ACTA CARSOLOGICA	31/1	3	35-54	LJUBLJANA 2002

COBISS: 1.08

MODERN TREND IN CAVE MONITORING

SODOBNI TRENDI JAMSKEGA MONITORIGA

ARRIGO A. CIGNA[1]

[1] (Società Speleologica Italiana), Fraz. Tuffo, I-14023 COCCONATO AT, ITALY

Prejeto / received: 15. 1. 2002

Izvleček UDK: 551.44.001.4

Arrigo A. Cigna: Sodobni trendi jamskega monitoringa

Opisan je razvoj jamskega monitoringa od 19. stoletja dalje. Prednost razvojnih teorij je omogočila doseči primerljive rezultate in napovedati razvoj jamske klime, še preden je prišlo do nepopravljivih procesov. Našteti so najpomembnejše parametri monitoringa. V zadnjih letih smo doživeli močan tehnološki razvoj in ocenjena je bila relativna pomembnost vsakega parametra. Novembra 1999 so odprli za obisk Kartchner Caverns, AZ, ZDA. Opravljenih je bilo nekaj predhodnih raziskav. Arizona Conservation Project, Inc. (ACPI) je predvidel 22 merilnih postaj. Dobili so oceno vpliva. Drugi primer je iz Cango Caves. Septembra 2000 so postavili preprosto mrežo za monitoring, ki naj bi delovala eno leto. Sestavljena je iz 15 preprostih "data loggerjev", razporejenih po jami. Merijo temperaturo zraka in vode, koncentracijo CO_2 in relativno vlažnost in vrednosti občasno prenesejo v računalnik izven jame. Prispevek podaja prve rezultate. Popolnoma avtomatičen monitoring bo postavljen v prihodnosti, ko bodo pregledani rezultati te prve preproste opazovalne mreže. Vzpostavili bodo popolnoma avtomatizirano mrežo, ko bodo razpolagali z rezultati prve preproste opazovalne mreže.
Ključne besede: mreža jamskega monitoringa, klimatologija, Kartchner Caverns, Cango Cave, ZDA, Južna Afrika.

Abstract UDC: 551.44.001.4

Arrigo A. Cigna: Modern trend in cave monitoring

The evolution of cave monitoring since 19th century is described. The advantage of the development of theories was the possibility to obtain comparable results and forecast the evolution of a cave climate before irreversible modifications take place. The most important parameters to be monitored are indicated. In recent years both important technological improvements have been obtained and the relative importance of each parameter has been reviewed. Kartchner Caverns, Arizona, USA, was opened to the public in November 1999. Some preliminary studies have been performed. Arizona Conservation Project, Inc. (ACPI) established 22 monitoring stations. An evaluation of the impact assessment was obtained. The second case concerns Cango Cave. A simple monitoring network has been installed in September 2000 to be operated for one year. It consists in about 15 rugged data loggers distributed along the cave. Air and water temperature, carbon dioxide concentration, and relative humidity are measured and the values are transferred periodically by a shuttle into a computer outside the cave. A totally automatic monitoring network will be installed in the future after the results of the first simple network are achieved.
Key words: cave monitoring networks, climatology, Kartchner Caverns, Cango Cave, USA, South Africa.

INTRODUCTION

Cave monitoring developed particularly nowadays on account of a greater attention paid to the protection of the cave environment. Already in the 19th century cave climate was studied for scientific purposes, particularly in Germany and Austria (Schawalbe, 1886; Fugger, 1891/1893; Crammer H., 1899). But at that time only temperature was measured and air flow, e.g., was recorded qualitatively.

During the first half of the 20th century such studies continued to be mainly devoted to record data without any further development of a theory with the aim of understanding the mechanisms involved and, eventually, forecasting their behaviour.

In this period Bock (1913) published an outstanding paper where he developed a mathematical treatment of the data concerning ice caves, both dynamic and static. Unfortunately this paper was totally ignored by the scientists of that time. In fact Kyrle (1923) did not make any use of Bock's paper also if he includes it (incorrectly !) in the references; also Crestani & Anelli (1939) ignored Bock in their book, which would have been a basic reference for anyone interested in cave meteorology in Italy during many years. It must be emphasised that these facts were not due to the language because all these authors knew German perfectly.

Probably Bock was forgotten because mathematics was nearly totally absent in the education of the cave scientist of the time. Therefore the description of the phenomena involved continued to be mainly qualitative and remained so for a long time.

Only in the second half of the 20th century, mathematics found again its place in cave climatology and the description of phenomena upgraded from qualitative to quantitative. (Cigna, 1958; 1960; 1961; 1967; Eraso, 1962/1963; Wigley, 1967; Wigley & Brown, 1969; etc.). Later on, such studies developed to cover most aspects of cave climatology and physics. Andrieux (1970/1972) and Badino (1995) are the authors of the most complete papers in this field.

The great improvement achieved in the last decades are mainly due to the new technology and particularly to the inexpensive data loggers which record unattended a great number of data. At the same time, the financial support of some show caves to carry on environmental researches and to evaluate the visitors' capacity was instrumental in the development of cave climatology.

PARAMETERS

A cave environment may be characterised by a rather large number of parameters depending on the local factors. Nevertheless in the majority of cases only a few of them play a major role and, therefore, they will be considered here for a further discussion.

TEMPERATURE

Temperature of air and water is the most common parameter, which has been measured and recorded on account of the availability of thermometers. Obviously both accuracy (the degree of correspondence of data with an absolute value) and precision (the degree of agreement among repeated measurements) must be taken into account in the choice of the most suitable instrument.

For simple evaluations of the temperature distribution along a cave a precision of at least 0.1°C can be accepted; the accuracy of the same order is generally enough because the same instrument generally records the data. A better accuracy may be required when data from different sources must be compared, e.g. 10^{-2} °C.

When rapid temperature changes must be studied a precision of the order of 10^{-3} °C should be assured. The same precision is also required when special situations are under investigation, e.g. when local cells of air circulation are studied in an ice cave, where convection is driven by a very small temperature difference.

Precision probes now replace the old mercury or alcohol thermometers with a high-stability platinum sensor assuring a resolution of 10^{-3} °C and enabling the detection of differences of the same order of magnitude.

HUMIDITY

Sling or whirling hygrometers were the simplest form of forced ventilated hygrometer. The wet and dry bulb thermometers are carried on a frame which is attached to a handle: the thermometers are ventilated by whirling the frame around the handle at an appropriate rate of rotation. Unfortunately the use of this instrument in a cave was the most common source of accident by crashing the thermometers against a stalactite or the wall of a crawl.

Its main advantage was the low price, because rather often the frame was home built and only the thermometers have to be bought. When financial constraints were less important the Assmann hygrometer was the instrument more commonly used. Presently this instrument is used for calibration purposes or for spot measurements. Humidity sensors, which can be classified into two categories, now replace these devices: the capacitive sensors and the dewpoint probes.

The first ones have a serious problem because, when the relative humidity is close to 100% (as it is common in caves), they give wrong results on account of the condensation occurring over the sensor. The dewpoint probes are not affected by such an inconvenience but their cost is about one order of magnitude greater than the cost of the capacitive devices.

The high cost can then be reduced by using an Assmann hygrometer with the thermometers replaced by a multiway differential thermocouple or by a ventilated capacitive sensor. Thus, the sensor would be more easily restored in a dry condition in case of condensation. It is also possible to avoid condensation around 100%, by heating the sensor and correcting correspondingly the result obtained.

