# Trigger criteria and production in Pilar Norte mine, El Teniente

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## ABSTRACT

Pilar Norte is one of the many mines in the El Teniente Copper deposit. Since its start of operation in 2010, and throughout its exploitation progress, it has not been exempting from Geomechanical issues, particularly large-scale rock bursts. The seismic monitoring conducted primarily involves the quantity of "shots" recorded by each seismic station, weighted, and limited by bands that compare the behavior of the last 7 days with the real-time records. For the past two years, this seismic monitoring has been complemented by comparing the production tonnage from blasting with the total tonnage in the sector. The results of this simple monitoring have been quite positive, as it has been observed how the response of the "weighted vibration" of the sectors immediately correlates with the extraction activities. This allows for an "alert" condition to be identified that deviates from the well-explained bands and is complemented by the seismic analyses conducted by the operational Geomechanics Unit.

## 1 INTRODUCTION

The El Teniente Mine is an underground copper mine located in Central Chile, in the Andes Mountain range, 70 km from Santiago, the capital of Chile. For the past 30 years, the seismic system has been the main geomechanical tool in the El Teniente Division. Currently, the seismic network comprises over 130 sensors (geophones and accelerometers) covering different mines within the deposit, recording thousands of events daily.

Based on seismic behavior, criteria are applied, considering the quantity of events and comparing them with weekly patterns. In the case of Pilar Norte, depicted in Figure 1, it is one of the most challenging mines due to its placement between two other mines.

Pilar Norte is designed for extraction using the Panel Caving method with hydraulic fracturing, and its levels are located at various altitudes in this sector (m.a.s.l):

- UCL: 2120 m
- Production: 2100 m
- Ventilation: 2085 m
- Pick hammer level: 2070 m
- Haulage: 1983 m

Given its complexity, another type of seismic criterion was applied to monitor its behavior, which considers the triggered behavior of the stations near that mine.

## 2 METHODOLOGY

Given the distribution of the seismic network at El Teniente, Pilar Norte Mine considers 16 sensors in its vicinity, which can be seen in Figure 1. As shown, they have vertical coverage, thanks to the production level of another mine located above the UCL of Pilar Norte. There are also sensors in the UCL sector and at the NTI levels. Finally, sensors below this mine contribute to vibration measurement, specifically located in the Andes Norte Project, which will be exploited in the not-too-distant future.
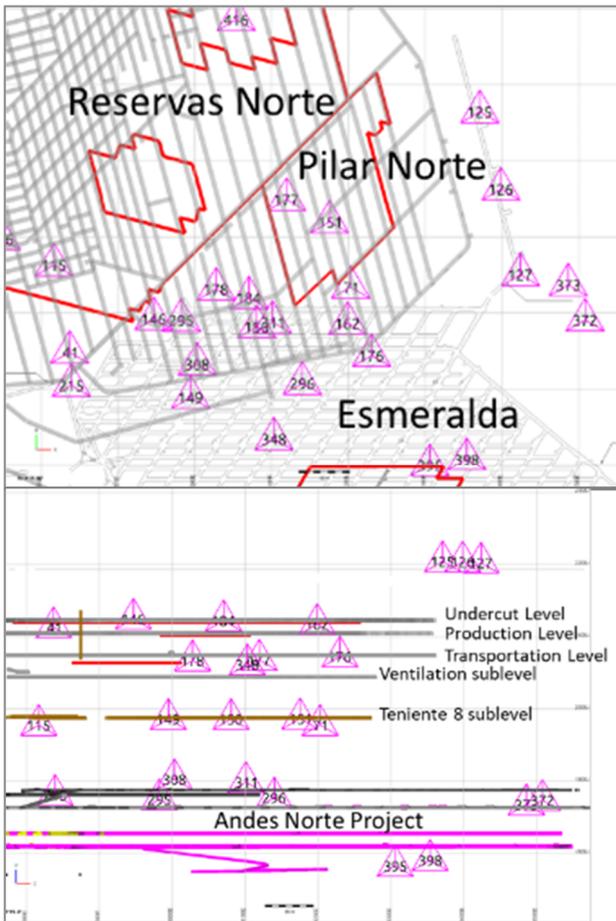
**Figure 1    Sensor's location in Pilar Norte Mine.**

