EXTREME INCREASE OF CO_2 IN BELGIAN CAVES

CAMILLE EK[1] and JEAN GODISSART[2]
[1]Université de Liège, Belgium, camille.ek@ulg.ac.be
[2]Union belge de Spéléologie, Belgium, jean.godissart@skynet.be

We began making CO_2 measurements in Belgian caves in 1966. Analyses were conducted in cave halls, galleries, fissures and shafts. They were collected during various seasons and at different levels above the floors of the conduits, and in the absence or presence of other human beings. Our first results were published in 1968. From that time on, we have carried out studies in Poland, Quebec, China and other countries. However, we have focused most of our work in Belgium. We have discovered over these forty years of study, a strong increase in the observed values of CO_2 in Belgian caves.

For example, a few of our observations follow. "Trou Joney" (Comblain-au-Pont, province of Liege) is a small and shallow cave. We measured at the central point of the main gallery, 1870 ppm CO_2 in July 1966, and 13,800 ppm at the same location in July 2007. At the bottom of the shaft of the "Comblain-au Pont" cave, we measured 600 ppm in July 1966 and found 1500 ppm in July 2008. In "La Merveilleuse" cave (Dinant, province of Namur), we measured 800 ppm at the central point of the Big Hall in August 1990, rising to 1700 ppm in August 2008. In the main gallery of the "Fontaine de Rivire" cave (Hamoir, province of Liege), we found 5000 ppm in August 1972, increasing to 12,000 ppm in 1991.

We conclude that the CO_2 content of the atmospheres of many caves in Belgium (at least) has become higher . The increase is very variable, but omnipresent. Are our measurements significant? We believe that we have validated our instruments and our methods. The increase is probably not a result of local industrial activities. The CO_2 curves of Mauna Loa Observatory (Hawaii) and "Mace Head" (Ireland) both show an increase of atmospheric carbon dioxide during the last half century. However, the upsurge of CO_2 observed in the caves is proportionately much greater than the increase in those well-known surface measurements.

There is a very complex interrelationship between temperature, vegetation and biomass activity, and CO_2 in the soil and underground. The increase of any one of these three parameters can induce changes in the two others, and hence in the partial pressure of CO_2 in cave air.

Inflation du CO_2 dans les grottes de Belgique. Nos premières mesures de dioxyde de carbone dans les grottes de Belgique datent de 1966 et les premiers résultats furent publiés en 1968. Nous avons mesuré le CO_2 dans les salles, les puits, les galeries et les fissures, en différentes saisons. Au fil de ces quelque quarante années, nous avons observé dans toutes les grottes une forte augmentation des concentrations de l'air en dioxyde de carbone au cours du temps.

Ainsi, par exemple, dans le fond du Trou Joney, une petite grotte peu profonde située à Comblain-au-Pont (province de Liège), nous avons mesuré 1870 ppm de CO_2 en juillet 1966 et 13800 ppm au même endroit en juillet 2007. Dans la grotte La Merveilleuse à Dinant (province de Namur), la teneur en CO_2 dans la grande salle était de 800 ppm en août 1990 et en août 2008 elle était passée à 1700 ppm. Dans la grande galerie de la grotte de Fontaine de Rivîre à Hamoir (province de Liège), nous avions trouvé 5000 ppm en août 1972 et nous en avons mesuré 9400 en octobre 2008.

Les teneurs en CO_2, dans les grottes belges en tout cas, sont donc en forte hausse. Cette augmentation est très variable mais elle est très générale et, à notre avis, elle n'est pas influencée par l'activité industrielle locale. Certes, les courbes de l'observatoire de Mauna Loa et de Mace Head montrent une augmentation du CO_2 dans l'atmosphère au cours du dernier demi-siècle, mais, dans les grottes étudiées, nous sommes en présence d'un phénomène beaucoup plus important.

