks or recalling tunnel layouts, and we welcomed them because no one had all the information, but everyone knew something that could save the miners," recalled Aguilar. The press continued to raise questions about reprimanding the mine owners, but Golborne urged them to focus on finding the miners; sorting out the causes of the cave-in could wait.⁶⁰

Below Ground: Days 6–13

On August 10, a coordinated drilling effort commenced, sending a surge of hope to family members camping nearby in what would later be called Campo Esperanza (or Camp Hope). The sound of drilling led to an eruption of joy and hope underground.. However, two miners were aware of the imprecision of this kind of drilling and recognized that it would take a near miracle to accurately drill through such hard rock and such depth. Their initial jubilation soon became clouded by doubt and fear.⁶¹

As the drill sound remained distant, on day 9 the miners voted to reduce food rations to one meal every 36 hours. Having lost a lot of weight, they nevertheless understood the need to continue with minimum caloric intake. As the days wore on, they began to discuss what awaited them if rescued. Franklin Lobos, a former soccer star in Chile, shared his dreams of opening a nonprofit foundation to improve the conditions of workers. Ariel Ticona anticipated the upcoming birth of a child. Twenty-five of the miners lived very close to the San José mine and had many stories in common. As the miners shared their stories and expectations, they decided to name themselves "the 33 Musketeers."⁶²

With the approaching drill sound as a backdrop and continuous hunger pangs in the foreground, the miners wrote letters and notes to loved ones. They developed a protocol in case of a drill breakthrough: they would use a bulldozer to clear debris from the drilling, they would paint the drill shaft with orange spray paint, and they would attach their letters to the drill tip.⁶³

Above Ground Search Operations: Days 6–14

The drills worked around the clock, stopping daily at 8 a.m. and 8 p.m. for maintenance. Sougarret and Aguilar continued to coordinate the drilling teams. They frequently reminded the teams of their common purpose: finding and rescuing the miners. When extra drilling parts and equipment were needed, Sougarret listened to the rationale for the request and placed expedited orders. The relationship between Sougarret and Véliz strengthened as Sougarret provided strategic oversight and Véliz (along with Cruz and Bermúdez) took charge of the technical details of the drilling efforts.⁶⁴

A New Technology for Measurement

On August 11, Felipe Matthews, a geologist with experience as a manager for drilling operations, arrived at the site. Four years earlier, he had founded a company, Geoatacama, to commercialize a technology for measuring drilling trajectories with greater precision. A gyroscope-like probe was inserted into a drilling hole and, regardless of the position of the mounted drill, the probe could find the vertical by virtue of the angular momentum of its spinning mass. The technology was simple but

not commonly used in mining. Matthews recalled, “I knew I had something unique to offer because drillers are not geologists and geologists cannot drill. I could work with both, and I also had this new technology to measure perforation trajectory that was more precise than mainstream technology.”⁶⁵

After the cave-in, Matthews reached out to Véliz and Cruz, who had attended the same university he did. The use of Matthews’s technology was quickly approved by Sougarret, after input from Véliz and Cruz. However, when Matthews made measurements on drill holes, they were inconsistent with those from the other companies on-site. Cruz called for an accuracy test: one person from each company was to go to an abandoned pipe on-site and measure its profile. A high-precision GPS was then used to measure the profile of the pipe. Matthews’s equipment was found to be the most accurate. Thereafter, he was put in charge of measuring the accuracy of all drilling profiles.⁶⁶

Planning Ahead

Parallel to drilling attempts, rescue plans were developed. Piñera had publicly declared that the trapped miners were to be rescued dead or alive; if dead, the bodies of the miners would be recovered and returned to their families for proper burial. Additionally, Piñera requested the development of multiple rescue options. To do so, an off-site team of consultants was formed. Fernando Silva, an independent consultant on this team, commented, “In the beginning we didn’t know if the miners were alive. . . . But Piñera communicated with us and also publicly announced that we would rescue the miners, dead or alive. This gave us a green signal to fully commit and develop rescue plans.”⁶⁷

