Multicriteria Analysis as a Fundamental Tool for Mineral Research. Case Study: Quadrilátero Ferrífero/Brazil

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Abstract. The "Quadrilátero Ferrífero" (Brazil) had a geological influence for the first explorers who entered Brazil, to explore and to search for precious metals. The geological features and their geomorphological consequences led and influenced the beginning of the occupation of the country area in Brazil. Thus, the presence of mineral deposits conditioned the colonization of the region by the Portuguese in the late seventeenth century. Therefore, in this work, the data, treated by Geographic Information System (GIS), were analyzed by multicriteria, in order to obtain the Synthesis Model of the area. Multicriteria Analysis consists of raster-type structure operations in a GIS environment, which produce a new information. It is understood that the Multicriteria Analysis procedure is widely used in the creation of new information. This analysis is done by assigning weights and values, indicated by a specialist in the phenomenon under study, as well as a specialist in the variable in question. The results of this analysis demonstrate the region is suitable for mining and corroborates a better understanding of the territory use for this activity with the synthesis map for a study area based on variables used. For this work, the variables of existing mine pit, lithology and areas with mining requirements, collected directly from the geological survey of Brazil were used as initial data for the study.

Keywords: Geoprocessing · Big data · Quadrilátero Ferrífero · Iron Ore · Multicriteria Analysis

1 Introduction

Investigations of the potential of the territory for the management of areas of geological interest - whether of production, recognition of values or protection - was chosen as the case study of the Quadrilátero Ferrífero area, in Minas Gerais, Brazil, as a function of its emblematic role for the sector. The Quadrilátero Ferrífero is the heart of exploration and mineral production in Minas Gerais, Brazil, in which significant conflicts of interest: great economic value related to mining and significant urban expansion, an area of important natural and environmental resources, landscape values of the

E. Topal (Ed.): MPES 2019, SSGG, pp. 191–199, 2020.
https://doi.org/10.1007/978-3-030-33954-8_24

mountains of Minas Gerais. In this sense, the case study, due to its complexity, favors a wide discussion about the potential of planning the mining landscape.

With this fact, the region became a mining province, due to the exuberant amount of mineral commodities present in the area. The geological formations led and influenced the beginning of the atropisation of the interior of Brazil. This relationship can be seen in the reflection of [1], “a knowledge about the formative processes of our planet and its evolution in time,” which has served as a guide for man since the beginning of its history.

The Quadrilátero Ferrífero is located in the Center-South of the State of Minas Gerais, Brazil, covering an area of approximately 7,000 km^2, located in a highland region, where it occupies a region surrounded by orthogonally arranged mountain ranges (Fig. 1). And the taxonomic origin of the region was named by Gonzaga de Campos [2, 3], due to the iron ore deposits found there.

According to [4], the Quadrilátero Ferrífero has its origin of structure associated with differential erosion, in which the quartzites and itabirites were located in areas of high altimetry. The phyllites are part of the rocky substrates of the median third of the slopes and, in the lower third, at the base of the geological substrate, the composition is rocks from the Belo Horizonte Complex, which are granite-gneiss rocks. Thus, in an interpretation of the space, the high altimetry is related to a set of ridges and places with erosive surfaces that have elevations composing as a whole a quadrangular form, associated with the fact that itabirite is a ferruginous rock of high content, name of the “Quadrilátero Ferrífero” region.

