

## Geomechanical characterization of carbonates of the Sete Lagoas Formation (Bambuú Group)

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### Abstract

The geomechanical properties of rock masses must be identified to assess their quality and employability; however, the methodologies may differ depending on the lithotype and analytical purposes. The present study aimed to estimate the not-well-known physical-mechanical properties of three types of carbonate rocks (calcarenite, calcilutite, and marble) of Sete Lagoas Formation, which are not recognized in scientific literature, southeast Brazil. These are important rocks from an economic point of view, as they comprise an important input for cement, fertilizers and construction material. Both physical indexes (apparent porosity, apparently dry and saturated specific mass, apparent absorption capacity and wave propagation velocity) and mechanical properties (uniaxial compression, *point load and slake durability*) were determined. Mechanical tests for these three rock types were correlated to those of other carbonate rocks from other countries, for comparisons. The results showed that the lithotypes under study are peculiar in terms of porosity, wave propagation velocity and strength. Also found were a very high durability and a very good correlation between specific mass and uniaxial compressive strength.

**Keywords:** carbonates, Bambuí Group, geomechanical, porosity, physical-mechanical properties.

### 1. Introduction

Geological materials are widely used in engineering works, such as components (foundations, flashboards, underground excavations, e. g.) as well as natural construction materials. For this last use, the search for more competent geological materials that can be used in addition to Portland industry products is fundamental (Thomsen *et al.*, 2016; Nezerka *et al.*, 2018).

The Bambuí Group covers an extensive area of the São Francisco Craton (SFC) extending from central southern Minas Gerais State to southern Bahia State and consists essentially of carbonates. The basal unit of this group (Sete Lagoas Formation) presents some variation in carbonate lithotypes, as a result of different genesis and deposition environment. These rocks are very important as a raw material in the fertilizer

and cement industry and as construction material. However, the lack of information about the mechanical properties of these rocks directly impacts their exploitation and usage characteristics, especially as construction material (aggregate, ballast etc.). Few and recent articles on carbonate-rich rocks, used as raw material for the cement industry, can be found in scientific literature (for marble - Khodabakhshian *et al.*, 2018; Seghir *et al.*, 2018, calcarenites - Baronio *et al.*, 2003; Andriani and Walsh, 2003; and for limestone - Nadelman and Kurtis, 2017; Singh *et al.*, 2019). In Brazil, the articles that deal with this subject are scarce, and rarer are those that discuss its geomechanical characterization, especially for this particular use.

This study aimed to determine physi-

cal and mechanical properties of three carbonate types (calcarenite, calcilutite and marble) from the Sete Lagoas Formation. The aim was to establish correlations between these properties, between rocks under study, and also with other results from literature, to provide a reliable geomechanical characterization.

Rock samples were collected from the study area (Figure 1) at three distinct sites, namely: calcarenites (PL), calcilutites (VS) and marble (MR). These sites are found respectively in the cities of São José da Lapa (Minas Gerais – 424 Road / Km – 30) and Vespasiano (Minas Gerais – 010 Road), closer to Belo Horizonte; while marble (MR) is found near Santana do Riacho, in Serra do Cipó (Minas Gerais / Brazil), which is 75 km from Belo Horizonte.

