ISSN 2039-6651
Anno 2015_Numero 27

Miscellanea INGV

Abstracts Volume 6th International INQUA Meeting on

Paleoseismology, Active Tectonics and Archaeoseismology

19 | 24 April 2015, Pescina, Fucino Basin, Italy

27

Istituto Nazionale di
Geofisica e Vulcanologia

INQUA Focus Group on Paleoseismology and Active Tectonics

paleoseismicity.org

Positive correlation between CO2 daily peaks and micro-earthquakes occurrence in deep fault-caves: an empirical model

Pérez-López, R. (1), Bañón, E. (2), López-Gutiérrez, J. (1), Lario, J. (3), Rodríguez-Pascua, M.A. (1), Martín-Velázquez, S. (4), Giner-Robles, J.L. (5), Silva, P.G. (6), del Moral., B. (1), Pueyo-Morer, E.L. (1)

(1) IGME – Instituto Geológico y Minero de España. Geological Hazard Division. GSS-Geological Survey of Spain. C/ Ríos Rosas 23, Madrid, 28003, Spain. Email: r.perez@igme.es
(2) Espeleoclub RESALTES, Molina del Segura Division, Murcia, Spain
(3) Facultad de Ciencias. UNED. Senda del Rey, 9, Madrid 28040, Spain
(4) Universidad Rey Juan Carlos, Madrid, Spain
(5) Dept. Geología y Geoquímica. Universidad Autónoma de Madrid, Spain
(6) Departamento de Geología. Universidad de Salamanca, Spain

Abstract: *The south-eastern part of Spain is determined by different active faults affecting limestone terrains. These terrains have been affected by endokarstic processes. The Benis Cave is the deepest explored cave in the region and it was related to an active fault. Evidence of recent paleoseismic activity and the peculiar topography of the cave, encouraged us to monitor the daily* CO_2 *content in the air composition at depth (-280m), and for a time period of four months. Our results show a preliminary positive correlation between micro-seismic activity in the surroundings (up to 60 km away), and the* CO_2 *concentration (daily increasing of 40ppm for the closest microearthquakes). Moreover, there is an empirical relationship between the daily increment value and the distance to the epicentre. Therefore, we propose an increase in the* CO_2 *concentration into the air karst related to the micro-seismic activity. Despite this preliminary worthy results, more data are needed to establish an accurate model for earthquake forecasting.*

Key words: *CO2 concentration, earthquake, time series, fault-cave, Spain.*

INTRODUCTION

Normally the gas emission related to earthquake occurrence has been analysed in surface rupturing associated to strong earthquakes (M<7) (Bonfanti et al., 2012, Zheng et al., 2013). Besides, the searching of earthquake-induced gas emission is mainly focused in radon (e.g. Birchard & Libby, 1980). In this work, we have monitored atmospheric CO_2 values within a deep cave, which was developed in relation to an active fault.

This cave was developed along the Benis Fault, in the south east part of Spain. We have introduced a CO_2 meter device into the Benis Cave at 280m in depth. Bearing in mind that the air in caves, deeper than 50m, exhibits a positive correlation to the daily barometric variations and there is some delayed response, we can correlate the CO2 sharp changes of the air concentration with other instantaneous processes like earthquakes. Hence, we have obtained a CO_2 time series for four months between the year 2012 and 2013.

The main objective of this work is to correlate the atmospheric CO_2 concentrations in a deep cave with the micro-seismicity. These events were spatially located up to 60 sqkm from the fault-cave. In conclusion, seven events could be related with an increasing of CO_2 emission and for the period of the preceding hours.

GEOLOGICAL SETTING

The Benis Cave is the deepest explored cave of the Murcia Region, south-eastward of Spain. This cave has been developed from the Early-Quaternary along an active fault striking N-S and dipping 75º towards the E (Pérez-López et al., 2009, 2010, 2012, 2013). This fault belongs to the Betic Range, and the movement affects the Prebetic units and the Subbetic ones (Fig. 1).