The trigger criterion used is an indicator that summarizes the seismic response through a mass vibration weight applied to mining. It weighs the quantity of triggering from each station based on a weight that depends on the distance to the sector, as follows:

$$\bar{t} = \sum_{n=1}^{n} (\alpha_i \times n_i) \qquad (1)$$

Where "t" represents the sum of triggers from each station, given its vibration value, and "Alpha" is the weighting factor dependent on the distance of the sensor location. For a station to be considered, the vibration threshold, i.e., the peak particle velocity (PPV) used for the stations, must be greater than or equal to PPV $\geq$ 4.2 × 10-5 [m/s].

Similarly, variations in seismic frequency associated with mining operations reflect changes in applied mining parameters and/or the

mechanical characteristics of the rock mass undergoing exploitation. Significant variations in seismic patterns, both temporal and spatial, are explained in terms of changes in these two factors. The association of seismic activity with mining parameters and/or rock mass characteristics suggests that modifying these parameters in a given rock mass scenario can help control the mass response, particularly induced seismicity.

The trigger frequency emerges as a fundamental criterion for recognizing changes in the rock mass response to mining and taking appropriate actions in mining development as warranted by these response changes.

This indicator considers the hourly frequency (daily average) of triggers occurring in a defined area of the mine (polygon generated in 3 dimensions). Simultaneously, a 7-day moving average is specified for this event frequency around which two limit bands are generated. The daily average is compared with the 7-day average, and these generated bands are created according to the Poisson probability function.

The probability of a number "n" of events occurring in a fixed time, if these events occur at a known average frequency and are independent of the time elapsed since the last event, can be represented by the Poisson probability function.

$$f(n, \lambda) = \frac{e^{-\lambda} \lambda^n}{n!} \qquad (2)$$

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Where n: number of events in the model and λ: expected frequency of the phenomenon modeled by the distribution

The upper band considers the quantity of events with a 95% reliability, while the lower band considers events with a 2% reliability. If the daily events line (red line in Figure 2) stays within these bands, the situation is defined as "Normal." Conversely, if the daily average is outside these bands, it will be considered an "Alert" situation

## 3 RESULTS

Applying the monitoring of weighted vibrations in conjunction with extraction behavior reveals the correlation between these two parameters, which contribute to safety. Comparing seismic response with mining activities in the fractured area shows a direct relationship. Figure XX illustrates the behavior of the CFT (Cumulative Frequency of Triggering) in the Pilar Norte sector from January 1, 2021, to July 1, 2023. In it, three lines can be observed. The red line represents the triggering behavior of the stations, the blue line represents the average behavior of the last 7 days, and the cyan lines represent safety bands that guide decision-making in the sector's operation, see Figure 2 below.
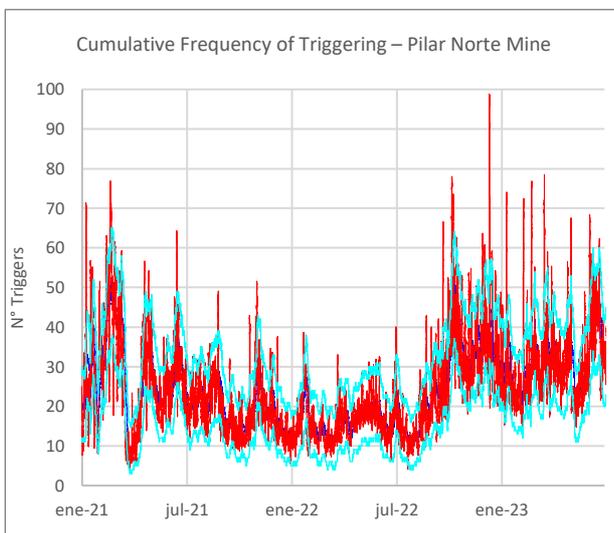


**Figure 2    Triggers behavior in Pilar Norte.**

The graph is not stable; it exhibits different behaviors with peaks that surpass the safety bands. According to the understanding developed, this criterion responds to mining activities in the area of interest. These activities can result from blasting to incorporate new areas into production or from continuous extraction in the caving propagation area.