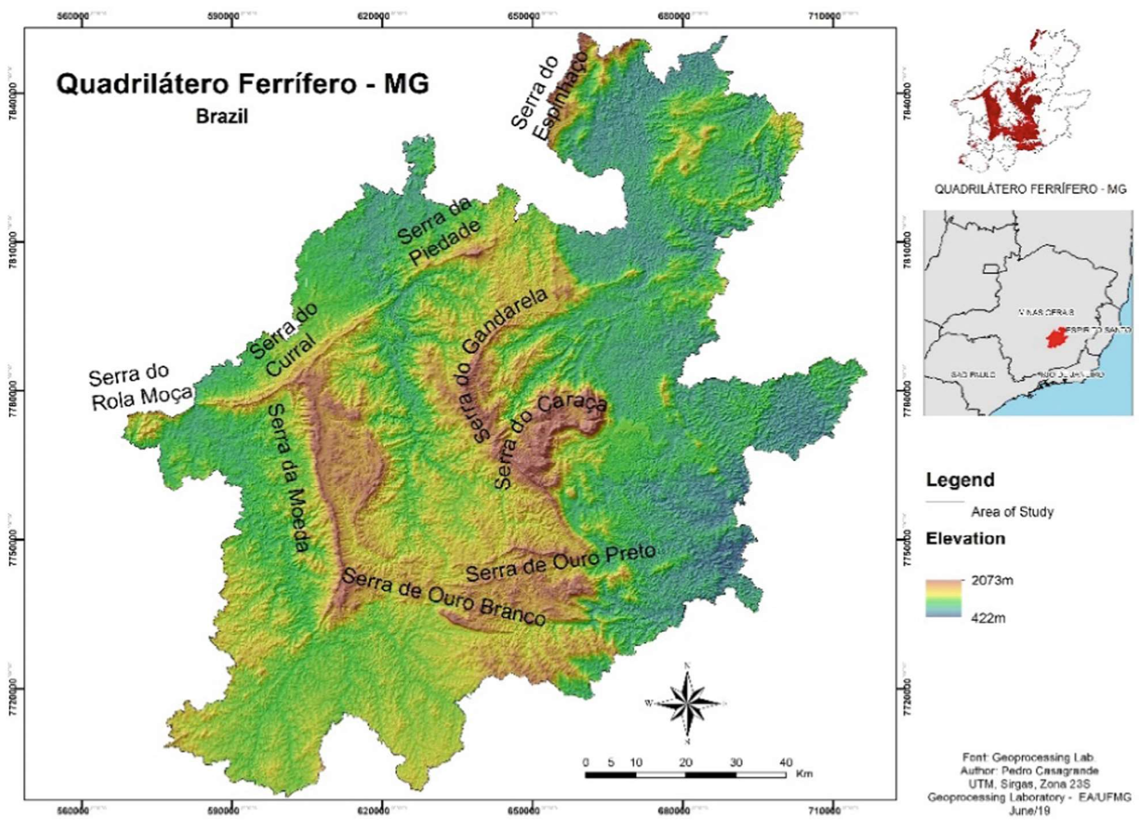

Fig. 1. Location of the Quadrilátero Ferríro and the elevation of the mountains in the area

The objective of this analysis is to identify mineral deposit prospecting targets from geoprocessing analyzes, since the structures of the physical environment correspond to each other when performed some spatial analysis procedure. Therefore, it is possible to identify targets for mineral research from this study procedure.

2 Methodology

The main goal of this analysis is to test the capacity of an innovative approach in the treatment of the (complex) context of mining research, with geology and its lithological variables related to the approach. The reasons for this study is to open up a new possibility for mineral research planning issues.

The work is based on the combination of variables by map algebra, with a view to creating an evaluation that results in a numerical and quantitative ranking, which indicates, for a given territorial cut, the potential of occurrence of a particular commodity, in the case the iron ore, in ascending order. On a relative scale, the territorial portions most favorable to the occurrence of this commodity are identified and more suitable for mineral research.

The mapping of targets for mineral exploration of iron results from the combination of the following variables: Geological Layers, Mining areas and Iron Ore Body.

The data, treated by GIS tools, underwent multicriteria analyzes, in order to obtain the Final Model. Multicriteria Analysis consists of raster-type structure operations in a GIS environment, which in turn produce new information [5].

The Multicriteria Analysis is a method based on Map Algebra, a term proposed by [6], in which the association of numerical (quantitative) values with spatial information is performed, providing mathematical operations. The application of this method has as objective the identification of the potential of the landscape through its uses and values from the thematic maps linked to the physical environment, being the whole procedure performed by geoprocessing techniques [7–9].

Multicriteria synthesis is characterized by the composition of an index resulting from the weighted sum of principal components that account for a research reason. The degree of importance of each variable, understood as the "weight", must be decided by a defensible criterion, either according to a bibliographic reference, or by consulting a group of experts, or even by measuring trends recognized in the territory. The processes of obtaining weights are classified by [10] into two groups: knowledge-driven evaluation (when consulting experts who give their opinions) or data-driven evaluation (when working with data resulting from the measurement of observed trends).

