

1000 AND 1 CAVES IN “LEFKA ORI” MASSIF, ON CRETE, GREECE

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Crete, the fifth largest island in the Mediterranean sea has been subject to numerous speleological, archaeological and geological expeditions over the years. Nearly 50% of the island is covered by limestones in the form of high rocky mountains. Lefka Ori massif is located to the west side (Chania district), it is the second highest on Crete (Pahnes, 2454m) but the largest in surface. The massif has a unique shape which is formulated by its 54 peaks - counting only those higher than 2000m altitude) and hosts some of the deepest caves in Greece including the deepest and the second deepest (both deeper than -1000m). Expedition reports from local or international teams targeting this amazing mountain are dating back in the early seventies and have revealed some unique caves and big shafts such as the well known Mavro Skiadi (shaft, -342m), Drakolaki cave (+175m), (Katavothra tou) Tzani (-280m), Gourgouthakas (-1208m), Lion cave (-1110m) and others. The majority of these reports - especially those published before the year 2003- are having limited information on the exact geographical location of the caves explored and/or located. With the word "exact" the author means coordinates of entrance recorded with a GPS (Global Positioning System) device which can be then re-used by other GPS or GIS (Geographic Information Systems) software. This fact (lack of entrance coordinates) influenced a new era of speleological projects in the area initiated by SELAS speleological club of Athens (in 2003) and a number of local and foreign contributors (clubs or individuals). Thanks to excellent cooperation developed between local and international teams (the contributors), **1255 cave entrance coordinates** have been recorded and consolidated in one single database. The effort lasted 9 years so far and the author apart from taking part in many of the above field trips, has been also the person collecting and consolidating the datasets from the teams involved. If we take into account the known work of other teams that concern datasets which are due to be shared with the author, the number of validated cave entrances in the massif are (today) **more than 1400**. The geocoded information provides new perspectives and opportunities in better understanding and exploiting speleological GIS datasets of the Lefka Ori massif. The subject of this paper is mainly presenting this dataset, the contributors and the effort and method used. Announcing the outcome of this project to the global speleological community is also interesting as a benchmark and to share experiences with other similar works carried out around the world.

1. Introduction

1.1 General

Lefka Ori is an amazing massif in an amazing island, Crete. When you are in the middle of this mountain e.g. *Pavlia Halara* area, there no roads, no trees (in high altitude) and no water. Based on the cave surveys recorded over the years, one may notice that the mountain has a high number of big vertical puits, especially when compared to mountain Idi (Psiloritis 2456m), to the east. The longest cave on the massif is *Tou Tzani o Spilios* with current length being more than 2.8km. There are also some unique shafts (-342 is the deepest) and some super deep caves (more than -1000m) which attracting today's local and foreign cavers to organize expeditions in this mountain.

With GPS technology being available to the public in early 90s (and becoming reliable, for the public, after 2000) it is clear that all previous works in the area need revisiting in order to record cave locations with proper entrance coordinates. By having accurate coordinates of cave entrances, these can be used for GIS purposes, enabling the correlation of caves entrances to several geographical or geological information. Its existence is also helpful to resolve issues occurring when trying to count caves in a specific area.

1.2 The project

Having said the above, this paper is about a single

database of cave entrance coordinates accompanied by some basic cave data collected between 2003 and 2012 by 17 expeditions and at least 8 trips in the area of Lefka Ori, on Crete. With the term "trip" we define the short expeditions usually lasting a weekend or long weekend (3-4 days) while proper expeditions usually last longer e.g. more than a week. Both trips and expeditions constitute the fundamental field work which was a key element of this effort. In parallel, there was a need in collecting, consolidating, clearing the datasets collected from field work which was also important. Part of this job was done in the field (Lefka Ori) during the expeditions and another part of it, was done afterwards at expedition level or at a cross expedition level (consolidation). Both the field work (expeditions) and the "homework" (consolidation of information) were fundamental for the subject of this paper which we call "*the project*". The author apart from participating or leading in the many of the field expeditions or trips, took the role of the central point of contact for the above mentioned consolidation.

There was no written agreement between clubs / teams involved in this effort nor any central guidance or formal leadership on this project. It all came out of people from many countries working nicely together for a common goal, willing to share with each other. It is also worth mentioning that the project is not over yet as there at least 2 expeditions that are due to share their results with the project and of course there will be more future expeditions in the mountain. For now, this paper is just about sharing the outcome and some findings of this project with the

public, as a first milestone (1000+ caves) was reached.

