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Correlation of Rock and Blast Properties with Elevated Quarry Floor and their Effects on Mining Costs

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Abstract: *This study investigates the relationships between rock properties, blasting parameters, and their impact on quarry floor elevation and mining costs at Mount Olives quarry. Rock properties (uniaxial compressive strength, tensile strength, density) and blasting parameters (blast hole diameter, explosive type, stemming length) were analyzed. Statistical models correlated rock, blast, and quarry floor properties. Results showed significant correlations between rock properties and blasting parameters, affecting quarry floor elevation and mining costs. Compressive strength and tensile strength influenced blast energy, while rock density impacted quarry floor stability. Mining costs were predicted using statistical models incorporating rock and blast properties. This research demonstrates the importance of understanding rock and blast interactions in optimizing quarry operations and reducing mining costs. The findings provide valuable insights for quarry managers, blasting engineers, and geotechnical professionals.*

Keywords: Rock properties, blasting parameters, quarry floor elevation, mining costs, statistical modeling.

INTRODUCTION

Mining operations, particularly in the quarrying industry, rely heavily on efficient blasting techniques and optimized rock fragmentation to control costs and ensure productivity (Domfeh et al., 2017; Taiwo et al., 2023). Elevated quarry floor, resulting from various geological factors and mining practices, can significantly influence the outcomes of blasting and subsequent mining costs (Ampadu et al., 2020, Taiwo et al., 2024). The elevated quarry floor in mining operations in Northcentral Nigeria introduces complexity to blast design and fragmentation due to variations in rock properties, potentially impacting mining costs; however, there is a lack of comprehensive research exploring the correlation among these rock and blast properties, and their direct effects on mining cost.

The aim of this research is to establish the correlation between rock and blast properties, particularly in the context of elevated quarry floor, and their direct impacts on mining costs. The specific objectives are to:

- Determine the properties of selected rocks at Mount Olives quarry.

- Obtain and generate data on blasting parameters.

- Determine the effect of blast and rock parameters on quarry floor and mining cost.

- Correlate and develop statistical models.

Geological factors significantly influence the rock properties encountered in quarries, and understanding these factors is fundamental to optimizing blast design and mining costs. In Northcentral Nigeria, the geological landscape is characterized by a diverse range of rock formations. Rock properties such as hardness, density, and fracture patterns play a pivotal role in blast design and fragmentation (Olaleye, 2010, Adebayo et al., 2024). Local geologists have identified the need for a systematic study to understand the correlation between rock properties, blast characteristics, and mining costs within the context of elevated quarry floors in Nigeria.

Blast design parameters such as hole diameter, spacing, and explosive type are critical considerations (Katsabanis et al., 2013, Hosseini et al., 2023). Research has shown that tailored blast design parameters that consider rock properties can significantly improve fragmentation efficiency and reduce operational costs. Elevated quarry floors introduce unique challenges to blast design and fragmentation due to variations in bench heights and the depth of the quarry. Research by Ampadu et al. (2020) explores the impact of pit depth on optimum pit slope angles in open-pit mining.

DESCRIPTION OF THE STUDY AREA

The study area for this research is Mount Olive Quarry, situated along the Baala-Eiyenkorin road in Asa Local Government Area, Kwara State, Nigeria, the area exhibits a diverse geological landscape comprising various rock formations. These formations encompass igneous rocks like granite, and less common metamorphic rocks such as schist and gneiss. Structural features like folds, faults, and fractures are also present, influencing rock distribution and characteristics.

The geological history of the area provides context for the formation of the igneous rocks which are potentially emplaced during past geological events. This historical perspective enriches the comprehension of the geological framework.

Furthermore, the region's geological context is economically pertinent due to the presence of valuable resource granite. Understanding the geological attributes of these resources is fundamental for sustainable and efficient resource utilization. Moreover, the geological setting influences the potential environmental and community impact of quarrying operations, necessitating rigorous environmental impact assessments and mitigation measures.

