



OPTIMIZATION OF FLYROCK AND GROUND VIBRATIONS IN BLAST DESIGN: A CASE STUDY FROM THE BALANGERO MINE IN ITALY

Matteo Iacopo LOMBARDO^{1*}, Sebastiano D'ALIO²

¹Student, School of Engineering and Architecture, Department of Civil, Chemical, Environmental and Materials Engineering, University of Bologna, Bologna, Italy, matteo.lombardo6@studio.unibo.it

²Student, School of Engineering and Architecture, Department of Civil, Chemical, Environmental and Materials Engineering, University of Bologna, Bologna, Italy, sebastiano.dalio@studio.unibo.it

DOI: 10.2478/minrv-2026-0023

received – 06.03.2026 / revised – 09.03.2026

accepted – 04.05.2026 / published – 22.09.2026

Abstract: This study investigates the optimization of flyrock and blast-induced ground vibrations in open-pit blasting operations through numerical simulation using O-Pitblast software. The reference site is the Balangero mine, located in the Lanzo Valleys (Piedmont, Italy), historically one of the most significant European deposits of serpentinite and asbestiform fibers. The explosive configuration consists of CHE-ANFO EXTRA cartridges (90x500 mm) as column charge, APB 1350 pentolite boosters, and Rock Star 25/50 delay detonators in compliance with Italian regulations prohibiting the use of bulk explosives. Three rectangular blast patterns were evaluated by varying hole spacing and number of holes per row, keeping constant the number of rows, the burden, and inter-hole (75 ms) and inter-row (1 s) delays, while varying spacing and the number of holes per row. Ground vibrations were assessed through an attenuation law with the following parameters: $k = 1500$, $\alpha = 0.6$, $\beta = -1.2$, (90% confidence level), without exceeding the Peak Particle Velocity (PPV) threshold of 15 mm/s at any surrounding structures. Flyrock clearance zones remained within 24 m for personnel and 16 m for equipment, well below regulatory limits. The result of this study highlights that detonation timing, particularly inter-row delay, is the critical variable in simultaneously controlling flyrock projection and seismic wave propagation.

Keywords: Open-pit, blast design, delays, hole spacing, fractures, O-Pitblast, ground vibrations, Peak Particle Velocity, attenuation law, flyrock

1. Introduction

In mining and quarrying operations, blasting is the primary technique adopted for mining exploitation. Usually, significant attention is given to fragmentation size and blast efficiency; however, the control of blast-induced side effects, such as flyrock projection and ground vibrations, represents a critical and fundamental challenge, carrying direct risks to personnel, equipment, environment and surrounding infrastructure.

During blasting operations, only a small fraction of the chemical energy stored in the explosive effectively contributes to rock fragmentation. Most of this energy is typically dissipated in non-productive forms, including seismic wave propagation (ground vibrations), thermal energy, acoustic energy and flyrock [1]. Controlling and minimizing this energy loss is essential not only for the blast efficiency but also for ensuring operational compliance.

Located in the Lanzo Valleys in Piedmont (Italy), the Balangero mine was historically one of the largest asbestiform deposits in Europe. It was exploited through an open-pit configuration until 1990, the year in which it was closed following the scientific consensus on the carcinogenicity of asbestos. Figure 1 shows the current state of the mine, where a well-defined bench geometry is still visible. Furthermore, the Balangero site represents a particularly instructive case study due to its proximity to residential buildings and the geomechanical complexity of its rock mass.

The present study focuses on the analysis and optimization of flyrock and ground vibrations among three different blast configurations, simulated using the O-Pitblast software. The objective of this work is to identify

* Corresponding author: Matteo Iacopo Lombardo, Student, Università di Bologna, Italy, +393201187689, matteo.lombardo6@studio.unibo.it

the optimal blast design parameters, such as spacing, number of holes, and detonation timing, that simultaneously satisfy safety clearance requirements for both flyrock and ground vibrations.



Fig. 1. Balangero mine (Google Earth screenshot)

2. Methodology

2.1 Simulation Software: O-Pitblast

O-Pitblast is a specialized software dedicated to the design and optimization of blast operations for open-pit quarries and mines. The software integrates topographic data, rock mass geomechanical properties, explosive characteristics, and detonation timing into a comprehensive numerical model. This allows us to generate a blast pattern highly representative of actual field conditions.