Les relations entre les paramètres climatiques, biologiques (tels la respiration de la biomasse) et le dioxyde de carbone dans les sols sont complexes et les variations de chacun de ces paramètres peuvent influencer les deux autres et par là la pression partielle du CO_2 dans les grottes.

1. Introduction

Our CO_2 measurements in cave air began in 1966. They were conducted in galleries, chambers, shafts, fissures; we analysed the air near the entrances and in remote parts, near the ceiling and near the floor. The first publication of our results appeared in the *National Speleological Society Bulletin* (Delecour et al., 1968). It showed that there is much more carbon dioxide in cave air than in the open air, much more in fissures than in galleries or chambers, and more in remote parts than near the entrances. Other results were published the same year in the *Annales de Spéléologie,* showing that CO_2 in caves mainly comes from the surface soil through fissures (Ek et al., 1968). In 1985, we described the seasonal rhythm of CO_2 partial pressure with a summer maximum and a winter minimum, and the slow decline of carbon dioxide from the soil to lower and lower levels in the caves (Ek & Gewelt, 1985).

Six Belgian caves have been selected here to display our results. All of them are located in the Paleozoic limestones south of Liège (Belgium), close to the 50th parallel North (Fig. 1). All caves exist in an oceanic temperate climate, with a mean temperature of about 10°C and an average annual rainfall of 800 mm. They are in a covered karst, under grasslands and woods, at elevations ranging between 80 and 240 m. The thickness of the roof between cave and surface ranges from 15 to 90 m. We have conducted analyses in several other countries (i.e., Canada, Poland, China), but those are not dealt with in this paper. Some of our measurements done between 1966 and 1990 were repeated in several caves in similar conditions between 2000 and 2009. This has allowed us to discover that carbon dioxide in these cave atmospheres has strongly increased in the recent decades, considerably more so than in the outer atmosphere.

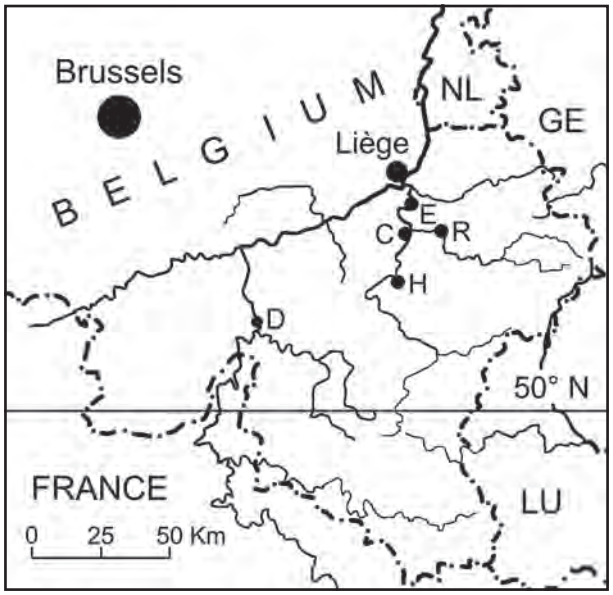

Figure 1: Location of the caves studied in Belgium. C: Comblain-au-Pont. D : Dinant. E : Esneux. H: Hamoir. R : Remouchamps.

2. Instruments and Methods

The first measurements of CO_2 were made in 1966 by C. Ek and his colleagues with an electrolytic field device (Ek et al., 1968). The analysis was based upon the titration of the carbon dioxide in a known volume of air absorbed in a 0.1 N NaCl solution. The time necessary to neutralize the absorbed carbon dioxide is measured. The CO_2 content of the sample is computed from the current (mA), the time (seconds), and the air sample volume (mL). The apparatus, packed in a wooden case, weighed 15 kg, and was thus relatively heavy; however it worked in caves for several years (Fig. 2).

