Caves and Mining in Brazil: The Dilemma of Cave Preservation Within a Mining Context

A.S. Auler and L.B. Piló

Abstract The exploitation of mineral reserves in Brazil, especially limestone and iron ore, is currently restricted due to the existence of caves. The vast majority of caves documented in the country over the last 4 years (approximately 3,000) have been identified through environmental studies conducted for mining operations. To determine whether a cave should be protected or not, a series of criteria were formally established by recent (2008/2009) federal laws. Four classes of cave relevance were formally designated, based primarily on geological and biospeleological criteria. *Maximum Relevance* caves must be protected, together with a 250 m buffer zone. *High Relevance* caves may be removed, provided that two other high relevance caves, preferably within the same geological unit and containing similar characteristics, are permanently protected. However, the acquisition of areas containing caves, especially within iron ore regions, has become extremely difficult due to the high price of iron ore. *Medium Relevance* caves may be subject to removal, but speleological compensation must be applied. *Low Relevance* caves may be mined with no need for environmental compensation. Although these laws occasionally permit cave destruction, their ambiguous specifications and numerous criteria produce a highly restrictive scenario in which approximately 85 % of all caves are categorized as Maximum or High Relevance. The situation is further exacerbated by the very low minimum length of 5 m for any void to be classified a cave, producing a high number of caves regardless of lithology. Conducting a full cave environmental study, besides being financially costly, takes approximately 1.5 years to complete, primarily due to the requirement to perform two biospeleological sampling events during dry and wet seasons. The protection of several caves within mining areas has significantly decreased access to exploitable reserves, causing caves to remain under severe economic pressure. While Brazilian law emphasizes cave preservation, it provides no specific provisions for the protection of other karst features or karst aquifers.

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1 Introduction

The rapid growth of mining activities in Brazil due to high prices on metal commodities in the international market (such as iron ore), coupled with internal market growth for construction and agriculture (cement and lime) has threatened caves and karst features. Over the last decade, new cave-related laws have called for substantial changes in the ways cave studies must be performed in areas marked for mining operations. Prior to detailed studies, any void over 5 m in horizontal and vertical length must be protected, together with a 250 m buffer zone surrounding the cave. The preservation or removal of caves depends on a detailed, 1–1.5 year-long study to determine the degree of cave significance. Cave significance studies require the analysis of a large number of criteria, mostly geological and biological. With a sudden surge of cave studies beginning in approximately 2008, there are now cave significance studies for over 1,000 caves, accounting for roughly 10 % of all caves registered in the national cave database (CECAV 2014).

Of the four possible outcomes of a cave significance study (Maximum Relevance, High Relevance, Medium Relevance and Low Relevance), only Maximum Relevance provides complete protection for a cave. However, depending on the criteria, even this degree of protection may not be permanent because additional studies may provide new data that may decrease the relevance status. While a High Relevance cave may be mined away, it requires two caves of the same rock type with similar characteristics to be preserved, which poses additional difficulties. This compensation arrangement makes areas that contain relevant caves extremely valuable to mining companies. Medium Relevance caves may be quarried away, pending cave- and karst-related environmental compensation that may not involve cave preservation. Low Relevance caves are not subject to protection or environmental compensation.

Cave-relevance studies performed so far have, for the vast majority of cases, classified caves of Maximum and High Relevance. Medium and Low Relevance caves have been largely absent. These highly restrictive criteria impose serious limitations on mining activity expansion given the very low minimum length of 5 m being classified a cave, thus resulting in a large number of caves, in addition to the requirement for a 250 m buffer zone and degree of relevance (Maximum or High). These criteria currently present some of the most serious restraints to mining development in Brazil and have had severe economic and social impacts on mining-dependent areas.

This challenging dilemma has precipitated intense pressure on the government to adopt a less restrictive legal framework. However, the increase in the number of cave studies has led to a complete reshaping of speleology in Brazil, with an ever-increasing number of professional speleologists. Although caves are in the spotlight, protected by a complex legal apparatus, there is no mention of other karst features, creating an unjustified bias towards the preservation of caves. This paper provides an overview of the environmental studies created under Brazil's recent cave laws and of the ever-growing challenge of preserving significant caves without impairing economic development.