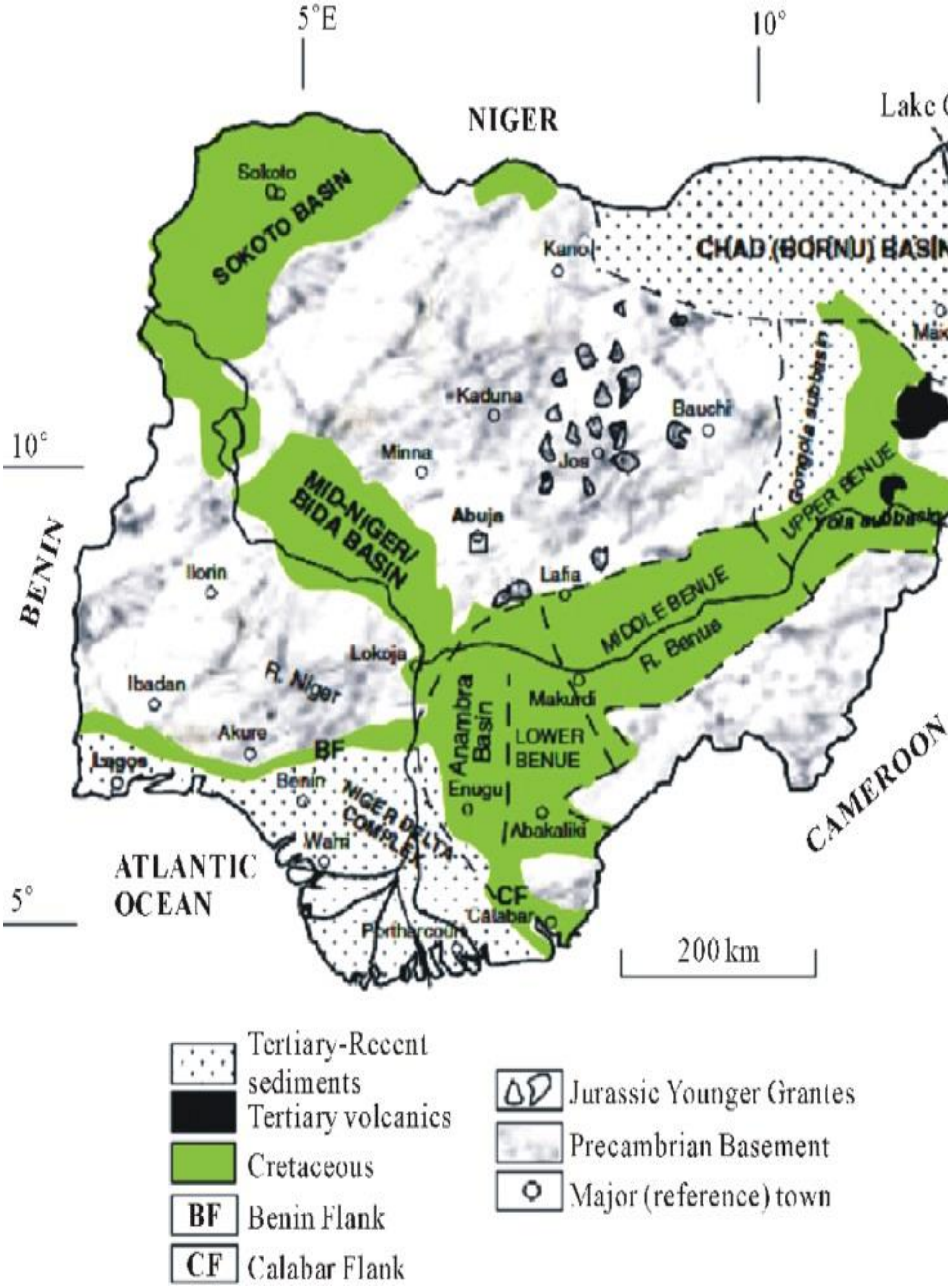

Fig 1: Geological map of Nigeria showing the major geological components (after Obaje *et al.*, 2009)