1.2.1 The field work

The above mentioned **17 expeditions** contributed **928** cave entrance coordinates to the project. As stated above, several trips took place, some were preparatory steps for expeditions to follow in an area while others were local cavers activity for months or years in the same area. The trips contributed **327** cave entrances, leading to the total number of caves now available in the database to be **1255**.

Table 1. Total caves in Lefka Ori, Crete between years 2003 and 2012.

Total caves in Lefka Ori Explorations 2003-2012	Total Caves
Validated and added in database	1255
Not added yet to the database	185
Total	1440
Estimated total	1400+

It is also know that 2 expeditions that operated in the area are due to share their results. These expeditions reported that they located **188** caves, not included in the database. By adding the above the total number of caves (validated with coordinates) in the area of Lefka Ori should be above **1400** caves. This is lower number that the sum of the above numbers as we anticipate there will be some overlapping of caves between the datasets.

The approximate time spent in the field was **308 days** (10 months) by approx. **308 cavers**. One may say that **for every day in Lefka Ori, more than 4 new caves were added** to the database. There were mainly 3 countries involved (Greece, Great Britain and France) with **9 clubs** taking the lead in organizing expeditions or field trips during these **9 years**. In addition cavers from **Romania, Italy, New Zealand** and **Israel** very actively and enthusiastically contributed by participating the above activities. More specifically, the table 2 indicates the clubs involved and their activities.

Several devices were used in the field for collecting data. The oldest type of GPS used (that came to our attention) it was a GARMIN GPS12XL The most frequently used devices were GARMINs e-trex family. Some minor GPS accuracy problems were detected but they are usually fewer when a modern device is used and when the user operating the device is more experienced. Using different devices means slightly different accuracy and somehow different information being recorded when in the field e.g date is added on the remarks in some devices while this is not in case in some others.

In addition several methods were used in the field when collecting data. If we see the main contributors of the project we may notice that SELAS and FOS were using mainly in the field excel spreadsheets or paper forms or handheld PDAs. Every subject (a cave) was assigned with a code number (initially a continual number or a number with a prefix indicating the area). Later – after 2009 SELAS introduced different coding for its one use: first 2 digits indicating the year when the cave was found (e.g.

09 for 2009) followed by a 3 digit number non continual usually segregating teams (under the same expedition) to avoid assigning the same code in 2 different subjects while on expedition (e.g. 09100 to 09199 was assigned to team / GPS 1, 09200 to 09299 was assigned to team / GPS 2, etc). Both SELAS and FOS recorded existing coding when they were finding caves marked already by previous expedition e.g. GSO21 marked by GSO expedition in 1992 was recorded in GPS with the same code.

This code (number or other) was then used to link the coordinates in GPS to any drawing or relevant information about the subject in notes taken by expedition members. A similar approach was used by the second most significant contributor, SUSS. The SUSS coding appear to be based on the teams, with 2 first digits being letters, indicating the team leader / GPS, followed by numbers indicating the subject (cave). Coordinates and other cave information were consolidated in a more clever XML format (one file for coordinates and basic information)

Some teams of SPOK club (Mavrokosta, Gkiouzelis and Gigourtsis) contributed to the project mainly in the form of MS Word® documents containing the coordinates and some basic cave info. Some others (Valantis Vlachos and Augoustinos Economou) contributed with .KML (Google Earth file) containing both coordinates and some notes about each subject (on the comment field). The UK based RRCPC (Red Rose Caving and Potholing Club) also contributed with MS Word reports while the French GS Catamaran in some cases with a .pdf official report for the expedition, in other cases (e.g. 2010 expedition) with GPS files.

Table 2. Activity and contributions by club.

Club name and origin	Caves contributed	Days in field	Members
SUSS (Sheffield, UK)	435	56	40
SELAS (Athens, Greece)	348	95	123
FOS (Athens, Greece)	220	32	57
SPOK (Heraklion Crete, Greece)	102	37	27
GS CATAMARAN / DOUBS (Doubs, France)	94	56	27
OSCA (Heraklion Crete, Greece)	38	3	4
RRCPC (UK)	18	29	30
Total	1255	308	308

Collecting data from the field can be challenging and requires proper organization and certain provisions by each expedition. If not organized well might lead in errors and that will require more effort to collect again.

