DISTRIBUTION OF CARBON DIOXIDE CONCENTRATION IN CUEVA DEL VIENTO (TENERIFE, ISLAS CANARIAS)

M. ARECHAVALETA*, P. OROMÍ*, L.L. SALA* & C. MARTÍN**

* Depto. Biología Animal, Universidad de La Laguna, Tenerife, Canary Is.
** Depto. Edafología y Geología, Universidad de La Laguna, Tenerife, Canary Is.

INTRODUCTION

It is well known that CO2 concentrations in the air of caves are frequently higher than outside. This phenomenon has been noted in both limestone and volcanic caves, even though the latter are usually located only a few metres below the surface. The origin of this CO2 may be due to different agents; according to James (1977) the most important sources are a) animal and plant respiration, b) production by microorganisms, c) diffusion through rock and soil, d) production from subterranean waters, and e) natural emission of volcanic gases. The contribution of each source to the final concentration is difficult to calculate, and is obviously different from one cave to another (James, *op. cit.*).

Likewise, CO2 concentration in a cave is not uniform, depending on several factors. The most important are the proximity of the emission sources - in the case of biological or volcanic origin - and, above all, the air renewal rate. The circulation of air is a consequence of variations in atmospheric pressure; the different temperature, relative humidity and chemical composition of the air occurring outside and inside the cave, also create differences in density (CIGNA, 1967) causing air movements. But the renewal rate at each sector of the cave mainly depends on its local section, and on the nearness of entrances and other connections to the exterior.

Carbon dioxide concentrations are on average noticeably lower in volcanic than in limestone caves. On one hand, the generally deeper location of limestone ones facilitates air stagnation; but more important is the chemical composition of the rock and abundance of water, which together contribute to higher CO 2 production.

The aim of this paper is to study the CO 2 distribution patterns in a lava tube and their relation with air movements in the cave. High concentrations of CO 2 - as well as methane - have been stated in the Canary Islands in artificial tunnels bored to extract water from very deep accumulations in volcanic rocks. However, no data concerning lava tubes are yet available in the literature. The measurements were taken in Cueva delViento (Tenerife), a lava tube which offers different climatic and structural conditions and therefore a variety of possibilities for comparison.

MATERIAL AND METHODS

This fact is also important for the air renewal rate.

For the present study the main tubes and some important lateral branches were divided into consecutive sectors of 200 m2 each, their length being variable depending on the width. A total of 132 sectors were studied, atmospheric CO 2 concentration and wind speed being quantified at each one.

The CO2 concentration was measured with an LFG 10 portable gas analyser made by Analytical Development Company Limited (ADC), capable of analysing simultaneously CO2 and CH4 concentrations. Its detection principle is infrared absorption spectrophotometry, with two possible measurement ranges: 0 to 10% or 0 to 100%. It has an internal pump rendering up to 200 ml/min. The reference measurements previously taken outside the cave were 0,01% for CO2 and 0,00% for CH4. The analyser was always calibrated before each workday. Wind speed was evaluated with a manual SALMOIRAGHI 1635 anemometer with a maximum accuracy of 1m/sec. The data were taken several times at each sector, always for 30 seconds and using the mean values as final data.

RESULTS AND DISCUSSION

According to the reference measures taken outside the cave each visit, the normal CO 2 atmospheric concentration is 0.01%. The proportion of methane was also measured, but its presence was never detected. Actually this was the expected result, since methane is very rarely found in the Canarian artificial water tunnels.

The data obtained in this study are shown in tables I to V, where the CO 2 concentration and wind speed are included for each sector, as well as their minimal distance from the nearest communication with the open air. In most of the cases carbon dioxide concentrations were comparable to the reference value outside; however, in some sectors the values obtained were extraordinarily high, sometimes up to 13 times the normal concentrations. These are notably higher than those attained by Calandri (1992) in volcanic caves from Madeira (between 0.01 and 0.025%).

Carbon dioxide concentration is correlated to breeze speed ($r = -0.2324$, $p < 0.01$) and to the distance from the nearest entrance ($r = 0.3936$, $p < 0.01$). Air renewal avoids stagnation, while higher levels appear in deeper or more remote zones of the cave, especially in blind galleries where the «cul de sac» effect facilitates an increase in CO 2 levels.

The higher values of CO 2 were obtained in Cueva de Felipe Reventón (see table I) and in some stretches of Cueva del Sobrado (table IV), almost always in the deep zone of both caves. In Cueva del Viento (Breveritas) the breeze is almost continuous and intense - «Viento» means wind - thus impeding accumulation of carbon dioxide. Only at its lower level called Galería de los Ingleses, concentrations are higher. This is a much deeper tube with no direct communication to the exterior and a unique connection with Cueva del Viento itself at Breveritas, far away from the nearest entrance; this makes environmental conditions very stable and CO2 distribution uniform.

In Galería Piquetes, CO 2 values never exceeded the normal ones in spite of its considerable length. This is explained by the constant breeze, probably due to the existence of abundant cracks at the end of the cave which allow the entrance of air.

Table I. Carbon dioxide concentration, wind speed and distance from the entrance at different sectors of Cueva Felipe Reventón. F1-F9: Main tube; L1: "Laberinto"; L2-L7: lateral branches.

