Diamond drilling plays its part in Chile mine rescue

They say it's always good to have a Plan B, in case Plan A fails. The recent rescue operations at the San José copper and gold mine in Chile went one step further with a Plan C: three separate drill rigs were used simultaneously in a race against time to tunnel down 700 m to rescue the trapped men. 33 days after it had started drilling, the Plan B drill bit, fitted with polycrystalline diamond compacts (PDC), broke through the roof of the mine tunnel and four days later, all 33 men had been safely removed from the mine. This report by ***Martin Jennings.***

On 5 August 2010, a cave-in occurred at the San José copper-gold mine in the Atacama Desert near Copiapó, Chile. The accident left 33 men trapped 700 m below ground, with all escape routes blocked off and only limited supplies of food and water to sustain them. What happened next was undoubtedly the greatest mine rescue operation ever undertaken.

The miners survived underground for a record 69 days, while three separate drilling operations were mounted to gain access to them. Finally, on 13 October, watched live on TV by an estimated audience in the billions, all 33 were rescued and brought to the surface, safe and relatively unharmed.

After the last trapped miner was winched to the surface, the rescue workers held up a sign stating "Misión cumplida Chile" (Mission accomplished Chile). The total cost of the rescue operation was estimated at US$20 million, a third covered by private donations with the rest coming from state-owned mining corporation, Codelco and the government itself.

The accident

The workings of the San José mine are reached by a long sloping, spiral roadway with many irregular turns, and not by a vertical mineshaft. The cave-in occurred roughly two thirds of the way down the mine. At the time, there were two groups of workers in the mine; one was near the entrance and escaped immediately without incident. Another group of 33 men, however, was deep inside the mine and their roadway exit from the mine was completely blocked off. The rock fall caused a thick dust cloud that blinded the miners for up to six hours and caused lingering eye irritation and burning.

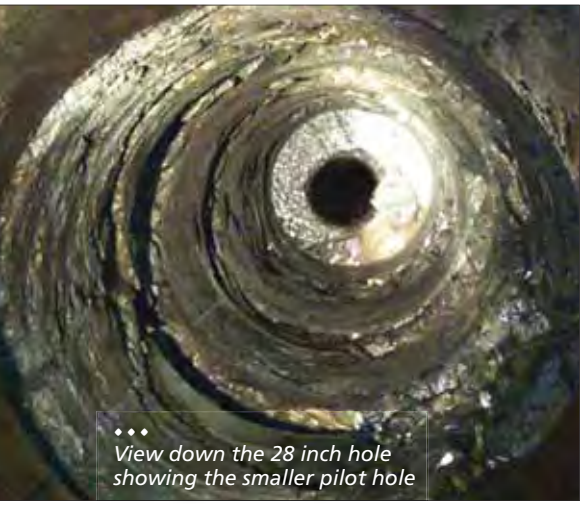
The trapped miners initially tried to escape through a ventilation shaft system, but the ladders required by mining safety codes were missing. (The shafts later became inaccessible to rescue teams due to subsequent ground movements). The company had failed to install the escape ladders that had been stipulated as a condition of restarting operations after authorities had closed the accident-plagued 100-year-old mine.

The shift supervisor, Luis Urzúa, recognizing the gravity of the situation and the difficulty involved in any rescue attempt, gathered his men in a secure room and organized the men and meagre resources for long-term survival. Mine rescuers attempted to bypass the rockfall at the main entryway through alternative passages but each route was blocked by fallen rock or threatened by ongoing rock movement.

A second collapse occurred at the mine on 7 August when rescuers were using heavy machinery while trying to gain access via a ventilation shaft. Because of fears that any further attempts to reach the trapped miners through existing shafts would cause further geological movement within the mine, the rescue team had to find alternative means to rescue the men. But first they had to find them.

Exploratory boreholes

It was decided to make a series of exploratory boreholes to find out if there were any survivors. Percussion drills were used to make eight exploratory boreholes about 15 cm in diameter. The rescue effort was complicated by out-of-date



View down the 28 inch hole showing the smaller pilot hole

CR120 bit hole opener goes into the ground

Timeline of events

5 August 2010 –
Rock-fall at the San José mine in Atacama Desert in northern Chile leaves 33 gold and copper miners trapped 2,300 ft below ground.