Nevertheless it must be stressed that the solutions reported above are acceptable only when the values of the relative humidity range not very close to 100%. On the other hand when it is necessary to distinguish, in the vicinity of 100%, between condensing or evaporating conditions the error affecting the measurements is too large and no longer acceptable. In this case evaporimeters could be used successfully (Badino, 2001) but this technique has still to be developed and tested in the cave environment.

CO_2

Until recent years CO_2 released by the visitors in a show cave was considered a serious threat to the cave environment and, particularly, to the development of formations. An exhaustive study carried out by the Laboratoire Souterrain de Moulis on an important French show cave, the Aven d'Orgnac, confirmed the relevant contribution of a natural source of CO_2 (Bourges et al., 1998). They could identify the origin of CO_2 from the atmosphere by isotopic analysis of C and He. Thus a volcanic origin could be excluded.

In particular the CO_2 entering the cave, as a gas released by oxidation phenomena in the humic layer above the cave, was of the order of some tonnes per day while the CO_2 exhaled by the tourists in the same time interval was less than 200 kg. This important result confirm the hypothesis already reported e.g. by Castellani (1988) concerning a possible natural origin of CO_2 in caves.

Therefore, what is important for the development and conservation of speleothems, is not the absolute concentration of CO_2, but the equilibrium between CO_2 in water and in air. I.e. if the CO_2 into the system is introduced through the water percolating into the cave, some CO_2 will move from the liquid phase into the atmosphere and the water, saturated with respect to $CaCO_3$, deposit it. If, on the contrary, the CO_2 is fed into the system through the atmosphere (e.g. if the CO_2 released by people would be not negligible in comparison to the natural CO_2) then some CO_2 will dissolve into the water that becomes undersaturated and, therefore, aggressive. In this case the development and the existence itself of formations would be endangered.

Such a mechanism should always be taken into account to understand the role of CO_2 in the cave atmosphere.

The measurements are carried out by infrared absorption by the CO_2. Each maker chooses different solutions to avoid interference not due to the CO_2. Presently, sensors with measurement ranges for any cave environment are available.

RADON

The measurement of radon in caves is performed for two purposes: scientific research and compliance with the law concerning radiation protection.

Spot measurements are made by means of ionisation chambers or other radiation detectors. Since radon concentration varies greatly it is preferable to obtain average values at least over some hours and, possibly, some days. Instruments with these characteristics are now available. But for long period monitoring other techniques are preferable, as etch track detectors. In this case a plastic film is exposed to radon gas only, by filtering out its decay products, for suitable time (up to some months, if the radon concentration is not too high). Then the films are recovered and the tracks released by the alpha particles are counted. A combination of the two methods is the most convenient: spot measurements to have a rough idea of the radon concentration and the etch tracks to obtain a value averaged over a longer time interval.

On account of the many rumours concerning radon and a diffuse fear spread out among people it is worthwhile to clarify that a connection between radon and lung cancer was identified only for miners. The existence of an illness for miners (Cigna, 1993) was firstly described by Titus Lucretius Carus (95 - 51 B.C.), who reports some statements taken from Epicurus (341 - 270 B.C.) concerning a miner's disease in the mines in the vicinity of Mt. Pangaion (Thrace, Greece). Later, in 1556 Agricola described a disease of the miners in the Schneeberger-Jachimov region in Erzgebirge (Czech Republic): *"Of the illnesses, some affects the joints, others attack the lungs, some the eyes, and finally some are fatal to men"*. Such diseases were diagnosed as cancer in 1879 (Härting & Hesse) and its possible association to radon was suggested about 40 years later when the high radon levels in mines of that region were discovered. However, the real cause of this disease, the inhalation of short-lived decay products of radon, was recognised in the 1950s only, when the first attempt of lung dosimetry were made (Aurand et al., 1955; Bale & Shapiro, 1955).

By applying the equivalence (ICRP, 1993):

$$1\ \text{becquerel}\times\text{hour/m}^3 \text{ is equivalent to } 3\times10^{-6} \text{ millisievert}$$

the limit of 3 millisievert/year, applicable to the public, would not be exceeded if, e.g., a person would not spend more than 100 hours/year in a cave with an average radon concentration of 10,000 becquerel/m^3 or, respectively, 1000 hours/year with with an average radon concentration of 1000 becquerel/m^3 (Cappa et al. 1996). In Fig. 1 the graphs referring to the limits of 3 millisievert/year and 10 millisievert/year, respectively, are reported.

Therefore, it must be emphasised that in the very great majority of caves, radon is not a problem for tourists and only sometimes it may imply some limitation to the working time of guides on account of legal constraints. In any case, a large number of publications shows that a correlation between radon concentration and cancer has not been ascertained for radon concentrations normally occurring in nature.

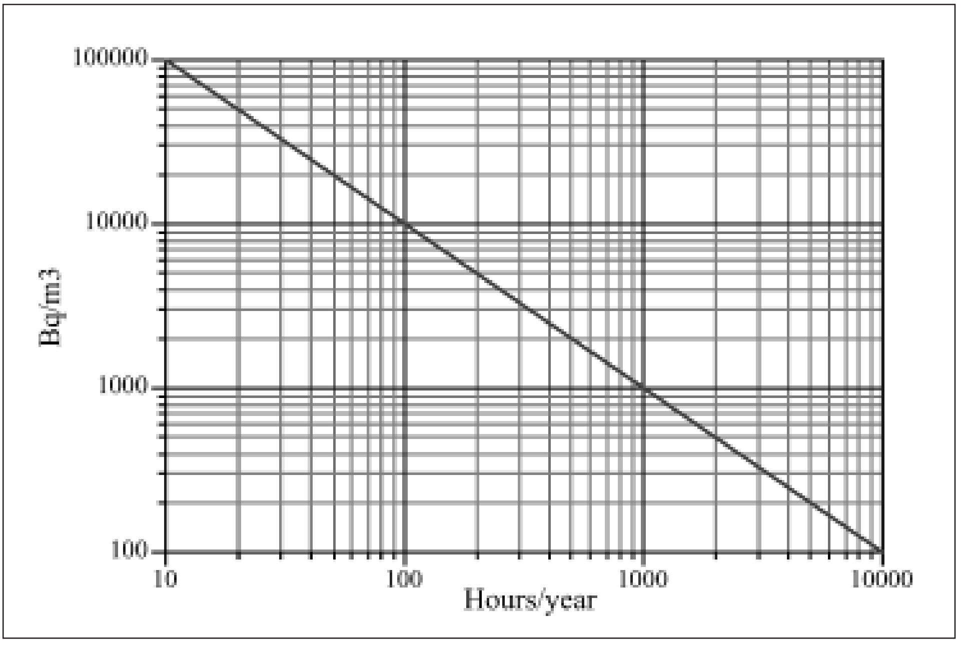

Fig. 1: Time (hours/year) which can be spent in a cave with an average radon concentration (Bq/m^3) without exceeding the effective dose.

AIR FLOW

The detection of airflow in caves may be obtained only by electronic devices in the great majority of cases on account of the very low velocities to be measured. Hot wire probes are usually employed but they have the characteristics to detect only the velocity and not the direction of the airflow that, in caves, may have two ways (in or out, with reference to a given environment).