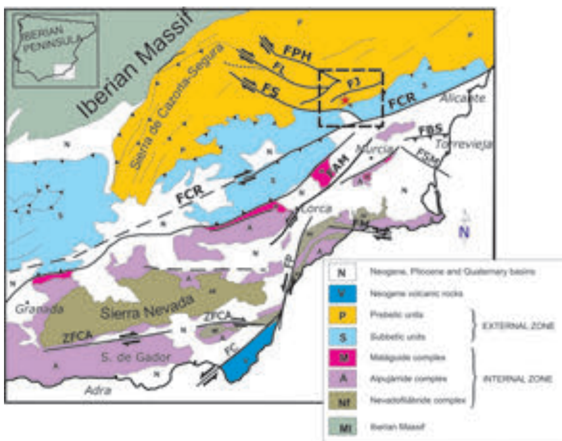

Figure 1: Geographical location and geological setting of the Benis cave (red star). All faults are actives, being the FS: Socovos Calasparra Fault, the FAM: Alhama de Murcia fault and FCR: Crevillente Fault.

The topography of the cave is divided mainly in two parts (Fig. 2). (1) Parallel vertical phreatic tubes developed along an E-trending calcite vein, and with metric section and evidence of slow flows of water and hydrothermal process (scallops). At 150 metres depth, the phreatic tubes connect with the fault plane and the cave develops a new section (2) fault-cave s.s. The karst affects the fault plane until the deepest zone (-350 m) of the cave, appearing endokarstic decoration due to dripstones (small stalactites and stalagmites), mantle flow of calcite and pop-corns. Pérez-López et al.(2009) described different paleoearthquakes affecting the cave and a ceiling collapse related to a seismic crisis in 1999, with earthquakes of magnitude M4.9.

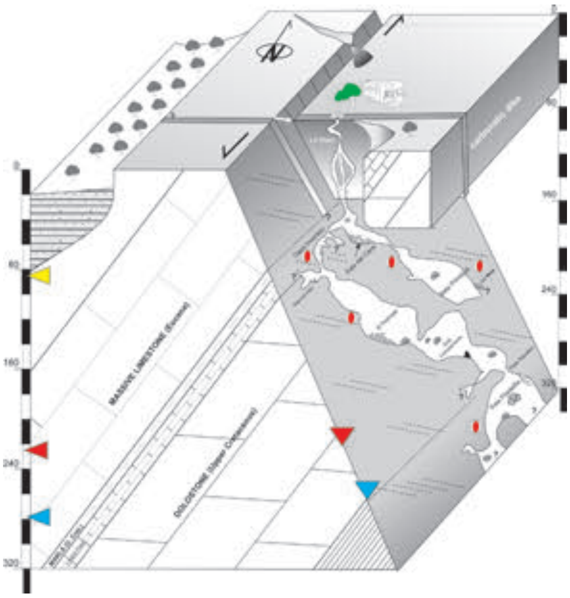

Figure 2: Diagram of the cave development and the fault plane. Yellow triangle is the infilling of the Quaternary deposits, red triangle is the depth where the cave were developed underwater (phreatic endokarstic zone) and the blue one is the last phreatic level into the cave. Beach balls indicate sites of paleoseismic evidence and kinematics grove marks.

CO2 DATA LOGGING: RESULTS

In December of 2012, we have installed a CO_2 data logger, CO_2METER ©, with a non-dispersive infrared (NDIR) sensor with automatic background calibration algorithm, and placed at 280m in depth. This sensor has accuracy of 30 ppm and it works for a CO_2 range of 1% (0-10.000 ppm). The resolution is 1 ppm and the temperature interval is -40 to 60ºC, for a relative humidity of 99%. The data logger recorded a data each 2 hours in an ongoing register during this time interval. We have also compiled the seismic events that have occurred in the vicinity of the cave during the same time interval. Moreover, we have used a hydrophobic device for avoiding condensation on the CO_2 sensor.

We have obtained daily time-series of CO_2 concentration (Fig. 3), from the 22nd of December, 2012 to the 3rd of May, 2013. The CO_2 emission daily values increase along the measurement time with a constant slope, related to the humidity saturation of the sensor. However, this sensor was working during 5 months with no failure. The bias of the CO_2 signal is a long-term trend (Fig. 3) related to the increasing of humidity at the sensor. Accordingly, we have used the difference between two correlative days instead of the daily absolute value of CO_2 into the cave.

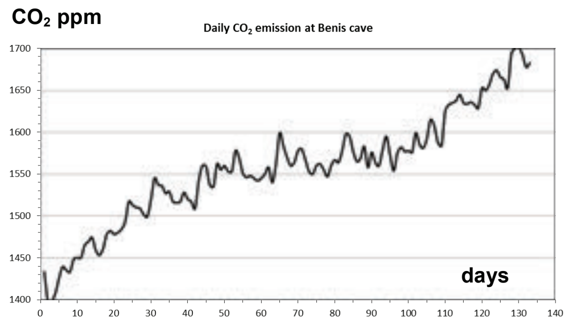

Figure 3: Daily CO_2 emission (ppm, Y-axis) at 290 m. depth within the Benis Cave. The time-series was built with the daily arithmetic mean during 133 days.