The incorporation of new areas in Pilar Norte occurs intermittently, unlike extraction, which is carried out continuously and may have a greater impact on the recorded seismic activity. To assess the performance of the CFT, it is compared with the extraction in the caving propagation area. It is in this sector where the highest seismicity occurs due to the sliding of

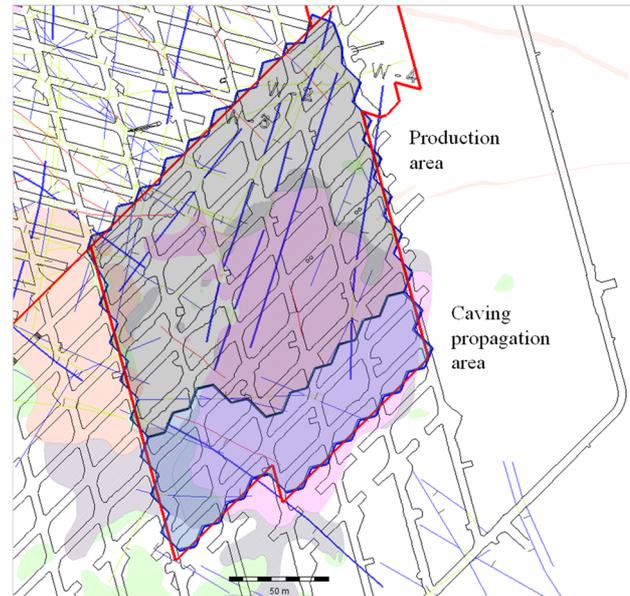existing discontinuities and the growth of new fractures, primarily induced by the extraction process (Figure 3).



**Figure 3    Pilar Norte sector. Caving production and Production Area.**

Since seismic activity does not necessarily respond immediately to extraction, calculations are simplified, and the CFT and extraction curves are reviewed with a 7-day moving average (Figure 4).
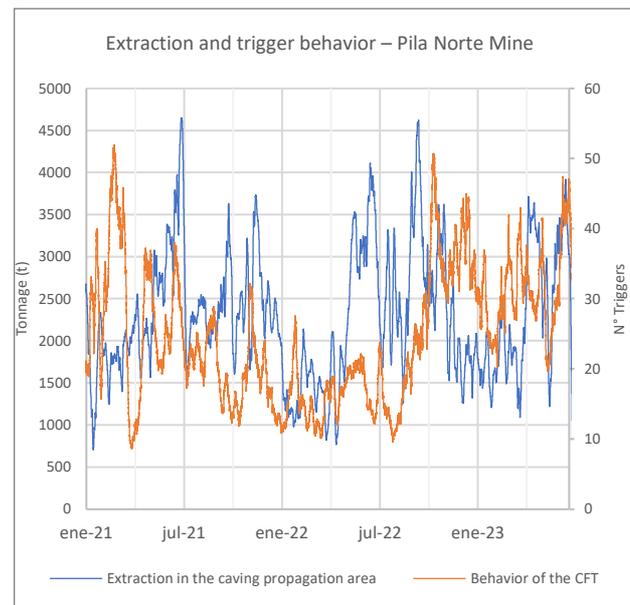


**Figure 4    Extraction and trigger behavior.**

At first glance, some periods exhibit a better correlation than others. To clarify the previous point, Figure 5 illustrates the behavior of the