7 August 2010 –
Second collapse hampers rescue efforts and blocks access to lower parts of the mine. Rescuers begin drilling boreholes to send down listening devices.

22 August 2010 –
17 days after the first collapse, a note is found attached to one of the probes, saying, "All 33 of us are well inside the shelter." The miners were in a shelter having lunch when the first collapse occurred, and had survived on rations. Food, medical supplies, clothes and bedding began to be sent down the borehole.

maps of the mine shafts and several boreholes drifting off-target because of the extreme drilling depth and the notoriously hard rock that caused the drills to drift off-line.

On the morning of 22 August, the eighth borehole, drilled by TerraServices, using a Schramm T685 WS drill drilling a 14 cm hole, broke through. It reached a ramp, at 688 m underground, about 20 m from an emergency shelter room where it was hoped that the miners may have taken refuge. The miners had heard the drills approaching for days and had prepared notes, which they attached to the tip of the drill with insulation tape when it poked into their space. Though the drilling engineers had thought they heard tapping on the drill tip, they were still surprised to discover the notes when the drill bit was pulled out, as the miners had already survived for 17 days, much longer than anyone had expected.

That afternoon, Chile's President Sebastián Piñera showed the media a note written on a piece of paper with a red marker that confirmed the miners were alive. The note read: "Estamos bien en el refugio los 33." (We are alright in the shelter, the 33). Those words became an emblem of the miners' survival and the rescue effort, appearing on websites, banners and t-shirts. Hours later, video cameras sent down the borehole made contact with the trapped miners, capturing the first grainy, black-and-white, silent images of the men.

Rescue plans

Several types of drilling equipment and different access strategies to reach the miners with escape boreholes were tried in parallel, divided into what became known as Plans A, B and C:

- Plan A started drilling on 30 August and had a target drill depth of 702 m at a 90° drilling angle.
- Plan B started drilling on 5 September and had a target drill depth of 638 m at an 82° drilling angle.
- Plan C started drilling on 19 September and had a target drill depth of 597 m at an 85° drilling angle.

28 inch LP drill being rigged up for action

30 August 2010 – *First attempt to drill a hole to rescue the men,* ***Plan A,*** *begins.*

5 September 2010 – ***Plan B*** *drilling begins.*

19 September 2010 – ***Plan C*** *drilling begins.*

24 September 2010 – *Miners had now been trapped underground for 50 days, longer than anyone else in history.*

9 October 2010 – ***Plan B*** *drill breaks through to the miners' workshop.*

11 October 2010 – *Fénix 2 rescue capsule is tested to ensure that it can pass up and down the newly completed shaft.*

The two Center Rock drills that made it all the way down: 5 and half inch CR120 bit hole opener (top) and 26 inch LP drill (bottom)

Plan A

Plan A used an Australian built Strata 950 model raise borer type drilling rig often used to create circular shafts between two levels of a mine without the use of explosives. The drill, which was provided by South African mining company Murray & Roberts, had just finished a shaft for Codelco's Andina copper mine in Chile and was immediately transferred to San José. The Strata 950 was the first of the three drills to begin boring an escape shaft.

In traditional raise boring operations, mining companies use a drilling technique known as up-reaming. Normally, this type of rig first drills a small pilot hole downward, after which large machine cutters are attached to the drill which is sticking out the bottom of the pilot hole. The massive cutters are pulled up as they grind through thick rock, boring along the pilot hole. In this case however, since the space below was blocked and the raise bore bit could not be attached from underground, the rig was modified to widen the hole from above.

If the pilot hole had been completed, further drilling would have caused rock debris to fall down the hole, and the miners would have had to remove the debris.

