# Geomechanical Challenge at El Soldado

## Integrated Operation

**El Soldado is a tightly integrated operation consisting of an underground and open pit copper mine, a concentrator and an oxide plant. In order to increase production underground, El Soldado introduced a variation to its standard sublevel open stoping mining method in 1983. Six years later, the open pit section of the mine was started, posing an additional complication for the geotechnical and mine design teams. These days, the engineers enjoy the challenge of an underground mine, which features a complex layout and problematic rock conditions with numerous open cavities, irregular orebodies of variable dimensions, and *in situ* stresses that vary in magnitude as well as in orientation. Extraction of the reserves must also follow a sequence that minimizes impacts on the overlying surface operations. A committed user of Atlas Copco drillrigs, the mine is currently re-equipping with Rocket Boomer L2 Cs for development, and Simba M6 Cs for production, all featuring a high level of computerization.**

Atlas Copco ROC L8 crawlers at El Soldado open pit.

In 2002, Anglo American plc agreed to purchase Disputada from Exxon Mobil for US$1.3 billion in cash. This substantially enhanced the quality of Anglo American's base metals portfolio, in addition to offering significant synergies with its other Chilean copper operations: the Doña Inés de Collahuasi and Mantos Blancos mines.

El Soldado mine is located 132 km north-west of Santiago, on the western slopes of the Coastal range, at about 830 m asl. In 2001, El Soldado produced 64,000 t copper in concentrate and 5,000 t copper cathode at an average cash cost of 57 US cents/pound. Reserves at El Soldado are estimated to be 115 million t grading 1.0% copper.