1.2.2 The homework

The above mentioned “babel” of different approaches used in the field created a challenge in the consolidation phase (between datasets from different expeditions). This challenge was undertaken by the author starting with

SELAS waypoints (as the author is a member of SELAS club). Waypoints were first loaded in OziExplorer® software by several GPS devices and a central file for all SELAS expeditions was formed. OziExplorer software has the ability to select waypoints 'not on map' and this was one of the first filters used to efficiently remove waypoints not relevant to the project work. GPSBabel.exe software was then used to remove duplicates based on name/code and a 'radius' range of 5 meters. This helped a lot to reduce the number of subjects to validate. Finally, by browsing notes taken by the expeditions and by visual analysis (on screen) the waypoint file was considered to have unique cave entries only. When that was accomplished for SELAS then SUSS data were added. It was necessary to create a custom converter from XML to .wpt for Ozi Explorer to be able to read the data contributed by SUSS. But when this was done the file nearly doubled. More entries followed in the years to come as the expeditions were developing. In some cases e.g. data from SPOK club were manually added while other data e.g. in .KML format were easily added by using the append function in OziExplorer software. This is mainly how the final file was created with 1255 entries of cave objects. The file is kept in the form of .wpt (OziExplorer waypoint file) and .kml file (Google Earth waypoints). In addition cave information is kept in a basic .csv (Comma Separated Values) format.

2. The evolution of the project.

Inspired by former expeditions and the mountain itself, a few SELAS members which were already familiar with the area (since 1997) organized their first attempt to explore the central massif in 2003. In a few days they found 36 caves and this is how the project started. The club continued in 2004 with two short trips and recorded 78 caves more. By the end of 2005 the club had found more than 200 caves. The areas where SELAS focused were firstly Pavlia Halara and then Ammoutsera and Sternes. At that time only RRCPC (Red Rose Caving and Potholing Club) from UK and SPOK from Crete were sharing some info about their trips in Lefka Ori and contributed with a datasets of waypoints indicating cave entrances. During the UIS 14th ICS in Kalamos Athens Rob Eavis and Robbie Shone members of Sheffield University Speleological Society (SUSS), UK got in touch with SELAS, became aware of the project and decided to organized the return of SUSS to the mountain. As a result SUSS organized 2 trips in 2006, a preparatory expedition (March) and a proper expedition at summer (June-July). Both trips targeted *Mavri Lakki* area. As a results, the SUSS team contributed 174 waypoints that year. Same year, a joint expedition between SELAS and FOS club members operated in Ammoutsera, Sternes and Pavlia Halara area.

In 2007 it is again a mixed team between FOS and SELAS members returning to the mountain. This time FOS is taking the lead and operated in Kako Kasteli area (North East side of the massif). During the FOS club preparatory trip **50 caves were recorded in 1 single day (by 3 people)**. In total, by the end of 2007, another 98 caves were added, 83 by FOS and 15 by SPOK club which was operating short trips to the mountain during

that year.

With **268** caves being contributed to the project, 2008 was definitely a very fruitful year. The result was mainly driven by SUSS's 'Crete 2008' expedition (124 caves, Mavri Laki area). FOS also returned to Kako Kasteli area for the 2008 expedition and collected 103 new caves. Finally SELAS joined GS CATAMARAN (from France) in 'Lion' expedition and they contributed with another 41 caves (Atzinolakas area, north side). Apart these caves, this expedition resulted in the exploration of Lion cave (-1110m), till today the second deepest cave in Greece. During the same year, the Hellenic Speleological Society of Crete (HSS Crete) organised an expedition to Psari peak area (North) and found 125 caves which are not shared with the project yet (pending publication). If we add HSS Crete findings, the caves found during 2008 were 393.