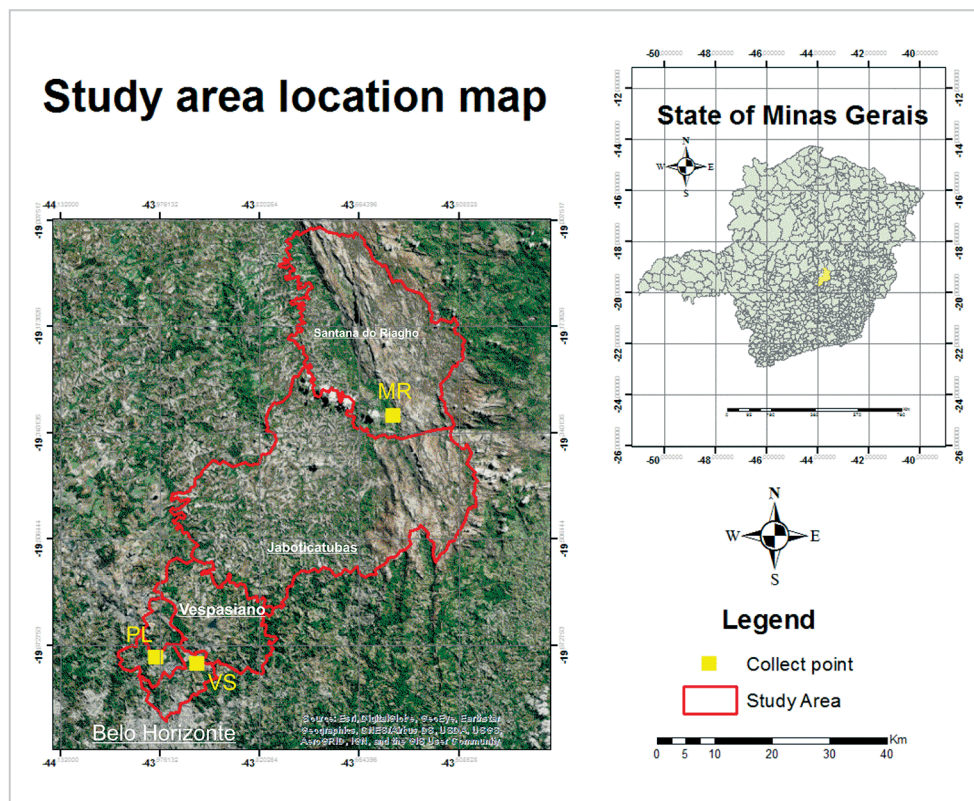


Figure 1 - Study area location map with sampling sites highlighted (in Yellow).

Thin section description of all rocks under study was performed by Ilambwetsi (2015) and allowed the recognition of important microscopic features such as fabric, structures, mineralogy etc. Below is presented a resume of the main aspects related to the physical and geomechanical behaviour of the carbonates.

Calcarenites (PL) consists of medium- to coarse-grained massive calcareous arenite. The sand-sized grains are predominantly angular, and are composed of fragments of limestones and quartz in roughly equal proportions. Reverse gradation is locally observed

and there are no other sedimentary structures. On the thin section, the rock is characterized by a carbonate-rich matrix, granular fabric and grain size varying from medium to coarse, moderately selected. Essential minerals are calcite, quartz, sericite and plagioclase. Calcite grains are mainly euhedral and with crystal twinning. Alteration of plagioclase can be observed, generating sericite and, sometimes saussurite formation.

Calcilutites (VS) present a fine matrix, micritic, and grey pale to light brown colour. Plane-parallel lamination and calcite veins are observed. Tectonic structures, such as boudins also occur.

A fine homogeneous granular fabric with well-selected and subangular calcite clasts can be observed. On crossed nicols, clasts do not present pleochroism.

Marble (MR) consists of banded carbonates with fine grain size and matrix, light and blue grey, with no predominant deformational or sedimentary structures. A plane-parallel stratification (micrite) can be noted, marked by sericite and clay minerals. There are some recrystallized quartz pockets with mica along microfractures and microveins. Sericite are elongated. Some possible gemination among calcite clasts was found.

## 2. Materials and methods

All tests were performed according to the International Society for Rock Mechanics - ISRM standards (1979, 2007), from regular samples. Tests were performed by using saturation and buoyance techniques and correlations between volume and mass. A total of 130 samples

were used for the analysis of physical and mechanical properties. Of these, 60 consisted of test-specimens from each rock and were used for strength tests (destructive). Samples collected in the field are of sound carbonaceous rocks (calcarenite, calcilutite and marble) and where differ-

entiated macroscopically (10X to 30X) for their color, texture and granulometry. As presented in the introduction section, it was also possible to microscopically differentiate the carbonates under study, mainly based on their mineralogy, grain size and microstructures.

## 3. Results and discussion

The results obtained in this study are shown and discussed below, for all lithotypes.