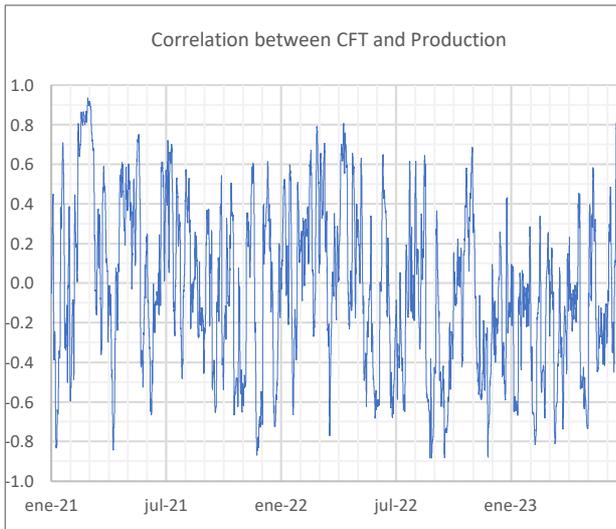linear correlation between the CFT and the extraction from the caving propagation area.



**Figure 5**    **Correlation curve between behavior of the CFT and extraction from the caving propagation area.**

To interpret how strong the correlation is between both data series, Cohen's criterion (1988) can be used, which indicates the following for absolute values:

- 0.1-0.3 represents a small effect.
- 0.3-0.5 a medium effect.
- 0.5 a large effect.

Based on the above, we observe a high positive correlation, with values greater than 0.5. In other words, when extraction increases, the level of triggers from nearby stations also increases. For values less than -0.5, there is a high negative correlation, meaning that despite a decrease in extraction, the trigger level increases. This is due to post-blasting operational protocols, where the sector is isolated for periods of at least 24 hours, halting extraction but leading to an increased frequency of events generated by blasting, resulting in a higher trigger of stations.

As a reference, Figure 7 shows the correlation between extraction from the caving propagation area and the frequency of seismic events. If we consider the same criterion mentioned earlier, in this case, a low correlation is observed, with values concentrated between -0.2 and 0.2.
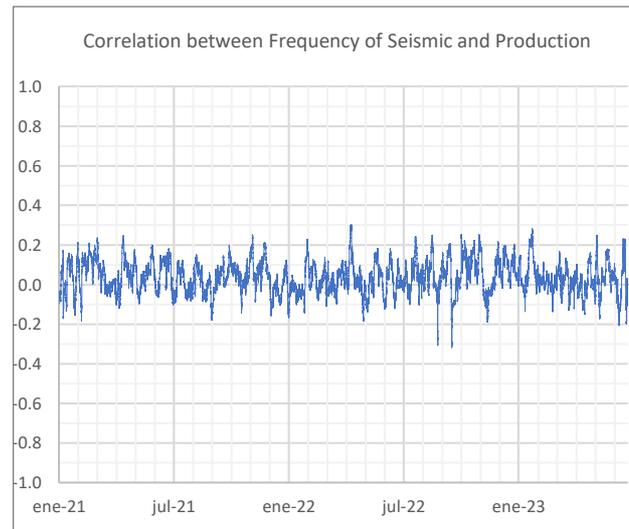


**Figure 6**    **Correlation curve between frequency of seismic and extraction from the caving propagation area.**

While there are multiple factors that can interfere with the seismicity of a sector, such as blasting, hydraulic fracturing, mining preparation, etc., monitoring through the level of triggers in a sector shows interesting results when correlated with extraction from the caving propagation area. This situation allows for the management of operational protocols in response to an increase or decrease in the trigger level, aiming to maintain the operational continuity of the sector.

## 4    CONCLUSION

The presented criterion counts the number of triggers from each station located within the seismic control halo and is not dependent on events that are in processing. Therefore, it takes into account the excitation of each sensor near the sector. It can be considered a flexible criterion because the PPV threshold can be defined according to the activity in the sector, meaning that the level of seismic risk to be assumed can be managed. This criterion helps us, in a simple way, better understand the relationship between mining behavior and seismicity.

## REFERENCES

Espíndola, J., Balboa, S. & Parraguez, R. (2021). Mina Pilar Norte, Minería 2018 a 2021. Informe interno, GRMD-SGO-INF-007-2021.

Muñoz, R. & Olguín, S. Criterio Frecuencia Triggers (CFT), Mina Pilar Norte. Presentación Interna.