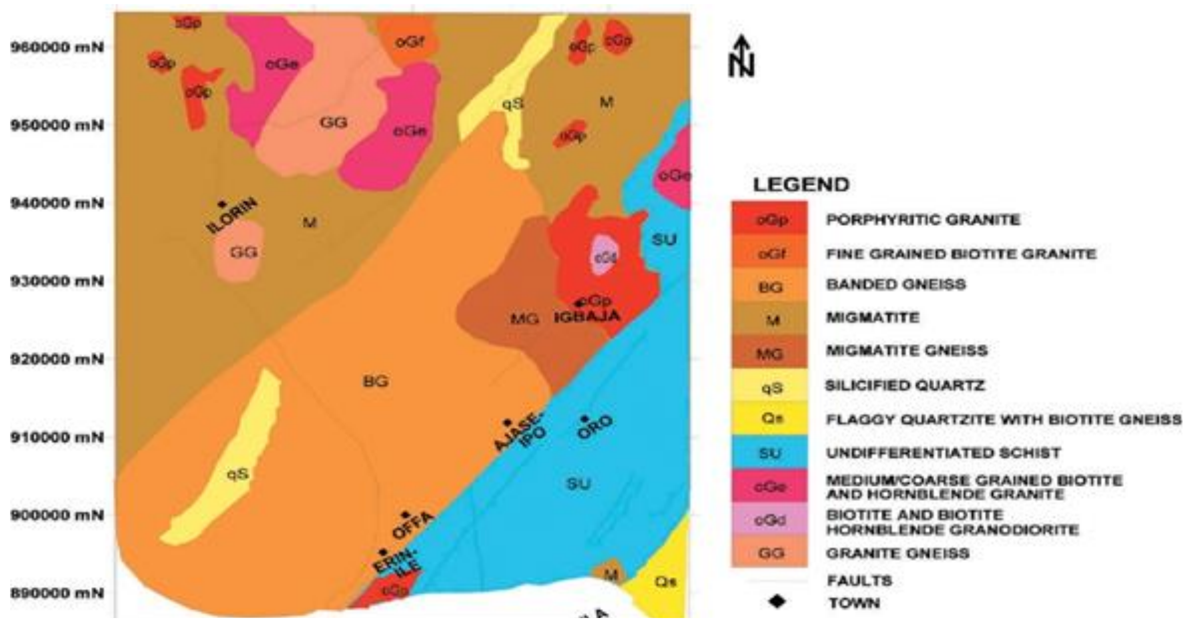

Fig. 2: The-geologic-map-of-the-study-area-after-Nigerian-Geological-Survey-Agency, 2006

METHODOLOGY

The geological survey played a crucial role in understanding the quarry site's conditions. Our methodology involved eight key steps: planning, field observations, geological mapping, sampling, geophysical surveys, laboratory analysis, data management, and interpretation. The survey's objective was to obtain a comprehensive understanding of the geological conditions at the quarry site. Various data collection methods were employed, including field notes, photographs, rock samples, geophysical data, and laboratory analysis results. These methods allowed for a thorough understanding of the site's geological features.

Rock Properties and Sampling

To comprehend rock properties, we collected representative samples and prepared them for laboratory analysis. Our sampling design considered factors like lithology, stratigraphy, and structural features. The laboratory tests determined density, compressive strength, hardness, and mineral composition using standardized methods (ASTM, 1994; ISRM, 1981, 1989).

Blast Data Collection and Analysis

Blast data collection involved gathering information on blast design parameters, explosive types, drilling patterns, and timing. Analysis of this data revealed the impact of these factors on quarry floor elevation and mining costs. Notably, variations in blast design significantly influenced floor elevation.

Drilling Patterns and Explosive Types

Drilling patterns and explosive types played critical roles in blast efficiency. Different patterns and explosives affected rock fragmentation, floor elevation, and overall mining costs. Understanding these relationships is essential for optimizing quarry operations.

Mining Cost Data Collection and Analysis

Data collection on drilling, blasting, excavation, and elevated floor impact costs revealed substantial contributions to overall mining expenses. Elevated floor costs, in particular, highlighted the need for optimized blast design.

Relationship Between Rock, Blast, and Quarry Floor Properties

Preliminary analysis suggests a correlation between rock properties, blast parameters, and quarry floor elevation. Optimizing blast design based on rock properties may minimize floor elevation and reduce mining costs. Further analysis is necessary to confirm these findings.

Blast Design Parameters

Blast design parameters, such as hole diameter, depth, and explosive type, significantly influenced quarry floor elevation. Understanding these parameters is crucial for optimizing blast design and minimizing costs.