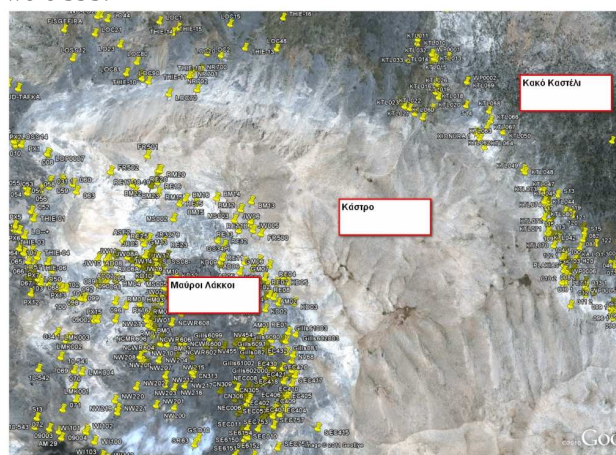


Figure 1. Dark dolomites of Mavri Lakki (bottom) and Kako Kasteli (top) appear to have significantly higher number of caves entrances when compared to e.g. Kastro peak (middle) which is covered by pure limestones

Late 2008 early 2009 was realized the first attempt to consolidate the above datasets in one unique database. The number of caves consolidated in the first attempt were slightly above 500 and it is the time when the aspiration to reach 1000 cave entrances was formulated. The outcome is announced over the web together with a call for other teams - that worked in the area - to contribute. The field work continued of course, so in 2009 we witnessed 3 expeditions: one by SUSS which returned to COLOSUSS (together with a few SELAS and SPOK members, Mavri Laki area). This expedition had no significant contribution in terms of new caves found but was focused in exploring COLOSUSS, a very important cave - which found to stop in a boulder chock at -553m. A few weeks later SELAS returns to Sternes area (and Sternes -463m cave) after a while (together with FOS and SPOK members) and contributed with 44 new cave entrances in the areas of Sternes and Thodoris. Last but not least, FOS club returned to Kako Kasteli area for a last time since then and found 34 new caves. The same year (2009) Valantis Vlachos (SPOK member) contributed 55 caves and some notes for caves found around Korda peak (between Kako Kasteli and Atzinolakas, north side of the mountain). These caves were found in several weekend trips by small teams of 4 to 6 people in a period between 2007 and 2009. Finally, concerning, HSS Crete operated

one more expedition to the mountain in 2009 and found 60 caves, with one being deeper than -400m (PS7)

The following year (2010) two expeditions took place the same period (nearly identical dates) and they camped only 400 meters away from each other. These were the SELAS expedition *Sternes 2010* and the GS Catamaran / GS Doubs (FR) expedition in the area. There was very good cooperation between the two expeditions, besides members were well known on both sides for 10-15 years. The two expeditions were using the same coding principle for marking caves but the work in different areas. The French team was working in Rousies area while SELAS is working in the area between Sternes and Mesa Soros. SELAS was working in parallel Sternes cave (-463) by performing enlargements on some passages. SELAS was joined that year by a team of fellow Romanian cavers. The outcome of the year was: 53 caves found by the French team and 32 caves found by the SELAS (GR, RO) team. Same year (2010) the *SUSS Crete 2010* expedition took place in Mavri Lakki with significant findings (139 caves found)

The following year (2011) there was only SELAS returning in Sternes area, this time followed by French, Romanian, Italian cavers and a New Zealander. 54 more caves were added (and the majority explored) and the team was officially celebrating the achievement of the 1000+ caves benchmark which was set as an aspiration in 2009. Finally, SELAS returned again in Sternes in 2012 with a small team but only 12 new caves are added to the database. Inch by inch, day by day the file reached 1250+ entries and may reach more and the more in the future as the potential of the place seems to be great.

Table 3. Clubs by area, by surface covered and caves found by area (excluding Psari area).

Club	Code on map	Sq km	Caves	Caves / km ³
SELAS	AM	10.3	348	33.8
SUSS	ML	6.8	435	64.0
FOS	KK	3	220	73.3
SPOK	ZR	4.2	65	15.5
SPOK	KR	2	55	27.5
CATAMARAN	RS	2.6	53	20.4
CATAMARAN	AT	2.6	41	15.8
Total		31.5	1217	38.6

3. Geology and Geography of the project

The mountain and more specifically the areas in scope are mainly covered by limestone's (white) and dolomites (dark gray). When browsing the data one may notice a correlation between the caves entrances and the rock type: grey dolomites appear to have more cave entrances than the white limestones (see Figure 1). It worths elaborating more in this aspect in a future paper as well as understanding if there is any correlation between the depth

/ length of the cave and the rock type at the level of entrance. For now, experience says that the deepest caves in the area have been all found close to the junction between the two types of rock (white limestones and grey dolomites).