In this study, in addition to core features such as the estimation of the material size distribution, the software was employed to simulate the spatial distribution of flyrock clearance zones and to simulate Peak Particle Velocity (PPV) values at specific monitoring points corresponding to the locations of surrounding infrastructures.

2.2 Ground Vibration Assessment

Ground Vibrations were estimated using the attenuation law, a widely adopted empirical model in blasting engineering:

$$PPV = K * SD^{\beta} \quad (1)$$

where PPV is the Peak Particle Velocity (mm/s), SD is the Scaled Distance defined by the following relation:

$$SD = \frac{D}{\sqrt[n]{Qe}} \quad (2)$$

where D is the distance (in meters) from the blast, Qe is the maximum charge per delay (kg). The parameters K, n and β depend on the site-specific geological conditions. In this study, the attenuation law parameters: $K = 1500$, $\alpha = 0.6$, $\beta = -1.2$ and $n = 2$, were prescribed as fixed input values for the simulation framework, reflecting a 90% confidence level. The fixed exponent $\beta = -1.2$ is consistent with values reported for metamorphic hard rocks: Nitheesh et al. (2021) [2] obtained $\beta = -1.19$ from trial blasts in charnockite, a high grade metamorphic rock with comparable properties. On the other hand, Görgülü et al. (2013) [3] documented K values ranging from 211 to 3671 in hard rocks open pit mine, placing $K = 1500$ within the central range. A PPV threshold of 15 mm/s was adopted by O-Pitblast as the default limit for infrastructures and residential buildings; therefore, all blast configuration results were required to be lower than this value to be considered valid. This value is consistent with internationally recognized vibrations standards, such as those established by the U.S. Bureau of Mines [4].

Two main monitoring infrastructures were identified: a residential building, 400 m from the blast area, and a second building, located 700 m from the blast area. As predicted by the attenuation law, a decrease of PPV was observed with increasing distance, a trend confirmed across all three blast configurations.

2.3 Flyrock Assessment

Flyrock clearance zones were estimated by O-Pitblast incorporating parameters such as explosive charge per hole, burden, stemming length, and rock mass properties. These zones were delineated by accounting for the three primary mechanisms governing flyrock: cratering, which involves vertical ejection of material; rifling, usually associated with stemming ejection due to incorrect design, and lastly face burst, resulting in material ejection toward the free face of the bench.

Two different clearance zones were identified, one for personnel and one for equipment. Each zone is associated with a minimum safety factor, applied to the estimated flyrock distance to account for uncertainties related to geological variability, blasting execution, and model limitations. Specifically, the software multiplies the calculated maximum distance by a safety factor (2 for personnel and 1 for equipment) to obtain a conservative value for the clearance zones. In this study, the maximum permissible clearance distance is 50 m for personnel and 25 m for equipment.

2.4 Explosive and Timing System

The explosive configuration and timing delays were kept identical across all three blast designs. To comply with Italian regulations prohibiting bulk explosives, cartridges were employed for both the column charge and bottom hole charge. The column charge consisted of CHE-ANFO EXTRA cartridges (90x500 mm), while the bottom hole charge consisted of APB 1350 pentolite cartridges (90x143 mm). The detonator used in this study was the Rock Star 25/50 electric detonator [5]. Table 1 shows CHE-ANFO EXTRA and APB 1350 key features:

Table 1. CHE-ANFO EXTRA and APB 1300 key features [6], [7]

Parameter	CHE-ANFO EXTRA	APB 1300
Density	0.8 kg/dm ³	1.55 kg/dm ³
RWS	80.5 %	-
VOD	2600 m/s	7300 m/s
Specific Energy	3.57 MJ/kg	-

The following scheme was adopted for the firing sequence: 75 ms of inter-hole delay within each row and 1 s delay between successive rows. These delay values were the result of iterative adjustment: it was proved that lower inter-hole delays produced PPV values exceeding the 15 mm/s threshold, while the 1 s inter-row delay was essential for distributing the explosive energy release, reducing peak ground vibrations.