### 3.1 Physical Indexes

Table 1 summarizes the physical indexes of the three carbonate rocks, empha-

sizing the average porosity, void indexes, apparent specific gravity, and density.

Table 1 - Physical indexes obtained for the studied carbonates.

Samples	Porosity ( $\eta$ ) %	Void Indexes (e)	Specific saturated mass ( $\rho_{sat}$ ) (g/cm <sup>3</sup> )	Specific dry mass ( $\rho_d$ ) (g/cm <sup>3</sup> )	Apparent absorption capacity (a) (%)
Calcarenite	74	2.79	2.76	2.75	0.27
Calcilutite	60	1.50	2.72	2.71	0.22
Marble	53	1.11	2.72	2.72	0.19

According to Table 1, the carbonates under study have similar physical properties, although they are genetically and mineralogically different. Marble presents somewhat different physical characteristics from the other two rocks, but when difference is observed, it is around 10%. While the mean porosity (<1%) and void index are low, the specific mass is high (2.7 g/cm<sup>3</sup>). These values differ widely from the findings of Mehrjini *et al.*

(2016) for carbonate rocks of a gas reservoir in southern Iran; Lima *et al.* (2016), for limestones of the Bedford and Edwards Plateau formations in the United States; and Liu *et al.* (2014), for laboratory tests of carbonates in China. These studies showed carbonate rocks with extremely high mean porosity, void indices, and water absorption capacity by tens, but with relatively lower densities compared to the studied carbonates. Same data can be observed

for carbonates analyzed by Ersoy and Kanik (2012) in northeastern Turkey (Pontides), which had a much higher porosity and apparent absorption capacity than the PL, VS, and MR carbonates. The low porosity and high specific mass found for carbonates of the Sete Lagoas Formation might be related to their low weathering degree (sound rock matrix) and to their massive aspect, with few open (and dissolved) fractures.

### 3.2 Point load test

Figure 2 shows all and mean values of  $I_{550}$  (point load strength) for the studied rocks. Besides, the strength

measured parallel to calcilutite, lamination was also evaluated, since this could induce anisotropic behaviour.

The results shown in Figure 2 support this hypothesis.

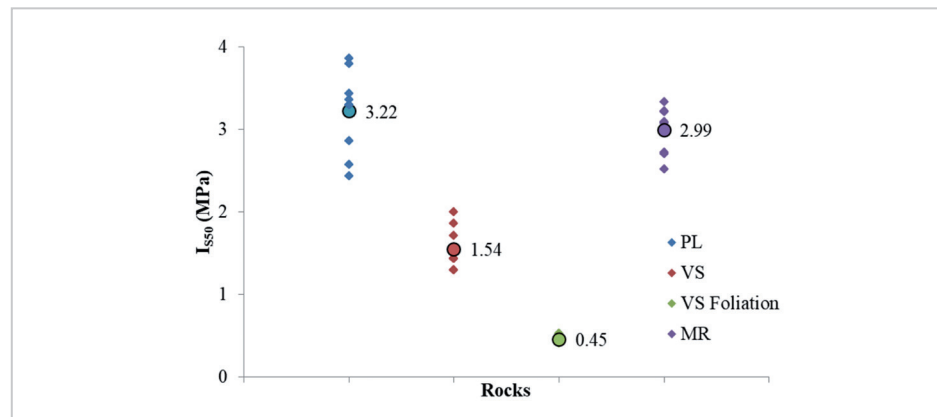


Figure 2 -  $I_{550}$  values obtained from the studied rocks, with emphasis on mean values.

Based on Figure 2,  $I_{550}$  values ranged from 0.40 MPa to 3.86 MPa, with the highest values recorded for calcarenite (PL) and the smallest ones for calcilutite, measured parallel to lamination (VS Foliation). Tsiambaos and Sabatakakis (2004) studied limestones in Greece and observed a range of  $I_{550}$  from 0.37 to 7 MPa, which is similar to that found here (0.4 to 3.8 MPa). Marble

(MR) presented an average of 2.9 MPa, similar to the mean value found for PL (3.2 MPa) with an intermediate value for VS (1.54 MPa).