Operating 500 kilometers from San José at the Codelco headquarters in Santiago, the off-site team included people with vast experience in mining, deep knowledge of the latest mining technologies, and risk management experience. For instance, Silva had over 20 years of experience in drilling design, construction, and operations, and was also an expert on fire protection safety code. Members of the off-site team conducted follow-up conversations with the local and international companies that sent rescue proposals to Chile’s Ministry of Mining website. They evaluated each proposal on criteria such as availability, cost, service schedule, maintenance and logistics, and state of the technology (in particular, if it had been used in Chile and was viable for these conditions). These evaluations were discussed with Golborne.⁶⁸ Silva noted:

We did a lot of conceptual work for the rescue away from the site. We studied a lot of options. For example, there was a mine nearby and there was a suggestion that a two-kilometer tunnel could be made in 16 months. We said no to that option because it was too slow. We said no to building a ramp because that would take 14 months. Saying no to options was not hard. It was harder to propose a workable alternative.⁶⁹

Meanwhile, Sougarret and Aguilar anticipated the future needs of the rescue operation by requesting research assistance on specific subjects, either calling on the off-site consulting team or government aides. For instance, they requested research on the type of piping to be used to establish communication lines with the refuge and to lower cameras to scan the space. They explored the use of exploratory robots with attached cameras in case the initial lowering of cameras did not show any signs of miners. Another expert contacted was Miguel Fortt, a physics professor at Universidad del Mar in Chile and a former miner with extensive experience in rescue efforts for mining accidents. He suggested that the miners could be reached via a series of PVC piping tubes. This piping could be used to deliver food and water until the miners were rescued. Testing on this plan began shortly thereafter.⁷⁰ Aguilar recalled, “We planned and thought through as many scenarios as we could, and

in meetings for every scenario we asked questions about, okay, tell me, what is the best, acceptable, and most negative outcome, and if it happens how will we respond?"⁷¹

Going 3-D with Drill Profiles

Meanwhile, Marcelo Arancibia, VP for South America at Maptek, an Australian software company, volunteered his company's 3-D mapping technology. Véliz and Cruz decided that Maptek's software would help in visualizing drill profiles; if the probe from Matthews's device was connected to Maptek's 3-D plotting software, the trajectory of a given drill hole could be graphed and the visual image produced could provide drillers with real-time feedback.⁷²

Sandra Jara, a geologist from Maptek, was sent to San José to assist. Matthews brought drill profile measurements to Jara, who made a visual profile of each drilling effort and showed it to the drilling supervisor and operator. If a profile had deviated, the team discussed course correction strategies. This approach was a radical departure from usual practices, as Matthews explained:

Under routine procedures, drilling accuracy is evaluated after the perforation is done and trajectory is measured. If the perforation is within the limits defined in the contract, the drilling company gets paid for its service. If there are differences, the drilling company can incur fines that could even lead to no pay whatsoever. The concept applied in this occasion—that is, to measure the perforation at regular intervals in order to make corrections—is very different from how drillers usually work.⁷³

This new process of continuous feedback on the drill profiles was beneficial but frustrating, as it brought frequent bad news about failed attempts. Meanwhile, the top leadership continued to emphasize the need for speed along with accuracy. Golborne came to the work site regularly to remind everyone of the scenario in which they would reach the refuge but not fast enough to matter. Drillers felt that Golborne's presence demonstrated the government's commitment to the rescue and helped them stay focused and acutely mindful of the time pressure and importance of their task.⁷⁴

Searching for Patterns in Drill Profile Data

Drillers knew that deviations during drilling depended on the rotational speed and weight of the drill: increasing rotational speed shifted the profile to the right, while the weight of the drill bars altered the vertical profile. The drill profile data collected thus far helped clarify the extent of drill shift and the role of speed and weight in the shifts. Examining the data, Cruz had an epiphany: "If we are to reach the refuge we will have to start drilling in a direction quite different from the refuge because there was an inevitable curve to every drill effort. It is like making a soccer goal at an angle where the curvature eventually brings the ball to the net." Initially Cruz's suggestion to drill in a direction away from the refuge seemed counterproductive to others. The metaphor of a soccer goal helped, as did Cruz's patience and clarity in explaining his conclusions. The drillers followed Cruz's strategy, and on day 14 one of the drills passed the 600-meter mark and seemed on course to the refuge. Anticipation and hope buoyed everyone above ground.⁷⁵