2 Legal Background

Prior to 1988, Brazil imposed no specific laws regarding caves. During the elaboration of Brazil's new constitution, a lobby of cavers succeeded in including caves as property of the union, together with lakes, rivers, sea and natural resources, including those of the subsoil (Brasil 1988). This new approach was the starting point from which a large number of legal initiatives took effect. Being both classified as property of the union, caves and mines became equally dependent on federal-level government decisions.

Two years later, IBAMA (The Brazilian Institute of Environment and Renewable Natural Resources) stated through its Directive 887 that caves should be included in environmental studies and could not be impacted (IBAMA 1990). The Directive proposed that caves be used for technical or scientific purposes only, including tourism and educational and cultural activities. This same Directive also made compulsory the need for permits when sampling or performing scientific studies in caves. Directive 887 also introduced the need to protect a 250 m buffer zone perpendicular to the limit (walls) of the mapped cave. In the same year, Federal Decree 99556 re-emphasized the need to protect all caves, stating that caves belong to Brazilian heritage and should be integrally protected (Brasil 1990). Thus, at this early stage, cave law was extremely restrictive because no cave, regardless of its size or importance, could be impacted. If all caves were to be protected, it would result in the shutdown of numerous mining projects. However, despite the law, in many situations speleological studies were not performed, which led to the loss of many caves.

In 1997, the National Center for Research and Conservation of Caves (CECAV) was created as a specialized department of IBAMA. With offices in cave-dense areas, CECAV activities included, at this early stage, the assessment of environmental studies related to caves in mining areas. The professional speleologists of CECAV provided much-needed expertise and represented a conservative force towards limiting cave impact by mining projects. Currently, CECAV is no longer involved in environmental licensing, and has instead shifted its focus towards cave research and management in federally protected areas.

A major legal change occurred in 2004, when Normative Resolution 347 from CONAMA (National Environmental Commission) (CONAMA 2004) recognized that caves may vary in environmental importance. For the first time, it was legally accepted that studies on ecological, scientific, cultural and scenic aspects should be performed to determine the significance of a cave. The same resolution instituted the creation of CANIE, a national cave database managed by CECAV.

The two most recent laws, Federal Decree 6640 (Brasil 2008) and Normative Instruction 2 (MMA 2009) provided rubrics outlining four classes of cave significance and the criteria involved in their determination. Maximum relevance caves must possess at least one of the following: (i) a unique or rare genesis, (ii) notable dimensions in length, area or volume, (iii) unique speleothems, (iv) geographical isolation, (v) essential shelter for threatened species, (vi) essential habitat for

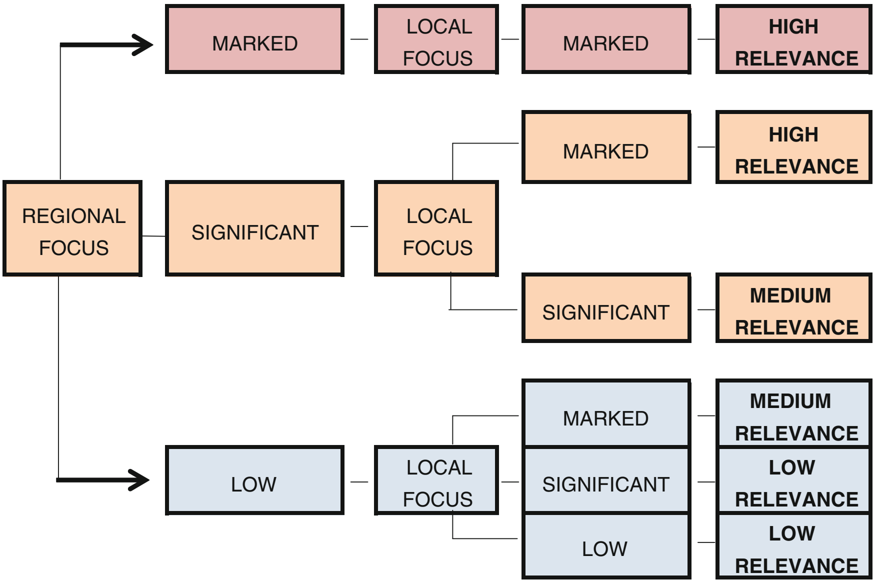

Fig. 1 Schematic flowchart showing the relationship between the degrees of relevance and importance of criteria (marked, significant and low) at both local and regional scales of analysis (MMA 2009)

endemic or relict troglobites, (vii) habitat for a rare troglobite, (viii) unique ecological interactions, (ix) significant paleoenvironmental importance and (x) significant historic, cultural and religious value.

