Cadernos Lab. Xeolóxico de Laxe
Coruña. 2008. Vol. 33, pp. 139 - 154

ISSN: 0213 - 4497

Mapping and modelling of granite cavities: Problems in the representation of forms and work scale

VAQUEIRO, M[1].; COSTAS, R.[1]; SUÁREZ, R.[1] and BARREIRO, B.[1]

(1) Clube Espeleolóxico Maúxo

Recibido: 22/9/2007 Revisado: 15/6/2008 Aceptado: 3/9/2008

Abstract

The granite forms existing in Galicia are classified in three groups by their dimensions: megaforms or large forms, mesoforms or intermediate forms, and microforms or minor forms. Megaforms are those whose minimum dimensions are around 100 m though may usually have kilometric dimensions. Mesoforms or intermediate forms are located between hundreds and dozens of meters. Finally, microforms or minor forms are those that measure less than 10 m though in extreme cases may reach the inferior limit assigned to mesoforms.
Granite caves are associations of these three types of microforms. In spite of their dimensional differences, the 3 types of forms have great importance in the interpretation of the genesis and evolution of the cavities. In the graphic representation of granite caves there are generally used the scales 1:50 or 1:100 with equidistances of half meter. Therefore, the minor forms only appear referenced in the cartography indicating the place where they are located. Symbols are classified in many different morphogenetic groups using as reference the same proposed in the Geomorphological Map Guide of IGME where there exist symbols to represent granitic megaforms (e.g., inselbergs, fractures or faults) but not the necessary ones to represent mesoforms and microforms, and even less for the subterranean domain normally ignored or underestimated up to now. An additional problem is that in pseudokarstic domains there co-exist two types of forms of endogenous (for example, exfoliation surfaces) and exogenous (for example, pothole) origins. In order to solve these problems, it was decided to employ the same symbology that is used with other type of rocks (e.g., limestone) though with a specific colour for the forms developed on plutonic rocks of endogenous or exogenous origins. The used symbols dif-

ferentiate subgroups. In the endogenous forms, the ones defined in the different stages: plastic (magmatic banding, liesegang spheres), fragile (protoclastic boulders), ductile (shear bands) and elastic (tafone). In the exogenous forms, the ones caused by mechanical erosion (rill and fluting) or deposition (speleothems) or chemical weathering (etched depressions formed by chemical etching).
The mapping of granite caves needs an adaptation of the techniques used in the karstic environments developed in soluble rocks. For the granites cave, sketches are defined by the angles and length (distance) of each shot to draw. Unfortunately, there are many harsh conditions derived from granite cave structure that affect the mapping works: passages are defined either by fissures or by block accumulations; cave bounds are generally diffuse, and to draw and model the subterranean void is necessary to determine a "virtual" limit in the tube and to use survey stations relatively close; measuring of passage dimensions makes the surveyors "to line the floor" not using tachymeters or laser instruments.
All these problems suppose the use of big sets of topographic data that will be processed to obtain a clear representation of the subterranean void. On the other hand, the objective is to approach, from survey sketches and data, a model of the subterranean void in granite caves. A model is much more than a single draw. In a model the subjacent structure would be represented: there exists a real limit enclosing a main cave structure, and it could be obtained from correlating adjacent cave passages in appropriate projections and complex views.
Many examples, referred to different types of granite caves (composite weathering block caves and structural caves), are included to explain the criteria used to apply the proposed symbols and legends. Complex projections and 3D-views were developed to explain the evolution and genesis of the subterranean granite cavities.

Key words: granite caves, microforms, mesoforms, megaforms, survey sketches, structure planes.

INTRODUCTION

The geomorphological mapping of granite landscapes present particularities inherent to this type of rock. The granite is a rock consolidated inside the Earth during its emplacement. The pair emplacement/cooling generates discontinuities that affect the intrusion in its outer zone. Some of these discontinuities serve as escape ways of tardimagmatic fluids. However, the discontinuities may be only seen when the rocky massif reaches the Earth's surface either by tectonic movements or after a weathering stage under the ground. Anyway, given the granite impermeability, the subedaphic or subaerial weathering will preferably progress using the system of discontinuities. Once the rocky massif is weathered, the erosion of the regolith gives morphology to the granite landscapes where the endogenous features prevail, called so by their origin and not related to the external processes. The meteoric agents: water, wind, ice and gravity may modify the morphology of the massif more or less intensively adding new features that will diversify the final geomorphology of the massif. It is that special association of forms of endogenous and exogenous origin (subedaphic and subaerial) which forms the granite landscape. For that reason the aspect of the rocky relief in surface is not due to only one type of processes but to a succession of them developed along millions of years. Geomorphologists do not normally consider the contributions of the intrusive magmatic and tectonic processes to the genesis of forms what causes to confuse endogenous and exogenous forms. Implicitly, it is assumed that both categories of forms were generated at the same time and during only one exogenous process. And this it is not because geomorphologists ignore the landscape polygenism but by the fact of not differentiating the forms by their genesis.