Below Ground: Days 14–16

The trapped miners awaited the long-anticipated drill breakthrough. Their reaction protocol was well rehearsed, and with excitement, they followed the sound of the approaching drill. With dawning fear, they realized the drill had passed the lowest tunnel and continued onward, stopping below

them. The miners fell silent as the shock and the implications sank in. They had hoped, prayed, and prepared for this day, working through hunger and painful letter-writing to loved ones. Finally, one of the miners, Edison Peña, screamed in despair. Most did not know what to do next. To give up? To hope for another drill attempt? Henríquez urged all to maintain their faith and pray. The miners would recall this as their darkest hour as they hoped in vain through the unbearable confinement. Many miners began to write good-bye letters. The following day, with barely any food left, cannibalism began to loom as an inevitable option; the men voted to lower rations to one bite of food every three days. With barely any strength left even to go to the bathroom, most just laid down.⁷⁶

Above Ground: Another Setback

The miss was a major setback. Local newspapers included headlines such as “El guatazo de los técnicos,” or “the technicians screw up.”⁷⁷ A deeply disappointed Sougarret communicated the news to families who now pleaded that the local miners be allowed to pickax through the mine entrance. Sougarret advised government officials not to approve such efforts as they may cause another accident. Piñera considered approving these actions if they posed no clear harm, but Sougarret spoke with Piñera and Golborne directly against this option until they conceded. Family members protested and police officers were deployed to control the crowd. “It was an extremely difficult position for me, and I will never forget when people said, ‘imagine your own loved ones trapped.’ It was one of the toughest decisions for me and emotionally very difficult,” reflected Sougarret.⁷⁸

Day 17

By day 17, many of the miners felt they could not survive much longer. They heard another drill approach but did not dare to hope again. The drillers had learned more about the tunnel layout from their past failed attempt and were hopeful that a breakthrough could be made by 6 a.m. This hole was being drilled at a faster speed (around 240 meters per day), but it was difficult to correct its course in case of deviations. At 5:50 a.m. the drill broke through a tunnel near the refuge.⁷⁹

The miners were, at first, silent in disbelief and then overcome with joy. They quickly gathered a can of spray paint and began tapping on the drill shaft. Sougarret used a stethoscope to try to amplify any tapping from trapped miners and thought he sensed signs of life. After about an hour of tapping back and forth, Eduardo Hurtado, the drill operator, began the tortuous, three-hour task of retracting the 700-meter, 20-metric-ton metallic drill shaft. Upon its retrieval, the shaft was marked with orange spray paint and carried many handwritten notes, one of which famously read, “Estámos bien en el refugio, los 33” (“We are fine in the shelter, the 33 of us”).⁸⁰

Piñera arrived at the San José site by noon. As he made an official announcement, jubilation erupted, and for hours people at Camp Hope hugged one another, cried, laughed, waved the Chilean flag, and honked their car horns. The international media was stunned.⁸¹