The methodological process can be summarized according to the following stages of work:

(a) Selection and mapping of the main components variables, with the definition of the values ("grade") of their subcomponent components from 0 to 10, according to the degree of pertinence according to experts opinion;

(b) In addition, we used the Delphi method, which is based on consensus maximization [5, 11], adding 100% for the combination in the Multicriteria Analysis by Weights of Evidence.
(c) Map composition is a synthesis by Map Algebra according to the weighted average, which was then symbolized according to the level of suitability for the mineral research use.

3 Results and Discussions of the Variables

The variables included in the index were Geological Layers, Mining areas and Iron Ore Body.

The maps were generated from open data created by the Brazilian Geological Service and prior knowledge of the study area, for the classification of geological characteristics, which evaluates the set of lithotypes according to their mineralogy and, consequently, according to the degree of possibility of iron deposition.

The assignment of grades from 0 to 10 to the geological components followed the indications of the legend of the geological map elaborated by the Brazilian geological service [12], noting that there is no perfect lithotype and totally homogeneous, which would result in note 10, or one so poor as to be note 0, since they are natural elements that can be altered by the geological history (Table 1).

Table 1. Grades for lithotypes.

Lithotype	Grades
Laterite	3
Dolomite	4
Phyllite	5
Schist	5,5
Sandstone	5
Itabirite	9
Granite/Gneisses	2

In general, itabirite occupies the top of the region, due to its resistance to erosion, which places it as of very high importance in the composition of the local landscape. This rock can be massive or powdery (friable), and when they are massive they present high mechanical resistance, [13].

Also according to [13], the mountain tops of the study area contain lithotypes of sandstone and other sedimentary rocks. These lithotypes are considered good aquifers and require the recommendation of preservation of these areas and the prevention of their waterproofing [12]. In such environments, caution should be exercised when cutting, embankment and deforestation, the consequences of which are exposure to rainwater, especially in hilly relief areas with concave and well drained surfaces, since these rocks are susceptible to erosion. In this sense, these aspects were expressed as shown in Fig. 2. This variable received a weight of 20% for the analysis.