Identifying a High Relevance cave is more complex, relying on comparisons between several items across caves both at a local and regional scale (Fig. 1). The local scale is defined as a continuous geomorphological feature (ridge, plateau, etc.) containing caves. The regional scale is the speleological unit, including a larger karst or cave area displaying physiographic homogeneity. A high relevance cave should be of high importance at both the local and regional scales, or of medium importance at the regional scale but of high importance at the local scale. A minimum of 22 criteria must be taken into consideration, and the presence of only one is enough to grant a cave High relevance status (Table 1).

Medium and Low Relevance caves are those which do not meet the Maximum or High relevance criteria. Due to the extensive number of criteria listed, caves are rarely classified as Medium or Low Relevance.

The legal apparatus, besides being complex, contains concepts and procedures that are either dubious or incorrect because the method was not tested prior to publication. The definition of a cave, for example, refers to a natural underground cavity accessible to humans, regardless of its dimensions and with or without a natural entrance (Brasil 2008). For instance, small passages accessible only to cave fauna and entrance-less caves detected by geophysics fall into a grey zone in which it is not possible to ascertain whether they should be considered or not. The

Table 1 Criteria that must be matched to classify a cave of high relevance (MMA 2009)

I—Type locality
II—Established populations of species with important ecological role
III—New taxons
IV—High species richness
V—High relative abundance of species
VI—Peculiar fauna composition
VII—Troglobites that are not rare, endemic or relict
VIII—Troglomorphic species
IX—Obligatory trogloxenes
X—Population of exceptional size
XI—Rare species
XII—High length when compared to other caves at regional scale
XIII—High area when compared to other caves at regional scale
XIV—High volume when compared to other caves at regional scale
XV—Significant presence of rare speleogenetic features
XVI—Perene lake or underground drainage, with marked influence over any of the criteria in this table
XVII—Diversity of chemical deposition with many types of speleothem and varied processes of deposition
XVIII—Notable configuration of speleothems
XIX—High influence of the cave over the karst system
XX—Interrelation of the cave with a maximum relevance cave
XXI—Aesthetic and scenic values of national and international significance
XXII—Systematic public visitation with a regional or national scope

These criteria refer to marked importance at both regional and local scales (Fig. 1). If none of these are met, additional criteria (significant importance at the local scale) must be applied

subjective wording used in some definitions, such as “notable” or “unique” among many others, produce differences in interpretation depending on the experience of the consultant; therefore, studies conducted by different teams can produce different relevance diagnoses.

Due to the highly restrictive nature of the legal framework, most mining projects with identified caves are facing losses in exploitable reserves. The economic impact of caves has led to a growing lobby of mining industry professionals advocating for less rigid laws to release the mines at the expense of imperiling caves.

3 A Review of Cave Significance Studies in Brazil

The promulgation of Decree 6640 in late 2008 prompted a marked increase in cave-related consulting work. Not only mining operations but any new development, regardless of area or cave potential, was required to commission a

Fig. 2 GPS-equipped cave-prospecting teams of 2–3 members walk alongside one another, creating 50 m-wide parallel lines that represent the walking route. Line spacing depends on cave potential and visibility (which varies with rock type, vegetation and relief). Ideally, spacing equals the distance of visibility/2. Areas between lines may be checked if necessary. Areas containing high-potential features such as dolines and rock outcrops must be inspected in more detail. Orange circles denote a 250 m buffer zone of identified caves

speleological assessment. The requirement applied to projects including reservoirs, electricity lines, urban developments, roads and railroads. Some of these new developments, such as transmission lines through the Amazon or very large reservoirs, can span hundreds of thousands of hectares, requiring a workforce of speleologists not readily available in Brazil. This situation created a demand for cavers that substantially altered the nature of caving activities in Brazil, which was previously dominated by non-professionals.

