13th International Congress of Speleology
4th Speleological Congress of Latin América and Caribbean
26th Brazilian Congress of Speleology

Brasília DF, 15-22 de julho de 2001

Evaluation of the Tourist Impact in the Kartchner Caverns (Arizona, Usa)

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Abstract

Kartchner Caverns opened to the public in November 1999. Some preliminary studies have been performed in the cave in its natural status. Arizona Conservation Projects, Inc. (ACPI) established 22 monitoring stations, from these specific areas, measurements of air, water, soil, temperature's were taken. Humidity and carbon dioxide concentrations were also measured.

An evaluation of the impact assessment was obtained and suggestions to improve the present situation were proposed.

Introduction

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).

Measurements

Temperature

According to the actual data, the information was transformed from the original °F into °C. Digital thermometers were used and calibrated monthly with the same standard mercury thermometer over the time interval considered here. The accuracy of a single measurement may be assumed to be ± 0.1°C. The distribution of the stations in the cave is reported in Fig. 1.

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 generic equation of a sinusoid being:

$$y = A+B*\sin(2\pi(x+\varphi)/T)$$

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).

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. 2 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 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.

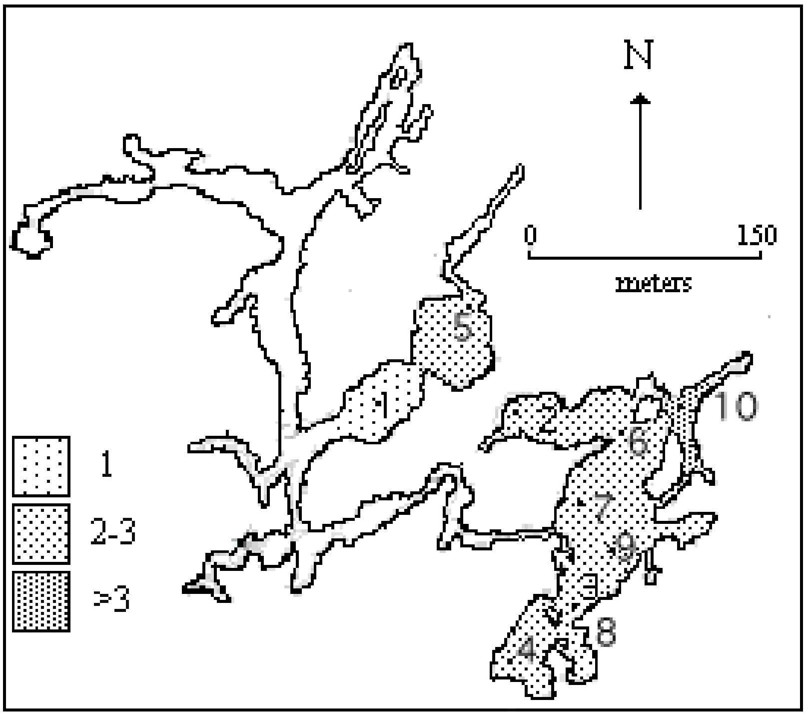

Fig. 1 Monitoring network. 1-Rotunda: 2-Cuk-de-Sac; 3-Main corridor; 4-Grand Central; 5-Lower Throne; 6-Big Room Overlook; 7-Kartchner Towers; 8-Jack Rabbit; 9- Sharon's Saddle; 10-Echo. The zones with the same delay (1, 2-3, and > 3 months) of the temperature wave propagation are also indicated.

Table 1 - Parameters of the temperature wave obtained from the sinusoidal best fit for the stations investigated.

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

Relative Humidity

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.

Obviously the relative humidity could be the object of future researches.

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. 3. The standard error associated to each value may be assumed to be around 100 ppm.