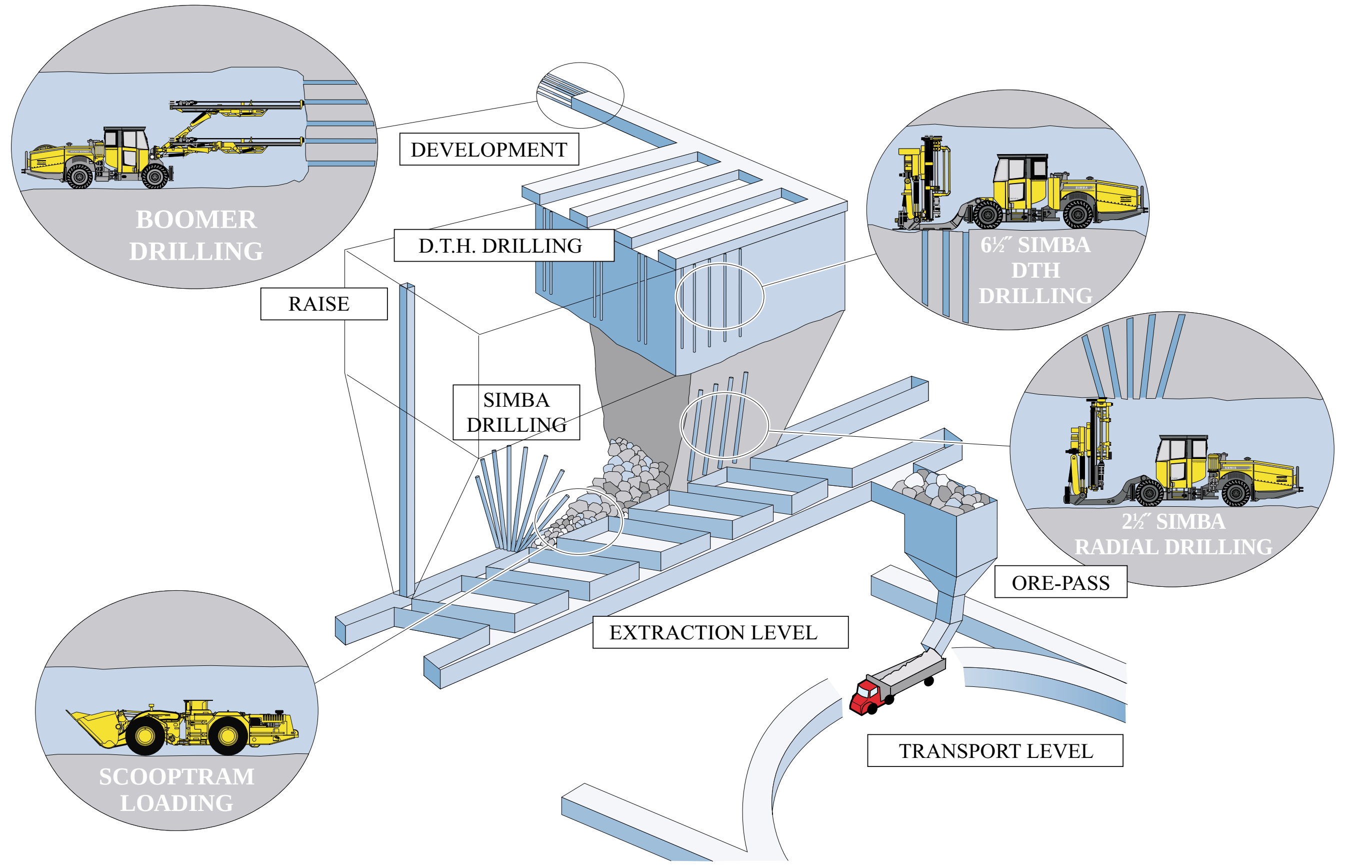
## History

The El Soldado and Los Bronces copper mines and the Chagres smelter, all located in Chile, are operated by Compañía Minera Disputada de las Condes.

In addition to its record as a successful mining company, Disputada's operations achieved recognition in 1999, when it became the first industrial company to receive Chile's National Environment Award, recognizing its leadership in environmental practices and its high standards in environmental management.

In 2001, Disputada produced 251,900 t copper at an average operating cash cost of 47 US cents/pound.

El Soldado location in central Chile.




*El Soldado underground mining schematic overview.*

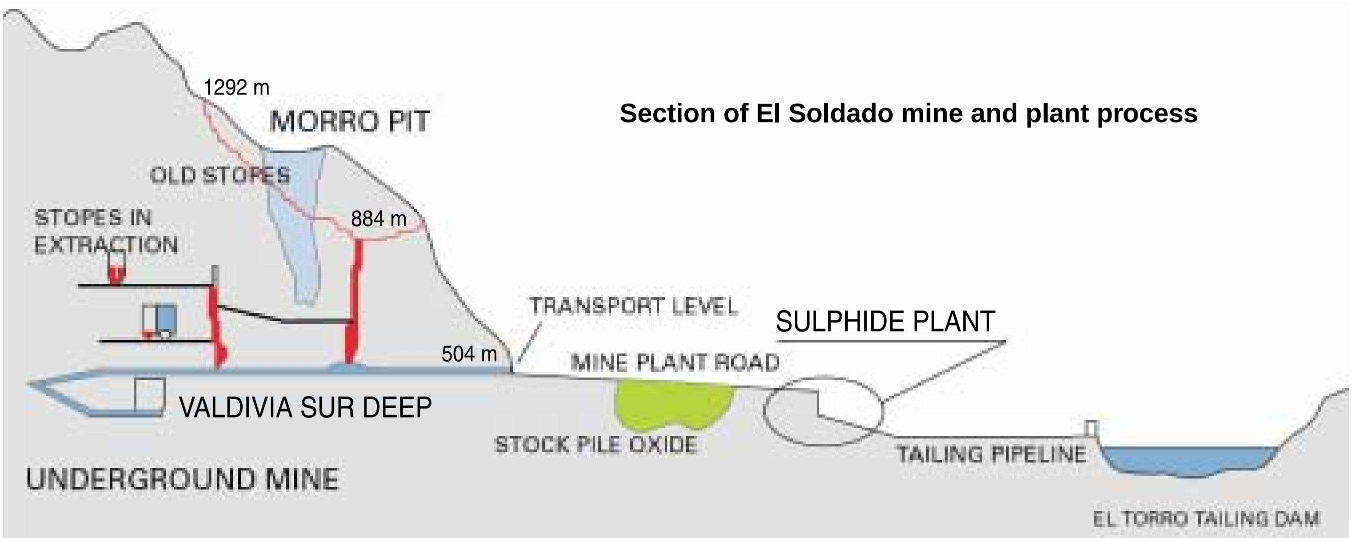
The total workforce of El Soldado is 286 people, of which 107 are employed in the underground mine. Of these, 24 are employed in maintenance. The mine operates Monday to Friday in two shifts of 9.5 h.