The first step in any speleological assessment involves cave identification, which is carried out by one or several 2–3-person teams walking 20–150 m alongside one another depending on cave potential (based on rock type) and visibility (which is usually controlled by relief, and vegetation especially) (Fig. 2). Considering the 5 m cave length limit, even low potential rocks may yield caves. Limestone areas may result in high cave densities on the order of 0.35 caves/hectare. Iron ore areas present lower densities, averaging approximately 0.15 caves/hectare. The largest cave assessment project ever performed in Brazil involved the characterization of a limestone area containing 750 caves.

Cave dimension is one of the most critical factors in determining cave significance. Length, depth, area and volume must be measured with a high degree of accuracy. A BCRA 5D grade cave survey (Day 2002) is the standard format for cave mapping, producing a high-precision cave map that determines cave length through the conservative definitions presented by Chabert and Watson (1981). Cave depth and area are easily obtained using cave surveying software and CAD drawing packages. Cave volume is a more complex parameter, and its precision depends on the number of cross-sections present, which are averaged by area according to the formula $V = (h_1 + h_2 + \cdots h_n) / n$ (where v is the cave volume, *h* is the average height of cross-sections and *n* is the number of cross-sections). Average height is calculated by dividing the cross-section area by the distance between the cross-section extremes. Survey work tends to progress at an average of two to three caves (with approximate dimensions of 20 m) per day for a mapping team of three people.

Geological assessment requires the analysis of several parameters related to the cave geomorphological context (whether associated with dolines, scarps, valleys, etc.), rock type, rock structure (including structural measurements), hydrological qualitative assessment, speleothem description, clastic sediment characterization and a brief nondestructive paleontological assessment. An experienced, two-person team is able to perform geological assessments of 2–3 caves a day.

Currently, laws require a seasonal approach to cave fauna characterization. Wet (austral summer) and dry (winter) sampling events are required. Because most caves are small, the number of external, non-cave obligate organisms tends to be high and the typical species-accumulation curve never stabilizes. Using the map, cave floor area is divided into a series of 10 m^2 quadrants with a 30-min sampling effort for each quadrant, resulting in average of approximately 110 specimens per cave. A three-member-strong biospeleological team can successfully sample 2–3 caves a day. The number of species collected tends to be extremely high, with some of the largest projects exceeding 30,000 specimens. Screening and identification tends to be time-consuming and external expert advice is needed to obtain the species level. The identification of potential troglobites requires a careful assessment by specialists. Over 100 new species have been sampled during cave environmental studies, only a small fraction of which have been scientifically described.

The total effort required for a complete cave assessment study is significant, considering laboratory and report-production time and involves a team of no less than 25 specialized personnel over a period of approximately 1.5 years. In a sample of 386 caves within iron rocks studied by Carste Consultores Associados, 17.6 % were of maximum relevance, 68.1 % were of High relevance and 12.7 % were of Medium Relevance. Only 1.6 % of the total sample was classified of Low Relevance. Considering both limestone and iron ore, the most frequent criteria that confers Maximum Relevance to caves is habitat for a rare troglobite (69 %) followed by notable dimensions in length, area or volume (14 %) for a total sample of 797 caves. For High Relevance caves, high relative abundance of species is the commonest parameter, occurring in 32 % of all caves considering the same sample.

4 Impact on Mining Projects

As was previously mentioned, the density of caves within iron ore and limestone tends to be high; thus, as a rule, with a minimum length of 5 m for cave identification, any area with rock outcrops will inevitably contain caves. With an obligatory buffer zone of 250 m (which results in a minimum protected area of 20 ha), cave existence can impose considerable restrictions on mining development.

Iron ore caves present an especially challenging situation due to their peculiar genesis. The original bedrock (Banded Iron Formation—BIF) comprises alternating layers of iron and silica. As silica tends to be geochemically more mobile, the removal of silica creates high-grade ore and the initial rock porosity that eventually evolves into caves. Thus, there is a well-marked relationship between the occurrence of iron ore caves and high-grade ore. Thus, cave preservation will likely restrict mining development. However, full exploitation of iron resources will lead to a loss of caves. This dilemma is not without serious economic and social consequences, as significant decreases in exploitable area (sometimes in excess of 50 % of the original planned mine) and delays from speleological studies lead to severe financial drawbacks.