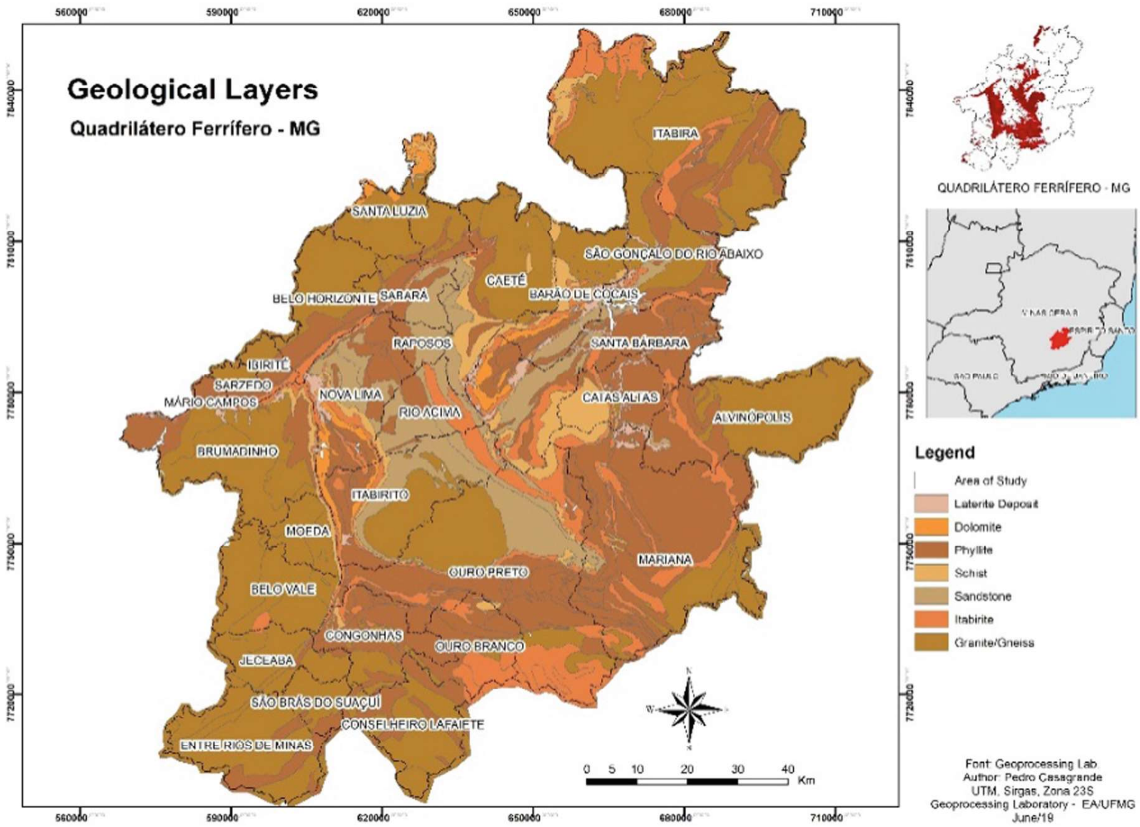

Fig. 2. Geological Layers of the study area.

The Mining areas map was elaborated considering the high concentration of mineral activity in some sectors of the region (Fig. 3), where the most mines are located on the surfaces dominated by hills whose altitudes are approximately 1000 m away. Their identification occurred by supervised classification of satellite with the use of geoprocessing software. The open-pit under study are currently active and this variable received weight of 40%. Once the pits were mapped, notes referring to the legend components of the variable were applied.

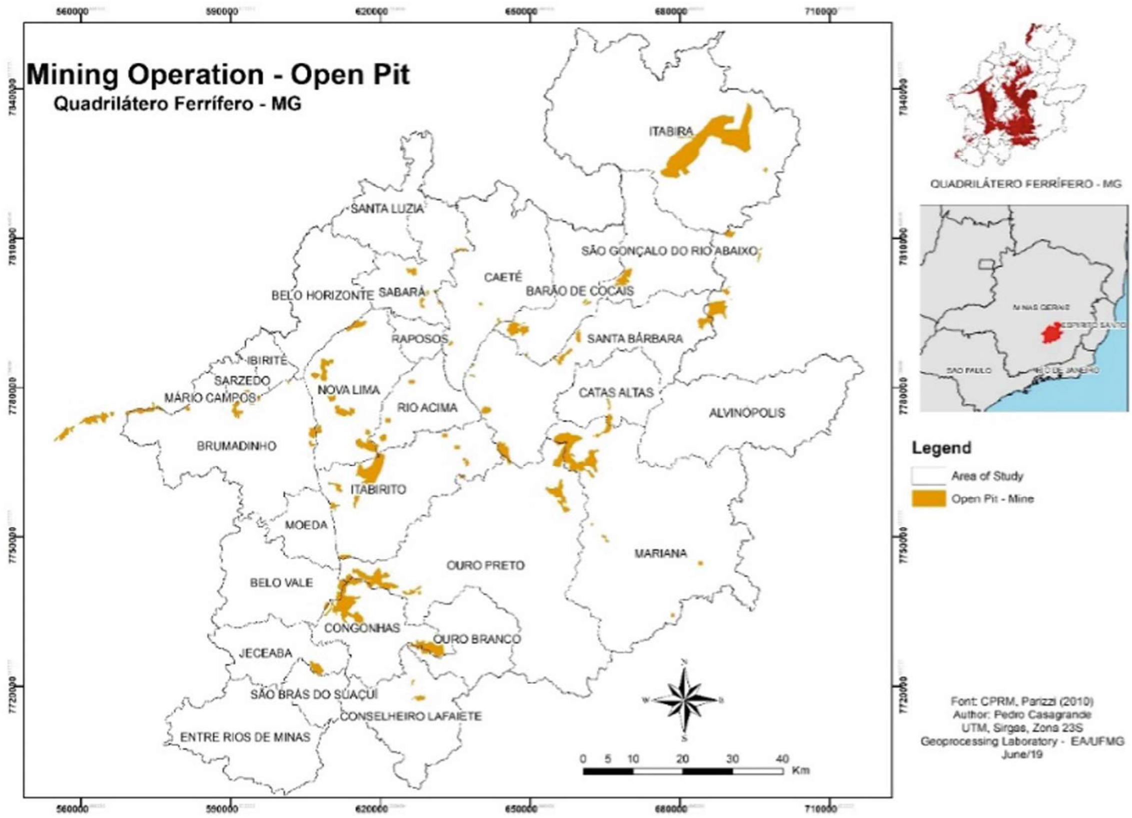

Fig. 3. Localization of the operation mine (open-pit) at the study area.