Another problem in the mapping of granite terrains is to establish the landscape age. Only in case there exist covers of sedimentary or volcanic rocks, a minimum age may be inferred for the forms which, as stated before, have different ages and are polygenic. Thus, in many cases the only criterion used to date a relief is the height above the general (the sea) or partial (defined by the height of the drainage network that dissects the relief in the zone) base level. In these cases it is accepted the general criterion that at greater altitude, greater antiquity. Only has the appearance of new methods as the chronology by cosmogenic nuclides allowed solving the problem of age of a landscape satisfactorily.

Finally, another common problem is the scale. In the specialized works, three types of forms are distinguished according to the size generically called mega-, meso- and microforms. However, there does not exist a complete symbology for their representation in the literature.

So, the rules for the elaboration of geomorphological mapping of Spain made by the IGME (MARTIN-SERRANO et al., 2005) only consider as symbology for the granitic megaforms at scale 1:50,000. Other authors (MARTÍNEZ-ÁLVAREZ, 1989) preferably limit the geomorphological cartography to sizes between meso- and microforms. Also, there exist works in the UIS (1999) oriented to the representation of the exo-karst though they refer to macroforms specially.

All these problems, generically applicable to the geomorphologic mapping of the granitic rock landscape, are even more evident when mapping the granite cavities that are, from the dimensional viewpoint, complex associations of forms whose dimensions go from metric size to hundredth of meters (microforms to mesoforms).

In this paper it is presented a methodological proposal for the representation and modelling of granite pseudokarstic cavities.

TOPOGRAPHY

The Nature, the Universe we know is a continuous space, and all the things which are surrounding us have a continuous nature *per se*.

To map or to model a real physic system requires transforming a continuous space into a discrete (non-continuous) space. The information used to draw a topographic map is not continuous but discrete or measured. This information does not represent the real space (paths, surfaces or volumes) using a continuous function but represents the space using a succession of vectors that points a subset of "zones" of the real space. The envelope function of all these zones is a continuous approximation of the real space.

The topographic work consists of transforming the different passages visited by cavers in a discrete set of points. The vector between two adjacent stations may be in accordance with the subterranean voids and microforms close to these stations, to guarantee that these forms are measured and included in the map. Then, to obtain a good envelope function is necessary to use vectors between adjacent stations with a small module. It implies a big set of data (a lot of survey stations) and a complex post-processing.

If the passages of granite caves are compared with the ones present in other lithologies (limestone, dolomites, gypsum, ...), it is possible to make the next considerations:

- In granite caves, where boulder structures are very common, it is necessary to distinguish between passages and conduits. The passage is the void to be transited and may be developed by continuous walls, removed blocks, or by many fallen blocks; the conduit forms part of the subterranean drainage network, and may be formed by different adjacent passages.
- It is important to note that usually in granite caves the limits of passage and sometimes also of conduits are undefined.
- In soluble rocks these do not occur. Usually, passages and conduits are the same and their limits are clearly defined.

It is very complex to survey granite caves directly using the same techniques that are used in limestone caves. The differentiation between passage and conduit is very important in these systems and, in a general sense, it implies that the cross-section of a passage does not represent the real structure of the cavity and their conduits. So, it will be necessary to define a methodology to draw and model the real conduit pattern which is hidden by the residual boulder and block structure.

TYPES OF GRANITE CAVITIES

Though all the caves in granite are related to the rock structure, there may be distinguished three types (TWIDALE and VIDAL ROMANÍ, 2005).

1.- Caves linked to fractures developed along major fracture planes that allow the easy circulation of water. Weathering is essentially due to ion washing, leading to further widening of the fracture.

2.- Caves associated with fields of residual or protoclastic blocks. Here the finer fractions of the granite regolith, if existed, have been washed away, leaving the coarse fractions -blocks and boulders- in situ. Voids between these residuals have become linked in some places, giving rise to caves of irregular development (TWIDALE and VIDAL ROMANÍ, 2005).

3.- Tafone is the third type of cavity linked to the elastic deformation stage of the massif, though similar types of cavities have been attributed to epigenic environments (TWIDALE, 1982). The term refers to a cavern or hollow developed inside a fracture-defined block. The inside wall may have alveoles (honeycomb structure), mamillated (convex relief) or scalloped (concave relief) forms (TWIDALE and VIDAL ROMANÍ, 2005) and also negative exfoliation forms (VIDAL ROMANÍ, 1984).

MORPHOLOGY AND PASSAGE PATTERNS

There have been observed four types of basic passages:

- Type I: Usually, open fractures with lateral continuous and well-defined limits.
- Type II: Passages limited by a continuous wall and by removed or fallen blocks. In this type of passage the limits are only partially defined.
- Type III: Passages formed only by removed and fallen blocks.
- Type IV: Weathering structures. Generally, this type of passages is a special case of type I.