The expeditions included in the project were operating in different sides of the mountain. The area covered by the teams is around **30 square kilometers** and represents nearly 10% of the total surface of the mountain. This segment of its surface has been searched by the expedition members but that doesn't mean that all caves existing in these areas have been found. In order to make this geographical distribution of expeditions visible to the reader the main area of the massif has been divided in 8 areas which are coded with a 2 letter code according to local name of the area / peak. In example KK stands for Kako Kasteli area. This coding is then linked to a color and a club which was operating expeditions in that particular area. Table 3 is the link between clubs and areas. On the same table you may find the surface of the area covered by each club (in square km) and the number of caves found in this part of Lefka Ori (so far). The area coding is presented in Figure 2

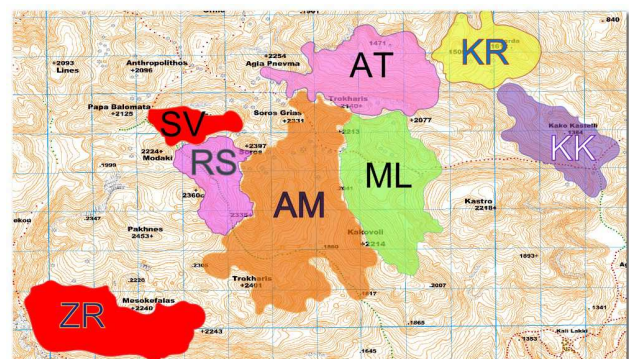


Figure 2: Target area by expedition as shown on table 7

The following figures are based on Google Earth® and represent some realistic views of the above color coded areas.

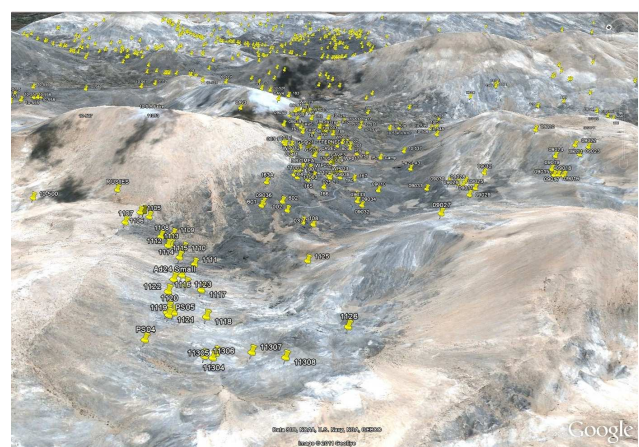


Figure 3: Satellite image with the caves plotted on it AM area (SELAS)

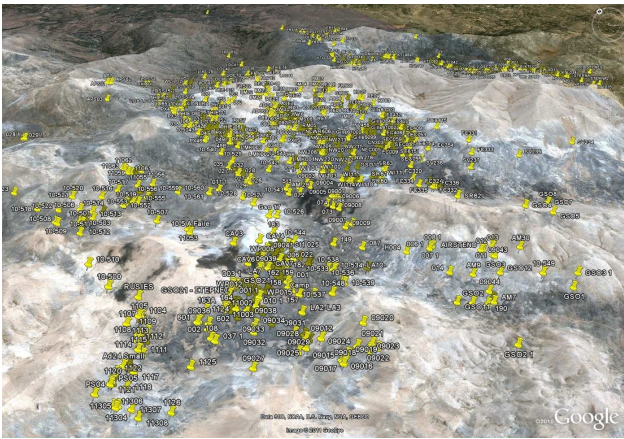


Figure 4: Satellite image (Google Earth) with the caves plotted on it. Areas shown are AM (SELAS) and ML (SUSS)

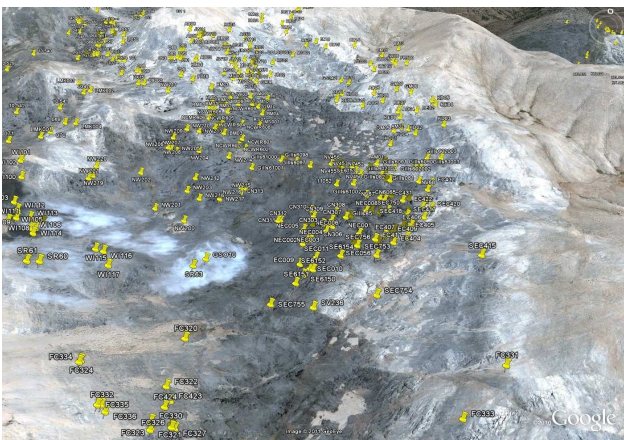


Figure 5: Satellite image (Google Earth) with the caves plotted on it, ML area (SUSS)



Figure 6: Satellite image (Google Earth) with the caves plotted on it, Kako Kasteli area (KK), FOS club

4. Results

It is very safe to say that the dataset contains information about more than 1001 caves. The dataset can have numerous uses and several studies can be made out of it. For example it can be used in correlation with the surface rock type and with the application of statistical techniques to make a forecast to calculate the potential of the entire mountain.