The direction may be identified by using two probes, one free and the other conveniently shielded from a direction. A comparison between the outputs of such sensors supplies the information about the direction of the airflow. A very promising solution could be a sonic anemometer using the Doppler effect; presently such devices are being developed and commercial models should be available in the next future (Badino, 2001).

MONITORING NETWORKS

Climatological data were obtained in the past by means of spot measurements with the obvious problem of having someone doing the work. Presently such a procedure is adopted only to obtain an evaluation of the environmental situation with the aim to set up a more automatic system. To this purpose data loggers (which are rather inexpensive) are commonly used.

SIMPLE

A simple monitoring network, which is often used as a preliminary one in view of setting up a fully automatic network, may be obtained with a number of data loggers that may record a large number of data being later discharged directly to a computer or to a shuttle. The latter device has the great advantage of avoiding the presence of a computer inside a cave, since it can discharge the data recorded by the data logger and transfer later to a computer.

The data loggers now available have such a storage capacity that allows a long interval of operation without any need of discharging.

The inconvenience, which sometimes may occur, is an unconformity between two successive runs due to a change of calibration or a change of positioning that may affects the measurement. But, obviously, paying some more care in the general operation may easily solve such problems.

AUTOMATIC

An automatic monitoring network is surely the best solution, notwithstanding its higher cost. On the long run its simpler operation and reliability largely compensate such a cost. Simple telephone cables generally assure the connections between the stations distributed along the cave and the main control circuit. The details of the layout may vary according the requirements of each system.

An important feature, which must be always taken into account, is the protection against main power supply failure and lightning. Uninterruptible power supply would avoid major damages to data storage and retrieval. The cave environment, notwithstanding its high humidity, does not provide a reliable and efficient earth terminal because of a relatively high electrical resistance of the limestone. For this reason, surges due to a lightning cannot be promptly grounded and damages to any electronic device into the cave are almost certain. Such problems may be avoided by supplying the cave sensors' data to the outside through fibre optics.

KARTCHNER CAVERNS (Arizona, USA)

This cave was discovered in 1974 on the property of Kartchner Family; fourteen years later a bill of the State of Arizona was passed and the creation of James and Lois Kartchner Cavern State

Park authorised. After a long and detailed study of the cave, the first section of Kartchner Caverns was opened to the public in November 1999.

The results of a multidisciplinary investigation were published in the Journal of Cave and Karst Studies, vol. 61, No. 2, August 1999, where maps of the cave with indication of the stations are reported. A paper concerning the development and management of the Kartchner Caverns is included in the proceedings of this congress (Travous & Ream, 2001). A paper on the tourist impact on this cave environment was presented at the 13th Int. Congr. of Speleology, Brasilia (Cigna, 2001a).

TEMPERATURE MEASUREMENTS

Air temperature was measured at irregular intervals in many stations distributed along the cave passages.

For this study, 10 stations with the most complete data record in the period from 1996 to 2000 were considered. A sinusoidal best fit was calculated for each station with the FitSin Programme (Giorcelli, 1998). The distribution of these stations in the cave is reported in Fig 2.

The generic equation of a sinusoid being:

$$y = A+B\times\sin(2\pi(x+\phi)/T)$$

where y is the temperature (°C), A is the average temperature, B is a coefficient equivalent to one half the amplitude of the sinusoid, x is the time (days), ϕ is the phase delay with respect to x = 0 (1st January 1996) and T is the period (= 365 days).

Table 1: Parameters of the temperature wave obtained from the sinusoidal best fit for the stations investigated in Kartchner Caverns.

Station	Average Temp. (°C)	Wave Amplitude (°C)	% of Outside	Date of max	Delay (days)
Outside	18.85	17.42	100	1-Aug	0
Rotunda	20.52	0.36	2.1	5-Sep	35
Cul-de-Sac	20.78	0.14	0.8	30-Sep	60
Main Corridor	20.21	0.54	3.1	30-Sep	60
Grand Central	18.68	0.90	5.2	30-Sep	60
Lower Throne	20.20	0.14	0.8	30-Sep	60
Big Room Overlook	21.11	0.04	0.2	30-Sep	60
Kartchner Towers	20.85	0.14	0.8	16-Oct	76
Jack Rabbit	20.26	0.04	1.1	22-Oct	82
Sharon's Saddle	20.99	0.34	2.0	15-Nov	105
Echo Pass. (Start)	20.64	0.10	0.6	28-Mar	238

Obviously the temperature wave, originated outside by the seasonal variation, propagates into the cave through different mechanisms (air, rock, tourists) with a delay and attenuation depending on the mechanisms involved for each station. In Fig. 3 two typical diagrams have been reported..

In Table 1 some parameters obtained from the equations calculated for each station are reported. The average temperature is given by the coefficient A; the wave amplitude is given by the double of coefficient B; the attenuation is reported as percent of the outside amplitude; the date of the "summer" peak and the delay with respect to the outside peak are finally given. The stations have been listed according the increasing values of the delay.

A first examination of these data shows that the delay in Rotunda is the shortest (about one month). Then, in a second group of stations (Cul-de-Sac, Main Corridor, Grand Central, Lower Throne, Big Room Overlook) the delay is of two months. Another group of stations (Kartchner

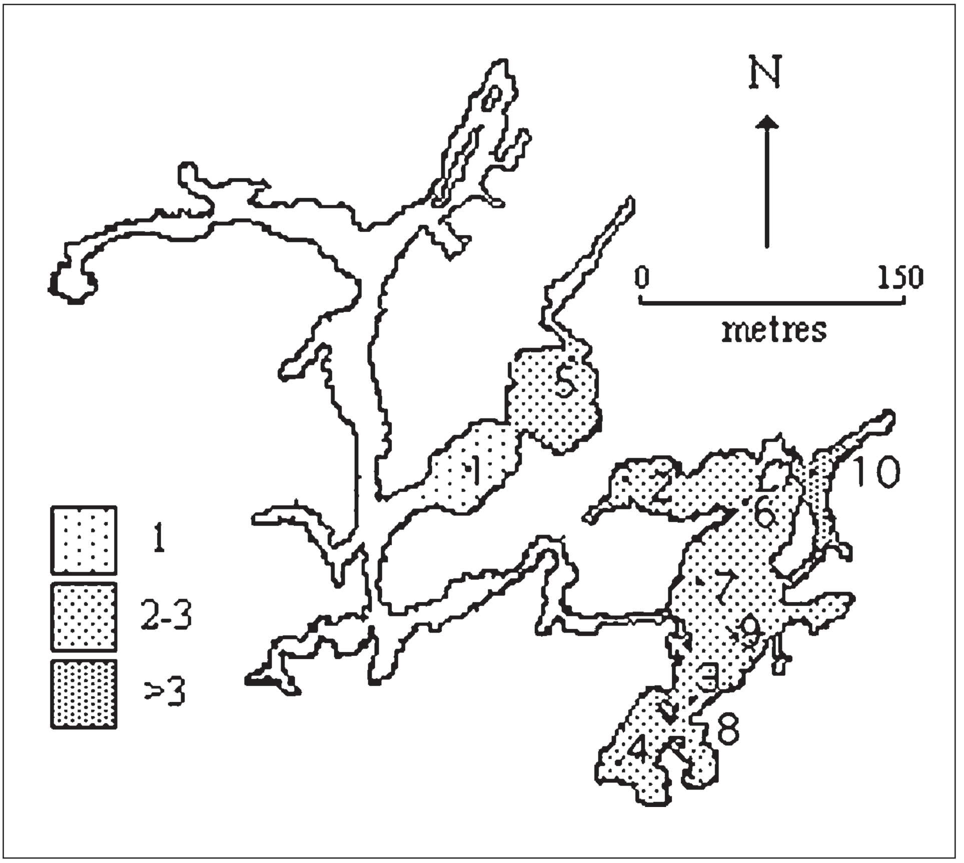

Fig. 2: Monitoring network in Kartchner Caverns.
1-Rotunda; 2-Cul-de-Sac; 3-Main corridor; 4-Grand Central; 5-Lower Throne; 6-Big Room Overlook; 7-Kartchner Towers; 8-Jack Rabbit; 9-Sharon's Saddle; 10-Echo. The zones with the same delay (1, 2-3, and > 3 months) of the temperature wave propagation are also indicated.