Inside caves linked to fractures developed along major fracture planes that allow the easy circulation of water, there can be found every type of passage pattern. And usually the real conduit structure is hidden by the accumulation of removed and fallen blocks (collapses areas), but it is possible to determine it from the study and correlation of the different adjacent passages.

In many passages of type I and II, it is possible to see a partial pattern of a subterranean conduit (VAQUEIRO, et al. 2006):

- The conduits and the morphologic features that characterise them (pot-hole, fluvial polish surfaces or lateral sapping) may be partially buried by sediments (terraces, varved sediments) or even result inaccessible for the chaos de boules produced by the collapse of the vaults. In general, when the conduits use a vertical or subvertical fracture they present a morphology of vadose type with an cross-section enlarged in the vertical and very narrow. When the subterranean network moves in favour of subhorizontal structural planes or with small dips, the cross-section of the channel is wider giving a morphology similar to phreatic conduits. This is due to the hardness and insolubility of the material excavated there, especially if it is compared with the equivalent processes in classic karstic environments.
- Some conduits present elliptical or circular sections. Generally, the ellipses are of oblique axis with elongation according to the subvertical shear plane, though they may be influenced by other subhorizontal discontinuities. The walls of these conduits are polished and in some cases are symmetric with respect to the fault plane. These conduits have complex sections formed by interference of several elliptical tubes of different dimensions. The resulting forms do not coincide with the "keyhole" sections (incised phreatic conduits) typical of the karst, but the existence of elliptical sections seems to indicate that each level in these conduits has been initially developed under phreatic conditions.

FIELDWORK

Subterranean survey

The aim of this work is to make geomorphological maps in granite caves.

The fieldwork takes into account to register the discontinuities and the main structural elements in the survey data form.

In granite caves the boulder structure and the separation between blocks may be a good approximation of the minimal distance between the most representative discontinuities. So, it is very important that the distance between two consecutive topographic stations does not surpass this value.

The common survey techniques used in karst systems were considered to start this project.

The most representative granite system until now in Galicia is the O Folón System. In this cave there are big passages type I, but in upper levels and inside collapses areas their passages generally present patterns types II or III which are characterized by a very irregular vault with small voids. In these situations, even though a short distance is used between survey stations, it is very difficult to have a good vision between the stations and the cave was surveyed lining the floor.

From each station and in accordance with the passage structure, a radial survey was made, pointing all the nearest structural elements and discontinuities and all the most representative geomorphological elements. In the survey form it was registered the basic information to classify a form in its morpho-genetic group.

To correlate adjacent voids and paths, it was necessary to make a route (or trace) combining open and close poly-lines (open and close polygons) with radial surveys.

Weathering caves, vaults and structures (passages type IV) have been mapped using a radial survey started up from the centre of vault or structure. The “lapas” have been surveyed like big vaults routing the cave with an open poly-line and making a radial survey in each station.

Surface survey

The surface overlaying caves linked to fractures developed along major fracture planes that allow the easy circulation of water, has been mapped taking into account the subterranean structure. So, these surfaces have been mapped like open paleo-channels using the same criteria that in subterranean voids.

Surroundings areas, domes and external mesoforms related to caves associated with fields of residual or protoclastic blocks, and also in weathering caves, have been surveyed routing the area with a closed poly-line which encloses the structure to be mapped. In many cases, it was surveyed a main global profile of the structure and another representative cross-sections.

Equipment to measure

To take the survey data there have been used tape measure, military compass and initially an analogical clinometer then replaced by a digital one (SolaTronic – Fisco, precision 0º/90º=0,1º).

Also, an analogical level NI020A Carl Zeiss Jena (precision 0,1 gon = 0,1º) has been used to take the horizontal angular measures, to guarantee the precision during the survey of big radials and in all situations in which it was possible to do it by the dimensions of the vault or passage. This equipment has been also used to carry out the survey of surface channels and dolines.

MAPPING

To make a cave map plotting the cave survey data, it is used the same methodology as in karstic systems, even though there are many particular criteria that should be taken in consideration.

Work scale

This geomorphological cartography is used to draw those granite micro and mesaforms which generally are less than many hundred meters in size. It has been decided to use 1:50 scale to draw views of details; 1:100 as basic scale; and 1:200/1:500 scales to draw global views.

Equidistance and level lines

For the scales of 1:50 and 1:100, it has been defined the value of 0.5 meters as equidistance between level lines.

Level lines will be determined by interpolating from the matrix of points obtained plotting the survey data.

Vertical passages or steeps

In vertical steeps the distance will be indicated in centimetres to avoid the use of decimal indicators.

Plant view

This view permits to determine the main subvertical discontinuities, which define the cave structure. These discontinuities will be used as reference to build any other cave view.