The lowest strength values were encountered for calcilutite; both perpendicular and parallel to lamination, which are due to the rock mineralogical composition and presence of microstructures. Mineralogically, although its main com-

ponent is calcium carbonate ( $\text{CaCO}_3$ ), calcilutite also presents clay minerals. Structurally, the main weakness plane VS develops parallel to its lamination, which, in the field, corresponds to a plane-parallel lamination. Finally, we have determined the calcilutites anisotropy of resistance, by dividing the higher by the lowest strength value, resulting in an index equal to 3.4.

### 3.3 Uniaxial compressive strength

The mean values of uniaxial compressive strength ( $q_u$ ) of the tested rocks ranged from 14.5 to 37.2 MPa, with the highest values found for calcarenites (PL) and the smallest for calcilutites (VS). Such

range corroborates with those observed by Tsiambaos and Sabatakakis (2004), and within the expected based on field observations. Also, these results are in accordance with the ones found for Point Load tests.

Correlations between  $I_{550}$  and  $q_u$  were tried. Figure 3 shows these correlations for all studied lithotypes. This correlation was very good for PL and VS, but only regular for MR.

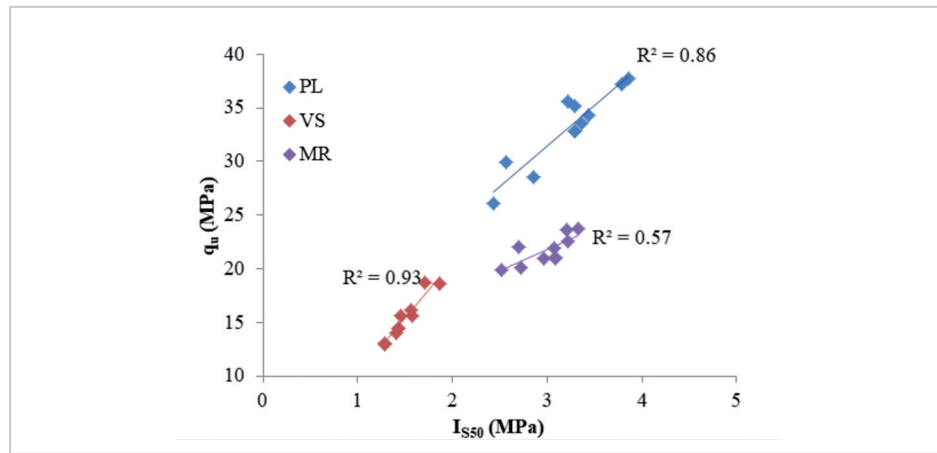


Figure 3 - Correlation between  $I_{S50}$  and  $q_u$  for the studied lithotypes.

This difference between the correlation values of the three lithologies can be explained by the fact that the marble (MR) presents discontinuities (micro-fractures and micro-veins) filled by the rock material itself and also by hydrothermal

fluids with recrystallization of calcite, as observed in the field and in thin sections.

These results allow the characterization of calcilitite (VS) and marble (MR) as soft rocks, whereas calcarenite can be classified as a medium strength

rock (ISRM, 1979). According to the classification proposed by Frazão and Frascá (2002), and based on the values defined by these authors for limestones, none of the rocks above could be used as ornamental rock.

### 3.4 Wave propagation velocity tests

Figure 4 illustrates the results of wave propagation tests on carbonates. The highest values are observed for calcilitites (6500 m/s) and the lowest values for marbles (4163 m/s). These findings are consistent with those of Devonian carbon-

ates studied by Tugrul and Zarif (1999), between 3210 and 6750 m/s. According to Goodman (1989), the propagation velocity of acoustic waves in limestones ranges from 6000 to 6500 m/s, which is within the range observed here for calcilitites but

higher than marbles and calcarenites. The results of wave propagation velocity show no clear correlation with physical and strength parameters for the rocks under study and should not be used to correlate with these properties.