Timing and Sequence of Blasts

The timing and sequence of blasts also affected quarry floor elevation. Analysis of blast timing revealed opportunities for improvement in blast efficiency.

RESULT AND DISCUSSION

Table 1: Summary of Rock Properties of the Rock in the Study Area

1.	Rock Type	Granite
2.	Compressive Strength	153.25 MPa
3.	Tensile Strength	19.5 MPa
4.	Density	2.9 g/cm^3
5.	Hardness	6 on mohr scale

Geological properties of granite have significant implications for quarry operations. These properties make drilling and blasting challenging, particularly in elevated quarry floor environments.

Effects on Mining Costs

The high compressive strength, density and hardness of granite increase

- Drilling cost due to equipment wear and slower drilling rates
- Explosive costs due to the need for powerful explosives
- Fragmentation variability, leading to additional secondary breaking costs.
- Equipment maintenance and replacement costs
- Blast optimization and planning

Table 2: Blast Parameters for a Blasting Operation

1.	Spacing	2.5 m
2.	Burden	3 m
3.	Hole Diameter	76 mm
4.	Hole Depth	10 m
5.	Drilling Pattern	Grid
6.	Explosive Type/quality: Blast Pattern design	High explosive/Water gel
7.	Blast Pattern Design	Rectangular
8.	Timing and Sequence of Blasting	25 milliseconds

The blast parameters influence quarry operations in the following ways:

1) Spacing and Burden - distribution of explosives energy and fragmentation effectiveness

2) Hole Diameter and Depth - volume of rock broken and explosive amount

3) Drilling Pattern - uniformly and efficiency of blast

4) Explosives Type/Quality - energy release and fragmentation quality

5) Blast Pattern Design - overall blast effectiveness

6) Timing and Sequence: controlled fragmentation and reduced adverse effects

Understanding and adjusting blasting parameters in relations to rock properties and elevated quarry floor are essential for optimizing quarry operations. Properly correlating these factors can significantly impact drilling costs, explosives efficiency, fragmentation quality and overall mining costs, highlighting the importance of precise and adaptive blast design in elevated quarry floor environment.

Table 3: Drilling Cost for the Blasting Operation

1.	Drilling Cost per meter	
	(inclusive consumables, fuel, accessories and labour)	₦6,500
2.	Total depth of hole	700 m
3.	Total Drilling time	56 hours
	Total Drilling cost	₦4,550,000

Variation in rock properties at different elevations can lead to increased drilling costs per meter, extended drilling times, and higher overall operational costs. Effective management and optimization of drilling and blasting operations are crucial to mitigating these costs and ensuring efficient and cost effective mining operations in elevated quarry floor environments.

Table 3: Blasting Cost for the Blasting Operation

1.	Explosive Cost	₦ 33,668,250
2.	Labour Cost	₦ 34,000
3.	Other Cost	₦ 388,000
	Total	**₦ 34,090,250**

The blasting cost increases with the number of holes to be blasted because more explosives were used while other factors have little or no effect on the blasting cost.

Table 5: Excavation Cost for five Blasting Operations

S/N	Blasting No	Excavation Cost
1.	First Blasting	₦ 5,670,000
2.	Second Blasting	₦ 5,570,000
3.	Third Blasting	₦ 6,300,800
4.	Fourth Blasting	₦ 5,980,300
5.	Fifth Blasting	₦ 6,797,400

Excavation cost is not proportional to blasting costs because the quarry floor geometry (elevated quarry floor) made excavation more challenging and costly regardless of blasting. More so, blast induced damage is done to the quarry face wall as a result of elevation of the quarry floor that does not allow maximum throw of blasted rocks to be achieved, therefore resulting in back breaking and uneven fragmentation of blasted rock. All these increase excavation cost, even where least drilling and blasting cost were achieved.