Towers, Jack Rabbit, Sharon Saddle) have a delay around three months and, finally, the last station (Start of Echo Passage) is characterised by the longest delay (about 8 months).

The attenuation of the temperature wave reported here, is calculated with reference to the ratio between the coefficient B of the respective best fit equations and not to the original values. According this procedure the disturbance of local temporary effects is avoided because smoothed functions are compared.

In most cases, also the relative humidity was measured at the same time and place with air temperature. The very largest majority of values range between 95 and 100%. A few values, only, reach 90% but the natural equilibrium area close to 100%. In this paper the relative humidity was not considered because it does not contribute any further to the knowledge of the cave climatology when temperature alone is investigated.

Only a couple of stations (Rotunda and Lower Throne) show an increase of 1°C from 1996 to present, superimposed to the usual seasonal variation. In order to investigate this behaviour the sinusoidal best fit was also tentatively applied to the values measured in these stations after subtraction of the steady increase quoted above.

Unfortunately, the correlation coefficient of the best fit was very low, on account of the rather large spread of the values yet for the original series of values; when the steady increase was subtracted, the correlation coefficient decreased to a point that the fit has a rather scarce meaning.

Following the distribution of the delay of the temperature wave in the different stations (Fig. 2), three main areas have been identified:

1 - About one month: Rotunda
2 - About two-three months: Cul-de-Sac, Main Corridor, Grand Central, Lower Throne, Big Room Overlook, Kartchner Towers, Jack Rabbit, Sharon's Saddle
3 - Longer than three months: Start of Echo Passage

The delay of one month is in good agreement with the fact that the Rotunda is the closest station to the entrance to the tourist cave. This means that the propagation through the entrance tunnel is prevalent above any other possibility.

The delay of two months correspond to a kind of "average delay" for most of the cave, and the longer delays (up to 8 months for the Start of the Echo Passage) may be due to local conditions.

In particular, such a long delay of 8 months could perhaps be due to an air circulation reaching the cave from the Echo Passage and opposing to the propagation of the temperature wave. If this is the case, it would be worthwhile to explore with great attention any possible connection through the Echo Passage to another branch still unknown

The evaluation of the temperature measurements has shown that a temperature wave is present everywhere in the cave with different delay time and attenuation with respect to outside.

While in most parts of the cave the average temperature is essentially constant, in two places (Rotunda and Throne) an increase, not very large (0.2°C/year) but steady, was detected. Such an impact could be due to the visitors, the lighting and the influence from outside.

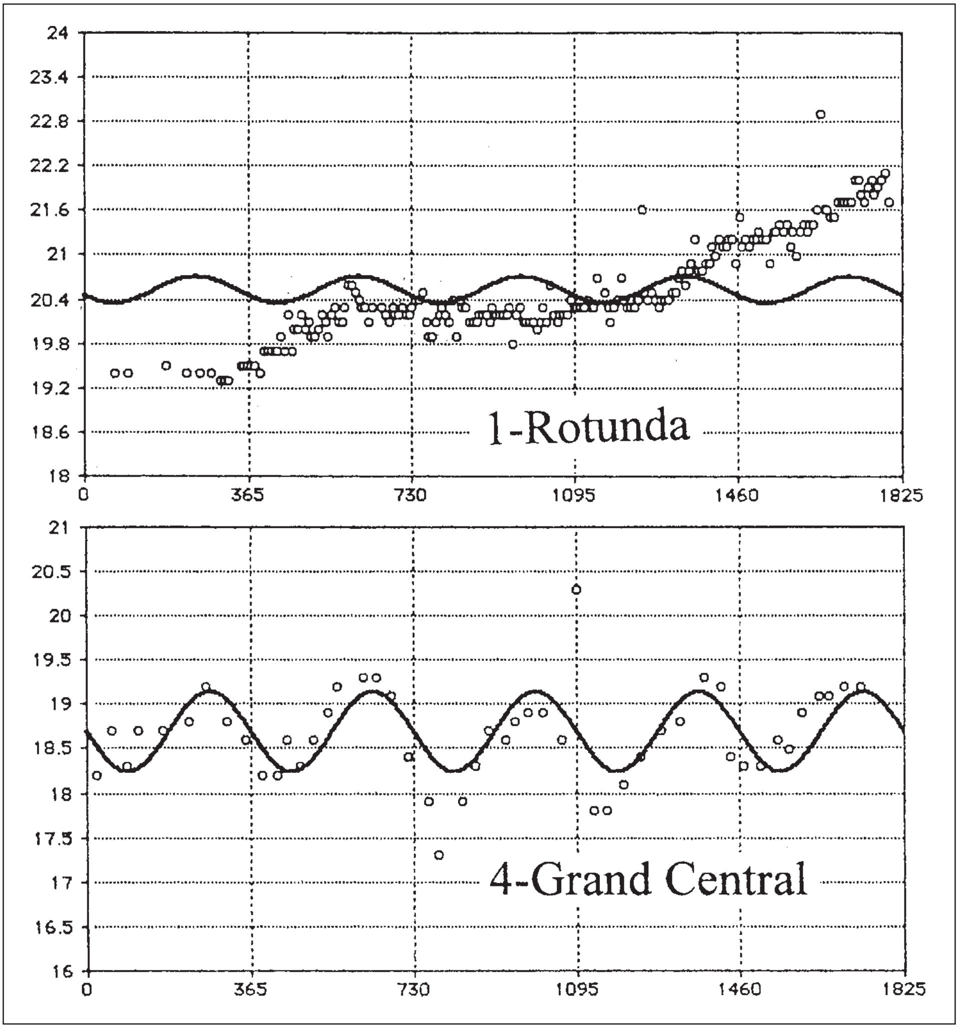

Fig. 3: Data interpolation for Grand Central and Rotunda in Kartchner Caverns. Temperatures are in °C.

CO_2 CONCENTRATION

Spot measurements of the CO_2 concentration were carried out by mean of a Draeger Pump from the end of 1997 and the results are reported in Fig. 4. The standard error associated to each value may be assumed to be around 100 ppm. An apparent correlation with opening to the public could be found at first, but it must be stressed that the main source of CO_2 in the cave environment is from a natural process of oxidation of the organic matter in the percolation water (Bourges et al., 1998).