3. Case Study: Balangero mine

3.1 Site Description and Rock Mass Properties

The Balangero mine is situated in the Lanzo Valleys, Piedmont (Italy), within the Piemonte Ophiolite ultramafic complex. The rock mass consists predominantly of serpentinite derived from alpine peridotites and dunites, intersected by chrysotile asbestiform veins, talc and carbonate layers and characterized by the presence of sub-vertical joints and schistosity planes. [8]

The geomechanical parameters adopted in the simulation are summarized in Table 2. It should be noted that the reported values do not reflect the current in situ conditions of the Balangero mine, where mining operations ceased in 1990. Therefore, there are no site specific geomechanical parameters available in the literature for the studied mine. Consequently, the adopted values were derived from multiple literature studies on serpentinite formations in other Italian regions and countries, by selecting parameters representative of rock masses comparable to those at Balangero. The rock mass was modeled under dry conditions, consistent with the general geological setting of the Balangero area.

Table 2. Serpentinite parameters [9], [10]

Parameter	Value
UCS	95 MPa
Young's Modulus (E)	40 GPa
Poisson's Ratio (ν)	0.25
Density	2.65 t/m ³
Rock Factor (A)	5
RMD	50

3.2 Blast Pattern Geometry

The studied bench geometry is characterized by a height of 12 m and a width of 10 m. All three blast designs share the following parameters: 3 rows, a burden of 3 m, a hole diameter of 102 mm, an inclination of 34° , a subdrilling of 1.5 m, and a stemming of approximately 20% of hole length. Figure 2 shows a screenshot of a bore hole used in the simulation.

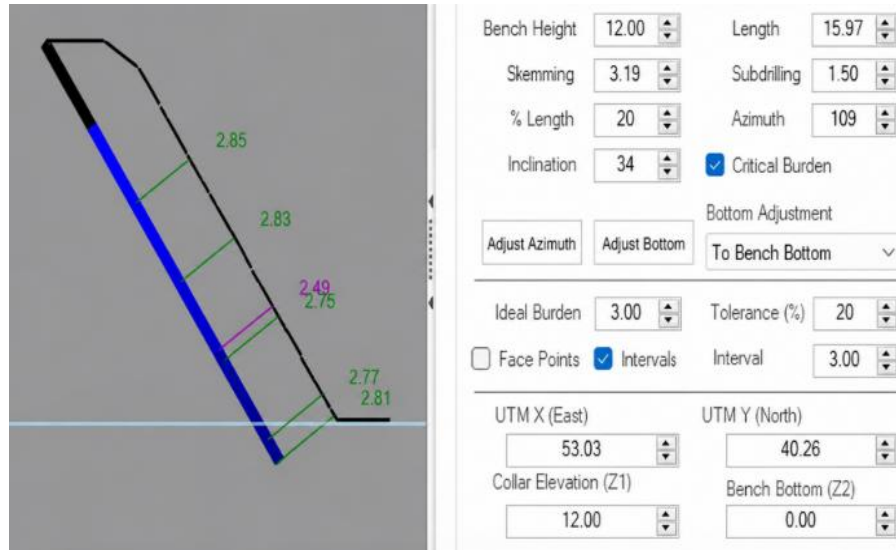


Fig. 2. Bore holes configuration (O-Pitblast screenshot)

4. Results and Discussion

4.1 Blast pattern 1: Spacing = 2.70 m, 5 Holes per Row

This first blast pattern configuration was used to understand how parameters like hole spacing and hole numbers per row affected the results in terms of PPV and flyrock. The first attempt features a hole spacing of 2.70 m, with 5 holes per row. The simulation gave us the following results: the nearest residential building, located at approximately 400 m, records a predicted PPV of 12.8 mm/s, while the second monitored structure, located at approximately 700 m, records 6.7 mm/s, well below the threshold. The results are shown in Figure 3.

