Geological risk assessment of the area around the Tito Bustillo Prehistoric Cave. Human Heritage (UNESCO, 2008). Asturias, North of Spain

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Abstract: - The massif of Ardines is an uplifted wave-cut platform developed over Upper Carboniferous limestones, and contains the Tito Bustillo and La Lloseta caves, two important prehistoric cave sites. The main geomorphological features are controlled by the structural pattern: sinkholes are aligned along fractures and they have an oval morphology and the San Miguel river valley flows parallel to the El Carmen-Collera fault. The geological and geomorphological characterization has been used as the basis for the protection area definition. The Natural Risk Index, NRI, has been used for determining the geological risk level in different zones of the study area and to propose the protection area in order to prevent and mitigate the level risk and to protect the cave and the rock mass containing it. The main geological risk affecting the Tito Bustillo cave is located in the blind valley of the San Miguel river, sinking into the cave it provoke the leakage of the farm activity products throughout the cave galleries. Furthermore, many sinkholes which they are other evident absorption zone of the karstic system, are included in the protection area. This method results significant for geological risk assessment and engineering geology, because it can be used in the planning and development of engineering works near of prehistoric caves, and it also can act as a useful tool for land uses management.

Key-Words: geological risk assessment, protection areas, prehistoric caves, Natural Risk Index

1 Introduction

In addition to the usually conservation works carried out around the Human Heritage monuments, the studies concerning to develop methods to prevent damage are whenever more necessary [1]. The geological risk assessment, as the provided in this study for Tito Bustillo prehistoric cave, can act as a useful tool in damage protection.

Nevertheless, in the karstic areas they are many difficulties to the geological risk evaluation, due to the multiple factors that can have an influence in its protection. Consequently, get a strategy that provides flexibility to adjust specific methods according to the conditions of the different regions is recommendable [2].

A method for geological risk assessment must be based on a detailed knowledge of the geological features in the area around and within the cave, since they are different geological processes that could affect the cave conservation. On the other hand, will must be defined, a protection area to restrict and even forbid such human activities which can modify the natural evolution of the geological process.

The Tito Bustillo prehistoric cave is located in the massif of Ardines, a calcareous hill near the Ribadesella village, in the Asturias province, North of Spain (Fig. 1). The cave is included in a karstic complex composed of three main cavities, Tito Bustillo, La Lloseta and La Cuevona caves, which they contain excellent samples of parietal art and several archaeological sites.

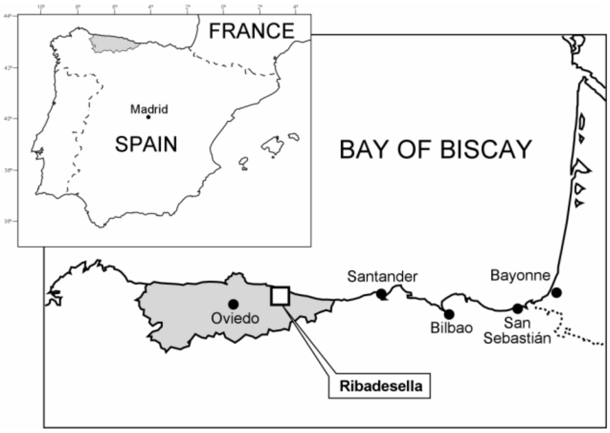

Figure 1. Location map of the Ribadesella village. Asturias, Spain.

The main geological processes affecting the cave, which suppose a risk, they are: the possibility of rock falls within the cave, the landslides and the periodical floods caused by the San Miguel river, and the contaminated water infiltration throughout the sinkholes. Furthermore, the leakage of farm residual toward the cave, must be always taken into account.

2 Geological environment

The Ardines massif is composed by Carboniferous limestones which pass to a formation composed by a succession of sandstones and mudstones through a mechanical contact, the Carmen-Collera thrust fault (Fig. 2). The massif is bordered to the north by the San Pedro river sediments and beach sediments. To the east it limits with the fluvial sediments of the Sella river estuary.

The structural pattern controls the presence and orientation of many geomorphological features [3], e.g. the San Miguel river valley is controlled and flows parallel to the El Carmen-Collera fault, even through the karst of the Ardines massif.