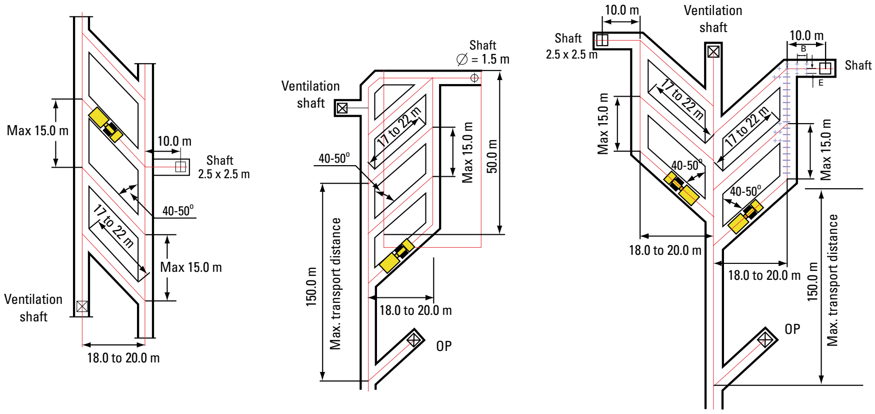
Mining at El Soldado started in 1842. Since 1978, when Exxon Minerals acquired the operation, about 70 million t of ore containing 1.8% copper have been mined by the underground sublevel open-stoping method. In 1989, the El Morro open pit commenced production to increase output to the present 18,000 t/day. Today, the underground mine provides 30% of the total concentrator feed, but rather more of the contained copper.

The sulphide plant's current capacity is 6.5 million t/year, of which the underground mine supplies 2.9 million t. This is expected to increase to 3.4 million t in 2003.

## Problematical Geology

The El Soldado deposit is located in the Lower Cretaceous Lo Prado formation, and is thought to be of epigenetic origin. The main host rocks






*Extraction level layout.*

are trachytes, followed in importance by andesites and tuffs. Copper mineralization occurs as numerous isolated orebodies, with a strong structural control, located throughout an area 1,800 m-long by 800 m-wide. The lateral limits of the orebodies are characterized by abrupt variations in the copper grade. The transition from high-grade mineralization of 1.2% to 2% Cu to low grade areas of 0.5% to 1.2% Cu takes place within a few metres. Orebodies typically exhibit an outer pyrite-rich halo, followed inwards by an abundant chalcopyrite and bornite core, with minor chalcocite and hematite. The main gangue minerals are calcite, quartz, chlorite, epidote and albite.

The orebodies are of tabular shape, with dimensions that vary from 100 to 200 m in length, 30 to 150 m in width, and 80 to 350 m in height. The ground conditions are classified as competent, with an intact rock strength greater than 200 Mpa, in a moderate stress regime ranging from 15 to 30 Mpa. These geotechnical conditions facilitate the development of large open cavities, normally as large as the orebodies, with dimensions from 40 to 90 m in width, 50 to 290 m in length, and up to 300 m in height.

The nature of the major structures, and the inherent condition of the rock mass, play a critical role in determining the extent of any likely instability surrounding excavations at El Soldado mine. Seven main fault systems, and a system of bed contacts, have been defined within the ore deposit limits as being significant in geotechnical terms. The induced state of stress after excavation is a significant mine design criteria, and a monitoring objective. In an attempt to obtain information on the *in-situ* stress in critical areas of the mine, measurements have been carried out.

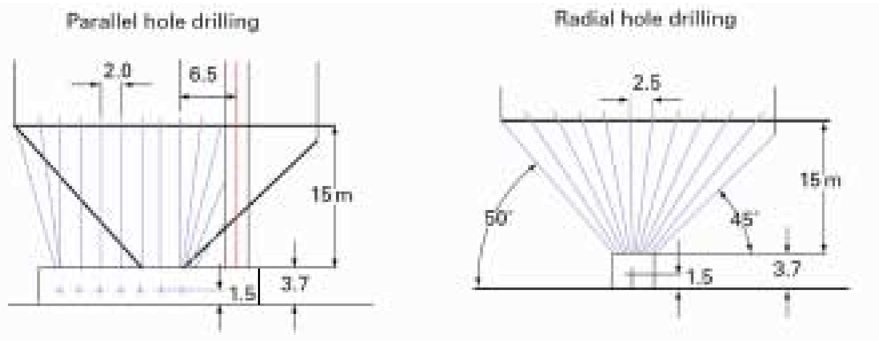
## Mine Stability

Mine stability is a matter of prime importance in the planning process, particularly as the El Morro open pit is situated immediately above the underground mine. An integral mine plan is therefore required, in which the sequence of extraction, both in the open pit and underground, needs to satisfy safety and efficiency criteria. In particular, the design and extraction sequence of underground stopes have to be managed in such a way that they do not affect the open pit operations, and minimize disturbance to unmined areas, enabling maximum resource recovery. This has to be balanced with the need to maintain high-grade feed, and the selectivity that comes with underground mining. There has been a large amount of development in the underground mine, creating a large number of stopes, and a complex layout.