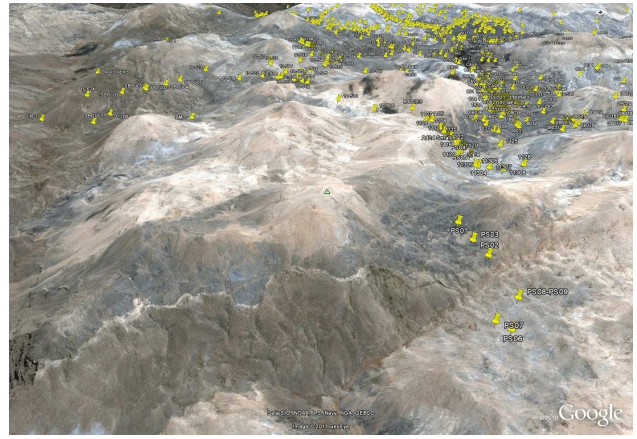


Figure 7: Satellite image (Google Earth) with the caves plotted on it, ZR and SV areas are shown on the lower right and the high left corner of the image (SPOK, SV and ZR areas). Upper right corner is showing RS (CATAMARAN) and AM areas (SELAS).

In addition out of these 1255 caves around 740 have been explored (or at least partly explored). The majority of the caves are between 4 (minimum) and 20 m depth as it is shown on the histogram presented below. Several similar studies can be made on the dataset that may reveal patterns, correlations or other learning points that will allow us to better understand the cave environment of Lefka Ori but these are out of scope of this paper.

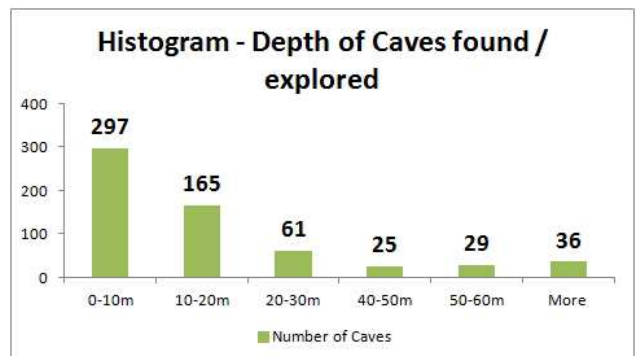


Figure 8: Histogram by depth of a dataset of 614 caves in Lefka Ori

5. Conclusions

Reaching and exceeding the 1000 caves milestone of the project revealed and confirmed the potential of the area and calls for more expeditions in the future. The potential of the area is significant and author's thesis is that the final number will be a multiple of the current number. In addition, only 60% of the caves found have been explored and many out of these explored might reveal new leads in the future. It is worthy to continue with the exemplary cooperation that the above mentioned teams had shown. It will also be worthwhile in exchanging views with other similar projects around the world to see if this process of collecting these datasets can be more effective and more efficient.

It is definitely important to preserve Lefka Ori for the

future generations. The wild environment of the massif is unique in Greece and in Europe, well known by people who walk it through as the "high desert". We welcome future expeditions to join our efforts provided that they will respect the environment, they will be having the kindness and the team spirit to contribute to this project and that they respect UIS code of ethics. Teams who are interested to contribute may contact the project and the author via (www.lefka-ori-caves.info) or SELAS club (www.selas.org). In addition EOS Chanion club situated in Chania will appreciate to be contacted / informed when expeditions are organized. The mountain is considered to be a protected National Park and as such it is surveilled by Samaria National Park (www.samaria.gr). Local authorities and municipalities are to be kept abreast as well - mainly municipalities of Sfakia to the South and Fre to the North side of the mountain. Lastly, please note that caves are protect by law in Greece.

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