SPECIAL REPORT:

Peruvian silver and base metal producer links mine to mill with new deep level cross cut and plans big increase in productivity with mechanized sublevel stoping

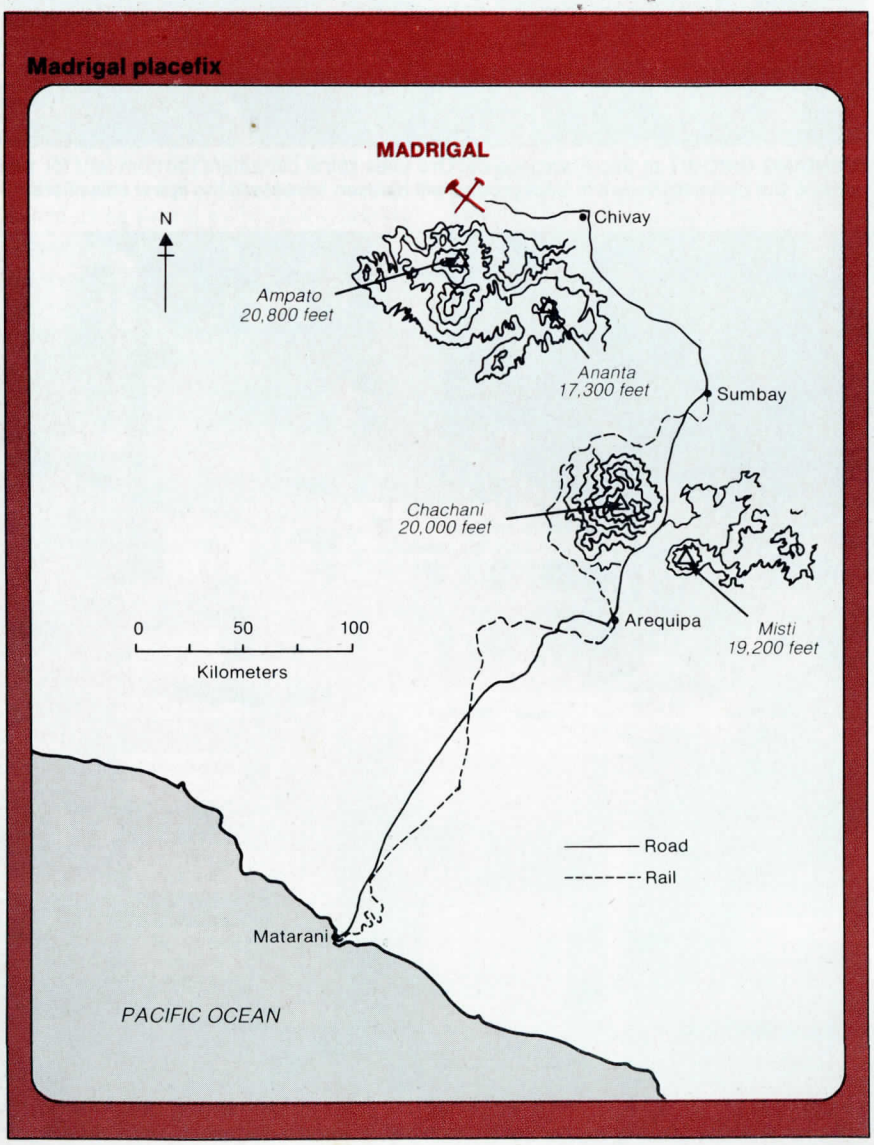
Minera Madrigal goes deeper for more tonnage

By **Robert J. M. Wyllie**
Editor

Earlier this year miners at Madrigal started driving a cross cut under a mountain. The new drift is deeper under the existing mine workings and will provide a direct link from the mine to the mill located at the cross cut portal. It will also give access to the lower levels of the mine and be the key link in an expansion program which will achieve increased production with less labor through more mechanized mining methods.

Compania Minera del Madrigal's mine is about 100 kilometers (60 miles) due north of the city of Arequipa in southern Peru. In fact, the mine is high in the western cordillera of the Andes and the 100 kilometers is, strictly speaking, for the birds. Land bound travelers must spend half a day driving the twisting dirt roads through the spectacular Andean passes and high valleys to reach the mine site.