Because of all the aspects that need to be taken into account before mining can start, extensive geotechnical monitoring is applied to rock conditions, to detect and identify failures and instabilities, to collect data for mine planning and stope design, and for ongoing assessment of mine stability. Over the longer term, the collected data provides control points to update

*Atlas Copco Rocket Boomer M2 C underground . . .*


*. . . and in surface workshop at El Soldado.*




*Uphole production drilling pattern.*

the geotechnical database, and to verify the assumptions made in the design.

## Underground Layout

The access points to the orebodies are located on the slope of the Chilean coastal range hosting the mine, several hundred metres above the valley floor. Today, the main entry is located at –100 level (730 m asl) and the haulage level is at 300 m below datum (530 m asl). The mine has been developed by a network of sublevels, providing access to the tops and bottoms of the mining areas. Sublevels are linked by ramps, with a maximum slope of 15%. Ore is loaded directly into orepasses with an overall capacity of 10,000 to 30,000 t, which connect sublevels with the haulage level. This ore is transported to a crusher located on surface, near the concentrator, using 50 t-capacity, highway-type trucks. Some ore is mined below the main haulage level, and this material is transported directly to the surface crusher using trucks and ramps.

Historically, the massive, but irregular, orebodies, and the competent ground conditions, made sublevel open stoping the preferred mining method. However, in 1983, fully mechanized sublevel and large-diameter blasthole open stoping (SBOS) was introduced as a variation of the standard method, enabling an increase in production rates.

Nominal stope dimensions are 30 to 60 m-wide, 50 to 100 m-long, and up to 100 m-high, though large orebodies are divided into several units, leaving rib and crown pillars as temporary support structures. Rib pillars are 30 to 50 m-wide, and crown pillars 25 to 40 m-thick.

The stopes are mined progressively downwards by a traditional SBOS method, and are left unfilled. Pillars are subsequently recovered by a mass blast technique, the last three of which were designed to break more than 1 million t of ore each.

The rock is very competent, and the stope cavities can be left open, sometimes standing for 5 or 10 years, depending on the sector and the rock structure. Smaller stope cavities normally have stable geometries, with less than 5% dilution from back extension or wall failure.

However, three large open stopes, the Santa Clara, California and Valdivia Sur stopes, have experienced controlled structural caving, filling the existing void and breaking through to the surface. If it is decided to fill a stope, then waste rock from development is used.

## Production Stopes

Production block access is provided by developing sublevels, with a pattern of 5.0 m x 3.7 m LHD drawpoints at the base of the stope. Block undercutting is accomplished with a fan pattern of 60 to 75 mm-diameter holes up to 25 m-long loaded with ANFO and HE boosters. Slots are made by enlarging a 2.5 x 2.5 m blast hole slot raise, at one end, or in the middle, of the stope. Blast holes of 165 mm-diameter and up to 80 m-long, are drilled with an underhand pattern.

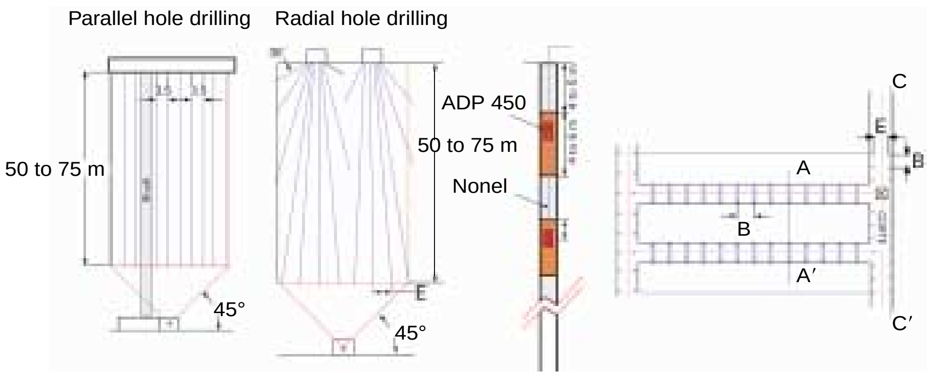
Blast size and blasting sequence is defined for each stope, according to major structural features and the proximity of existing cavities. Dilution control is improved, and blasthole losses avoided, by carefully considering the particular geometries created by the intersection of major discontinuities and the free faces of the planned excavation.

Often, faults present geometries which generate wedges that can slide into the cavity, affecting fragmentation and generating oversize rock at drawpoints. The presence of cavities, or simultaneous mining in nearby locations, also impose restrictions in the mining sequence and size of blast.