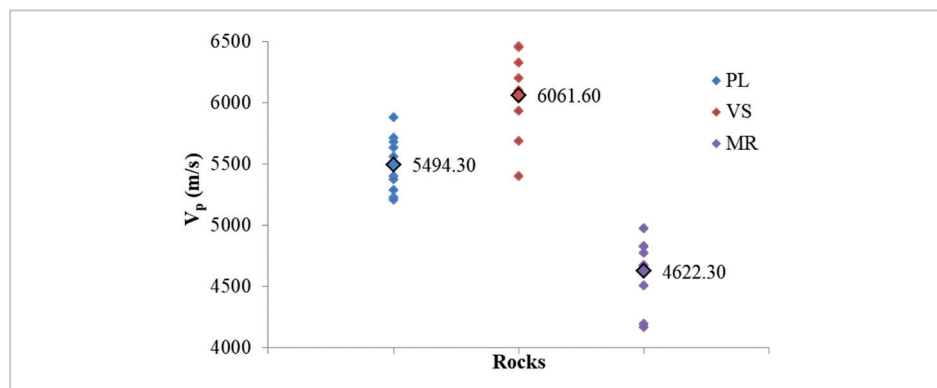


Figure 4 -  $V_p$  values for the studied lithotypes, with emphasis on mean values.

### 3.5 Slake durability test

According to the studies of Franklin and Chandra (1972) and Gamble (1971),

and based on the results shown in Figure 5, the carbonates of the Sete Lagoas Forma-

tion are characterized as extremely durable rocks (> 99% after the first cycle).

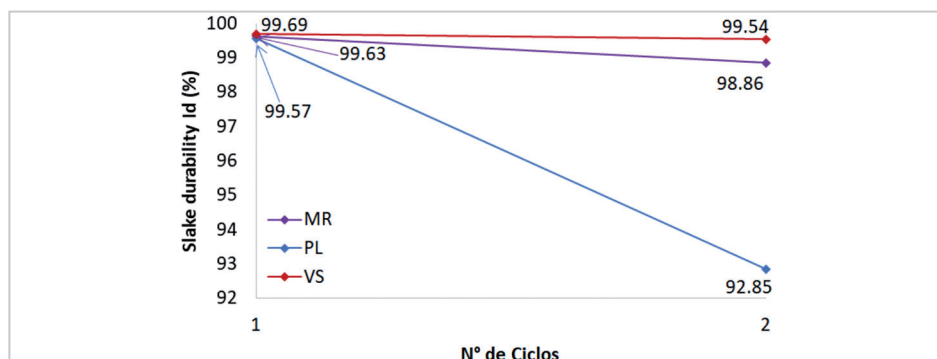


Figure 5 - Two-cycle durability index for PL, VS, and MR carbonates.

In general, these rocks are highly durable, mainly calcilutite, which almost did not undergo any alteration, since their

mass remained constant at the end of both cycles. These results are in line with the results from physical indexes, which show

low porosities and high specific masses, so indicating a massive behaviour of the rocks under study.

### 3.6 Correlations between mechanical properties

The regression analyses performed between the mean values of physical and mechanical properties are shown in Figure 6 (a to d). Correlations are not linear between  $V_p$  and  $I_s(50)$  and  $q_u$  (Figure 6 (a) and 6 (b)), suggesting that velocity is not a good property to correlate with strength for carbonate rocks under study.

Actually, the results show an unexpected behavior, as a reduction in strength, although not always continuous, is observed for an increasing  $V_p$ . This can be related to the influence of lamination planes on velocity propagation, generating unexpected low velocities for the rocks under study.

For the comparison between strength and physical properties (Figure 6 (c) and 6 (d)), correlations are linear, and regular for porosity but very good for specific mass. These results suggest that specific mass can be used as an index property for determining strength for the rocks under study.