The assigned grades were linked to the presence or absence of active iron mine (ope-pit), as shown in Table 2.

Table 2. Grades for open-pit.

Lithotype	Grades
Occurrence of open-pit	7
Non-occurrence of open-pit	1

The location map of the Iron Ore Body (Fig. 4) was elaborated considering lithology data in relation to its position (geographic and geological). In general, occurring in the ridges of the region, and the variable received weight of 40%. The weights are in Table 3.

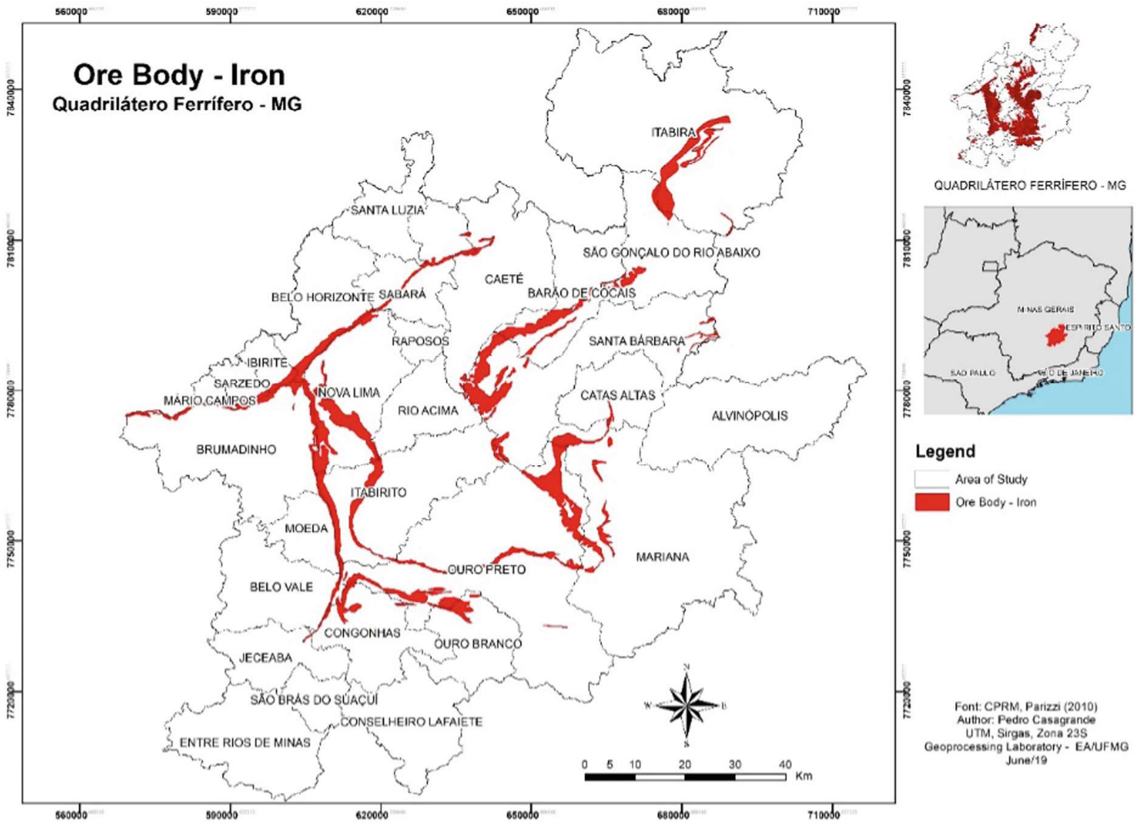

Fig. 4. Location of the body of iron ore in the study area

Table 3. Grades for ore-body.

Lithotype	Grades
Occurrence of ore-body	9
Non-occurrence of ore-body	1

Once all the partial maps were composed, with their caption components classified according to the degree of pertinence for mineral research, and the relative importance of each variable decided, the final composition process was promoted according to the general table of weight values (Table 4).

Table 4. Grades for lithotypes.