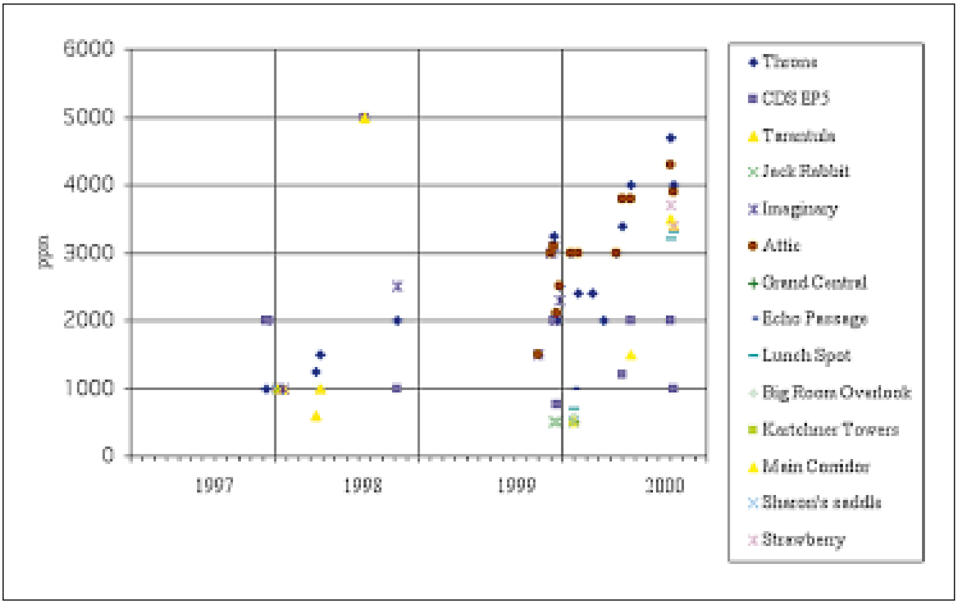

Fig. 4: CO_2 concentrations in Kartchner Caverns from December 1997 to September 2000.

In fact many high values were obtained in the section of the cave not yet open to the public where there are no artificial sources of CO_2 (Travous & Ream, 2001). In addition a closer examination of the distribution of values during each year shows a tendency to find higher values in the summer months, when the natural oxidation process is enhanced. The values found in Kartchner Caverns show no difference from those obtained in other caves, e.g. Cango cave (South Africa) (Cigna, 2001b) from a region with similar amount of precipitation.

Since the main source of CO_2 in the cave is natural and the surface above it has not be influenced by the buildings and the other facilities, it may be assumed that such a source is totally independent from the development of the show cave.

By taking into account that the CO_2 released by the visitors is a very minor fraction of the natural one, it may be concluded that the CO_2 is far from being a limiting factor in the development of the cave.

MAIN REMARKS

In addition to the usual improvements aiming to reduce the amount of energy delivered to the cave by visitors and lighting system, some additional devices could provide a useful contribution.

In particular, an air curtain system could be installed in each entrance tunnel. This simple device would result in a double advantage because it would "wash" the visitors and transfer into a suitable filter a good amount of the dust (lint, etc.) brought in by each person. In addition, if the systems were placed in proximity of the door leading into the cave, it would reduce greatly the air exchange between the tunnel and the cave.

To further reduce the impact of the tunnel on the cave, an air conditioning of the "conservation chambers" regulated to a temperature of 18-19°C and a relative humidity of 100% could be installed. Since the volume of such chambers is relatively limited the power requested would not be large.

It must be emphasised that Kartchner Caverns have been developed according the best standard, because each particular solution adopted in the most advanced show caves in the world have been implemented. This is one of the greatest successes ever obtained in this field and should be taken as an example for any further development of a tourist cave.

CANGO CAVE (OUDTSHOORN, S. AFRICA)

Cango Cave was discovered in 1780 by a Hottentot herd-boy working in Van Zyl's farm. The section normally visited by tourists is known as Cango I and extends about 600 m from the entrance; another section follows, Cango II, for about 400 m. The whole cave morphology is essentially horizontal and the cave develops at the same fossil level. To proceed any further than the end of Cango II it is necessary to reach a lower level (about 20 m below) still active with a streamlet (the Sump). Normally this level is totally flooded and the access to Cango III is possible only after lowering the water level by a pump. The flooded part is 179 m long and the Cango III can be reached by climbing up to the same level of the previous sections of the cave (Fig. 5).

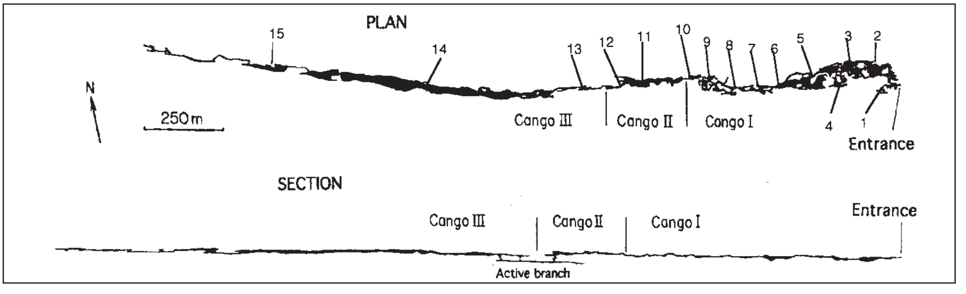

Fig. 5: The Cango Cave: 1- Gents Washrrom; 2- Van Zyl's Hall; 3-Both's Hall; 4-The Vestry; 5-Drums Rooms; 6-Lot's Chamber; 7-Smythe's Ladder; 8-Crystal Palace; 9-Ice Chamber; 10-Transformers; 11-Brokern Stalagmite; 12-Sump; 13-Base Camp; 14-Alpine Room; 15-Isolation Chamber (After Crombie et al., 1978, modified).

In April 2000 a series of spot measurements of air temperature and relative humidity along the whole cave, from the entrance to "Isolation Chamber" in Cango III (some 1700 m from the entrance) were obtained. Data supplied by a preliminary monitoring network from August 2000 to August 2001 are here reported.

PRELIMINARY MONITORING NETWORK

A simple monitoring network is constituted by 15 data loggers distributed along the cave, which record temperature (T) at 6:00, 12:00, 18:00 and 24:00 of every day. Some of them record

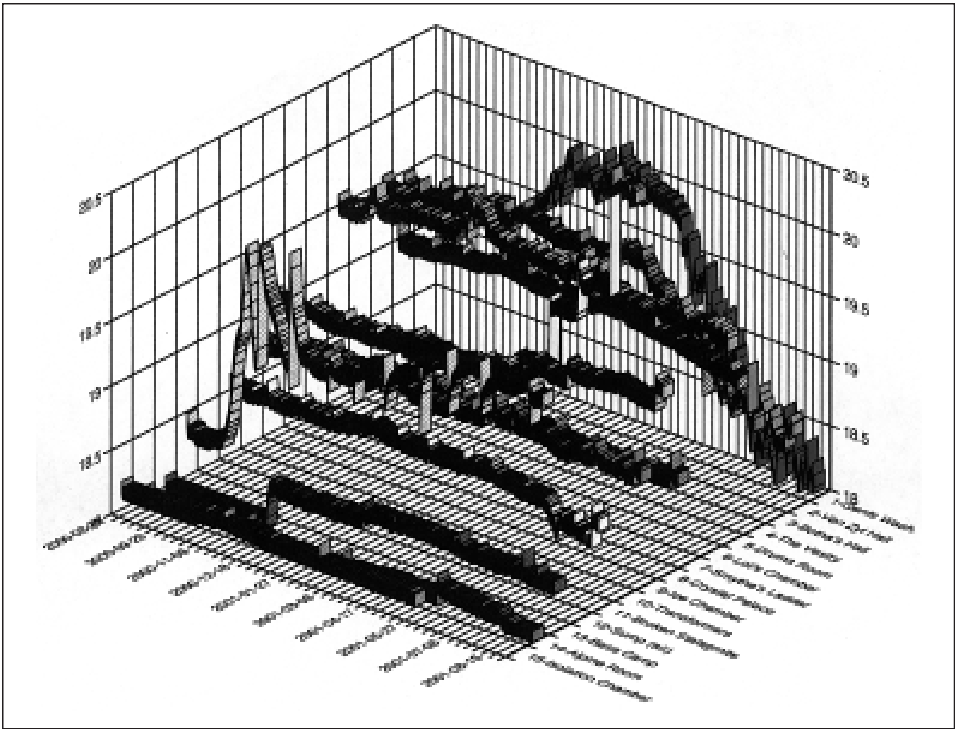

Fig. 6: Temperature distribution in Cango Cave from August 2000 to August 2001.