Plan B

Plan B involved a Schramm Inc T130XD air core drill owned by Geotec S.A. (a Chilean-American joint venture drilling company) that was chosen by Drillers Supply SA (the general contractor of Plan B) to widen one of the three 5.5 in (14 cm) boreholes that were already keeping the miners supplied with palomas. These drills are used to drill top holes for the oil and gas industry and for mineral exploration and water wells

Drillers Supply SA are a distributor for Center Rock Inc, a Pennsylvania, USA based drilling supply company that specialises in Down-The-Hole Drilling hammers (DHD). Center Rock's president and CEO, Brandon Fisher, and Richard Soppe, manager of the company's DHD sales & product development, knew that the company's technology could help aid in the rescue of the 33 miners, and return them to their families long before the projected date, which at that time was as far away as Christmas,

A plan was developed jointly by Center Rock and Drillers Supply International, owner Greg Hall, based in Cypress, Texas, and Drillers Supply SA owner Mijali Proestakis, from Antofagosta, Chile. Drillers Supply played an integral part in convincing the Chilean

The Center Rock and Drillers Supply teams with the two drills that broke through into the mine

12 October 2010 – *Rescue begins at 23:20 CLDT.*

13 October 2010 – *Last of the 33 miners is brought up to the surface and rescued, at 21:56 CLDT.*

14 October 2010 – *First 3 miners released from hospital.*

19 October 2010 – *Last of the 33 miners released from hospital.*

officials to accept their plan. Their team virtually eliminated the language barriers. Igor Proestakis, a Field Engineer for Drillers Supply, picked the Center Rock crew up from the airport when they arrived in Chile, dropped them off when they left, and every day in between. Igor, along with Greg and Mijali were on the rescue site the entire time with Center Rock. This was the creation of what the world came to know as "Plan B".

On September 4, 2010, Brandon Fisher and Richard Soppe arrived at the site of the rescue. Layne Christensen, a Kansas City, Kansas based company, sent in two drillers, Jeff Hart and Matt Staffel, who had been drilling water wells in Afghanistan to support US troops stationed there. Helping the drillers, were two rig hands, Doug Reeves and Jorge Herrera, also working for Layne. About two weeks after the collapse, Layne's Latin American affiliate Geotec Boyles Bros. brought in the Schramm T130XD drill.

The Schramm was directed to bore toward the workshop, a space that was accessible by the miners. The initial hole that discovered that the miners were alive was 5.5" in diameter. Center Rock would use their DTH (down-the-hole) drilling technology to open the 5.5" hole to 12". This was successful using Center Rock's CR120 hammer with 12" x 5.375" pilot hole opener bit. The next step was to drill a hole big enough for the rescue capsule. Center Rock started drilling with a 28" LP drill, then reduced to a 26" LP drill. This was the drill that would eventually make it all the way down. Center Rock's Low Profile (LP) drill is a pneumatic-based drilling system that in this instance used four or five hammers instead of just one. Acting like a jackhammer, each hammer steadily pounds the bit to crush the rock as the drill rotates. The percussion-technology hammer drill could drill at more than 40 m (130 ft) a day.

Originally the idea was that the compressed air would circulate the cuttings upward and away from the bits. Due to the weight of the drill pipe with inner RC tubes, there was concern that this reverse circulation method could not be carried through safely. Center Rock introduced the idea to the Chilean Mining Agency to let the cuttings fall through to the bottom. The proposal was accepted and the miners worked day in and day out to remove the cuttings from that area.

An estimated 500 kg (1,100 lb) of cuttings fell down every hour. Working in shifts 24 hours a day, the miners had to keep the passage clear with the industrial-sized battery-powered sweepers, shovels and wheel barrows trapped in the mine with them. The miners had to remove on their own a total mass of drilling cuttings estimated at up to 700 metric tons, considering a borehole diameter of 70 cm (28 in), with a depth of 688 metres (2,257 ft) and a rock density of 2.7 tonnes/cubic metre.

Center Rock's CR series of hammer drills

Plan C

Plan C was a powerful Canadian built RIG 421 oil drilling rig operated by Calgary-based Precision Drilling Corporation and was the last drill to become involved in the rescue process; it began drilling on Sept. 19. The rig is a special drill used for oil and gas drilling that could drill a wide enough escape shaft in a single pass without a pilot hole. RIG 421 is a Diesel-Electric Triple that was 43 m (141 ft) tall and needed 40 truckloads to bring its pieces from Iquique, Chile to Copiapó. 10,000 cubic metres of rock and gravel were cleared to make a stable platform for it on the rough hillside.