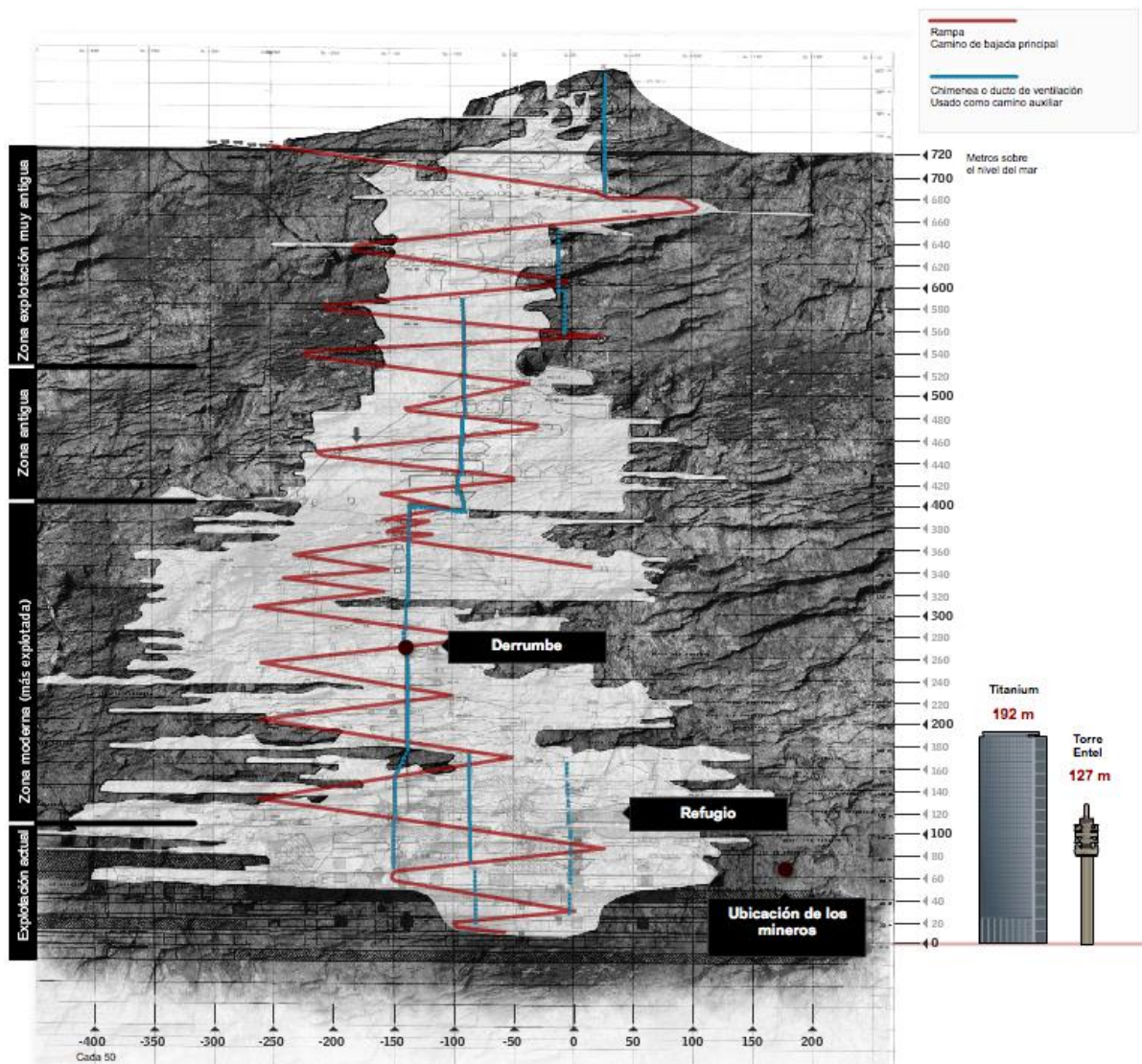
The search workers had finally finished their determined race against time. Now Sougarret and Aguilar tried to focus them on the rescue options. Nothing was certain yet. Food, water, medical care, communications, and much more was needed to be transported through the breakthrough shaft.⁸² The miners had been reached, but not rescued. The team had achieved a breakthrough, but the crisis was far from over. Golborne recalled, “17 days of only frustration . . . That frustration was finally over . . . After that we saw the light at the end of the tunnel. Time was of the essence.”⁸³

Exhibit 1 Copiapó, Location of the San José Mine



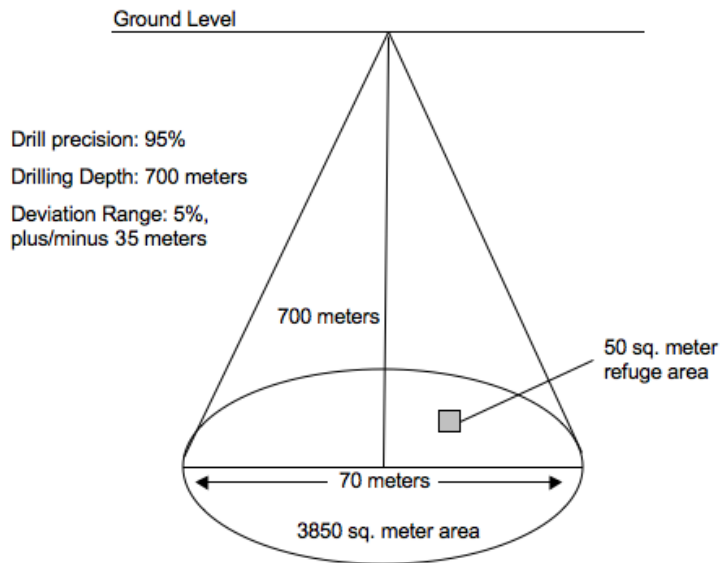
Source: University of Texas Libraries, University of Texas at Austin, Perry Castañeda Map Collection, <http://www.lib.utexas.edu/maps/chile.html>, accessed October 17, 2011.