Variable	Weight (%)
Geological Layers	20
Mine (Open-Pit)	40
Ore-Body (Iron)	40

The three variables, once unified, corroborate the elaboration of the Map of Potential areas for mineral research (Fig. 5). As a result, the site with the greatest potential for mineral exploration and a possible mining is located in the main axes that form the Quadrilátero Ferrífero, at the top of the hills. It is also worth mentioning the context of the edges of the hills, places that occur, even in a specific way, of targets for research and extraction of iron.

The sites with low possibility of occurrence are located under the context of the Belo Horizonte Complex (Granite and Gneisses) present in the study region. Thus, the analysis performed is likely to condition the axes for mineral exploration. However, it should be noted that several of these areas are environmental preservation according to local legislation.

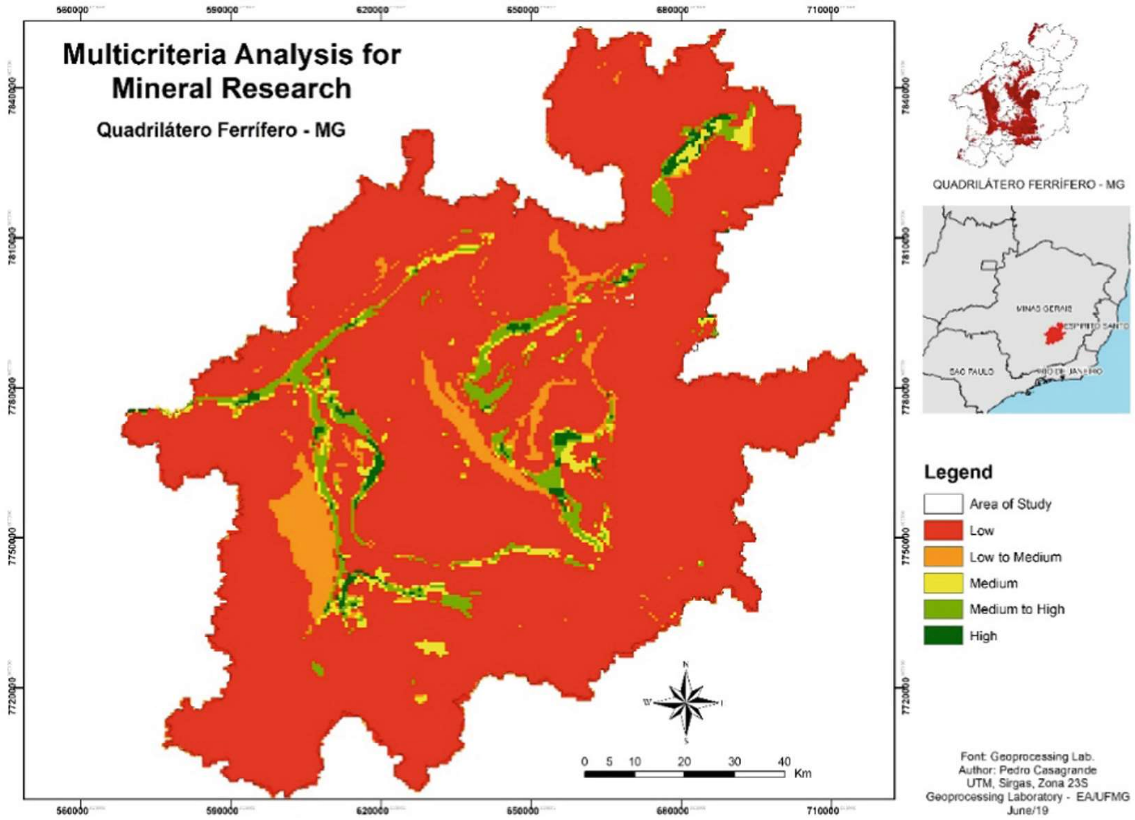

Fig. 5. Synthesis map for iron-ore mineral research targets.

4 Conclusion

Geology is the basis of mineral research, which in turn is an element of financial risk because the entire procedure is high financial cost. Thus, if it is possible to induce targets for mineral exploration from previously known and public data, the likelihood of success and, therefore, savings in exploration costs can be of significant value. Although, the studies of public agencies of geological services of each country can help companies to identify targets for mineral prospecting and to be more assertive in prospecting new mining ventures.

This methodological process can be uses as tool to mineral research, but it has some limitation such as a lack of data source or incompatible between scales of the data source.

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