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Chemistry of the water in the Nerja Cave System (Andalusia, Spain)

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Abstract: The main physical-chemical characteristics of the drip water in the Nerja Cave (southern Spain) were monitored on an approximately monthly basis between 1991 and 1994 at ten different points. The water from precipitation and from the saturated zone of the aquifer was similarly monitored. The chemistry of the drip water can be explained basically both by the climatic concentration in the soil of the components dissolved in the rainwater, and particularly by the dissolution of the highly-fissured Triassic dolomitic marble in which the Cave has developed. The considerable number of visitors, some 500,000 per year, causes significant variations in the temperature, humidity and CO_2 content in the interior atmosphere of the Cave. This is also reflected in the different physical-chemical characteristics of the drip water in the chambers open to the public, as compared with those which remain closed: slightly higher values of mineralisation and equilibrium pCO_2, and lesser of temperature and SI, are found in the visit area, as well as a higher variability of the measurements. Another anthropogenic effect is the percolation of water pumped out of the saturated zone, used for watering the gardens, in the sector of the Cave closest to the entrance. This drip water presents the highest mineralisation and pCO_2 values of the cave system.

INTRODUCTION

The Nerja Cave is situated in the south of Spain, some 50 km to the east of Málaga (Andalusia). It was discovered in 1959 and was opened to the public in the following year. Since then, it has been one of the most visited natural attractions in Spain, with approximately 500,000 visitors a year. The majority of these come during holiday periods (Easter and summer), when daily maximums of around 4000 are attained. Its popularity is influenced by its location in a major tourist zone (Costa del Sol), and naturally, by the beauty of the chambers and speleothems that can be found there.

The Cave extends through a series of chambers and galleries to a total distance of almost 5 km, having a height of 70 m and occupying a volume of over 800,000 m^3 (Sociedad Excursionista de Málaga, 1985). Its shape is relatively simple - elongated in a more or less N-S direction (Fig. 1). The cave entrance is situated at an altitude of 158 m, and is less than 1 km from the sea. Tourist visits are restricted to the third of the cave nearest the entrance (Fig. 1).

The mean annual temperature of the air outside the Cave is 16.5°C (January 11.4°C; August 24°C) and the mean rainfall is slightly under 500 mm yr^{-1}. The climate is Mediterranean with a fairly marked dry season from May to October. Since the end of the 1970s, a general tendency to below average rainfall has been recorded, excepting only the years 1983-84 and 1989-90. Indeed, the period 1991-93, when most of this research was carried out, was abnormally dry. These climatic conditions, together with repeated forest fires, are the principal reasons why the vegetation and cover soil above the Cave are currently scarce. The mean annual actual evapotranspiration is in the order of 425 mm; the excess water available for infiltration is therefore very limited. Direct data regarding the partial pressure of CO_2 in the soil do not exist; however, from the mean value of evapotranspiration, it can be estimated to be of about $10^{-2.5}$ atm (0.3% vol.) (Brook et al., 1983). This value has been corroborated by way of hydrogeochemical modelling in a nearby sector with fairly analogous characteristics (Cardenal et al., 1994).

Preliminary studies based on the content of Rn-222 in the air of the Cave indicate that the air in the zone open to the public is replaced every 5 days on average (Dueñas et al., 1993). This rate is, for instance, higher than that found in the Carlsbad Caves, USA (Wilkenings and Watkins, 1976) and in the Altamira Cave, Santander, Spain (Fernández et al., 1986).

Although previous -but discontinuous- data exist on the main atmospheric parameters inside the Cave, it is worth noting that since 1991 a systematic monitoring has been introduced. This was carried out on a daily basis until the end of 1993, since when continuous recording sensors - of temperature, humidity and CO_2 content in the Cave air- have been in place. Some of the first data from this record will be presented later on. The research is complemented by monitoring of the physical-chemical characteristics of the water inside the Cave and at various key locations outside it. This paper deals mainly with the results of that hydrochemical monitoring.

GEOLOGICAL AND HYDROGEOLOGICAL SETTING

From a geological point of view, the Cave is situated in the Alpujarride Complex (Internal Zones of the Betic Cordillera). This complex has two lithological formations. The lower formation is of a metapelitic nature (schists and quartzites), and is thought to date from the Palaeozoic. The upper formation is carbonated: dolomitic marble towards the base and calcareous marble towards the top, with discontinuous metapelitic intercallations, dating from the middle-upper Triassic. The Cave is developed over the dolomitic marble which presents a dense microfissuration. In some places the rock appears completely shattered, giving rise to a typical saccharoidal texture, with grains made up of single dolomite crystals. Outside the Cave, discordant detrital Neogene deposits appear over the Alpujarride materials (Fig.1).

Although the structure of the Alpujarride Complex is highly complex on a regional scale, in the immediate surroundings of the Cave it is fairly simple: the marble has an almost tabular arrangement, dipping 15-20° to the south. The existence of normal and/or strike-slip faults with a NW-SE direction is worth noting, these having caused significant vertical movements since the Pliocene.

The Triassic carbonate materials constitute an aquifer of regional importance whose recharge is produced mainly by the infiltration of precipitation on the mountainous outcrops to the north of the Cave, where the peaks reach almost 1800 m. Surface karstic forms (karren, dolines, sinkholes, etc.) hardly exist in these carbonate materials, in which, on the other hand, a fairly well-developed surface drainage system does exist, favoured by the considerable slopes in the terrain, as well as by the local loose lithological texture of the dolomitic marble.

The discharge of the aquifer, apart from wells, is produced by a series of springs, among which the Maro spring is of particular significance, situated less than 1 km to the east of the Cave (Fig. 1), at an altitude of