Exhibit 2 Structure of the San José Mine

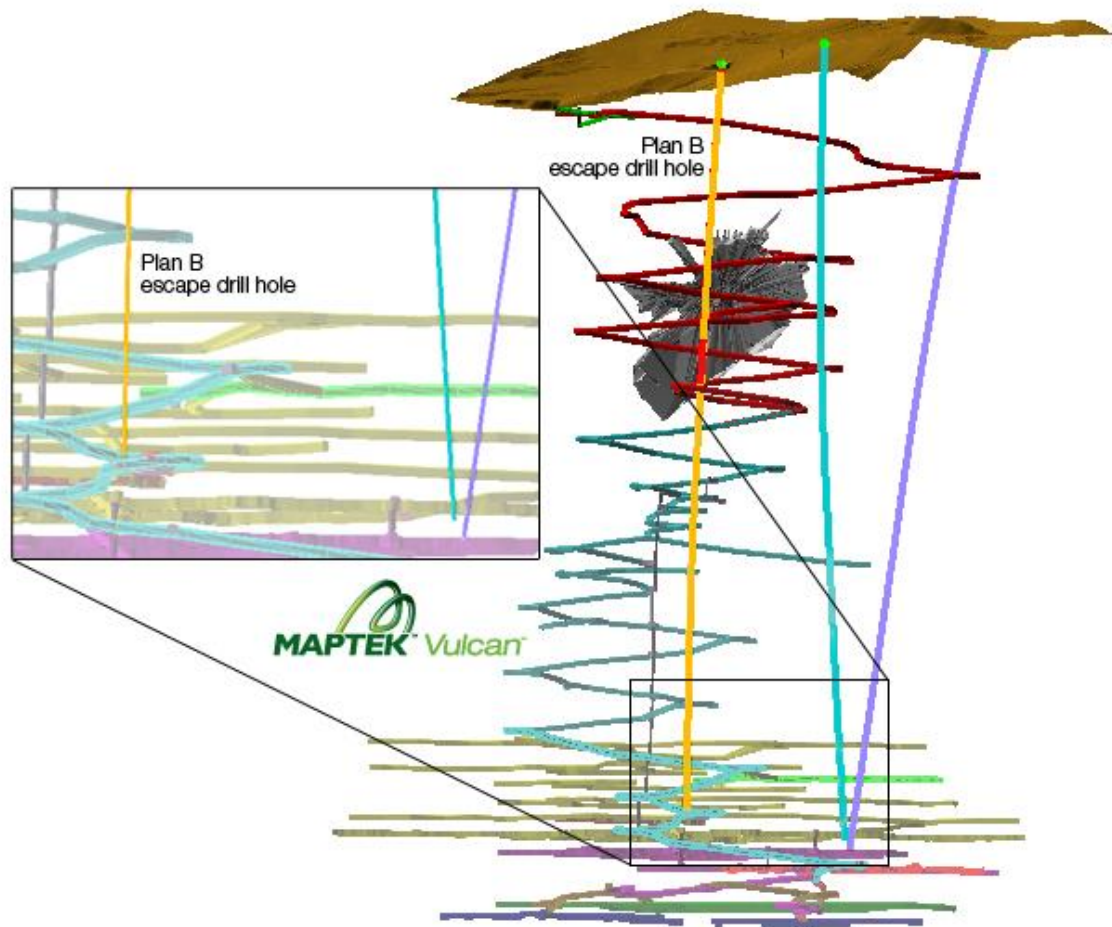


Source: El Mercurio, http://www.emol.com/especiales/2010/coberturas-especiales/rescate_mineros/la_mina.asp, accessed October 14, 2011.

Exhibit 3 The Drilling Challenge



Source: Casewriter, based on notes from interviews.

Exhibit 4 Continuous Drill Profiling by Vulcan 3-D Software from Maptek

Source: Maptek, http://www.maptek.com/news/Chile_rescue_images.html, accessed October 16, 2011.

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