When production started in 1972 the principal economic metals in the complex sulphide ore were copper, lead, and zinc. With today's high precious metal prices, the approximate 2 ounces of silver per ton is a very important product.



Santa Rosa Vein

Production is based on the important Santa Rosa vein which crops out for a distance of about 4 kilometers (2.5 miles) striking roughly east-west.

Flat lying tertiary volcanics, mainly andesites, occur throughout the Madrigal area. These so-called Tacasa volcanics total more than 2,500 meters (8,250 feet) in thickness. They came from the volcanos whose eroded caps are now the snow covered peaks that surround the area. The layered volcanics are broken by a pattern of steeply dipping, roughly east-west trending fractures in which are found the mineralized zones.

The Santa Rosa vein occurs in the base of the alpha zone, a strong fault and shatter zone striking north 75° west and dipping from 40° to 75° northeast. Its width varies from 2 to 6 meters (6.6 to 20 feet) in the upper part of the mine with an average of 4 meters (13 feet). In addition to the Santa Rosa vein, this fracture zone also includes the North Vein (or Veta Norte) which is split off the main Santa Rosa vein and a stockwork system.

Erosion of the flat lying volcanics has produced deep north-south trending canyons with steep walls. Mining operations at Madrigal take place in the mountain between two of these canyons or quebradas. The mill and surface installations are located in the Cahuira River canyon and the Santa Rosa vein crops out on the eastern slopes of this quebrada. There are seven daylight levels from the top of the mountain at 4,000 meters (13,000 feet) down to 7 level which opens out into the canyon floor at 3,680 meters (12,150 feet). The mill is located further down the canyon at 3,360 meters (11,100 feet). Ore is hauled out along 7 level and transported to the mill by an aerial tram that runs down the canyon.

At present all production comes from above 7 level. However, the lower levels are being opened up by ramping down from the canyon floor. The decline is now

BARRING DOWN loose hanging from roof at Madrigal mine, where an expansion program is underway to increase production and productivity in lower levels of mine.

at 9 level. When 12 level is mined from the mill to below the 9 level position they will be connected by a raise.

Above 7 level the mine is divided into four main blocks. From west to east they are Cahuira, Central West, Central East, and Sahuaito (the latter is the name of the quebrada on the eastern flank of the mine).

Cahuira was the best grade block. It has provided the bulk of ore production which is now at a level of 1,200 to 1,300 tons per day for the whole mine. Average ore grade for the mine is 1 percent copper, 2.2 percent lead, 4.8 percent zinc, and 2.2 ounces silver per ton.

Drilling below the 7 level has proved ore but at lower grade than the upper levels. Average grades are expected to be 0.5 percent copper, 2 percent lead, 4 percent zinc, and 1 ounce silver per ton. However, the vein width is much greater below 7 level, averaging 10 meters (33 feet). As in the upper levels the hanging wall and footwall are strong and hard.

The Cahuira block has only about 2 years of productive life remaining. Its production is now tailing off to around 100 tons per day while the balance of the 1,300-ton mill call is coming from the later developed blocks to the east.

Cut and fill has been the predominant mining method at Madrigal. Shrinkage has been used in narrow stopes in the strongwalled veins. Although costs are low, output is low so cut and fill is preferred to put rock in the box and improve cash flow.

Standard cut and fill stopes in the Cahuira block are up to 80 meters (270 feet) in length with a height equal to the level interval or 50 to 60 meters (165 to 200 feet). Stopes are developed by drilling fill raises on 80-meter centers on the footwall of the vein from lower to upper level. Stoping begins by taking three horizontal cuts of about 2.5 meters (8 feet) each from fill raise to fill raise. The ore is mucked out and the stope is filled through the two raises to within 2 meters (6 feet) of the back. Fill is dry rock or surface rubble mined from the top of the mountain and dropped through fill passes to the stoping sections. The stope is connected to the footwall haulage drift by a short raise equipped with an ore chute and a manway. The stope is equipped with a slusher to spread fill and to eventually scrape ore. Later, rubber-tired LHD units were installed in the larger stopes.