also the relative humidity (RH) and one the water temperature. Also a couple of sensors for CO_2 was installed in the cave and their outputs were transmitted to a data logger in the entrance for easy data retrieval. Data were transferred periodically by a shuttle into a computer outside the cave.

Temperature measurements are summarised in Fig. 6. Notwithstanding a series of spot measurements obtained in April 2000 gave RH values below saturation, some condensation occurred and the RH sensors went out of range with few exceptions. For this reason a relatively long set of data was available only for Station 2 (Van Zyl's Hall) which is rather close to the entrance (about 84 m).

A comparison between the outside and Van Zyl's Hall RH values (Fig. 7) shows that there is no evident correlation. The changes of the RH in the Van Zyl's Hall are due to minor local exchanges between outside and inside atmosphere and not to the existence of a steady airflow.

CO_2 sensors installed in Stations: 2 (Van Zyl's Hall) and 5 (Drums Room) provided data from December 2000 to October 2001 which are reported in Fig. 8 together with the daily number of visitors. Station 13 in Cango 3 (Base Camp) could not give any result because the CO_2 concentration in the whole Cango 3 resulted always above 10,000 ppm, outside the range of the sensor.

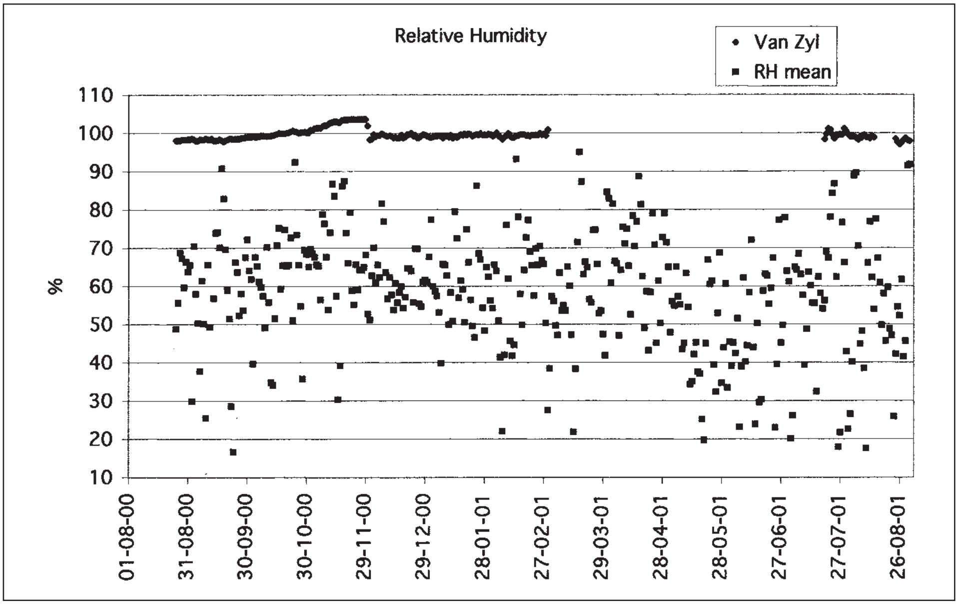

Fig. 7: Relative Humidity measured outside and in Van Zyl's Hall (Cango Cave).

TEMPERATURES MEASUREMENTS

By a comparison of the measurements carried out in the cave in March 1896 (Corstorphine, 1897 air temperatures ranging "from 65 to 66°F" (18.3 to 18.9°C) were recorded in Cango cave. Since values are given as a whole number of °F, it may be attributed an approximation of about ±0.5°C.

In addition to the data reported in the previous section, an additional set is available. From September 1 to 3, 1956 the Cave Research Sub-Committee of the Cape Section of the South African Spelaeological Association made some meteorological observation at the Cango Cave (Du Plessis, 1958a).

In Table 2 a comparison between these measurements and those obtained by the monitoring network operating at present, are reported. This comparison is obviously indicative only, because the stations are not really identical but refer to sites very close by. By taking into account the accuracy of the thermometers it can be assumed that the increase of temperature in the stations here considered, if any, is not greater than some tenth of °C in about half a century.

Table 2: Air temperature measurements from 1896 to 2000.

STATION	°C (March 1896) (± 0.5)	°C (Sept. 1956) (± 0.3)	°C (Sept. 2000) (± 0.2)
1/10 - Entrance/Transformers	18.3 ÷ 18.9	-	-
5/6 - Drum Room /Lot's Chamber	-	18.7	18.6 ÷ 19.6
10 - Transformers	-	17.8 ÷ 18.6	18.6

The first measurements were recorded in Cango Cave in 1896 when the global number of visitors from its development as a show cave was around few thousands people. Same values were obtained when the South African Spelaeological Association carried out some measurements in 1956 (Du Plessis, 1958a) and the visitors reached about 900,000; from that time to now other 7 millions people visited the cave. As it was reported above, the increase of air temperature during this time interval, if any, is not greater than some tenth of °C.

This fact means that the visitors capacity (Cigna & Forti, 1989) of Cango Cave was reasonably not exceeded notwithstanding management criteria (light, entertainment, etc.) not optimised from the point of view of the environmental impact.

The temperature measured in Cango 3, where the impact of visitors is absolutely negligible (few tenth of persons since its discovery) may be assumed as an undisturbed value not affected by any external influence (seasonal variation, visitors).

The average increase observed by moving from the inner stations to the entrance is probably due mainly to the influence of the seasonal variation from outside. The exceptions to such an increase found in stations 7-Gen. Smythe's Ladder, 6-Lot's Chamber and 4-The Vestry, could be due to either the evaporation latent heat or some hypothetical air flow from inner passages still unknown, as it was reported above.

When data sets ranging over one year will be available, the propagation velocity of the seasonal heat wave inside the cave could be evaluated and provide some more information on the real cause of such exceptions.

CO_2 CONCENTRATION

The values of CO_2 concentration are plotted in Fig. 8 together with the daily number of visitors. The values measured in Van Zyl's Hall started from around 3000 ppm in the first part of December, increasing to nearly 5000 ppm at the beginning of January and decreasing slowly to 4000 ppm successively. In the Drum Room the behaviour is similar with a starting value around 4500 ppm and a maximum around 8000 ppm about one week later than that observed in Van Zyl's Hall. In Cango 3, Base Camp, i.e. just after the sump that divides Cango 3 from Cango 2, the values are constantly out of range of the sensor (0-10,000 ppm) in agreement with the values ranging from 12,500 to 16,300 reported by Maxwell (1980). In the future the sensor in Cango 3 will be substituted in order to cover a wider range.