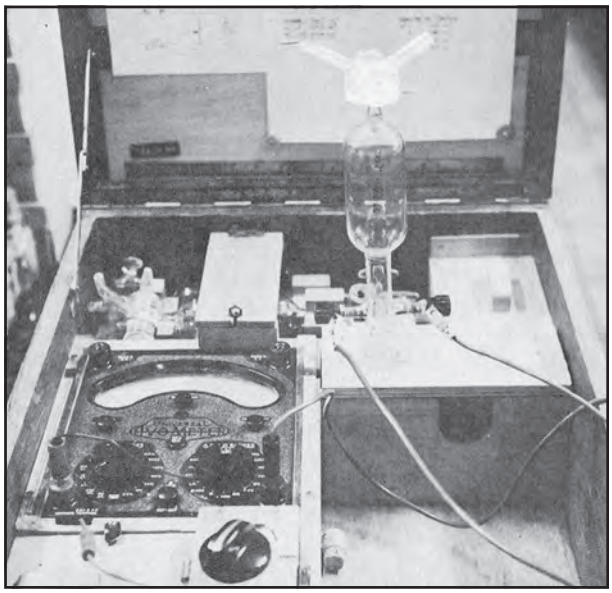

Figure 2: Electrolytic field device for measuring atmospheric CO2, by Koepf (Ek et al., 1968).

From 1981 onward, we used the gas pump Precision Detector (by Gastec) which is lighter and faster but working with single use detector tubes. In these tubes, carbon

dioxide reacts with hydrazine or, for higher concentrations, with potassium hydroxide; in both cases, the CO_2 concentration is given by a direct reading on the graduated scale of the tube. The minimal precision guaranteed by the manufacturer is +/-25% but the effective precision is much better and the reproducibility is about +/-10%. In some cases, for example in confined places, the operator used a carbon dioxide absorbing mask in order to avoid human CO_2 exhalation (Fig. 3).

Figure 3: Gastec pump detector giving a direct reading of CO2 concentration (Ek & Gewelt, 1985).

Current surveys (since 2008) are conducted using a X-am 7000, a portable gas measuring and monitoring instrument by Draeger equipped with an IR (infrared radiation) probe ranging from 300 ppm up to 50,000 ppm CO_2 which has been the most suitable device for our purpose (Fig. 4). This equipment, weighing 1.6 kg (one tenth that of our first device), is also able to record data from remote places thanks to its pump sampling function, thus avoiding human contamination. Before each working day, the device was calibrated in the open air against the known concentration of CO_2. Whenever we changed measuring instruments we checked several times the concordance of the techniques.

Figure 4: X-am 7000 by Draeger, infrared portable device.

3. Results

Six caves have been selected here to display our results (Fig. 1). All of them are located in the Paleozoic limestones south of Liège (Belgium). The carbon dioxide content of the air of all the caves displays seasonal fluctuations, with a summer maximum and a winter minimum, as exemplified in Figure 5.

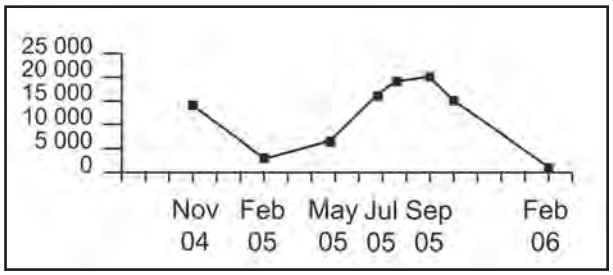

Figure 5: Seasonal variation in the CO2 concentration in the atmosphere of Comblain-au-Pont Cave.

Over the course of the 40 years covered by this study, the values of CO_2, and particularly the summer maximums, have been on a noticeable increase. Here are a few examples of these rises:

3.1. Fontaine de Rivîre Cave in Hamoir

This cave lies in Devonian limestones, in the province of Liège, some 40 km south of the city of Liège. Its entrance opens at 135 m a.s.l. It is about 1100 m long. The rock above the cave is about 85 m thick. It is a phreatic maze connected to a wide gallery ending in a large chamber (20,000 m^3) with a lake (Godissart, 1994). Between 1972 and 2008, the summer concentration of CO_2 increased from 5000 to 9000 ppm (Fig. 6.1).