When there are many cave levels, it is considered as base level the one in which the active and present water-carry is located. The other levels will be plotted in different layers or will be plotted laying on top preserving the water-carry as main reference.

Profile view

To obtain a global profile view it will be used the set of main discontinuities determined over the plant view. It will be taken the subset of those discontinuities (their planes) in which main cave route is defined. Usually, this route will enclose the present active water-carry.

Then, the cave will be locally projected over each plane of discontinuity in this subset, and these partial projections will be assembled using the route of cave determined by the main discontinuities.

With reference to the local discontinuity plane, it may be used projected profiles or extended profiles. When we have two adjacent paths, with different routes, if we build a project profile, the first and last points of both paths will be coincident, but the distances among the stations will be projected and they cannot be used to measure the cave directly over the map. But, if we build an extended profile, the distances among survey stations will be the real distances, but the first and last points will not be coincident and then subhorizontal or transversal structures will not be also correlated directly on the view.

In projected profile the extremes of the two paths are coincident in the draw, and in geomorphological maps it is very important because it will permit to correlate the geomorphological data from adjacent voids.

Partial and global profile views permit to route the main sub-horizontal or horizontal discontinuities of the cave.

Cross-sections and complex cross-sections

It has been remarked that in granite caves there exists a big difference between the passage (a void to transit) and the conduit. Sometimes, the conduit and the passage may be coincident, but usually, the conduit will be determined by the continuous limits defined by many adjacent passages. The term "conduit" implies water flow activity, but in this paper it is used in the sense of "global cross-section". If these global cross-sections may be or not a real conduit, it will be determined by a specific geomorphological work or analysis.

A global cross-section is plotted using a plane orthogonal to the main local discontinuity. This plane will cut the cave making the cross-sections for each individual passage. When all these partial cross-sections are composed on the same plane using their real position and elevation (the vector to route the points of these sections), it will be obtained a first complex cross- section.

There is possible then to plot the envelope outline of the complex cross-section, approaching the continuous limits of the global cross-section.

CAVE SURVEY SYMBOLOGY AND REFERENCES

There is not an adequate legend that represents the granitic forms and even less in the case of subterranean environments. To solve this, an adaptation of the existing nomenclature is proposed in this work and, when necessary, there was made a proposal of new symbols. The nomenclature used herein is based on four types of legends:

- Cave symbols, edition 1999, from the official UIS Symbol List, by Survey and Mapping Working Group, UIS Informatics Commission at the International Union of Speleology. (They can be found in this web page: http://www.uisic.uis-speleo.org/wgsurmap.html).
- Cave symbols list, edition 1992, from the official FEE Symbol List. (MARTÍNEZ I RIUS, 1992)