The measurements carried out in 1995 by the University of the Free State, (Grobbelaar et al., 1996) reported values in good agreement with those reported above. In particular the daily fluctuation due to the presence of visitors is identical with a range of few hundreds of ppm.

The peak of the number of visitors, around 2500 persons per day, is nearly one week before the maximum of CO_2 concentration observed in Van Zyl's Hall.

The evaluation of the data shows that the main source of CO_2 in the cave is the natural process of oxidation of the organic matter in the percolation water (Bourges et al., 1998) while the amount of CO_2 released by visitors is at least one order of magnitude lower. This fact is confirmed by the measurements carried out by Grobbelaar et al. (1998) when the increase due to the visitors was around some hundreds of ppm against a background of some thousands. In addition the CO_2 concentration increases in the inner part of the cave reaching a value above 10,000 ppm in the confined section of Cango 3 where the visitors have no influence at all.

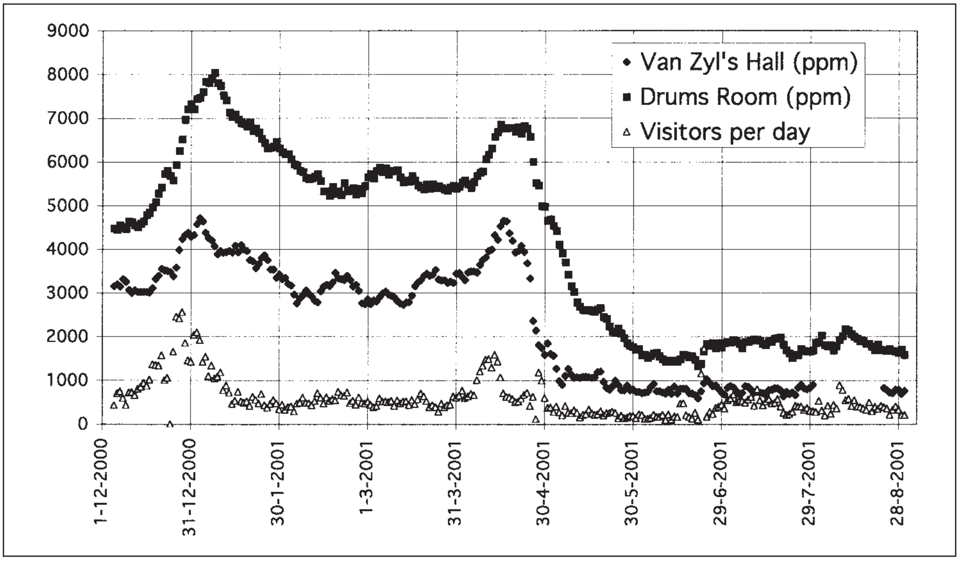

Fig. 8: Cango Cave: CO_2 concentration in Van Zyl's Hall and Drums Room and daily number of visitors.

Final remarks

The different appearance between the first halls of the Cango Cave and the inner parts is quite evident because the formations and the rock surface of the former are somewhat corroded while in the inner parts the formations are still growing.

Such a difference has been attributed to the use of the cave as a show cave. The results obtained in the first months of operation of the preliminary monitoring network do not support the conclusion that the CO_2 released by tourists could affect the chemical equilibrium concerning the formations. In fact the CO_2 released by natural oxidation process of organic matter in the percolation water is much larger than the CO_2 released by visitors.

In any case, it must be pointed out that, if the corrosion of the formations and the rock surface would be recent, the rock painting discovered by the Abbé Breuil in 1929 (Craven, 1988) would have totally disappeared notwithstanding any possible restoration occurred in the meantime. The corrosion of formations must therefore be attributed mainly to natural causes as the decomposition of guano (Craven, 1994). In fact the "dirty yellowish brown colour" observed by a visitor in the 19th century (Du Plessis, 1958b) was due to such a corrosion and was already present when the number of visitors was absolutely too small to produce any impact.

On the other hand, the plastic closure of the cave entrance installed on the gate many ten of years ago and only recently removed, might have modified the air circulation; the first halls could now act as a "warm trap" with a consequent increase of the temperature in this section. When more data from the preliminary monitoring network will be available a firmer conclusion concerning this point could be drawn.

ACKNOWLEDGEMENTS

I am very grateful to Mr. Kennet E. Travous, Director Arizona State Parks, and all of the management staff at Kartchner Caverns, for the opportunity they gave to me to study the cave. I would thank particularly Ms. Ginger Nolan for her invaluable help in providing me the data of the monitoring network and a continuous assistance in their interpretation.

I am also very grateful to Mr. Michel Schultz for my first visit to the Cango Cave in 1991, to Mr. Hein Gerstner and the whole staff of the management of the Cango Caves for their co-operation during my study; in particular I thank Mr. Steve Mouton for his special dedication to operate the monitoring network.

Thanks also to dr. J. Martini and dr. S.A. Craven who kindly provided copy of some references.

REFERENCES

Andrieux, C., 1970/1972: *Contribution à l'étude du climat des cavités naturelles des massifs karstiques*. Annales de Spéléologie, 25(2): 444-490; Annales de Spéléologie, 25(3): 491-559; Annales de Spéléologie, 26(1): 5-30; Annales de Spéléologie, 26(2): 367-386; Annales de Spéléologie, 27(1): 5-77.

Aurand, K., Jakobi, W., Schraub, A., 1955: *Zur biologischen Strahlenwirkung des Radon und seiner Folgeprodukte.* Sonderbd. zu Strahlentherapie, **35**: 237-243.

Badino, G., 1995: *Fisica del clima sotterraneo*. Mem. Ist. Ital. Speleologia, Bologna, **7**, s. II.

Badino, G., 2001: *Personal communication, August 2nd, 2001.*

Bale, W.F., & Shapiro, J.V., 1955: *Radiation dosage to lungs form radon and its daughter products.* Proc. 1st Conf. on Peaceful Uses of Atomic Energy, Geneva; United Nations, New York: **13**: 233-236

Bock, H., 1913: *Mathematisch-physikalische Untersuchung der Eishöhlen und Windrören*. In: Simonys F. (Ed.) - Höhlen in Dachstein. Deutsche Vereins-Druckerei, Graz: 102-144.

Bourges, F., D'Hulst, D., & Mangin, A., 1998: *Étude de l'Aven d'Orgnac*. Rapport final, Lab. Souterrain de Moulis - Géologie Environnement Conseil.

Cappa, G., Cigna, A.A., Tommasino, L., & Torri G., 1996: *Review of the radon concentration measurements in Italian caves and some aspects of radiation protection.* In: Cigna A.A. (Ed.), *BOSSEA MCMXCV*. Proc. "Show Caves and Environmental Monitoring" Symp. Int., Frabosa Soprana (Cuneo) 24-27/III/1995:149-161

Castellani, V., 1988: *Frasassi e speleomonitoraggio*. Speleologia, a. 9, **18**: 33-75.

Cigna, A., 1958: *Prime ricerche meteorologiche nella grotta di Bossea (Cuneo).* Atti VIII Congr. Naz. Speleol., Como 1956. Mem. IV, Rass. Spel. Ital., **2**:191-201.