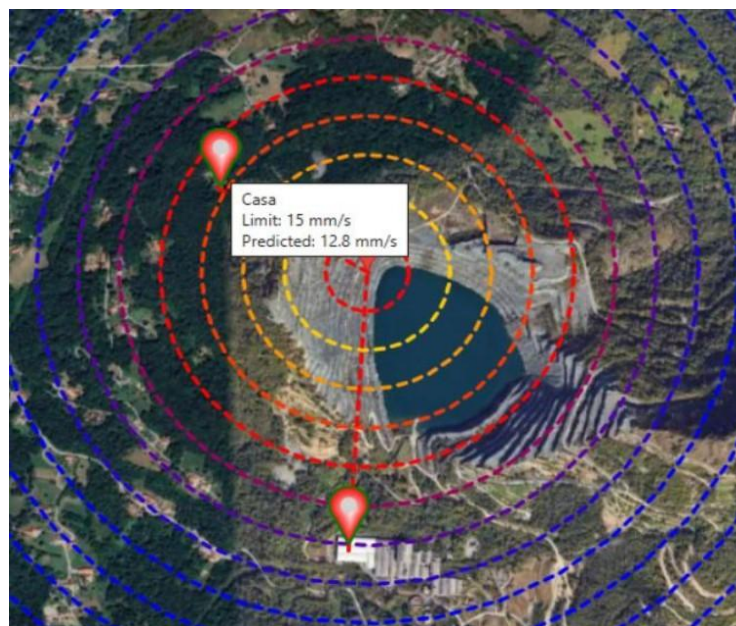


Fig. 3. First blast pattern PPV results (O-Pitblast screenshot)

Regarding flyrock, the clearance zone for equipment is 16 m (limit 25 m), for personnel it is 24 m (limit 50 m). The results are shown in Fig. 4.



Fig. 4. First blast pattern clearance zones (O-Pitblast screenshot)

Both obtained results, in terms of PPV and flyrock clearance zone, were below the imposed thresholds. Although these results met the initial safety requirements, the main goal of this study was to optimize the blast design. Therefore, subsequent simulations were conducted to further reduce these values by varying the spacing and the number of holes per row.

4.2 Blast pattern 2: Spacing = 2.60 m, 6 Holes per Row

In the second attempt, the spacing was decreased to 2.60 m, at the same time the number of holes per row was increased to 6 to maintain a constant volume of blasted material. This reduction in spacing is based on a counter-intuitive principle: the induced detonation overpressure is less effectively utilized in fragmenting the rock between adjacent holes when the spacing is higher. Consequently, a fraction of the pressure energy is not converted into fragmentation work but instead propagates as elastic energy through the ground, increasing PPV at the monitoring points.

As a result, the predicted PPV at the nearest building decrease from 12.8 to 12.6 mm/s, while the predicted PPV of the second building remains constant at 6.7 mm/s, unaffected by the spacing change due to its greater distance. Fig. 5 shows the simulation results.

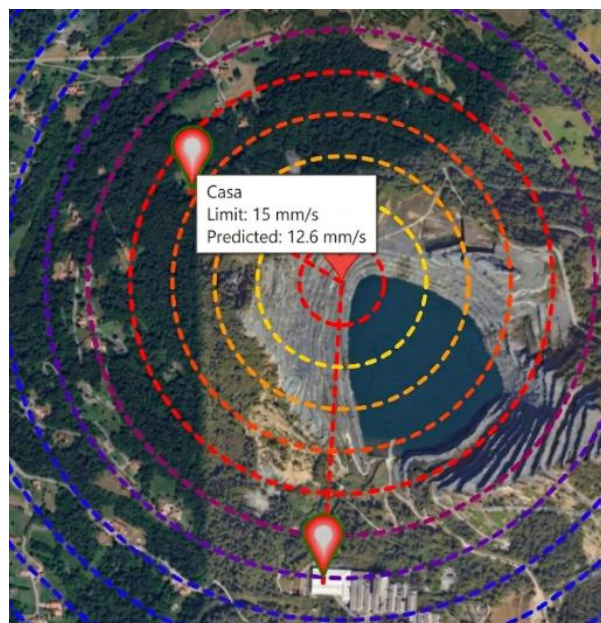


Fig. 5. Second blast pattern PPV results (O-Pitblast screenshot)

Simultaneously, flyrock clearance zone decrease from 16 to 15 m for equipment and from 24 to 23 m for personnel. Narrowing the spacing promotes more fractures between adjacent blast holes, allowing detonation gases to effectively expand through those fractures. Therefore, the total blast energy is primarily directed toward rock fragmentation, minimizing the wasted energy contributing to flyrock generation. Fig. 6 shows the clearance zones for the second blast pattern.