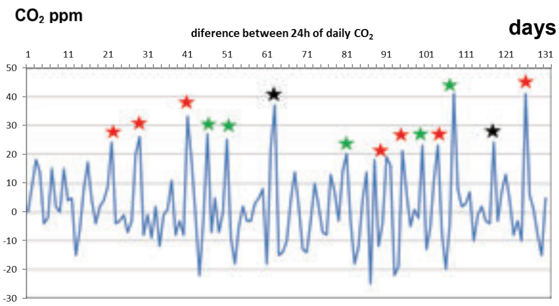

Figure 4: Daily CO_2 variation (Day_{n+1}-Day_n) (Y-axis, ppm). Red stars indicate earthquakes in the same day. Green stars are peaks related to earthquakes in 24h and black stars are days with no earthquake record.

EARTHQUAKES WITHIN THE AREA

We have used the earthquakes recorded by the seismic network of the *Instituto Geográfico Nacional*, from the online catalogue (National Geographical Service of Spain, http://www.ign.es/ign/layoutIn/sismoFormularioCatalogo.do). The earthquakes were recorded from the 22th of December, 2012 to the 3th of May, 2013. The radio of searching was 70 km, because of the main active faulting in the Betic Range are 60 km away from the measurement point.

The IGN catalogue has recorded 89 earthquakes with a maximum magnitude of M3.7 during this time interval. One of these earthquakes was located 5 km away of the pit-cave (with positive correlation), four are located 10 km away (three with positive correlation, located southward of the pit-cave, the negative is located northward) and seven were located 20 km away, with positive correlation. Finally, there are three earthquakes with positive correlation 60 km away to the pit cave and also, southward of the pit cave. The horizontal error is 1 km (IGN catalogue description, www.ign.es).

DISCUSSION

Figure 4 shows the difference between two correlative CO_2 values (CO_2 day2-CO_2day1). The idea behind this graph is to obtain abrupt changes in 24 hour interval, to be correlated with the earthquake occurrence in the surroundings. Furthermore, we have included the earthquakes recorded in this area related to daily increasing (coloured stars) for searching temporal correlations. Other earthquakes within the search zone did not vary the air content of the cave. These earthquakes are located east and northward of the cave.
As worthy result, we have found a relationship between the atmospheric CO_2 value and the seismic weak events ($M<2.5$) 20 km away and southward of the pit-cave. The daily coincidence between earthquake and sharp CO_2 increase is represented in the Fig.4 by red stars. In these cases, the daily variation is greater than 20 ppm. This is important because the accuracy is 30 ppm for a punctual measurement and 10 ppm for the daily measurement. Green stars are earthquakes which occurred within 24 hours of the CO_2 peak and black stars are the two uncorrelated cases.
Moreover, we have plotted the maximum CO_2 daily difference and the distance of the epicentre (Fig. 5). There are only six points because there are two equal points. We have not weighed each point with the seismic energy released due to the earthquake size are very small $1.1 <M<2$ in relation to the distance of the epicentre. The greater earthquake of M3.7 did not affect the cave air composition apparently.

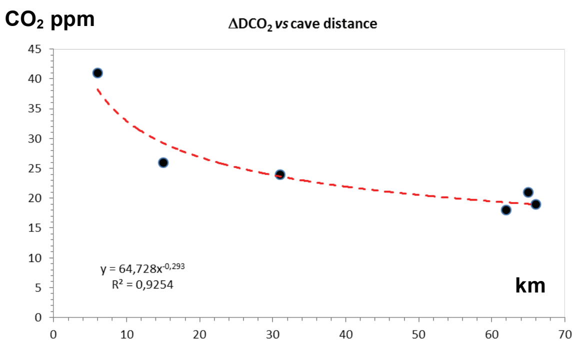

Figure 5: Function of the CO_2 daily variation (in ppm) of the cave atmosphere at 280m depth with the distance of the epicentre.