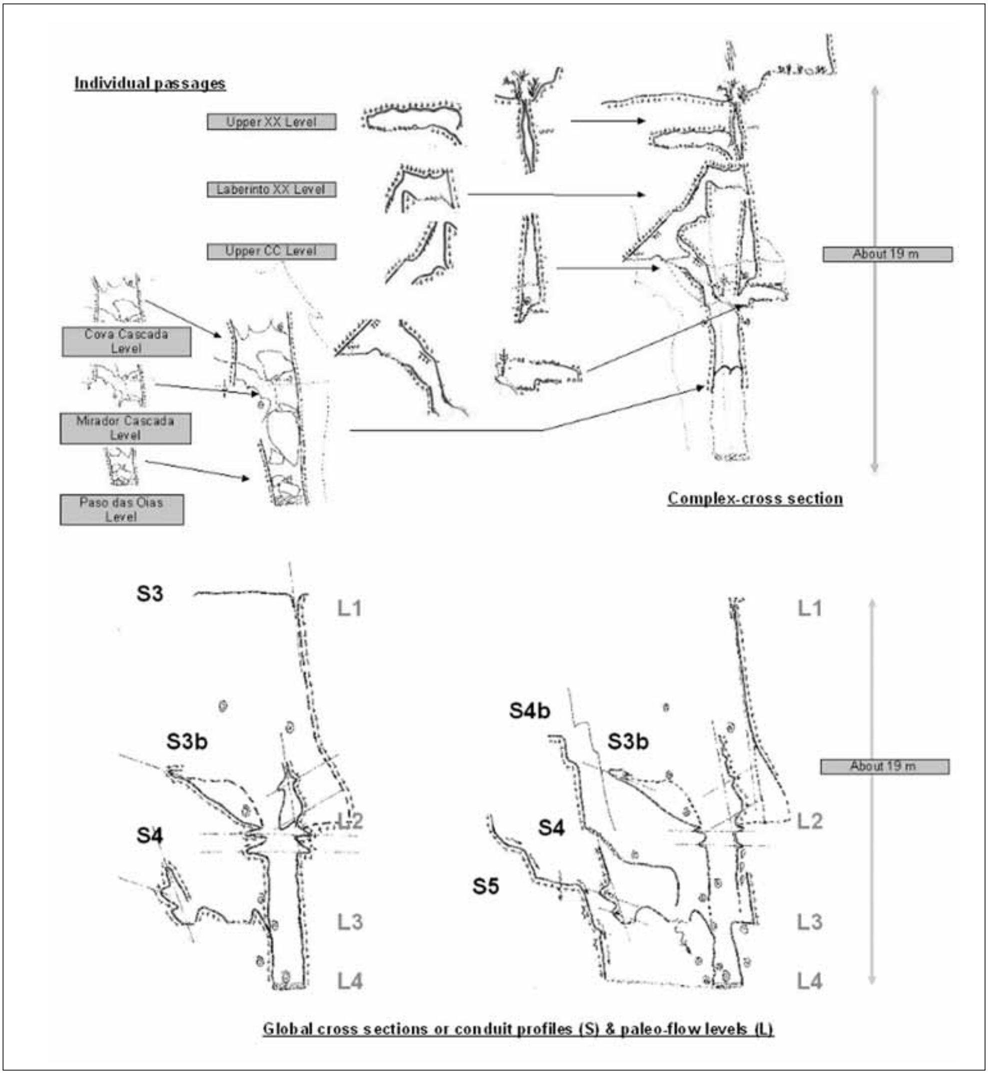


Figure1.- Different cross sections of the O Folón System conducts. See Figure 2 to locate them in the longitudinal profile of the cave.

- Geomorphologic symbols for the "Mapa geomorfológico de España" (MARTIN-SERRANO et al., 2004).
- New symbols designed for this work.

We decide to employ the same symbology that is used with other type of rocks (e.g., limestone) though with a specific colour for the forms developed on plutonic rocks of endogenous or exogenous origins. So, different morpho-genetic groups have been proposed in accordance with the ones defined by IGME:

- Structure elements and forms
- Chemical and physical weathering in magmatic rocks
- Elements related to water flows: Mechanical erosion
- Depositional forms: Sedimentary deposits and speleothems

The symbols used in these morpho-genetic groups have been taken from other type of rocks and in many cases, from another morpho-genetic group. To define the real group in which the form is classified, it has been defined a colour for each morpho-genetic group. So, some "official" symbols have been used, extending their original meaning.

– Structure elements and forms

COLOUR : GREEN (RGB: 5, 225, 5)

Planar discontinuities with indication of dip: used to indicate the dip of not open discontinuities. It was used to indicate the dip of fracture families where there have been generated shelter-type structures, as well as other fracture and weathering planes with small opening (less than 30 cm) and not open. Line of 0.2 mm thick. Line length 6 mm. Arrow length 2 mm.

Direction and slope or dip: used to indicate the dip of open discontinuities. It was used to indicate the dip of the set of discontinuities through which the main galleries have been generated. The direction is a vector normal to the fracture orientation and the dip was measured with clinometer on the gallery wall. Line of 0.2 mm thick. Length of lines 6 mm and 1 mm.

Sheeting with sliding: 0.4 mm thick. Length of lines: 6 mm and 1 mm.

Breakdown doline/collapse limits: Limits of the collapse doline. Line of 0.4 mm thick. Length of lines: 6 mm and 1 mm.

– Chemical and physical weathering in magmatic rocks

COLOUR : BLACK (RGB: 0, 0, 0)

Tafone: used to indicate the presence of not mappable tafone with or without honeycombs. Line of 0.4 mm thick. Breath and height of the element 2.5 mm x 4.5 mm. Symbol location: in the perimeter of the front or plane where the form is located.

Pseudo-karren, pseudo-rills: used to represent flutings. The symbol of karren is used. Line of 0,4 mm thick. Breath and height of the element 0.75 mm x 6 mm. Symbol location: in the perimeter of the front or plane where the form is located.

Weathering microforms: used to indicate any other form or not specified weathering microform, like alveoles, weathering fronts, etc. When forms are not big enough, symbol indicates only the location. But when forms are mappable, symbols are placed in the perimeter of the front or plane where the form have been developed. Line of 0.2 mm thick. Breath and height of the element 0.75 mm x 1.4 mm. Symbol location: in the perimeter of the front or plane where the form is located.

Lateral notches: used to indicate lateral notches. In A Furna and O Folón Cave there appears a weathering front in some conduits, with hollow in the sub-horizontal fracture plane. Line of 0.2 mm thick. Variable breath and height of the element. Arrow perpendicular to bow. Symbol location: in the perimeter of the front or plane where the form is located.

– Elements related to water flows

COLOUR : BLUE (RGB: 5, 114, 225)

Anastomosis: used to represent the existence of diffuse flows. Also used in sump zones with absorption or diffuse resurgence. Line of 0.4 mm thick. Variable length and breath according to extension of forms. Distribution: indicates the development zone.