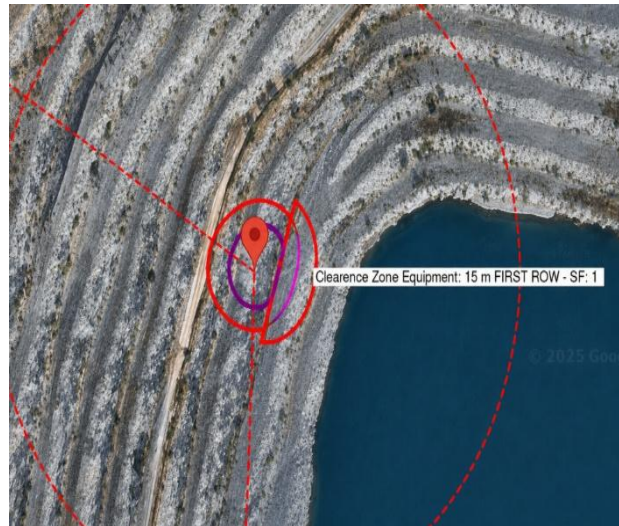


Fig. 6. Second blast pattern clearance zones (O-Pitblast screenshot)

4.3 Blast pattern 3: Spacing = 2.50 m, 6 Holes per Row

In the third and final attempt, the spacing was further decreased from 2.60 to 2.50 m, while the number of holes per row was kept equal to 6. Under this scenario, the predicted PPV at the nearest residential building further decreases to 12.5 mm/s, marginally lower than in the previous two cases. The second monitored building still records a stable predicted PPV equal to 6.7 mm/s, reflecting the results of the previous blast pattern. The progressive decrease in PPV from the first to the third pattern confirms that hole spacing is a dominant geometric factor in controlling vibrations. Fig. 7 shows the PPV results.

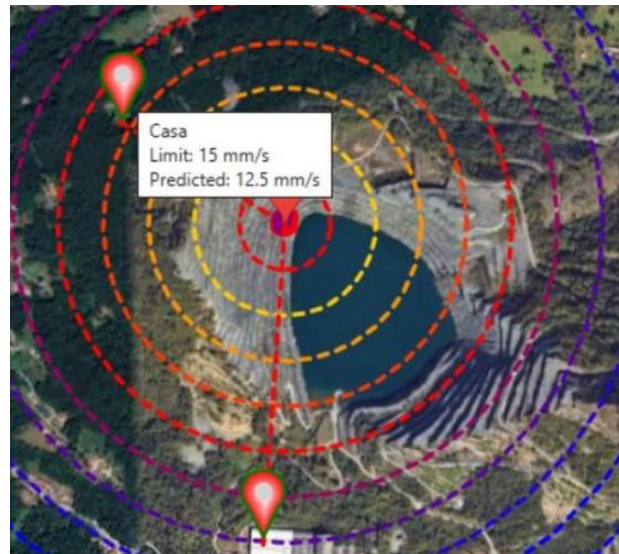


Fig. 7. Third blast pattern PPV results (O-Pitblast screenshot)

Simultaneously, the flyrock clearance zones were further minimized to 11 m for equipment and 21 m for personnel. Although all values remained well below the threshold limits, this result confirms that decreasing spacing leads to lower flyrock projections due to higher fractures between adjacent holes. Fig. 8 shows the clearance zones for the third blast pattern.

In Table 3 a comparative summary of the results obtained from the different simulation scenarios is presented.

Table 3. Comparison of the results obtained

Blast Pattern	Hole Spacing	Holes per Row	PPV (400 m)	PPV (700 m)	Flyrock - Equipment	Flyrock - Personnel
1	2.7 m	5	12.8 mm/s	6.7 mm/s	16 m	24 m
2	2.6 m	6	12.6 mm/s	6.7 mm/s	15 m	23 m
3	2.5 m	6	12.5 mm/s	6.7 mm/s	11 m	21 m

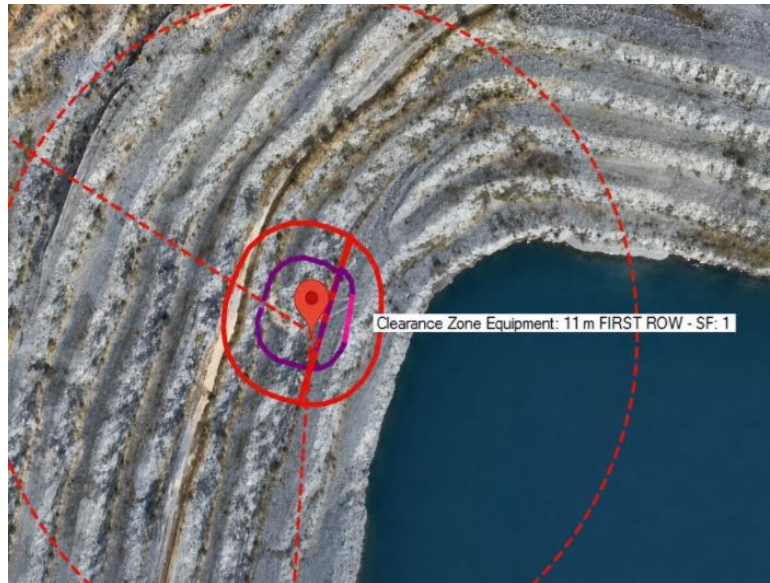


Fig. 8. Third blast pattern clearance zones (O-Pitblast screenshot)