3.2. Trou Joney in Comblain-au-Pont

Trou Joney is a small cave, 30 km south of Liège, in the same province. It lies in Carboniferous limestone, at an elevation of 185 m. Its length is only 60 m and the rock above the cave is about 15 m thick. The single gallery is choked at the bottom with gravel and fine sediments. We carried out a carbon dioxide survey in July 1966, and a monthly survey all along 1978 (Ek, 1979). At the bottom of the cavity, the CO_2 rose in summer from 1715 to 13,800 ppm between the first and the last date (Fig. 6.2).

3.3. Sainte-Anne Cave and Brialmont Caves in Esneux

These two caves are located 9 km south of Liège, in Devonian limestones. The entrance of Sainte-Anne is at an altitude of 85 m a.s.l. whereas Brialmont, which is situated above the first one, opens at 180 m a.s.l. They are probably

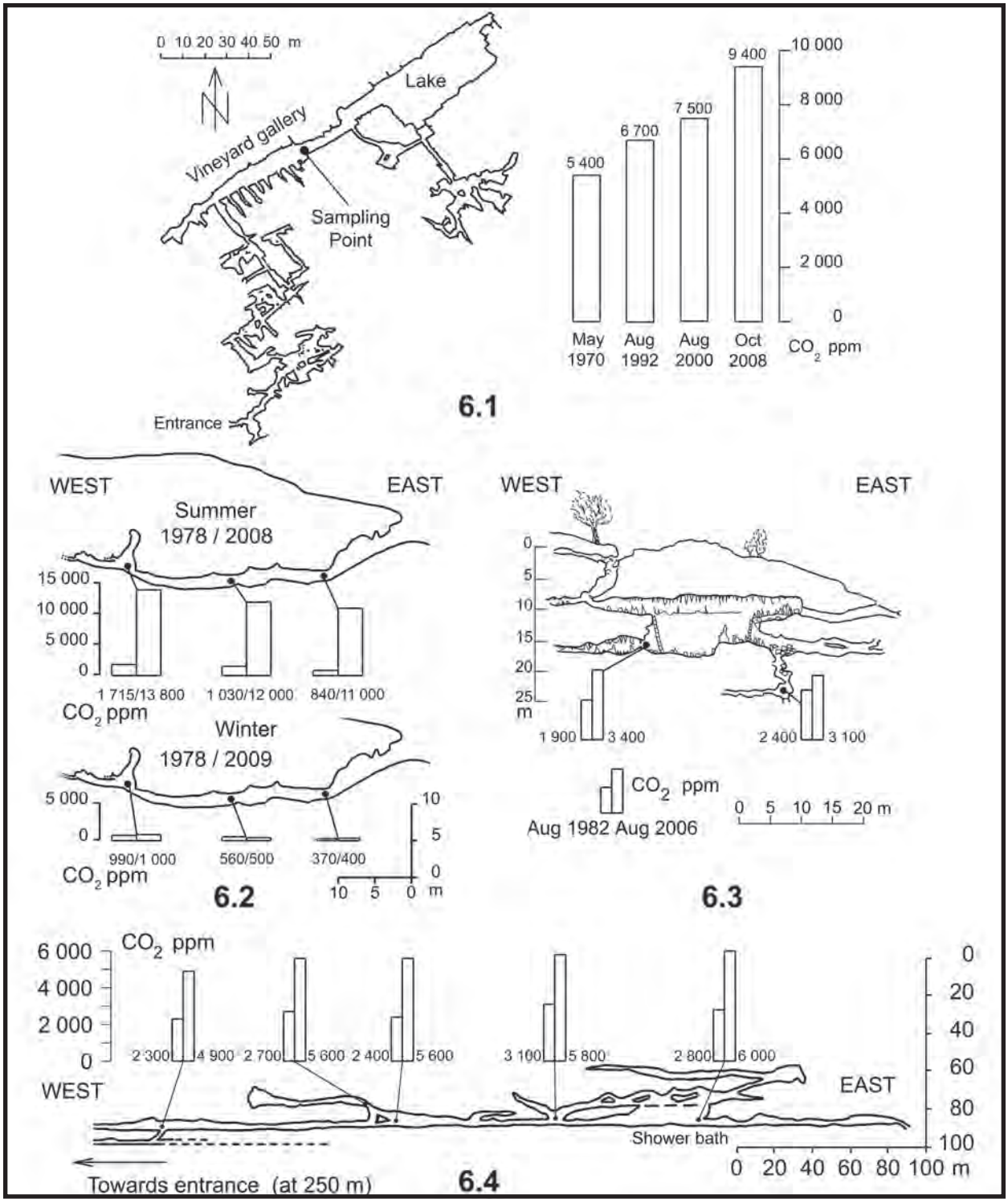

Figure 6: Carbon dioxide in cave air.

6.1. Rivîre Cave, Hamoir. Sketch map and location of the principal point of CO2 measurements.

6.2. Trou Joney, Comblain-au-Pont. Long profile and comparison of CO2 values in summer 1978 and 2008 and in winter 1978 and 2009.

6.3. Brialmont Cave, Esneux. Long profile. Location of comparative CO2 measurements. Topographical survey by Naveau, S.S.D., 1971.

6.4. Ste-Anne Cave, Esneux. Long profile. CO2 concentrations in January 1983 and January 2008.

parts of the same system, but to date the connection has not been made by cavers. Both caves consist of subhorizontal galleries. Brialmont is two-tiered. Beneath it, Sainte-Anne is four-tiered. The galleries are spacious and connected by shafts and fissures. The total development of Sainte-Anne is about 1500 m and an