Table 6: Elevated Quarry Floor Cost for Five Blasting

S/N	Blasting No	Height of Elevated floor	Elevated Floor Cost
1.	First Blasting	3.2 m	₦ 23,927,535
2.	Second Blasting	4.3 m	₦ 19,089,270
3.	Third Blasting	3.8 m	₦ 25,003,998
4.	Fourth Blasting	4.1 m	₦ 18,778,230
5.	Fifth Blasting	3.1 m	₦ 14,065,218

The table shows the costs implication for the elevated quarry floor which is estimated to be 54% of the mining cost for five different blasting operations carried out. This is because elevated floors necessitate further drilling and blasting, increasing overall costs due to the need for rework and additional resources. Proper planning and optimization of these parameters are crucial to avoid elevated floors and manage overall mining costs effectively. Ensuring accurate drilling and blasting parameters can significantly enhance the efficiency and cost effectiveness of quarry operations.

Table 7: Correlation for the Blast Parameters

	Spacing in meters	**Burden in meters**	**Hole Depth in meters**	**Timing and Sequence of Blasting in milliseconds**
Spacing in meters	1	0.134	0.856	0.535
Burden in meters	0.134	1	0.033	0.250
Hole Depth in meters	0.856	0.033	1	0.294
Timing and Sequence of Blasting in milliseconds	0.535	0.250	0.294	1

Table 7 above presents Pearsons correlation coefficients, illustrating the relationships between four blasting coefficients over time in blasting operations. The coefficients indicate positive relationships, meaning that as one variable increases, the others also tend to increase. Pearson's correlation coefficient not only shows the direction of the relationship but also measures its strength.

The values in the table suggest that there is generally a weak to moderate relationship between most blast parameters. However, the relationship between hole depth and spacing stands out as being strong. Other parameters, such as hole diameter, drilling pattern, explosive type/quantity, and blast pattern design, were not included in the analysis because they remained constant throughout the blast sequence, making correlation testing unsuitable for these variables.

Impact of Rock and Blast Properties on Mining Cost

Rock Properties

* **Hardness (Moh's hardness:6):** Increase energy consumption

* **Density (2.9 g/cm^3):** Requires more explosive energy

* **Rock Strength:** Affects drilling and blasting difficulty

Blast Properties

* **Explosive types and strength:** impacts fragmentation efficiency

* **Blast hole spacing and depth:** optimal spacing reduces costs

* **Charge design:** proper design improves fragmentation and reduces costs.

Correlation of Blasting Cost

Table 8: Present Correlation Blast Parameters

	Explosive Cost in Naira	**Labour Cost in Naira**	**Other Costs in Naira**
Explosive Cost in Naira	1	0.979	-0.824
Labour Cost in Naira	0.979	1	-0.895
Other Costs in Naira	-0.824	-0.895	1

Correlation analysis of the blasting cost shows that there is a strong positive linear relationship between the explosive cost and labour cost which means as explosive cost increases so the cost of labour cost increases while there is a strong negative relationship between other costs which means that as explosive and labour cost increases other costs decreases.

Correlations between the Height of Elevated floor and Elevated Floor Cost

Table 9: Correlation between the Height of Elevated Floor and Elevated Floor Cost

	Height of Elevated Floor Cost in meter	**Elevated floor Cost in Naira**
Height of Elevated Floor Cost in Naira	1	0.113
Elevated floor Cost in Naira	0.113	1

There correlation coefficient between the two variables is 0.1 which is a positive relationship. It means that as the height of elevated floor increases, the cost of elevated floor also increases but there is only a small increase in the cost of elevated floor.

Regression Analysis

Blasting Parameters

Table 10: Blast Parameters Coefficient

Variables	**P-Value**
Spacing in meters	0.629
Burden in meters	0.893
Hole Depth in meters	0.771

Since the p-value of all the variables is greater than the significance level of 0.05, it indicates there is insufficient evidence in the sample to conclude that a non-zero correlation exists.

a. **Elevated Floor:** The p-value of the elevated floor is 0.857 which is greater than the significant level of 0.05 which means that there is no sufficient evidence to conclude that a non-zero correlation exists.

MODELING USING REGRESSION ANALYSIS

Statistical Equation for Blast Parameters

The dependent variable y is the timing and sequence of blasting in milliseconds. The independent variables x is the spacing in meters, burden in meters, and hole depth in meters. The prediction equation will help determine the timing and sequence of blasting in milliseconds given the spacing, burden, and hole depth in meters.