Sector	Entrance at (m)	CO2 (%)	Wind (m/s)
F1	35	0,01	-
F2	81	0,01	-
F3	110	0,01	-
F4	158	0,01	0,18
F5	203	0,01	-
F6	261	0,01	0,016
F7	305	0,13	-
F8	364	0,09	-
F9	436	0,05	-
L1	331	0,13	0,13
L2	296	0,03	-
L3	261	0,05	-
L4	364	0,07	-
L5	364	0,07	-
L6	423	0,11	0,01
L7	499	0,07	-

Table II. Carbon dioxide concentration, wind speed and distance from the entrance at different sectors of Galería Piquetes (main tube).

Sector	Entrance at (m)	CO2 (%)	Wind (m/s)
P1	23	0,01	0,01
P2	93	0,01	0,01
P3	133	0,01	0,01
P4	173	0,01	0,02
P5	213	0,01	0,06
P6	285	0,01	0,02
P7	337	0,01	0,02
P8	372	0,01	0,04
P9	412	0,01	0,03
P10	472	0,01	0,02
P11	532	0,01	0,03
P12	567	0,01	0,07
P13	610	0,01	0,04
P14	690	0,01	0,02
P15	715	0,01	-
P16	748	0,01	-
P17	781	0,01	0,01
P18	955	0,01	-
P19	880	0,01	-
P20	831	0,01	-

Table III. Carbon dioxide concentration, wind speed and distance from the entrance at different sectors of Galería Belén.

Sector	Entrance at (m)	CO2 (%)	Wind (m/s)
B1	139	0,01	-
B2	73	0,01	-
B3	22	0,01	-

Table IV. Carbon dioxide concentration, wind speed and distance from the entrance at different sectors of Cueva El Sobrado. S1-S15: main tube; S-V: Viento-Sobrado connection; RIP: Sobrado Inferior; PET1-PET2: Cueva Petrólea; INT1-INT23: main tube of Galería Intuición; MR1-MR4: lateral branch of Galería Intuición

Sector	Entrance at (m)	CO2 (%)	Wind (m/s)	Sector	Entrance at (m)	CO2 (%)	Wind (m/s)
S1	22	0,01	0,13	INT5	931	0,01	-
S2	66	0,01	-	INT6	879	0,01	-
S3	142	0,01	-	INT7	835	0,01	-
S4	221	0,05	-	INT8	785	0,01	-
S5	316	0,02	-	INT9	733	0,01	-
S6	221	0,05	-	INT10	697	0,01	-
S7	273	0,01	-	INT11	639	0,01	0,23
S8	356	0,03	-	INT12	574	0,01	-
S9	431	0,05	-	INT13	514	0,01	-
S10	531	0,05	-	INT14	429	0,01	0,50
S11	604	0,05	-	INT15	371	0,01	0,33
S12	657	0,05	-	INT16	327	0,01	
S13	682	0,09	-	INT17	294	0,01	-
S14	682	0,07	-	INT18	261	0,01	-
S15	769	0,10	-	INT19	221	0,01	-
S-V	531	0,05	-	INT20	176	0,01	-
RIP1	35	0,01	-	INT21	121	0,01	0,03
RIP2	26	0,01	-	INT22	66	0,01	0,11
PET1	10	0.05	-	INT23	19	0,01	-
PET2	88	0,03	-	MR1	429	0,03	-
INT1	1116	0,01	-	MR2	502	0,03	-
INT2	1072	0,01	-	MR3	547	0,03	-
INT3	1028	0,01	-	MR4	584	0,03	-
INT4	974	0,01	-				

Table V. Carbon dioxide concentration, wind speed and distance from the entrance at different sectors in Cueva de Breveritas. V1-V19: Main tube of Cueva de Breveritas; V-I: Connection with Galería de los Ingleses; C1-C8: Galería de los Pájaros; BR1-BR4: Breveritas inferior; IN1-IN14: Galería de los Ingleses.

Sector	Entrance at (m)	CO2 (%)	Wind (m/s)
V1	20	0,01	0,26
V2	67	0,01	0,16
V3	127	0,01	0,10
V4	177	0,01	-
V5	256	0,01	0,36
V6	346	0,01	0,15
V7	382	0,01	-
V8	428	0,01	0,14
V9	495	0,01	0,19
V10	569	0,01	0,15
V11	630	0,01	0,13
V12	709	0,01	-
V13	762	0,01	0,36
V14	889	0,01	0,23
V15	952	0,01	-
V16	981	0,01	0,18
V17	1101	0,01	0,60
V18	1176	0,05	0,16
V19	1233	0,05	0,18
V-I	1233	0,01	0,16
C1	981	0,01	-
C2	1024	0,01	-
C3	1087	0,01	-
C4	1160	0,01	0,53
C5	1240	0,01	0,25
C6	1360	0,01	0,08
C7	1425	0,01	-
C8	1477	0,01	-
BR1	21	0,01	-
BR2	56	0,01	-
BR3	96	0,01	-
BR4	136	0,01	-
IN1	1403	0,09	-
IN2	1444	0,09	-
IN3	1484	0,09	-
IN4	1524	0,09	-
IN5	1574	0,09	-
IN6	1624	0,09	0,17
IN7	1677	0,09	-
IN8	1737	0,09	0,11
IN9	1779	0,09	-
IN10	1819	0,09	0,43
IN11	1859	0,09	-
IN12	1899	0,09	-
IN13	1947	0,09	-
IN14	1993	0,09	-

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