underground river flows in its two lower levels. Above it, Brialmont, with 180 m of development, is dry (Figures 6.3 and 6.4). It is in this cave system in 1984 that we discovered the slow diffusion of carbon dioxide from the soil to the successive lower levels of the caves. We also established the strong annual rhythm of CO_2 concentration (Ek & Gewelt, 1985). Returning to these caves a quarter of a century later, we discovered a strong rise in carbon dioxide. In August 2006, the galleries of Brialmont showed an increase of much more than 30% (Fig. 6.3). In January 2008, Sainte-Anne displayed values approximately double those of 1982 (Fig. 6.4). In these caves, although the measurements of 1982 were carried out each month, unfortunately we have only single values in 2006 and 2008.

3.4. La Merveilleuse Cave in Dinant

La Merveilleuse lies in the Carboniferous limestone, 75 km south of Brussels as the crow flies. It opens at about 150 m a.s.l. and its development measures about 750 m. We analyzed the CO_2 there in 1990, 2003 and 2008. The values measured in the halls and galleries in August of each of these three years are displayed in figure 7.1. It is clear that between our first and last measurements, the CO_2 concentration in the cave air has approximately doubled, except at the aperture of two shafts, where carbon dioxide variations are probably related to a deep underground stream (Fig. 7.1). In August 2003, we carried out a detailed survey of a small confined chamber: the Temple de Diane (Fig. 7.2 and 7.3). We measured 4000 ppm CO_2 near the ceiling and 5100 near the floor. In August 2008, these figures had increased to 15,400 and 18,000 ppm respectively!