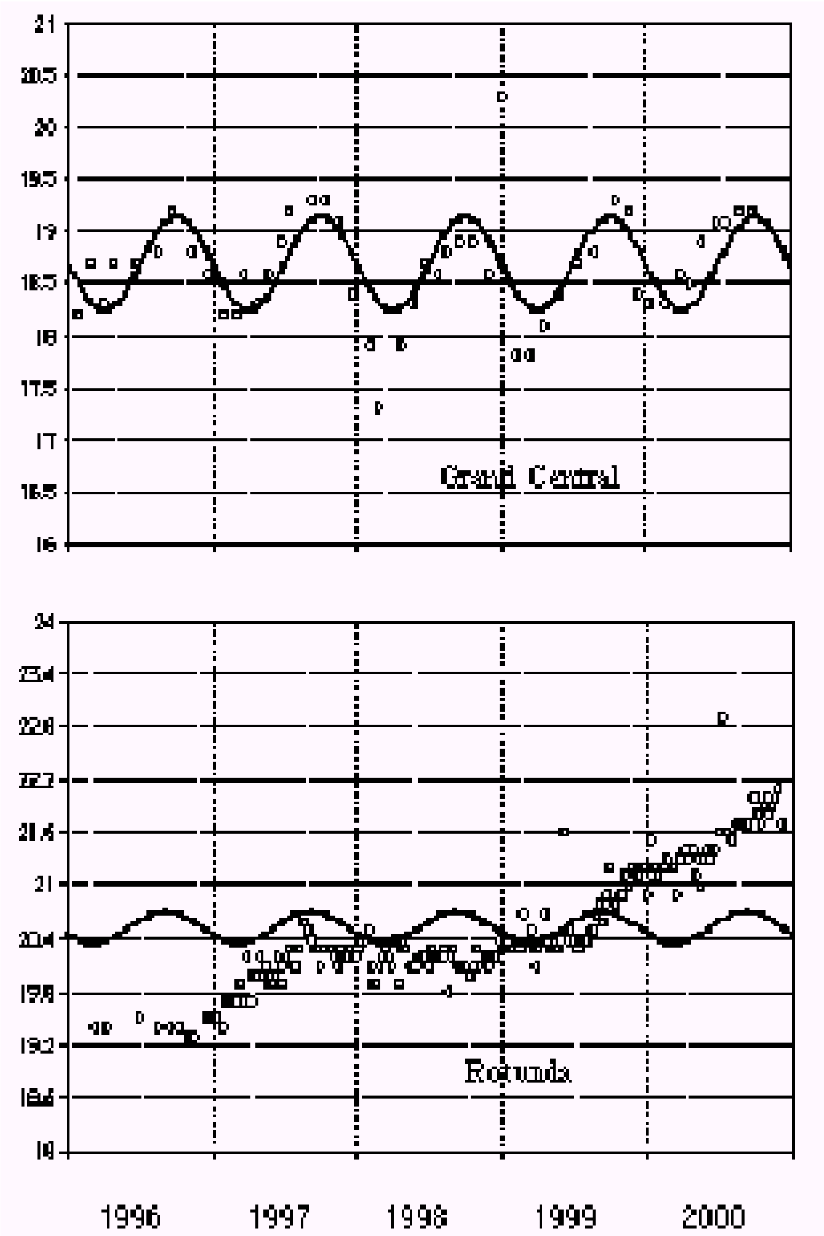

Fig. 2 - Data interpolation for Grand Central and Rotunda. Temperatures are in °C.

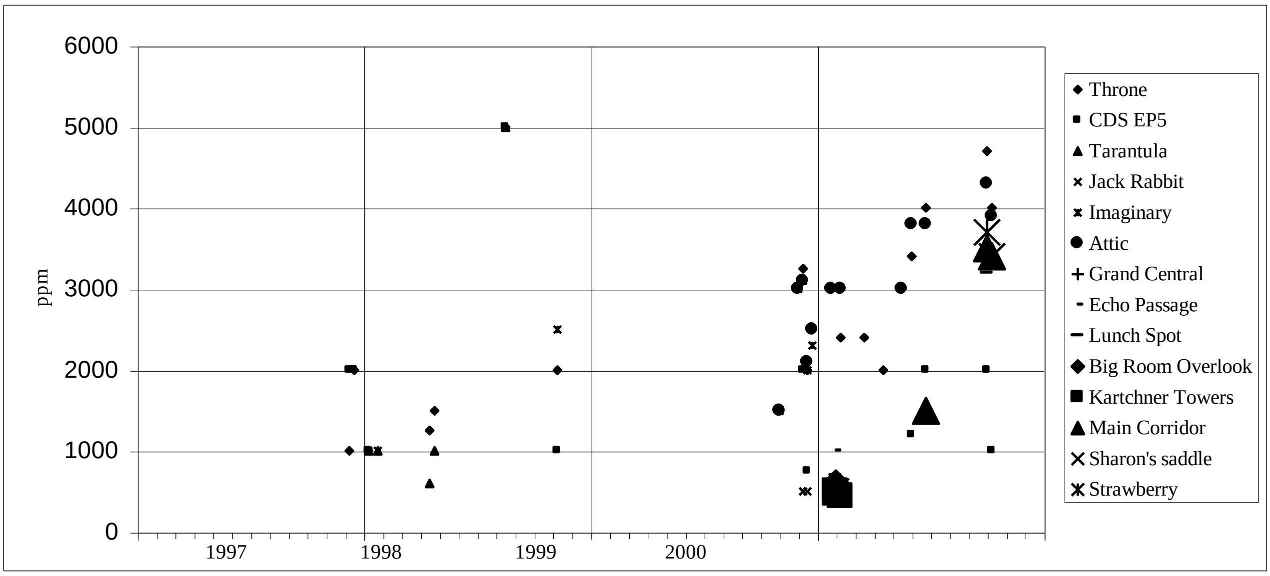

Fig. 3 - CO_2 concentrations in Kartchner Caverns from December 1997 to September 2000.

Discussion

Temperatures

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. 1), three main areas have been identified:

About one month: Rotunda

About two-three months: Cul-de-Sac, Main Corridor, Grand Central, Lower Throne, Big Room Overlook, Kartchner Towers, Jack Rabbit, Sharon's Saddle

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.

CO_2 concentration

From Fig. 2 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).

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, 2001) from a region with similar amount of precipitation.

Conclusions

Temperatures

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.

CO_2 concentration

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.

Final remarks

The small increase of the temperature found in two stations, as reported above, requires a further investigation to identify its causes.

A series of frequent temperature measurements (e.g. every 15 min) for about a couple of months, in some places around the stations concerned, possibly at different heights, could contribute to clarify the origin of the perturbation. In fact a detailed correlation both with the flux of visitors and the lights on could be studied. In order to distinguish between these two sources (visitors and lights) the lamps could sometimes be switched on during a few nights when visitors are absent and look for any possible impact.

Once the mechanism of the cave climate is fully understood, an automatic monitoring system could be installed to keep under control air and water temperature, relative humidity and airflows. Obviously these parameters would not necessarily be measured in every stations, but only in critical points which the simple preliminary network has pointed out.

The operation of the misting system should be limited to avoid the dispersion of dust arising from the trail construction. On the long run, the misting system could result in a negative balance between risks and benefits because it releases water, which in principle is not karst water. On the other hand, the relative humidity is a self-adjusting parameter (obviously within a limited range, which is not exceeded in this case) and no intervention is required.

When lamps are replaced, a special care should be assured in order use the most efficient kind available at the moment. In this way any improvement resulting from the lamp technology will be automatically transferred in the cave light system.

Finally, 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.

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.

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