The general prediction equation is expressed in Equation 1

$y = B_0 + B_1 x_1$ …..Equationn 1

where y, Bo, Bi, xi, i y, Bo, Bi, xi, i are dependent variable, the constant, coefficient of the independent variable, independent variable, and the integer number pointing to multiple variables respectively

Since we have three independent variables for the blast parameters, the prediction equation is expressed in Equation 4.2

$y = B_0 + B_1 x_1 + B_2 x_2 + B_3 x_3$ ………..Equationn 2

Where

Y is timing and sequence, B_o is Constant, B_1 is Coefficient of spacing, X_1 is Coefficient of burden, B_2 is Coefficient of Hole Depth, X_2 is Spacing in Meters, B_3 is Burden in Meters, X_3 is Hole Depth in Meters

The model to predict timing and sequence of Blasting is presented in Equation 3

$y = 13.060 + 5.373x_1 + 1.343x_2 + 0.373x_3$ ……..Equationn 3

Where x_1, x_2 and x_3 x_1, x_2 and x_3 are spacing in meters, burden in meters, and hole depth in meters.

Y is Timing and Sequence (Ts), X_1 is Spacing in Meters (Sp), X_2 is Burden in meters (B), X_3 = Hole Depth in meters (Hd).

Therefore, the equation can be re- written as

Ts = 13.060+5.373 Sp + 1.343 B + 0.373 Hd ……...Equation 4

Modeling for the Cost of Elevated Floor

Here the dependent variable y is the elevated floor cost in naira and the independent variable x is the height of the elevated floor.

Since the general prediction equation as expressed in

$y = B_0 + B_1 x_1$ ……....... Equation 1

Then the prediction equation for the cost of an elevated floor given the height of the floor is as presented in equation 4.5

$y = B_0 + Bx$ ....Equation 5

Where y, B_o, B, xy, B_o, B, x are elevated floor cost, constant, coefficient of height of elevated floor, and height of elevated floor.

y is Elevated floor cost (EFC)

B_o is Constant

B is Coefficient of height of elevated floor

X is Height of elevated floor (H)

$y = 16724854.28 + 931890.789x$ ....Equation 6

Where x is the height of elevated floor and y is the cost of elevated floor.

EFC = 1672854.23 + 931890.789 H .... Equation 7

CONCLUSION

The research had correlated blast parameters and Rock properties. It further determined varied elevated quarry floor after blasting as well analyzed their effects on mining cost at Mount Olives quarry and developed statistical model to predict elevated floor

Moreover, the result of rock properties revealed that the selected rock has compressive strength, tensile strength, density and hardness of 135.25 MPa, 19.5 MPa, 2.9 g/cm3 and 6 on moh scale respectively. Hence ,the rock is classified as very strong.

Furthermore the quarry's blasting parameters consisted of 76 mm blast hole diameter, 10-15 m depth, High Explosive/Watergel explosive type, 25-30 ms delay timing, 2-3 m spacing, and 2-3 m burden, which upon analysis revealed inconsistencies in blast design and execution.

The study also revealed significant correlations between various rock properties and blasting parameters, specifically: rock compressive strength and drilling costs, rock density and explosive consumption, blast hole diameter and fragmentation size, and delay timing and vibration level. Additionally, finding revealed that increased rock hardness and compressive strength resulted in higher drilling and blast costs.

Through regression analysis, significant correlations were identified between rock properties and blasting parameters leading to the creation of a predictive Statistical model for mining costs, facilitating optimized blasting and mining operations

Recommendations

1. Implement the Statistical Model: Integrate the developed Statistical model into daily quarry operations to optimize drilling and blasting practices. This will help in preventing the formation of elevated quarry floors and reducing associated costs.
2. The developed statistical models should be used to predict mining costs and Optimize Quarry operations

3. Blast parameters should be tailored to specific rock properties to achieve optimal fragmentation and reduce costs.
4. Regular rock property tests should be conducted to achieve optimal fragmentation and reduce cost.
5. Quarry floor elevation should be monitored regularly to adjust blast design and minimize cost
6. By implementing these recommendations Mount Olives Quarry can optimimize their operations, reduce mining costs and improve overall efficiency

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