Cigna, A.A., 1960: *Ricerche sugli aspetti del fenomeno carsico profondo nel gruppo delle Grigne (Lombardia) - II Ricerche di meteorologia ipogea nel gruppo delle Grigne (Lombardia).* Atti Soc. It. Sc. Nat., Milano, **99**(1): 87-104.

Cigna, A.A., 1961: *Air Temperature Distributions near the Entrance of Caves.* Atti Symp. Int. di Spel., Varenna 1960. Mem. V(2) Rass. Spel. Ital.: 259/267.

Cigna, A.A., 1967: *An analytical study of air circulation in caves.* Int. J. Speleology, **3**(1-2): 41/54.

Cigna, A.A., 1993: *Speleology by Titus Lucretius Carus.* Atti Simp. Int. Protostoria della Speleologia, Città di Castello 13-15 Sett. 1991. Ediz. Nuova Prhomos, Città di Castello: 17-24.

Cigna, A.A., 2001a: *Evaluation of the tourist impact in the Kartchner Caverns (Arizona, USA).* Proc. 13th Int. Congr. of Speleology, Brasilia July 15-22, 2001, Paper 014/S6, Abstract: 256.

Cigna, A.A., 2001b: *Results of the preliminary monitoring network of Cango Caves (Oudtshoorn, South Africa).* Proc. 13th Int. Congr. of Speleology, Brasilia July 15-22, 2001:Paper 015/S6, Abstract: 257

Cigna, A.A., & Forti, P., 1989: *The environmental impact assessment of a tourist cave. Cave Tourism.* Proc. Int. Symp. 170th Anniv. Postojnska jama, Postojna, Nov. 10-12, 1988. Centre Scient. Res. SAZU & Postojnska jama Tourist and Hotel Organiz.: 29-38.

Corstorphine, G.S., 1897: *The Cango Cave.* In: First Annual Report of the Geological Commission, Cape of Good Hope, for 1896: 42-45.

Crammer, H., 1899: *Eishöhlen- und Windröhren Studien.* Ab. K.K. Geographischen Gesellschaft, Wien, I: 19-76.

Craven, S.A., 1988: *Scientific work at the Cango Caves.* The Bulletin South African Spelaeological Association 29: 31-41.

Crestani, G., & Anelli, F., 1939: *Ricerche di meteorologia ipogea nelle Grotte di Postumia*. Mem. Ist. Ital. Speleologia, Postumia, Mem. III. Pubbl. N. 143 Uff. Idrogr. Mag. Acque, Ust. Poligr. Stato, Roma.

Du Plessis, L.A., 1958a: *The meteorology of the Cango Caves*. In: Cango, the Story of the Cango Caves of South Africa. Maskew Miller Ltd., Cape Town, 67-73.

Du Plessis, L.A., 1958b: *Where nomads lived*. In: Cango, the Story of the Cango Caves of South Africa. Maskew Miller Ltd., Cape Town, 1-10.

Eraso, A., 1962/1963: *Ideas sobre la climática subterránea.* Estudios del Grupo Espeleológico Alavés: 21-41.

Fugger, E., 1891/1893: *Eishöhlen und Windröhren.* XXIV Jahres-Berichte K.K. Ober-Realschule Salzburg: 1-70; XXV Jahres-Berichte K.K. Ober-Realschule Salzburg: 71-134; XXVI Jahres-Berichte K.K. Ober-Realschule Salzburg: 135-223.

Giorcelli, F., 1998: *FitSin 2.1.* Personal communication

Grobbelaar, J.U., Smith, V.R., Praekelt, H.E., du Preez, P.J., & Brink, J.S., 1996*: Scientific Study Aimed at Establishing a Management Strategy for the Cango Caves, Outdtshoorn*. Final Report Tender No. 38, 1995, Municipality of Oudtshoorn, 76+3 p.

Härting, F.M., & Hesse, W., 1879: *Der Lungenkrebs, die Bergkrankheit in den Schneeberger Gruben.* Vierterljahresschrift für gerichtl. Medizin und öff. Sanitatswesen, N. Folge, **30**: 296-309; **31**: 102-132; 312-337.

Kyrle, G., 1923: *Grundgriss der Theoretischen Speläologie.* Druck der Österreichischen Staatdruckerei, Wien.

ICRP, 1993: *Protection Against Radon-222 at Home and at Work.* Ann. ICRP, **23** (2), Pergamon.

Schawalbe, B., 1886: *Über Eishöhlen und Eislöcher.* Festschrift 50 Jubelfeier Dorotheenstädtischen Real-Gymnasiums Berlin: 1-57.

Travous, K.E., & Ream, J.P., 2001: *Developing and managing an environmentally responsible tourist cave*. Proc. 13th Int. Congr. of Speleology, Brasilia July 15-22, 2001, Paper 086/S6, Abstract: 269.

Wigley, T.M.L., 1967: *Non-steady flow through a porous medium and cave breathing*. J. Gephys. Res. **72**: 3199-3205.
Wigley, T.M.L., & Brown, M.C., 1969: *Geohydrological implications of cave breathing*. Abh. V Int. Kingr. Spel., Stuttgart: S 23/1-7.

SODOBNI TRENDI JAMSKEGA MONITORIGA

Povzetek

Jamsko okolje je zelo ranljivo in zahteva posebno skrb za ohranitev ravnotežja. Opisan je razvoj jamskega monitoringa od 19. stoletja, od prvih zapiskov, temelječih na kvalitativnem pristopu, do jamske klimatologije, ki uporablja tudi matematični pristop. Prednost razvojnih teorij je omogočila doseči primerljive rezultate in napovedati razvoj jamske klime, še preden je prišlo do nepopravljivih procesov. Najpomembnejše parametre za monitoring dobimo, če upoštevamo tudi natančnost, ki jo zahteva določena meritev glede na različne cilje raziskave. V zadnjih letih smo doživeli močan tehnološki razvoj in relativna pomembnost vsakega parametra je bila ocenjena glede na najbolj napredne raziskave. Upoštevana je tudi optimizacija stroškov glede na rezultate. Predstavljena sta dva konkretna primera.

Novembra 1999 so odprli za obisk Kartchner Caverns, AZ, USA. Nekaj predhodnih raziskav je bilo opravljenih v jami v njenem naravnem stanju. Arizona Conservation Project, Inc. (ACPI) je predvidel 22 merilnih postaj: na njih so merili temperaturo zraka, vode in tal, kakor tudi vlažnost in koncentracijo CO_2. Dobili so oceno vpliva in podali predloge za izboljšanje trenutnega stanja. Drugi primer je iz Cango Caves, najpomembnejše turistične jame v Afriki z nekaj sto tisoč obiskovalcev letno. Trenutno skušajo v jami s pomočjo monitoringa določiti največje število obiskovalcev. Septembra 2000 so postavili preprosto mrežo za monitoring, ki naj bi delovala eno leto. Sestavljena je iz 15 preprostih "data loggerjev", razporejenih po jami. Merijo temperaturo zraka in vode, koncentracijo CO_2 in relativno vlažnost in vrednosti občasno prenesejo v računalnik izven jame. Prispevek podaja prve rezultate. Popolnoma avtomatičen monitoring bo postavljen v prihodnosti, ko bodo pregledani rezultati te prve preproste opazovalne mreže. Avtomatski merilci bodo vključevali poleg parametrov, ki jih merijo že zdaj, tudi zračni tok in nihanje vodne gladine.