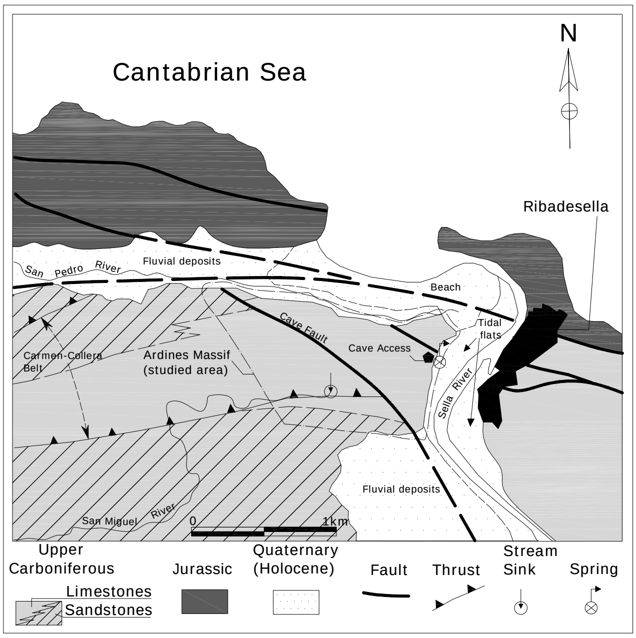

Figure 2. Geological context of the Tito Bustillo prehistoric cave.

These structural pattern controls the presence and orientation of many geomorphological features [3], e.g. the San Miguel river valley is controlled and flows parallel to the El Carmen-Collera thrust fault like this through the karst of the Ardines massif.

Finally, the hercinian main thrust faults structures, are compartmented by three fault sets (Fig. 3) related with the last Alpine orogeny.

3 Geomorphological features

The Ardines massif shows some different geomorphological environments and forms:

1) The uplifted wave-cut littoral platforms are present along the Asturian coast [4], related with the Flandrian transgression sea. The plane surface of the Ardines massif is a typical example. The northern limit of the massif corresponds to a paleocliff that today limits the San Pedro river valley.

2) Karstic, exokarstic and endokarstic features, are the most abundant geomorphological forms in the massif. Their formation is controlled by the structural features zones that act as main fluid-flow pathways. The most common exokarstic features are the sinkholes. They are oval and reach to about 50 m in width and appear aligned along fracture zones. The endokarstic system, with more than 1.500 m long complex karstic network, has two main manifestations, the Tito Bustillo and La Lloseta caves.

3) Finally, fluvial features, as flood plains and terraces, are present in the limits of the massif related to the presence of many fluvial systems: the San Pedro river in the north, the Sella river in the east and the San Miguel river in the southeast, the latter penetrates into the karstic system and flows through the Tito Bustillo cave (Fig. 3).

4 Determination of the NRI index

The Natural Risk Index determination, NRI geological risk, is based on the evaluation of nine parameters which are empirical rated from zero to 10, in agreement with the particularities of the studied area and according to the criteria exposed in [5]. The expression used to estimate the NRI index is:

$$NRI = \frac{P \cdot (0.1 \cdot S \cdot Ed + 2 \cdot Pt + W + Sp + 2 \cdot Ls + 2 \cdot Sd + 2 \cdot Ps)}{110} \quad (1)$$

where:

P, proximity, is the minimum distance between the study zone and the picture gallery into the cave.
S, slope angles, and *Ed*, elevation difference, contemplate the possibility of landslides and consequently are evaluated together.
Pt, position, reflects the influence of geological processes or structures on the cave based on its location.
W, weathering, expresses the degree of weathering using the recommendations exposed in [6].
Sp, seepage, take into account water flow from the analysed zone toward the cave.

Ls, landslide, estimates the presence and type of landslide affecting the zone.
Sd, are the structural discontinuities, considers the possibility that a landslide affects to a structural discontinuity, which determine and control the cave morphology.
Ps, proximity structures, take into account the distance between the actual geological processes and the discontinuity considered.

studied area. As a result, they have been adjusted with a value of two. Slope angle and elevation difference are evaluated together and their contribution is corrected by a decimal number, 0.1.

Considering a hypothetically extreme situation, the total value of the numerator will be 1.100.

Usually, the rank values without units of a security index in Engineering Geology must be from one to 10, consequently, the denominator of the NRI expression take de value of 110.