The next cut then starts over the ore pass raise and is advanced to one of the fill raises. Enough ore is scraped out to leave a drilling pattern for the next cut. Once this cut is complete all broken ore is slushed out and the fill cycle for this half of the stope is started. Simultaneously a cut is started in the other half and advances towards the opposite fill raise. The objective is to time the completion of the two cuts in one half of the stope with the completion of the backfilling in the other half. Timber sets are then installed over the two-compartment access and the ore pass raise is blocked and stabilized with fill material. The fill cycle then starts in the just-mined half of the stope as the cut cycle begins in the first half.

Sublevel Stoping

In addition to cut and fill and shrinkage, sublevel stoping has also been employed in wide stopes at Madrigal. This method will find increasing application below 7 level where the ore body is generally wider.

Sublevel stopes are 100 meters (330 feet) long and 60 meters (200 feet) high. The sublevel interval is 4.5 meters (15 feet). Sublevels are driven in the vein in the center or on its footwall side. They are then slashed out to a height of 4 meters (13 feet) across the whole width of the vein (which may be up to 10 meters).

The ore between the sublevels is drilled from the upper level to the lower level.

Productivities achieved in the three mining methods are 5 tons per manshift in cut and fill, 10 tons per manshift in shrinkage, and 50 tons per manshift in sublevel. It is obvious which is the method of the future at Madrigal.

Very importantly, the application of sublevel stoping will allow full mechanization of drilling with jumbos as well as ore handling with rubber-tired LHD equipment.

At present some 320 men are required in the mine. Intensive mechanization and adoption of sublevel stoping will reduce the labor force to about 100 while maintaining or increasing production.

When ore production is mainly derived from the lower levels of the mine, it may be necessary to raise tonnage to compensate for the expected lower grades. Daily ore output required might be as high as 2,000 to 3,000 tons. This will all be dropped to the 12 level and hauled directly out to the mill. It might be necessary to install a preconcentration step to achieve the treatment capacity required.

Major raises are mined with an Alimak raise climber. Working two shifts per day, raises are mined at a rate of 35 meters (115 feet) per month and a 120-meter (400-foot) raise was completed in 100 days.

The cross cut on 12 level is being driven with a section of 4 by 5 meters (13 by 16 feet). It is expected to intersect the Santa Rosa vein structure at a distance of about 1,320 meters (4,400 feet) from the portal and about 200 meters (660 feet) below the 9 level.

Reagent consumption at Madrigal concentrator

Reagent	Consumption, grams per ton
Zinc sulphate	177
Sodium cyanide	44
Xanthate, Z_3	29
Dow + AP	29
Sodium bichromate	36
Sodium bisulphite	87
Copper sulphate	243
Lime	1,211
Xanthate, ZII	32
Sodium sulphate	4

It has not yet been decided whether the ore will be hauled out along this level by rail or belt conveyor. In any event, the aerial tram is now operating at capacity and the only way to extract the ore from the sections below 7 level is by the new cross cut.

Three Concentrates

After crushing and screening to ½-inch size, the ore is stored in the 1,200-ton-capacity fine ore bin. The crushing and screening plant is particularly noteworthy for its clean and dust-free environment. The dust sealing and extractions systems are very efficient.

Two feeders withdraw ore from the fines bin and feed it at a rate of 48 tons per hour to the grinding section. Primary grind is in a 6 by 12-foot Allis Chalmers rod mill whose discharge is split to two 8 by 8-foot Allis Chalmers ball mills. The ball mills are in closed circuit with 15-inch hydrocyclones.

The feed to flotation goes straight to two banks of 16 each 36-inch Galigher cells for bulk copper-lead flotation. The bulk copper-lead concentrate is cleaned three times before passing to the separation section where the copper is floated while the lead is depressed. A copper concentrate grading 30 percent Cu with 3 to 4 percent Pb and about 3 percent zinc is produced. Recovery of copper into the copper concentrate is around 73 percent. Lead concentrate grades up to 68 percent Pb with 3 to 4 percent copper and a similar amount of zinc.