Direction of paleoflow and paleochannel levels: This symbol is not only used alone but combined with varves, potholes… to indicate paleo-flow levels. Line of 0.4 mm thick. Variable length and breath according to extension of forms. Distribution: indicates the paleochannel development.

***Potholes*:** Line of 0.2 mm thick. Variable size according to extension of forms. Distribution: indicates the location.

Lateral notches: used to indicate lateral erosional notches. Arrow perpendicular to bow. Symbol location: in the perimeter of the front or plane where the form is located.

– Other forms

COLOUR : GREEN (RGB: 5, 225, 5)

***Onglets or pressure scales*:** These forms are convex forms developed by charge concentration on the contact points between tilted blocks and the cavity walls or even in other blocks. Line of 0.4 mm thick. Variable length and breath according to extension of forms. Distribution: indicates the location.

Block fall/collapse/subsidence: Line of 0.2 mm thick. Dimensions according to the size of the forms. Distribution: indicates the location.

– Sedimentary deposits and speleothems

COLOUR : RED (RGB: 205, 18, 18)

Varves: Varved deposits or ritmites. Line of 0.2 mm thick. Extension according to the size of deposit. Tilting according to the dip of the deposit.

Botryoids: This symbol represents opal-A, crusts and botryoidal deposits with nodular forms up to 5 mm of diameter.

Line of 0.2 mm thick. Breath and height variable according to the size of the form. Symbol location: in the perimeter of the front or plane where the form is located.

Cylindrical speleothems: used to represent individualized forms of opal-A speleothems, both acicular and vermicular and pseudo-helictites with antler variety.

As there is no clear genetic differentiation of the forms and to avoid the overlap of many symbols, it was combined with the previous one. In exceptional cases it may refer to pigotite stalactites.

Line of 0.2 mm thick. Breath and height variable according to the size of the form.. Symbol location: in the perimeter of the front or plane where the form is located.

Pigotite *Draperies/Sinter curtain*: A curtain or scarf-like speleothem that hangs down from inclined cave ceilings or walls. They are a composite dark (non-translucent) flowstone-dripstone speleothem. The most common form is a straight line slightly curved, with water flowing down along an inclined rock wall, but well-developed curtains have been found.

Line of 0.2 mm thick. Breath and height variable according to the size of the form. Symbol location: in the perimeter of the front or plane where the form is located.

Pigotite Stalactites

Line of 0.2 mm thick. Breath and height variable according to the size of the form. Symbol location: in the perimeter of the front or plane where the form is located.

Stalagmites

Line of 0.2 mm thick. Breath and height variable according to the size of the form. Symbol location: in the perimeter of the front or plane where the form is located.

Flowstone

Line of 0.2 mm thick. Breath and height variable according to the size of the form. Symbol location: in the perimeter of the front or plane where the form is located.

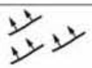
– Other elements.

COLOUR : SALMON (RGB: 205, 92, 61)

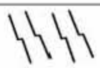
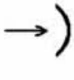
Bones: any organic remain. Line of 0.4 mm thick. Length 6 mm. Symbol location: it indicates the zone where they appear.

Human activity: This symbol is used for man-made changes and/or remains in caves including artwork (engravings), pottery… In many cases it is used to indicate modern mining alterations. Line of 0.4 mm thick. Maximum diameter 6 mm. Symbol location: in the perimeter of the front or plane where the site is located.

Structure elements and forms

	**Planar discontinuities with indication of dip**
	**Direction and slope or dip**
	**Sheeting with sliding**
	**Breakdown doline/collapse limits**

Chemical and physical weathering in magmatic rocks

	**Tafone**
	**Pseudo-karren**
	Weathering microforms
	**Lateral notches**

Elements related to water flows

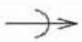
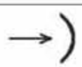
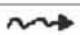
	**Anastomosis**
	**Direction of paleoflow and paleochannel levels**
	***Potholes***
	**Lateral notches**
	**Flow**

Table 1.- Proposed cave symbol list.

Other forms

	***Onglets or pressure scales***
	**Block fall/collapse/subsidence**

Sedimentary deposits and speleothems

	**Varves**
	**Botryoids**
	**Cylindrical speleothems**
	**Pigotite *Draperies/Sinter curtain***
	**Pigotite Stalactites**
	**Stalagmites**
	**Flowstone**

Other elements

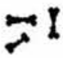
	**Bones**
	**Human activity**

Table 1.- Proposed cave symbol list.

MODELLING

The geomorphological map and their different views completed with specific symbology may permit to obtain a new complex views and sketches to analyse the evolution of the cave. So, this part of the project has been named modelling phase.

Approaching global conduits

In previous chapters it had been explained the method used to draw many types of global cross-sections: When the cave profile is intersected with any orthogonal plane, adjacent voids from individual passages can be related drawing then a global cross-section.