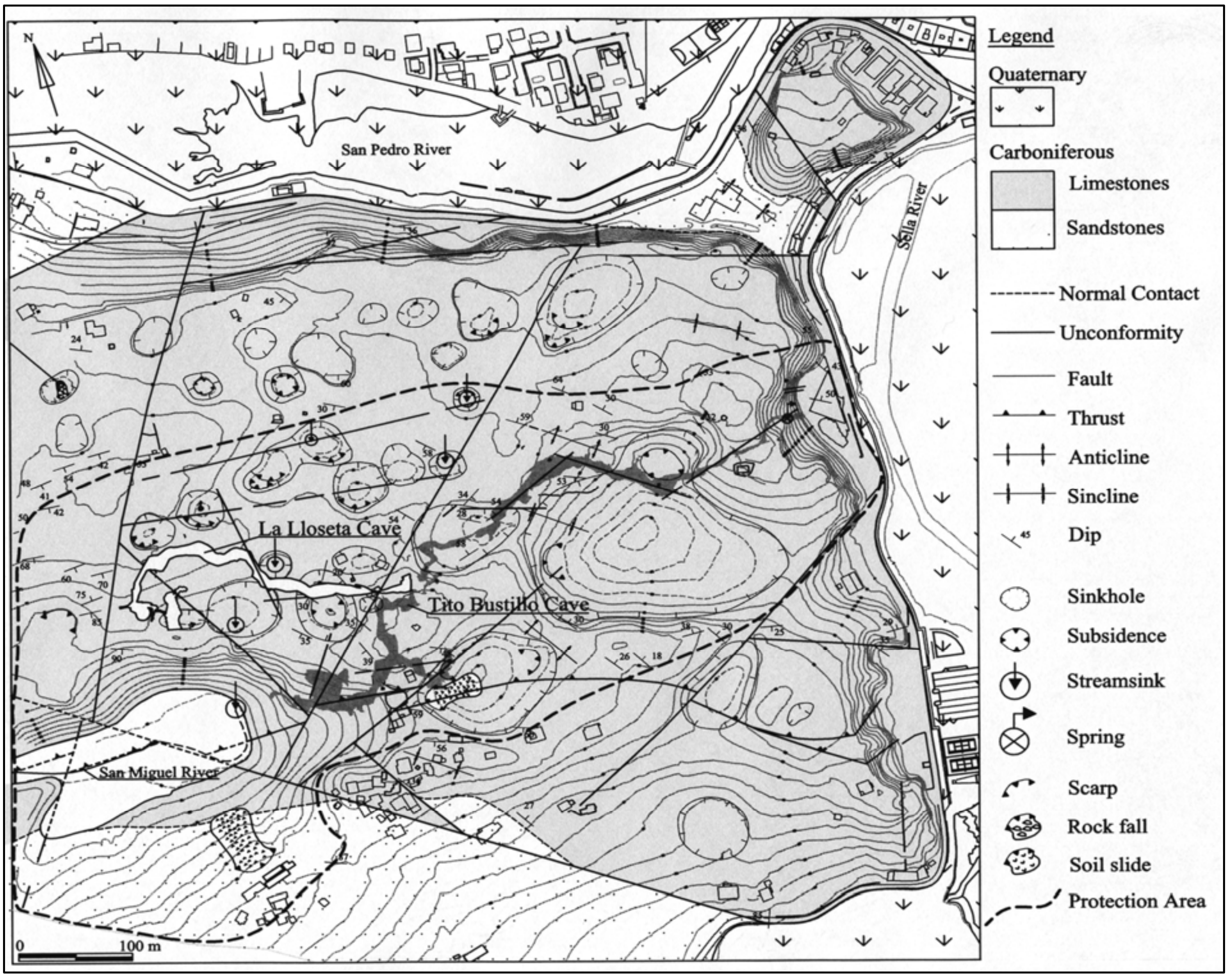

Figure 3. Geological Map around the Tito Bustillo Cave and Protection Area.

According to this proposal, the risk level will be very high when a zone located above the cave can suffer a rock fall, because the slope angle and the elevation difference are high or water could drain toward the cave through a fault which defines a gallery of the cavity and the weathering degree is high. The NRI value could decrease if this zone has the same characteristics, but is far away of the cave.

The NRI has been developed in an empirical way in order to evaluate the significance of each parameter in the geological risk. Position, landslide and structural discontinuities are the most important parameters concerning the geological risk in the

The risk level is expressed as a numerical value which also is classified in a category, Table I, and indicates the risk level related to geological processes without direct human intervention, affecting at well-defined point or zone of the study area around the Tito Bustillo Cave.

	NATURAL RISK INDEX "NRI"			
	0-2	**3-5**	**6-8**	**9-10**
RISK LEVEL	LOW	MEDIUM	HIGH	VERY HIGH

Table 1. Risk levels based on the NRI value.

5 Conclusions

The proposed methodology permit:

a) Taken into account the previous analysis of the geological and geomorphological characteristics, the geological processes which are actives in the studied zone, can be checking.

b) The Protection Area based on the geological risk assessment can be defined. This area will imply the restriction of any activity that can directly or indirectly modify the natural evolution of geological processes and therefore increase the risk level therein.

c) It is useful for geological risk assessment around the prehistoric caves and could be also applied for natural or historical monuments.

Acknowledgments

The authors are grateful to the Government of Asturias Principate, Spain, for their cooperation in the development of this investigation.

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