4. Conclusions

We observed in the caves of Belgium a huge rise in pCO_2. This generally has been an increase of around 100% in forty

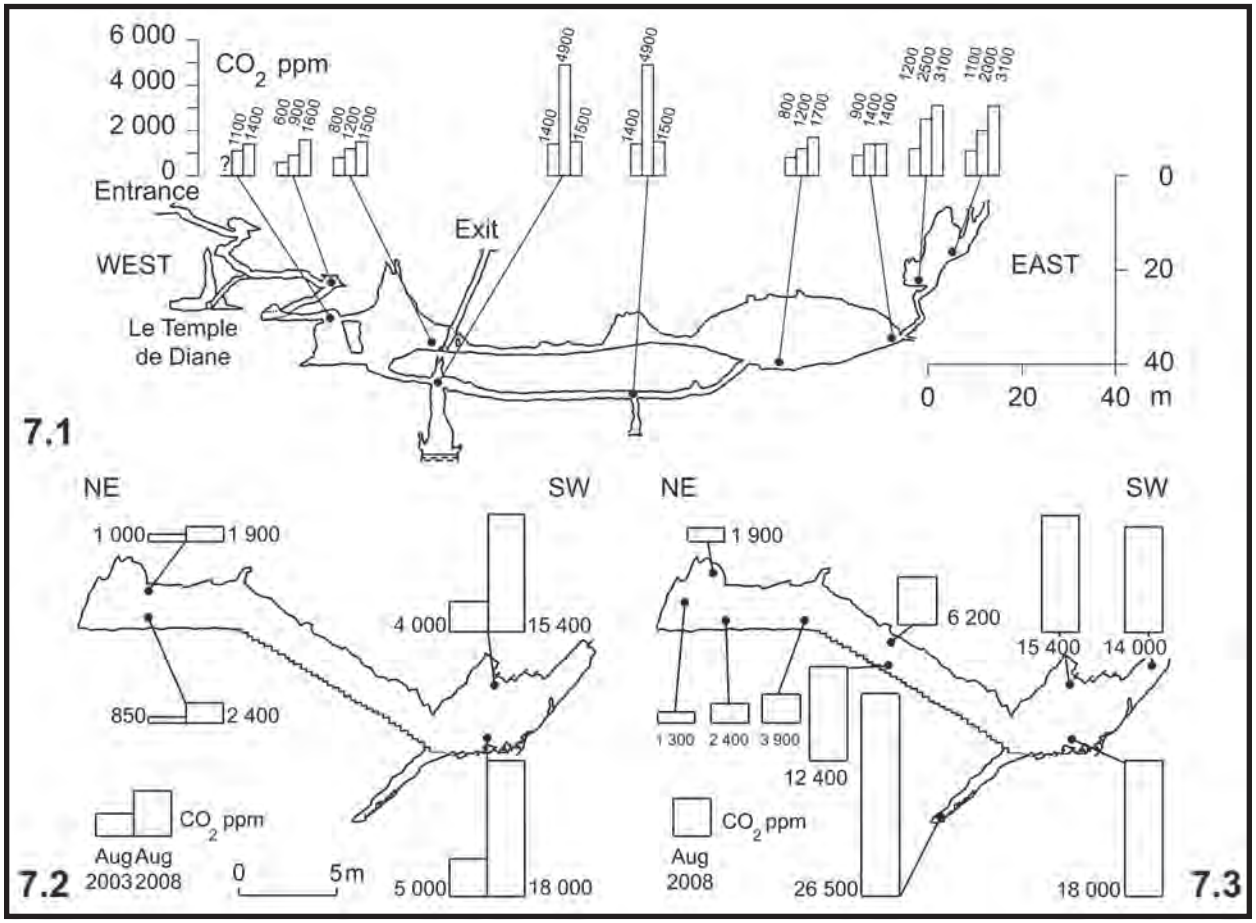

Figure 7: La Merveilleuse Cave, Dinant. Carbon dioxide in air.
7.1. La Merveilleuse. Long profile. CO2 measurements in August 1990, 2003 and 2008.
7.2. Le Temple de Diane. Long profile. Comparison of some CO2 measurements in Aug. 2003 and Aug. 2008.
7.3. Le Temple de Diane. Long profile. Detailed CO2 survey in August 2008.