5. Conclusion

This study has demonstrated the effectiveness of simulation-based blast patterns to optimize the control of flyrock and ground vibrations in the Balangero mine, leading to several key conclusions. All the different blast patterns comply with the imposed regulatory limits for both flyrock clearance zones (25 m for equipment, 50 m for personnel) and ground vibrations ($PPV \leq 15$ mm/s in every monitored structure). Among the investigated design parameters, decreasing hole spacing from 2.70 to 2.50 m leads to a significant decrease in both PPV values and flyrock clearance distances. This behavior is attributed to a more efficient distribution of the total energy blast, ensuring that detonation gases are effectively utilized for fracturing the rock mass rather than being dissipated through ground vibrations or flyrock. Furthermore, the inter-row timing delay of 1 s is identified as the most critical design parameter for ground vibration control, as temporally separating the energy release between rows results in a significant reduction of PPV. Finally, O-Pitblast proves to be an effective decision support tool for simultaneously managing multiple conditions, allowing the evaluation of safety compliance before any physical blasting operation takes place.

References

- [1] **Ghojoghi E., Farsangi M.A.E., Mansouri H., Rashedi E., 2024**
Prediction and minimization of blasting flyrock distance, using deep neural networks and gravitational search algorithm, JAYA, and multi-verse optimization algorithms, Heliyon, e37876 10.1016/j.heliyon.2024.e37876
- [2] **Nitheesh N., Padmanabhan G., Sudipta Chattopadhyaya, Rao B.P.C., 2021**
Performance Evaluation of Controlled Blasting and Prediction of Attenuation Relation for Charnockite Rocks, Springer, ISSN 2366-2557 <https://doi.org/10.1007/978-981-16-5601-9>
- [3] **Görgülü K., Erkan Arpaz, Ahmet Demirci, Arzu Koçaslan, M. Kürşat Dilmaç, A. Gürkan Yüksek, 2013**
Investigation of blast-induced ground vibrations in the Tulu boron open pit mine, Springer, 10.1007/s10064-013-0521-4
- [4] **Siskind D.E., Stagg M.S., Kopp J.W., Dowding C.H., 1980**
Structure Response and Damage Produced by Ground Vibration From Surface Mine Blasting, Report of Investigation 8507. U.S. Bureau of Mines RI8507-BlastingVibration-scanned.pdf
- [5] **Austin Powder Company, 2018**
RockStar 25/50, Product Information Brochure, DE_ROCKSTAR_25-50
- [6] * * *
VS Italia. CHE-ANFO-EXTRA Technical Data. CHE-ANFO-EXTRA-Dati-tecnici.pdf

[7] **Austin Powder Company**, 2019

APB Booster Technical Information Brochure, Microsoft Word - AP-Boosters APBÂ® - PIB - TDS -E

[8] **Debret B., Andreani M., Godard M., Nicollet C., Schwartz S., Lafay R.**, 2013

Trace element behavior during serpentinization/de-serpentinization of an eclogitized oceanic lithosphere: A LA-ICPMS study of the Lanzo ultramafic massif (Western Alps), Chemical Geology, 117-133

<https://doi.org/10.1016/j.chemgeo.2013.08.025>

[9] **Diamantis K., Fereidooni D.**, 2023

Assessing the Strength and Deformation Properties of Serpentine Rocks in Dry and Saturated Conditions, Iranian Journal of Science, 47:1169–1178 <https://doi.org/10.1007/s40995-023-01512-9>

[10] **Punturo R., Visalli R., Cirrincione R.**, 2023

A Review of the Mineralogy, Petrography, and Geochemistry of Serpentine from Calabria Regions (Southern Italy): Problem or Georesource, Minerals, 13, 1132 <https://doi.org/10.3390/min13091132>



This article is an open access article distributed under the Creative Commons BY SA 4.0 license. Authors retain all copyrights and agree to the terms of the above-mentioned CC BY SA 4.0 license.