Using these views, it is possible to make a first model for the cave removing virtually collapses areas and correlating the continuous limits to outline the envelop of the global conduit.

Paleo-levels and paleo-flows

Taking a set of many global cross-sections, this is, a succession of different cross-sections obtained by cutting the main cave route with different orthogonal planes, it is possible to make many new complex views and sketches to determine the relation between the different paleo-levels or paleo-flows along the cave.

Two types of plots are considered:

- Views superposing many sequential complex cross-sections. Symbols are used to remark the different morpho-genetic group preserved in each section.
- Three-dimensional views using the succession of complex cross-sections. In this case:
  - All the cross-sections are obtained by parallel planes. It implies that all the planes are related with the same main discontinuity.
  - It is used a special type of perspective in which the planes containing cross-sections are plotted parallel to the draw plane. Its dimensions are preserved (XZ plane) and the distance between two adjacent sections may be plotted with a reduction factor of 0.5.
  - To define the surface it is necessary to plot a envelope grid. Here, it is used a horizontal or vertical equidistance of 1 m.
  - Symbols are used to remark the different morpho-genetic group present in each point.

Using these views it is easy to make a first geomorphological analysis directed to obtain:

- Levels or continuous surfaces in which there are elements related to water flows (indicators of mechanical erosion).
- Paleo-levels determined by channels or continuous surfaces hanging over the present water-carry.
- Superposed levels and paleo-flows spring from a recursive downcutting of a main water flow.

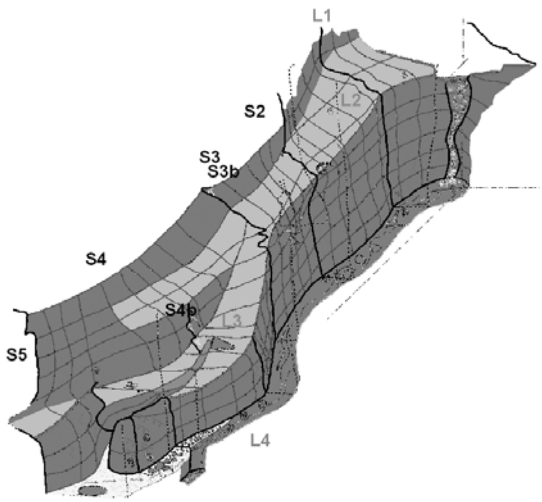


Figure 2.- Three-dimensional cartoon with different stages of incision levels of O Folón Cave from the absorption area to spring area.