Production ore from stopes is loaded out with 10 cu yd LHDs. One-way distances of 100 to 150 m are maintained to orepass tips, which are not equipped with grizzlies, as oversize rock is drilled and blasted in place at the drawpoints. Orepasses terminate in hydraulically-controlled chutes at the –300 haulage level, where the 50 t trucks are loaded with run-of-mine ore or development waste.

A square pattern of 1.90 m x 1.7 m split-set bolts, 2.05 m-long, in combination with wire mesh, is used to maintain working areas free of rock fall, and to protect personnel and equipment. This approach to ground control is not intended for heavy rock loads, or massive stress-induced instabilities, but is adequate for local support. Where needed, cable bolting is used to support unfavourable geometries, such as large

*Downhole production drilling pattern.*




Atlas Copco Simba M6 C drilling radial holes.

wedges or low dip bedding layers, and also to support drawpoints and orepasses where the rock conditions have changed dramatically. Occasionally, cable bolts are used to minimize, or prevent, caving in the sublevel stopes.

Development headings average 18.5 sq m cross section, and drilling rounds consist of 55 holes, 44 mm-diameter, and 3.85 m-deep.

Large-diameter blasthole open stoping has worked well at El Soldado. The mine drills up to 75,000 m/year using DTH, and 60,000 m/year top hammer. The current method allows the exploitation of larger units, reducing preparation costs and improving productivity costs. Another advantage of the method is that it is selective, allowing extraction of only the mineral. The current cost distribution is: development 32%; service and other 28%; drilling and blasting 17%; extraction 12%; and transport 11%.

## Equipment Maintenance

El Soldado is going through a phase of equipment replacement. Two of the three Atlas Copco Boomer H127s equipped with the COP 1032 rock drill are being replaced by new Rocket Boomer M2 C units featuring Advanced Boom Control (ABC) system. These will work alongside the remaining H127 unit, drilling 43 mm holes. The old machines will be rebuilt, one as a secondary drillrig, and the other as a scaler.

For production, El Soldado employs three Atlas Copco Simba 264 equipped with the COP 64 DTH rock drill for 6.5 in holes. There are also an Atlas Copco Simba H221 and an H252, both used for radial drilling of DTH holes ranging between 65-75 mm. The Simba 264 machines will be gradually replaced by the new generation Simba M6 C DTH drillrigs, which, along with the Rocket Boomer M2 C units, feature the ABC Regular, but which will be eventually upgraded to ABC Total.

El Soldado expects 20% to 30% more drilling capacity per hour with the new Simba M6 C machines, on account of mechanized tube handling and better control of drilling parameters. The robust design should give better utilization and lower maintenance.

The ANFO explosive charging units used are 3 PT-61 trucks built in co-operation with Dyno Nobel, where Atlas Copco DC carriers replaced the PT machines. These trucks are used for both face and longhole charging. Furthermore, there is a new Rocmec DC 11 ANFO charging truck, which also features an Atlas Copco carrier, with a new ANOL CC type of charging vessel replacing the old Anol and Jetanol units. The machine is also equipped with an Atlas Copco GA 11 compressor, and replaced an older PT61 unit.

For loading and transportation, five Atlas Copco Wagner ST 8B LHDs are employed. Recently, three 13 cu yd Atlas Copco Wagner ST 1810 LHDs with monitoring system were delivered to the mine, for waste haulage.

Rock reinforcement is carried out with an Atlas Copco Boltec H335-1432 bolting machine.

El Soldado is currently installing a computer-based system, which will allow it to interface with virtually all of its equipment to retrieve machine health information. The underground leaky feeder communication system is linked to the LHDs and drillrigs.

Both the open pit and the underground areas have dedicated workshops. To further serve the underground area, there is one preventive maintenance workshop located on the surface, and field maintenance is carried out on the Simbas.

## Outlook

El Soldado's main objective is to continue with its tradition of excellence in safety and cost competitiveness. The underground mine production will be consolidated at over 3.0 million t/year, and variants of the exploitation method will be introduced to recover minor volume reserves, using automated radial drilling to over 40 m depth. El Soldado's mining plan is intrinsically linked to its geotechnical and geometric conditions, and so improvements to the monitoring and data-collection systems, in order to obtain more precise geotechnical engineering, are constantly being studied.

## References

This article is based on interviews with management of El Soldado, and the following paper:

Contador N and Glavic M, *Sublevel Open Stoping at El Soldado Mine: A Geomechanical Challenge.* ■


The face of innovation