Iron ore prices have increased dramatically over the last decade, due mostly to the expansion of the Chinese market. Prices have soared from USD $13.82 per dry metric ton in December 2003 to USD $135.79 in December 2013 (Index Mundi 2014), a staggering rise of 883 %, prompting the expansion of existing mines and the development of new ones.

In a simple modeling exercise, a single cave located within an iron ore area in Brazil (such as Carajás in northern Brazil) together with its 250 m buffer zone will represent a major loss in ore reserves (Fig. 3). Considering current ore prices and an initial protection buffer of 20 ha for a 200 m deep stepped bench, the total weight would exceed 280 billion tons, totaling in excess of USD $38 billion for Carajás high-grade ore. Depending on the site, this can be regarded as minimum because some deposits are in excess of 300 m in depth (Trendall et al. 1998). Although the same considerations are valid for other rock types, the total financial loss will be much smaller owing to less-valuable mineralization.

Since 2008, over 1,000 caves have had full environmental studies completed for various mining projects. As of December 2013, only approximately 30 caves have been granted approval for removal. Considering the vast majority of caves have been classified as high relevance, this delay is due mostly to difficulties revolving around environmental compensation. The requirement to choose two caves of equal relevance and characteristics for each high relevance cave to be removed has proved a daunting task, and in iron ore areas especially. Due to the relationship between caves and high-grade ore, there is increasing demand and limited availability for these highly priced areas. Furthermore, an additional environmental assessment is required for caves to be used for compensation. The impossibility of applying the “2 per 1” rule has prompted the release of the Directive 30 (ICMBIO 2012), which opens new possibilities, including the provision of financial support

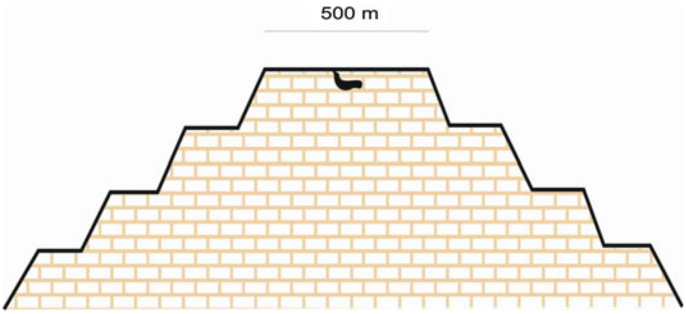

Fig. 3 In a simple simulation, a cave, with its 250 m radius of protection, plus the vertical extent of the ore body (in excess of 300 m in the Carajás deposit) may represent financial losses on the order of more than $USD 20 billion

for the creation or maintenance of conservation units with caves. These new possibilities are now being explored by several mining companies, although due to highly bureaucratic processes not a single approval has been granted.

5 Final Remarks

The need to distinguish between significant and non-significant caves to allow for mining expansion has profoundly altered the cave and mining situation in Brazil. The presence of caves is now considered a major restriction to mine development, which has led to a focus of cave assessment studies and especially those concerned with biospeleology. The rather restrictive nature of the law has also resulted in increased political pressure to speed up the environmental study process, which has in turn solicited counter-pressure from environmentalist groups.

This new impetus towards cave studies has resulted in a spectacular increase in the volume of cave data. The number of new caves identified surpasses 1,000 per year, a very large amount considering that by 2008, only approximately 7,000 caves had been registered in the Brazilian cave database. New geological and biological findings have resulted in the discovery of a great number of new, cave-adapted species and minerals, and many of these findings represent proprietary data that are yet to be published.

With the restrictive nature of the law and the expansion and operation of several mines at peril, government involvement is ever-increasing. Economic and social impacts due to cave preservation are considerable and are thus prompting increasing pressure on cave specialists.

None of the existing laws take the karst system into consideration. Although their relationship to caves is recognized, karst features remain unprotected. This paradoxical situation results in a cave-focused approach that fails to address karst as an integrated system, leading to potential fragmentation and losses in both geo- and biodiversity.

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