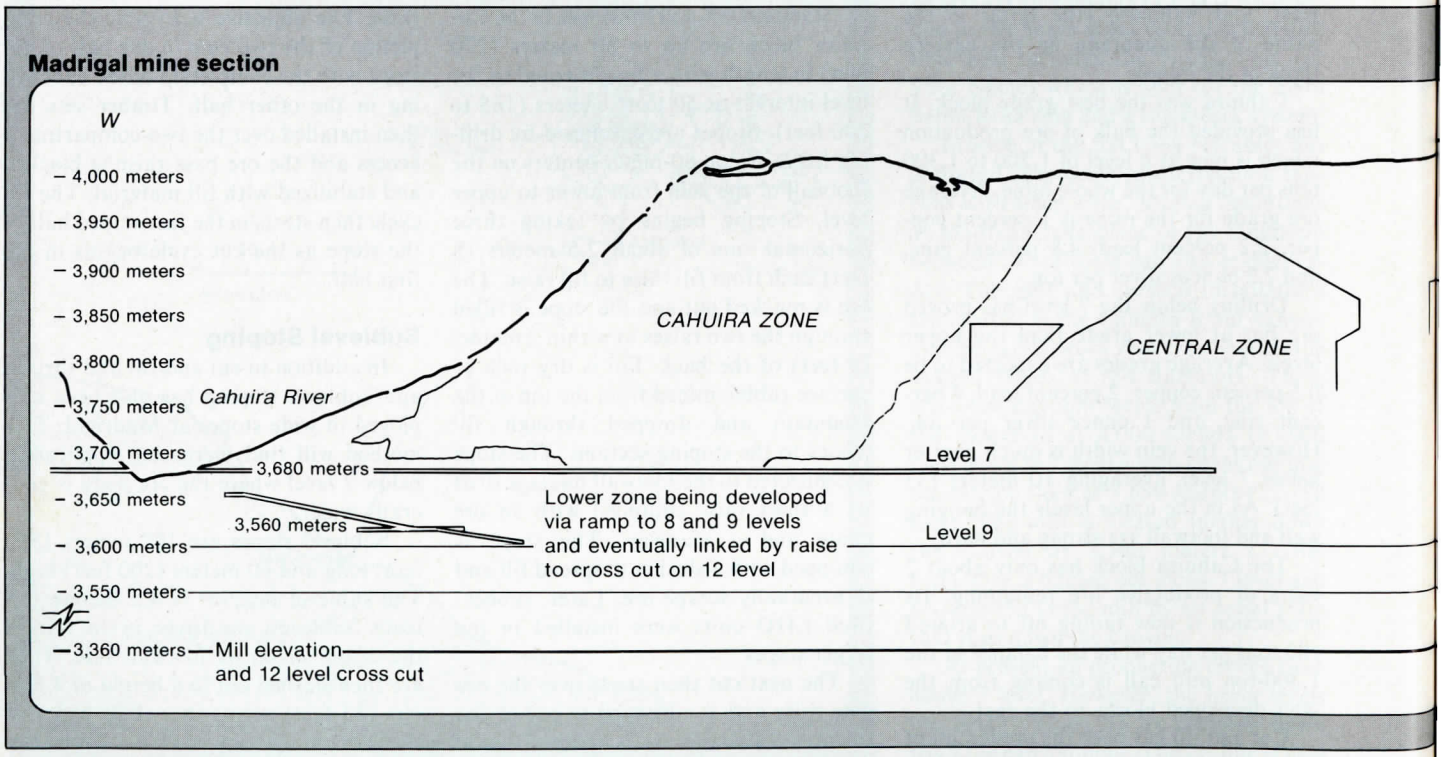
The tailing of the bulk copper-lead float is the feed to the zinc concentration section. After roughing and three cleaning steps a 58 percent zinc concentrate with just over 1 percent each of copper and zinc is produced. Recovery of zinc into zinc concentrate is 85 percent.

Three thickeners and three twin-disc filters produce the separate concentrate filter cakes. Concentrates are hauled by truck to the Peruvian Southern Railroad at Sumbay, 125 kilometers (80 miles) away. From here they are railed to the Pacific coast port of Matarani.