It was chosen for the rescue operation because it can drill large holes deep into the ground and because it works faster than mining drills. Unlike the Strata 950 and the Schramm T-130, the RIG 421 brings debris back up to the surface.

It suffered a setback due to the difficulty of aiming the larger drill at a 2.5 m x 2.5 m target and the hardness of the rock when the drill diverted from its course. The drill then needed to be removed, resized and repositioned, which slowed its progress. "We've drilled wells all around the world. The actual drilling of the hole in the ground isn't that difficult. When you're given a target to aim for it's a little more difficult," said Shaun Robstad, superintendent with Precision Drilling. Many family members of the miners once had high hopes for this Canadian rig, but it had to reduce its drill size and lagged behind.

114 inch drill, part of Center Rock's extensive LP range

PCD domed mining inserts manufactured by MegaDiamond were an important feature of the drill bit design

Drilling results

The widened shaft of Plan B's Schramm T130XD reached the trapped miners at 08:05 on 9 October after a 10 hour stoppage to change the drill-bit.

By this time, the Plan A Strata 950's pilot hole had reached 598 m (1,962 ft) deep (85% – it had not yet started its widened shaft). Plan C's Rig-421, the only machine at the site which drills a shaft wide enough immediately, had reached 372 m (1,220 ft) (62%).

Diamond drilling

A major contributing factor to the speed at which Plan B drilled the rescue shaft was the use of polycrystalline diamond (PCD) inserts in the drill bits. The drill bits contained PCD domed mining inserts manufactured by MegaDiamond, based in Provo, Utah, USA, and now part of the Schlumberger group.

MegaDiamond's domed inserts are available in various grades, which give the optimal combinations of abrasion and impact resistance that are required for mining operations.

In particular, the proprietary insert design incorporates transition layers between the diamond layer and tungsten carbide substrate to improve impact strength and thermal integrity. Those properties were to prove invaluable in these drilling conditions, where the hole was not only deep but also curved. The hard rock itself was so abrasive that it wore out the steel of the drill.

Extraction plans

While the three separate drills pushed forward, rescue teams were creating the capsule that would eventually carry the miners to safety. The diameter of the rescue borehole was 66 cm (26 in), meaning each miner had to have a waistline of no more than 90 cm (35 in) to escape. In order to ensure they were able to fit in the capsule, an exercise regimen for the miners had been implemented.

The steel rescue capsules, named Fénix (Phoenix), were constructed by the Chilean Navy with design help from NASA. The NASA team proposed about 75 design features, including suggestions that the capsule be built so a miner could get himself in and secured easily, be equipped with an oxygen tank, and include technology to cut down on friction while in the shaft. The Chilean Navy incorporated most of NASA's suggestions and produced three rescue pods, named Fénix 1, 2 and 3 respectively. Fénix 1 was presented to journalists and the miners' relatives to try out for size.

The capsule in which the 33 men were rescued was the Fénix 2. The capsule was 54 cm (21 in) in diameter, narrow enough to avoid hitting the sides of the tunnel and with retractable wheels to allow for a smoother ride to the surface. It had an oxygen supply, lighting, video and voice communications, a reinforced roof to protect against rock falls, and an escape hatch with a safety device to allow the miner to lower himself back down if the capsule became stuck.