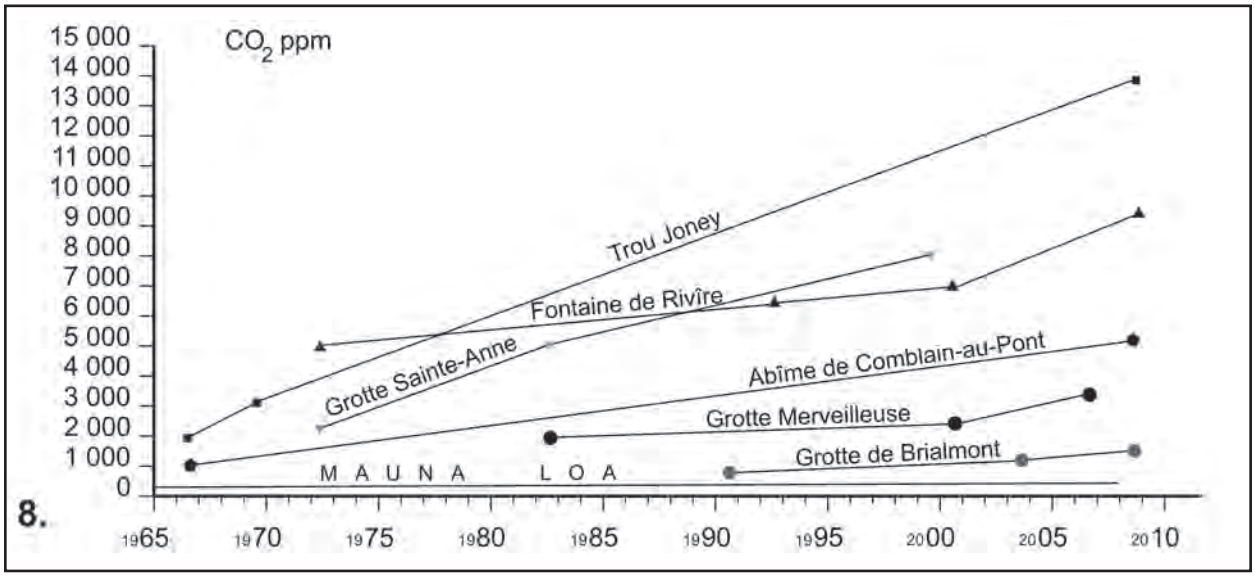

Figure 8: Changes in CO2 concentrations in some Belgian caves between 1966 and 2008. Below, Mauna Loa curve of CO2 evolution.

years, and in some places even more. This increase is variable, as shown in Figure 8, but all of the caves visited showed some increase.

Of course the pCO_2 curve of Mauna Loa (Machta, 1972), from 1960 to 2008 displays a slight increase, but this is much less significant: rising from 314 ppm in 1960 to 387 ppm in 2008, about 22% in a half-century. From 1960 until now, the rate of rise at Mauna Loa has increased from 0.9 ppm per year in the nineteen sixties to 2.0 ppm per year during the beginning of the third millennium. Closer to Belgium, Mace Head (Ireland) shows the same slope. The worldwide rise of atmospheric CO_2, although sharing the same trend, is much too small to explain the inflated values observed in the caves.

Carbon dioxide in most caves mainly originates from the soil. This idea is supported by investigations by Bourges et al. (2001), Calmels et al. (2005) and Baldini and colleagues (2006). It is the emission of CO_2 by the soil biomass which is the presumed cause of the increase observed in the caves. A slight rise of temperature has been observed in Belgium, which can favor increased activity by the vegetation. The year of 2006 was the warmest since the beginning of meteorological surveys (1833), and 2007 was warmer than 2006. On the other hand, the general rise of atmospheric pCO_2 induces a rise of the rate of photosynthesis which leads, in turn, to an increase of root respiration and of microbial activity in the soil (Koerner et al., 2005). This could certainly enhance the carbon dioxide concentration in soil air, hence in the caves.

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