More Mineralized Zones

The Santa Rosa vein structure is the only one presently mined at Madrigal. It is not the only mineralized zone. The Poscohuaico zone lies about 1 kilometer north of the Santa Rosa vein. Its three veins also crop out on the Cahuira canyon wall. On the east flank of the Sahuaito canyon, about 2 kilometers south of the Santa Rosa vein, is the San Felipe

Madrigal mine section



San Isidro zone. The veins in all of those zones have been the target of limited drilling and investigation. Much more drilling is needed to outline the real potential of these attractive mineralized zones. In addition, the mine geologists would like to run geophysical surveys in the area in order to define drilling targets. This is particularly the case on the east side of the quebrada where there is up to 30 meters (100 feet) of alluvial cover on much of the area of potential interest.

Although the limited exploration work on other mineralized zones in the Madrigal district has indicated that the base metal and silver grades are lower than at Santa Rosa, gold content is higher. Values of about 1 gram per ton are indicated. Remember, with $600 gold, that equals about $20 per ton plus the value of anything else the ore contains.

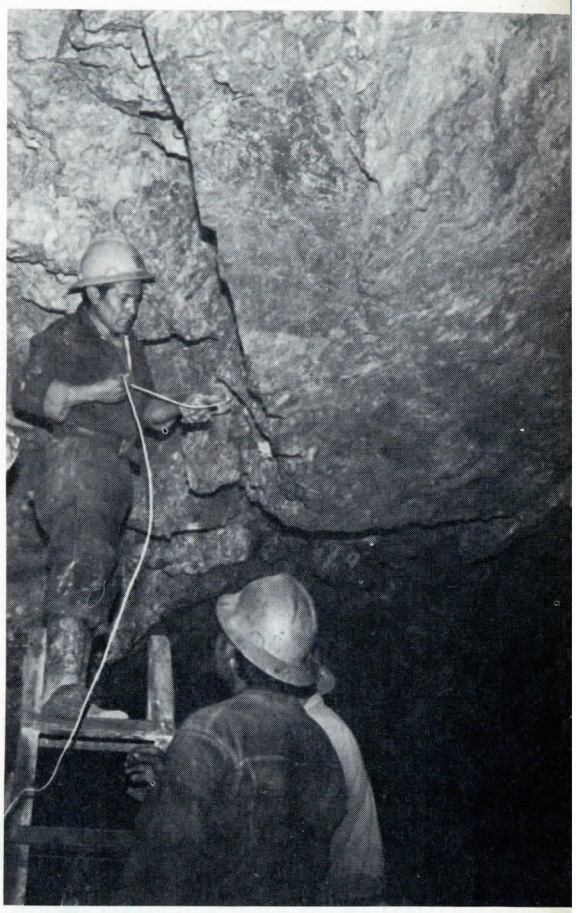
Like most, if not all, mines in Peru, Madrigal is found in a mineralized zone that has been known for many centuries. It is in fact in the southern part of the great mineralized district of southern Peru which includes the famous Caylloma silver mining area. The northern part of the belt is mainly silver mineralization while the southern part, in which Madrigal is located, tends to have base metal (copper, lead, zinc) mineralization with accompanying silver.

There is evidence from shallow workings in the Santa Rosa vein that colonial period Spanish miners mined or explored in the area. However, it did not become an important producing center and the first modern claims in the area were not recorded until the 1940's.

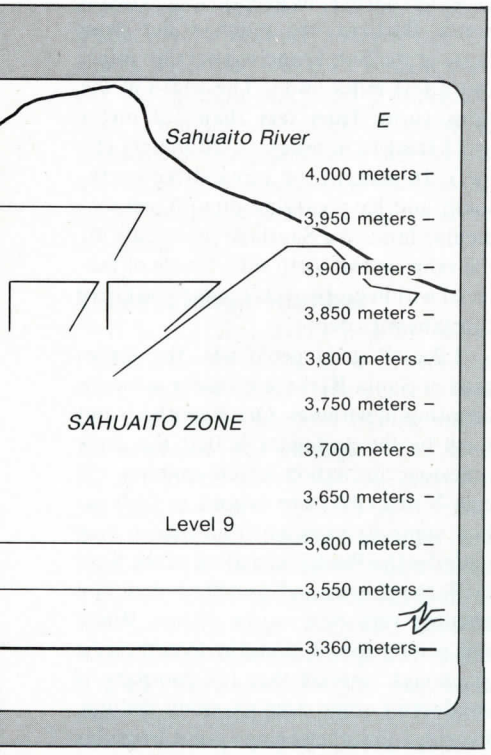
Major problems associated with exploration and development of Madrigal were its remote location and lack of communications.