There is an empirical relationship between the CO_2 anomaly and the earthquake distance of the epicentre according to the following expression:

$$\Delta CO_2(24h) = 64.73 \cdot X^{(-0,29)} \qquad \text{[eq. 1]}$$

Where ΔCO_2 is the daily increasing of CO_2 (ppm) with and error of ± 6 ppm, and X is the distance between Benis Cave and the epicentre of the earthquake. Of course, more data are required and stronger earthquake.
In this area, there are no reports about a sharp daily increasing of CO_2 in deep caves related with non-seismic activity, as atmospheric CO_2 sink, dramatic increasing of organic activity and/or massive dissolution of waters. There is no underground aquifer human irrigation from the middle of the XXth century in this zone.
The CO_2 inorganic sources (i.e. not-related to organism breathing) in caves are related to the diffusion into the external atmosphere, diffusion into the voids in underlying rocks, and to dissolution in percolating waters. However, we will have to analyse the isotopic CO_2 data in the air, the soil of the cave at this depth and the pit cave in future research. In this work, we propose that the micro-seismic activity increases the CO_2 gas flux-rate across the karst, independently of the gas source.

CONCLUSIONS

1. There is a positive correlation between micro-earthquakes ($M<2.5$) and atmospheric anomalies within the Benis fault-cave. Seismic events are related to sharp daily increase in atmospheric CO_2 (>20 ppm).
2. The area of influence for this gas mobilisation is up to 60 km and southward of the pit cave.
3. Furthermore, there is an empirical relationship between the concentration of CO_2 emission and the distance of the epicentre, for the geological units of the Betic Range.

These preliminary results have to be completed with more data, CO_2 devices in other caves related with more active faulting and accurate models of CO_2 sinking and diffusion in karst. Also, isotopic analyses of atmospheric CO_2 into the Benis cave are required. Finally, autocorrelation analysis and the Fourier transform could help to find similarities between both time series.

Acknowledgements: Thanks are given the SpeleoClub RESALTES and all the members who collaborated in this project. This work is a contribution of the Spanish projects SISMOSIMA CGL2013-47412-C2-2-P, and QTECTBÉTICA CGL2012-37281-C02.01.

References

Bonfanti, P., Genzano, N., Heinicke, J., Italiano, F., Martinelli, G., Pergola, N., Telesca L., Tramutoli, V., (2012). Evidence of CO2-gas emission variations in the central Apennines (Italy) during the L'Aquila seismic sequence (March-April 2009). *Bollettino di Geofisica Teorica ed Applicata* , 53, 1, 147-168.

Birchard, G. F. and Libby, W. F. (1980) Soil radon concentration changes preceding and following four magnitude 4.2–4.7 earthquakes on the San Jacinto fault in Southern California. *J. Geophys. Res.* 83(B6), 3100–3106.

Pérez-López, R., Rodríguez-Pascua, M.A., Giner-Robles, J.L., Martínez-Díaz, J.J., Marcos, A., Bejar, M. and Silva, P., (2009). Spelaeoseismology and palaeoseismicity of the "Benis Cave" (Murcia, SE of Spain): coseismic effects of the 1999 Mula earthquake (mb 4.8). *Geological Society of London Special Publications*, 316: 207-216.

Pérez-López, R., E. Bañón, M. Rentero, J.L. Giner-Robles, M.A. Rodríguez-Pascua1, P.G. Silva, J.C. García López-Davalillo y

García-López M., (2010). Análisis Térmico Preliminar de la Sima De Benis (-350m), Murcia. In: *Avances de la Geomorfología en España. XI Reunión Nacional de Geomorfología. Comunicaciones*, 1:1-5.Solsona.Spain

Pérez-López R., E. Bañón, J. Lario, P.G. Silva, M.A. Rodríguez-Pascua, J. García-Mayordomo, E. Pueyo, A. Marcos-Nuez., (2012). Shallow Vertical Geothermal Gradient and Heat Flow within the Benis Cave (-320m, Cieza): Quaternary slip-rate for active fault-caves. *Geotemas*,13, 463-466.

Pérez-López, Raúl, Enrique Bañón, Emilio L. Pueyo, J. Lario, M.A. Rodríguez-Pascua, P.G. Silva, (2013). Weak signal of CO2 emission in deep caves related with weak earthquakes (M<2.5) in tectonically active areas. In: *Reunión Anual de la Unión Geofísica Mexicana*, *GEOS, VOL 33*, nº1. Puerto Vallarta. México.

Zheng, G., S. Xu, S. Liang, P. Shi, J. Zhao, (2013). Gas emission from the Qingzhu River after the 2008 Wenchuan Earthquake, Southwest China. Chemical Geology 339, 187–193.