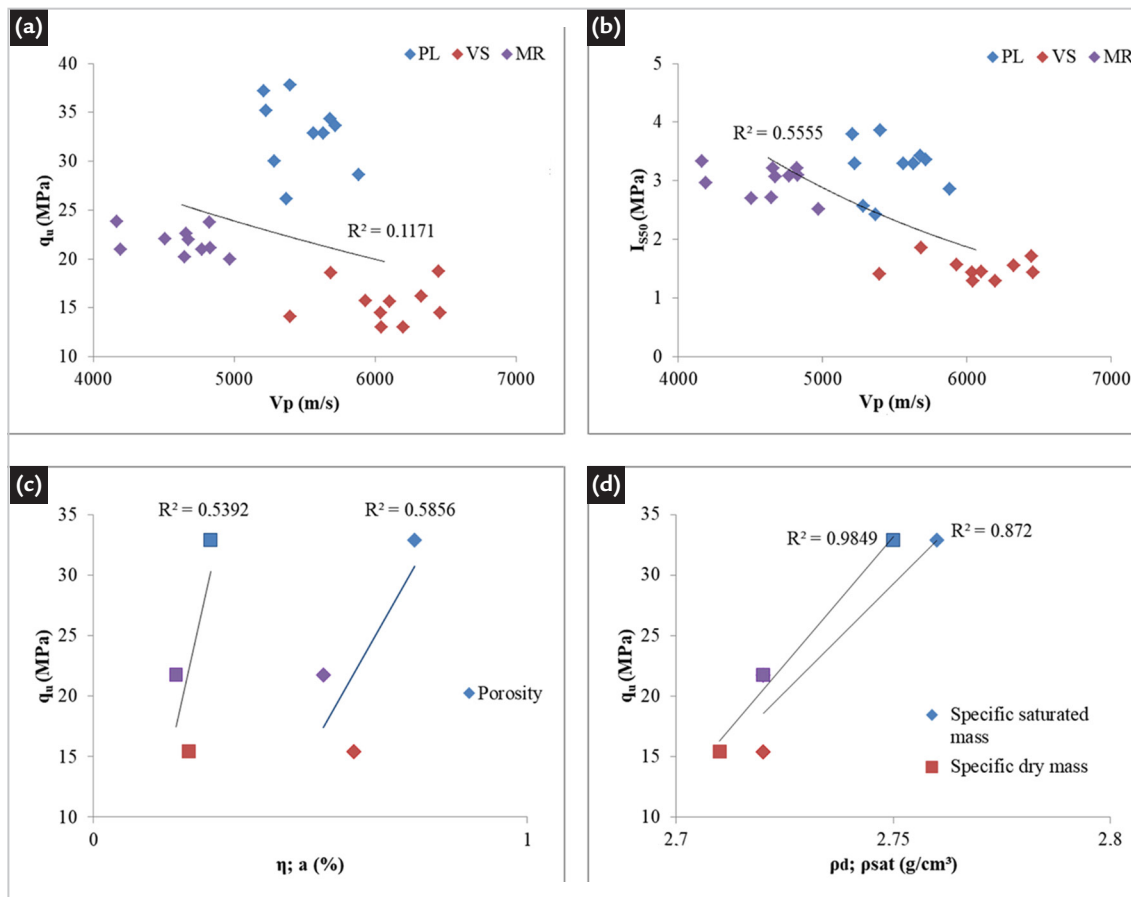


Figure 6 - Correlations between mechanical and physical properties. Values presented on the figures represent average values of PL (blue), VS (red), MR (purple).

### 4. Conclusion

Carbonates from Sete Lagoas Formation exhibit very low porosities and high density, which give them particular characteristics. These physical properties conditioned strength ( $I_{S50}$  and  $q_u$ ) behavior of these rocks, as both calcilutite and marble can be classified as weak rocks, while calcarenites can be classified as medium strength rocks. Wave

velocity has shown a great influence of lamination, leading to an unusual behavior of this property when compared to strength, as it is reduced for higher strength values. Durability of rocks was very high, showing that these rocks are very resistant to weathering.

The three lithotypes are widely used in different applications (cement manu-

facturing, pavement coating, aggregate, railway ballasts etc.), but the results obtained in strength tests suggest that they should not be used as ornamental rocks.

Specific mass can be used as an index property for determination of uniaxial compressive strength, as a very good correlation was found for these two properties.

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