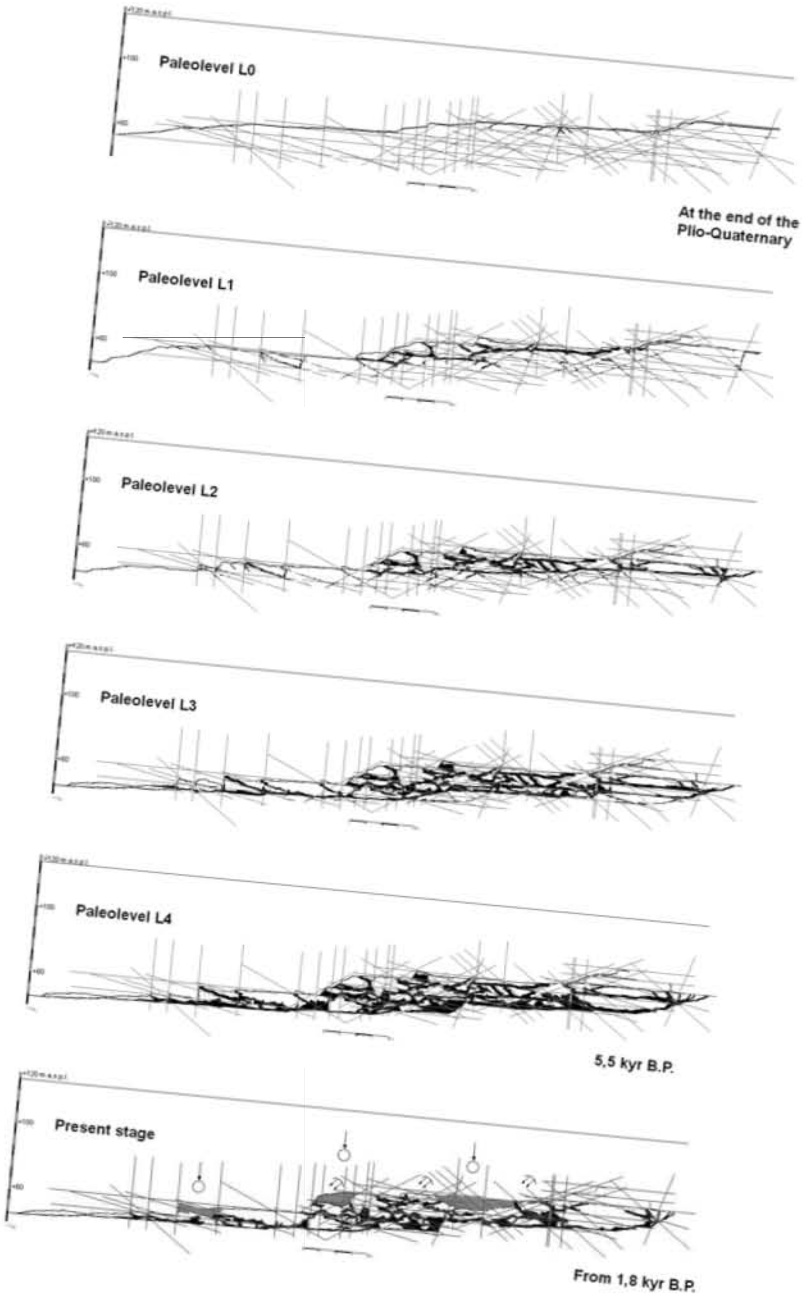


Figure 3.- Evolution of the longitudinal profile of O Folón System during the progressive opening of the structure by fluvial erosion from the Plio-Quaternary till present times.

Correlating structure and paleo-levels: Approaching a cave evolution

Superposing the paleo-level model of the cave over the main projected profile, it is possible to correlate structure and paleo-levels. Main drainage networks and channels may be then correlated and related with a specific paleo-flow. A complete geomorphological work permits to approach a possible sequence for cave evolution, routing many different snapshots that enclose the recursive downcutting process and the transition between main subterranean channels.

This sequence has been completed detaching the last snapshot (the present stage) in many sequential pictures referred to the pre- and post-structural collapse. This collapse has been dated by radiocarbon using pigotite deposits related to structures developed post cave collapse.

DISCUSSION AND CONCLUSIONS

Graphical representation of subterranean granite spaces requires the use of specific speleological topographic criteria adapted to the characteristics of this lithology. There is not an adequate legend that represents the granitic forms and even less in the case of subterranean environments. In this work, the symbology, which was defined for other lithologies, has been used to represent similar morphologies in granite voids even though their genesis may be very different.

A basic point in this project has been the abstraction done in the granite voids to distinguish passages and conduits, and also the work carried out to assemble adjacent cross-sections rebuilding global cross-sections that approach the conduit patterns.

These complex views (superposing many sequential complex cross-sections, three dimensional views,...) are a graphical tool to make a geomorphological analyse of the cave looking for the paleo-levels and paleo-flows.

ACKNOWLEDGEMENTS

We thank Ana Martelli for reviewing the paper English version and Juan Ramón Vidal, master and friend, for his criticism of the ideas expressed in this paper which helped to improve it. The work and surveys would not have been done without the help of friends in the “Clube Espeleolóxico Maúxo” - Speleological Association. Special thanks to Begoña Barreiro, Reinaldo Costas, Xavier Groba and Rosa Suárez who took part intensively in taking the data for the elaboration of the new cartography of O Folón.

BIBLIOGRAPHY

MARTÍN-SERRANO, A., SALAZAR, A., NOZAL, F. and SUÁREZ, A. (2004). *Mapa Geomorfológico de España a Escala 1:50.000*. Guía para su elaboración. Instituto Geológico y Minero de España. Madrid.

MARTÍNEZ I RIUS (1992). *Topografía Espeleológica*. Federación Española de Espeleología. Badalona.

TWIDALE, C. R. (1982.) *Granite landforms*. Ed. Elsevier, 372 pp.

TWIDALE, C. R. and VIDAL ROMANÍ, J.R. (2005) - *Landforms and geology of granite terrains*. A.A. Balkema Publishers Leiden. Great Britain.

VIDAL ROMANÍ, J.R. (1984). Geomorfología Granítica. Modelos de deformación post-tectónica. *Memorias e Noticias*, 143-158.

VAQUEIRO RODRÍGUEZ, M., BARREIRO BEN, B., COSTAS VÁZQUEZ, R., SUÁREZ PÉREZ, R. and GROBA GONZÁLEZ, X. (2006). Rebuilding paleoflows and structures in the granitical system cave of “O Folón” (Vigo, Galicia – Spain). *Cadernos Laboratorio Xeolóxico de Laxe*. Vol. 31, pp. 88-105.

VAQUEIRO RODRÍGUEZ, M., GROBA GONZÁLEZ, X. and VIDAL ROMANI, J.R. (2007). *The Granite Structural System of “O Folón”. Coruxo – Vigo (Galicia, Spain).* Poster: Special Edition for The International Conference on Granite Caves. Artes Gráficas ROEL. Depóstio Legal: VG 855-2007. Vigo.