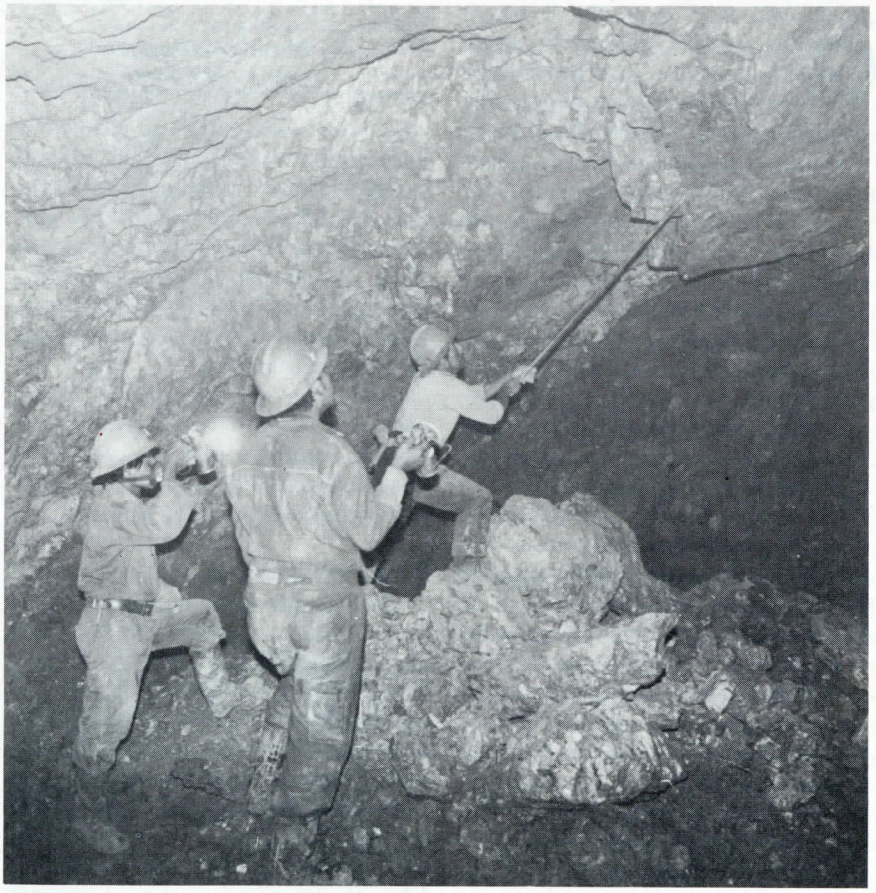
In the 1960's an exploration syndicate, which included Homestake Mining Company of the United States, conducted a major exploration and evaluation program at the Santa Rosa vein. Eventually, under the leadership of Homestake, the Madrigal company was formed to bring the property into production. In 1972, after five years of development work, the mine was in production at a daily rate of 500 tons. This was expanded to 725 daily tons by 1975 and then again to 1,000 tons in 1978. Current levels of 1,300 daily tons may again be substantially increased either as a result of mining the lower part of the Santa Rosa vein, or by adding ore from the other mineralized zones under investigation.

A more detailed account of the geology of the Madrigal area and information on mine development and the original mining methods (on which much of the present account is based) will be found in the report "Madrigal, newest copper, lead, zinc mine in the Peruvian Andes," by Madrigal general manager John H. Schissler. ■



CHARGING up blastholes at the Madrigal mine, where Santa Rosa is main vein.





PORTAL of the decline which provides access to lower levels of the mine. Above portal is the loading station for aerial tram which moves ore from 7 level portal to the mill.