Schematic of the Fénix 2 rescue capsule

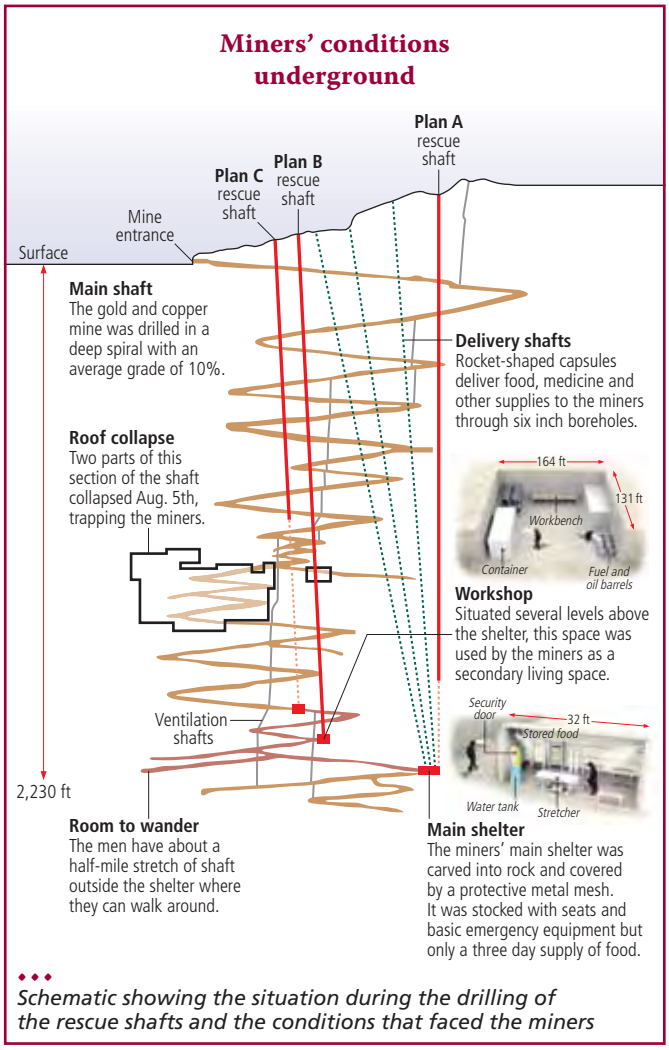
Rescue

The original plan was for the capsule to return to the surface empty after delivering the first rescue worker, to deliver a second rescuer to the mine before bringing the first miner to the surface. However, to avoid delay, rescuers decided to send a miner to the surface in the capsule returning after the first rescuer was sent down. The capsule had completed an "empty" trial run the previous day, stopping just 15 m (49 ft) before the end of the shaft.

The rescue

The first rescuer, Manuel González, descended to the mine and made contact with the men just before midnight on October 12. The capsule was quickly rechecked for safety and, after 15 minutes, the first miner, Florencio Ávalos, began his ascent from the mine; the scene was filmed live from inside the mine and from the surface and broadcast worldwide. The mine's shift supervisor, Luis Urzúa, whose disciplined leadership was credited with keeping the men alive on an emergency food supply during their first 17 days without contact from the outside world, was the last miner to make the journey.

Each transit of the capsule (down or up) was projected to take 15 minutes, for a total time of 33 hours for the entire rescue operation; however, after the capsule's first few transits, it became apparent that the trip might take somewhat less than predicted. In the end, the Fénix 2 made 39 live round trip journeys in just under 24 hours, travelling about 50 km (31 miles) with human cargo.



Schematic showing the situation during the drilling of the rescue shafts and the conditions that faced the miners

Luis Urzúa, after stepping free from the rescuers, greeting his son and then embracing President Piñera said, "I've delivered to you this shift of workers, as we agreed I would." The president replied, "I gladly receive your shift, because you completed your duty, leaving last like a good captain." President Piñera went on to say "You are not the same after this, and Chile won't be the same either."

The rescue operation was a truly international effort. The rescue of the miners involved not only technology, but also the cooperation and resources of companies and individuals from around the world, including Latin America, South Africa, Australia, the United States and Canada. NASA specialists helped develop a sophisticated health agenda. Canada brought in their "Plan C" drill. An Austrian system of cranes and pulleys designed for the rescue capsule eventually pulled the miners to the surface. But overall, it was widely a Chilean-led team and effort. As one NASA specialist said while visiting early on in the rescue, "The Chileans are basically writing the book." ◆

Fénix 2 capsule being lowered into the ground

Drilling carried on 24 hours a day for 33 days

Luis Urzúa, the leader of the trapped miners and the last of the 33 to be lifted to freedom, celebrates with President Piñera